

**Official Transcript of Proceedings**  
**NUCLEAR REGULATORY COMMISSION**

Title:                   Advisory Committee on Reactor Safeguards  
                              Thermal Hydraulic Phenomena Subcommittee

Docket Number:       (n/a)

Location:               teleconference

Date:                    Tuesday, May 5, 2020

Work Order No.:       NRC-0902

Pages 1-112

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

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

DISCLAIMER

UNITED STATES NUCLEAR REGULATORY COMMISSION'S  
ADVISORY COMMITTEE ON REACTOR SAFEGUARDS

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

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

**NEAL R. GROSS**

COURT REPORTERS AND TRANSCRIBERS

1323 RHODE ISLAND AVE., N.W.

WASHINGTON, D.C. 20005-3701

(202) 234-4433

[www.nealrgross.com](http://www.nealrgross.com)

1  
2  
3  
4  
5  
6  
7  
8  
9  
10  
11  
12  
13  
14  
15  
16  
17  
18  
19  
20  
21  
22  
23  
24  
25

UNITED STATES OF AMERICA

NUCLEAR REGULATORY COMMISSION

+ + + + +

ADVISORY COMMITTEE ON REACTOR SAFEGUARDS

(ACRS)

+ + + + +

THERMAL HYDRAULIC PHENOMENA SUBCOMMITTEE

+ + + + +

TUESDAY

MAY 5, 2020

+ + + + +

The Subcommittee met via Teleconference,  
at 1:00 p.m. EST, Walter Kirchner, Chairman,  
presiding.

COMMITTEE MEMBERS:

WALTER KIRCHNER, Chairman

RONALD G. BALLINGER, Member

DENNIS BLEY, Member

JOSE MARCH-LEUBA, Member

DAVID A. PETTI, Member

JOY REMPE, Member

ACRS CONSULTANT:

MICHAEL CORRADINI

STEVE SCHULZ

1  
2  
3  
4  
5  
6  
7  
8  
9  
10  
11  
12  
13  
14  
15  
16  
17  
18  
19  
20  
21  
22  
23  
24  
25

DESIGNATED FEDERAL OFFICIAL:

ZENA ABDULLAHI

ALSO PRESENT:

PAUL CLIFFORD, NRR

TOM EICHENBERG, Tennessee Valley Authority

1  
2  
3  
4  
5  
6  
7  
8  
9  
10  
11  
12  
13  
14  
15  
16  
17  
18  
19  
20  
21  
22  
23  
24  
25

T-A-B-L-E O-F C-O-N-T-E-N-T-S

PAGE

Opening Remarks . . . . . 4

Regulatory Requirements . . . . . 7

Timeline and Stakeholder Comments . . . . . 25

Revise Guidance and Analytical Limits

    Reactor Coolant System Pressure . . . . . 39

    Damaged Core Coolability . . . . . 47

    Radiological Consequences . . . . . 51

Cladding Hydrogen Uptake Models . . . . . 84

Burnup Extension . . . . . 88

Public Comment . . . . . 107

Discussion . . . . . 109

Adjourn . . . . . 112

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

1:04 p.m.

CHAIR KIRCHNER: Okay. Let me ceremoniously bang the table with a gavel. The meeting will now come to order. This is a meeting of the ACRS Metallurgy and Reactor Fuels Subcommittee and Thermal Hydraulics Subcommittee of the Advisory Committee on Reactor Safeguards. I am Walter Kirchner, Chairman of today's subcommittee meeting. ACRS members in attendance are -- and at this point, I'll just ask for an affirmation if you're there. Ron Ballinger?

MEMBER BALLINGER: Yep, I'm here.

CHAIR KIRCHNER: Dennis Bley?

(No response.)

CHAIR KIRCHNER: Jose March-Leuba?

MEMBER MARCH-LEUBA: Yes, I'm here.

CHAIR KIRCHNER: David Petti?

MEMBER PETTI: Here.

CHAIR KIRCHNER: Joy Rempe?

MEMBER REMPE: Here.

CHAIR KIRCHNER: Matt Sunseri?

PARTICIPANT: Walt, Matt said that he was not going to be able to participate.

CHAIR KIRCHNER: Okay. Thank you. And I

**NEAL R. GROSS**

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

1 also note that Pete Riccardella would not be able --  
2 he had a conflict as well. Vesna Dimitrijevic?

3 MEMBER BALLINGER: Vesna said that she was  
4 not going to be able to attend.

5 CHAIR KIRCHNER: Okay. Thank you. Now  
6 have I left anyone out? Joy Rempe?

7 MEMBER REMPE: You already asked, and yes,  
8 I'm here.

9 CHAIR KIRCHNER: Okay. Sorry, Joy. All  
10 right.

11 MEMBER REMPE: Not a problem.

12 CHAIR KIRCHNER: All right. And  
13 consultants, I believe we have Mike Corradini?

14 MR. CORRADINI: Yes.

15 CHAIR KIRCHNER: And Steve Schulz?

16 MR. SCHULZ: I'm here.

17 CHAIR KIRCHNER: Thank you. Okay. Zena  
18 Abdullahi is the Designated Federal Official for this  
19 meeting. During today's meeting, the subcommittee  
20 will hear presentations and will hold discussions with  
21 the NRC staff regarding Regulatory Guide 1.236,  
22 Pressurized Water Reactor Control Rod Ejection and  
23 Boiling Water Reactor Control Rod Drop. There's a  
24 long history related to this Regulatory Guide. The  
25 staff was -- the staff briefed the ACRS Committee on

**NEAL R. GROSS**

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

1 the draft Regulatory Guide 1327, I believe back as far  
2 as 2007 and again in October 2016.

3 In today's meeting, the staff will present  
4 the finalized draft of DG-1327 which is now Regulatory  
5 Guide 1.236. This meeting is open to the public. The  
6 ACRS section of the U.S. NRC public website provides  
7 our charter, bylaws, agendas, letter reports, and full  
8 transcripts of all open and full and subcommittee  
9 meetings, including slides presented there.

10 The meeting notice and agenda for this  
11 meeting are posted there. We have received no written  
12 statements or requests to make an oral statement from  
13 the public. At this point, the Committee will gather  
14 information, analyze relevant issues, facts, and  
15 formulate proposed positions and actions as  
16 appropriate for deliberation by the full committee,  
17 and that would be in June.

18 A transcript of the meeting is being kept  
19 and will be made available at the NRC website. This  
20 meeting is being held virtually as part of the COVID-  
21 19 preventative measures. We ask everyone except the  
22 subcommittee members and presenters to mute their  
23 microphones until the public session starts as shown  
24 in the meeting agenda.

25 The meeting participants should first

1 identify themselves and speak with clarity and volume  
2 so that they may be readily heard. We will now  
3 proceed with the meeting, and I will start by calling  
4 on Paul Clifford of NRR. Good afternoon, Paul. Are  
5 you there?

6 MR. CLIFFORD: Good afternoon. I am here  
7 and ready.

8 CHAIR KIRCHNER: Okay. Did anyone from  
9 NRR management also wish to make a statement before we  
10 begin?

11 MR. CLIFFORD: I do not believe that is  
12 the case.

13 CHAIR KIRCHNER: Okay. Thank you, Paul.  
14 Why don't you go ahead then, Paul. We look forward to  
15 your presentation. I might note that this is very  
16 timely.

17 MR. CLIFFORD: Well, thank you very much.  
18 Okay. So hello, everybody. Good afternoon. Welcome  
19 to virtual ACRS. My name is Paul Clifford, and I am  
20 the Senior Level Advisor for Reactor Fuel in the  
21 Office of Nuclear Reactor Regulation. I've been with  
22 the NRC in the Division of Safety System since 2003.  
23 Prior to that, I worked in the commercial nuclear  
24 industry for 16 years, starting in Combustion  
25 Engineering in Connecticut, then moving to Arizona to

**NEAL R. GROSS**

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

1 work at the Palo Verde Nuclear Generating Station.  
2 And finally, I moved to Maryland and worked at Calvert  
3 Cliffs.

4 The focus of my 30-plus years of  
5 experience has been nuclear fuel design and  
6 performance, poor reload safety analyses, and plant  
7 operations. Today, I will be presenting Reg Guide  
8 1.236 which provides guidance for evaluating a nuclear  
9 reactor's initial response to a postulated control rod  
10 ejection or control rod drop accident. So let's  
11 begin.

12 Today, we will start off with an overview  
13 of the postulated reactivity insertion accidents and  
14 applicable regulatory requirements, then a timeline of  
15 the staff's guidance and how it evolved with an  
16 expanding empirical database. I will describe  
17 stakeholder comments received by two public comment  
18 periods along with major changes to the guidance  
19 prompted by those comments.

20 Next, I will walk through the guidance  
21 with emphasis on what has changed since 2016 which is  
22 the last time I briefed the ACRS, then I will describe  
23 cladding hydrogen uptake models which were developed  
24 to aid in the implementation of this guidance. And  
25 finally, I will describe staff efforts to support a

**NEAL R. GROSS**

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

1 relatively new industry initiative on fuel rod burnup  
2 extension.

3 CHAIR KIRCHNER: Paul, this is Walt. Just  
4 to show you that these virtual meetings work, I can  
5 interrupt you. May I ask very simply why you went  
6 from the previous reactivity insertion accidents title  
7 for the Reg Guide to the rather more prescriptive PWR  
8 rod ejection, BWR rod drop title?

9 MR. CLIFFORD: Well, I think there's  
10 always been some confusion --

11 CHAIR KIRCHNER: Go ahead.

12 MR. CLIFFORD: Okay, sorry. I think  
13 there's always been some confusion with the title and  
14 classification of these types of accidents. People  
15 referred RIAs as reactivity insertion accidents. Some  
16 referred to them as reactivity initiated accidents.  
17 I was never a big fan because there are many accidents  
18 which involve reactivity insertion, and the accident  
19 is actually not initiated from reactivity perspective.  
20 It's initiated from the failure or the movement of a  
21 particular blade or a control element.

22 And as I mentioned, the guidance is  
23 stylized to these particular classes of events and not  
24 all accidents involved in reactivity. So that's kind  
25 of why I moved back because we're really dealing with

**NEAL R. GROSS**

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

1 how to properly analyze these accidents and to assess  
2 the impacts and to show compliance with the  
3 regulations.

4 CHAIR KIRCHNER: Thank you. I would  
5 submit that the material that's in the Reg Guide has  
6 broad applicability beyond just the ejection and drop  
7 accidents.

8 MR. CLIFFORD: Yeah, I understand.

9 MEMBER MARCH-LEUBA: Yeah. Paul, this is  
10 Jose. I wanted to agree again with my colleague,  
11 Walt, that almost all of this Reg Guide applies to  
12 reactivity excursion events, whether it is because of  
13 a rod or something else. And the question I have is  
14 by changing the title, are we changing the  
15 requirements a plant would have to satisfy if they  
16 have a reactivity excursion by any other means?

17 I realize this is a Reg Guide. It's not  
18 a rule. But are we saying if you have a reactivity  
19 excursion, say, for example, you are injecting cold  
20 unborated water into the core and producing a critical  
21 event, would you generalize that differently, that rod  
22 ejection?

23 MR. CLIFFORD: Yes, you would. So there  
24 are different classifications of events, I'm sure  
25 you're aware. There are reactivity events that are

**NEAL R. GROSS**

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

1 classified as AOOs. There are others that are  
2 classified as postulated accidents. And each one of  
3 the accidents can have a different set of acceptance  
4 criteria. I understand that the reactor kinetics are  
5 the same. However, the acceptance criteria and the  
6 guidance and the GDCs for which you're judging  
7 compliance are different for the different accidents.

8 MEMBER MARCH-LEUBA: So it would be based  
9 on the frequency for the excursion event that would  
10 make it more like a severe accident in which you can  
11 have more relaxed acceptance criteria?

12 MR. CLIFFORD: That's correct. Generally,  
13 the lower the probability of the initiating event, the  
14 higher allowable consequences.

15 MEMBER MARCH-LEUBA: But the consequences  
16 are more severe. The consequences are pretty severe,  
17 even on the control rod. But okay, we'll go through  
18 this during your presentation.

19 MR. CLIFFORD: Right, okay. So sounds  
20 like I'm in trouble. We haven't even gotten off the  
21 title page yet. Okay. Moving on to Slide 3. The  
22 reason for concern with this type of accident, the  
23 safety significance of a reactivity insertion accident  
24 is evident from the fatal accident that occurred at  
25 the U.S. Army's prototype modular reactor, SL-1.

**NEAL R. GROSS**

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

1           On January 3rd, 1961, SL-1 experienced a  
2 prompt critical power excursion felt almost  
3 instantaneously by a steam explosion as a result of an  
4 improper central control rod withdrawal. All three  
5 reactor operators were killed as a result of the  
6 physical trauma received in the violent explosion.  
7 And even if the operators had shielded themselves from  
8 the explosion, lethal amounts of radiation was  
9 released into the building. This old INL safety  
10 poster shows what remained of the SL-1 reactor. It is  
11 a good reminder.

12           MEMBER MARCH-LEUBA: Yes, Paul. I know  
13 you will talk over all of Slide 3. I am very glad you  
14 presented this picture because this is a visual of how  
15 important this Reg Guide is. We are trying to  
16 protect. We're making sure that the plants have the  
17 proper power-dependent and pressure limits or what  
18 their limits you -- so this doesn't happen.

19           Now in a different time this week, we've  
20 been talking about a different reactivity event. Is  
21 there anything special in this event that was because  
22 it was a rod? You have put up prompt criticality  
23 source of reactivity in the core. It would have  
24 behaved differently, say, for example, a cold  
25 unborated water slug.

**NEAL R. GROSS**

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

1 MR. CLIFFORD: Well, certainly, yes. So  
2 the width of the pulse has a significant effect on the  
3 performance and response of the fuel through that  
4 pulse. I mean, this type of prompt reactivity occurs  
5 as a result of the quick withdrawal of a single rod  
6 element results in a very localized prompt critical  
7 excursion. And it's the height and the width of the  
8 response in a local reactor power that influences how  
9 the rod responds, whether the rod fails, and whether  
10 you melt fuel or fail cladding or in a resulting --

11 MEMBER MARCH-LEUBA: Is it whether you  
12 have enough reactivity? If you have 0.9 dollars of  
13 reactivity, this will happen. So you have 1.2, 1.3,  
14 this will happen. If you have 1.05, it may not  
15 happen.

16 MR. CLIFFORD: That is correct. The width  
17 of the prompt pulse is directly related to the  
18 amplitude. So --

19 MEMBER MARCH-LEUBA: So the insertion  
20 reactivity or positive reactivity, the insertion rate  
21 is important on the development. But it's not because  
22 it is a rod. It is because rods can move fast where  
23 other types of reactivity essentially may or may not  
24 move that fast.

25 MR. CLIFFORD: I agree. I agree.

1 Fundamentally, you're designing your core. And if you  
2 think about it, you have other accidents where you  
3 rely upon the actions of a lot of safety-related  
4 systems. Your reactor trips or ESFAS or ECCS or  
5 something to mitigate the consequences.

6 This event, this accident -- this family  
7 of accidents I should say is really developed to limit  
8 the design of the fuel, as you mentioned, how much  
9 work you can have in a single blade, how much  
10 enrichment you can put in the core. You're designing  
11 the core so that the initial response, the prompt  
12 critical response would be limited and that you'll  
13 also have inherent feedback from Doppler that'll turn  
14 the power around before you even get to the point  
15 where you're relying on engineered safety functions to  
16 act.

17 MEMBER MARCH-LEUBA: Yeah, which you  
18 probably don't have time to react if you're in prompt  
19 critical.

20 MR. CLIFFORD: Absolutely.

21 MEMBER MARCH-LEUBA: Okay. I just wanted  
22 to emphasize that this is a really good visual of what  
23 we're trying to achieve today. We're going to prevent  
24 this.

25 MEMBER BLEY: This is Dennis Bley. Since

**NEAL R. GROSS**

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

1 you brought this one up, SL-1 as I recall was very  
2 highly enriched, like, over 90 percent. So we had no  
3 Doppler in this plant. It was all thermal response  
4 that shut it down. Is that true?

5 MR. CLIFFORD: I'm not 100 percent sure.

6 I mean --

7 MEMBER MARCH-LEUBA: I am looking at the  
8 size of the core, and I agree with Dennis. This  
9 cannot be other than highly enriched core if you were  
10 to make it critical.

11 MR. CLIFFORD: Okay. So as this poster  
12 shows, it's important that we protect against this  
13 class of accidents. And I believe that this nuclear  
14 accident was likely in the minds of the Atomic Energy  
15 Commission when they drafted the General Design  
16 Criteria in 10 CFR Part 50 just a few years later.  
17 Let's get to the specific regulatory requirements.

18 Appendix A, GDC 28 limits the amount and  
19 the rate of reactivity insertion to protect the  
20 reactor coolant pressure boundary and ensure a  
21 coolable geometry. Essentially, it looks like it's  
22 written to protect against this. In addition to the  
23 reactivity requirements, there are dose requirements  
24 to the general public located in 10 CFR Part 50 and  
25 Part 100. Reg Guide 1.236 provides and acceptable

**NEAL R. GROSS**

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

1 means to meet these regulations.

2           Reactivity insertion accidents are safety  
3 significant because of their potential ability to  
4 challenge fuel rod integrity, fuel bundle geometry,  
5 and the integrity of the reactor coolant boundary.  
6 The uncontrolled movement of a single control rod out  
7 of the core results in a positive reactivity insertion  
8 that promptly increases local power and is considered  
9 the limiting reactivity insertion accident. Of the  
10 various postulated single failures to the control rod  
11 drive system which would lead to an uncontrolled  
12 movement of a single control rod, the PWR control rod  
13 ejection and BWR and control drop are considered the  
14 most limiting scenarios for the current operating  
15 fleet.

16           MEMBER MARCH-LEUBA: Hey, Paul. Sorry.  
17 This is Jose again. Sorry to interrupt, but this is  
18 how real meetings go. We are always interrupting you.  
19 A year or two ago over several review cycles, we have  
20 wondered if you have to assume an additional single  
21 failure.

22           So if you initiate the event, it's a  
23 control rod ejection. Do you need to assume that  
24 another rod doesn't scram, if it fails to scram? And  
25 we worked this with the staff. And at the end, I'm

**NEAL R. GROSS**

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

1 not sure how we resolved it. But they convinced us  
2 that no, you don't have to. What's your view on that?

3 MR. CLIFFORD: I think when you get into  
4 the assume single failure, you're in the GDC 27. And  
5 this Reg Guide does not address GDC 27. But from my  
6 experience working in the industry, we would always  
7 assume that instead of an N-1 scram worth, it would be  
8 an N-2 scram worth for the rod ejection event.

9 However, in the current plant  
10 configurations of the operating fleet, N-1, N-2  
11 doesn't make a difference because this is not a  
12 limiting shutdown margin accident. And as I  
13 mentioned, it's initially turned around by Doppler.  
14 So the assumption of an N-1 or N-2 scram configuration  
15 does not affect this accident.

16 MEMBER MARCH-LEUBA: It doesn't affect the  
17 first ten seconds of the transient, but it makes an  
18 impact 36 hours behind. So basically you're telling  
19 me that this Regulatory Guide is silent on the single  
20 failure criteria and other GDCs would control that?

21 MR. CLIFFORD: Correct. We focus -- the  
22 stated purpose of this Reg Guide is that it provides  
23 guidance on how to evaluate the initial response of  
24 the reactor. In other words, the first five seconds  
25 and how you show compliance with those applicable

**NEAL R. GROSS**

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

1 regulations in 28 and in the dose requirements which  
2 all are occurring in the first five seconds.

3 MEMBER MARCH-LEUBA: Yeah, our job as ACRS  
4 members is to try to look a little bit in the future  
5 or what is changing instead of just blindly applying  
6 the rule. And one thing that's changing is reactors  
7 are becoming smaller and they have less control rods.  
8 So when it's in a very large PWR, N-1 or N-2 makes no  
9 difference.

10 In these small reactors, N-2 is a lot  
11 minus 2. When N is only 10, that minus 2 makes a big  
12 difference, but I get your meaning. This Reg Guide  
13 does not address the issue, and this has to be address  
14 by other Reg Guides or GDCs.

15 MR. CLIFFORD: Yes, 100 percent.

16 MEMBER MARCH-LEUBA: Yeah, okay. Thank  
17 you.

18 MR. CLIFFORD: Okay. Now getting into the  
19 accident sequence for these postulated accidents. The  
20 control rod ejection is postulated to occur because of  
21 the mechanical failure which causes an instantaneous  
22 circumferential rupture of the control element drive  
23 mechanism housing or its associated nozzle. This  
24 results in the reactor coolant pressure ejecting the  
25 control rod and drive shaft to the fully withdrawn

**NEAL R. GROSS**

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

1 position.

2 BWR sequence of events is a little  
3 different. A control blade is inserted into the core  
4 and becomes decoupled from the drive mechanism. The  
5 drive mechanism is subsequently withdrawn. The  
6 control blade is assumed to be stuck in place, and at  
7 a later moment, the control rod suddenly falls free  
8 and drops to the control rod drive position.

9 MEMBER MARCH-LEUBA: This is Jose again.  
10 Sorry to be disrupting what you were planning to say.  
11 But we have also been talking in our meetings about  
12 especially on the PWR event what we call a missile.  
13 So if the control rod housing breaks and the control  
14 rod gets ejected, I think this new Reg Guide is mostly  
15 worried or concerned about the thermodynamics inside  
16 the core.

17 We were concerned, does that ejected  
18 control rod has to be treated as a missile and see  
19 what it hits? We know that some reactors have missile  
20 shields for such events. I'm going to say again that  
21 your Reg Guide is silent on this issue.

22 MR. CLIFFORD: Yes, this Reg Guide is  
23 silent on that issue because that involves the  
24 mechanical design of the reactor vessel itself. And  
25 that responsibility resides in the Division of

**NEAL R. GROSS**

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

1 Engineering, and that's a different section. I  
2 believe that's SRP Section 394 or 395, and there's  
3 guidance in that Reg Guide on the -- what's the word  
4 I'm looking for -- the integrity of the vessel and the  
5 pedigree at which the vessel is manufactured. And it  
6 involves GDC 14 compliance. So once again, this Reg  
7 Guide doesn't get into GDC 14.

8 MEMBER MARCH-LEUBA: Yeah, the question we  
9 were -- I'm just bringing up things we've talked about  
10 in our previous meetings over the last couple of  
11 years. And we were not very sure whether -- who's in  
12 charge of reviewing this missile or even if you have  
13 to review it as a missile or not? This guy -- what  
14 we're reviewing today is not covered by that. That  
15 should be some other topic of responsibility.

16 MR. CLIFFORD: Yes, it needs to reside in  
17 the Division of Engineering because they are  
18 responsible for reviewing the reactor vessel.

19 MEMBER MARCH-LEUBA: And changing the  
20 topic but it's related. We also talked about when you  
21 open the hole on the vessel, you have the first five  
22 seconds are the most important ones when you have the  
23 power excursion and the Doppler turned it around. But  
24 you are also creating a LOCA.

25 Is this supposed to be covered by the

**NEAL R. GROSS**

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

1 small-break LOCA analysis that was performed somewhere  
2 else in Chapter 15? I'm going to say again you're  
3 silent on it because you can have the first five  
4 seconds, the big power pulses. Those are the  
5 important ones. But then as you -- if you have a  
6 LOCA, you have to make sure you don't uncover the  
7 core, right?

8 MR. CLIFFORD: Right. So I would say that  
9 this reactivity initiated accident class of events was  
10 stylized from a point of limiting fuel rod design and  
11 control element design so that you would avoid the  
12 catastrophic failure and show compliance with GDC 28.  
13 A break in the reactor vessel that would result in a  
14 slow depressurization of the RCS would then require  
15 engineered safety functions and systems to limit the  
16 consequences of that type of very slow evolving loss  
17 of coolant accident. So ultimately, your ECCS would  
18 be actuated and your ECCS would be relied upon to  
19 ensure long-term cooling (telephonic interference) and  
20 the removal of decay heat.

21 MEMBER MARCH-LEUBA: I understand your  
22 point of view. What I'm worried -- I've been worried  
23 for several -- I've been a member for now three years,  
24 and I worry there is some discontinuity, some  
25 compartmentalization of the review. My job is to look

**NEAL R. GROSS**

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

1 at the first five seconds. Somebody else will look at  
2 the LOCA.

3 I would have loved to see this RG point or  
4 assess and verify that the small-break LOCA spectrum  
5 analysis covers the break that you discussed today.  
6 And just a simple -- ensure that you -- because the  
7 guys that do the small-break LOCA -- look at pipes  
8 that connect to the vessel. That's where things  
9 break. And now we're postulating that a control rod  
10 housing is breaking and it's a different size,  
11 different location. How do we know it's covered?

12 And what I'm worried -- and I'm not saying  
13 this happened -- is Paul is telling me, I made sure  
14 the electronics were okay. My -- temperature didn't  
15 melt. I didn't violate any of my calorie per grams  
16 limit. And the small-break LOCA is on Chapter 15 and  
17 say, well, we look at all the pipes and when they  
18 break, nothing happens, and nobody looked at the  
19 housing breaking.

20 MR. CLIFFORD: I agree with what you're  
21 saying, and I understand where you're going. And that  
22 really comes from the discontinuity in 50.46 because  
23 50.46 which is a regulation on -- which governs the  
24 design of your emergency core cooling system,  
25 specifically limits breaks to those in piping and not

**NEAL R. GROSS**

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

1 in penetrations in the reactor vessel.

2 So there could be multiple penetrations in  
3 the reactor vessel. And if you were to break those,  
4 then you would have a loss of coolant accident. But  
5 it's outside of the regulatory requirements for the  
6 ECCS system. So in other words, you're not designing  
7 your ECCS to mitigate the consequences of a vessel  
8 break. And I don't know the history of all of that  
9 because, once again, that really resides in the  
10 Division of Engineering. But I believe it's because  
11 the penetrations are all designed to GDC 14 standards.  
12 And GDC 14, to meet those standards, you have to show  
13 that there's an extremely low probability of gross  
14 failure of those vessel penetrations.

15 MEMBER MARCH-LEUBA: By this, you are  
16 assuming it broke because you're saying my rod ejects.

17 CHAIR KIRCHNER: Again, Jose, this is --  
18 because as Paul used the operative words, this is the  
19 stylized event specifically targeted at GDC 28 and  
20 hence sets a limit on things like control rod work or  
21 reactivity in the core, et cetera, for purposes of GDC  
22 28.

23 MEMBER MARCH-LEUBA: Yeah. I'm not saying  
24 I see any problem anywhere. I'm just trying to make  
25 people think if you see there are holes, and I see

**NEAL R. GROSS**

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

1 some discontinuities. I'm not seeing a problem. I  
2 mean, it depends on what people think how we're doing  
3 this stuff. Please do continue.

4 MR. CLIFFORD: Okay. So next, we will  
5 discuss a timeline and stakeholder comments. Now onto  
6 Slide 8. This timeline shows the evolution in  
7 regulatory guidance beginning in 1974 with the release  
8 of Reg Guide 1.77 and ending with today's briefing.  
9 Note the two public comment periods for DG-1327 which  
10 was subsequently designed Reg Guide 1.236. And now  
11 we'll go on to Slide 9 and talk about each of these.

12 Before we begin with the requirements or  
13 the guidance, it's important to know that in-pile  
14 prompt critical power excursion type testing is  
15 required to understand the phenomena, to identify  
16 damage mechanisms and failure modes, to calibrate  
17 analytical models, and finally, to establish  
18 analytical limits to ensure acceptable fuel  
19 performance. In 1974, the year Reg Guide 1.77 was  
20 issued, the empirical database consisted of ten in-  
21 pile property activity insertion tests conducted  
22 within the capsule driver core of the Special Power  
23 Excursion Reactor Test program, referred to as SPERT-  
24 CDC. These tests were conducted in 1969 and 1970.

25 Reg Guide 1.77 used the empirical

**NEAL R. GROSS**

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

1 database, although limited at the time, to provide  
2 acceptable analytical methods and models and  
3 assumptions for modeling a PWR control rod ejection.  
4 In addition, it provided coolable geometry limits,  
5 limits on reactor coolant system pressure, and limits  
6 on radiological consequences, and these are provided  
7 here on the slide. Two hundred and eighty calories  
8 per gram was the peak radial average fuel enthalpy  
9 allowed. Reactor system pressure was limited to  
10 Service Level C, and offsite dose consequences were  
11 limited to well within the guidance in Part 100.

12 Now well within translates to 25 percent.  
13 So for the maximum hypothetical accident which is of  
14 a lower frequency, the allowance would be 100 percent  
15 of 10 CFR Part 100. But for this class of accidents  
16 which is considered more likely, the radiological  
17 consequences are limited to 25 percent of the limits.

18 MR. CORRADINI: Paul?

19 MR. CLIFFORD: Yes.

20 MR. CORRADINI: Can I just get a  
21 clarification? I think I know what peak radial  
22 average fuel enthalpy means. That means you're  
23 looking for the peak in the radial direction, the  
24 average within the pellet. Is that correct?

25 MR. CLIFFORD: Correct.

1 MR. CORRADINI: Okay. Which means you get  
2 some sort of spatial distribution in the pellet which  
3 has to be then -- I don't want to use the word back  
4 calculated but evaluated because there might be  
5 regions which are solid and there might be regions  
6 where there's melt.

7 MR. CLIFFORD: Correct. But as we'll get  
8 into, the allowable melt is very limited.

9 MR. CORRADINI: Okay, understood. And  
10 then the second part of this is with UO<sub>2</sub>, I'm just  
11 trying to remind myself of the numbers. With UO<sub>2</sub>, 280  
12 calories per gram average over the pellet is a small  
13 amount of melt is in existence if I do just a  
14 thermodynamic balance, right?

15 MR. CLIFFORD: Correct. And that portion  
16 of molten fuel would increase with burnup as melting  
17 point diminishes.

18 MR. CORRADINI: Correct, right. Sorry,  
19 that's right because of the change of property.  
20 Excuse me. Got it. Thank you.

21 MR. CLIFFORD: Okay. So moving to Slide  
22 10, we're going to 1980. So from 1978 to 1980, a  
23 series of in-pile tests were conducted at the Power  
24 Burst Facility in Idaho. This led to additional data,  
25 and this data suggested a need for new analytical

**NEAL R. GROSS**

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

1 limits.

2 A paper was published which recommended  
3 changes to the existing criteria. The coolability  
4 criteria was reduced from 280 calories per gram to 230  
5 calories per gram. Cladding failure thresholds were  
6 reduced from 170 to 140 for irradiated fuel. It was  
7 noted that the failure mode strongly dependent on  
8 prior irradiation history. And based upon advanced  
9 analytical methods and evaluations, it was concluded  
10 that there was no eminent safety concern for the  
11 operating fleet. The guidance in Reg Guide 1.77 was  
12 not revised. However, many plants voluntarily  
13 implemented reduced limits.

14 Moving on to 2004. By 2004, the empirical  
15 database had increased significantly with in-pile  
16 testing being performed in France, Japan, and Russia.  
17 In response to reported PCMI cladding failures at  
18 lower than expected deposition energies, the NRC  
19 completed a detailed safety assessment. Based upon  
20 the research which was conducted, the expanded  
21 empirical database, and advanced analytical methods,  
22 RIL-0401 concluded that there was no eminent safety  
23 concern in the current fleet. However, different from  
24 in the past, it was decided that the guidance would be  
25 updated based on the latest and greatest information.

**NEAL R. GROSS**

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

1           So building upon the expanded empirical  
2           database, the NRC issued interim guidance in 2007.  
3           There were ACRS briefings before the interim went out.  
4           There was a public comment period before the interim  
5           guidance went out. The guidance is documented in  
6           Appendix B, the Standard Review Plan 4.2.

7           The guidance provides hydrogen-dependent  
8           PWR and BWR PCMI cladding failure thresholds, cladding  
9           delta P-dependent failure thresholds for high  
10          temperature failure modes, burnup-dependent  
11          coolability criteria, and finally, transient fission  
12          gas release. This guidance was classified as interim  
13          because the staff was awaiting further test results to  
14          help resolve some scaling issues with the data.

15          Moving on to today, Slide 13 presents the  
16          current empirical database. Tests conducted since the  
17          interim guidance in 2007 are highlighted in red. This  
18          data collectively was used in the development of the  
19          final guidance within Reg Guide 1.236.

20          MEMBER MARCH-LEUBA: Paul, this is Jose  
21          again. Can you spend a little more time on the  
22          difference between the black dots and the open dots?  
23          What are we looking at here?

24          MR. CLIFFORD: I'm glad you said that. I  
25          actually had a note to say something about that, but

**NEAL R. GROSS**

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

1 I missed it. Okay. So the open dots -- well, first  
2 of all, there's different symbols based on where the  
3 tests were conducted. There's a different symbol for  
4 SPERT versus PBF versus BGR and IGR which is -- let's  
5 see what that -- those are the test reactors in  
6 Russia. Impulse Graphite Reactor, I believe that's  
7 what IGR stands for, the French reactor CABRI and the  
8 Japanese reactor NSRR.

9 The close symbols are those that failed.  
10 The open symbols are those that did not fail. It's  
11 important to note that not everybody reported the same  
12 information for CABRI and for NSRR. They reported the  
13 enthalpy at the time of failure. But for IGR and  
14 BGR, they just reported the maximum enthalpy. So you  
15 don't know when it failed. You only know that it  
16 failed, whereas NSRR and CABRI, you know when it  
17 failed. So it's a little more -- it's much more  
18 valuable from that perspective.

19 MR. CORRADINI: Paul, can you -- I guess  
20 I wanted you to talk through the red since some of the  
21 red failures are at low values, and I guess I want to  
22 understand the new data that you emphasized.

23 MR. CLIFFORD: Well, the red was just  
24 emphasized as being the most current data. We'll get  
25 through how I used this data because the data is all

**NEAL R. GROSS**

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

1 used differently, depending on what the failure mode  
2 is. And we'll get into that in the coming slides.

3 MR. CORRADINI: Thank you.

4 MEMBER MARCH-LEUBA: So you have -- this  
5 is Jose again. You have looked at it, I mean, all  
6 your life and understand it. Do you see any  
7 correlation with new fuels, new materials, better  
8 cladding, or it's all the same?

9 MR. CLIFFORD: We can get into that.  
10 Certainly, there are burnup effects and there are  
11 corrosion effects and there are also fabrication  
12 effects. And all those are considered in this Reg  
13 Guide.

14 MR. CORRADINI: But I think what Jose is  
15 asking is if it were M5 versus ZIRLO versus Zirc-4  
16 versus Zirc-2, is there a difference?

17 MR. CLIFFORD: Yes, and there are  
18 different analytical limits for each one of those  
19 cladding types.

20 MEMBER BALLINGER: This is Ron. In fact,  
21 most of the Zircaloy-2 and Zircaloy-4, you don't see  
22 those in cores anymore at all, right?

23 MR. CLIFFORD: Right.

24 MEMBER BALLINGER: The last batch of  
25 Zircaloy in a core I think has probably already been

**NEAL R. GROSS**

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

1 discharged. So it's either all ZIRLO or M5, right?

2 MR. CLIFFORD: So for the PWRs, I don't  
3 believe there's any reactors that are taking fresh  
4 batches with Zirc-4. I think that's --

5 MEMBER BALLINGER: Yeah, that's what I was  
6 --

7 MR. CLIFFORD: -- the last one.

8 MEMBER BALLINGER: -- thinking. So the --  
9 rates for M5, they're much, much lower than for Zirc-  
10 4. And the hydrogen pickup rate is also much lower  
11 than for Zirc-4. Am I right?

12 MR. CLIFFORD: Yes, and that is  
13 specifically accounted for in this guidance.

14 MEMBER BALLINGER: Yeah.

15 MR. CLIFFORD: And I'll get to that.

16 CHAIR KIRCHNER: Just a quick break here,  
17 Paul. Members, when you ask a question or make a  
18 statement, please identify yourself. That will help  
19 for people who are not on Skype but are on a public  
20 line. Thank you.

21 MR. CLIFFORD: Okay. As we go through the  
22 guidance, I'll try to keep that in my mind to make  
23 sure I get into the alloy specific aspects of it and  
24 the fuel specific aspects of it. If I don't, just ask  
25 me some questions. So we're moving on to Slide 14,

**NEAL R. GROSS**

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

1 and this is the first public comment period in 2017.

2 So there was an ACRS briefing in 2016.  
3 Shortly afterwards, DG-1327 went out for public  
4 comment. Comments were received from 12 stakeholders  
5 with a total of 124 comments. Over 100 comments were  
6 accepted and prompted changes to the guidance. This  
7 pie chart below shows the distribution of comments to  
8 the various sections of the Reg Guide.

9 And if you quickly look at it, you see the  
10 lion's share of comments were in the analytical  
11 methods section, the range of applicability and in the  
12 failure threshold curves. However, there were  
13 comments received in really all aspects of the  
14 guidance. And as I mentioned, 100 of the comments  
15 were accepted and the NRC made changes to the guidance  
16 in response to those comments.

17 In 2017, DG-1327 went out for a second  
18 round of public comments. There was comments received  
19 from seven stakeholders with a total of 54 comments.  
20 Over 30 comments were accepted and prompted changes to  
21 the guidance. Here's the distribution of the comments  
22 received in 2019.

23 It's worth noting that there a large  
24 portion of the comments were on the radiological  
25 source term information, and those comments were

**NEAL R. GROSS**

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

1 mostly directed at removing that information from this  
2 Reg Guide and putting it back into Reg Guide 1.183.  
3 There were also comments on the failure threshold  
4 curves.

5 It's kind of worth noting that every time  
6 we've gone out for comments, we received  
7 recommendations on how to redraw the figures, one way  
8 or another. And each time we've gone out, we have  
9 redrawn the figures. And I'll get to that later on,  
10 but I think that leads to a little regulatory  
11 instability when you start continuous -- when you  
12 continuously redraw figures based on the same data  
13 set. And I'll get to what the staff's recommendations  
14 on that is.

15 MR. CORRADINI: Paul, this is Corradini.  
16 One thing that you don't have to answer now but  
17 whatever is logical to put in. When you identify peak  
18 radial average enthalpy -- fuel enthalpy, is there a  
19 spatial area over which this is analyzed? That is,  
20 are we looking at a single pin, at a fuel assembly, at  
21 a group of fuel assemblies, because I think that has  
22 evolved over time given the ability to do better  
23 resolution of reactor physics. And I can't remember  
24 where that sits now.

25 MR. CLIFFORD: No, you're 100 percent

1 correct. It really depends on the granularity of the  
2 physics model that's used to calculate that. Going  
3 back in time, you would see a physics node would be  
4 approximately six inches. But since then, they've  
5 grown shorter because the computational abilities are  
6 much stronger. So you can afford more detailed  
7 resolution when you're solving your equations. So I  
8 think it depends on what's approved and when it was  
9 approved.

10 MR. CORRADINI: In terms of the analysis.  
11 But what I was trying to get at is -- well, I'll ask  
12 it again later when you get to loss of coolable  
13 geometry. I'm trying to understand the spatial area  
14 over which loss of coolable geometry is considered.  
15 If I had a single pin or a single two or three pins  
16 for whatever that would undergo failure, cladding  
17 failure, that's different than would be a fuel  
18 assembly. I'm just trying to understand how that's  
19 done now with the new guidance.

20 MR. CLIFFORD: Okay. Yeah, we'll get to  
21 it in the new guidance. But to answer your question  
22 now, it is based essentially down to the pellet. You  
23 can now see the coolability criteria down to a pellet  
24 or whatever node that the limiting node is. That node  
25 might be three or four pellets that are you're

**NEAL R. GROSS**

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

1 calculating, but it's down to that one single point in  
2 the most limiting rod.

3 MR. CORRADINI: Thank you.

4 MR. CLIFFORD: Okay. So --

5 MR. SCHULZ: Paul, excuse me. This is  
6 Steve Schulz.

7 MR. CLIFFORD: Yes.

8 MR. SCHULZ: You mentioned a radiological  
9 source terms and fission product release fractions  
10 that the number of comments there were disposition by  
11 referring them to Reg Guide 1.183, 1.195. Does that  
12 mean that those are in process of being redeveloped,  
13 and then therefore the information that was developed  
14 here that affected those guides is going to be  
15 addressed in the future?

16 MR. CLIFFORD: Yes, we are actively  
17 updating those Reg Guides now. As you may now, Reg  
18 Guide 1.183 has kind of a long history. It went out  
19 for public comment in DG-1199, I believe, many years.  
20 Lots of comments were received and resolved. However,  
21 the Reg Guide was never issued final. That was one of  
22 the reasons that prompted me to take the relevant  
23 information that was going to be in that revision to  
24 that Reg Guide 1.183 and move it into Reg Guide 1.236.  
25 Knowing that, it really didn't -- it shouldn't reside

**NEAL R. GROSS**

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

1 there but just a means to get it out. But the  
2 comments we received were that it shouldn't reside  
3 here if it's confusing to the industry because you're  
4 now going to have a duplication of information in two  
5 different Reg Guides and they're not identical. So --

6 MR. SCHULZ: Right.

7 MR. CLIFFORD: -- the comments were move  
8 it back where it belongs to Reg Guide 1.182, and  
9 that's what we plan on doing. We're actively updating  
10 that and we're pushing to move that forward this year.

11 MR. SCHULZ: This year, okay. That was --  
12 the second part of my question was on schedule.

13 MR. CLIFFORD: So we have a major action  
14 involving burnup extension. So we need to update that  
15 Reg Guide, not just to bring it to the current state  
16 of knowledge but also to update it to support the  
17 higher burnups.

18 MR. SCHULZ: That's right. And the  
19 elements that are associated with the newer fuel  
20 designs are also affecting that Reg Guide and that  
21 effort?

22 MR. CLIFFORD: Well, certainly, the burnup  
23 has a direct impact on the source terms.

24 MR. SCHULZ: Okay. Thank you.

25 MR. CLIFFORD: But the source term was not

**NEAL R. GROSS**

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

1 just burnup specific. We needed a new source term  
2 that would have a higher power level at extended  
3 burnups so that it would support even current fuel  
4 management techniques. Right now, people can't meet  
5 the Reg Guide 1.183 applicability limit. I believe  
6 you can't be higher than 6.3 kilowatts a foot beyond  
7 54 gigawatt-days. They can't meet that with modern  
8 fuel management.

9           So we needed to expand that power burnup  
10 window, and we did that in the early revision to Table  
11 3 which is the gap fractions. But now we're going to  
12 extend that even further to encompass the extended  
13 burnup. So it's both extended burnup and extended  
14 power.

15           MR. SCHULZ: Good. Thank you.

16           MR. CLIFFORD: Okay. So in response to  
17 two rounds of public comments, we made many changes  
18 and I'm just going to go over the major ones. And  
19 we'll get into more detail as we get into the specific  
20 guidance. But we expanded the allowable fuel burnup  
21 or the applicability range of the guidance out to 68  
22 gigawatt-days rod average burnup. That's in Section  
23 C-1.

24           We improved the analytical requirements.  
25 As I mentioned, there were lots of comments to on to

**NEAL R. GROSS**

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

1 provide clarity to the requirements or the  
2 organization. For instance, we lumped them all  
3 together. And as a result of comments, we tried to  
4 put the PWR-specific guidance in one section and the  
5 BWR-specific guidance in a different section just to  
6 make it clear.

7 We revised the PCMI cladding failure  
8 threshold curves in Section C-3. We removed the  
9 radiological source term information which was put in  
10 for the second round, now being taken out for the  
11 final. And that included the analytical requirements,  
12 the fission product gap release fractions, and an  
13 acceptable analytical procedure for calculating design  
14 specific gap fractions which has not existed. We  
15 amended the implementation section to reflect the  
16 Commission's revised backfit guidance, and we added  
17 hydrogen uptake models to aid in the implementation.

18 MEMBER REMPE: Paul, this is Joy Rempe,  
19 and I have a question that's more related to  
20 knowledge-management of the agency. We followed the  
21 Reg Guide. We've been given these slides which have  
22 more of a technical basis for changes, and there was  
23 a memo that was passed to us yesterday.

24 But in some cases when I look at the  
25 comments you received and responses back, you made

**NEAL R. GROSS**

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

1 some changes. Is there some sort of Technical Basis  
2 Document that underlies this Reg Guide for knowledge-  
3 management within the agency so they can understand  
4 more about what's in the Reg Guide and the basis for  
5 it?

6 MR. CLIFFORD: Right. So there was a memo  
7 made 40 or 50 pages long that provided the technical  
8 and regulatory basis for what was in the Reg Guide.  
9 And that was developed to support the interim  
10 criteria. And then that was revised to then support  
11 the changes in the first -- should I say the 2017  
12 version of DG-1327.

13 And then further changes to the Reg Guides  
14 are document as part of a public comment response  
15 table which is also captured in ADAMS. And then we  
16 would have then, of course, the second round of public  
17 comment responses. We would show the changes to the  
18 documents there.

19 So you're right. It is kind of a  
20 piecemeal -- if you went back in history, it is a  
21 little piecemeal that you would have three sources  
22 defining the technical basis for the Reg Guide. It  
23 would be the initial memo, then it would be the  
24 revisions and the public comment response table from  
25 2017, and then it'd be revisions from the public

**NEAL R. GROSS**

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

1 comment response table in 2019.

2 MEMBER REMPE: So is that trail at least  
3 documented somewhere internally within the agency? I  
4 know it's in ADAMS, and I just don't know all the  
5 links and things. But if a staffer wants to figure  
6 this out, to at least know how to get to the piecemeal  
7 trail.

8 MR. CLIFFORD: Yeah, if you -- it's  
9 probably the introduction section of the Reg Guide,  
10 one of the first pages. There's kind of a history  
11 there, and it describes the basis, exactly what I  
12 said. And all three of those documents are in ADAMS  
13 and they're referenced in the Reg Guide.

14 MEMBER REMPE: I didn't see, like, your  
15 memo provided us references, but perhaps I've missed  
16 that somewhere in the introduction.

17 MEMBER BALLINGER: This is Ron Ballinger.  
18 Talking about the memo related to the 68 gigawatt-days  
19 for time?

20 MR. CLIFFORD: No.

21 MEMBER REMPE: That came yesterday --  
22 (Simultaneous speaking.)

23 MEMBER BALLINGER: That's yesterday.

24 MR. CLIFFORD: That's yesterday.

25 MEMBER BALLINGER: But in a lot of these

**NEAL R. GROSS**

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

1 Reg Guides, there is a technical basis that's in one  
2 place. And might we not consider instead of forcing  
3 the reader, because this is a fairly important Reg  
4 Guide, to go and have sort of ASME codes fingered in  
5 five different locations pages and have it in one  
6 place that kind of unifies everything. It's  
7 especially good for this knowledge-management thing,  
8 but just for people's sanity when they want to go look  
9 this up.

10 MR. CLIFFORD: No, I mean, that's a good  
11 recommendation. That could be a good recommendation  
12 for the ACRS to update that.

13 MEMBER REMPE: Thank you.

14 MR. CLIFFORD: So we're at a natural break  
15 here. Before we move on to the next topic which is  
16 walking through the guidance, are there any more  
17 questions on the timeline or the comments we received  
18 to date?

19 MEMBER REMPE: I'm not sure if this is a  
20 good place or later, and I'm willing to wait till  
21 later. But I had a question about the applicability  
22 for this Reg Guide. Is this a good place to ask this  
23 and your logic for it and why you have what you have  
24 there, or should I wait?

25 MR. CLIFFORD: I think if we wait and hold

1 that question because I'm going to be walking through  
2 the different failure modes and how the different  
3 analytical limits are applied to different fields. So  
4 maybe that'll answer it naturally as we go through it.

5 MEMBER REMPE: Okay. So this is, like,  
6 Section 1.1 of your Reg Guide is where I -- like, you  
7 ruled out greater than five percent.

8 MR. CLIFFORD: And so that's the question,  
9 why we ruled out greater than five percent?

10 MEMBER REMPE: There's a couple of  
11 different ones like that that I'm just wondering what  
12 the logic will be. Is everything going to just be  
13 case by case in the future? You've talked about the  
14 new fuel. Well, they may go to higher enrichment.  
15 What about if you have a modular reactor with PWR fuel  
16 operating at BWR pressures? Is that something that --  
17 are these all just going to have to be case by case?

18 MR. CLIFFORD: Yeah. I mean, if you read  
19 the introduction paragraph of the applicability  
20 section, it does kind of state that this is applicable  
21 to the current operating fleet for the PWRs and BWRs.  
22 And the design-specific changes to modular reactors or  
23 advanced reactors would need to be addressed on a  
24 case-by-case basis. I guess the applicant would need  
25 to come in and say why the Reg Guide continues to be

**NEAL R. GROSS**

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

1 applicable to their design given whatever changes  
2 they're making to that design.

3 It's difficult to try to make any blanket  
4 statements on how you could apply this to a different  
5 design because I just don't understand what that  
6 design is. I mean they could have an entirely  
7 different pulse width profile or different blade  
8 widths, or there could be a lot of different aspects  
9 of it.

10 MEMBER BALLINGER: This is Ron Ballinger  
11 again. I mean I think the limits, the way they're  
12 posed in terms of differential pressures and burnups  
13 and hydrogen content and those kinds of things kind of  
14 lay out the field. In an SMR, as long as the SMR fits  
15 in those fields, the fact that if one is operating PWR  
16 fuel with BWR differential pressure is naturally taken  
17 care of, right?

18 MR. CLIFFORD: Yes, in that particular --

19 MEMBER BALLINGER: Anything that would  
20 related to the source term is now going to be shifted  
21 to Reg Guide 1.183, right?

22 MR. CLIFFORD: Correct. As we go through  
23 the presentation, if we haven't addressed it, we can  
24 circle back.

25 CHAIR KIRCHNER: Okay. Paul, this is --

**NEAL R. GROSS**

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

1 is this a logical break point?

2 MR. CLIFFORD: Yeah, sure.

3 CHAIR KIRCHNER: Okay. Then why don't we  
4 take a -- on my NRC computer, it says it's 2:00 p.m.  
5 Eastern Time -- Daylight Time. Let's take a 10-minute  
6 break and reconvene at 2:10, 10 minutes from now.

7 (Whereupon, the above-entitled matter went  
8 off the record at 2:00 p.m. and resumed at 2:10 p.m.)

9 CHAIR KIRCHNER: Okay. Let's reconvene  
10 our meeting. This is Walt Kirchner from the ACRS, and  
11 this is a meeting of the Thermal Hydraulics and  
12 Metallurgy and Reactor Fuel Subcommittee. We are  
13 addressing Reg Guide 1.236, and Paul Clifford of the  
14 staff is the presenter. So Paul, if you're ready,  
15 please continue.

16 MR. CLIFFORD: Okay. Welcome back,  
17 everybody. Next, we're going to walk through the  
18 guidance with emphasis on what has changed relative to  
19 2016 version of DG-1327, the version that was  
20 presented to the ACRS. So we're not going to get into  
21 intermittent changes between the two public comment  
22 periods. We're just going to say this was a line in  
23 the sand in 2016, and here's the final.

24 So we begin with the RCS pressure  
25 analytical limit. The changes to the text are in

**NEAL R. GROSS**

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

1 blue. We modified the text based on comments  
2 received, noting that not all existing plants use the  
3 same pressure criterion. It's consistent with the  
4 current guidance and the practice, and it protects the  
5 reactor coolant pressure boundary, hence satisfying a  
6 portion of GDC 28.

7 CHAIR KIRCHNER: Now Paul, just for the  
8 record, when one does your pressure calculations, you  
9 take no credit for the fact that you actually have a  
10 LOCA, in the case of the PWR of sizable LOCA. Does it  
11 have actual failure of the control rod drive housing?  
12 So that is not credited. Is that correct?

13 MR. CLIFFORD: That is true. Any leakage  
14 through the postulated break in the control rod drive  
15 mechanism housing is not credited. However, it's  
16 probably worth noting in the first few seconds when  
17 you get your peak pressure even if you did credit it,  
18 it probably would not have a big impact since it's --  
19 I forget the size. I want to say 0.04 square feet is  
20 something that pops in my mind.

21 CHAIR KIRCHNER: Yeah, I think that it's  
22 probably in the order of a six-inch flange.

23 MR. CLIFFORD: I think it's smaller than  
24 that.

25 CHAIR KIRCHNER: Smaller than that? The

1 nozzles would be smaller. I wasn't sure about the  
2 flange size.

3 MR. CLIFFORD: I don't know. 0.04 square  
4 feet is something that just pops in my head.

5 CHAIR KIRCHNER: Okay. Thank you.

6 MR. CLIFFORD: Okay. Moving on to the  
7 next guidance, this is damaged core coolability. So  
8 here are some photographs of fuel rod test specimens  
9 from the SPERT-CDC test program which I mentioned took  
10 place in 1969 and 1970. When we define an analytical  
11 limit for damaged core coolability, we are trying to  
12 preserve the fuel pellet stack within the fuel rod  
13 cladding within a fuel assembly bundle array,  
14 essentially a known configuration which limits fuel-  
15 coolant interaction and also preserves a geometry  
16 that's amenable to coolant.

17 MR. CORRADINI: This is -- Paul, this is  
18 fresh fuel, Paul? This is Corradini.

19 MR. CLIFFORD: So if we went back and  
20 looked at it, I believe this was all fresh fuel --

21 MR. CORRADINI: Thank you.

22 MR. CLIFFORD: -- or really low burnup,  
23 within five or ten -- probably five gigawatt-days.

24 MR. CORRADINI: Thank you.

25 MEMBER PETTI: And Paul, the energy

**NEAL R. GROSS**

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

1 deposition is an average number? This is Dave. It's  
2 not the peak is it, or --

3 MR. CLIFFORD: I believe it was the peak  
4 deposited in the fuel.

5 MEMBER PETTI: Okay. Thank you.

6 MR. CLIFFORD: You could almost see the  
7 line, how they got to 280 at this point in time. At  
8 240, the cladding was failed but it was still a rod  
9 structure. It still had the same geometry which could  
10 be shown to be coolable. It wasn't -- it released its  
11 fission gas, but it didn't melt and the cladding  
12 maintained its structure.

13 So onto the guidance itself. Here's the  
14 wording that's in the guidance document. There's only  
15 editorial changes relative to 2016. The coolability  
16 limits remain unchanged. A loss of fuel rod geometry  
17 is limited to 230, and that's based on the earlier  
18 tests, not just SPERT but also reinforced with PBF and  
19 NSRR.

20 The limited centerline melt which is  
21 consistent with many plants FSAR design basis. Even  
22 though it allows melt, it's limited to 10 percent  
23 volume in the centerline region, hence avoiding molten  
24 fuel-coolant interaction. It should be noted that  
25 fuel melt criteria becomes more limiting at about 30

**NEAL R. GROSS**

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

1 gigawatt-days per metric ton of uranium.

2 In other words, you'll stop melting fuel  
3 below 230 calories per gram as you increase burnup.  
4 So the higher burnup fuel will be limited by the melt  
5 criteria. Note that these limits are designed to  
6 preserve coolability and satisfy GDC 28. And as I  
7 mentioned --

8 MEMBER REMPE: Paul?

9 MR. CLIFFORD: Yes.

10 MEMBER REMPE: This is Joy. I'm sorry.  
11 I thought you were done. If you have to finish a  
12 sentence, go ahead and finish it first.

13 MR. CLIFFORD: I was just going to remind  
14 it's just editorial changes made since 2016.

15 MEMBER REMPE: Okay. When I was looking  
16 through this -- and I apologize if I asked you this at  
17 the meeting whenever last time we met on it. But why  
18 is there so much focus on melting versus liquefaction,  
19 because in the severe accident world, we know that  
20 fuel and cladding materials can become liquid at lower  
21 temperatures than melting.

22 MR. CLIFFORD: Right. So what we're  
23 trying to do is really limit the fuel-coolant  
24 interaction. So if we're limiting it to just  
25 centerline melt, then we're not going to have that

**NEAL R. GROSS**

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

1 interaction with the coolant, even if the cladding  
2 fails.

3 CHAIR KIRCHNER: This is Walt. Joy, I  
4 think the other thing here is the time. This is  
5 almost instantaneous whereas in the severe accident  
6 world, you're setting time and temperature and you get  
7 changes in the phase diagrams, et cetera, et cetera.  
8 But this is -- here, we're dealing with a rather short  
9 time frame, and I think --

10 (Simultaneous speaking.)

11 MEMBER REMPE: So I think there's --

12 CHAIR KIRCHNER: -- focusing on melt  
13 versus other phase -- parts of the phase diagram.

14 MEMBER REMPE: I figured timing would be  
15 one of the big ones, but I just was wondering. I  
16 don't see any sort of lower temperature phenomena  
17 occurring because of the cladding and the fuel  
18 becoming liquid. I realize your point about timing is  
19 what I suspected the answer would be. But I never  
20 noticed that in any of these tests, I guess is what  
21 you're saying.

22 MEMBER PETTI: Joy, this is Dave. I can  
23 remember being in Idaho when --

24 (Simultaneous speaking.)

25 MEMBER REMPE: Dave, you're going to have

**NEAL R. GROSS**

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

1 to talk louder. I just cannot hear you.

2 MEMBER PETTI: Oh, okay. I remember  
3 talking to the guys that were doing the fuel-coolant  
4 interaction analysis on one of the PBF tests that was  
5 particularly Korea. And the severe accident loss was  
6 just starting, so they knew about that stuff at the  
7 same time. But it never came in. It must have been  
8 the time to get an interaction on a phase diagram. It  
9 was the kinetics of, frankly, it's got to take some  
10 time to occur, and it's just not occurring in the  
11 millisecond time scale here.

12 MEMBER REMPE: Yeah, that's what I was  
13 wondering, if they never seen it at all. Thank you.

14 MEMBER PETTI: An interesting question,  
15 for sure.

16 MEMBER REMPE: I wish you could find a way  
17 to get the volume up, Dave. I can kind of hear you.  
18 But boy, it's hard compared to other speakers.

19 MEMBER PETTI: I'm talking directly into  
20 cell phone. Even on the computer, I can't -- nobody  
21 can hear me through my headphones for some reason.

22 CHAIR KIRCHNER: For those of us in Idaho,  
23 just yell out the back window.

24 (Laughter.)

25 MEMBER REMPE: I didn't think of that.

**NEAL R. GROSS**

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

1 You're right.

2 MR. CLIFFORD: Okay. Moving on to Slide  
3 22, we're going to get into fuel failure estimates and  
4 radiological consequences. So to perform a proper  
5 radiological consequence assessment, first you need a  
6 conservative estimate of the number of rods that fell,  
7 and then you need an estimate of how much fission gas  
8 is released from each of the rods that fell. In the  
9 Reg Guide, we provide guidance on estimating the total  
10 number of failed fuel rods from several different  
11 failure modes.

12 First, there's a high temperature cladding  
13 failure threshold which will be applied to prompt  
14 critical scenarios. And there's the traditional  
15 assumption of cladding failure if you violate your DNB  
16 critical power ratio design limits which are applied  
17 to non-prompt power excursions, then there's PCMI  
18 cladding failure. And finally there's a presumption  
19 of cladding failure upon centerline melt. We'll be  
20 getting into each one of these.

21 The guidance for estimating or providing  
22 a conservative estimate of the amount of fission gas  
23 which is released from each failed rod includes  
24 steady-state gap inventories, releases during the  
25 transient as a result of separation of grain

**NEAL R. GROSS**

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

1 boundaries, and there's also additional releases if  
2 there's fuel melt. That guidance is being moved to  
3 Reg Guide 1.183 as we talked about.

4 So let's get into the guts of the guidance  
5 with respect to estimating fuel rod failures. We  
6 begin with high-temperature failure modes, and I'm  
7 just showing you the guidance. We're going to get  
8 into more detail when we get to Slide 25.

9 So the empirical database supporting this  
10 failure mode is comprised mostly of tests conducted in  
11 Japan NSRR test facility and Russia's BGR and IGR  
12 test facilities. Tests reported which had failures  
13 reported due to PCMI were removed from the database.  
14 Also, tests that were conducted in the CABRI sodium  
15 loop were also removed since the cladding would not  
16 have experienced any high temperature excursion.  
17 There are two failure modes which are reported. The  
18 first is brittle failure due to post-DNB oxygen-  
19 induced embrittlement, and the second is ductile  
20 failure due to post-DNB balloon and rupture.

21 So sensitivity studies. Here's the  
22 database plotted not as a function of burnup but as a  
23 function of cladding differential pressure. Note that  
24 the tests reported peak fuel enthalpy and not enthalpy  
25 of failure. So you're looking for the intersection

**NEAL R. GROSS**

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

1 between the failed solid symbols and the non-failed  
2 hollow symbols. And this red dotted line attempts to  
3 draw that kind of a line of demarcation between the  
4 failed and the non-failed.

5 As I mentioned in one of the earlier  
6 slides, sometimes the reported enthalpy at failure was  
7 provided. Sometimes it was just the peak enthalpy.  
8 And these particular events, it was peak enthalpy. So  
9 you don't know when it failed. You just know that it  
10 failed. So you have to look at the intersection  
11 between the two, the failed and the non-failed test  
12 segments.

13 The data exhibits a clear trend with  
14 decreasing failure enthalpy with increasing cladding  
15 differential pressure. It's also worth noting that  
16 any fission gas released during the transient would  
17 contribute to rod internal pressure and hence cladding  
18 DP, and the failure trend does not continue  
19 indefinitely, below 100 calories per gram. Reported  
20 cladding temperatures remained below 800 degrees F and  
21 is no longer sensitive to failure.

22 MEMBER MARCH-LEUBA: Hey, Paul, this is  
23 Jose. Reinforcing what you just said a moment ago,  
24 and I know you understand this. But I wanted to see  
25 if I understand it. Let's look at the one, two,

**NEAL R. GROSS**

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

1 three, four, five block squares at three megapascal.  
2 It tells me if I read it correct that one of them  
3 failed at 140, the other one failed at 160, the other  
4 one 200, 240, 300. But what you said is that most  
5 likely, they all failed at 140. It's only that the  
6 transient was so large that even though it failed at  
7 140, it continued to go all the way to 300. Is that  
8 what you said?

9 MR. CLIFFORD: Yes, that's exactly what  
10 I'm saying.

11 MEMBER MARCH-LEUBA: Okay. Thank you.

12 MR. CLIFFORD: Okay. So you guys can  
13 actually see my pointer on the screen when I move it?

14 CHAIR KIRCHNER: Yes, we can see it.

15 MEMBER MARCH-LEUBA: Yes, we can see it.

16 MR. CLIFFORD: Okay. I guess I didn't  
17 know that. Good, okay. Now we're moving on to Slide  
18 27. Okay. This figure shows the proposed cladding  
19 failure threshold along with the supporting empirical  
20 database. This failure threshold has remained  
21 unchanged since 2016. So at the beginning of this  
22 curve, you're protecting against brittle failure, then  
23 you move into ductile failure. And then at the end,  
24 there'd be no failures because the enthalpy is so low  
25 that you don't experience a significant transient.

**NEAL R. GROSS**

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

1                   MEMBER BALLINGER:     Paul, this is Ron  
2     Ballinger.    Quite a long time ago now, there was a  
3     study done where they did burst tests.   Admittedly, I  
4     believe it was on unirradiated fuel cladding.   But  
5     depending on the temperature, the differential  
6     pressure, and that's what I'm talking about here,  
7     differential pressure, the actual failure geometry of  
8     the cladding was quite different.   It ranged from just  
9     a little bit of a perforation kind of thing to a case  
10    where they had a fair amount of uniform expansion,  
11    almost superplastic behavior, and that would have a  
12    big difference, a big effect on coolable geometry.   Is  
13    any of that built into this?

14                  MR. CLIFFORD:    No, we're not trying to  
15    define -- like in LOCA, for instance, you have balloon  
16    and burst models which predict the extent of the  
17    balloon because you're interested in the effect of the  
18    balloon on kind of the long term thermal hydraulics.

19                  MEMBER BALLINGER:   But you are trying to  
20    factor in coolable geometry.   That's one of the  
21    requirements, right?

22                  MR. CLIFFORD:    Correct.   With respect to  
23    GDC 28, you're just trying to limit the rate and the  
24    amount of reactivity insertion and how that  
25    corresponds to basically violently failing the rod.

**NEAL R. GROSS**

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

1 Ballooning and bursting the rod, you still preserve a  
2 bundle geometry that's still felt to be amenable to  
3 cooling. And also, this event -- this class of event  
4 is very localized. It's not going to be a core-wide  
5 phenomenon like a LOCA would be where you're worried  
6 about ballooning a lot of rods and blocking flow for  
7 a large portion of the core. These are very localized  
8 activity events.

9 MEMBER BALLINGER: I remember photographs  
10 and things where the balloon section was basically six  
11 inches long.

12 MR. CLIFFORD: And realistically, if you  
13 look at the database for ballooning, there is a  
14 tremendous amount of spread in the size and shape of  
15 the balloon. And also those events are so slow  
16 compared to this prompt critical. You don't have a  
17 long time to heat up the cladding.

18 MEMBER BALLINGER: Okay. Yeah, I remember  
19 that. Okay, thanks.

20 MR. CLIFFORD: So as I mentioned, this is  
21 the basis for the high temperature cladding failure  
22 mechanisms. Here's the analytical limit, and it  
23 hasn't changed since 2016. One important item as I  
24 mentioned is the influence of transient fission gas  
25 release.

**NEAL R. GROSS**

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

1           Now during normal operation, fission gas  
2           is released.    And depending on fuel design and  
3           operating history, rod internal pressures will  
4           continue to increase as a result of this fission gas  
5           release.  It may even exceed reactor system pressure.  
6           During the transient, additional fission gas may be  
7           released which would also contribute to rod internal  
8           pressure.  Hence, this is a contribution which must be  
9           accounted for when applying this curve.  Looking at  
10          the available database, staff came up with burnup-  
11          dependent transient fission gas release correlations  
12          which are provided in the guidance to help estimate  
13          rod internal pressure.  These correlations are  
14          unchanged from 2016.

15                   MEMBER MARCH-LEUBA:  It took me a while to  
16                   unmute.  Can you explain the figure a little bit?  Can  
17                   you tell us what the figure says?

18                   MR. CLIFFORD:  Okay.  So the figure  
19                   provides measured transient fission gas release for  
20                   each of the tests as a function of the peak enthalpy  
21                   increase during the event.  And the symbols are color  
22                   coordinated based on the burnup.  So the green symbols  
23                   are the lower burnup, below 30 gigawatt-days.  The  
24                   blue symbols are intermediate burnup, between 30 and  
25                   50.  And the red symbols are greater than 50 gigawatt-

**NEAL R. GROSS**

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

1 days, so higher burnup.

2 And as with the other curves, the open  
3 symbols did not fail. So after the test, they  
4 would've been punctured and they would have measured  
5 the fission gas in the rod. And then the closed  
6 symbols are ones that failed, and they used different  
7 means to then measure the fission gas that was  
8 released into the test capsule.

9 MEMBER MARCH-LEUBA: So then I understand  
10 the red solid line is trying to bound all the failed  
11 rods with the red dots which are high burnup.

12 MR. CLIFFORD: Correct. Right. So when  
13 looking at the data, once again, there's a lot of  
14 spread in the data as there always is spread in the  
15 data when you're talking fission gas release. So  
16 transient gas release, not surprising to see this  
17 spread. But just from looking at the data, I guess we  
18 felt that there was an observation of higher fission  
19 gas release for the higher burnup rods. So at the  
20 same energy deposition, the higher burnup rods, about  
21 50 gigawatt-days, would release more fission gas --  
22 more relevant fission gas release.

23 MEMBER MARCH-LEUBA: And the blue solid  
24 line is trying to bound all of the green and blue dots  
25 --

**NEAL R. GROSS**

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

1 MR. CLIFFORD: Correct, right.

2 MEMBER MARCH-LEUBA: -- which are the ones  
3 below 50? And fission gas release percent, is that a  
4 percent of the theoretical calculated maximum,  
5 calculated production?

6 MR. CLIFFORD: Correct. So that --

7 MEMBER MARCH-LEUBA: What evidence?

8 MR. CLIFFORD: So that is a percent of  
9 fission gas that was created as a result of the burnup  
10 history. So of course, the moles of gas increases  
11 with time and with irradiation. So it's not the moles  
12 of gas. It's the percentage of the gas that's  
13 released. So that would be multiplied by the moles of  
14 gas at --

15 (Simultaneous speaking.)

16 MEMBER MARCH-LEUBA: So if I read 25  
17 percent FGR, I mean, 75 percent of the gas is the  
18 fission gases where it's still retaining, say, inside  
19 the crystalline structure, inside a pellet?

20 MR. CLIFFORD: Correct.

21 MEMBER BALLINGER: Though we have to be --  
22 this is Ron again. We have to be a little bit careful  
23 when we look at this because it's really -- it doesn't  
24 say it in the figure, but it's 25 percent of the gas  
25 released in the area for which the power excursion

**NEAL R. GROSS**

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

1 occurs. It's not the full rod, right?

2 MR. CLIFFORD: And that's the reason if  
3 you look at the text right above it is 2.3.3. We say  
4 you should calculate it along the length of the rod.

5 MEMBER BALLINGER: Right.

6 MR. CLIFFORD: So --

7 MEMBER BALLINGER: Along the length of the  
8 rod. Okay, okay.

9 (Simultaneous speaking.)

10 MEMBER MARCH-LEUBA: Go ahead, Paul.

11 MR. CLIFFORD: -- calculated it so like in  
12 the area where the rod was ejected which would be the  
13 top of the core, you might have 20 percent release.  
14 But six inches below that, you'd have 0 percent  
15 release because the change in fuel enthalpy would be  
16 --

17 MEMBER MARCH-LEUBA: Yeah.

18 MR. CLIFFORD: You wouldn't see a  
19 transient. So it's only a high percentage of those  
20 pellets that actually experience the release -- I mean  
21 the transient.

22 MEMBER BALLINGER: So the actually impact  
23 of the differential pressure is probably not that  
24 large.

25 MR. CLIFFORD: It's not that large.

**NEAL R. GROSS**

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

1       However, there was a least one test where it ballooned  
2       and failed when it shouldn't have, and that's really  
3       what focused the world's attention -- the nuclear  
4       world's attention on the potential for the transient  
5       fission gas release.

6                   MEMBER    MARCH-LEUBA:        Just   for   my  
7       education, Paul.  Is this the internal of the whole  
8       cycle burnup of production of gas, or is it only the  
9       gas that is produced during the peak during excursion  
10      as the rod is ejected?  This is a transient meaning  
11      during those two minutes -- two seconds where the  
12      power increased, you produce some gas.  And this is  
13      the fraction of that two second production that gets  
14      released, or is it the fraction of the gas that was  
15      produced since I started up?

16                   MR. CLIFFORD:  It's the fraction of gas  
17      since you started up, but --

18                   MR. SCHULZ:  It's the latter, yeah.

19                   MR. CLIFFORD:  Yeah, it's not -- if you  
20      were using this information for calculating doses, of  
21      course you would have to take into account the decay  
22      of each of the radionuclides and stuff like that that  
23      occur and how much activity was released.  But here,  
24      we're just talking moles of gas going into rod  
25      internal pressure.

**NEAL R. GROSS**

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

1 MEMBER MARCH-LEUBA: So it's mostly  
2 helium, but there is some --

3 MR. CLIFFORD: Mm-hmm.

4 MEMBER MARCH-LEUBA: Okay. Thank you.  
5 Somebody else had a question. I'm over and out.

6 MR. SCHULZ: Paul, this is Steve Schulz.  
7 It looks this is what again is being transferred to  
8 Reg Guide 1.183?

9 MR. CLIFFORD: So this was maintained in  
10 this Reg Guide because it feeds into the mechanical  
11 analysis of rod internal pressure. There would also  
12 be this information along with a breakdown of how to  
13 treat this for each of the radionuclide groups when  
14 calculating activity releases as a result of transient  
15 fission gas release. But that would be slightly  
16 different.

17 MR. SCHULZ: Would you not expect in terms  
18 of the fission gas release calculation from the event?  
19 Just in terms of the mechanics of the calculations,  
20 it's not trivial to implement the analysis of the  
21 steady state and now the transient fission gas release  
22 creating that pressure. So wouldn't you want to make  
23 sure that you have a consistent approach in this  
24 evaluation of gas release and the one that's used in  
25 1.183?

**NEAL R. GROSS**

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

1 MR. CLIFFORD: It will be consistent. The  
2 only difference will be this would be concerned mostly  
3 just about the moles of gas released, not the activity  
4 of each, because, for instance, if you have a long-  
5 term stable nuclide, krypton-85, it's not decaying.  
6 So whether it was born on day one or it was born a  
7 second before the transient, it's still going to be  
8 there and it's going to be released and you'll have to  
9 account for the dose count.

10 But if it was iodine-131 which has a much  
11 shorter half-life, the iodine that was created three  
12 weeks before the accident isn't active anymore. So it  
13 doesn't really affect it. So there has to be guidance  
14 on how to treat each of the radionuclides with respect  
15 to calculating the activity that's released or the  
16 additional activity that's released during the  
17 transient. But it's still using the same database to  
18 come up with a baseline. So you would see this figure  
19 in Reg Guide 1.183, but it would be focused more on  
20 how to use this information to determine the activity  
21 released from each of the radionuclide groups.

22 MR. SCHULZ: Yeah, that's post-accident,  
23 if you will, post-event in terms of the radiological  
24 release.

25 MR. CLIFFORD: Mm-hmm.

1 MR. SCHULZ: Okay. Thank you.

2 CHAIR KIRCHNER: Paul, I think -- this is  
3 Walt. I think you described it well. This is for the  
4 structural, the pressure loading calculation, not for  
5 the source term. But they would be consistent. You  
6 would start with this and then have to look at the  
7 speciation, half-lives, et cetera, et cetera. But for  
8 purposes of the  $PV=nRT$ , this is what is added to the  
9 existing rod internal pressure.

10 MR. CLIFFORD: That is correct. Okay. So  
11 let's move on to calculating additional failure modes,  
12 or using additional failure modes to calculate the  
13 total number of failed rods. So we get into the  
14 requirements associated with DNB and CPR.

15 Based upon comments received, the  
16 application of the high temperature cladding failure  
17 curve which we just talked about was changed from all  
18 zero power scenarios to all prompt critical power  
19 scenarios to be more consistent with the empirical  
20 database. So the way this is now worded was if you're  
21 at prompt critical excursion, you use Figure 1. If  
22 you're non-prompt, then you use your DNB, CPR thermal  
23 design limits to estimate cladding failure. Any  
24 questions?

25 (No response.)

1 MR. CLIFFORD: And the use of DNB as a  
2 cladding failure metric, that's the way it's always  
3 been done. Okay. Over on to the next failure  
4 mechanism which is PCMI, Pellet-Clad Mechanical  
5 Interaction. Here's the guidance that's in the Reg  
6 Guide for estimating the number of fuel rod failures  
7 due to PCMI. We'll get into a lot more discussion.  
8 What we're trying to protect is the failure of the  
9 cladding due to the mechanical interaction of the  
10 expanding pellet. So onto the details, Slide 31.

11 The PCMI empirical database as a function  
12 of fuel enthalpy rise versus cladding excess hydrogen.  
13 Hydrogen which is absorbed during normal operation  
14 forms zirconium hydrides which reduce the cladding's  
15 ductility. Hydrogen uptake depends on several  
16 factors, time and temperature, power history and  
17 fluence, alloy-specific corrosion and hydrogen pickup  
18 kinetics, proximity to dissimilar metals, and RCS  
19 chemistry. Low burnup and low corrosion fuel rods  
20 retain sufficient cladding ductility and will likely  
21 fail by the high temperature mechanisms we previously  
22 discussed.

23 Besides overall cladding hydrogen content,  
24 PCMI database exhibits sensitivity to hydride  
25 distribution and orientation. Hydride distribution is

**NEAL R. GROSS**

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

1 influenced by thermal and mechanical treatment during  
2 manufacturing and the stress state prevailing during  
3 hydride precipitation. This force micrograph shows  
4 the cross section of a high burnup PWR cladding  
5 manufactured in a stress-relieve annealed state.

6 This OD oxide layer is clearly visible at  
7 the top. Hydrides preferentially precipitate in a  
8 circumferential direction in the SRA state. Hydrides  
9 preferentially reside along the cooler outside  
10 surfaces as shown in the micrograph.

11 MEMBER BALLINGER: This is Ron Ballinger  
12 again. The PWR cladding sample would be Zircaloy-4,  
13 and the BWR cladding sample would be Zircaloy-2?

14 MR. CLIFFORD: In this micrograph?

15 MEMBER BALLINGER: Yeah.

16 MR. CLIFFORD: I believe VA-2 was the  
17 Japanese cladding MDA which is --

18 MEMBER BALLINGER: Okay. So it's not  
19 Zircaloy-2 or 4?

20 MR. CLIFFORD: VA-2 on here. Now this  
21 figure here is Zirc-2.

22 MEMBER BALLINGER: Okay. The one on the  
23 right is Zirc-2? Okay.

24 MR. CLIFFORD: And all BWRs currently use  
25 Zirc-2.

**NEAL R. GROSS**

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

1 MEMBER BALLINGER: Right. The one on the  
2 left is not Zircaloy-4?

3 MR. CLIFFORD: No, I believe it's more  
4 like a ZIRLO alloy.

5 MEMBER BALLINGER: Okay, okay.

6 MR. CLIFFORD: But it's not the alloying  
7 that affects the hydride preferential orientation  
8 distribution.

9 MEMBER BALLINGER: But it does affect the  
10 amount?

11 MR. CLIFFORD: Correct, it affects the  
12 amount of oxidation and the amount of hydrogen uptake.  
13 But it doesn't affect the morphology of the zirconium  
14 hydride which is influenced by the manufacturing.

15 MEMBER BALLINGER: Yeah.

16 MR. CLIFFORD: So if you look to the  
17 right, the second micrograph shows a cross section  
18 from a high burnup BWR fuel which is manufactured in  
19 a fully recrystalized state. RXA cladding exhibits  
20 randomly oriented hydrides. Note that the radial  
21 hydrides provides the pathway for crack propagation.  
22 As a result, the RXA cladding is more sensitive to  
23 hydrogen content.

24 MEMBER BALLINGER: This is a texture  
25 effect?

1 MR. CLIFFORD: Correct. So if you look at  
2 the sample on the left, the failure begins on the OD  
3 in a brittle manner through the oxide and the hydride  
4 rim on the OD of the cladding and then exhibits more  
5 of a ductile failure as it moves to the lower hydrogen  
6 region towards the ID, whereas if you look at the  
7 figure on the right where you have basically this  
8 pathway of radial oriented hydrides, you see it behave  
9 in both the brittle and a ductile fashion. It begins  
10 as brittle failure with a straight line, and then you  
11 see the classical 45 degree tearing in a ductile  
12 fashion as you move away from the hydrides.

13 Okay. So because of the sensitivity to  
14 hydrogen, separate PCMI failure threshold lines were  
15 established which account for the impacts associated  
16 with not only the amount of hydrogen or the texture or  
17 the cladding which affects hydride precipitation but  
18 also initial RCS temperature. So you'll see four PCMI  
19 curves, one for SRA material at high temperatures, one  
20 for SRA cladding materials at low temperature, and the  
21 same is true for RXA material.

22 So here we're accounting for -- and also  
23 it's a function of the initial hydrogen content of the  
24 cladding at the time of the accident. So you're  
25 accounting for alloy effects and the hydrogen pickup

**NEAL R. GROSS**

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

1 fraction and the corrosion rate. You're accounting  
2 for fabrication effects for SRA versus RXA, and then  
3 you're accounting for temperature effects, whether the  
4 effect begins at cold zero power conditions or hot  
5 operating conditions.

6 So let's get into a comparison of these  
7 four curves. This plot shows the SRA high temperature  
8 cladding failure from the DG-1327 along with a revised  
9 curve from Reg Guide 1.236 and the supporting  
10 database. In response to comments, the algebraic form  
11 of the failure correlation was changed. The new  
12 correlation exhibits a steeper decline showing a  
13 higher sensitivity to initial hydrogen content but  
14 then a saturation effect.

15 To provide regulatory stability, the staff  
16 elected to use a more conservative fit as opposed to  
17 the prior best estimate fit of the failure data. Best  
18 estimate curves are susceptible to constant change as  
19 new data becomes available. And as we started in  
20 2007, as more data became available, the staff found  
21 themselves redrawing the curves, trying to reestablish  
22 a best estimate fit.

23 And it's noting that in 2007, the rate at  
24 which data became available was very low. CABRI had  
25 been shut down for many years. Following Fukushima,

**NEAL R. GROSS**

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

1 the Japanese were conducting less tests at NSRR. But  
2 now today's environment, we're getting more data from  
3 JEA. They're back up and running. CABRI just  
4 finished their qualifications and starting to run  
5 tests. We expect multiple tests a year. And now, we  
6 spent a lot of money starting up the TREAT reactor at  
7 INL.

8 So we expect more data to be available as  
9 we move forward, and we wanted to design these curves  
10 and draw these curves so it was more likely that the  
11 new data would confirm the continued applicability of  
12 the curve as opposed to necessitating changes to the  
13 curve because it was found to be non-conservative. So  
14 with regulatory stability in mind, we move from a best  
15 estimate fit to more of a lower bound drawing of the  
16 curve.

17 MEMBER PETTI: So Paul, I have a question.

18 MR. CLIFFORD: Sure thing.

19 MEMBER PETTI: At the high hydrogen pickup  
20 numbers, there's a bunch of solid squares that are  
21 below the curve. Why would you have drawn your curve  
22 to make one be above it --

23 MR. CLIFFORD: Right. I mean --

24 (Simultaneous speaking.)

25 MR. CLIFFORD: Right. There's a certain

**NEAL R. GROSS**

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

1 amount of engineering judgment that goes into drawing  
2 these curves. We weren't statistically trying to come  
3 up with a 95/95 only because it was such a limited  
4 data set. So I think we're looking for the overall  
5 trends with an emphasis on trying to bound most of the  
6 data but not all of the data.

7           There are certain points on the curve  
8 which I show that were considered to be faulted either  
9 due to there was an incident where one of the more  
10 recent tests, the water was initially water-logged  
11 which meant it had failed before the event occurred.  
12 So the results aren't really applicable. And some of  
13 the earlier CAPRI tests had a lot of spallation and  
14 hence hydride lenses on the cladding which would fail  
15 at a much lower enthalpy and aren't allowed by the  
16 current design of fuel. So we didn't intend to bound  
17 all the data. We just bounded most of the data.

18           MEMBER BALLINGER: This is Ron Ballinger  
19 again. On Slide -- just pick one, Slide 34 which is  
20 what you're on and pick -- I don't know. I don't  
21 know. Pick 250 ppm hydrogen. This is all Zircaloy-4  
22 data, or is there any M5 or ZIRLO data here? And is  
23 there a difference?

24           MR. CLIFFORD: Yes, yes. There is a  
25 difference. M5 is RXA. So the Zirc-2 -- the database

**NEAL R. GROSS**

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

1 for the RXA consists of RXA Zirc-2 for BWRs and M5 for  
2 PWRs.

3 MEMBER BALLINGER: Right.

4 MR. CLIFFORD: This database consists of  
5 mostly Zirc-4 which is SRA.

6 MEMBER BALLINGER: Right. And so what I'm  
7 trying to be mindful of is that there is no more Zirc-  
8 4.

9 MR. CLIFFORD: That is true, but we don't  
10 expect that the failure enthalpy -- once you remove  
11 the corrosion dependence of the alloy which is  
12 accounted for in the x-axis here, the excess cladding  
13 hydrogen, that it's going to be the morphology or the  
14 orientation of the hydrides that has a first-order  
15 effect. And that's dependent on the manufacturing.  
16 So whether it's SRA ZIRLO or whether it's SRA Zirc-4,  
17 both of which are represented here, it doesn't have a  
18 first-order effect. They're both SRA.

19 MEMBER BALLINGER: But it's multivariate.  
20 For the same hydrogen concentration in, say, ZIRLO or  
21 M5 or whatever versus Zircaloy-4, you'd have a much  
22 higher burnup for Zirc-4.

23 MR. CLIFFORD: And that would be accounted  
24 on how you apply these curves. That is correct. Like  
25 for instance, if this was an SRA version of a good

**NEAL R. GROSS**

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

1 niobium-based alloy like optimized ZIRLO, you wouldn't  
2 have more than 200 ppm at the end of life, so --

3 MEMBER BALLINGER: That's why I picked  
4 250.

5 MR. CLIFFORD: So you wouldn't have to  
6 fall down this curve. You wouldn't --

7 MEMBER BALLINGER: Right.

8 MR. CLIFFORD: -- come down this slope.  
9 You would be up at 150 delta calories per gram for the  
10 first two cycles.

11 MEMBER BALLINGER: Right.

12 MR. CLIFFORD: So you're considering that  
13 in how you apply the curves.

14 MEMBER BALLINGER: Yeah.

15 CHAIR KIRCHNER: Yeah, Paul. Yeah, this  
16 is Walt. Thank you for that observation because I was  
17 going to ask you to just point out what a typical  
18 excess cladding hydrogen level would be at full  
19 burnup.

20 MR. CLIFFORD: Okay. So --

21 CHAIR KIRCHNER: It's well below 500.  
22 Isn't that correct?

23 MR. CLIFFORD: Well not for the legacy  
24 ones. Zirc-4 could get out to 700, and ZIRLO could  
25 get out to 500 or 600. But as I mentioned, we're not

**NEAL R. GROSS**

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

1 really loading ZIRLO and Zirc-4 anymore. We're using  
2 optimized ZIRLO and M5 and other advanced cladding  
3 alloys. So you're starting to see end of life at  
4 about 200 or lower, so --

5 MEMBER BALLINGER: And that's why -- I  
6 mean a lot of this curve is irrelevant.

7 CHAIR KIRCHNER: Yeah, the reason I wanted  
8 to bring it up, though, is because Dave had pointed  
9 out some of the points that aren't necessarily well  
10 captured by the red line that's drawn here out at 600  
11 or 700 ppm. But that probably, going forward, is  
12 irrelevant.

13 MR. CLIFFORD: That's true. So here's the  
14 first of the four curves. This is the SRA at hot, and  
15 there's an adjustment to account for the temperature  
16 scaling. So there's a slight change in the SRA. The  
17 RXA because I mentioned the radial hydrides that can  
18 form, the random orientation of the RXA hydrides, some  
19 of which would be radial. It shows that it's much  
20 more sensitive. So you're going to see a steeper,  
21 earlier decrease in ductility with excess hydrogen.  
22 So here's the curve.

23 What you'll notice here is in DG-1327. We  
24 didn't have any data beyond 300 ppm, so the curve was  
25 truncated there. We got some more data and noting the

**NEAL R. GROSS**

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

1 saturation effect. We just drew the curve through  
2 that last data point that we had there at 700. And  
3 this is for the hot -- so this would be for -- hot  
4 would be, for instance, M5 in a PWR and cold would be  
5 RXA Zirc-2 and in a BWR for reactor startup  
6 conditions. So those are the changes in the curves.

7 MR. SCHULZ: Excuse me, Paul. I've got a  
8 -- this is Steve Schultz -- a general question, and it  
9 comes from your comment that experimental data now has  
10 the opportunity to come in, that there's more work  
11 that's going to be done. Can you help with  
12 understanding of, if you will, the purpose of this  
13 experimental work? When you look at what's been done  
14 here and all the experimental data that is available  
15 so far, in a way, you kind of narrowed in on the right  
16 parameters.

17 You've got some data that is being well  
18 captured in a conservative way by the curves that have  
19 been drawn. What do you see as the future benefit of  
20 this new data? You indicated that you wanted to have  
21 curves that aren't going to change in spite of it.  
22 That is to say, I presume you're suggesting that a Reg  
23 Guide review in the future might be five or 10 years  
24 out depending on data that comes in. But I mean what  
25 is the value of the new data that's going to be

**NEAL R. GROSS**

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

1 created --

2 MR. CLIFFORD: So --

3 MR. SCHULZ: -- that you see?

4 MR. CLIFFORD: -- fuel designs don't stand  
5 still. They're continuously evolving. We've seen a  
6 lot of different zirconium-based alloys that have been  
7 introduced in the last 10 years, and each one of those  
8 is going to have different oxidation kinetics and  
9 potentially a different formation of hydrides along a  
10 different preferential orientation that have to be  
11 accounted for.

12 But we're starting to see tests that are  
13 being done for ATF designs. Doped fuel is a big thing  
14 that's coming our way. So there's a lot of tests  
15 that'll be run on doped fuel, and there's various  
16 doping agents. There's going to be coated cladding,  
17 whether they put chromium on the outside of the  
18 cladding or some other the metallic barrier. We could  
19 see that, and there would be testing done kind of to  
20 confirm the applicability.

21 Higher enrichment, we expect to see  
22 licensing actions for higher enrichment and higher  
23 burnups, first to 68 gigawatt-days. That's why we  
24 went to the trouble of evaluating the database, and I  
25 have a presentation on that upcoming. But then

**NEAL R. GROSS**

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

1 further to 75 gigawatt-days, so you might see more of  
2 an intrinsic or inherent burnup phenomena that occurs  
3 that causes failure at lower enthalpies, maybe due to  
4 higher gaseous swelling, due to the availability of  
5 more fission gas along grain boundaries or within the  
6 grains. So there are changes that are occurring, and  
7 there are tests that are being done to try to capture  
8 those for either demonstrating that the existing  
9 failure limits are applicable or for doing new ones.

10 MR. SCHULZ: That's what I want to do to  
11 get to because -- and it's stated in the Reg Guide  
12 clearly that the expectation or the desire would be  
13 for the new cladding to be demonstrated to either  
14 match or be modified to this curve as a result of data  
15 being provided.

16 MEMBER BALLINGER: But the newer -- and  
17 this is Ron again. The newer cladding -- any newer  
18 cladding, in order for it to be used, would push  
19 things to the left in terms of hydrogen pickup and  
20 corrosion rates and things like that. And the only  
21 thing that would push things out to the right, which  
22 would be to higher hydrogen, would be burnup. And  
23 until we raise the enrichment limit considerably,  
24 we're not going to get burnup much higher, certainly  
25 not more than 100.

**NEAL R. GROSS**

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

1 MR. SCHULZ: That goes back to Joy's  
2 earlier question too which we might come to later.

3 MR. CLIFFORD: Right. So when we -- I  
4 think that memo was distributed maybe yesterday or the  
5 day before, staff's memo on the applicability to  
6 higher burnup for Reg Guide 1.236. In that memo, we  
7 not only assess the sensitivity with burnup and the  
8 extent of the database. But we also identified data  
9 gaps.

10 So we've identified several important data  
11 gaps if we want to go to higher burnup to try to  
12 confirm whether or not there's intrinsic burnup  
13 effects or fill in the gaps that are in the existing  
14 database. For example, looking at this Slide 37, not  
15 a whole lot of data here, right? So it would be -- I  
16 think we're very limited in RXA data. And since a lot  
17 of reactors are moving towards say M5 which is an RXA  
18 material, it would be good to get more information.

19 So maybe we move on to -- also, we're  
20 sticking with PCMI but moving into a different topic.  
21 We're getting into the impact or the potential impact  
22 of barrier lining on the application of PCMI failure  
23 thresholds. So in response to numerous fuel rod  
24 failures during normal operation in the BWR fleet in  
25 the '70s and '80s, the industry developed barrier

**NEAL R. GROSS**

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

1 cladding.

2           The root cause of these fuel failures was  
3 PCI stress corrosion and cracking. Barrier cladding  
4 consists of a natural or low alloy zirconium liner on  
5 the cladding ID of standard Zirc-2 cladding. It has  
6 been shown to be less susceptible to PCI SCC. One  
7 unexpected benefit of the liner was its higher  
8 affinity for hydrogen.

9           Micrograph on the bottom right shows a  
10 cross-section of a radiated Zirc-2 barrier cladding.  
11 Zirconium hydrides are clearly visible. Note the  
12 concentration of hydrides within the barrier liner  
13 along the ID. Hence, the liner depletes the base  
14 metal of the detrimental effects of hydrogen. And  
15 also, studies have shown that the liner will remain  
16 intact even at higher concentrations of hydrides.

17           Next, you'll see -- here's the plot for  
18 the RXA failure threshold at hot zero power and the  
19 supporting database. The blue symbols represent test  
20 segments consisting of Zirc-2 cladding with a barrier  
21 liner. Note that these barrier tests are the most  
22 important test results since they define the shape of  
23 the curve.

24           So the test results shown in blue are  
25 shifted to account for the presence of up to 30

**NEAL R. GROSS**

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

1 percent of the hydrogen in the barrier lining. Using  
2 the scale test results, the staff developed RXA PCMI  
3 cladding failures for both fuel rod types with and  
4 without barrier cladding. Are there any questions?

5 CHAIR KIRCHNER: Five-second rule, Paul.

6 (Laughter.)

7 MR. CLIFFORD: Okay. So we're moving on  
8 to a different topic. So let me note something here,  
9 and I think it's important. So by having the barrier  
10 liner, not only were you protecting against PCI stress  
11 corrosion cracking and allowing plants to maneuver  
12 more aggressively, you were also basically absorbing  
13 all the hydrogen, hence forming less hydrides in the  
14 base material. So it was giving you the double  
15 benefit.

16 And if plants were to move away from  
17 zirconium liner, then they wouldn't have that second  
18 benefit, and thus at the same excess hydrogen level  
19 would have a higher impact on the cladding ductility,  
20 hence the shift in the curve. Okay. We'll go to the  
21 next slide. Now we're getting into a different agenda  
22 topic which is the hydrogen models.

23 In support of the now-dormant 50.46(c)  
24 rulemaking, the staff developed acceptable  
25 conservative cladding hydrogen uptake models. These

**NEAL R. GROSS**

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

1 models were part of the public comment period for DG-  
2 1263 in 2014 and were published in a draft Reg Guide  
3 1.224 in 2015. These models have been part of  
4 previous ACRS briefings on the 50.46(c) rulemaking.

5 CHAIR KIRCHNER: You picked up on that  
6 now-dormant wording.

7 (Laughter.)

8 MR. CLIFFORD: Given the status of  
9 50.46(c), the staff decided to include these hydrogen  
10 models in Reg Guide to help facilitate implementation  
11 of the hydrogen dependent PCMI failure curves.

12 MEMBER BALLINGER: This is Ron again. I  
13 keep coming back to the difference between M5 and  
14 Zircaloy-4. The lower curve is for Zircaloy-4, and  
15 the upper curve is probably for Zircaloy-2. But  
16 there's no M5 data there on the lower one.

17 MR. CLIFFORD: Hold on. So you're looking  
18 at -- hold on.

19 MEMBER BALLINGER: Over at Slide 40.

20 MR. CLIFFORD: Right, okay. So the top  
21 curve is the BWR cladding, so that was Zirc-2. Below  
22 that is just the empirical database for Zirc-4. So  
23 for the BWR Zirc-2 where there is a noticeable impact  
24 of fluence --

25 MEMBER BALLINGER: Yeah.

**NEAL R. GROSS**

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

1 MR. CLIFFORD: -- we developed kind of a  
2 fluence-dependent correlation for hydrogen pickup  
3 fraction. For the PWR alloys where we don't see that,  
4 we developed conservative bounding pickup fractions  
5 which would then be combined with an approved fuel  
6 mechanical design code which calculates oxide  
7 thickness to then translate into hydrogen content  
8 which would then --

9 MEMBER BALLINGER: But the M5 slope would  
10 be shallower, right?

11 MR. CLIFFORD: Well, correct. M5 has the  
12 benefit of having both lower corrosion, a much lower  
13 corrosion rate, but also a lower pickup fraction.

14 MEMBER BALLINGER: Right.

15 MR. CLIFFORD: So yeah, the data to the  
16 bottom right is just Zirc-4 data. And what I'm  
17 showing here is just if you use a prediction of oxide  
18 and you use a 20 percent pickup fraction, you bound a  
19 majority of the data for measured hydrogen content.  
20 So it's just one acceptable model for translating on  
21 approved fuel mechanical design into an estimate of  
22 cladding hydrogen content just to implement those  
23 failure curves.

24 MEMBER BALLINGER: Are we being sure that  
25 we're not compounding conservatism, especially with

**NEAL R. GROSS**

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

1 M5, to negate some of the advantages of M5?

2 MR. CLIFFORD: Compounding conservatism?

3 MEMBER BALLINGER: In other words, if you  
4 got a conservative hydrogen pickup curve where M5 is  
5 considerably below that, does that, in effect,  
6 penalize M5, because now that translates back into the  
7 allowable enthalpy in an insertion accident. Am I  
8 missing something here?

9 MR. CLIFFORD: So it just happened if you  
10 look at the last paragraph in that C-1, it says, the  
11 hydrogen pickup fractions should be used along with a  
12 best estimate prediction of peak oxide thickness from  
13 an approved model. So --

14 MEMBER BALLINGER: Right.

15 MR. CLIFFORD: -- it's using a  
16 conservative hydrogen pickup model but with a best  
17 estimate prediction of corrosion. So I don't think  
18 it's overly conservative. It's certainly more  
19 conservative than if the industry was to measure a lot  
20 of data, come in and get an approved hydrogen model.  
21 I think it would be less conservative than this, but  
22 --

23 (Simultaneous speaking.)

24 MEMBER BALLINGER: I keep -- if I go back  
25 to Slide -- where am I -- Slide 37 or 36 where the

**NEAL R. GROSS**

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

1 knee in that curve is in some cases around 150 ppm.  
2 That conservatism can shift where you are in the knee  
3 in that curve, right?

4 MR. CLIFFORD: Correct.

5 MEMBER BALLINGER: Okay.

6 MR. CLIFFORD: I would say, though, this  
7 is excess cladding -- excess hydrogen. So you figure  
8 hot full conditions, you may have 70 ppm in solution  
9 and the remainder in being excessed in the form of  
10 hydride. So you would need -- see the curves falls at  
11 about -- and just eyeballing it -- falls at about 80.

12 MEMBER BALLINGER: Yeah.

13 MR. CLIFFORD: So you would need more than  
14 150 ppm before you started to see the detrimental  
15 effects. And I don't believe for M5 you would see  
16 more than 150 ppm at end of life. So it's not being  
17 overly conservative for the advanced cladding alloys.

18 MEMBER BALLINGER: Okay. All right. I've  
19 got to think about it. Okay.

20 MR. CLIFFORD: That's the problem with  
21 animating stuff. You've got to walk through each of  
22 these changes. Okay. So once again, these hydrogen  
23 models are there to aid in the implementation of the  
24 failure curves. You've seen them before in 2014 and  
25 2015. Anymore questions on this topic?

**NEAL R. GROSS**

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

1           Okay. Hearing none, good. We're moving  
2           on to the last topic which is the burnup extension.  
3           In support of the near-term licensing actions to  
4           extend allowable fuel rod burnup out from 62 gigawatt-  
5           days per metric ton of uranium to 68 gigawatt-days per  
6           metric ton of uranium, the staff completed a critical  
7           assessment of the empirical database supporting each  
8           portion of Reg Guide 1.236.

9           And there's the ML number for the -- so we  
10          investigated the sensitivity of the phenomena to  
11          burnup, and then we assessed the extent of the  
12          empirical database. And here's just a graph shown  
13          earlier that just shows all of the data as a function  
14          of burnup so you can see the extent of the data beyond  
15          the current burnup limits. It's important to note and  
16          this is kind of a source of confusion. When they  
17          report data -- sorry. When they report burnup,  
18          they're reporting a burnup -- the average burnup on  
19          the segment -- the test segment.

20          And the test segments can be four inches  
21          or they can be -- I think the largest were close to  
22          two feet or three feet in length. So when you're  
23          looking at the reported burnup, it's closer to a nodal  
24          burnup or even closer to a pellet burnup. But it is  
25          a rod average burnup, so you've got to kind of adjust

**NEAL R. GROSS**

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

1 it based on that.

2 So what I'm saying here is the empirical  
3 data for the test segments, if you consider that a rod  
4 average 68 gigawatt-days which is the target we're  
5 trying to achieve here is approximately 75 gigawatt-  
6 days on a test segment. So when we're looking at the  
7 extent, we're saying, well, how much data is there out  
8 to 75 on the local fuel burnup? I just wanted to  
9 introduce that.

10 So we'll start with the high-temperature  
11 cladding failure threshold. Here's the database as a  
12 function of burnup with failure enthalpy. Or once  
13 again, this isn't failure enthalpy. It's the enthalpy  
14 and then the closed symbols -- solid symbols show  
15 which tests failed.

16 As a function of burnup, you'll notice if  
17 you go across at 150 here, you don't see a sensitivity  
18 to burnup. And it was determined that the cladding  
19 failure threshold was more sensitive to differential  
20 pressure. And of course, there is a relationship  
21 between differential pressure and burnup because  
22 higher burnup has more fission gas release, more  
23 fission gas release, higher delta P. So there is  
24 somewhat of a connection between burnup and  
25 differential pressure.

**NEAL R. GROSS**

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

1           And if you look at the extent of the  
2           database of these higher burnups, you see these points  
3           here. You guys can see my thing here and I'll make it  
4           real fancy. Hold on a sec. Look at this, huh? My  
5           simulated laser pointer, it shows that these points  
6           survived above 100 calories per gram which is towards  
7           the end of life here. In fact, you didn't have  
8           failures up to 150 calories per gram, even in the  
9           higher burnup segments. So it was felt that the  
10          phenomena, in fact, was not sensitive to burnup and  
11          there was data out past higher burnups to support  
12          expansion in the applicability. Now --

13                 MEMBER BALLINGER: This is Ron again.  
14                 Back up a slide. What's the uncertainty? The  
15                 differential pressure is a calculated number, right?

16                 MR. CLIFFORD: Well, it would be on how  
17                 you apply it. But in this database, it was something  
18                 that was designed. It was measured.

19                 MEMBER BALLINGER: Okay.

20                 MR. CLIFFORD: They set the initial  
21                 pressure to achieve a certain target.

22                 MEMBER BALLINGER: Right. But in real  
23                 life, it would be a calculated number?

24                 MR. CLIFFORD: Correct.

25                 MEMBER BALLINGER: Okay, which has

**NEAL R. GROSS**

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

1 uncertainty, and I'm looking at the numbers. We're  
2 talking about three or four MPA. Well, okay.

3 MR. CLIFFORD: And realistically, this  
4 event, because you have more reactivity in a fresher  
5 bundle, by the time you get to high burnup, the  
6 reactivity in that bundle, hence the worth of the  
7 blade next to that bundle would be a lot lower. So  
8 this event is more limiting for fresher fuel, and  
9 fresher fuel probably don't have a DP because the RCS  
10 pressure is not decreasing during the event. It's  
11 just barely changing in the first couple seconds. So  
12 you're not seeing -- it's not like a LOCA where you  
13 also have pressure is dropping. So you have to have  
14 an initial pressure beyond system pressure to even  
15 move to the right on this scale over here. So --

16 MEMBER BALLINGER: Yeah.

17 MR. CLIFFORD: -- chances are for the rods  
18 that are more susceptible, you're going to be in this  
19 realm right here.

20 MEMBER BALLINGER: But at the end of, say,  
21 third cycle, the fuel rod is actually probably being  
22 driven --

23 MR. CLIFFORD: Correct.

24 MEMBER BALLINGER: -- by adjacent  
25 assemblies, right?

**NEAL R. GROSS**

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

1 MR. CLIFFORD: Right. But if it resides  
2 out in the core peripheral, there's going to be no  
3 worth --

4 CHAIR KIRCHNER: Actually, it's running on  
5 plutonium, Ron.

6 MEMBER BALLINGER: It's running on  
7 plutonium, yes.

8 MR. CLIFFORD: So your concern is the  
9 pedigree of the calculation of rod internal pressure  
10 that gets used to implement this?

11 MEMBER BALLINGER: Yeah. I mean, those  
12 burnups, especially with fission gas release, the  
13 starting differential pressure is going to be very,  
14 very low, right, because you've got system pressure on  
15 one side and you've got almost liftoff on the other  
16 side, right?

17 MR. CLIFFORD: Yeah, right. The limit on  
18 rod internal pressure from the design -- the  
19 mechanical design calculation is that you can't lift  
20 off. So right, you could be 800 pounds per square  
21 inch above system pressure and a very high burnup rod  
22 at end of life.

23 MEMBER BALLINGER: Right. Okay. I just  
24 am saying that things get a little bit muddled when  
25 these calculations become tenuous.

**NEAL R. GROSS**

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

1 MR. CLIFFORD: Potentially. It depends on  
2 how fine they want to do the calculations. I've  
3 always felt that if you wanted to try to predict the  
4 exact number of rods that fail by each mechanism for  
5 each core loading, and since you have a differential  
6 pressure, a dependent failure threshold, and you have  
7 a cladding hydrogen dependent failure threshold, then  
8 that could -- it could be very difficult to find the  
9 worst possible scenario because you're no longer  
10 looking for the highest-worth ejection. So you just  
11 can't do a quick physics calculation saying, what's  
12 the maximum ejected rod worth, and do an analysis  
13 there, because there may be a rod worth that's of  
14 lower magnitude but is next to a cladding that has  
15 higher hydrogen content, hence a lower failure  
16 threshold.

17 MEMBER BALLINGER: And those calculations  
18 are basically almost full core calculations nowadays,  
19 right, rod by rod?

20 MR. CLIFFORD: I don't know. I don't know  
21 off the top of my head. I mean, there's been a lot of  
22 evolution in the analytical methods over the last  
23 couple of years as we're moving towards 3D space-time  
24 kind of kinetics as opposed to the 1D 1970s versions.

25 MEMBER BALLINGER: Yeah.

**NEAL R. GROSS**

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

1 MR. CLIFFORD: But where I was going with  
2 it, you want to do a very, very detailed consensus  
3 evaluation where you figure out how many rods fail for  
4 every mechanism and every point during a cycle for  
5 each reload. It could be very difficult, but  
6 remember, what we're trying to do here is estimate  
7 fuel failures that goes into a dose calc. This is not  
8 very limiting from a dose calc.

9 Even though you're only allowed 25  
10 percent, you could still fail. You could survive even  
11 if you failed 20 percent of the core. You could meet  
12 your dose requirements, and there's no way to get to  
13 20 percent fuel failure because the event is very  
14 localized.

15 MEMBER BALLINGER: Right.

16 MR. CLIFFORD: So you could do a bounding  
17 assessment once and say, look, I'm going to look at  
18 these failure thresholds and show that. I'm never  
19 going to get to this point because I've done a  
20 bounding dose assessment and I just can't fail any  
21 rods and then break down to some reload checklist  
22 item. But we're just providing the level of detail  
23 should somebody want to get into the weeds.

24 Okay. So where was I? Okay, PCMI. Now  
25 we're moving on to the burnup dependence of PCMI.

**NEAL R. GROSS**

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

1 Okay. This plot shows the SRA PCMI failure threshold  
2 along the empirical database. The data suggests that  
3 PCMI is more sensitive to and better represented by a  
4 function of cladding hydrogen content as opposed to  
5 burnup.

6 Here's the same data, both rise and peak  
7 enthalpy but as a function of burnup instead of excess  
8 cladding hydrogen. It's important to note that you  
9 would expect some burnup effects on cladding PCMI  
10 performance under RIA conditions. For example,  
11 increased exposure leads to a closure of the initial  
12 fuel pellet to cladding gap which would have an effect  
13 on PCI performance. And also, higher exposure leads  
14 to enhanced gaseous swelling, would affect PCMI  
15 loading.

16 So you would expect some inherent burnup-  
17 dependence in PCMI. However, when you start looking  
18 at the data, at least up to 68 gigawatt-days, you  
19 don't really see it. Here's another plot. Here is  
20 the empirical database with cladding excess hydrogen  
21 as a function of fuel burnup. So it gives you an idea  
22 of the extent of the database.

23 So at least as far as this database is  
24 concerned, as you get into higher burnup, your failure  
25 mechanism is clearly related to hydrogen and not

**NEAL R. GROSS**

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

1 related to burnup. You don't have a lot of data here.  
2 But when you start looking across -- this point right  
3 here is suspect. That's SIBQ (phonetic) which was  
4 monologued.

5 When you start looking here at about 125  
6 calories per gram, you don't see failures at 40 and  
7 you don't see failures at 65. So you don't see a  
8 strong burnup dependence, and you have to consider  
9 this because you could have an M5 as we talked about  
10 that doesn't have the hydrogen uptake. So it doesn't  
11 fall down that curve, all the way down to 65 calories  
12 per gram failure threshold. It stays up at 150 even  
13 at end of life.

14 So that's why you need to try to  
15 understand the sensitivity of the failure with burnup.  
16 And here, going across the data, there's no obvious  
17 trend in decreasing. If you just looked at the right,  
18 you would think there would be a trend like you could  
19 draw a line like this. But the only reason that these  
20 are failing is because they're at high hydrogen  
21 content which we're capturing with the failure  
22 criteria.

23 MEMBER BALLINGER: This is Ron again. Do  
24 we have Slide 43, your Slide 43, that one? Well, wait  
25 a minute. Okay.

**NEAL R. GROSS**

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

1 MR. CLIFFORD: So the other one, they're  
2 animated, so --

3 MEMBER BALLINGER: Okay. All right. I'm  
4 just trying to --

5 MR. CLIFFORD: You start here. This is  
6 44, and you add this additional plot, then you change  
7 one of the plots out.

8 MEMBER BALLINGER: Okay. I think we're a  
9 little bit -- I don't think -- maybe I have the wrong  
10 set of slides, but I don't have that sequence.

11 MR. CLIFFORD: If you have it, just -- if  
12 you have the PDF version, the PDF version doesn't  
13 capture the --

14 MEMBER BALLINGER: Oh, okay, okay.

15 MR. CLIFFORD: -- information.

16 MEMBER BALLINGER: Yeah.

17 MR. CLIFFORD: So back, if you're looking  
18 at the data, there's not a pronounced sensitivity with  
19 burnup, at least to this burnup level. It's certainly  
20 more sensitive to cladding hydrogen content. And if  
21 you start looking at the database, remember that the  
22 kind of saturation effect on higher hydrogen contents.  
23 So there's a kind of asymptotic limit for SRA at 65  
24 and RXA at 50 calories per gram.

25 And then when you start looking at both

**NEAL R. GROSS**

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

1 burnup effects and failure of really high burnup test  
2 specimens, they're not failing below those limits  
3 here. So 65, 50 is right here. So you're not failing  
4 in these data points. They failed above those limits.  
5 So based on that information, we felt it was  
6 acceptable to extend the range of applicability out to  
7 68 gigawatt-days for the PCMI. And we look at both  
8 RXA and SRA. I'm just showing you the SRA right here.

9           Next part is the damaged core coolability  
10 analytical limit. And here it is right here, the 230  
11 calories per gram and the limited amount of melt. And  
12 here's the supporting database for these limits. It's  
13 really the entire. But realistically, you're looking  
14 at this cloud of data over here at very low burnups.

15           We identified a need for more data out  
16 here because if -- let's walk through the logic here.  
17 So while there's no data out here at very high  
18 burnups, the criterion itself since there's two parts  
19 of the criterion and the first one being the 230.  
20 It's kind of the upper -- the ceiling. But then the  
21 next part being the limited melt which decreases with  
22 increasing burnup.

23           You are capturing a burnup effect using  
24 the melt criteria. But we identified this as a data  
25 gap, that we needed to have tests run on higher burnup

**NEAL R. GROSS**

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

1 rods, especially if you started to go to higher  
2 enrichment, because as you go to higher enrichment,  
3 you're going to have more reactive worth at higher  
4 burnup. So in that scenario, (telephonic  
5 interference) to here so that we could verify that the  
6 ten percent melt limit would be conservative because  
7 we just don't have data in this region here.

8 MR. CORRADINI: Paul, this is Corradini.  
9 I don't completely follow what you just said. Are you  
10 telling me the black dots below your little red star  
11 or your red pointer are ten percent melt fuel volume  
12 limits and you're worried that with higher enrichment  
13 and higher burnup, you'd actually fall below those?  
14 Is that what you're trying to get at? I'm still not  
15 clear about what you're saying.

16 MR. CLIFFORD: Okay. So right now, we  
17 have the two criteria. The first one is the 230 which  
18 is really based on fresh fuel.

19 MR. CORRADINI: Right.

20 MR. CLIFFORD: And the second part of it  
21 is no melting which is going to capture burnup effects  
22 on how you predict melting, both from a radio power  
23 profile and also a melting threshold which are both  
24 burnup dependent. But what we don't have is, for  
25 instance, what if you had a loss of coolable geometry

**NEAL R. GROSS**

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

1 before you melted because of some intrinsic effect and  
2 really high burnup? Right now, you would expect that  
3 fresh fuel is going to be about 260 calories per gram  
4 is when you're going to melt. And high burnup fuel is  
5 going to drop down to below 200, somewhere down here  
6 --

7 MR. CORRADINI: Right.

8 MR. CLIFFORD: -- just based on radio  
9 power profile, plutonium production, and melting  
10 temperature. So it's going to drop down to about  
11 here. But what if you had a loss of coolable geometry  
12 up here? For instance, your gaseous swelling would be  
13 enhanced at high burnup. So maybe the pellet would  
14 essentially push its way out. Not melt but it would  
15 swell so violently at the higher burnup that it  
16 dispersed into the coolant. So we don't have the data  
17 to account for that phenomena. So --

18 MR. CORRADINI: Okay. I think I get it.

19 MR. CLIFFORD: Right. These dark symbols  
20 are just when the cladding fails, not when it melts  
21 and not when you lose the integrity of the cladding.

22 MR. SCHULZ: Paul, this is Steve Schulz.  
23 You're talking about a combination of phenomena that  
24 may not have been incorporated or considered at lower  
25 burnup.

**NEAL R. GROSS**

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

1 MR. CLIFFORD: Well, let me rephrase this.  
2 So at low burnup, you're not going to run into the  
3 melt criteria until you're up above 260. But you have  
4 an empirically based threshold at 230 based on the  
5 destruction of the rod geometry. So at 230, it didn't  
6 melt, but you still violently failed the rod so that  
7 you couldn't guarantee coolability because it was no  
8 longer one or two pieces of rod. It was multiple  
9 sections of rod.

10 MR. CORRADINI: Even though you didn't  
11 melt, you would have a loss of coolable geometry in  
12 that region?

13 MR. CLIFFORD: Correct.

14 MR. CORRADINI: Okay.

15 MR. CLIFFORD: So as you go up and burnup,  
16 the melt criteria becomes more limiting and eventually  
17 drops down to 200 calories per gram at end of life.  
18 So it's much smaller than the 230. But who's to say  
19 that the other phenomena -- not the melt phenomena but  
20 just the phenomena of the expansion of the pellet and  
21 the response of the pellet and how it failed the rod  
22 in a very complex manner. Who is to say that doesn't  
23 become more limiting at higher burnup.

24 MR. SCHULZ: Or in combination. That's  
25 what I was getting to.

**NEAL R. GROSS**

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

1 MR. CLIFFORD: Yeah, so that's just a data  
2 gap right now. But once again, for today's fuel, the  
3 way enrichments are, by the time you get out to high  
4 burnup, you have very low worth. The blade or the rod  
5 next to that or within that high burnup assembly is  
6 very limited in worth. So you just can't get enough  
7 power into that fuel assembly. So you're not going to  
8 go above 200 calories per gram in an end of life fuel  
9 rod. I know you're worried about this, but if you  
10 were to go to eight percent enrichment, you could.

11 MR. CORRADINI: Okay. I see your point  
12 now.

13 MR. CLIFFORD: So next section was the  
14 transient fission gas release and a burnup assessment.  
15 Here's the transient fission gas release database.  
16 This is measured fission gas release versus fuel  
17 burnup just to give you a feel for the extent of the  
18 database. Here is the extent of fuel rod burnup  
19 versus peak fuel enthalpy.

20 So it's important to look at both, how  
21 much high burnup fuel was included in the database and  
22 how hard they pushed that fuel. So here, you can see  
23 that they pushed the high burnup fuel up above 100  
24 calories per gram which is good. In other words, if  
25 all this data for supporting high burnup was down

**NEAL R. GROSS**

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

1 here, then you really wouldn't get a good accurate  
2 measure. But since you're pushing the high burnup  
3 fuel, it gives you -- it has more pedigree to it.

4 So the empirical database does show a  
5 sensitivity with burnup as we described before, and  
6 also the amount of deposited energy. And that's why  
7 the staff developed these burnup dependent  
8 correlations which is shown right here. So it's  
9 important to note that these four data points that are  
10 at or above 70 are these four data points here, one,  
11 two, three, and four. So all four of the high burnup  
12 specimens remained below the correlation. So based on  
13 the extent of the database and the fact that the  
14 correlations bounds the high burnup test specimens, we  
15 felt we could extend the range of applicability out to  
16 68.

17 In conclusion for the burnup extension,  
18 based on the extent and the sensitivity of important  
19 parameters and phenomena of burnup, the staff found  
20 that Reg Guide 1.236 to be applicable up to a fuel rod  
21 average burnup of 68. This assessment is predicated  
22 on the use of approved core neutronics models and fuel  
23 rod thermal-mechanical models which are validated up  
24 to at least 68 gigawatt-days. In the course of the  
25 evaluation, we also identified two limitations.

**NEAL R. GROSS**

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

1           The first is as you go march down towards  
2 higher burnup, you're going to have a longer residence  
3 time. A longer residence time could mean higher  
4 corrosion, cladding corrosion levels. If you have  
5 excess cladding corrosion, you could localize defects  
6 in the cladding such as a spallation or hydride  
7 blisters.

8           And tests conducted on cladding with these  
9 localized defects have shown significantly reduced  
10 cladding failure threshold. So therefore, the  
11 applicability of the failure thresholds is limited to  
12 fuel rod designs and cladding alloys and plants which  
13 control and limit oxide thickness to prevent these  
14 localized effects. And right now, when we approve a  
15 cladding alloy, we approve the alloy up to a specified  
16 oxide thickness, and that thickness is based upon  
17 poolside examinations which have shown that there's no  
18 localized effects, no spallation up to a certain  
19 thickness. So we've accounted for it, but we just  
20 wanted to reinforce it here in the Reg Guide.

21           And the second limitation was that fuel  
22 fragmentation, relocation, and dispersal is an  
23 important phenomena. It affects the ability to  
24 demonstrate coolable geometry, and it has been shown  
25 to be sensitive to burnup. This Reg Guide does not

**NEAL R. GROSS**

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

1 provide an acceptable means of addressing fuel  
2 fragmentation and dispersal at higher burnups. So are  
3 there any questions on the burnup extension portion?

4           Hearing none, I will move on to the final  
5 slide, 3:30. So based upon the latest research data,  
6 revised research data and new analyses and  
7 international perspectives, the NRC has developed the  
8 guidance that's within Reg Guide 1.236. It represents  
9 a significant advancement in guidance which separately  
10 captures fabrication, burnup, and corrosion effects on  
11 fuel rod performance under RIA conditions.

12           We have been actively involved with the  
13 industry and the ACRS beginning well before 2007.  
14 There have been several previous ACRS briefings  
15 beginning with the interim criteria. Actually,  
16 beginning with RIL-0401 and then the interim criteria  
17 and then the draft guidance and now the final  
18 guidance. In addition, there's been numerous public  
19 workshops and three rounds of public comments if you  
20 consider the standard review plan which was the  
21 interim to be the first round. That's my  
22 presentation.

23           CHAIR KIRCHNER: Thank you, Paul. Very  
24 good. Excellent piece of work. So before we turn to  
25 the public, Members, have you any specific questions

**NEAL R. GROSS**

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

1 to ask of Paul at this juncture, and that includes  
2 consultants?

3 Okay. Hearing none, when can we open the  
4 public line so that we can request any comments from  
5 the public?

6 MS. ABDULLAHI: Is anyone here?

7 CHAIR KIRCHNER: Go ahead. Please state  
8 your name and then make your comment, please.

9 MS. ABDULLAHI: Maybe your line is muted  
10 from last time unless it's a bridge line.

11 CHAIR KIRCHNER: I'm sorry. I couldn't  
12 understand the comment.

13 MEMBER MARCH-LEUBA: That was Zena trying  
14 to figure out if the line is open.

15 CHAIR KIRCHNER: Oh, okay. Thank you.

16 MR. EICHENBERG: Hello. Can you hear me?

17 CHAIR KIRCHNER: Yes, go ahead.

18 MR. EICHENBERG: Yes, this is Tom  
19 Eichenberg, Tennessee Valley Authority, and --

20 CHAIR KIRCHNER: Go ahead.

21 MR. EICHENBERG: -- I just wanted to ask  
22 a simple question, if there is any anticipated  
23 timeline for cleanup for SRP 4.2.

24 (Simultaneous speaking.)

25 CHAIR KIRCHNER: Paul, you don't have to

**NEAL R. GROSS**

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

1 answer that. Hold on, Jose. Paul, we -- Tom from  
2 TVA, we normally take comments. If you have a  
3 question about a schedule or such, direct that to Zena  
4 who is the Designated Federal Official and we'll go  
5 through proper channels and give you an answer to your  
6 question.

7 MR. EICHENBERG: Okay. Thank you.

8 CHAIR KIRCHNER: Any other members of the  
9 public wishing to make a comment?

10 Hearing none, I think we can close the  
11 public line, and then I would like to turn to members.  
12 Right now, our plan would be for a letter at the June  
13 Committee meeting. Are there any other comments from  
14 members about that?

15 MEMBER MARCH-LEUBA: Hi, this is Jose. I  
16 just wanted to say how impressed with the whole  
17 presentation. I mean, this was very thorough, very  
18 informative, and it's impressive whenever -- Paul,  
19 whenever we ask you a question, you know what we're  
20 asking before we finish talking. So I wanted to thank  
21 you for a fantastic presentation, and I think this is  
22 a very good RG and I support writing a letter in June.

23 MR. CLIFFORD: Thank you very much.

24 MEMBER BALLINGER: This is Ron. I mean,  
25 I think this along with unfortunately the, what did

**NEAL R. GROSS**

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

1 you say, now dormant 10 CFR 46(c) have taken so long  
2 that with the evolution of cladding, much of this  
3 stuff -- much of the information, while extremely  
4 valuable, is moot.

5 MR. CORRADINI: This is Corradini. I  
6 guess I do want to ask Paul something besides, as  
7 usual, telling him he did an excellent job of trying  
8 to explain to us when we were confused. Paul, if we  
9 go back to the slide -- now I'm going to get it wrong  
10 -- Slide 40 where you basically point in that the  
11 hydrogen uptake models now are included consistent  
12 with 50.46(c). Was that required, or does that just  
13 make it easier for the applicants to use it and clear  
14 to have it as part of this RG?

15 MR. CLIFFORD: It's not required, no.  
16 We're just providing it to aid in the implementation  
17 because not all vendors have approved hydrogen uptake  
18 models for each one of alloys, so no.

19 MR. CORRADINI: So you're basically making  
20 it consistent is the way I understood.

21 MR. CLIFFORD: Right. We're just giving  
22 them the option of using something that we've provided  
23 and that we already find acceptable.

24 MR. CORRADINI: Okay, fine. But other  
25 than that, as usual, I thought it was an excellent

**NEAL R. GROSS**

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

1 presentation and you helped us a lot when we were  
2 confused -- when I was confused.

3 MEMBER REMPE: Paul, this is Joy, and I  
4 also find your presentations, as usual, very  
5 enlightening. But that's what motivated my question  
6 about knowledge management because I think you have --  
7 your background did reference this earlier memo. But  
8 the later memo, I still could not find referenced in  
9 the Reg Guide. I also think that as you went through  
10 the presentation, you provided us some background that  
11 I'm not sure is easily found by other staff members in  
12 the future as they start trying to accommodate new  
13 fuels. And I would hope that our letter would mention  
14 the need for something that's a little more  
15 comprehensive that's a background document to support  
16 this Reg Guide.

17 (Simultaneous speaking.)

18 MEMBER PETTI: This is Dave. I have a  
19 question for Paul. I think about all of this, and I  
20 think about accident-tolerant fuels. And you look at  
21 how much time and effort it took to get this database.  
22 And even today, some of it has some holes in it. Have  
23 you given any thought to what you think it's going to  
24 take to get enough data from an accident-tolerant fuel  
25 perspective, whether it'd be the cladding or the new

**NEAL R. GROSS**

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

1 fuels?

2           What I worry about is it could be a two-  
3 part answer. It could be, well, we just need some  
4 data to confirm. That leads you down one path. But  
5 what if something else shows up? When you make a  
6 change over here and you find out it causes a  
7 deleterious effect over there that you didn't think  
8 of, that could really take a lot of effort. Have you  
9 given any thought as you following the accident-  
10 tolerant fuel program from this perspective?

11           MR. CLIFFORD: Okay. So I think accident-  
12 tolerant fuel is a good example because there's both  
13 cladding -- design changes in the cladding and design  
14 changes in the pellet itself. And of course, the  
15 further you migrate away from the empirical database,  
16 the more difficult it will be to license. I mean,  
17 something like silicon carbide which does not possess  
18 significant ductility relative to a new metal, that's  
19 going to be a challenge and it's going to likely fail  
20 at a lower threshold.

21           So that's something that would have to be  
22 evaluated. But given -- if it's paired with the  
23 existing UO2 design, you understand the behavior of  
24 the UO2 for a given deposit of energy. So maybe  
25 there's separate effects that could be used to help

**NEAL R. GROSS**

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

1 speed up the licensing process and limit how many in-  
2 pile tests that have to be done on an irradiated  
3 cladding material that's not Zircaloy.

4 But once you get to changes in the fuel  
5 pellet where you just don't understand the response of  
6 the fuel pellet to a certain energy deposition,  
7 uranium silicide and uranium nitride, there's going to  
8 have to be a lot of RAI tests done, in-pile testing  
9 done at TREAT or CABRI or NSRR to establish the  
10 failure modes for that fuel design because you've got  
11 significantly different compositions of the pellet,  
12 both from an alloy perspective and the microstructure  
13 of the pellet and the grain sizes.

14 And the melting temperature of the pellet  
15 could be significantly different. Thermal  
16 conductivity of the pellet is different. Swelling  
17 rates are different. So if you start changing from  
18 the UO2 pellet to something else, there's a lot of  
19 work that has to be done.

20 CHAIR KIRCHNER: Along those lines, Paul,  
21 there are a number of concepts in terms of changing  
22 the cladding or coatings. And so I was thinking back  
23 in your presentation the positive effect of the liner  
24 for the BWR fuel cladding. Has there been any  
25 preliminary look at what some of these coatings and

**NEAL R. GROSS**

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

1 such might to in terms of changing either ductile or  
2 brittle fracture properties for the cladding under  
3 these kind of accident conditions?

4 MR. CLIFFORD: So for the coatings, well,  
5 certainly, the coating is going to ensure that there's  
6 almost no hydrogen present on the cladding at the  
7 beginning of the transient because the oxidation rates  
8 of chromium are so low compared to zirconium that you  
9 would not even begin to fall down that PCMI failure  
10 curve. You would always be at the very top which  
11 gives you tremendous benefit.

12 With respect to the actual performance,  
13 the strain capability of the cladding with the  
14 coating, we don't expect there to be much because the  
15 coatings are generally two to three percent thickness  
16 of the underlying substrate. So it's not going to  
17 have a significant impact on the mechanical  
18 performance of the bare cladding if you want to think  
19 of it as bare.

20 CHAIR KIRCHNER: Whether it's brittle or  
21 ductile. Okay.

22 MEMBER BALLINGER: This is Ron. The  
23 argument that is being made was made for putting these  
24 things in lead test assemblies or the like that are  
25 already in core.

**NEAL R. GROSS**

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

1 CHAIR KIRCHNER: Yes.

2 MR. CLIFFORD: Yes, so I don't -- overall,  
3 I don't think coated cladding is a significant  
4 challenge from a licensing perspective. I think the  
5 challenges are going to be something that's a  
6 nonmetallic cladding or a change, ceramic pellet to a  
7 metallic pellet or a metallic bore or something else.

8 CHAIR KIRCHNER: Yes.

9 MR. SCHULZ: Paul, this comment follows  
10 Ron Ballinger's comment and your introduction today  
11 and that is that, as you stated, some of us have been  
12 involved with this issue for either near or more than  
13 three decades. And so as a result, a lot of the  
14 information and data that has gone into this  
15 technology is from cladding materials which are no  
16 longer used.

17 At the same time, I did want to comment  
18 that the NRC team has done a very excellent job in the  
19 handling and disposition and analysis of the public  
20 comments that were put in. And as you stated, there  
21 were many. But the thoroughness by which you address  
22 those comments, including some very specific  
23 evaluations that have been done of different and new  
24 types of cladding, are very helpful in both the issue  
25 of moving forward with how this can be applied to

**NEAL R. GROSS**

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

1 current design, how it can be applied to future  
2 design, and also did contribute to an element of  
3 knowledge management and technical capture.

4 But I do agree with Joy that it would be  
5 good to somehow figure out or make sure that the  
6 information that's been developed from the responses  
7 to those questions is captured in the archives of the  
8 NRC. I did try to access one or two -- one of the  
9 referenced documents from the questions, and I  
10 couldn't get it in ADAMS. It said it wasn't  
11 available. So that's just an example. It's not a  
12 complaint, but it's an example that we need to make  
13 sure that the information is held for future use.

14 CHAIR KIRCHNER: Okay. Members, any  
15 further questions or comments at this point?

16 (No response.)

17 CHAIR KIRCHNER: I'm using a ten-second  
18 rule because often we have trouble getting our cursor  
19 back on the unmute the microphone.

20 (Laughter.)

21 CHAIR KIRCHNER: Okay. That's ten  
22 seconds. Well, then at this point, I want to thank  
23 you again, Paul, and thank all the members for  
24 participating. I ask Steve and Mike, our consultants,  
25 if you have any specific comments, would you please

**NEAL R. GROSS**

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

1 get those to me within the next couple of weeks. And  
2 also, Members, I will be putting together a draft  
3 letter again for the June meeting. So with that, I  
4 think we are complete with our work today. Thank you  
5 all, also in the public attending. And with that, we  
6 are adjourned.

7 (Whereupon, the above-entitled matter went  
8 off the record at 3:45 p.m.)

9  
10  
11  
12  
13  
14  
15  
16  
17  
18  
19  
20  
21  
22  
23  
24  
25

**May 5, 2020 Subcommittee Meeting**

**ATTENDEES**

**ACRS SUBCOMMITTEE MEMBERS**

Walter Kirchner (Chairman)

Vesna Dimitrijevic

Ronald Ballinger

Dennis Bley

Jose March-Leuba

Joy Rempe

David Petti

**ACRS Consultants**

Michael Corradini

Stephen Schultz

**ACRS Staff**

Zena Abdullahi (Designated Federal Official)

Scott Moore (ACRS Director)

Lawrence Burkhardt (Technical Branch Chief)

Christina Lui

Alesha Ballinger (Branch Chief, PMDA)

Thomas Dashiell

Makeeka Compton

Paula Dorm

Joanne Johnson

Shandeth Montgomery

Hossein Nourbakhsh

Janet Riner

Tammy Skov

Derek Widmayer

Weidong Wang

Quynh Nguyen

Christopher Brown

**NRC staff**

Paul Clifford (presenter)

Edward O'Donnell (RG 1.236 Senior Staff)

Donald Agama

Andrew Bielen

Andrew Proffitt

Ngola Otto

**External Attendees**

Alex (Guest)

Gregory Broadbent

Stephen Geier

Kent Halac (GEH)

Charles Heck (GEH)

Nathanael Hudson

Shawn Lamb (GEH)

Christan McElory (GEH)

David Mitchell

Brian Mount

Kurshad Mufruglu (Guest)

Nathan Peck (GEH)

Scott Pfeffer (GEH)

Eric S. Scott

Eric Thomas

Ken Yueh

**Telephone Attendees**

Electric Power (Guest)

GE Nuclear Energy (Guest)

RNT G

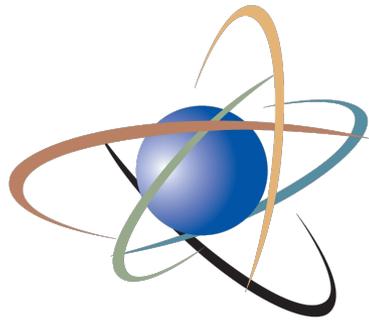
**Wireless Caller (Guest)**

+467XXXXXXXX (Guest)

201XXXXXXXX (Guest)

571XXXXXXXX (Guest)

910XXXXXXXX\*Guest)



# U.S. NRC

UNITED STATES NUCLEAR REGULATORY COMMISSION

*Protecting People and the Environment*

## Draft Regulatory Guide 1.236 PWR Control Rod Ejection and BWR Control Rod Drop Accidents

ACRS Metallurgy and Reactor Fuels Subcommittee  
May 5, 2020

Paul M. Clifford  
Division of Safety Systems  
Nuclear Reactor Regulation

# Agenda

1. Regulatory Requirements
2. Timeline and Stakeholder Comments
3. Revised Guidance and Analytical Limits
  - a. Reactor Coolant System Pressure
  - b. Damaged Core Coolability
  - c. Radiological Consequences
4. Cladding Hydrogen Models
5. BU Extension

## Reason for Concern

LEST WE FORGET



SL-1

1-3-61

- Fatal accident at Army's prototype modular reactor – Stationary Low Power Reactor (SL-1)
- Improper withdrawal of central control rod resulted in prompt critical power excursion and steam explosion

**Protection Against Violent  
Explosion and Loss of  
Pressure Boundary**

# Regulatory Requirements

- 10 CFR 50, Appendix A GDC 28 requires reactivity control systems to be designed with appropriate **limits** on potential **amount** and **rate** of reactivity increase to assure that the effects of postulated reactivity accidents can neither (1) result in **damage to the reactor coolant pressure boundary greater than local yielding** nor (2) sufficiently disturb the core, its support structures, or other reactor pressure vessel internals to **impair significantly the capability to cool the core**.
- 10 CFR 100.11 and 10 CFR 50.67 establish **radiation dose limits** for individuals at the boundary of the exclusion area and at the outer boundary of the low population zone.

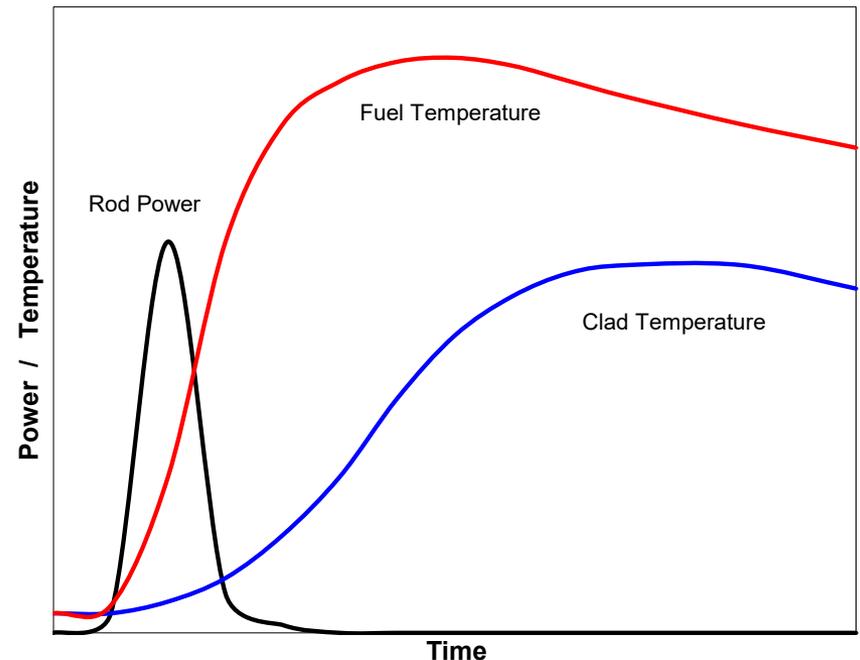
**RG 1.236 provides an acceptable means to meet requirements**

# Reactivity Insertion Accidents

- Reactivity insertion accidents are safety significant because of their potential ability to challenge fuel rod integrity, fuel bundle geometry, and the integrity of the reactor pressure boundary
- The uncontrolled movement of a single control rod out of the core results in a positive reactivity insertion that promptly increases local core power
  - Considered the limiting reactivity insertion accident
- Of the various postulated single failures of the CRD system which may initiate an uncontrolled movement of a single control rod, PWR CRE and BWR CRD are considered the most limiting scenarios for the current operating fleet

# Postulated Accidents

- A PWR CRE event is postulated to occur because of a mechanical failure that causes an instantaneous circumferential rupture of the control element drive mechanism housing or its associated nozzle. This results in the reactor coolant system pressure ejecting the control rod and drive shaft to the fully withdrawn position.
- A BWR CRD event is postulated to occur because of the following sequence of events: a control rod (blade) inserted into the core becomes decoupled from its drive mechanism, the drive mechanism is subsequently withdrawn, the control blade is assumed to be stuck in place, and at a later moment, the control rod suddenly falls free and drops to the control rod drive position.



# Agenda

1. Regulatory Requirements
- 2. Timeline and Stakeholder Comments**
3. Revised Guidance and Analytical Limits
  - a. Reactor Coolant System Pressure
  - b. Damaged Core Coolability
  - c. Radiological Consequences
4. Cladding Hydrogen Models
5. BU Extension

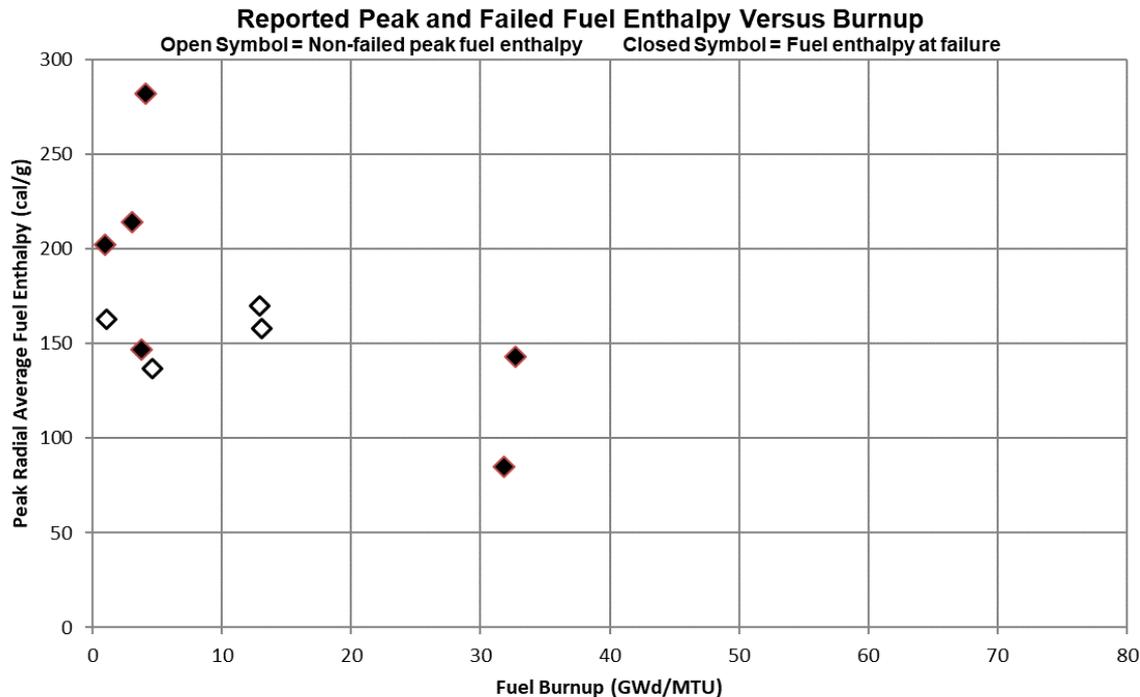
# Timeline

- 1974 RG 1.77, Assumptions used for Evaluating a Control Rod Ejection Accident for Pressurized Water Reactors
- 1980 *Nuclear Safety* article (MacDonald et.al.) suggests need for new analytical limits for coolable geometry and failure threshold
- 2004 RIL-0401, An Assessment of Postulated Reactivity-Initiated Accidents (RIAs) for Operating Reactors in the U.S.
- 2007 SRP 4.2, Appendix B, Interim Acceptance Criteria and Guidance for the Reactivity Initiated Accidents
- 2017 DG-1327 1<sup>st</sup> public comment period
- 2019 DG-1327 2<sup>nd</sup> public comment period

# Timeline - 1974

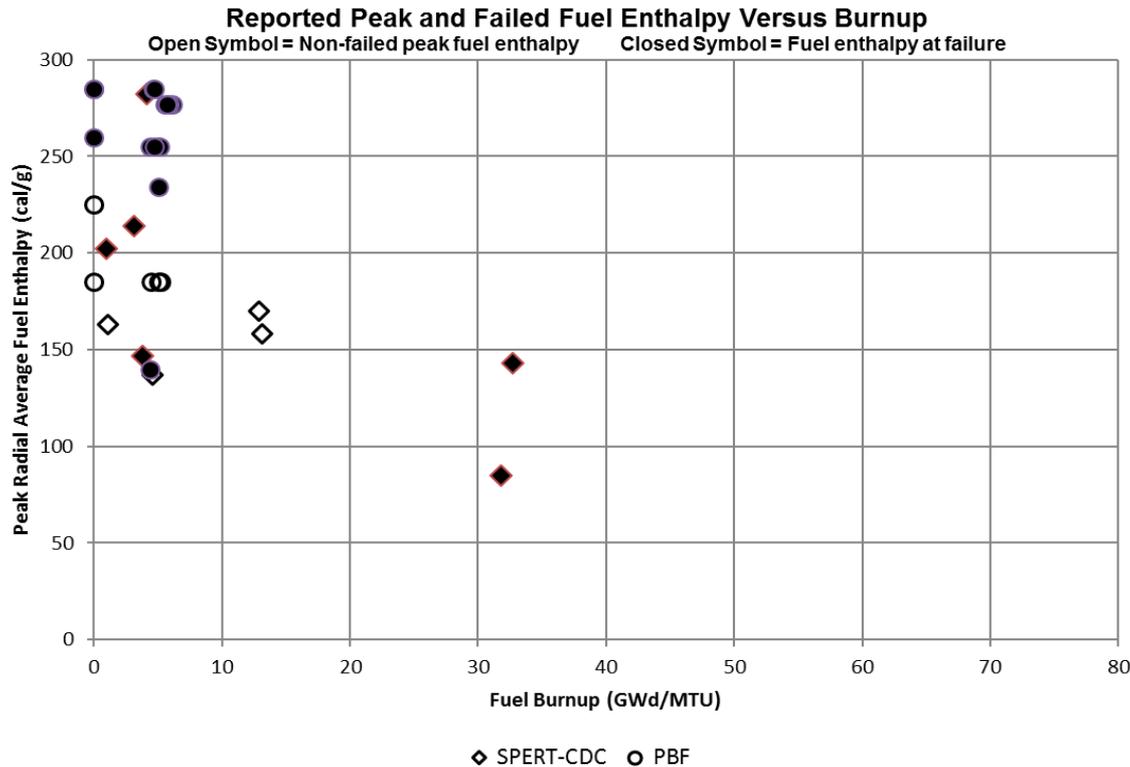
## 1974 RG 1.77, Assumptions used for Evaluating a Control Rod Ejection Accident for Pressurized Water Reactors

- Acceptable PWR analytical methods and assumptions
- Fuel radial average energy density limited to 280 cal/g at any axial node
- Maximum reactor pressure limited to ASME B&PV Service Level C
- Offsite dose consequences limited to “well within” the guidelines in 10CFR Part 100



# Timeline - 1980

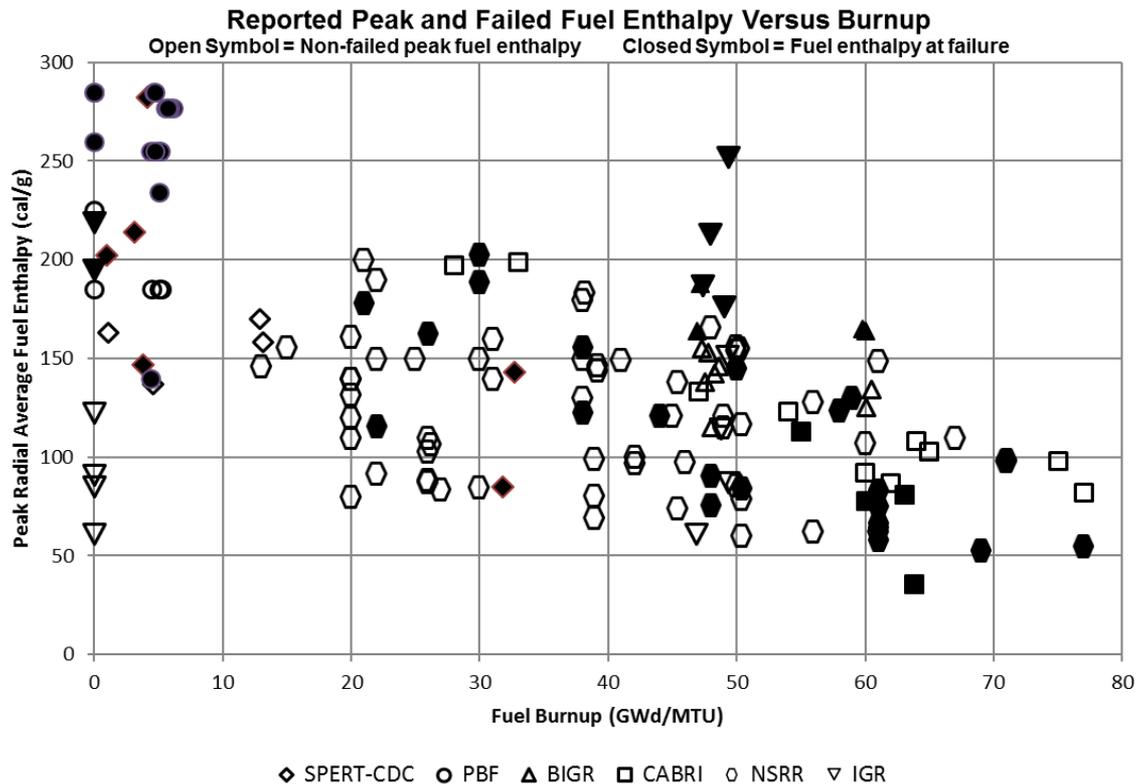
- 1980 *Nuclear Safety* article (MacDonald et.al.) suggests need for new analytical limits for coolable geometry and failure threshold
- Coolability criteria reduced to 230 cal/g at any axial node
  - Cladding failure threshold reduced from 170 cal/g to 140 cal/g for irradiated fuel rods
  - Failure mode strongly dependent on prior irradiation history
  - Based on advanced analytics, no imminent safety concern



# Timeline - 2004

## 2004 RIL-0401, An Assessment of Postulated Reactivity-Initiated Accidents (RIAs) for Operating Reactors in the U.S.

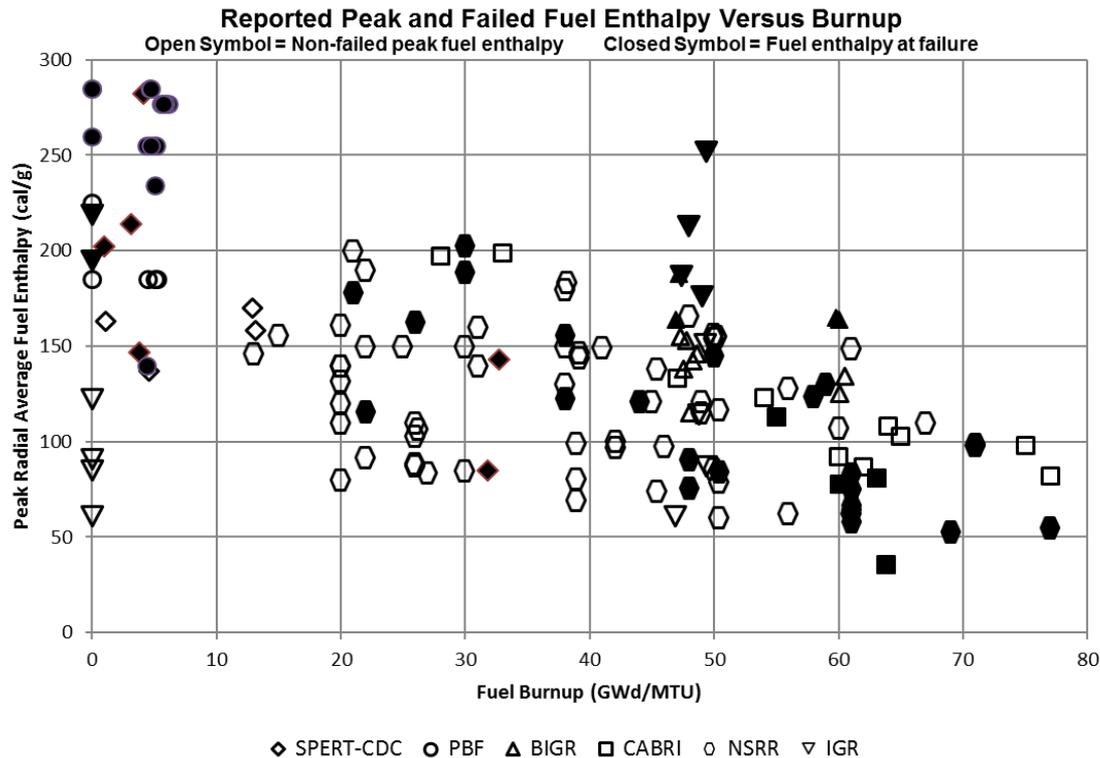
- PCMI cladding failure at much lower fuel enthalpy
- Based on advanced analytics, no imminent safety concern



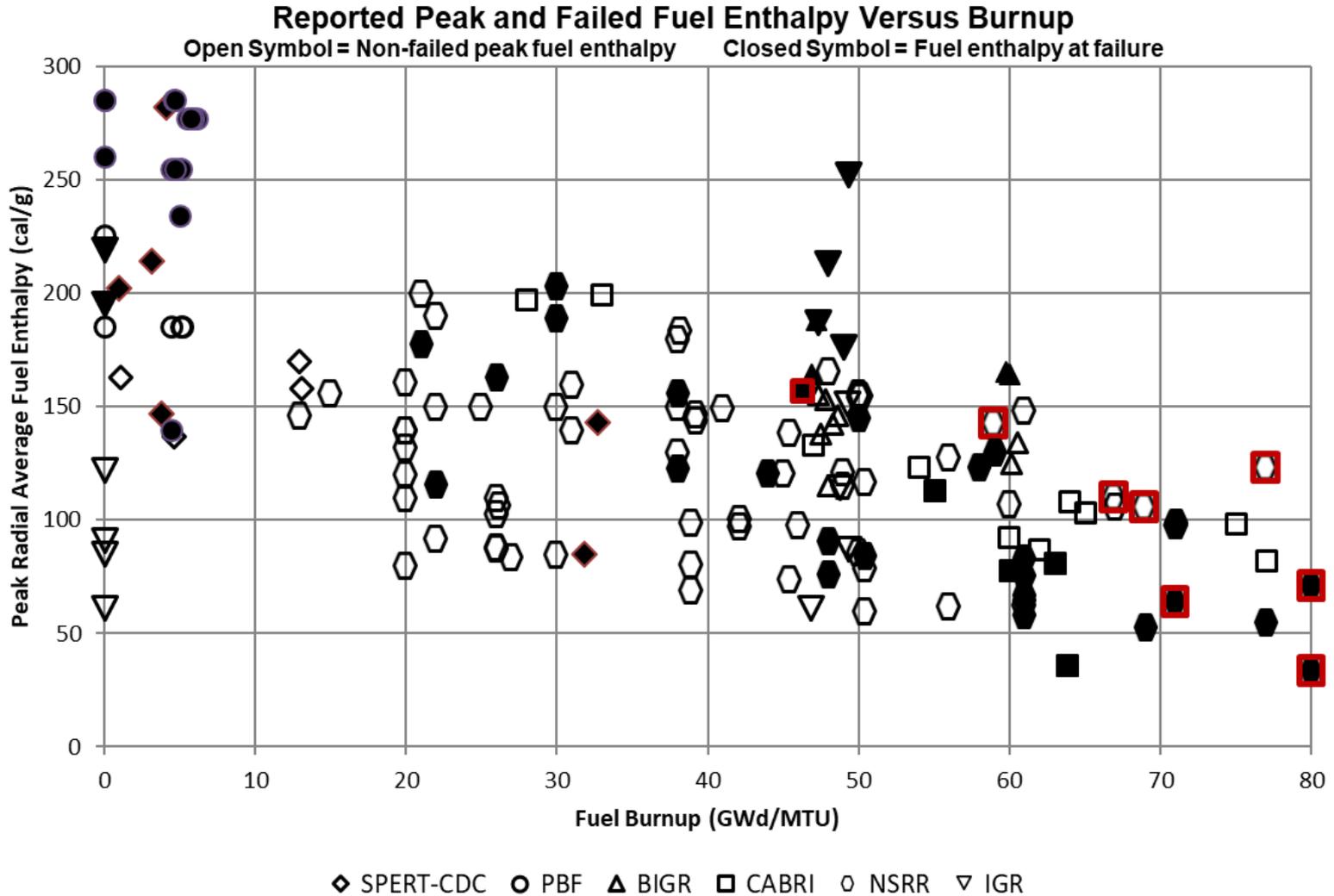
# Timeline - 2007

## 2007 SRP 4.2, Appendix B, Interim Acceptance Criteria and Guidance for the Reactivity Initiated Accidents

- Hydrogen-dependent PWR and BWR PCMI cladding failure thresholds
- Cladding  $\Delta P$ -dependent cladding failure thresholds
- BU-dependent coolability criteria
- Transient FGR

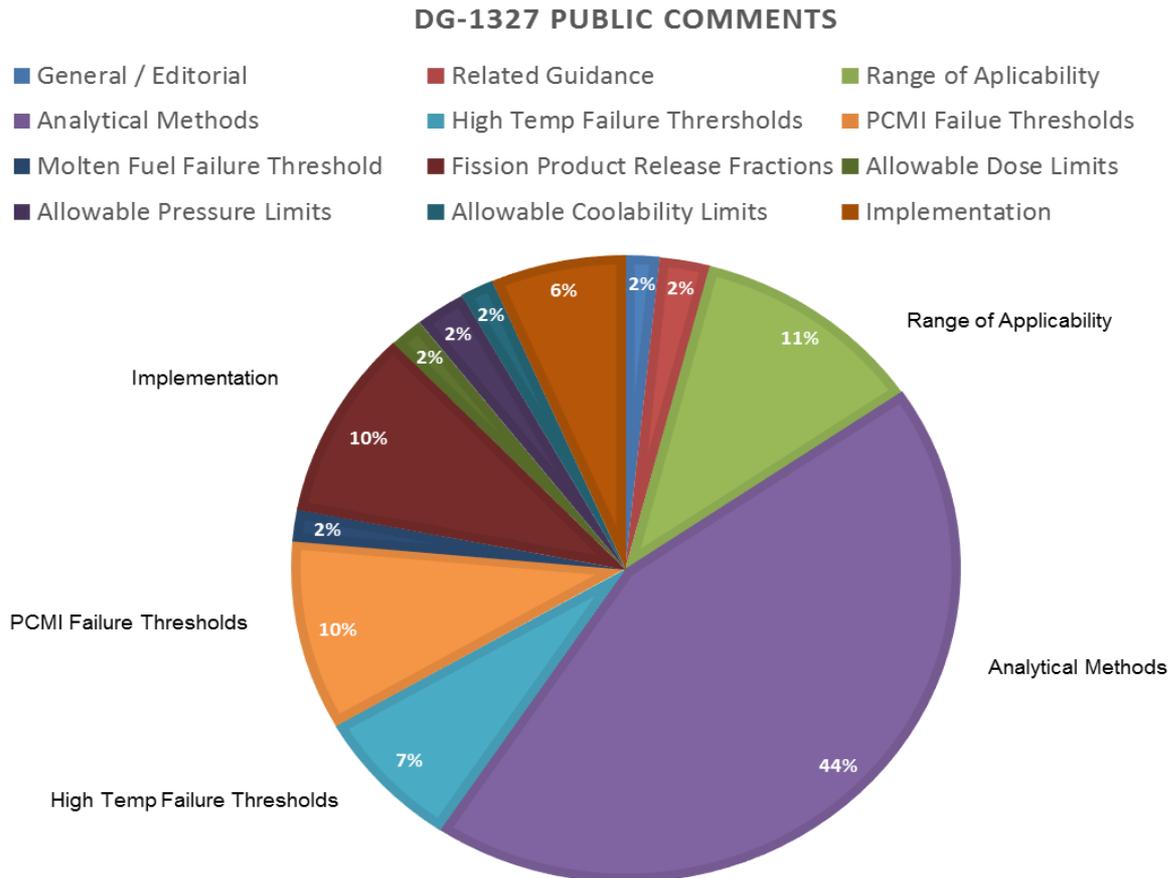


# Empirical Database Circa 2019



# Public Comment - 2017

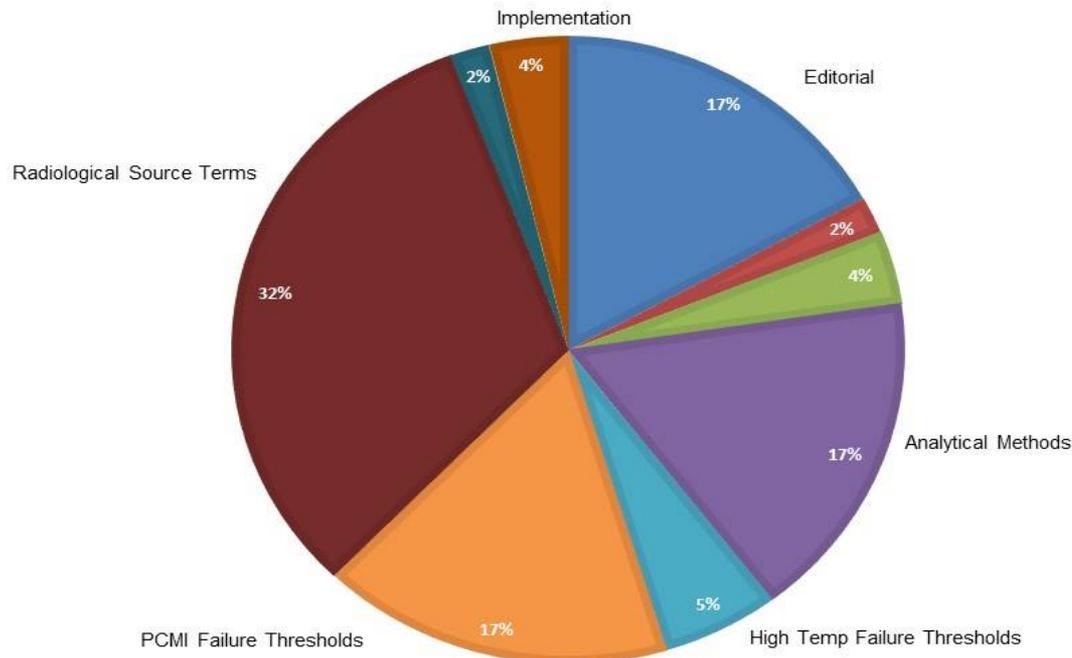
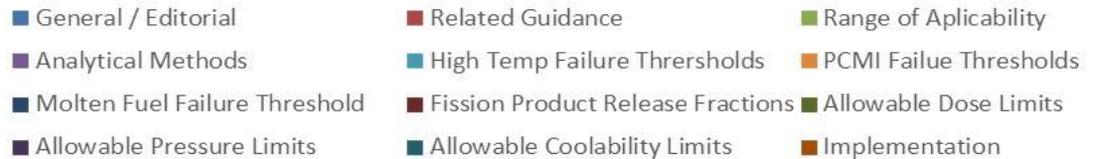
- **Comment submissions received from 12 stakeholders with a total 124 comments**
  - **Over 100 comments were accepted**



# Public Comment - 2019

- **Comment submissions received from 7 stakeholders with a total 54 comments**
  - **Over 30 comments were accepted**

DG-1327 PUBLIC COMMENTS - 2019



# Major Changes

- Expanded fuel burnup range to 68 GWd/MTU (Section C.1)
- Improved analytical requirements (Section C.2)
- Revised PCMI cladding failure threshold curves (Section C.3)
- Removed radiological source term information (Section C.4)
  - Analytical requirements
  - Fission product gap release fractions → [Future revision to RG 1.183](#)
  - Analytical procedure
- Amended implementation to reflect revised Backfit guidance (Section D)
- Added cladding hydrogen uptake models (Appendix C)

# Agenda

1. Regulatory Requirements
2. Timeline and Stakeholder Comments
- 3. Revised Guidance and Analytical Limits**
  - a. Reactor Coolant System Pressure
  - b. Damaged Core Coolability
  - c. Radiological Consequences
4. Cladding Hydrogen Models
5. BU Extension

# RCS Pressure Analytical Limit

## 5. Allowable Limits on Reactor Coolant System Pressure

For new license applications, the maximum reactor coolant system pressure should be limited to the value that will prevent stresses from exceeding Emergency Condition (Service Level C), as defined in Section III of the American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code (Ref. 14). For existing plants, the allowable limits for the reactor pressure boundary specified in the plant's updated final safety analysis report should be maintained.

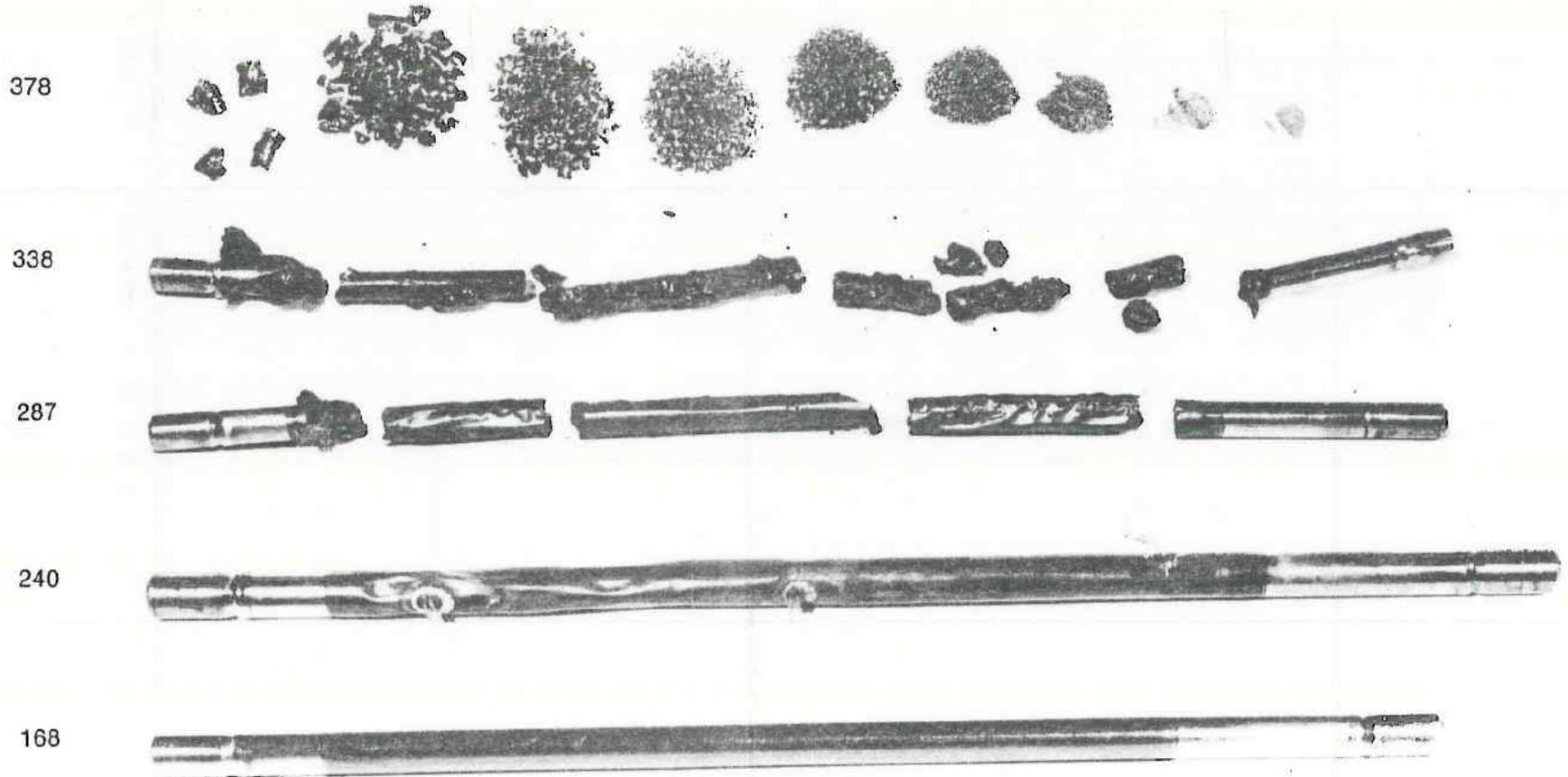
- Consistent with current guidance and practice
- Protects reactor pressure boundary - satisfies GDC-28

# Agenda

1. Regulatory Requirements
2. Timeline and Stakeholder Comments
3. Revised Guidance and Analytical Limits
  - a. Reactor Coolant System Pressure
  - b. Damaged Core Coolability**
  - c. Radiological Consequences
4. Cladding Hydrogen Models
5. BU Extension

# Protect Against Loss of Fuel Bundle Geometry

Energy deposition  
(cal/g UO<sub>2</sub>)



69-6057

Fig. 3 Posttest photographs of SPXM rods tested in the CDC.

# Coolability Analytical Limits

## 6. Allowable Limits on Damaged Core Coolability

Limiting peak radial average fuel enthalpy to prevent catastrophic fuel rod failure and avoiding molten fuel-coolant interaction is an acceptable metric to demonstrate that there is limited damage to core geometry and that the core remains amenable to cooling. The following restrictions should be met:

- a. Peak radial average fuel enthalpy should remain below 230 cal/g.
  - b. A limited amount of fuel melting is acceptable provided that it is less than 10 percent of fuel volume. If fuel melting occurs, the peak fuel temperature in the outer 90 percent of the fuel volume should remain below incipient fuel melting conditions.
- Loss of fuel rod geometry limit (230 cal/g) based on earlier SPERT, PBF and NSRR prompt critical experiments
  - Limited centerline melt (current license bases) avoids molten FCI
  - Fuel melt becomes more limiting at ~30 GWd/MTU
  - Preserves coolable geometry - satisfies GDC-28

# Agenda

1. Regulatory Requirements
2. Timeline and Stakeholder Comments
3. Revised Guidance and Analytical Limits
  - a. Reactor Coolant System Pressure
  - b. Damaged Core Coolability
  - c. Radiological Consequences**
4. Cladding Hydrogen Models
5. BU Extension

# Radiological Consequences

1. Requires a conservative estimate of the total number of failed fuel pins from all failure modes
  - Prompt critical high temperature cladding failure
  - Non-prompt DNB/CPR cladding failure
  - PCMI cladding failure
  - Centerline fuel melt cladding failure
  
2. Requires a conservative estimate of fission product release fractions
  - Steady-state gap inventories
  - Transient fission gas release
  - Fuel melt fission gas release

→ Future revision to RG 1.183

# HT Cladding Failure Threshold

## 3.1 High-Temperature Cladding Failure Threshold

Figure 1 shows the empirically based high-temperature cladding failure threshold. This composite failure threshold encompasses both brittle and ductile failure modes and should be applied for events with prompt critical excursions (i.e. ejected rod worth or drop rod worth greater than or equal to \$1.0). Because ductile failure depends on cladding temperature and differential pressure (i.e., rod internal pressure minus reactor pressure), the composite failure threshold is expressed in peak radial average fuel enthalpy (calories per gram (cal/g)) versus fuel cladding differential pressure (megapascals (MPa)).

For prompt critical scenarios which experience a prolonged power level following the prompt pulse, fuel cladding failure is presumed if local heat flux exceeds thermal design limits (e.g., departure from nucleate boiling and critical power ratios).

For non-prompt critical excursions, fuel cladding failure is presumed if local heat flux exceeds thermal design limits.

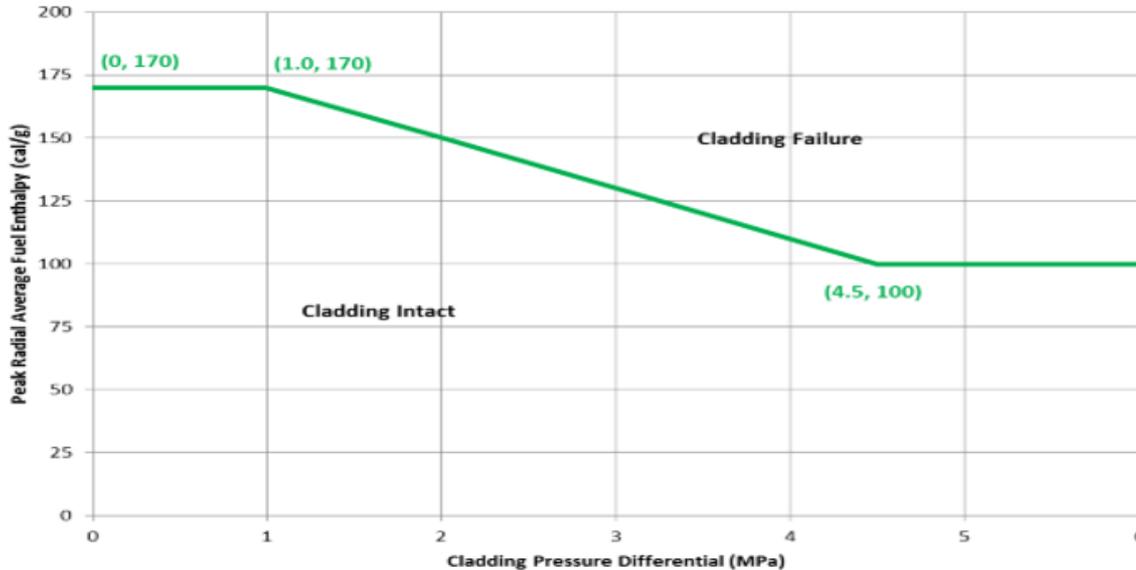
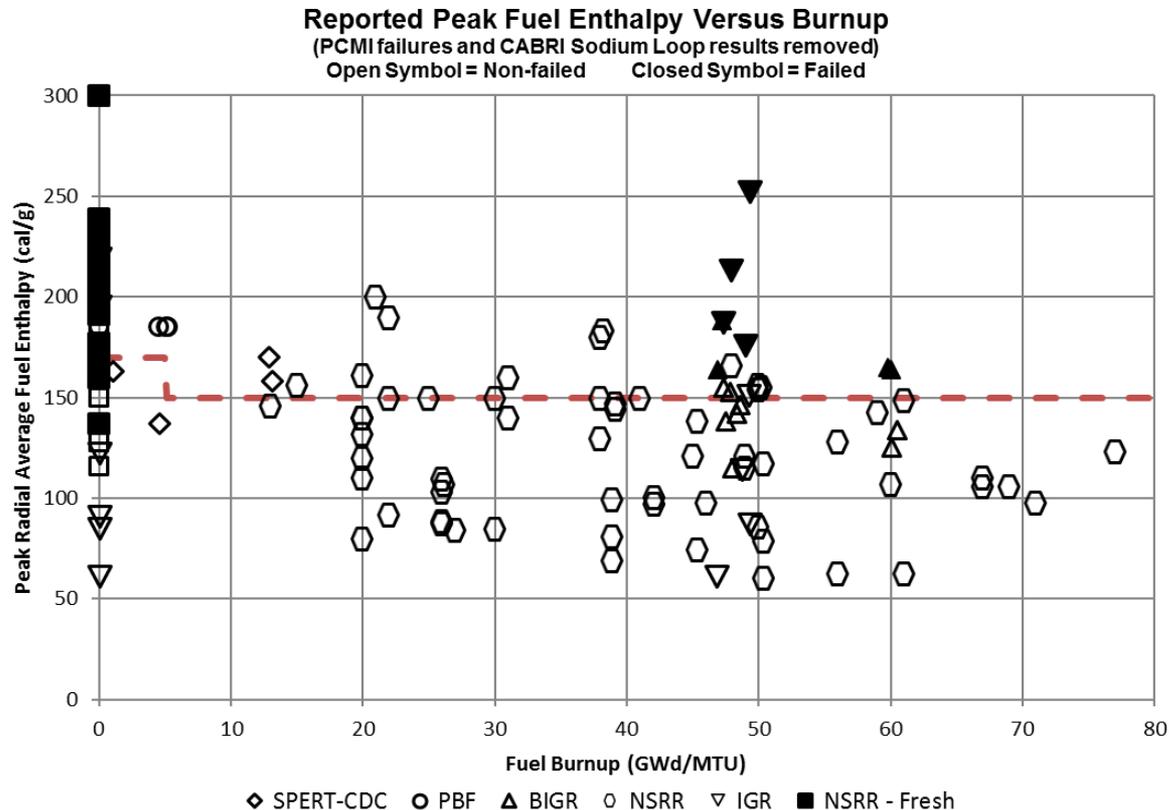


Figure 1. High-Temperature Cladding Failure Threshold

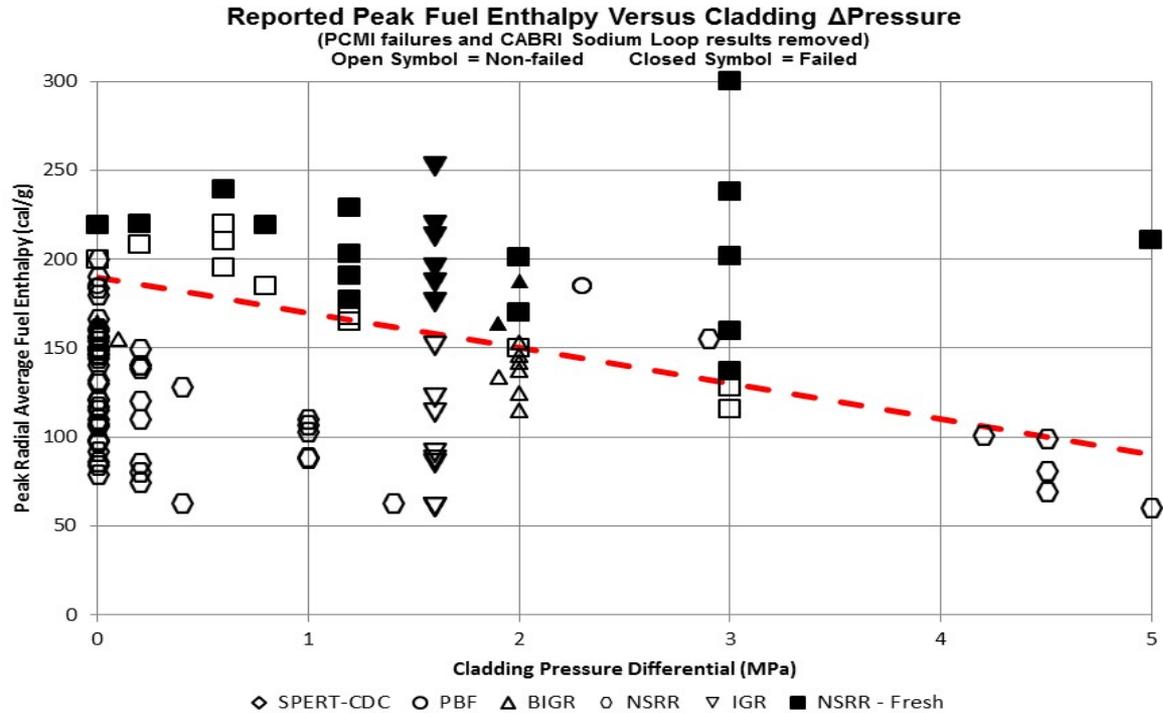
# HT Cladding Failure Mechanisms

- High temperature cladding failure mechanisms
  - Brittle Failure: High-temperature post-DNB (film-boiling) oxygen-induced embrittlement and fragmentation
  - Ductile Failure: High-temperature cladding creep (balloon/rupture)



# Sensitivity Study

- Database suggests ductile failure sensitive to cladding  $\Delta P$ 
  - Transient FGR contributes to rod internal pressure
- Below 100 cal/g fuel enthalpy, cladding remains below 800 °F and is no longer susceptible to HT failure
- Minimal BU effects

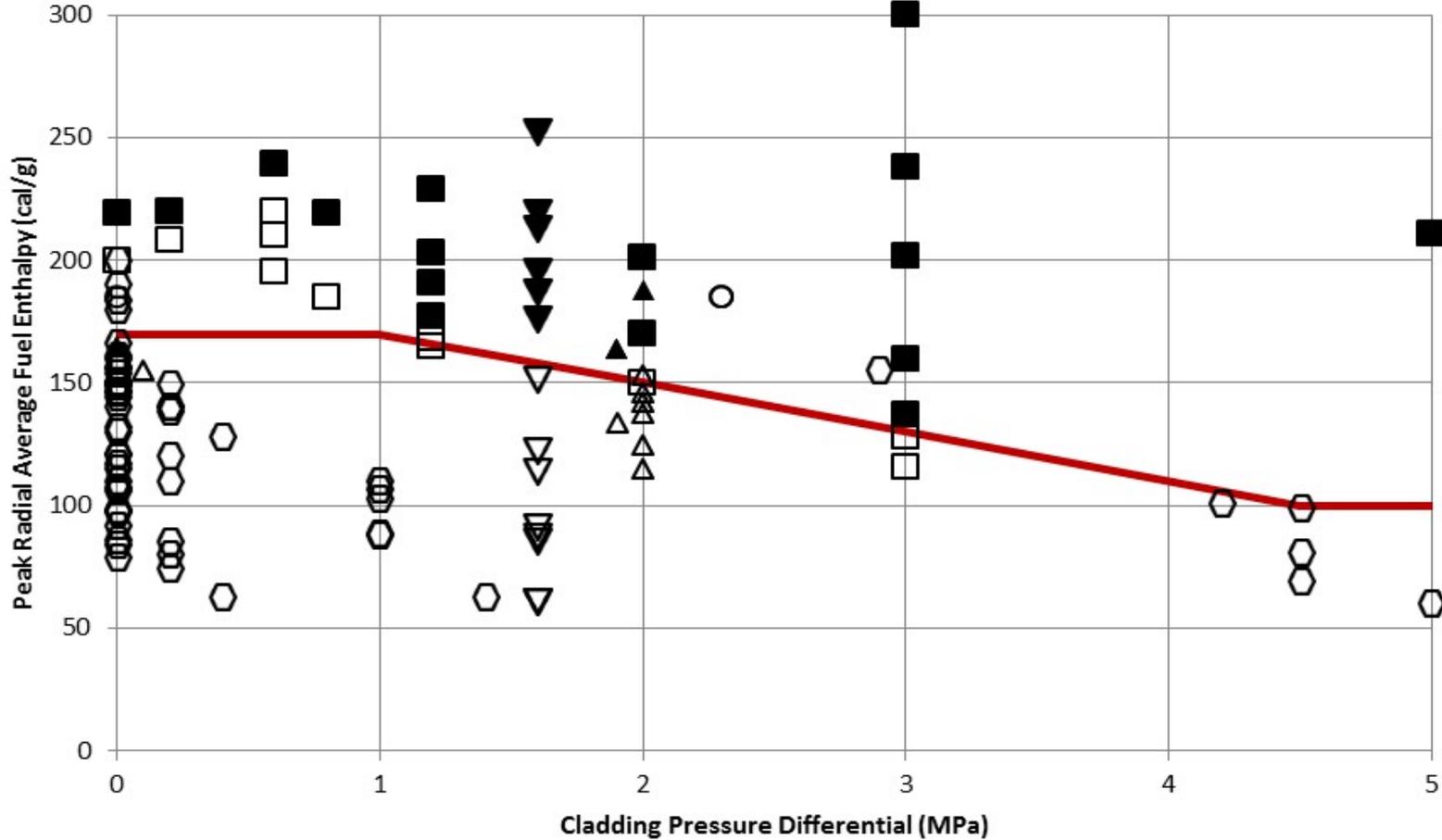


# HT Cladding Failure Mechanisms

**Reported Peak Fuel Enthalpy Versus Cladding  $\Delta$ Pressure**

(PCMI failures and CABRI Sodium Loop results removed)

Open Symbol = Non-failed      Closed Symbol = Failed

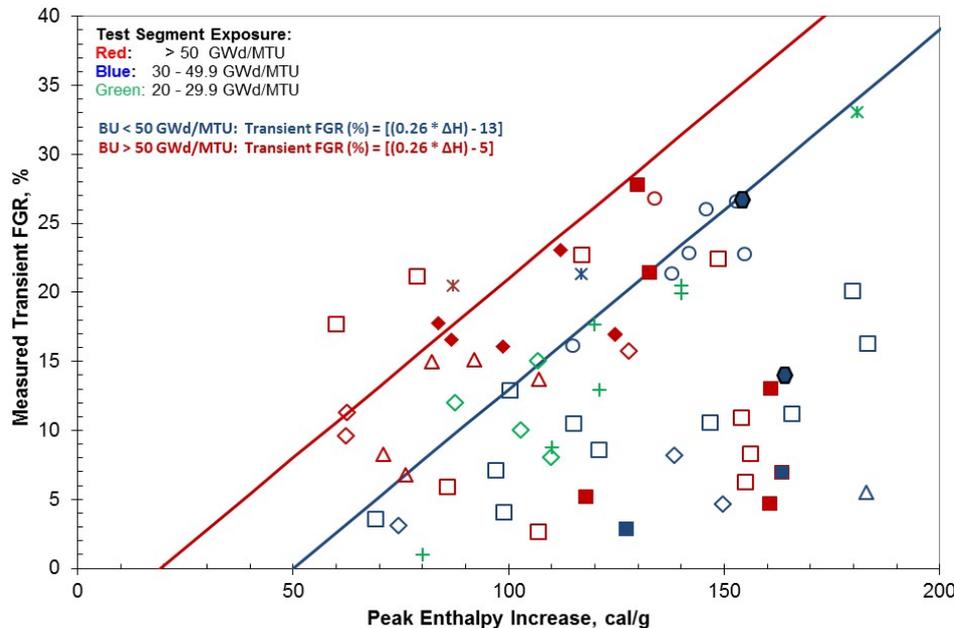


◆ SPERT-CDC    ○ PBF    ▲ BGR    ○ NSRR    ▼ IGR    ■ NSRR - Fresh

# Impact of Transient FGR on RIP

2.3.2 Figure 1 provides an acceptable high temperature cladding failure threshold as a function of cladding differential pressure. When applying Figure 1, the cladding differential pressure must include both the initial, pre-transient rod internal gas pressure plus any increase associated with transient fission gas release (FGR). An approved fuel rod thermal-mechanical performance code should be used to predict the initial, pre-transient rod internal conditions (e.g., moles of fission gas, void volume, FGR, rod internal pressure). The amount of transient FGR may be calculated using the burnup-dependent correlations provided in Figure 6.

2.3.3 Due to the large variation in predicted radial average fuel enthalpy rise along the axial length of a fuel rod, the applicant may elect to (1) calculate transient FGR for several axial regions and (2) combine each axial contribution, along with the pre-transient gas inventory, within the calculation of total rod internal pressure.



- Unchanged from DG-1327

# DNB/CPR Cladding Failure

## 3.1 High-Temperature Cladding Failure Threshold

Figure 1 shows the empirically based high-temperature cladding failure threshold. This composite failure threshold encompasses both brittle and ductile failure modes and should be applied for events with prompt critical excursions (i.e. ejected rod worth or drop rod worth greater than or equal to \$1.0). Because ductile failure depends on cladding temperature and differential pressure (i.e., rod internal pressure minus reactor pressure), the composite failure threshold is expressed in peak radial average fuel enthalpy (calories per gram (cal/g)) versus fuel cladding differential pressure (megapascals (MPa)).

For prompt critical scenarios which experience a prolonged power level following the prompt pulse, fuel cladding failure is presumed if local heat flux exceeds thermal design limits (e.g., departure from nucleate boiling and critical power ratios).

For non-prompt critical excursions, fuel cladding failure is presumed if local heat flux exceeds thermal design limits.

- Consistent with current guidance and practice

# PCMI Cladding Failure

## 3.2 PCMI Cladding Failure Threshold

Figures 2 through 5 show the empirically based PCMI cladding failure thresholds. Because fuel cladding ductility is sensitive to hydrogen content, zirconium hydride orientation, and initial temperature, separate PCMI failure curves are provided for RXA and SRA cladding types at both low initial cladding temperature conditions (i.e., below 500 degrees F down to BWR cold startup) and high initial cladding temperature conditions (i.e., at or above 500 degrees F). The RXA cladding failure threshold is further refined for cladding designs with and without a barrier liner (e.g., sponge or low allow cladding inside diameter liner). The SRA cladding failure threshold is applicable regardless of the presence of a barrier liner. The PCMI cladding failure threshold is expressed in peak radial average fuel enthalpy rise ( $\Delta\text{cal/g}$ ) versus excess cladding hydrogen content (wppm). Excess cladding hydrogen content refers to the portion of total hydrogen content in the form of zirconium hydrides (i.e., it does not include hydrogen in solution).

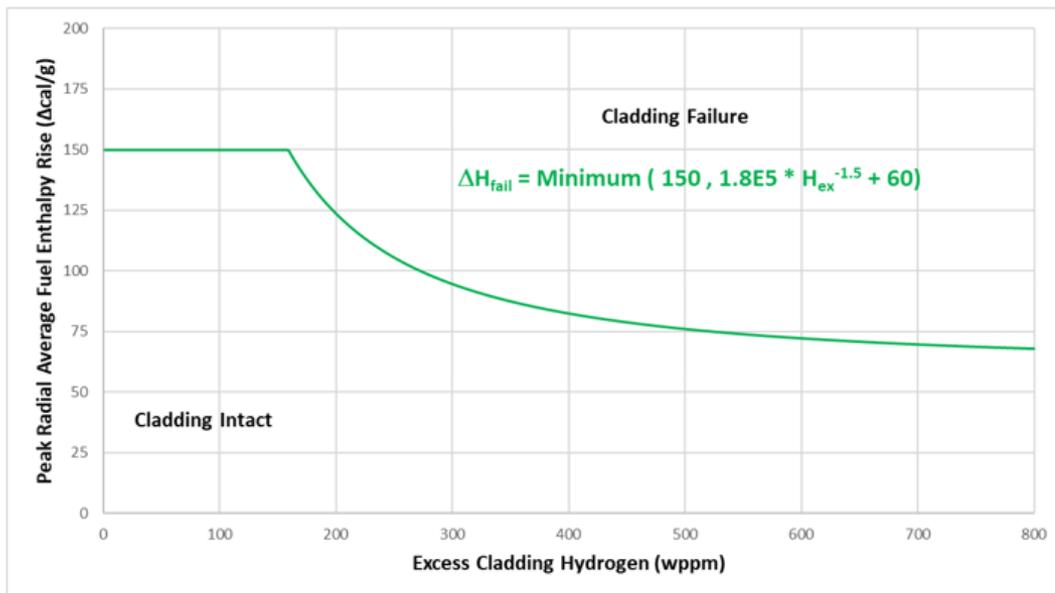
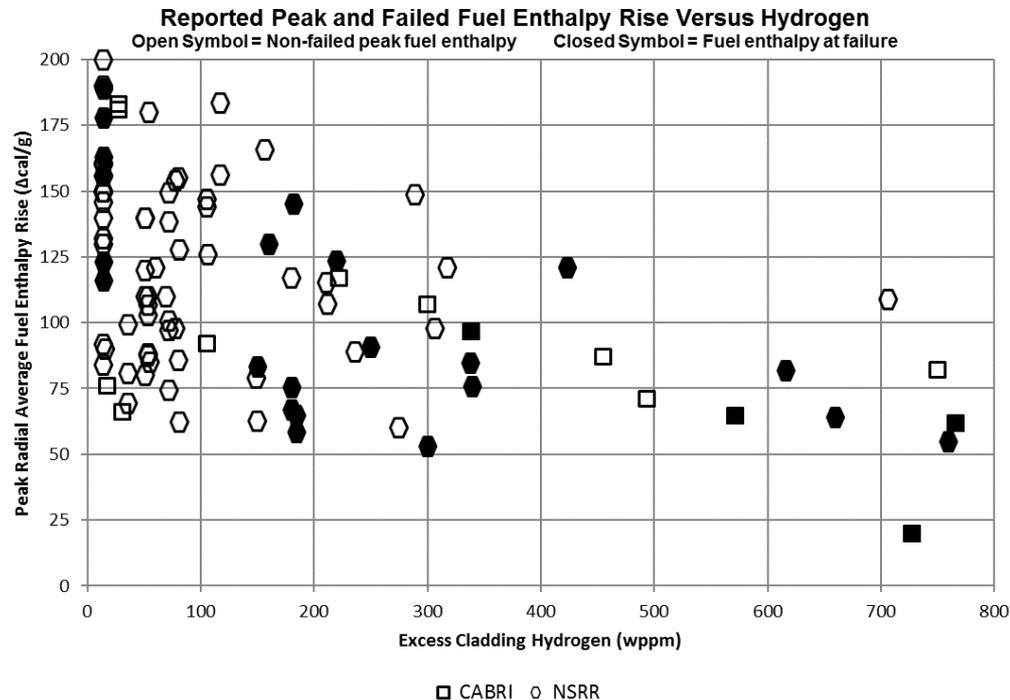


Figure 3. PCMI Cladding Failure Threshold—SRA Cladding at or above 500 Degrees F

# Hydrogen-Enhanced PCMI

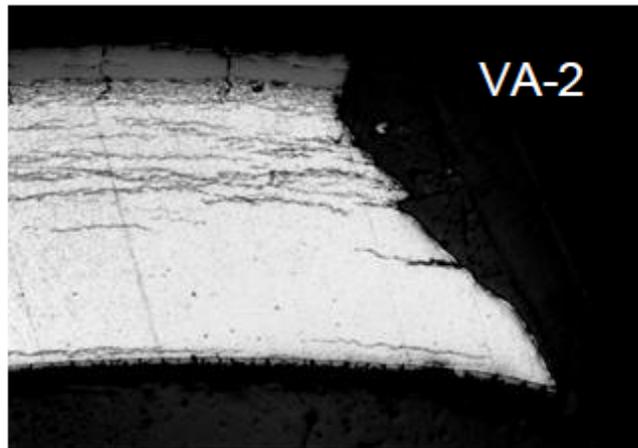
- Hydrogen, absorbed during normal operation waterside corrosion, forms zirconium hydrides which reduce the cladding's ductility
- Hydrogen uptake depends on several factors:
  - Time-at-temperature (residence time)
  - Power history and fluence
  - Alloy-specific corrosion and hydrogen pickup kinetics
  - Proximity to dissimilar metals
  - RCS chemistry
- Low burnup and low corrosion fuel rods retain sufficient cladding ductility and will likely fail by high temperature mechanisms before PCMI



# Hydride Orientation

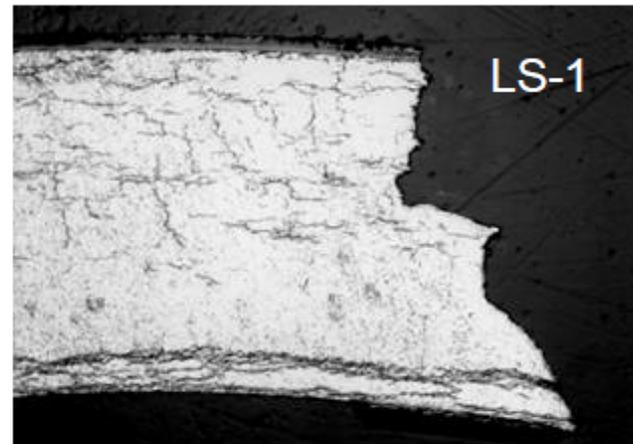
- Besides overall concentration, PCMI sensitive to hydride distribution and orientation which are influenced by:
  - Thermal and mechanical treatment during manufacturing
  - Stress state prevailing during hydride precipitation

PWR cladding  
(stress-relieve annealed)



Burnup: 79 GWd/t  
H content: 760 ppm  
Failure at 55 cal/g

BWR cladding  
(recrystallization annealed)

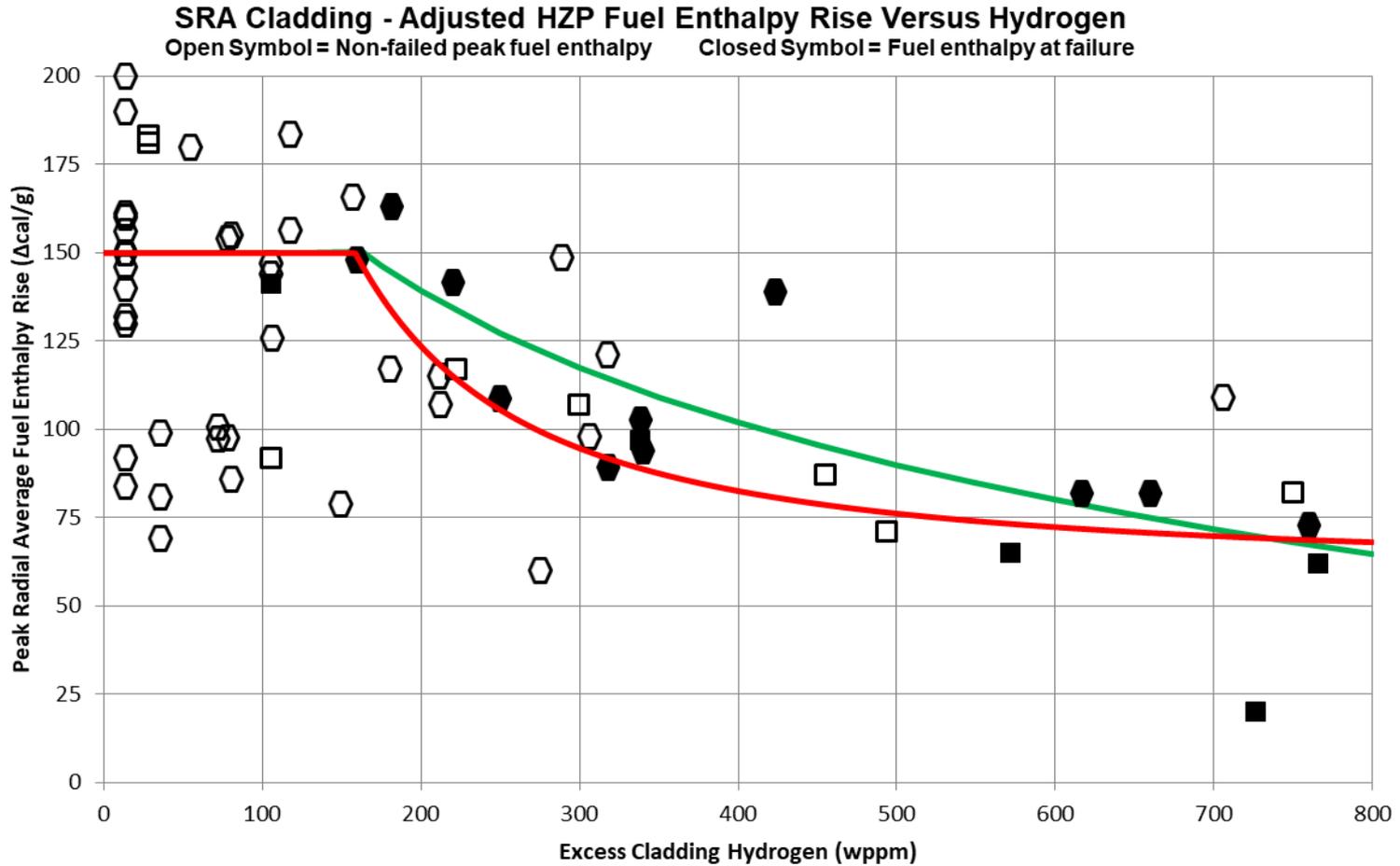


Burnup: 69 GWd/t  
H content: ~300 ppm  
Failure at 60 cal/g



- Separate PCMI cladding failure threshold lines established which account for impacts associated with initial RCS temperature, excess hydrogen, and hydride sensitivity
  1. SRA cladding at high RCS coolant temperature
  2. SRA cladding at low RCS coolant temperature
  3. RXA cladding at high RCS coolant temperature
  4. RXA cladding at low RCS coolant temperature

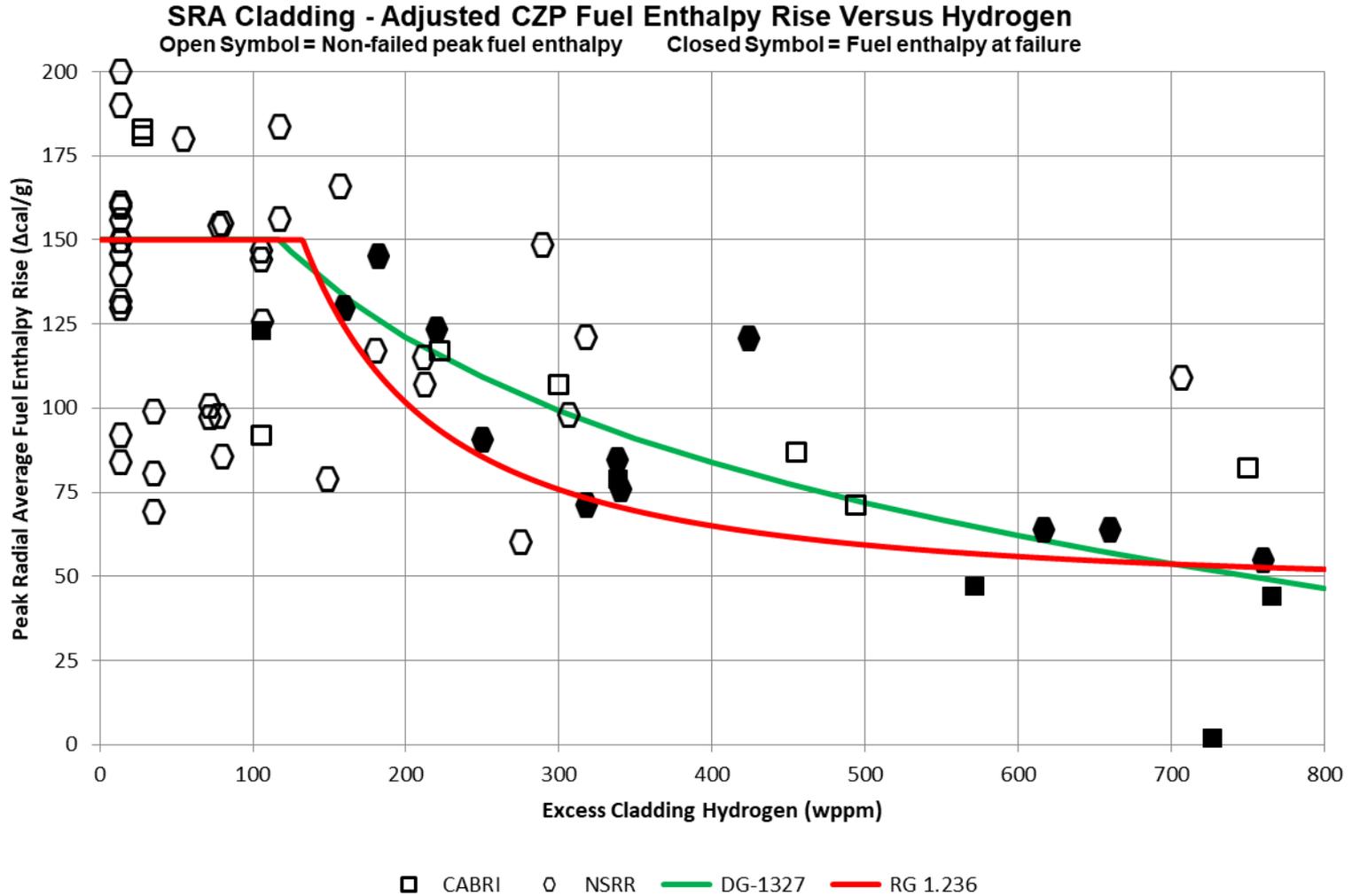
# SRA Hot PCMI Failure Threshold



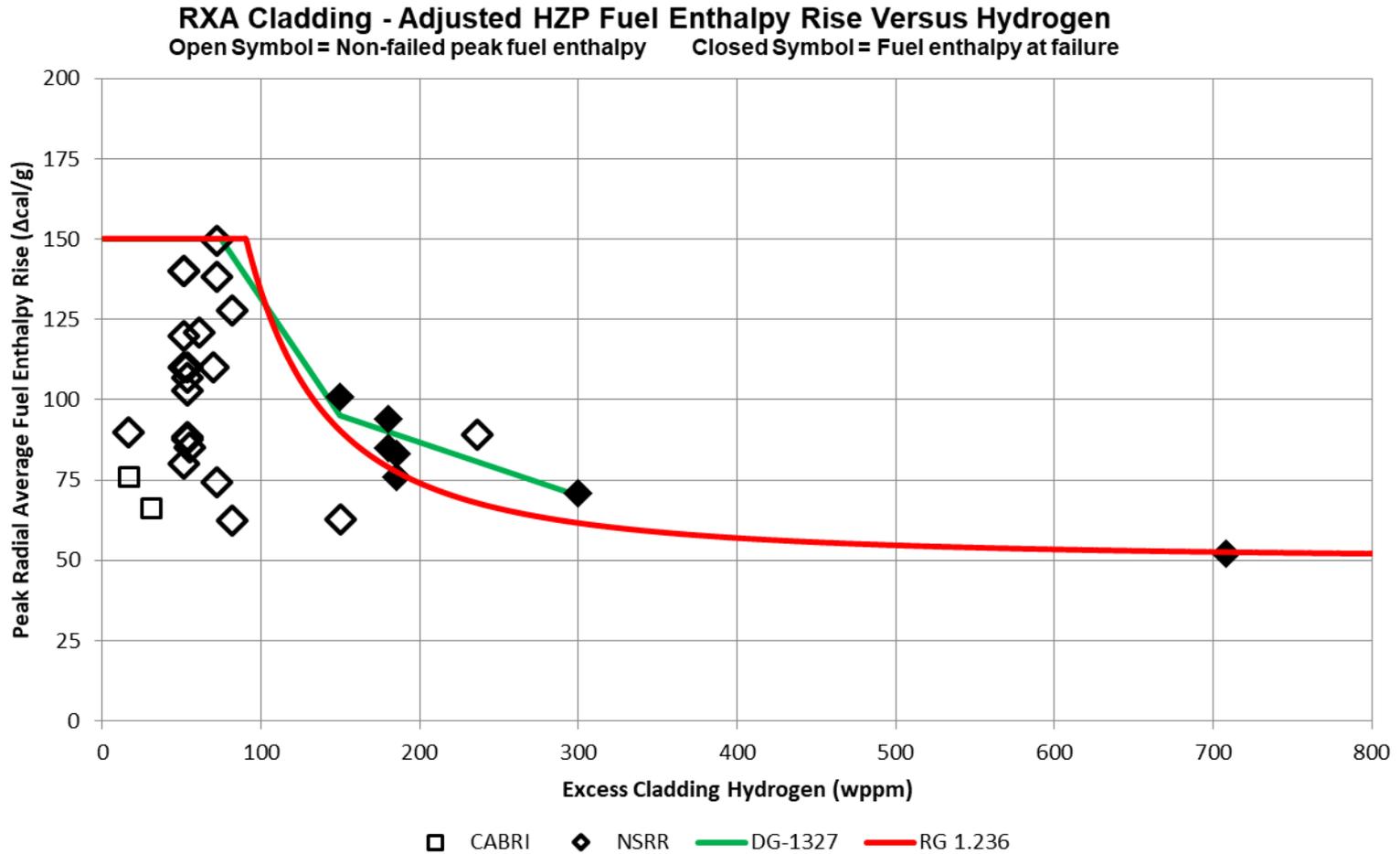
□ CABRI    ◊ NSRR    — DG-1327    — RG 1.236



# SRA Cold PCMI Failure Threshold

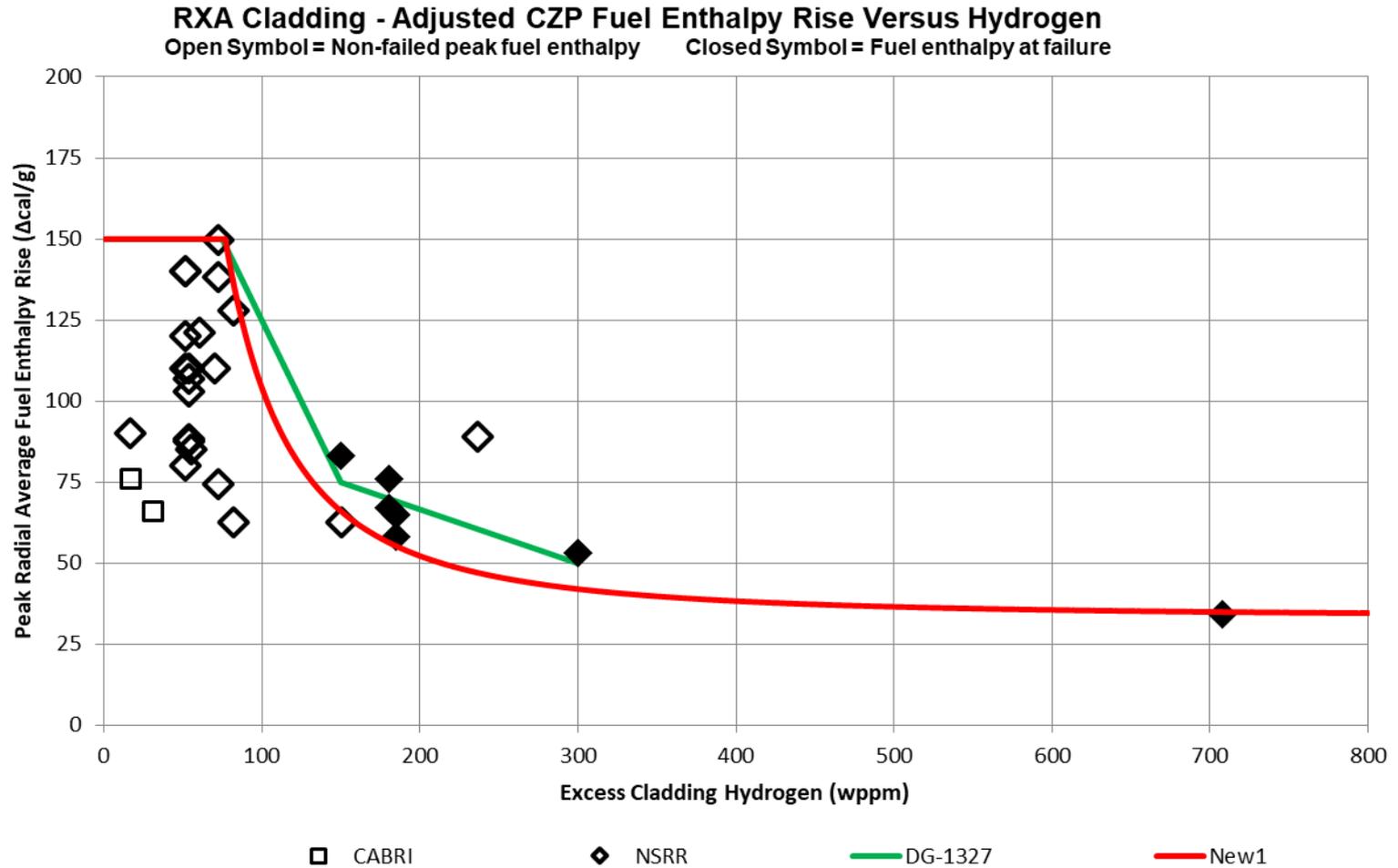


# RXA Hot PCMI Failure Threshold



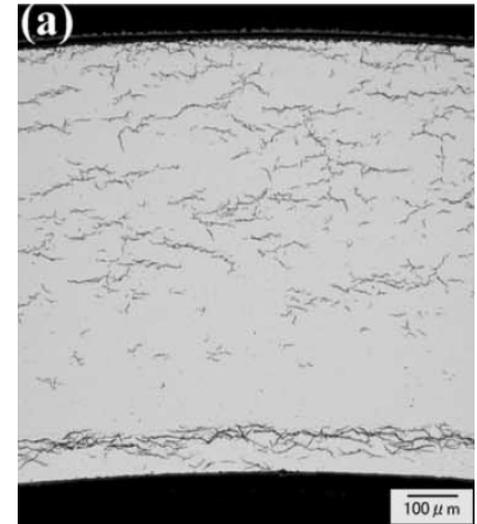
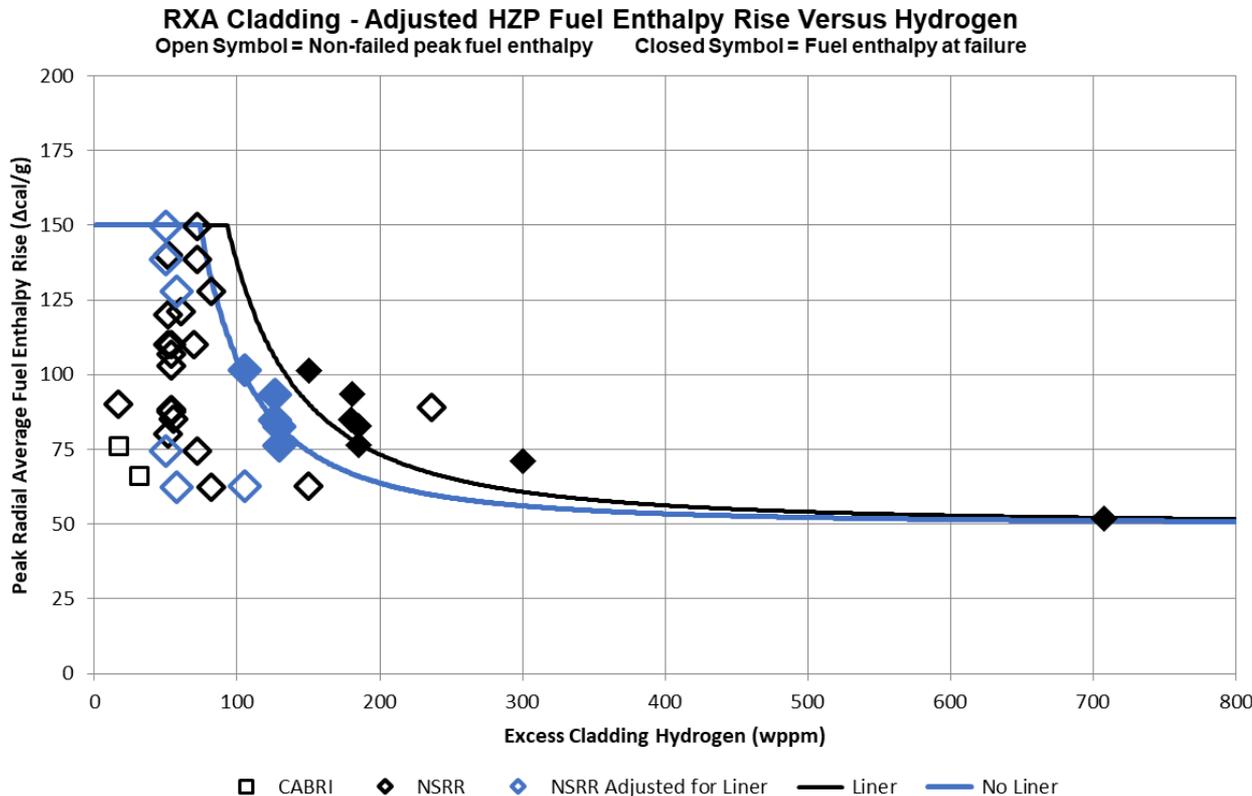


# RXA Cold PCMI Failure Threshold



# Impact of Barrier Liner

- In BWR liner (i.e., barrier) fuel, the natural or low alloy zirconium liner acts as a sponge for hydrogen.
  - Depletes base metal of detrimental effects of hydrides
  - Liner remains ductile even with high concentration of hydrides



# Agenda

1. Regulatory Requirements
2. Timeline and Stakeholder Comments
3. Revised Guidance and Analytical Limits
  - a. Reactor Coolant System Pressure
  - b. Damaged Core Coolability
  - c. Radiological Consequences
- 4. Cladding Hydrogen Models**
5. BU Extension

# Hydrogen Uptake Models

- Originally published in draft RG 1.224 (2015) in support of 50.46c rule
  - DG-1263 public comment period in 2014

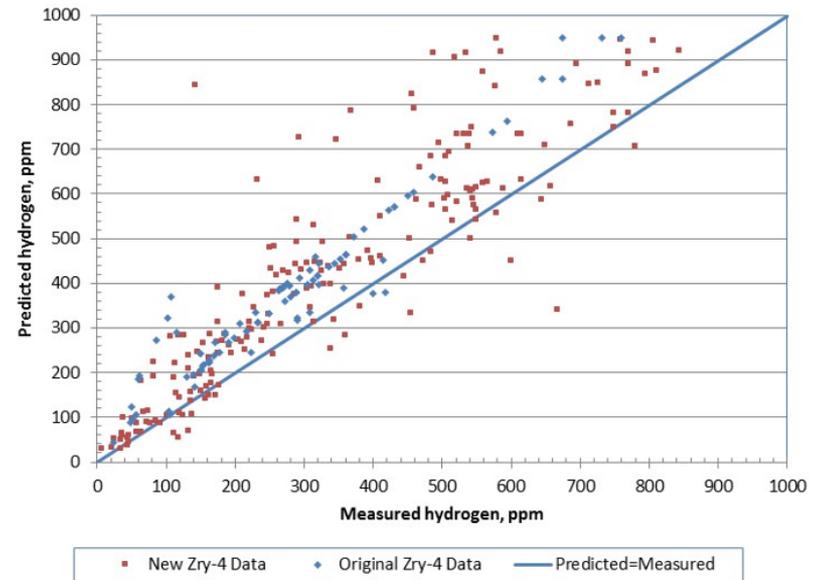
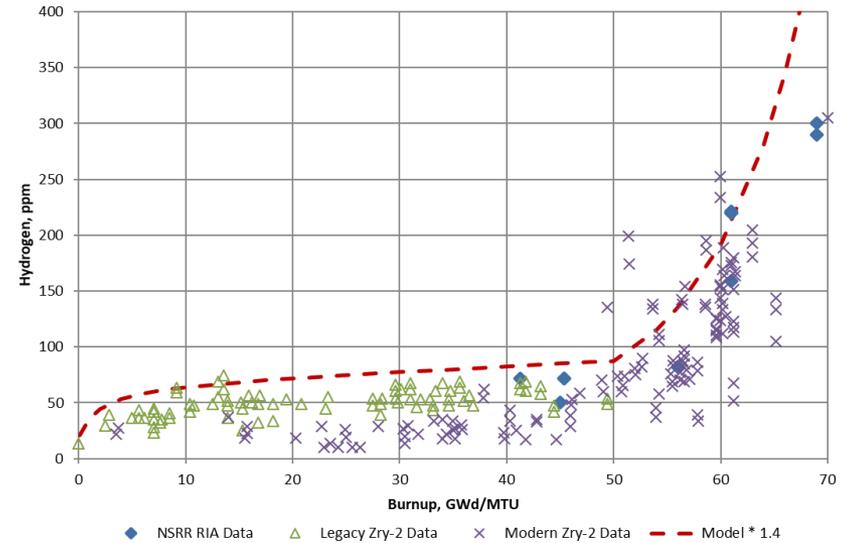
## C-1. Zirconium Cladding Alloys in Pressurized-Water Reactors

Corrosion rates and the amount of corrosion at fuel discharge vary widely across the pressurized-water reactor (PWR) fleet because of alloy composition, operating conditions, and residence time (i.e., effective full-power days). Fuel vendors have approved fuel performance analytical tools along with corrosion models. In general, these corrosion models can predict a best estimate corrosion thickness as a function of effective full-power days and local operating conditions (fuel duty).

An examination of the empirical database of measured cladding hydrogen content for the current commercial zirconium alloys reveals that PWR cladding alloys do not exhibit the same breakaway hydrogen uptake at higher fluence levels as observed in Zircaloy-2 data for boiling-water reactors (BWRs). However, the pickup fraction does appear to be alloy specific. With consideration of the extent, uncertainty, and variability of the supporting database, the staff developed the following upper bound pickup fractions:

Zircaloy-4	20% hydrogen absorption
ZIRLO®	25% hydrogen absorption
Optimized ZIRLO™	25% hydrogen absorption
M5®	15% hydrogen absorption

These hydrogen pickup fractions should be used, along with a best estimate prediction of the peak oxide thickness using an approved fuel rod thermal-mechanical model, to estimate the cladding hydrogen content.

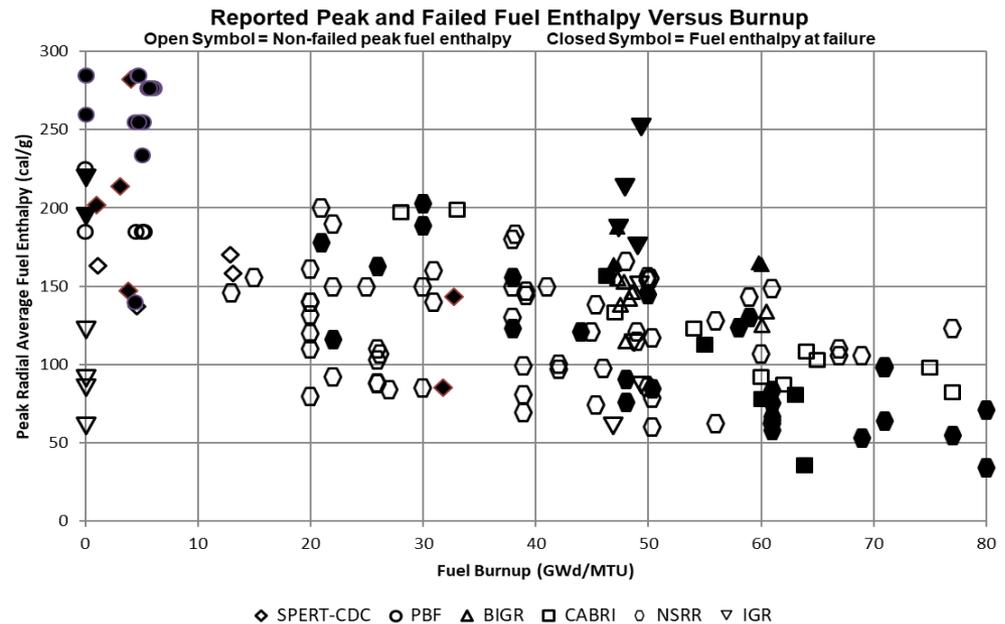


# Agenda

1. Regulatory Requirements
2. Timeline and Stakeholder Comments
3. Revised Guidance and Analytical Limits
  - a. Reactor Coolant System Pressure
  - b. Damaged Core Coolability
  - c. Radiological Consequences
4. Cladding Hydrogen Models
- 5. BU Extension**

# Burnup Extension

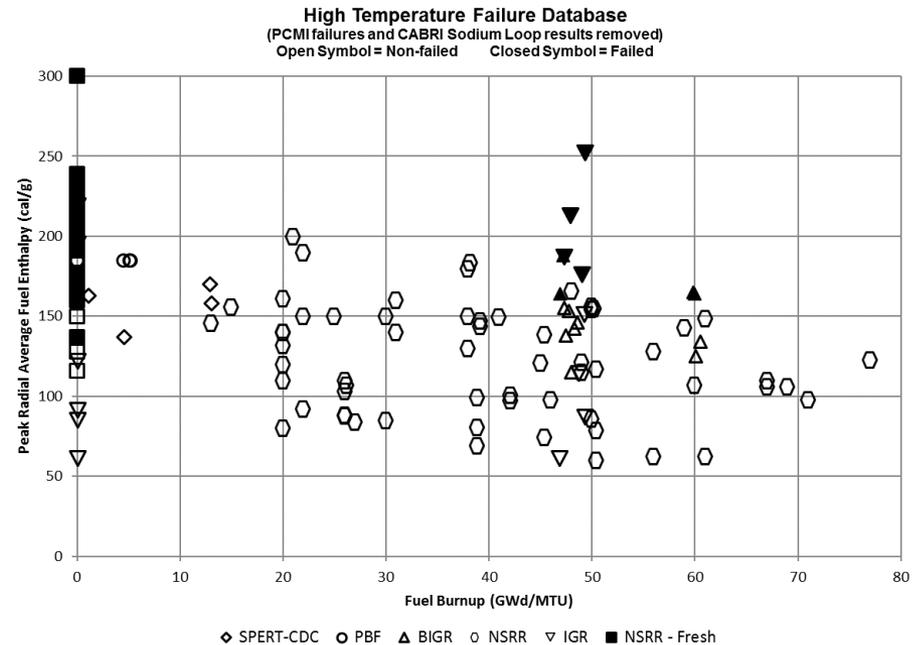
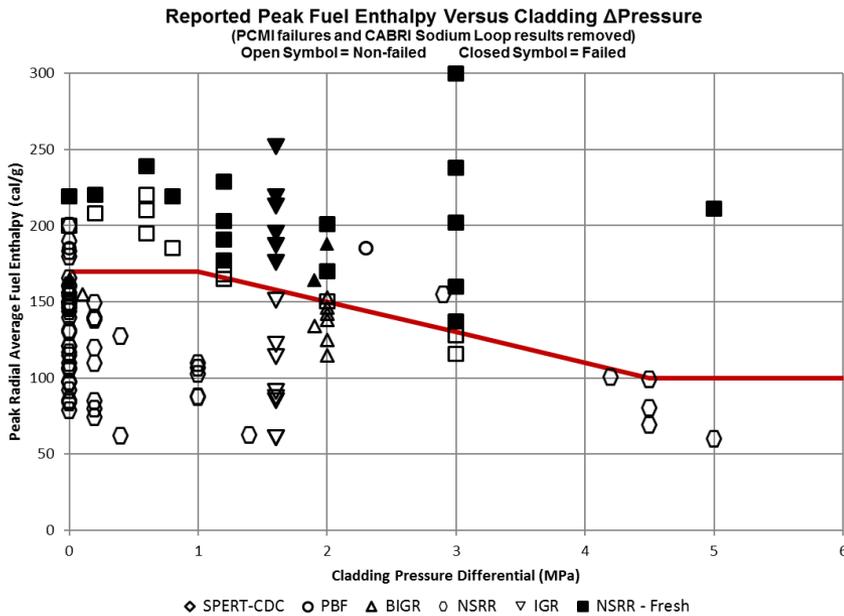
- In support of near-term licensing actions to extend allowable fuel rod average burnup to 68 GWd/MTU\*, staff completed a critical assessment of the empirical database supporting RG 1.236 guidance (ML20090A308)
- For each portion of the guidance, the staff (1) investigated sensitivity with burnup and (2) assessed the extent of empirical database



\* Empirical database reports test segment (i.e., local) burnup. Rod average 68 GWd/MTU equivalent to approximately 75 GWd/MTU test segment burnup.

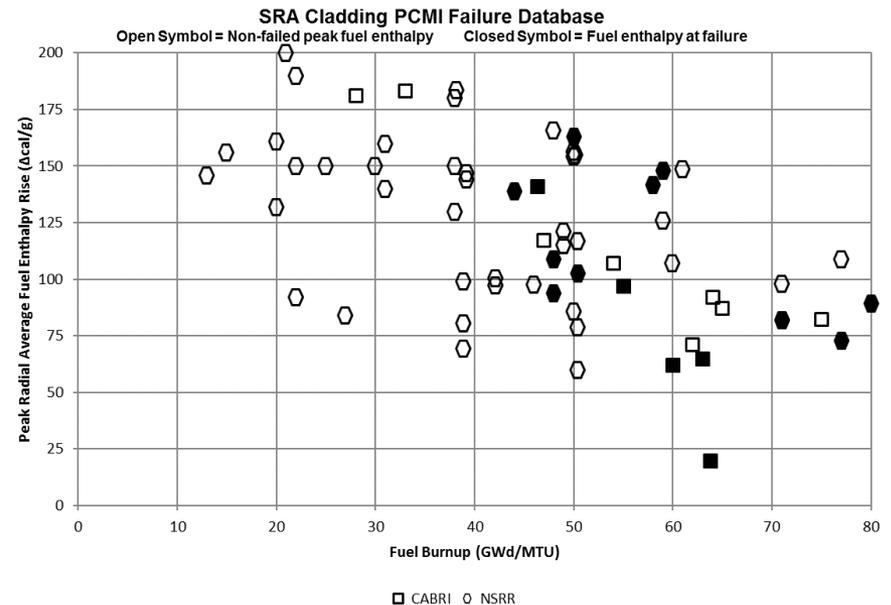
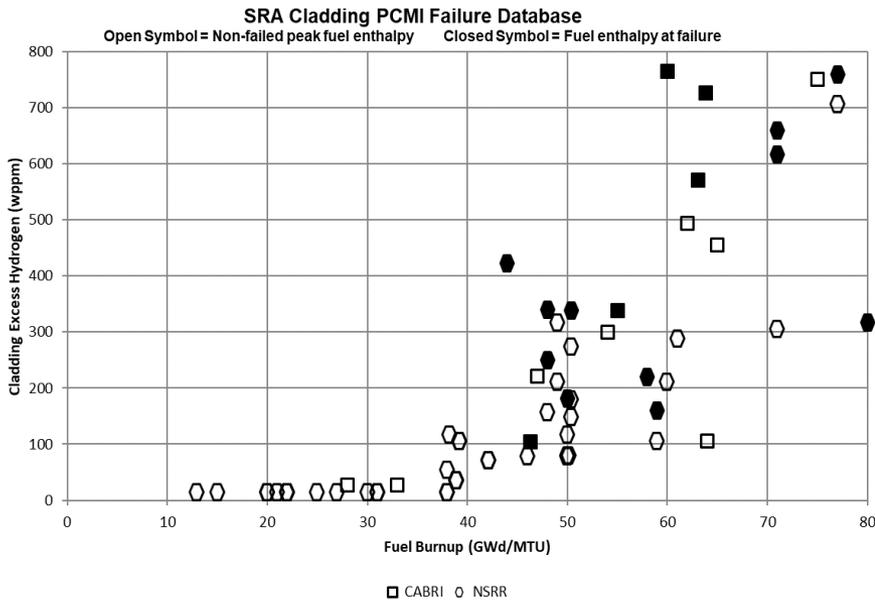
# HT Cladding Failure Thresholds

- Empirical database does not exhibit sensitivity with burnup
  - Burnup effects captured in rod internal pressure (cladding  $\Delta P$ )
- Extended burnup test specimens survived above 100 cal/g



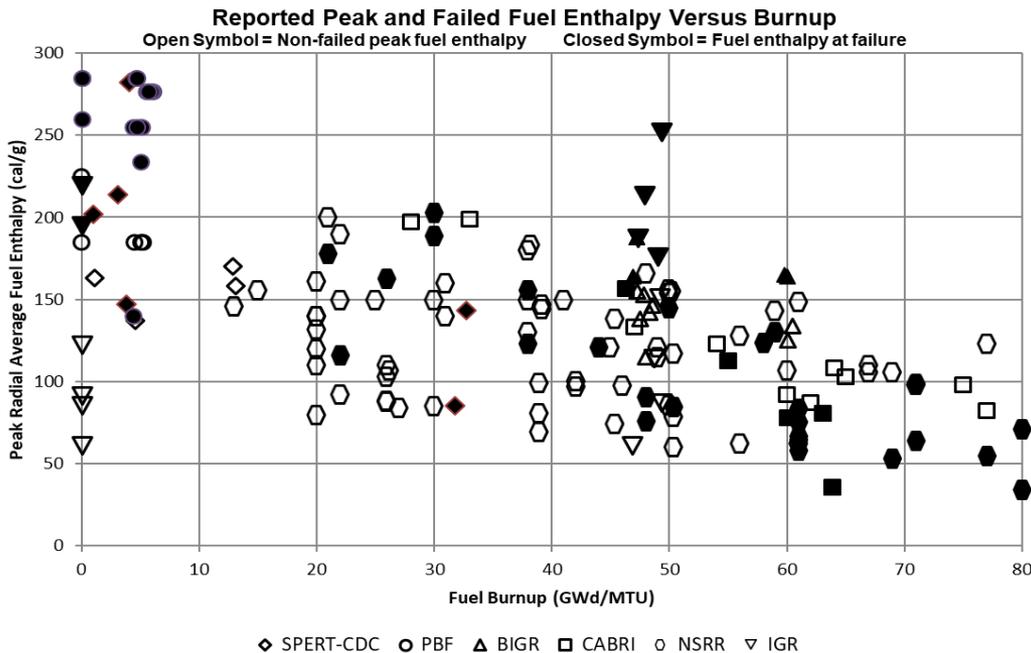
# PCMI Cladding Failure Thresholds

- Empirical database does not exhibit pronounced sensitivity with burnup
  - PCMI failure more sensitive to cladding hydrogen content
- Extended burnup test specimens survived above asymptotic limit (SRA -65  $\Delta$ cal/g, RXA 50  $\Delta$ cal/g)



# Damaged Core Coolability

- While the damaged core coolable geometry empirical database does not include any high-burnup fuel rod segments, the detrimental effects of higher burnup must be accounted for to satisfy the limited fuel melt restriction.

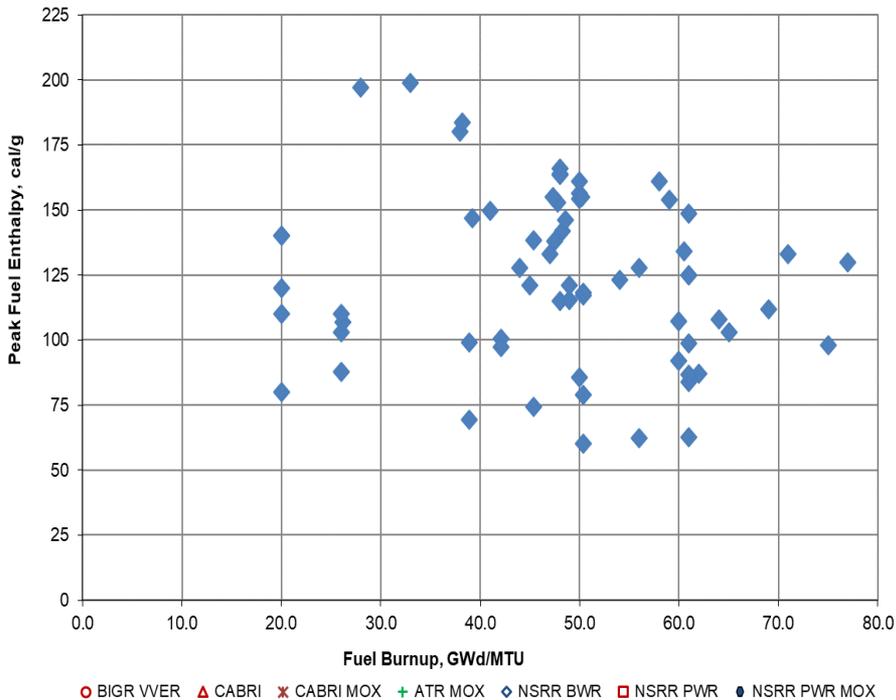


- Peak radial average fuel enthalpy should remain below 230 cal/g.
- A limited amount of fuel melting is acceptable provided that it is less than 10 percent of fuel volume. If fuel melting occurs, the peak fuel temperature in the outer 90 percent of the fuel volume should remain below incipient fuel melting conditions.

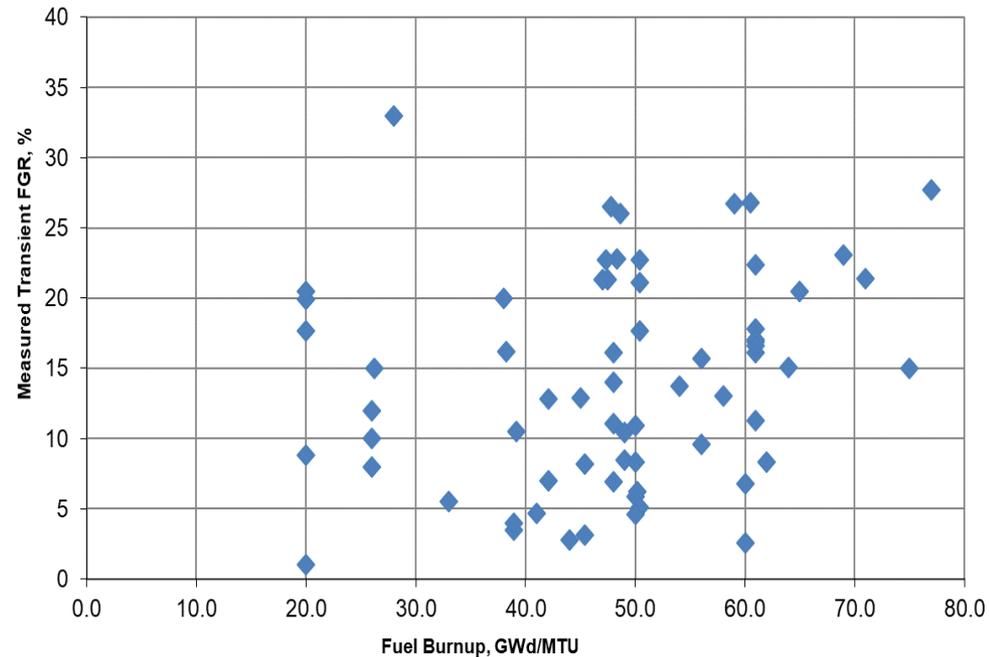
# Transient FGR

- Empirical database shows sensitivity with burnup and deposited energy
  - BU-dependent FGR correlations
- Extended burnup test specimens fall below high burnup correlation

RIA Transient FGR Database



RIA Transient FGR Database



# Burnup Extension

- Based upon the extent of the empirical database and sensitivity of important parameters and phenomena to burnup, the staff found RG 1.236 to be applicable up to a fuel rod average burnup of 68 GWd/MTU.
- This assessment was predicated on the use of approved core neutronics and fuel rod thermal-mechanical models. The following limitations were identified:
  - Excess cladding corrosion will promote localized effects (e.g., spallation, hydrogen blisters) which have been shown to significantly reduce the cladding failure threshold. Hence, the applicability of the high temperature and PCMI cladding failure thresholds to any fuel burnup, including extended burnup up to 68 GWd/MTU rod average, is limited to fuel rod designs, cladding alloys, and plants which control and limit oxide thickness to prevent these localized effects.
  - Fuel fragmentation, relocation, and dispersal (FFRD) is a phenomenon which challenges coolable geometry and has been shown to be sensitive to fuel burnup. The susceptibility of fuel pellets to fragment into fine particles increases with burnup. RG 1.236 does not provide guidance related to an acceptable treatment of FFRD.

# Conclusions

- Based upon latest research data, revised research data, new analysis, and international perspectives, the NRC staff has developed CRE/CRD guidance in RG 1.236
  - Represents a significant advancement in guidance
    - Separately captures fabrication-, burnup-, and corrosion-effects on fuel rod performance under RIA conditions
- ACRS and stakeholder involvement starting prior to 2007
  - Several ACRS briefings beginning prior to Interim Guidance
  - Numerous public workshops and 3 rounds of public comments