

Official Transcript of Proceedings
NUCLEAR REGULATORY COMMISSION

Title: Advisory Committee on Reactor Safeguards
Materials, metallurgy and Reactor Fuels
Subcommittee

Docket Number: (n/a)

Location: Rockville, Maryland

Date: Tuesday, March 3, 2009

Work Order No.: NRC-2699

Pages 1-148

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UNITED STATES OF AMERICA
NUCLEAR REGULATORY COMMISSION
ADVISORY COMMITTEE ON REACTOR SAFEGUARDS
SUBCOMMITTEE ON MATERIALS, METALLURGY AND
REACTOR FUELS

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TUESDAY

MARCH 3, 2009

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ROCKVILLE, MARYLAND

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The Subcommittee convened in Room T2B3 in the Headquarters of the Nuclear Regulatory Commission, Two White Flint North, 11545 Rockville Pike, Rockville, Maryland, at 8:30 a.m., Dr. J. Sam Armijo, Chair, presiding.

SUBCOMMITTEE MEMBERS PRESENT:

J. SAM ARMIJO

MARIO BONACA

HAROLD RAY

WILLIAM SHACK

JOHN D. SIEBER

CONSULTANT TO THE SUBCOMMITTEE PRESENT:

JOHN DAVIES

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NRC STAFF PRESENT:

MICHAEL BENSON, Designated Federal Official

VANICE PERIN

PAUL CLIFFORD

MICHELLE FLANAGAN

BILL RULAND

ALSO PRESENT:

TOM TOMLINSON

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

8:29 a.m.

CHAIR ARMIJO: All right. Good morning. The meeting will now come to order. This is a meeting of the Materials, Metallurgy and Reactor Fuels Subcommittee. I'm Sam Armijo, Chairman of the Subcommittee. ACRS members in attendance are Mario Bonaca, Harold Ray, Bill Shack, Jack Sieber. Dr. John Davies is also attending as a consultant for the subcommittee. Michael Benson is the ACRS staff and is the designated federal official for this meeting.

The purpose of this meeting is to inform the subcommittee about the staff's plans to address the pellet-clad interaction failure mechanism during abnormal operational occurrences, particularly under power uprate conditions and really focus on conventional fuel cladding as opposed to the barrier design.

The subcommittee will gather information, analyze relevant issues and facts and formulate proposed positions and actions as appropriate for deliberation by the full committee. The rules for participation in today's meeting have been announced

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1 as part of the notice of this meeting previously
2 published in the federal register. We have received
3 no written comments or request for time to make oral
4 statements from the public regarding today's meeting.

5 We have established a bridge phone line
6 for today's meeting. It's my understanding that there
7 are people on the line. They will have an opportunity
8 to make comments or ask questions when we get into the
9 discussion period. In the interim I would ask that
10 they keep their phones on mute and just listen to the
11 presentations.

12 A transcript of the meeting is being kept
13 and will be made available as stated in the Federal
14 Register Notice. Therefore, we request that
15 participants in this meeting use the microphones
16 located throughout the meeting room when addressing
17 the subcommittee. The participants should first
18 identify themselves and speak with sufficient clarity
19 and volume so that they may be readily heard.

20 We will now begin the meeting with my
21 presentation. The purpose of my remarks are to get
22 everybody on the same page with respect to the PCI
23 failure mechanism, what is known, what is well
24 established and ultimately how this might have an
25 impact on fuel performance during these abnormal

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1 operational transients.

2 I will start with the first slide. Our
3 meeting objectives is really to assess the risk of PCI
4 and PCI in the context of stress corrosion cracking.
5 This is not strictly a mechanical phenomenon we're
6 addressing. It's mechanical chemical phenomenon. And
7 its influence on fuel reliability during abnormal
8 operational occurrences. I have anticipated and I
9 meant to say abnormal.

10 We want to discuss the options to quantify
11 so we understand what the risk is. Obviously to limit
12 the risk of fuel failures and the options include
13 analytical capabilities of the staff, fuel design
14 options, and, of course, operational options that the
15 utility might take in the event of some of these
16 transients.

17 Next slide. The driving force for this
18 meeting is a recommendation made in the ACRS letter
19 dated December 20, 2007, during the review of the
20 Susquehanna Extended Power Uprate review. That
21 recommendation stated that, "The staff should develop
22 the capability and perform a thorough review and
23 assessment of the risk of Pellet-Cladding Interaction
24 (PCI) fuel failures with conventional fuel cladding
25 during anticipated operational occurrences." That was

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1 really intended to be the broad issue during AOOs of
2 any type.

3 There were also added comments by some of
4 the members expressing concern about the increased
5 risk of PCI using conventional cladding. The concern
6 that the protections against power transients and
7 linear heat generation rate limits with less than 1
8 percent cladding strain, that those limits which would
9 be nice in the event of purely a mechanical phenomenon
10 just don't protect you from PCI. Much lower strains
11 are known to cause failure.

12 Finally, the staff inability by modeling
13 to address the risk of PCI fuel failures, although
14 some parts of the industry, particularly the EPRI
15 FALCON code have such capability.

16 Next slide. I'm going to go quickly
17 through this so everyone, as I said, is on the same
18 page and bring you back to the history of the PCI
19 research and the conclusions that came from that.
20 Some of the material that we will be talking about is
21 over 20 years old or more.

22 We are going to talk about the features of
23 PCI and the mechanism, what controls it, power, delta
24 power, rate of power increase, burn-up, what are the
25 mitigation actions that are proven to be very

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1 successful during normal operation which include
2 operating constraints that are known as PCIOMRs.

3 For those who don't know what that means,
4 it's a term invented by GE which is Preconditioning
5 Interim Operating Management Recommendations. Those
6 interim operating management recommendations lasted
7 for many, many, many years. In fact, some versions
8 are still used with conventional cladding.

9 Another mitigating action was reduce the
10 linear heat generation rate for fuel in BWRs by that
11 mechanism going from 8x8 bundles to 10x10 bundles
12 reduced the LHGR, at least in the early designs.
13 We'll see that is no longer true.

14 Then there was a lot of work to develop
15 PCI resistant designs. One designs was qualified for
16 the BWR and that's the barrier fuel or the zirconium
17 liner fuel. Then for mitigating actions was against
18 AOOs you had two options, prompt operator action or
19 PCI resistant designs.

20 Having been involved in the development of
21 the barrier fuel in the early days in industry, our
22 driver was not solely the economic benefits of having
23 PCI resistant fuel during normal operation. We had a
24 great concern driven by the Nuclear Regulatory Agency
25 that wanted a solution, a design solution to the PCI

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1 problem. Otherwise, there would need to be regulatory
2 action to get that under control. That was part of
3 our drivers.

4 Now, let's take a quick look at the
5 features of PCI, what it looks like, what the
6 mechanism is so that everybody sees what we're talking
7 about.

8 Next slide. Now, you have to look very
9 sharp at this picture. It's a BWR fuel rod. It's a
10 picture in a fuel pool. If you look very closely
11 right in the middle of that fuel rod surface you will
12 see a thin vertical black line. If I had a pointer I
13 could show it to you but you probably can see it once
14 I tell you about it. Right there.

15 That's a typical PCI axial crack. The
16 other important thing to note is it is much, much less
17 than 1 percent plastic strain. If you do a prilometer
18 measurement on that, you'll find that change in
19 diameter is much less than 1 percent plastic strain
20 typically. Maybe 2 tenths or sometimes not even
21 measurable. That is typical of a very brittle
22 fracture of a fundamentally ductile material.

23 Next slide. Now, what is PCI? This is a
24 cross-section of a PCI crack and the cross-section is
25 taken at the pellet-pellet interface. The lower part

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1 is the gray area where the vertical crack is the fuel.

2 There is the gap and then there is the cladding. You
3 see in the cladding a branching, a crack. The crack
4 initiates at the point of local stresses where the
5 pellet is cracked. That branching crack is a brittle
6 crack, as I said, in a fundamentally ductile material.

7 This picture here for people who look at
8 fractography, it's a high-magnification photograph of
9 the surfaces of those cracks. This is from a failed
10 fuel rod. People who look at these pictures can
11 demonstrate that the fracture services are -- somebody
12 gave me a little pointer here and I don't know it will
13 reach over there.

14 You see these flat areas? Those are
15 indicative of a brittle crack propagation. These
16 areas on the right is another portion of this same
17 failure where you can see the inner grain, the
18 crystalline structure of the material. This is proof
19 that this mechanism is not a simple mechanical
20 phenomenon.

21 It's mechanical and chemical. Obviously
22 when you have a chemical factor involved the
23 mechanical properties are degraded substantially.
24 What was an acceptable strain level under purely
25 mechanical loading is totally unacceptable under

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1 stress corrosion cracking conditions.

2 The next slide shows demonstration of the
3 influence of what causes stress corrosion cracking.
4 This picture shows the inner surface of fuel cladding.

5 The fuel has been removed and the photograph on the
6 left, this one here, you are looking at the inner
7 surface of the fuel cladding. The white horizontal
8 line -- Mike, I think my pointer isn't -- yeah, that
9 white horizontal line is where the pellet-pellet
10 interface is. The dark line patterns are deposits of
11 fission products, deposits on the inside of the
12 cladding.

13 The cladding was then flattened and on the
14 right hand side you can see that there is an opening.

15 That was a crack. If we looked at the inside of that
16 crack it would be the brittle fracture of PCI crack.
17 It showed that the crack is coincident with the
18 location where there was a high concentration of
19 fission products.

20 Next slide. Now, a lot of work has been
21 done. It's from some of this work and a lot of this
22 was Dr. Davies' work and other people at GE. In this
23 particular case the cladding deposits were scrapped
24 from the cladding and the concentrations were measured
25 chemically and compared with the predicted fission

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1 product concentration from just the burn-up of the
2 fuel.

3 You can see that there was a lot of
4 enhancement as the volatile fission products collect
5 on the ID of the cladding. The enhancement -- I'm
6 sorry. The chemicals that we are particularly
7 concerned about are iodine and cadmium. The reason
8 for that is iodine and cadmium are both known to cause
9 brittle fracture of zirconium cladding both in reactor
10 and in laboratory experiments.

11 All of the other fission products have
12 been tested in one way or another and none of them
13 have been found to cause stress corrosion cracking of
14 zirconium cladding. We are left with dilemma. We
15 don't know whether it's iodine or cadmium that is
16 causing the cracking but it really doesn't matter
17 because there's plenty of both in moderate burn-up
18 fuel or high burn-up fuel.

19 Next slide. Now, here is what happens
20 when you do raise the power of a fuel rod and the
21 underlying mechanism. The lower yellow region of this
22 sketch is a region where fuel has no PCI risk. The
23 power is low enough that there is neither sufficient
24 stress on the cladding nor sufficient fission product
25 concentrations to cause any problems. If you raise

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1 the power rapidly into the orange region, which I'll
2 call the failure region above some threshold power,
3 two things are happening. First, you the fuel is
4 getting hot, fission products are coming out of the
5 fuel and depositing on the cladding in addition to
6 what is already deposited during steady state.

7 In addition, you have a mechanical
8 transient where the stress of the cladding as the
9 pellets expand puts a peak stress on the cladding in
10 this failure zone. Peak stress relaxes out with time
11 but if it doesn't relax out quick enough, you can have
12 a PCI failure. You have a combination of mechanical
13 loading and aggressive chemical environment occurring
14 during the period of the ramp.

15 The next picture here shows what the
16 mechanism is. This has all been published not only by
17 the people of GE but others. What happens in the fuel
18 rod you have the heating of the fuel when you raise
19 the power. The pellets expand. They are cracked and
20 they form an hourglass pattern due to the thermal
21 properties of the fuel. You have maximum stresses at
22 pellet-pellet interfaces and that is exactly where you
23 have the maximum concentrations of iodine and cadmium.

24 In addition you have actual locking of the
25 pellets within the fuel column. You have thermal

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1 expansion. All the pellets aren't exactly lined up
2 perfectly so you have a stochastic stacking so there
3 is some variability in the PCI failure data but not
4 too much variability as a result of that feature.
5 Basically you have bi-axial stresses, you have high
6 concentrations of fission products, and you have a
7 material that is inherently susceptible unless you do
8 something with the design.

9 Next slide. What are the well known
10 controlling operational parameters? First of all,
11 there is such a thing as called a PCI failure
12 threshold. People argue about that and have done a
13 lot of research on that. It is generally agreed that
14 this PCI threshold below about seven or eight
15 kilowatts a foot in BWR fuel there is no risk of PCI.

16 Above that level there is risk and it increases as
17 you go to higher powers. As a result when you operate
18 at higher powers you typically precondition the fuel
19 by changing power very, very slowly and I'll just show
20 that next.

21 This sketch is just a schematic of what I
22 call the PCI map in which the vertical axis is linear
23 heat generation rate or actual power. That is really
24 on a nodal basis in the fuel element and plotted
25 against burn-up. The yellow region is the nonfailure

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1 region. Basically you can operate the fuel with
2 impunity in that region without any risk of PCI
3 failure.

4 After you cross the PCI threshold, which
5 is a function of burn-up, then you are in the failure
6 region and the failure region is bounded by the dark
7 line which is really the fuel duty which is a peak
8 linear heat generation rate as a function of burn-up.

9 Now, the PCI threshold, as I mentioned, is somewhere
10 in the 8 to 10 kilowatt per foot range. It's burn-up
11 insensitive.

12 Once you have about 15,000 megawatt days
13 per kilogram uranium burn-up you've got plenty of
14 fission products and you have plenty of radiation
15 hardening on the cladding to cause stress corrosion
16 cracking. It doesn't seem to get worse with burn-up
17 and some people might argue that the risk gets less
18 with burn-up but that is not proven. Above the fuel
19 duty region is a region of concern to the committee
20 and this is the region where these AOOs can occur.
21 That is what we want to get into.

22 Next chart. Typically the failure
23 probability from PCI increases dramatically as you go
24 higher in power and also higher in power change. This
25 is just a schematic. If you look at actual ramp data,

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1 which we will present in more detail by Dr. Davies,
2 you can see the data that is supporting this. This is
3 not strictly data from GE but it is also data from a
4 variety of other sources.

5 Next chart. This is strictly from the GE
6 database that was used during the development of the
7 barrier fuel program. All of this is for conventional
8 Zircaloy 2 fuel cladding that was ramped in the R2
9 reactor in Sweden. The power was raised from below
10 the threshold to the point at which it either failed
11 or operated successfully without failure.

12 You can see as you go higher and higher in
13 power you have a higher probability of failure. Once
14 you get up into the 16 kilowatt per foot range you
15 have almost certainty of failure. That is our
16 concern. If you get into a situation where you can't
17 control the power, the power is controlled by some
18 other event, for example loss of feedwater heater
19 event can you get into a PCI failure situation and is
20 that an unanalyzed situation. That is a certain to
21 the committee.

22 Next slide. So what are the mitigation
23 options? Well, obviously during normal operation the
24 industry has done a very good job. Initially the old
25 8x8 assembly which had typically 64 fuel rods was

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1 increased to 10x10 which gave you 100 fuel rods and
2 all the power was spread among those 100 fuel rods.
3 That obviously reduced the risk because the linear
4 heat generation rate was decreased dramatically, maybe
5 30, 35 percent. In the interim over the years people
6 have found it to be very economical just to raise the
7 power, put more enrichment in and you wind up that
8 today's 10x10 fuel has the same peak LHGRs as the old
9 8x8. That remedy has disappeared.

10 During normal operation the
11 preconditioning techniques of the various fuel
12 suppliers are very effective. They are costly and
13 they are time consuming but they work. That is used
14 typically with conventional cladding. The PCI
15 resistant fuel, the liner fuel, has been demonstrated
16 to work very well with or without preconditioning.
17 Some people do still use preconditioning and others
18 don't.

19 In the case of AOOs, and particularly
20 those AOOs in which there is no scram. These are slow
21 transients but fast enough to cause PCI. There is no
22 scram function. The power in the reactor can go maybe
23 as high as 120 to 125 percent of the peak of the rated
24 power so you're into a regime, a power regime, where
25 PCI is still a threat, stresses still occur, fission

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1 products still come out, and you have a limited amount
2 of time to stop the transient. That calls for prompt
3 operator action if you don't have a PCI resistant
4 design. If the prompt operator action is slower than
5 the PCI time to failure, then you obviously are going
6 to fail the fuel and that's the fundamental concern
7 that we are raising here.

8 As far as -- one thing that we are not
9 concerned about is under the same test conditions that
10 we showed earlier with the conventional cladding, a
11 very large database has been created showing the
12 resistance of a PCI resistant design. In this
13 particular case it's a zirconium barrier cladding
14 design. This has been ramped. The power is as high
15 as 18 kilowatts per foot and with much higher
16 reliability. In fact, it protects you during the AOOs
17 by design, not by operator action or any other means.

18 Our concern is not with a PCI resistant design but
19 with the conventional fuel cladding. Our concern is
20 that use of conventional fuel cladding under these
21 conditions should be discouraged.

22 With that I think I will wrap it up. Our
23 concern is the growing use of non-PCI resistant fuel
24 in BWRs. Our concern is that the PCI failure times
25 are very short at AOO power levels. Dr. Davies will

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1 show some data to demonstrate that. The early 10x10
2 mitigation benefits have been lost as people have
3 turned those reduced powers back into economic benefit
4 by raising the power again.

5 The number of fuel elements at risk during
6 AOOs increase in proportion to the magnitude of the
7 EPU so the risk is not getting smaller. It's getting
8 larger numerically. The other thing is we don't have
9 within the NRC adequate analytical capability to
10 quantify the risk of failure. There is a wealth of
11 data which could be used with NRC codes in a way
12 similar to what the FALCON code does to quantify that
13 risk and evaluate it so that we know where we stand in
14 these situations.

15 With that I think I have covered
16 everything I want to cover. Unless there are any
17 questions I'll just hold the backups for later if
18 there is something that we need to discuss.

19 With that I think our next presenters
20 would be Dr. Paul Clifford and the NRC staff. Any
21 questions?

22 MEMBER RAY: Is there -- everything you
23 talked about, Sam, had to do with raising power, ramp
24 rate, increasing power. I just kept thinking to myself
25 is there symmetrical problem on the downside with a

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1 unit trip or something like that in terms of stress
2 levels?

3 CHAIR ARMIJO: No. Actually, I have never
4 known a fuel rod to fail when you reduce power. You
5 reduce power as a result of failure, that's typical.
6 Actually it unloads. Everything unloads. As you drop
7 power the pellets contract thermally so the stresses,
8 whatever stresses are there and there is just no --
9 this is stress corrosion cracking mechanism. Unless
10 there is a mechanism to put stress on the cladding, it
11 just won't happen.

12 MEMBER RAY: Well, that's what I was
13 thinking about. Is there a mechanism on a down-power,
14 rapid down-power that has the same affect?

15 CHAIR ARMIJO: We've never seen that.

16 MR. RULAND: Okay. Good morning, Dr.
17 Armijo.

18 CHAIR ARMIJO: Yeah, Bill.

19 MR. RULAND: And subcommittee members. My
20 name is Bill Ruland. I'm the Director of the Division
21 of Safety Systems in the Office of NRR. We appreciate
22 the committee holding this forum. In our view it
23 facilitates a discussion of generate topics and
24 sharing information without a specific licensing
25 action before us. It gives us time to think about and

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1 kind of debate in a much more what I would call open
2 relaxed forum. It helps us -- gives us time to think
3 about exactly what our actions ought to be.

4 As you are well aware -- secondly, Dr.
5 Armijo, thank you for that presentation. For somebody
6 that is relatively new to the fuel business here it
7 was a very succinct and educational for me. I hope
8 you are going to hear from the staff today discussing
9 some of the considerations that we have made about PCI
10 and how to regulate it.

11 As you had alluded to, the NRC was
12 actively involved in observing and interacting with
13 licensees and vendors 20 years ago when this
14 phenomenon was present. Ultimately we have observed
15 that the industry basically conducted themselves in a
16 proper manner reducing the likelihood of PCI. We are
17 here to decide at this juncture what, if any,
18 regulatory actions we need to take. Again, thank you
19 for this opportunity.

20 Is Paul or Michelle going first? Go
21 ahead, Michelle.

22 MS. FLANAGAN: Yes, I will give my
23 presentation first. My name is Michelle Flanagan and
24 I work in the Office of Research in the Fuel and
25 Source Term Team Branch. I am presenting today the

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1 challenges in addresses pellet-cladding interaction,
2 or PCI.

3 I would like to begin with a brief history
4 of PCI by highlighting four reports that are
5 documenting work that was done in the 1970s and '80s.

6 The first of these is a compendium written by Mike
7 Tokar presented to the ACRS in 1979 which documented
8 the rise in PCI fuel failures in the 1970s and then
9 NRC's response and attempts to understand and model
10 PCI.

11 The second report documents an attempt to
12 develop an empirical model to predict operational PCI
13 fuel failures where the idea was to take a large body
14 of data from Canadian reactors and online refueling
15 operations in order to develop an empirical model.
16 Unfortunately the database wasn't completely relevant
17 to light water reactor applications and that left an
18 insufficient database for developing an empirical
19 model at that time.

20 The next report documents an experimental
21 program to test challenging operational transients.
22 In this experimental program at the PBF facility power
23 ramps were run with standard, doped and lined radiated
24 fuel rods simulating rapid power excursions that would
25 be expected under conditions of a turbine trip without

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1 bypass, generator load rejection without steam bypass,
2 and then two additional larger power excursions trying
3 to approach the limit of PCI failure.

4 All four of these tests were run without
5 detection of radiological release indicating that the
6 fuel had been sufficiently robust to survive these
7 rapid power transients. This experimental program was
8 established to answer two questions, whether a power
9 plant should be derated following a severe operational
10 transient, and whether NRC should further regulate
11 PCI. Given that there were no fuel failures in these
12 four power excursions, the determination at that time
13 was no.

14 The fourth report, and the last one that I
15 will describe, documents a modeling effort to develop
16 a mechanistic model. Here the author has described
17 the ideal tool for predicting fuel failure due to PCI
18 during a wide range of operational transients as an
19 integral mechanistic model. This mechanistic model
20 would be able to handle the effects of radiation
21 history, rod power, power increase, ramp rate, and
22 hold time, and be able to handle all design
23 differences between fuel manufacturers.

24 Stochastic variables like fabrication
25 times could be incorporated to produce true

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1 probabilistic predictions and accurate power-time
2 curves including local power peaking and numerous
3 experimental benchmarks would be critical to the
4 success of failure predictions.

5 However, the report concluded that at that
6 time a comprehensive mechanistic understanding about
7 cladding interaction-induced damage had not yet been
8 achieved and unambiguous benchmarks were scarce.
9 Rather, PCI failure prediction could be approached by
10 mechanistic models of individual phenomenon
11 contributing to PCI and by formulating empirical
12 relationships from numerous commercial, test reactor,
13 and lab observations.

14 This understanding and approach is largely
15 reflected in our current regulatory approach where
16 operating limits are introduced to prevent PCI that
17 are based on power ramp data. Stress and strain are
18 accurately modeled by -- are accurately accounted for
19 by modeling fuel thermal expansion, fuel gaseous and
20 solid swelling, as well as irradiation effects on
21 cladding and fuel mechanical properties.

22 In response to these regulatory
23 requirements the industry has addressed PCI through
24 fuel design. Fuel design approaches to prevent
25 failure due to PCI have focused on both pellet and

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1 cladding. Liner cladding, doped fuel pellet, large
2 grain pellets, and chamfered pellet ends have all been
3 modifications introduced to preclude PCI.
4 Modifications to both the pellet and the cladding
5 design have proven effective at reducing
6 susceptibility to PCI failure.

7 PCI has been revisited in some more recent
8 publications worth noting here. The first is authored
9 by Brian Cox and is technically comprehensive and
10 includes an interesting graph documenting the decline
11 in work in the PCI area by counting the number of
12 publications in the open literature on the topic.

13 The second two documents are OECD
14 publications representing international assessments of
15 fuel safety criteria. All three of these more recent
16 documents largely reflect the approach and
17 understanding to PCI that was taken in developing
18 NRC's regulatory approach in the 1980s.

19 We understand the benefit of staying in
20 tune with work in many research areas and there are
21 current research programs investigating trying to
22 further understand the mechanisms of PCI. One of
23 these programs is the Studsvik Cladding Integrity
24 Project of which NRC has been a participant since
25 2004.

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1 By participating in this program the NRC
2 is able to leverage its resources at very little
3 resource expense, participate in an international
4 research program attempting to develop a mechanistic
5 understanding of the phenomenon affecting PCI.

6 In addition to a broad experimental
7 program investigating not only PCI but other fuel
8 phenomenon the SCIP program is also attempting to use
9 the results to improve fuel clad modeling
10 capabilities. The program that NRC is participating
11 in currently is a five-year program and it's nearing
12 the end of its work scope. A follow-on program has
13 been proposed and the research proposal has been
14 reviewed by NRC and we anticipate participating in the
15 second phase.

16 The goal of the second phase is
17 understanding PCI with a focus on pellet properties
18 including understanding how the chemical properties of
19 the pellet can affect susceptibility to PCI and
20 understand the effect of local stresses and the effect
21 of burn-up.

22 I would like to conclude by saying that
23 the NRC staff continues to participate in
24 international programs, to dialogue with the
25 international research community, and to monitor new

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1 developments concerning PCI. That concludes my
2 presentation. Thank you very much for your attention
3 and I'll take any questions if there are any.

4 CHAIR ARMIJO: I have a quick question.
5 On the fuel design, I guess chart No. 5, you say these
6 are current industry activities. Of these various
7 options the only things that actually have been
8 introduced into actual commercial use are the liner
9 and the things like chamfered pellet ends but a lot of
10 other things were done, very high repressurization to
11 reduce fuel pellet temperatures.

12 My real concern and my colleagues is
13 backsliding from designs that were developed partly
14 with NRC encouragement. In fact, to a great extent
15 with NRC encourage to develop PCI resistant designs
16 and now we are backsliding and tolerating the use of
17 non-PCI resistant designs without really understanding
18 what level of risk we are taking on. If that becomes
19 prevalent, particularly with higher powers, we are
20 moving back to a risk environment that had been
21 solved. That is really the concern. We know that
22 there are even better designs possibly than the liner
23 fuel. The doped pellets look very promising but we
24 don't know too much about them in large statistical
25 quantities of operation. There are a lot of ways to

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1 solve this problem but there should be a design
2 solution, not just a operational solution and that is
3 really where I'm pressing to find out what the NRC
4 staff is going to do because the way I read the
5 Standard Review Plan if you have -- if you can
6 demonstrate that your cladding will not exceed 1
7 percent plastic strain mechanically you're okay but
8 these pictures that are not unique should demonstrate
9 the PCI happens long before at much lower strains than
10 1 percent. During these transients do they happen
11 fast enough to cause adequate delta power? Are they
12 sustained long enough for the crack to initiate and
13 propagate through the cladding before an operator can
14 terminate the transient? Those are the real key
15 issues and without a good model, and I don't think it
16 has to be all that mechanistic. I think there is a
17 wealth of empirical data and test data that can be
18 used by the staff productively to remake such an
19 assessment. We'll talk more about that but I just
20 want to make sure that we're on the same track. I'm
21 focused on the BWRs. I'm focused on the BWRs where
22 there isn't an automatic scram in such events, those
23 transients. I don't know all the transients that
24 might be of concern. That's the staff's thing so I
25 have chosen to discuss the loss of feedwater heater

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1 situation in our various discussions because that
2 seems to be one of the most aggressive transients. I
3 think it's good that the staff is continuing to work
4 with international programs but I think there is just
5 a ton of data available for BWR fuel and cladding that
6 the staff could use productively now in their models.

7 MR. CLIFFORD: Thanks. Yes, the staff
8 certainly recognizes your concerns. We agree in
9 concept with everything you're saying. My
10 presentation will touch upon our assessment of the
11 safety significance of PCI. Then I have some backup
12 slides on alternative approaches for addressing your
13 concerns which I'll be saving for the roundtable
14 discussion and we can go through the pros and cons of
15 each approach.

16 MEMBER SHACK: Well, can I just come back?
17 You know, Sam goes on what is required. Is this one
18 of these cases if you literally followed the NRC
19 regulations it probably wouldn't work but you guys
20 don't bother to change them because everybody in
21 practice is doing something else? It's sort of like
22 water chemistry. If you look at the reg guide on
23 water chemistry, if people actually followed that, we
24 would be horrified but they don't. You know, we're
25 saying the amount of energy you can put into the fuel

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1 and a control rod withdrawal accident if that really
2 happened but we don't worry about it because we know
3 although the regulations really aren't adequate
4 there's not really a problem because it's being taken
5 care of for other reasons like economics. Is that the
6 situation you think we're in here?

7 MR. CLIFFORD: I think that's the
8 situation we were in. I think back in the '70s and
9 '80s when there were failures routinely -- I shouldn't
10 say routinely but when there was a higher frequency of
11 failures that the NRC was concerned and the industry
12 took a lead and tried to keep it out of the
13 regulations by saying:

14 "Hey, we're going to take the lead. We're
15 going to address this. We're going to show that our
16 field design has inherent protection so that we're not
17 going to see these routine high frequency failures
18 during power maneuvering," and that's what they did.
19 I think that success certainly took a lot of the
20 emphasis out of the staff going back and codifying
21 specific criteria.

22 CHAIR ARMIJO: I totally agree. Once you
23 had a design solution --

24 MEMBER SHACK: But I think it's a little
25 unfair in some ways to keep bringing up the 1 percent

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1 strain. That may be the regulatory requirement but
2 they are not really relying on that.

3 CHAIR ARMIJO: But they were relying on
4 the design solution.

5 MEMBER SHACK: Right, kind of over all.

6 CHAIR ARMIJO: If that choice of that
7 particular fuel design is up to the utility and if
8 they ignore the design solution, now we are relying on
9 a success criteria that doesn't protect you against
10 the mechanism. That is my concern.

11 MR. CLIFFORD: The 1 percent protects you
12 against the prompt transient. Not the RIA but the
13 prompt transient. Not the full minute transient but
14 the 20 second transient. Also you can model it with
15 high accuracy and you can come up with high confidence
16 criteria based upon separate-effects tests so it is
17 something that can be done readily and can be done
18 accurately.

19 That has always been kind of the problem
20 with PCI, stress corrosion cracking. It's the
21 difficulty in modeling the phenomena because of the
22 chemical interaction. Let me get to my presentation
23 and we'll move into this.

24 CHAIR ARMIJO: Okay. Let's do that.

25 MEMBER RAY: I was reminded of Alan

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1 Greenspan in your remarks, though, Bill, about people
2 self-regulating for economic self-interest.

3 MEMBER SIEBER: Is it a fact or not a fact
4 that you can control PCI failures by controlling ramp
5 rate?

6 CHAIR ARMIJO: Yes.

7 MEMBER SIEBER: What we did was much more
8 conservative than the regulations required.

9 CHAIR ARMIJO: The regulations never
10 specified any kind of ramp rates. The ramp rates that
11 are aggressive that are sufficient to cause PCI
12 failures are very, very -- they are not the RIA type
13 ramp rates. Typically if you are over 1 or 2 percent
14 power increase per hour, you're into the PCI failure
15 regime.

16 MEMBER SIEBER: That's what we did,
17 though. On the other hand, there is no way that I
18 know of to mitigate AOs.

19 CHAIR ARMIJO: Prompt operator action.

20 MR. CLIFFORD: We'll talk about that a
21 little bit.

22 MR. RULAND: We will talk about that.

23 MEMBER SIEBER: Okay.

24 MR. CLIFFORD: First, I would like to set
25 the record straight. While I do have advanced degrees

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1 in nuclear engineering and metallurgy and do not hold
2 a Ph.D.

3 CHAIR ARMIJO: Okay. I will withdraw the
4 honorable doctor.

5 MEMBER SIEBER: Today you are.

6 CHAIR ARMIJO: You are among friends.

7 MR. CLIFFORD: There is no sense going
8 through here. I think Dr. Armijo went through this in
9 his presentation. The staff agrees with the ACS
10 concern that the stress corrosion cracking phenomenon
11 has the potential to produce fuel cladding failures
12 during an AOO. We don't argue that fact.

13 However, the staff has concerns with some
14 of the specific recommendations that was provided in
15 the Susquehanna letter. I'm just going to walk
16 through a few of them. First, regulations cannot
17 impose requirements for specific design features such
18 as a barrier lining. The regulations have to specify
19 performance requirements.

20 CHAIR ARMIJO: Let me just pick at that
21 point. What if you just said, "Look, we want you to
22 use demonstrated PCI resistant fuel and show us why
23 that is PCI resistant. We don't care what design you
24 use. You just have to convince us of such a design."
25 Why would the regulations not permit you to do that?

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1 MR. CLIFFORD: When we went to the
2 roundtable I have three alternatives. That happens to
3 be Alternative No. 3 but just answer it now. It's not
4 legally enforceable. The lawyers would argue it's not
5 specific and it would almost be voluntary.

6 CHAIR ARMIJO: Well, we'll talk about that
7 some more. We

8 MR. CLIFFORD: We'll get into that.

9 MEMBER SHACK: I sort of had that
10 discussion on 50.46(b). We went into those sorts of
11 things where we try to put in performance
12 requirements. You say you want performance
13 requirements and yet you tell us you want performance
14 requirements but they have to be specific.

15 CHAIR ARMIJO: And then you get too
16 specific and then it's untenable.

17 MR. CLIFFORD: 50.46(b) is a perfect
18 example. 50.46(b) shows compliance with GDC-35 which
19 shows that the core needs to maintain coolability.
20 Now, you could just say show me that you have safety
21 injection tax and LPICs and an RWT and you're okay.
22 That would be like the equivalent of saying, "Show me
23 you have barrier and you're okay." That's not good
24 enough.

25 For GDC-35 we say, "Show me you've got the

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1 hardware. Now show me a detailed analytical process
2 and we are going to give you specific analytical
3 requirements, the 2200, the 17 percent ECR. It goes
4 down to that level of validating a model showing that
5 your predictions are accurate, reviewing the model,
6 having specific criteria.

7 CHAIR ARMIJO: But in parallel with the
8 plan on 50.46 there is testing. You could specify a
9 test that must demonstrate it passed a certain kind of
10 ramp test.

11 MR. CLIFFORD: Right.

12 CHAIR ARMIJO: And that is very specific
13 and it will be very enforceable. Somebody would just
14 have to run these tests to show that the fuel would
15 meet your requirements. There are different ways to
16 skin this.

17 MR. CLIFFORD: Exactly. I think we should
18 get to that in the roundtable, what are the different
19 ways of approaching this.

20 Next in the issue is that regulations have
21 to apply universally. They cannot just apply to
22 conventional fuel. The ACRS letter did specify look
23 at just conventional fuel, nonbarrier line fuel.

24 Next is that all domestic fuel designs
25 have some susceptibility for stress corrosion cracking

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1 under the right conditions and that each potential
2 design feature while it provides some resistance such
3 as a barrier the degree of resistance varies whether
4 it's a natural zirconium barrier or a low alloy
5 barrier or whether you are using doped pellets. You
6 would need to fully understand the degree of
7 protection that is being provided by each of these
8 design features and whether or not they are
9 susceptible to something like burn-up or other
10 phenomena.

11 Stress corrosion cracking is not really an
12 inherent EPU issue. I did fuel management for 15
13 years. You can flatten the core very easily. If you
14 give fuel management engineer sufficient time and a
15 good computer, he is going to find a very flat power
16 distribution.

17 CHAIR ARMIJO: That's not my concern. At
18 peak the LHGRs are still the same. The core power
19 density increases in proportion to the EPU so if
20 you've got 20 percent more power coming out of that
21 core, you are going to have 20 percent more fuel
22 somewhere that is at the higher power levels. You
23 don't reduce power when you go to EPU.

24 MR. CLIFFORD: You can get the same thing
25 without an EPU is what I'm saying.

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1 CHAIR ARMIJO: I understand.

2 MR. CLIFFORD: If you have a higher
3 average discharge burn-up, you are essentially getting
4 to the same plateau by forcing all the pins to be at
5 roughly the same power which is closer to the limits.

6 CHAIR ARMIJO: Right. I understand that
7 but the fact is to get more energy out of that core
8 you've got to run more fuel at a higher linear heat
9 generation rate. More inches of fuel or feet of fuel
10 so I don't think EPU changes the mechanism. It just
11 changes the length of fuel element at risk. You've
12 just got more hot fuel.

13 MR. CLIFFORD: Right. I guess my point is
14 if we wanted to develop a specific way of approaching
15 this or change the regulations it would apply to all
16 licensees, not just the EPU applicant.

17 CHAIR ARMIJO: I agree. That analytical
18 model would be applicable whether you are operating
19 the EPU or original license power or whatever.T

20 MR. CLIFFORD: The next issue it's really
21 not strictly a BWR issue. The issues with power
22 maneuvering and blade movement that led to some
23 failures 20 years ago that was specifically a BWR
24 issue because PWRs don't move -- control the rods
25 through the cycle. They use soluble boron.

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1 Nonetheless, if you start moving into the AOO theater
2 and saying that you need to protect against stress
3 corrosion cracking during all AOOs then you could find
4 PWR events which could lead to a susceptibility.

5 CHAIR ARMIJO: And I don't disagree with
6 you, Paul. I think with a good analytical model you
7 can distinguish why PWRs might have more inherent
8 resistance to failure under those conditions, external
9 pressure being so much higher, all these sorts of
10 things. Again, you have to have a model that is good
11 enough. They have to be down to the very high
12 mechanistic, which fission product gets which crack
13 surface. There is a lot of empirical information
14 around that I think you could use very effectively.

15 MR. CLIFFORD: The last point in the
16 Susquehanna letter says that operator actions will
17 assure acceptable low number of failures. That is the
18 type of terminology we are used to seeing, that
19 classification known as infrequent AOOs. There are
20 moderate frequent AOOs and infrequent AOOs. Moderate
21 frequent AOOs must show strict compliance to GDC-10
22 which basically says you can't have any fuel failures
23 during an AOO period. Not one.

24 Whereas infrequent AOOs are generally a
25 less frequent event or an event in combination with a

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1 single failure which would say, "Okay, you are allowed
2 a certain number of failures. However, that's
3 generally tied to dose where you are allowed a small
4 fraction of 10 CFR Part 100. What is acceptable as
5 far as the number of failures would then be tied
6 directly or calculated off-site releases.

7 The next few slides are going to discuss
8 kind of the staff's review of what the current safety
9 significance is with stress corrosion cracking. As
10 sam actually showed a nice photo there, a PCI failure
11 is a hairline crack. The idea is you propagate a
12 crack. It goes through a wall and you have the
13 potential to release the fission gas that is available
14 for release in the plenum region which is also a
15 function of burn-up.

16 There is no challenge to the core cooling
17 geometry because the fuel rod maintains the structural
18 integrity. There is no challenge to the pressure
19 vessel integrity because there is no molten fuel
20 cooling interaction. There is no challenge to the
21 containment integrity because there is no high energy
22 line breaks associated with any AOs.

23 There is no challenge to any system
24 designed to mitigate the transient or to minimize
25 offsite activity releases unless we start postulating

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1 an event in combination with loss of offsite power or
2 an event in combination with independent single
3 failure. The AOOs by themselves are not going to
4 challenge the other barriers for the release of
5 activity. Ultimately it would fall under a lower
6 safety significance. Of course, if you were to use
7 risk assessment it would even fall lower because, you
8 know, you're always going to maintain coolable
9 geometry.

10 The next slide talks about the probability
11 of having a PCI failure. PCI requires a power
12 excursion that is large enough to produce cladding
13 stresses due to fuel swelling but also long enough to
14 where you have time to nucleate and propagate these
15 cracks. There are two components of the this event or
16 of any event leading to a PCI failure.

17 You could argue that there is a low
18 probability of occurrence because of these two issues.

19 The first issue is the limiting envelope for the
20 power excursion. You postulate this loss of feedwater
21 heater or any other AOO. You have to have a power
22 increase for PCI failure.

23 This isn't a depressurization event or
24 anything else. It's a power increasing event so power
25 goes up. It can't go high enough and fast enough

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1 where you get an automatic plant trip because as soon
2 as you get a trip, although the power may be high, you
3 don't have the time for the cracks to propagate so
4 that limits the power excursion.

5 What also limits the power excursion is
6 the fact that you have to analytically show with the
7 power excursion that you don't have any fuel failures
8 calculating using the current very conservative
9 analytical models. I'm trying to demonstrate that
10 with this illustration here.

11 If you look at it the outer clear cube is
12 essentially what you would predict a best estimate
13 failure. You have an increase in temperature,
14 cladding temperature which you are going to start to
15 approach a dry-out regime which would predict fuel
16 failure. You have fuel swelling which is going to
17 impart a cladding strain so you are going to start
18 approaching your cladding strain SAFDL.

19 Then you also have fuel temperature
20 increasing with this power increase so you are going
21 to start approaching your center line melt SAFDL. You
22 are approaching all of these things and the idea is
23 the darker cube represents you are doing this with
24 very conservative models and you are using a 95/95
25 probability confidence.

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1 You could argue whether you would get PCI
2 failure before you would reach this outer cube but the
3 real question is would you get PCI failure before you
4 reached the inner cube because that is what you are
5 limiting power to.

6 CHAIR ARMIJO: I think I understand what
7 you are trying to show but this is a very difficult
8 chart. You are hitting all of the risk issues, the
9 high temperature fuel melting. If we just look on --
10 later when we get into the discussion we'll talk about
11 just the PCI problem and that's time and linear heat
12 generation rate and power ramp rates.

13 MR. CLIFFORD: Right.

14 CHAIR ARMIJO: If PCI can happen earlier
15 than what your operator response time is, then there's
16 a problem and it's got to be addressed.

17 CHAIR ARMIJO: The issue, I mean, if you
18 just rule out that, you know, you could approach your
19 MCPR safety limit or you could approach your fuel
20 center line melt and you stick strictly to swelling
21 and cladding strength. What the graph is trying to
22 show is, yeah, our limit is 1 percent total strength
23 which has got plastic and elastic components to it but
24 you take mechanical data to show you what your failure
25 point is, separate effects mechanical data on

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1 irradiated material. That gives you when you believe
2 it will fail due to the mechanical interaction. Not
3 the chemical but the purely mechanical interaction.

4 Then you apply very conservative models
5 and methods. For fuel swelling you have an
6 uncertainty, more than a factor of two. When you
7 start putting that into an analytical solution, what
8 you find is you are trying to preclude this 1 percent
9 total strain. Realistically you would achieve only a
10 small fraction of that because of the uncertainty that
11 is applied to your modeling.

12 The question is really with all of these
13 uncertainties applied to the current methodology would
14 you still get stress corrosion cracking before you
15 cross that analytical boundary.

16 MEMBER RAY: You seem to be mixing, in my
17 mind anyway, the word uncertainty and conservatism
18 because uncertainty goes both ways. I think what
19 you're saying -- you mean to say conservatism. Don't
20 you?

21 MR. CLIFFORD: Yes. You build in
22 conservatism by accounting for all the uncertainties.

23 MEMBER RAY: I don't think so but, anyway.

24 MR. CLIFFORD: It's the difference between
25 a best estimate like the argument, okay, well, we

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1 looked at it and it was less than 1 percent plastic
2 strain on a failed component.

3 MEMBER RAY: But a best estimate in a high
4 uncertain area, regime, isn't something that you can
5 put a lot of confidence in by definition.

6 MR. CLIFFORD: I'm glad you mentioned
7 that. When we get down to the actual potential
8 alternatives to addressing that, that is a key issue
9 that we want to talk about.

10 MEMBER RAY: Okay.

11 MR. CLIFFORD: Because while this is
12 uncertain, there is probably a lot more uncertainty
13 introduced by trying to model the chemical affects of
14 stress corrosion cracking.

15 CHAIR ARMIJO: There is where I think you
16 should get yourself stuck on saying, "I've got to
17 really understand the thermodynamics and chemistry
18 down to the detailed level." Once you have sufficient
19 burn-up and you're going to have plenty of aggressive
20 chemicals to cause this problem so it really becomes
21 then a stress issue. How much stress do you put on
22 during these transients. Like I say, there's a ton of
23 experimental data, Halden data, GE data, a number of
24 papers that show you what the response of the material
25 is to that kind of a stress. I think you could

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1 productively analyze it mechanically and say, "Okay,
2 while 1 percent strain protects you against a lot of
3 other things, by the way, PCI you have to demonstrate
4 that you stay below two-tenths percent strain to
5 demonstrate that you've got PCI resistance during this
6 event.

7 MR. CLIFFORD: Right, for an event that
8 last a certain period of time.

9 CHAIR ARMIJO: Right. And then the issue
10 is how fast is it and how long did it last and is it
11 over before anything bad can happen.

12 MR. CLIFFORD: That is certainly one way
13 of approaching it. If you want to keep it purely
14 empirical, then you do have to be able to model it
15 because you have differences in fuel design that you
16 have to account for. A lot of the tests that were
17 done were done on 8x8 fuel rods and then you have to
18 convert it to 10x10. Then there have been differences
19 in --

20 CHAIR ARMIJO: Those are amenable to
21 design analysis. The stresses, the fuel temperatures,
22 all of that stuff is just straightforward analysis.
23 There is nothing fundamentally different in the
24 various fuel designs other than and even within that
25 really makes it an impossible job. Different pellet

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1 shapes, whether it's disked, whether it's chamfered,
2 how much prepressurization. All of that is amenable
3 to design.

4 MR. CLIFFORD: Right.

5 CHAIR ARMIJO: To analysis. The point
6 that we're trying to get at is once you have that
7 capability and you start exercising it you are going
8 to get a lot of insights into what is okay and what is
9 not okay. You may find -- I'm not prejudging but you
10 may find because of all of these conservatisms that
11 are built into your current requirements the risk is
12 pretty small, even for conventional cladding. I don't
13 think so but we'll see. Unless you do that analysis
14 in a rigorous way, right now I believe it's an
15 unreviewed safety issue because it violates general
16 design criteria. Some of these transients are not
17 infrequent AOOs but loss of feedwater heaters happen
18 roughly once a year in the fleet so they are not
19 infrequent.

20 MEMBER SIEBER: Let me ask a really
21 general question that you've already discussed. On
22 the previous slide you talk about no challenges to
23 coolability, pressure vessel integrity, containment
24 integrity. If you look at the whole body of
25 regulations and consider PCI failures against the

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1 regulations which are designed to protect the public
2 as opposed to protecting your investment, what
3 regulation really would you pick out that comes
4 closest to saying anything at all about PCI failures?

5 MR. CLIFFORD: It's good to clarify it.
6 There are no regulations governing this. There is
7 nothing in 10 CFR 50 except for Appendix A GDC-10 but
8 not all plants are GDC plants so it gets a little
9 confusing there, too.

10 MEMBER SIEBER: If I were to operate the
11 plant in such a way, for example, took high ramp rates
12 and did all kinds of things, fuel that didn't have PCI
13 protection built into it, I really wouldn't be
14 violating the regulation. What I would be doing is
15 screwing up my investment, increasing waste generation
16 and so forth. But it seems to me if you want to
17 regulate pellet-clad interaction failures, there has
18 to be a legal reason to do that and you have to be
19 able to point to some overriding principle that is
20 already set out in the regulations that says I need to
21 develop techniques whether they are analytical or
22 operating techniques or what have you to be able to
23 regulate either operational operating characteristics
24 or mechanical characteristics of the clad or the cord
25 design itself to avoid big power peaks and so forth in

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1 there. It's not clear to me -- even though I agree
2 that PCI is not a good thing to have but it's not
3 clear to me what the basis for regulating it really
4 is.

5 MR. CLIFFORD: That's a good point. As I
6 mentioned, you've got the GDCs and then you have
7 regulations on dose for citing purposes and I'm not
8 sure --

9 MEMBER SIEBER: You can have fuel failures
10 and not exceed your dose limit.

11 MR. CLIFFORD: Absolutely. What we are
12 talking about here today, it's important to put this
13 up on the table, we are talking about a change in
14 regulatory policy. Revising the reg guide, changing
15 our policy on how you interpret GDC-10. That's
16 different than rulemaking per se like we're doing with
17 50.46.

18 MEMBER SIEBER: It's either that or
19 rulemaking.

20 MR. CLIFFORD: But there's nothing in the
21 rule. You have to create a new rule.

22 MEMBER SIEBER: Not any rule that I know
23 of.

24 MR. CLIFFORD: Correct. It's a change in
25 policy and when we --

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1 CHAIR ARMIJO: Yeah. You may want to call
2 that a change in policy.

3 MR. CLIFFORD: When you start changing
4 policy, then you have to get into a back-fit space and
5 we could talk about that later how this thing may fall
6 out in a back-fit analysis but we'll get to that. The
7 next --

8 MEMBER SIEBER: Thank you. I guess I
9 understand what the framework is and I think it's
10 important to think about the framework.

11 CHAIR ARMIJO: But, Jack, how is PCI any
12 different than failure by a burn-out, you know, CPR
13 issue?

14 MEMBER SIEBER: Failure by what?

15 CHAIR ARMIJO: You exceed the critical TPR
16 ratio and you fail fuel. We regulate that routinely
17 and it's a big concern. Now, why is the PCI fuel
18 failure mechanism not a concern? I would think as a
19 regulatory agency we look at all credible failure
20 mechanisms and treat them appropriately and
21 consistently and there is no fuel failure mechanism
22 that we wink at and say, well, that's special.

23 Even though it is no safety significance,
24 the arguments point out on your slide 4 those are the
25 same arguments that the industry, and I was one of the

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1 guys years ago used to ask the NRC to hold off until
2 we could develop a PCR resistant fuel design because
3 these were true then and they are true today.

4 The issue is when we're backsliding we
5 have solved the problem and we're backsliding to
6 status quo ante, if you will. That is something that
7 the NRC should discourage. If an event happens in an
8 AOO or a lot of fuel fails that wasn't analyzed, I
9 think it's going to be very negative impact on the
10 industry and on the NRC.

11 If we haven't analyzed it, you know, it's
12 a bad situation to be in. Very poor situation to be
13 in. That is my point. If we analyze it and we come
14 to the conclusion it's okay, I'm fine with it and I
15 think the NRC should be fine with it. If we don't
16 analyze it for a variety of potential or regulatory
17 policy issues or this issue, I think we are being
18 deficient.

19 MEMBER RAY: I don't understand how to
20 separate Jack's argument as applied to fuel cladding
21 from the same argument that you might try and apply to
22 the containment. In other words, it's just a barrier.
23 Right?

24 MR. CLIFFORD: Um-hum.

25 MEMBER RAY: I'm puzzling over what seems

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1 like a difference in the way we would approach the
2 containment to the way we are approaching this
3 phenomenon.

4 MR. CLIFFORD: Containment by design can't
5 fail during any hypothetical accident. Cladding is
6 allowed to fail based on the probability of an
7 accident provided you meet those requirements.

8 MEMBER RAY: Let me think about that. In
9 any event, what I'm really talking about is how we
10 regulate it, not what the outcome is.

11 MR. RULAND: Licensees all are required to
12 have a corrective action program for all safety
13 related components. I would argue that when the fuel
14 is failing for excessive pellet-clad interaction, you
15 could examine the corrective action criteria to say
16 licensees are bound to take action to prevent
17 recurrence. One of the things licensees have done in
18 the past is, in fact, to develop barrier fuel.

19 We as a regulator don't specify exactly
20 how that should be dealt with. Some licensees dealt
21 with it by using the PCIOMR requirements. Some
22 developed the barrier fuel but ultimately it's the
23 licensee that has got to make the choice about how to
24 prevent recurrence of those fuel failures.

25 MEMBER SIEBER: But that is a performance

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1 based approach.

2 MR. RULAND: Correct.

3 MEMBER SIEBER: And ultimately the
4 licensee is only limited by what the regulations tell
5 him to do.

6 MR. RULAND: Correct.

7 MEMBER SIEBER: You can operate with PCI
8 failure.

9 CHAIR ARMIJO: Okay. We've got to let
10 Paul finish his presentation and then we'll take a
11 little break but let Paul finish.

12 MR. CLIFFORD: Okay. The previous slide I
13 discussed kind of a box around the maximum power
14 excursion you could endure without violating one of
15 the other criteria, the other SAFDLs. The other
16 issue, which is kind of unique to stress corrosion
17 cracking, is the duration of the power excursion break
18 and this figure I'm showing and this is nothing new.

19 I think Sam pointed this out. You know,
20 the power can only go up so high. Otherwise, you'll
21 get a trip or predicted failure by your other three
22 SAFDLs the timing of which you need so many minutes at
23 this elevated power in order to have the crack
24 propagation and through-wall failure.

25 Then there is the other issue as well when

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1 could you credit a reasonable operator response. It's
2 not an infinite time. I think what the ACRS has seen
3 when they saw the Susquehanna issue is they saw a
4 typical chapter 15 data analysis where they took out
5 the feedwater heater and then assumed 10 minutes
6 nothing happens. Very conservative approach and the
7 power sat up there for 10 minutes. Yet, Susquehanna
8 also showed that they had the event in real life and
9 the operators responded rapidly. It was a very, very
10 benign transient. We need to take this into account
11 from the time perspective. We can't ignore the fact
12 that there is plenty of indication in the control room
13 that would prompt the operators to take some reaction
14 and they are not going to be asleep at the wheel.

15 CHAIR ARMIJO: That I agree with you
16 because we didn't investigate during Susquehanna the
17 actual event that they talked about but we don't know
18 whether it was 100 degree Fahrenheit, delta T
19 subcooling or whether it was less, when it happened
20 during the cycle, beginning of cycle, end of cycle.

21 All of those sorts of things are subject
22 to analysis and you could explain why they had
23 success. That doesn't mean they couldn't have failed
24 until you analyze the most limiting case. I feel we
25 are kind of flying blind based on favorable experience

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1 but it doesn't always have to happen that way.

2 MR. CLIFFORD: This is my last slide. The
3 staff has completed -- well, has thought about the
4 safety significance of this. There are limited staff
5 resources to work on activities. Then we kind of have
6 our plates full with supporting the current licensing
7 fleet as well as new reactor design certifications.

8 In addition I would like to say we don't
9 believe in stress corrosion cracking safety
10 significant warrants immediate action. Nor do we feel
11 that it really takes higher priority than other
12 ongoing regulatory improvements such as the work
13 revising reg guide -- I mean 10 CFR 50.46(b) or the
14 recently completed work revising reg guide 1.183 gap
15 source terms.

16 We have to weigh -- because of the limited
17 resources we have to weigh what we work on and it's
18 real life so you've got to do that. There is not an
19 infinite number of engineers. Right now it's on our
20 radar screen but I would say it's on the back burner.

21 CHAIR ARMIJO: Is there any scheduled
22 upgrade of your analytical codes to handle this? In
23 your research program is there any upgrade FRAPCON, or
24 whatever code you use, to analyze risk of PCI during
25 AOOs? Is there any program at all?

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1 MR. CLIFFORD: I would echo what Michelle
2 said earlier. I think we are kind of watching the
3 SCIP II program which is working towards developing
4 analytical tools and seeing what success the
5 international community has before we go off and try
6 to duplicate.

7 CHAIR ARMIJO: So the answer is no.

8 MR. CLIFFORD: No.

9 CHAIR ARMIJO: I understand. It's a good
10 word. I've been told no a lot of times.

11 MR. FLANAGAN: For more information I
12 could probably get back to you on it but just to start
13 to answer your question, the data available from the
14 SCIP program, the SCIP I ramp test, is fed to the code
15 developers for FRAPCON and FRAPTRAN and they are using
16 it to benchmark their codes so there is integration of
17 FRAPCON and FRAPTRAN with the results of the SCIP
18 program and the ramp test there.

19 CHAIR ARMIJO: Is that in your research
20 program or is that something else outside of the
21 research program, that activity?

22 MR. FLANAGAN: I mean, it's an integral
23 part of the code maintenance is to benchmark with
24 results that come out. I have to get back to you on
25 more specifics.

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1 CHAIR ARMIJO: Okay. That's all right. I
2 would be interested in learning more about that.

3 MR. CLIFFORD: Okay. That's my
4 presentation. As I mentioned, I have some alternative
5 strategies that we can put up on the screen when we
6 get to the roundtable discussion.

7 CHAIR ARMIJO: Okay. We are really close
8 to schedule. I thank everybody, including myself, for
9 not overdoing it. Let's take a 10-minute break.
10 Let's reconvene at 10:00 and Dr. Davies will give his
11 presentation.

12 (Whereupon, at 9:44 a.m. off the record
13 until 10:01 a.m.)

14 CHAIR ARMIJO: All right. Let's get back.
15 We are reconvening. I lost control of the meeting
16 and it's my fault.

17 MEMBER SIEBER: It only takes two of us.

18 CHAIR ARMIJO: Dr. Shack, would you join
19 us? All right. We are reconvening. The next
20 presentation will be by Dr. John Davies, our
21 consultant. Dr. Davies is a Ph.D. chemist from Durham
22 University in England. In addition to his many years
23 of work with GE in the nuclear business he worked for
24 the UK AEA at Harwell for about four years. Most of
25 his time has been with the GE fuel related businesses.

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1 John was responsible for the power ramp
2 testing program that GE did to qualify barrier fuel
3 for boiling water reactor service, PCI resistant fuel.

4 In the course of doing that he did a lot of testing
5 of conventional fuel cladding and he is going to
6 provide us with information that I believe is relevant
7 to the AOO issue, particularly with respect to the
8 time to failure as a function of power.

9 John, it's all yours.

10 DR. DAVIES: So part of Sam's PCI's
11 concern and question lies in the results of these
12 carefully controlled power ramp tests that we
13 performed in support of barrier fuel so he plucked me
14 out of retirement and invited me to come to this
15 meeting to share with you some of the details that are
16 relevant. If you look at -- well, let's stay just
17 where we are, Michael.

18 In the corner of that report is a date
19 which says 1984 which is when we did that work. In
20 the '70s is when PCI raised its ugly head. Yes, we
21 could control it but there were penalties associated
22 with loss of operating flexibility and even electrical
23 output. There was a great incentive to develop PCI
24 resistant fuel.

25 In the end our program, as the title

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1 infers, was focused on the barrier fuel, but when we
2 started out program there were quite a few ponies on
3 the track. Everybody who had a skill in metallurgy or
4 chemistry had a preferred PCI remedy. By the time we
5 got into our segmented rod program the pure zirconium
6 liner was the preferred choice.

7 If you look at the next slide, it sort of
8 describes our program. It was a segmented rod program
9 where we are incubating our remedy fuel rods in
10 segmented rod assemblies and power reactors. By
11 incubating I kind of mean they were being irradiated
12 to build up an inventory of fishing products at
13 relatively low powers.

14 We could visit those reactors during
15 refueling and retrieve and characterize some of the
16 fuel rod segments in the hotcell and then perform
17 power ramp tests in a test reactor followed in the end
18 by hotcell characterization of the ramp tested rods.
19 Now, the whole program was designed around the General
20 Electric test reactor at the Valocitas nuclear center.

21 Just as we were more or less getting
22 started we felt we had to close down that reactor
23 because of its proximity to the perceived earthquake
24 fault so we had to move our testing to the Studsvik R2
25 reactor. It turned out to some extent to have a

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1 silver lining, that move, because the R2 reactor is in
2 many ways a better machine.

3 Both test reactors are 50 megawatt
4 reactors but in GTR the test rods are in the pool
5 outside the core and power is increased by moving the
6 rods closer to the core and the power was monitored
7 neutronically. In the Studsvik reactor they have a
8 loop and the fuel rods are tested inside this loop
9 situated within a pressurized helium-3 core. Helium-3
10 is a poison, or a neutron absorber and so by
11 evacuating the helium-3 from the loop you can raise
12 the power on the fuel rod.

13 You can see that it was a substantial
14 program there were six different ramp test campaigns
15 going on over six or seven years. That is a tribute,
16 if you like, to the commitment that we had to develop
17 some kind of PCI resistant fuel. Another couple of
18 things you can take from that chart and one is the
19 Studsvik people are very good.

20 Some of their instrumentation evolved so
21 by the end we were getting some additional
22 measurements in 1983, for example. The number of
23 campaigns also explains to some extent the rather
24 large number of standard cladding reference rods that
25 we tested in this program because every time you go

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1 back to the reactor you need to know that you are
2 where you were the last time in terms of response to
3 the ramp and failure.

4 If I look at the next slide it shows our
5 segmented rods. The GETR core was about -- it was
6 designed around the GETR core which is about a meter
7 long and so these fuel rod segments were about a meter
8 long and they were screwed together into assemblies
9 which contained four segments.

10 On the top figure you can see some of the
11 features. We had to insert hafnium sleeves in the
12 plenum of the fuel rod segment and hafnium pellets at
13 the ends of the fuel columns just to depress flux
14 peaking in the spaces between the segments so that was
15 one of the features.

16 Another thing that you can see is that
17 each of these fuel rod segments contain what is called
18 a getter insert in those days. I don't know if they
19 still do it. GE had a hydrogen getter in the plenum
20 of the fuel rod because we had suffered some primary
21 hydrating damage. It turned out to be a rather
22 valuable thing because it was used as a failure
23 indicator. When you bring your rod back to the
24 hotcell we did neutron radiography. If the rod had
25 failed there would be a little hydrogen in the GETR.

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1 We had two of these assemblies. Next
2 slide.

3 CHAIR ARMIJO: John, the only thing I
4 would like to add is all of this fuel was made in a
5 conventional fuel factory. It was not a laboratory
6 experiment. These were conventional fuels made in our
7 factory. I believe by that time we were in Wilmington
8 so everything was standard production because the
9 whole idea was to qualify production fuel. If we
10 could develop a PCI resistant fuel it had to be
11 production quality, not laboratory quality.

12 DR. DAVIES: Yeah. As a chemist, you
13 know, I firmly believe that that chemical component of
14 the PCI mechanism is very important. One of the
15 features of these segmented rods is you just have to
16 unscrew them and test them as single rods.

17 There is no like refabrication in hotcells
18 of full-length rods into segments during which
19 process. However careful you are there is the
20 possibility of introducing perhaps a little oxygen and
21 changing the stoichiometry of the fuel which may be a
22 very important feature. That's our segmented rods.

23 Now, we had two of these 8x8 bundles.
24 This is a picture of the matrix and the cross-hatched
25 rods labeled 1 were all segmented. That is, there

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1 were four segments per fuel rod. If you look at the
2 little table down below, there were 40 of these rods
3 in an 8x8 bundle and there were four segments per rod
4 so we had 160 segments.

5 I mentioned earlier that in the end we
6 were very much focused on the zirc barrier but at the
7 beginning there were other barriers, for example. In
8 fact, the DOE program, which DOE funded this work, DOE
9 and Commonwealth, when we started out the program we
10 were pursuing both a zirconium lining and an
11 electroplated copper barrier.

12 The copper barrier looked very promising
13 but in the process of this program it became clear
14 that the benefit of copper would wear out after about
15 20 gigawatt-days so the program became focused on the
16 zirconium liner.

17 These bundles were carefully situated
18 during the power reactor irradiations in the periphery
19 of the core. This particular monocello segmented rod
20 bundle you can see item No. 1 there encompasses, I
21 think, it looks like four different cycles. These
22 bundles were always pre-irradiated in low-power
23 locations so that we were careful not to precondition
24 these segments so that they wouldn't be susceptible to
25 PCI.

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1 Looking at the next slide, we have an
2 example of the power history of a typical segment
3 actually including at the very end the ramp test. You
4 can see this segment was all the time operating in the
5 power reactor it looks like below six kilowatts per
6 foot. Then there was a time period when it was
7 retrieved and characterized in the hotcells and
8 probably shipped across to Sweden and finally ramp-
9 tested in the Studsvik R2 test reactor.

10 The next slide just summarizes the pre-
11 ramp characterization that these segment were
12 subjected to. And, of course, the principal need was
13 to verify suitability for ramp testing. We didn't
14 want anything that, for example, had a strong eddy
15 current signal somewhere or some indication that
16 perhaps it was bowed and it would be a problem in the
17 loop.

18 We also collected profilometry data that
19 we were able to use after the ramp test as a baseline
20 for measuring the cladding strains. Probably the most
21 important measurements that we made were these cesium-
22 137 nondestructive gamma scanning measurements which
23 we compared to a standard rod of known burn-up. From
24 that we could determine the axial burn-up distribution
25 along the rod.

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1 Then, of course, a physicist could tell us
2 what the fissile isotope profiles were for uranium-
3 235, Pu-239 and plutonium-241 which was important
4 input to the test reactor guys so they could
5 accurately predict the power profiles during our ramp
6 test.

7 Next slide is another picture of the rod
8 segment, this time in the vertical orientation which
9 is the way they were tested. Off to the side you can
10 see that we have the rod, the 29-inch rod was divided
11 -- a fuel column was divided into 10 axial nodes each
12 one of which we had the fissile content distribution
13 for.

14 The next slide then we are still in pre-
15 ramp characterization shows the typical gamma scans
16 which are representative of burn-up profiles along the
17 top, bottom, and middle segments. It shows the 10
18 axial nodes which are carefully characterized as I
19 have just described.

20 The next slide comes to the ramp sequences
21 that we employed. What we were anxious to do is to
22 determine the power at which these rods would fail.
23 We were pushing them to quite high powers. It looks
24 like 18 kilowatts per foot.

25 Now then, as I said, in the Studsvik R2

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1 reactor the power was controlled by evacuating helium-
2 3 out of the neutron-absorbing coil that was
3 surrounding the fuel rod and the loop and with the
4 pressures they employed, which I believe were like 6
5 megaPascals of helium-3, with the test reactor at full
6 power you really could only get a factor of 2 increase
7 in power using the helium-3 evacuation. If you wanted
8 to go to 18 kilowatts per foot, you had better start
9 off around 9 kilowatts per foot and this is what we
10 did.

11 We had what we called a standardization
12 power which was a little higher than we believe the
13 segment had experienced in the power reactor, 9
14 kilowatts per foot. We held that for six hours just
15 to get the rod standardized after it had been
16 characterized in a hotcell and shipped overseas, etc.

17 Then we went up a power staircase at a ramp rate of
18 actually 2 kilowatts per foot per minute, 6.6
19 kilowatts per meter per minute, and then held at each
20 step for one hour.

21 If we could get the fuel rod to survive to
22 18 kilowatts per foot, we held it, it looks like, for
23 four hours. In those days we had assured ourselves
24 through our own work and other people's work that if a
25 fuel rod was going to fail by PCI it would happen

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1 within four hours. Then if it survived it was taken
2 off test in most cases, in many cases.

3 Another kind of ramp that we employed we
4 called a single-step ramp on the next page. That was
5 ramp sequence B. The fastest that we could exhaust
6 the helium-3 or that Studsvik could exhaust the
7 helium-3 out of their coil using a bellows device that
8 they had could give you a step ramp at a ramp rate of
9 18 kilowatts per meter per minute. We did quite a lot
10 of tests at that ramp rate which was three times
11 faster than we had on the staircase.

12 However, there were also some "what if"
13 engineers in our department that said when you move a
14 control blade a number of notches the actual ramp rate
15 is much higher than that. It is approaching 320
16 kilowatts per meter per hour. One of the things that
17 Studsvik managed to do by one of the later campaigns
18 was to rapidly evacuate the helium not into the
19 bellows but into some kind of free volume, free large
20 volume that they had to, therefore, give this rather
21 rapid power increase.

22 We called this kind of ramp the C prime
23 ramp because we already used another fast ramp that we
24 called C and that is shown in the next slide. We
25 thought this was kind of cute what we were able to do

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1 here because we could get two tests for the price of
2 one. Basically the Studsvik R2 core was a little bit
3 shorter than the GETR core and quite a bit shorter
4 than the length of our fuel column.

5 We could have the fuel rod fully inserted
6 into the helium core which is the first part of the
7 picture. You can see the form factor, power form
8 factor that we could get, say, on node 5, and that
9 would be either an A ramp or a B ramp. Then after
10 that was completed with the six-hour hold Studsvik in
11 their ingenuity were able to just raise the rod up in
12 the loop 200 millimeters and perform a ramp on the
13 node 9 of the rod.

14 If you look across to the right of the
15 slide you can see what happened on node 9 in an A ramp
16 which was followed by a C ramp. Little gentle steps
17 may be up to the 8 kilowatts per foot when node 5 was
18 being powered ramped. Then this big step ramp to
19 whatever the test spec called for at this higher ramp
20 rate.

21 It turns out that the standard reference
22 fuel rods, which is what this meeting is focused on,
23 in general would fail during the first round, the A or
24 B round. The second round was very useful for getting
25 two results, if you like, on one fuel rod when you are

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1 testing the PCI resistant fuel like zirc barrier. It
2 would in general survive the first ramp and in general
3 it would also survive the second round, although
4 occasionally as Paul pointed out in his talk, not many
5 of these remedies are perfect. They're resistant but
6 nobody claimed immunity so we get occasional failures.

7 The next slide then shows the results of a
8 double ramp test. The little triangles represent the
9 burn-up profile on the rod so it must have been a
10 middle segment. Then you can see the first ramp
11 exercised node 5 or 12 inches above the bottom of the
12 fuel column. The second ramp exercised node 3 or 4.

13 Moving on to the next slide. What
14 Studsvik does so well is ramp test. They collect all
15 of the data into the process computer and they give us
16 the power history, time to failure, and this kind of
17 thing, failure power. They also had real-time chart
18 recorder outputs. The next three slides are kind of
19 showing some of these chart recorder outputs.

20 I think when I wrote the report I wanted
21 my document guide to just stick a piece of chart
22 recorder into the report but he chose to redraw them
23 and make them look better. However, these are real-
24 time plots. In this particular case one of the
25 instruments that the Studsvik people came up with by

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1 1983 was a rod length indicator so we are able to
2 measure perhaps not dismetral strains but we are able
3 to measure axial strains as you are increasing the
4 power on the rod. Here is a side-by-side thing.

5 You can see the peak power on this fuel rod going up
6 a staircase to a final power of 600 roughly watts per
7 centimeter. You can see the rod elongation in
8 microns. Clearly each time you have a power step Sam
9 showed a nice figure before how the fuel pellets kind
10 of grab onto the cladding so the rod elongation is
11 really a measure of the expansion of the fuel column
12 as it gets hotter and basically stresses the cladding.

13 Then you can see the stresses or strains relaxing.

14 Now, then at the two higher powers there
15 is a very interesting things because you can see that
16 you get secondary strains just as the primary strain
17 is starting to relax. That, of course, demonstrated
18 here and in Halden tests is a consequence of fission
19 gas release. At these higher powers you get quite a
20 substantial release of krypton and xenon which gets
21 into the gap and degrades the gap conductivity which
22 used to be helium. The fuel gets hotter.

23 I think Paul in his presentation says that
24 the fission gases come out a little bit after you
25 reach the peak power and that is what happening here.

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1 It's just a very good indication of the fission gas
2 release degrading the fuel power. There are several
3 models of PCI that you need a critical cladding strain
4 and you also need a critical concentration of iodine
5 or cadmium or whatever.

6 We believe in the case of the zirconium
7 barrier the critical cladding stress has relaxed
8 before you reach the critical fission product
9 concentration which is perhaps why it works. Anyway,
10 it's just very interesting experimental data.

11 The next is another chart recorder output.

12 What I have to point out to you is the time is going
13 from right to left on this chart. If you look at the
14 bottom graph you see the evacuation of helium-3. Then
15 if you look at the third line you can see what happens
16 to the power. There is a power step increase and that
17 kind of holds. Then there is a little aberration on
18 that chart which is called here a power spike. It's
19 not really a power spike. It's an apparent power
20 spike. If you look at the rod elongation you can see,
21 yes, the axial strain is relaxing but all of a sudden
22 there is a significant delta L. Then the rod
23 elongation is on a different trajectory.

24 Then on the top graph or chart you can see
25 at some point the radioactivity in the loop takes off.

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1 That, of course, is when we know for sure this little
2 rod has failed. What these other indicators are
3 pointing out and we need to remind ourselves is that
4 in these pressurized water loops the pressure outside
5 the rod, outside the cladding is higher than the
6 pressure inside the rod.

7 Before you can ever release any activity,
8 you have to get some steam in. We all know that these
9 PCI cracks are little things, tiny little things, and
10 so there is in some cases significant delay between
11 initial failure and activity release. We are now
12 convinced that these large delta Ls and apparent power
13 spikes are the primary indications of failure time.

14 The thermoconductivity of steam is better
15 than that of Xenon which may be during a power ramp
16 has displaced a lot of the helium. Also when the
17 steam gets into the fuel rod it wants to react with
18 the hot fuel and to some extent the cladding and form
19 hydrogen. Hydrogen is a very good -- has a very good
20 thermal conductivity. This is what we believe and are
21 convinced are the primary indicators.

22 In these power ramp tests we didn't just
23 collect power to failure or failure power. We were
24 able to collect time after ramp step to failure.
25 There is another indication in the next graph of one

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1 of these little power spikes. Again, it's not a power
2 spike.

3 It is an apparent power spike because you
4 have had this sudden increase in fuel gap conductivity
5 and release of a little bit of stored energy but the
6 power is still what it says it is, 39 kilowatts per
7 meter. The initial failure predates or pretimes the
8 activity release by several minutes. I think it's
9 like 10 minutes or nine minutes in this particular
10 case. That is something we got out of Studsvik.

11 The next chart --

12 MEMBER SIEBER: Well, before you get too
13 far just to refresh my memory I would like to ask a
14 question. In a regular operating reactor the big
15 changes in coolant activity occur on power increases
16 and then they come back down for some higher
17 equilibrium level.

18 If you are really monitoring to see if you
19 have PCI failures, you have to look for activity
20 changes associated with power ramps which either come
21 from total power or control rod movement. Then it
22 sort of disappears and you just have an overall higher
23 activity in the coolant altogether.

24 CHAIR ARMIJO: A lot depends on
25 how clean your core is. If you have a lot of tramp

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1 uranium and a lot of other stuff, then you don't have
2 much ability. The point of this discussion is to show
3 that while that wasn't the focus of the program to
4 find out what was real time to failure after power
5 ramp.

6 It fell out that there was a lot of other
7 information that we didn't need to qualify barrier
8 fuel but could be relevant to the AOO situation where
9 time is of the essence, operator response time versus
10 PCI failure time. These data that John found were
11 actually in our report. We never had any use for it
12 but I think are relevant today.

13 MEMBER SIEBER: My memory goes back 50
14 years to the original Navy cores and that was the
15 technique that we used at the time to try to figure
16 out whether we have fuel failures or not.

17 CHAIR ARMIJO: My belief is that in the
18 operating plants the only we had was activity but the
19 time to failures were actually shorter than our
20 measurement of activity increase.

21 MEMBER SIEBER: Thank you.

22 MEMBER SHACK: I mean, for example, in
23 these two examples on 15 you would have about, I don't
24 know, nine minutes or something to take some action to
25 stop things. In this other one you would have a

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1 minute basically to do it. If you had a transient
2 with that kind of --

3 CHAIR ARMIJO: Exactly. As I said, when I
4 asked John to look into the old data, fortunately he
5 had his old report and he had a good memory because
6 the question was, "How much time? If these transients
7 that I'm worried about are over before the PCI event
8 can happen, that's the problem?" Well, he found a lot
9 of data and that is why you need a little bit of time
10 showing how carefully these experiments were done so
11 that we could be confident that those failure times
12 are backed up with either elongation data, thermal
13 power spike, or activity release.

14 MEMBER SIEBER: But you're not counting on
15 operator action in the fraction of a minute that the
16 spike occurs. Changes are other than --

17 CHAIR ARMIJO: It has to happen before
18 there's a spike.

19 Okay, John. We've got to pick it up a
20 little bit.

21 DR. DAVIES: This is basically the same
22 slide that Sam showed except there is a bar which
23 indicates the size of the ramp steps. Some of these
24 must have been B or C ramps and others where there is
25 just a two kilowatt preferred state.

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1 CHAIR ARMIJO: Okay.

2 DR. DAVIES: Staircase or A ramps. The
3 last slide here is speaking to the hotcell post-ramp
4 characterization which was really done to confirm
5 whether the rods or sound or failed, but also to
6 characterize the defects. The next slide speaks to
7 one of the points that was being discussed earlier in
8 that this is some results of spiral profilometry on a
9 twice-ramped fuel rod which in this case did not fail.

10 It's clear that there is a little bit of volatility
11 in this cladding. The top chart shows pre-ramp
12 diameter profile. The second chart shows a little bit
13 of cladding strain equal to .2 percent delta D over D
14 after the first ramp in like the middle of the rod.
15 Then the final chart shows the strain at the bottom of
16 the rod which is, again, in the same range. Certainly
17 substantially less than 1 percent strain. We are
18 talking here plastic strain, obviously.

19 Then, finally, I've got a couple of slides
20 that just show some more of these PCI cracks with
21 their typical features. The next one, Michael, which
22 are multiple crack nucleation, crack branching, and
23 very, very little strain of the cladding.

24 Okay. Now, the final slide in this
25 presentation is a slide that Sam put together based on

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1 the data that I fed him in the last month or so where
2 he took these failure times. I think if somebody is
3 going to speak to that slide it should be Sam.

4 CHAIR ARMIJO: Okay. What I did in this
5 report -- I want to emphasize this General Electric
6 report was jointly funded by GE, the Commonwealth
7 Edison Company, Department of Energy. Everything in
8 that report, everything in that program is public
9 record. There is nothing proprietary in it so it is
10 available to everybody and there is a lot of detailed
11 information with perhaps scientific interest on people
12 worried about standard cladding but we were worried
13 about how reliable the liner fuel would be. We were
14 very aggressive in over testing to demonstrate a lot
15 of margin. When this situation on the AOs came up,
16 the question I had was how much time do we have for
17 operator action. If we go into these transients above
18 our normal fuel peak powers, how much time does it
19 take before failure. John had the data. These data I
20 plotted them as a function of failure time against
21 peak power and then broke them up into different burn-
22 up categories.

23 You can see that in the very low burn-up,
24 7 megawatt-days per kilogram uranium, we could get
25 failures but we had to go to 18 kilowatts per foot

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1 before we would fail anything but it would happen
2 within nine minutes. As you got to higher and higher
3 burn-ups you were having routinely failures in the
4 times of one to two to three to four minutes.

5 The question then is in the case of AOOs
6 that might take you up to 14 or 16 or possibly even 18
7 kilowatts per foot do you really have operator
8 response time that could protect you. My guess is
9 it's not likely unless you have an automatic scram or
10 unless you have some other inherent conservatism that,
11 in fact, you never did get to 16 kilowatts a foot or
12 the subcooling was much less than the 100 degrees that
13 people analyzed for.

14 You know, you're going to be failing this
15 fuel unless you can prove that your conventional
16 cladding has exceptional PCI resistance. If you look
17 at the literature of Canadian fuel, GE fuel,
18 Westinghouse fuel, conventional fuel, conventional
19 cladding is not PCI resistant. The issue here is how
20 much time do you have. We have data that I believe
21 the staff should take a careful look at that shows you
22 don't have a lot of time.

23 Unless you analyze this event, you are
24 putting fuel at risk, I believe, in violation of the
25 general design criteria when you know better. You

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1 can't ignore the stress corrosion cracking phenomenon.

2 That is the reason for bringing Dr. Davies in to
3 explain it. This is the largest database of standard
4 BWR fuel testing, the most careful experimental
5 program. It wasn't compromised by refabrication of
6 conventional power fuel. It was a very expensive
7 program. I did a rough calculation that every one of
8 those data point cost in 1984 dollars something like
9 \$30,000 a data point so it was a pretty expensive
10 program, very carefully done, and the data I think are
11 something that should be a basis for any kind of
12 analytical model to test the model against experiment.

13 MEMBER SIEBER: Do you know off hand which
14 GDC applies?

15 CHAIR ARMIJO: Ten. I think it's GDC-10.

16 MEMBER SHACK: But do I interpret this
17 correctly then, Sam, it's 16 kilowatt a foot? I have
18 a distribution of failure times ranging from 1 minute
19 to 60 minutes so I should really plot that as a
20 distribution and look for a mean.

21 CHAIR ARMIJO: Yeah, you could do that.
22 The issue is the percentage -- I did just an eyeball.
23 I said, look, what is fraction of fuel -- of failures
24 that happen in less than 10 minutes and it's a good
25 fraction. Yeah, there are lots of ways of treating

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1 this data. This is very coarse but the fortunate
2 thing is the data exist. Many of these data points
3 are power spike or elongation changes? I mean power
4 spikes. Usually elongation -- in fact all the time
5 elongation change and power spike were the same. Some
6 of the data points are just activity release so some
7 of those later delayed ones were mixed.

8 MEMBER SHACK: We're mixing apples and
9 oranges here.

10 CHAIR ARMIJO: I plotted failure time
11 whichever came first. If the test demonstrated -- we
12 thought we saw an activity spike, well, the activity
13 spike was always after the thermal spike but sometimes
14 there was no thermal spike and so activity spike is
15 the only thing there.

16 In a way it is mixing apples and oranges
17 but I think for conservatism I focus on the very short
18 times because after 10 or 20 minutes I think there
19 should be plenty of time for operator action but
20 certainly not in one, two, three, or four minutes.
21 That is why I think that we've got to take this issue
22 very seriously.

23 I agree with Paul that this containment
24 can take this. The BWR is sized to take a lot of fuel
25 failures but this industry is working to have zero

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1 fuel failures during normal operations. Here as a
2 regulator we are kind of indifferent, or appear to be
3 indifferent to fuel failures during abnormal
4 transients.

5 I don't think we should. I think we
6 should demand that the licensee demonstrate either by
7 analysis or by test, or preferably both, that the
8 fuel, whatever it is, whether it's a liner fuel or
9 conventional fuel, is capable of performing without
10 fuel failures with some margin. I don't know how much
11 windage you put into it but these, I think, are
12 fairly frequent transients, at least the loss of
13 feedwater heater.

14 It's not so infrequent that you could just
15 disregard it. That is really the point. That is why
16 we brought this issue up. I've got to give credit to
17 our colleague Dr. Dana Powers. I discussed this issue
18 with him and he said, "The way to handle this is let's
19 have this collegial discussion. Put everything on the
20 table and let's see what is the best way to handle it.

21 I appreciate the staff being very cooperative to meet
22 with us and discuss that so at this point I think we
23 could really open it up for roundtable discussion.

24 Again, if there is anyone on the bridge
25 line, you folks have not had the benefit of seeing the

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1 slide presentation material but it is published record
2 and the staff, I'm sure, can make that available to
3 you. If there's comments or questions from anyone in
4 the meeting, including attendees here, we would be
5 happy to entertain them and I'll open it up for
6 discussion. I'll leave it there.

7 MR. CLIFFORD: If no one else has
8 anything, I had some questions for Dr. Davies.

9 The initial gap size is probably very
10 important to the power ramp test. Do you believe that
11 the six-hour preconditioning is enough to bring the
12 fuel gap size, you know, the fuel pellet and the fuel
13 gap size for typical values that you would see during
14 operation for periods of time?

15 DR. DAVIES: I would say in cooperation
16 with the Studsvik people who have also done a lot of
17 this work we convinced ourselves that it was. Our
18 fuel modeling guys convinced us.

19 CHAIR ARMIJO: You are talking about just
20 basically --

21 MR. CLIFFORD: If it had an abnormally
22 large gap or an abnormally small gap it would affect
23 how quickly you got stress and stain on the cladding.

24 CHAIR ARMIJO: If you had a very big gap -
25 -

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1 MR. CLIFFORD: It would delay it.

2 CHAIR ARMIJO: -- it would stress it. The
3 focus on all of these tests was to make the test
4 aggressive. You could argue that these tests are way
5 too aggressive but we don't think so. Our focus was
6 definitely to say, hey, if we can fail all of the
7 conventional cladding and we only fail a very small
8 fraction of the liner cladding, we have actually
9 demonstrated sufficiently that we can do this ramp
10 test in the power reactor which we did. Some 348
11 bundles in the Quad Cities reactor were irradiated at
12 low power and with full blades.

13 MR. CLIFFORD: I was kind of looking
14 forward to when if you want to develop an analytical
15 model and you want to benchmark it against this, it is
16 important that you don't introduce uncertainty by
17 having the right or wrong gap size in your model which
18 would affect your comparison to the data.

19 CHAIR ARMIJO: The gaps in the data on the
20 mechanical design, the pellet design, all of that is
21 available in these reports. In your typical models
22 you'll find, yeah, it has an effect but you have the
23 tools to deal with those variables and they are not
24 profound. I mean, unless you have an extraordinarily
25 large gap you're going to fail fuel. Unless you have

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1 extraordinarily good cladding you are going to fail
2 fuel. It's very aggressive.

3 The dominate thing in this mechanism is
4 chemistry. You must have sufficient stress but if you
5 didn't have the fission products available, nothing
6 would happen. You would have mechanical strain and
7 everybody knows how to analyze that. At least they
8 claim to. We did open up the bridge line if there's
9 any comments or questions from people on the phone, if
10 anybody is on the phone. We were told there would be.

11 MEMBER SHACK: Can you compare these
12 experiments with the ones in the Power Burst facility?

13 The statement is they survived those tests. What is
14 different about those?

15 CHAIR ARMIJO: I don't -- I looked at them
16 years and years ago. I have forgotten what's in them.

17 MEMBER SHACK: Would the research people
18 know?

19 MS. FLANAGAN: The tests in the Power
20 Burst facility were much shorter duration and they
21 were a larger power excursion. Also the survivability
22 was measured by radiological release and so they were
23 looking for the indication of failure through
24 radiological release rather than -- that is the
25 second --

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1 MEMBER SHACK: That is the second thing
2 rather than --

3 MS. FLANAGAN: The duration were in
4 seconds and the power increases were much greater than
5 those here.

6 MEMBER SHACK: Okay. So they were really
7 looking at a different class of accidents.

8 MS. FLANAGAN: Yes. I have the --

9 MEMBER SHACK: How are the SCIP tests
10 being conducted?

11 MS. FLANAGAN: Those range, I think, in
12 duration so it's not just -- there are ramp tests as
13 well as mechanical tests out of pilot simulate the
14 loading that are in PCI failures so there's both.

15 CHAIR ARMIJO: The Studsvik people had a
16 series of ramp test programs in addition to what they
17 did for the GE program and they called it intra-ramp,
18 over-ramp. Some people called it ever-ramp because it
19 never stopped. The fact is they had the same
20 facility, very good experimental capabilities, and
21 there is a wealth of data, different designed fuel
22 rods, different cladding materials.

23 I believe with a little bit of research to
24 dig out that data you would have an enormous data base
25 that people may have not focused on time to failure,

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1 real time to failure when you get to real high power.

2 Some of the tests were limited to very low power,
3 below 13 kilowatts a foot. That is not particularly
4 interesting. It's when you get up into higher than
5 the fuel duty that's when you really are in the AOO
6 regime and that is where you should concentrate.

7 This is one set of data. I think it's a
8 particularly good set of data but it's not the only
9 one. I think there is sufficient information with
10 this kind of data just even empirically that would
11 tell you we have -- I won't call it an unreviewed
12 safety issue but it is certainly an unreviewed fuel
13 failure mechanism in that it actually can happen.

14 There is no reason why it can't happen unless
15 you do the analysis and demonstrate, hey, subcooling
16 isn't 100 degrees. It's really 25 degrees so nothing
17 ever really reached those powers. It's all
18 hypothetical or something else. We had big gaps in
19 this fuel or we did something else. You don't have a
20 solid answer unless you have the analytical model or
21 analyze each event on a case-by-case basis.

22 My argument is we shouldn't analyze the
23 event after we fail fuel. We should analyze the event
24 before we put the fuel in and make sure that we have a
25 high assurance that we won't fail fuel even in these

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1 non-safety -- you know, low-safety significance
2 events. I think it's a regulatory significant event.

3 I think it's an industry significant event but that's
4 my opinion.

5 MS. FLANAGAN: I wanted to add one thing.

6 Harold came up so he may have something to add to
7 this also. The SCIP II program one of the first goals
8 or the first phase of that program is to review a lot
9 of the Studsvik ramp experiments that have been done
10 to perform a literature review to see where those
11 tests are relevant and where they can be used. The
12 intention is to go back and revisit some of those
13 experiments that were done.

14 MR. FLANAGAN: Michelle, I would urge the
15 staff, the NRC since you are participants in the
16 program, to get that program to review these data.
17 The reports are available. They were done in the same
18 test reactors so there is no reason to discount them.

19 I think it is the biggest and largest database that
20 they've got. But also urge them to focus on time to
21 failure as measured by power spike or delta elongation
22 change or activity release because that's what you
23 need.

24 The other thing is I really don't know how
25 much is theoretical and how much is actual on an AOO

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1 like a loss of feedwater heater is what the duration
2 of the event is. The duration is until the operator
3 takes some action. That is the way I understand it.
4 That could be a few minutes and, in some cases, people
5 have had -- Hope Creek had an event where they didn't
6 even realize they had a loss of feedwater heater
7 event. Fortunately it was a very mild one. Not
8 everything turns out happy. Some things turn out bad.

9 I think if we have a big BWR that has an abnormal
10 operating occurrence and fails a lot of fuel and is
11 unexpected, well, shame on us. We never should have
12 let that happen. That's my opinion. I will wait to
13 see what the committee thinks.

14 MEMBER RAY: Let me just read into the
15 transcript the report number of the Power Burst. This
16 is the report that Michelle mentioned. It's
17 experimental results of the operational transient test
18 1-1 and 1-2 in Power Burst facility. It's 1985.
19 NUREG/CR-3948. CR-3948. The other program is trans-
20 ramp.

21 CHAIR ARMIJO: Yeah. There was trans-
22 ramp, over-ramp, intra-ramp, all of those. At that
23 time I was with GE but we participated in most of
24 those. They were good programs and they investigated
25 a lot of different variables which could be important

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1 to the staff in assessing different designs.

2 MR. CLIFFORD: Before I discuss
3 alternatives, just for my own education since we have
4 the experts here in the room, about five years ago the
5 staff started reviewing the ACR 700 which was the
6 advanced can-do design. This was a very important
7 issue early on because the can-dos, I don't know if
8 they all do, but the ACR 700 was planning on operating
9 about 18 kilowatts a foot. Apparently they have come
10 up with this can loop, I think is the terminology they
11 use. I think its graphite.

12 DR. DAVIES: Graphite.

13 MR. CLIFFORD: Graphite liner that they
14 feel can survive extended periods of time at upwards
15 of 18 kilowatts a foot.

16 CHAIR ARMIJO: As a matter of fact, Paul,
17 that fuel is manufactured by Canadian GE and John and
18 I were involved in that. It was one of our early
19 candidates as a solution to the PCI problem. That
20 went into the segmented rod program as one of the
21 candidate solutions. The Canadian fuel were the early
22 -- probably the earliest people that were impacted by
23 PCI.

24 They are unique in that they have
25 collapsible cladding and very high-density fuel. When

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1 they put this -- they don't know the mechanism by
2 which can loop works, either a lubricant, there is an
3 argument there, or maybe it's getting the iodine in
4 some way but it works. They demonstrated that and
5 they have used it for years.

6 The problem is their fuel is laying on its
7 side, the cladding is collapsed so the can loop is
8 trapped between the pellet and the cladding. In BWRs
9 we are vertical and we have a gap. We tested it and
10 it failed. It was good up to a point and at a certain
11 burn-up level it started to fail. We also tested like
12 this copper barrier. Up to a certain burn-up it was
13 great and it failed.

14 We tested a number of things. Annular
15 pellets. A whole bunch of things and that's all in
16 the literature. Including variations in cladding
17 thickness, cladding heat treatment always sticking
18 with conventional stuff. We didn't find any really
19 robust design that we would risk ramping hundreds of
20 bundles in a power reactor.

21 With the support of the NRC, by the way.
22 I mean, that was not just a casual experiment. The
23 only thing we found that would work was this
24 particular design. We have tested other designs that
25 GE tested and others have tested. Things that you'll

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1 be reviewing added to fuels, for example. If those
2 work, great.

3 I'm for PCI resistant fuel. I'm not a
4 salesman for one particular design but it has to be
5 PCI resistant because I think the industry has gotten
6 to the point where we shouldn't tolerate marginal
7 materials, particularly if we want excellence in
8 operation and certainly excellence in regulation.

9 The can-do stuff, your point, it does work
10 for them. Maybe it's because of their unique
11 collapsed cladding feature and they do go to high
12 powers. Our original 7x7 GE fuel went to 18 kilowatts
13 a foot which I don't think anybody really wants to do
14 that anymore.

15 MR. CLIFFORD: Another thing. It has
16 always been my understanding that it was the fission
17 products present in the initial stacks at the start of
18 the transient. Do you believe that there is a
19 contributing factor of the fission gas release during
20 the transient?

21 CHAIR ARMIJO: I do because, think about
22 it, there is 10 times as much cesium as there is
23 iodine and cesium iodide is a very stable compound.
24 We did testing and John probably did it, or Herman
25 Rosenbaum, one of our colleagues, to demonstrate that

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1 if you put cesium iodide inside of zirconium and
2 cladding and trying to crack it in laboratory tests.
3 You couldn't crack it. I think during the transient
4 you don't have equilibrium. Even though you have 10
5 times as much cesium, you probably have some free
6 iodine that is the aggressive species.

7 Another argument is it is whatever builds
8 up over the course of time. There is plenty there.
9 To a certain extent it doesn't really matter whether
10 it happens in the course of the transient and that is
11 what is the determining factor or whether it's over a
12 period of time what has accumulated on the cladding
13 ID.

14 It would be nice to know but I don't think
15 it's critical that we know that. I'm sure John has
16 his own opinion. Everybody who has done this kind of
17 testing has an opinion and we still have the dilemma
18 is it cadmium or iodide because if you do fractography
19 you can duplicate those same fracture surfaces in
20 laboratory experiments using cadmium as you do with
21 iodide so we don't have a full-proof fingerprint but
22 we tested every one of those fission products to try
23 and get stress corrosion cracking to happen in
24 laboratory tests. These were very carefully done
25 experiments including irradiated cladding. Those were

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1 the only things that would crack it.

2 MR. CLIFFORD: For this roundtable
3 discussion I thought it would be helpful, or at least
4 stimulate discussion, if I threw up three alternate
5 strategies for dealing with PCI stress corrosion
6 cracking from a regulatory perspective and give you
7 some pros and cons. These issues haven't been vetted
8 or haven't been --

9 MEMBER SIEBER: Some day it does.

10 CHAIR ARMIJO: Today it doesn't.

11 MR. CLIFFORD: There's three and I'll just
12 go through each one and then we can go back and talk
13 about if you guys would prefer to see one versus
14 another or what is the best approach or a combination
15 of any of the three or maybe there is a fourth. I
16 don't know.

17 The first one would be kind of view it as
18 a Chapter 15 Safety Analysis and maintain the current
19 rigorous analytical requirements that all of Chapter
20 15 has and ensure that there is no predicted fuel
21 failure. The pros that would be consistent with the
22 current approach, with the current Chapter 15
23 approach, it would show high confidence compliance to
24 GDC-10. I believe it was required that you really
25 quantify the resistance of any and all design features

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1 for PCI.

2 Cons would be I think if you approach it
3 this way, which really Chapter 15, which I've been
4 doing for a long time, it's really the worst of the
5 worst of the worst stacked on top of one another.
6 It's not just modeling assumptions. It's all the
7 assumptions of where the transient starts. You have
8 to ignore all administrative controls. It's just what
9 the tech specs allow.

10 You have to assume you are in some corner
11 of operating space allowed by tech spec even though
12 you physically couldn't be there or you physically
13 couldn't generate megawatts while you were there.
14 It's just the nature of Chapter 15. I think the
15 negatives of this very strict compliance approach
16 would be because of the large uncertainty that I
17 believe would exist once you try to develop an
18 analytical resolution and once you stack uncertainties
19 and try to come up with a 95/95 prediction, I think
20 you would always predict fuel failure.

21 I think you would predict it well below
22 when you would actually see it. If you look at the
23 scatter on the ramp data and you are looking at a 99.9
24 percent confidence, you know, the lowest failure and
25 then you add uncertainty for that to account for

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1 differences in design features, I think you would
2 always predict fuel failure.

3 CHAIR ARMIJO: What if you had a PCI
4 resistant design and you didn't predict fuel failures
5 and you had a conventional design and you predicted
6 hundreds of fuel failures? To me that's what we ought
7 to encourage, robust design.

8 MR. CLIFFORD: That is Alternative 3 and
9 we'll move onto that. Let me just go through each
10 one. There were some events like look at rod
11 withdrawal error. I mean, you have PCIOMRs that say,
12 "Do not move at this speed under these conditions."
13 Well, if it's Chapter 15, you've got to assume the
14 operator is not looking at those and he's going to
15 drive a rod in an inadvertent manner and it's going to
16 almost force failure.

17 CHAIR ARMIJO: You don't give him -- okay,
18 this goes above the fuel duty?

19 MR. CLIFFORD: No, even below the fuel
20 duty. They could drive a rod that is currently
21 operating at 8 kilowatts a foot up to 13 kilowatts a
22 foot.

23 CHAIR ARMIJO: But that is a localized
24 event.

25 MR. CLIFFORD: It is.

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1 CHAIR ARMIJO: It's not the whole core
2 event.

3 MR. CLIFFORD: But strict compliance would
4 say you can't fail so you have to so analytically you
5 would never fail in that situation. Any rod.

6 MEMBER SIEBER: Any rod.

7 CHAIR ARMIJO: Again, the issue there if
8 you wanted to comply with that you say demonstrate
9 that your fuel won't fail and they have an option.
10 That's what it was designed to do.

11 MR. CLIFFORD: Okay.

12 CHAIR ARMIJO: I'm kind of being bull-
13 headed to say, "I don't care what the risk is. I'm
14 going to use conventional cladding," I think is a very
15 foolish approach.

16 MR. CLIFFORD: Okay. This Alternative 1
17 think the cost would be high and I think just due to
18 development of high-confidence models and potentially
19 running more ramp tests to provide further
20 quantification of the PCR resistance of today's design
21 features. For instance, if they have .6 percent iron
22 inner liner that is going to affect the PCI resistance
23 and maybe there aren't many tests out there so maybe
24 they've got to go run a few tests. I think the
25 implementation is expensive and it would take a long

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1 time.

2 CHAIR ARMIJO: To that point, Paul, all of
3 these things have been tested. When they went to the
4 higher iron and when the Swedes added some tin to
5 their liner it was all -- it wasn't as large a
6 database as for the basic but they all tested the
7 variant in ramp test. The burden would be on them to
8 show you that they have sufficient test data to
9 justify their claim.

10 MR. CLIFFORD: Absolutely.

11 CHAIR ARMIJO: I don't think they would be
12 an added burden unless there was something wrong with
13 the way they did their test and you were critical or
14 skeptical.

15 MR. CLIFFORD: But if their tests were
16 designed to ensure that they wouldn't fail during
17 power maneuvering, that may be a different subset of
18 tests to show that you are not going to fail during an
19 AOO.

20 CHAIR ARMIJO: I agree with you there
21 because most people test within the fuel duty envelope
22 and ignore the very high powers. I think that
23 certainly is not adequate. If you have a lot of
24 failures in the fuel duty envelope in u-preconditioned
25 fuel, that doesn't give you -- that doesn't make you

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1 feel warm about the AOO event.

2 MR. CLIFFORD: Correct. That's my point.

3 That is something we need to throw on the table and
4 talk about. Alternate two would be kind of to show
5 using best estimate approach that you could either
6 develop operator response times or change plant
7 protection system setpoints or install new trips so
8 that you would limit the envelope to something below
9 two or three minutes, whatever you felt comfortable
10 with.

11 This would be more of a best estimate
12 approach, try to make some physical changes. Of
13 course, once again, if you had PCI resistant design
14 features that would buy you more time so it would mean
15 maybe less changes to the plant itself so you pay
16 either way. It's kind of a way of instituting PCI
17 resistant design features.

18 CHAIR ARMIJO: Are you thinking about
19 making these operator actions tech specs?

20 MR. CLIFFORD: The thing with operator
21 actions, in Chapter 15 if I look at the PWR side of
22 the house, which I'm more familiar with, generally you
23 have ANSI requirements on operator response. Most of
24 the time it's the 10 minutes.

25 There is one event off the top of my head,

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1 steam generator tube rupture where they have credited
2 operator response in significantly less time just
3 because they could demonstrate that the operators have
4 been trained in that scenario and it was a multitude
5 of instrumentation that would provide them with
6 adequate information to diagnose the tube rupture and
7 then respond.

8 We would have to weigh all of these
9 issues. As I mentioned, the actual fuel design this
10 three minutes would depend on the features of the fuel
11 design. If it's barrier maybe it's 8 minutes, 10
12 minutes, 12 minutes. If it's nonbarrier, maybe it's
13 three minutes. If it's doped fuel maybe it's seven
14 minutes.

15 CHAIR ARMIJO: With the PCI resistant
16 design it's hours, it's not minutes. You can't blur
17 the distinction between the conventional design
18 cladding and the liner cladding. It's an order of
19 magnitude difference in resistance. Those people
20 would have a very easy time demonstrating to you that
21 they had the margin because the data is there if you
22 accept the data.

23 The people that are trying to sell a
24 nonresistant design in these situations would have a
25 very difficult time, I think. I don't think it would

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1 put a burden on people -- there shouldn't be a burden
2 put on people, licensees that are using a design
3 solution that's been demonstrated as compared to
4 people that are using something demonstrated to be
5 very respectable.

6 MR. CLIFFORD: This approach also, just
7 like alternate one, relies upon an analytical
8 solution, although to maybe less of a stringent
9 requirement. Alternate three is really what I think
10 Sam is alluding to. It's kind of a requirement,
11 although I'm not sure legally how it would be enforced
12 but kind of a requirement of physical protection
13 versus analytical margin where you would demonstrate
14 that you have a certain measure of PCI resistance.

15 Maybe the PCI resistance is designed for
16 power maneuvering but it offers a certain extension
17 into AOO space. Or you could require that the
18 physical protection would protect you against all
19 potential AOOs.

20 CHAIR ARMIJO: Yeah. You know, I'm a big
21 fan of design solutions rather than operational
22 solutions. The utilities, in fact, most of the
23 utilities favor the design solutions but as we saw
24 with the Susquehanna situation, that was not their
25 solution. I had concerns that there were other

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1 reactors coming down for Extended Owner Uprates that
2 were going to follow the Susquehanna approach which I
3 believe is absolutely what the NRC should discourage.

4 I would wish the industry on its own would
5 avoid that sort of thing, particularly if they are
6 putting so much emphasis on zero fuel leaks during
7 normal operation how they could tolerate the risk of
8 fuel leaks during an abnormal operating transient and
9 trigger all the regulatory fallout that would come if
10 an event like that happened.

11 MR. CLIFFORD: Right.

12 CHAIR ARMIJO: The idea here is to prevent
13 failures. It may not represent the view of the full
14 committee but my view is that we have design solutions
15 that have been demonstrated by rigorous testing
16 including power reactor large scale ramp testing. If
17 you don't have anything better than that, then you are
18 going to have to show cause to demonstrate to the
19 staff that there is good reason to believe that the
20 fuel won't fail during these AOs by whatever criteria
21 you set up.

22 MEMBER SIEBER: Well, this is where we are
23 right now. Right? This third one.

24 MR. CLIFFORD: No, we are not even there
25 yet because right now the Standard Review Plan

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1 provides kind of a staff recommended methodology for
2 showing that you don't fail fuel with three SAFDLSSs.
3 Although they provide a level of protection, Sam's
4 concern is they don't specifically provide -- they
5 don't provide a sufficient level of protection for
6 PCI.

7 MEMBER SIEBER: That gets to a more
8 fundamental question that I have been planning to ask
9 for the last couple of hours. I have tried
10 unsuccessfully to do a search of regulations including
11 regulatory guides Branch Technical Positions as
12 standard review plan to find those referencing GDC-10.
13 GDC-10 is so broad that it covers instrumentation of
14 pressure boundaries and so forth, but to find out
15 exactly what we expect of the licensees today has
16 anybody done a search like that? If so --

17 MR. CLIFFORD: The Standard Review Plan, I
18 mean, I'll paraphrase here, clearly states that PCI
19 stress corrosion cracking is a known phenomenon and
20 that we have not developed specific criteria.
21 However, as a surrogate we are using two criteria to
22 provide some level of stress corrosion cracking and
23 that would be fuel center line melt and the cladding
24 strain requirement of roughly 1 percent depending on
25 cladding design.

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1 MEMBER SIEBER: That's where we are right
2 now but clearly it does not cover PCI failures.

3 CHAIR ARMIJO: But it could if you said,
4 well, we're going to look at that 1 percent string
5 number in view of data that says, hey, look, that 1
6 percent strain number is just too much strain for --

7 MR. CLIFFORD: The 1 percent serves its
8 purpose. It does protect against a different event.

9 CHAIR ARMIJO: Right.

10 MR. CLIFFORD: So we wouldn't alter that.
11 You would have to add something else.

12 CHAIR ARMIJO: Right. I agree. One
13 percent is for a different purpose but for PCI you
14 have to demonstrate this and pick a number, two-tenths
15 of a percent strain. I think people would have with
16 conventional cladding a very difficult time doing it
17 either two-tenths percent or demonstrate you have PCI
18 resistant fuel and people take their choice. What is
19 more convincing to the staff and what is the best way
20 to solve the problem. I think all of these things to
21 me could be made to work but I think what can't be
22 done is that we can't kind of wink at it. It's there.
23 The data are there. While it is a low safety
24 significance, I don't disagree with you all of the
25 reasons why the public is protected. The health and

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1 safety of the public is protected which is our primary
2 goal but there is also the integrity of the Nuclear
3 Regulatory Commission's self in that it doesn't let
4 something like this go by with a wink. I think the
5 Commission years ago jaw-boned the industry and I was
6 on the other side of the table at that time and very
7 wisely chose not to regulate before people had
8 solutions. When the solutions were implemented and
9 demonstrated, 1 percent stayed there, fuel melting
10 stayed there, and the pot was right. I think when
11 people started to say, "Well, we're not going to use
12 those demonstrated solutions. We are going to go back
13 to the things that gave the Commission concern years
14 ago," we shouldn't let that happen by whatever means,
15 regulatory or jaw-boning or threats or whatever you
16 want to do but I think it would be very foolish to
17 just ignore it.

18 MEMBER SIEBER: Well, without some kind of
19 rulemaking or major change to the Standard Review Plan
20 the only place that I see that you can deal with this
21 issue the way Sam would like you to deal with it is to
22 deal with the 1 percent because that is the only thing
23 that is existing that you can use, David, to change.
24 It would help me if somebody, perhaps our staff, could
25 give me a copy of the Standard Review Plan section. I

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1 can search on my computer but it's a cheap computer
2 and it's slow and I haven't got it yet.

3 CHAIR ARMIJO: Yes, Jack. I think Zena
4 has researched these issues and the general design
5 criteria and why we think fundamentally.

6 MEMBER SIEBER: I would just like to read
7 it.

8 CHAIR ARMIJO: Yeah.

9 MR. CLIFFORD: It is right there.

10 MEMBER SIEBER: I'm trying to be -- thank
11 you. I'm trying to be methodical.

12 MEMBER RAY: What she just provided Jack
13 does it answer the question do we acknowledge this
14 phenomenon presently in the regulatory process?

15 MR. CLIFFORD: Yes. It clearly states
16 that PCI stress corrosion cracking could occur and
17 that we have chosen to use two other surrogates
18 limited, not precluded.

19 MEMBER RAY: Again, those surrogates are?

20 MR. CLIFFORD: It's the plastic strain.
21 It's actually total, 1 percent total strain and fuel
22 melting.

23 MEMBER RAY: Well, it sounds like Jack's
24 point is correct that if we don't believe those
25 surrogates are sufficient, I guess I'm trying to

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1 figure out what is the argument for their adequacy?

2 No one has presented one I don't guess.

3 MR. CLIFFORD: I think if you go back in
4 time back to the '80s the staff recognized that there
5 needed to be maybe more specific requirements for
6 stress corrosion cracking so there was a lot of money
7 spent, a lot of time on trying to develop very
8 detailed analytical methods and develop acceptance
9 criteria. Then after a period of time hitting some
10 road blocks maybe it was more difficult to try to
11 develop an analytical solution than they originally
12 thought. The issue just kind of slowly withered away.

13 It was probably due to the introduction of barrier
14 fuel that --

15 CHAIR ARMIJO: The incentive disappeared.

16 MR. CLIFFORD: The incentive went away
17 because they weren't having failures.

18 CHAIR ARMIJO: The 1 percent and the fuel
19 melting some of that was Power Burst facility result
20 issues, events like that.

21 MR. CLIFFORD: Right.

22 CHAIR ARMIJO: It's still, you know, very
23 important for those kinds of events and it's valid.
24 We know that 1 percent strain is just too much strain
25 for stress corrosion cracking phenomenon and so that

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1 would be the area where it would be legitimate to set
2 a new requirement for stress corrosion cracking since
3 you know that these things happen with essentially no
4 strain.

5 MR. CLIFFORD: I think if we walk through
6 the process of what we would do, each plant has its
7 own licensing basis. It's not what the SRP says.
8 It's what the FSAR says so each has its own licensing
9 basis. What we are talking about here is trying to
10 revise the licensing basis of each reactor. You just
11 can't change staff policy and say here it is. There
12 is a process you've got to go through. If we wanted
13 to establish some new regulatory requirements, .2
14 percent or something much more analytical as far as
15 show me you can model this for all fuel designs, show
16 me you can predict it with high confidence and show me
17 it doesn't happen for any AOO, then this is really
18 just the staff would need to do. We would need to
19 develop an independent mechanistic tool capable of
20 predicting stress corrosion cracking to some measure.

21 Then we would need to define the new SAFDLs and we
22 would need to develop this regulatory guidance and
23 potential testing requirements if we felt there
24 weren't enough tests out there. Of course, we would
25 have to get the public involved and the industry

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1 involved in workshops. Eventually you would revise
2 NUREG-0800, the standard review plan, Section 4.2
3 which is what you have in front of you. It's not
4 rulemaking.

5 MEMBER SIEBER: To try to put that on
6 current reactors that would be a --

7 MR. CLIFFORD: That's the last bullet.
8 You have to say, okay, you have a change of staff
9 regulatory position on how to interpret a regulation,
10 although there is not a specific regulation on it.

11 I think Zena wants to say something.

12 MS. ABDULLAHI: Hi. This is Zena
13 Abdullahi. I have a question. From what I understand
14 from the processes of NRR or NRC GDC-10 said the SAFDL
15 should not be violated during steady state operations
16 and AOO. The fuel vendors came along and then they
17 say these are potential failure mechanisms and here
18 are how we are going to prevent them. Okay? PCI is
19 actually among one of those requirements. If you go
20 to Amendment 22 to GESTAR it would say PCI should be
21 prevented and all of the grade boundary changes, etc.,
22 will be followed.

23 MEMBER SIEBER: What is that reference
24 again?

25 MS. ABDULLAHI: I can provide you for

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1 sure. Now you have all these -- how the licensees or
2 field vendors can meet those requirements to
3 demonstrate that they can meet GDC-10. What we have
4 agreed with them is, okay, to meet this you have 1
5 percent strain. To meet this you would show the gap
6 is this. There is a way of NRC-approved processes in
7 which they would demonstrate they have met so.

8 They are supposed to do AOO to make sure
9 that they don't also fail on a PCI failure during an
10 AOO. They could have done that through the barrier
11 fuel or they could have done that if they have a
12 barrier fuel they were saying, "I'm fine as long as I
13 have 1 percent strain." For instance, from what I
14 understand one of the vendors they tell you, "I will
15 do that analysis based on control rod withdrawal
16 error, maybe loss of feedwater analysis, to show you
17 that I do meet the PCI issues."

18 The second question then becomes I think
19 what Sam was asking is 1 percent failure in this case
20 may not be enough for those that load the core with
21 non-PCI.

22 MR. CLIFFORD: I don't disagree with what
23 Sam is saying. I'm saying the way the staff has
24 accepted -- the staff has set standards for
25 themselves. The SRP is really an internal document

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1 but when the fuel vendors and each licensee when their
2 methodology was approved we accepted something so that
3 is part of their licensee basis and we would have to
4 change that.

5 CHAIR ARMIJO: If you know there's a
6 problem, you've got to do something. You just can't
7 let it sit. Paul, I think you are putting a horrible
8 burden on the NRC for you to do all of this work when
9 the burden should be on the guys, the licensees, that
10 are using marginal materials in their fuel. I think
11 you've got to find a different solution. I mean, this
12 is an enormous workload.

13 I don't think it needs to be a detailed
14 mechanistic model. It should be mechanistic enough
15 that you have confidence in it because you can set a
16 goal. You can set the bar so high you can never
17 finish on modeling. There is never a limit. It could
18 be an empirical model and people have to come with you
19 with data to demonstrate if they go up to this high
20 power typical of a loss of feedwater heater event that
21 they have tested enough fuel to demonstrate that it
22 won't fail within 10 minutes or some number. The
23 burden is on them. It is a recognized problem. The
24 data is there. The 1 percent strain number doesn't
25 protect you. At least that is my opinion and I think

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1 if you look in the literature you'll find more and
2 more evidence of that. The industry just can't let it
3 sit but I think this is a huge burden that will
4 basically encourage the NRC to do nothing and I don't
5 think that is what you want to do.

6 MEMBER SIEBER: Well, the question still
7 remains how do you do it? For example, in order to
8 change the 1 percent you have to do the study that
9 says 1 percent isn't good enough. Then you have to
10 say is it cost beneficial or does public health and
11 safety demand it. You've got those two paths.

12 MEMBER RAY: Wait a minute. Hold on.
13 Just a minute, Sam. You're making the licensing basis
14 argument and that is basically what Jack is speaking
15 to as well. But let's assume just for the sake of
16 argument that barrier fuel had been where we started
17 and now we are talking about removing that and,
18 thereby, creating the potential for this phenomenon to
19 occur. That puts the ball in the other court. Does
20 it not from a licensing basis standpoint? If you look
21 at the licensing basis does it say you don't need
22 barrier fuel?

23 MR. CLIFFORD: The licensing basis isn't
24 specific to anything.

25 MEMBER RAY: Correct. That's right.

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1 Therefore, if the point is -- I realize it's not as
2 crisp as this, but if the point had been we always had
3 barrier fuel and now somebody wants to remove that
4 feature from the fuel because it's cheaper to make,
5 that would be a change initiated by the licensee, not
6 something that the NRC would have to defend as a
7 change.

8 MEMBER SIEBER: It's not part of the
9 license basis. The fact that you use barrier fuel or
10 not is not part of the license basis.

11 MEMBER RAY: Jack --

12 MEMBER SIEBER: The only thing is the
13 license basis is the 1 percent strain.

14 MEMBER RAY: No, I don't agree because if
15 you make a change that introduces a new vulnerability,
16 you can't say I'm free to do that because I'm not
17 prevented from doing it.

18 MR. CLIFFORD: I think he's got a point.
19 To a degree you are right if someone comes in and asks
20 us to review a new product, then the door is open at
21 that point, much more than going back to a guy who is
22 using the same fuel he has used for 30 years and
23 saying, "Oh, by the way, I need you to do something
24 different."

25 CHAIR ARMIJO: Paul, I think it's kind of

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1 a strange situation here because if someone comes in
2 to you with a whole lot of test data and analytical
3 data on a new fuel that is, say, an additive that is
4 PCI resistant, and they are going to be here pretty
5 soon, if not already, you are going to run them
6 through a very tough ringer to demonstrate that their
7 performance will meet your requirements including PCI.

8 But here are guys that have been using something that
9 is not nearly as good and somehow they are
10 grandfathered. You've got to find a solution.

11 MR. CLIFFORD: It's kind of unfortunate.
12 What you could do is if you go down these steps and
13 you get down to revising your standard review plan and
14 you say this is how our policy, then someone coming
15 with a new fuel design you could then impose those but
16 if someone is using the old fuel, I think you are then
17 going to have to hit the back-fit analysis.

18 MEMBER SIEBER: The way the staff gets
19 notified that a licensee is going to use some
20 different kind of fuels with the reload safety
21 analysis and says the licensee redoes all the
22 calculations that it needs to do. If it meets the one
23 percent and no center line melting, that's all it's
24 got to say. You can't say I went from brand premium
25 to brand el cheapo.

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1 MR. CLIFFORD: Yeah, but --

2 MEMBER RAY: Jack, I've got to disagree.

3 MEMBER SIEBER: That's --

4 MEMBER RAY: Supposing this reload safety
5 analysis the design that it's based on creates some
6 new vulnerability?

7 MEMBER SIEBER: It's not new. All you
8 have to do is meet the requirement.

9 MEMBER RAY: No, not true. If you create
10 a new problem with a design change, you can't do that
11 under a reload safety analysis or 50.59. You can't --

12 MEMBER SIEBER: All you have to do is meet
13 the requirements.

14 CHAIR ARMIJO: Jack, I think that is so
15 restrictive that you've got to meet something even
16 more fundamental. I think the General Design
17 Requirements gives you the basis, the regulatory basis
18 that says when something isn't addressing the real
19 issue in our existing requirements we've got to do
20 something about it. We've got to do it in a practical
21 way not putting an extraordinary burden on the staff
22 to do a ton of work for a handful of people who insist
23 on using something that creates a vulnerability that
24 doesn't need to be there. I don't know the solution.

25 MEMBER SHACK: Can we do a quick flip

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1 through the slides to see the next two?

2 CHAIR ARMIJO: Oh, there's two more. I
3 thought this was the last one. I'm sorry.

4 MEMBER SIEBER: -- for RGC.

5 MR. CLIFFORD: The best solution was if
6 you came up with a new position on stress corrosion
7 cracking, which would be a change to the current
8 SRP and once you came up with that you would
9 communicate that effectively through the industry so
10 everyone knows what the new expectations are and then
11 it would be more of a forward fit than it would be a
12 back-fit.

13 MEMBER SIEBER: Yes.

14 MEMBER RAY: What is the existing position
15 on pellet clad interaction?

16 MR. CLIFFORD: The existing position is
17 that a combination of the current SAFDLs will not
18 preclude stress corrosion cracking but it will limit
19 it.

20 CHAIR ARMIJO: How many fuel rods and
21 under hat conditions and all that sort of stuff.
22 Every one of these I've looked at the FSARs for Hope
23 Creek and Browns Ferry and every one of these guys are
24 going to have transients that at least go up to 20
25 percent above rated power, somewhere in that range.

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1 You go into some of the individual licensee reports
2 and they are all predicting clad strains in the .6,
3 .7, .8 percent strain. Looking at that data plus the
4 data we have on PCI and the time data it says
5 something is wrong here and we just can't ignore it.
6 I think the staff has every right I think. I'm not a
7 lawyer but I don't think there is a legal issue. I
8 think this is a technical issue and the staff should
9 find a way that makes sense that is practical that
10 doesn't put enormous time burdens and resource burdens
11 on itself for a problem that is created by the
12 arbitrary use of a marginal design when other options
13 are available. If you get so restrictive we could
14 wind up like the Securities and Exchange Commission
15 investigating Bernie Madoff for eight years and never
16 doing anything to prevent him from fleecing his
17 customers. I mean, you know, you shouldn't be so
18 constrained by these criteria when you know they are
19 not adequate. To me it's sort of Alice in Wonderland.

20 I'm just wondering why the staff is so constrained
21 and maybe Bill and you guys have got to think this
22 through. There's got to be a way to handle this
23 problem without enormous burden on all the innocent
24 parties including yourselves.

25 MR. CLIFFORD: You know, the process of

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1 51.09 back-fit was put there for a reason. I agree
2 with you. From a technical perspective I understand
3 but, you know, the staff is often criticized for being
4 a moving target. If someone comes in for a license
5 application, it's going to get treated differently
6 than the one that came in the week before. 51.09 is
7 supposed to make regulatory consistencies so we are
8 not all over the map and different reviewers don't
9 analyze things differently. That's really the purpose
10 of the SRP.

11 CHAIR ARMIJO: Consistency and reliability
12 of the regulatory process is very important. When you
13 have technical information that says the phenomenon is
14 putting the fuel at risk is not adequately addressed
15 by the requirements you've got to do something.

16 MR. CLIFFORD: I agree. The problem I
17 have -- I really shouldn't say it's a problem. The
18 issue I have it's not like 50.46 where we have new
19 information and we feel we need to act. Now this
20 information is new. I've only been with the staff for
21 six years and this issue is 20 years old so I'm
22 wondering if someone on the staff saw that information
23 and made a cognizant decision that they didn't need to
24 change something.

25 CHAIR ARMIJO: That's a speculation. Let

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1 me just finish on that. That's a speculation, Paul.
2 You don't know if anybody on the staff looked at these
3 time-to-failure data. I didn't look at it and I was
4 involved in it because it wasn't important to me. The
5 staff, I think, did the right thing. They had a
6 design solution and all the BWRs used it not only in
7 the United States but in Europe and Asia. They all
8 were using it. The staff said, "Yeah, they is no
9 incentive to pursue this thing."

10 MEMBER RAY: That's my point. Aren't you
11 arguing -- regardless of what anybody else may argue,
12 aren't you arguing that there has been a change in the
13 solution no longer being universally applied?

14 CHAIR ARMIJO: Back-sliding they call it.

15 MEMBER RAY: Well, back-sliding is kind of
16 pejorative. The point is you are arguing that action
17 wasn't taken to put in the standard review plan, or
18 wherever, requirements to address this issue because
19 it became a non-issue with the development of the
20 barrier fuel.

21 I'm arguing with Jack that the removal of
22 that solution, not by the NRC but by some parts of the
23 industry, now creates an adequate basis upon which the
24 staff can take action. He's arguing that while there
25 is this time in the past when somebody made a judgment

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1 that you didn't need to do anything notwithstanding
2 the existence of a solution so now the removal of the
3 solution means I still can't do anything and that
4 seems to me to be flawed logic.

5 MR. CLIFFORD: I think the problem is I
6 don't know whether it was universally applied. GE
7 still has the capability of selling nonbarrier fuel so
8 I don't know that every GE reactor for the last 30
9 years has used barrier, the implementation of barrier
10 because GESTAR clearly allows them to use nonbarrier
11 fuel.

12 MS. ABDULLAHI: May I make a correction on
13 that? GE Subsection 1.12(b) of Amendment 22 requires
14 them to look at and demonstrate that for each fuel
15 design that they will not -- the PCI will not occur.
16 The 1 percent still applies. If you go to Subsection
17 1.1(d) of Amendment 22 it requires that if they have
18 -- if the staff has any new concerns on the fuel
19 design and the way you meet it that GE would have to
20 answer it and NRC would have to review and approve it.

21 I don't want to read it because I don't know what is
22 proprietary and what is not proprietary. In any case,
23 staff has another knob in their power for Amendment
24 22. In the past everybody was GE.

25 MEMBER SHACK: That's GE. There are other

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1 manufacturers.

2 MS. ABDULLAHI: Now you have new fuel
3 vendors that may not have the traditional knob
4 Westinghouse being one case.

5 MEMBER SIEBER: Change in policy is not
6 due to barrier or nonbarrier. It's the inclusion of
7 stress corrosion cracking during AOO versus the
8 inclusion of stress corrosion cracking during normal
9 operation.

10 CHAIR ARMIJO: Stress corrosion cracking
11 can occur during the AOOs. We haven't had it happen
12 yet but we are pressing the fuel. Duty is getting
13 tougher. We are putting more fuel at risk just
14 numerically, not necessarily higher powers. Let's
15 take the 20 percent power uprate in a BWR. You are
16 pushing a lot more water through that same core. Core
17 power density has increased. If you have a bypass of
18 feedwater heater, you are putting a lot more water in.

19 I don't know if the transient will actually be more
20 severe, quicker, or the time response time that people
21 are used to today is still good enough. All of those
22 issues are put to bed by the use of inherently
23 resistant design. To me despite all the regulations
24 that say you get a free pass, the NRC has to do
25 something and say it better than that. I don't think

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1 it should take years and an enormous burden on the NRC
2 staff to do something that puts the burden on the
3 licensee that wants to use marginal materials to
4 justify. I don't think there is going to be an army
5 of those guys but if there is, all the more reason to
6 be prepared.

7 CHAIR ARMIJO: There is someone here at
8 the -- I'm sorry I didn't see you.

9 MR. GALLIATO: Thank you. My name is
10 Thomas Galliato. I represent AREVA today. I'm here
11 also with our manager of Corporate Regulatory Affairs
12 Ronny Gardner. My current position is in the Richmond
13 facility for AREVA as manager of Materials and Thermal
14 Mechanics Group.

15 We appreciate the opportunity to make a
16 few comments today to support this important task.
17 First a couple of points of background. We are one of
18 the vendors -- AREVA is one of the vendors that for
19 years, in fact, has provided the options of both liner
20 and nonlinear clad. It's not that we, if you will,
21 backslide to go away from liner clad. We have always
22 offered our conventional product as it is called. We
23 certainly don't consider that product, that nonlinear
24 clad product as marginal in any way. We feel not only
25 does it meet all the regulatory requirements but it

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1 also meets our expectations of fuel performance for
2 the life of the fuel.

3 We have sold liner and nonliner clad in
4 the U.S. and worldwide to most all of our customers.
5 Interestingly enough since the year 2000 we've had
6 about an equal number of failures in liner and
7 nonliner clad in normal operational situations, not in
8 AOOs necessarily.

9 I'm also confident, although I don't have
10 the data with me today, that many of our customer
11 plants have gone through AOOs. In fact, we mentioned
12 one earlier today, the Susquehanna activity in 2007
13 with the loss of feedwater heater. That was conducted
14 successfully. That was our fuel. There was no fuel
15 failures involved and we came out of that clean, if
16 you will, with a clean core.

17 CHAIR ARMIJO: I would just like to make a
18 comment. Current fuel is failing. Equivalence of
19 number of fuel failures of AREVA fuel I'm not privy to
20 that but if the mechanisms are not PCI mechanisms,
21 there are other mechanisms going on, primarily debris.

22 That's kind of a -- that just clouds the issue. I
23 think the Hope Creek event could be analyzed. I don't
24 know how severe it was. I don't know if the
25 subcooling was 100 degrees or 50 degrees or 25

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1 degrees. Whether you got through it or didn't get
2 through it, who knows if there was a reason so you've
3 got to analyze that. I think you have the information
4 to demonstrate to the staff that this stuff is -- that
5 your fuel could pass a real licensing basis analysis
6 or an AOO. If you can't, then you have to do
7 something different. I don't believe that AREVA would
8 say that their PCI resistance of their liner and
9 nonliner fuel are equivalent. If that is, I would be
10 stunned.

11 MR. GALLIATO: We're not saying quite
12 that.

13 CHAIR ARMIJO: You're saying something
14 almost like that.

15 MR. GALLIATO: We are also saying the
16 delta between the liner and nonliner cladding, as you
17 might expect from ramp testing data that is out there,
18 published out there, or that we have run in our own
19 proprietary database, shows a certain delta that is
20 not necessarily transferrable to commercial fuel
21 operation in a real plant. In other words, there are
22 uncertainties. There are manufacturing variations.
23 There are operator variations plant-to-plant that
24 will, in essence, degrade some of the benefit that you
25 might see from ramp testing from liner clad. I gant

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1 you liner clad does come as a benefit in a PCI related
2 situation but I think the size of that benefit is not
3 necessarily recognized in real life situations as it
4 might appear from ramp testing.

5 CHAIR ARMIJO: I think you can argue about
6 the relative margin between two different designs but
7 I think it is very well demonstrated in power
8 reactors, and in the case of this program large-scale
9 demonstration pulling blades at power thousands of
10 nodes with liner fuel, you would never even think
11 about doing that with conventional cladding.

12 If you did, you would repeat the
13 unfortunate Oskacham event where many years ago there
14 was a belief by a European fuel vendor that PCI was a
15 U.S. problem so they went ahead and they pulled a
16 blade in a Swedish reactor. They failed 30 to 40
17 bundles in that one event. You can't be casual about
18 this problem. You've got to be serious.

19 You can't take a marketing view that says,
20 "We'll sell whatever the guy wants," and say it is
21 almost equivalent. That is too cute. There is a huge
22 difference in the PCI resistance of these materials.
23 The industry and AREVA should take that into account
24 in what they do and what they advise their customers.
25 I'm not persuaded by your arguments.

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1 MR. GALLIATO: With all due respect, Sam,
2 we certainly don't cavalierly treat our customers that
3 way. We treat them to the best product that we can
4 design and produce to provide them with fuel
5 performance under all their situation. In fact, there
6 are a number of -- as we have discussed in some cases
7 here earlier, there are a number of factors that
8 affect PCI. Of course, stress is one of the key ones.

9 Corrosive environment is another and time
10 is another that we have discussed before. As a result
11 of that there are many things that influence those
12 three factors and one of them being, as we said
13 earlier also, pellet-clad gap, the type of heat-treat
14 for your clad, the type of clad that you use, the end
15 configuration of pellets.

16 All of these things go into generation of
17 stress and stress levels that your cladding seized
18 during an operational event. In part because of that
19 we feel that under an AOO situation basically there
20 are a limited number of bundles that are susceptible
21 initially to PCI failure and those are the ones with
22 the highest stress when the event starts.

23 We believe from our stress analyses and
24 our modeling activities that we've done that those
25 high-stress bundles typically would be the ones that

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1 have most recently seen a sequence exchange event.
2 Based on that level of stress where they have not yet
3 been conditioned, they are at a higher level of stress
4 than most other clad in the core.

5 If you look at those and look at the
6 number of those involved, we believe that you are not
7 necessarily looking at a core-wide event under an AOO
8 situation. You are looking at a more limited event.
9 One of the slower transients I'll say in the minutes
10 to our type transients.

11 MR. GALLIATO: I think in addition to that
12 AREVA for years has pursued fabrication improvements,
13 mechanical design improvements, as well as analytical
14 method improvements. We have instituted many of those
15 over the years and we are continuing to do that.

16 Some of the ones that we are currently
17 working on are proprietary in nature and we can't
18 really discuss here. Nevertheless, the industry
19 overall, and AREVA is part of that industry, is
20 working to improve fuel performance on a regular
21 basis. It's not that we are trying to sell defective
22 or nonstandard or lower standard product to our
23 customers.

24 We want our customers to be successful.
25 In order to do that we have invested lots of time,

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1 resources, and effort into developing fuel in either
2 case, barrier liner clad or nonbarrier liner clad. We
3 believe that both products meet the needs of the
4 industry. In fact, both have performed fairly well.
5 Based on the number of rods that we expect to be
6 involved in an AOO type event, those being the higher
7 stress type rods at the beginning of that event.

8 The various designs features employed and
9 the benefit that we depend on for operator
10 intervention we believe that the PCI failures would
11 not necessarily be a significant impact on operations
12 of the plant.

13 CHAIR ARMIJO: Well, you know, I'm sure
14 everything you say is what you mean but I think the
15 issue here is can you demonstrate to a technical body
16 whether it's the NRC or your customers, that you have
17 data and adequate analytical models to demonstrate
18 that the margin to failure with your conventional
19 cladding during the loss of feedwater heater event is
20 adequate. Not just words but our data, good analyses
21 that have been reviewed by the staff and I don't think
22 you can. That is really the issue that we have as
23 regulators to determine whether the staff really is
24 persuaded by our concern or not. AcRS advises the
25 staff and the Commission. Right now this is a

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1 subcommittee. We don't speak for the full committee.

2 None of us do but once we do review this with a full
3 committee there will be a position. It is a technical
4 committee. My expectation is they will look for a
5 technical solution or a technical answer. It is just
6 not credible to me that AREVA takes the position that
7 they will sell liner or nonliner and their
8 equivalent --

9 MEMBER SHACK: Adequate.

10 CHAIR ARMIJO: -- adequate for duty. But
11 that's your commercial position and I'm not -- I don't
12 vote on that. That's your position. I'm not
13 persuaded that you demonstrated certainly to the staff
14 that with data and analysis that you can back that up.

15 MR. GALLIATO: We would welcome any
16 opportunity to provide that data to you as best we
17 have it.

18 CHAIR ARMIJO: Yes.

19 MR. GALLIATO: Thank you.

20 CHAIR ARMIJO: Thank you. There were some
21 people on the bridge line and I thought we overheard
22 some conversation. I didn't know if you wanted to
23 make a comment or ask a question. If you will, we
24 will take you off mute or whatever if anybody is still
25 there.

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1 MR. MITCHELL: Yes. This is David
2 Mitchell, Westinghouse. Can you hear me?

3 CHAIR ARMIJO: Yes, we can.

4 MR. MITCHELL: One of the things I'm
5 concern with this, I mean, the conversation that I've
6 heard has been very BWR-centric but if you end up
7 revising things, you are going to be basically
8 enclosing the solution off the PWRs possibly.

9 MEMBER SIEBER: True.

10 CHAIR ARMIJO: Well, I don't know if that
11 is an absolute requirement. I don't know if there
12 aren't situations where the PWRs might have an issue.

13 That is beyond the scope of today's meeting. If it
14 was determined by the staff that there was no PCI AOO
15 issue in PWRs, then there is no reason for them to be
16 subject to the same criteria if it's a BWR unique
17 problem. I don't think that necessarily follows that
18 the whole class gets punished for a problem for one or
19 two people.

20 MEMBER SHACK: It can happen.

21 CHAIR ARMIJO: I think you should try and
22 avoid it. I certainly wouldn't support laying
23 requirements on a PWR if they can demonstrate and have
24 demonstrated that they don't have the problem.

25 MR. CLIFFORD: I think that falls back

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1 into what is your level of demonstration.

2 CHAIR ARMIJO: It's really the staff has
3 the burden to determine based on what they know and
4 whether or not they are satisfied.

5 MR. CLIFFORD: Sam, I'm trying to read
6 your mind. It sounds to me that you are looking more
7 towards some measure of design margin, physical
8 protection for PCI resistance for BWR fuel not
9 necessarily revision to Chapter 15 with detailed 95/95
10 confidence predictions for each and every potential
11 scenario at the worst time in life, worst conditions.

12 That is my flavor. That is kind of like what I get
13 from your discussions that option 3 is --

14 CHAIR ARMIJO: I like the low-cost short-
15 schedule. That part I like but, you know, right now
16 we are in this Alternative 3. We have voluntary
17 implementation. Right?

18 MEMBER SIEBER: You have another --

19 MR. MONTGOMERY: I'm just going to let you
20 guys talk for a second but I did want to put a point
21 out.

22 CHAIR ARMIJO: Isn't that where we are
23 now, Alternative 3?

24 MR. CLIFFORD: Well --

25 CHAIR ARMIJO: Trying to jaw-bone people

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1 and say, "You ought not to be doing this."

2 MR. CLIFFORD: Well, your point is there
3 is nonbarrier fuel out there so I guess we are not
4 there.

5 MEMBER SHACK: No, that is Alternative 4
6 which is we are good enough as we are.

7 MR. CLIFFORD: Just one thing, Sam.
8 Something has changed with nonbarrier fuel between the
9 late '70s and now, I mean, simply because we are
10 having failures in normal operation in those days with
11 nonbarrier fuels. We seemed to have successful
12 operations so they have made enough design changes.
13 Now, I think what you're asking for is a demonstration
14 in some way that that improvement that we see in
15 normal operation, in fact, carries over to AOO which
16 we don't seem to have except by this anecdotal
17 evidence that some guys have gone through an AOO and
18 survived. What you would really like is a better
19 quantification, demonstration of that improvement
20 whether it needs to be a Chapter 15 or Alternative 2
21 where we kind of had a best estimate, more of a
22 realistic estimate picture I think is something we
23 could discuss further. What you are really after is
24 some demonstration and the level of demonstration
25 maybe we can negotiate but at the moment we seem to be

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1 operating on a faith-based assumption that we have
2 clearly made things better under normal operation
3 because we just don't have those failures.

4 CHAIR ARMIJO: How much of it carries
5 over?

6 MEMBER SHACK: We are now pushing with
7 the EPU's somewhere.

8 CHAIR ARMIJO: My point is the PCI
9 resistance, you know, the industry has done a
10 marvelous job in these operating restrictions. They
11 have come up with elegant solutions to keep the fuel
12 from fading from PCI. They have been doing it for
13 many, many years for the people who have chosen to use
14 conventional cladding and it works and it's very
15 reliable. The problem is those tools aren't available
16 in an AOO. You can't recondition up to 60 kilowatts a
17 foot. There is no way to do it so it's going to
18 happen and you are just relying on the intrinsic
19 properties of the cladding and the fuel design. The
20 improvements in fuel design, sure there have been.
21 Pellets are in pretty little shapes and stuff like
22 that, but that is amenable to analysis and
23 demonstration to the staff. Hey, look, because of
24 this, this, this, and this and this database we can
25 demonstrate there is a very low risk of failure with

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1 this particular design. If it happens to be
2 conventional cladding, fine. Just prove it rather
3 than assuming. You got the point.

4 MR. MONTGOMERY: My name is Robert
5 Montgomery. I'm with Anitec and I'm here today
6 listening in trying to understand the situation. I
7 think Dr. Shack has kind of summed my position up as
8 well and that is we are in this situation where we
9 have some design feature changes that have protected
10 us in terms of normal fuel reliability, fuel operation
11 during normal events moving into, I hate to use the
12 word, licensing base but into more like the Chapter 15
13 event I think it changes the ball game quite a bit. I
14 think as someone who would probably be tasked with
15 coming up and making presentations to demonstrate this
16 margin we are going to end up more in an Option 2 or
17 Alternative 2 or 3 basis. I don't see how we can even
18 be in Option 1 and 2 and not 3 because if I come up
19 here and say I calculate X amount of margin, then how
20 do we demonstrate that margin without very expensive
21 tests. We are getting into this whole process of my
22 code is better than your code and my calculations --
23 there is going to be a lot of work here is what I'm
24 saying and it's not going to be a very straightforward
25 process without either a lot of experimental data

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1 which was done in the '70s for one type of cladding
2 and one type of material but it has not been done for
3 other types of material. Or a very large amount of
4 analytical work, or both really, I think, to cover all
5 the basis.

6 CHAIR ARMIJO: There has been a lot of
7 testing on various materials. There is a huge
8 database already. Unless somebody has done something
9 radically different in conventional cladding, and
10 really there is only two things, stress relieving and
11 recrystallized and Zirc 2 is no different than Zirc 4.

12 All of this stuff has been done so it is a matter of
13 analyzing the margin based on data. The data exist.
14 You guys have a code. I'm not sure it's the best code
15 but it's the only code that's out there that I know of
16 that isn't proprietary and that's FALCON. You have a
17 tool but, unfortunately, the staff doesn't. I believe
18 the NRC staff should have a tool and shouldn't be
19 dependent on the industry's analyses. I don't want
20 this to turn into a massive effort, a burden on the
21 staff when the real issue is the licensee has to
22 demonstrate that he's got adequate margin.
23 Demonstration, as Bill said, is the key either from
24 existing data or existing analytical models or
25 combinations of those things. You can't let it go

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1 unexplored or unquestioned.

2 MR. CLIFFORD: It seems tome the only way
3 to get out of developing these very detailed codes
4 would be to have sufficient empirical data to show
5 that you don't need operator response within 10
6 minutes for your design. Then you could just use your
7 old system codes to show that your power is going to
8 be below what your testing ramps were.

9 MEMBER SIEBER: I think you need more than
10 that. You need a foundation. The 1 percent strain
11 has to come out of the standard review plan and be
12 replaced by something that has been studied that we
13 now consider adequate to protect against PCI failures.

14 Then the next question is how do you impose that on
15 licensees without a threat to the public health and
16 safety. I'm not sure that's clear. It becomes
17 voluntary at that point. That is a path forward as I
18 see it.

19 MEMBER SHACK: There is this forward
20 implementation which makes life simpler if you have no
21 expectations.

22 CHAIR ARMIJO: Reload license would be a
23 forward implementation.

24 MEMBER SHACK: I think more like a fuel
25 change.

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1 MEMBER SHACK: You could impose it on a
2 new plant.

3 MR. CLIFFORD: Calculating the stress and
4 then figuring out how accurate your stress versus your
5 chemical interaction is is very difficult. If you
6 could just limit it to time that would be the easiest
7 way of doing it. If you could show that your design
8 could survive these ramps for 10 minutes, then you
9 wouldn't need to calculate.

10 MEMBER SHACK: It just convinces us that
11 10 minutes is okay. Pick a time, any time.

12 CHAIR ARMIJO: Whatever the number is.
13 You pick the time but then the licensee has to show --

14 MEMBER SHACK: You need some reason to
15 pick the time.

16 MR. CLIFFORD: It's just like tube
17 rupture. You had to demonstrate. You had to take
18 different teams of operators and put them in the
19 simulator and show that they would respond within the
20 time.

21 MEMBER SHACK: Okay, but I need a model
22 then to show that my fuel can last for 10 minutes,
23 too.

24 MR. CLIFFORD: The idea is if you just
25 stuck with strictly empirical based.

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1 MEMBER SHACK: If I had enough empirical
2 data to do that. I don't know whether I do or I
3 don't.

4 CHAIR ARMIJO: First the burden is on --

5 MEMBER SIEBER: The licensee is back here.

6 CHAIR ARMIJO: The burden is on the fuel
7 manufacturer and the licensees to show that they have
8 the data. If they don't have the data, then they got
9 to get it. They should have the data and maybe they
10 already -- you know, they claim they have tested so if
11 they have tested and the staff believes it's a valid
12 test and they can demonstrate that they have taken it
13 up to these AOO powers and it doesn't fail for 20
14 minutes or 10 minutes and staff says 10 minutes is the
15 number, then it's done. There is a solution but there
16 is no solution by simply saying, "Well, 1 percent and
17 fuel melting is the requirement and they can
18 calculate --

19 MEMBER SHACK: I think they take a lot of
20 comfort over the improvement in normal operation. I
21 don't know how exactly you credit that but clearly,
22 you know, you have made enough changes. That is one
23 of the reasons I suspected it sits on the back burner
24 is that you are just not seeing this. I agree that
25 there is no demonstration that carries over to the

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1 AOO.

2 CHAIR ARMIJO: The improvement in normal
3 operation for a lot of mechanisms the debris problem
4 is being addressed. All corrosion problems --

5 MEMBER SHACK: You mean you're not seeing
6 the PCI type problems which you were before.

7 CHAIR ARMIJO: But PCI problems were put
8 to bed years ago with the preconditioning rules and
9 all of the guys who run that kind of fuel have become
10 very skilled at doing that and they do it very
11 carefully and it would really be an error before that
12 would happen. Fundamentally the fuel is the same
13 stuff. Marginally different, no doubt about it, but
14 you can demonstrate it.

15 If you demonstrate it and the staff says
16 the time response is shorter than the failure time and
17 fuel is protected, go with God. I'm happy. But at
18 this stage right now I don't think so. I don't think
19 it's going -- my big concern is it's going to happen
20 one of these days and we'll be sitting here saying,
21 "Gee, it happened. Now what?" Now that we've come
22 down with hobnail boots on the industry for an event
23 that we could foresee or do we try and prevent it? I
24 would urge we try and prevent it.

25 MR. MONTGOMERY: I just had one, again,

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1 before it's time to go for lunch. Just one more, Dr.
2 Armijo. I would like to make a statement. With
3 regards to the time, you know this. It's not as
4 straightforward as has been kind of projected here
5 today. You just can't just say 10 minutes is the time
6 we want because the PCI failure mechanism is a time-
7 stress relationship and a very complex relationship.
8 I could be at low stress for 20 minutes and have
9 failure or I could be at high stress for one minute
10 and have failure depending on the event you're talking
11 about. What if we are -- in terms of this defining a
12 time, it's not a straightforward process.

13 CHAIR ARMIJO: Well, if you look at the
14 last chart, Dr. Davis' chart -- could we bring that
15 up?

16 MR. CLIFFORD: I think so.

17 CHAIR ARMIJO: I think that is pretty --

18 MR. MONTGOMERY: Dr. Davies' chart is very
19 interesting, yes.

20 PARTICIPANT: What's the name of it?

21 CHAIR ARMIJO: See, what that chart is
22 telling you, and this mixes up B ramps and A ramps. I
23 just put all the data on because I didn't want to
24 analyze it but the data is available. It belongs to
25 the United States, if you will. Okay? You could

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1 analyze that data and you can see at lower powers,
2 lower peak powers, it takes longer.

3 Yeah, there's a lot of scatter but if you
4 start breaking it down into pure B ramps it's much
5 cleaner. In fact, in my first version I just used the
6 B ramps that John had but life is more complicated
7 than that. You have all sorts of things happening. I
8 think there is a time dependence and it's demonstrated
9 by these data that at lower power, peak power, it's
10 going to take longer.

11 As you get low enough it will never fail.

12 We have some data points that don't fail. Not every
13 rod will fail but enough of them will that there ought
14 to be concern, a lot of concern. If you demonstrate
15 that, hey, look, whatever the staff picks as a number,
16 the response time to arrest one of these transients
17 they are satisfied that 10 minutes is enough, all the
18 licensee would have to do is show that they have
19 tested enough fuel to convince the staff that at these
20 powers the time to failure is less than the criteria.

21 You're done. I didn't say it was easy but I think
22 you should have that data right now or else question
23 why you're ignoring this problem.

24 MR. CLIFFORD: Thank you.

25 CHAIR ARMIJO: Okay.

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1 MR. CLIFFORD: This plot right here is
2 standard cladding.

3 CHAIR ARMIJO: This is standard
4 recrystallized zircaloy 2 cladding, standard
5 manufacturing. There has been slight changes over the
6 years in manufacturing but when this work was done a
7 number of different claddings were studied,
8 recrystallized stress relief, Zirc 2, Zirc 4. There
9 was a lot of hoopla in the industry at the time that
10 there were very big differences. I think if the staff
11 would review all the Halden data -- not Halden but
12 Studsvik ramp test data and everything else they would
13 come to their own conclusion of whether there is
14 significant differences among the conventional
15 cladding materials. I don't think you'll find much.
16 There could be but you won't find much. There could
17 be slight differences due to pellet shape and things
18 like that. Fundamentally they are all susceptible to
19 PCI. That is why the industry requires PCIOMRs for
20 normal operating situations. If the cladding and
21 design has improved so much, why don't you just
22 relieve yourself of the burden of PCIOMRs. Is it PCI
23 resistant? The answer is it's not so you still keep
24 the PCIOMR but somehow when you get into the AOO space
25 you think somehow we don't need anything and I think

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1 you do. Again, the whole purpose of this meeting is
2 to exchange information, exchange ideas. Paul, I
3 would like to see your backup slide, get copies of
4 your backup slides of these alternatives. I know they
5 are not vetted but I've got to make a report to the
6 full committee on what we discuss and things like
7 that.

8 MR. CLIFFORD: I'll e-mail them.

9 CHAIR ARMIJO: Certainly nothing will
10 happen unless a full committee wants a presentation or
11 a discussion in a future full committee. At that
12 point then we do something. Write a letter or
13 something like that. In the meantime I just want
14 those alternatives just as part of a report. I
15 understand it's not vetted. It's not staff position.

16 MEMBER SHACK: Just a practical question.

17 Suppose you had the FALCON code in Sam's data and you
18 just decided it fit the data reasonably well. Do you
19 really need your own independent code?

20 MR. CLIFFORD: It's always been staff
21 practice to have an independent code. You're saying
22 FALCON would be independent code?

23 MEMBER SHACK: For an application you
24 check FALCON. Everybody is going to end up checking
25 against the data whether you're checking FALCON

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1 against the data or FRAPCON against the data. If the
2 model doesn't fit the data it isn't going to work. If
3 they both fit the data, yes, I agree. You address
4 model uncertainty by having two different models that
5 fit the data and, therefore, you see just how much
6 variation I can have. If I wasn't in Chapter 15 space
7 and I was off in some other space --

8 CHAIR ARMIJO: Or the industry, somebody,
9 whoever owns FALCON code, submits to the staff for
10 review and approval as a topical report. You go
11 through it and scrub it and --

12 MR. CLIFFORD: I think as part of that
13 review we would want to develop an independent tool.

14 MEMBER SHACK: You can't get around the
15 model uncertainty problem except by doing that, I
16 agree. You accept other models and other situations
17 without having an independent model. Not in every
18 case do you have an independent model.

19 MR. CLIFFORD: That's probably true but
20 I'm a fields guy.

21 CHAIR ARMIJO: We have somebody at the
22 microphone. We'll have just probably one last comment
23 because we are going to try to close up right on time.

24 MR. TOMLINSON: Thank you. My name is Tom
25 Tomlinson. I'm with RETAQS.

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1 CHAIR ARMIJO: Sorry?

2 MR. TOMLINSON: My name is Tom Tomlinson
3 with RETAQS.

4 CHAIR ARMIJO: RETAQS. Sorry. I don't
5 know who RETAQS is.

6 MR. TOMLINSON: We are a very small
7 consulting firm.

8 CHAIR ARMIJO: Okay.

9 MR. TOMLINSON: In the '80s I was a
10 reactor manager and a senior reactor operator at a BWR
11 and I operated nonbarrier fuel for quite a while and I
12 saw all those PCI failures. I then implemented
13 barrier fuel and did wonderful things with barrier
14 fuel and saw how robust it was. I just wanted to
15 caution the Committee that as of late things have
16 started to happen with barrier fuel that we didn't
17 expect in the past. We are now seeing duty related
18 type failures in barrier fuel. General Electric has
19 gone back and imposed or recommended imposing PCIOMR
20 recommendations or modified version on barrier fuel.
21 Although barrier fuel clearly has improved fuel
22 performance from a duty related perspective, I don't
23 think it solved all the problems. Today you seem to
24 have precluded barrier fuel from your concerns and I
25 would caution you they still belong in there in some

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1 regard.

2 CHAIR ARMIJO: Let me answer that question
3 because that is an important question on a point you
4 raised. We have had failures, PCI failures in barrier
5 fuel. We've had also PCI failures recently in the
6 last few years on PWR fuel. Every one of these cases
7 has been resolved to be caused by the missing pellet
8 surface phenomenon. The barrier fuel was never
9 designed to resist a generalized strain or generalized
10 stress. It only worked with a very localized stress.

11 Pellet quality is key to fuel performance whether
12 it's barrier or nonbarrier. Barrier is not capable of
13 protecting you against pellets with missing pellet
14 surface. We demonstrated it at Hope Creek. We
15 demonstrated it with hot cell examinations at KKL,
16 recent Westinghouse fuel failures, AREVA fuel
17 failures. Everyone of them had a chip and a crack.
18 Barrier's resistance to PCI with really high quality
19 fuel, good pellets, is proven. In retrospect I look
20 back at some of the early failures, why we had
21 failures in some of our ramp tests of our barrier
22 fuel, and I'm just speculating but it's not unlikely
23 that we had some chipped pellet somewhere in there.
24 Fundamentally we have proven with years of operation
25 that this fuel is very resistant, very robust. As

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1 long as we keep the quality of the pellets up, it's
2 got its inherent resistance. If the pellets are
3 chipped, all bets are off and it's up to the industry
4 to make sure. I think the industry is focusing. All
5 the manufacturers are working on means to preclude
6 chipped pellets. Like I say, we had some recent
7 failures in PWR fuel totally unexpected. They were
8 PCI. When they did their hot cell work they found it
9 was right in the chip. I think there are such things
10 as resistant designs and nonresistant designs but one
11 fix doesn't cure every problem. The focus here is on
12 conventional cladding and this problem. I appreciate
13 the staff's ideas. I think we're going to talk about
14 this some more. I like short and simple. I like
15 demonstration. We'll see what the committee thinks.
16 I would appreciate copies of your charts.

17 MR. CLIFFORD: I will e-mail them.

18 PARTICIPANT: Mr. Chairman, over here.

19 CHAIR ARMIJO: Oh.

20 MEMBER RAY: While Dr. Davies is here,
21 could you go back one slide?

22 DR. DAVIES: This one?

23 MEMBER RAY: Yes. Is the aggressive
24 chemical moving up that crack over time? Is that part
25 of the failure mechanism?

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1 DR. DAVIES: Clearly.

2 MEMBER RAY: Okay. So any of these codes
3 that just calculate stress and strain are going to be
4 lucky to calculate --

5 CHAIR ARMIJO: I don't think you need
6 that, Harold. All you need -- if you initiate a crack
7 you don't need to go much further than that. All you
8 have to do is -- the code doesn't have to be so
9 detailed like it's going to be cracking at so many
10 microns per minute. We don't need that sort of stuff.

11 MEMBER RAY: I thought his answer was that
12 it requires aggressive chemical to keep the crack
13 growing.

14 DR. DAVIES: Indeed.

15 MEMBER SHACK: But Sam is saying once it's
16 initiated you can't take it from growth. He's willing
17 to settle for an initial model.

18 CHAIR ARMIJO: Right. If you want to say
19 your first indication of failure is a combination of
20 initiation and growth, I don't care, you know. You
21 can make the model requirement so complex and so
22 demanding that you will never finish. It makes it an
23 impossible job. You've got to make it more practical.
24 I think there are many options of doing it.

25 MEMBER RAY: Let me just read here now

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1 because we've mentioned codes. Michelle talked about
2 this as part of the Studsvik program. They had a
3 modeling exercise and here are the codes that were in
4 that modeling exercise: STAV7, FALCON, FEMAXI6,
5 METEOR, RODX, and FRAPCON. FRAPCON was run by
6 somebody else besides. There are four, five, six
7 codes that might claim could be able to do some of
8 this. This particular transient I'm looking at was a
9 five or six-hour transient but they also had some
10 shorter ones that they did modeling of. Not to
11 belabor it but strains and stresses were widely
12 divergent.

13 CHAIR ARMIJO: Calculated or actual
14 measures?

15 MEMBER RAY: Calculated. These are all
16 calculated.

17 CHAIR ARMIJO: Measured is what counts.
18 All of these ramp tests usually the Studsvik programs
19 are very carefully done and I'm sure they measured
20 strains and things like that. I think it was just a
21 wealth of data but somebody has got to work on it to
22 extract what's important for this particular issue.

23 With that I think -- well, I don't know.
24 I think I am obliged to go to 12:30 but I don't have
25 to if there are no more questions.

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1 MEMBER RAY: We have a meeting at 1:00,
2 don't we?

3 CHAIR ARMIJO: Okay. Any questions,
4 comments? Going. First, thanks to the staff. Thanks
5 to Dr. Davies for braving the winter weather to come
6 out here and share what he knows. This meeting is
7 adjourned.

8 (Whereupon, at 12:20 p.m. the meeting is
9 adjourned.)

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■ Meeting Objectives:

- Assess the risk of PCI/SCC fuel failures during BWR Anticipated Operational Occurrences at EPU.
- Discuss options to quantify / limit the risk of fuel failures.
 - Analytical
 - Fuel design
 - Operational

■ ACRS Letter, Dec. 20, 2007 Susquehanna Extended Power Uprate

- "The staff should develop the capability and perform a thorough review and assessment of the risk of Pellet-Cladding Interaction (PCI) fuel failures with conventional fuel cladding during anticipated operational occurrences."

■ Added Comments:

- Concerned about the increased risk of PCI failure of conventional BWR fuel cladding during AOOs for plants operating at EPU.
- PAPT/LHGR limit of $< 1\%$ cladding strain will not protect fuel from PCI/SCC. Much lower strains known to cause failure.
- Staff inability to address the risk of PCI failures – lack of analytical capability.

■ PCI Background

- Features / Mechanism
- Controlling parameters
 - Peak power - Kw/ft
 - Power increase - Δ Kw/ft
 - Rate of power increase - Δ Kw/ft/hr
 - Burnup
- Mitigating actions – normal operation
 - Operating constraints (PCIOMRs),
 - Reduced LHGRs (8x8 to 9x9 to 10x10)
 - PCI resistant designs
- Mitigating actions – AOOs
 - PCI resistant designs
 - Operator actions

- PCI

- Features

- Mechanism

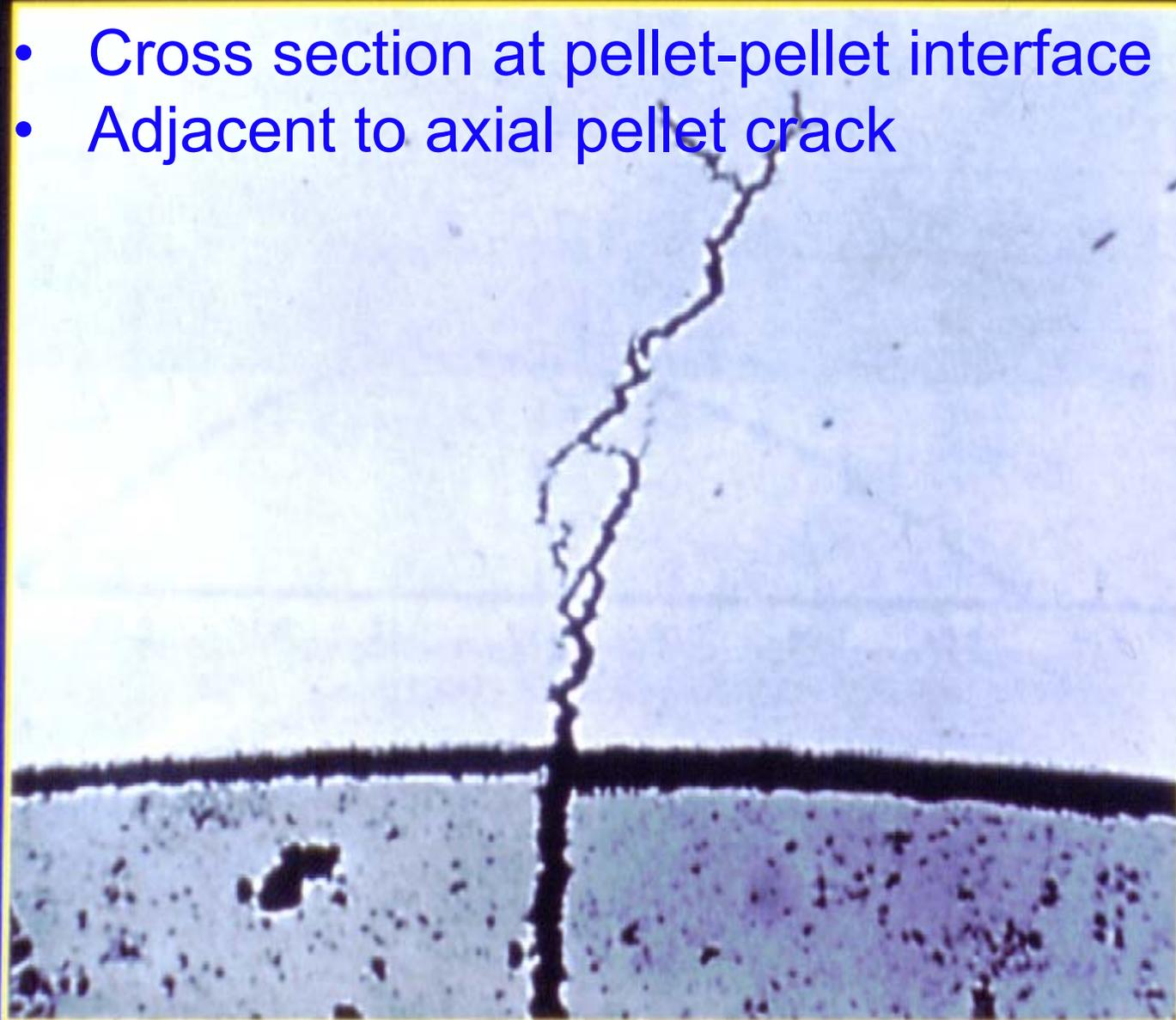
PELLET CLAD INTERACTION CRACK



- BWR fuel rod
- Typical axial crack
- $\ll 1\%$ plastic strain

Branching in Incipient PCI Crack

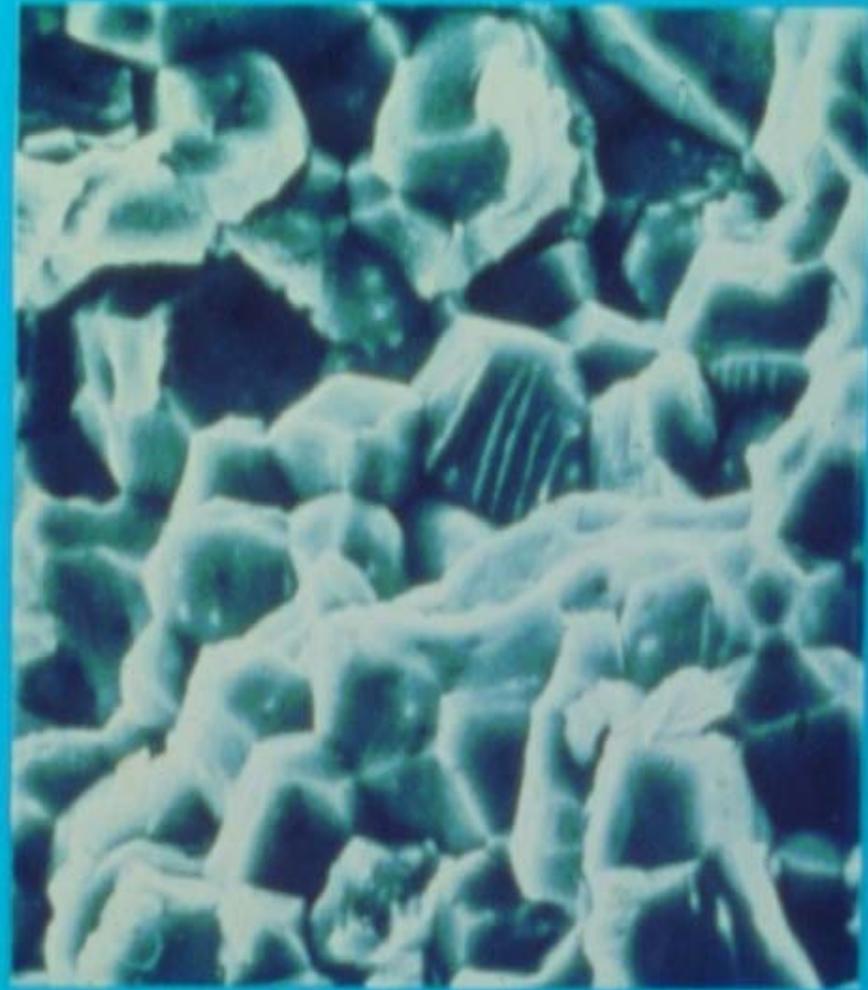
- Cross section at pellet-pellet interface
- Adjacent to axial pellet crack



DETAILS OF FRACTURE SURFACE OF INCIPIENT PCI CRACK IN FAILED ROD

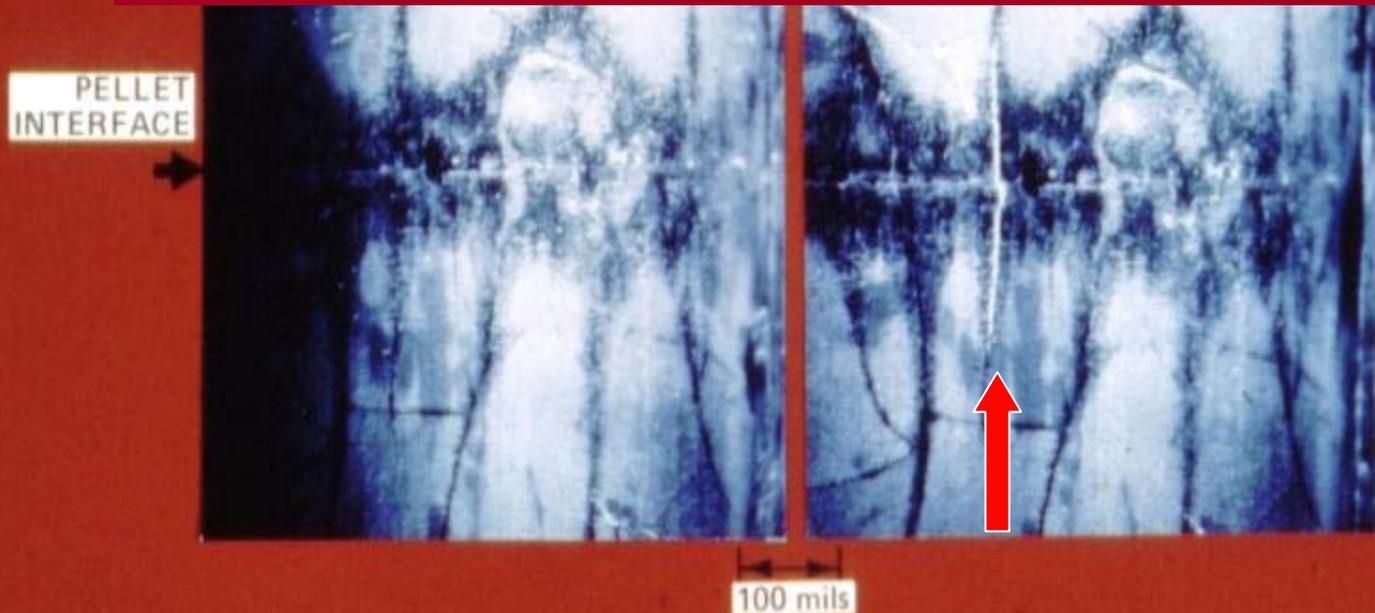


X1000



X3000

- Inner cladding surface of undefected fuel rod
- Incipient PCI crack revealed by flattening
- Crack nucleates at:
 - fission product deposits
 - P/P interface

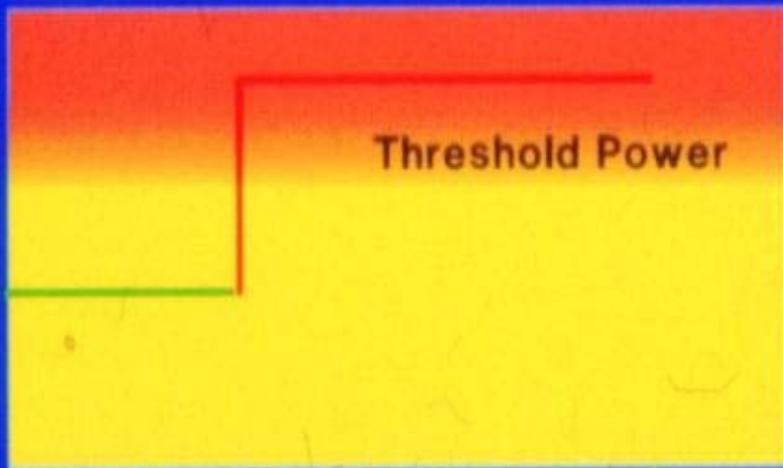


ANALYSIS OF CLADDING DEPOSITS

Element	Concentration Observed	($\mu\text{gm/gmU}$) Predicted	Enhancement Factor
CESIUM	119,000	1,940	61
TELLURIUM	42,600	318	134
BARIUM	20,000	995	20
IODINE	11,600	201	58
CADMIUM	2,700	41.2	66
CERIUM	2,410	2,150	1.1
PALLADIUM	1,030	669	1.5
TIN	629	34.3	18
SILVER	567	45.9	12
STRONTIUM	577	671	0.9

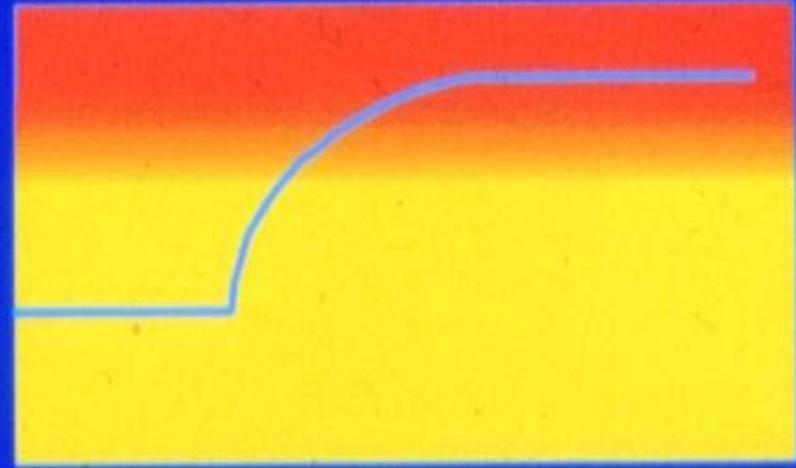
POWER RAMP EFFECTS

Power



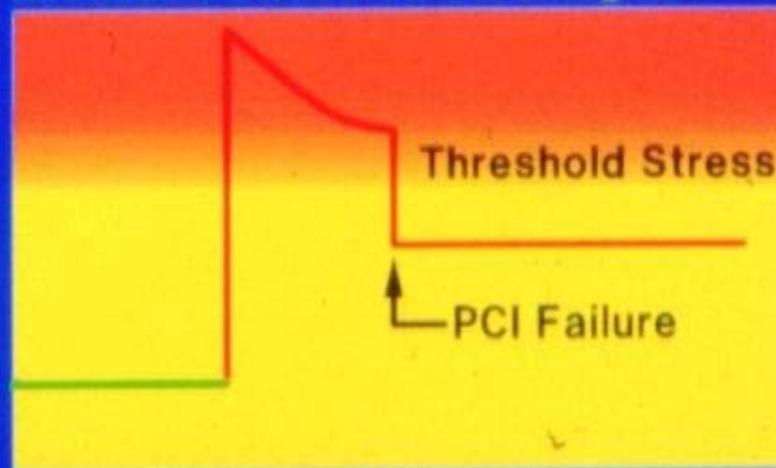
Time

Iodine, Cadmium Release



Time

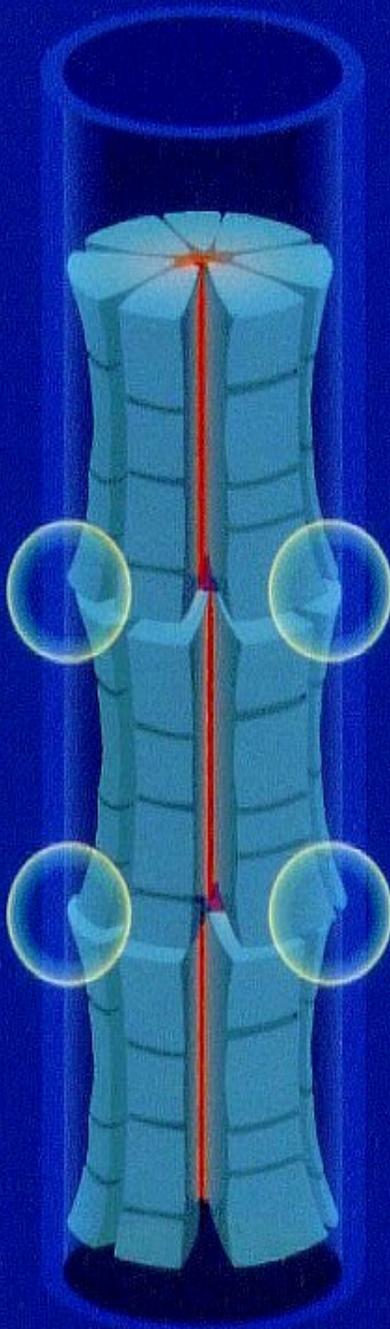
Localized Stress on Cladding ID



Time

PCI FAILURE MECHANISM

Maximum
- Biaxial Stresses
- Iodine, Cadmium



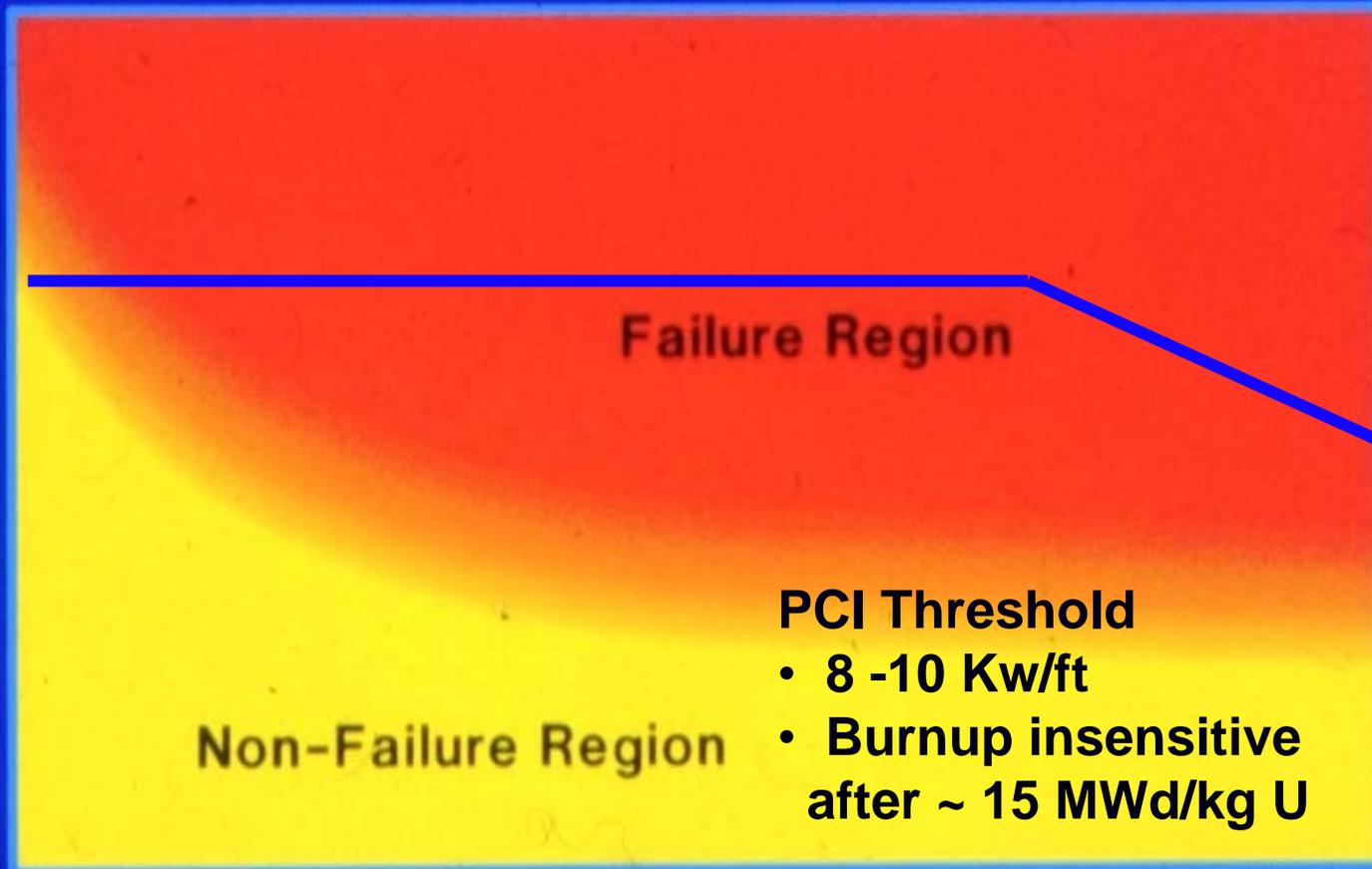
Axial Locking of Fuel Column
- Thermal Expansion
- Stochastic Stacking

Controlling Operational Parameters

- PCI threshold power
- Allowable power ramp rates
- Preconditioning

PCI-MAP

Power



Burn up

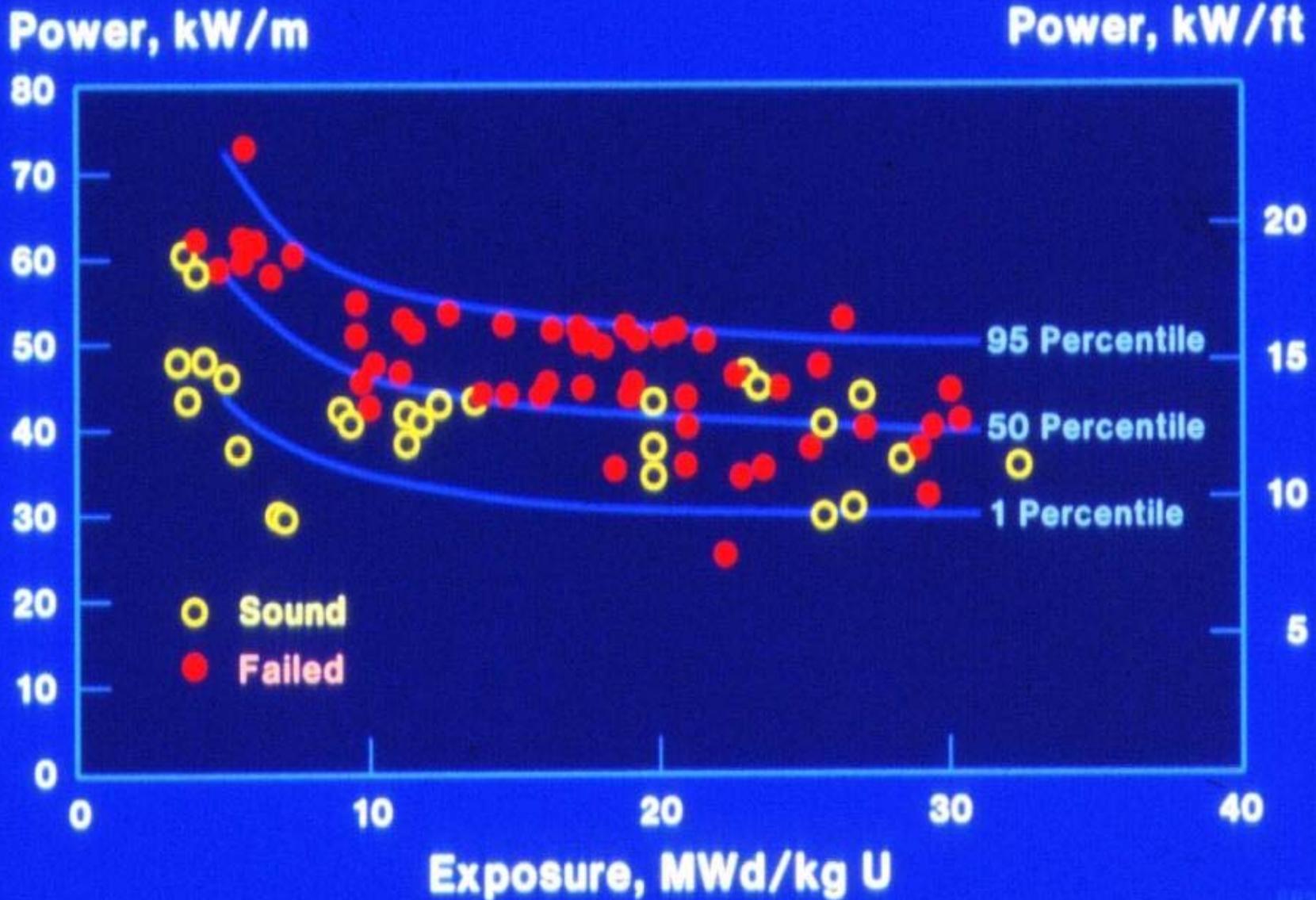
FAILURE PROBABILITIES

Power



Burn up

BWR STANDARD FUEL



PCI Mitigation Options

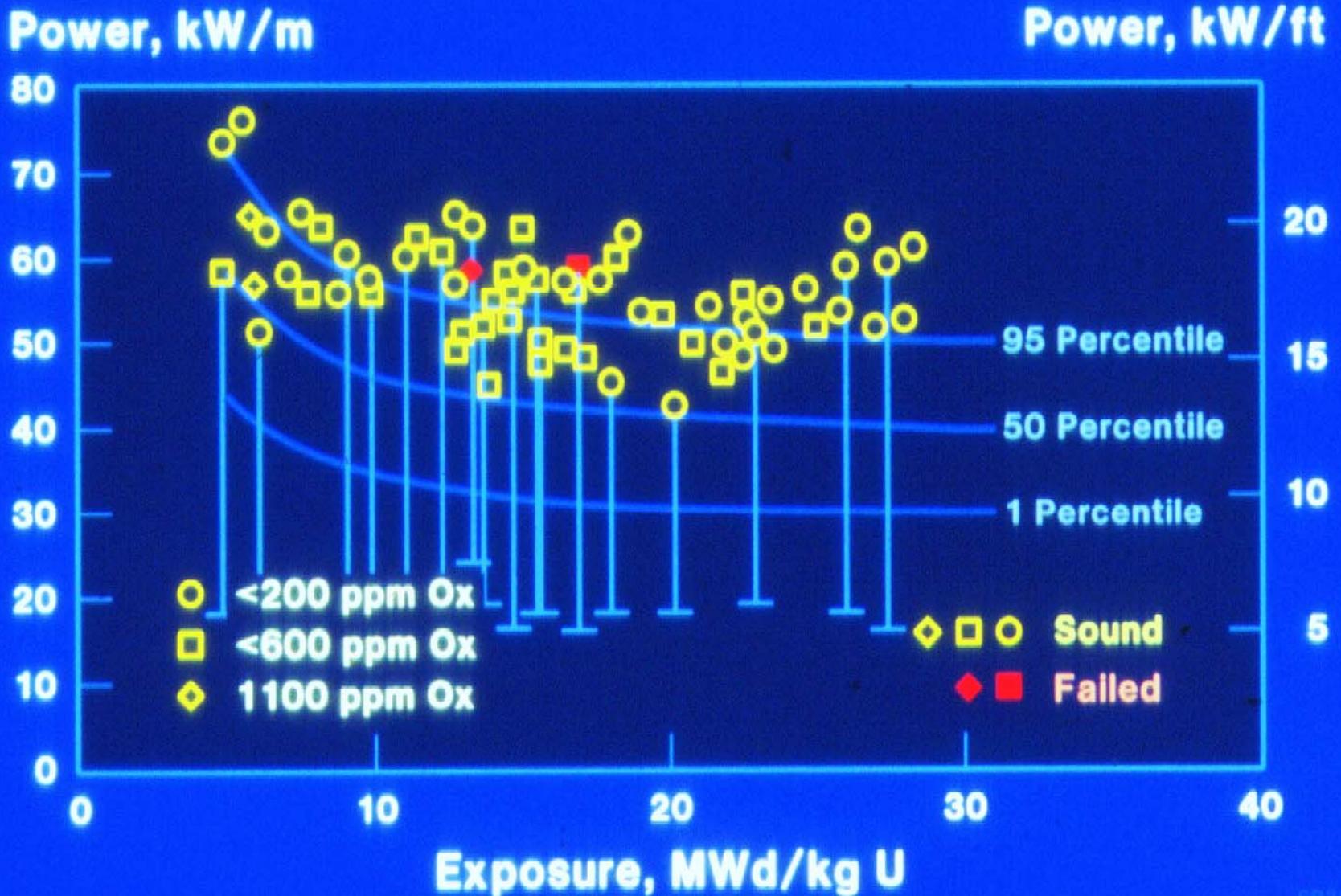
■ Normal Operation

- Lower LHGRs (8x8 to 9x9 to 10x10)
- Preconditioning
- PCI resistant fuel

■ AOOs

- PCI resistant fuel
- Prompt operator action

Zirconium Barrier Fuel

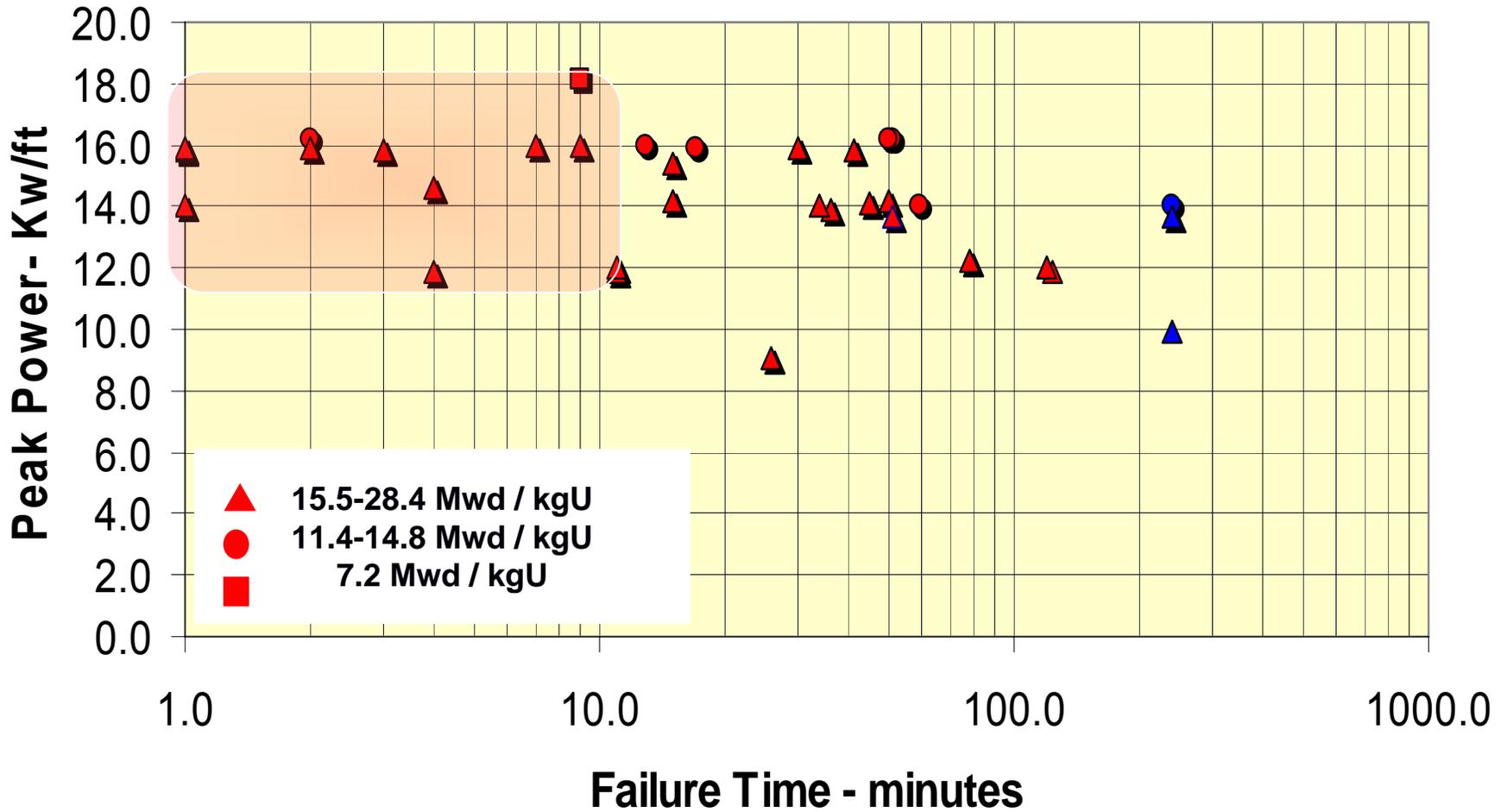


Reasons for Concern

- Growing use of non-PCI-resistant fuel.
- PCI failure times are very short at AOO power levels.
- Early 10X10 mitigation benefit gradually lost.
- Number of fuel elements at risk during AOOs increases in proportion to magnitude of EPU.
- Inadequate analytical capability to quantify risk of failure.

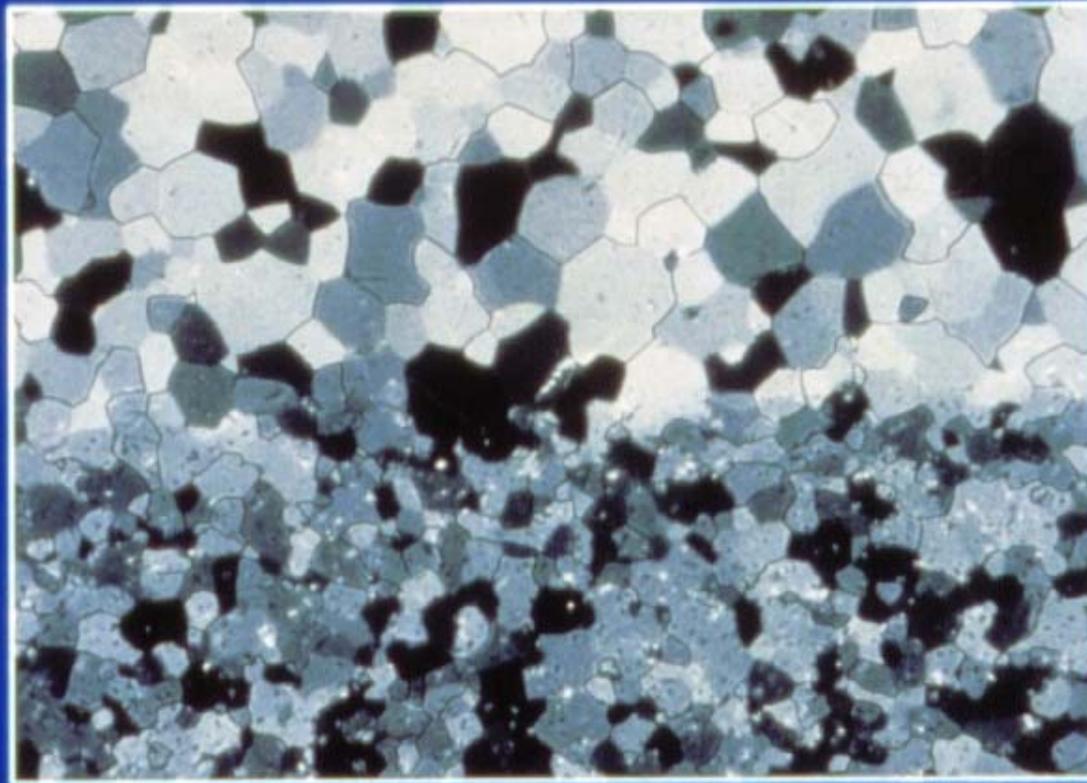
Backups

Ramp Tests -- Standard Cladding



ZIRCONIUM-ZIRCALOY INTERFACE

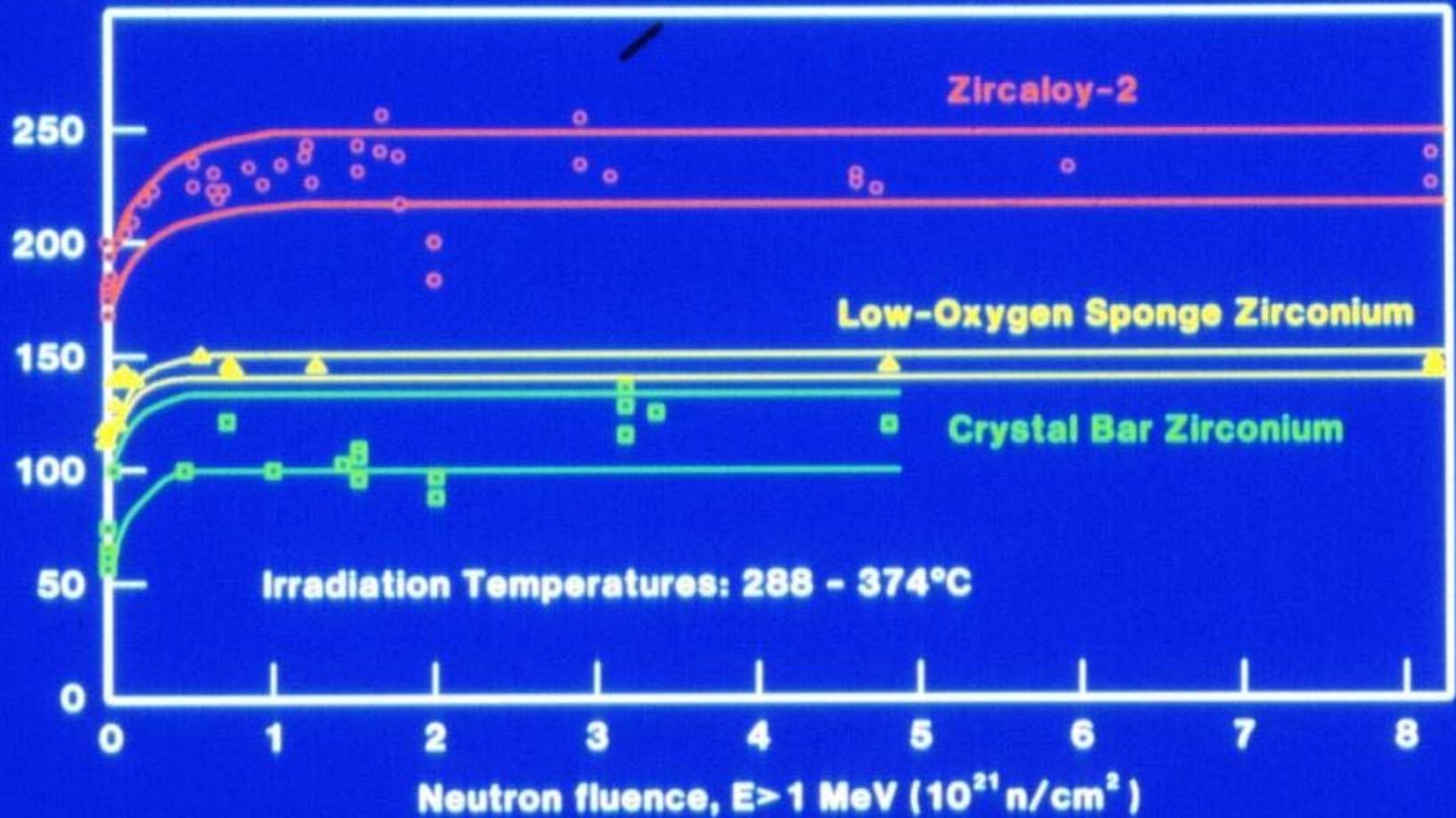
Zr-liner Fuel Cladding



10 μ m

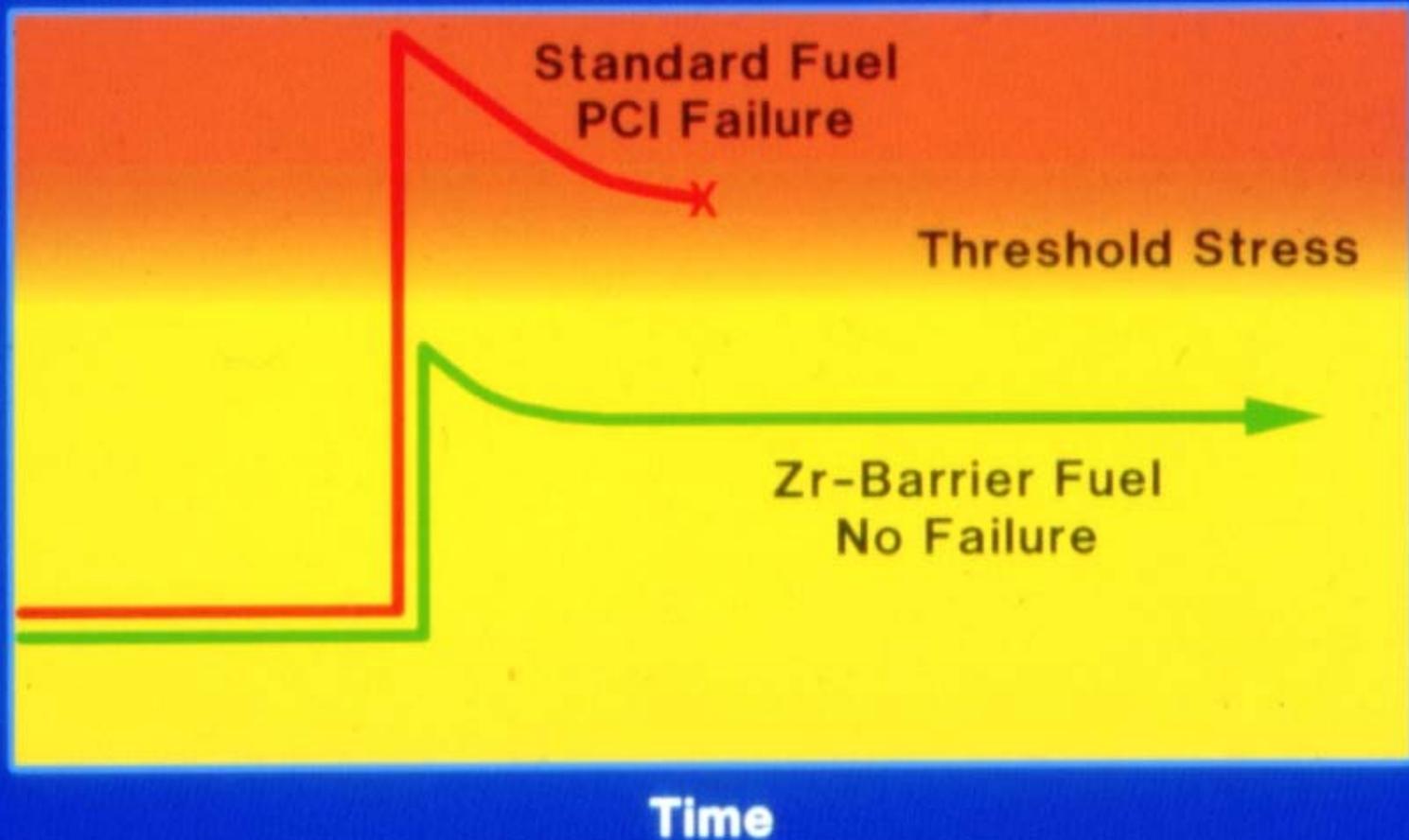
SP465.02

Knoop Hardness

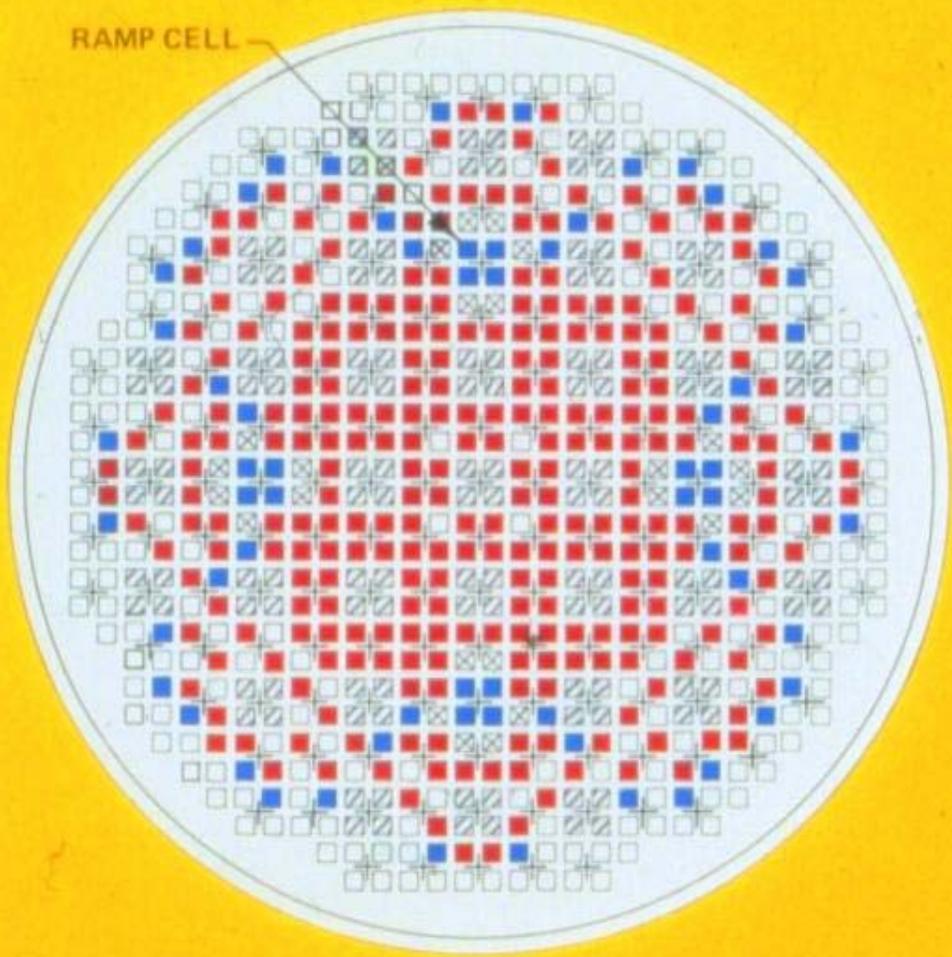


Zr-BARRIER - PCI RESISTANCE MECHANISM

Localized Stress
On Cladding ID



Quad Cities Unit 2
CORE
CONFIGURATION
Cycle 7
(348 barrier bundles)

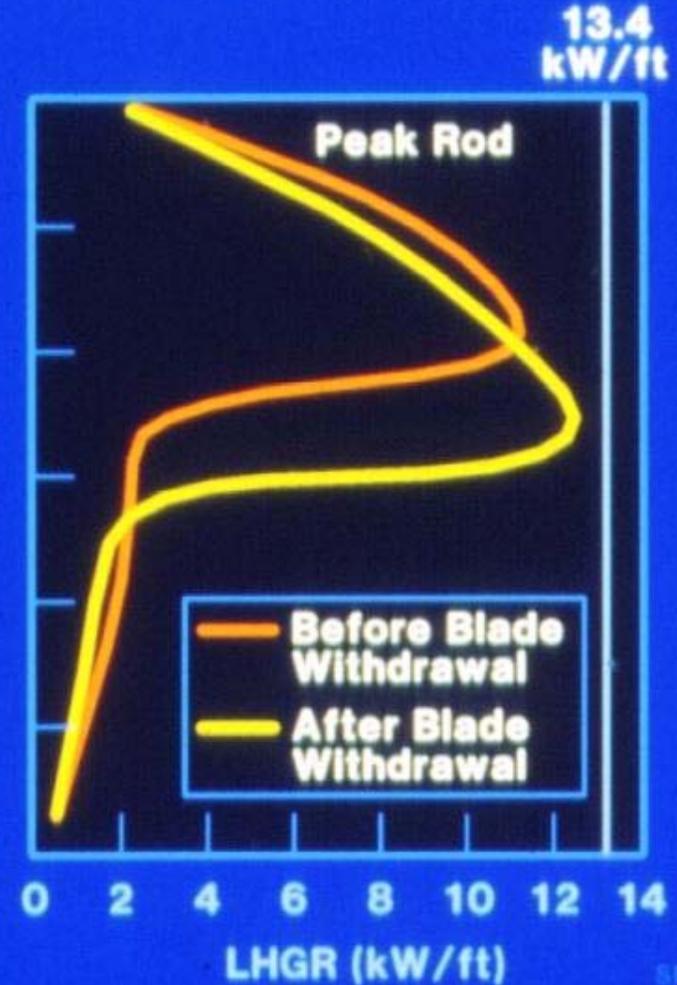
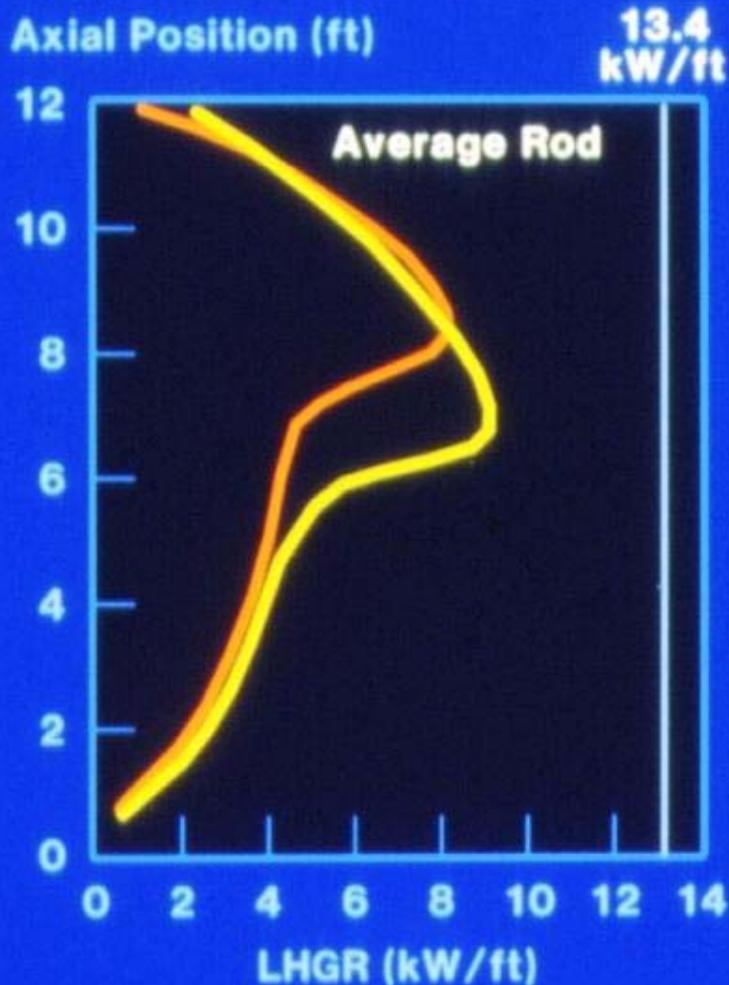


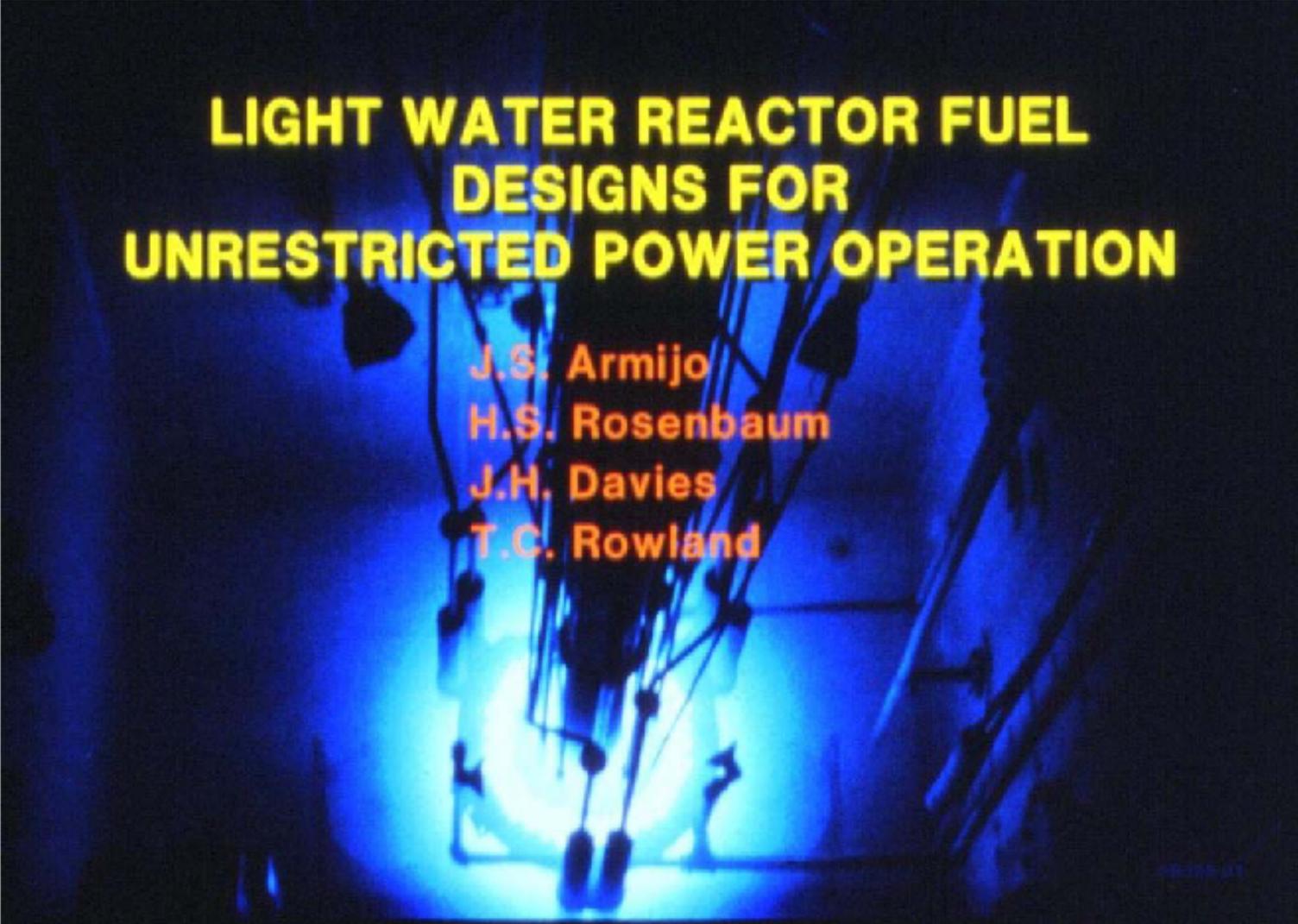
BWR/3 724 BUNDLES

- SPECIAL BARRIER
- STANDARD BARRIER
- ⊗ BUFFER ZONE (NONBARRIER)
- ▨ CONTROL CELLS (NONBARRIER)

31568-01

AXIAL POWER DISTRIBUTIONS FOR BLADE PULL OF SIX NOTCHES (1.5 FEET)





LIGHT WATER REACTOR FUEL DESIGNS FOR UNRESTRICTED POWER OPERATION

J.S. Armijo

H.S. Rosenbaum

J.H. Davies

T.C. Rowland



U.S. NRC

UNITED STATES NUCLEAR REGULATORY COMMISSION

Protecting People and the Environment

Challenges in Addressing Pellet-Cladding Interaction (PCI)

ACRS Briefing

March 3, 2009

Michelle Flanagan
Office of Nuclear Regulatory Research

HISTORY OF PCI

- Report to ACRS concerning NRC efforts on PCI (Tokar, 1979)
 - Documents rise in PCI failure, NRC response
- PCI Fuel Failure Analysis Report (PNL, 1979)
 - Modeling effort to develop empirical model for predicting failure

HISTORY OF PCI

- Operational Transient Test Series (PBF Facility, 1982)
 - Experimental program to investigate PCI failure during BWR operational transients
 - Fuel survived power excursion tests
- PCI-Related Cladding Failures During Off-Normal Events (INEL, 1984)
 - Modeling effort to develop integral mechanistic model for PCI



REGULATORY APPROACH

- USNRC Standard Review Plan
(NUREG-0800, Section 4.2)
 - Empirical approach:
 - Operating limits to prevent PCI
 - Based on power ramp data
 - Mechanistic approach:
 - Monitor stress and strain by accurately modeling:
 - Fuel thermal expansion
 - Fuel swelling
 - Irradiation effects on cladding and fuel mechanical properties



CURRENT INDUSTRY ACTIVITIES

- Fuel design approaches to prevent failure due to PCI have focused on both pellet and cladding
 - Liner cladding
 - Doped fuel pellet
 - Large grain pellets
 - Chamfered pellet ends
- Modifications to both pellet and cladding design have proven effective at reducing susceptibility to PCI failure

WORK OF OTHERS

- Pellet-Clad Interaction (PCI) Failures of Zirconium Alloy Fuel Cladding (Cox, 1990)
- Nuclear Fuel Safety Criteria - Technical Review (OECD, 2001)
- Fuel Safety Criteria in NEA Member Countries (OECD, 2003)



CURRENT NRC RESEARCH

- Studsvik Cladding Integrity Project (SCIP)
 - International participation in the Project
 - NRC has been a participant since 2004
 - Extensive test program focused on understanding various nuclear fuel phenomenon, including PCI



ANTICIPATED NRC RESEARCH

- **SCIP II – follow on program**
 - NRC has reviewed program proposal and anticipates participation in Phase II
 - Phase II goal is understanding PCI with a focus on pellet properties including:
 - chemical properties of the pellet
 - the effect of local stresses
 - the effect of burnup



CONCLUSIONS

- The NRC staff continues to participate in international programs, to dialogue with the international research community, and to monitor new developments concerning PCI



PCI/SCC Regulatory Approach

ACRS Materials, Metallurgy & Reactor Fuels Subcommittee Meeting

March 3, 2009

Paul M. Clifford
Division of Safety Systems
Nuclear Reactor Regulation

Susquehanna EPU

ACRS Letter on Susquehanna EPU (December 20, 2007)

- The staff should develop the capability and perform a thorough review and assessment of the risk of pellet-cladding interaction (PCI) fuel failures with conventional fuel cladding, during anticipated operational occurrences (AOOs).
 - The staff should develop qualified analytical tools to demonstrate that operator actions will assure an acceptably low number of failures. If this can be demonstrated by analysis, then the required operator actions should be incorporated into the regulatory process through commitments or inclusion in the updated FSAR.

Staff Response to ACRS Letter (January 17, 2008)

- In response to recommendation 6, the NRC staff will investigate current computational capabilities to model the complex phenomena associated with non-uniform fuel pellet expansion and stress-corrosion cracking (SCC). As necessary, the staff will develop guidance related to an application methodology and regulatory approach for implementing a PCI/SCC fuel failure criteria.

Staff Concerns

- Regulations specify performance requirements
 - May not impose specific design features (e.g. barrier liner)
- Regulations apply universally
 - Not restricted to “conventional fuel”
- All domestic fuel designs susceptible to PCI/SCC
 - Barrier fuel design provides PCI/SCC resistance, but not immune from failure during power maneuvering or AOOs
 - Various design features (e.g. natural Zr barrier, low alloy Zr barrier, doped pellets) provide varying levels of PCI/SCC resistance
- PCI/SCC not strictly an EPU issue
- PCI/SCC not strictly a BWR issue
- “...operator actions will assure an acceptably low number of failures.”

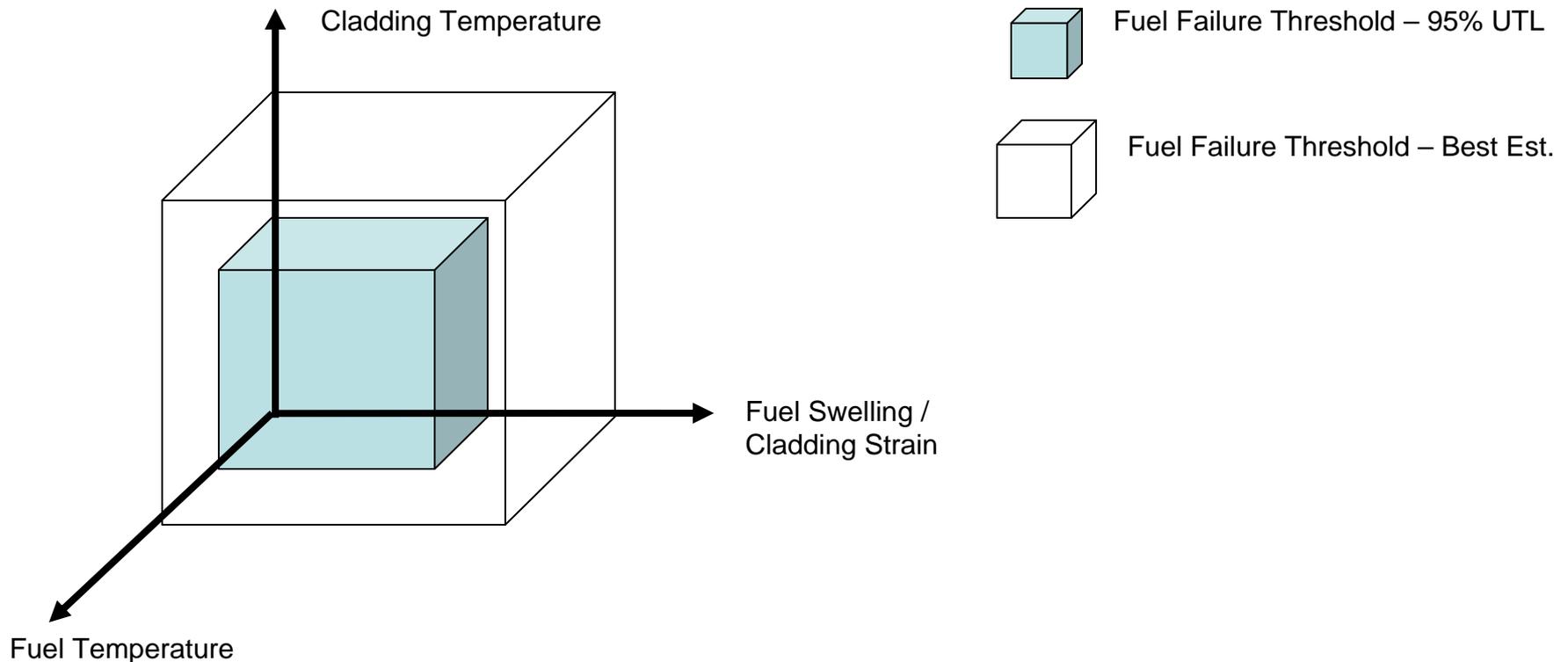
Low Safety Significance

- PCI/SCC may yield fuel rod cladding failure (i.e., through wall crack releasing fission gas within plenum)
 - No challenge to core coolable geometry
 - No challenge to pressure vessel integrity
 - No challenge to containment integrity
 - No challenge to systems designed to mitigate transient and minimize offsite activity releases

Low Probability of Occurrence

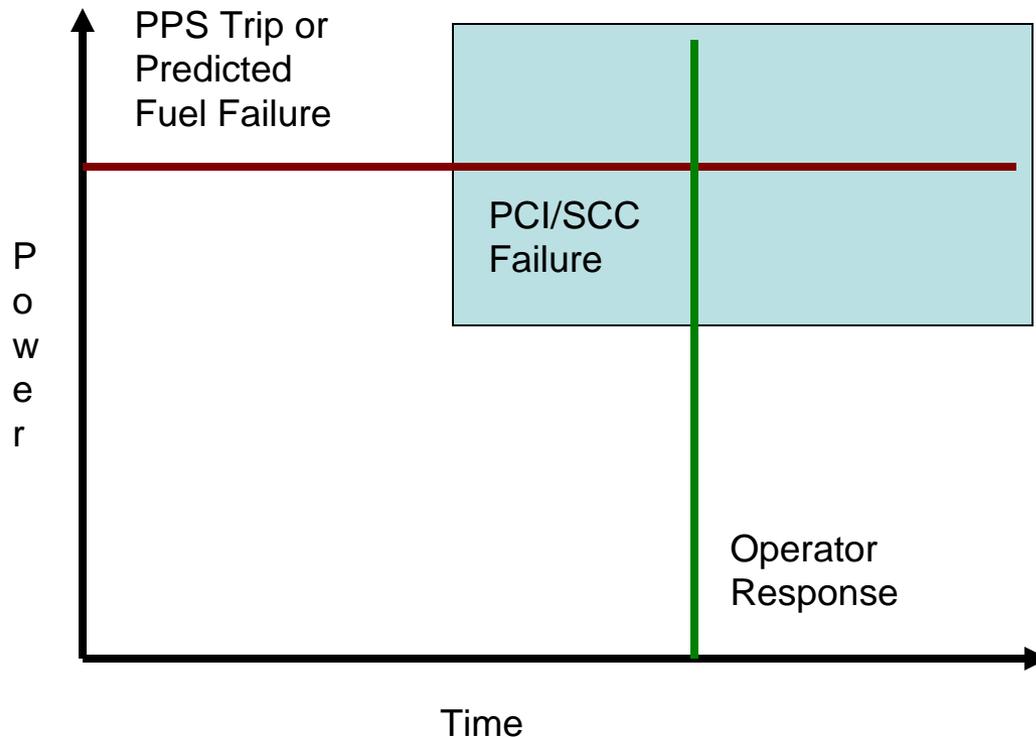
Limited envelope on magnitude of power excursion

- Power level must remain below automatic trip setpoint.
- Power level must remain below level which results in predicted fuel failure calculated using conservative analytical models along with conservative assumptions and initial conditions.



Limited envelope on duration of power excursion

- Duration beyond time necessary for PCI/SCC crack growth.
- Duration below timing for reasonable Operator response.



PCI/SCC Work Priority

- Limited staff resources devoted to support regulatory actions for operating fleet as well as new reactor design certifications.
- PCI/SCC safety significance does not warrant immediate action nor higher priority in staff workload planning than ongoing regulatory improvements.
 - Revision to 10 CFR 50.46(b) ECCS Acceptance Criteria
 - Revision to RG 1.183 Gap Source Terms
 - Revision to RG 1.77 RIA Acceptance Criteria
- Staff will continue to participate in international programs, to dialogue with the international research community, and to monitor new developments concerning PCI/SCC.

GEAP-22076
UC-78
JULY 1984

FUEL RAMP TESTS IN SUPPORT OF A BARRIER FUEL DEMONSTRATION

**COMMONWEALTH RESEARCH CORPORATION
SUBCONTRACT 3-20-46
U.S. DEPARTMENT OF ENERGY
PRIME CONTRACT DE-AC02-77ET34001**

VOLUME I

**J. H. DAVIES
E. ROSICKY
E. L. ESCH
T. C. ROWLAND**

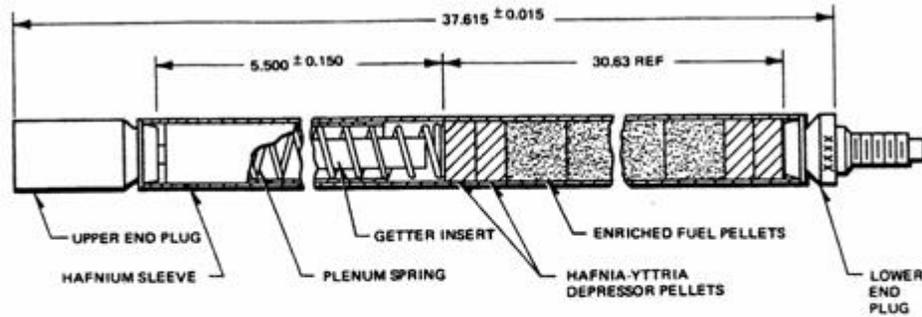
GENERAL  ELECTRIC

SEGMENTED ROD PROGRAM

- Irradiate standard and PCI-remedy fuel rods in segmented rod assemblies in power reactors
- Retrieve and characterize rod segments in hotcell
- Perform power ramp tests in a test reactor
- Ramp test campaigns:

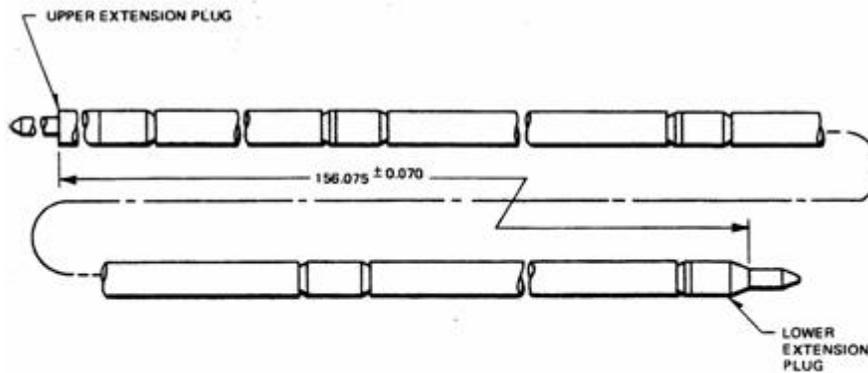
YEAR	NO. OF RODS	TEST REACTOR
1977	9	GETR
1978	12	Studsвик R2
1979	36	Studsвик R2
1980	27	Studsвик R2
1981	18	Studsвик R2
1983	11	Studsвик R2

- Hotcell characterization of ramp-tested rods



(DIMENSIONS IN INCHES)

FUEL ROD SEGMENT



(DIMENSIONS IN INCHES)

SEGMENTED ROD ASSEMBLY

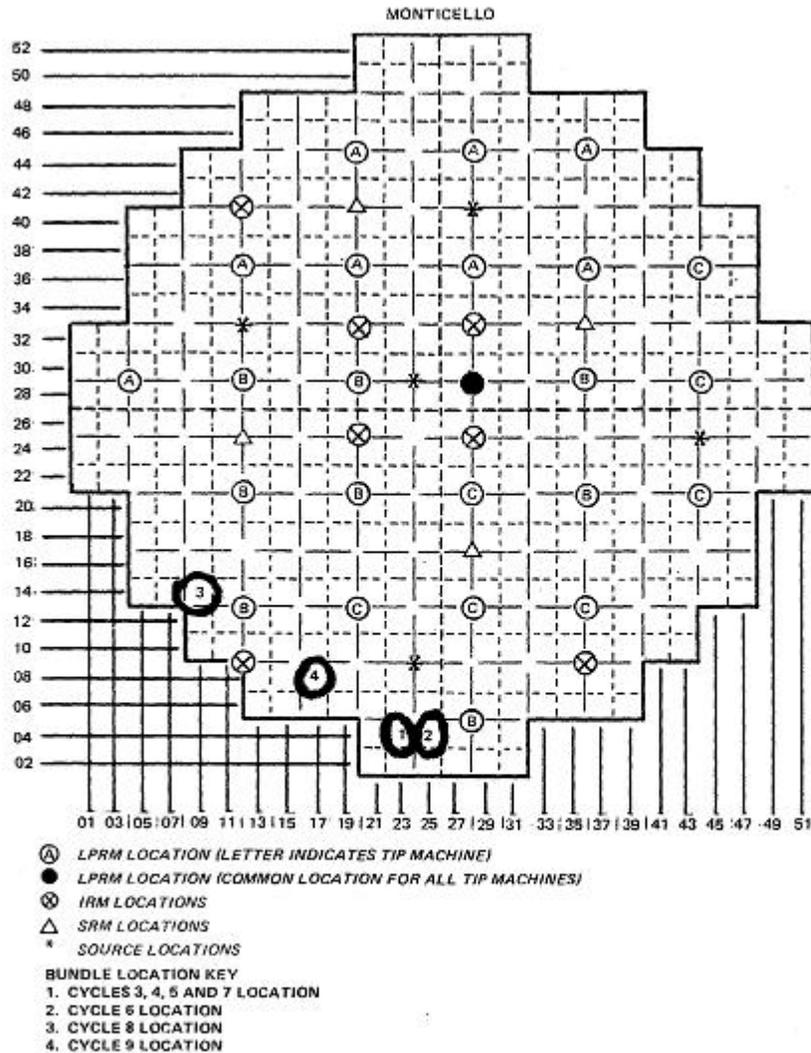
WIDE-WIDE GAP

	A	B	C	D	E	F	G	H
1	4	3	2	2	2	2	2	3
2	3	2	1	1	1	1	1	2
3	2	1	G	1	1	1	G	1
4	2	1	1	1	1	1	1	1
5	2	1	1	1	WS	1	1	1
6	2	1	1	1	1	1	1	1
7	2	1	G	1	1	1	G	1
8	3	2	1	1	1	1	1	2

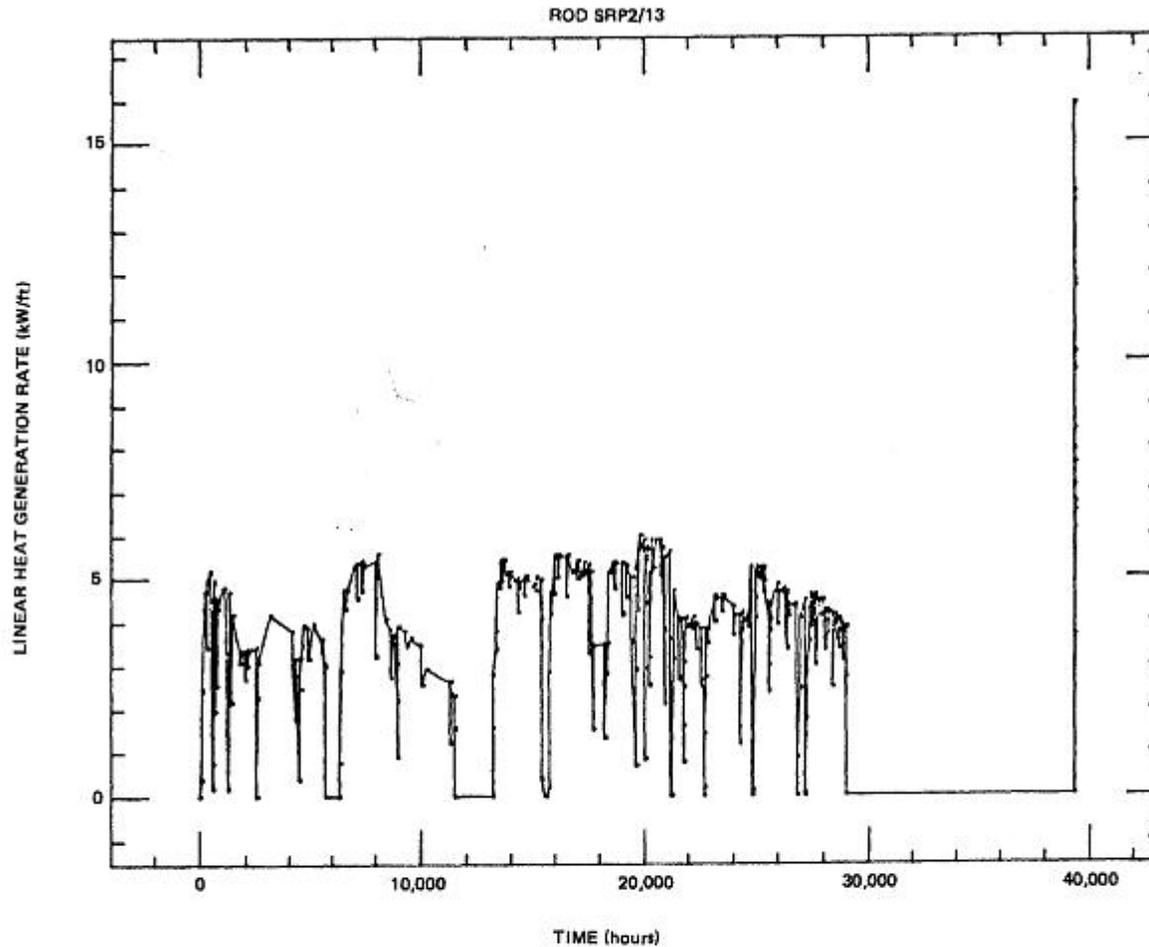
ROD TYPE	ENRICHMENT (wt % U-235)	NUMBER OF RODS
1	2.87	40
2	—	14
3	—	4
4	—	1
G	—	4
WS	—	1

WS — SPACER CAPTURE WATER ROD
 G — GADOLINIA RODS (REPLACED BY SEGMENTED UO₂ RODS DURING FIRST RECONSTITUTION)
 SEGMENTED RODS ARE CROSSHATCHED

FUEL LATTICE - 8x8 STR BUNDLE



SEGMENTED ROD BUNDLE LOCATION IN CORE

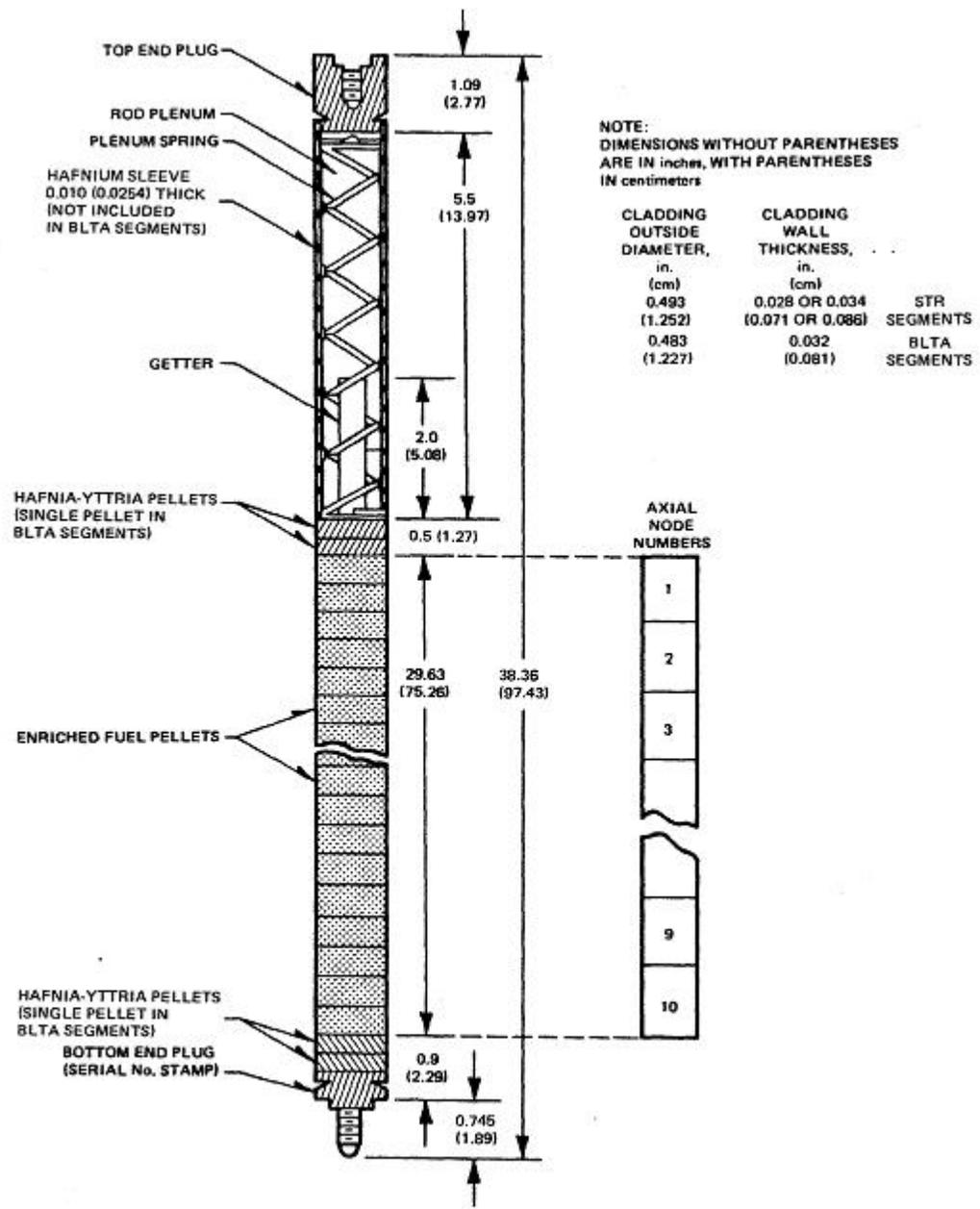


**TYPICAL IRRADIATION HISTORY OF A FUEL SEGMENT
(including base irradiation and power ramp test)**

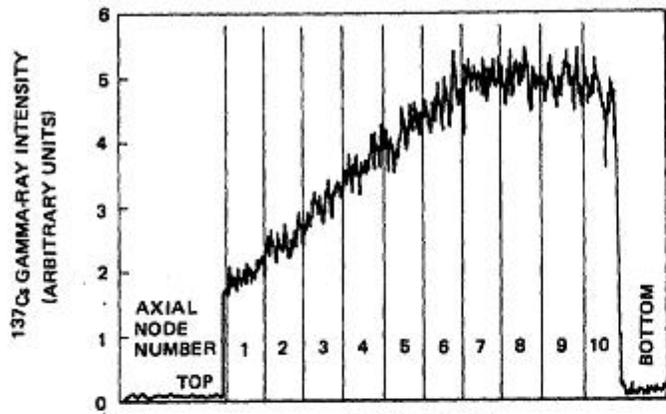
HOTCELL PRE-RAMP CHARACTERIZATION

- *LEAK CHECK*
- *VISUAL EXAMINATION*
- *EDDY CURRENT TESTING*
- *NEUTRON RADIOGRAPHY*
- *DIAMETER PROFILOMETRY*
- *LENGTH AND BOW MEASUREMENTS*
- *¹³⁷Cs GAMMA SCANNING*
 - - *Axial burnup and fissile isotope profiles*

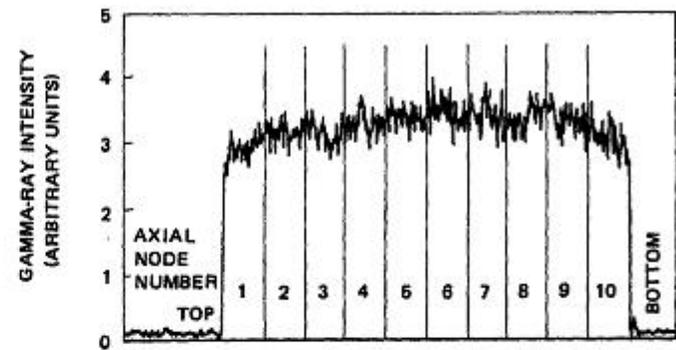
- | |
|--|
| <ul style="list-style-type: none">• Suitability for ramp testing• Baseline mensuration data |
|--|



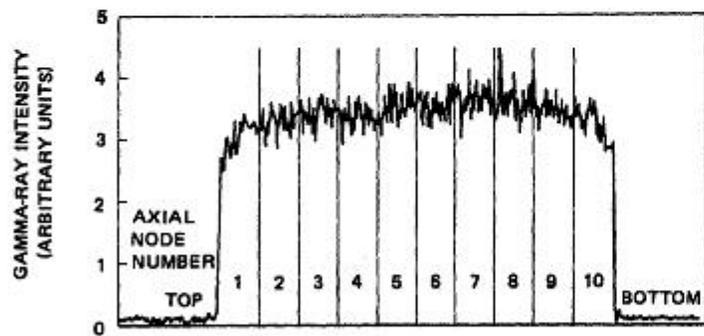
TEST FUEL ROD



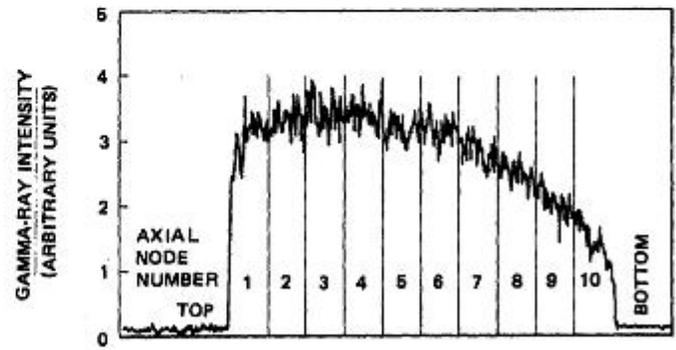
a) TOP SEGMENT



b) UPPER MIDDLE SEGMENT



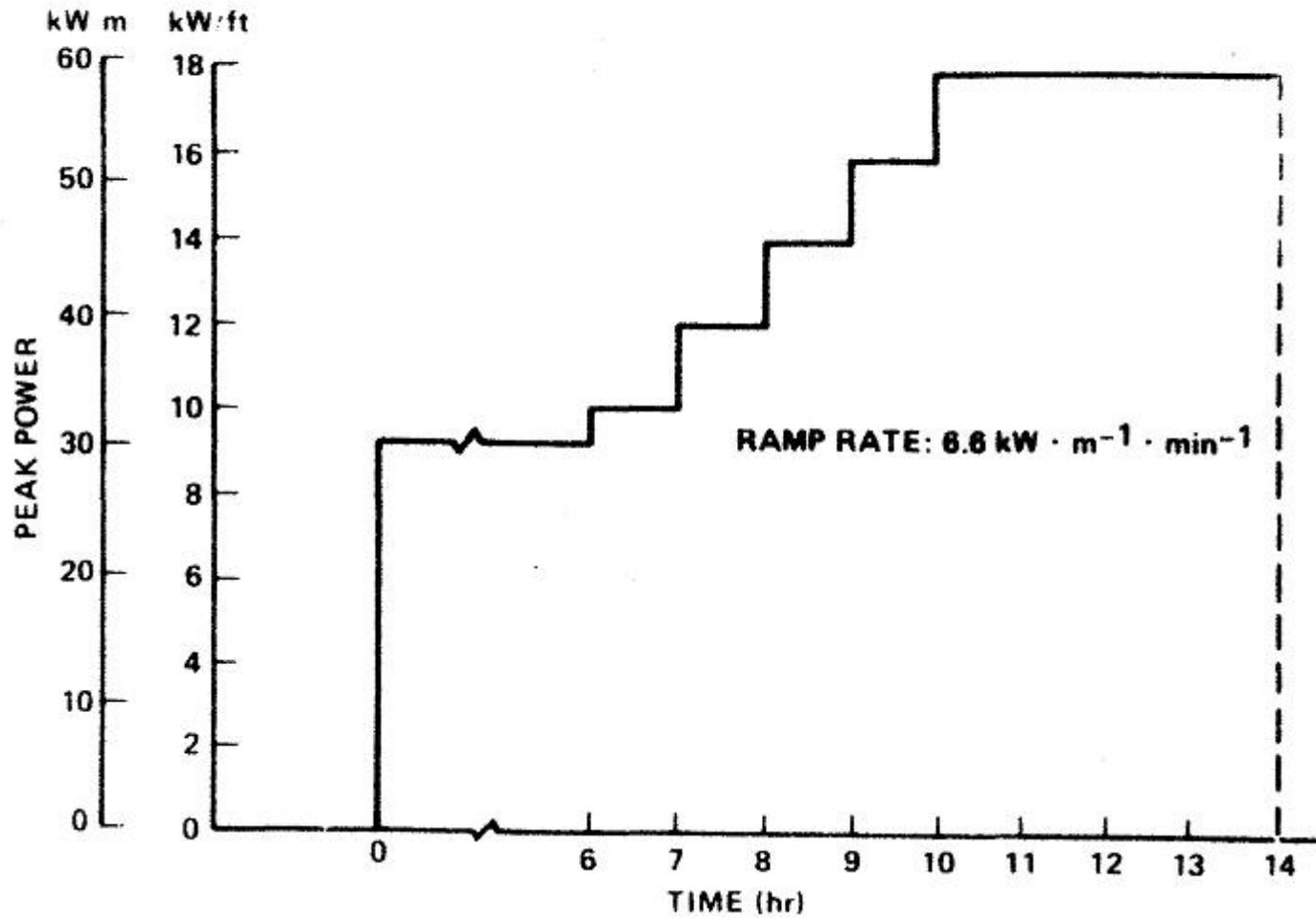
c) LOWER MIDDLE SEGMENT

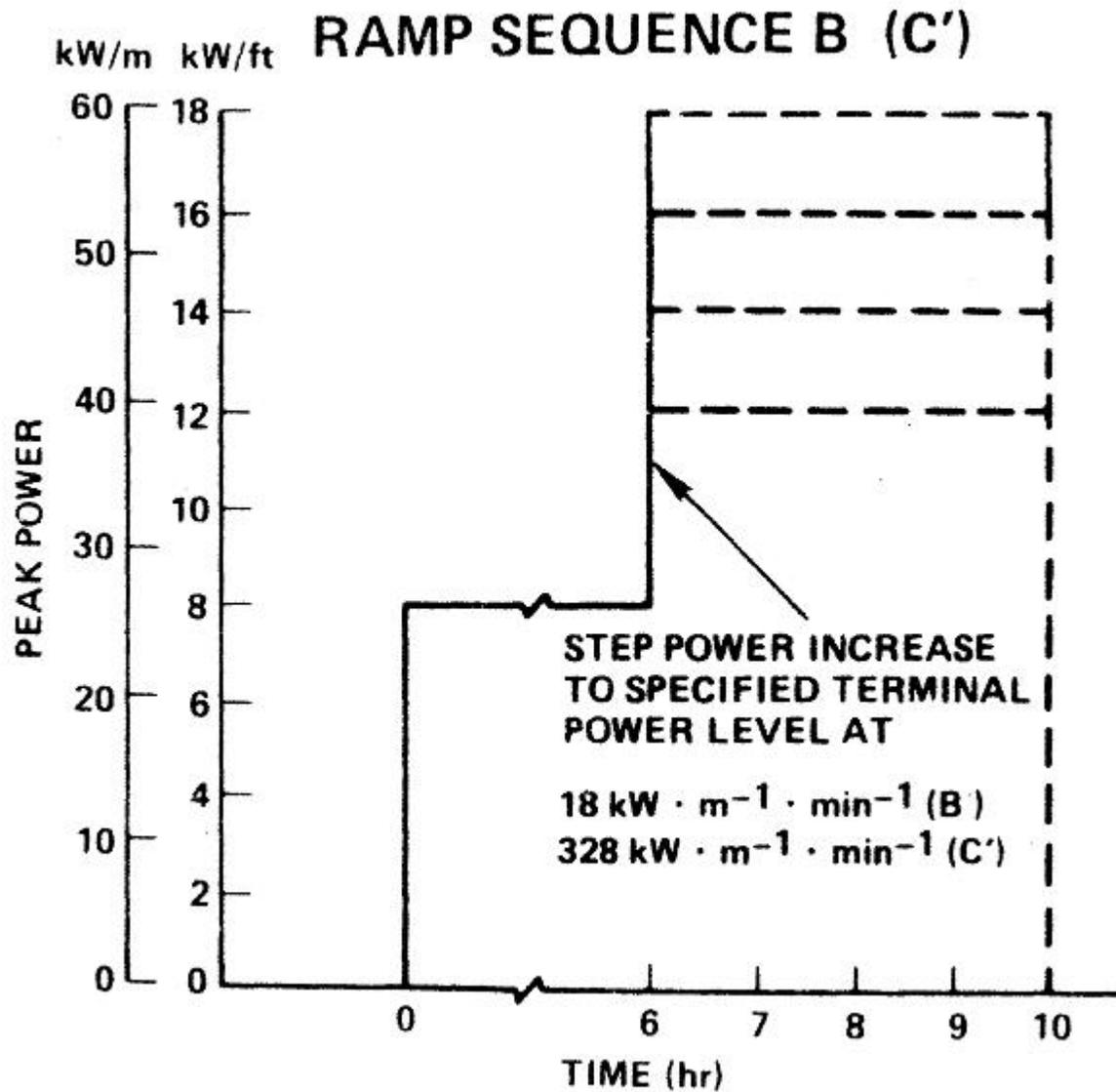


d) BOTTOM SEGMENT

TYPICAL ^{137}Cs GAMMA SCANS OF FUEL ROD SEGMENTS
(following base irradiation)

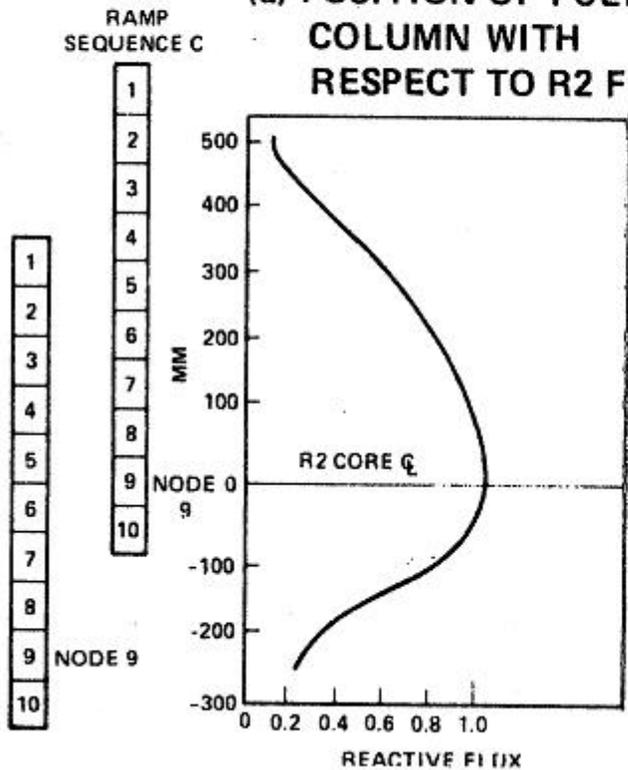
RAMP SEQUENCE A



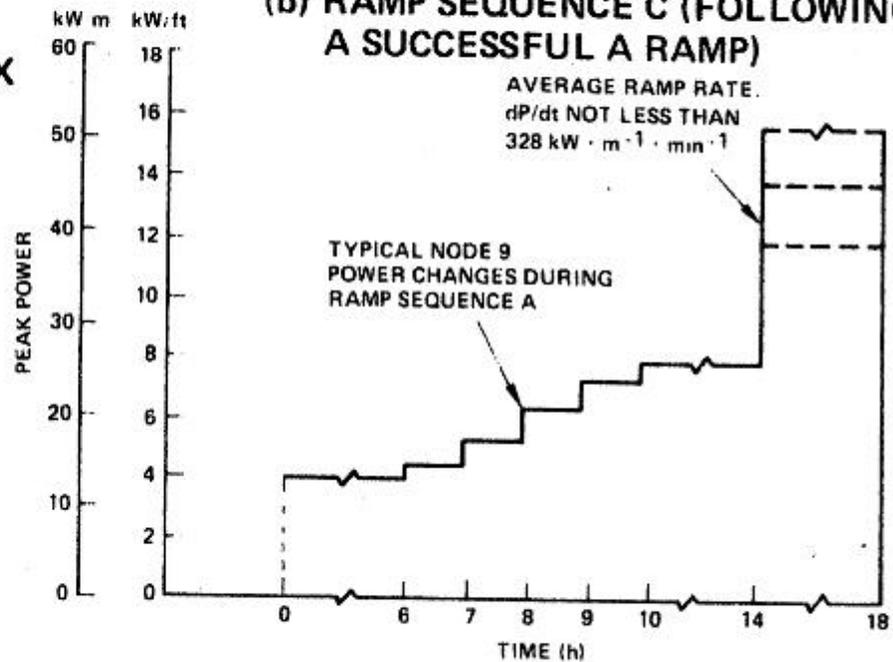


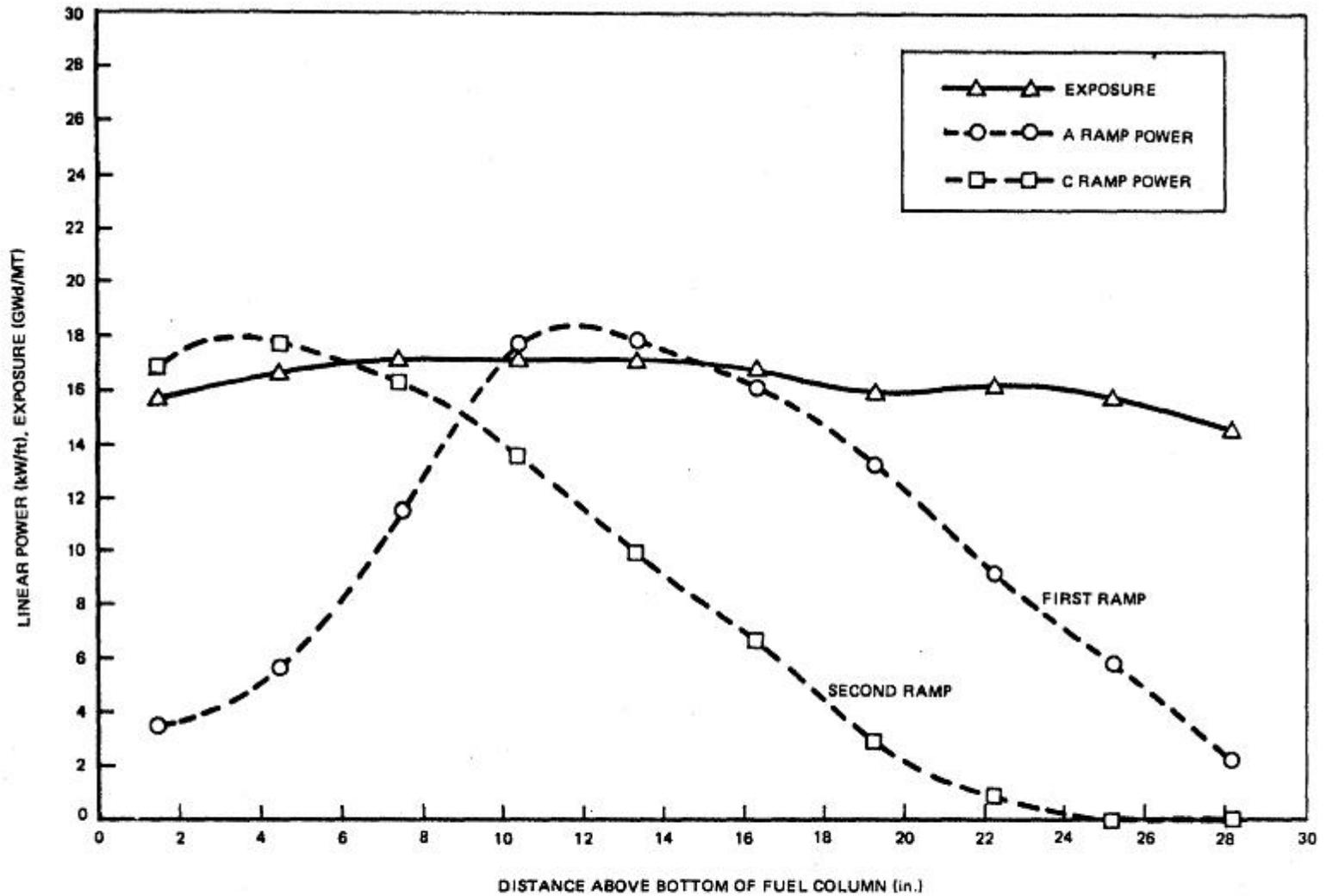
PERFORM 2nd RAMP ON SOUND ROD

(a) POSITION OF FUEL COLUMN WITH RESPECT TO R2 FLUX

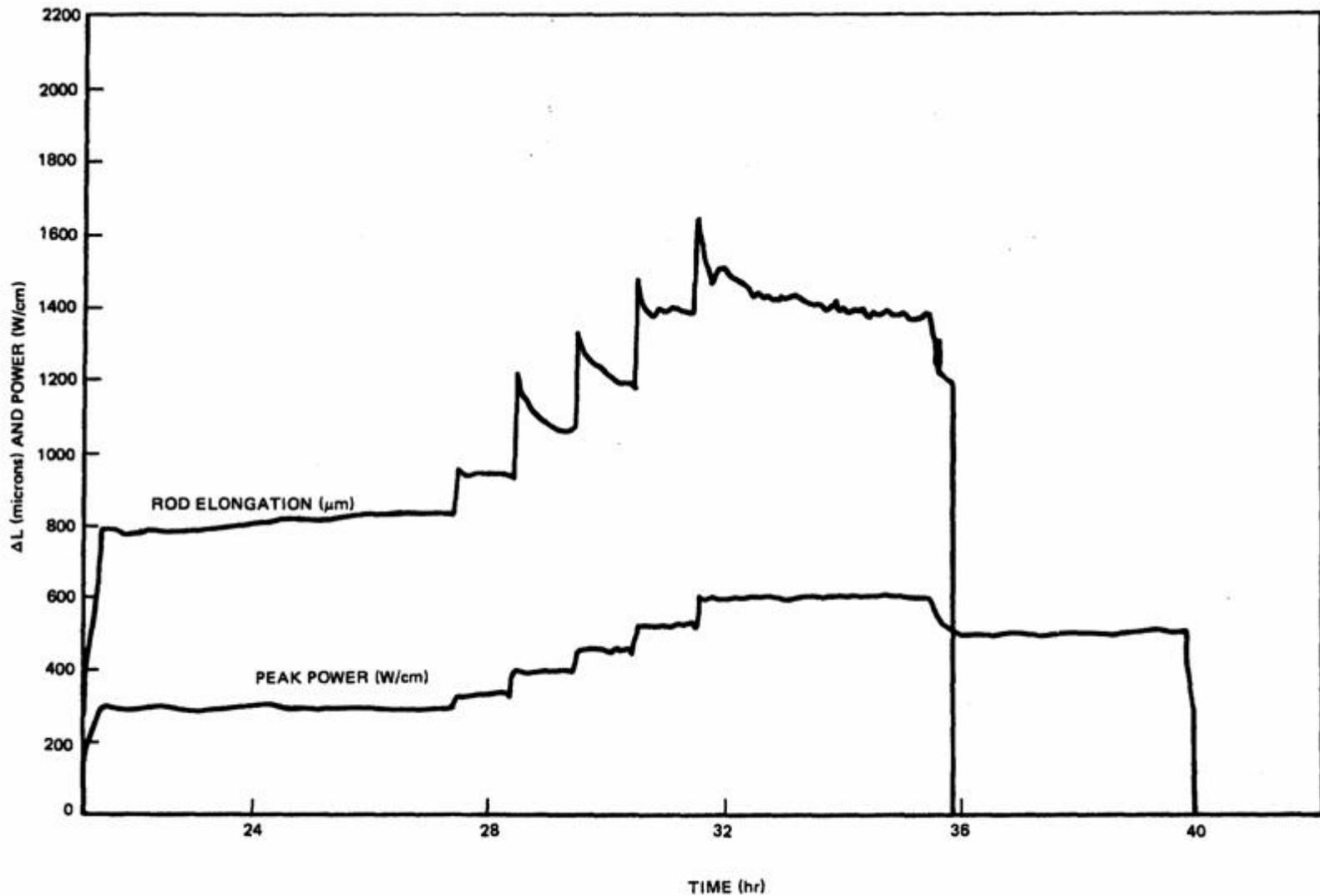


(b) RAMP SEQUENCE C (FOLLOWING A SUCCESSFUL A RAMP)

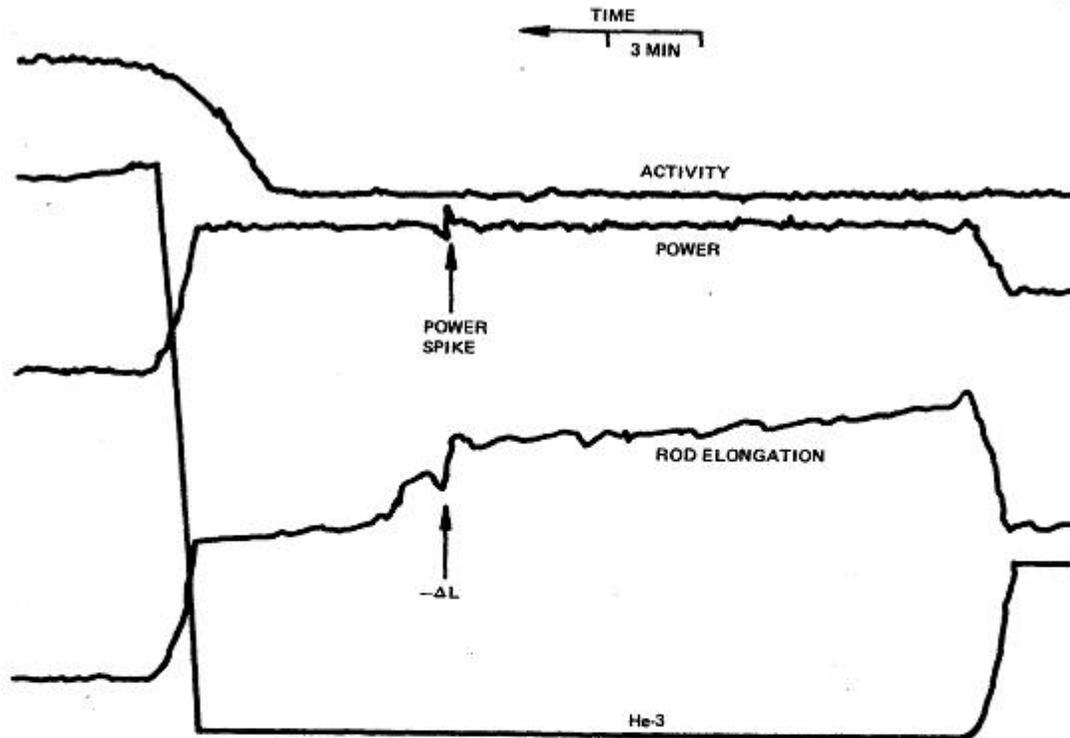




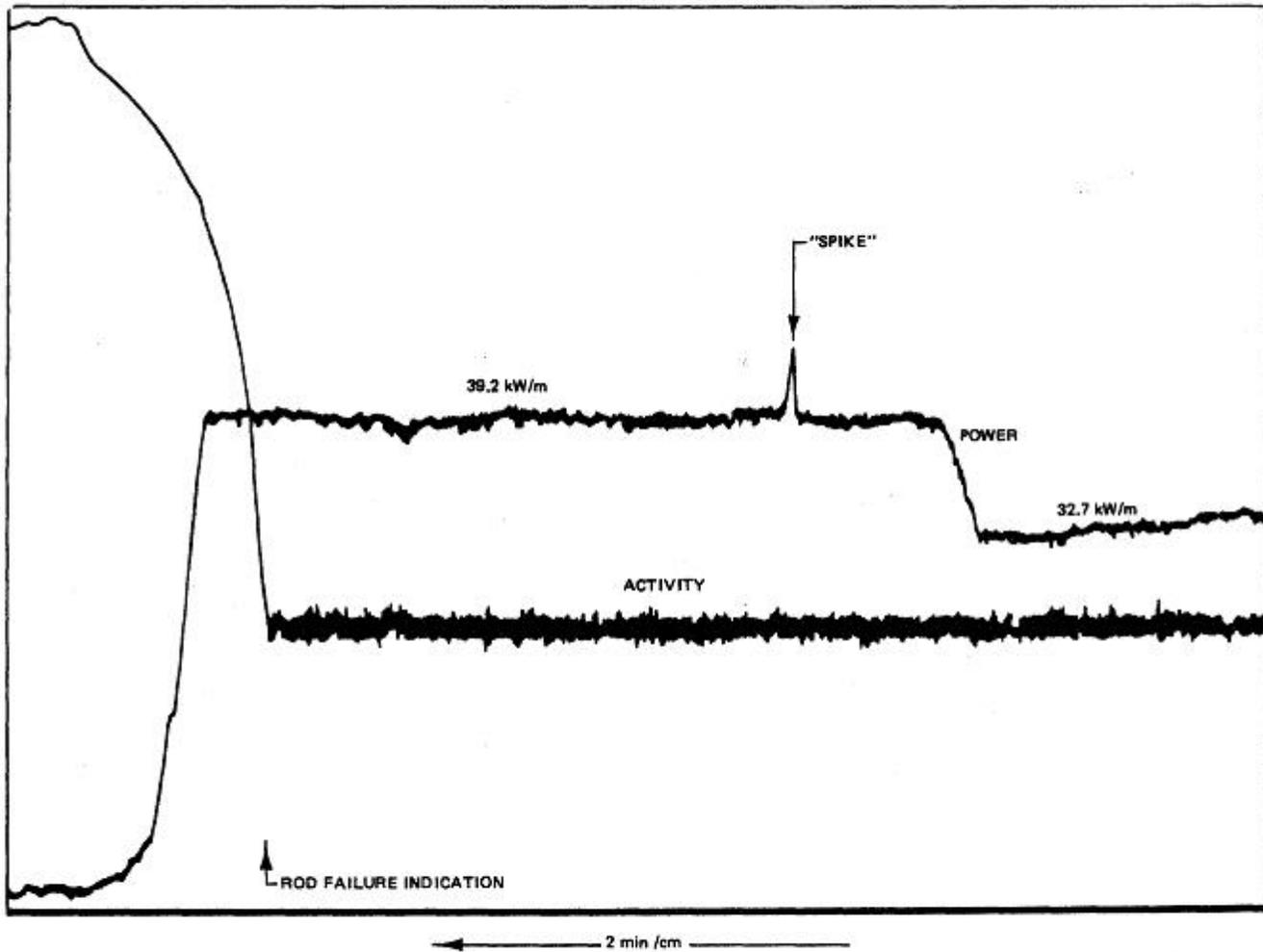
AXIAL BURNUP and RAMP TEST POWER PROFILES
(SRP-3/58)



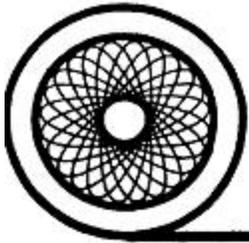
ROD ELONGATION & PEAK POWER vs. TIME
(SRP-3/97)



REAL TIME PLOT OF LOOP INSTRUMENTATION DATA
(SRP-3/96)

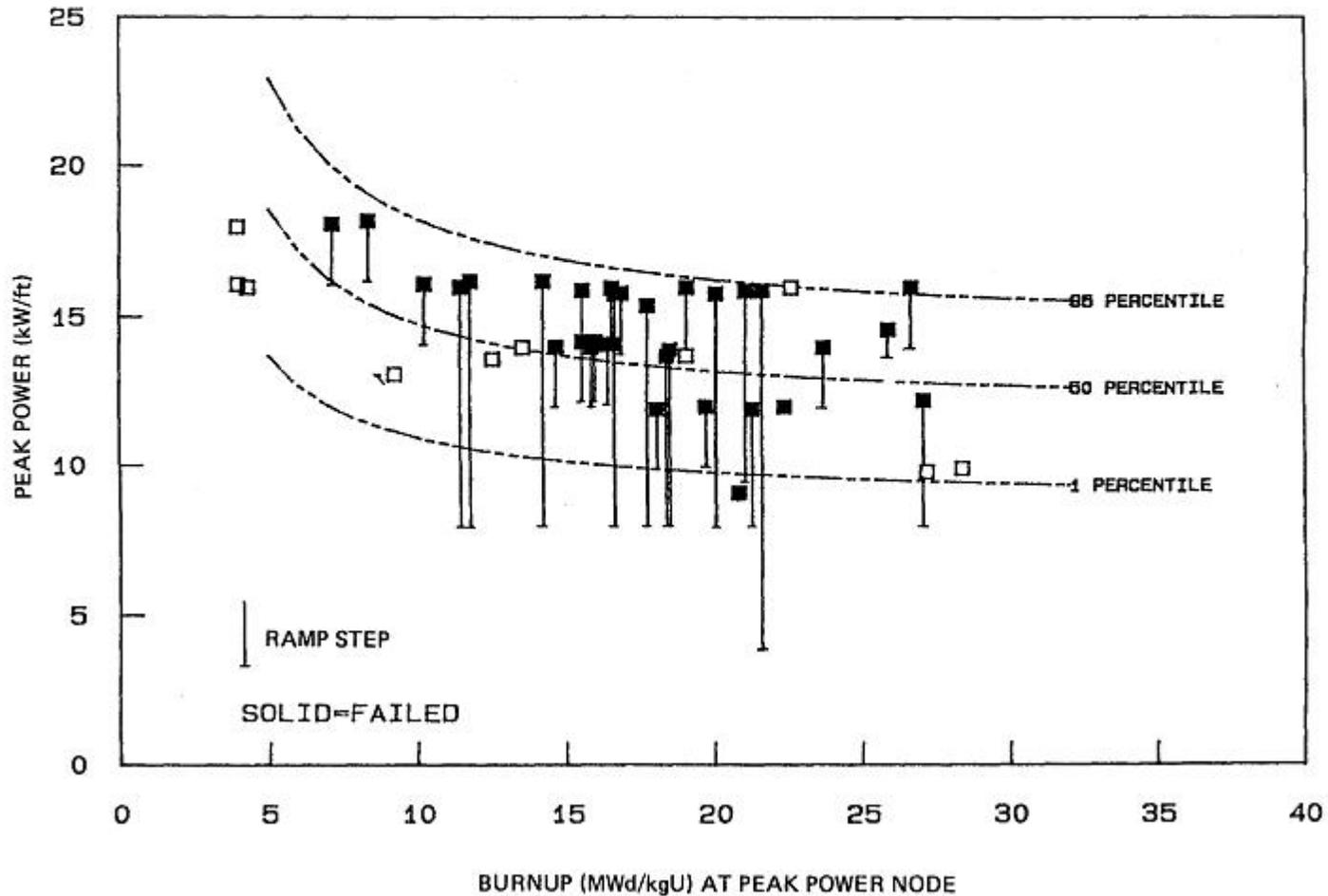


REAL TIME PLOT OF ROD POWER AND LOOP ACTIVITY
(indicating rod failure)



SRP RAMP TEST RESULTS

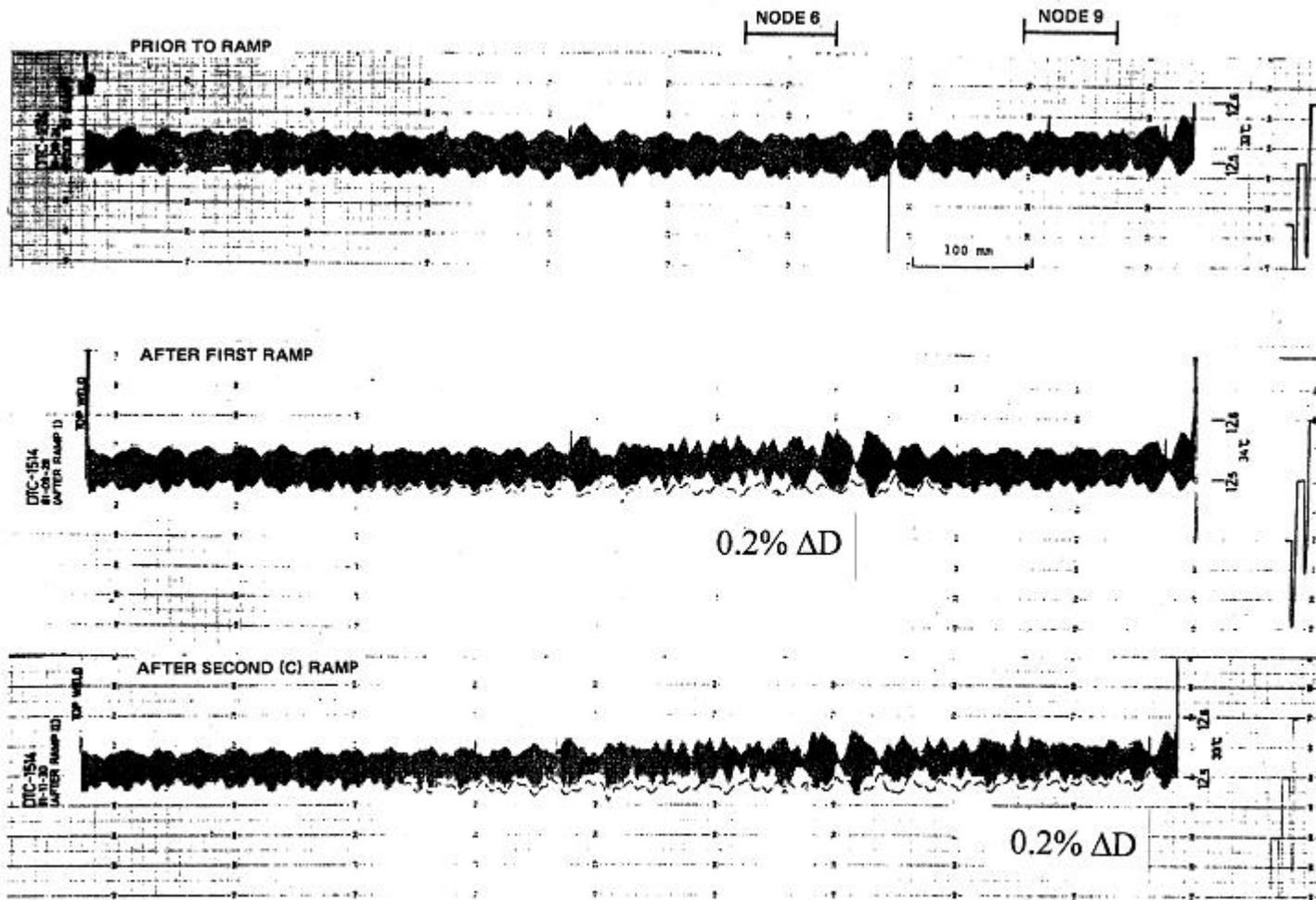
STANDARD CLADDING



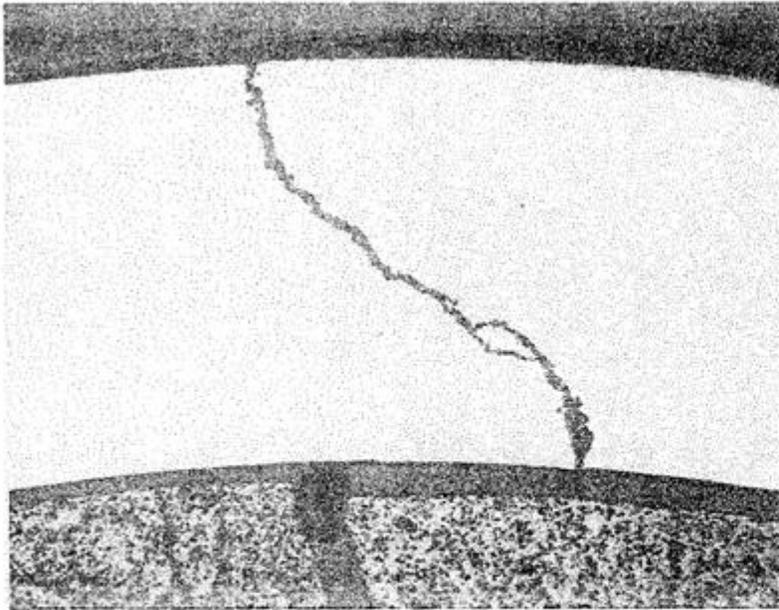
HOTCELL POST-RAMP CHARACTERIZATION

- *VISUAL EXAMINATION*
- *EDDY CURRENT TESTING*
- *NEUTRON RADIOGRAPHY*
- *DIAMETER PROFILOMETRY*
- *GAMMA SCANNING*
- *Nd BURNUP MEASUREMENTS*
- *FISSION GAS PUNCTURE AND ANALYSIS*
- *METALLOGRAPHY*

- **Confirm sound or failed**
- **Characterize defects**

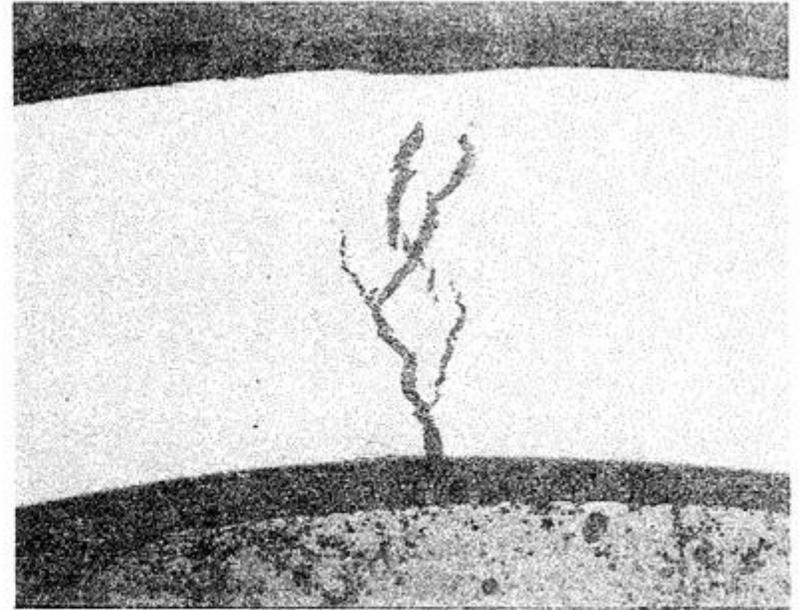


RESULTS OF SPIRAL PROFILOMETRY ON TWICE-RAMPED ROD (SRP-3/61)



(a) SRP-2/11

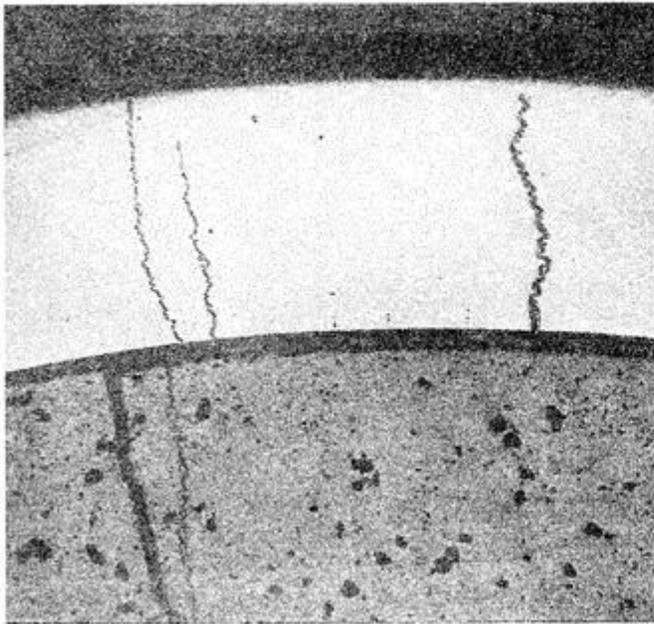
C601-02
50X



(b) SRP-2/14

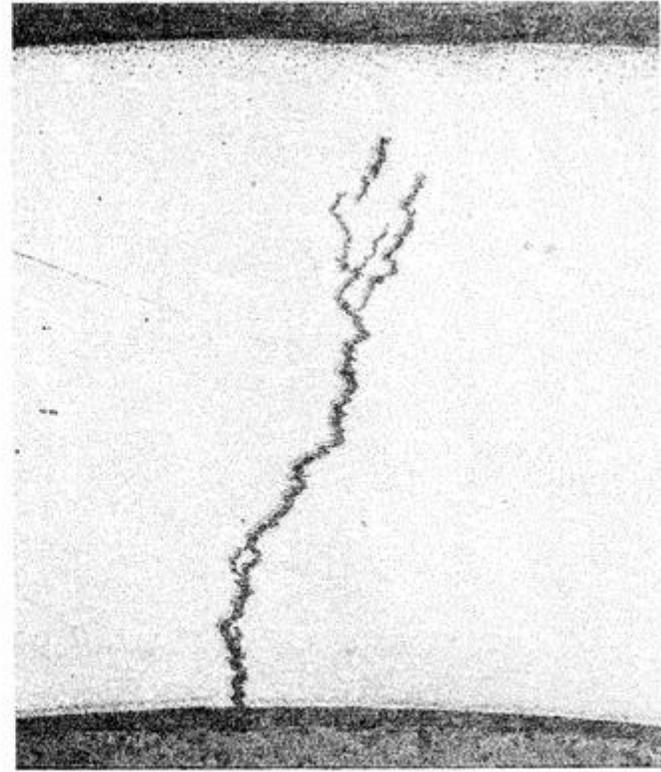
C597-03
50X

PCI CRACKS IN FAILED STANDARD RODS



C226-15
50X

SRP-3/12

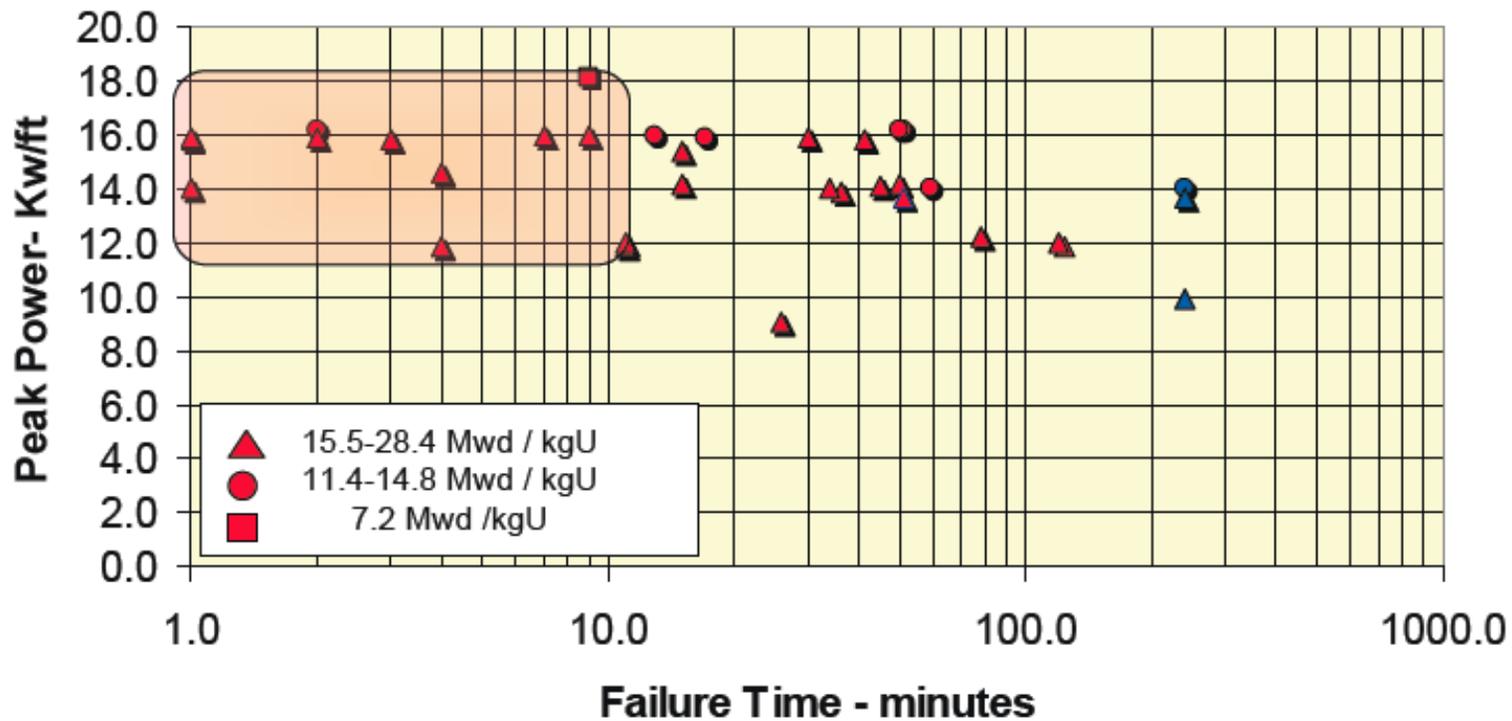


C218-02
100X

(d) SRP-3/27

PCI CRACKS IN FAILED STANDARD RODS

Ramp Tests -- Standard Cladding



JSA



Backup Slides

PCI/SCC Roundtable Discussions

Rigid Chapter 15 Safety Analysis

Scope : No predicted fuel failures using strict analytical requirements.

PROs

- Compliance with GDC10 (high confidence)
- Quantification of PCI/SCC resistance of all fuel designs under AOO conditions

CONs

- Due to large SCC modeling uncertainty, predicted fuel failure well below actual failure threshold
- RWE likely to yield predicted failure
- Likely to impose overly burdensome requirements
- Development and validation of PCI/SCC model.

Cost - High Schedule - Long

Limited Duration with Best-Estimate Models

Scope : BE models demonstrate that Operator training and automatic PPS response limit duration of any power excursion to below SCC threshold (approx. 3 minutes)

PROs

- Compliance with GDC10 (using BE methods)
- Plant/Operator changes minimize PCI/SCC potential
- Quantification of PCI/SCC resistance of all fuel designs under AOO conditions

CONs

- Development and validation of PCI/SCC model.

Cost - Medium Schedule - Long

Physical Protection without Specific Demonstration

Scope: Voluntary implementation of proven design features along with current regulatory approach

PROs

- Physical protection versus analytical margin

CONS

- No legally enforceable SCC requirement

Cost - Low Schedule - Short

- Establishing generic PCI/SCC regulatory criteria will be a long, complex process.
 - Develop a detailed mechanistic fuel rod design model capable of predicting complex mechanical / chemical attack.
 - Develop a PCI/SCC Specified Acceptable Fuel Design Limit (SAFDL).
 - Develop regulatory guidance and testing requirements.
 - Elicit public and industry comment.
 - Revise NUREG-0800, Standard Review Plan Section 4.2.
 - Complete backfit determination pursuit with 10 CFR 50.109.
 - If the proposed change in regulatory staff position qualifies as either an exception (e.g. compliance, adequate protection) or cost-justified substantial increase in safety under the provisions of 10 CFR 50.109, then develop an implementation schedule.

- Implementation of generic PCI/SCC regulatory criteria will be a long, complex process.
 - Develop PCI/SCC analytical methods.
 - Perform new ramp testing to validate models.
 - NRC review of models and methods.
 - Revise UFSAR AORs for 103 reactors.
 - NRC review of UFSARs.
- Competition with ongoing regulatory improvements of equal or greater magnitude.
 - Revision to 50.46(b) ECCS Acceptance Criteria
 - Revision to RG 1.77 RIA Acceptance Criteria