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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

NRC STAFF PRESENT:

MICHAEL BENSON, Designated Federal Official

VANICE PERIN

PAUL CLIFFORD

MICHELLE FLANAGAN

BILL RULAND

ALSO PRESENT:

TOM TOMLINSON

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

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

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

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

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

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

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

Next slide. The driving force for this meeting is a recommendation made in the ACRS letter dated December 20, 2007, during the review of the Susquehanna Extended Power Uprate review. That recommendation stated that, "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." That was really intended to be the broad issue during AOOs of any type.

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

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

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

We are going to talk about the features of PCI and the mechanism, what controls it, power, delta power, rate of power increase, burn-up, what are the mitigation actions that are proven to be very successful during normal operation which include operating constraints that are known as PCIOMRs.

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

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

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

Having been involved in the development of the barrier fuel in the early days in industry, our driver was not solely the economic benefits of having PCI resistant fuel during normal operation. We had a great concern driven by the Nuclear Regulatory Agency that wanted a solution, a design solution to the PCI problem. Otherwise, there would need to be regulatory action to get that under control. That was part of our drivers.

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

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

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

Next slide. Now, what is PCI? This is a cross-section of a PCI crack and the cross-section is taken at the pellet-pellet interface. The lower part is the gray area where the vertical crack is the fuel. There is the gap and then there is the cladding. You see in the cladding a branching, a crack. The crack initiates at the point of local stresses where the pellet is cracked. That branching crack is a brittle crack, as I said, in a fundamentally ductile material.

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

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

It's mechanical and chemical. Obviously when you have a chemical factor involved the mechanical properties are degraded substantially. What was an acceptable strain level under purely mechanical loading is totally unacceptable under stress corrosion cracking conditions.

The next slide shows demonstration of the influence of what causes stress corrosion cracking. This picture shows the inner surface of fuel cladding. The fuel has been removed and the photograph on the left, this one here, you are looking at the inner surface of the fuel cladding. The white horizonal line -- Mike, I think my pointer isn't -- yeah, that white horizontal line is where the pellet-pellet interface is. The dark line patterns are deposits of fission products, deposits on the inside of the cladding.

The cladding was then flattened and on the right hand side you can see that there is an opening. That was a crack. If we looked at the inside of that crack it would be the brittle fracture of PCI crack. It showed that the crack is coincident with the location where there was a high concentration of fission products.

Next slide. Now, a lot of work has been done. It's from some of this work and a lot of this was Dr. Davies' work and other people at GE. In this particular case the cladding deposits were scrapped from the cladding and the concentrations were measured chemically and compared with the predicted fission product concentration from just the burn-up of the fuel.

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

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

Next slide. Now, here is what happens when you do raise the power of a fuel rod and the underlying mechanism. The lower yellow region of this sketch is a region where fuel has no PCI risk. The power is low enough that there is neither sufficient stress on the cladding nor sufficient fission product concentrations to cause any problems. If you raise the power rapidly into the orange region, which I'll call the failure region above some threshold power, two things are happening. First, you the fuel is getting hot, fission products are coming out of the fuel and depositing on the cladding in addition to what is already deposited during steady state.

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

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

In addition you have actual locking of the pellets within the fuel column. You have thermal expansion. All the pellets aren't exactly lined up perfectly so you have a stochastic stacking so there is some variability in the PCI failure data but not too much variability as a result of that feature. Basically you have bi-axial stresses, you have high concentrations of fission products, and you have a material that is inherently susceptible unless you do something with the design.

Next slide. What are the well known controlling operational parameters? First of all, there is such a thing as called a PCI failure threshold. People argue about that and have done a lot of research on that. It is generally agreed that this PCI threshold below about seven or eight kilowatts a foot in BWR fuel there is no risk of PCI. Above that level there is risk and it increases as you go to higher powers. As a result when you operate at higher powers you typically precondition the fuel by changing power very, very slowly and I'll just show that next.

This sketch is just a schematic of what I call the PCI map in which the vertical axis is linear heat generation rate or actual power. That is really on a nodal basis in the fuel element and plotted against burn-up. The yellow region is the nonfailure region. Basically you can operate the fuel with impunity in that region without any risk of PCI failure.

After you cross the PCI threshold, which is a function of burn-up, then you are in the failure region and the failure region is bounded by the dark line which is really the fuel duty which is a peak linear heat generation rate as a function of burn-up. Now, the PCI threshold, as I mentioned, is somewhere in the 8 to 10 kilowatt per foot range. It's burn-up insensitive.

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

Next chart. Typically the failure probability from PCI increases dramatically as you go higher in power and also higher in power change. This is just a schematic. If you look at actual ramp data, which we will present in more detail by Dr. Davies, you can see the data that is supporting this. This is not strictly data from GE but it is also data from a variety of other sources.

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

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

Next slide. So what are the mitigation options? Well, obviously during normal operation the industry has done a very good job. Initially the old 8x8 assembly which had typically 64 fuel rods was increased to 10x10 which gave you 100 fuel rods and all the power was spread among those 100 fuel rods. That obviously reduced the risk because the linear heat generation rate was decreased dramatically, maybe 30, 35 percent. In the interim over the years people have found it to be very economical just to raise the power, put more enrichment in and you wind up that today's 10x10 fuel has the same peak LHGRs as the old 8x8. That remedy has disappeared.

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

In the case of AOOs, and particularly those AOOs in which there is no scram. These are slow transients but fast enough to cause PCI. There is no scram function. The power in the reactor can go maybe as high as 120 to 125 percent of the peak of the rated power so you're into a regime, a power regime, where PCI is still a threat, stresses still occur, fission products still come out, and you have a limited amount of time to stop the transient. That calls for prompt operator action if you don't have a PCI resistant design. If the prompt operator action is slower than the PCI time to failure, then you obviously are going to fail the fuel and that's the fundamental concern that we are raising here.

As far as -- one thing that we are not concerned about is under the same test conditions that we showed earlier with the conventional cladding, a very large database has been created showing the resistance of a PCI resistant design. In this particular case it's a zirconium barrier cladding design. This has been ramped. The power is as high as 18 kilowatts per foot and with much higher reliability. In fact, it protects you during the AOOs by design, not by operator action or any other means. Our concern is not with a PCI resistant design but with the conventional fuel cladding. Our concern is that use of conventional fuel cladding under these conditions should be discouraged.

With that I think I will wrap it up. Our concern is the growing use of non-PCI resistant fuel in BWRs. Our concern is that the PCI failure times are very short at AOO power levels. Dr. Davies will show some data to demonstrate that. The early 10x10 mitigation benefits have been lost as people have turned those reduced powers back into economic benefit by raising the power again.

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

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

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

MEMBER RAY: Is there -- everything you talked about, Sam, had to do with raising power, ramp rate, increasing power. I just kept thinking to myself is there symmetrical problem on the downside with a unit trip or something like that in terms of stress levels?

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

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

CHAIR ARMIJO: We've never seen that.

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

CHAIR ARMIJO: Yeah, Bill.

MR. RULAND: And subcommittee members. My name is Bill Ruland. I'm the Director of the Division of Safety Systems in the Office of NRR. We appreciate the committee holding this forum. In our view it facilitates a discussion of generate topics and sharing information without a specific licensing action before us. It gives us time to think about and kind of debate in a much more what I would call open relaxed forum. It helps us -- gives us time to think about exactly what our actions ought to be.

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

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

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

MS. FLANAGAN: Yes, I will give my presentation first. My name is Michelle Flanagan and I work in the Office of Research in the Fuel and Source Term Team Branch. I am presenting today the challenges in addresses pellet-cladding interaction, or PCI.

I would like to begin with a brief history of PCI by highlighting four reports that are documenting work that was done in the 1970s and '80s. The first of these is a compendium written by Mike Tokar presented to the ACRS in 1979 which documented the rise in PCI fuel failures in the 1970s and then NRC's response and attempts to understand and model PCI.

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

The next report documents an experimental program to test challenging operational transients. In this experimental program at the PBF facility power ramps were run with standard, doped and lined radiated fuel rods simulating rapid power excursions that would be expected under conditions of a turbine trip without bypass, generator load rejection without steam bypass, and then two additional larger power excursions trying to approach the limit of PCI failure.

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

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

Stochastic variables like fabrication times could be incorporated to produce true probabilistic predictions and accurate power-time curves including local power peaking and numerous experimental benchmarks would be critical to the success of failure predictions.

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

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

In response to these regulatory requirements the industry has addressed PCI through fuel design. Fuel design approaches to prevent failure due to PCI have focused on both pellet and cladding. Liner cladding, doped fuel pellet, large grain pellets, and chamfered pellet ends have all been modifications introduced to preclude PCI. Modifications to both the pellet and the cladding design have proven effective at reducing susceptibility to PCI failure.

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

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

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

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

In addition to a broad experimental program investigating no only PCI but other fuel phenomenon the SCIP program is also attempting to use the results to improve fuel clad modeling capabilities. The program that NRC is participating in currently is a five-year program and it's nearing the end of its work scope. A follow-on program has been proposed and the research proposal has been reviewed by NRC and we anticipate participating in the second phase.

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

I would like to conclude by saying that the NRC staff continues to participate in international programs, to dialogue with the international research community, and to monitor new developments concerning PCI. That concludes my presentation. Thank you very much for your attention and I'll take any questions if there are any.

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

My real concern and my colleagues is backsliding from designs that were developed partly with NRC encouragement. In fact, to a great extent with NRC encourage to develop PCI resistant designs and now we are backsliding and tolerating the use of non-PCI resistant designs without really understanding what level of risk we are taking on. If that becomes prevalent, particularly with higher powers, we are moving back to a risk environment that had been solved. That is really the concern. We know that there are even better designs possibly than the liner fuel. The doped pellets look very promising but we don't know too much about them in large statistical quantities of operation. There are a lot of ways to solve this problem but there should be a design solution, not just a operational solution and that is really where I'm pressing to find out what the NRC staff is going to do because the way I read the Standard Review Plan if you have -- if you can demonstrate that your cladding will not exceed 1 percent plastic strain mechanically you're okay but these pictures that are not unique should demonstrate the PCI happens long before at much lower strains than 1 percent. During these transients do they happen fast enough to cause adequate delta power? Are they sustained long enough for the crack to initiate and propagate through the cladding before an operator can terminate the transient? Those are the real key issues and without a good model, and I don't think it has to be all that mechanistic. I think there is a wealth of empirical data and test data that can be used by the staff productively to remake such an assessment. We'll talk more about that but I just want to make sure that we're on the same track. I'm focused on the BWRs. I'm focused on the BWRs where there isn't an automatic scram in such events, those transients. I don't know all the transients that might be of concern. That's the staff's thing so I have chosen to discuss the loss of feedwater heater situation in our various discussions because that seems to be one of the most aggressive transients. I think it's good that the staff is continuing to work with international programs but I think there is just a ton of data available for BWR fuel and cladding that the staff could use productively now in their models.

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

MEMBER SHACK: Well, can I just come back? You know, Sam goes on what is required. Is this one of these cases if you literally followed the NRC regulations it probably wouldn't work but you guys don't bother to change them because everybody in practice is doing something else? It's sort of like water chemistry. If you look at the reg guide on water chemistry, if people actually followed that, we would be horrified but they don't. You know, we're saying the amount of energy you can put into the fuel and a control rod withdrawal accident if that really happened but we don't worry about it because we know although the regulations really aren't adequate there's not really a problem because it's being taken care of for other reasons like economics. Is that the situation you think we're in here?

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

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

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

MEMBER SHACK: But I think it's a little unfair in some ways to keep bringing up the 1 percent strain. That may be the regulatory requirement but they are not really relying on that.

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

MEMBER SHACK: Right, kind of over all.

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

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

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

CHAIR ARMIJO: Okay. Let's do that.

MEMBER RAY: I was reminded of Alan

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

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

CHAIR ARMIJO: Yes.

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

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

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

CHAIR ARMIJO: Prompt operator action.

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

MR. RULAND: We will talk about that.

MEMBER SIEBER: Okay.

MR. CLIFFORD: First, I would like to set the record straight. While I do have advanced degrees in nuclear engineering and metallurgy and do not hold a Ph.D.

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

MEMBER SIEBER: Today you are.

CHAIR ARMIJO: You are among friends.

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

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

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

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

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

MR. CLIFFORD: We'll get into that.

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

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

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

For GDC-35 we say, "Show me you've got the hardware. Now show me a detailed analytical process and we are going to give you specific analytical requirements, the 2200, the 17 percent ECR. It goes down to that level of validating a model showing that your predictions are accurate, reviewing the model, having specific criteria.

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

MR. CLIFFORD: Right.

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

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

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

Next is that all domestic fuel designs have some susceptibility for stress corrosion cracking under the right conditions and that each potential design feature while it provides some resistance such as a barrier the degree of resistance varies whether it's a natural zirconium barrier or a low alloy barrier or whether you are using doped pellets. You would need to fully understand the degree of protection that is being provided by each of these design features and whether or not they are susceptible to something like burn-up or other phenomena.

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

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

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

CHAIR ARMIJO: I understand.

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

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

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

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

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

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

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

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

Whereas infrequent AOOs are generally a less frequent event or an event in combination with a single failure which would say, "Okay, you are allowed a certain number of failures. However, that's generally tied to dose where you are allowed a small fraction of 10 CFR Part 100. What is acceptable as far as the number of failures would then be tied directly or calculated off-site releases.

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

There is no challenge to the core cooling geometry because the fuel rod maintains the structural integrity. There is no challenge to the pressure vessel integrity because there is no molten fuel cooling interaction. There is no challenge to the containment integrity because there is no high energy line breaks associated with any AOOs.

There is no challenge to any system designed to mitigate the transient or to minimize offsite activity releases unless we start postulating an event in combination with loss of offsite power or an event in combination with independent single failure. The AOOs by themselves are not going to challenge the other barriers for the release of activity. Ultimately it would fall under a lower safety significance. Of course, if you were to use risk assessment it would even fall lower because, you know, you're always going to maintain coolable geometry.

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

You could argue that there is a low probability of occurrence because of these two issues. The first issue is the limiting envelope for the power excursion. You postulate this loss of feedwater heater or any other AOO. You have to have a power increase for PCI failure.

This isn't a depressurization event or anything else. It's a power increasing event so power goes up. It can't go high enough and fast enough where you get an automatic plant trip because as soon as you get a trip, although the power may be high, you don't have the time for the cracks to propagate so that limits the power excursion.

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

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

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

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

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

MR. CLIFFORD: Right.

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

CHAIR ARMIJO: The issue, I mean, if you just rule out that, you know, you could approach your MCPR safety limit or you could approach your fuel center line melt and you stick strictly to swelling and cladding strength. What the graph is trying to show is, yeah, our limit is 1 percent total strength which has got plastic and elastic components to it but you take mechanical data to show you what your failure point is, separate effects mechanical data on irradiated material. That gives you when you believe it will fail due to the mechanical interaction. Not the chemical but the purely mechanical interaction.

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

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

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

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

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

MR. CLIFFORD: It's the difference between a best estimate like the argument, okay, well, we looked at it and it was less than 1 percent plastic strain on a failed component.

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

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

MEMBER RAY: Okay.

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

CHAIR ARMIJO: There is where I think you should get yourself stuck on saying, "I've got to really understand the thermodynamics and chemistry down to the detailed level." Once you have sufficient burn-up and you're going to have plenty of aggressive chemicals to cause this problem so it really becomes then a stress issue. How much stress do you put on during these transients. Like I say, there's a ton of experimental data, Halden data, GE data, a number of papers that show you what the response of the material is to that kind of a stress. I think you could productively analyze it mechanically and say, "Okay, while 1 percent strain protects you against a lot of other things, by the way, PCI you have to demonstrate that you stay below two-tenths percent strain to demonstrate that you've got PCI resistance during this event.

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

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

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

CHAIR ARMIJO: Those are amenable to design analysis. The stresses, the fuel temperatures, all of that stuff is just straightforward analysis. There is nothing fundamentally different in the various fuel designs other than and even within that really makes it an impossible job. Different pellet shapes, whether it's disked, whether it's chamfered, how much prepressurization. All of that is amenable to design.

MR. CLIFFORD: Right.

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

MEMBER SIEBER: Let me ask a really general question that you've already discussed. On the previous slide you talk about no challenges to coolability, pressure vessel integrity, containment integrity. If you look at the whole body of regulations and consider PCI failures against the regulations which are designed to protect the public as opposed to protecting your investment, what regulation really would you pick out that comes closest to saying anything at all about PCI failures?

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

MEMBER SIEBER: If I were to operate the plant in such a way, for example, took high ramp rates and did all kinds of things, fuel that didn't have PCI protection built into it, I really wouldn't be violating the regulation. What I would be doing is screwing up my investment, increasing waste generation and so forth. But it seems to me if you want to regulate pellet-clad interaction failures, there has to be a legal reason to do that and you have to be able to point to some overriding principle that is already set out in the regulations that says I need to develop techniques whether they are analytical or operating techniques or what have you to be able to regulate either operational operating characteristics or mechanical characteristics of the clad or the cord design itself to avoid big power peaks and so forth in there. It's not clear to me -- even though I agree that PCI is not a good thing to have but it's not clear to me what the basis for regulating it really is.

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

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

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

MEMBER SIEBER: It's either that or rulemaking.

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

MEMBER SIEBER: Not any rule that I know of.

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

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

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

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

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

MEMBER SIEBER: Failure by what?

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

Even though it is no safety significance, the arguments point out on your slide 4 those are the same arguments that the industry, and I was one of the guys years ago used to ask the NRC to hold off until we could develop a PCR resistant fuel design because these were true then and they are true today.

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

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

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

MR. CLIFFORD: Um-hum.

MEMBER RAY: I'm puzzling over what seems like a difference in the way we would approach the containment to the way we are approaching this phenomenon.

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

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

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

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

MEMBER SIEBER: But that is a performance based approach.

MR. RULAND: Correct.

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

MR. RULAND: Correct.

MEMBER SIEBER: You can operate with PCI failure.

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

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

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

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

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

All of those sorts of things are subject to analysis and you could explain why they had success. That doesn't mean they couldn't have failed until you analyze the most limiting case. I feel we are kind of flying blind based on favorable experience but it doesn't always have to happen that way.

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

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

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

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

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

CHAIR ARMIJO: So the answer is no.

MR. CLIFFORD: No.

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

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

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

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

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

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

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

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

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

MEMBER SIEBER: It only takes two of us.

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

John was responsible for the power ramp testing program that GE did to qualify barrier fuel for boiling water reactor service, PCI resistant fuel. In the course of doing that he did a lot of testing of conventional fuel cladding and he is going to provide us with information that I believe is relevant to the AOO issue, particularly with respect to the time to failure as a function of power.

John, it's all yours.

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

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

In the end our program, as the title

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

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

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

Just as we were more or less getting started we felt we had to close down that reactor because of its proximity to the perceived earthquake fault so we had to move our testing to the Studsvik R2 reactor. It turned out to some extent to have a silver lining, that move, because the R2 reactor is in many ways a better machine.

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

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

Some of their instrumentation evolved so by the end we were getting some additional measurements in 1983, for example. The number of campaigns also explains to some extent the rather large number of standard cladding reference rods that we tested in this program because every time you go back to the reactor you need to know that you are where you were the last time in terms of response to the ramp and failure.

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

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

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

We had two of these assemblies. Next slide.

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

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

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

Now, we had two of these 8x8 bundles. This is a picture of the matrix and the cross-hatched rods labeled 1 were all segmented. That is, there were four segments per fuel rod. If you look at the little table down below, there were 40 of these rods in an 8x8 bundle and there were four segments per rod so we had 160 segments.

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

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

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

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

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

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

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

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

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

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

Now then, as I said, in the Studsvik R2

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

We had what we called a standardization power which was a little higher than we believe the segment had experienced in the power reactor, 9 kilowatts per foot. We held that for six hours just to get the rod standardized after it had been characterized in a hotcell and shipped overseas, etc. Then we went up a power staircase at a ramp rate of actually 2 kilowatts per foot per minute, 6.6 kilowatts per meter per minute, and then held at each step for one hour.

If we could get the fuel rod to survive to 18 kilowatts per foot, we held it, it looks like, for four hours. In those days we had assured ourselves through our own work and other people's work that if a fuel rod was going to fail by PCI it would happen within four hours. Then if it survived it was taken off test in most cases, in many cases.

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

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

We called this kind of ramp the C prime ramp because we already used another fast ramp that we called C and that is shown in the next slide. We thought this was kind of cute what we were able to do here because we could get two tests for the price of one. Basically the Studsvik R2 core was a little bit shorter than the GETR core and quite a bit shorter than the length of our fuel column.

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

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

It turns out that the standard reference fuel rods, which is what this meeting is focused on, in general would fail during the first round, the A or B round. The second round was very useful for getting two results, if you like, on one fuel rod when you are testing the PCI resistant fuel like zirc barrier. It would in general survive the first ramp and in general it would also survive the second round, although occasionally as Paul pointed out in his talk, not many of these remedies are perfect. They're resistant but nobody claimed immunity so we get occasional failures.

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

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

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

1983 was a rod length indicator so we are able to measure perhaps not dismetral strains but we are able to measure axial strains as you are increasing the power on the rod. Here is a side-by-side thing. You can see the peak power on this fuel rod going up a staircase to a final power of 600 roughly watts per centimeter. You can see the rod elongation in microns. Clearly each time you have a power step Sam showed a nice figure before how the fuel pellets kind of grab onto the cladding so the rod elongation is really a measure of the expansion of the fuel column as it gets hotter and basically stresses the cladding. Then you can see the stresses or strains relaxing.

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

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

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

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

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

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

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

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

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

In these power ramp tests we didn't just collect power to failure or failure power. We were able to collect time after ramp step to failure. There is another indication in the next graph of one of these little power spikes. Again, it's not a power spike.

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

The next chart --

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

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

CHAIR ARMIJO: A lot depends on how clean your core is. If you have a lot of tramp uranium and a lot of other stuff, then you don't have much ability. The point of this discussion is to show that while that wasn't the focus of the program to find out what was real time to failure after power ramp.

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

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

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

MEMBER SIEBER: Thank you.

MEMBER SHACK: I mean, for example, in these two examples on 15 you would have about, I don't know, nine minutes or something to take some action to stop things. In this other one you would have a minute basically to do it. If you had a transient with that kind of --

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

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

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

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

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

CHAIR ARMIJO: Okay.

DR. DAVIES: Staircase or A ramps. The last slide here is speaking to the hotcell post-ramp characterization which was really done to confirm whether the rods or sound or failed, but also to characterize the defects. The next slide speaks to one of the points that was being discussed earlier in that this is some results of spiral profiolometry on a twice-ramped fuel rod which in this case did not fail. It's clear that there is a little bit of volatility in this cladding. The top chart shows pre-ramp diameter profile. The second chart shows a little bit of cladding strain equal to .2 percent delta D over D after the first ramp in like the middle of the rod. Then the final chart shows the strain at the bottom of the rod which is, again, in the same range. Certainly substantially less than 1 percent strain. We are talking here plastic strain, obviously.

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

Okay. Now, the final slide in this presentation is a slide that Sam put together based on the data that I fed him in the last month or so where he took these failure times. I think if somebody is going to speak to that slide it should be Sam.

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

You can see that in the very low burn-up, 7 megawatt-days per kilogram uranium, we could get failures but we had to go to 18 kilowatts per foot before we would fail anything but it would happen within nine minutes. As you got to higher and higher burn-ups you were having routinely failures in the times of one to two to three to four minutes.

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

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

Unless you analyze this event, you are putting fuel at risk, I believe, in violation of the general design criteria when you know better. You can't ignore the stress corrosion cracking phenomenon. That is the reason for bringing Dr. Davies in to explain it. This is the largest database of standard BWR fuel testing, the most careful experimental program. It wasn't compromised by refabrication of conventional power fuel. It was a very expensive program. I did a rough calculation that every one of those data point cost in 1984 dollars something like $30,000 a data point so it was a pretty expensive program, very carefully done, and the data I think are something that should be a basis for any kind of analytical model to test the model against experiment.

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

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

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

CHAIR ARMIJO: Yeah, you could do that. The issue is the percentage -- I did just an eyeball. I said, look, what is fraction of fuel -- of failures that happen in less than 10 minutes and it's a good fraction. Yeah, there are lots of ways of treating this data. This is very coarse but the fortunate thing is the data exist. Many of these data points are power spike or elongation changes? I mean power spikes. Usually elongation -- in fact all the time elongation change and power spike were the same. Some of the data points are just activity release so some of those later delayed ones were mixed.

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

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

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

I agree with Paul that this containment can take this. The BWR is sized to take a lot of fuel failures but this industry is working to have zero fuel failures during normal operations. Here as a regulator we are kind of indifferent, or appear to be indifferent to fuel failures during abnormal transients.

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

It's not so infrequent that you could just disregard it. That is really the point. That is why we brought this issue up. I've got to give credit to our colleague Dr. Dana Powers. I discussed this issue with him and he said, "The way to handle this is let's have this collegial discussion. Put everything on the table and let's see what is the best way to handle it. I appreciate the staff being very cooperative to meet with us and discuss that so at this point I think we could really open it up for roundtable discussion.

Again, if there is anyone on the bridge line, you folks have not had the benefit of seeing the slide presentation material but it is published record and the staff, I'm sure, can make that available to you. If there's comments or questions from anyone in the meeting, including attendees here, we would be happy to entertain them and I'll open it up for discussion. I'll leave it there.

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

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

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

CHAIR ARMIJO: You are talking about just basically --

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

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

MR. CLIFFORD: It would delay it.

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

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

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

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

MEMBER SHACK: Can you compare these experiments with the ones in the Power Burst facility? The statement is they survived those tests. What is different about those?

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

MEMBER SHACK: Would the research people know?

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

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

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

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

MS. FLANAGAN: Yes. I have the --

MEMBER SHACK: How are the SCIP tests being conducted?

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

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

I believe with a little bit of research to dig out that data you would have an enormous data base that people may have not focused on time to failure, real time to failure when you get to real high power. Some of the tests were limited to very low power, below 13 kilowatts a foot. That is not particularly interesting. It's when you get up into higher than the fuel duty that's when you really are in the AOO regime and that is where you should concentrate.

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

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

My argument is we shouldn't analyze the event after we fail fuel. We should analyze the event before we put the fuel in and make sure that we have a high assurance that we won't fail fuel even in these non-safety -- you know, low-safety significance events. I think it's a regulatory significant event. I think it's an industry significant event but that's my opinion.

MS. FLANAGAN: I wanted to add one thing. Harold came up so he may have something to add to this also. The SCIP II program one of the first goals or the first phase of that program is to review a lot of the Studsvik ramp experiments that have been done to perform a literature review to see where those tests are relevant and where they can be used. The intention is to go back and revisit some of those experiments that were done.

MR. FLANAGAN: Michelle, I would urge the staff, the NRC since you are participants in the program, to get that program to review these data. The reports are available. They were done in the same test reactors so there is no reason to discount them. I think it is the biggest and largest database that they've got. But also urge them to focus on time to failure as measured by power spike or delta elongation change or activity release because that's what you need.

The other thing is I really don't know how much is theoretical and how much is actual on an AOO like a loss of feedwater heater is what the duration of the event is. The duration is until the operator takes some action. That is the way I understand it. That could be a few minutes and, in some cases, people have had -- Hope Creek had an event where they didn't even realize they had a loss of feedwater heater event. Fortunately it was a very mild one. Not everything turns out happy. Some things turn out bad. I think if we have a big BWR that has an abnormal operating occurrence and fails a lot of fuel and is unexpected, well, shame on us. We never should have let that happen. That's my opinion. I will wait to see what the committee thinks.

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

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

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

DR. DAVIES: Graphite.

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

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

They are unique in that they have collapsible cladding and very high-density fuel. When they put this -- they don't know the mechanism by which can loop works, either a lubricant, there is an argument there, or maybe it's gettering the iodine in some way but it works. They demonstrated that and they have used it for years.

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

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

With the support of the NRC, by the way. I mean, that was not just a casual experiment. The only thing we found that would work was this particular design. We have tested other designs that GE tested and others have tested. Things that you'll be reviewing added to fuels, for example. If those work, great.

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

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

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

CHAIR ARMIJO: I do because, think about it, there is 10 times as much cesium as there is iodine and cesium iodide is a very stable compound. We did testing and John probably did it, or Herman Rosenbaum, one of our colleagues, to demonstrate that if you put cesium iodide inside of zirconium and cladding and trying to crack it in laboratory tests. You couldn't crack it. I think during the transient you don't have equilibrium. Even though you have 10 times as much cesium, you probably have some free iodine that is the aggressive species.

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

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

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

MEMBER SIEBER: Some day it does.

CHAIR ARMIJO: Today it doesn't.

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

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

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

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

I think you would predict it well below when you would actually see it. If you look at the scatter on the ramp data and you are looking at a 99.9 percent confidence, you know, the lowest failure and then you add uncertainty for that to account for differences in design features, I think you would always predict fuel failure.

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

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

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

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

CHAIR ARMIJO: But that is a localized event.

MR. CLIFFORD: It is.

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

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

MEMBER SIEBER: Any rod.

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

MR. CLIFFORD: Okay.

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

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

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

MR. CLIFFORD: Absolutely.

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

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

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

MR. CLIFFORD: Correct. That's my point. That is something we need to throw on the table and talk about. Alternate two would be kind of to show using best estimate approach that you could either develop operator response times or change plant protection system setpoints or install new trips so that you would limit the envelope to something below two or three minutes, whatever you felt comfortable with.

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

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

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

There is one event off the top of my head, steam generator tube rupture where they have credited operator response in significantly less time just because they could demonstrate that the operators have been trained in that scenario and it was a multitude of instrumentation that would provide them with adequate information to diagnose the tube rupture and then respond.

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

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

The people that are trying to sell a nonresistant design in these situations would have a very difficult time, I think. I don't think it would put a burden on people -- there shouldn't be a burden put on people, licensees that are using a design solution that's been demonstrated as compared to people that are using something demonstrated to be very suspectable.

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

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

CHAIR ARMIJO: Yeah. You know, I'm a big fan of design solutions rather than operational solutions. The utilities, in fact, most of the utilities favor the design solutions but as we saw with the Susquehanna situation, that was not their solution. I had concerns that there were other reactors coming down for Extended Owner Uprates that were going to follow the Susquehanna approach which I believe is absolutely what the NRC should discourage.

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

MR. CLIFFORD: Right.

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

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

MR. CLIFFORD: No, we are not even there yet because right now the Standard Review Plan provides kind of a staff recommended methodology for showing that you don't fail fuel with three SAFDLSs. Although they provide a level of protection, Sam's concern is they don't specifically provide -- they don't provide a sufficient level of protection for PCI.

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

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

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

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

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

CHAIR ARMIJO: Right.

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

CHAIR ARMIJO: Right. I agree. One percent is for a different purpose but for PCI you have to demonstrate this and pick a number, two-tenths of a percent strain. I think people would have with conventional cladding a very difficult time doing it either two-tenths percent or demonstrate you have PCI resistant fuel and people take their choice. What is more convincing to the staff and what is the best way to solve the problem. I think all of these things to me could be made to work but I think what can't be done is that we can't kind of wink at it. It's there. The data are there. While it is a low safety significance, I don't disagree with you all of the reasons why the public is protected. The health and safety of the public is protected which is our primary goal but there is also the integrity of the Nuclear Regulatory Commission's self in that it doesn't let something like this go by with a wink. I think the Commission years ago jaw-boned the industry and I was on the other side of the table at that time and very wisely chose not to regulate before people had solutions. When the solutions were implemented and demonstrated, 1 percent stayed there, fuel melting stayed there, and the pot was right. I think when people started to say, "Well, we're not going to use those demonstrated solutions. We are going to go back to the things that gave the Commission concern years ago," we shouldn't let that happen by whatever means, regulatory or jaw-boning or threats or whatever you want to do but I think it would be very foolish to just ignore it.

MEMBER SIEBER: Well, without some kind of rulemaking or major change to the Standard Review Plan the only place that I see that you can deal with this issue the way Sam would like you to deal with it is to deal with the 1 percent because that is the only thing that is existing that you can use, David, to change. It would help me if somebody, perhaps our staff, could give me a copy of the Standard Review Plan section. I can search on my computer but it's a cheap computer and it's slow and I haven't got it yet.

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

MEMBER SIEBER: I would just like to read it.

CHAIR ARMIJO: Yeah.

MR. CLIFFORD: It is right there.

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

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

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

MEMBER RAY: Again, those surrogates are?

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

MEMBER RAY: Well, it sounds like Jack's point is correct that if we don't believe those surrogates are sufficient, I guess I'm trying to figure out what is the argument for their adequacy? No one has presented one I don't guess.

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

CHAIR ARMIJO: The incentive disappeared.

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

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

MR. CLIFFORD: Right.

CHAIR ARMIJO: It's still, you know, very important for those kinds of events and it's valid. We know that 1 percent strain is just too much strain for stress corrosion cracking phenomenon and so that would be the area where it would be legitimate to set a new requirement for stress corrosion cracking since you know that these things happen with essentially no strain.

MR. CLIFFORD: I think if we walk through the process of what we would do, each plant has its own licensing basis. It's not what the SRP says. It's what the FSAR says so each has its own licensing basis. What we are talking about here is trying to revise the licensing basis of each reactor. You just can't change staff policy and say here it is. There is a process you've got to go through. If we wanted to establish some new regulatory requirements, .2 percent or something much more analytical as far as show me you can model this for all fuel designs, show me you can predict it with high confidence and show me it doesn't happen for any AOO, then this is really just the staff would need to do. We would need to develop an independent mechanistic tool capable of predicting stress corrosion cracking to some measure. Then we would need to define the new SAFDLs and we would need to develop this regulatory guidance and potential testing requirements if we felt there weren't enough tests out there. Of course, we would have to get the public involved and the industry involved in workshops. Eventually you would revise NUREG-0800, the standard review plan, Section 4.2 which is what you have in front of you. It's not rulemaking.

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

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

I think Zena wants to say something.

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

MEMBER SIEBER: What is that reference again?

MS. ABDULLAHI: I can provide you for

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

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

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

MR. CLIFFORD: I don't disagree with what Sam is saying. I'm saying the way the staff has accepted -- the staff has set standards for themselves. The SRP is really an internal document but when the fuel vendors and each licensee when their methodology was approved we accepted something so that is part of their licensee basis and we would have to change that.

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

I don't think it needs to be a detailed mechanistic model. It should be mechanistic enough that you have confidence in it because you can set a goal. You can set the bar so high you can never finish on modeling. There is never a limit. It could be an empirical model and people have to come with you with data to demonstrate if they go up to this high power typical of a loss of feedwater heater event that they have tested enough fuel to demonstrate that it won't fail within 10 minutes or some number. The burden is on them. It is a recognized problem. The data is there. The 1 percent strain number doesn't protect you. At least that is my opinion and I think if you look in the literature you'll find more and more evidence of that. The industry just can't let it sit but I think this is a huge burden that will basically encourage the NRC to do nothing and I don't think that is what you want to do.

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

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

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

MEMBER RAY: Correct. That's right.

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

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

MEMBER RAY: Jack --

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

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

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

CHAIR ARMIJO: Paul, I think it's kind of a strange situation here because if someone comes in to you with a whole lot of test data and analytical data on a new fuel that is, say, an additive that is PCI resistant, and they are going to be here pretty soon, if not already, you are going to run them through a very tough ringer to demonstrate that their performance will meet your requirements including PCI. But here are guys that have been using something that is not nearly as good and somehow they are grandfathered. You've got to find a solution.

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

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

MR. CLIFFORD: Yeah, but --

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

MEMBER SIEBER: That's --

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

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

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

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

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

MEMBER SHACK: Can we do a quick flip

through the slides to see the next two?

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

MEMBER SIEBER: -- for RGC.

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

MEMBER SIEBER: Yes.

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

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

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

You go into some of the individual licensee reports and they are all predicting clad strains in the .6, .7, .8 percent strain. Looking at that data plus the data we have on PCI and the time data it says something is wrong here and we just can't ignore it. I think the staff has every right I think. I'm not a lawyer but I don't think there is a legal issue. I think this is a technical issue and the staff should find a way that makes sense that is practical that doesn't put enormous time burdens and resource burdens on itself for a problem that is created by the arbitrary use of a marginal design when other options are available. If you get so restrictive we could wind up like the Securities and Exchange Commission investigating Bernie Madoff for eight years and never doing anything to prevent him from fleecing his customers. I mean, you know, you shouldn't be so constrained by these criteria when you know they are not adequate. To me it's sort of Alice in Wonderland. I'm just wondering why the staff is so constrained and maybe Bill and you guys have got to think this through. There's got to be a way to handle this problem without enormous burden on all the innocent parties including yourselves.

MR. CLIFFORD: You know, the process of

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

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

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

CHAIR ARMIJO: That's a speculation. Let

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

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

CHAIR ARMIJO: Back-sliding they call it.

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

I'm arguing with Jack that the removal of that solution, not by the NRC but by some parts of the industry, now creates an adequate basis upon which the staff can take action. He's arguing that while there is this time in the past when somebody made a judgment that you didn't need to do anything notwithstanding the existence of a solution so now the removal of the solution means I still can't do anything and that seems to me to be flawed logic.

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

MS. ABDULLAHI: May I make a correction on that? GE Subsection 1.12(b) of Amendment 22 requires them to look at and demonstrate that for each fuel design that they will not -- the PCI will not occur. The 1 percent still applies. If you go to Subsection 1.1(d) of Amendment 22 it requires that if they have -- if the staff has any new concerns on the fuel design and the way you meet it that GE would have to answer it and NRC would have to review and approve it. I don't want to read it because I don't know what is proprietary and what is not proprietary. In any case, staff has another knob in their power for Amendment 22. In the past everybody was GE.

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

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

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

CHAIR ARMIJO: Stress corrosion cracking can occur during the AOOs. We haven't had it happen yet but we are pressing the fuel. Duty is getting tougher. We are putting more fuel at risk just numerically, not necessarily higher powers. Let's take the 20 percent power uprate in a BWR. You are pushing a lot more water through that same core. Core power density has increased. If you have a bypass of feedwater heater, you are putting a lot more water in. I don't know if the transient will actually be more severe, quicker, or the time response time that people are used to today is still good enough. All of those issues are put to bed by the use of inherently resistant design. To me despite all the regulations that say you get a free pass, the NRC has to do something and say it better than that. I don't think it should take years and an enormous burden on the NRC staff to do something that puts the burden on the licensee that wants to use marginal materials to justify. I don't think there is going to be an army of those guys but if there is, all the more reason to be prepared.

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

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

We appreciate the opportunity to make a few comments today to support this important task. First a couple of points of background. We are one of the vendors -- AREVA is one of the vendors that for years, in fact, has provided the options of both liner and nonliner clad. It's not that we, if you will, backslide to go away from liner clad. We have always offered our conventional product as it is called. We certainly don't consider that product, that nonliner clad product as marginal in any way. We feel not only does it meet all the regulatory requirements but it also meets our expectations of fuel performance for the life of the fuel.

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

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

CHAIR ARMIJO: I would just like to make a comment. Current fuel is failing. Equivalence of number of fuel failures of AREVA fuel I'm not privy to that but if the mechanisms are not PCI mechanisms, there are other mechanisms going on, primarily debris. That's kind of a -- that just clouds the issue. I think the Hope Creek event could be analyzed. I don't know how severe it was. I don't know if the subcooling was 100 degrees or 50 degrees or 25 degrees. Whether you got through it or didn't get through it, who knows if there was a reason so you've got to analyze that. I think you have the information to demonstrate to the staff that this stuff is -- that your fuel could pass a real licensing basis analysis or an AOO. If you can't, then you have to do something different. I don't believe that AREVA would say that their PCI resistance of their liner and nonliner fuel are equivalent. If that is, I would be stunned.

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

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

MR. GALLIATO: We are also saying the delta between the liner and nonliner cladding, as you might expect from ramp testing data that is out there, published out there, or that we have run in our own proprietary database, shows a certain delta that is not necessarily transferrable to commercial fuel operation in a real plant. In other words, there are uncertainties. There are manufacturing variations. There are operator variations plant-to-plant that will, in essence, degrade some of the benefit that you might see from ramp testing from liner clad. I gant you liner clad does come as a benefit in a PCI related situation but I think the size of that benefit is not necessarily recognized in real life situations as it might appear from ramp testing.

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

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

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

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

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

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

We believe from our stress analyses and our modeling activities that we've done that those high-stress bundles typically would be the ones that have most recently seen a sequence exchange event. Based on that level of stress where they have not yet been conditioned, they are at a higher level of stress than most other clad in the core.

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

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

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

We want our customers to be successful. In order to do that we have invested lots of time, resources, and effort into developing fuel in either case, barrier liner clad or nonbarrier liner clad. We believe that both products meet the needs of the industry. In fact, both have performed fairly well. Based on the number of rods that we expect to be involved in an AOO type event, those being the higher stress type rods at the beginning of that event.

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

CHAIR ARMIJO: Well, you know, I'm sure everything you say is what you mean but I think the issue here is can you demonstrate to a technical body whether it's the NRC or your customers, that you have data and adequate analytical models to demonstrate that the margin to failure with your conventional cladding during the loss of feedwater heater event is adequate. Not just words but our data, good analyses that have been reviewed by the staff and I don't think you can. That is really the issue that we have as regulators to determine whether the staff really is persuaded by our concern or not. AcRS advises the staff and the Commission. Right now this is a subcommittee. We don't speak for the full committee. None of us do but once we do review this with a full committee there will be a position. It is a technical committee. My expectation is they will look for a technical solution or a technical answer. It is just not credible to me that AREVA takes the position that they will sell liner or nonliner and their equivalent --

MEMBER SHACK: Adequate.

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

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

CHAIR ARMIJO: Yes.

MR. GALLIATO: Thank you.

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

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

CHAIR ARMIJO: Yes, we can.

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

MEMBER SIEBER: True.

CHAIR ARMIJO: Well, I don't know if that is an absolute requirement. I don't know if there aren't situations where the PWRs might have an issue. That is beyond the scope of today's meeting. If it was determined by the staff that there was no PCI AOO issue in PWRs, then there is no reason for them to be subject to the same criteria if it's a BWR unique problem. I don't think that necessarily follows that the whole class gets punished for a problem for one or two people.

MEMBER SHACK: It can happen.

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

MR. CLIFFORD: I think that falls back

into what is your level of demonstration.

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

MR. CLIFFORD: Sam, I'm trying to read your mind. It sounds to me that you are looking more towards some measure of design margin, physical protection for PCI resistance for BWR fuel not necessarily revision to Chapter 15 with detailed 95/95 confidence predictions for each and every potential scenario at the worst time in life, worst conditions. That is my flavor. That is kind of like what I get from your discussions that option 3 is --

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

MEMBER SIEBER: You have another --

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

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

MR. CLIFFORD: Well --

CHAIR ARMIJO: Trying to jaw-bone people

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

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

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

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

CHAIR ARMIJO: How much of it carries over?

MEMBER SHACK: We are now pushing with the EPUs somewhere.

CHAIR ARMIJO: My point is the PCI resistance, you know, the industry has done a marvelous job in these operating restrictions. They have come up with elegant solutions to keep the fuel from fading from PCI. They have been doing it for many, many years for the people who have chosen to use conventional cladding and it works and it's very reliable. The problem is those tools aren't available in an AOO. You can't recondition up to 60 kilowatts a foot. There is no way to do it so it's going to happen and you are just relying on the intrinsic properties of the cladding and the fuel design. The improvements in fuel design, sure there have been. Pellets are in pretty little shapes and stuff like that, but that is amenable to analysis and demonstration to the staff. Hey, look, because of this, this, this, and this and this database we can demonstrate there is a very low risk of failure with this particular design. If it happens to be conventional cladding, fine. Just prove it rather than assuming. You got the point.

MR. MONTGOMERY: My name is Robert Montgomery. I'm with Anitec and I'm here today listening in trying to understand the situation. I think Dr. Shack has kind of summed my position up as well and that is we are in this situation where we have some design feature changes that have protected us in terms of normal fuel reliability, fuel operation during normal events moving into, I hate to use the word, licensing base but into more like the Chapter 15 event I think it changes the ball game quite a bit. I think as someone who would probably be tasked with coming up and making presentations to demonstrate this margin we are going to end up more in an Option 2 or Alternative 2 or 3 basis. I don't see how we can even be in Option 1 and 2 and not 3 because if I come up here and say I calculate X amount of margin, then how do we demonstrate that margin without very expensive tests. We are getting into this whole process of my code is better than your code and my calculations -- there is going to be a lot of work here is what I'm saying and it's not going to be a very straightforward process without either a lot of experimental data which was done in the '70s for one type of cladding and one type of material but it has not been done for other types of material. Or a very large amount of analytical work, or both really, I think, to cover all the basis.

CHAIR ARMIJO: There has been a lot of testing on various materials. There is a huge database already. Unless somebody has done something radically different in conventional cladding, and really there is only two things, stress relieving and recrystallized and Zirc 2 is no different than Zirc 4. All of this stuff has been done so it is a matter of analyzing the margin based on data. The data exist. You guys have a code. I'm not sure it's the best code but it's the only code that's out there that I know of that isn't proprietary and that's FALCON. You have a tool but, unfortunately, the staff doesn't. I believe the NRC staff should have a tool and shouldn't be dependent on the industry's analyses. I don't want this to turn into a massive effort, a burden on the staff when the real issue is the licensee has to demonstrate that he's got adequate margin. Demonstration, as Bill said, is the key either from existing data or existing analytical models or combinations of those things. You can't let it go unexplored or unquestioned.

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

MEMBER SIEBER: I think you need more than that. You need a foundation. The 1 percent strain has to come out of the standard review plan and be replaced by something that has been studied that we now consider adequate to protect against PCI failures. Then the next question is how do you impose that on licensees without a threat to the public health and safety. I'm not sure that's clear. It becomes voluntary at that point. That is a path forward as I see it.

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

CHAIR ARMIJO: Reload license would be a forward implementation.

MEMBER SHACK: I think more like a fuel change.

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

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

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

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

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

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

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

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

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

CHAIR ARMIJO: First the burden is on --

MEMBER SIEBER: The licensee is back here.

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

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

AOO.

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

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

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

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

MR. MONTGOMERY: I just had one, again,

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

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

MR. CLIFFORD: I think so.

CHAIR ARMIJO: I think that is pretty --

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

PARTICIPANT: What's the name of it?

CHAIR ARMIJO: See, what that chart is telling you, and this mixes up B ramps and A ramps. I just put all the data on because I didn't want to analyze it but the data is available. It belongs to the United States, if you will. Okay? You could analyze that data and you can see at lower powers, lower peak powers, it takes longer.

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

As you get low enough it will never fail. We have some data points that don't fail. Not every rod will fail but enough of them will that there ought to be concern, a lot of concern. If you demonstrate that, hey, look, whatever the staff picks as a number, the response time to arrest one of these transients they are satisfied that 10 minutes is enough, all the licensee would have to do is show that they have tested enough fuel to convince the staff that at these powers the time to failure is less than the criteria. You're done. I didn't say it was easy but I think you should have that data right now or else question why you're ignoring this problem.

MR. CLIFFORD: Thank you.

CHAIR ARMIJO: Okay.

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

CHAIR ARMIJO: This is standard recrystallized zircaloy 2 cladding, standard manufacturing. There has been slight changes over the years in manufacturing but when this work was done a number of different claddings were studied, recrystallized stress relief, Zirc 2, Zirc 4. There was a lot of hoopla in the industry at the time that there were very big differences. I think if the staff would review all the Halden data -- not Halden but Studsvik ramp test data and everything else they would come to their own conclusion of whether there is significant differences among the conventional cladding materials. I don't think you'll find much. There could be but you won't find much. There could be slight differences due to pellet shape and things like that. Fundamentally they are all susceptible to PCI. That is why the industry requires PCIOMRs for normal operating situations. If the cladding and design has improved so much, why don't you just relieve yourself of the burden of PCIOMRs. Is it PCI resistant? The answer is it's not so you still keep the PCIOMR but somehow when you get into the AOO space you think somehow we don't need anything and I think you do. Again, the whole purpose of this meeting is to exchange information, exchange ideas. Paul, I would like to see your backup slide, get copies of your backup slides of these alternatives. I know they are not vetted but I've got to make a report to the full committee on what we discuss and things like that.

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

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

MEMBER SHACK: Just a practical question. Suppose you had the FALCON code in Sam's data and you just decided it fit the data reasonably well. Do you really need your own independent code?

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

MEMBER SHACK: For an application you check FALCON. Everybody is going to end up checking against the data whether you're checking FALCON against the data or FRAPCON against the data. If the model doesn't fit the data it isn't going to work. If they both fit the data, yes, I agree. You address model uncertainty by having two different models that fit the data and, therefore, you see just how much variation I can have. If I wasn't in Chapter 15 space and I was off in some other space --

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

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

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

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

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

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

CHAIR ARMIJO: Sorry?

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

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

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

CHAIR ARMIJO: Okay.

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

CHAIR ARMIJO: Let me answer that question because that is an important question on a point you raised. We have had failures, PCI failures in barrier fuel. We've had also PCI failures recently in the last few years on PWR fuel. Every one of these cases has been resolved to be caused by the missing pellet surface phenomenon. The barrier fuel was never designed to resist a generalized strain or generalized stress. It only worked with a very localized stress. Pellet quality is key to fuel performance whether it's barrier or nonbarrier. Barrier is not capable of protecting you against pellets with missing pellet surface. We demonstrated it at Hope Creek. We demonstrated it with hot cell examinations at KKL, recent Westinghouse fuel failures, AREVA fuel failures. Everyone of them had a chip and a crack. Barrier's resistance to PCI with really high quality fuel, good pellets, is proven. In retrospect I look back at some of the early failures, why we had failures in some of our ramp tests of our barrier fuel, and I'm just speculating but it's not unlikely that we had some chipped pellet somewhere in there. Fundamentally we have proven with years of operation that this fuel is very resistant, very robust. As long as we keep the quality of the pellets up, it's got its inherent resistance. If the pellets are chipped, all bets are off and it's up to the industry to make sure. I think the industry is focusing. All the manufacturers are working on means to preclude chipped pellets. Like I say, we had some recent failures in PWR fuel totally unexpected. They were PCI. When they did their hot cell work they found it was right in the chip. I think there are such things as resistant designs and nonresistant designs but one fix doesn't cure every problem. The focus here is on conventional cladding and this problem. I appreciate the staff's ideas. I think we're going to talk about this some more. I like short and simple. I like demonstration. We'll see what the committee thinks. I would appreciate copies of your charts.

MR. CLIFFORD: I will e-mail them.

PARTICIPANT: Mr. Chairman, over here.

CHAIR ARMIJO: Oh.

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

DR. DAVIES: This one?

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

DR. DAVIES: Clearly.

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

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

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

DR. DAVIES: Indeed.

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

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

MEMBER RAY: Let me just read here now

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

CHAIR ARMIJO: Calculated or actual measures?

MEMBER RAY: Calculated. These are all calculated.

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

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

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

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

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

- 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 - ΔKw/ft
  - Rate of power increase - ΔKw/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

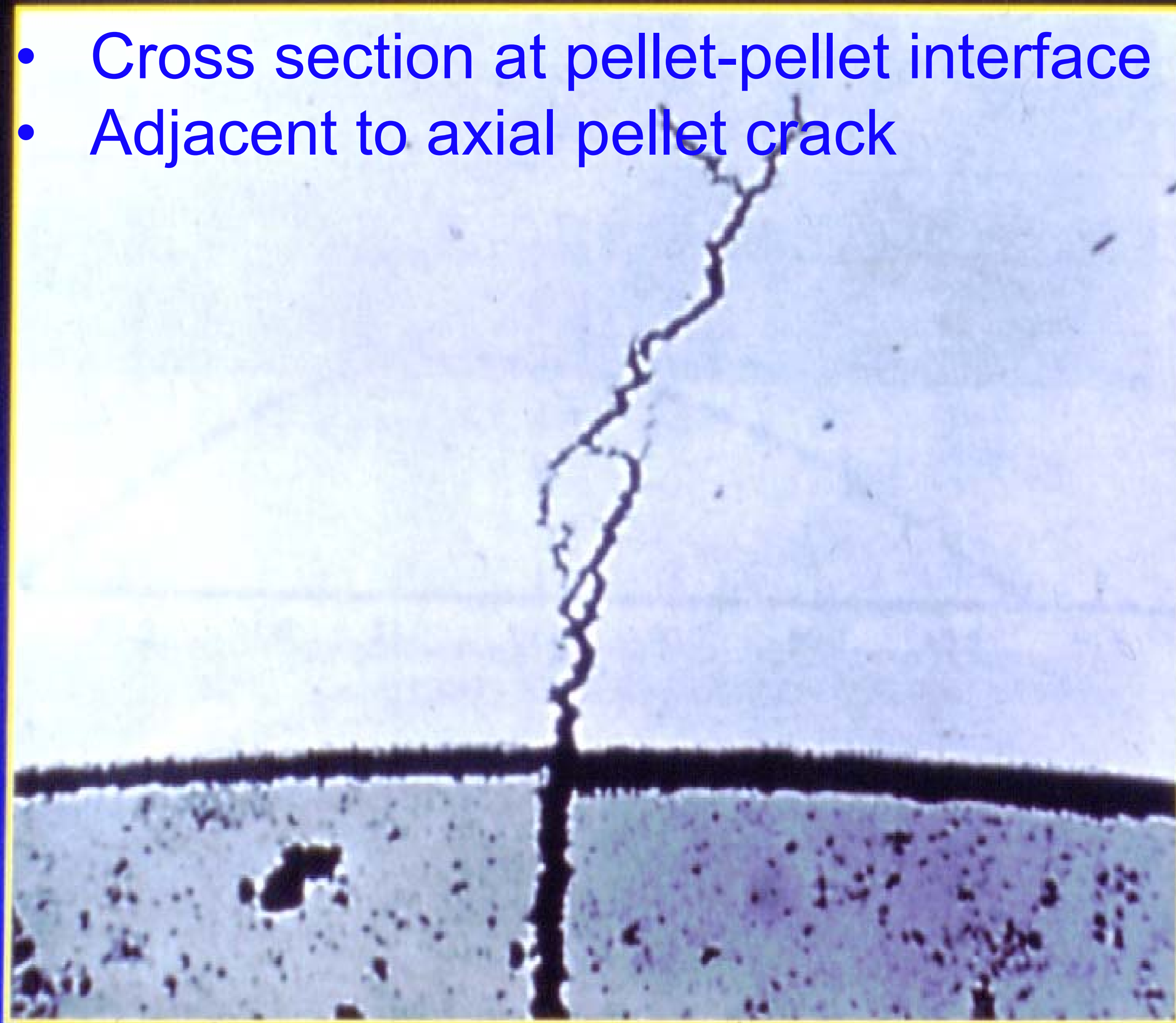
- PCI
  - Features
  - Mechanism

PELLET CLAD INTERACTION CRACK

- BWR fuel rod
- Typical axial crack
- << 1% plastic strain

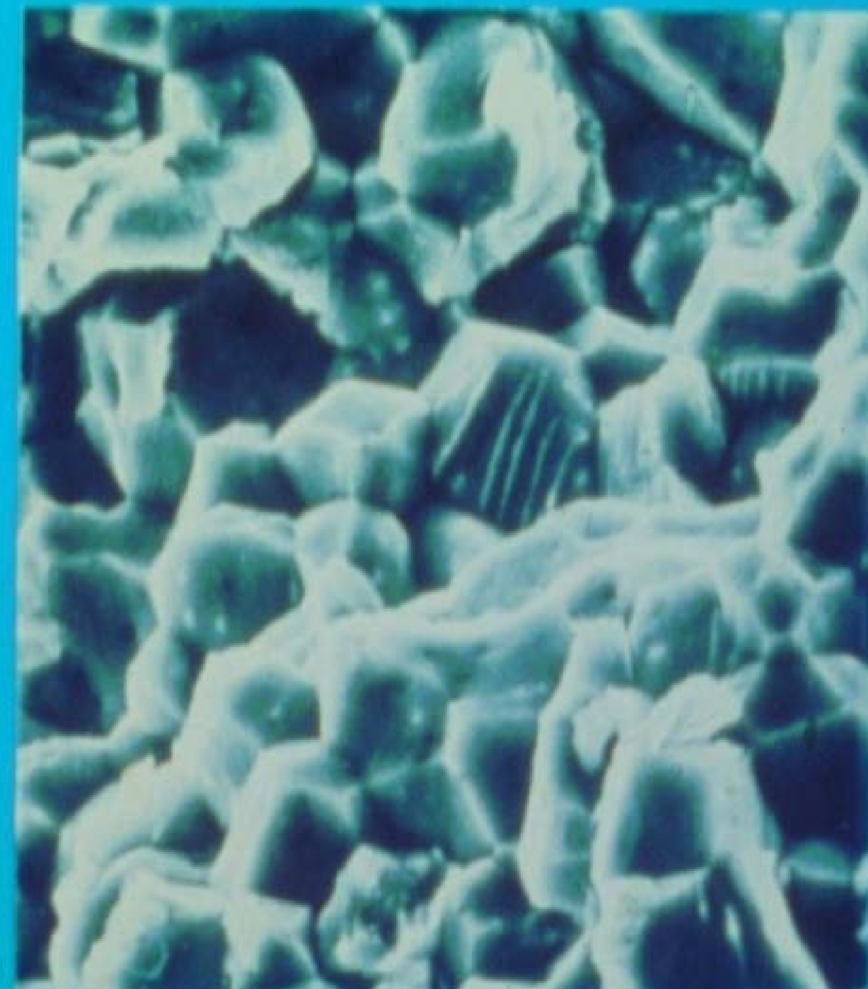
Branching in Incipient PCI Crack

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



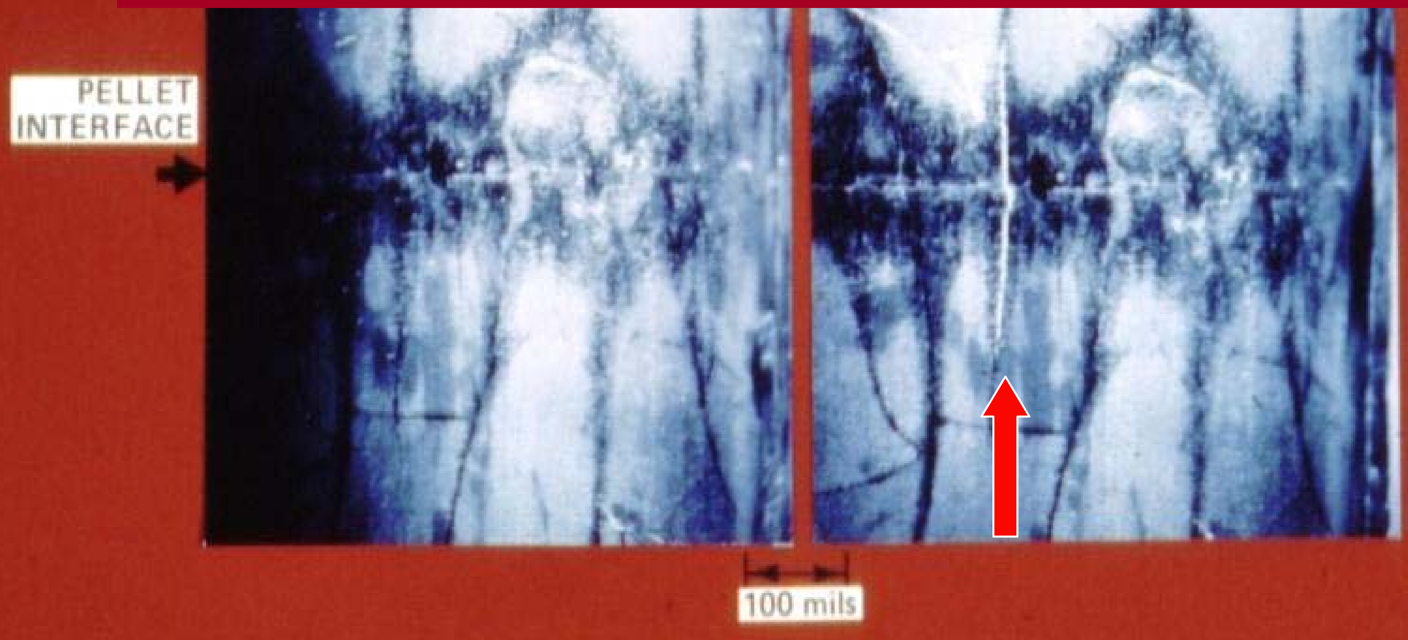
DETAILS OF FRACTURE SURFACE OF INCIPIENT PCI CRACK IN FAILED ROD

X1000



X3000

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



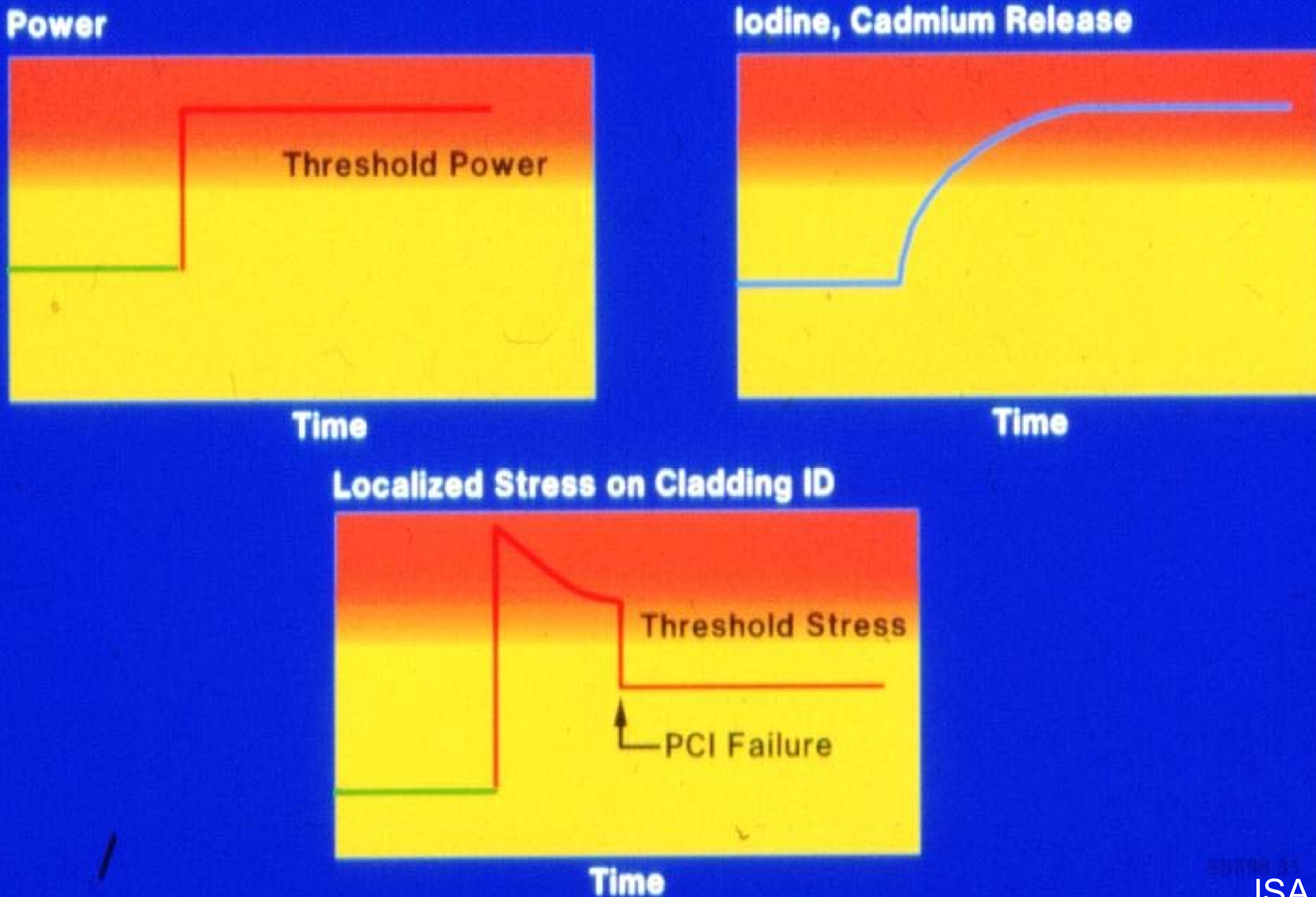
ANALYSIS OF CLADDING DEPOSITS

Element	Concentration Observed	(μgm/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

JSA 9

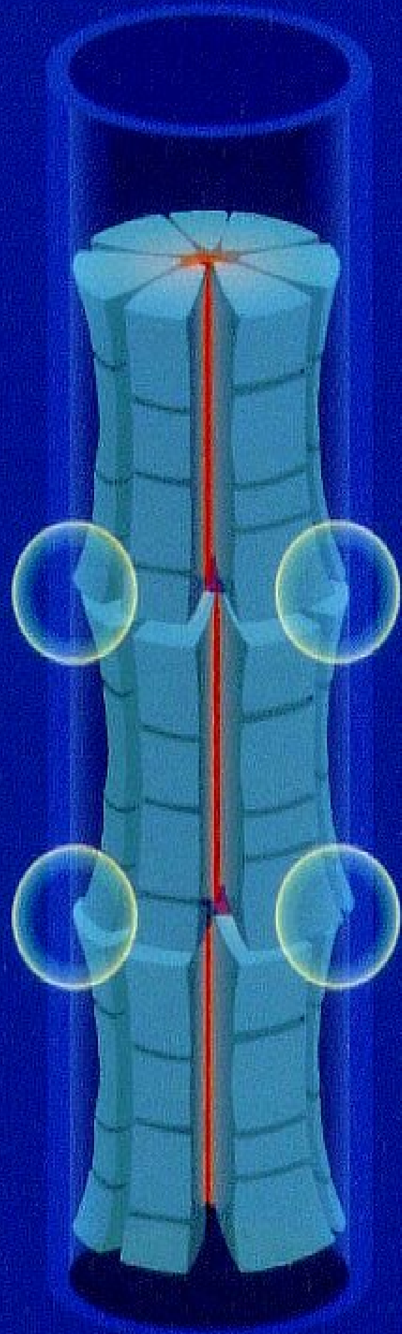
D255.24

POWER RAMP EFFECTS



JSA 10

PCI FAILURE MECHANISM



Maximum
- Biaxial Stresses
- Iodine, Cadmium

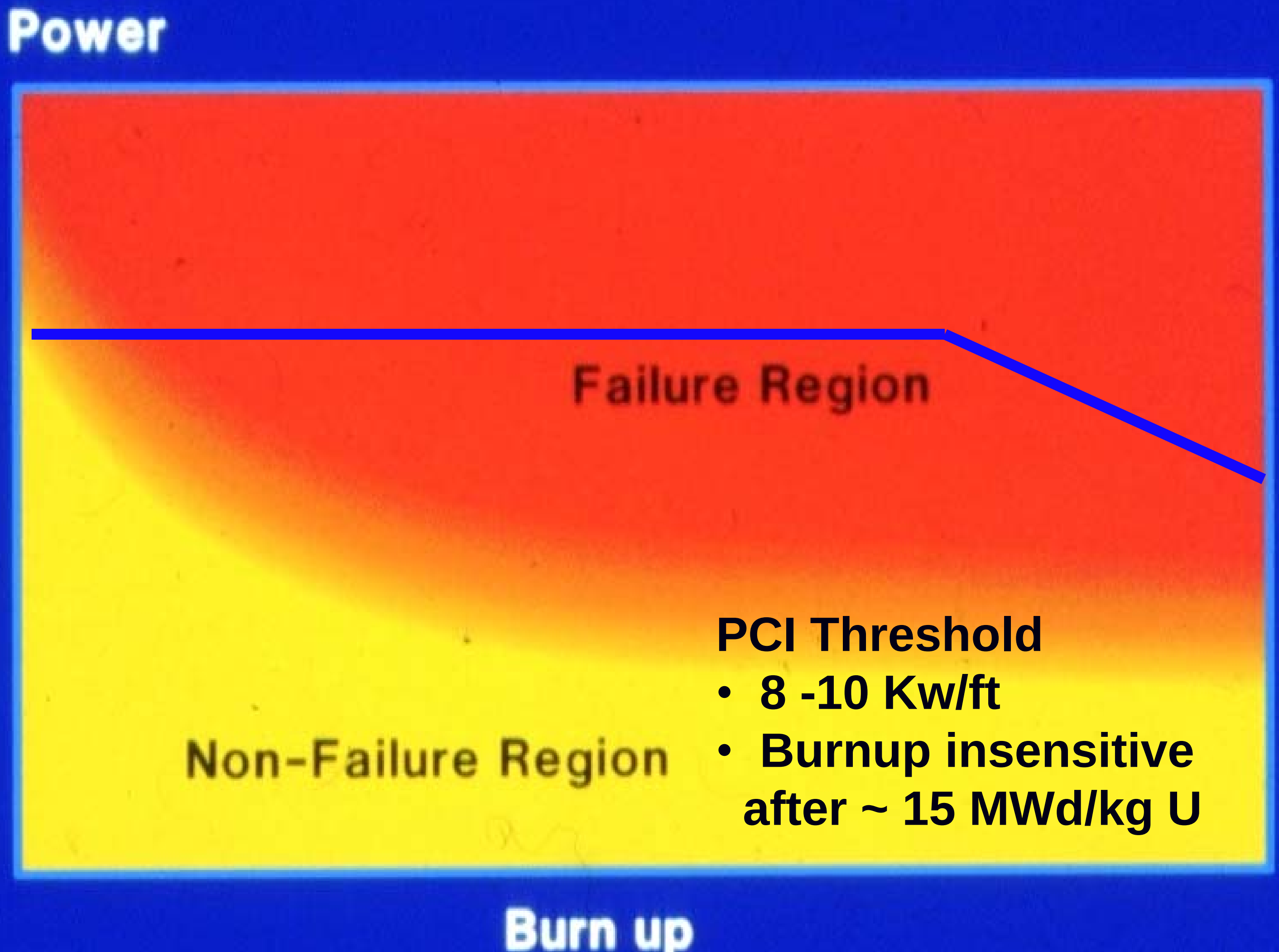
Axial Locking of Fuel Column
- Thermal Expansion
- Stochastic Stacking

SB398.20

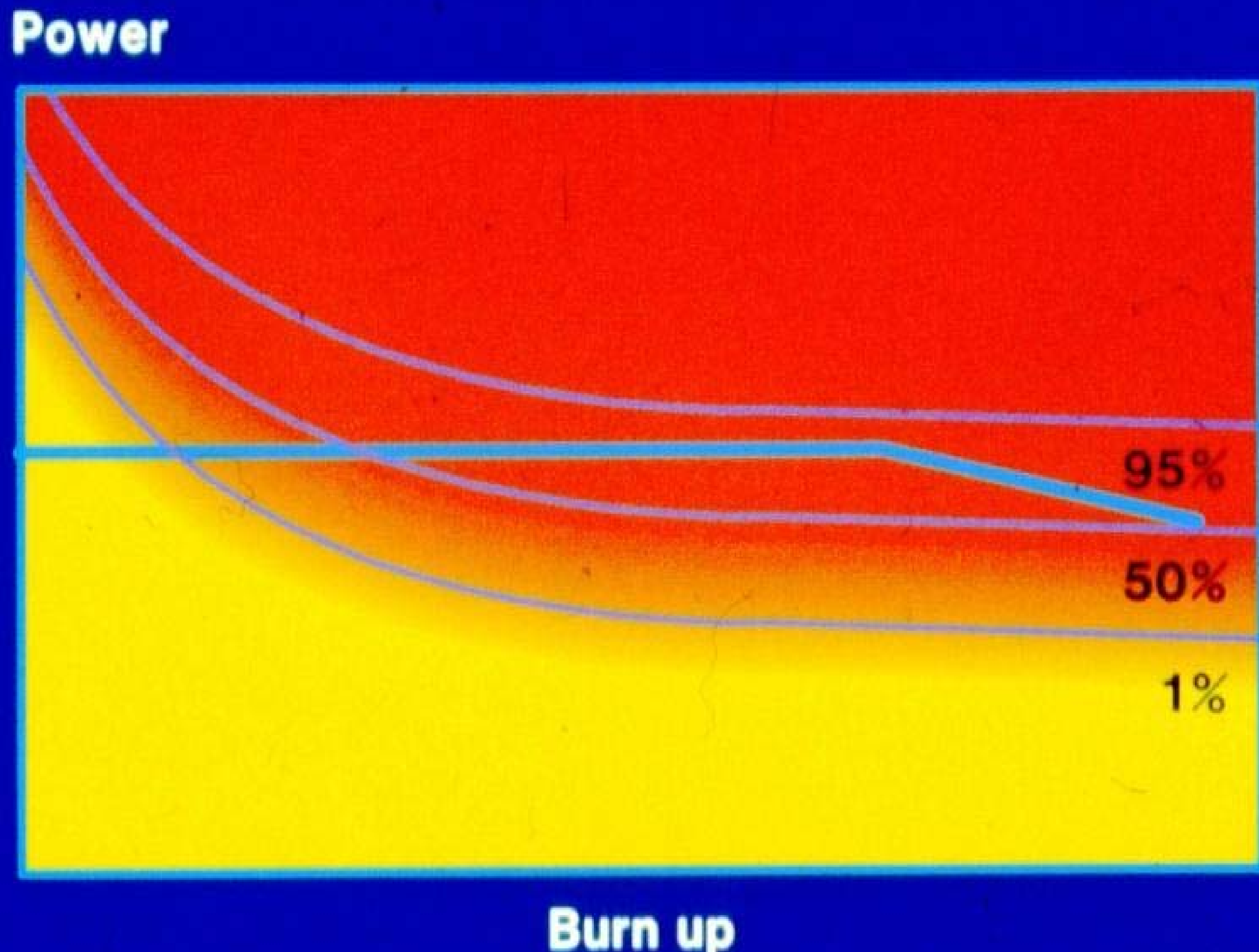
Controlling Operational Parameters

- PCI threshold power
- Allowable power ramp rates
- Preconditioning

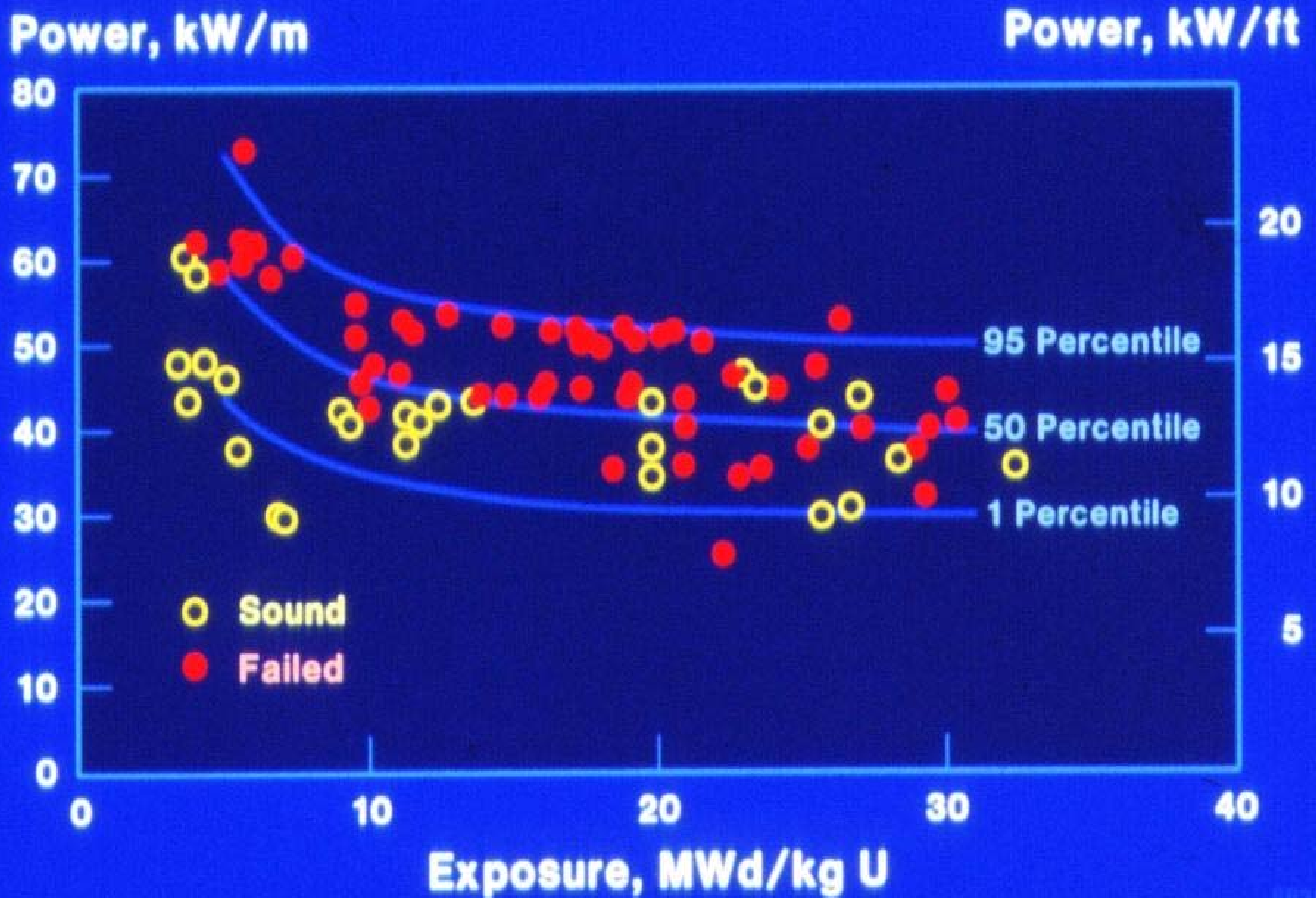
PCI-MAP


Power
Failure Region
Non-Failure Region
PCI Threshold
• 8 -10 Kw/ft
• Burnup insensitive
after ~ 15 MWd/kg U
Burn up

FAILURE PROBABILITIES



BWR STANDARD FUEL

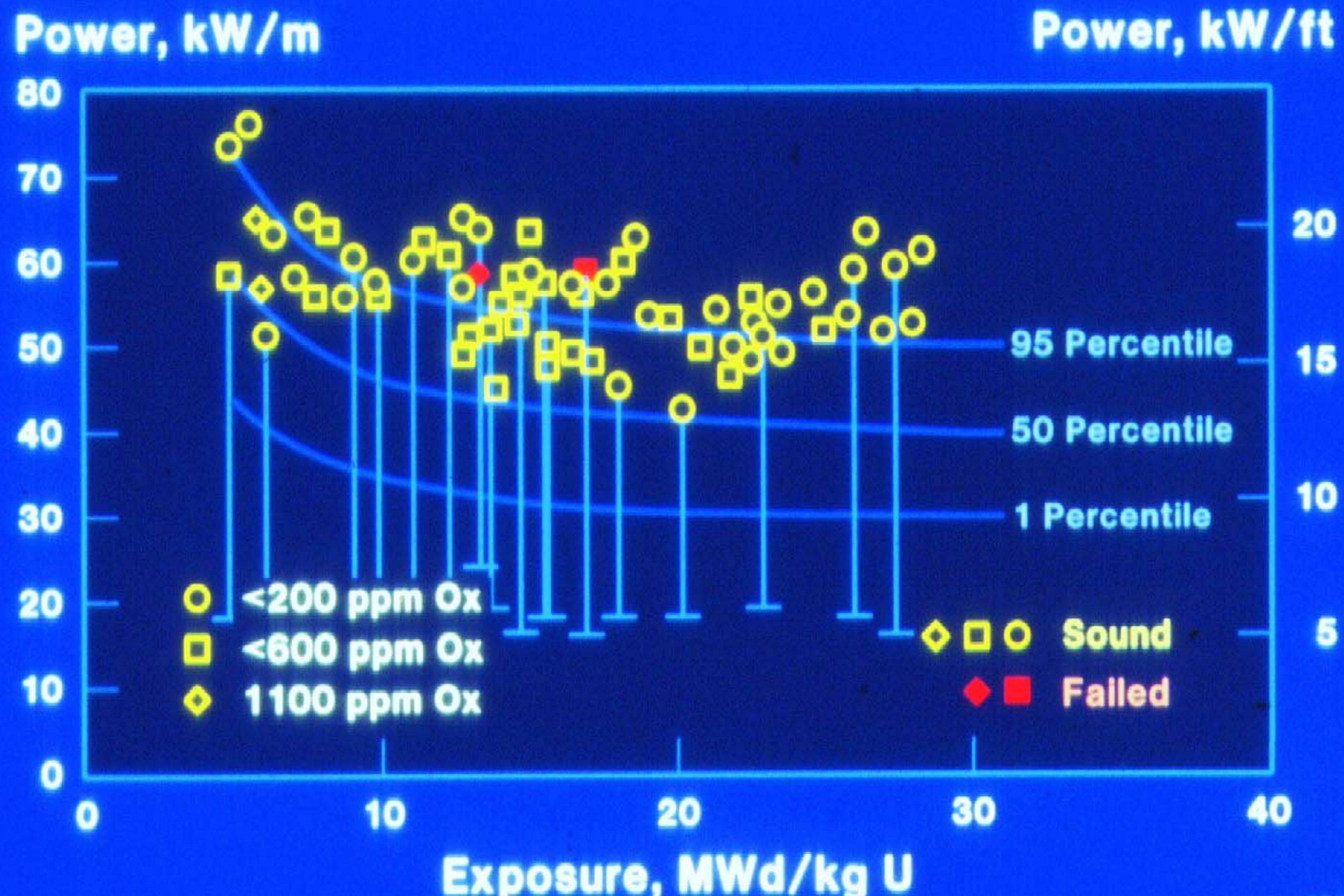


JSA 15

PCI Mitigation Options

- Normal Operation
  - Lower LHGRs (8x8 to 9x9 to 10x10)
  - Preconditioning
  - PCI resistant fuel
- AOOs
  - PCI resistant fuel
  - Prompt operator action

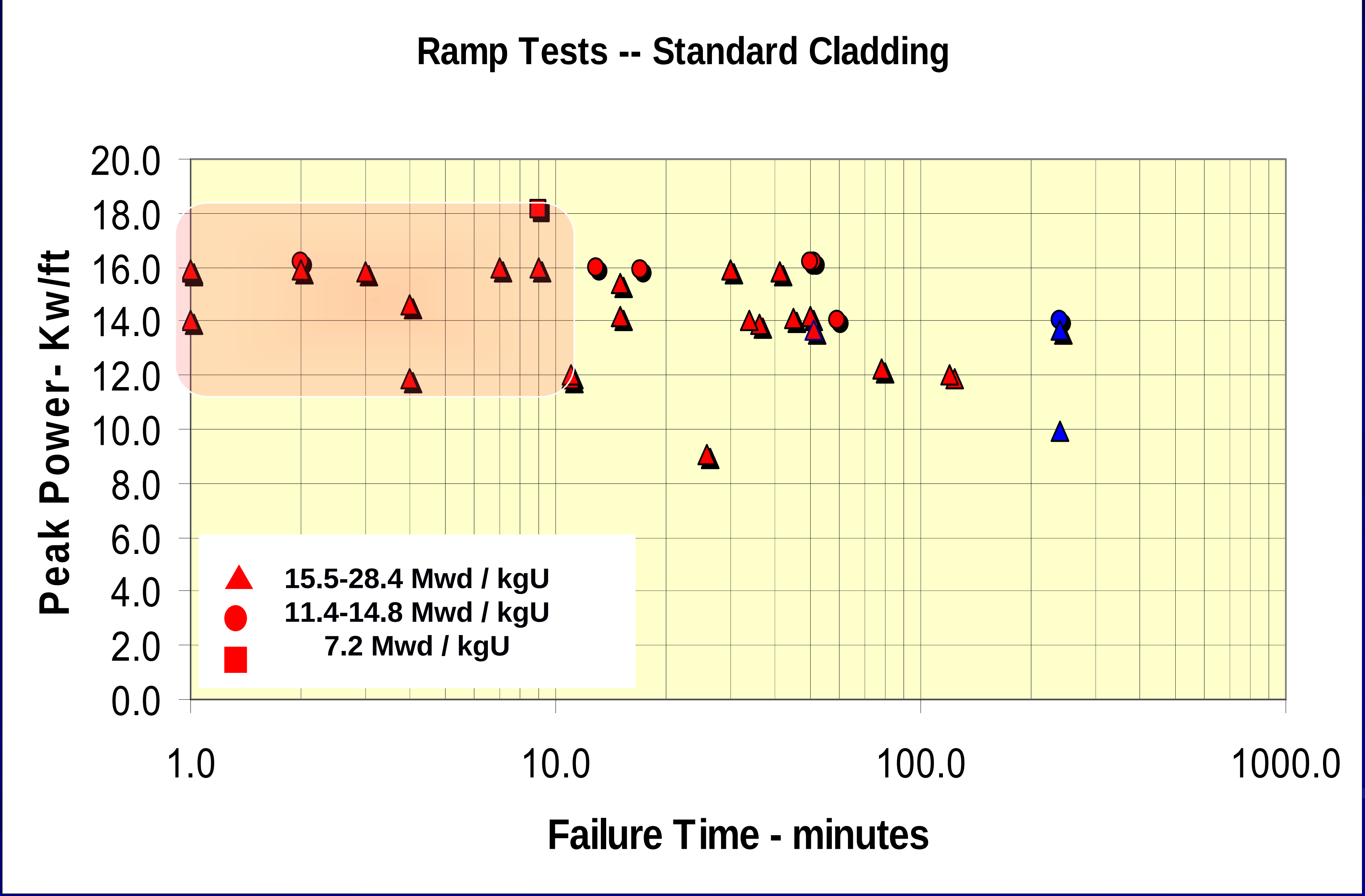
Zirconium Barrier Fuel



Reasons for Concern

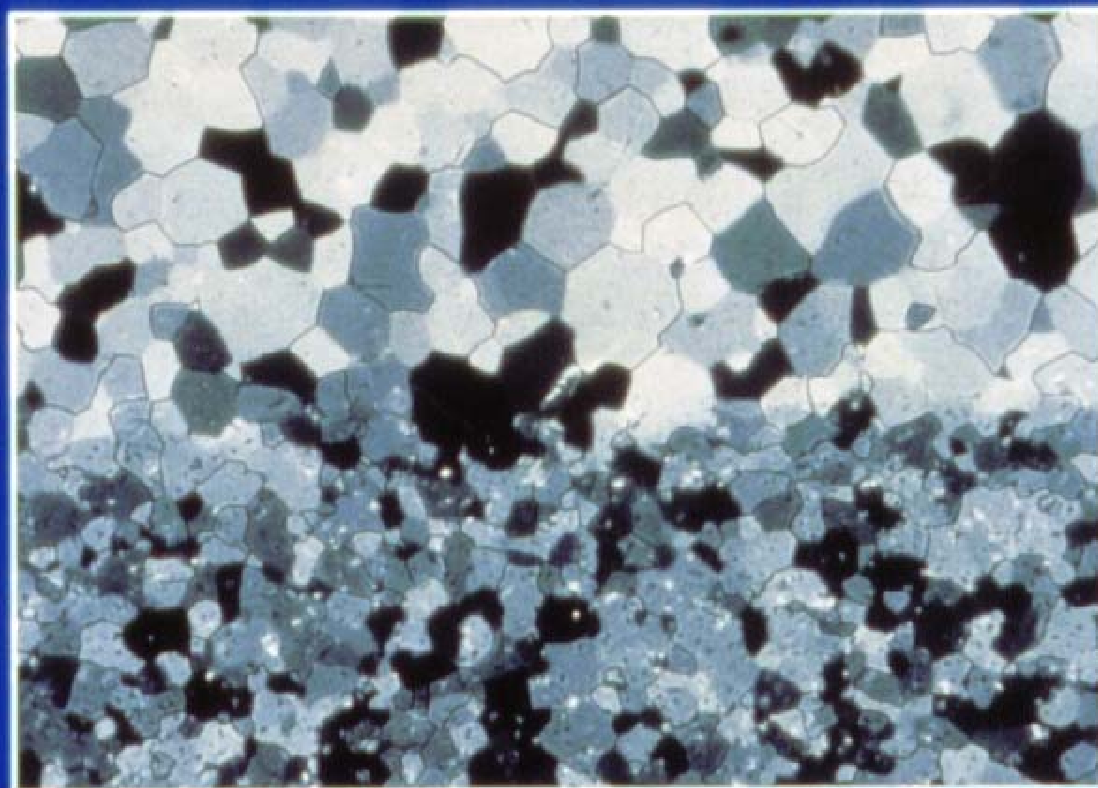
- Growing use of non-PCI-resistant fuel.
- PCI failure times are very short at AOO power levels.
- Early 10X10 mitigation benefit gradually lost.
- Number of fuel elements at risk during AOOs increases in proportion to magnitude of EPU.
- Inadequate analytical capability to quantify risk of failure.

Backups

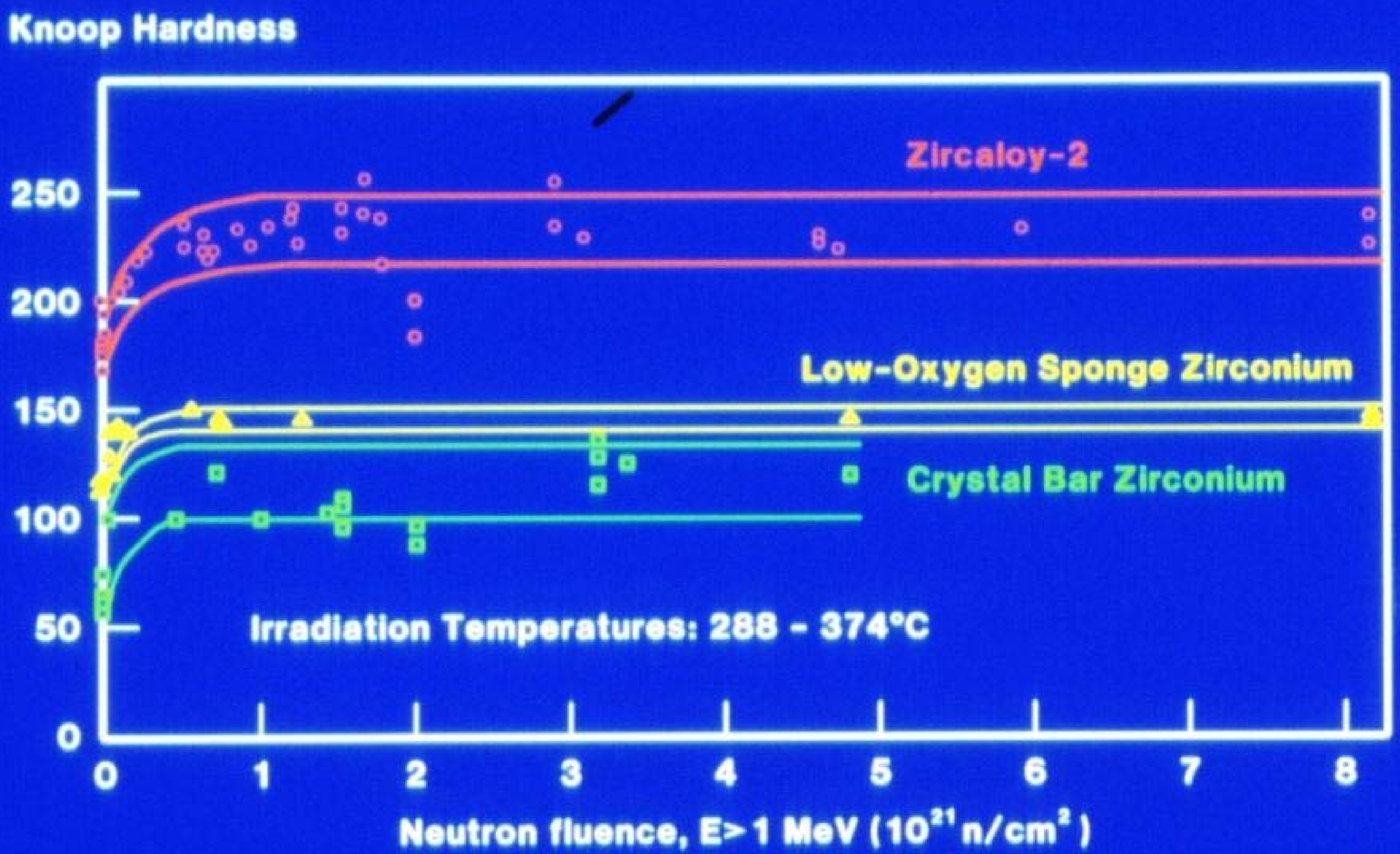

Ramp Tests -- Standard Cladding
Peak Power- Kw/ft
20.0
18.0
16.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
1.0
10.0
100.0
1000.0
Failure Time - minutes
15.5-28.4 Mwd / kgU
11.4-14.8 Mwd / kgU
7.2 Mwd / kgU

ZIRCONIUM-ZIRCALOY INTERFACE

Zr-liner Fuel Cladding

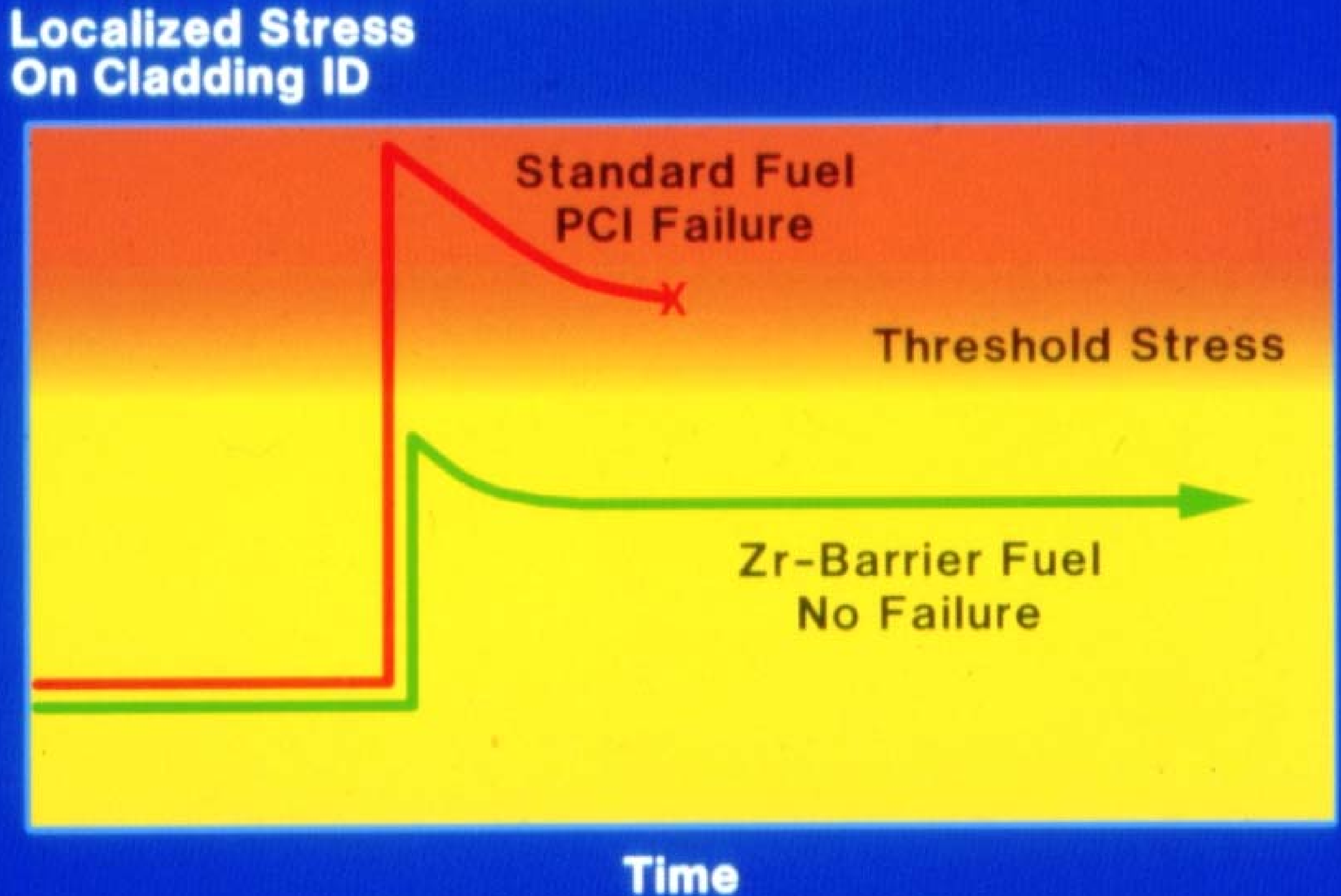


10 μm



Knoop Hardness
Zircaloy-2
Low-Oxygen Sponge Zirconium
Crystal Bar Zirconium
Irradiation Temperatures: 288 - 374°C
0
50
100
150
200
250
0
1
2
3
4
5
6
7
8
Neutron fluence, E>1 MeV (10^{21} n/cm^2)

Zr-BARRIER - PCI RESISTANCE MECHANISM

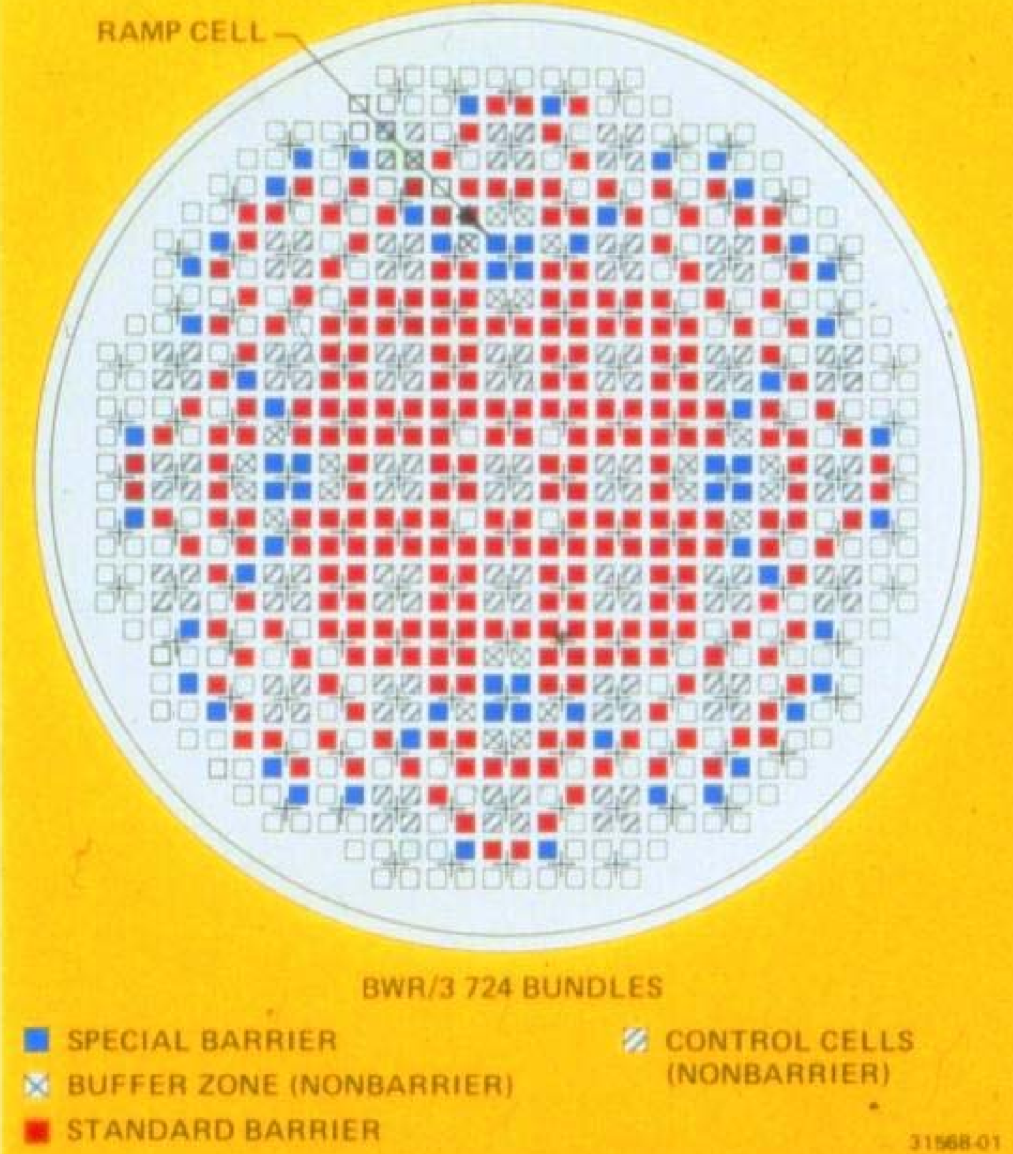


Quad Cities Unit 2

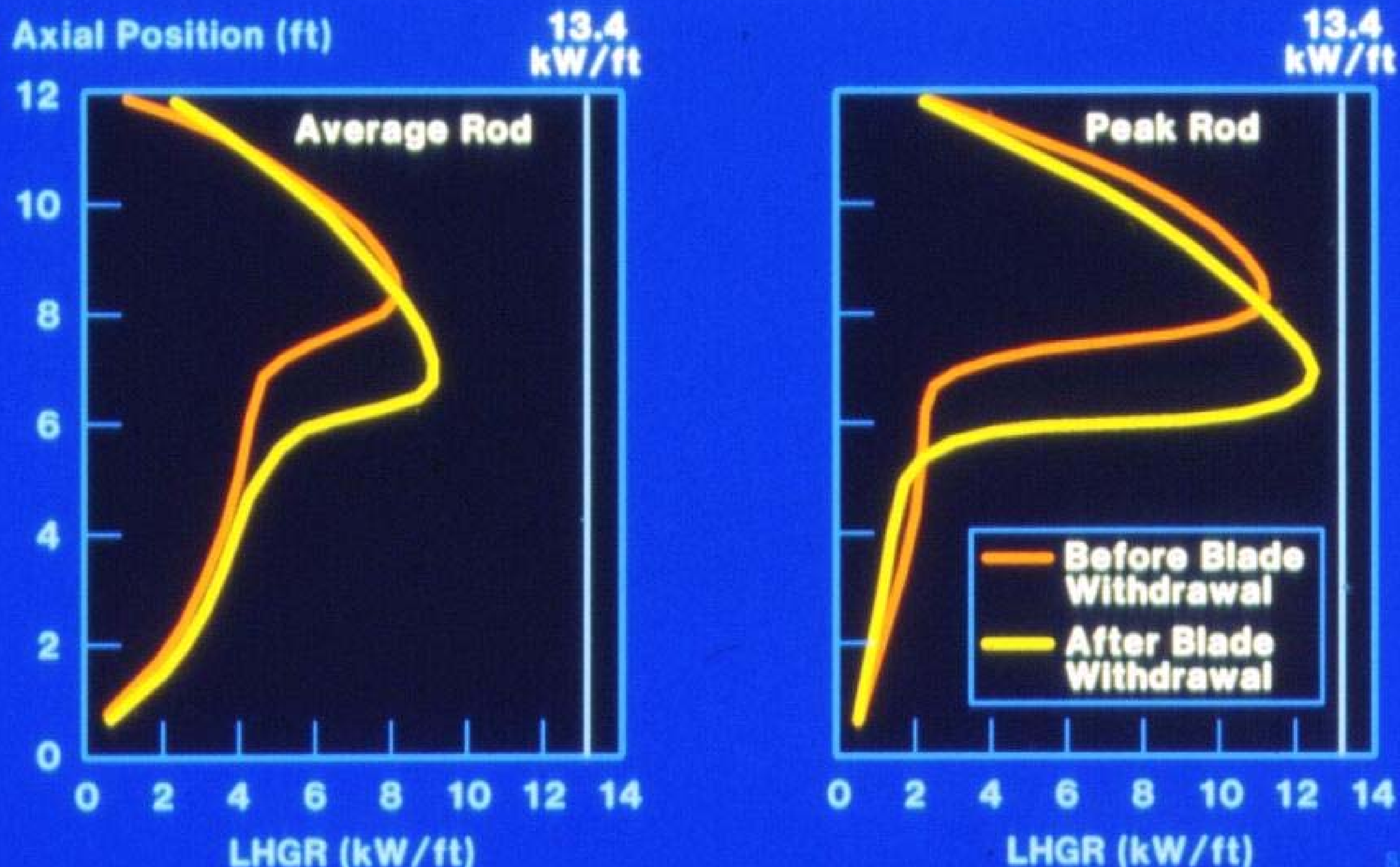
CORE CONFIGURATION

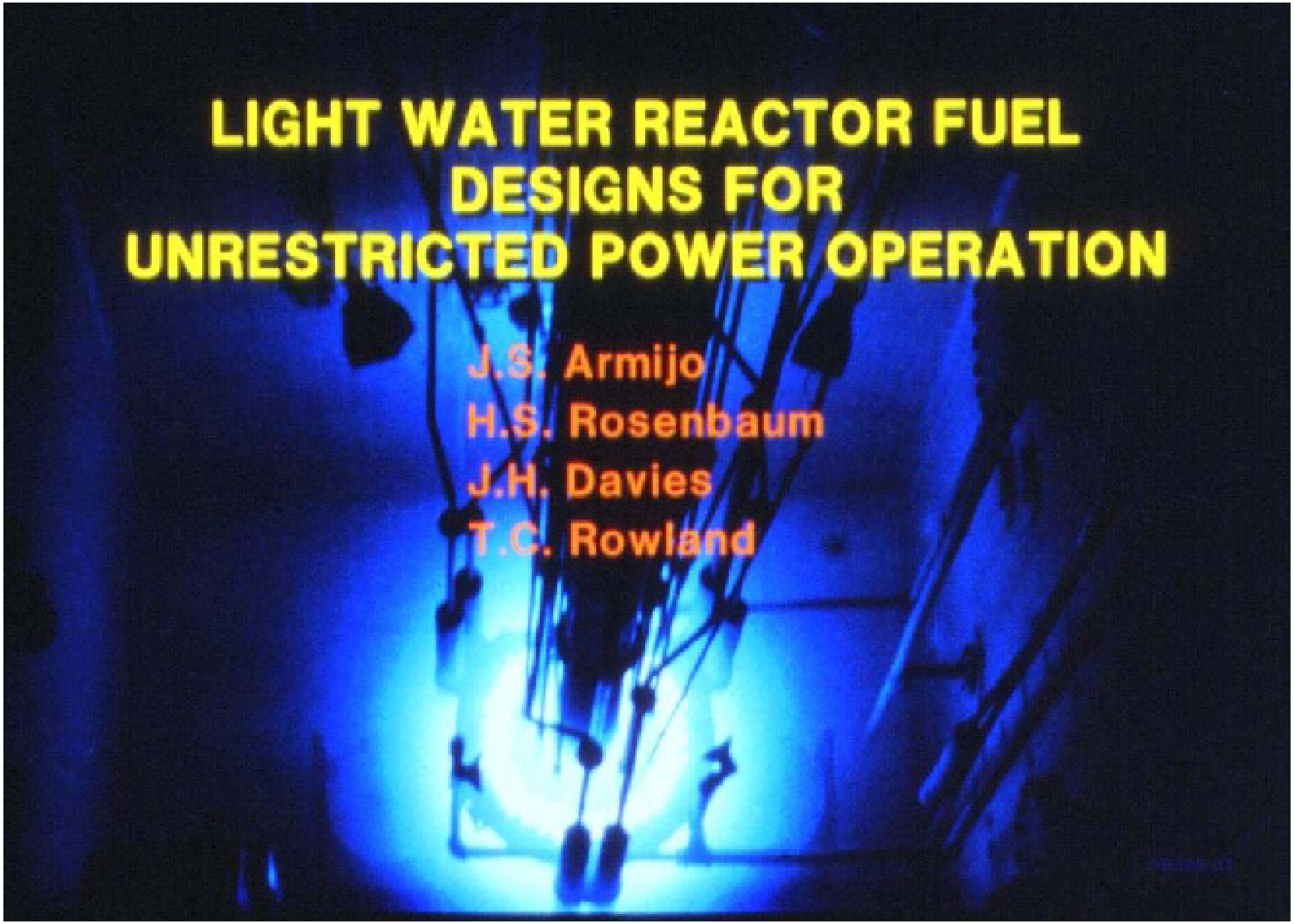
Cycle 7

(348 barrier bundles)



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
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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

UNITED STATES NUCLEAR REGULATORY COMMISSION
Protecting People and the Environment

PCI/SCC Regulatory Approach

ACRS Materials, Metallurgy & Reactor Fuels Subcommittee Meeting

March 3, 2009

Paul M. Clifford
Division of Safety Systems
Nuclear Reactor Regulation

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

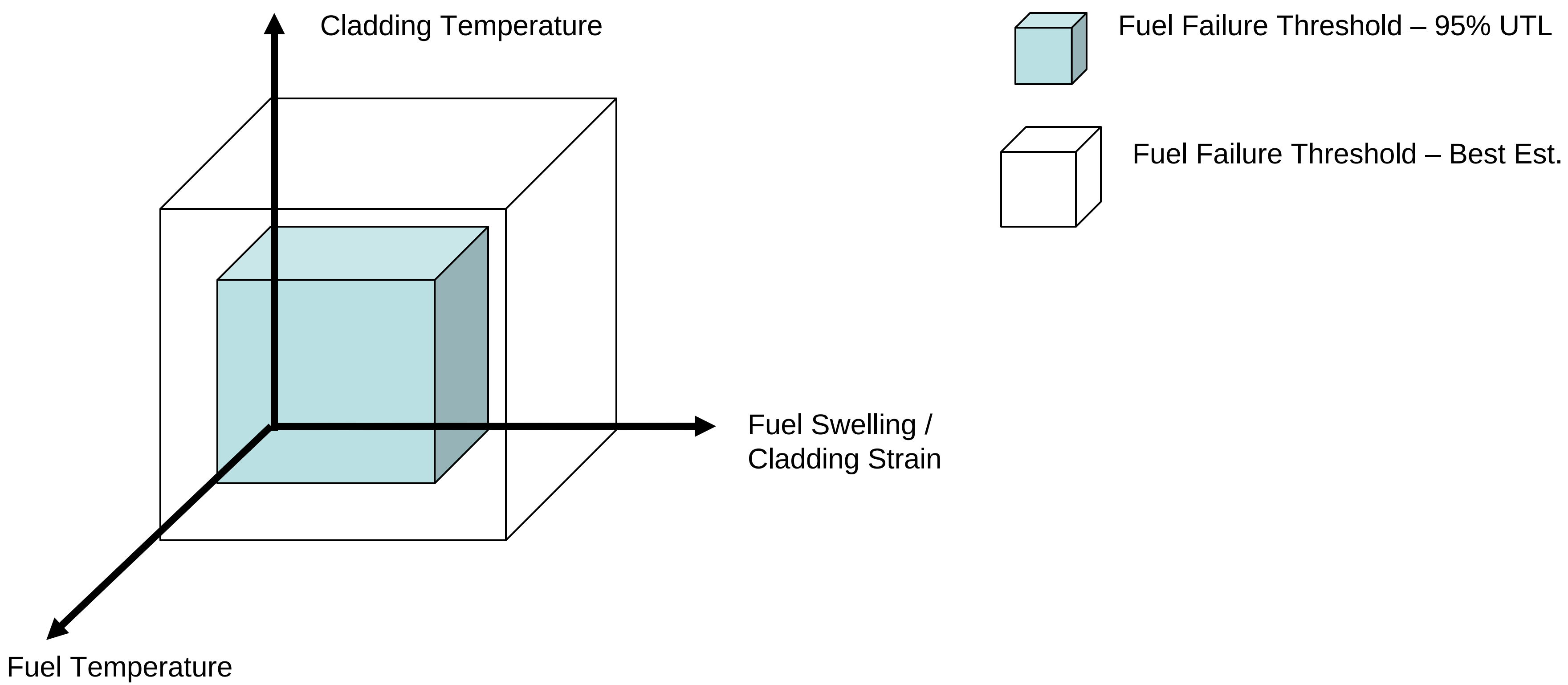
- Regulations specify performance requirements
  - May not impose specific design features (e.g. barrier liner)
- Regulations apply universally
  - Not restricted to “conventional fuel”
- All domestic fuel designs susceptible to PCI/SCC
  - Barrier fuel design provides PCI/SCC resistance, but not immune 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

Limited envelope on magnitude of power excursion

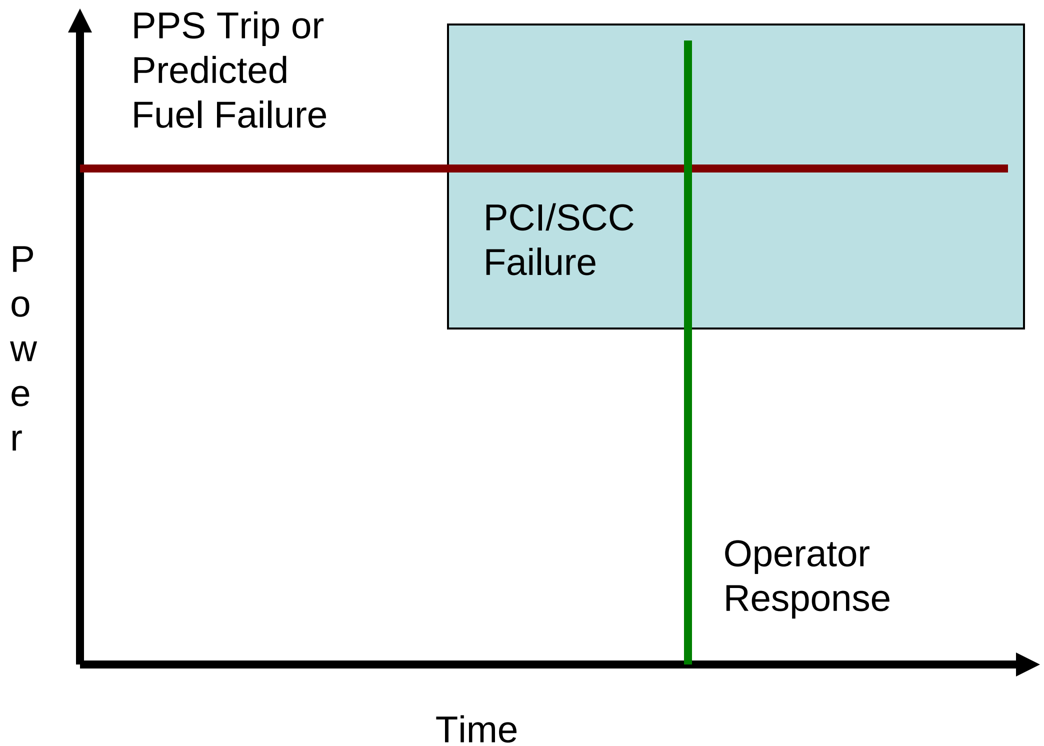
- Power level must remain below automatic trip setpoint.
- Power level must remain below level which results in predicted fuel failure calculated using conservative analytical models along with conservative assumptions and initial conditions.



Low Probability of Occurrence (cont.)

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

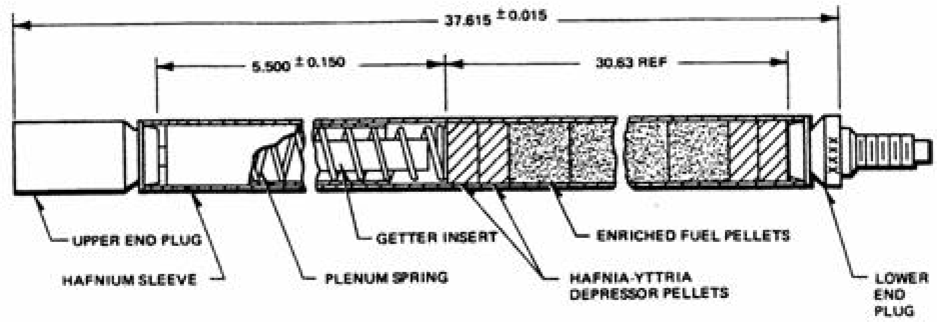
GENERAL ELECTRIC

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:

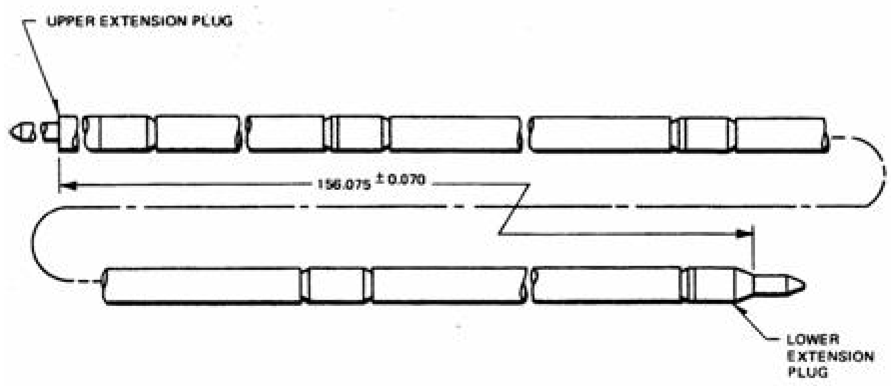
YEAR	NO. OF RODS	TEST REACTOR
1977	9	GETR
1978	12	Studsvik R2
1979	36	Studsvik R2
1980	27	Studsvik R2
1981	18	Studsvik R2
1983	11	Studsvik R2

- Hotcell characterization of ramp-tested rods



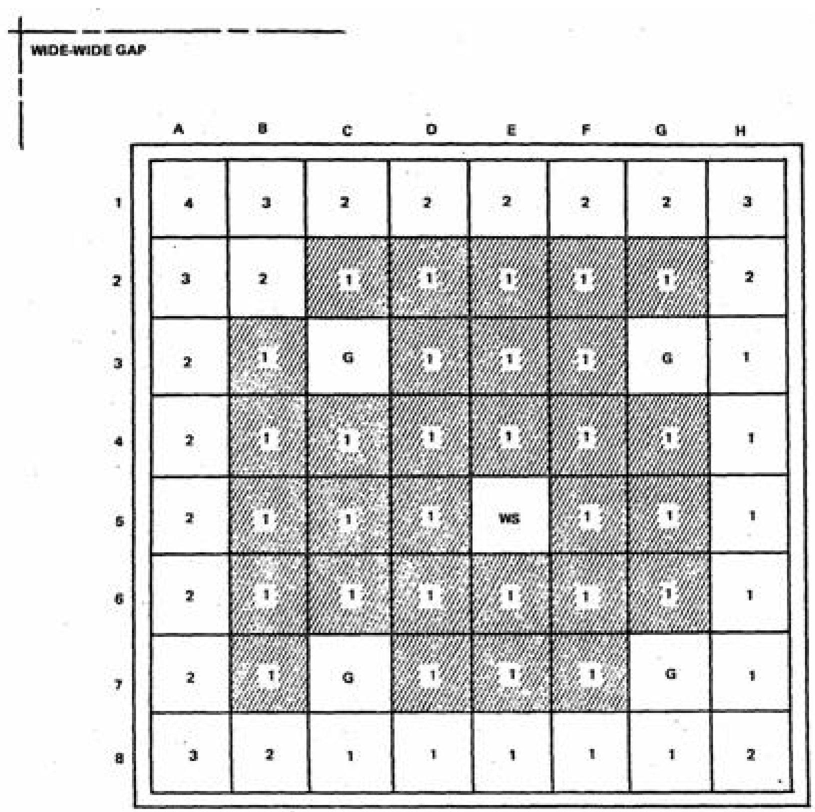
(DIMENSIONS IN INCHES)

FUEL ROD SEGMENT



(DIMENSIONS IN INCHES)

SEGMENTED ROD ASSEMBLY



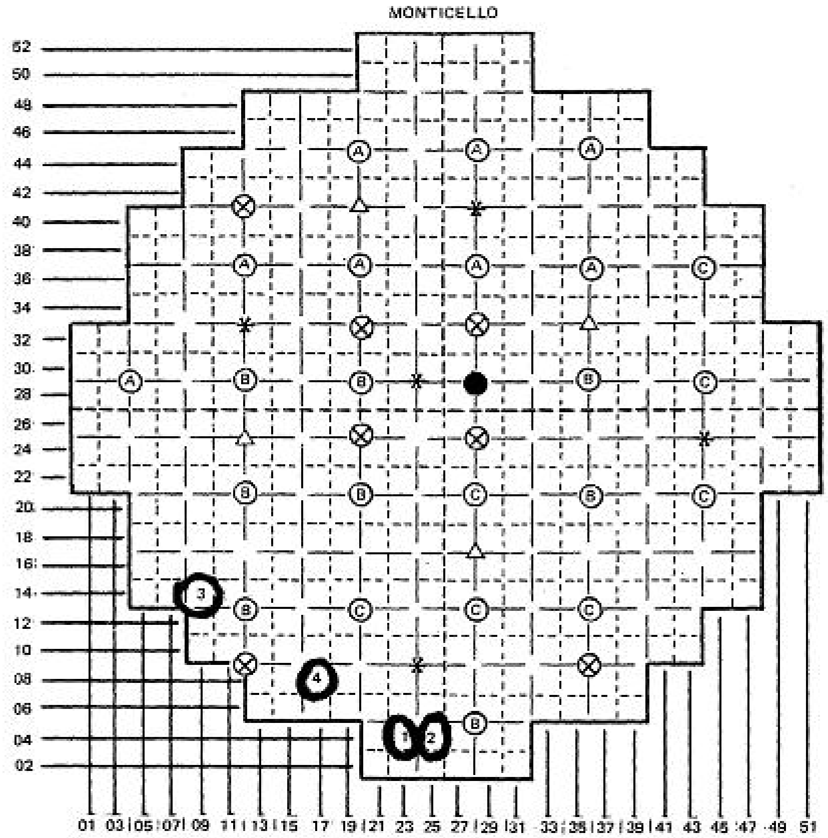
ROD TYPE	ENRICHMENT (wt % U-235)	NUMBER OF RODS
1	2.87	40
2	–	14
3	–	4
4	–	1
G	–	4
WS	–	1

WS – SPACER CAPTURE WATER ROD

G – GADOLINIA RODS (REPLACED BY SEGMENTED UO_2 RODS DURING FIRST RECONSTITUTION)

SEGMENTED RODS ARE CROSSHATCHED

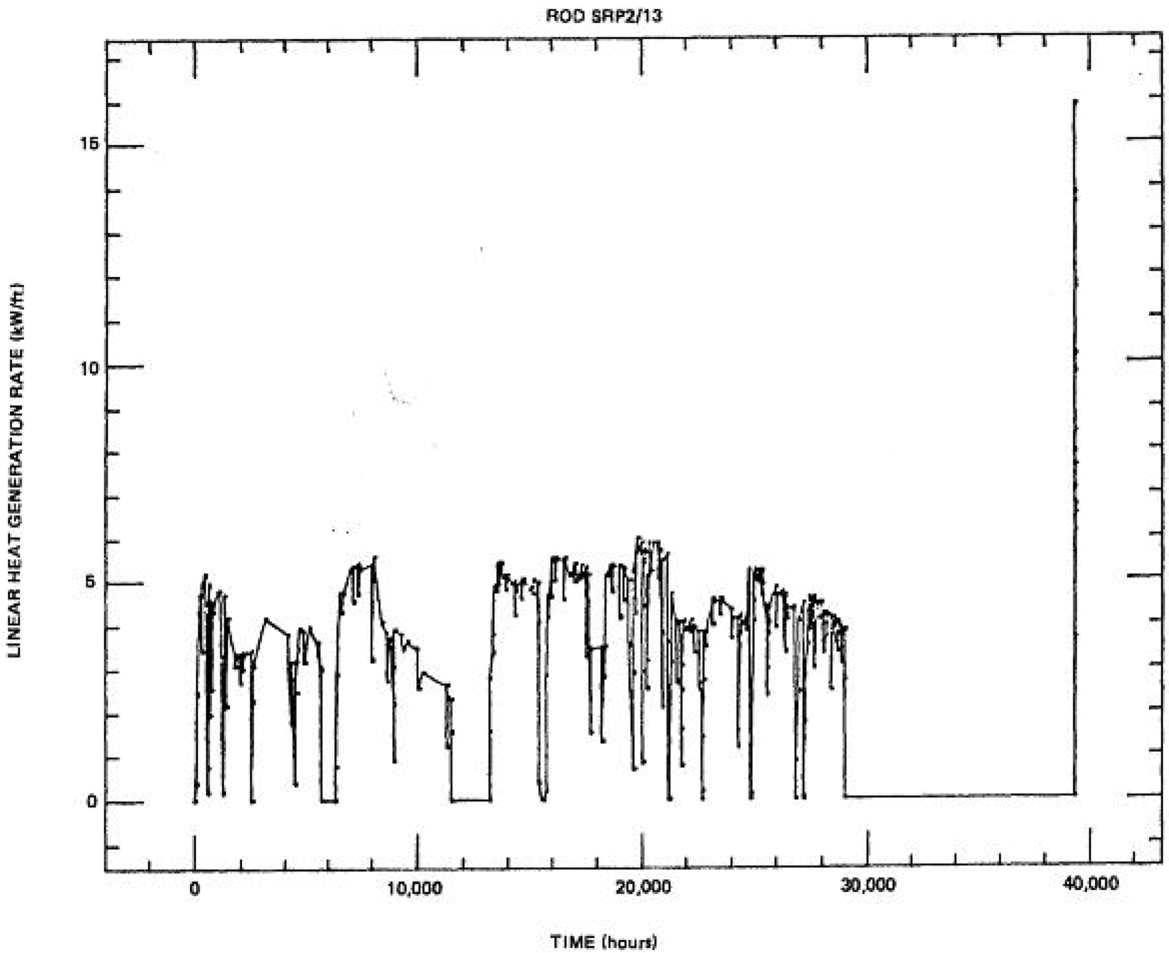
FUEL LATTICE - 8x8 STR BUNDLE



Ⓐ *LPRM LOCATION (LETTER INDICATES TIP MACHINE)*
● *LPRM LOCATION (COMMON LOCATION FOR ALL TIP MACHINES)*
⊗ *IRM LOCATIONS*
△ *SRM LOCATIONS*
* *SOURCE LOCATIONS*

BUNDLE LOCATION KEY
1. CYCLES 3, 4, 5 AND 7 LOCATION
2. CYCLE 6 LOCATION
3. CYCLE 8 LOCATION
4. CYCLE 9 LOCATION

SEGMENTED ROD BUNDLE LOCATION IN CORE

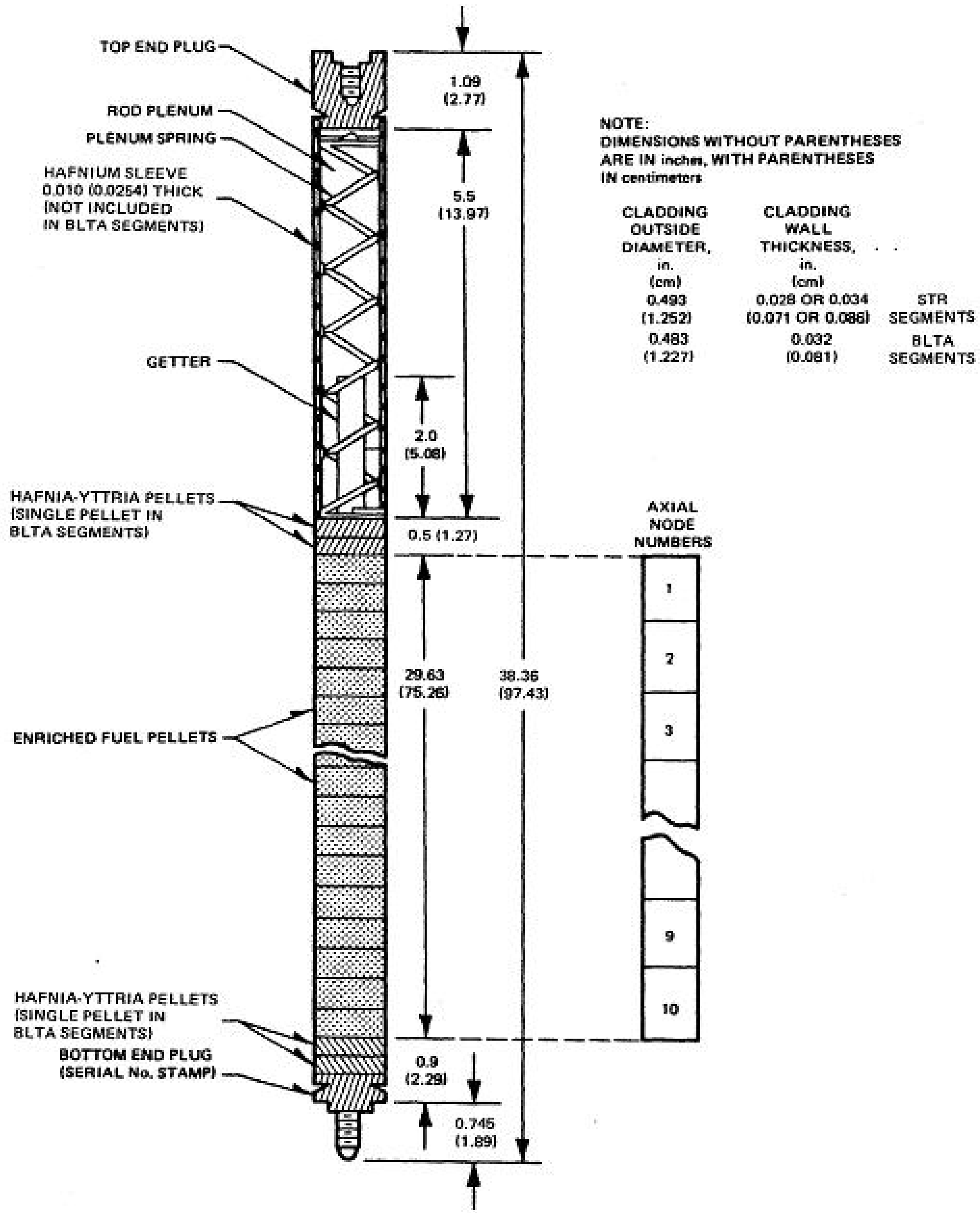


TYPICAL IRRADIATION HISTORY OF A FUEL SEGMENT
(including base irradiation and power ramp test)

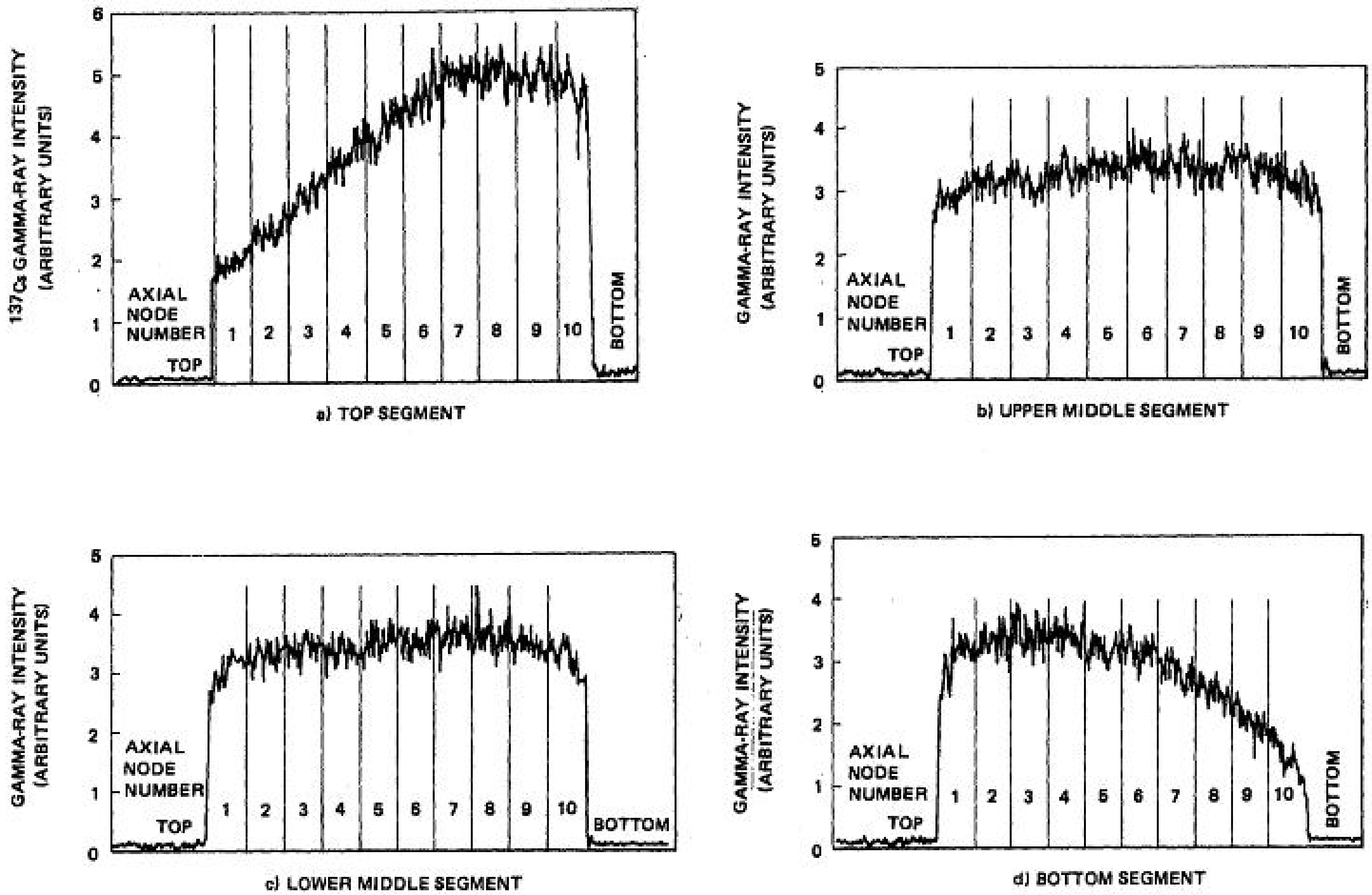
HOTCELL PRE-RAMP CHARACTERIZATION

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

- **Suitability for ramp testing**
- **Baseline mensuration data**

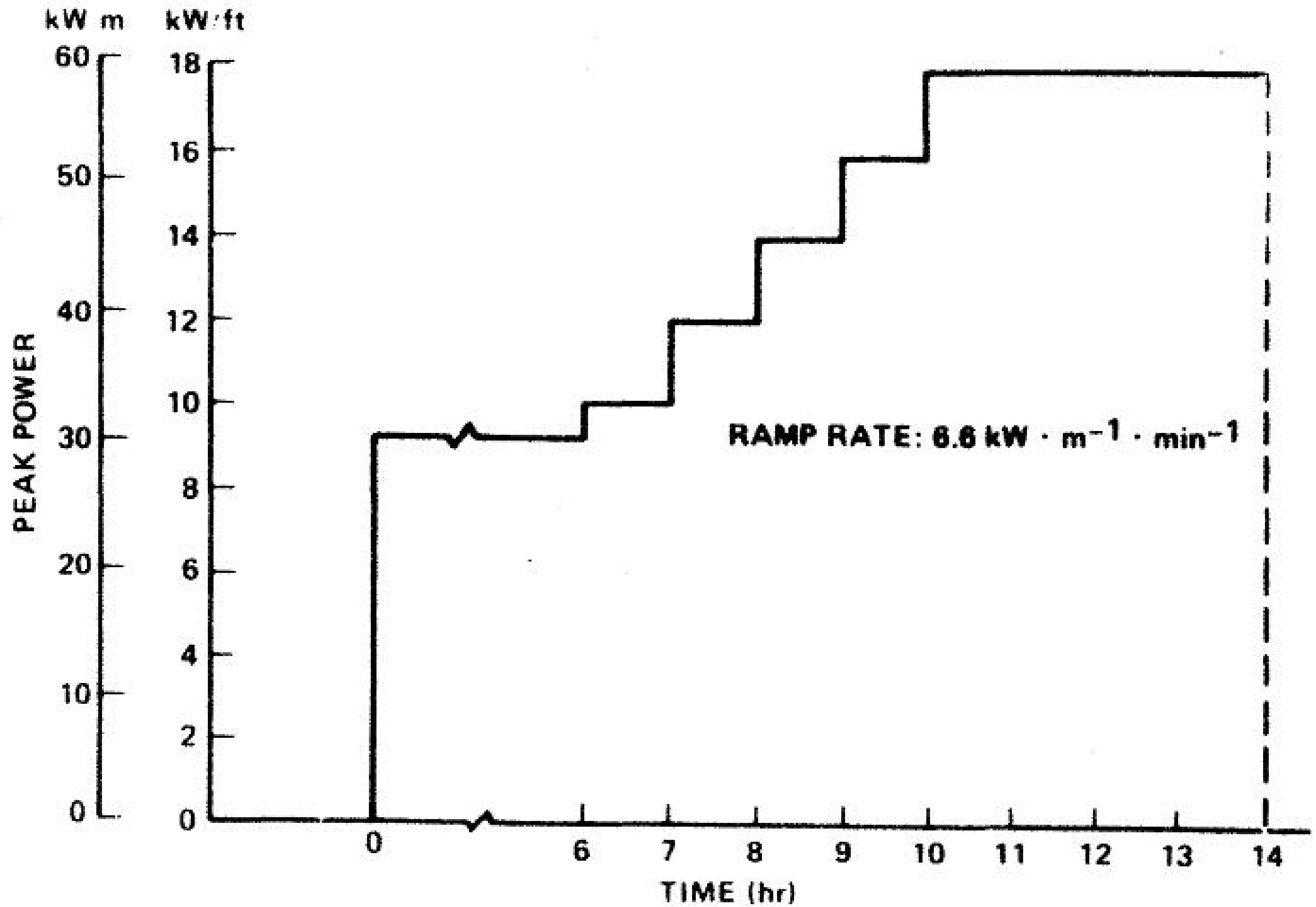


TEST FUEL ROD

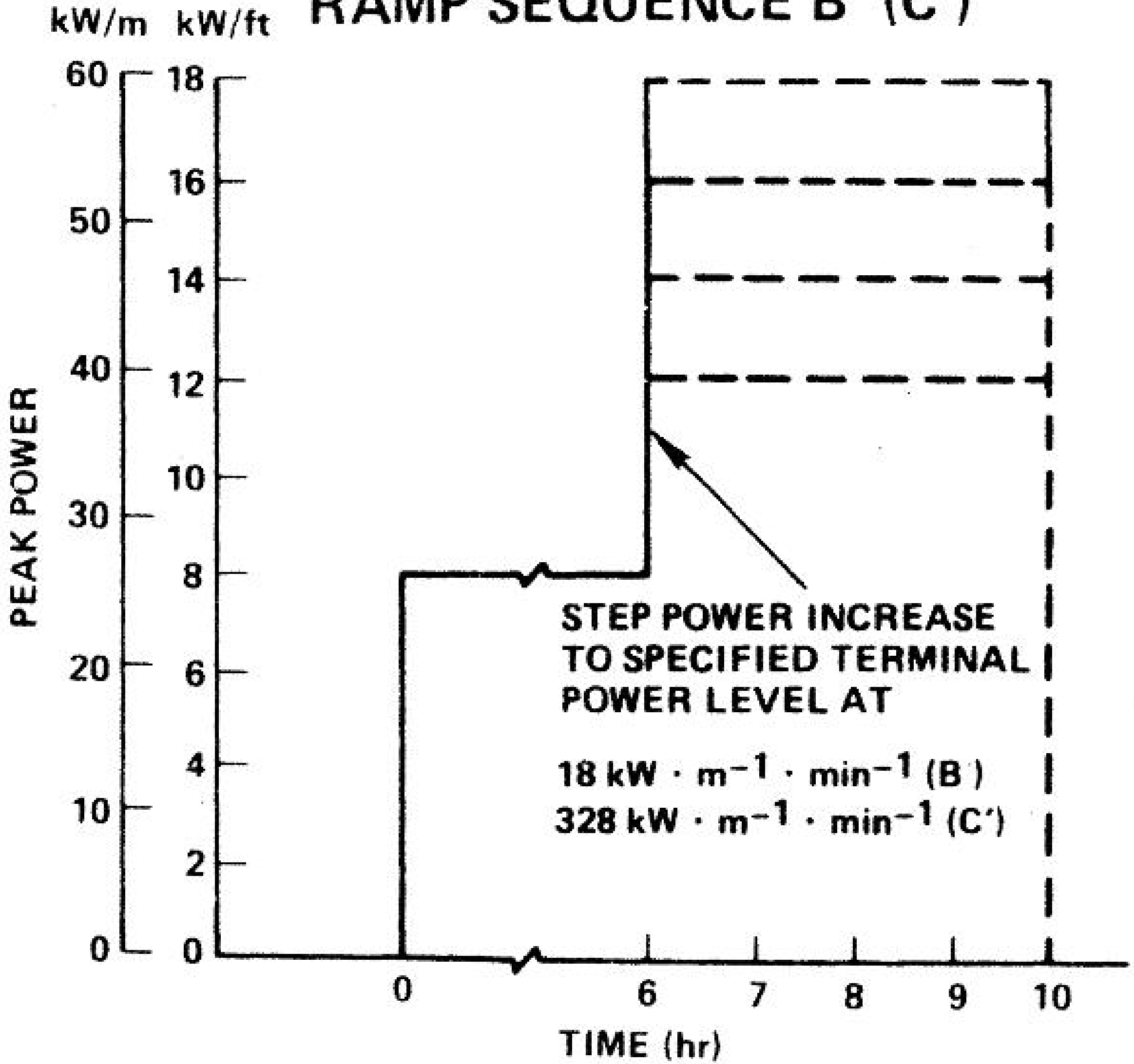


TYPICAL ^{137}Cs GAMMA SCANS OF FUEL ROD SEGMENTS
(following base irradiation)

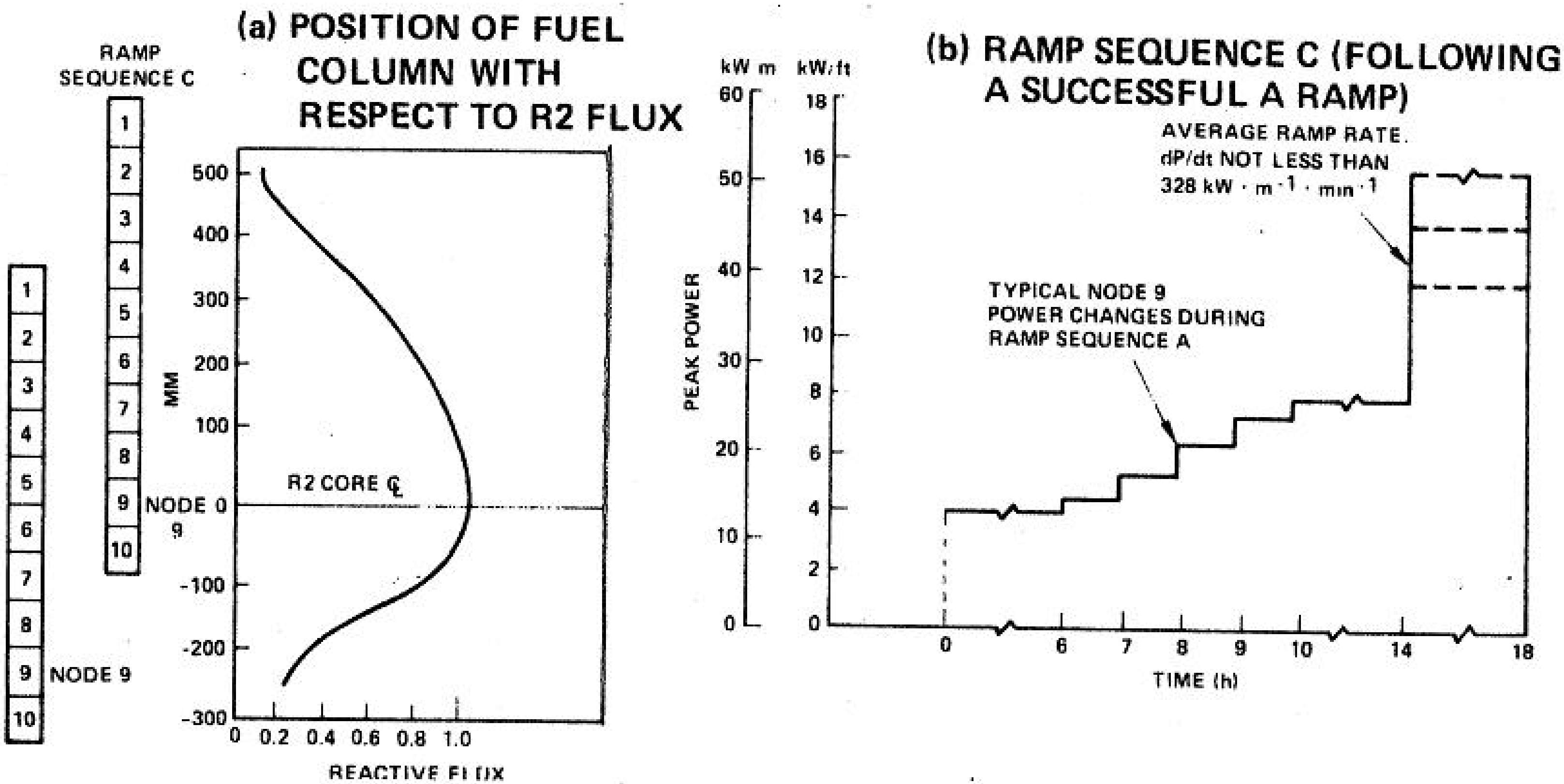
RAMP SEQUENCE A

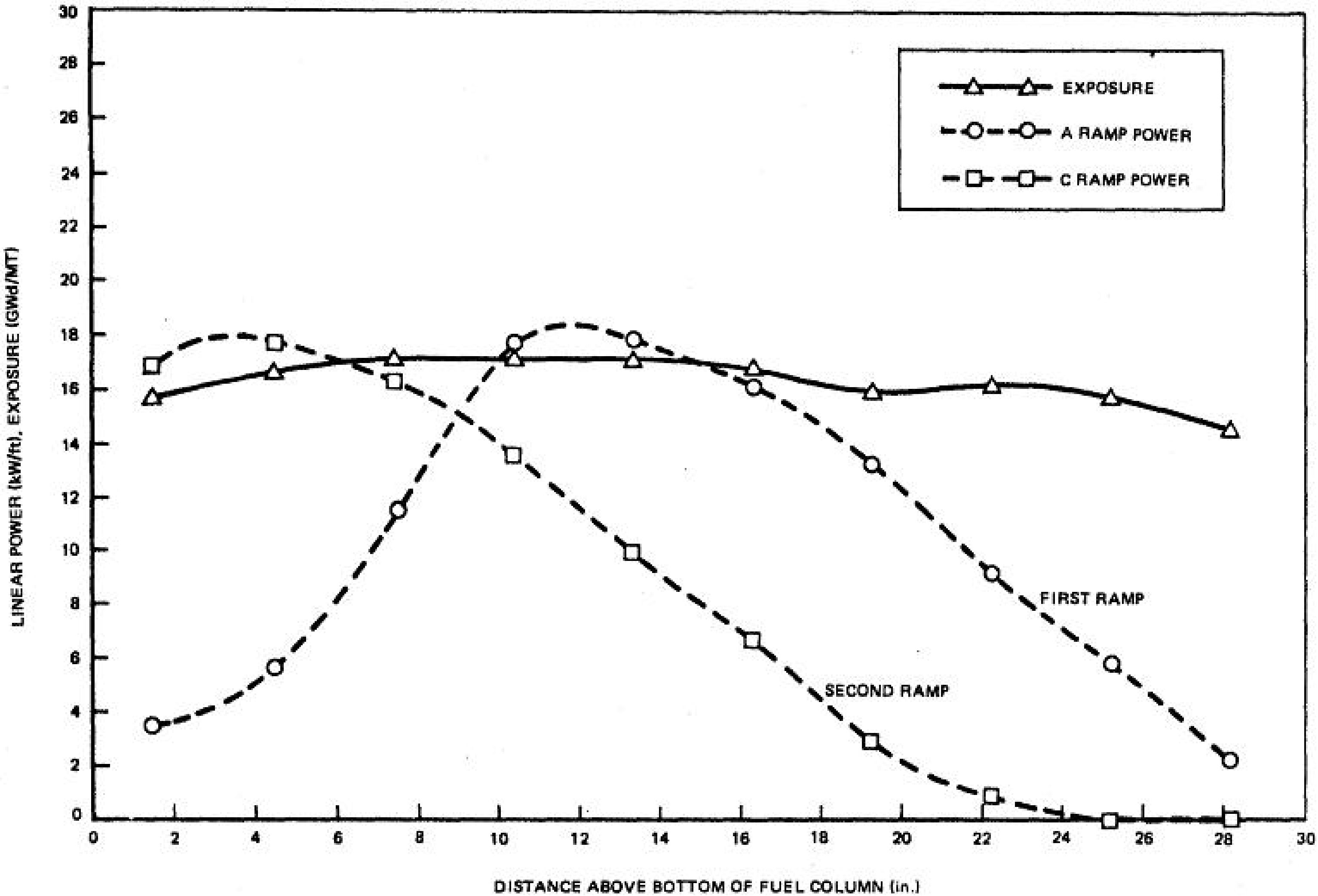


RAMP SEQUENCE B (C′)

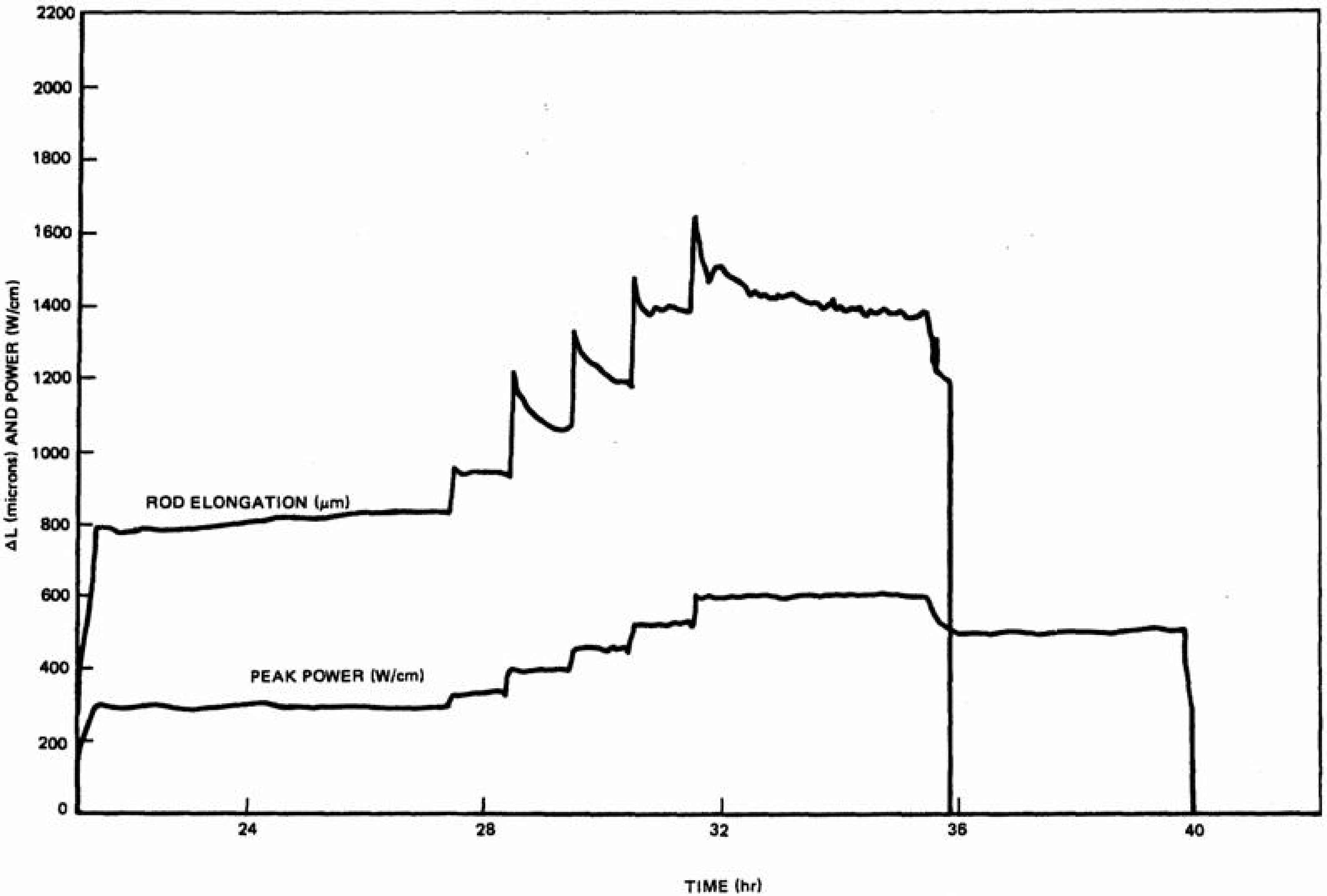


PERFORM 2nd RAMP ON SOUND ROD

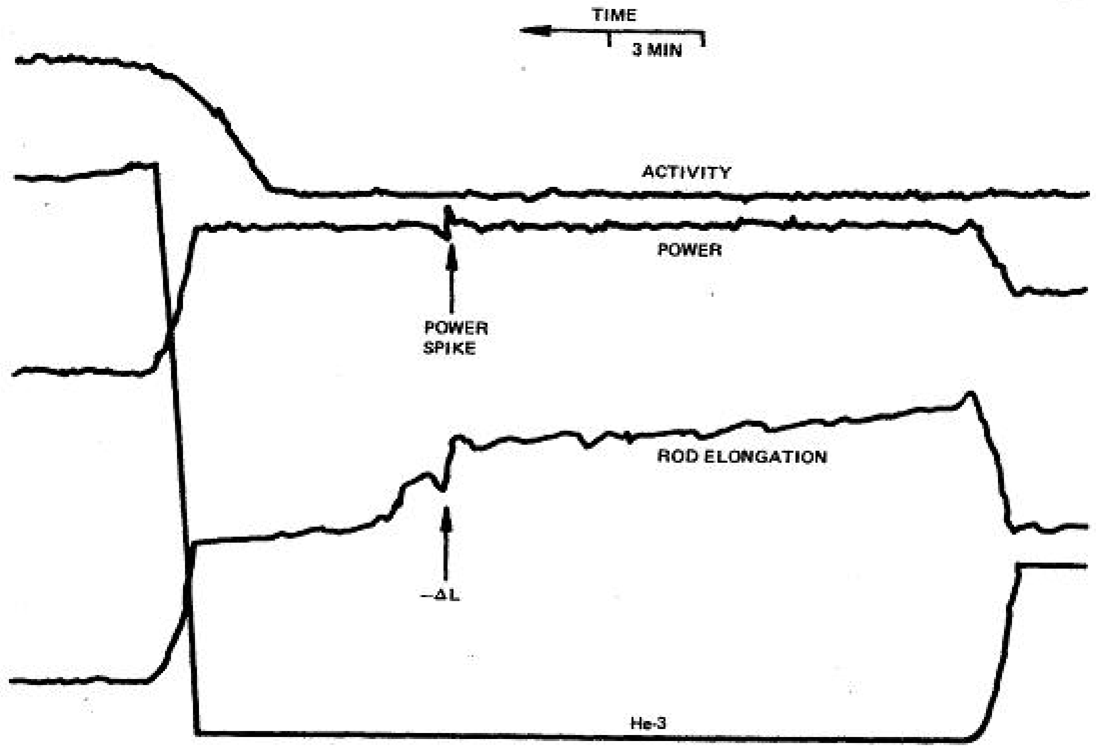




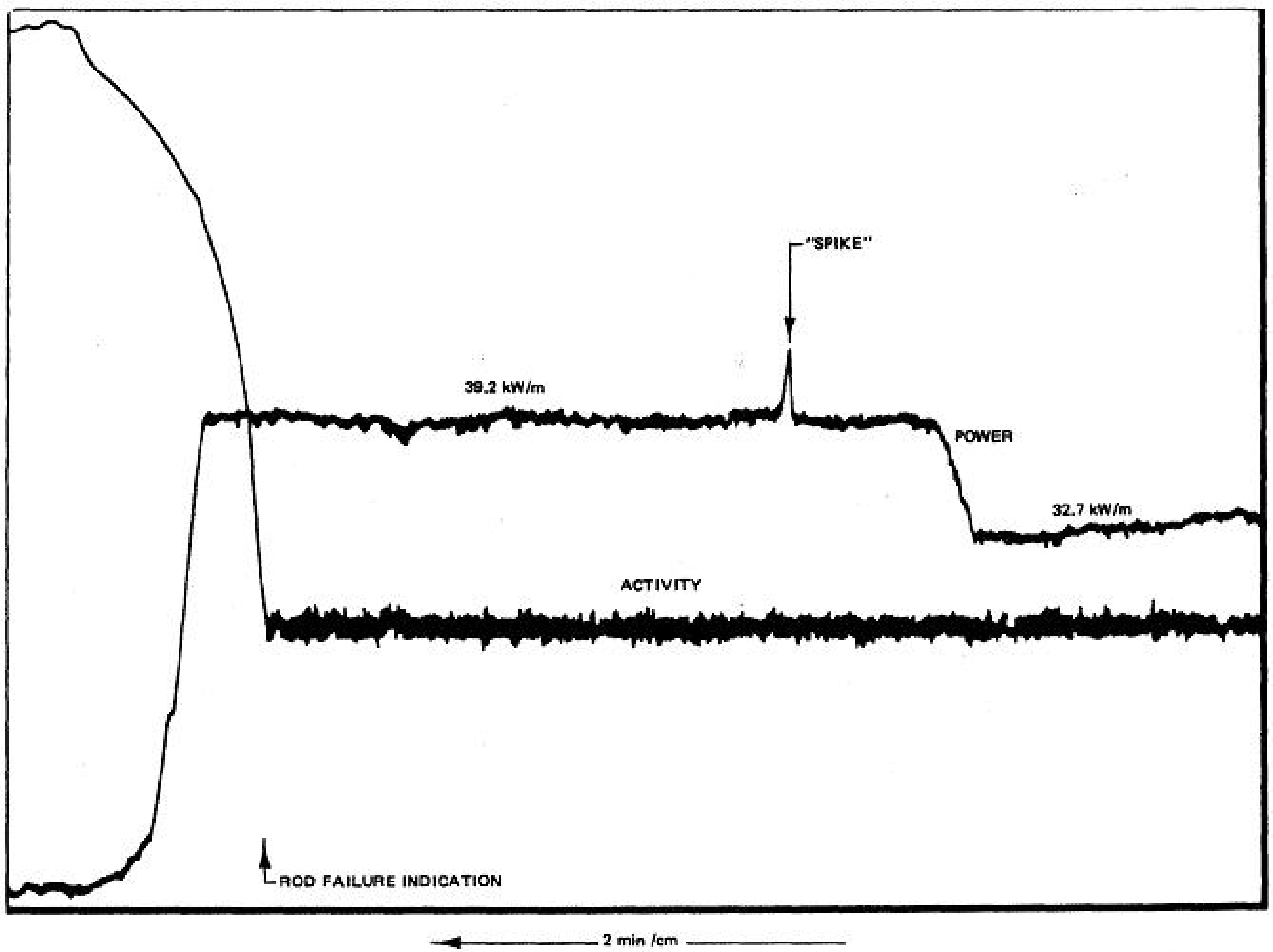
AXIAL BURNUP and RAMP TEST POWER PROFILES (SRP-3/58)



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



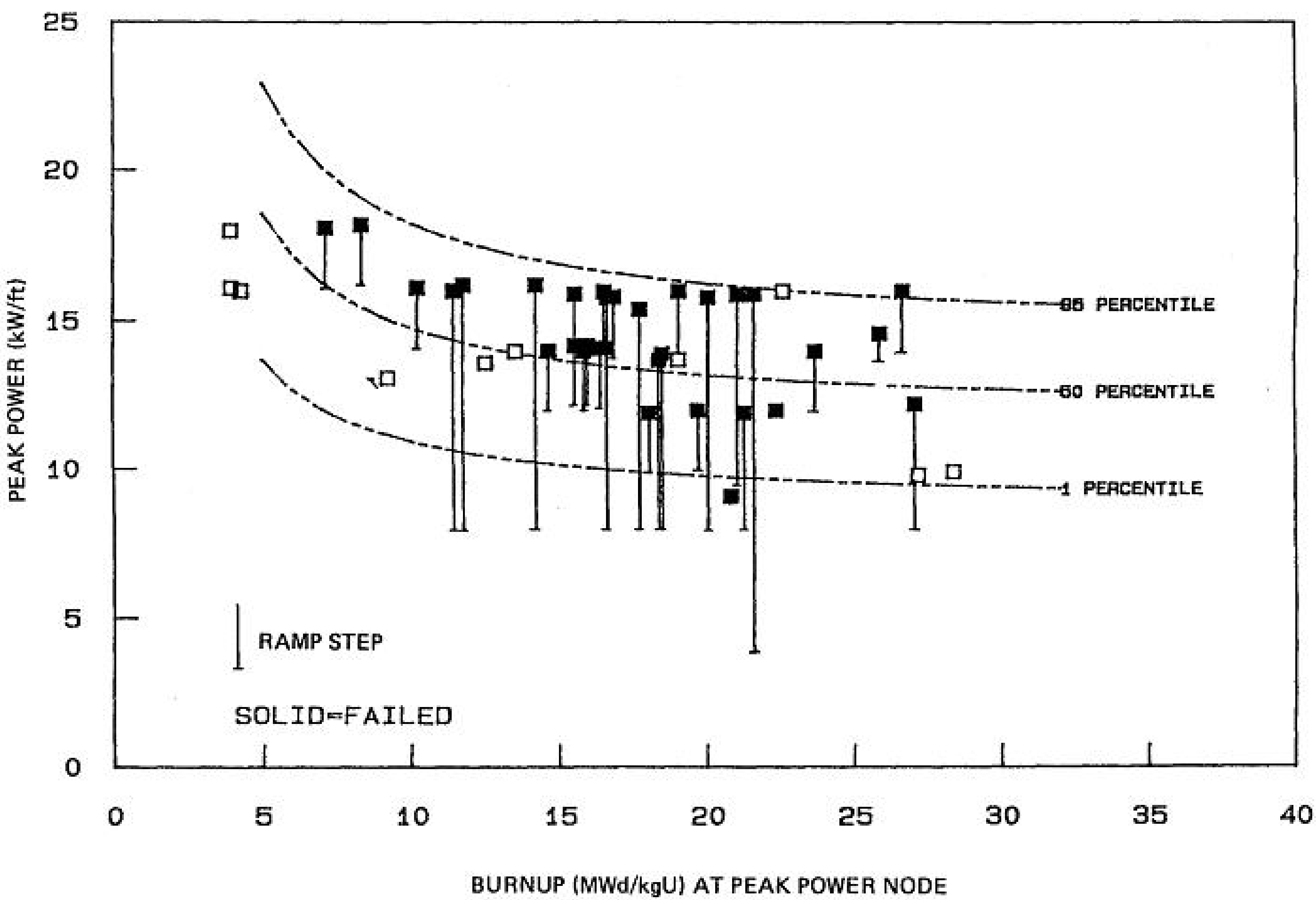
REAL TIME PLOT OF LOOP INSTRUMENTATION DATA
(SRP-3/96)



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

SRP RAMP TEST RESULTS

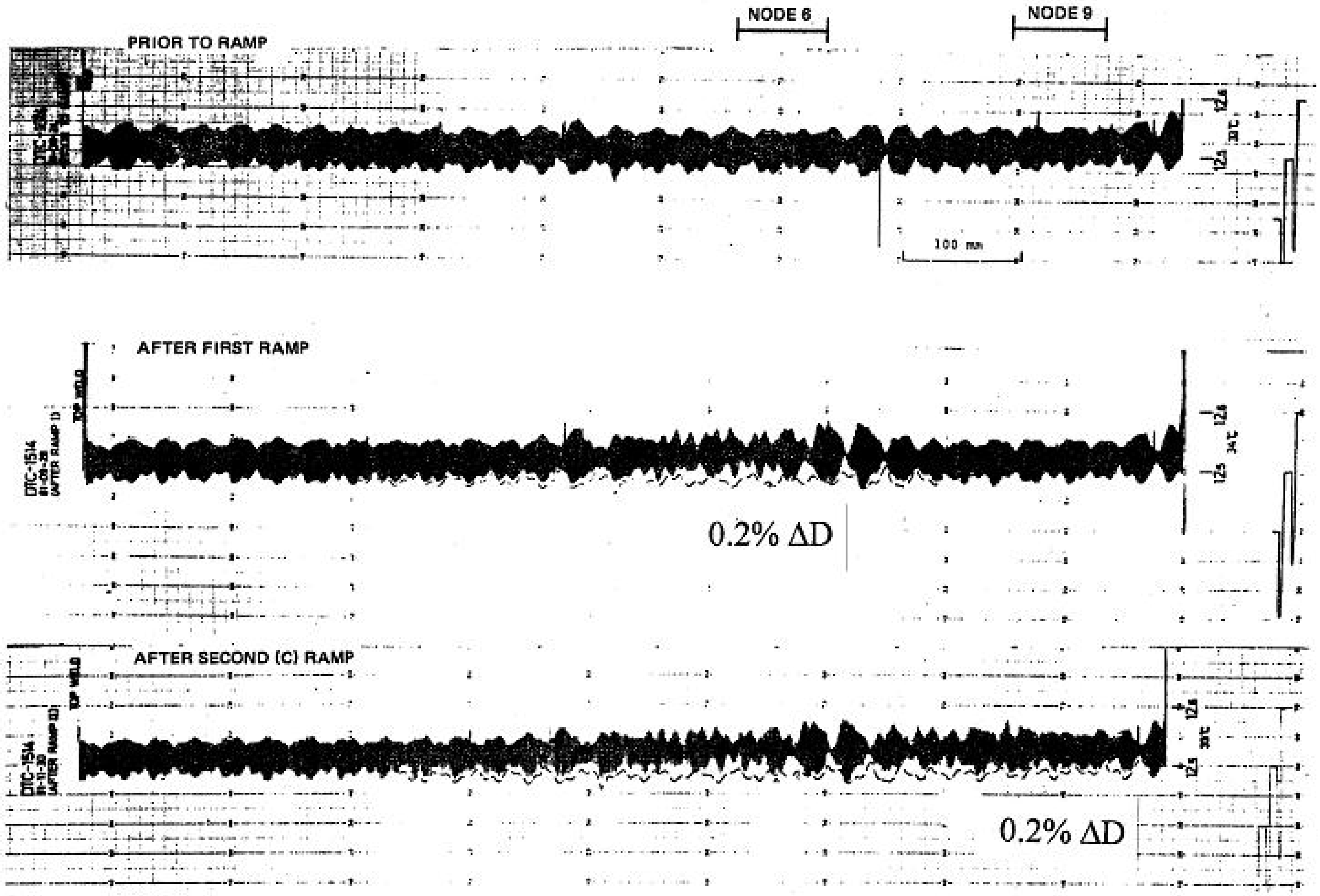
STANDARD CLADDNG



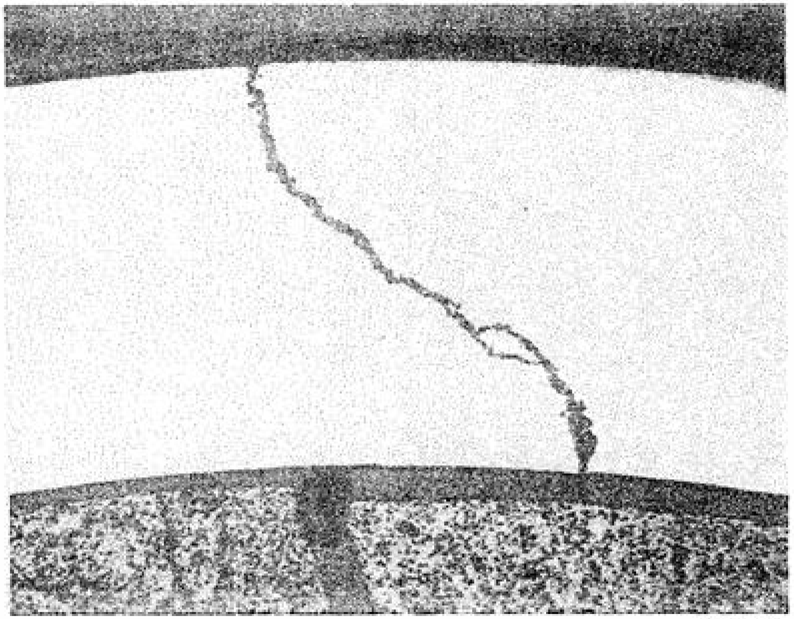
HOTCELL POST-RAMP CHARACTERIZATION

- *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**

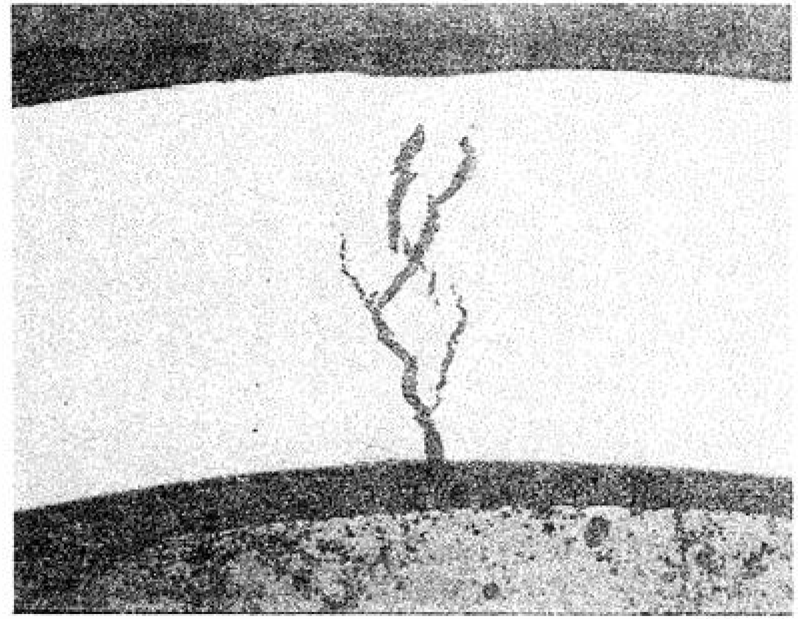


RESULTS OF SPIRAL PROFILOMETRY ON TWICE-RAMPED ROD (SRP-3/61)



C601-02
50X

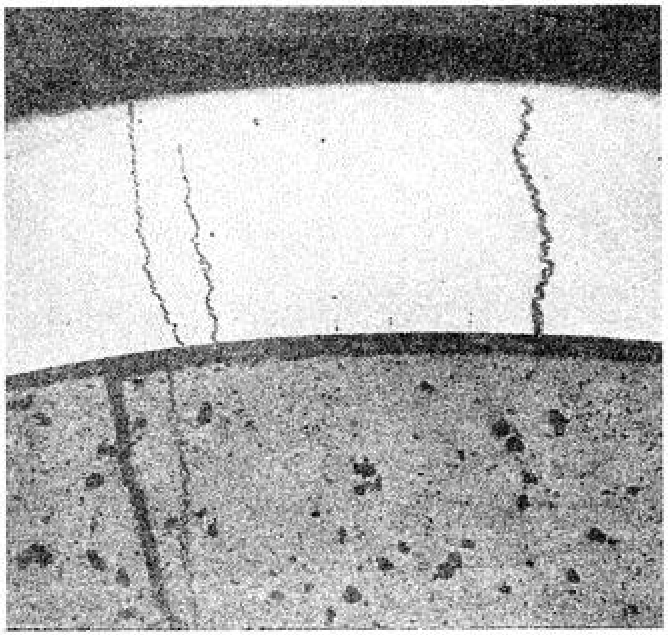
(a) SRP-2/11



C597-03
50X

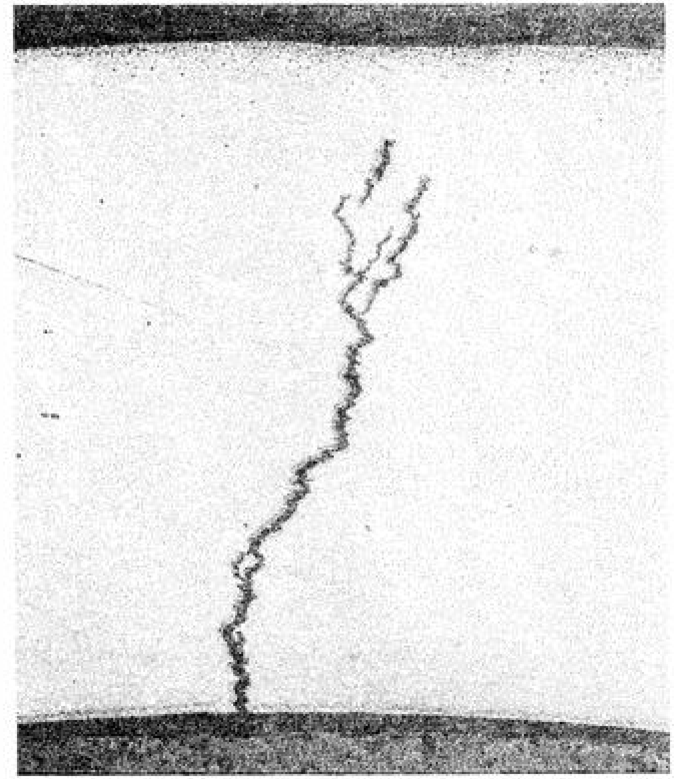
(b) SRP-2/14

PCI CRACKS IN FAILED STANDARD RODS



C226-15
50X

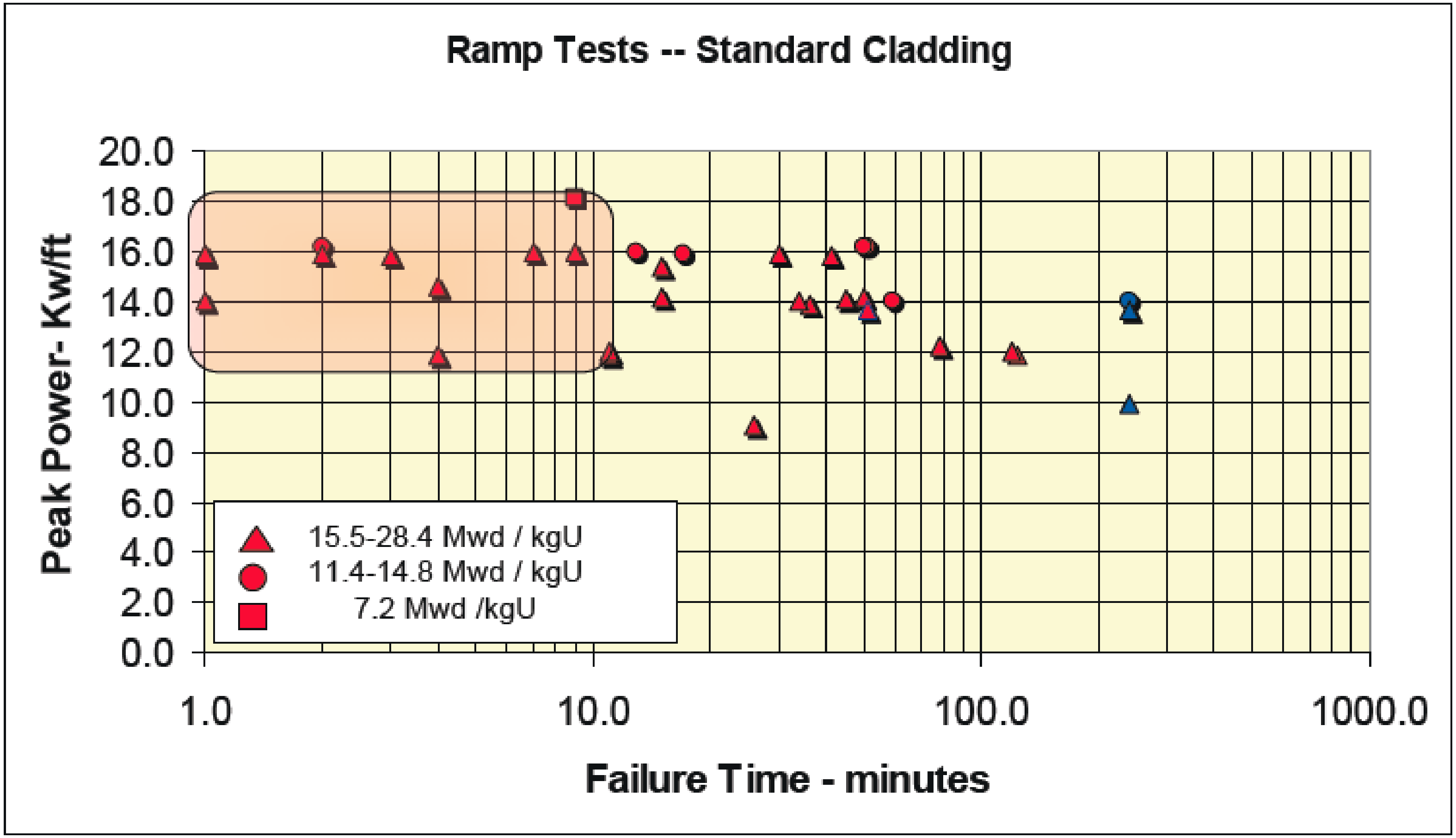
SRP-3/12



C218-02
100X

(d) SRP-3/27

PCI CRACKS IN FAILED STANDARD RODS



Ramp Tests -- Standard Cladding
20.0
18.0
16.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
Peak Power- Kw/ft
1.0
10.0
100.0
1000.0
Failure Time - minutes
15.5-28.4 Mwd / kgU
11.4-14.8 Mwd / kgU
7.2 Mwd /kgU

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Backup Slides

PCI/SCC Roundtable Discussions

PCI/SCC Alternative #1

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

PCI/SCC Alternative #2

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

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PCI/SCC Alternative #3

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

Alternative 1: NRC Work Scope

- 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.

Alternative 1: Implementation

- Implementation of <u>generic</u> 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