Official Transcript of Proceedings

NUCLEAR REGULATORY COMMISSION

Title: Advisory Committee on Reactor Safeguards

Docket Number: (n/a)

Location: Rockville, Maryland

Date: Friday, April 11, 2014

Work Order No.: NRC-702 Pages 1-48

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

UNITED STATES OF AMERICA

NUCLEAR REGULATORY COMMISSION

+ + + + +

613TH MEETING

ADVISORY COMMITTEE ON REACTOR SAFEGUARDS

(ACRS)

+ + + + +

FRIDAY

APRIL 11, 2014

+ + + + +

ROCKVILLE, MARYLAND

+ + + + +

The Advisory Committee met at the Nuclear Regulatory Commission, Two White Flint North, Room T2B1, 11545 Rockville Pike, at 8:30 a.m., John W. Stetkar, Chairman, presiding.

COMMITTEE MEMBERS:

JOHN W. STETKAR, Chairman

HAROLD B. RAY, Member-at-Large

RONALD BALLINGER, Member

SANJOY BANERJEE, Member

DENNIS C. BLEY, Member

CHARLES H. BROWN, JR. Member

MICHAEL L. CORRADINI, Member

DANA A. POWERS, Member

COMMITTEE MEMBERS: (Continued)

JOY REMPE, Member

PETER RICCARDELLA, Member

MICHAEL T. RYAN, Member

GORDON R. SKILLMAN, Member

DESIGNATED FEDERAL OFFICIAL:

EDWIN M. HACKETT

NRC STAFF:

PAUL CLIFFORD, NRR

BEN PARKS, NRR

DAVE PELTON, NRR

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

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

8:31 a.m.

CHAIRMAN STETKAR: Meeting will now come to order. This is the second day of the 613th meeting of the Advisory Committee on Reactor Safeguards. And the first topic we'll address today is thermal conductivity degradation, and it will be lead by Dr. Banerjee.

MEMBER BANERJEE: Thank you, Mr. Chairman. In order not to take any of the brief one hour away from the staff, I think I'll hand it over to Paul without further ado to give you the background and also some other things related to thermal conductivity degradation impact. As you know, we had two EPUs which really raised this issue. One was Saint Lucie 2 and the other was Turkey Point. So I'm sure that Paul will clarify all these things. Thank you.

MR. CLIFFORD: Good morning. My name is Paul Clifford from the Division of Safety System and I'll be describing kind of the root cause and corrective actions associated with the fuel thermal conductivity degradation issue that we've been struggling with for the last few years. Ben Parks from the Reactor Systems Branch will also be presenting remotely from San Francisco. So let's go

ahead and start.

Okay. So the purpose of this briefing is just to provide a status report on the staff's actions to address fuel thermal conductivity. Back on February 20th of 2013 we spent an entire day providing a status of this same issue to the Subcommittee. During that extended briefing we went through in detail how we calibrate and validate fuel thermal-mechanical models, specifically the fuel temperature solutions. We also provided a point-by-point assessment of each and every one of the fuel thermal performance codes, the short-term corrective actions and the long-term correction actions for each one of them. And we also provided an impact on the safety analysis and proposed corrective actions.

So the thermal conductivity of the fuel pellet degrades over time due to irradiation damage, changes in chemical composition and porosity of the pellet and the progressive buildup of fission products. Many of the older fuel performance codes that will be discussed today were developed in a period when there wasn't sufficient empirical data to identify the phenomenon or to properly quantify the phenomenon. So we did not account for this continued degradation of fuel conductivity.

This figure here illustrates changes in fuel conductivity with exposure and temperature. And these are empirically derived curves from the Halden facility. What this figure shows is measured minus predicted fuel temperature for a specific test rode, IFA-562.2 test rod 17, which was irradiated in the Halden lab over an extended period of time. The red dots show a more recent code. This was in FRAPCON, a version of FRAPCON predictions versus measurements. And you can see it does a very reasonable job. The black symbols are an earlier version of code that did not properly account for degradation.

This figure here shows a plot of the Halden database and it shows the progression of data as it became available. You'll see each one of these diamonds represents a particular instrument and fuel assembly which would have several rods which were irradiated over a long period of time and temperature measurements were recorded. And here you can see that prior to 1990 there was only low to medium-burnup data available. Now we overlay the different performance codes for each of the different vendors. I should note that these are the approval dates. The actual validation and calibration of the models was probably done three or four years before each one of these data

points. And you can see that the earlier generation of codes were developed with a limited database so they didn't properly capture this phenomenon.

MEMBER BANERJEE: So PAD4 actually was developed when there was a lot of data, but you didn't take it into account, right?

MR. CLIFFORD: And you'll see -- well, you know, each one of them was validated against a different database. This happens to be the FRAPCON database. There's also some proprietary data that was used in each one, so you'll see certain codes like PAD4 don't account for it thoroughly. They account for it to some degree, whereas some of the earlier codes such as RODEX2 don't account for it at all.

Okay. So what's the impact of TCD? Well, if you're thermal conductivity is wrong, then your fuel temperature is wrong and that has downstream effects on a lot of the safety analysis. For example, your LOCA stored energy would be non-conservative. Your predicted pellet thermal expansion would be wrong. And this would affect your steady state conditions at the initiation of a transient such as your initial gap size. But it would also affect your delta thermal expansion because your temperatures were wrong, which would then affect your stress and strain

on your cladding, because your fuel temperature is low, your fission gaps release would be low and this would affect from a steady state perspective your gas gap conductivity.

It would also affect your initial rod internal pressure, which would affect your burst models during a LOCA and it would also affect your design calculations of end-of-life cladding liftoff. And it may also affect the gap fractions, which is the distribution and population of your isotopes in your gap, which is limited to your dose calculation. Having a wrong fuel temperature calculation would also affect your power to melt limits, which you'd develop for your AOO over-power transients and it could also affect your doppler reactivity feedback predictions.

MEMBER BANERJEE: Now a question arose during the Subcommittee meeting, if I remember, as to whether the effects were primarily related to LOCA and whether there were effects which impacted other types of accidents. And I think the answer was it was primarily LOCA, right?

MR. CLIFFORD: No, I would say --

MEMBER BANERJEE: That's some other accident.

MR. CLIFFORD: -- it is tentacles that go into all aspects of Chapter 15 and Chapter 6 of the FSAR.

MEMBER CORRADINI: But it changes stored energy generally.

MR. CLIFFORD: Well, it has a first order effect on LOCA because of the stored energy, certainly for the large-break LOCA. But it would affect many aspects. Certainly your -- as I mentioned here, if your fission gas release was wrong, that could affect a lot of different valves. It's not just LOCA?

MEMBER BANERJEE: Okay.

MEMBER BALLINGER: How much of an effect after gap closure? In other words, if you have fuel clad contact --

MR. CLIFFORD: Right.

MEMBER BALLINGER: -- and then the gap conductance is issue, the gap drop is gone. So how much of a -- in other words --

MR. CLIFFORD: Right, but your temperature distribution across your pellet is still wrong.

MEMBER BALLINGER: Yes, that's true.

MR. CLIFFORD: So that's --

MEMBER BALLINGER: So your cladding temperature is not going to be --

MR. CLIFFORD: No, the cladding temperature wouldn't be affected at all in either case.

Okay. So we're going to start talking about the fuel mechanical models. We'll start with the BWRs. So in this slide I've listed the legacy codes that don't account for thermal conductivity and then the more modern codes that do. AREVA's RODEX2A is a code that does not account for thermal conductivity. GE's GSTRM does not account for thermal conductivity. GE has recently retired that code. So that's how I noted that here on the slide. Now the modern codes such as GE's PRIME, Westinghouse's STAV 7.2 and AREVA's RODEX4 properly account for thermal conductivity and are in use. AREVA has recently submitted the GALILEO code and we have just started that review. So the BWRs are in good shape.

The PWRs, there are four codes that are in use that do not account for thermal conductivity degradation and they're listed here. And we're currently reviewing a new version of PAD, PAD4 for Westinghouse. And as I mentioned, we'll be also reviewing GALILEO. GALILEO happens to be applicable to both Bs and Ps. And these codes are under review and when they're completed, hopefully we'll see

retirement of some of these legacy codes.

During the Subcommittee meeting we walked through each and every one of the codes, the applicability, the impact of TCD, the short-term corrective actions via penalties and the long-term correction actions for each one of the codes.

MEMBER REMPE: During the Subcommittee meeting we discussed about maybe this should be a lifetime for a, you know, licensing approval. So because I thought that there was an issue; and help me remember how to say it, but some of the -- even though they know that -- and they've got all these kind of spinders that cut on the old codes, they don't want to switch to the new one because it's more expensive for the utility to switch. And so that's an issue. And has anything happened on that?

MR. CLIFFORD: Well, that's still an issue and we're engaged with industry on how to address that. There's a slide coming up where it shows how it could be done and how it has been done. And we'll discuss that when we get to it.

MEMBER REMPE: Okay.

MEMBER BANERJEE: I guess going back to the question about non-LOCA impact, after the Subcommittee meeting there was discussion about this

and I think the staff said they were looking into it, but because some of the models used were very conservative for the non-LOCA analysis, that the impact was not expected to be really significant. But maybe I just got that wrong.

Maybe, Ben, you were there, you could comment on that?

MR. PARKS: Yes, at the time we'd only seen sort of quantitative studies probably for the power uprate plant and because they were looking at EPU power levels, we didn't have like a licensing basis sort of apples-to-apples comparison. So that's what we said. We think that they're conservative enough that it's fine.

Some of the vendors have since studied thermal conductivity along with other issues in their codes and applied some marginal penalty factors to their AOO analyses, but they've been very small. So in our review experience probably in about the intervening year what we've seen is the effects of TCD on the downstream safety analyses, aside from the realistic LOCA model, has been pretty minor.

MEMBER BANERJEE: Okay. Thanks. Well, there was another issue with regard to PAD5, if I remember, that we had no commitment for the transition

from PAD4 to PAD 5. And that was an issue that arose as well during the Subcommittee meeting, right?

MR. CLIFFORD: Right, and there's a slide on that.

MEMBER BANERJEE: Okay.

MR. CLIFFORD: Okay. So correction actions. So really the root cause of this particular issue is the fact that we approved these codes many years ago based upon the data that was available at the time. And as more data became available, these codes became less applicable to the way they were actually utilizing the fuel. In the last 20 years average assembly discharge burnups have gone up. More data has been collected. So the fuel is being used more aggressively, but the codes haven't kept up to date. So that's really the root cause. Now correction actions, you know, the lesson learned here would be that the staff really needs to scrutinize any future changes to fuel to ensure that there is a sufficient empirical database to provide high-confidence model predictions.

And here are like I would say the three big hitters, you know, things that we can see on the horizon. I mean, increases in fuel burnup. We have to make sure that we have sufficient data so we don't

end up in the same place 10, 20 years from now with burnups beyond the current 60 gigawatt days per metric ton. The approval of additives to the fuel can affect conductivity and many other aspects of how the fuel pellet performs both during normal operation and in transient. So we got to make sure we have a sufficient database before we approve additives. And also as we move down toward MOX; we know MOX is coming, we have to make sure we have sufficient data and also if we wanted to go beyond five percent enrichment.

Now, staff is also considering establishing a process whereby we would require periodic re-qualification of analytical models or potentially establishing a sunset clause in our approvals. And this goes back to what Joy was saying earlier. We need to do a better job of instituting a process for requiring that these codes are continually validated, either by us or by the vendors, or establishing a process whereby the staff could just retire these codes or force their retirement if action is not taken.

MEMBER CORRADINI: It would be either or though. It wouldn't be they must retire. If they want to do a reanalysis and show that they continue to

qualify based on new data, then that's fine, too.

MR. CLIFFORD: Oh, yes. I mean, that's the ultimate success path right there.

Here's an example of what we did to PRIME when we approved PRIME in 2010. And this is a little wordy, but this the actual text from the staff's SE. "In summary, it requires that GE is to continuously evaluate data as it becomes available and to ensure that PRIME's models predict to a best estimate all of the data including the new data and to evaluate the uncertainties and the application of the uncertainties based on the data."

And this is also consistent with a suggestion we received from an IAEA peer review where they noted that unlike Europe the NRC does not require codes to be validated or put a specific period of approval on them. So they recommended that we institute some procedures or establish some procedures for doing that.

MEMBER BANERJEE: Is there any thoughts what the period should be?

MR. CLIFFORD: Well, I think, you know, we're starting discussions with AREVA and Westinghouse. We've already established a process with GE. But I think this extends -- this is more

than just a fuel thermal-mechanical issue. I mean, you could say it's all of the legacy methodologies there still in place should be questioned.

MEMBER BANERJEE: It applies to thermal-hydraulics codes as well.

MR. CLIFFORD: Exactly. I mean, we're always getting more data, the technology is improving and our understanding is improving. So, you know, we should be qualifying codes.

MEMBER BANERJEE: But you're discussing what might be appropriate periods in different areas. I mean, the period is not going to be the same.

MR. CLIFFORD: Right.

MEMBER BANERJEE: But thermal-hydraulics as to fuel or whatever, but in fact arrive at something.

MR. CLIFFORD: And as we go through the review and approval process for GALILEO and for PAD5, you know, we hope that we can come up with a solution similar to what we did for PRIME. We have that opportunity now.

MEMBER BANERJEE: So is this discussion primarily limited to fuel?

MR. CLIFFORD: Right now it's limited to fuel thermal conductivity --

MEMBER BANERJEE: Okay.

MR. CLIFFORD: -- but there are staff that are considering a broader interpretation.

MEMBER BANERJEE: All right.

MR. PELTON: This is Dave Pelton. If I recall right, the discussions with the IRRS really -- they were trying to tab this to their periodic safety review process, a 10-year reevaluation process where they have specific expectations on licensees to basically bring their design bases and licensing bases up to the state-of-the-art. And that's really what they were trying to focus with with this particular issue versus a phenomenal specific periodicity. So it's really more trying to tie it to the PSR process.

MEMBER BANERJEE: Okay. Thanks.

MEMBER BROWN: Do the Europeans use the same codes?

MR. CLIFFORD: Well, we're starting to see more cooperation, you know, between the parent companies and the U.S. companies. For instance, GALILEO was developed mostly in Europe. So it's built by the European version of AREVA and it's now being implemented in the U.S., or it's under review, but that's their goal. But, no, the legacy codes are

generally the older versions, the old combustion-generated coal, the old B&W, the old Exelon Nuclear.

MEMBER BROWN: Yes.

MR. CLIFFORD: You know, the legacy codes.

MEMBER BROWN: No, I ask only relative to the standpoint if they use the same -- and we talked and it seemed inconsistent to have different periodicities. They ought to have some congruence between the two. I understand that point, but from a practical standpoint it seems like we ought to synchronize between the two major areas that do this. That's all. I was just wondering if that was in place or part of the thought process over the long term.

MR. CLIFFORD: Well, there are different regulatory positions, you know, between the different governments. I mean, as you mentioned, the Europeans have more of a strict 10-year period where -- and they'll go back every 10 years and relicense the plant.

MEMBER BROWN: I understand that point.

CHAIRMAN STETKAR: I don't know what's done. Do you call in -- I mean, there are some American -- I'm familiar with Switzerland, so there's Westinghouse, GE plants in Switzerland. And assuming -- I don't know whose fuel they use, though. So I

1 don't know what codes they use during their 10-year
2 periodic safety review, for example, you know, because
3 they have a 10-year periodic safety review.
4 MR. CLIFFORD: That's correct. And a lot
5 of the fuel is manufactured in the United States.
6 CHAIRMAN STETKAR: Yes.
7 MR. CLIFFORD: And so, but these companies
8 of -- most of them out there, there's some level of
9 tech transfer. So at some point back in time they've
10 bought the methods and they've probably evolved their
11 methods, kind of branched off from the parent
12 organization.
13 MEMBER BANERJEE: The way things are
14 evolving right now, though, for some reason which is
15 not entirely clear to me, AREVA seems to be evolving
16 from COPERNIC to GALILEO even though COPERNIC is a
17 fairly modern code, isn't it?
18 MR. CLIFFORD: Well, they're using
19 COPERNIC now. COPERNIC accounts for thermal
20 conductivity degradation. Probably not as well as
21 GALILEO will because it was kind of in a gray area.
22 Right now they are retiring this code called TACO3.
23 MEMBER BANERJEE: Right.
24 MR. CLIFFORD: And they are replacing
25 their B&W fleet that's using TACO to COPERNIC.

MEMBER BANERJEE: Right.

MR. CLIFFORD: So they're moving to COPERNIC where it's available. But COPERNIC I don't believe was applicable to all fuel types. I think its approval was limited to maybe B&W fuel and Westinghouse. I'd have to go back and look at that, but I don't think it's universally applicable to all PWRs.

MEMBER BANERJEE: I see. But it's an AREVA code, right?

MR. CLIFFORD: Correct.

MEMBER BANERJEE: Yes. And Westinghouse is going to PAD5?

MR. CLIFFORD: Correct. Sometime. The fuel vendors, you know, they own the methods, but they don't own the plants. So, and in order to transition from PAD4 to PAD5 the licensees would not only have to redo the analysis, but the would have to update their tech specs, because the COLA lists the approved methodologies. So each one of their customers would have to come in for a license amendment request. So I think there's some resistance there.

MEMBER BANERJEE: Okay.

MEMBER CORRADINI: But just to close this, the reason that there's hesitation there's got to be

not only the tool, but also you have to then relicense all the users of the tool so they understand -- when they've changed they know how to use the tool correctly. In other words, it's not just changing; I don't know all these names, TACO to whatever the hell the other thing is, it's that when you change over, the users of the tool then have to submit a report to show that they know how to use the new tool appropriately for their reloads, for whatever, right?

MR. CLIFFORD: There's a handful of utilities that do their own work and they would have to be relicensed. Like Duke does their own work.

MEMBER CORRADINI: Sure.

MR. CLIFFORD: APS does their own work.

MEMBER CORRADINI: Right. So let me turn the tables a bit. So to the extent that -- well, and just to be a little bit fair, to the extent that we're asking all of them to redo all their stuff, there's got to be some look within the staff on how to essentially make things a bit more streamlined on this side so that you don't have multiple approvals once you make the change. That's the activation energy issue, because nobody wants to change because not only is it the tool, it's all those that are performing the analysis have to be relicensed.

MEMBER BLEY: Just relicensed. For me I'm --

MEMBER CORRADINI: Yes, I mean, if you're going to take thermal-hydraulic --

MEMBER BLEY: If you're going to run thermal-hydraulic, do you have to get a license from NRC?

MR. CLIFFORD: For instance --

MEMBER BLEY: I never heard of this before, so I apologize.

MR. CLIFFORD: Arizona Public Service is a good example because I used to work there, so I know how it worked for them. They do their own reload analysis.

MEMBER BLEY: Right.

MR. CLIFFORD: They don't do the LOCA, but they do everything other than the LOCA. So when they wanted to get approval from the staff to do their own work, first they had to get the tech transfer from Westinghouse for the rights to the codes. And they had to get trained by Westinghouse.

MEMBER BLEY: Okay.

MR. CLIFFORD: And then they had to demonstrate to the staff that they could use the --

MEMBER BLEY: Okay. So that's not an

actual license.

MEMBER CORRADINI: That's not a license.

MR. CLIFFORD: It's an approval.

MEMBER CORRADINI: It's an approval. It's the equivalent of it.

MR. CLIFFORD: It would be in your licensing basis through their FSAR or through the tech specs.

CHAIRMAN STETKAR: Yes, but that's the same as if I run a hand calculator to calculate, you know, acceptable vibration on a pump. It's part of my licensing basis. But it's not a separate license to run that hand calculator, is it?

MEMBER CORRADINI: So, let me take an example of -- now a dead plant. In Kewaunee when they were doing their own reload analysis, if they chose to use RETRAN, they had to get an approval by the NRC that even though they got the EPRI code that they knew how to use it appropriately for their reload analysis. So you want to call it a license. You can call it whatever you want. They had to get an NRC approval. And that's an enormous undertaking.

CHAIRMAN STETKAR: Just to run the code?

MEMBER CORRADINI: Yes, because you don't just turn it on. You have to know that you it on

correctly. You have to perform essentially a calculational data book. You have to have it checked. You have to make sure that you've done a series of audit calculations. All of that has to be submitted to NRC so they approve it.

CHAIRMAN STETKAR: Does Kewaunee need to get separate approval from the NRC to run MELCOR?

MEMBER CORRADINI: MELCOR is not in the design base.

CHAIRMAN STETKAR: So codes are in the design basis to run your design-basis accident analysis.

MEMBER CORRADINI: Not MELCOR.

CHAIRMAN STETKAR: Okay.

MEMBER CORRADINI: I mean --

CHAIRMAN STETKAR: Sorry, I'm not a formal hydraulics guy. Whatever codes you guys use.

MEMBER CORRADINI: It would have been CONTEMPT.

CHAIRMAN STETKAR: Okay.

MEMBER CORRADINI: I mean, we could walk through -- I mean, if you want to look at this generically --

CHAIRMAN STETKAR: But the same thing would happen --

MEMBER CORRADINI: -- the issue is much greater than what you're talking about, because if I talk about equipment qualification, there's a whole series of containment codes that have to be used and approved, otherwise you can't do your EQ properly. So if you go back -- and again, I'm using this example since the plant is down. When they're doing equipment qualification, they weren't using MELCOR, CONTAIN or GOTHIC. They were using CONTEMPT.

CHAIRMAN STETKAR: All right.

MEMBER CORRADINI: Because that was approved many years ago under a set of procedures that they -- so I think --

MEMBER BLEY: We might be reading too much into this, but do individual people get approved to run these codes, or does a utility, the licensee gets approved to run the code and that's like a letter to --

MR. CLIFFORD: Right, but there's only a handful of utilities that do their own work.

MEMBER BLEY: Okay.

MEMBER CORRADINI: But the only reason I'm emphasizing this is --

MEMBER BLEY: Northeast used to do a lot of their own work at one time, yes.

MEMBER CORRADINI: Well, but the small utilities started doing this, but as it became more onerous, they just them simply buy services from the vendors. So it's more complicated than it first seems about just changing something.

MEMBER BANERJEE: Easier to get private services.

MEMBER CORRADINI: But then you don't own your license. Well, you should talk to them.

MEMBER BANERJEE: Anyway, so that's a different decision, yes.

MR. CLIFFORD: Okay. So starting in slide 16, Ben Parks will take over. Ben, just, you know, change the page when you want to. Okay?

MR. PARKS: You bet. Thanks, Paul.

My name is Ben Parks. Good morning. I'll be talking about the TCD impact and emergency core cooling system evaluations.

As Dr. Banerjee inquired earlier and as Paul discussed -- I should just ask, can you folks hear me okay?

ALL: Yes.

MR. PARKS: Okay. Good. So as Dr. Banerjee was asking, we've seen the primary or the most significant impact in the emergency core cooling

system evaluations either in the year since we've discussed at the Subcommittee. We have seen some vendors quantify the effect in transient and AOO analyses, and it's been very minor.

In particular, the biggest impact has been in the realistic models that we have for large-break loss of coolant accidents. We don't see as much in small-break loss of coolant accidents because, A, the PCT for those events occurs much later, so the event is driven by decay heat. And because those models are Appendix K, they're much more conservative.

So, Paul, if we could go to slide 17.

MR. CLIFFORD: Okay.

MR. PARKS: A quick review here. We got where we were with respect to the large-break LOCA model because in December 2011 a utility sponsored a study to ask; it was Westinghouse, hey, Westinghouse, what is the effect if you account for thermal conductivity degradation in our model for our large-break loss of coolant accident. The model was ASTRUM. When Westinghouse did that study they found that the PCT would increase significantly, and that is significantly with a capital S. That means more than 50 degrees in terms of the predicted peak cladding temperature.

So based on that result, which we learned about in December of 2011, we issued Information Notice 2011-21 and it basically communicated to the industry that a vendor had done this work, a utility sponsored it and the effects were significant. And the message was if you use a realistic evaluation model, you may wish to contact your vendor and find out what the effect would be on your evaluation. Since then fuel vendors and licensees have addressed the effects of TCD on ECCS evaluations in various ways. In February 2013, I, like Paul, went through each approved evaluation model that is used to analyze a loss of coolant accident and I described what was being done. Here for this meeting I'll talk about each vendor just to keep the presentation a little bit more brief.

So, Paul, if we could go to slide 18. Okay. I was already talking about slide 18. So basically, you know, we talked about the efforts by each vendor to address TCD. We talked about how big the effects were that we were seeing. The overall conclusion was that the most significant PCT effect occurred in the realistic evaluation models. In large part the estimated effects were less than 100 degrees Fahrenheit and it seemed like a fuel pin diameter

where you could hold up a lot of stored energy tended to exacerbate the effects of TCD.

So on slide 19 we'll talk about GE. Basically GE has transitioned from SAFER/GESTR to SAFER/PRIME. Since they have done that licensees have submitted 50.46 reports with estimated effect of TCD. And in a couple of cases for EPUs. We'll be defending the Peach Bottom EPU here soon. We've actually seen analysis results using PRIME. The effects were on the order of 50 to 60 degrees. In some cases they weren't even 50 degrees. So going forward, new licensing analyses are being performed using SAFER/PRIME. So we've gone to the new methodology.

Paul, on slide 20, please. AREVA has more evaluation models for ECCS performance. Their BWR evaluation model is applying an augmentation factor to account for thermal conductivity degradation. The main observation is the beginning of life conditions are limiting because BWRs use burnup-dependent MAPLHGR limits. So as they burn through their cycle, their peak linear e-rate comes down and that tends to make more highly-burnt fuel less limiting.

Still in AREVA space here, Westinghouse/CE's realistic model that's called realistic large-break LOCA, it's doing the same thing.

To the initial stored energy they're applying a RODEX4-based augmentation factor that's increasing the store energy that they model and that's how they're correcting those. The correction is -- in terms of the systems analysis it's explicit.

That leaves the B&W evaluation model. It uses TACO3 for stored energy input. If you go all the way back up to Paul's timeline slide you can see TACO3 was approved before the NRC's database was beginning to have highly-burnt fuel, but again the model is Appendix K-conformant. And so decay heats to be the big significant parameter there just because the decay heat model is so conservative. And as an added conservatism in B&W space, generally those plants apply a very high linear heat rate in the model. So that's another conservatism on top of the Appendix K.

So they haven't generated any explicit analyses or modeled this, however, you know, the staff believes that the model is sufficiently conservative and the results are, you know, as applied on a plant-specific basis, conservative enough that we don't really need to pursue further action from the B&W plant. You know, just put a number on it. We're looking at PCTs for this family of plants around 1,800 to 1,900 degrees Fahrenheit. So there's still 300

degrees of margin, you know, generally speaking to regular spray limits here.

Paul, on slide 21, please. That leaves us with Westinghouse's evaluation model. We saw a lot of activity for those using realistic models, so that's the code qualification document that was approved I think in the late '90s and the ASTRUM more recent model that's based on order statistics. Those plants with very high PCTs generated explicit estimates of effects of TCD and they submitted reports. So that means, you know, if they had analyzed their ECCS performance using this model before they had anything to account for TCD, they went back and they used fuel performance inputs that were based on a modified version of PAD4 that accounted for TCD. And they went back and they looked at those cases that were significantly affected by TCD and they re-ran them. So we had a -- here's my delta PCT.

MEMBER BANERJEE: So, Ben, just going back to this PAD4 TCD, let's call it --

MR. PARKS: Yes.

MEMBER BANERJEE: -- compared to PAD5 what exactly would be the difference? The PAD4 TCD already contains some sort of a correlation for the TCD effect, right?

MR. PARKS: Right, Dr. Banerjee.

MEMBER BANERJEE: And it sort of gets the fission gas, right, because that was already fitted to data, I assume.

MR. PARKS: Correct.

MEMBER BANERJEE: So what's the difference?

MR. PARKS: Between PAD4 TCD and PAD5 I don't know, and we may actually not know because PAD5 is going to be rolled out with a different evaluation model that's currently under review. So right now these estimates and the new analyses that we would look at, they all rely on PAD4 TCD. Okay. So I guess, you know, too, if I made non-answers to your questions, it's too soon to tell on one had. And on the other, you know, we did it with a different evaluation model.

MEMBER BANERJEE: Okay. That's fine.

MR. PARKS: Okay. So I talked about the very high PCT plants, though we're talking about plants whose PCTs might be above 1,900 or whom the vendor subsequently went back and said, okay, you have a 14-by-14 fuel matrix with a high diameter fuel pin. You're going to be very significantly affected. You need to estimate your effects explicitly. There is a

general group. We're talking about plants that have PCTs maybe 1,650 or below.

And the owners group picked up the work for them, and what they did was they sort of based a generic estimate on the explicit work that had been done for those high PCT plants and they applied it across the fleet. And that's in keeping with how vendors typically estimate the effects of an error or a change in an evaluation model anyway.

And we looked at it and, you know, it was a reasonable estimate. And, you know, on top of that, we're talking about lower PCTs to begin with. So we wound up finding that that was okay. I don't think we ever embarked on a very detailed evaluation of that owners group-sponsored work.

Okay. So Westinghouse's BWR model, it uses STAV 7.2. And it accounts for TCD already, so there's nothing to do there. And we're talking about I think four plants at this point using that model.

Westinghouse plants using Appendix K EM. So we're talking about part BASH. They submitted estimates of the effect. I believe that that was explicit for each plant. When you're talking about an Appendix K model, it's a single PCT transient. So that's a straightforward effort. It's also possible

for Appendix K, I think more possible to apply a generic study to a broader group of plants.

Those of you who remember back in February 2013, we talked about Westinghouse's evaluated CE plants. And this is a group that has pretty high PCT. They're clustered around 2,050 degrees Fahrenheit and their model was not fully accounting for the effects of TCD, so we'll go to the next slide and talk about them a little bit more.

Paul, slide 22, please.

MR. CLIFFORD: Yes.

MR. PARKS: The message that I carry here in 2013 was we had a little bit more work to do and we'd report back. And what I'm going to show is on this slide basically the big reason here is, one, Appendix K. So, you know, the CE evaluation model predicts a pretty high conservative PCT. And, two, in a power uprate review; we did this for Saint Lucie I believe Unit 2, we asked them to increase the stored energy to make it artificially more significant in the transient. And we found that they would have to increase the stored energy by much more than the effective TCD in order to cause the first blowdown peak to become limiting in the evaluation.

So, you know, decay heat is the driving

factor in the CE evaluation model. So this figure, we have a red line and a blue line. So for a CE plant in the 2,700 megawatt class -- and this is a cartoon. You know, I traced over these myself, so those are my plots. Red is the CE evaluation model. That's a PCT trace versus time. And that's what it generally looks like for the CE plants. You have a big blowdown and then you go back into this later decay-heat driven peak, and it's usually the decay heat that is the driving phenomenon.

The blue trace is realistic evaluation model for the same plant at the same power level. As you can see, the PCT tends to occur much earlier, but also the PCT is much lower. And so what I saw was if you analyze these plants with a realistic evaluation model, chances are PCT is going to be much lower. And based on that Saint Lucie power uprate review experience, we also knew that you'd have to increase the initial stored energy by quite a bit in order to make the initial phases of transient limiting in the Appendix K model. And so, you know, based on this sort of retrospective look, it was my determination that we didn't really need any further action for these CE plants that were still under Westinghouse cognizance.

So that's a brief overview of what I covered in a lot of detail in February 2013, plus this little bit of, you know, what we looked at after that. That concludes basically what we looked at for the ECCS evaluation models.

MEMBER SKILLMAN: Hey, Ben, this is Dick Skillman. About how much increase did you have to apply to the stored energy to get that red curve, please?

MR. PARKS: Okay. So the red curve doesn't increase the stored energy, but if you look in the first 10 seconds, you see that first peak?

MEMBER SKILLMAN: Yes.

MR. PARKS: The first peak, in order to get it to approach -- we did this with sensitivity studies with the vendor. In order to get it to approach the magnitude of the larger peak, okay, they were increasing the stored energy by an appreciable fraction. You know, we're talking about like 0.4 times -- or an increase of 40 percent, which is more than TCD.

MEMBER SKILLMAN: Yes, okay. Thanks. That's what I was asking. Thank you, Ben.

MR. PARKS: And that's a recollection. I mean, we're talking about a review that was two years

ago and I'm putting a number to it. So there's a margin of error here in my own memory. Okay?

MEMBER BANERJEE: So, Ben, just going back to Saint Lucie 2, it was FATE S3B that was used, right?

MR. PARKS: FATES 3B. That's correct.

MEMBER BANERJEE: Yes. FATES 3B. Okay. FATES 3B. Okay. And that did not account for TCD?

MR. PARKS: It did not.

MEMBER BANERJEE: Right. But did you not impose a more restrictive radial power fall-off for that? My memory is very vague, but I'm trying to recall.

MR. CLIFFORD: Yes. There was a penalty applied, yes, in that review. And that was more to account for the non-conservative fission gas release and the effect on rod internal pressure.

MEMBER BANERJEE: Okay. Thank you. That clarifies it.

MR. PARKS: Right, what we trying to do -- the ECCS review wasn't mine. I was involved with it. But, you know, our general effort was to sort of insulate the ECCS evaluation so that we could look at the inputs that they have and understand how much they would have to increase or change in order for us to be

concerned about the effects coming through the ECCS evaluation.

MEMBER BANERJEE: Okay.

MR. PARKS: If that makes sense.

MEMBER BANERJEE: Yes, I think I've got it.

MR. PARKS: Okay. So, Paul, slide 22 concludes my slides.

MR. CLIFFORD: Was 23 yours?

MR. PARKS: I'm sorry, slide 22 does not conclude my slides.

(Laughter.)

MR. PARKS: Okay. Just briefly, what we're looking at now; I apologize for that, we've gotten TCD estimates for the most significantly affected evaluation models. And at this point I can say that I understand why we haven't gotten the ones that we haven't gotten and I'm comfortable that we don't need to go looking for them.

In the meanwhile, vendors have transitioned or they are transitioning to methods that account for the effect of TCD. We've seen it with SAFER/PRIME and GE's larger migrations of PRIME. We're seeing it with the other vendors in their evaluations models that are currently under review.

What we're looking at in the grander scheme is for ECCS evaluation pretty much everybody's going to have to do a reanalysis anyway for 50.46c, so what we're seeing is those vendors who have significant effects and who included with their report a proposed schedule to provide a reanalysis. They're matching that up with the 50.46c rulemaking. So we're looking at 2016 to 2018 time frame for a full reanalysis to resolve all this stuff. And that's reasonable because we want them to use NRC-approved evaluation models and in some cases right now they're not. They're using sort of engineering patches to account for this stuff. So, you know, that's the timeline that we're looking at to get this stuff resolved.

And, you know, meanwhile, we're reviewing a TCD disposition for anything that comes into us for review and approval. It's reasonable for us to say, hey, what does thermal conductivity degradation do to this analysis, but in large part what we're seeing is they're answering the question before we can even ask it. So the bottom line is here in italics at the bottom of the slide anything submitted to us is expected to account for TCD. Well, I mean, there's always an exception. You know, have a good reason not

to.

MEMBER BANERJEE: Can you tell us a little about the subject which came up at the Subcommittee meeting, which was FS LOCA, which is somewhat similar to ASTRUM? Westinghouse is doing something in that direction. What is that supposed to take into account?

MR. PARKS: Okay. So generally speaking, Westinghouse modularizes its fuel performance codes and its ECCS evaluation models. So if I'm a licensee and I put these methods in my tech specs as core operating limit report references, I'll reference my fuel performance methodology, PADs, if you will, and I'll reference my ECCS evaluation model. So that would be node pumps and ASTRUM. Okay. If I want to upgrade let's say from PAD3.4 to PAD4.0, Westinghouse will do some work and estimate the effects of a transition from PAD3.4 to PAD5.0.

Okay. Now, to your question, Dr. Banerjee, what about full spectrum LOCA and what about PAD5.0? What we expect to happen is we're going to see licensees go from PAD4 to PAD5 and implement this FS LOCA at about the same time. So the two will be modular and you're going to expect that PAD5 would be approved before you implement FS LOCA. But since

they're both under review at the same time, that's probably a reasonable thing to expect.

MEMBER BANERJEE: Okay. Thank you.

MR. CLIFFORD: Okay. Slide 24 discusses 50.46c. You may be aware that staff has recently submitted a proposed rulemaking to 50.46, a complete revision of 50.46 actually. That went out last week for public comment. Recognizing that it's going to take years to complete the rulemaking and even longer to implement this across the 100 operating reactors, the staff completed a detailed plant-specific safety assessment to show that each and every plant continued to operate safely relative to the new requirements, and each year the staff is committed to perform an update to show on a plant-specific basis that there's margin relative to the new requirements until such time as all the plants are in compliance with the new requirements.

This annual update was significantly complicated by the TCD evaluations. So in November 2013 the PWR Owners Group volunteered to revise their safety assessment, replacing their 2011 margin assessment. And the staff used that information to then update our plant-specific database of an ECCS performance safety module.

So in conclusion, as we showed in the timeline, there are several legacy codes that are still in use that do not properly account for TCD. And a regulatory process needs to be established for assessing the continued applicability of all legacy codes and to set up kind of a validation, a continuous periodic validation and process by which the staff can take action to either retire codes or to require that they are recalibrated.

The TCD issue has required a significant effort by both the NRC staff and the industry to assess its impacts because of the tentacles that go into fuel design, non-LOCA and LOCA space. And I think the lesson learned is we need to stay ahead of these things and not get into these situations in the future.

We've received AREVA's GALILEO and Westinghouse's PAD5 and they're currently under review. And we will hope to get those implemented across the fleet as soon as we can. So the short-term solution has been the introduction of penalty factors and reanalysis. The long-term solution is to just retire these legacy codes and replace them with more modern versions.

MEMBER BANERJEE: So, this is very

interesting from the point of view of information for the Committee. Do you expect that we would have to take certain actions, or you'd come to us in the future for our advice on some specific aspects of this matter, other than informational you would need us to --

MR. CLIFFORD: Well --

MEMBER BANERJEE: -- review some things? Just give us a heads up for the future what might be in the pipeline.

MR. CLIFFORD: Right. And, you know, it's your prerogative to get briefed on the new methods as the staff reviews them.

MEMBER BANERJEE: Right. Well, we realize that, but is there any specific items that we should review, like PAD5 or GALILEO or something?

MR. PARKS: Well, I think you would be interested in PAD5, GALILEO and full spectrum LOCA, And AREVA's revised realistic LOCA model methods.

MEMBER BANERJEE: Okay.

MEMBER CORRADINI: So can I broaden it? And maybe this is not just for you, but maybe a bigger picture is to see -- because you kind of walked us through these, but there are other tools that are in the same boat that are sort of hydraulic tools,

etcetera. So are you using these fuel codes and this issue to kind of more regularize how you look at calculational tools and either refurbishing them or replacing them in terms of allowing them to be used? You know what I'm asking?

MR. CLIFFORD: Yes. Yes. We've started a dialogue with the different vendors to try to come up with a uniform approach to establishing some procedure and process for doing that.

MEMBER CORRADINI: I guess my recommendation to Dr. Banerjee is that the chairman of the Subcommittee would maybe start off the Subcommittee meeting with the big picture and then use these as the example of how they're trying to regularize it, because I think at least I would like to see --

MEMBER BANERJEE: It's part of --

MEMBER CORRADINI: -- the bigger picture first before we pick an example.

MEMBER BANERJEE: Right. Okay. Well, I think that was a very effective summary of what's been going on, and we learned a lot. Do the members have any other questions before I turn it back to the Chairman five minutes ahead of time?

MEMBER BROWN: Yes, I had one question.

You commented that because of the TCD thing you've completed a plant-specific analysis. Safety assessment. Not an analysis, but a safety assessment --

MR. CLIFFORD: Yes.

MEMBER BROWN: -- to show that the continued operation of all the fleet is satisfactory up until you have tall the Is dotted and all the Ts crossed and the rules complete and all that type of stuff.

MR. CLIFFORD: Right.

MEMBER BROWN: Now when you did that, I'm presuming that there was enough margin in the designs, ECCS, the responses, their folks' analyses that would absorb this degradation or this decrement to performance. Did any of them come close, I mean, when you say there's margin left, are any of them right on the edge, or --

MR. CLIFFORD: Well, you know, when they go on this margin hunt to identify conservatisms in the methodology that they can harvest, they generally take as few as they need to get under 2,200, to show that they're below 2,200. So there's more available, but they only grab what they need on a plant-specific basis. So the calculated PCTs and ECRs all went up.

They're all below the new requirements, which are stricter than the existing regulations. I don't know if that answers your question or not. They all went up.

MEMBER BROWN: Right. Their end results of the calculations, or their analysis went up.

MR. CLIFFORD: Right.

MEMBER BROWN: But you're saying even though the requirement came down, they were still within that by removing some of the other conservatisms within their -- and you've identified or can say that there are other ways --

MR. CLIFFORD: Right. I mean, a good --

MEMBER BROWN: -- where they could have done something if they had to?

MR. CLIFFORD: A good example of one of the conservatisms that pretty much the entire fleet used was, you know, they usually do LOCA analysis at one burnup point. They take the maximum stored energy. So that's the highest peaking rod in the core over the life of the core. Well, what they did is did a burndown credit. They looked at rods at different times in life. So they were later in life. TCD was more of an impact, but at the same time they were operating at lower power. So they could just credit

the existing tech spec limits on power and then run a specific calculation for a higher burnup rod at lower power and show that met the requirements.

MEMBER BROWN: Okay. So you used a more time and life analysis to compensate --

MR. CLIFFORD: Exactly.

MEMBER BROWN: -- as opposed to the worse case in that circumstance? Okay.

MEMBER BANERJEE: I guess the effect was most apparent on some of the EPUs like Turkey Point 3 and 4 where they had to review some peaking factors or something; I've forgotten the details now, decrease some HHS side delay times. There were a whole bunch of things that needed to be done to take into account this TCD effect. But that was pat of what was eventually approved for the EPU.

MR. CLIFFORD: Right. In that specific analysis, you know, we reviewed and approved. The margin assessments that are done are done in accordance with 50.46a(3), the original ones that were done. And that requires that they use reasonable methods to estimate the error, the impact of the error or change and then to schedule the reanalysis.

MEMBER BANERJEE: Right.

MR. CLIFFORD: So the estimate isn't

official.

MEMBER BANERJEE: Right.

MR. CLIFFORD: It's not approved by the NRC. It's the reanalysis that would be reviewed and approved. So you're going to see changes. When they finally do everything with approved methods, you're going to see differences.

MEMBER BANERJEE: And that would be PAD5?

MR. CLIFFORD: Correct. Right. So Westinghouse wants to coordinate 50.46c with the final resolution to TCD, which would be PAD5 and full spectrum LOCA.

MEMBER BANERJEE: Well, thanks. Thank you, Ben. Thank you, Paul.

And, Madam Chairman, it's in your hands now.

CHAIRMAN STETKAR: Thank you very much. And I'd like to thank Ben and Paul. I learned a lot.

With that, we are adjourned as far as the transcripted part of our meeting and we will take a break until 9:45 and come back for P&P.

(Whereupon, the meeting was adjourned at 9:29 a.m.)

U.S.NRC

UNITED STATES NUCLEAR REGULATORY COMMISSION

Protecting People and the Environment

Status Report on Fuel Thermal Conductivity Degradation

April 2014

Paul Clifford
Division of Safety Systems
Office of Nuclear Reactor Regulation

Purpose

- The purpose of this briefing is to provide a status report on the staff's actions to address fuel thermal conductivity degradation (TCD).

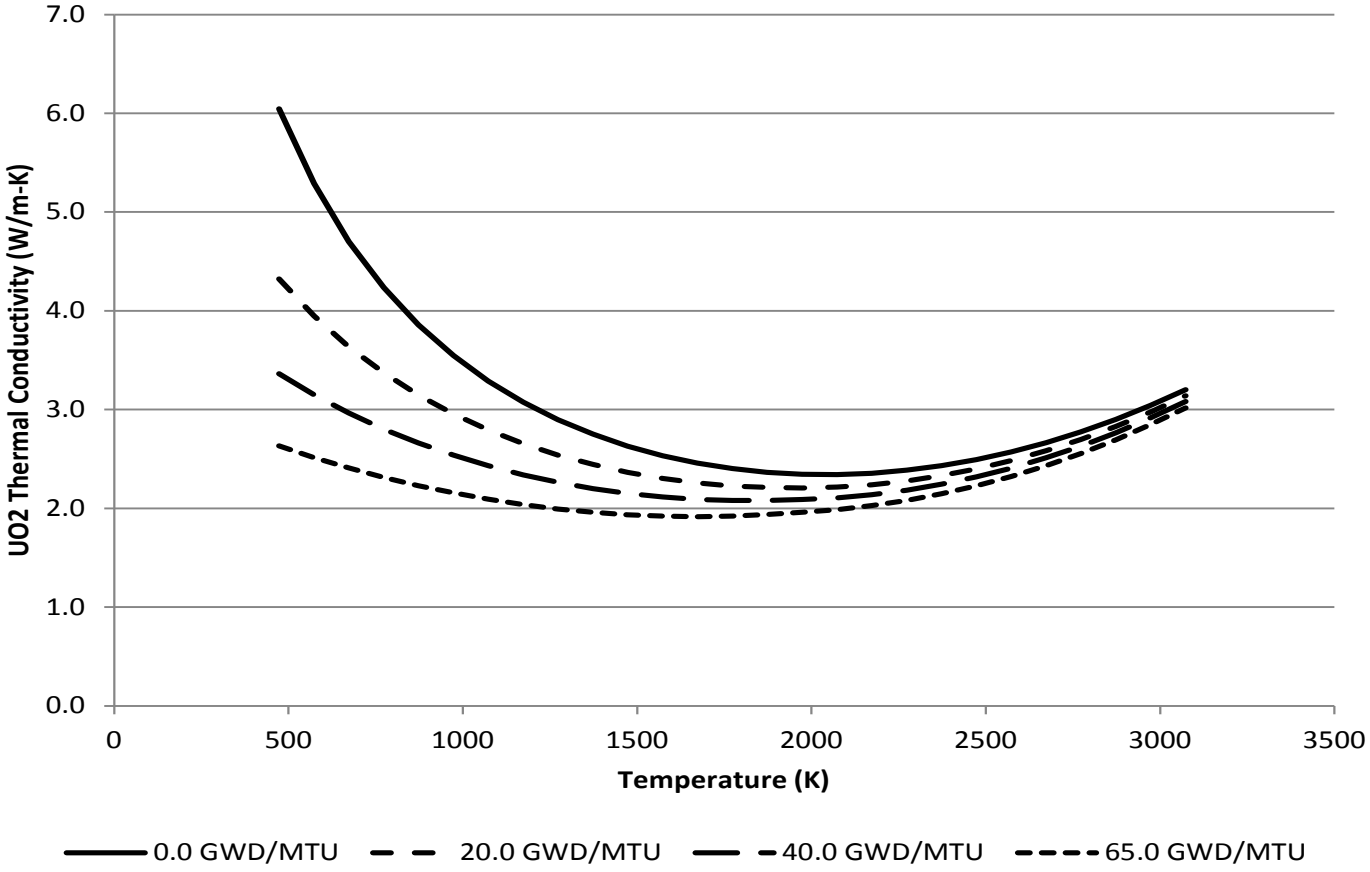
- ACRS Materials, Metallurgy, and Reactor Fuels Subcommittee was briefed on this topic in February 2013.
  - Calibration and Validation of Fuel Thermal Models
  - Status Report on Fuel Rod Performance Codes
  - Status Report on Safety Analysis
  - Root Cause and Corrective Actions

Introduction

- Irradiation damage and the progressive buildup of fission products within fuel pellets result in reduced thermal conductivity of the pellets.
- Legacy fuel rod thermal-mechanical codes do not include this reduction in thermal conductivity with increasing exposure because earlier test data were inconclusive as to the significance of the effect.
- Beginning in the 1990s, measurements collected from instrumented fuel assemblies (IFA) at the Halden research reactor have indicated steady degradation in the thermal conductivity of uranium fuel pellets with increasing exposure.

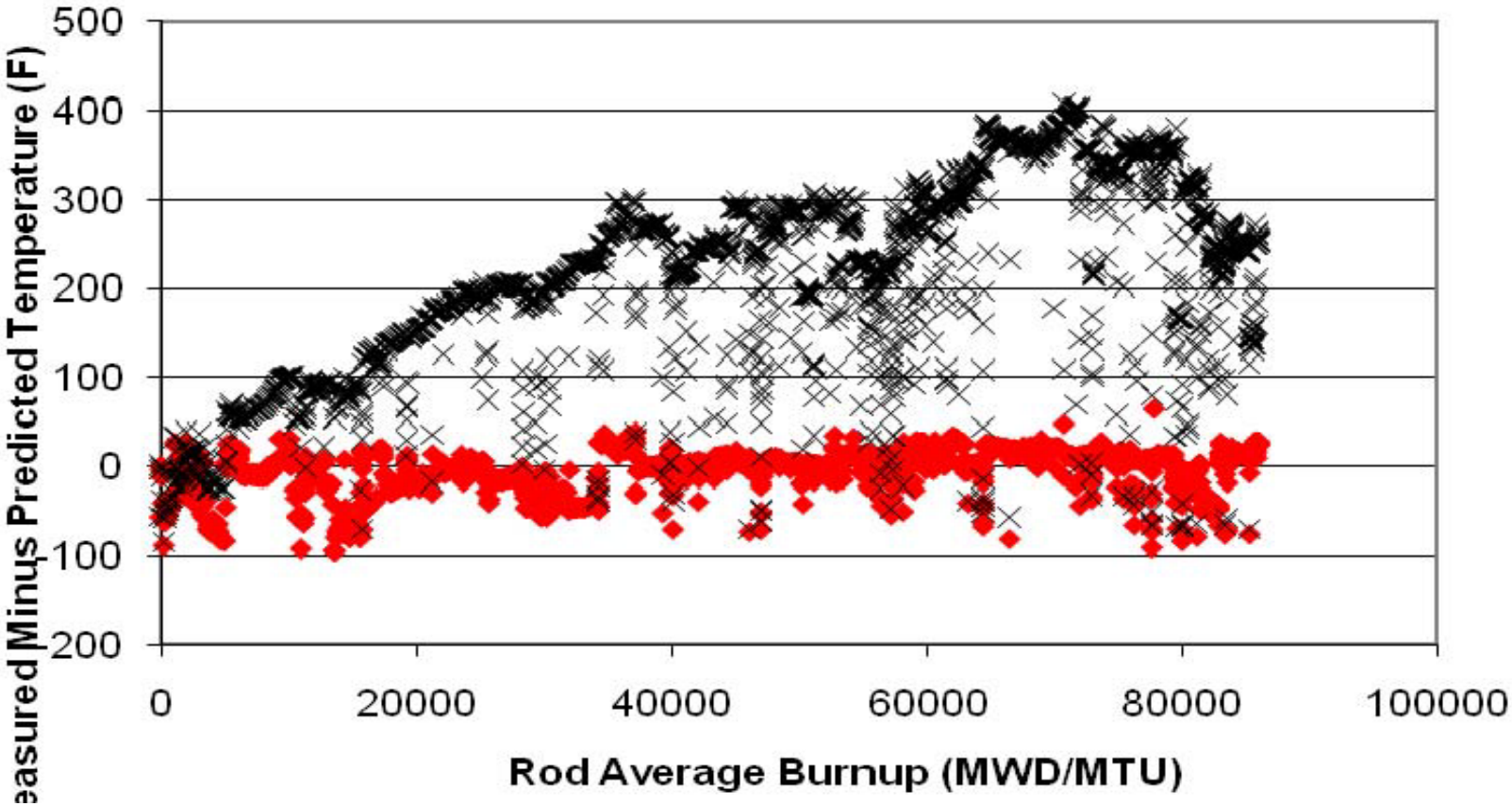
Fuel Thermal Conductivity

- Figure below illustrates the exposure-dependence of fuel thermal conductivity.

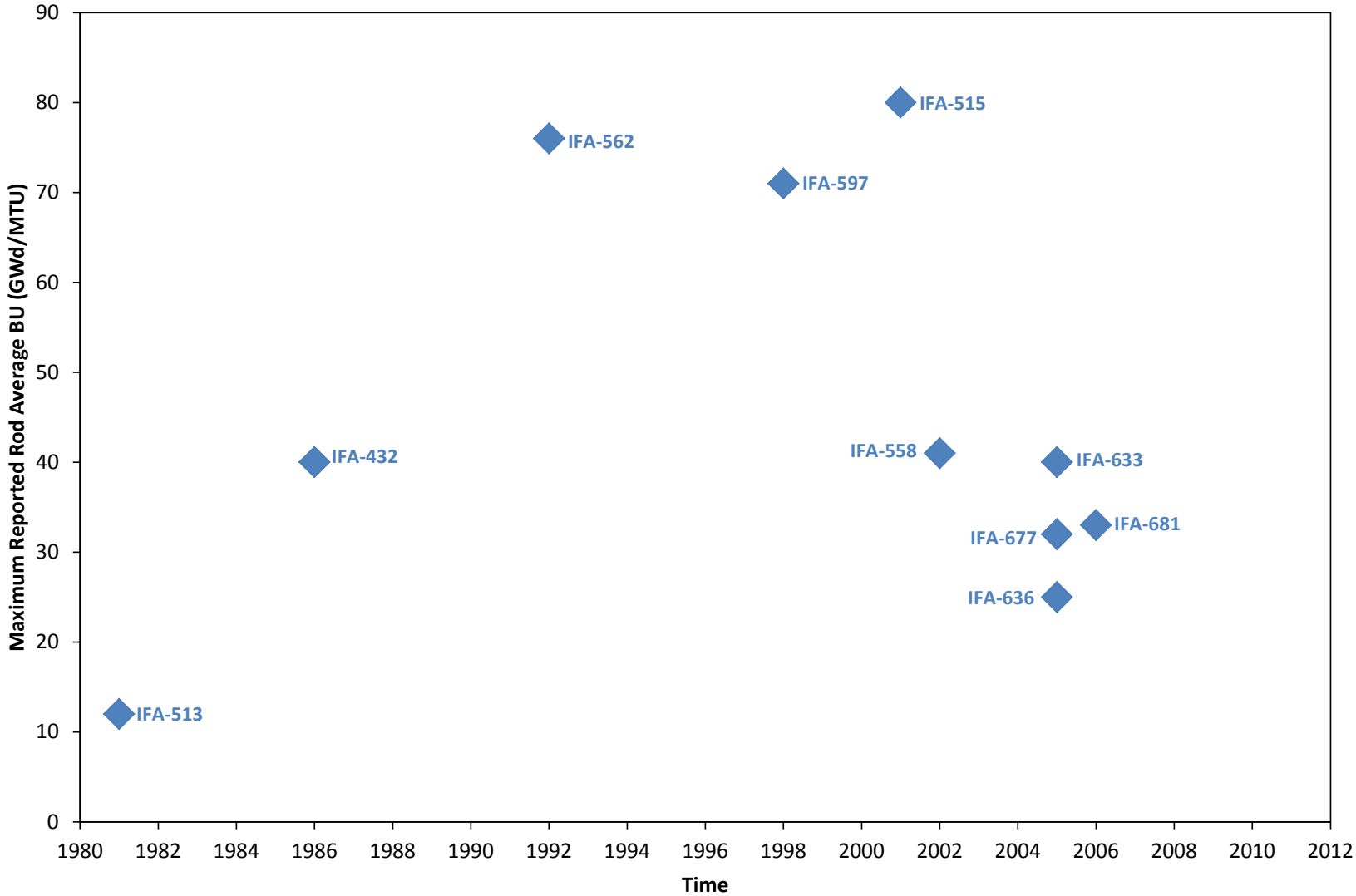


Predicted Fuel Temperature

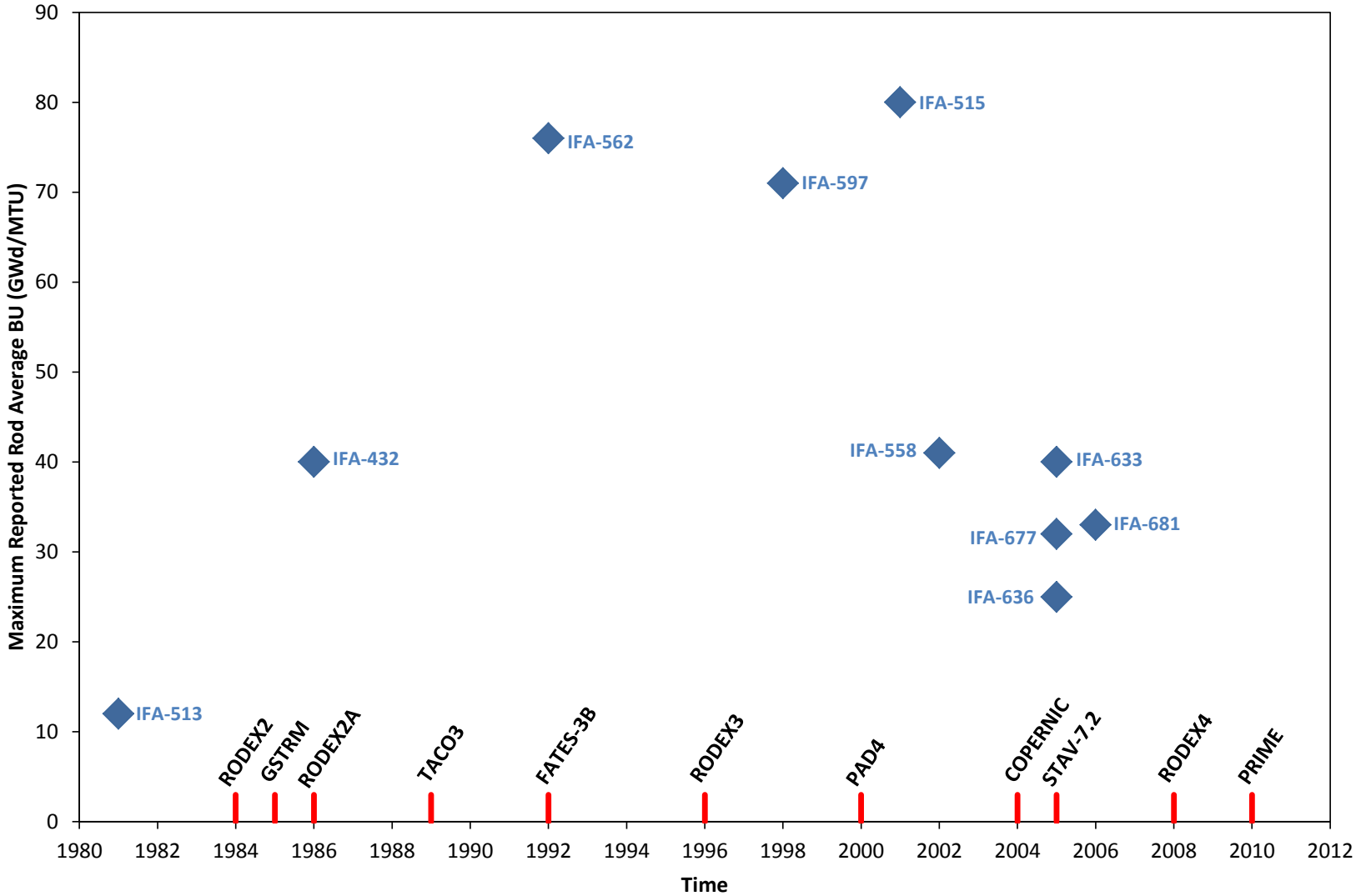
- Figure below illustrates temperature predictions for Halden IFA-562.2 test rod 17.



Halden Fuel Temp. Database



Fuel Performance Models



Impact of TCD

- Degraded thermal conductivity results in a higher fuel pellet temperature (at any given power level). An artificially low fuel temperature prediction (steady-state) or ΔT (transient) will impact the following calculations:
  - LOCA stored energy
  - Pellet thermal expansion
    - Initial pellet-to-cladding gap size
    - PCMI stress and strain
  - Fission gas release
    - Fuel pellet-to-cladding gap gas conductivity
    - Rod internal pressure: LOCA rod burst and EOL cladding liftoff
    - Gap fractions (input to dose calculations)
  - Fuel melting point (power-to-melt limits)
  - Doppler reactivity

Status Report on Fuel Rod Thermal-Mechanical Performance Codes

BWR Fuel Models

- Legacy fuel performance models which do not account for TCD with exposure.
  - RODEX2A (AREVA)
  - ~~GSTRM (GEH)~~ Retired

- Modern fuel performance models which explicitly account for TCD with exposure.
  - PRIME (GEH)
  - STAV7.2 (W)
  - RODEX4 (AREVA)
  - GALILEO* (AREVA)

* Currently under staff review.

PWR Fuel Models

- Legacy fuel performance models which do not account for TCD with exposure.
  - RODEX2 (AREVA)
  - TACO3 (AREVA)
  - PAD4 (W)
  - FATES-3B (W)

- Modern fuel performance models which explicitly account for TCD with exposure.
  - COPERNIC (AREVA)
  - PAD5* (W)
  - GALILEO* (AREVA)

* Currently under staff review.

Corrective Actions

Corrective Actions

Corrective Actions:

- Scrutinize future changes to fuel design and/or operating limits, along with supporting empirical database, to ensure a high level of confidence in model predictions.
  - License fuel burnup limits (e.g., beyond 62 GWd/MTU)
  - Fuel pellet additives (e.g., aluminum silicate, cromiuim, beryllium)
  - Fissile content (e.g., beyond 5% ^{235}U enrichment, MOX)

- Consider requiring a periodic re-qualification of analytical models or establishing a sunset clause within staff's approval.

PRIME SE Condition

- PRIME models have been calibrated and validated by direct comparison to the existing empirical database. Further, model uncertainties described within the application methodology were derived by direct comparison of model predictions to the existing empirical database. To ensure PRIME's best-estimate predictions and applied uncertainties remain valid, GNF must demonstrate and document, in a letter addressed to the Director, Division of Safety Systems, Office of Nuclear Reactor Regulations, the continued applicability of PRIME every five years (starting in 2015).
  - In preparation of this letter, GNF must review available sources for applicable commercial and research reactor fuel performance data which may augment the existing PRIME qualification database (e.g., international research activities, poolside examinations, hot-cell programs, power ramp programs).
  - In the letter, sources for new data should be clearly identified. If no new data for a particular model (e.g., fission gas release model) has been discovered, the letter should state this fact and identify which sources were investigated.
  - PRIME model predictions and uncertainties should be compared against the augmented database. New data should be easily differentiated on the plots. At a minimum, the letter should separately address the following model predictions and their respective uncertainties: (1) fuel temperature, (2) fission gas release, (3) fuel irradiation swelling, (4) cladding creep, (5) cladding strain (due to over power conditions), and (6) void volume / rod internal pressure.
  - Any data discarded from the augmented qualification database should be identified and dispositioned.
  - The letter should identify and disposition any bias on model predictions or increase in uncertainty.

IAEA Suggestion

- IAEA Integrated Regulatory Review Service (IRRS) report (IAEA-NS-IRRS-2010/02) included the following suggestion:

  "NRC should consider limiting its approval of codes submitted by vendors to a specific period of time to ensure the codes are periodically evaluated and updated, as necessary, to reflect lessons learned and the latest knowledge."

TCD Impact in
Emergency Core Cooling System Evaluations

Review

- In December 2011, a licensee quantified the effect that that accounting for TCD would have on the predicted peak cladding temperature in a best-estimate ECCS evaluation.
  - Analysis relied on a newly developed version of the Westinghouse PAD code for fuel stored energy input for the ECCS evaluation.
  - Compared to a non-TCD analysis using PAD 4.0 for input, the predicted PCT increased significantly.
- Based on this result, the NRC staff issued IN 2011-21 describing the result and reiterating 10 CFR 50.46(a)(3) reporting requirements.
- Fuel vendors and licensees have addressed effects of TCD on ECCS evaluations in various ways.

ACRS S/C Briefing – February 2013

- Staff presented an overview based on the various approved evaluation models:
  - Efforts taken by the EM vendor to address TCD
  - Magnitude of effects
  - 50.46 reports received from licensees using evaluation models

- Most significant PCT effects occurred in realistic evaluation models
  - Most other estimated effects were less than 100° F
  - Plant characteristics exacerbated effects
    - Larger fuel pin diameter, for example

GEH BWR Evaluation Models

- Transition from SAFER/GESTR to SAFER/PRIME
- Licensees have submitted 50.46 reports with estimated effect of TCD
- New licensing analyses are performed using SAFER/PRIME

AREVA Evaluation Models

- BWR evaluation model applies an augmentation to account for TCD
  - Beginning of life conditions are limited because of burnup-dependent MAPLHGR limits

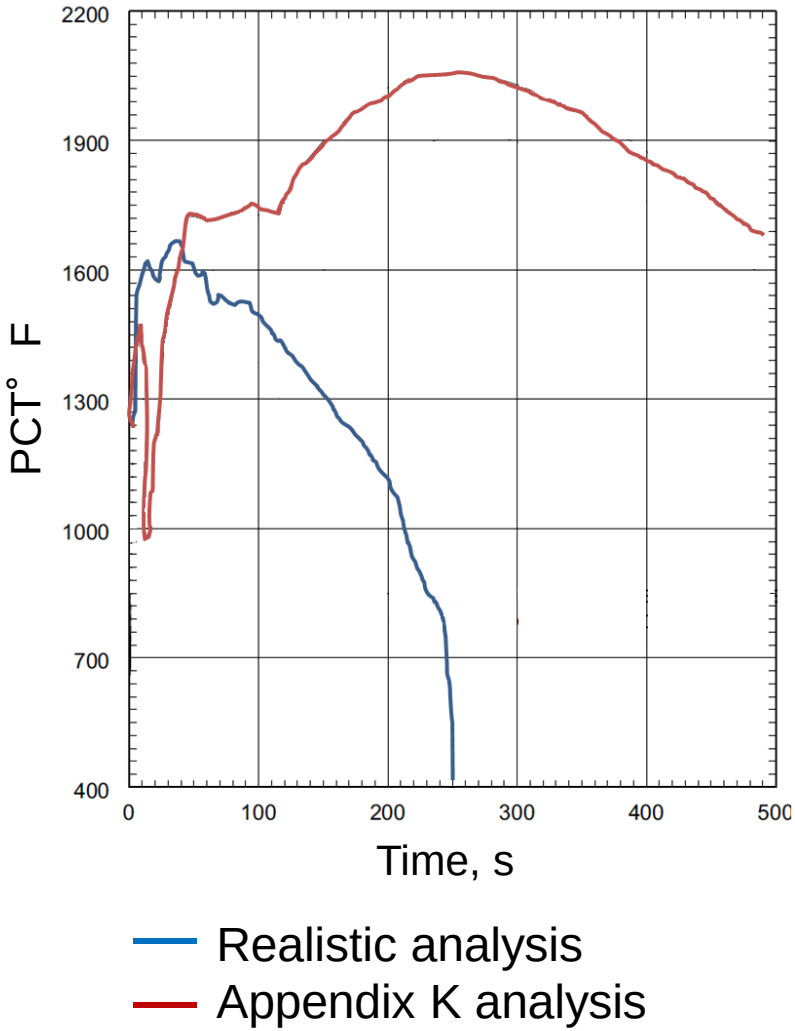
- Westinghouse/CE realistic model uses RODEX4 augmentation factors

- B&W model:
  - Uses TACO3 for stored energy input
  - Appendix K-conformant
  - Very high initial linear heat rate

Westinghouse Evaluation Models

- Realistic Models (CQD & ASTRUM)
  - Very high PCT plants generated explicit estimates of effect of TCD and submitted reports
  - PWROG-sponsored work generated estimates for lower-PCT plants based on the previous, explicit work
- BWR model uses STAV 7.2 and accounts for TCD
- W plants using Appendix K EM have submitted estimates of effect
- CE plants – next slide

CE Plants under Westinghouse Cognizance



- Plants are analyzed using Appendix K-conformant methods
- Despite high-PCT values, decay heat tends to be the limiting energy source
- Comparison to realistic analysis indicates that high PCT values are due to Appendix K conservatism
- Significant increase in initial stored energy is required to change dynamics of limiting event
- Shown: “cartoon” comparing PCT vs. time for an Appendix K analysis and a realistic analysis
- 2700 MWt Plant

Going Forward

- TCD estimates have been reported to NRC for most significantly affected evaluation models
- Vendors have transitioned, or are transitioning, to methods that account for TCD effects
- Re-analyses will be submitted in concert with 10 CFR 50.46c rulemaking
- In the meantime, staff reviews TCD disposition for analyses submitted for review and approval
  - *Submitted analyses are expected to account for TCD explicitly*

50.46c Related Activities

- The 50.46c ECCS performance safety assessment documents plant-specific safety margin relative to the new requirements, confirms continued safe operation for the entire fleet, and informs the implementation plan for the proposed 10 CFR 50.46c rule.
- The staff's annual update was complicated by ongoing fuel TCD evaluations.
- In November 2013, the PWROG completed a revision to their 2011 ECCS margin assessment report to address impact of TCD.
- In January 2014, the staff completed an update to the 50.46c ECCS performance safety assessment.

Conclusions

- Legacy fuel performance models do not properly account for TCD with increasing exposure.
  - Regulatory process needed to assess continued applicability of legacy codes and take necessary action.

- Significant effort spent by NRC staff and industry to address TCD and downstream impacts.
  - Awaiting Westinghouse LBLOCA submittals.

- Legacy fuel performance models being replaced with modern computer codes.
  - AREVA's GALILEO and Westinghouse's PAD5 under review.