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ADVISORY COMMITTEE ON REACTOR SAFEGUARDS

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UNITED STATES OF AMERICA

NUCLEAR REGULATORY COMMISSION

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ADVISORY COMMITTEE ON REACTOR SAFEGUARDS

(ACRS)

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THERMAL-HYDRAULIC PHENOMENA SUBCOMMITTEE

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OPEN SESSION

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TUESDAY

DECEMBER 5, 2017

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ROCKVILLE, MARYLAND

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The Subcommittee met at the Nuclear Regulatory Commission, Two White Flint North, Room T2B1, 11545 Rockville Pike, at 1:00 p.m., Jose March-Leuba, Chairman, presiding.

COMMITTEE MEMBERS:

JOSE MARCH-LEUBA, Chairman

RONALD G. BALLINGER, Member

DENNIS C. BLEY, Member

MICHAEL L. CORRADINI, Member

WALTER L. KIRCHNER, Member

DANA A. POWERS, Member

JOY REMPE, Member

DESIGNATED FEDERAL OFFICIAL:

ZENA ABDULLAHI

ALSO PRESENT:

JOSH BORROMEO, NRR

CHRIS HOXIE, RES

ANDREA VEIL, Executive Director, ACRS

AARON WYSOCKI, ORNL

PETER YARSKY, RES

TAREK ZAKI, RES

*Present via telephone

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

1:03 p.m.

CHAIRMAN MARCH-LEUBA: The meeting will now come to order. This is a meeting of Thermal-Hydraulic Subcommittee of the Advisory Committee on Reactor Safeguards. I am Jose March-Leuba. ACRS Members in attendance today are Ron Ballinger, Dana Powers, Michael Corradini, Dennis Bley, Walter Kirchner, and Joy Rempe. Zena Abdullahi is a designated federal official for this meeting.

The research staff will brief us on the preliminary assessment of the experiments conducted of the KATHY thermohydraulic test facility. The main body of this experimental data is to aid in the development of the methodology to predict failure to the weight and then assuring temperature excursion during hours of instability power oscillations.

This subcommittee has heard proprietary presentations by vendors on this same topic. And today we're looking forward to hearing about the KATHY experiments and the research preliminary assessments of the results. And I understand in process on the preliminary.

MR. YARSKY: Yes.

CHAIRMAN MARCH-LEUBA: Part of this

presentation will be closed to the public to allow discussion of proprietary matters. We have one open bridge line arranged for interested members of the public to listen in. A separate and closed bridge number is available for NRC staff.

We have received no written comments or requests for time to make oral statement from members of the public regarding to this meeting, but as customary, the line will be open at the end at the open section of the meeting to allow for spur of the moment comments.

As the meeting is being transcribed, I request that participants use the microphones located throughout this room when addressing the subcommittee. Participants should first identify themselves and speak with sufficient clarity and volume so that they can be readily heard.

Let me remind you now to please ensure that all your devices have been placed in silent mode to minimize disturbances within the meeting. We will now proceed with the meeting and call upon Peter Yarsky to assess the initial open portion of the meeting. Go for it.

MR. YARSKY: Thank you. I'm Dr. Peter Yarsky from the research staff. And before getting into a discussion of the KATHY experiments, I wanted to take a few moments to provide some background information on MELLA+ ATWS instability and the predicted failure to rewet phenomenology.

In this presentation I'll provide a brief description of the MELLA+ operating domain, which I'm sure many members are very familiar with. So I'll try and do this very briefly. And if at any point this gets very boring, you can ask me to speed up and skip a number of slides. But I wanted to make sure that everyone had some background before we started talking about the experiment itself.

This includes a quick discussion of the safety significance of the MELLA+ domain and what we mean when we say ATWS with instability. We'll talk about trace calculation results that have informed recent license amendment requests reviews, as well as what the NRC identified as a predicted mechanism for potential fuel heat up during ATWS-I scenarios from MELLA+ BWRs. And lastly, I'll touch on some considerations that are important for doing plant specific evaluations.

The MELLA+ domain represents an expansion of the operating domain relative to extended power operate for BWRs, and notably allows operation at high power levels, 120 percent of the original license thermal power level. But at low core flow rates about 80 percent of the rated core flow rate.

This operation at high power to flow ratios introduces new aspects to the progression of anticipated transient without scram events for BWRs operating in this domain. In particular, ATWS events are mitigated by an automatic trip of the dual recirculation, a dual trip of the re-circulation pumps, which causes a power and flow decrease of the pumps run down.

The power in the reactor then increases as a result of a reduction of feed water temperature. When the core flow rate is low, this dual re-circulation pump trip mitigating feature is less effective and this means that there's a higher power level in the core following the trip of these pumps.

What this means in the power flow operating domain is that a plant operating at originally license thermal power, which would be the point at 100 percent, 100 percent on this power flow map. If that plant were to experience a ATWS and a dual re-circulation pump trip, it would follow the black curve in terms which trajectory on the power flow map and would wind up at a given power flow, can I show with the pointer here?

No, I'm not able to do that.

CHAIRMAN MARCH-LEUBA: You have to use the mouse to do that.

MR. YARSKY: Yes. I'm trying to use the mouse, but it's not showing up on the screen. But there's two points indicated at the end of the black curve versus the red curve. If a plant were operating in the MELLA+ domain, its evolution during this event would result in a much higher power to flow ratio.

If we were to look at those points relative to stability, what one would see is that the progression of the event of an ATWS with a dual re-circulation pump trip initiating from the MELLA+ corner would wind up at the red point marked MELLA+. And at this point the reactor is predicted to be much more unstable meaning that it would cross the stability boundary much earlier in the event.

And this can lead to what we refer to ATWS wimp instability. So there's an ATWS event, and during the progression of that event the reactor becomes unstable and large amplitude power and flow oscillations are observed.

MEMBER CORRADINI: Just, can you go back. Just to be sure, go back a slide. The OLTP is where we set the --

MR. YARSKY: No, this power and flow map that I'm showing is a little bit of a cartoon. It doesn't represent any particular plant. The stability boundary is set by actual -- essentially the geometry of the core and the pressure losses in the core is a big contributing factor to where the stability boundary is. It's generally analyzed on a cycle specific basis in the stability boundary moves.

MEMBER CORRADINI: Okay.

MR. YARSKY: So it's not meant to say that the blue curve representing the OLTP line is in some way related to the stability boundary. This is just a --

MEMBER CORRADINI: That's just, okay.

CHAIRMAN MARCH-LEUBA: For reference, OLTP stands for Original License Thermal Power.

MR. YARSKY: So that they intersect in this particular figure is more a coincidence than that it would be driven by some consideration of the ATWS event.

CHAIRMAN MARCH-LEUBA: Since I drew the figure in my previous life, the intention I had there is that originally the reactor would have been stable. And as we start to add modifications to it, it became more and more unstable.

MR. YARSKY: Right.

CHAIRMAN MARCH-LEUBA: If you lose your pumps.

MR. YARSKY: Right. And if using this in combination with this figure, what this also indicates is that while a plant operating at EPU power levels may experience some instability during the progression of the event, at MELLA+ that instability could be expected to occur earlier in the event. So there's not just that the reactors were to become more unstable, but even in going from EPU to MELLA+, you could expect the reactor would become unstable earlier in the event.

So in terms of thinking about an ATWS with instability, I wanted to give you an overview of a typical event and then to provide some trace results of analysis of that event. And what this event is that we've analyzed previously is a turbine trip with a full bypass capability. So a 100 percent turbine bypass capability assume.

What will occur is, during a turbine trip, the turbine stop valves will close and create a pressure pulse that will result in an increase in the reactor power level. As that turbine stop valve closes, this will also initiate the dual re-circulation pump trip.

And the closure of the turbine stop valves will remove source of extraction steam that's used to supply steam to the feed water heater cascade. And that loss of extraction steam will feed water temperature to begin to decrease.

This particular event is expected to yield unstable conditions and result in large amplitude power instability. The operators will undertake two key actions as part of the emergency operating procedures to mitigate the event, one of which is to initiate the standby liquid control system injection which injects soluble boron into the reactor pressure vessel to shut down the reactor core.

The other mitigating event is to manually control the reactor water level to a low level. This had the effect of removing the sub-cooling from the core inlet flow. So reducing the water level so that the injected feed water is coming in through the spargers injects to a stem atmosphere so that that water can heat up before it reaches the core inlet.

MEMBER KIRCHNER: How would the operators physically reduce the water level?

MR. YARSKY: At the very end I was going to talk about some differences between plant designs. But in some BWRs the feed water pumps themselves are motor driven. In which case the operators have direct control over the feed water pumps in terms of the head that's supplied by the feed water pumps. So that they can reduce that flow rate in order lower the reactor water level.

And they can use the feed water pumps as a high pressure injection makeup system to maintain the water level at a desired water level, based on that plant's specific emergency operating procedure.

MEMBER KIRCHNER: But their standard guidelines would always adjust the water level to above the core height. Or what's the --

MR. YARSKY: Well, in the emergency operating procedures, and this would be in a general sense, each plant has its own plant-specific emergency operating procedures. But you have different target water levels. And depending on the event progression, if things get worse, you would change what water level you're controlling the level to.

MEMBER KIRCHNER: And had you analyzed those scenarios --

(Simultaneous speaking.)

MR. YARSKY: We've analyzed a variety of water level scenarios as part of a generic work that we've done for MELLA+. So we were looking at a representative plant that had some features of BWR/4, or BWR/5 and we're looking some of these plant differences. And so we looked at the sensitivity to the results, depending on where the operators controlled the reactor water level.

Initially what the operators will try and do is to just lower the water level is it dropped at least 50 below the feed water start. So, that's their initial objective.

MEMBER KIRCHNER: And where is that in relation to the core?

MR. YARSKY: So that would be maybe, like, top of active fuel. I want to say plus --

(Simultaneous speaking.)

CHAIRMAN MARCH-LEUBA: Say that again about the active fuel. Very high, right?

MEMBER CORRADINI: But because of the two phase level, I'm still killing reactivity.

MR. YARSKY: Right, because you're injecting into this two phase mixture above the liquid level. What's happening is this that cold injection is condensing steam in that space so that the liquid water that's reaching the core has that sub-cooling removed.

MEMBER CORRADINI: Okay.

MR. YARSKY: So the reactor operators will attempt to lower the reactor water level to achieve at least a two foot gap between the feed water injection spargers and the reactor water level.

MEMBER CORRADINI: Three foot gap, this way or that way?

MR. YARSKY: Two feet so that level is below the spargers.

CHAIRMAN MARCH-LEUBA: The typical presentation of the EOP, the procedures says control within this band. Top band is two feet below the sparger, bottom band is top water fuel. And the operator has freedom to put that wherever he wants. And, I mean freedom to try to keep it stable like this.

MR. YARSKY: Yes. There may be other things going on. Most operating are written to be symptom based. So you're responding to symptoms in your plant as opposed to a particular kind of event.

MEMBER CORRADINI: Okay. Thank you.

MR. YARSKY: Okay. What I would like to do is present the results with trace analysis for a particular representative case. This calculation was performed for a generic BWR/5 plant model. We assume a 100 percent turbine bypass capacity. The initial core flow rate is 85 percent of rated. The power level is 120 percent of the original license thermal power.

We analyzed this at a middle of cycle

exposure point, in particular the peek hot excess point. And what we simulate are two manual operator actions. The first is an attempt to control the reactor water level. In this case, the operators strive to control a reactor water level to the top of active fuel.

And we assume that the operators will initiate the standby liquid control system at 120 seconds into the event.

MEMBER REMPE: So just to make sure with all this generic stuff. My understanding was that what you said earlier is what you've been analyzing a mixture of a reactor that's part BWR/4, part BWR/5. Now this is solely a BWR/5. So this is a new analysis for a just a BWR/5 plant?

MR. YARSKY: Well, to clarify, what we had done was we had built a generic model that had features of a BWR/4 and a BWR/5 that we could turn on and off. So the plant model had maybe two reactor core oscillation cooling systems, one that would look like a core oscillation cooling system for a BWR/4 and a second one that would look like a five.

MEMBER REMPE: Okay.

MR. YARSKY: And then what we can do is use flags to turn on and off features to make the model look like a four or to make the model look like a five.

So in this case, it's that same generic model that you're familiar with, but the options are set to deactivate all of the BWR/4 features and to activate all of the BWR/5 features.

MEMBER REMPE: Although it's not the topic for today, but my understanding is you are now getting ready to do a plant specific --

MR. YARSKY: Yes.

MEMBER REMPE: -- evaluation for a plant that's coming in.

MR. YARSKY: Right. Exactly. Yes. And at the end of this presentation I wanted to tease that little bit.

MEMBER REMPE: Good.

MR. YARSKY: Not by presenting any results, but at least by pointing out aspects of this generic analysis where we looked at and identified some features that are important to capture in a plant specific analysis. So this analysis cannot really be extended to every plant. There are aspects of each individual plant that will need to be considered. And we'll sort of talk about what those important considerations are.

MEMBER REMPE: Good, thanks.

MEMBER CORRADINI: So remind me a couple

of key differences between a four and a five.

MR. YARSKY: So one of the key differences is that in a BWR/3 or a BWR/4, the standby liquid control system injects into the lower plenum of the vessel. In a BWR/5 or a BWR/6, the standby liquid control system injects into the high pressure, core spray, sparger line which means that that injection is above the core. But in the upper plenum above the core but below the separator dome.

MEMBER CORRADINI: So, but from the standpoint of modeling, can TRACE even know the difference other than location elevation?

MR. YARSKY: Yes.

MEMBER CORRADINI: Because it's a lump parameter calculation?

MR. YARSKY: If we want to talk about the standby living control system modeling that we do, we take into account that when the injection is into upper plenum, it's being injected into a two phase upturbulent environment. And what's being injected into the lower plenum that is potentially being injected as, like, a cold fluid into a warm fluid at lower flow rates.

And we have a methodology to account for that difference, but I would, if we wanted to get into the details of that, we should do so in the closing.

MEMBER CORRADINI: That's fine. That's fine. But it's an elevation difference and two phase versus single phase.

MR. YARSKY: Right. In terms of the standby liquid control system. There's also differences in the reactor core isolation cooling system. In the BWR/5, the reactor core isolation cooling system injects also the upper plenum. But in a BWR/4 it injects into the feed water line.

MEMBER CORRADINI: Okay.

MR. YARSKY: So there are differences such as these that we reflect in the modeling. And so in this case that I'm presenting, we're just doing a BWR/5. And in this representative case, we just want to talk about how we reach the prediction of fuel heat up and what is the mechanism for this fuel heat up.

So this just sort of provides an environment to discuss what's going on at a local level.

CHAIRMAN MARCH-LEUBA: Going back to four versus five, if you inject boron from the top, you have two options. You can mix, in which case it would mix and go around and come back to the core. Or not mix and stratify. But if it doesn't mix, it drops into the core and it goes into the bypass region where it effect is shutting down the core. Whereas when you inject in the bottom of the vessel --

PARTICIPANT: It has the core?

CHAIRMAN MARCH-LEUBA: No, it stratifies.

(Simultaneous speaking.)

MEMBER CORRADINI: Sort of fall to the bottom of the vessel and pool in the bottom head of those --

CHAIRMAN MARCH-LEUBA: But the operator=s solution is very cold and had like 20, 30 percent high residue.

MR. YARSKY: Yes.

MEMBER CORRADINI: Okay. That helps. But on the other hand though the way TRACE is formulated, we have --

(Simultaneous speaking.)

MR. YARSKY: We have a special methodology to account for the physics of a stratification and --

MEMBER CORRADINI: Other calculations?

MR. YARSKY: Right. Well that methodology is based on experiments that were performed by General Electric. And so the nature of that methodology if we wanted to get into it, we should probably do so in a closed session.

MEMBER CORRADINI: That's fine. I just wanted to remind myself. Thank you very much.

MR. YARSKY: Okay. So I'm presenting here a sequence of events. And eventually what I'm going to show is a video of the event, a visualization of what's going on. And we can step through key moments in that. So it's not important to take in this whole table right now. But I wanted to sort of give you a preview to what I'm going to show you to put it in context.

In this event, we're going to have a ten second mal-transient. I'm going to show you a video of the event happening in real time. So that this early part, a lot of things are going to happen. So I want to just sort of give you this background.

The turbine stop valves are going to close at ten seconds. A turbine bypass valves are going to open at 11 seconds. And feed water flow will start to decrease around 12 seconds. And then what occurs in the event after this initial, very rapid period where the turbine stop valves close and the turbine bypass valves open.

We then enter a somewhat slow phase where the loss of extraction steam to the feed water heater pass gates results in the steady, but somewhat slow decrease in feed water temperature which will eventually increase reactor power to the point where the reactor becomes unstable.

This will happen around the 100 second mark at which point we'll be able to watch evolution of the instability, the nature of the instability. And then following that period, the instability itself is mitigated and the power oscillations are reduced by a combination of the effectiveness of operator actions, in terms of boron injection and reducing the reactor water level.

CHAIRMAN MARCH-LEUBA: Are your feed water pumps steam driven or --

MR. YARSKY: In this particular model, the feed water pumps are motor driven.

CHAIRMAN MARCH-LEUBA: So is the control of the feel water flow?

MR. YARSKY: Yes.

CHAIRMAN MARCH-LEUBA: But there is no operator action in one second?

MR. YARSKY: Right. So this twelve second period here, what's happening is the feed water controller is still operating, and it's reacting based on its three element control to the absence of steam flow to the turbine.

CHAIRMAN MARCH-LEUBA: So you would expect the operator to take action, but not that fast?

MR. YARSKY: Yes. So when you talk about the feed water flow starting to decrease, and Jose, that's a very excellent point. In this particular instance it is the automatic controller, the automatic three element controller that's normally functioning during plant operation.

It's still assumed to function before operators have the opportunity to intervene. And in this particular case, because it's a motor driven feed water system, those controllers are still active. Yes. And in this particular case it's reacting to the decrease in steam flow.

So here's a plot of the transient reactor power for this representative case when you can see it's very early in the event. The closure of the turbine stop valves causes this power pulse. We'll skip ahead.

CHAIRMAN MARCH-LEUBA: The mouse not working?

MR. YARSKY: The mouse is not working. So I can see it on my screen, but I can't -- oh wait. Oh. Oh there we go. Okay.

CHAIRMAN MARCH-LEUBA: It's extended.

MR. YARSKY: Yes, okay. So this point here --

MEMBER CORRADINI: It also disappears when you're not using it.

MR. YARSKY: Yes. Okay. So now I can use the mouse to point. So this power peak here, this occurs because of the back pressure wave from the closure of term and stop valves. There's very shortly, very shortly thereafter the dual re-circulation pump trip, which reduces the flow, causing the power to come down. This happens very quickly.

Then there's a slow progression where you can see the power level increasing. What's occurring here is that the feed water injection is getting colder, and that colder water is reaching the core. It's trying to push the boiling boundary higher into the core and this increases the reactor power.

Eventually the reactor becomes unstable. And then we can see is around the 230 second point, the oscillations have been dying away or have been damped by the effectiveness of the operator actions.

CHAIRMAN MARCH-LEUBA: I cannot see it there already, but can you tell about the model oscillation. Is it in phase, out of phase.

MR. YARSKY: Yes. This is why it's very important. I'm pre-empting my next slide. So what we see is that the oscillation mode is initially in the core-wide mode, and that during the event a bi-modal oscillation occurs. And this is a coupled oscillation mode between the core-wide and the regional mode.

And so this is just sort of where we first see that oscillation using our visualization methodology. But I want to show you is a video of this so we can watch the event progression. So if you'll give me a moment to do that.

MEMBER CORRADINI: But, as you're doing that the operators start taking control over the controller at what time?

MR. YARSKY: About two minutes.

MEMBER CORRADINI: Okay. So 115 seconds.

MR. YARSKY: 110 seconds for the feed water control and 120 seconds for --

MEMBER CORRADINI: Or that the controller is doing what it thinks it should do?

MR. YARSKY: Right. Yes.

MEMBER CORRADINI: What does it think it should do?

MR. YARSKY: It thinks it should be maintaining the reactor water level at the nominal level. However, because of the three element controller, there is going to be a delta level that arises because of the air due to no steam flow.

MEMBER CORRADINI: Okay. Thank you.

MR. YARSKY: So it'll be trying to maintain normal water level with some offset.

MEMBER CORRADINI: Thank you.

MR. YARSKY: So in the first ten seconds, there's just a null transient. And then you'll see the turbine trip come in. Power goes up and responds to the turbine, turbine stop valve closure and then comes down and responds to the duel re-circulation pump trip.

At this point in the event there's, this is a relatively slow portion in the event. What I'm going to do is I'm going to advance the time a little bit. So if you'll pardon my fast forwarding.

PARTICIPANT: My God.

MR. YARSKY: What I wanted to do is not immediately go to the point of instability, but just a few seconds beforehand. And the area of this movie that's interesting to watch is the plot of the axial power shade. So that's shown here. And what you can see is that the axial peeking becomes stronger more bottom peaked as the feed water temperature comes down.

And then we begin to see the onset of the instability at this 100 second mark. And then each one of these boxes represents one of the fuel assemblies in the core and its height, of course, represents the power in that fuel assembly. And so here, this is the axially integrated power. So this is total assembly power.

CHAIRMAN MARCH-LEUBA: Walt, Walt, Walt. Microphone.

(Simultaneous speaking.)

MR. YARSKY: Yes. And as you can see there are certain points where the power is reduced. That's where the control blades are inserted in this middle cycle point. It's around this point in the transient that we begin to see the evolution of the bi-modal oscillation where you can see this aspect of the regional oscillation occurring. And it's here also that we see the frequency of the oscillation double. So this is how we know it's this non-linear modal coupling.

What's notable is once the oscillation develops this feature, even though it appears as though the total core power oscillation magnitude is lower, the oscillation magnitude in the hot assemblies is actually higher.

MEMBER KIRCHNER: Let me ask you --

PARTICIPANT: Mic.

MEMBER KIRCHNER: How competent are you at what you're showing when it starts oscillating? What's your model doing that it oscillates like this across the core radially?

MEMBER BLEY: What drives it?

MEMBER KIRCHNER: What drives the asymmetry that was --

MR. YARSKY: So this is a well understood feature of modal of kinetics. So if you were to look at the different modes of a neutron flux, certain higher modes can have their reactivity excited. And there's a non-linear coupling.

So there's second order coupling between different modes of a neutron flux. And it's just once you get these huge amplitude oscillations that are occurring in the fundamental or core-wide mode, there's essentially reactivity spillover into these higher order modes of the neutron flux.

And so that causes the power to increase and decrease on different sides of the core. The flow then responds in kind.

MEMBER KIRCHNER: How physical do you think that is though, in reality?

MR. YARSKY: This regional model --

MEMBER KIRCHNER: Your model is doing it, but the regional mode, what --

(Simultaneous speaking.)

MR. YARSKY: Yes. The regional mode is something that --

MEMBER KIRCHNER: -- that would start it off on one side of the core versus the other.

MR. YARSKY: Oh. In this particular model, we force the plane of symmetry. So we did this with channel grouping. But there's nothing to say that it couldn't -- so we're trying to say like a north/south oscillation. There's nothing to say it couldn't be an east/west.

MEMBER KIRCHNER: Yes. That's my point.

MR. YARSKY: And east/west oscillation. There's also the possibility that the north/south mode and the east/west mode can become coupled and you can have --

MEMBER KIRCHNER: I was hoping you would tell me that your initial conditions weren't completely symmetric.

MR. YARSKY: The initial conditions are completely symmetric.

MEMBER KIRCHNER: Oh, they are completely symmetric.

MR. YARSKY: They are completely

symmetric.

MEMBER CORRADINI: So then, I guess I didn't understand your answer to Walt. What did you mean by force? I don't understand what you mean by force.

MR. YARSKY: So in this particular core, there are 764 fuel assemblies.

MEMBER CORRADINI: Right.

MR. YARSKY: And what we need to be able to capture is that the neutron flux on one side of the core can be different than the other side of the core. So in our neutronics model we simulate 764 unique channels. But in the TRACE thermal hydraulics model, what we do is we can group together two channels, one with its symmetric sister. So we have 382 TRACE channel components.

MEMBER CORRADINI: Right.

MR. YARSKY: But because we make those two channel components of the same thermal hydraulic condition, this would only allow the flow oscillation or the difference in bumble flows to appear and across only one of the axes.

MEMBER CORRADINI: So they wouldn't rotate the way you would --

MR. YARSKY: Right. If we were to model

the core with 764 TRACE channel components, then we would not be able to know a priori which one of these degenerate modes would excite first.

MEMBER KIRCHNER: So, that's my point. Yes.

MR. YARSKY: So in this case what we've done is we've picked one and we said it will be the north/south mode, even though the east/west mode would be a degenerate. But it would have the same reactivity characteristics, but we don't know which one would --

MEMBER CORRADINI: But, I guess to get back to Walt's original question about what starts it off. It would seem there's got to be a numerical reason that it starts off. Like some tolerance that if I torque down on the tolerance I would delay, or if I allow the tolerance to be larger, I would start it earlier. I would expect a numerical tolerance is the kick off point.

MR. YARSKY: Yes. But we studied --

(Simultaneous speaking.)

MR. YARSKY: What we studied more recently is that there is some uncertainty in when the regional mode kicks in.

MEMBER CORRADINI: Okay.

MR. YARSKY: And we can improve the

reliability and consistency of our calculations by using a feature in our methodology referred to as white noise where we kind of just keep a small level of excitation present in the calculation in all of the different core-wide and first harmonic mode.

And so what this would mean is once the conditions are right for that mode to be unstable, there's a little bit of noise there to --

MEMBER CORRADINI: To kick it off.

MR. YARSKY: -- to keep it excited. So once it becomes unstable, an oscillation would grow.

MEMBER CORRADINI: Yes.

MR. YARSKY: In these calculations what we found is, because we ran these calculations by just showing you without that feature turned on, that there's about a 15 to 20 second delay of when that mode appears relative to when we would expect that mode. If you had a little bit of noise present --

CHAIRMAN MARCH-LEUBA: I mean, is not really a delay, is that they start so small, you can't see it. It has to grow. I mean, if you blow it up, you see oscillations are growing.

(Simultaneous speaking.)

MR. YARSKY: Well, if you were to plot them side by side, what you would see is the large amplitude oscillations would be apparent about 15 or 20 seconds.

CHAIRMAN MARCH-LEUBA: And the noise exist in the real reactors. It's there, so.

MEMBER KIRCHNER: Right. Well, my point was going to be that in the real reactor, you've got different burn up patterns. It's not symmetric like it is in your analytical space for your initial conditions. And that would be an obvious source for starting a curtivation (phonetic) that you show in numerically here.

So my question is to what extent are your numerical oscillations that are going around bounded by physics so that you're confident when you do an analysis like that? And then compared to an actual reactor where you will have non-symmetry that you're bounding the kind of oscillations that you're seeing around the core? Do you see what my question is?

MR. YARSKY: I think I understand. Let me attempt --

MEMBER KIRCHNER: Yes.

MR. YARSKY: -- to respond. One of the things that we do to justify the TRACE application to these kinds of problems is to qualify or assess TRACE against stability measurements. And in these kinds of measurements, you're looking at these different modes of oscillation, but in context where they're stable. And can TRACE predict that harmonic contour or that shape of the perturbation and the correct to K ratio.

So when you have TRACE comparisons against those stability measurements that we have confidence that we're able to predict that behavior in the linear stable range. When you get into this unstable behavior, I think the only real plant data that we have in an integral sense that we can use for assessment purposes is the Oskarshamn event.

MEMBER BALLINGER: Yes. That's what I was going to mention.

MR. YARSKY: Right. And in that one case, we were able to represent the plant performance, the plant data very well. The TRACE assessment indicates very good agreement between our TRACE predictions and the data measured during the event.

MEMBER KIRCHNER: Okay.

MR. YARSKY: So I would refer you back to the body of assessment that we have for TRACE.

CHAIRMAN MARCH-LEUBA: Yes. But bottom line is all these modes have been observed in real reactors.

MEMBER KIRCHNER: No. I don't doubt it.

I just, you look at a video like that and don't convince yourself that's actually what's going to happen.

CHAIRMAN MARCH-LEUBA: Well, no, no. This is one particular, this is --

MEMBER KIRCHNER: This is kind of an idealized case.

CHAIRMAN MARCH-LEUBA: As role TRACE calculation, this is one particular implementation, one particular observation. If you run into more, it's going to be different.

MR. YARSKY: And we've run many, many of these calculations with subtly different inputs, with different noise features, with different sensitivities to level. We've run a number of these different calculations.

I'm presenting one here because when I talk about the predicted heat up mechanism, I want to put in context what's happening in the plant, what's happening in the core, you know, what's driving the event overall. So when I start talking about what's happening around the core hotspot, you sort of have an environment to talk about it.

CHAIRMAN MARCH-LEUBA: And with that in mind for the record, all these oscillations have occurred in real reactors from the first three seconds or so. Then a scram happens. This is a calculation of what will happen if the scram were to fail.

MEMBER CORRADINI: Right.

CHAIRMAN MARCH-LEUBA: That has never been reported.

MEMBER BALLINGER: The prime directive is don't let it happen.

CHAIRMAN MARCH-LEUBA: Yes. That's the moral of the story. Scram.

MR. YARSKY: Yes. So what I'm providing here is a plot of the peak cladding temperature during this event as a function of time. And there are two key phases that I would like to discuss. The first is the cyclic dryout/rewet phase. This is relatively short in this event.

But what occurs eventually as the power and flow oscillations increase in magnitude and in particular the flow oscillation. As the flow oscillation increases in magnitude, the hotspot and the hot assembly will experience periods of dryout. And this will occur when the local flow rate is low.

In that period of dryout, the fuel will heat up a little bit. But the flow is oscillatory, so it'll eventually return and then you'll have an increase flow. And what that will do is it will rewet that dried out spot, remove that heat and the temperature will come down. And so as the event progresses and oscillation magnitude is increasing, we'll eventually hit a point where there is a cyclic dryout/rewet.

What we then predict is that if this keeps going that they'll be a temperature excursion. What we show in this calculation is the temperature excursion first to a little bit below 2200 Fahrenheit. However, once the oscillation mode becomes this bi-modal coupled mode where the regional mode kicks in and local power oscillation magnitude increases, we see that PCT then crossover above 2200 Fahrenheit.

MEMBER CORRADINI: So ignoring the blue line, you always see this double bump because of going from single mode to bi-mode?

MR. YARSKY: No. You do not always see this bump.

MEMBER CORRADINI: So when you're doing this, you don't see the bump, sometimes?

MR. YARSKY: It really does depend. You may have this happening before, you may have the side to side happen before the core-wide happens, so that could be a possibility in which case you wouldn't see --

MEMBER CORRADINI: Okay.

MR. YARSKY: -- this bump. In this particular case, I got to address the bump. The bump is happening because that regional mode kicks in and causes local oscillation magnitude to increase.

MEMBER CORRADINI: But we've entered a bad region at more like at 120 seconds where cyclic dryout/rewet stops.

MR. YARSKY: Right. At that point there's a temperature excursion and it would be, what we would say is that once that temperature excursion comes in, it would be very difficult to reliably predict what the PCT consequence would be.

MEMBER CORRADINI: So we've gone past the point of no return.

MR. YARSKY: Right.

MEMBER CORRADINI: Okay.

MR. WYSOCKI: And that's it. This is Aaron Wysocki, Oak Ridge. To go with what Pete said, we've done simulations where it begins in phase and remains in phase, where it begins out of phase and remains out of phase and where they crossover like that. So it really depends on the --

MR. YARSKY: Right.

MR. WYSOCKI: -- reactor and the event.

MR. YARSKY: Right, but looking at what's going on this local level of the hotspot, you go into a period of cyclic dryout/rewet and then something trips you into this temperature excursion. And where that occurs is once the cladding surface temperature reaches the minimum stable film boiling temperature, TRACE predicts that that hotspot will lock into a film boiling heat transfer regime. So it will have, like, a very low heat transfer coefficient which then causes the temperature excursion.

MEMBER KIRCHNER: Just to clarify, as Mike was asking this, kind of right there when you're crossing the blue whether it's this blue line or not.

MR. YARSKY: This part here.

MEMBER KIRCHNER: Yes. But just before that, the double bump, that's the regional part --

MR. YARSKY: Yes. This is the onset of the regional mode and with that --

(Simultaneous speaking.)

MEMBER KIRCHNER: I would ask you at some point to consider just putting an actual asymmetry into the initial conditions in the core and seeing what happens.

MR. YARSKY: Right, if we were to --

MEMBER KIRCHNER: So that one could then

physically separate out how much of this is numerical, and how much of it -- I'm not doubting that it's real --

MR. YARSKY: Yes.

MEMBER KIRCHNER: -- and you're not getting your good comparison in a macro sense, but just put a perturbation somewhere in the core and see how your local perturbations progress. I would expect a very similar TRACE and such. But if it weren't similar, then I would be concerned, right?

MR. YARSKY: Right. One thing that we could do is to put a some sort of control rod mal-alignment into the model. What this would have the effect of is changing that harmonic shape. And so it wouldn't necessarily be that the oscillations would occur along the same line of symmetry.

So it's because the core is symmetric that that harmonic mode symmetry is occurring in that north/south, east/west plane. But if we were to say put the control odds a little off kilter, it's likely that that symmetry plane would rotate. So it's --

MEMBER KIRCHNER: This experiment, numerical experiment that I'm suggesting would then give you a little more confidence about how much of what when you're in the area is numerically induced versus physically induced. Do you see where I'm getting at? Codes will go into that, like you said, you can put white noise in or something --

MR. YARSKY: Right.

MEMBER KIRCHNER: -- to stimulate it. But otherwise, sometimes the reason you get these kind of oscillations is that's the way the numerical solver is going around the core.

MR. YARSKY: Right. Right.

CHAIRMAN MARCH-LEUBA: This oscillator just to summarize it, they predicted by many different codes and they even predicted by hand calculations.

MEMBER KIRCHNER: No, you're missing my point. My point isn't that. I'm not questioning the validity and it's been observed experimentally. What I'm saying is you want to know what's numerically induced versus what's physically induced.

CHAIRMAN MARCH-LEUBA: The fact that you had the same behavior with hand calculations, it's telltale that you are almost there.

MEMBER KIRCHNER: You're still missing my point. My point is that numerically as the oscillation progresses around the core east/south, north/west whatever its doing, how much of that is your solver algorithm --

CHAIRMAN MARCH-LEUBA: Your typically --

MEMBER KIRCHNER: -- and how much is --

CHAIRMAN MARCH-LEUBA: Typically you start by changing Delta T, that=s the easy way to do it. If it's numeric and you change, it pops up immediately. And you --

MEMBER KIRCHNER: That will change the overall behavior. You're missing my point still. You want to separate out what your solver, your numerical algorithm is doing in instigating the oscillation versus what physical --

CHAIRMAN MARCH-LEUBA: When you do --

MEMBER KIRCHNER: -- trick point --

CHAIRMAN MARCH-LEUBA: When you do it with hand calculations, there's no --

MEMBER KIRCHNER: I know you can make that hand calculation oscillate. That's not the point that I'm making. You've got a 3D representation, and what you want to do is put a physical variance somewhere, like burn up depletion or control rod as you suggested. And then see how it goes around.

MR. YARSKY: Yes. Okay. I think that the work that we've done with the noise sensitivity study will likely address a lot of your concern here, and it's something that we were concerned with as well.

I think to get at what you talking about, this effect that there could sort of be like a ghost in the numerics of code calculation itself.

I feel like we've done a lot of work to address that, but not by inserting a spatial asymmetry. It's something that we could do, but I can send you or I can send the Committee references to work that we've done to look at things like time step size, to look at things like noise. Yes. I can forward those along and maybe that could address your concern.

CHAIRMAN MARCH-LEUBA: Before you change this slide, this is a phase calculation with a Tmin correlation, correct?

MR. YARSKY: Yes.

CHAIRMAN MARCH-LEUBA: And the reason you are, were going to want to the closed session and talk about the KATHY experiment is because there is some uncertainty on that correlation. Can you address that?

MR. YARSKY: In two slides what I wanted to do is I have a slide that sort of steps through this fuel heat up mechanism.

CHAIRMAN MARCH-LEUBA: Okay.

MR. YARSKY: And at that point I think that would be an excellent point to talk about this topic of Tmin.

What we found in the base case calculation that I presented is that large amplitude regional power oscillations developed with this model coupling and that this results in high temperatures in certain hotspots in the core with the PCT exceeding 2200 Fahrenheit. So we would diagnose this as a condition of fuel damage.

We found that operator actions to reduce level and operator actions to inject stem by the control system were effective in reducing oscillation magnitude and eventually shutting down the reactor. However, these actions were not effective in a timely enough manner to avoid this temperature excursion and this local PCT exceeding 2200.

Based on our calculation --

MEMBER KIRCHNER: This is the value of what you're doing. So you just said that for this stylized reactor case that, what was it 120 seconds the one you did?

MR. YARSKY: Yes.

MEMBER KIRCHNER: That's because that's what's in the EOP, right?

MR. YARSKY: Well that is a plant specific consideration of when --

MEMBER KIRCHNER: You just, well forget

the plants. You just took your model and you made that point of injection 90 seconds.

MR. YARSKY: Right.

MEMBER KIRCHNER: Would it kill off the oscillations and keep you below the 2200 threshold?

MR. YARSKY: I don't know if --

MEMBER KIRCHNER: You don't have to answer me --

MR. YARSKY: If there is --

MEMBER KIRCHNER: It's the value of having a model like this --

MR. YARSKY: Right.

MEMBER KIRCHNER: -- that you can look at --

MR. YARSKY: You would be able to look --

MEMBER KIRCHNER: -- that kind of thing.

MR. YARSKY: -- a changing the operator action timing and if that operator action timing is very early, what you may see is that that mitigating action could be sufficient to preclude instability from occurring at all.

(Simultaneous speaking.)

MR. YARSKY: -- the plant specific license amendment request of like exceptionally fast operator action.

CHAIRMAN MARCH-LEUBA: We have seen that for MELLA classifications where one plant couldn't survive 120 and they did it in 90.

MR. YARSKY: Right.

CHAIRMAN MARCH-LEUBA: And there was a lot of operator training and study --

(Simultaneous speaking.)

MR. YARSKY: -- if the operators could react --

CHAIRMAN MARCH-LEUBA: -- to ensure that they could do 90.

MR. YARSKY: -- in that time frame.

CHAIRMAN MARCH-LEUBA: And neither were able to. But they were able to do it in a 7 seconds.

MR. YARSKY: Yes.

CHAIRMAN MARCH-LEUBA: It was not, it was borderline. I mean, the evidence, if I remember correctly, it was like 60. But some of the tryouts to 80, 85.

MR. YARSKY: Right.

CHAIRMAN MARCH-LEUBA: So they couldn't go much lower than 90. But it was very effective. I mean --

MR. YARSKY: Right.

CHAIRMAN MARCH-LEUBA: -- surviving this or not surviving that was.

MR. YARSKY: So from our TRACE result we look at that sort of local hotspot to better understand what TRACE was predicting in terms of the mechanism of what leads to these, to this fuel heat up.

And what is occurring is oscillation magnitude is increasing and we talked bout on that other figure this period of cycling dryout/rewetting. And as the oscillation magnitude continues to grow, the amount of time that the hotspot remains in a dryout condition increases as the flow oscillation magnitude increases.

And so in each part of that dryout phase, the peak temperature gets a little higher. And then during the rewet portion, that heat can be removed, but if some of it remains, then the average temperature of the hotspot begins to increase.

And we refer to this mechanism as ratcheting. And that average temperature will continue to increase until it hits a point where the cladding surface fails to rewet. And then there's no more rewetting. And then that leads to the temperature excursion.

In TRACE, and this is a, just like the trade systems analysis code feature, that film boiling lock is diagnosed by the temperature exceeding the minimum stable film boiling temperature.

MEMBER CORRADINI: So when you cross that, you switch key transfer modes in the calculation?

MR. YARSKY: Right. So once the temperature crosses that line, you go from transition boiling to film boiling and you lock into film boiling. And so you'll stay locked in film boiling until you're able to quench the surface. And then once you're locked into film boiling, the temperature undergoes, you see this temperature excursion.

So that's the mechanism by which the ATWS and stability can lead to potential fuel damage is that oscillations increase in amplitude, lead to cyclic dryout/rewet. As the oscillation amplitude increases, cyclic dryout/rewet leads to ratcheting. Ratcheting eventually leads to film boiling. And once you're in film boiling you undergo temperature excursion. So that's the mechanism that we predicted with the TRACE model.

MEMBER BALLINGER: So when you say fuel damage, you're talking about increasing, going about the 2200 degrees?

MR. YARSKY: Yes.

MEMBER BALLINGER: What about ballooning and things like that?

MR. YARSKY: So we are able to model --

MEMBER BALLINGER: By the time you get to 2200 degrees, I got a feeling that if it's a pressurized rod --

MR. YARSKY: There will be a burst population, and also we will have perforated a large number of pins by this point. So every time you're in dryout you're likely to, and perforate the pin in some way.

MEMBER BALLINGER: You're not going to shut off channels. Like ballooning.

MR. YARSKY: Well there will be a flow are reduction if there is a lot of ballooning, and if that ballooning and bursting is occurring in a co-planer way. Right now what we're able to predict in TRACE is there's a function of balloon in burst. We're able to look at the change in oxidation.

For right now, that balloon and bursting incidents doesn't feed back into the calculation in terms of the change in flow area. So we partially account for that, but we don't fully account for that.

MEMBER CORRADINI: But back to my original comment. As soon as it starts creeping up, you're past the point of no return and all bets are off as to how we --

MR. YARSKY: Right. And keep in mind this is a beyond design-basis event so that. So perforating the rods is allowed. The real criterion, the regulatory criterion here really is that the core must remain in a cool-able geometry. And so, that's why we're looking at fuel damage.

One thing we haven't looked at yet is the population of fuel damage. So what fraction of the core has undergone fuel damage and what does that mean in terms of core cool-ability. That's something that we haven't done in our research yet.

MEMBER REMPE: There were some --

CHAIRMAN MARCH-LEUBA: In the NRR side, I remember that you were going to say that. In the NRR side we did look at a small fraction of possible places where you would have damage. So if only 0.1 percent of the core goes beyond 2200, it might be still a coolable geometry.

MR. YARSKY: Right. That's something that we haven't done in our confirmatory analysis --

(Simultaneous speaking.)

CHAIRMAN MARCH-LEUBA: -- so when does that used that argument for MELLA+.

MEMBER REMPE: Right and I thought it was discussed, I can remember --

CHAIRMAN MARCH-LEUBA: Right.

MEMBER REMPE: -- what plant is was discussed in because it was more of a vicious discussion. That they decided that it was enough of the core remained coolable that -- it was back when Chris Jackson was here. But I thought, I mean that was something we discussed and I thought there was some basis it --

CHAIRMAN MARCH-LEUBA: But basically if only one pin goes over 2200 and oxidizes on this occur, it does not prevent core coolable geometry.

(Simultaneous speaking.)

MEMBER REMPE: Right. But more than one was predicted.

CHAIRMAN MARCH-LEUBA: If it's ten, okay. If it's 10,000, no.

MEMBER REMPE: Yes. Again, my memory, but I thought research didn't support the decision by --

MR. YARSKY: Well it's in the research confirmatory analysis. We don't yet have the capability to predict damage population. So one thing I think that would be necessary in order to do that would be to model the assemblies with sufficient resolution that you have the actual rod to rod distribution of powers represented.

The reason for that being is because this predicted fuel mechanism is, this predicted fuel mechanism depends on this incidence of dryout and rewet to get things started. So if your rod power distribution is such that you have maybe a peak rod that could be at a peaking factor of 1.2, but then you have ten rods that are a peaking factor of 1.1, you would probably would want to capture that those additional ten rods at the 1.1 peaking factor in your analysis.

Whereas, in the TRACE calculation now we have essentially, like the bulk of the assembly is represented with a couple or a few rod groups and then you model the hot rod. I think we need to better capture that rod to rod power distribution before we have confidence in saying some given fraction of the core has experienced fuel damage.

And so I think that for our confirmatory analysis research hasn't developed that capability yet, but I think that we will. And then we'll be able to answer question of what is the predicted damage population. The next step after knowing that population would then be to make some sort of determination with regards to core coolability. But that'll be step two after we do step one.

MEMBER CORRADINI: But if I could just take a step back from all these steps. There is some temperature that's not the takeoff temperature, not 2200f. But currently staff is saying once I pass this, we'll call intermediary temperature, I have no known way back from it. Therefore, that's a loss of coolable damage.

MR. YARSKY: Well what you could say, but try and be very specific about --

MEMBER CORRADINI: I'm not trying to give a number, I'm trying say there's something --

MR. YARSKY: Their licensee would be able to demonstrate that they have met the core coolability requirement. A way to make that demonstration would be to show that they completely avoid this fuel issue.

MEMBER CORRADINI: That's one way.

MR. YARSKY: That's one. So if they're able to demonstrate that they never get into this mechanism during the event, that is a manner in which they can demonstrate that they've met the regulatory criterion.

MEMBER CORRADINI: But they may also argue that, take Ron's suggestion that if I stable all ballooning then --

MR. YARSKY: For instance, if they were able to stay below CHF, if they were able to demonstrate that the SLMCPR limit was met for the entire event, then clearly they've avoided, they are still going to meet the coolable geometry. So there's a way that you can perform the analysis with a more stringent criterion in order to demonstrate that you've met the regulatory criterion.

CHAIRMAN MARCH-LEUBA: But just two things. First, you can reach the -- the point of no return where you're going to failure to rewet and continue to overheat and never reach 2200 because your power is not high enough. And you figure if we had not moved into a --

MR. YARSKY: Right. So if you return to this figure, we could postulate an event where you would have a failure to rewet, but still not exceed 2200.

MEMBER CORRADINI: Are you still then --

MR. YARSKY: That would be a possibility, but it would be very difficult I think given our uncertainties in the models to say if I were to predict a PCT of 1450 kelvin --

(Simultaneous speaking.)

MR. YARSKY: -- well, you know, how certain am I or could I really say that that temperature is less than 2200. Especially given considerations of you know, hey what if because of a numerical effect the oscillation started ten seconds earlier or --

CHAIRMAN MARCH-LEUBA: The other thing I wanted to point out on this figure is that you have an oscillation in the whole band, the 10 by 10 bundle. But this is the regulatory flux of the hottest pin on the bundle.

MR. YARSKY: No, it's actually more subtle than that. I mean, for a cartoon type understanding what's going on, you could think of this figure as the hot spot, but it's not. This represents that each point in time the highest temperature on any cladding in the core. So it's searching. So it's really happening around this bump is that this point is a different point now. There's a different hot spot. So this is not the temperature history of a particular spot in the core.

From the standpoint of just understanding the phenomenon, you could look at this figure and think of it in that way and you would have the understanding necessary I think to move on. But it's a very important subtle point of this figure that it is not, it's not a history of an individual spot.

CHAIRMAN MARCH-LEUBA: But it's not all the rows in the bundle. It's like a small section of the bundle.

MEMBER BALLINGER: Well, he could probably interrogate --

(Simultaneous speaking.)

MR. YARSKY: Yes. What I'm saying is I could do that on the rods, but I think that that exercise will not be valuable until we have a significant number of rod groups represented in every channel component. Taken into account the distribution of rod powers --

CHAIRMAN MARCH-LEUBA: TRACE has typically 35/7 rod groups in the bundle, right?

MR. YARSKY: Right. I think we would want to up that number significantly before we start talking about damage population. So damage population I think is the next step, but we need to model more to do it.

MEMBER BALLINGER: But if I might to help because I asked about Walt, so I=ll point at Walt. I'm still not clear about what Jose understands and I'm not clear about the 3/5/7 rod itself in abundant. The cartoon movie you showed us, and I'll go back. Your seven hundred and something. You divided into two so there three hundred and something. So let's say you did the seven hundred and something, that's a bundle.

MR. YARSKY: That's a bundle.

MEMBER BALLINGER: You see that bundle. I am looking at seven representative heat structures that I think to be rods and no more.

MR. YARSKY: Right. Correct.

MEMBER BALLINGER: That's what I want to make clear about.

CHAIRMAN MARCH-LEUBA: That's what I meant by programs.

MR. YARSKY: Right.

MEMBER BALLINGER: But TRACE thinks of it as a funny looking heat structure.

CHAIRMAN MARCH-LEUBA: Yeah, but --

MEMBER KIRCHNER: And for this particular example, how much of the core is above that threshold.

CHAIRMAN MARCH-LEUBA: Yes. That's why he said he doesn't know.

MR. YARSKY: I don't know. I don't --

(Simultaneous speaking.)

MR. YARSKY: That's something that we are going to look at analyzing in the future to be able to answer that particular question. What fraction of the core experiences this condition? We don't have that yet.

MEMBER KIRCHNER: And then I would ask you, don't answer me or anything like that. But I'll ask you, are you aware of the draft RIA Reg Guide that is out for, on it?

MR. YARSKY: I'm not immediately familiar with it.

MEMBER KIRCHNER: Do I have the right person, Clifford?

MR. YARSKY: Paul Clifford?

MEMBER KIRCHNER: Yes. You need to look at that because then he has draft criteria for what's to find this core coolability, et cetera.

MEMBER BLEY: Three activities --

MR. YARSKY: Yes.

MEMBER BALLINGER: But it's based on an enthalpy insertion, right?

MEMBER KIRCHNER: No. It's also temperature and core coolability and how that is defined and whether you get to ballooning or not.

MEMBER BALLINGER: Yes. That's for sure there.

MEMBER KIRCHNER: I just ask you to look at it because --

MR. YARSKY: Yes. Certainly if there's, if we can translate something like the flow area reduction due to ballooning and burst. Or the population of rods above a certain temperature or above a certain enthalpy, if that can be translated to a coolability determination, there's information about how to do that already.

(Simultaneous speaking.)

MR. YARSKY: That's step two that we were talking about earlier.

MEMBER KIRCHNER: But I think that's where that particular Reg Guide is going. That's how they're going to define core coolability. So a certain number of that --

MR. YARSKY: Yes, I'll certainly look that up.

MEMBER KIRCHNER: That are impacted by reaching whatever threshold he is using in that Reg Guide.

MR. YARSKY: Yes. That could certainly be useful. I think once we expand on methodology, look at many more rod groups then that's a natural progression.

CHAIRMAN MARCH-LEUBA: Food for thought. This expansion of a group may not even be necessary to put into TRACE. It can be a post processing result. Once you have the flow of the pressure of the void of the bundle, you can just put this rods, second rod on this. You don't have to complicate TRACE more than it already is.

MR. YARSKY: Well, when we get to the preliminary analysis I think we'll show you some of what's happening in the bundle and these phenomena are pretty complex and in many ways subtle.

So I would really like to leave it up to the code to really analyze that. And I would even go as so far as to strap in power reconstruction onto it as well.

CHAIRMAN MARCH-LEUBA: That would be great. But you're talking many, much CPU.

MR. YARSKY: It's true. It's true. But I think if that's the question we want to answer. Now if licensees continue to present results where they have very quick operator action timing, and we'll get to a slide to talk about other things that are specific for a plant's specific evaluation.

If they continue to provide analysis that demonstrate they avoid this heat mechanism altogether, then the subtler points of that may not be --

PARTICIPANT: Be necessary.

MR. YARSKY: -- may not be necessary. But if we are going to have to answer the questions like if two percent or three percent of the core is damaged, does the core remain in a coolable geometry. I think we need to do more as terms of our methodology before we can be prepared to perform that kind of confirmatory analysis.

CHAIRMAN MARCH-LEUBA: I remember being on that side of the table making the argument that you are much better off taking positive steps of training the operators to lower the fuel water faster than sharpening your pencil and doing better calculations.

And I know you're in the business of doing calculations. But from the point of your sector CO-of the reactor, I'm much more happy training my operators to lower the water level in 90 seconds then you saying that you have now had operators that trust me, 120 is okay.

MR. YARSKY: Yes. But I think those of you who appreciate this from the perspective of Office of Research, we have to look at and do the confirmatory analysis that's necessary based on what the applicant proposes, or what the licensee proposes.

(Simultaneous speaking.)

MR. YARSKY: And so that's really not up to the Office of Research.

CHAIRMAN MARCH-LEUBA: I'm sorry. Maybe

we can finish today sometime however we move, because the important part, the interesting part is in the closed session.

MR. YARSKY: In the closed session. I'm going to spend one minute on the slide. Less than that. Thirty seconds. I just wanted to go through a list of those parameters that can really change the analysis on a plant specific application just to give you an awareness that, you know, if you see a different application, these results can be very different because all of these factors can have a significant impact on how the event progresses and then what the consequences of the events are.

Of course the fuel in quartazine (phonetic), that's going to affect the stability characteristics of the core. It's going to affect the relative stability characteristics of the regional versus the core-wide mode. The turbine bypass capacity is a factor.

In our analysis we looked at different turbine bypass capacities and found there are certain competing effects with respect to turbine bypass capacity. That this can have an impact on the event. One of the most significant is manual operator action timing. And I think we've talked about this over the course of the presentation.

There's also the impact of the Slick injection location and boron enrichment. We talked about a little bit. There are advantages to upper plenum injection over lower plenum injection for instance.

If the feed water pumps are motor versus steam driven can have a significant impact. Steam driven feed water pumps will trip when they lose, when the turbine trips which will give a benefit in terms of the early reactor water level response.

There's also the issue of the feed water heater cascades. We talked about how feed water temperature is what sort of brings the power up and leads to the instability of that. How much thermal inertia is in that feed water heater cascade can have a significant impact.

Lastly, just to mention it. In the case of Nine Mile Point 2, if you design and implement automatic protective features, that of course will have a significant impact.

So in summary, to put what we're going to talk about in the closed session into context is that for MELLA+ BWR plants, instability during ATWS events is likely to occur and expected to occur earlier in the event.

If large amplitude power oscillations occur during an ATWS-I event prior to mitigation, the fuel may experience cyclic dryout/rewet. During that cyclic dryout/rewet phase, if temperature ratcheting occurs we predict that there could be a temperature excursion leading to fuel damage.

And that's all I have for the open session.

CHAIRMAN MARCH-LEUBA: Great. So at this point we are going to close this session and we'll not have any phone open any longer. So I want to ask for questions in the room. Somebody wants to make any comments or questions.

And is the phone line open? It's supposed to be. Anybody on the phone line would like to make a comment? Another question?

(Off microphone comments.)

CHAIRMAN MARCH-LEUBA: Can you verify it's open? Because I don't think -- when it's open, you can hear.

Okay. The line was open. There is nobody listening. So at this point we are going to close the open session and we are going to take a 15 minute recess until 2:25.

(Whereupon, the above-entitled matter went off the record at 2:26 p.m. and resumed at 4:13 p.m.)

CHAIRMAN MARCH-LEUBA: And we're definitely on the record now. This part is open session. We are going to describe the conclusions.

We just opened the phone line. If anybody is on the line, can you please identify yourself?

(No audible response.)

CHAIRMAN MARCH-LEUBA: Even though you hear crackles that means nobody on the mind but -- is anybody on the line? We still have it open. This is open session.

Peter, continue with the conclusions.

MR. YARSKY: Okay, thank you.

In terms of conclusions, I just wanted to provide a brief summary of what we had talked about up until now. The first is that the KATHY test loop can closely match expected prototypical conditions of ATWS-I stability.

The NRC test bundle that we used in the conduct of these tests include many features of modern BWR fuel assemblies.

And we performed tests both with and without simulated neutronic feedback and this was to determine the conditions for instability, cyclic dryout/rewet, and failure-to-rewet conditions. These, of course, being prototypic for modern fuel assemblies operated and experiencing conditions with MELLLA+ ATWS-I.

Based on our preliminary analysis and comparisons of the temperature data from the KATHY tests, it appears to indicate that a failure-to-rewet temperature is in reasonable agreement with a model of homogeneous nucleation temperature plus contact temperature.

And until the research staff can complete our TRACE assessment and complete a more thorough analysis of the experimental results, we have recommended using a Tmin model based on homogeneous nucleation plus contact temperature in TRACE predictions of ATWS-I consequences for MELLLA+ BWRs.

Our area of future work is to conduct the inverse heat conduction analysis of the KATHY heater rods and this will be so that we can determine heat transfer coefficients during the nucleate boiling, transition boiling, film boiling, and quenching regimes that occur during the event.

As applicable, we will provide new correlations based on our improved understanding of the mechanisms affecting failure to rewet.

We will perform the TRACE assessment against the experimental data.

And lastly, we'll be able to conduct sensitivity analyses using TRACE with modifications so that we can look at the impact these models of Tmin and film boiling heat transfer have and determine if alternative models to those that are currently present in TRACE provide a better fit to the data under these conditions.

CHAIRMAN MARCH-LEUBA: Are you able to find TRACE to use the homogeneous nucleation for Tmin?

MR. YARSKY: Yes.

CHAIRMAN MARCH-LEUBA: And including the quenching of Tmin? Because right now TRACE only quenches on axial conduction.

MR. YARSKY: It would --

MEMBER CORRADINI: It switches.

MR. YARSKY: Yes.

MEMBER CORRADINI: It switches at this temperature threshold.

CHAIRMAN MARCH-LEUBA: I'm not sure it does.

MR. YARSKY: It would go into transition

boiling.

CHAIRMAN MARCH-LEUBA: And can you refine that? Because I remember a lot of discussions with one of the vendors about how the axial conduction was working. I know that's how they do it.

MEMBER CORRADINI: Oh, you have to have only the axial conduction model on, you think?

CHAIRMAN MARCH-LEUBA: The axial conduction is the only one that gets you off -- gets you down to --

MEMBER CORRADINI: But once you pass you --

MR. YARSKY: Jose, we had a closed session, where we could have freely discussed different models of quenching. And I am not comfortable in an open discussing the specifics of how other --

CHAIRMAN MARCH-LEUBA: But of TRACE.

MR. YARSKY: -- vendors --

CHAIRMAN MARCH-LEUBA: I am asking about TRACE.

MR. YARSKY: Even without the fine mesh axial conduction model, the heat transfer regime would go from film boiling to transition boiling.

CHAIRMAN MARCH-LEUBA: But how do you cool it?

MR. YARSKY: In the transition boiling heat transfer regime, you would have an improved heat transfer coefficient.

CHAIRMAN MARCH-LEUBA: In transition, yes. But if you are above Tmin in TRACE --

MR. YARSKY: Yes.

CHAIRMAN MARCH-LEUBA: -- now you are flooded with water. You will still have film boiling.

MR. YARSKY: Right. So there's conduction but there is also film boiling heat transfer. So for instance, as temperature increases, you still get improved heat transfer because the film boiling heat transfer coefficient is not zero.

CHAIRMAN MARCH-LEUBA: Okay.

MEMBER CORRADINI: I think what he's just asking is if I had the heat flux on constantly, there's no way to cross back over in that regime.

CHAIRMAN MARCH-LEUBA: That's correct.

MEMBER CORRADINI: That's what he was asking. If I pass the boundary and I have a re-flood, there's no way to go backwards.

MR. YARSKY: Right. Right. That would physically be the case if there was no --

CHAIRMAN MARCH-LEUBA: Well, when we do the detailed modeling with TRACE of your data, I saw some of your data that keeps the temperature of thermocouples high when in reality, it went down faster.

So and that is -- I don't know what mechanism it is but what is the axial conduction that TRACE already has, it is an expensive --

MEMBER KIRCHNER: It's not axial conduction.

CHAIRMAN MARCH-LEUBA: It's not?

MEMBER KIRCHNER: You've gone into a flow regime where there's ample amounts of water and you'll get a collapse of film boiling en masse.

CHAIRMAN MARCH-LEUBA: But we are talking about Tmin.

MEMBER CORRADINI: But I think in his case, again, I'm just -- in his -- his -- yours -- KATHY case, I think my memory is one of the models in TRACE allows for the fact there's a mass flow rate tenet. Since you've got this oscillatory mass flow, you come back into a regime where you cool and you --

MR. YARSKY: Yes, well like for instance --

MEMBER CORRADINI: That's what I thought.

MR. YARSKY: -- you would go from a dispersed flow film boiling heat transfer regime to an inverted annular film boiling heat transfer regime, which would affect a change in the heat transfer coefficient once you had a re-flooding condition.

So even with just film boiling --

MEMBER KIRCHNER: You don't need to have film conduction model for that. It's not even --

MEMBER CORRADINI: I mean it would drag down the speed of calculation.

MEMBER KIRCHNER: Right.

MEMBER CORRADINI: You could have it highly hyper-nodalized but I think you'd still --

MEMBER KIRCHNER: When you're in those conditions, it's not like the wet front just comes right down from the top or the bottom. You just collapse the film boiling regime because of the presence of water.

CHAIRMAN MARCH-LEUBA: Well that's what the channel is. I'm asking what the numerics do. I've seen him not do that.

MR. YARSKY: For that to occur in TRACE, the inverted annular film boiling heat transfer coefficient would have to be sufficiently high to cool the temperature below Tmin before you have film collapse.

CHAIRMAN MARCH-LEUBA: That's correct. And --

MR. YARSKY: And there's, of course, axial conduction can be modeled in different resolutions in TRACE. You can have the fine mesh axial conduction model or you can have a course mesh axial conduction model.

CHAIRMAN MARCH-LEUBA: Just keep it in mind. Let's not discuss it. Let's not fix the models here but keep it in mind.

MR. YARSKY: Yes but one of the things that we will be doing, as we do the TRACE assessment, is we will be looking at you know what is the effect of having the fine mesh axial conduction, fine mesh axial conduction with very fine nodes, coarse mesh axial conduction, and no axial conduction.

CHAIRMAN MARCH-LEUBA: The bottom line is that the time after scram, TRACE has to model it, too.

When you do your evaluation, let's not model just the time before the scram on KATHY but the time after the scram, when it re-wets. TRACE has to follow that. It would be nice if it did.

MR. YARSKY: It would be very nice if TRACE did. In our current preliminary analysis, of course, our focus is on diagnosing and understanding the incidents of failure to re-wet.

What happens afterwards is something that we will have to look at as future work. If there are phenomenon that occur on a very localized level, like for instance, quenching, and quenching ends up being very important, then the KATHY facility experimental data, because of how far apart the thermocouples are, might not be the best data to support some sort of conclusion where we start rethinking quenching.

CHAIRMAN MARCH-LEUBA: Well you cannot see the front --

MR. YARSKY: Right so a different experimental basis, if we wanted to really study quenching behavior might be appropriate.

CHAIRMAN MARCH-LEUBA: Yes, don't ignore the time after scram on your evaluation. And again, this is --

MR. YARSKY: We won't. But if there is an indication that TRACE is conservative, that may be a conclusion in itself.

CHAIRMAN MARCH-LEUBA: Yes.

MR. YARSKY: We may not have sufficient data to justify changing the quench model because the thermocouples are arrayed in such a manner that it may be difficult to infer information about a quenching using this particular experiment.

CHAIRMAN MARCH-LEUBA: As long as we don't ignore the data and we address it, even if it is by waving your hands, I am happy.

MR. YARSKY: Okay.

MEMBER REMPE: On your future work, I don't see anything about what you discussed earlier today about input on what debris coolability means. And is that because maybe it's not so important?

MR. YARSKY: Oh, one thing that the Office of Research is looking into is developing a capability in TRACE to calculate the population of the core that has experienced damage.

MEMBER REMPE: Right.

MR. YARSKY: That's not within the scope of this. It would be -- so this project is being driven by using these requests from the Office of NRR. Separate to that and part of a long-term research strategy is to develop this capability in anticipation of future incoming requests.

MEMBER REMPE: I'm just wondering if there will be that many. I said the wrong word. I said debris coolability but for core coolability. I'm just wondering if some of those requests would go down, in light of the work. I mean I would think that that issue might not come up as much, in light of some of the work that's done. But you think it will still be important for --

MR. YARSKY: Well --

MEMBER REMPE: Because if that was high, it might not be so important anymore.

MR. YARSKY: In my thinking, at least observing how things have gone from MELLLA to EPU to MELLLA+ is that based on say an incomplete understanding of these phenomena led us to look at intermediate criteria, for instance, looking at temperature criteria short of the regulatory criterion of core coolability to say if you can meet say some limits on temperature like PCT limits, then you're able to demonstrate compliance with the regulatory criteria. But this has resulted in certain applicants, for instance, changing operator action timings and then making regulatory commitments to adhere to more restrictive operator action timing requirements.

So, I could foresee in the future analyses a pencil sharpening being done to further expand an operating domain or to further relax those conditions, in which case the real criterion, the real regulatory criterion is that core coolability question.

MEMBER REMPE: Right but there's only, again, that many -- there is a limited number of plants even coming in for EPUs that are BWRs.

MR. YARSKY: I think most of the BWRs went for EPUs, except for the twos. I imagine we would see a similar influx for the MELLLA+s.

MEMBER REMPE: Really? Because I guess I was thinking that there wouldn't be that many more. The ones who have come in for EPUs have done it, pretty much.

MR. YARSKY: Yes.

MEMBER REMPE: And then there's a limited number that have come in for MELLLA+ and those are kind of going a certain way with methods they're selecting, et cetera. So I just am wondering if they try and expand that region, expand the flow region, I guess there might be more. I just was curious.

MR. YARSKY: Yes, it's just my gut feeling. It may be completely inaccurate. I don't know.

MEMBER REMPE: Yes, the other thing is with the future work, there is this plant-specific evaluation that will be supporting a plant coming in. I think you said it's on our agenda for April. It's coming into you guys sooner, right?

MR. BORROMEO: Oh, we have it and we're currently reviewing it now.

MEMBER REMPE: And I'm wondering, with respect to interacting with us, would we best do the results of your analysis as part of our evaluation in April or should we plan to have a discussion earlier to talk about some of the insights from your plant-specific analysis?

MR. YARSKY: We were discussing having research meet with the Thermal-Hydraulic Subcommittee in advance of the LAR but I think that that's something that we need to continue to discuss internally and also with the ACRS staff to figure out which is the best plan, in terms of schedule and everything else.

MEMBER REMPE: If you think it's a half day, then definitely, I think it ought to be done separately. If it's an hour discussion, we can work it all in together. But I just was curious now because I'm involved in the one that's coming to us in April and I wondered if we should be --

MR. YARSKY: I think the staff needs to think about it a little more in terms of -- especially in light of the presentation we've given today and other presentations that we've made, if we might not just be repeating ourselves if we come in for half a day.

MEMBER REMPE: Okay. Well I definitely would think I would want to have an hour during those discussions of the plant.

MR. YARSKY: Oh, certainly. Yes, I think it's something that just needs to be sorted out. The direction we were leaning in was to have a separate meeting with the Thermal-Hydraulic Subcommittee.

MEMBER REMPE: Okay.

MR. YARSKY: But I don't think any final determination yet has been made with respect to the ACRS schedule.

MEMBER REMPE: So Mike and Jose --

CHAIRMAN MARCH-LEUBA: That would be a generic presentation on TRACE calculations?

MR. YARSKY: No, a presentation on the Brunswick plant-specific confirmatory analysis.

CHAIRMAN MARCH-LEUBA: But only TRACE calculations.

MR. YARSKY: Only TRACE calculations only Brunswick.

CHAIRMAN MARCH-LEUBA: That would be nice.

MEMBER REMPE: When is it?

MR. BORROMEO: April 20th.

MEMBER REMPE: That's our subcommittee meeting. That's actually on the application, the LAR. So you're planning to fold it in is what I'm hearing.

MR. YARSKY: We're leaning separate.

MS. ABDULLAHI: And this one is AREVA. Okay, Brunswick is AREVA methods, right?

MEMBER REMPE: Right.

MR. BORROMEO: But AREVA and GE methods together. So that's what makes it fun.

MS. ABDULLAHI: Which part of it are GE -- oh, we can't talk about it.

Okay. Just for the ATWS-I part, it is AREVA, I think. And so there will be something different about it.

MR. YARSKY: Well, the plant-specific confirmatory analysis performed by the Office of Research would not address any of the -- like we would be presenting our results, right?

CHAIRMAN MARCH-LEUBA: So if I have a vote on that, if we could have his presentation in the middle of the Brunswick MELLLA+ presentation with the applicant, and with the vendors, and everything, we won't have enough time. You see how this thing goes.

MEMBER REMPE: Well okay, we've gone through a lot of power uprates in the past, right?

CHAIRMAN MARCH-LEUBA: Yes, the other part about power rate will go fast. It's his part.

MEMBER REMPE: Yes, well, again, if we're going to do it before April 20th, it's not on the agenda, to my knowledge. And so that's something we ought to get going soon because April's not that far away, frankly, for a schedule change.

MR. YARSKY: Well, certainly we have to complete the confirmatory analysis. There's a lot of work to be done there.

MEMBER REMPE: So yes, how soon --

MEMBER CORRADINI: I'm not sure, Joy -- I'm not sure why inserting it at this point is necessary. I think we have the general direction. You want it because of why?

MEMBER REMPE: Well, they are going to the effort to do a plant-specific Brunswick evaluation. Do we want to have it before the power uprate discussion on April 20th or not? That's why I'm bringing it up.

MS. ABDULLAHI: Is that EPRI or MELLLA+?

MR. YARSKY: MELLLA+.

MEMBER REMPE: You're right, it's a MELLLA+ but they are using the AREVA methods --

MR. YARSKY: I think it's the Power Uprate Subcommittee.

MEMBER REMPE: Yes, it's the Power Uprate Subcommittee but it's a MELLLA+ evaluation for Brunswick, which already has its EPU.

And again, if they've got this plant-specific analysis, it sure seems like that we'd want to hear about it as part of our review of the MELLLA+, right?

MEMBER CORRADINI: And Jose doesn't think it will fit within the time period of --

CHAIRMAN MARCH-LEUBA: It's not a one-hour presentation. See how it went here with the --

MEMBER CORRADINI: But wait. It doesn't have to be. We're now planning the future. I'm not sure if this is the appropriate way to do it. But why does it have to be like he did it here? It doesn't have to be.

MEMBER REMPE: Well, I don't know how much material there will be and I just am bringing it up because we need to have it on the agenda.

MEMBER CORRADINI: Well I mean reverse this thing. Schedule it in, you have an hour, they figure out what they want to present in the hour, and that's the end of it.

MS. ABDULLAHI: But are they going to keep the schedule?

MR. BORROMEO: We're committed to April 20th or 19th I think I just saw in my email.

MEMBER POWERS: It is fairly well-known, Mike, it is fairly well-known that predictions are difficult, especially about the future.

MEMBER CORRADINI: Okay.

MEMBER REMPE: You are still completing the Brunswick analysis. It's not done yet?

MR. YARSKY: The Brunswick analysis is not complete at this point.

MEMBER REMPE: Do you have an estimated date for when you think it will be?

MR. YARSKY: We have a revised estimated date that we have to finalize.

MEMBER CORRADINI: So are you telling -- this is going to be part of the staff's analysis anyway to accept what's being done anyway, right? So does that imply that everything's going to be delayed?

MR. YARSKY: No.

MEMBER CORRADINI: Oh. All right.

MEMBER REMPE: So you may not have it done before the staff finishes the April --

MR. BORROMEO: Oh, no, they'll have it. Research has committed to having it done before the April meeting.

MR. YARSKY: Right.

MR. BORROMEO: And I think we said sometime of early next year, right?

MR. YARSKY: Yes.

MEMBER REMPE: And it will be used in your evaluation that you're going to be presenting to us.

MR. BORROMEO: Yes.

MEMBER REMPE: So we definitely want to have something at the meeting on it, if we don't do it separately.

MR. YARSKY: Absolutely.

MEMBER POWERS: Can I put my vote in for sometime after May?

MEMBER REMPE: No.

MR. YARSKY: It would certainly -- I think it would not fruitful for us to present the analysis after the April meeting.

MEMBER REMPE: I would think so. But I just was trying to get some facts here. And so again --

MR. YARSKY: We are not far enough along in the analysis for me to provide a hard date of when the analysis will be complete. After the Thanksgiving holiday, we have had several meetings to align the team that's working on it. Because this is a team that is almost essentially the entire Reactor Systems Analysis Group working on different aspects of it.

When we have a better idea of the date, we will be working with the ACRS staff to schedule time to talk to you. And what we had been discussing with NRR and internally was having a separate meeting with the Thermal-Hydraulics or Power Uprate Subcommittee to present the plant-specific results in advance of the LAR meeting.

MEMBER REMPE: March looks pretty open for the calendar for ACRS and so I'd shoot hard for that but you'd need to get stuff to us then ahead of time.

MR. YARSKY: Right. We need to complete the analysis. There are other scheduling things so we just need to consider the staff level.

CHAIRMAN MARCH-LEUBA: You have the Christmas break to work on it.

MR. YARSKY: I'm going to be honest with you, Jose. I am not doing the heavy lifting on the Brunswick plant-specific analysis. So I am kind of plugged into that activity but I am not the technical lead on any of the --

CHAIRMAN MARCH-LEUBA: So you are not opposed against them working over Christmas.

MR. YARSKY: So I would not be the person that would be working over the holiday.

MEMBER REMPE: Anyway, I just was curious because I would like to kind of understand the timing.

MR. YARSKY: Absolutely. And as we get a better idea on schedule, we'll get on the calendar.

If the scope of what we're coming up with that we would want to present starts to look like it would fit in an hour, then maybe we could reconsider the meeting with you guys separately beforehand. But it seems the indication I'm getting from Jose is to meet with you beforehand anyway.

CHAIRMAN MARCH-LEUBA: I can see this going half a day easily. I cannot see how we can do this in one hour.

MEMBER REMPE: The MELLLA+ discussions are getting easier. The issue with this is the --

CHAIRMAN MARCH-LEUBA: I don't have any problem with MELLLA+. I have got a problem with TRACE calculations. They will be interesting. Everybody likes them.

MEMBER REMPE: I appreciate the time to discuss it because it will draw our attention to what we need to figure out what we're doing.

MEMBER POWERS: It definitely sounds to me like June subcommittee would be really good.

MEMBER REMPE: And we can just delay your retirement because Shirley has asked me to find a way to do that.

CHAIRMAN MARCH-LEUBA: Okay, I am going to use the power of the office. I am going to call it closed. Since we already called for comments earlier, we don't have to do it now.

So this meeting is adjourned.

(Whereupon, the above-entitled matter went off the record at 4:35 p.m.)

U.S.NRC

United States Nuclear Regulatory Commission

Protecting People and the Environment

BACKGROUND ON MELLLA+, ATWS-I, AND FAILURE TO REWET PHENOMENOLOGY

Dr. Peter Yarsky
US NRC Office of Nuclear Regulatory Research

OUTLINE

1. Description of the maximum extended load line limit analysis plus (MELLLA+) domain.
2. Safety significance of the MELLLA+ domain.
3. Description of ATWS-I.
4. TRACE calculation results.
5. Predicted mechanism if fuel heat-up.
6. Plant-specific considerations.

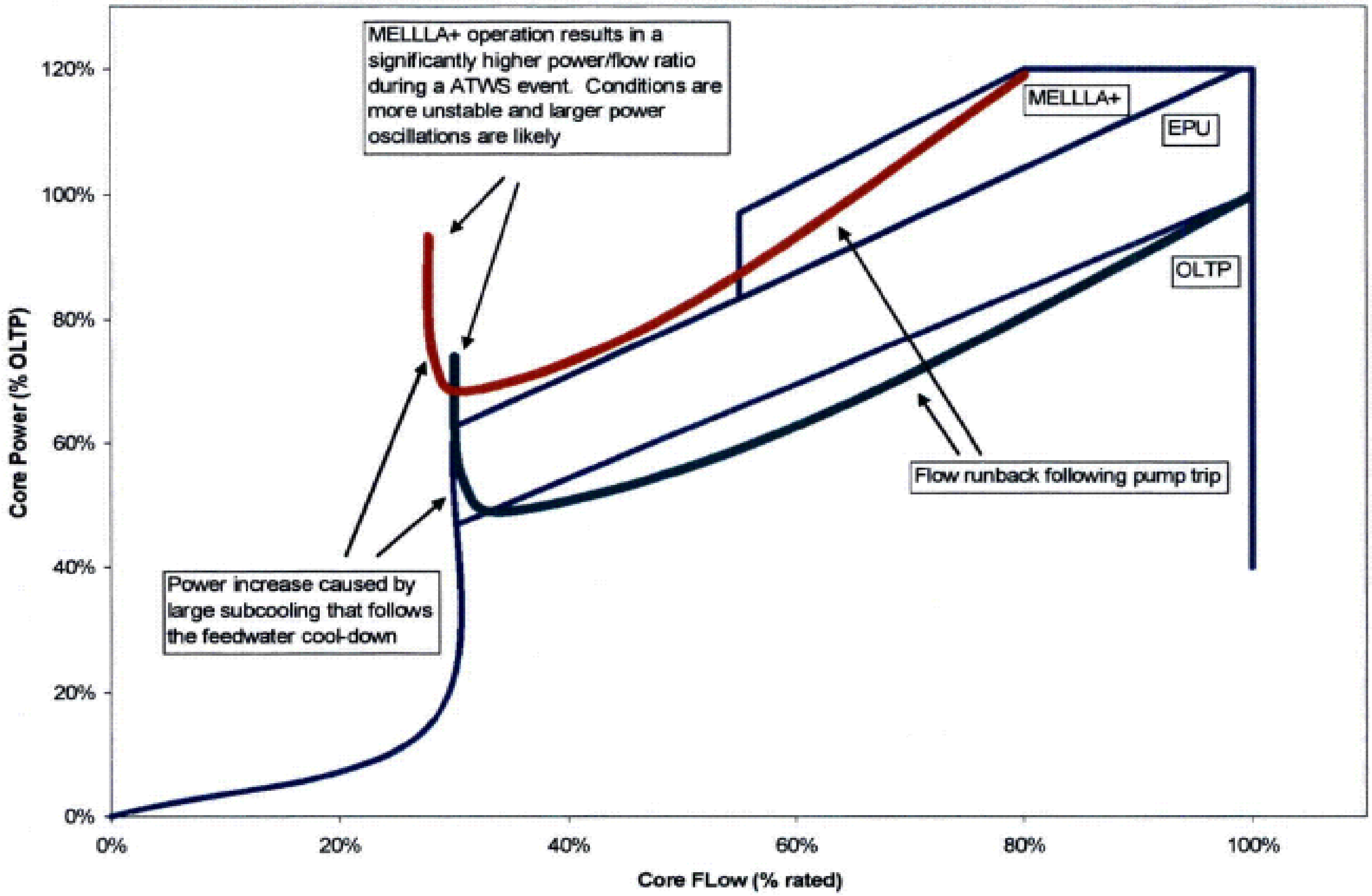
MELLLA+ DOMAIN

- Maximum Extended Load Line Limit Analysis Plus (MELLLA+) is an expanded BWR operating domain allowing high thermal power (120%) at low flow (80%)
- MELLLA+ operation introduces new aspects to the progression of Anticipated Transient Without SCRAM (ATWS) events

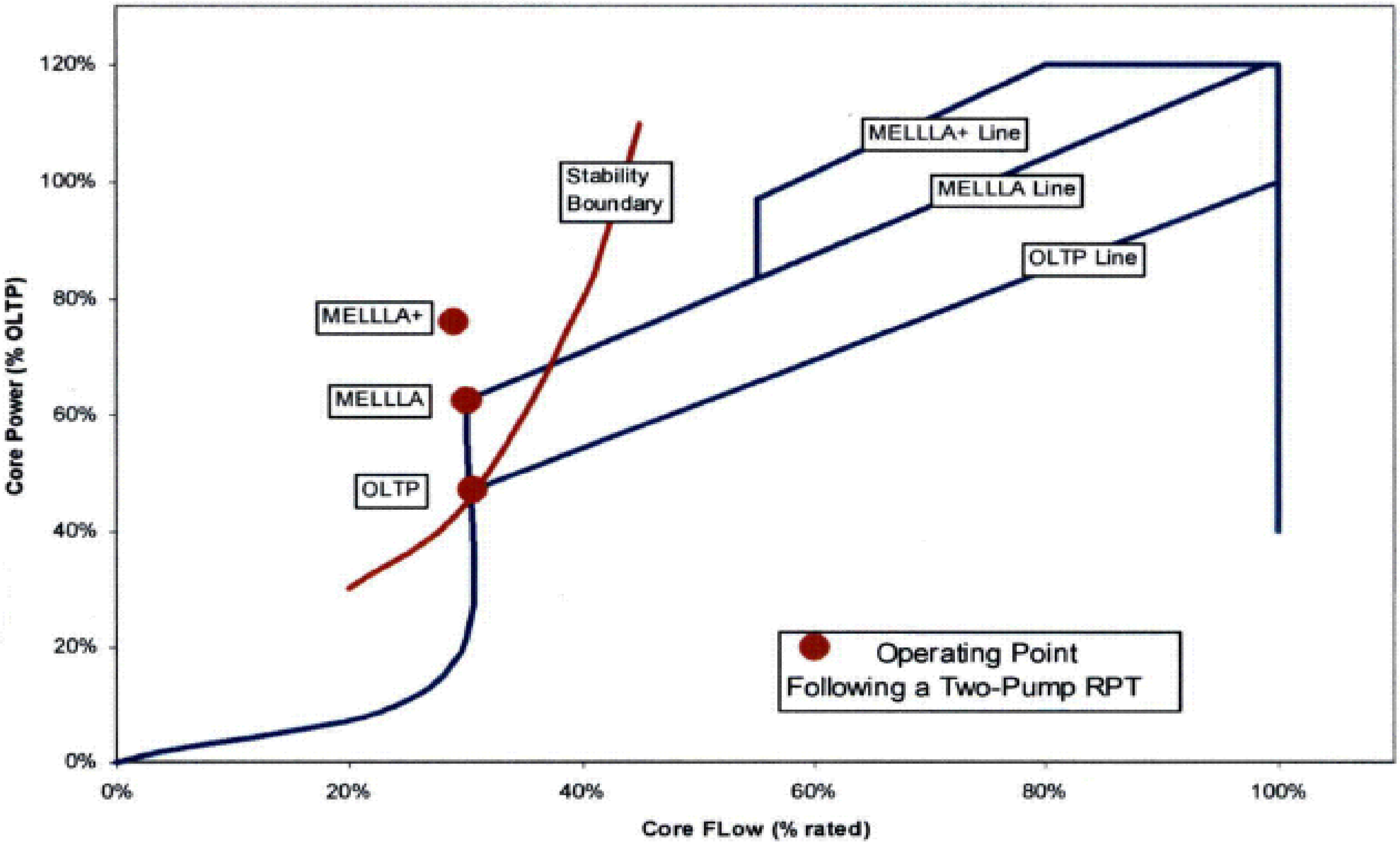
SAFETY SIGNIFICANCE OF THE FCW

- During ATWS events, the reactor power is decreased by a trip of the recirculation pumps (2RPT).
- The power and flow decrease as the pumps run down.
- Power then increases due to a decrease in feedwater temperature.
- When the flow rate is low (80 %RCF), the 2RPT becomes less effective in the reduction of gross core power.

OPERATING DOMAIN AND RPT



OPERATING DOMAIN AND RPT



OVERVIEW OF ATWS-I

- ATWS event considered is a turbine trip event with turbine bypass capability (TTWBP).
- The TTWBP results in a pressure pulse, a trip of the recirculation pumps, and a loss of extraction steam to the feedwater heater cascade.
- The TTWBP ATWS is expected to yield unstable conditions and large amplitude power instability.
- Operators control reactor water level and inject boron through the standby liquid control system (SLCS) to mitigate the event.

ATWS-I RESULTS

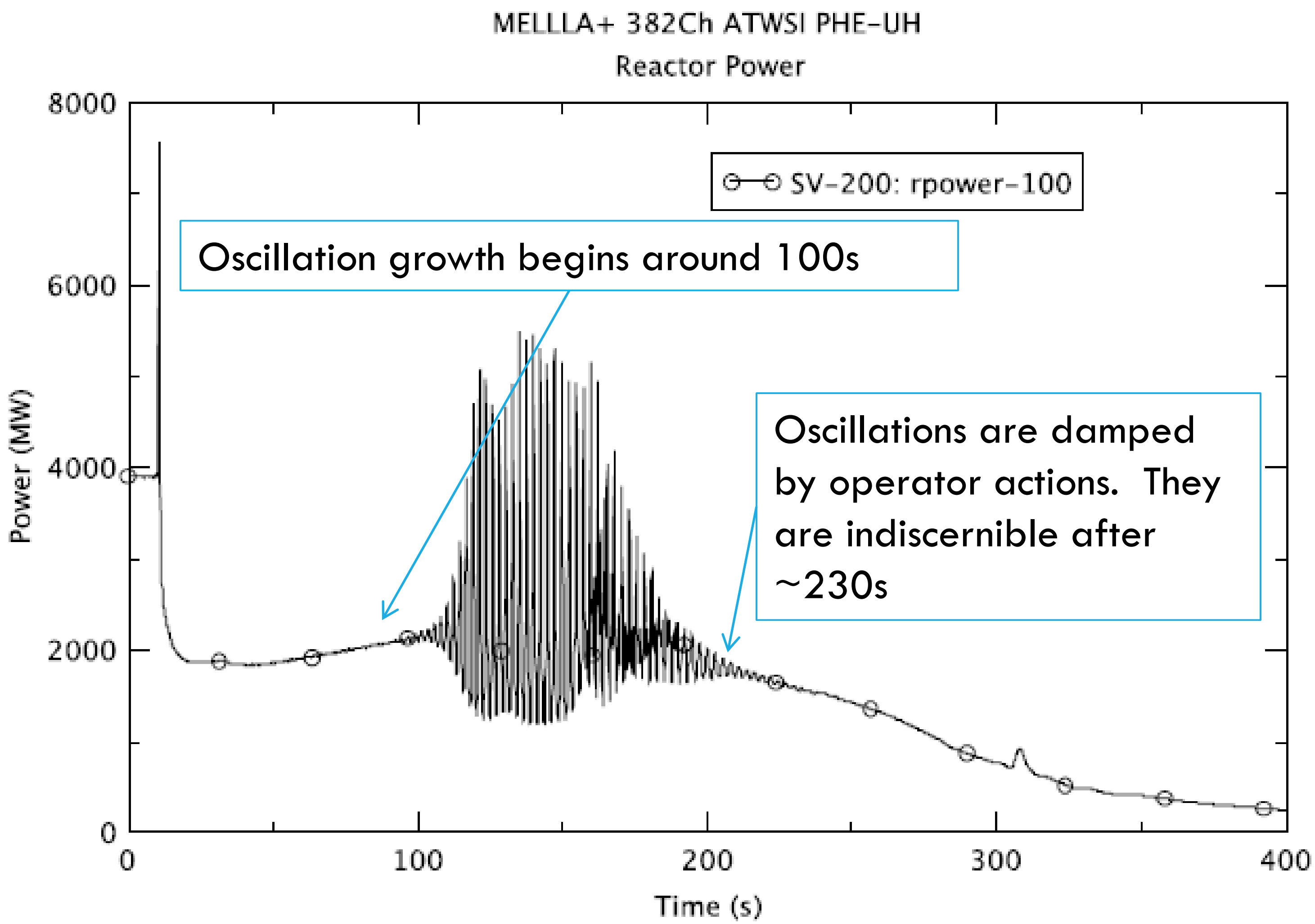
Representative Case:

- Generic BWR/5 model
- TTWBP with 100% bypass capacity
- Initial core flow rate is 85% rated
- Initial power is 120% of originally licensed thermal power (OLTP)
- Core exposure is peak-hot-excess (PHE)
- Operators attempt to control reactor water level to top of active fuel (TAF) starting 110 seconds into event
- Operators initiate SLCS at 120 seconds into event

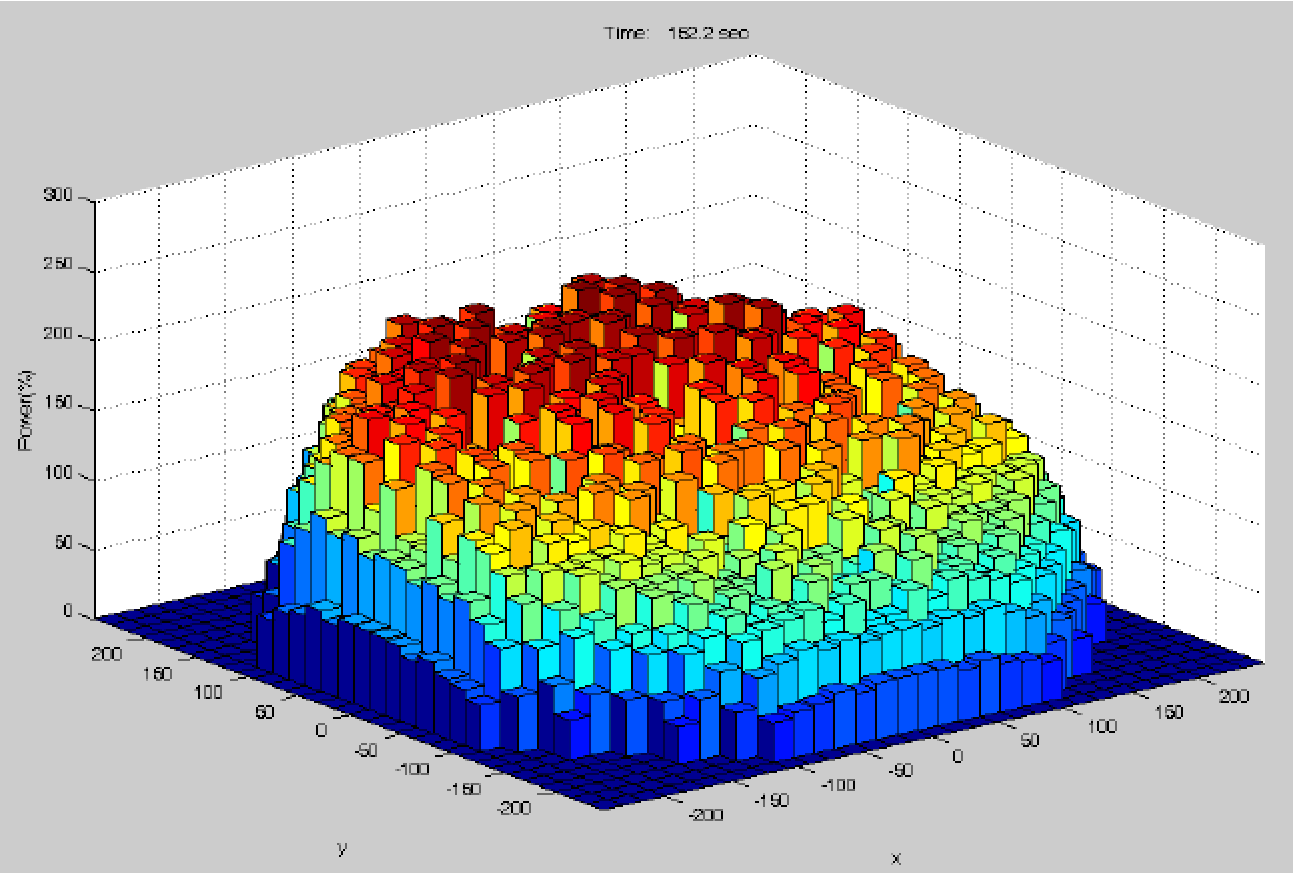
PHE ATWS-I CASE – SEQUENCE OF EVENTS

Time (s)	Event
0.0	• Null transient simulation starts.
10.0	• Null transient simulation ends. • Turbine trip is initiated by closing the TSV. • Recirculation pumps are tripped on the turbine trip. • Feedwater temperature starts decreasing.
10.1	• TSV closes completely and starts opening again to simulate 100% turbine bypass.
11.1	• TSV (bypass) completes opening.
~11.4	• Steam flow starts decreasing.
~12.3	• Feedwater flow starts decreasing.
~95	• Power oscillation (instability) starts.
120	• Water level reduction (WLR) is initiated by reducing the normal water level control system setpoint linearly to TAF over 180 s.
130	• Boron injection is initiated and linearly ramped to full flow at 190 s.
~144	• Bi-modal oscillation of the core power is initiated.
~160	• Boron starts accumulating in the core.
~163	• Downcomer water level begins decreasing. • Peak cladding temperature of ~1700 K occurs.
~240	• Power oscillation ends.
400	• Simulation ends.

TRANSIENT REACTOR POWER



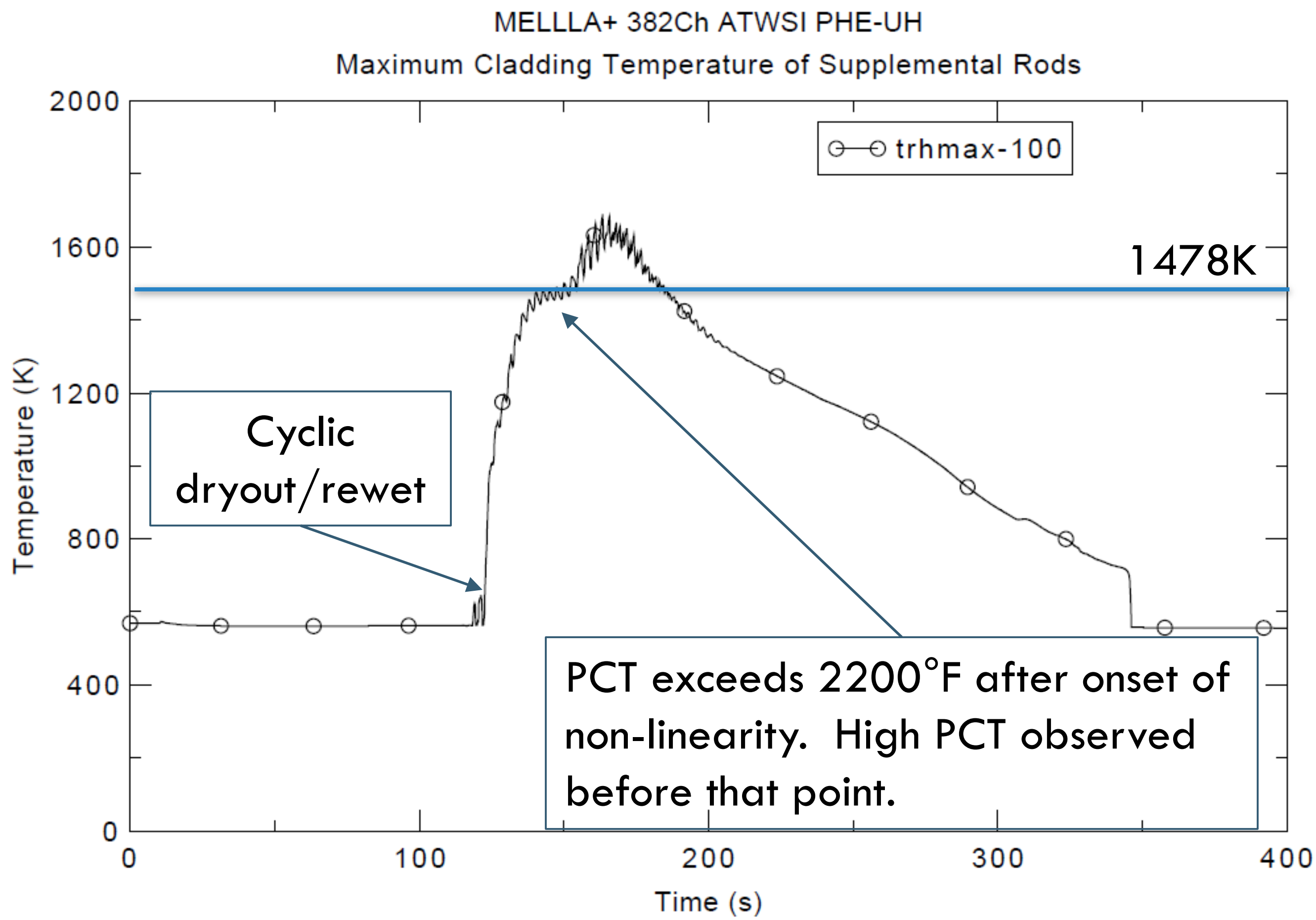
BI-MODAL OSCILLATIONS



VISUALIZATION

PHE – Case 2

PEAK CLADDING TEMPERATURE RESULTS



BASE CASE CONCLUSIONS

Point in cycle studies confirm that PHE is the most limiting state-point

- Large amplitude regional power oscillations develop (modal coupling with frequency doubling).
- High amplitude power oscillations (local) results in calculation of high PCT (~1700 K [2600 °F]).

Operator action to reduce level

- Effective in reducing FW flow, limiting increase in core inlet subcooling and eventually eliminating inlet subcooling.

Operator action to inject boron through SLCS

- Effective in suppressing power oscillations and reducing core power level.

PREDICTED FUEL HEAT-UP MECHANISM

- Oscillation magnitude increases and the fuel undergoes periodic dryout/rewet cycling.
- As oscillation magnitude continues to grow, the rewet period of the cycle becomes insufficient to remove all of the energy accumulated in the fuel during the dryout period. This is accompanied by a "ratcheting" of the fuel temperature upwards after each dryout/rewet cycle.
- Once temperature ratchets up to the minimum stable film boiling temperature, the cladding surface "locks" into film boiling heat transfer.
- Once locked in film boiling, and while reactor power is high, fuel temperature excursion occurs.

PLANT SPECIFIC FACTORS AFFECTING EVENT PROGRESSION AND CONSEQUENCES

- Fuel and core design.
- Turbine bypass capacity.
- Manual operator action timing.
- SLCS injection location and boron enrichment.
- Feedwater pumps (motor vs. steam driven).
- Feedwater heater cascade thermal inertia.
- Automatic protective features (i.e., NMP2).

SUMMARY

1. Instability is likelier to occur and is expected to occur earlier for MELLLA+ plants during ATWS, meaning that operator actions designed to mitigate the instability may not be effective before large amplitude power/flow oscillations develop.
2. If large amplitude power/flow oscillations develop during the ATWS-I event, prior to mitigation, the fuel may expect cyclic dryout/rewet.
3. During the cyclic dryout/rewet phase, the temperature may increase due to “ratcheting,” resulting in the fuel failing to rewet. Failure to rewet leads to excessive fuel heat-up and fuel damage.