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ADVISORY COMMITTEE ON REACTOR SAFEGUARDS

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 NUCLEAR REGULATORY COMMISSION

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ADVISORY COMMITTEE ON REACTOR SAFEGUARDS

(ACRS)

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THERMAL-HYDRAULIC PHENOMENA SUBCOMMITTEE

+ + + + +

OPEN SESSION

+ + + + +

TUESDAY

DECEMBER 5, 2017

+ + + + +

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

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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

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

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

12 As the meeting is being transcribed, I
13 request that participants use the microphones located
14 throughout this room when addressing the subcommittee.

15 Participants should first identify themselves and
16 speak with sufficient clarity and volume so that they
17 can be readily heard.

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

24 MR. YARSKY: Thank you. I'm Dr. Peter
25 Yarsky from the research staff. And before getting

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1 into a discussion of the KATHY experiments, I wanted
2 to take a few moments to provide some background
3 information on MELLA+ ATWS instability and the
4 predicted failure to rewet phenomenology.

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

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

23 The MELLA+ domain represents an expansion
24 of the operating domain relative to extended power
25 operate for BWRs, and notably allows operation at high

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1 power levels, 120 percent of the original license
2 thermal power level. But at low core flow rates about
3 80 percent of the rated core flow rate.

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

12 The power in the reactor then increases
13 as a result of a reduction of feed water temperature.

14 When the core flow rate is low, this dual
15 re-circulation pump trip mitigating feature is less
16 effective and this means that there's a higher power
17 level in the core following the trip of these pumps.

18 What this means in the power flow operating
19 domain is that a plant operating at originally license
20 thermal power, which would be the point at 100 percent,
21 100 percent on this power flow map. If that plant were
22 to experience a ATWS and a dual re-circulation pump
23 trip, it would follow the black curve in terms which
24 trajectory on the power flow map and would wind up at
25 a given power flow, can I show with the pointer here?

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1 No, I'm not able to do that.

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

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

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

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

23 MEMBER CORRADINI: Just, can you go back.

24 Just to be sure, go back a slide. The OLTP is where
25 we set the --

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

9 MEMBER CORRADINI: Okay.

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

14 MEMBER CORRADINI: That's just, okay.

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

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

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

25 MR. YARSKY: Right.

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1 CHAIRMAN MARCH-LEUBA: If you lose your
2 pumps.

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

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

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

24 And the closure of the turbine stop valves
25 will remove source of extraction steam that's used to

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1 supply steam to the feed water heater cascade. And
2 that loss of extraction steam will feed water
3 temperature to begin to decrease.

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

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

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

21 MR. YARSKY: At the very end I was going
22 to talk about some differences between plant designs.

23 But in some BWRs the feed water pumps themselves are
24 motor driven. In which case the operators have direct
25 control over the feed water pumps in terms of the head

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1 that's supplied by the feed water pumps. So that they
2 can reduce that flow rate in order lower the reactor
3 water level.

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

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

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

18 MEMBER KIRCHNER: And had you analyzed
19 those scenarios --

20 (Simultaneous speaking.)

21 MR. YARSKY: We've analyzed a variety of
22 water level scenarios as part of a generic work that
23 we've done for MELLA+. So we were looking at a
24 representative plant that had some features of BWR/4,
25 or BWR/5 and we're looking some of these plant

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1 differences. And so we looked at the sensitivity to
2 the results, depending on where the operators
3 controlled the reactor water level.

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

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

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

12 (Simultaneous speaking.)

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

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

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

23 MEMBER CORRADINI: Okay.

24 MR. YARSKY: So the reactor operators will
25 attempt to lower the reactor water level to achieve

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1 at least a two foot gap between the feed water injection
2 spargers and the reactor water level.

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

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

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

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

17 MEMBER CORRADINI: Okay. Thank you.

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

25 We analyzed this at a middle of cycle

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1 exposure point, in particular the peak hot excess point.

2 And what we simulate are two manual operator actions.

3 The first is an attempt to control the reactor water
4 level. In this case, the operators strive to control
5 a reactor water level to the top of active fuel.

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

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

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

22 MEMBER REMPE: Okay.

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

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

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

8 MR. YARSKY: Yes.

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

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

14 MEMBER REMPE: Good.

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

24 MEMBER REMPE: Good, thanks.

25 MEMBER CORRADINI: So remind me a couple

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1 of key differences between a four and a five.

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

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

13 MR. YARSKY: Yes.

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

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

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

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

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

10 MEMBER CORRADINI: Okay.

11 MR. YARSKY: So there are differences such
12 as these that we reflect in the modeling. And so in
13 this case that I'm presenting, we're just doing a BWR/5.

14 And in this representative case, we just want to talk
15 about how we reach the prediction of fuel heat up and
16 what is the mechanism for this fuel heat up.

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

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

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1 inject in the bottom of the vessel --

2 PARTICIPANT: It has the core?

3 CHAIRMAN MARCH-LEUBA: No, it stratifies.

4 (Simultaneous speaking.)

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

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

11 MR. YARSKY: Yes.

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

15 (Simultaneous speaking.)

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

18 MEMBER CORRADINI: Other calculations?

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

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

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

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

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

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

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1 the reactor becomes unstable.

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

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

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

14 CHAIRMAN MARCH-LEUBA: So is the control
15 of the feed water flow?

16 MR. YARSKY: Yes.

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

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

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

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

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

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

18 CHAIRMAN MARCH-LEUBA: The mouse not
19 working?

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

23 CHAIRMAN MARCH-LEUBA: It's extended.

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

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

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

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

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

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

23 MR. YARSKY: Yes. This is why it's very
24 important. I'm pre-empting my next slide. So what
25 we see is that the oscillation mode is initially in

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1 the core-wide mode, and that during the event a
2 bi-modal oscillation occurs. And this is a coupled
3 oscillation mode between the core-wide and the regional
4 mode.

5 And so this is just sort of where we first see
6 that oscillation using our visualization methodology.

7 But I want to show you is a video of this so we can
8 watch the event progression. So if you'll give me a
9 moment to do that.

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

13 MR. YARSKY: About two minutes.

14 MEMBER CORRADINI: Okay. So 115 seconds.

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

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

19 MR. YARSKY: Right. Yes.

20 MEMBER CORRADINI: What does it think it
21 should do?

22 MR. YARSKY: It thinks it should be
23 maintaining the reactor water level at the nominal
24 level. However, because of the three element
25 controller, there is going to be a delta level that

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1 arises because of the air due to no steam flow.

2 MEMBER CORRADINI: Okay. Thank you.

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

5 MEMBER CORRADINI: Thank you.

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

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

16 PARTICIPANT: My God.

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

24 And then we begin to see the onset of the
25 instability at this 100 second mark. And then each

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1 one of these boxes represents one of the fuel assemblies
2 in the core and its height, of course, represents the
3 power in that fuel assembly. And so here, this is the
4 axially integrated power. So this is total assembly
5 power.

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

8 (Simultaneous speaking.)

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

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

24 MEMBER KIRCHNER: Let me ask you --

25 PARTICIPANT: Mic.

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

5 MEMBER BLEY: What drives it?

6 MEMBER KIRCHNER: What drives the
7 asymmetry that was --

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

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

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

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

24 MR. YARSKY: This regional model --

25 MEMBER KIRCHNER: Your model is doing it,

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1 but the regional mode, what --

2 (Simultaneous speaking.)

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

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

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

13 MEMBER KIRCHNER: Yes. That's my point.

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

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

21 MR. YARSKY: The initial conditions are
22 completely symmetric.

23 MEMBER KIRCHNER: Oh, they are completely
24 symmetric.

25 MR. YARSKY: They are completely

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1 symmetric.

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

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

8 MEMBER CORRADINI: Right.

9 MR. YARSKY: And what we need to be able
10 to capture is that the neutron flux on one side of the
11 core can be different than the other side of the core.

12 So in our neutronics model we simulate 764 unique
13 channels. But in the TRACE thermal hydraulics model,
14 what we do is we can group together two channels, one
15 with its symmetric sister. So we have 382 TRACE channel
16 components.

17 MEMBER CORRADINI: Right.

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

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

25 MR. YARSKY: Right. If we were to model

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

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

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

11 MEMBER CORRADINI: But, I guess to get back
12 to Walt's original question about what starts it off.

13 It would seem there's got to be a numerical reason
14 that it starts off. Like some tolerance that if I
15 torque down on the tolerance I would delay, or if I
16 allow the tolerance to be larger, I would start it
17 earlier. I would expect a numerical tolerance is the
18 kick off point.

19 MR. YARSKY: Yes. But we studied --

20 (Simultaneous speaking.)

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

24 MEMBER CORRADINI: Okay.

25 MR. YARSKY: And we can improve the

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

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

9 MEMBER CORRADINI: To kick it off.

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

12 MEMBER CORRADINI: Yes.

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

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

23 (Simultaneous speaking.)

24 MR. YARSKY: Well, if you were to plot them
25 side by side, what you would see is the large amplitude

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1 oscillations would be apparent about 15 or 20 seconds.

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

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

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

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

20 MEMBER KIRCHNER: Yes.

21 MR. YARSKY: -- to respond. One of the
22 things that we do to justify the TRACE application to
23 these kinds of problems is to qualify or assess TRACE
24 against stability measurements. And in these kinds
25 of measurements, you're looking at these different

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1 modes of oscillation, but in context where they're
2 stable. And can TRACE predict that harmonic contour
3 or that shape of the perturbation and the correct to
4 K ratio.

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

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

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

19 MEMBER KIRCHNER: Okay.

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

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

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

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

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

5 MEMBER KIRCHNER: This is kind of an
6 idealized case.

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

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

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

23 CHAIRMAN MARCH-LEUBA: And with that in
24 mind for the record, all these oscillations have
25 occurred in real reactors from the first three seconds

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1 or so. Then a scram happens. This is a calculation
2 of what will happen if the scram were to fail.

3 MEMBER CORRADINI: Right.

4 CHAIRMAN MARCH-LEUBA: That has never been
5 reported.

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

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

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

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

22 In that period of dryout, the fuel will
23 heat up a little bit. But the flow is oscillatory,
24 so it'll eventually return and then you'll have an
25 increase flow. And what that will do is it will rewet

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1 that dried out spot, remove that heat and the
2 temperature will come down. And so as the event
3 progresses and oscillation magnitude is increasing,
4 we'll eventually hit a point where there is a cyclic
5 dryout/rewet.

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

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

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

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

21 MR. YARSKY: It really does depend. You
22 may have this happening before, you may have the side
23 to side happen before the core-wide happens, so that
24 could be a possibility in which case you wouldn't see
25 --

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1 MEMBER CORRADINI: Okay.

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

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

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

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

16 MR. YARSKY: Right.

17 MEMBER CORRADINI: Okay.

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

24 MR. YARSKY: Right.

25 MR. WYSOCKI: -- reactor and the event.

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

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

14 MR. YARSKY: This part here.

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

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

19 (Simultaneous speaking.)

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

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

25 MEMBER KIRCHNER: So that one could then

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1 physically separate out how much of this is numerical,
2 and how much of it -- I'm not doubting that it's real
3 --

4 MR. YARSKY: Yes.

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

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

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

22 MEMBER KIRCHNER: This experiment,
23 numerical experiment that I'm suggesting would then
24 give you a little more confidence about how much of
25 what when you're in the area is numerically induced

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1 versus physically induced. Do you see where I'm
2 getting at? Codes will go into that, like you said,
3 you can put white noise in or something --

4 MR. YARSKY: Right.

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

9 MR. YARSKY: Right. Right.

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

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

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

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

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1 CHAIRMAN MARCH-LEUBA: Your typically --

2 MEMBER KIRCHNER: -- and how much is --

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

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

12 CHAIRMAN MARCH-LEUBA: When you do --

13 MEMBER KIRCHNER: -- trick point --

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

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

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

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

4 I feel like we've done a lot of work to
5 address that, but not by inserting a spatial asymmetry.

6 It's something that we could do, but I can send you
7 or I can send the Committee references to work that
8 we've done to look at things like time step size, to
9 look at things like noise. Yes. I can forward those
10 along and maybe that could address your concern.

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

14 MR. YARSKY: Yes.

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

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

22 CHAIRMAN MARCH-LEUBA: Okay.

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

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

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

15 Based on our calculation --

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

20 MR. YARSKY: Yes.

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

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

25 MEMBER KIRCHNER: You just, well forget

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

3 MR. YARSKY: Right.

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

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

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

9 MR. YARSKY: If there is --

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

12 MR. YARSKY: Right.

13 MEMBER KIRCHNER: -- that you can look at
14 --

15 MR. YARSKY: You would be able to look
16 --

17 MEMBER KIRCHNER: -- that kind of thing.

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

23 (Simultaneous speaking.)

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

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1 action.

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

5 MR. YARSKY: Right.

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

8 (Simultaneous speaking.)

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

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

13 MR. YARSKY: -- in that time frame.

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

16 MR. YARSKY: Yes.

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

21 MR. YARSKY: Right.

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

25 MR. YARSKY: Right.

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

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

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

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

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

25 In TRACE, and this is a, just like the trade

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1 systems analysis code feature, that film boiling lock
2 is diagnosed by the temperature exceeding the minimum
3 stable film boiling temperature.

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

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

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

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

25 MR. YARSKY: Yes.

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1 MEMBER BALLINGER: What about ballooning
2 and things like that?

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

4 MEMBER BALLINGER: By the time you get to
5 2200 degrees, I got a feeling that if it's a pressurized
6 rod --

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

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

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

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

24 MEMBER CORRADINI: But back to my original
25 comment. As soon as it starts creeping up, you're past

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1 the point of no return and all bets are off as to how
2 we --

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

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

14 MEMBER REMPE: There were some --

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

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

23 (Simultaneous speaking.)

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

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

3 CHAIRMAN MARCH-LEUBA: Right.

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

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

14 (Simultaneous speaking.)

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

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

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

21 MR. YARSKY: Well it's in the research
22 confirmatory analysis. We don't yet have the
23 capability to predict damage population. So one thing
24 I think that would be necessary in order to do that
25 would be to model the assemblies with sufficient

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1 resolution that you have the actual rod to rod
2 distribution of powers represented.

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

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

20 And so I think that for our confirmatory
21 analysis research hasn't developed that capability yet,
22 but I think that we will. And then we'll be able to
23 answer question of what is the predicted damage
24 population. The next step after knowing that
25 population would then be to make some sort of

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1 determination with regards to core coolability. But
2 that'll be step two after we do step one.

3 MEMBER CORRADINI: But if I could just take
4 a step back from all these steps. There is some
5 temperature that's not the takeoff temperature, not
6 2200f. But currently staff is saying once I pass this,
7 we'll call intermediary temperature, I have no known
8 way back from it. Therefore, that's a loss of coolable
9 damage.

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

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

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

18 MEMBER CORRADINI: That's one way.

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

24 MEMBER CORRADINI: But they may also argue
25 that, take Ron's suggestion that if I stable all

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1 ballooning then --

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

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

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

19 MEMBER CORRADINI: Are you still then --

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

24 (Simultaneous speaking.)

25 MR. YARSKY: -- well, you know, how certain

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1 am I or could I really say that that temperature is
2 less than 2200. Especially given considerations of
3 you know, hey what if because of a numerical effect
4 the oscillation started ten seconds earlier or --

5 CHAIRMAN MARCH-LEUBA: The other thing I
6 wanted to point out on this figure is that you have
7 an oscillation in the whole band, the 10 by 10 bundle.

8 But this is the regulatory flux of the hottest pin
9 on the bundle.

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

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

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

4 MEMBER BALLINGER: Well, he could probably
5 interrogate --

6 (Simultaneous speaking.)

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

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

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

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

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1 a bundle.

2 MR. YARSKY: That's a bundle.

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

6 MR. YARSKY: Right. Correct.

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

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

11 MR. YARSKY: Right.

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

14 CHAIRMAN MARCH-LEUBA: Yeah, but --

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

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

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

20 (Simultaneous speaking.)

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

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

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

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

9 MR. YARSKY: Paul Clifford?

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

13 MEMBER BLEY: Three activities --

14 MR. YARSKY: Yes.

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

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

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

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

24 MR. YARSKY: Yes. Certainly if there's,
25 if we can translate something like the flow area

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1 reduction due to ballooning and burst. Or the
2 population of rods above a certain temperature or above
3 a certain enthalpy, if that can be translated to a
4 coolability determination, there's information about
5 how to do that already.

6 (Simultaneous speaking.)

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

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

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

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

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

22 CHAIRMAN MARCH-LEUBA: Food for thought.
23 This expansion of a group may not even be necessary
24 to put into TRACE. It can be a post processing result.
25 Once you have the flow of the pressure of the void

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1 of the bundle, you can just put this rods, second rod
2 on this. You don't have to complicate TRACE more than
3 it already is.

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

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

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

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

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

23 PARTICIPANT: Be necessary.

24 MR. YARSKY: -- may not be necessary. But
25 if we are going to have to answer the questions like

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1 if two percent or three percent of the core is damaged,
2 does the core remain in a coolable geometry. I think
3 we need to do more as terms of our methodology before
4 we can be prepared to perform that kind of confirmatory
5 analysis.

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

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

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

22 (Simultaneous speaking.)

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

25 CHAIRMAN MARCH-LEUBA: I'm sorry. Maybe

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

4 MR. YARSKY: In the closed session. I'm
5 going to spend one minute on the slide. Less than that.

6 Thirty seconds. I just wanted to go through a list
7 of those parameters that can really change the analysis
8 on a plant specific application just to give you an
9 awareness that, you know, if you see a different
10 application, these results can be very different
11 because all of these factors can have a significant
12 impact on how the event progresses and then what the
13 consequences of the events are.

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

20 In our analysis we looked at different
21 turbine bypass capacities and found there are certain
22 competing effects with respect to turbine bypass
23 capacity. That this can have an impact on the event.

24 One of the most significant is manual operator action
25 timing. And I think we've talked about this over the

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1 course of the presentation.

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

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

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

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

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

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1 the event.

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

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

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

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

17 (Off microphone comments.)

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

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

25 (Whereupon, the above-entitled matter went

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1 off the record at 2:26 p.m. and resumed at 4:13 p.m.)

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

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

7 (No audible response.)

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

12 Peter, continue with the conclusions.

13 MR. YARSKY: Okay, thank you.

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

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

22 And we performed tests both with and
23 without simulated neutronic feedback and this was to
24 determine the conditions for instability, cyclic

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1 dryout/rewet, and failure-to-rewet conditions.
2 These, of course, being prototypic for modern fuel
3 assemblies operated and experiencing conditions with
4 MELLLA+ ATWS-I.

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

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

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

23 As applicable, we will provide new
24 correlations based on our improved understanding of

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1 the mechanisms affecting failure to rewet.

2 We will perform the TRACE assessment
3 against the experimental data.

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

11 CHAIRMAN MARCH-LEUBA: Are you able to
12 find TRACE to use the homogeneous nucleation for T_{min}?

13 MR. YARSKY: Yes.

14 CHAIRMAN MARCH-LEUBA: And including the
15 quenching of T_{min}? Because right now TRACE only
16 quenches on axial conduction.

17 MR. YARSKY: It would --

18 MEMBER CORRADINI: It switches.

19 MR. YARSKY: Yes.

20 MEMBER CORRADINI: It switches at this
21 temperature threshold.

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

24 MR. YARSKY: It would go into transition

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1 boiling.

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

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

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

11 MEMBER CORRADINI: But once you pass you
12 --

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

17 CHAIRMAN MARCH-LEUBA: But of TRACE.

18 MR. YARSKY: -- vendors --

19 CHAIRMAN MARCH-LEUBA: I am asking about
20 TRACE.

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

24 CHAIRMAN MARCH-LEUBA: But how do you cool

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1 it?

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

5 CHAIRMAN MARCH-LEUBA: In transition,
6 yes. But if you are above T_{min} in TRACE --

7 MR. YARSKY: Yes.

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

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

15 CHAIRMAN MARCH-LEUBA: Okay.

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

19 CHAIRMAN MARCH-LEUBA: That's correct.

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

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

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

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

8 MEMBER KIRCHNER: It's not axial
9 conduction.

10 CHAIRMAN MARCH-LEUBA: It's not?

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

14 CHAIRMAN MARCH-LEUBA: But we are talking
15 about T_{min}.

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

22 MR. YARSKY: Yes, well like for instance
23 --

24 MEMBER CORRADINI: That's what I thought.

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

6 So even with just film boiling --

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

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

11 MEMBER KIRCHNER: Right.

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

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

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

22 MR. YARSKY: For that to occur in TRACE,
23 the inverted annular film boiling heat transfer
24 coefficient would have to be sufficiently high to cool

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1 the temperature below T_{min} before you have film
2 collapse.

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

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

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

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

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

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

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

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

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

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

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

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

24 CHAIRMAN MARCH-LEUBA: Yes.

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

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

9 MR. YARSKY: Okay.

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

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

18 MEMBER REMPE: Right.

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

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

9 MR. YARSKY: Well --

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

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

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

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

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

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

16 MR. YARSKY: Yes.

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

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

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1 MEMBER REMPE: Yes, the other thing is with
2 the future work, there is this plant-specific
3 evaluation that will be supporting a plant coming in.

4 I think you said it's on our agenda for April. It's
5 coming into you guys sooner, right?

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

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

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

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

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1 and I wondered if we should be --

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

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

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

14 MEMBER REMPE: Okay.

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

18 MEMBER REMPE: So Mike and Jose --

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

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

23 CHAIRMAN MARCH-LEUBA: But only TRACE
24 calculations.

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1 MR. YARSKY: Only TRACE calculations only
2 Brunswick.

3 CHAIRMAN MARCH-LEUBA: That would be nice.

4 MEMBER REMPE: When is it?

5 MR. BORROMEO: April 20th.

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

9 MR. YARSKY: We're leaning separate.

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

12 MEMBER REMPE: Right.

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

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

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

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

24 CHAIRMAN MARCH-LEUBA: So if I have a vote

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1 on that, if we could have his presentation in the middle
2 of the Brunswick MELLLA+ presentation with the
3 applicant, and with the vendors, and everything, we
4 won't have enough time. You see how this thing goes.

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

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

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

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

17 MEMBER REMPE: So yes, how soon --

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

22 MEMBER REMPE: Well, they are going to the
23 effort to do a plant-specific Brunswick evaluation.
24 Do we want to have it before the power uprate discussion

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1 on April 20th or not? That's why I'm bringing it up.

2 MS. ABDULLAHI: Is that EPRI or MELLLA+?

3 MR. YARSKY: MELLLA+.

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

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

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

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

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

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

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

24 MEMBER REMPE: Well, I don't know how much

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1 material there will be and I just am bringing it up
2 because we need to have it on the agenda.

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

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

9 MR. BORROMEO: We're committed to April
10 20th or 19th I think I just saw in my email.

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

14 MEMBER CORRADINI: Okay.

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

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

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

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

23 MEMBER CORRADINI: So are you telling --
24 this is going to be part of the staff's analysis anyway

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1 to accept what's being done anyway, right? So does
2 that imply that everything's going to be delayed?

3 MR. YARSKY: No.

4 MEMBER CORRADINI: Oh. All right.

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

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

10 MR. YARSKY: Right.

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

13 MR. YARSKY: Yes.

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

16 MR. BORROMEO: Yes.

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

20 MR. YARSKY: Absolutely.

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

23 MEMBER REMPE: No.

24 MR. YARSKY: It would certainly -- I think

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1 it would not fruitful for us to present the analysis
2 after the April meeting.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

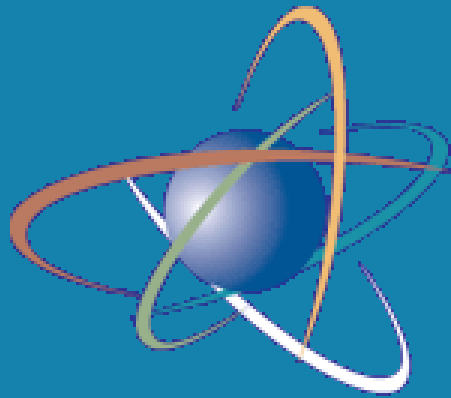
15 CHAIRMAN MARCH-LEUBA: Okay, I am going
16 to use the power of the office. I am going to call
17 it closed. Since we already called for comments
18 earlier, we don't have to do it now.

19 So this meeting is adjourned.

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

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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.

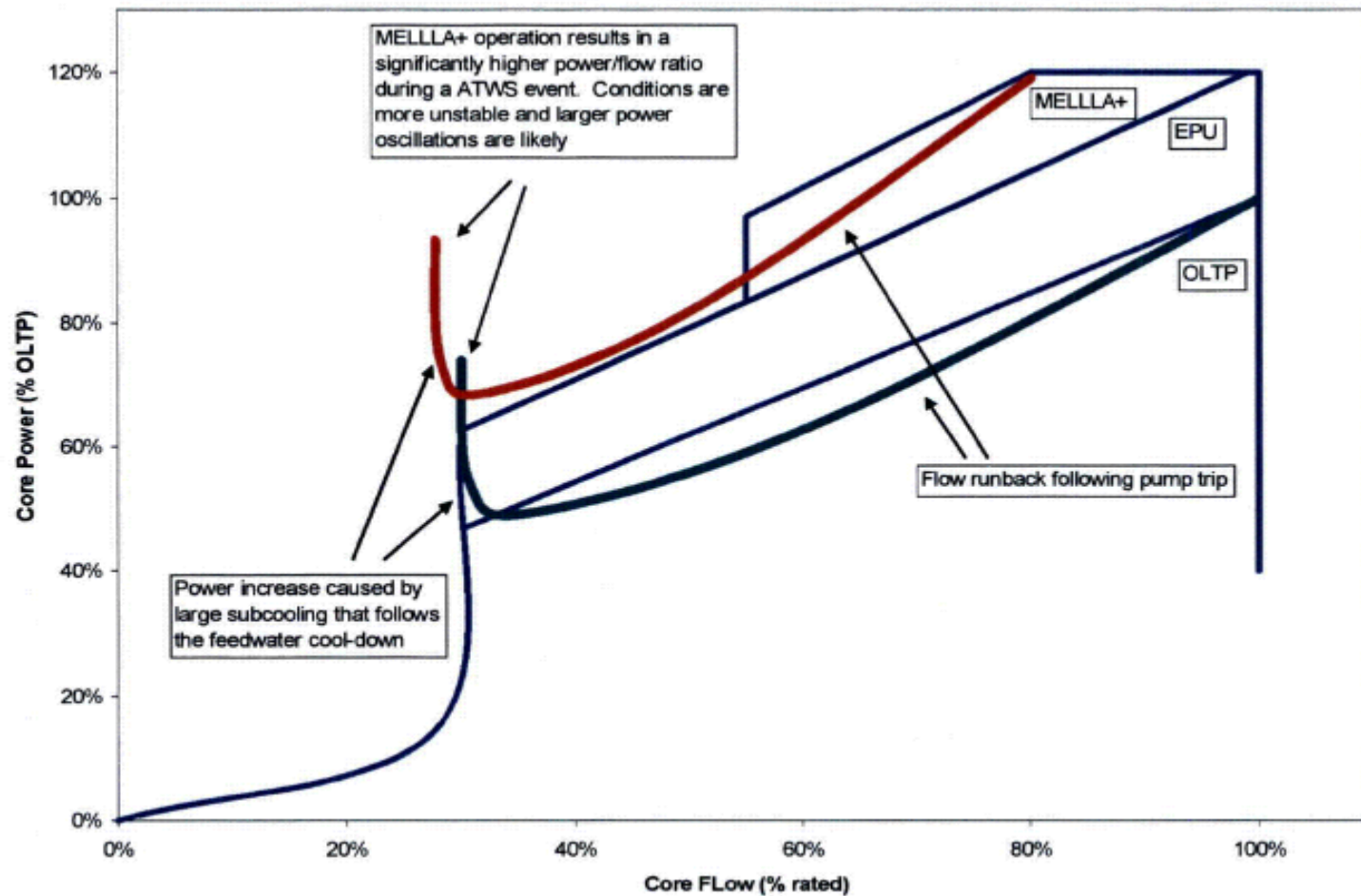
MELLLA+ DOMAIN

- 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

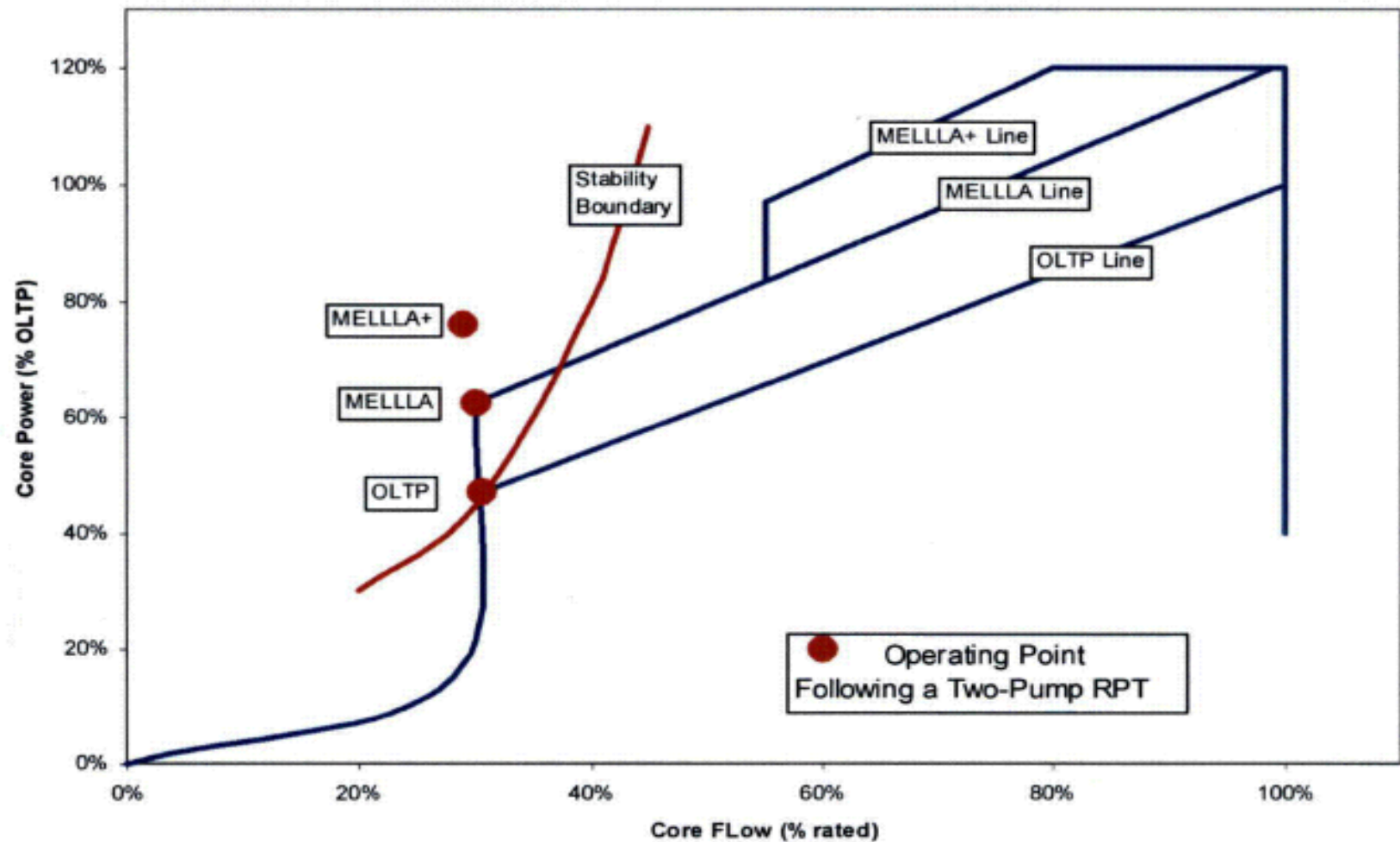
SAFETY SIGNIFICANCE OF THE FCW

- 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

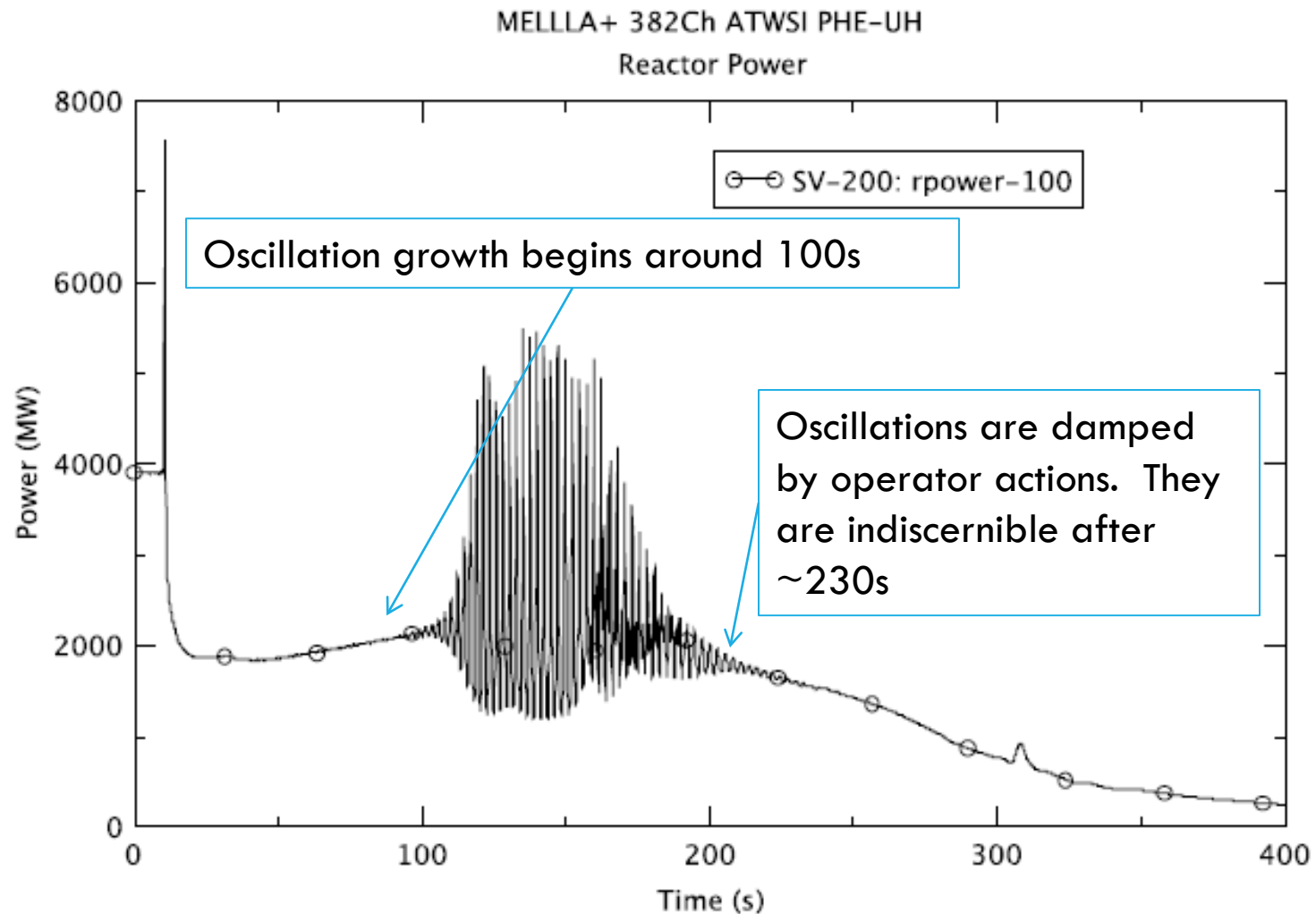
Representative Case:

- 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

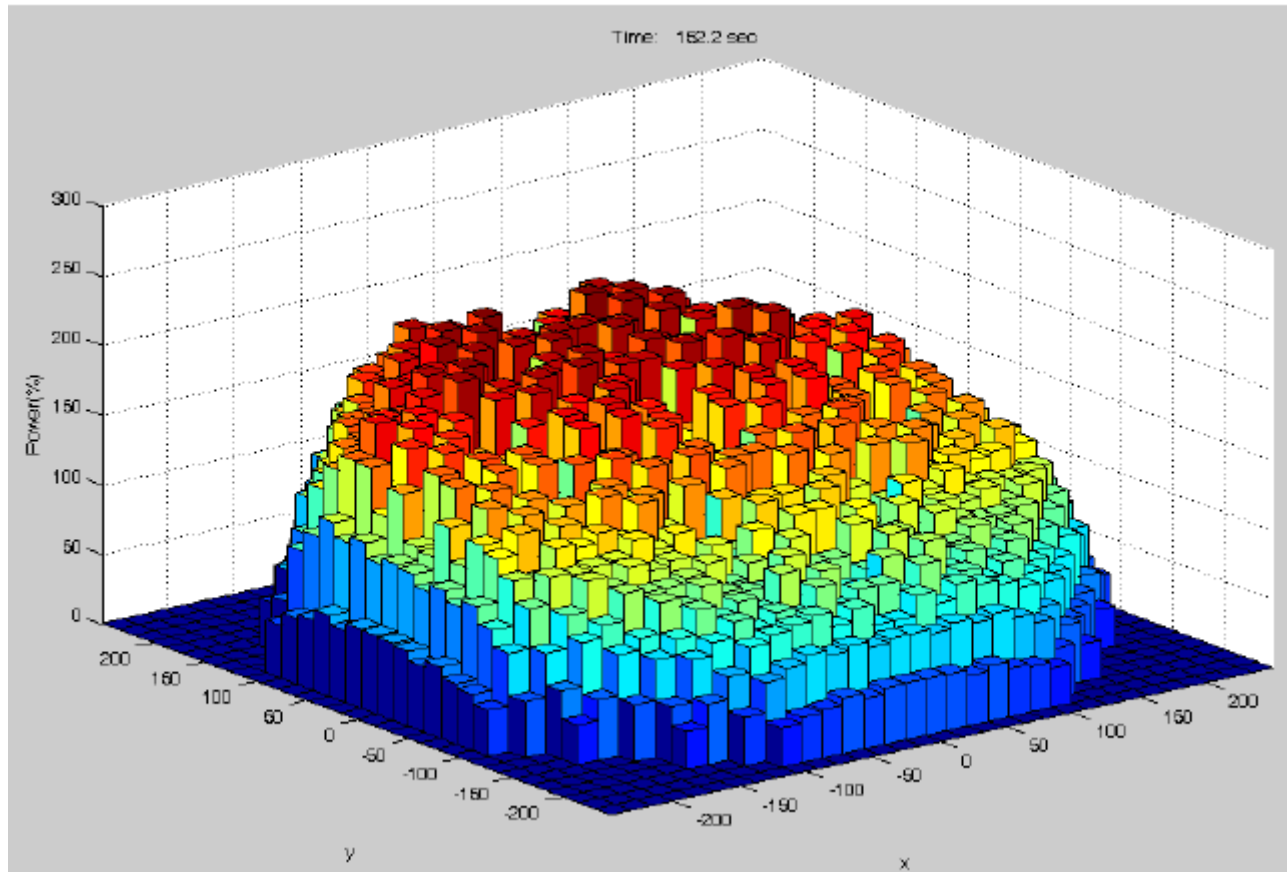
PHE ATWS-I CASE — SEQUENCE OF EVENTS

| Time (s) | Event |
|----------|--|
| 0.0 | <ul style="list-style-type: none"> Null transient simulation starts. |
| 10.0 | <ul style="list-style-type: none"> 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 | <ul style="list-style-type: none"> TSV closes completely and starts opening again to simulate 100% turbine bypass. |
| 11.1 | <ul style="list-style-type: none"> TSV (bypass) completes opening. |
| ~11.4 | <ul style="list-style-type: none"> Steam flow starts decreasing. |
| ~12.3 | <ul style="list-style-type: none"> Feedwater flow starts decreasing. |
| ~95 | <ul style="list-style-type: none"> Power oscillation (instability) starts. |
| 120 | <ul style="list-style-type: none"> Water level reduction (WLR) is initiated by reducing the normal water level control system setpoint linearly to TAF over 180 s. |
| 130 | <ul style="list-style-type: none"> Boron injection is initiated and linearly ramped to full flow at 190 s. |
| ~144 | <ul style="list-style-type: none"> Bi-modal oscillation of the core power is initiated. |
| ~160 | <ul style="list-style-type: none"> Boron starts accumulating in the core. |
| ~163 | <ul style="list-style-type: none"> Downcomer water level begins decreasing. Peak cladding temperature of ~1700 K occurs. |
| ~240 | <ul style="list-style-type: none"> Power oscillation ends. |
| 400 | <ul style="list-style-type: none"> Simulation ends. |

TRANSIENT REACTOR POWER



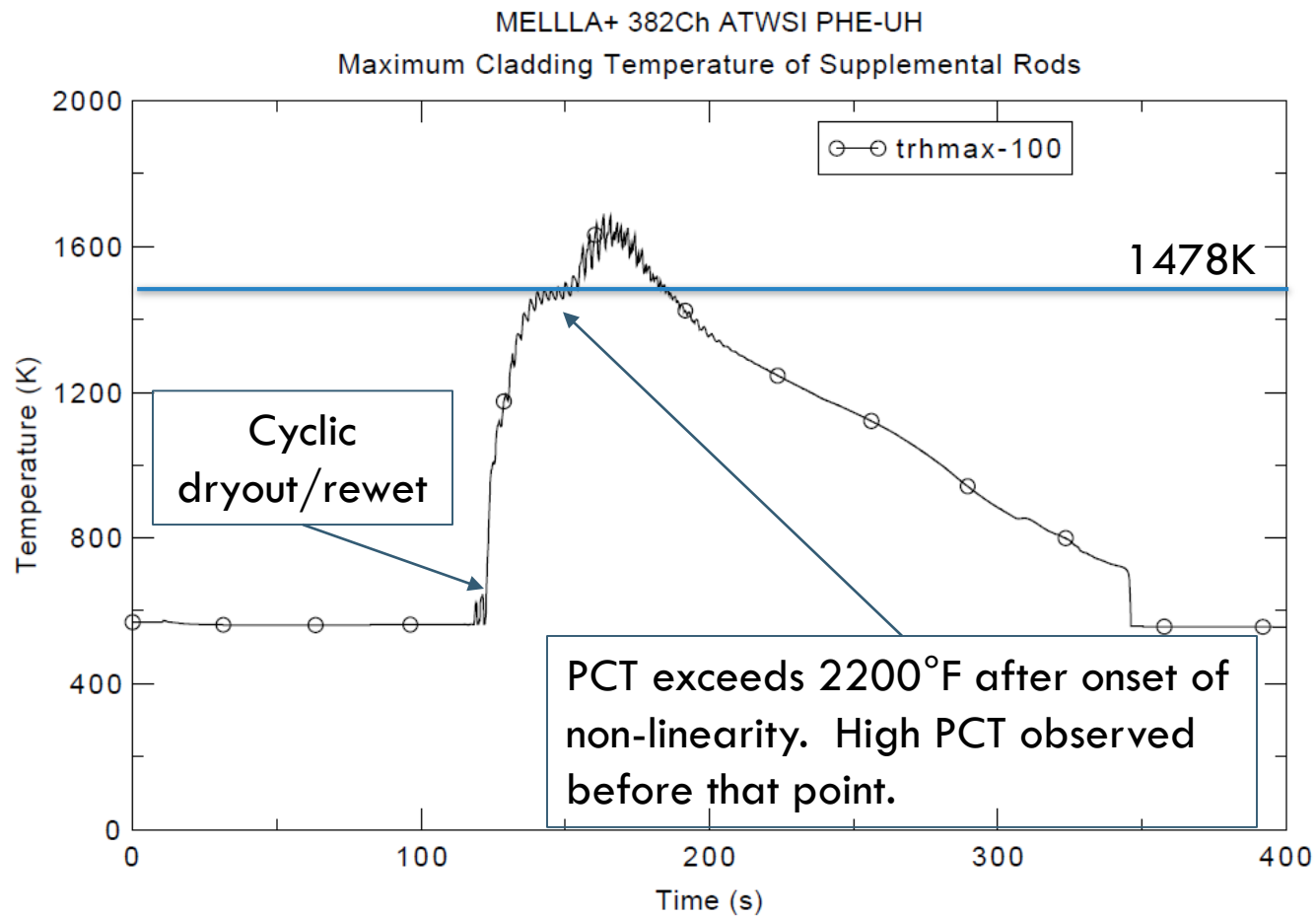
BI-MODAL OSCILLATIONS



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 MELLRA+ 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.