AREVA

Simple Alternatives

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> Why?

- For 10 years we have struggled with research and analysis to set new Reactivity Insertion Accident (RIA) criteria
- The approach selected is highly involved, expensive, and time consuming
- Herein we suggest simpler approaches to consider that remain based on the science and properties involved
- These alternatives may not be suitable for the final criteria but can help guide us to a reasonable interim that is not overly deleterious to plant operation or safety

> What?

- Operational and safety concerns
  - Restrictions on fuel cycle designs
    - Cycle efficiency
    - Possible increase in core leakage and fluence on vessel
- Alternate development of high burnup failure threshold
- Bases for separation of failure and coolability

Operational Impacts

> Ejected Rod Limit Impact on Current Fuel Designs

- Certain PWRs tend to be limited by the ejected rod limits established by the record of analysis in terms of ejected worth and initial peaking.
- These plants tend to be cores with a heavy lead bank.
- Of the last ten operating cycles of two W 193 FA plants five of the cycles were within 6% of the design limit on ejected rod worth.

Core	EOC HZP Ejected Rod Worth, pcm	FSAR EOC HZP Ejected Rod Worth Limit, pcm	% Diff
Unit A Cycle 11	910*	910	0.0
Cycle 12	907	910	-0.3
Cycle 13	844	910	-7.3
Cycle 14	858	910	-5.7
Cycle 15	805	910	-11.5
Unit B Cycle 11	725	910	-20.3
Cycle 12	868	910	-4.6
Cycle 13	794	910	-12.7
Cycle 14	864	910	-5.1
Cycle 15**	766	910	-15.8

* Operation restrictions were required to maintain below 910 pcm.

**Not in operation, in design phase

Current Fuel Cycle Design

- 910 pcm corresponds to about a $2 rod ejection
- Currently, loading pattern is affected in these designs by the proximity of the limit.
- To meet the limit the shuffle pattern was changed to reduce the nominal peaking around the worst ejected rod location.
  - This either requires fresh fuel to be replaced by once burned fuel or once burned fuel replaced by fuel a higher burnups.
  - This in turn causes higher peaks elsewhere and results in a less than optimal fuel utilization.
- A $2 ejected rod corresponds to a peak delta enthalpy of ~90 cal/g.
- A neighboring assembly to the ejected rod has a delta peak enthalpy of ~65 cal/g and has a peak pin burnup of ~52GWD/MTU.
- Our customer has requested higher limits for this core to reduce the impact on fuel cycle designs.
- RIL 0401 proposed limits would impact these plants.

Interim RIA Limits

- If the RIA coolability limits are excessively conservative, then all the below conditions can occur with no safety value added.
  - Cycle specific 3-D kinetics calculations or artificially conservative boundary conditions to show design is acceptable are needed.
  - The changes required to meet the limit could require a total change in the loading scheme. Significant changes in the loading scheme can adversely affect:
    - Cycle length
    - Fuel economics
    - OPDT F(ΔI), AFD, and rod insertion operational envelopes
    - Vessel fluence
  - Additional risk may occur for emergency fuel redesigns for removing failed fuel or damaged assemblies.
    - Easy fix may not be acceptable if taken above the damage limit.
    - Increased time to redesign extends outage.
    - To preclude the coolability from being an issue, more conservatisms and allowances will be added which further reduces the effective limit and further impacts the base design.

Operation Summary

- RIL 0401 proposed limits will adversely affect some operating plants.
  - The lower the failure threshold and coolability limit the more extensive the fuel cycle design verification process becomes.
  - Fuel cycle economics and other safety parameters such as peaking and fluence may be affected.
- Coolability limits that are the same as the failure threshold can add additional risk during outages.
- There is little or no benefit of having excessive conservatisms on the RIA interim limits when compared to operational impacts.

Simpler Approach to the Failure Limit

Using irradiated tensile properties

> Why?

- To provide a sanity test for expected failure threshold at high burnup,
- To suggest the amount of retained margin in a proposed threshold, or
- To indicate a potential basis for an interim threshold.

> How?

- Evaluate the gap or soft pellet dimension of high burnup fuel at HZP
- Use the measured elasticity and plasticity of high burnup cladding to determine the pellet expansion before cladding failure
- Combine to set a maximum pellet expansion
- Use UO_2 thermal expansion to evaluate the Cal/g required to fail cladding

> What?

- M5 Corrosion and Spallation
  - A substantial number of examinations of irradiated M5 clad fuel pins have been conducted
  - Corrosion levels typically run between 15 and 30 µm up to burnup levels of 70 GWd/mtU
  - No corrosion of over 40 µm has been observed
  - No spallation of the cladding has been observed

> What?

- Evaluation of 60 GWd/mtU Zr-4

Gap between pellet and clad, HZP	23 µm
Elastic expansion of cladding, 270 C	34 µm
Ductile expansion of cladding, 270 C	58 µm
Total pellet expansion without failure	115 µm

- Energy addition required for pellet expansion 94 cal/g
- This result is consistent with RepNa 4 and approximately 30 cal/g above the RIL 0401 proposal

Alternative Approach to Coolability Limit

Based on preserving the energy associated with the potentially degraded portion of the pellet

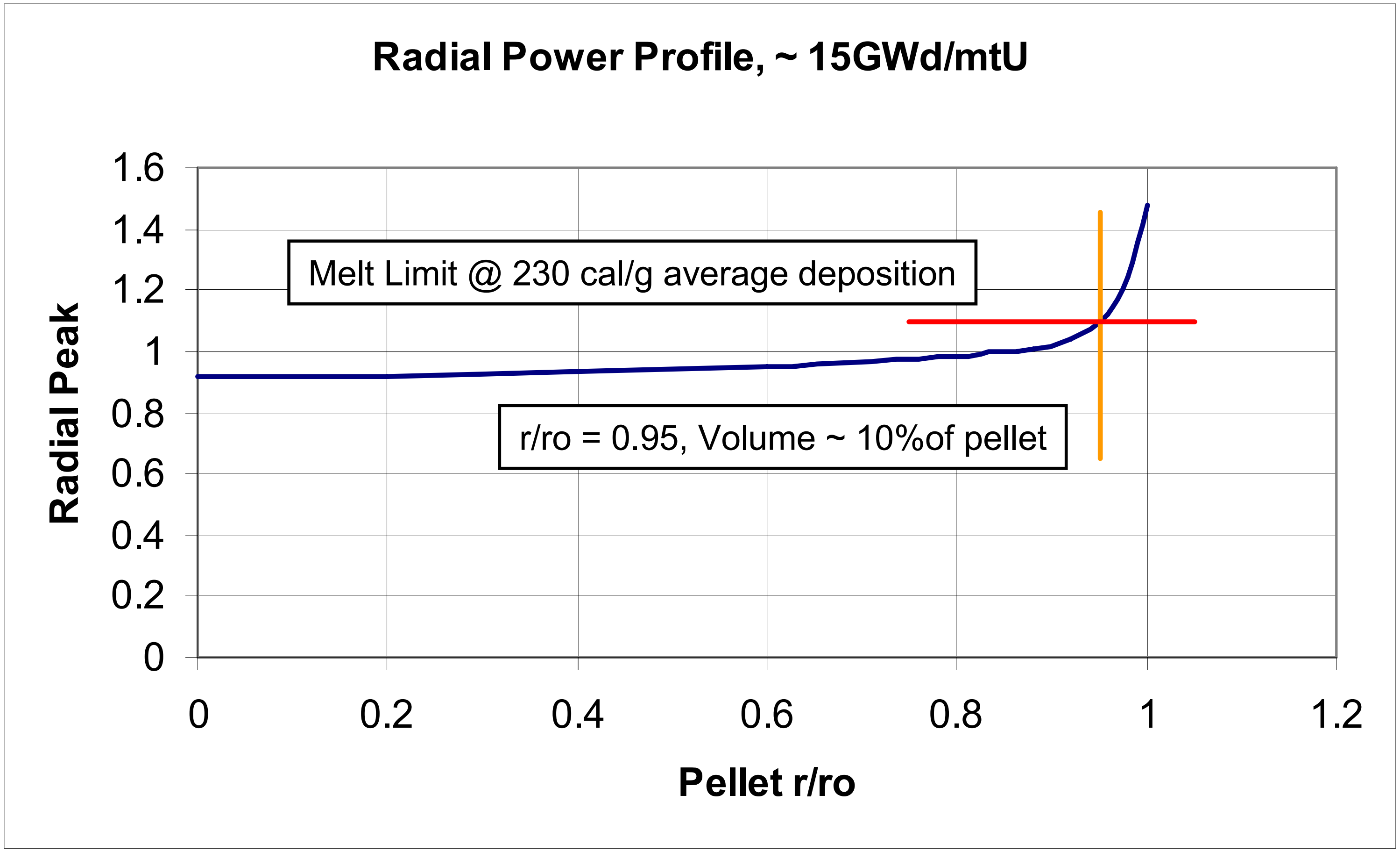
> Why?

- In 2002 industry submitted a topical report proposing a separate coolability limit based on fuel melting
- While AREVA feels this approach is valid, the following simplistic approach to an interim coolability limit builds on known results while incorporating identified burnup dependencies

> How?

- Early testing indicates that an energy deposition of up to 230 cal/g results in clad failure but no fuel dispersion
- Use the portion of fuel that would be exposed to energies capable of melting UO_2 to specify a pellet damage fraction and the associated energy
- Use known pellet alteration mechanisms, Rim Growth, to increase the size of the pellet damage region with burnup
- Set the coolability limit to maintain the energy content of the “damaged region.”

> How?


Radial Power Profile, ~ 15GWd/mtU
Melt Limit @ 230 cal/g average deposition
r/ro = 0.95, Volume ~ 10%of pellet
Radial Peak
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0
0.2
0.4
0.6
0.8
1
1.2
Pellet r/ro

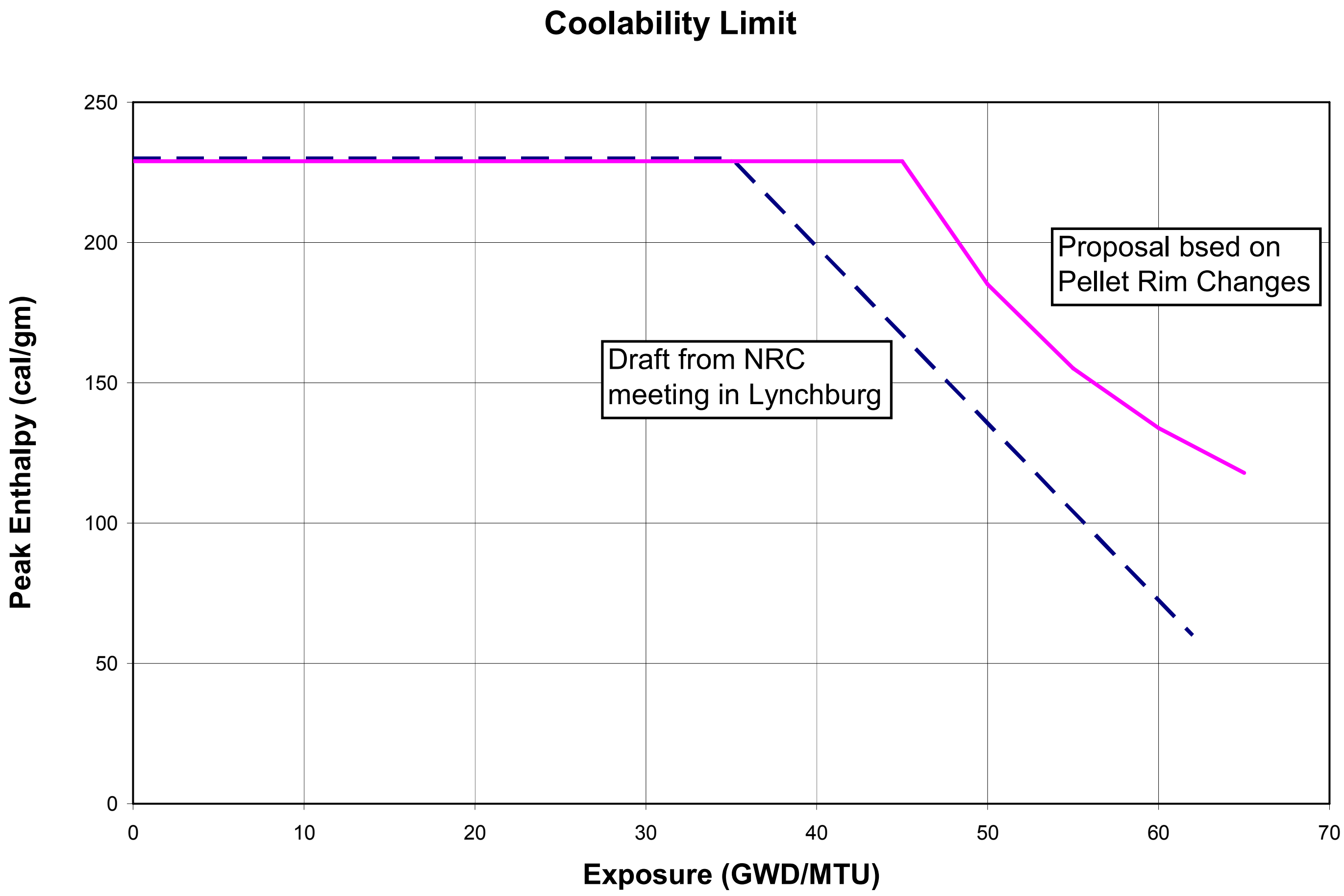
> How?

- Pellet damage fraction before rim formation is approximately 10 %.
- Rim structure becomes significant at 45 GWd/mtU
- Rim growth between 6 and 10 microns/GWd/mtU
- Damaged region

0 to 45 GWd/mtU	10.0 %
50 GWd/mtU	12.5 %
55 GWd/mtU	15.0 %
60 GWd/mtU	17.0 %

- Set the coolability limit to maintain the energy of the "damaged region."

> What?


Coolability Limit
Peak Enthalpy (cal/gm)
250
200
150
100
50
0
0
10
20
30
40
50
60
70
Exposure (GWD/MTU)
Proposal bsed on Pellet Rim Changes
Draft from NRC meeting in Lynchburg

> What?

- The approach is almost intuitive but it:
- Maintains the nature (cal/g limits) of the current criteria,
- Places the interim limits within a comfortable range,
- Response to know physical changes in fuel structure,
- Provides a coolability limit not severely consequential to fuel cycle management