Overall Objectives for Interim REA Threshold Criteria

- REA is a localized event
  - Should not depend on pulse width or on control rod worth
  - Local peak enthalpy and enthalpy increase are appropriate limits

- Separate limits for coolability and cladding failure are appropriate
  - REA is a Condition IV event and should be consistent with other Condition IV events which due not preclude cladding failure and account for any potential failure in the dose consequence

- PWR REA Enthalpy criteria are appropriate for HZP REA

- DNB remains proper basis for at power events

Overall Objectives for Interim REA Threshold Criteria (Cont'd)

- Best estimate oxide thickness is an appropriate parameter for cladding failure threshold in PWRs
  - Parameter already typically evaluated for reload design
  - Can be tracked by PIE exams for changing RCS chemistry and cladding alloys
  - Good surrogate for hydrogen content

- Modern claddings have good behavior even at limiting fuel duty

Westinghouse Efforts

- Contributed to industry efforts
  - Initial 3D estimates for NEI letter on limited impact for commercial reactors in response to concerns with RepNA1 low energy failure
  - Provided data and input into industry efforts
  - Made presentations at WRSM on 3D analysis of core response
  - Conducted hotcell REA simulation testing (expansion due to contraction (EDC)) on irradiated ZIRLO™ to demonstrate cladding capabilities

- Developed and licensed 3D REA methods in response to customer needs
  - Indicated that Westinghouse would use industry limits
  - Temporary limits of 100 cal/gm enthalpy increase

ZIRLO™ REA Simulation
Expansion due to Contraction (EDC) REA Simulation

- Increasing Temperature Increases Strain Capability with Deflection Limited Strain

Specimen Number	1	2	3	4
Local Oxide Thickness, um	17	17	50-60	50-60
Local Hydrogen Content, ppm	125	125	550	550
Test Temperature , °C	25	25	25	340
Failed/Non Failed	Non Failed	Non Failed	Failed	Non Failed
Max Total Hoop Strain, %	> 6.7	>17.3	3.4	10.8

ZIRLO™ Resistance to Oxide Spalling
Summary of Oxide Stability Experience

- Data population of ZIRLO™ fuel rods with high oxide is small due to good corrosion resistance and current operating strategies

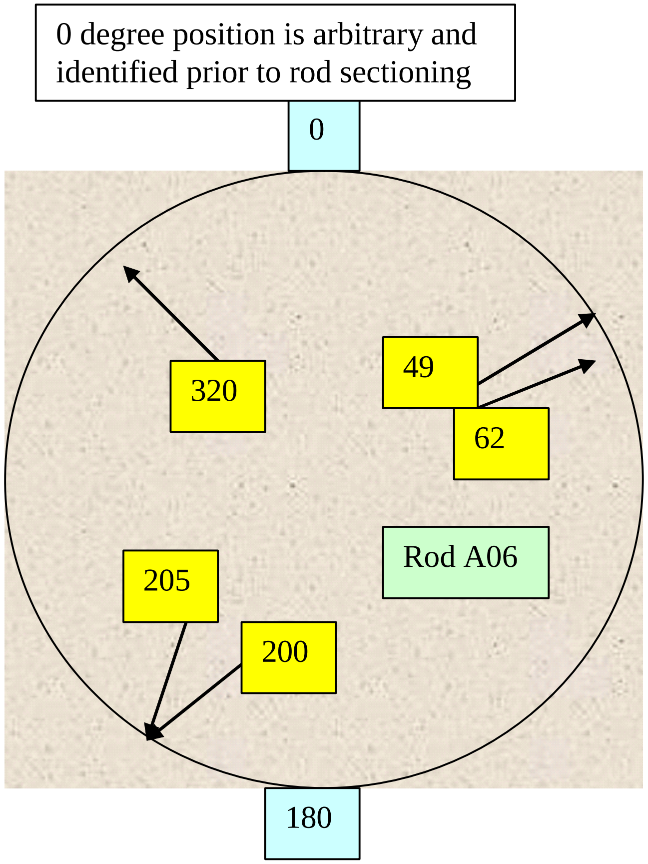
- No spalling in ZIRLO™ observed during reactor operation even in high duty rods with oxide thicknesses above 100 microns

- Oxide data base has 25 ZIRLO™ rods with oxide thickness of 80 microns or more
    - No spalling indications

- Adjacent rods similar powers were visually inspected
    - No spalling observed

- Visual inspection of high burnup rods from Vandellos (CIPO-I rod included) reported that the ZIRLO™ oxide “maintained its integrity in maximum thickness zones” (i.e., No spalling was observed prior to handling)

Observations on Vandellos ZIRLO™ Rods for CIPO-1



- About 70 K BU and 100 um oxide at high duty
- Minor flaking reported at circumferential locations
- Indications are at about 90 degree increments
- Pattern indicates interaction with grids during removal contributed to minor oxide flaking
- No general in reactor spalling
- Neutron radiography confirms uniform cladding performance (i.e., no hydride blisters)

Example of High Duty VC Summer Oxide on ZIRLO™ Rods

- FDI of 850
- Oxide thickness about 100 micron
- No spalling or flaking

ZIRLO™ Oxide is Stable in Reactor

- Oxide database has 25 ZIRLO™ rods with oxide thickness of 80 microns or more
  - No spalling

- ZIRLO™ consistently more resistant to oxide spalling than Zircaloy 4 at the high oxide thickness and high duty applications.

- Flaking or spalling observations with ZIRLO™ have been attributed mainly to post operation rod handling of very high duty fuel

Westinghouse Efforts (Cont'd)

- Efforts to break impasse between RIL0401 letter and Industry Topical
  - 2005 Letter to NRC on RIL0401 letter
  - 2005 ACRS presentation
  - ICAPP 06 paper with interim limits

Physics Aspects of REA Event

- Based on Westinghouse reload design experience, typically the most limiting ejected rod is located near the core periphery and severely impacts a maximum of five assemblies in the vicinity of the rod
- In a high energy, short pulse width REA, the energy shape is top skewed with a narrow peak at high energy, and the limiting deposited energy is over a small axial increment
- With both the radial and axial region limited, overall less than 1% of the fuel mass of the core is within 80% of the peak pellet energy
- The radial and axial skewing becomes more and more accentuated as the ejected rod worth increases
- Thus, the more limiting the transient, the more skewed the local power census curve will become

Physics Aspects (cont.)

- Reactor conditions needed to obtain worst case energy depositions in an REA are very limited
  - Limiting conditions occur near end of cycle with deep control rod bank insertion – very unusual condition, but it must be considered when performing licensing evaluation
  - Reactors spend less than 1% of calendar time at hot zero power (HZP) conditions – much less at EOC where REA is most limiting
  - The ejected rod worth increases with the rod insertion, so the most limiting point is with the rods at the insertion limit

- Thus the conjectured control rod insertion at HZP, needed to achieve the maximum energy deposition calculated, would be allowed under the Technical Specifications, but would require an operator to ignore two separate alarms and is not expected in typical operations
- Thus the limiting conditions are valid for only a fraction of the actual operating cycle

Justification of Two Separate Limits

- The two separate limits were established for different purposes
  - Failure Threshold: Basis for assuming a fuel rod will fail and release fission gases which must be accounted for in the dose calculations
  - Coolability Limit: Basis for assuming that the fuel assembly structure will retain its coolable geometry in accordance with GDC 28 and 10 CFR 50.46 definitions

- RIL0401 or other proposed limits that either collapse the limits into one or establish limits so low that no fuel failure would occur would change this Condition IV event into a Condition II event, which would require it to be analyzed differently

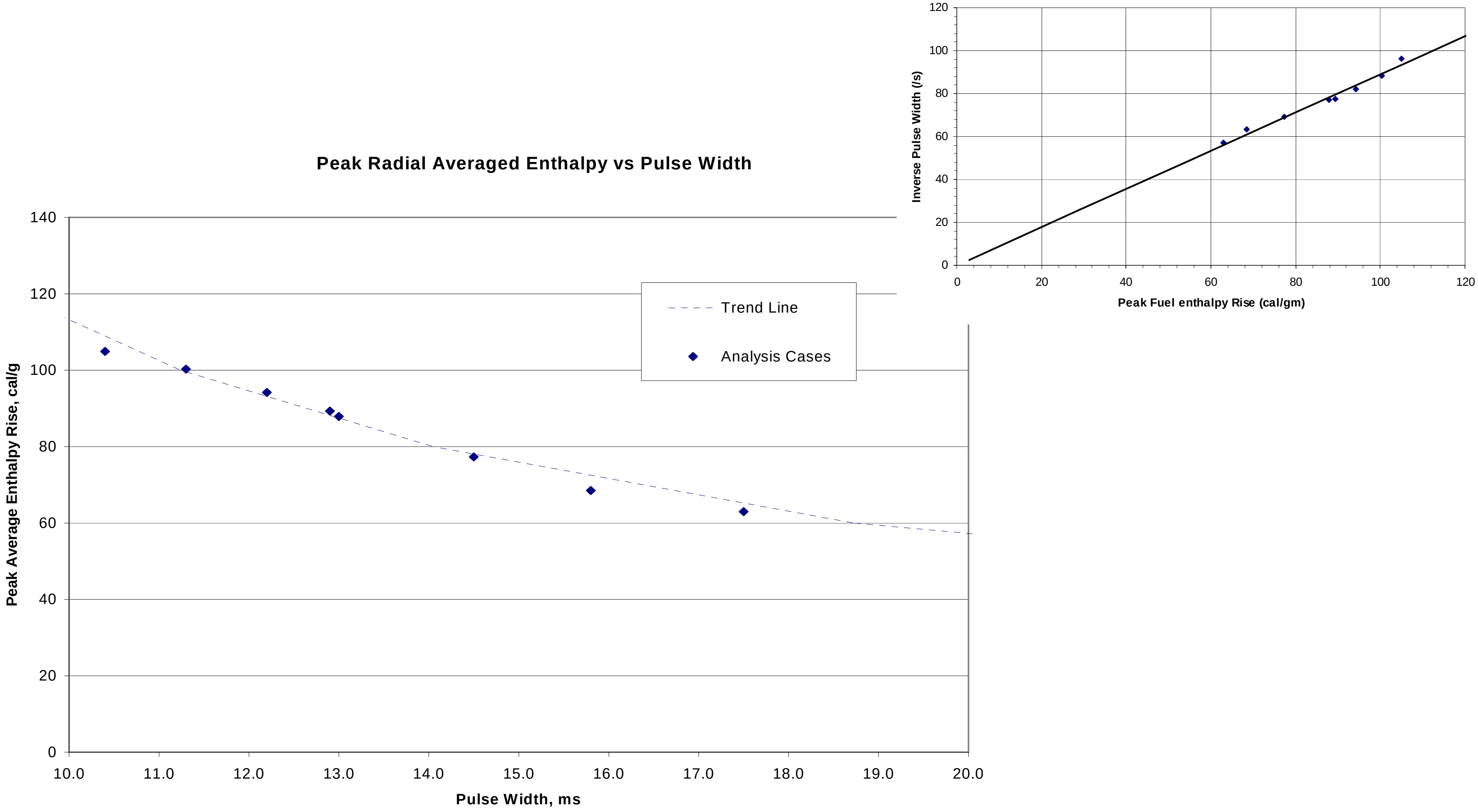
Justification of Coolability Limit

- Justification of the Coolability Limit is based on the following facts:
  - Data supports that any fuel dispersal for failure below a given energy deposition will not result in a large pressure pulse that would jeopardize coolable geometry of the fuel or damage the RCS
    - Hot fuel particles released during experiments go into DNB (i.e., effervescent effect – pressure releases within the capability of the fuel structure to withstand)
    - Behavior is independent of burnup
    - Molten releases will yield large pressure pulses which would damage fuel structures and the RCS – coolability not maintained

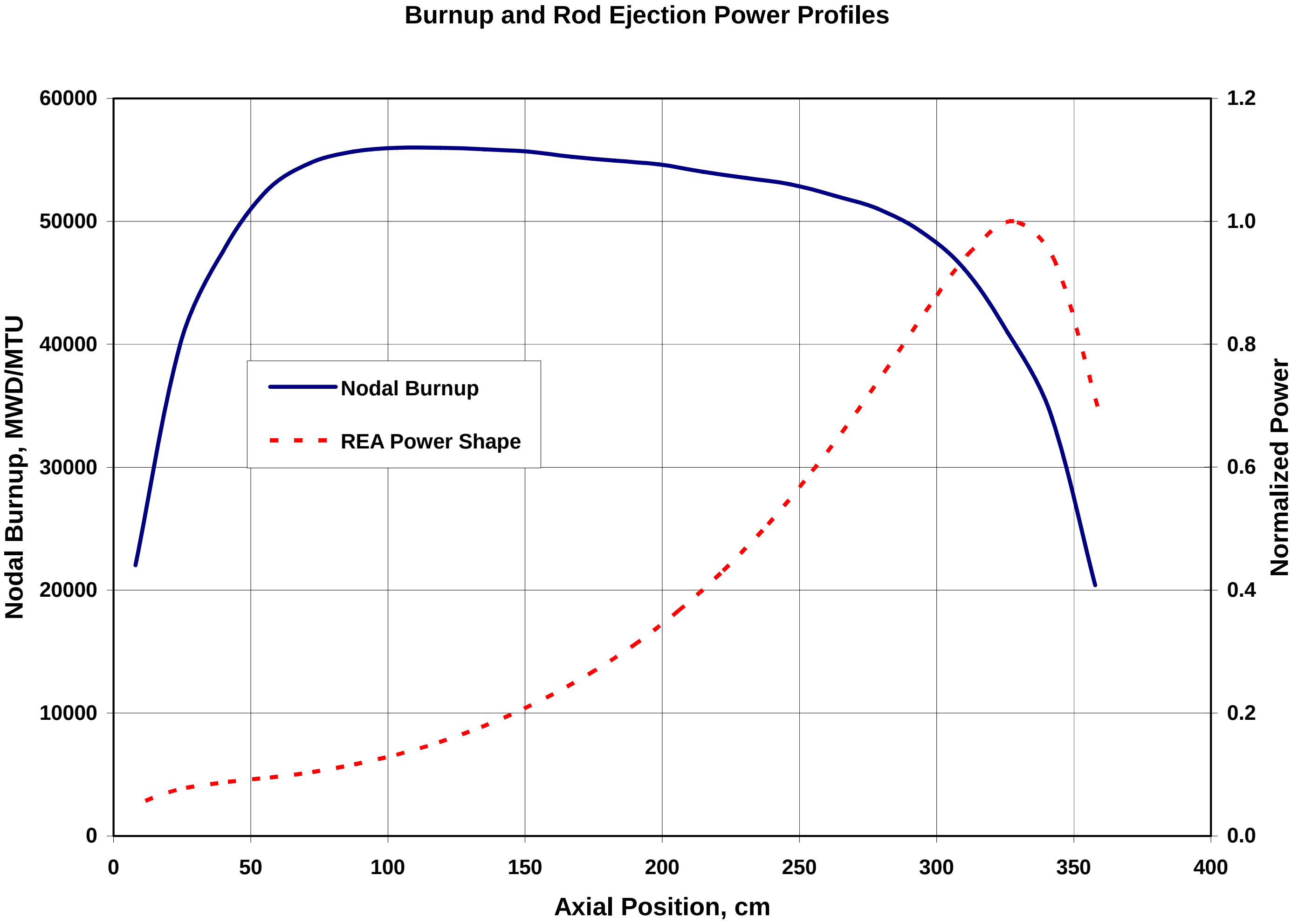
  - Establishing a coolability limit below fuel melt precludes damaging pressure pulses

  - Since fuel melt is a linear behavior out to 92 GWD/MTU, a linear limit can be established that precludes melt at all burnups that would be achievable for current generation fuel designs and reactor designs

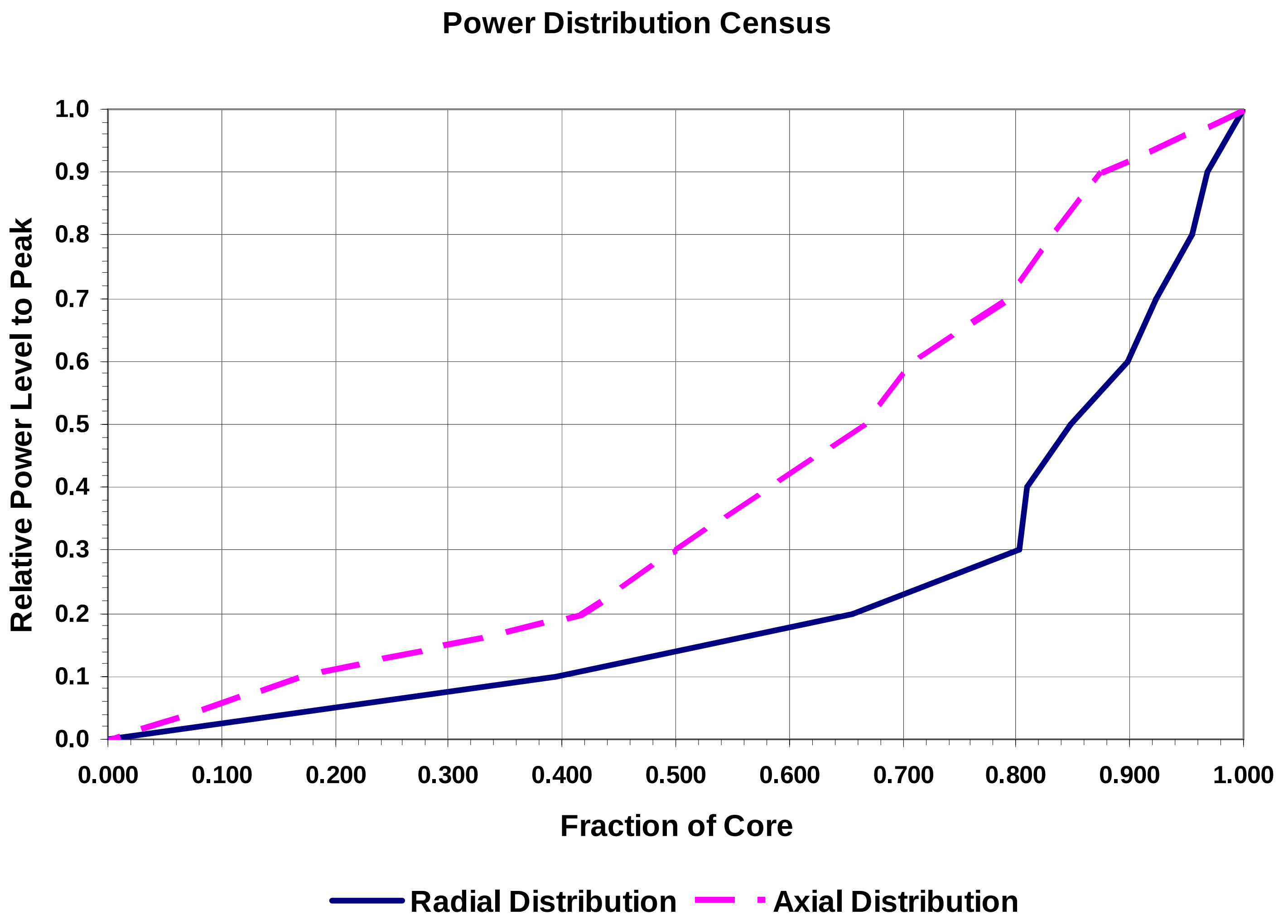
Peak Fuel Enthalpy Increase vs Pulse Width 3D REA Evaluations (Insert: Inverse Pulse Width vs Peak Fuel Enthalpy 3D REA Evaluations)



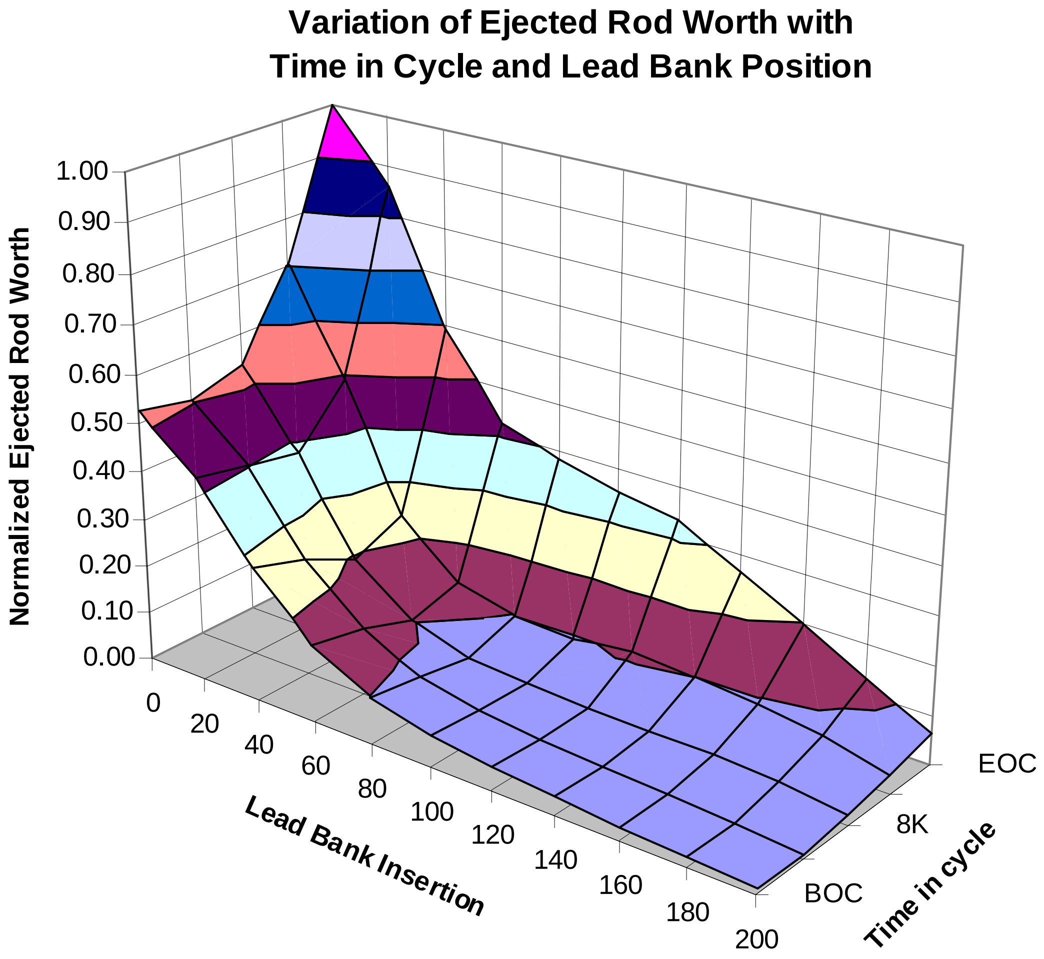
Typical REA Energy Pulse Axial Profile and High Burnup Profile



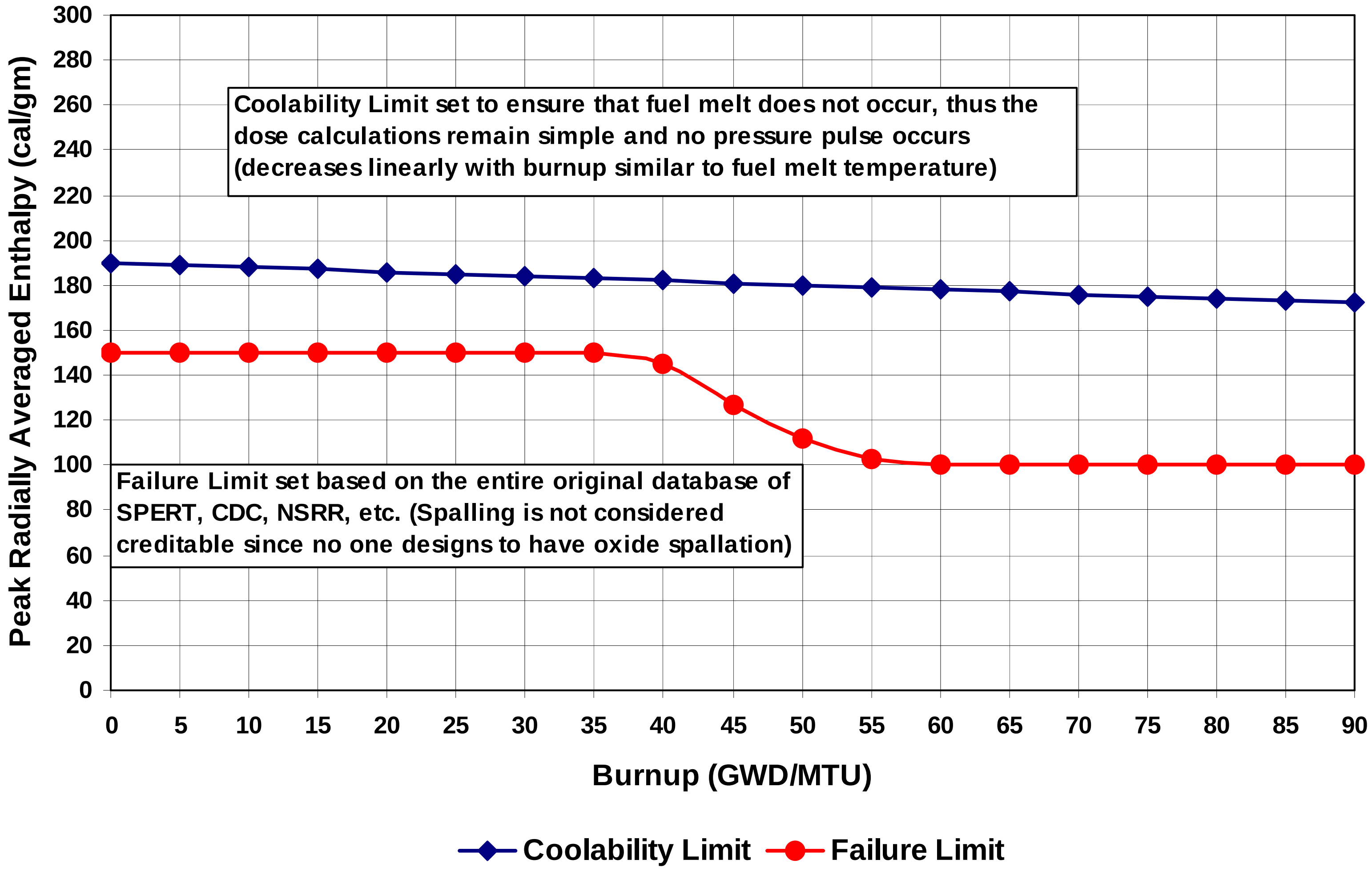
Limiting Rod Ejection Core Power Census



Sensitivity of HZP Ejected Rod Worth to Cycle Depletion/Rod Insertion



Suggested New Limits

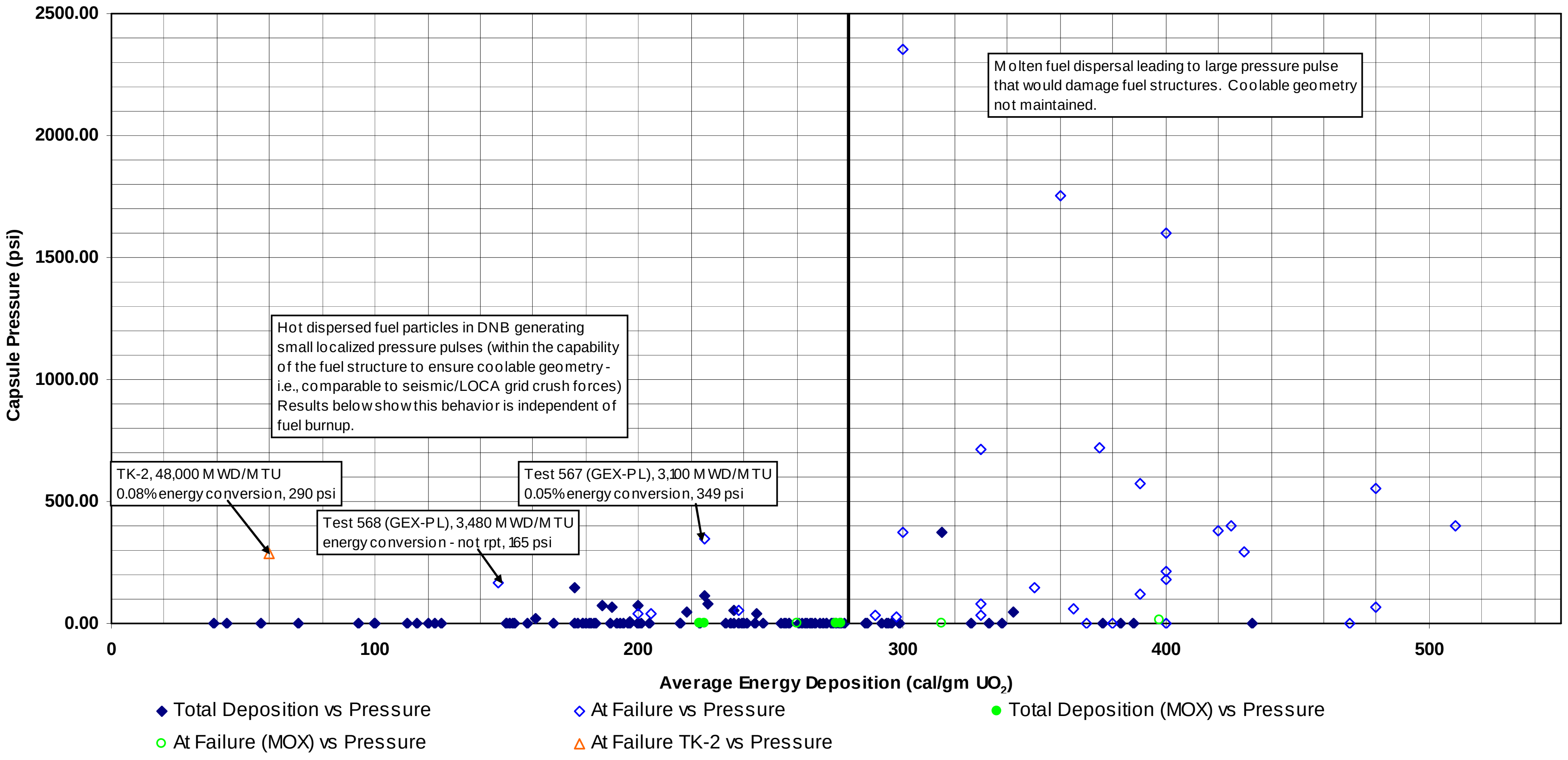


Coolability Limit set to ensure that fuel melt does not occur, thus the dose calculations remain simple and no pressure pulse occurs (decreases linearly with burnup similar to fuel melt temperature)

Failure Limit set based on the entire original database of SPERT, CDC, NSRR, etc. (Spalling is not considered creditable since no one designs to have oxide spallation)

Backup Slide

Pressure Pulse Impacts



Molten fuel dispersal leading to large pressure pulse that would damage fuel structures. Coolable geometry not maintained.

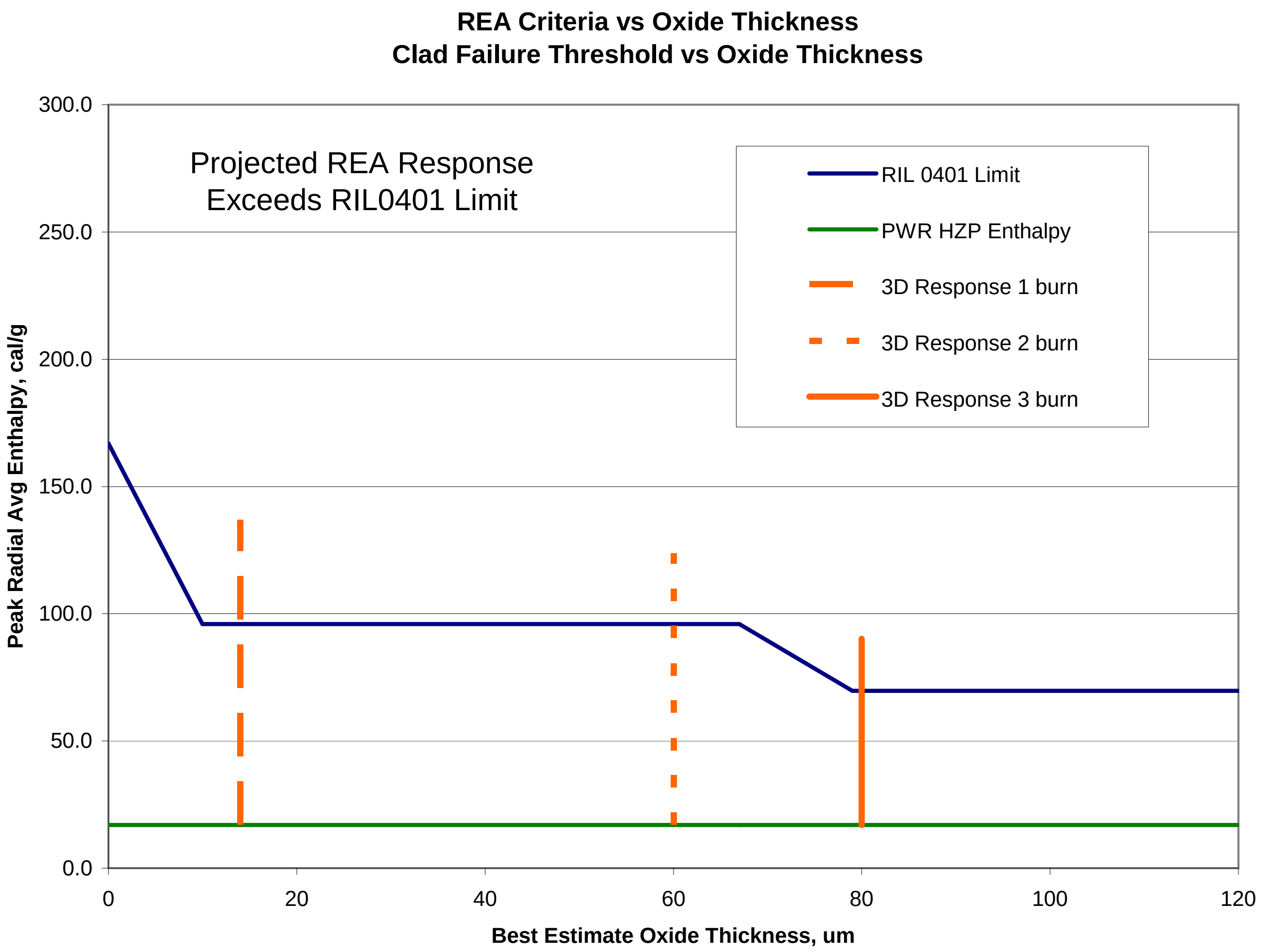
Hot dispersed fuel particles in DNB generating small localized pressure pulses (within the capability of the fuel structure to ensure coolable geometry - i.e., comparable to seismic/LOCA grid crush forces) Results below show this behavior is independent of fuel burnup.

TK-2, 48,000 MWD/MTU
0.08% energy conversion, 290 psi

Test 567 (GEX-PL), 3,100 MWD/MTU
0.05% energy conversion, 349 psi

Test 568 (GEX-PL), 3,480 MWD/MTU
energy conversion - not rpt, 165 psi

Cladding Failure Threshold



Westinghouse