GE Hitachi
Nuclear Energy

BWR Control Rod Drop Accident

Methodology, Application and Regulatory Compliance

Information is Not Proprietary

Unverified Draft intended for Discussion

BWR CRDA Scenario and Assumptions

Scenario

•Control blade becomes decoupled, drive is withdrawn, blade sticks and does not move, later blade falls out to the position of the drive

Conservative Assumptions for the Analyses

•Scenario can happen for any cycle exposure

•Scenario can happen for any temperature from cold to hot standby

•Blade is stuck at the full-in location before it falls

•Blade falls at the terminal velocity

•Blade falls all the way to the position of the drive

•Blade worth adds fully to a core that is already critical

•Blade falls at the worst possible time during the nominal pull sequence

•Clad perforation occurs when the enthalpy rise limit is exceeded

CRDA Application Methodology

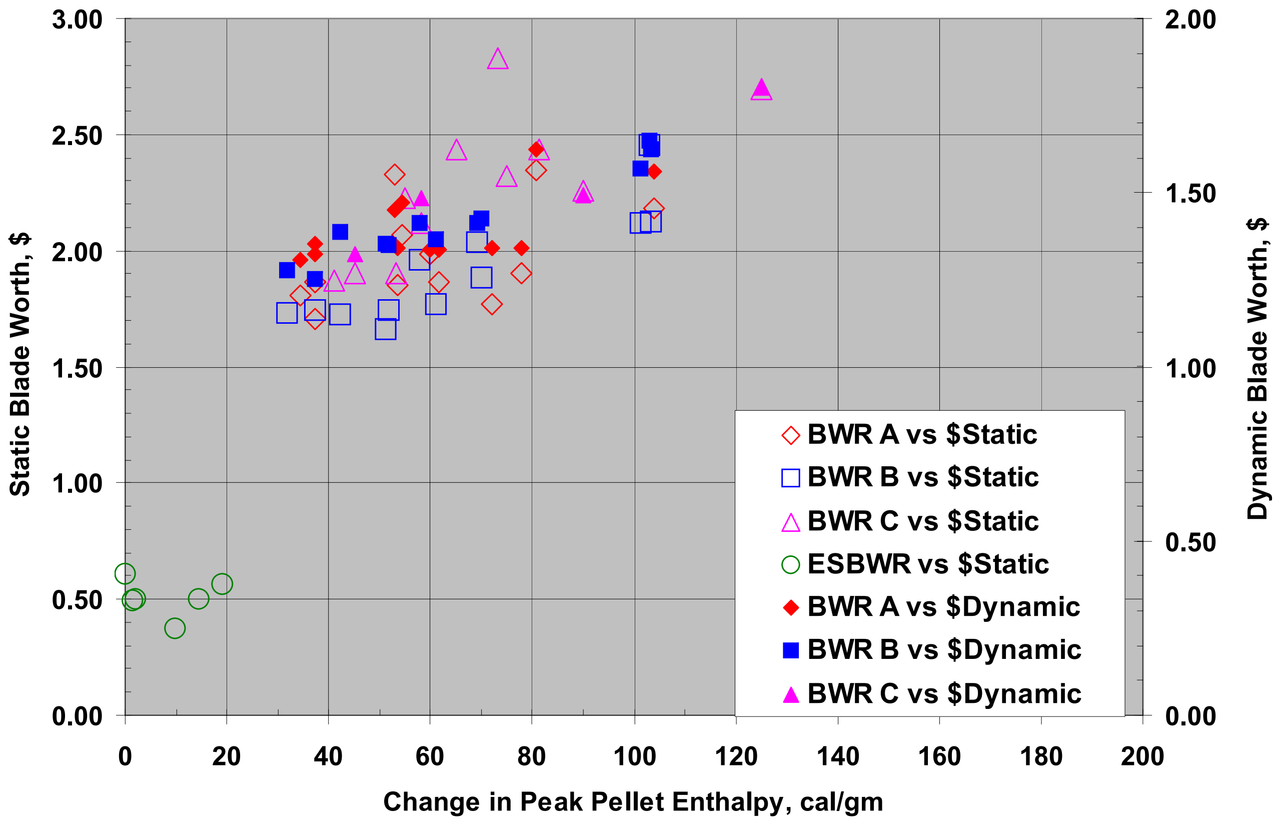
- Reference: Response to ESBWR RAI 4.6-23 S02
- Similar approach could be used for operating BWRs if the new requirements apply. Do they?
- Compliance with GDC 28 in Appendix A of 10 CFR 50 can be ensured by maintaining CRDA reactivity less than that which produces calculated deposited fuel enthalpies below the conservative threshold for deposited fuel enthalpy for which BWR clad failure is presumed (per Appendix B of SRP 4.2, Rev. 3)
- Generic approach independent of core cycle is not likely to be workable because
  - Key input is control blade worth that is cycle specific
  - Consideration of bounding blade worth is too conservative and will be detrimental to core design and plant operation

CRDA Modeling Elements

- Additional basic modeling
  - Hydride correlation to nodal exposure can be used if radial hydride distribution can be neglected, otherwise the cost and time for development and qualification increases dramatically.
- Additional model qualification
  - CRDA data for commercial BWRs does not exist
  - Data from experimental reactor tests is not representative
- Additional modeling elements required following clad perforation are problematic for a number of reasons.
  - The bulk of the experimental data shows little or no change in rod geometries for deposited energies below 230 cal/gm.
  - The mechanics for postulated fuel dispersal following clad rupture and the modeling of subsequent fuel relocation will require many assumptions that are difficult to verify using the current test data which rarely shows any fuel dispersal.
  - Modeling of consequential effects of a pressure pulse will be difficult. Even the best CFD models grossly over estimate the thermal to mechanical energy conversion factors and fail to match the limited test data for pressure propagation in geometries that are much simpler than those for a reactor core.

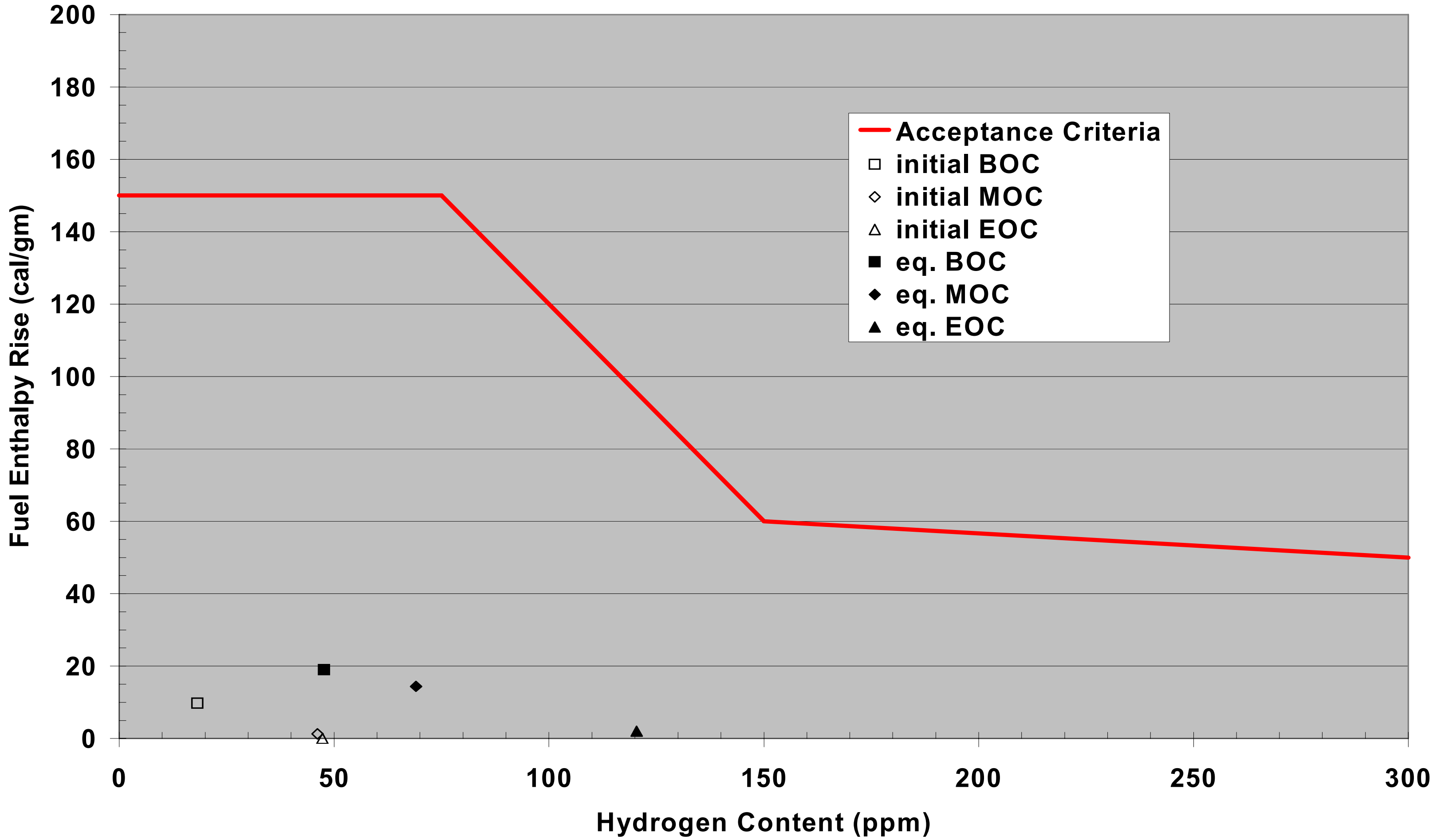
CRDA Application Methodology

A conservative screening model that characterizes change in peak pellet enthalpy as a function of static control blade worth could help to reduce the burden of performing cycle-specific compliance checks



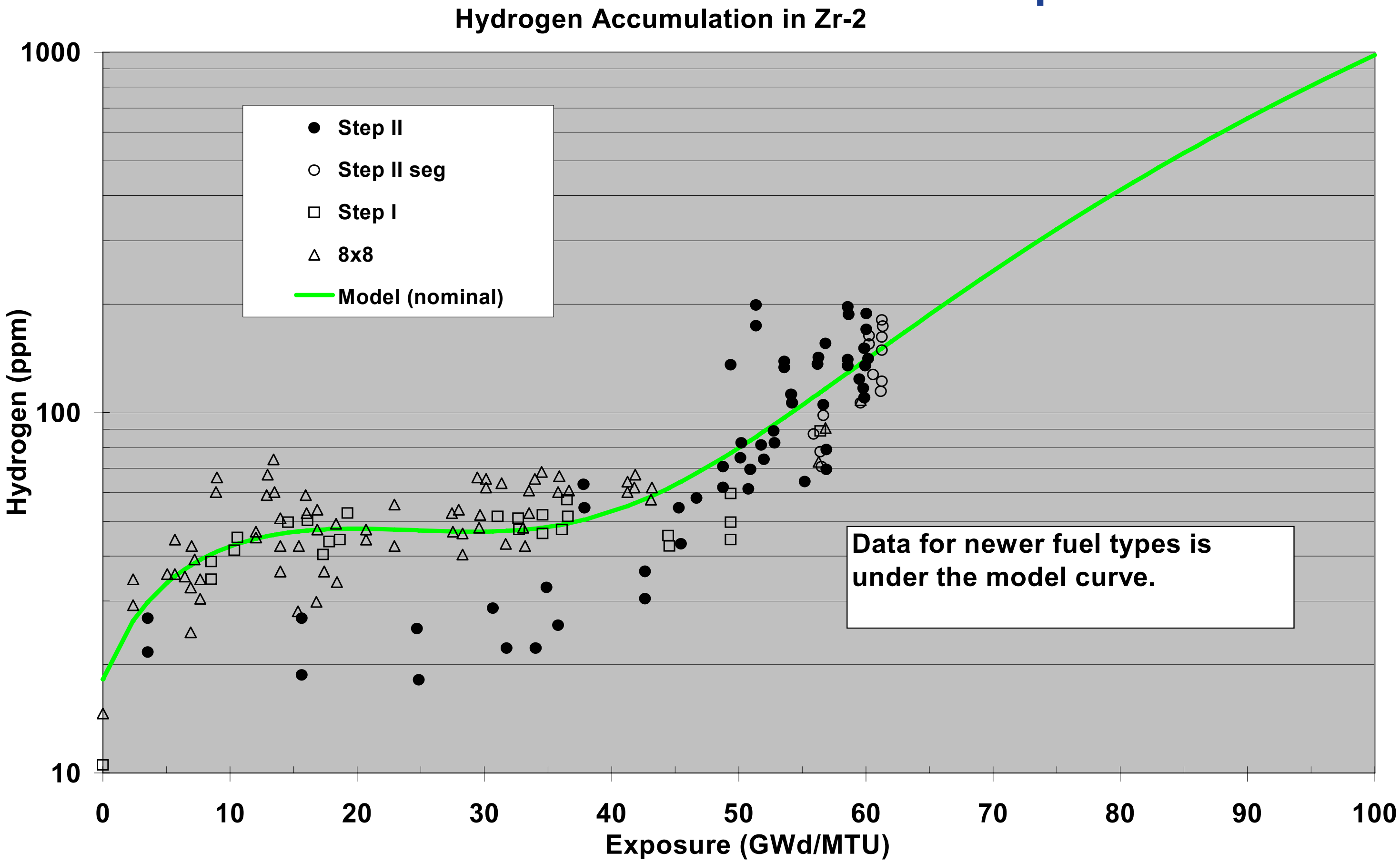
CRDA Application Methodology

BWR Acceptance Criteria in terms of Hydrogen



CRDA Application Methodology

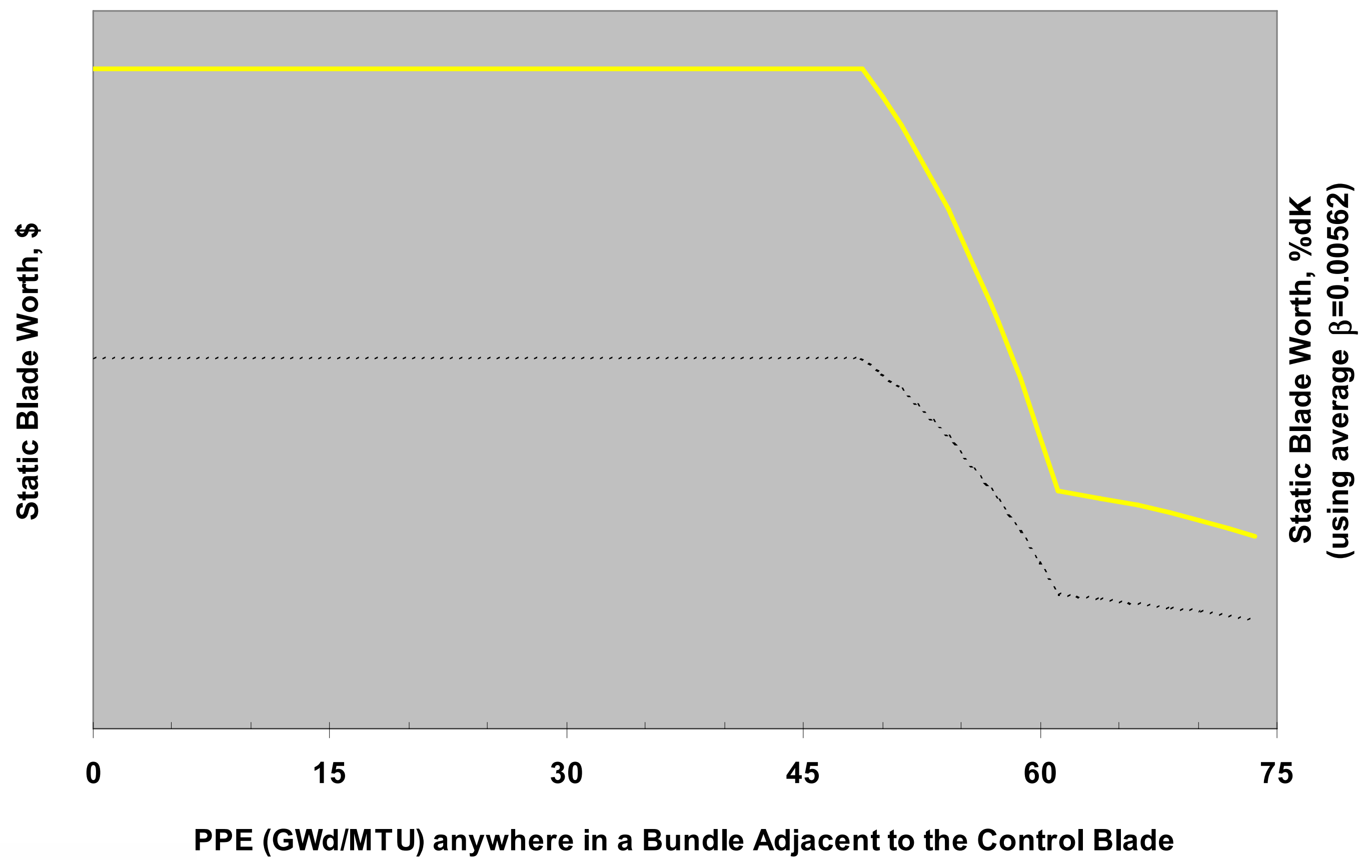
Apply Hydrogen vs Exposure to recast Acceptance Criteria in terms of Peak Pellet Exposure



CRDA Application Methodology

Use screening model to recast Acceptance Criteria into a static blade worth criteria versus peak pellet exposure.

Maximum Acceptable CRDA Blade Worth vs. Peak Pellet Exposure



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CRDA Application Methodology

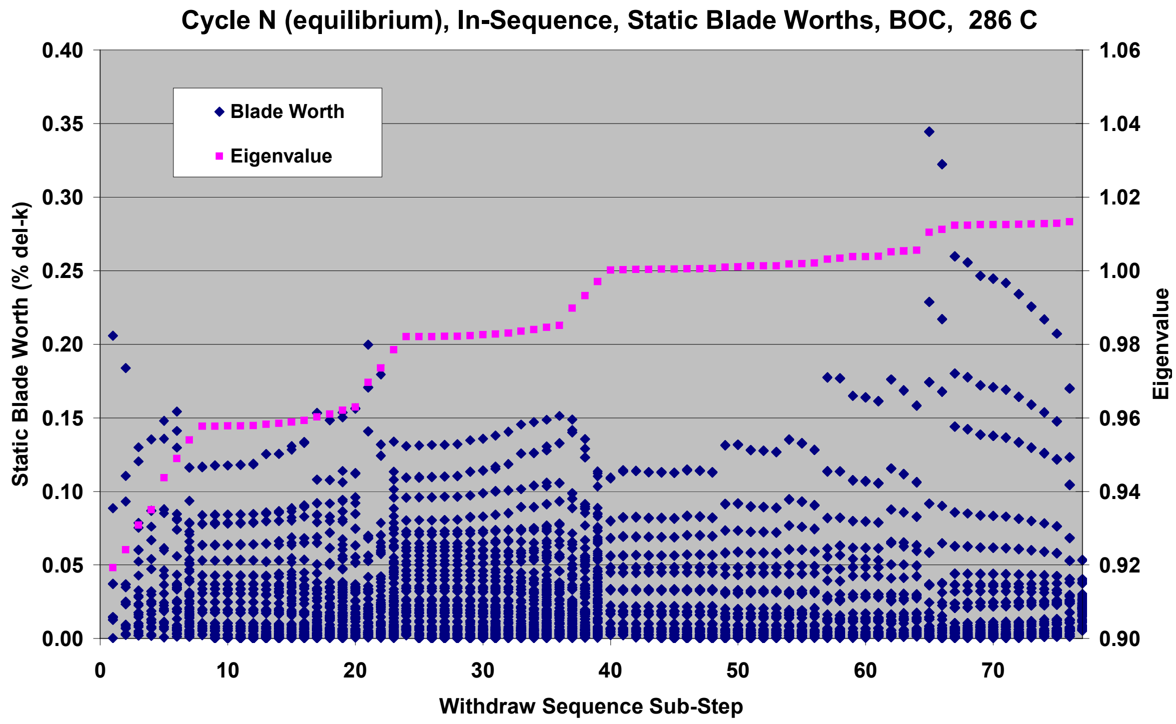
Implementation of a tiered approach can reduce the overall effort to show cycle-specific compliance but it will still require new development and NRC review and approval

1. Exhaustively evaluate all static blade worths for a projected blade-pull sequence for different temperature conditions and different cycle exposures and compare to the see if any are above the maximum blade worth allowed by the screen criteria.
2. For any exceptions to (1), use core simulator to perform conservative adiabatic calculations and compare the calculated enthalpy rises directly to the SRP 4.2 (Rev. 3) Appendix B threshold for presumed cladding failure.
3. For any exceptions to (2), perform best-estimate coupled neutronic/hydraulic calculations to prove enthalpy rises are below the presumed cladding failure threshold.

CRDA Application Methodology

An example of the exhaustive blade worth assessment that was performed for the ESBWR

- Both initial and equilibrium cores
- 4 temperatures each: 80, 100, 160, 286 C
- 3 cycle exposures each: BOC, MOC, EOC
- 10,644 evaluations for each of 12 conditions per core



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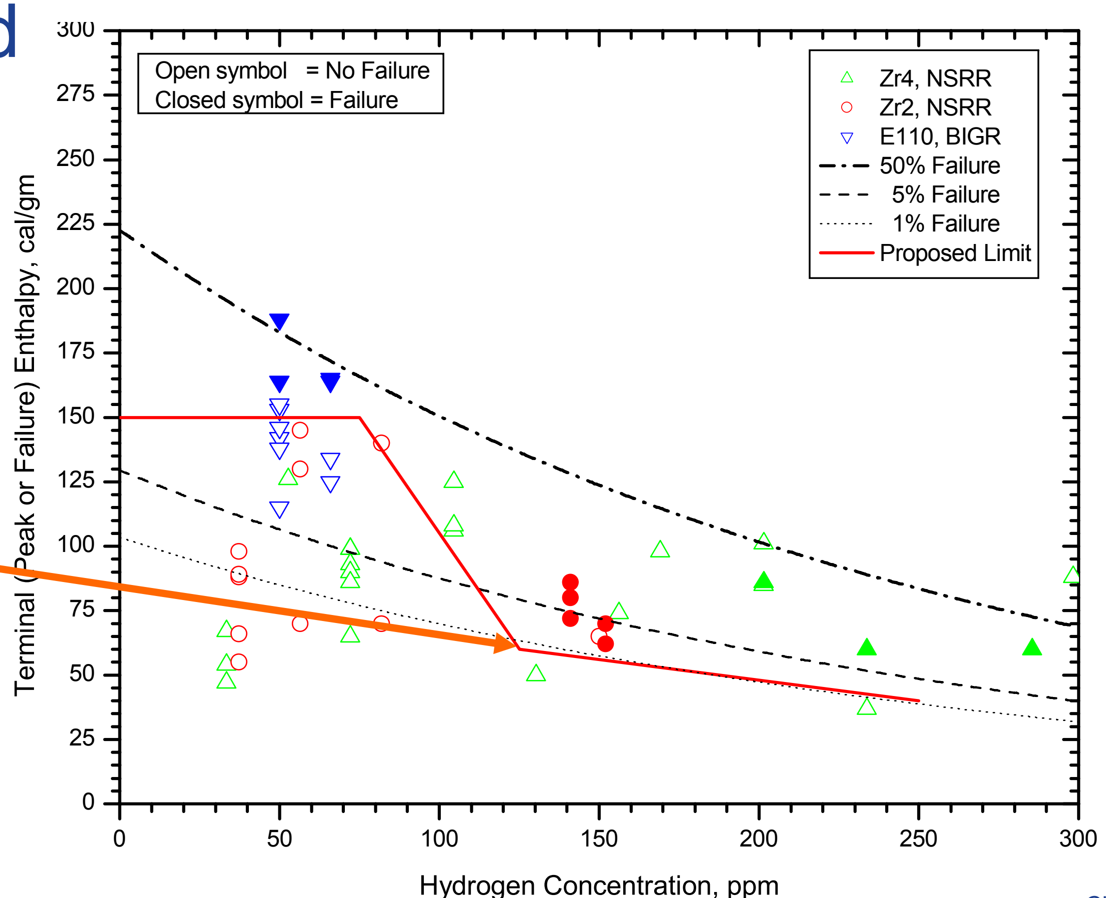
Interim Coolability Criteria (cont.)

Interim criteria requires that all 4 coolablity criteria be met if the lower bound clad failure limit has been exceeded

Lower bound Failure Limit **(1% failure probability)**



Interim Coolability Criteria

Interim Criteria (Appendix 4B of SRP 4.2)

1. Peak radial average fuel enthalpy must remain below 230 cal/g.
2. Peak fuel temperature (pellet periphery?) must remain below incipient fuel melting

GEH/GNF support implementation of these two criteria

- Current methods explicitly address burnup effects on pellet
  - Radial power distribution
  - Thermal conductivity
  - Fuel melting temperature
- Compliance demonstration for criteria 1 and 2 is straight forward but it still requires an exhaustive evaluation for the possible control blade worths; however, this effort is already necessary to show compliance with the lower bound cladding failure threshold.

Interim Coolability Criteria (cont.)

Interim Criteria (Appendix 4B of SRP 4.2)

3. Mechanical energy generated as a result of non-molten fuel-to-coolant interaction and fuel rod burst must be addressed with respect to reactor pressure boundary, reactor internals, and fuel assembly structural integrity.
4. No loss of coolable geometry due to fuel pellet and cladding fragmentation and dispersal and fuel rod ballooning.

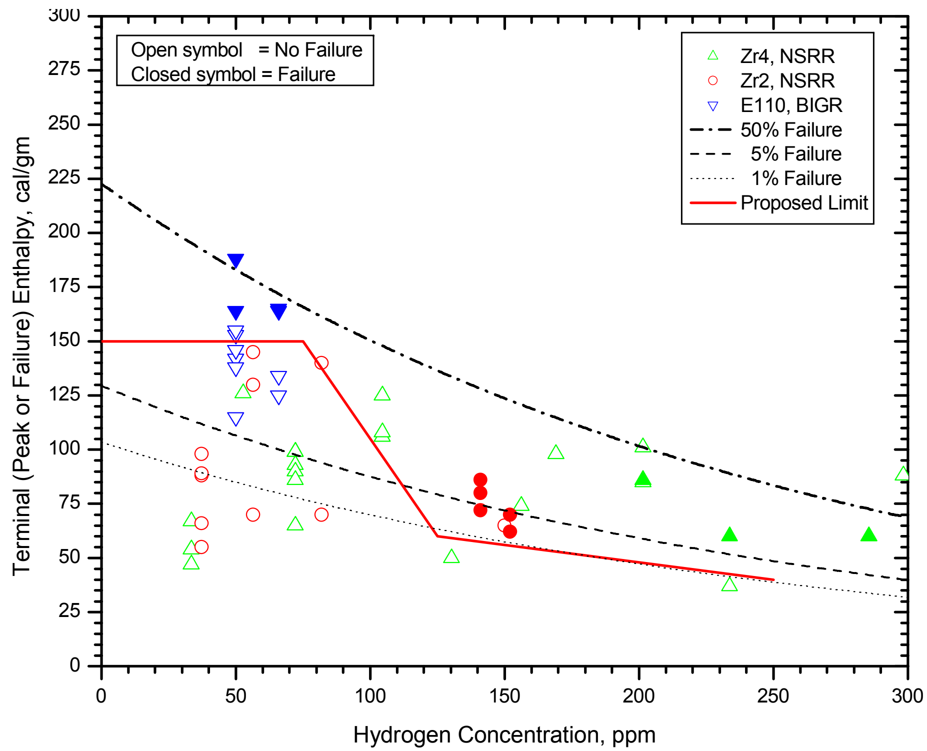
GEH/GNF positions (criteria 3 & 4)

Difficult to demonstrate compliance - No specific guidelines. Costs and schedule estimates are uncertain without better definition of what will be acceptable.

- Criterion 3
  - Mechanistic models are inadequate. New models would have to be developed, reviewed and approved unless use of existing simplistic correlations was allowed.
- Criterion 4
  - Key factors that influence the amount of dispersal have not been well characterized so conservative assumptions will be required.
  - Model development, validation and qualification will be difficult since most of the data show no significant change in rod geometry and little or no fuel dispersal for energy depositions less than 230 cal/gm.

GEH/GNF Proposed Simplistic Compliance Approach (1 of 2)

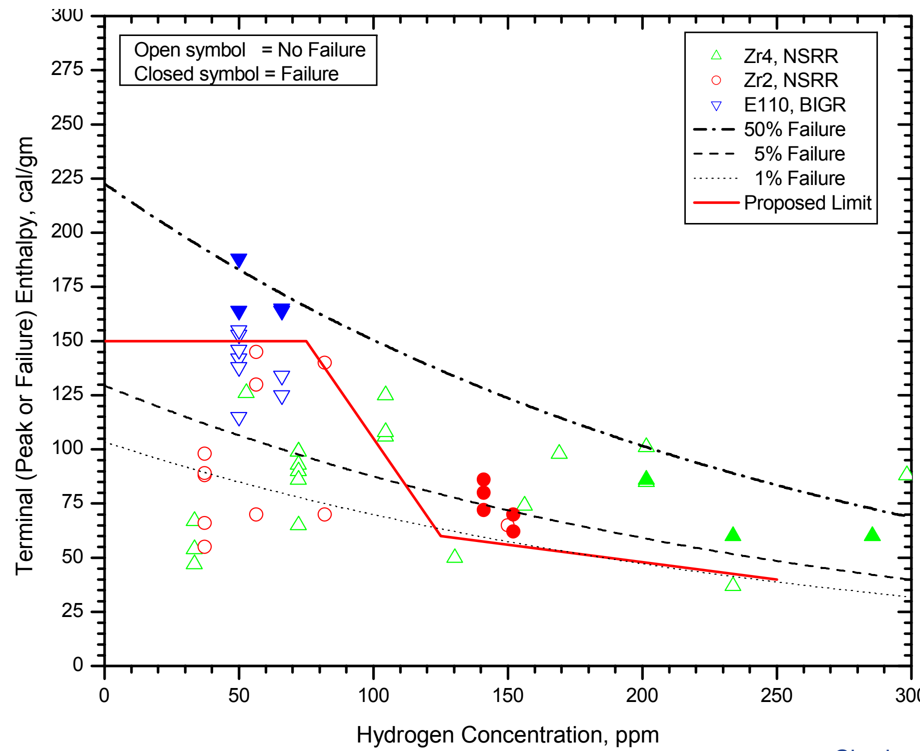
1. Address the radiological consequences only after exceeding the lower bound failure limit.
2. Always show compliance with interim criteria [1] radial averaged peak pellet enthalpy <230 cal/gm and [2] no periphery pellet melting.
3. Consider simple ways to address interim criteria [3] and [4] or eliminate them.



GEH/GNF Proposed Simplistic Compliance Approach (2 of 2)

Some possible ways to address interim criteria 3 and 4

- Generically prove redundancy with criteria 1 and 2 by showing that all cases with less than <230 cal/gm and no peripheral pellet melting also satisfy criteria 3 and 4.
- Develop and defend a generic curve that establishes the cal/gm limit versus exposure below which criteria 3 and 4 are always met
- Address criteria 3 and 4 only when clad failure probability exceeds a specified probability



CRDA Application Methodology
Cost Estimates vs. Safety Benefit

- Compliance will be demonstrated. How much will it cost versus the safety benefit that will be obtained?
  - Screening criteria for no clad perforation is met (relatively low total cost)
  - Adiabatic calculations required (medium cost)
  - Best estimate (3D kinetics/thermal-hydraulics) calculations required (high cost)
  - Clad failure limit exceeded thus invoking criteria 3 and 4 and the potential need for mechanistic models (very high cost)
- Implementation of the reduced clad failure limit together with coolability criteria 1 and 2 provide the most safety benefit relative to the total cost to implement.
- In their current form, criteria 3 and 4 greatly increase cost and cost uncertainty but essentially provide no incremental improvement in safety.

CRDA Application Methodology
Time Estimates & Competing Resources

•Compliance will be demonstrated. How long will it take and how will this divert limited resources from addressing real fuel failures versus possible fuel failures from a postulated accident?

Estimate of Implementation Time Frames

• GEH/GNF Methodology Development	2 years
• NRC Review and Approval of Methodology	1-2 years
• Analysis of US fleet	1-2 years
• NRC applications review for licensees submitting re-evaluations to show compliance	1-2 years

There is a large uncertainty in the total time (also cost) to implement the new criteria, develop the associated methodologies and complete the review and approve cycle because of the required interactions between the suppliers, licensees and the NRC.