GE Energy, Nuclear (GEEN)
Global Nuclear Fuel (GNF)

BWR
Control Rod Drop Accident (CRDA)

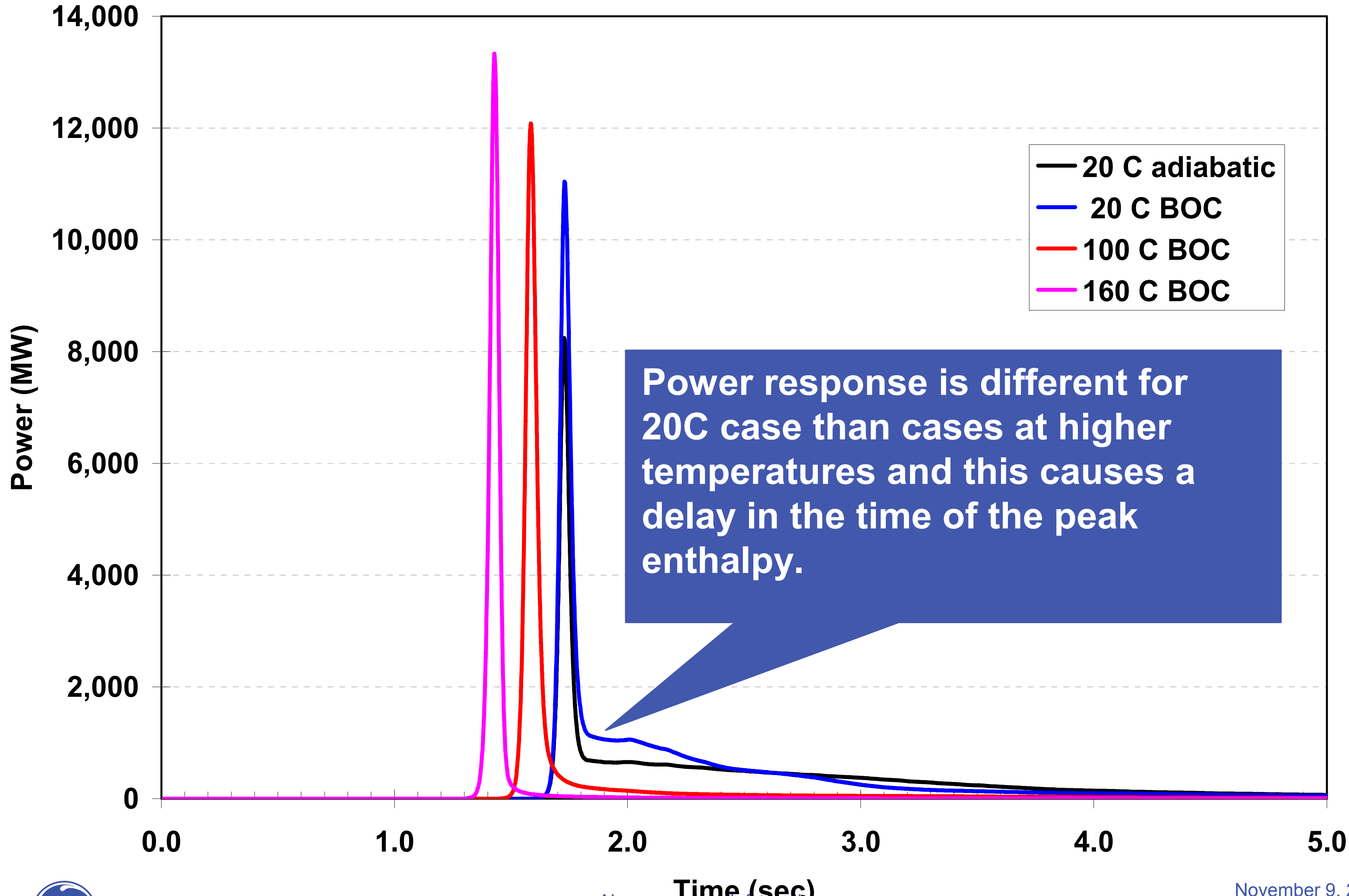
imagination at work

BWR Best-Estimate CRDA Calculations

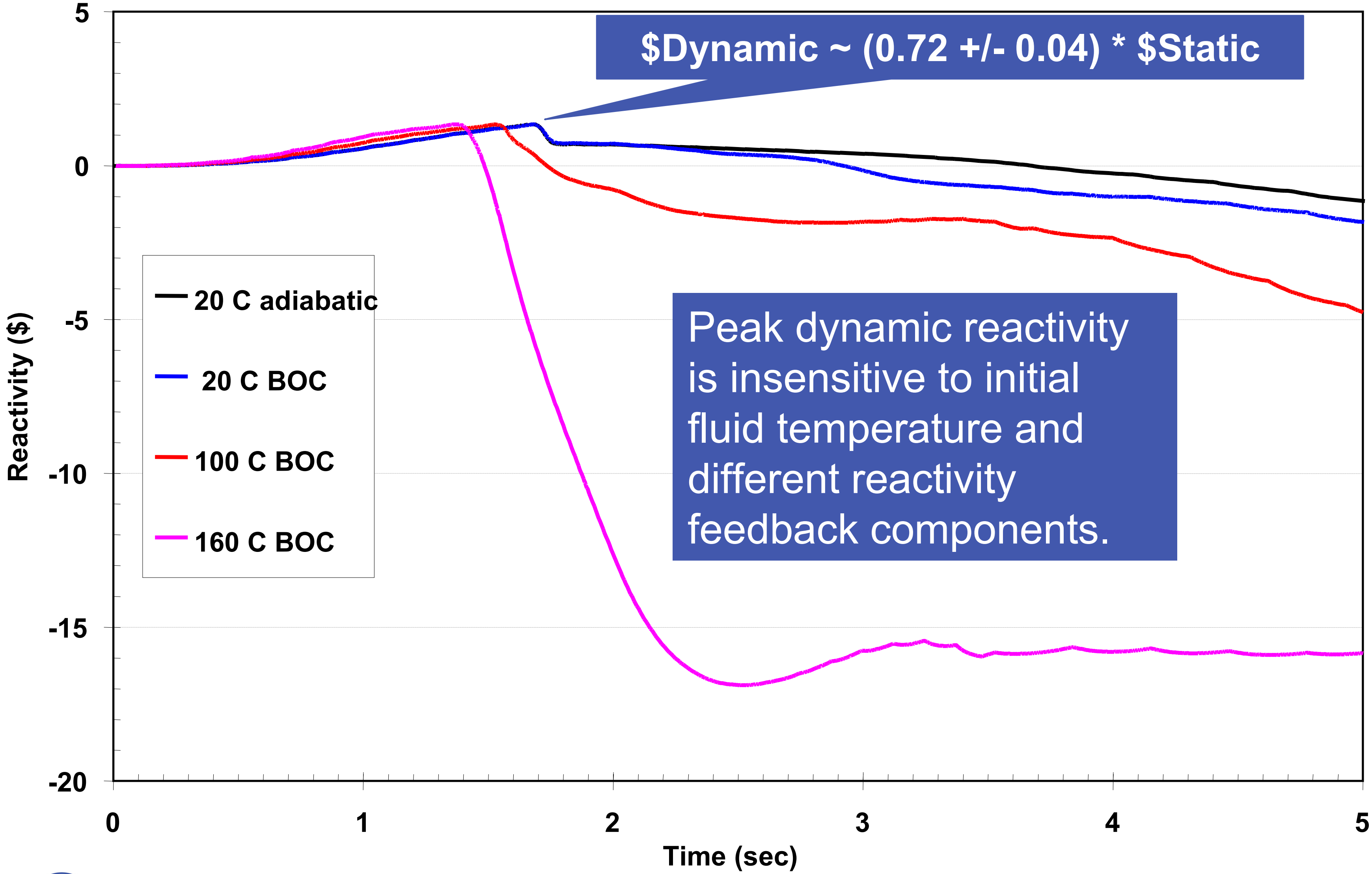
Calculation Inputs

- Realistic feedback due to Doppler, fluid temperature, and voids
- Realistic control blade worths at different exposures
  - > Control blade worths are the key variable but …
  - > Impact depends on how blade worths were achieved
  - > BPWS limits static blade worths to ~1.1%ΔK ~$1.87
  - > Some conservative out-of-sequence cases were included
  - > Core loading and shutdown margin limits possible worths
- Different initial fluid temperatures used because feedback mechanisms are different

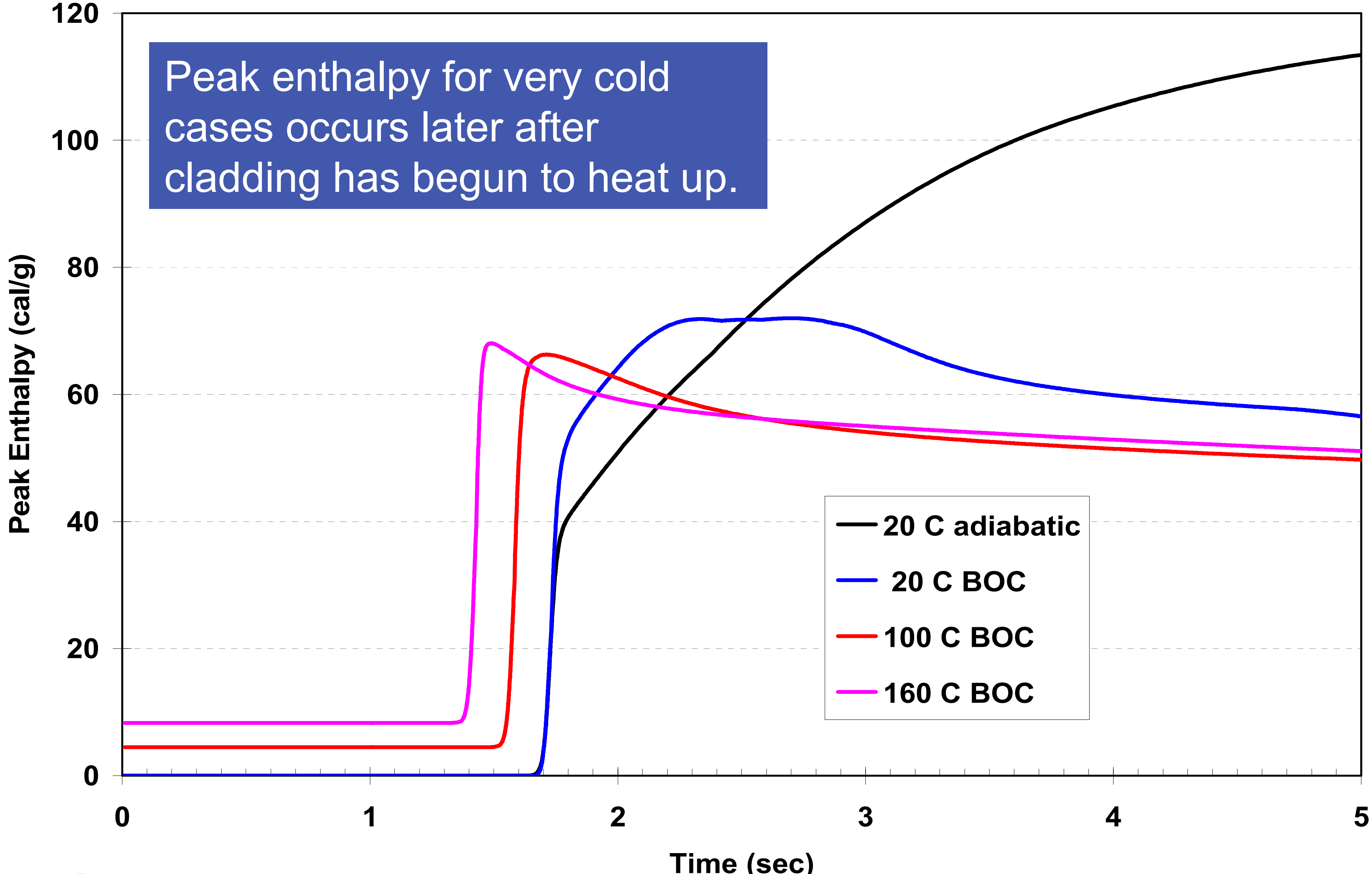
Power Responses (~ 1.1% delta-K static worth)



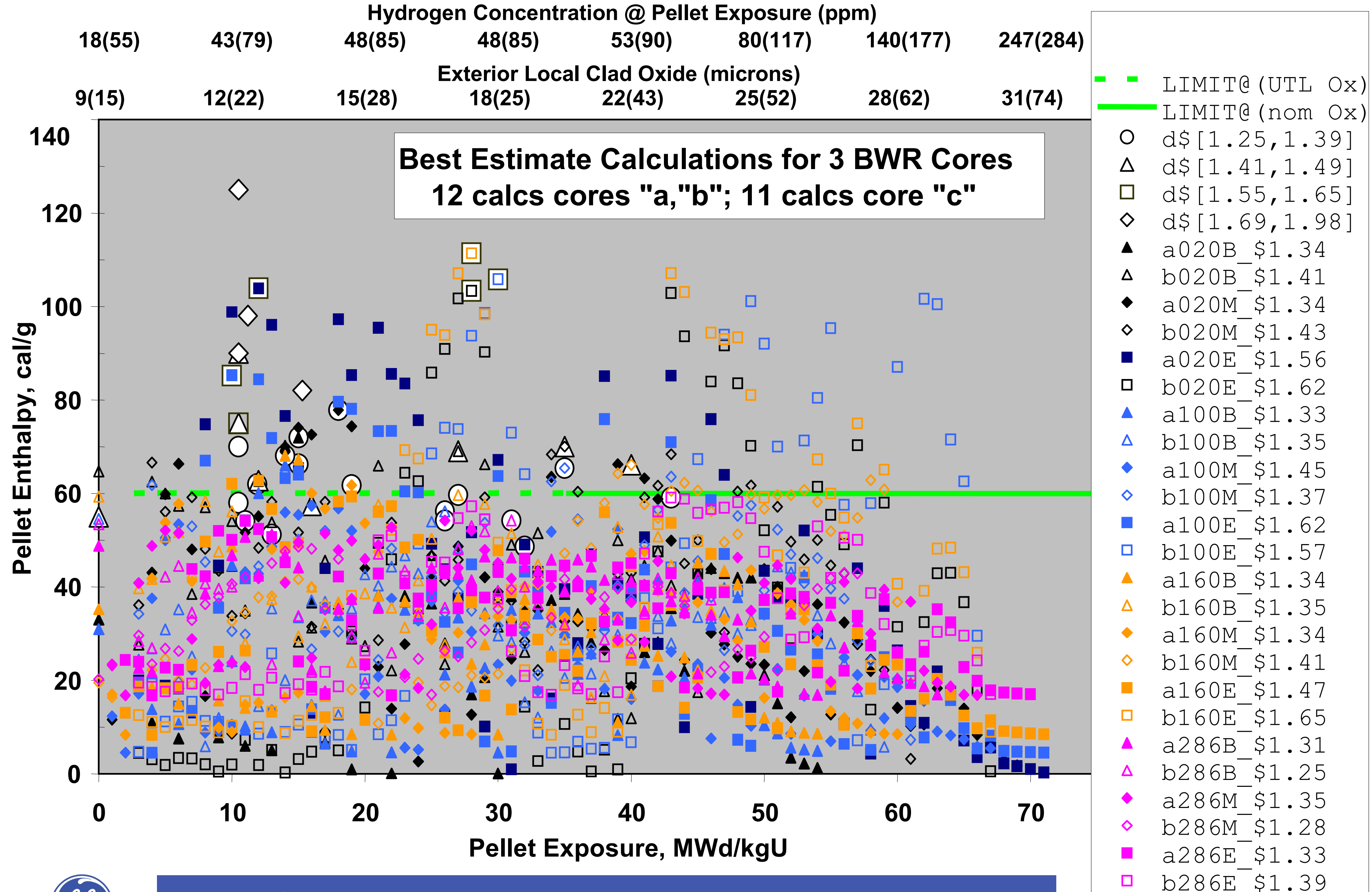
Dynamic Reactivity Responses
(~ 1.1% delta-K static worth ~ $1.87 static ~ $1.33 dynamic)



Total Enthalpy Responses
(~ 1.1% delta-K static worth)



BWR Best-Estimate Calculated CRDA Enthalpies



60 cal/gm at 20 microns is unworkable for BWRs.

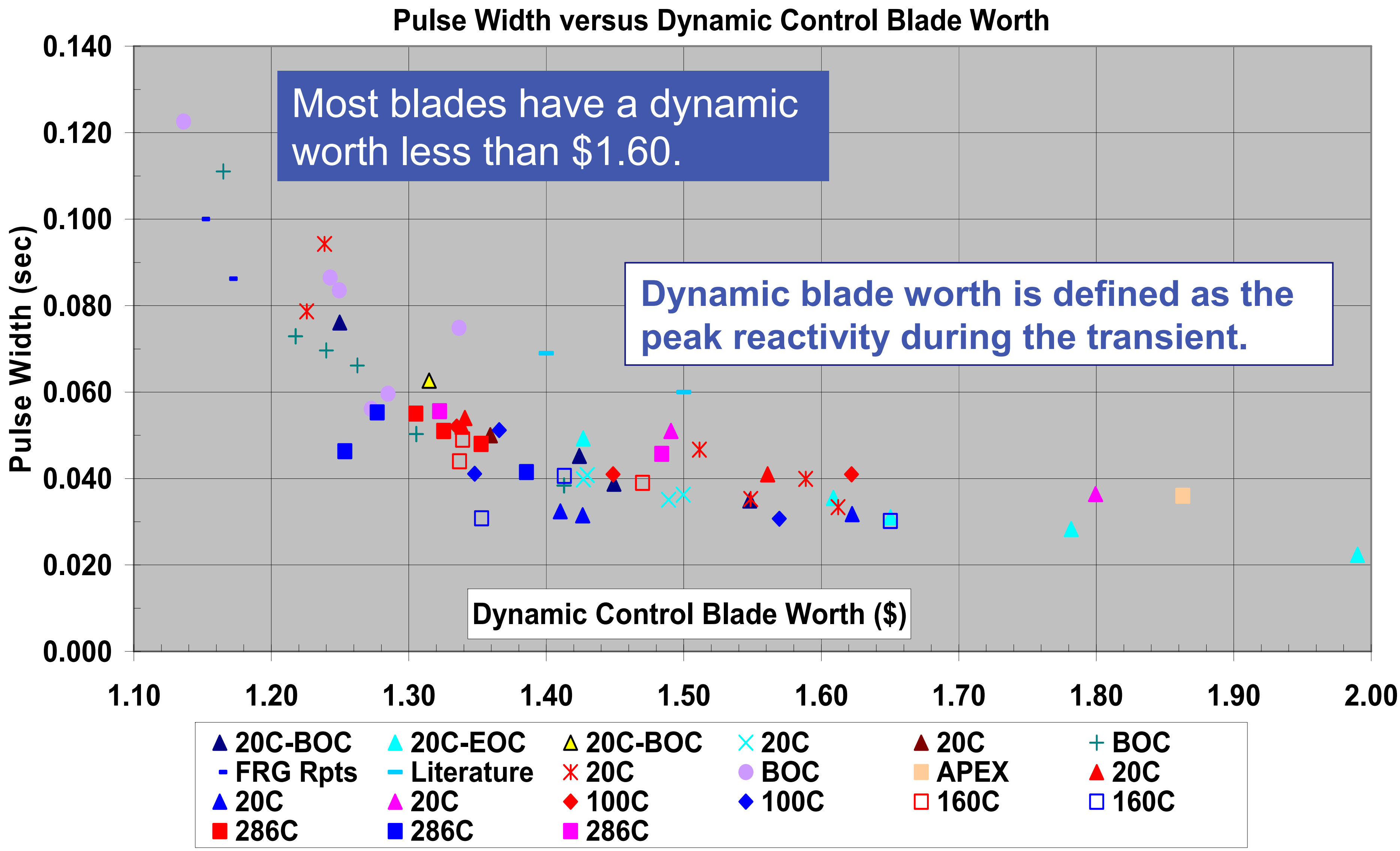
Conclusion from the BWR Best-Estimate CRDA Calculated Enthalpies versus Exposure

A limit of 60 cal/gm at 20 microns of oxide will make design of BWR cores impossible.

RIL 0401 BWR limit…

> Difference from PWR limit has not been justified;
> Is extremely conservative relative to observed failures (will be shown);
> Does not yet consider role of pulse width.

BWR Pulse Widths versus Control Blade Worth



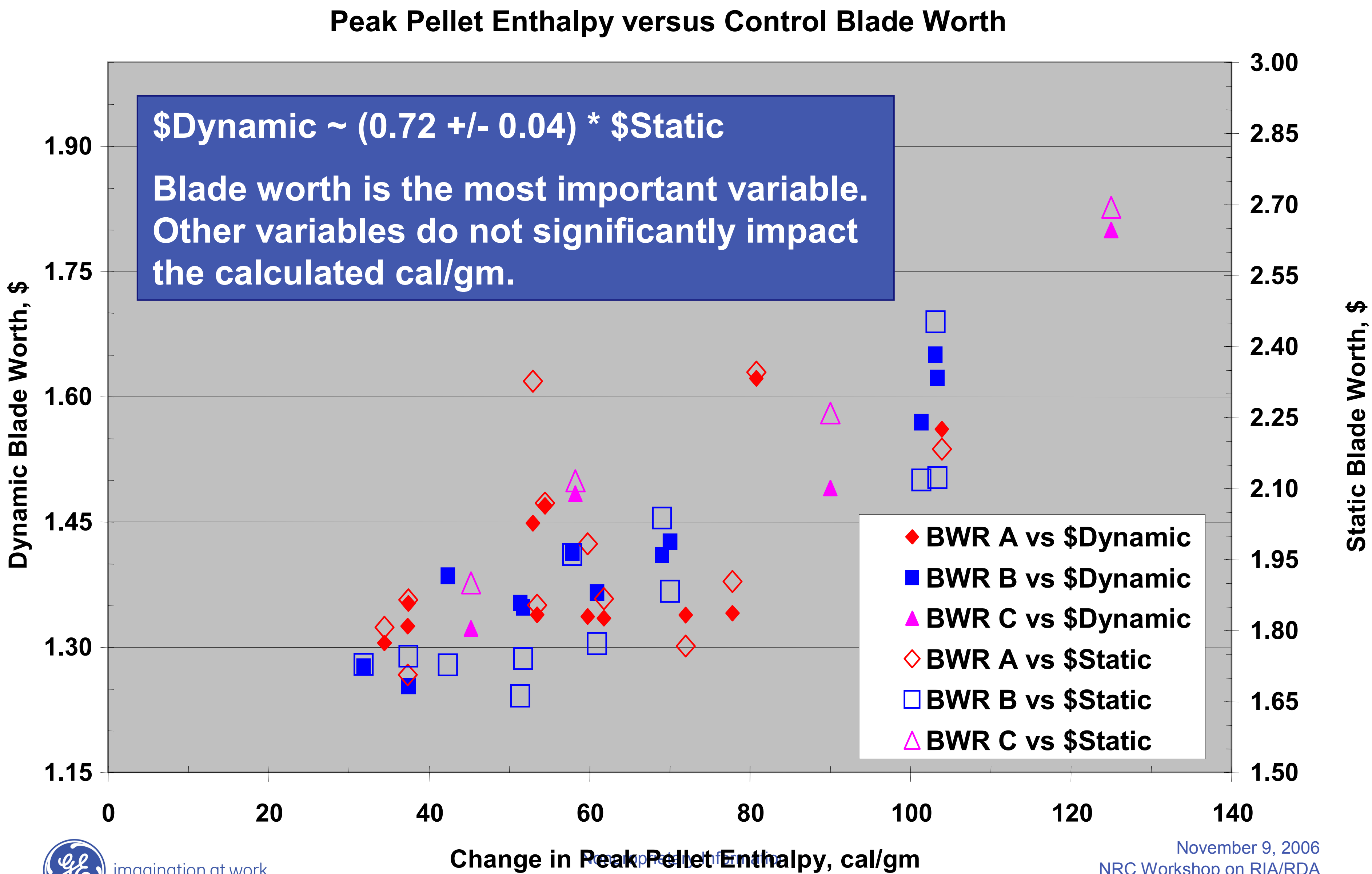
Pulse Width Observations

- BWR pulse widths are a function of the control blade worth and the fundamental nuclear characteristics of a BWR (i.e., fuel to moderator ratio) neither of which can be fundamentally changed without encountering other constraints such as thermal margins, peak clad temperature and shutdown margin.
- BWR Pulse Widths can be correlated to dynamic control blade worth.
- Results are remarkably consistent between different methods.

Even for very large control blade worths the pulse widths remain larger than 20 msec.

BWR pulse widths are substantially larger than for most experiments where cladding failures and fuel dispersal were observed.

Change in Peak Enthalpy vs. BWR Blade Worth



Observations from Change in Peak Enthalpy vs. BWR Blade Worth

- Calculated cal/gm values are…
  - > Correlated better to dynamic blade worth;
  - > Correlated to static blade worth so static methods can be used for identifying cases that are likely to be limiting;
  - > Are better metric for a limits than imposing a blade-worth limit.
- Characterizing response as the *change in enthalpy* removes bias associated with different initial fluid temperatures.
- Need to define the reference temperature for zero enthalpy (0, 20 or 25 C ?) if the criteria is to be based on total enthalpy.

Other BWR Observations

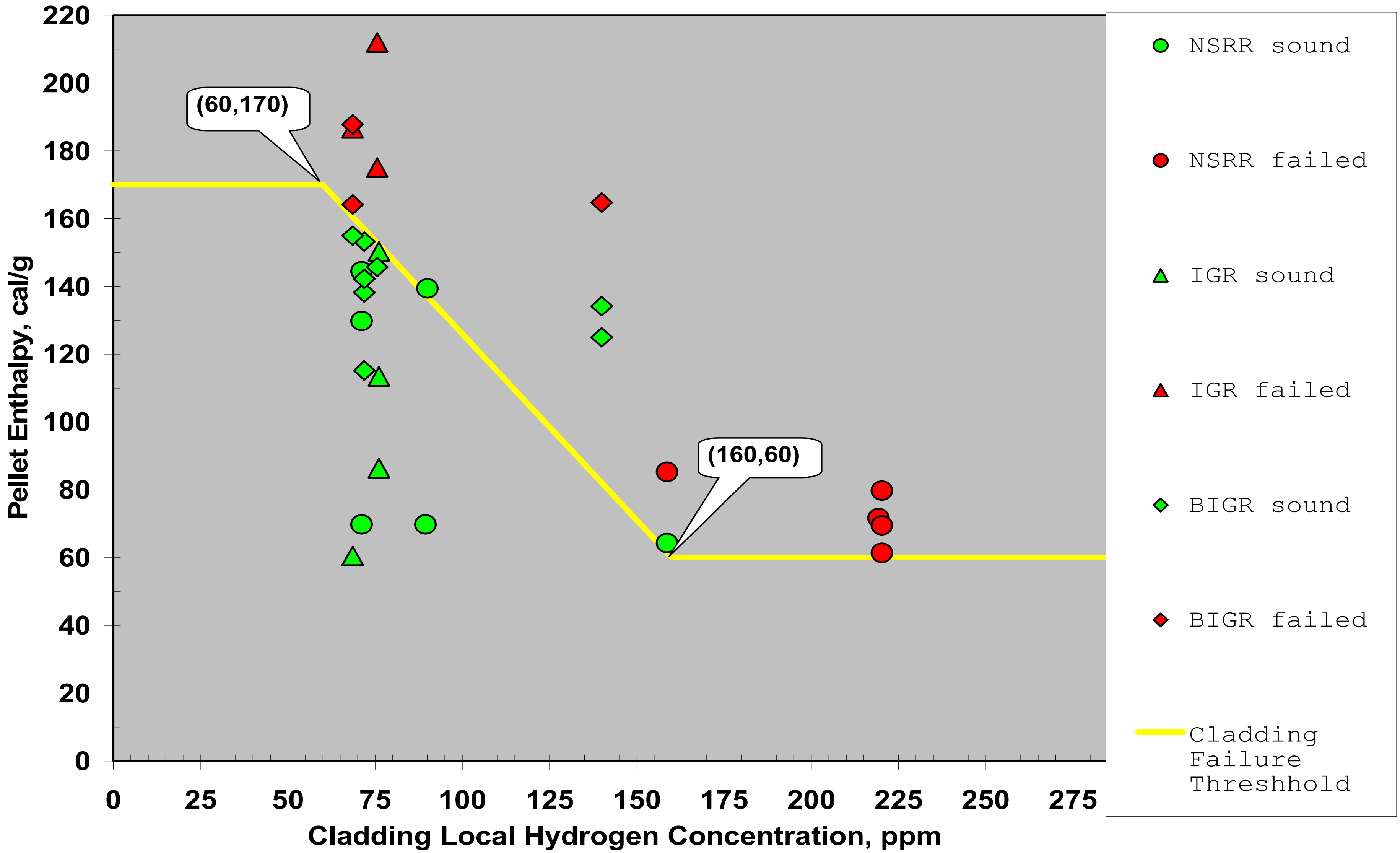
- Initial fluid temperature is important for determining clad properties, but sensitivity studies show that it is not a key variable for determining calculated cal/gm values (for dynamic blade worths under $2).
- For very low temperatures the cladding thermal/mechanical properties are influenced by the non-Gaussian power response.
- Dynamic reactivities tend to be higher for the temperatures in the middle of the startup range (between 120 to 180 C).
- Sensitivity studies show that the point in the fuel cycle is important for determining the peak pellet exposure but is not a key variable for determining the calculated cal/gm values.
- Responses for calculations in the operating range above ~5% are bounded by startup cases and do not indicate boiling transition (BT).

How might the BWR failure limit be expressed?

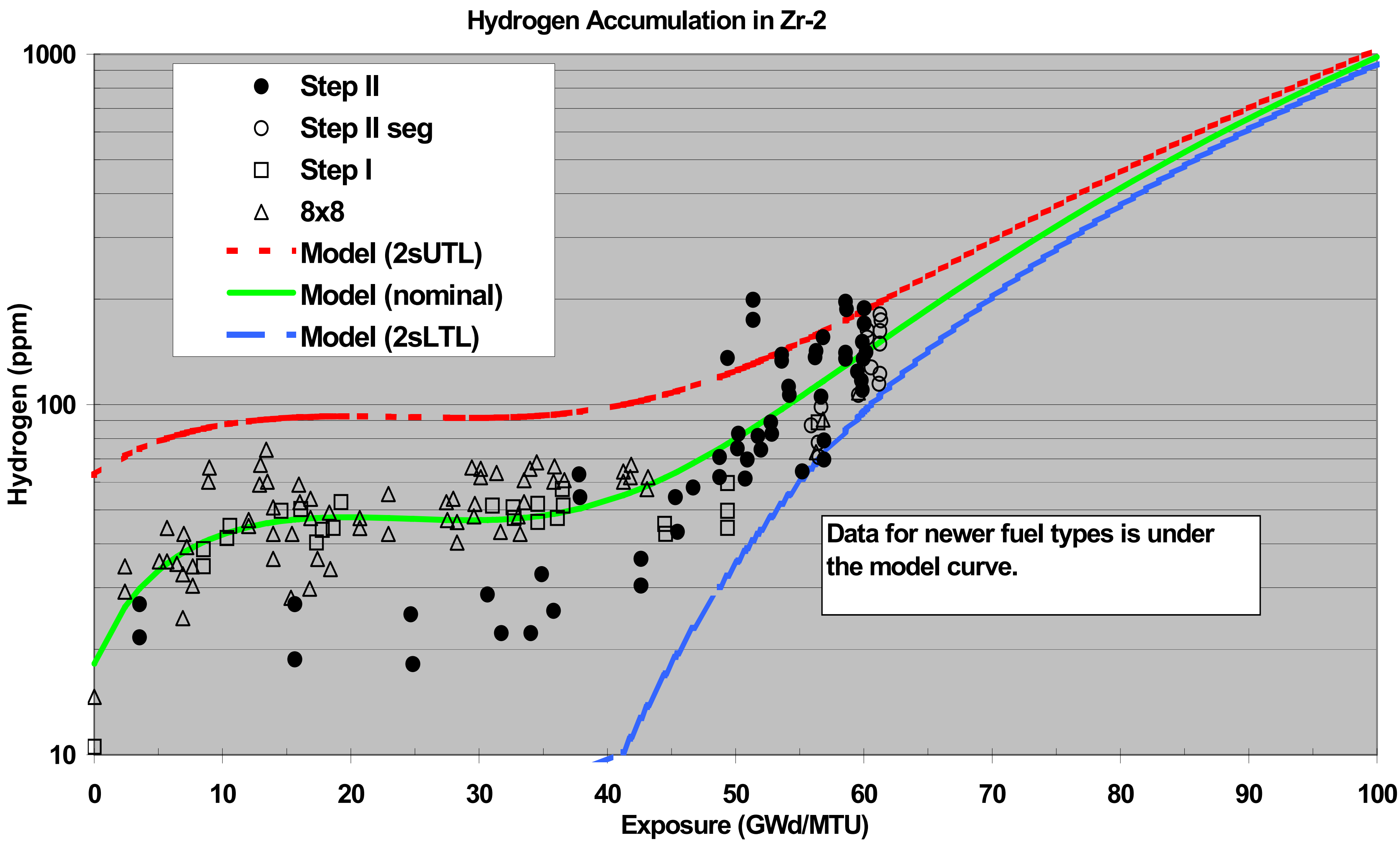
- Experiments for Zr-2 cladding indicate that there is a threshhold hydrogen concentration for hydrogen concentrations where failures occur.
- Transformation of oxide thickness into hydrogen concentrations introduces uncertainties that can be avoided by using measured hydrogen data for Zr-2 cladding.

A possible approach appropriate for BWRs is to apply the measured hydrogen concentrations from Zr-2 experiments to transform a cal/gm limit versus hydrogen concentration into an equivalent limit in terms of peak pellet exposure.

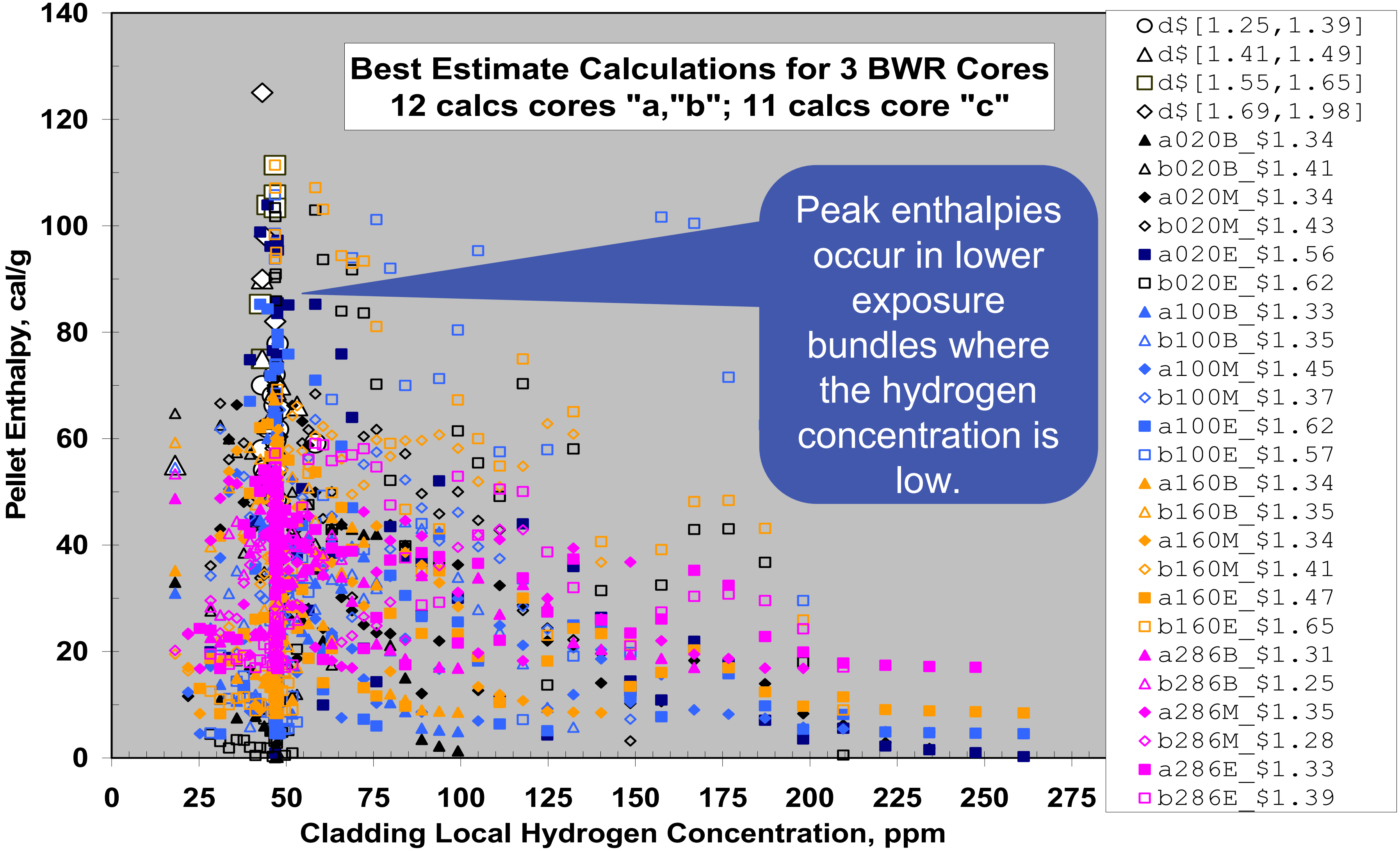
Data Suggest Correlation to H2 Concentration



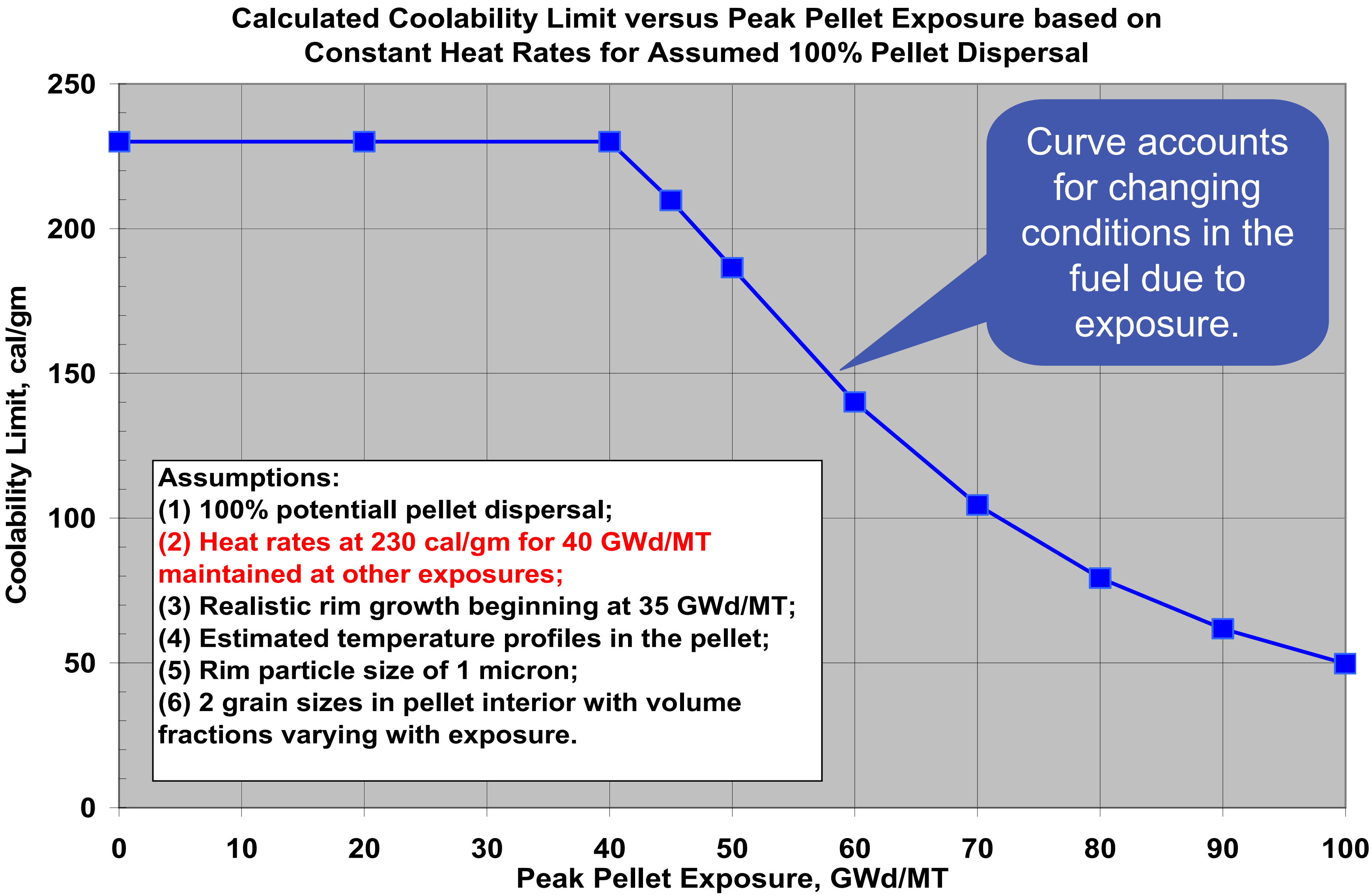
Hydrogen Accumulation in BWR Zr-2 Cladding



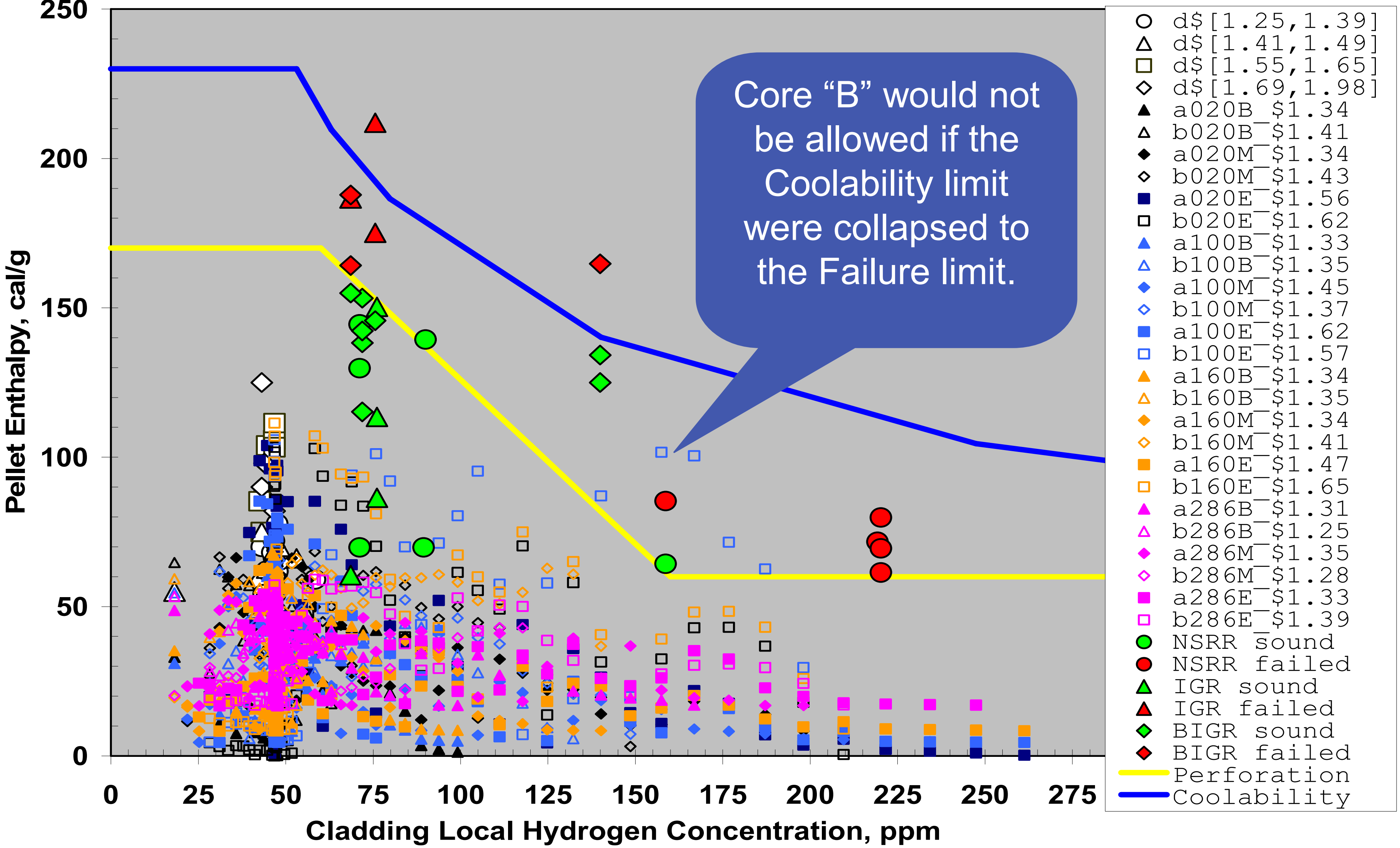
BWR Best-Estimate Calculated RDA Enthalpies versus Local Hydrogen Concentration



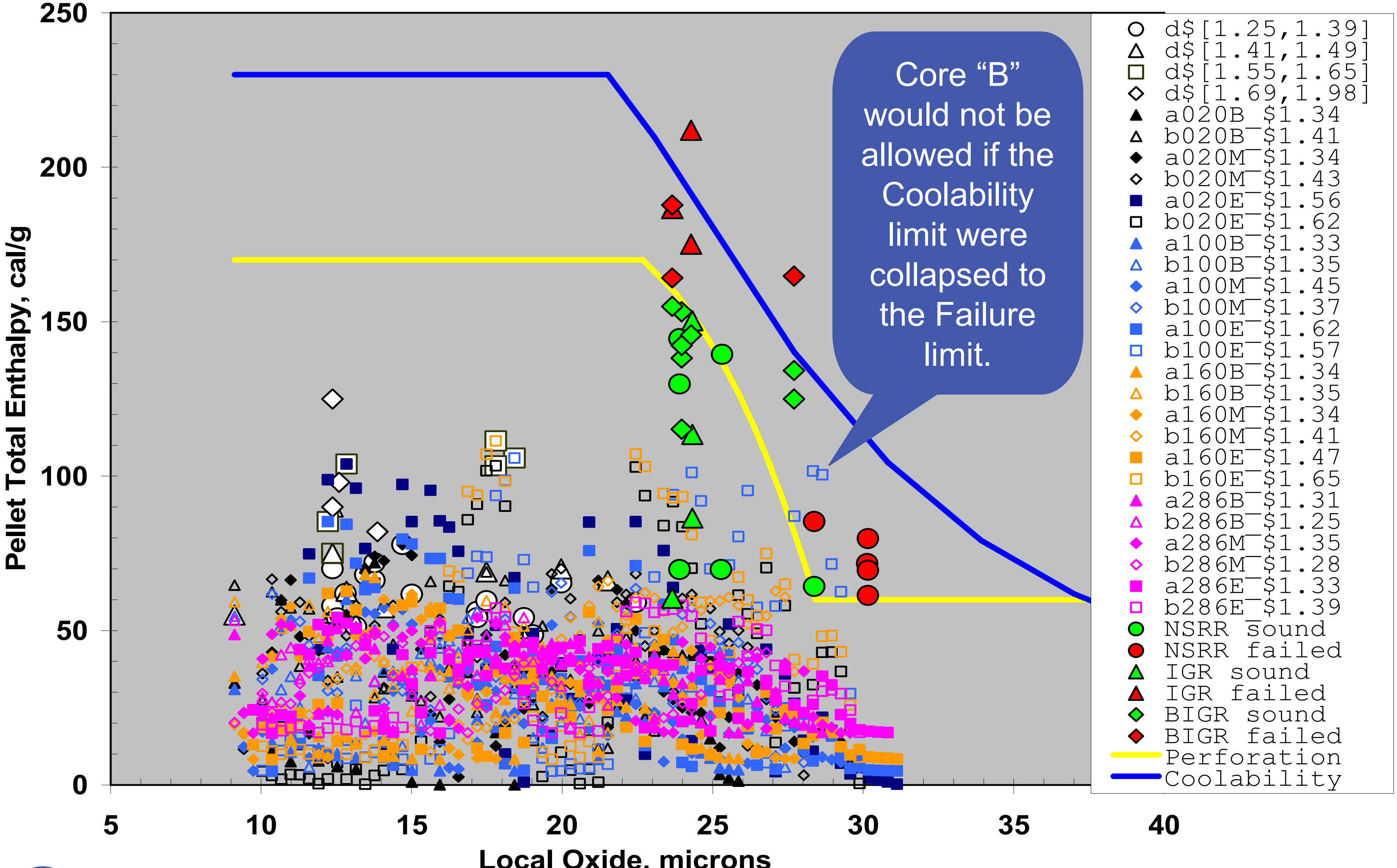
Concept for Coolability
(based on BWR fuel but can be applied to PWR fuel also)



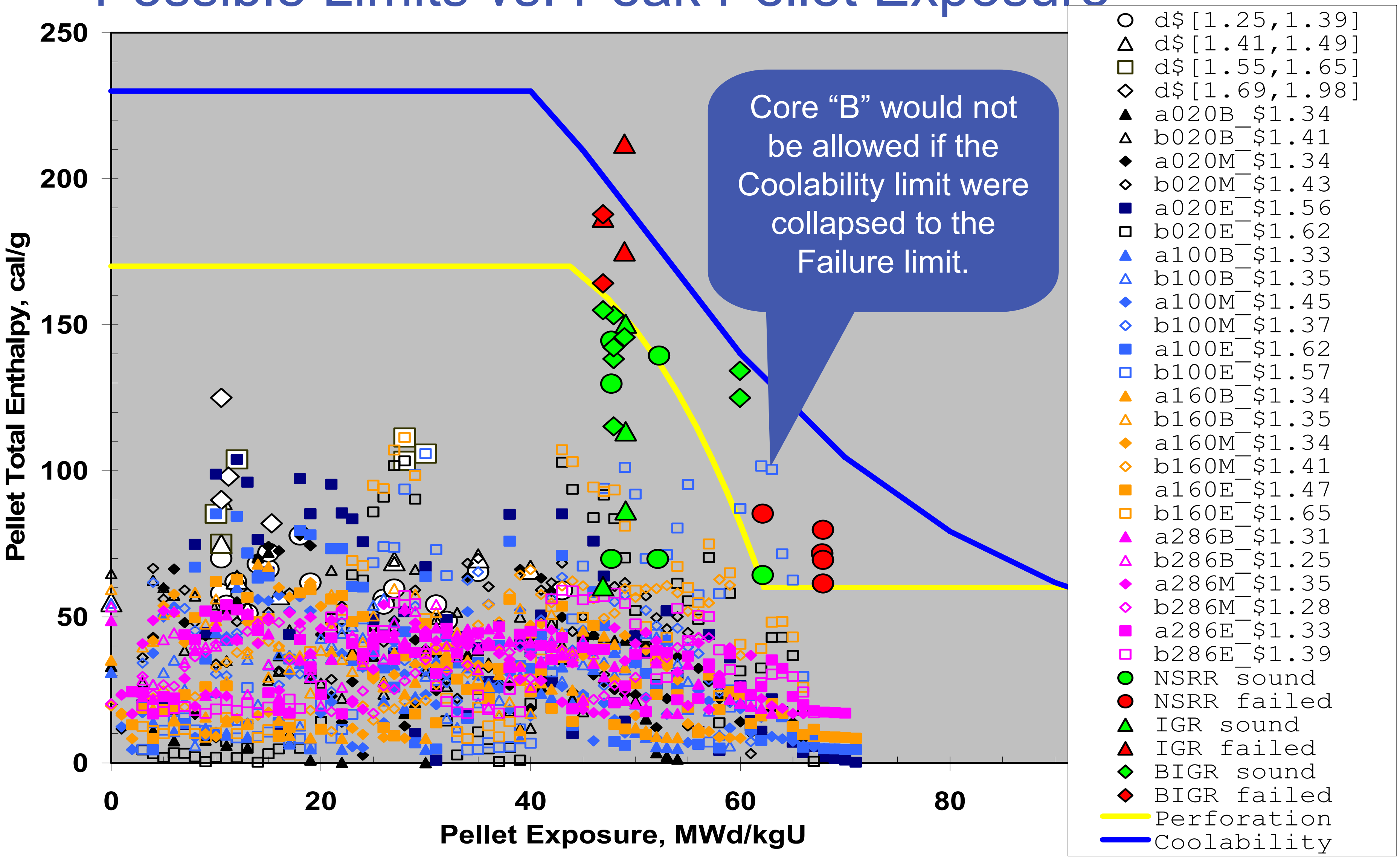
BWR Best-Estimate Calculated RDA Enthalpies & Possible Limits vs. Local Hydrogen Concentration



BWR Best-Estimate Calculated RDA Enthalpies and Possible Limits vs. Local Oxide



BWR Best-Estimate Calculated RDA Enthalpies & Possible Limits vs. Peak Pellet Exposure



BWR Key Conclusions and Recommendations

- RIL-0401 BWR clad failure limit of 60 cal/gm based on oxide is not well characterized and is overly restrictive for a low-probability accident even when best-estimate methods are applied.
- Collapsing of the coolability limit to the failure limit is inappropriate given the purpose of the coolability limit.
  - Coolability should be based on concerns about energy deposition into the coolant not the threshhold for cladding failures.
- Pulse width impact on experimental failures should be addressed.

BWR Key Conclusions and Recommendations (continued)

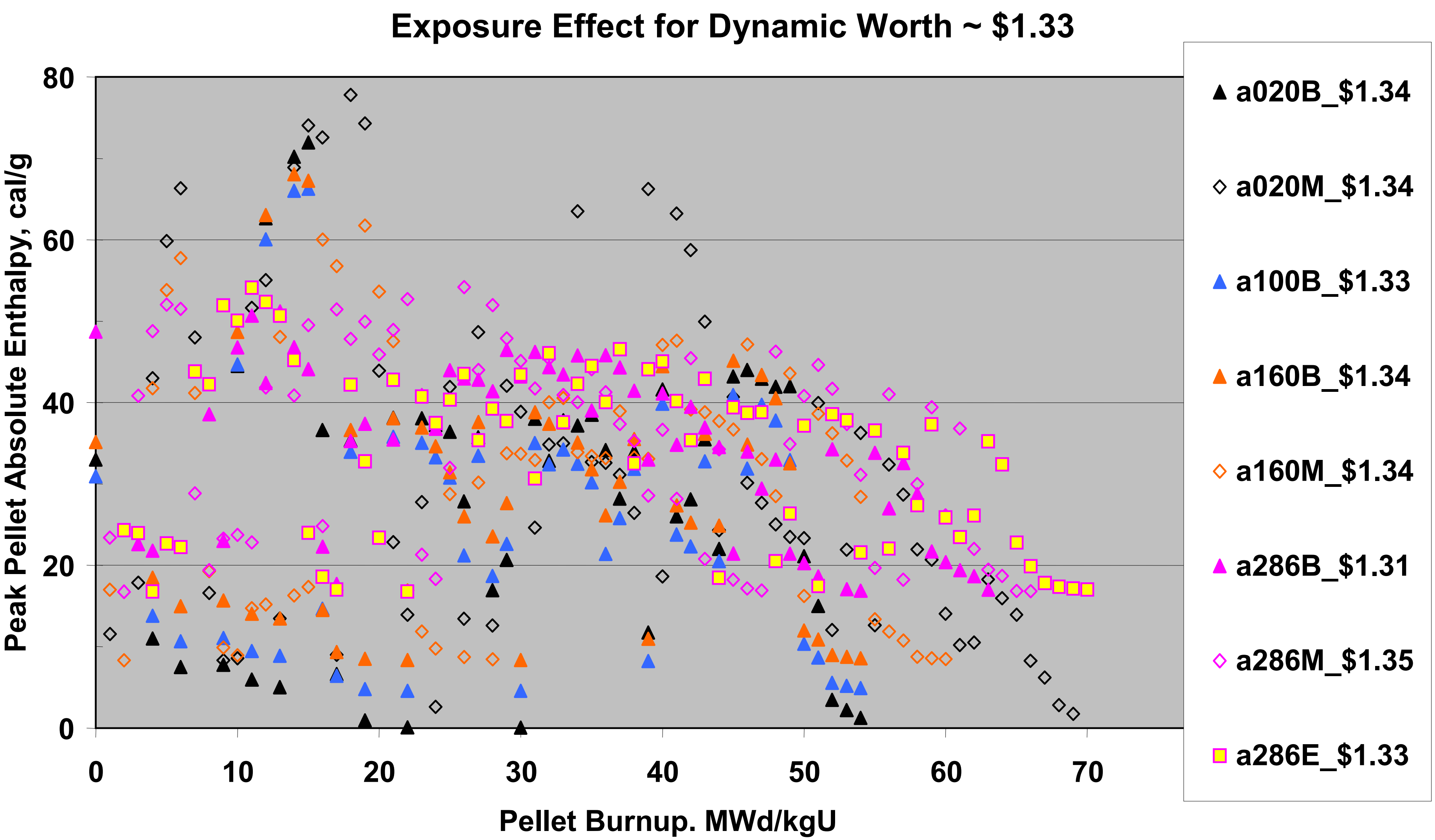
Cladding failure limit…

- can be determined in terms of hydrogen concentration from experimental data;
- can be related to a total cal/gm limit in terms of burnup by using hydrogen data for Zr-2 cladding;
- can be related to a total cal/gm limit in terms of oxide thickness by using vendor oxide data

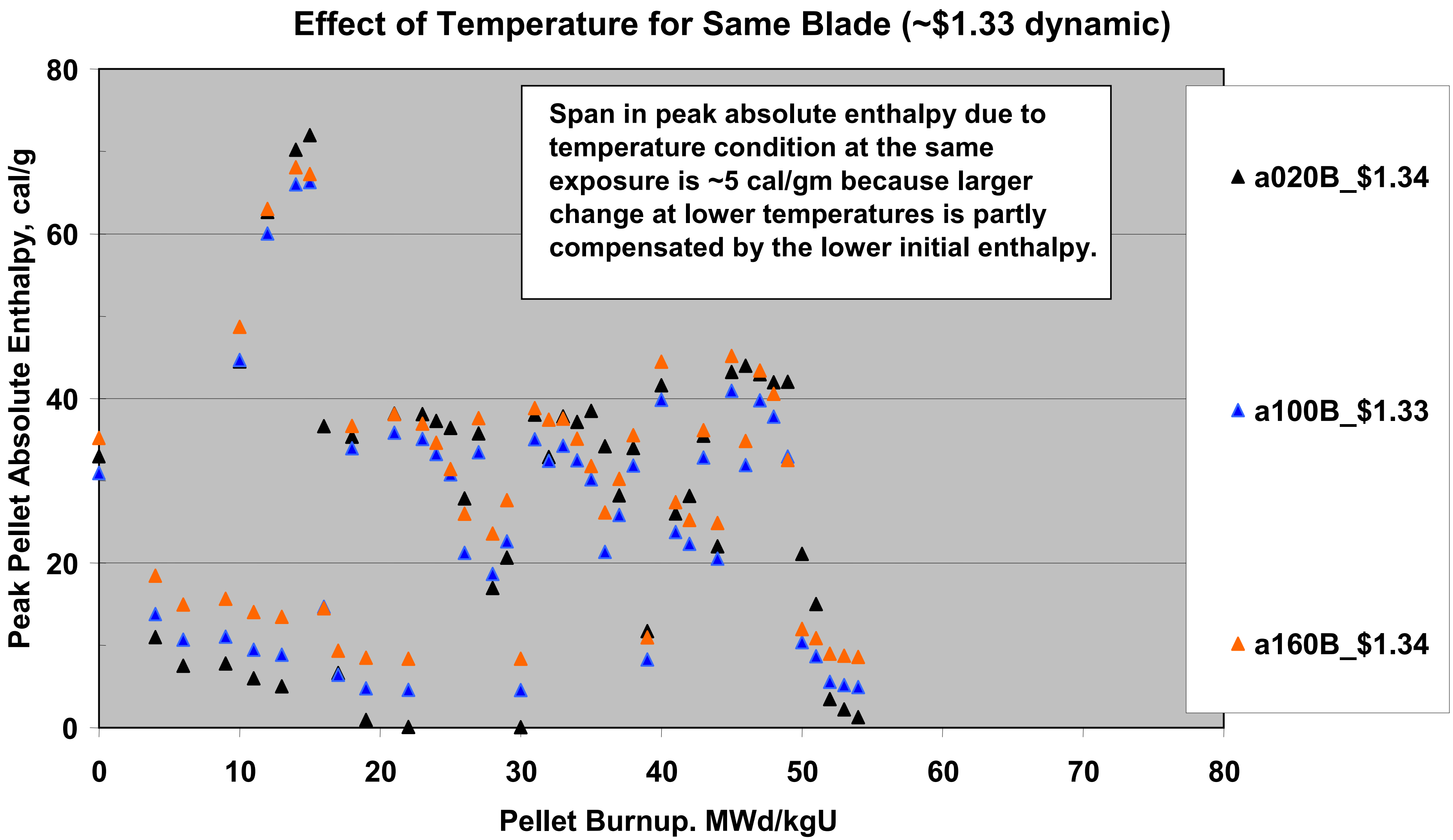
One approach for determining a BWR cladding failure limit has been shown. Other approaches have been suggested that provide similar limits.

BACKUP SLIDES

BWR RDA Peak Enthalpy Sensitivity to Exposure



BWR RDA Peak Enthalpy Sensitivity to Temperature



imagination at work

Nonproprietary Information