Potential Impacts on Design Basis Accidents

Paul Clifford
Office of Nuclear Reactor Regulation
Division of Safety Systems

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Design Basis Accidents

- Classified as Condition IV events, the following postulated DBAs are allowed to predict fuel cladding failure provided criteria associated with coolable geometry and radiological consequences are satisfied.
  - Loss-of-Coolant accident (LOCA)
  - Pressurized water reactor (PWR) control rod ejection (CRE) accident
  - PWR main steam line break (MSLB) accident
  - PWR single reactor coolant pump locked rotor or sheared shaft (LR/SS)
  - Boiling water reactor (BWR) control rod drop accident (CRDA)
- Remaining DBAs do not predict cladding failure (e.g., PWR SGTR, PWR FWLB, BWR MSLB).

* DBA classification varies among licensees.

Fragmentation Mechanisms

- Fuel pellet fragmentation appears to be largely driven by a rapid expansion of trapped fission gas along grain boundaries and within the porous high burnup structure.
  - The amount of fission gas (mols) within a fuel pellet is proportional to local fuel burnup

- During postulated DBAs, fuel pellets are susceptible to fragmentation as a result of (1) a rapid local power (and fuel temperature) excursion or (2) fuel rod ballooning and rupture.

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Postulated Phenomena

- Fuel fragmentation
  - Release trapped fission products into rod plenum (available for release upon cladding breach)
- Fuel fragmentation and relocation within the fuel rod
  - Alter local heat flux distribution along fuel rod
- Fuel fragmentation and dispersal out of the fuel rod
  - Complicate accident progression and safety evaluation
    - Introduce analytical requirements associated with fuel particle transport, deposition, and criticality
    - Introduce fuel coolant interaction (FCI)
    - Introduce debris
  - Alter cooling requirements for long-term decay heat removal for both intact portion of core and dispersed fuel particles.

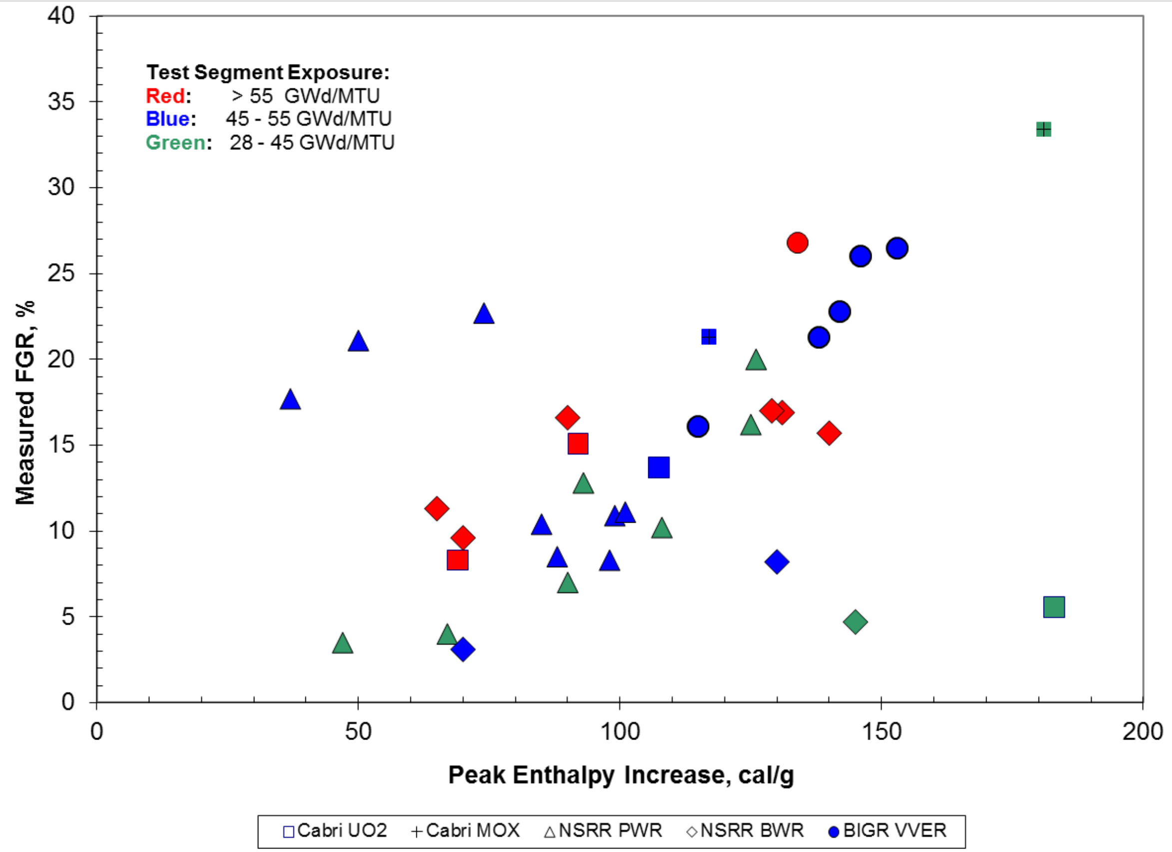
Fission Gas Release

- During normal operation, FGR into the rod plenum is governed by diffusion and is well characterized by approved fuel rod thermal-mechanical models and a large empirical database.

- Pellet fracturing and grain boundary separation release additional fission gas trapped within the pellet.
  - FGR measurements following reactivity-initiated accident (RIA) tests provide a basis for estimating fracture-induced FGR for postulated DBA which experience a rapid power excursion
  - Additional research is needed to quantify the amount of fracture-induced FGR as a result of rod ballooning and rupture

FGR Database

- RIA FGR database shown as a function of fuel enthalpy increase.
  - FGR measurements from French (CABRI), Japanese (NSRR), and Russian (BIGR) test programs.



Relocation

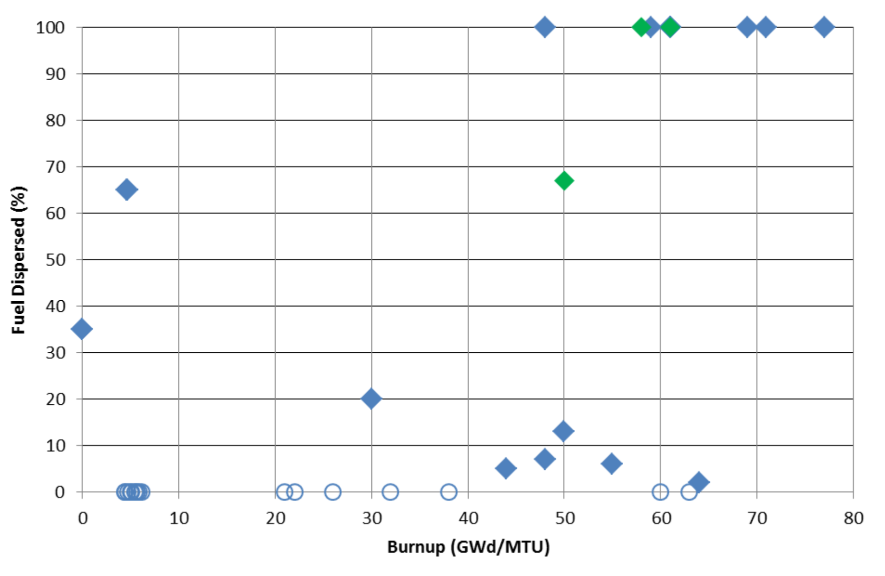
- Existing LOCA database provides information to estimate the amount of fuel relocation within the balloon region of the fuel rod.

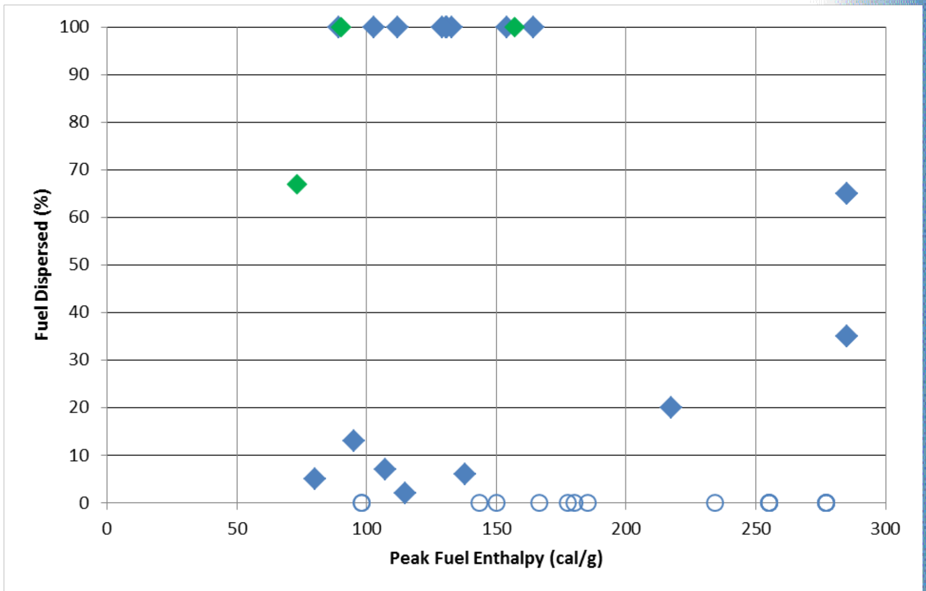
- State-of-the-art realistic LOCA models account for the potential increase in local heat flux as a result of fuel relocation.

- Based on a short time duration in dry-out conditions, fuel relocation during Non-LOCA DBAs is not likely to be a significant issue.

Fuel Dispersal Database

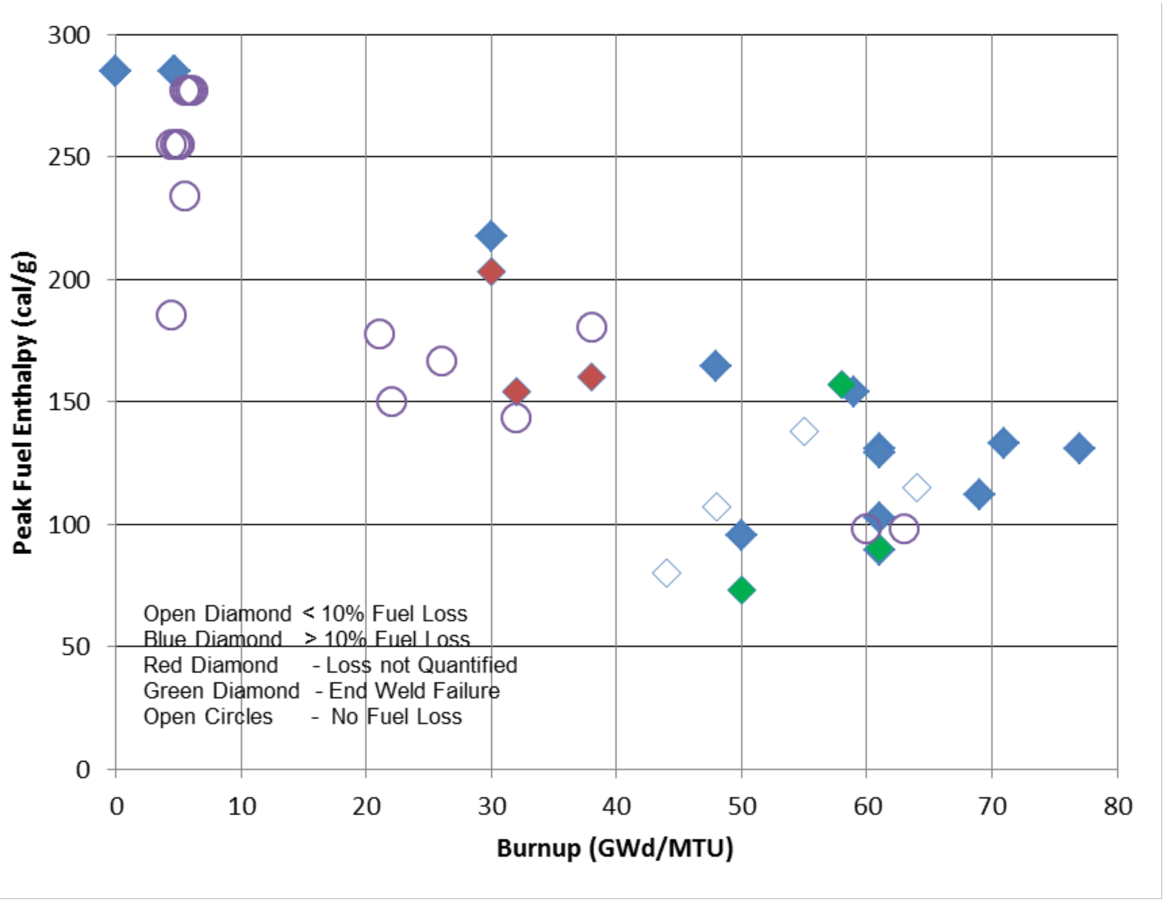
- Research findings and observations from LOCA test programs are applicable to Non-LOCA DBAs which experience fuel rod ballooning and rupture.
- For DBAs which experience a rapid power increase, research findings and observations from RIA test programs are available.





RIA Dispersal Database

- Susceptibility to fuel dispersal correlates with fuel burnup and peak fuel enthalpy.



Estimating Fuel Dispersal

- While improved analytical methods are needed to estimate core-wide population of burst fuel rods during a postulated LOCA, existing Non-LOCA methods already predict the population of failed fuel rods.

- More research may be necessary to establish high confidence fuel fragmentation models (e.g., size distribution versus burnup).

- Once these models are available, it will be possible to estimate the amount of dispersal, if any, during DBAs.

Fuel Coolant Interaction

- The amount and rate of FCI energy deposition depends on many variables including fuel enthalpy, particle size distribution, and coolant conditions.
  - Significant differences likely between DBAs
- Experimental data and analytical models already exist to assess FCI during severe accidents.
- DBA analytical models may need to be updated to simulate the potential impacts of FCI.
  - Pressure surge resulting from rapid deposition of energy
  - Changes in local coolant conditions and accident progression
- Once these models are available, it will be possible to estimate the potential impacts of FCI, if any, during DBAs.

Fuel Particle Transport

- More research may be necessary to establish high confidence fuel particle transport models to predict deposition and demonstrate long-term decay heat removal.

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Conclusion

- The latest research revealed several new phenomenon associated with high burn-up fuel fragmentation, relocation and dispersal. Quantitative assessment of their consequences and safety implications is needed through joint NRC/industry/international effort in the near future.
- All of this additional research, costs associated with developing new regulatory requirements and guidance, and costs associated with implementation, could be significantly reduced by designing fuel and loading patterns which avoid cladding failure in higher burnup fuel rods susceptible to fragmentation.