AREVA Perspective on Fuel Fragmentation and Dispersal During Design Basis Accidents

Bert Dunn, Lisa Gerken
AREVA
Lynchburg, VA
Introduction - LOCA

- Cladding swelling and rupture have been treated by LOCA evaluation models since the 1973 rule without consideration of relocation and dispersal.

- Relocation
  - In tube relocation has recently been included within LOCA EMs
    - Direct calculation
    - Indirect evaluation based on experiments or tangential modeling
  - NRC is now requiring direct calculation of in tube relocation

- Dispersal outside the cladding
  - Has never been treated in LOCA models
  - Dispersal requires cladding rupture
  - Fuel particles released from rods considered well cooled in RCS
Introduction – Non-LOCA

- Historically clad swelling, rupture, and pellet fragment relocation or dispersal not considered in non-LOCA events

- RIAs for PWRs did not pass through CHF
  - Some recent calculations pass through CHF but do not incur rupture

- Rod drop accidents in BWRs do not go through CHF
  - Legacy methods may go through CHF but improved state of the art methods will not

- Other DBAs do not experience swelling and rupture
  - PWRs: do not pass through CHF
  - BWRs: rod peak powers are reduced with burnup
LOCA Observations - Relocation

- Tests indicate that the possibility of relocation within the hot rod is credible for LOCA
- Cladding rupture temperature and strain are highly variable
- Evaluations of the packing factor of the rubble show substantial variability

![Graph showing Packing Factor vs Rupture Strain]

Data All Sources
LOCA Observations - Dispersal

- NRC Research
  - Fuel particles must be smaller than rupture opening
  - Burnup must be under threshold ~ 60 GWd/mtU
- Concern may be largely an artifact of conservative modeling
- BWR: Expect realistic evaluations to show no rupture
- PWR
  - PWR RLBLOCA results
    - Mean hot rod PCT ~ 1500°F
    - Embedded conservatisms > 200°F
    - Expected true mean PCT < 1300°F
  - Best estimate prediction is no cladding rupture
- Combining the low probability of LBLOCA and probability of rupture, the likelihood of significant dispersal within the core is very small
LOCA Dispersal Modeling Approach

- Possible modeling approach based on RLBLOCA methodology
- Swelling and rupture of rods can be modeled as statistically based in a realistic EM
  - Model several rod power levels each characteristic of a fraction of the core
  - Use statistical model for rupture, swelling, relocation and an estimate for rupture opening, and fraction of pellet material dispersed
    - Reasonably known:
      - Rupture & swelling based on current data (0630, EDGAR, REBEKA, etc.)
    - Limited information:
      - Relocation
    - Little information:
      - Rupture opening & fraction dispersed

March 13 & 14 2014 NRC Stakeholders Briefing on Fuel Dispersal
Statistical Approach

- Rupture Temperature Uncertainty (NuReg-0630)

Fig. 3 ORNL correlation of rupture temperature as a function of engineering hoop stress and temperature-ramp rate with data from internally heated Zircaloy cladding in aqueous atmospheres.
Zr-4 Rupture Strain Uncertainty

Not circular when in a bundle, requires irregular shaping

Fig. 6 Maximum circumferential strain as a function of rupture temperature for internally heated Zircaloy cladding in aqueous atmospheres at heating rates less than or equal to 10°C/s.
Needed Information for Mechanistic Evaluation

- Fraction of material released from fuel rod
- Potential for fragment aggregation within core
- Effects of accident tolerant cladding
- Effects of pellet doping
AREVA Perspective

▸ The potential for clad swelling, rupture, and relocation is sufficient to require consideration in LOCA evaluations but that should be done realistically

▸ Relocation
  ◆ Increased probability for high burnup fuel
  ◆ Research on the effect of burnup and pellet fragmentation thresholds is useful
  ◆ Research on packing factor useful
Dispersal during LOCA

- Only limited amounts, nearly all fine particles, will be dispersed into the RCS
- Limited dispersal of larger fragments, if these are trapped in the assemblies they can be cooled there
- Fine particles will flow within the RCS and be cooled effectively
- Only large accumulations in the core would pose a significant risk of over heating
AREVA Perspective

- Analysis of fuel dispersal using conservative bounds of currently available data likely to be extreme
- Research should continue and regulation should await the research
  - Relocation can be considered with best-estimate plus uncertainty
  - The risk of adverse consequences from fuel dispersal is small
  - Regulation of fuel dispersal should await further studies and evaluations

March 13 & 14 2014 NRC Stakeholders Briefing on Fuel Dispersal
Nomenclature

- BWR: Boiling Water Reactor
- CHF: Critical Heat Flux
- DBA: Design Basis Accident
- LBLOCA: Large Break Loss of Coolant Accident
- LOCA: Loss of Coolant Accident
- NRC: Nuclear Regulatory Commission
- PCMI: Pellet Clad Mechanical Interaction
- PCT: Peak Clad Temperature
- PIE: Post Irradiation Examination
- PWR: Pressurized Water Reactor
- RCS: Reactor Coolant System
- RIA: Reactivity Insertion Accident
- RLBLOCA: Realistic LBLOCA