AREVA Perspective on Fuel Fragmentation and Dispersal During Design Basis Accidents

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Introduction - LOCA

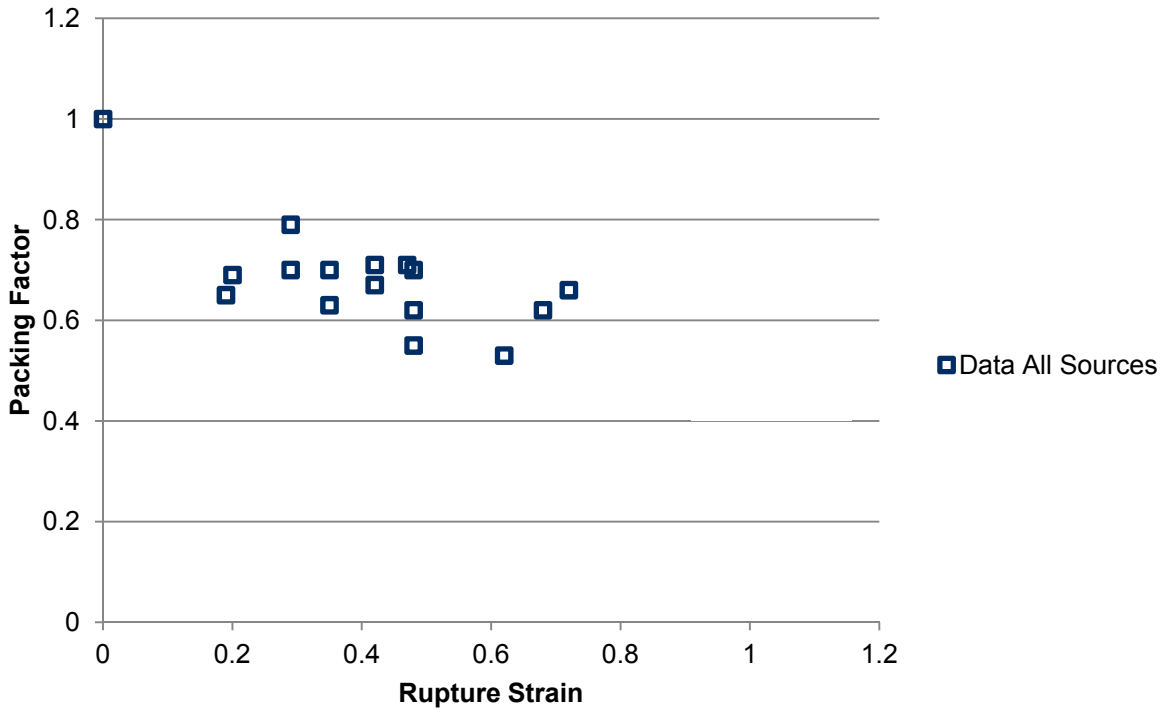
- **Cladding swelling and rupture have been treated by LOCA evaluation models since the 1973 rule without consideration of relocation and dispersal**
- **Relocation**
  - **In tube relocation has recently been included within LOCA EMs**
    - Direct calculation
    - Indirect evaluation based on experiments 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



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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 ~ 1500ºF
    - Embedded conservatisms > 200ºF
    - Expected true mean PCT < 1300ºF
  - 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

Statistical Approach

- **Rupture Temperature Uncertainty (NuReg-0630)**

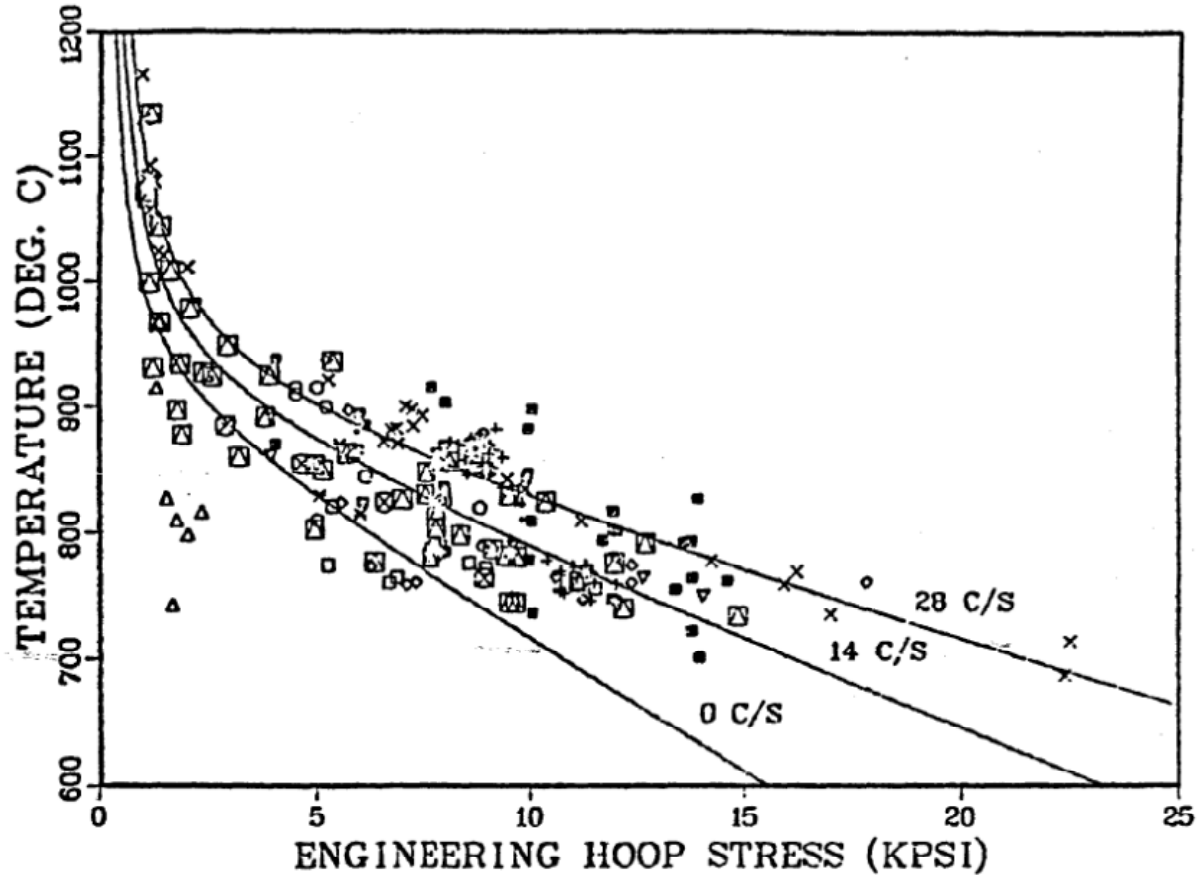

Fig. 3 ORNL correlation of rupture temperature as a function of engineering hoop stress and temperature-ramp rate with data from internally heated Zircaloy cladding in aqueous atmospheres.

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Statistical Approach

- **Zr-4 Rupture Strain Uncertainty**

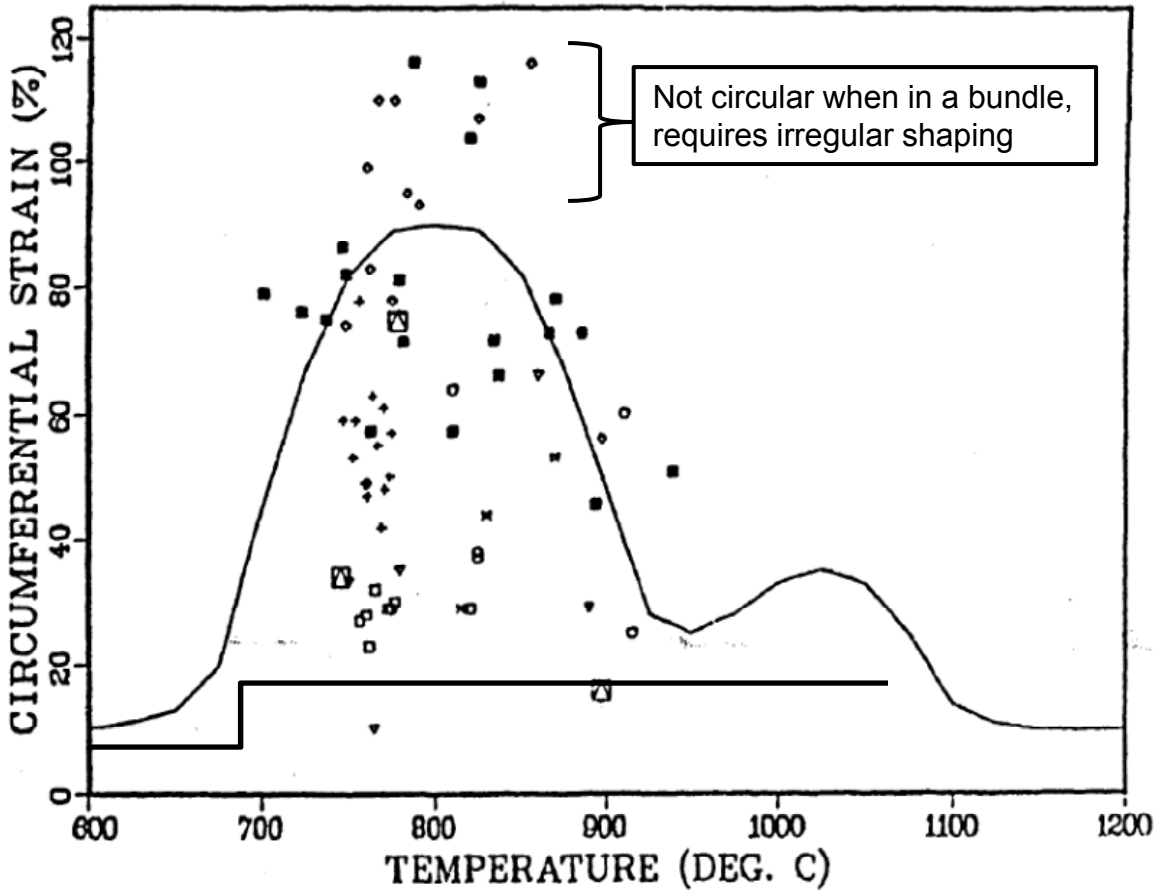

Fig. 6 Maximum circumferential strain as a function of rupture temperature for internally heated Zircaloy cladding in aqueous atmospheres at heating rates less than or equal to 10°C/s.

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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

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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

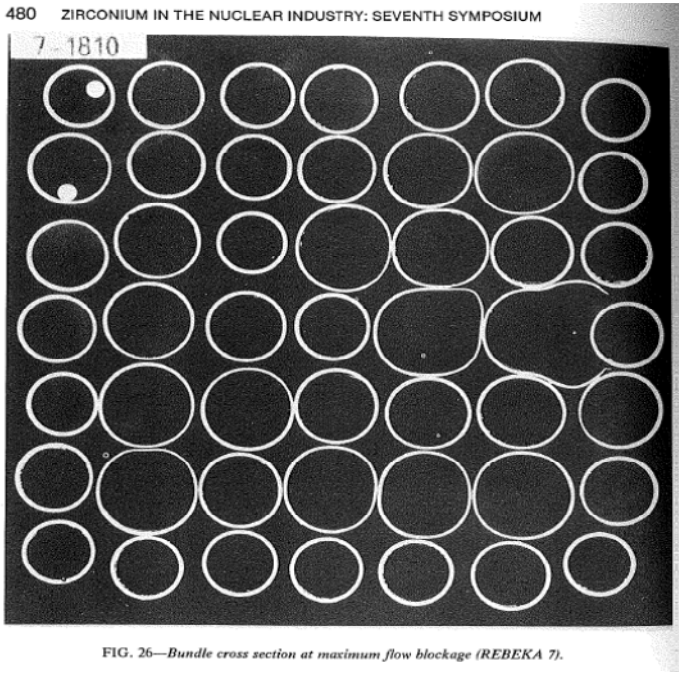

FIG. 26—*Bundle cross section at maximum flow blockage (REBEKA 7).*

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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

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