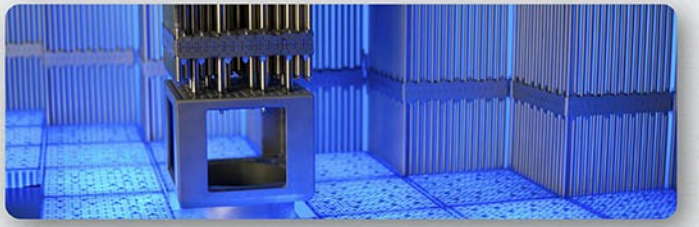

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Interfaces Between Storage & Transportation Casks

– Panel on High Burnup Fuel –

Industry's View on Spent Fuel Reconfiguration

Albert Machiels
Senior Technical Executive

2011 SFST Technical Exchange
Rockville, Maryland
November 1, 2011

Topics

- Technical Considerations for Transportation Accident Conditions
  - Key Focus: Sub-criticality requirement
- Fuel Relocation
  - “Bounding” Scenarios
    - Cladding properties are ignored
  - Example of “Best-estimate” Scenario
    - Cladding properties are used
- Conclusion

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Technical Considerations Relevant to Transportation Accidents

- Key Focus: Criticality Evaluation Under Transportation Accident Conditions
- Multi-pronged approach:
  1. Criticality Risks During Railroad Transportation of Spent PWR Fuel
     - ✓ Risk information
  2. Moderator Exclusion
     - ✓ No moderator = No potential for criticality of LWR fuel
  3. "Full" Burnup Credit
     - ✓ Ability to account for depletion of fissile material and buildup of most neutron absorbers
  4. Structural response of cladding to impact loads
     - ✓ Potential for rod breakage and fuel relocation (reconfiguration) under accident conditions
  5. *Potential impact of fuel reconfiguration on criticality*
     - ✓ *Maximum reactivity increase due to hypothetical fuel reconfiguration*

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Technical Considerations Relevant to Transportation Accidents

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- Multi-pronged approach:

….

3. "Full" Burnup Credit
   - ✓ Ability to account for depletion of fissile material and buildup of most neutron absorbers

- From ICNC 2011 Track 1 Closing Review (C. Parks, ORNL)
  - "Removal of extreme conservatism can result in an overall improvement in safety by balancing criticality risks with other operational risks"
  - "Standards and methodologies were originally developed for the front end of the fuel cycle with pure materials, e.g., transport regulations and fissile exceptions. How should these be applied to the back end … ?"

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Fuel Reconfiguration – Worst Case Scenarios NUREG/CR-6835 (September 2003)

Table 6: Maximum increase in k_{eff} for each fuel failure scenario*

Scenario	MPC-24 *(fresh fuel)*	MPC-68 *(fresh fuel)*
Single missing rod	0.0018	0.0038
Multiple missing rod	0.0140	0.0120
Cladding removed from all fuel rods	0.0468	0.0441
Fuel rubble (no cladding)	0.0563	0.1149
Assembly slips 20 cm above or below neutron poison panels	0.0021	0.0362
Variation in pitch (without cladding)	0.0703	0.1225

**** "Although the scenarios considered go beyond credible conditions, they represent a theoretical limit on the effects of severe accident conditions" (NUREG/CR-6835, p. 1)***

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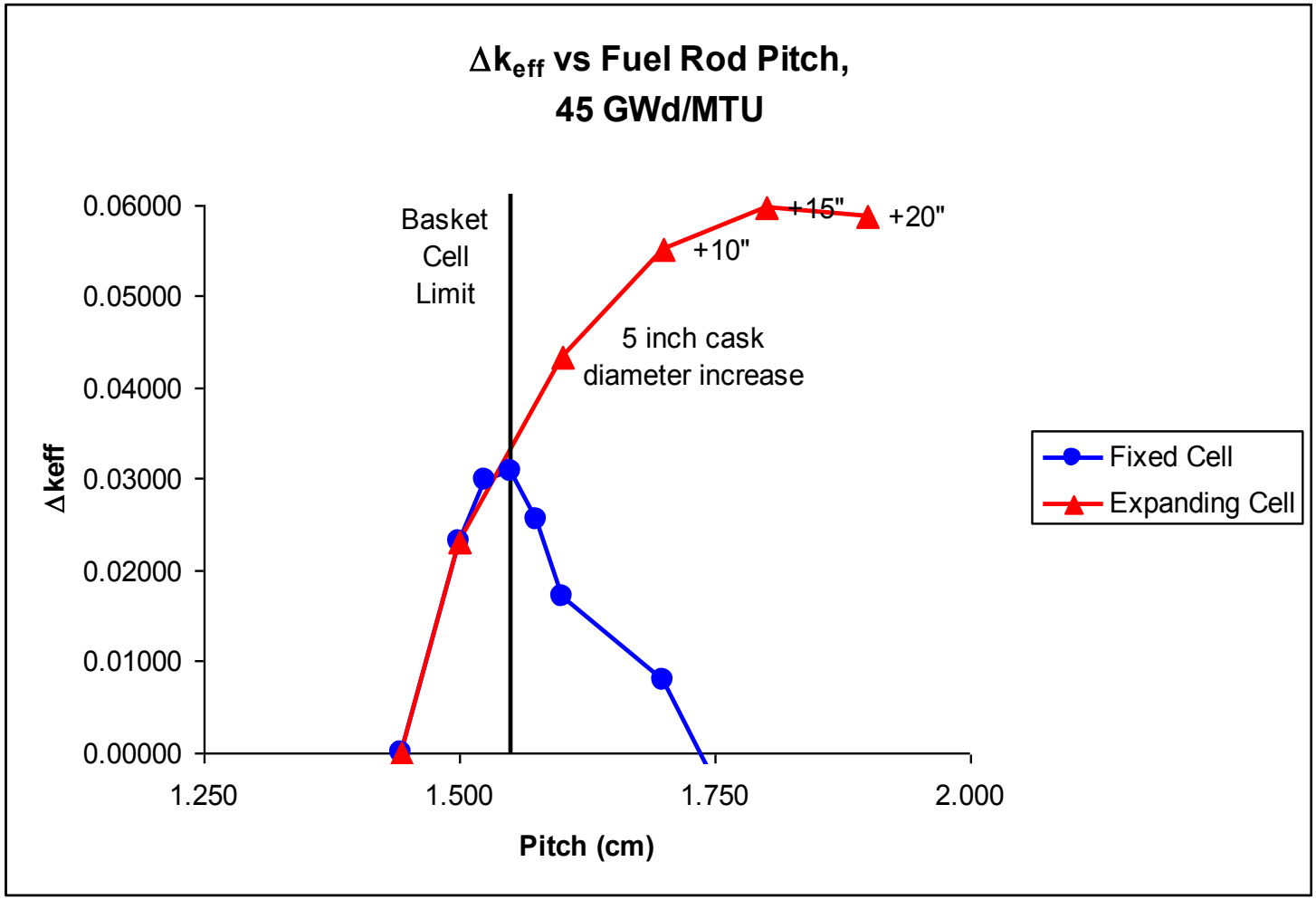
Fuel Reconfiguration – Worst Case Scenarios



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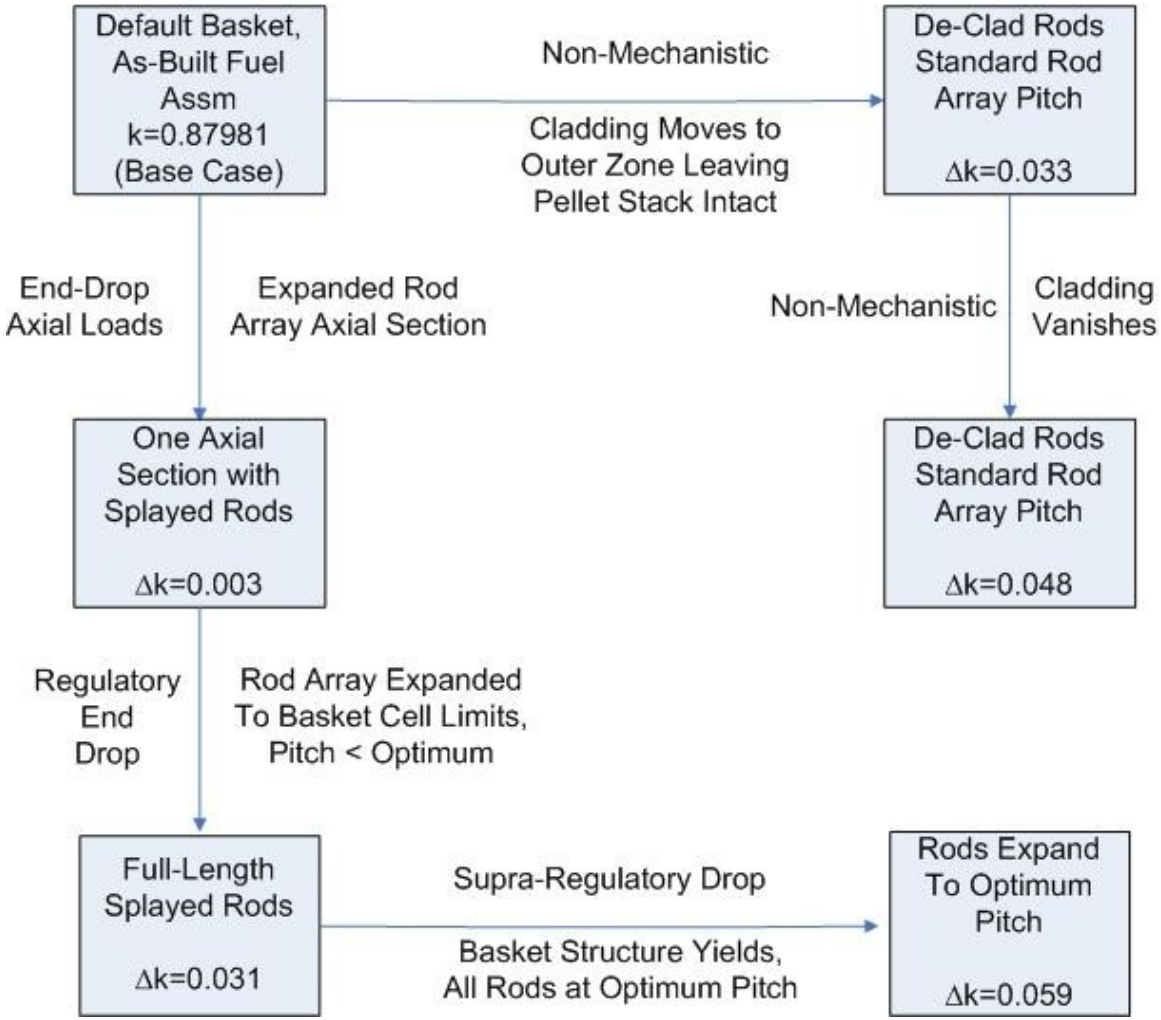
Fuel Reconfiguration – Scenario De-construction



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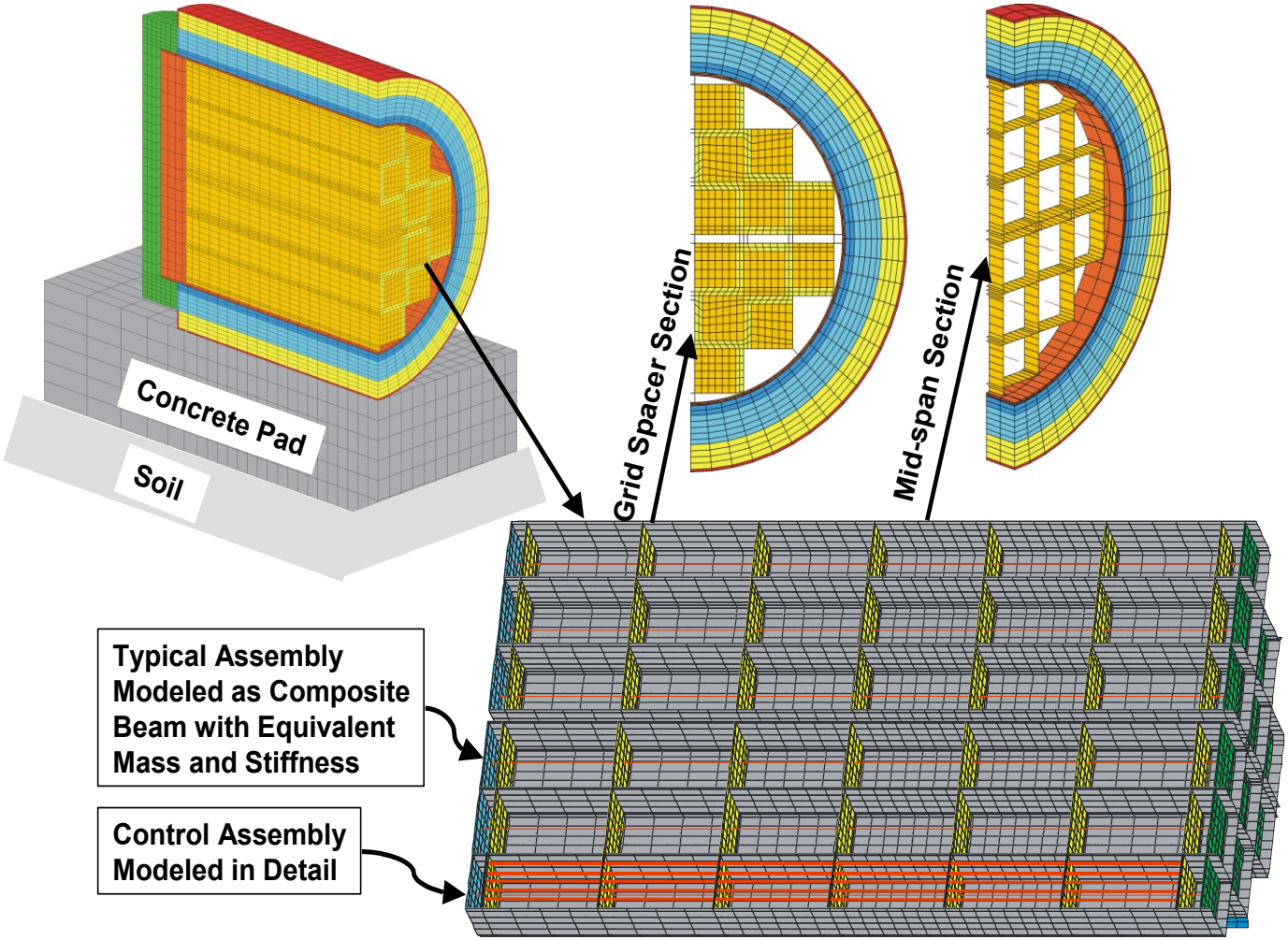
Fuel Damage Evaluation – Best-Estimate Approach



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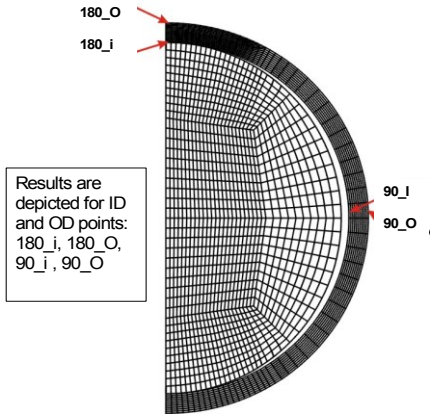
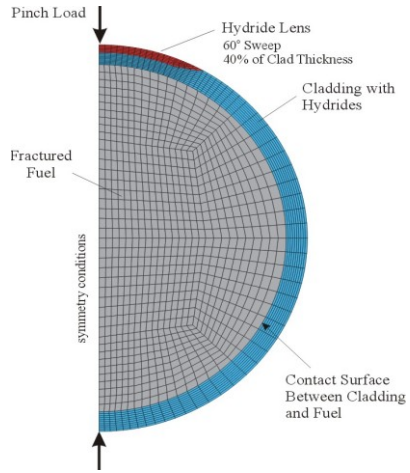
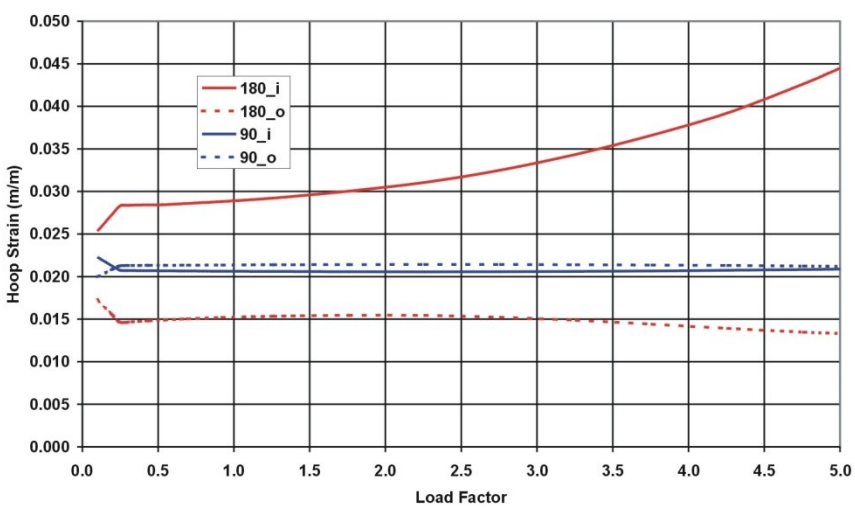
Fuel Damage Evaluation – Best-Estimate Approach



Deformed Grid



Finite Element Model



- The fuel column, as an integral part of high-burnup spent fuel rods, plays the primary role in limiting cladding stresses
- The fuel-cladding gap is found to be the major protagonist for failure initiation that has the potential to propagate to through-wall fracture
- Using highly conservative assumptions on the role of the gap in inducing through-wall failure ➔ through-wall failure probability: ~1E-5/rod

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Conclusion

- Fuel relocation
  - Cannot rule out small increases in k_{eff}, but increases in k_{eff} are unlikely and less than safety margin
  - Best-estimate analyses show limited assembly damage

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Conclusion

- Key question: Given what we learned, how does that knowledge support existing –or coming up with new– regulatory guidance?
  - Storage → *no change!*
  - Transportation accident conditions
    - Holistic approach [risk information/moderator exclusion and burnup credit (defense-in-depth)/impact of fuel relocation (worst cases and best-estimate cases)] → *non-issue!*
  - Normal conditions of transport
    - *May have to account the impact of low fuel temperature!*
    - But instrumentation of initial shipments (together with potential feedback of international experience) can provide straightforward resolution path

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Selected Publicly Available EPRI References

- *Transportation of Commercial Spent Nuclear Fuel – Regulatory Issues Resolution*, Report 1016637 (December 2010)
  - Also presented (and published) at the 16th Int'l Symposium on the Packaging and Transport of Radioactive Materials (3-8 October 2010)
- *Criticality Risks During Transportation of Spent Nuclear Fuel – Revision 1*, Report 1016635 (December 2008)
  - Also published in "Packaging, Transport, Storage & Security of Radioactive Material" Volume 21, No. 1, 2010, pp. 51-61
- *Benchmarks for Quantifying Fuel Reactivity Depletion Uncertainty*, Report 1022909 (August 2011)
  - Also presented (and published) at the International Conference on Nuclear Criticality 2011 (19-22 September 2011)

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Selected Publicly Available EPRI References (continued)

- *Options for Pursuing Moderator Exclusion for Applications to Spent-fuel Transportation Packages*, Report 1011815 (December 2005)
- *Spent-fuel Transportation Applications – Modeling of Spent-fuel Rod Transverse Tearing and Rod Breakage Resulting from Transportation Accident*, Report 1013447 (October 2006)
- *Spent-fuel Transportation Applications – Longitudinal Tearing Resulting from Transportation Accidents*, Report 1013448 (December 2006)
- *Spent-fuel Transportation Applications – Assessment of Cladding Performance: A Synthesis Report*, Report 1015048 (December 2007)

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Selected Publicly Available EPRI References (continued)

- *Spent-fuel Transportation Applications – Normal Conditions of Transport*, Report 1015049 (June 2007)
  - Also presented (and published) at the IAEA International Conference on Spent Fuel Management (May 29-June 4, 2010)
- *Fuel Relocation Effects for Transportation Packages*, Report 1015050 (June 2007)
  - Accepted (August 5, 2011) for Publication in Nuclear Technology

- These reports (as well as several others) can be downloaded free of charge from:

http://mydocs.epri.com/docs/public/00000000000abcdefg.pdf

in which "abcdefg" represents the report number

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