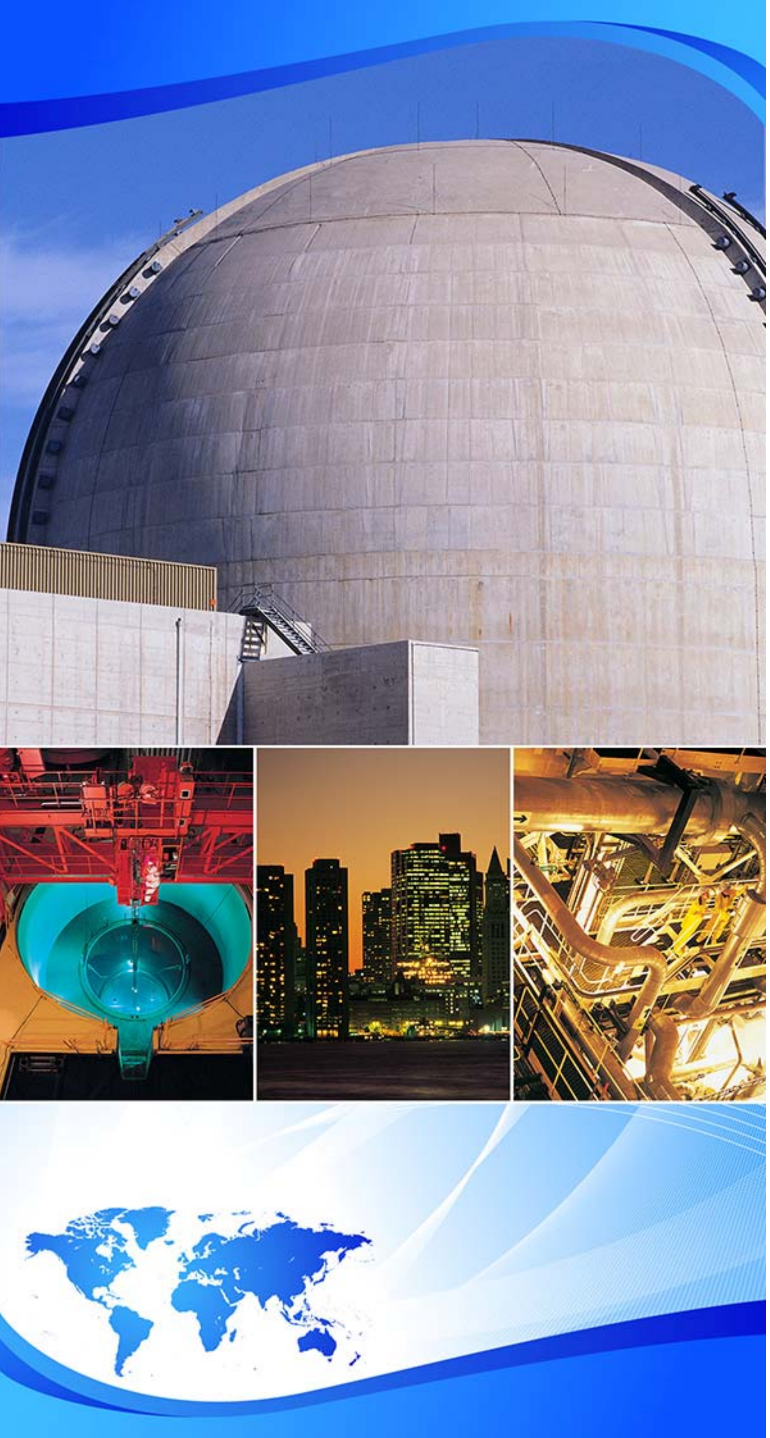

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Multi-facet Approach for Evaluating Criticality Risks during Transportation of Commercial Spent Nuclear Fuel

PATRAM 2010
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Topics

- Introduction
- Probability of Criticality Event during Transportation
- Misloading
  - Impact on nuclear reactivity
    - Under-burned fuel
    - Fresh fuel
- Fuel Reconfiguration
  - Impact on nuclear reactivity
  - Best-estimate fuel damage assessment
- Recap
- Conclusion

Introduction

Storage of Nuclear Fuel

No burnup restriction

Transportation of Nuclear Fuel

Restricted for burnup >45 GWd/MTU

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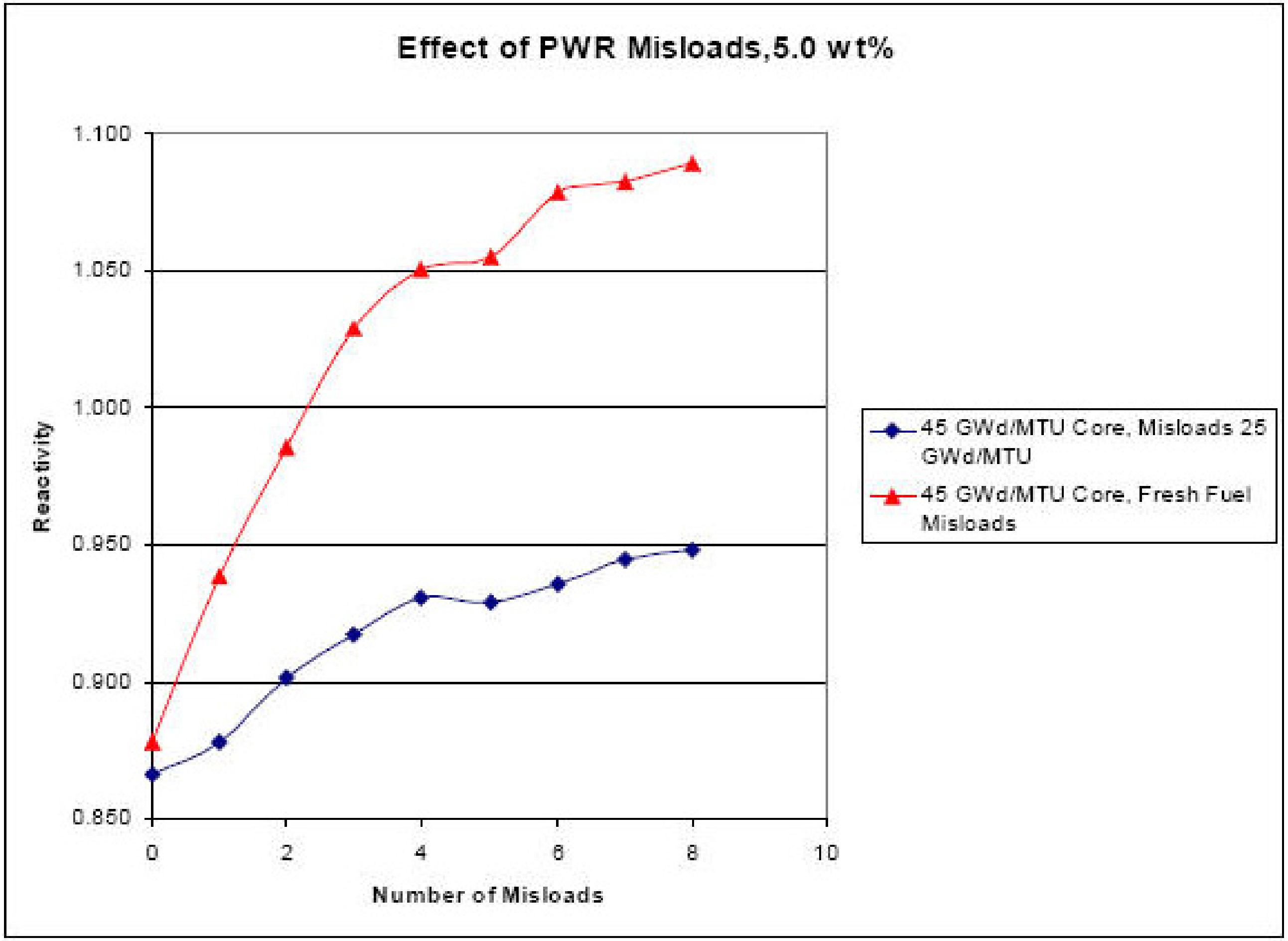
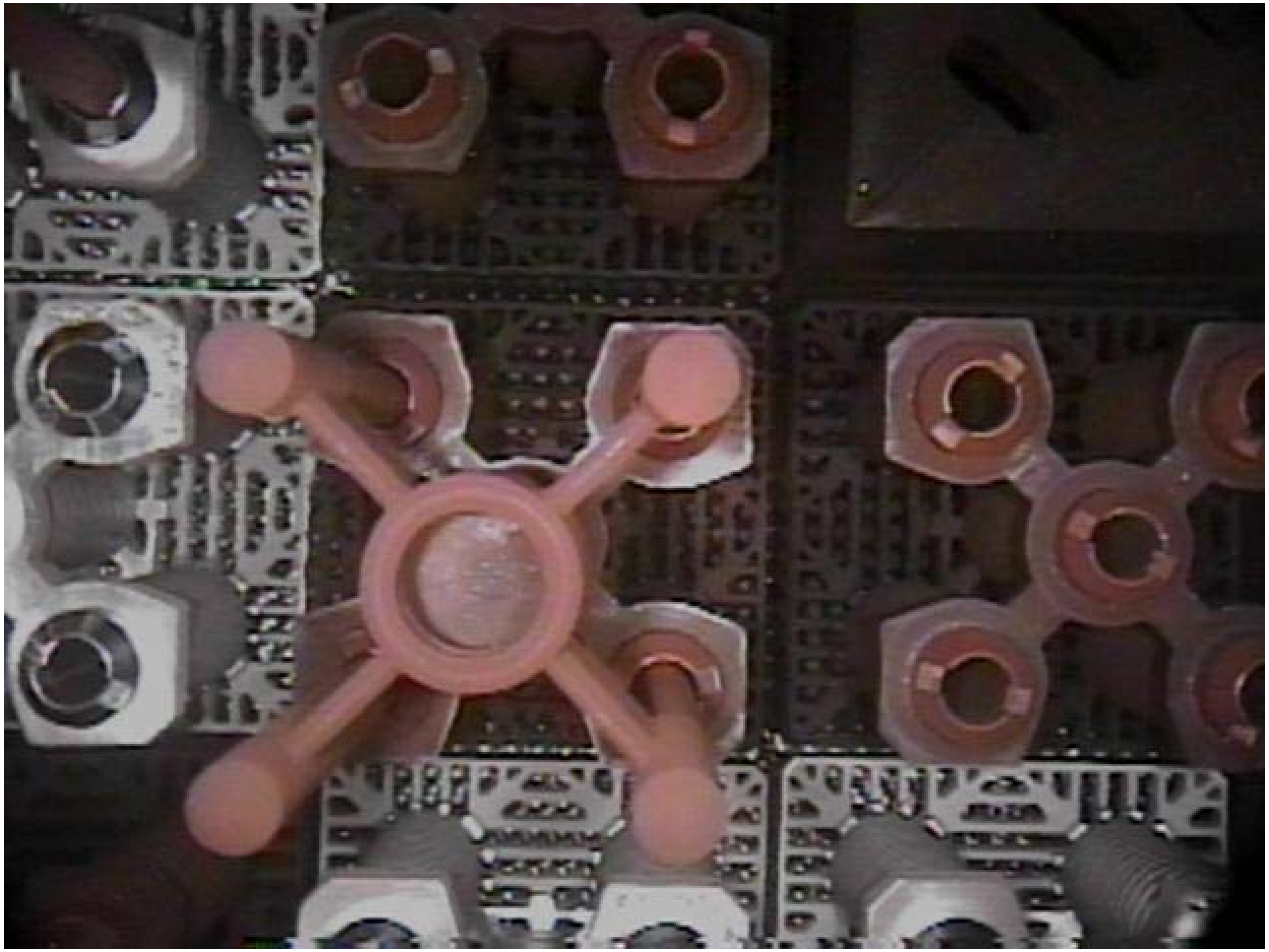
Probability of Criticality Event during Rail Transportation

Description	Freight Trains
Train Accidents per Train-Mile (All Accidents, All Speeds, All Track Classes), 2000 - May 2006.	2.7E-06
Probability of Accident of Interest, Given Any Accident (>2% Strain and Immersion) per Modal Study	7.8E-09
Frequency of Accidents of Interest for Criticality/Train-Mile	2.1E-14
Assumed Average Number of Miles per Shipment	2,000
Frequency of Accidents of Interest for Criticality/Shipment	4.2E-11
Likelihood of Shipping a Misloaded Spent Fuel Cask	2.6E-06
Likelihood of an Accident with a Potential for Criticality/Shipment	1.1E-16

Misloading of Under-burned and Fresh Fuel – Impact on Nuclear Reactivity (Cask k_{eff})



Misloading – Fresh versus Once-burned Assemblies



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)***	GBC-32 (45 GWd/MTU)	MPC-68 ***(fresh fuel)***
Single missing rod	0.0013	<0.0010	0.0036
Multiple missing rod	0.0140	0.0130	0.0120
Cladding removed from all fuel rods	0.0468	0.0349	0.0441
Fuel rubble (no cladding)	0.0563	0.0233	0.1[illegible]49
Assembly slips 20 cm above or below neutron poison panels	0.0021	0.0435	0.0362
Variation in pitch (without cladding)	0.0703	Not calculated	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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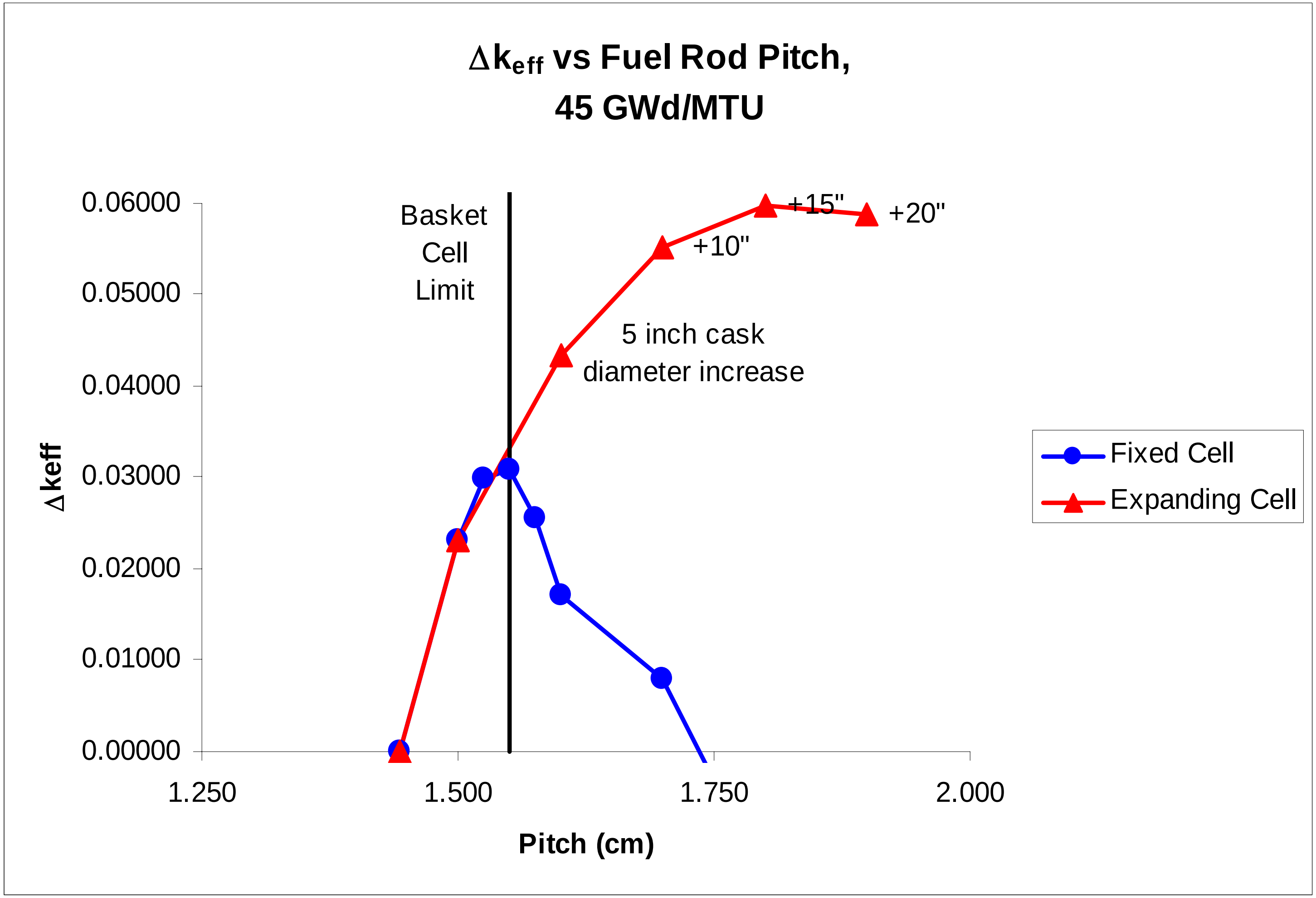
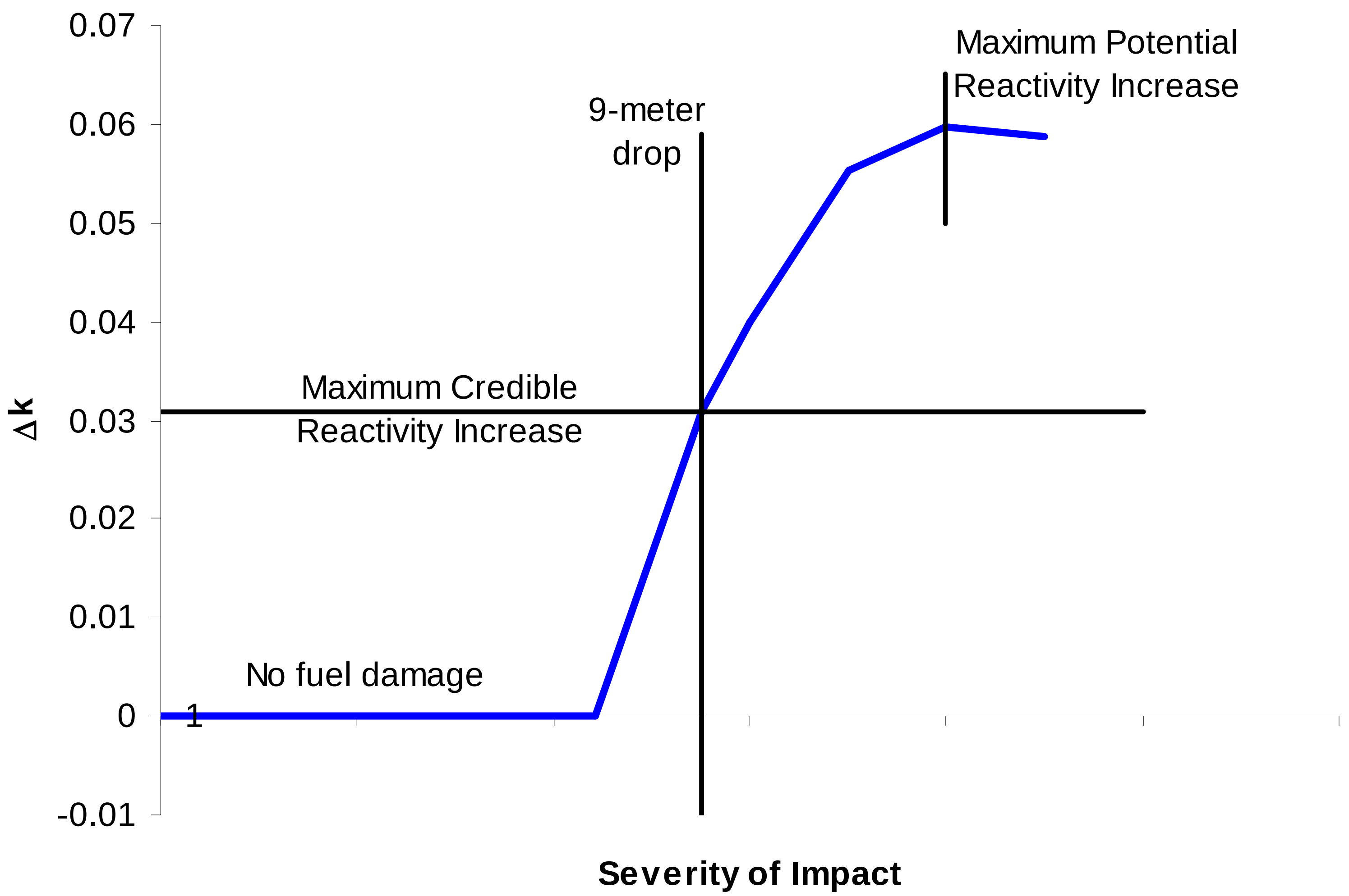
Fuel Reconfiguration – Worst Case Scenarios



Fuel Reconfiguration – Worst Case Scenarios



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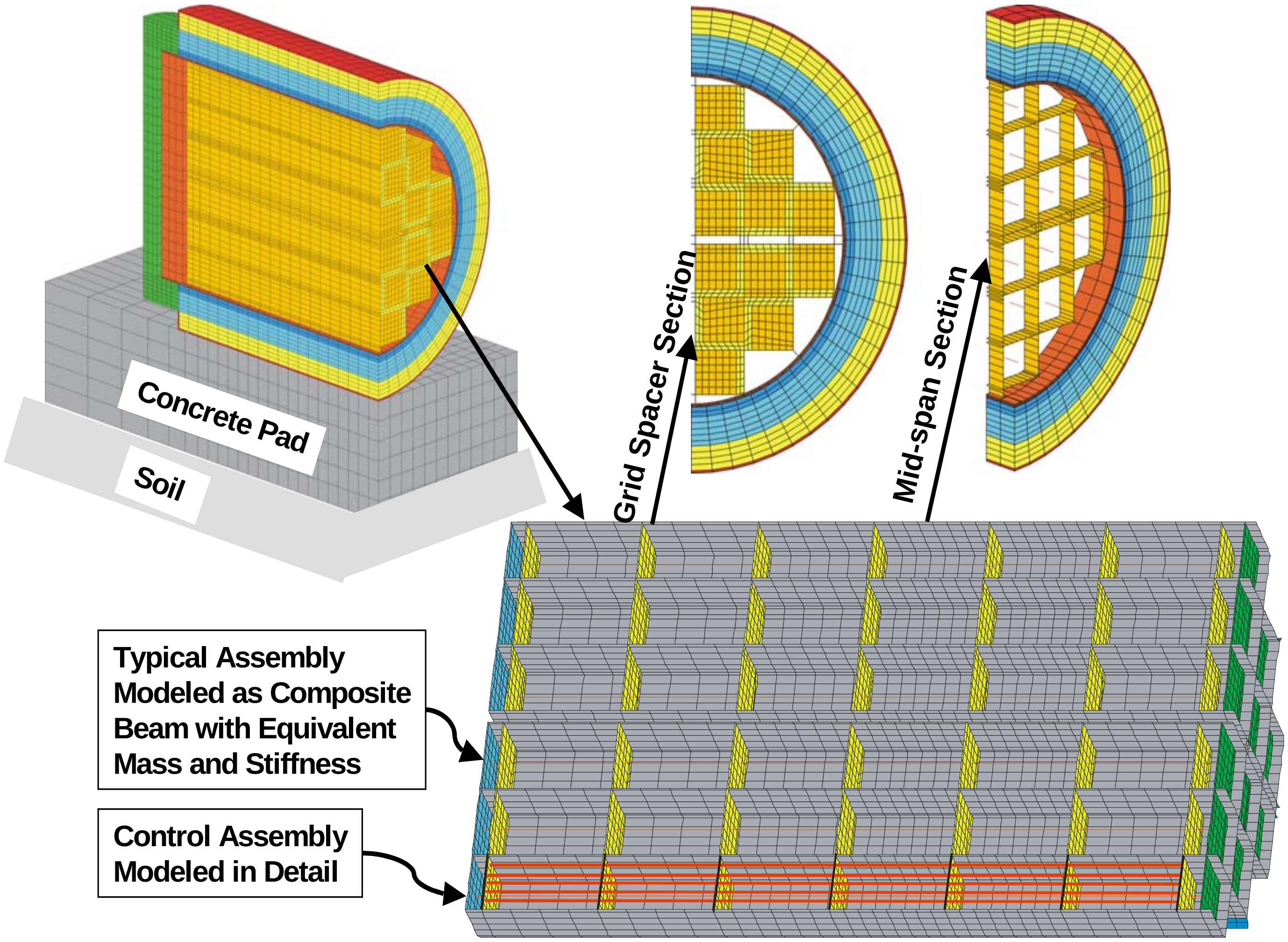
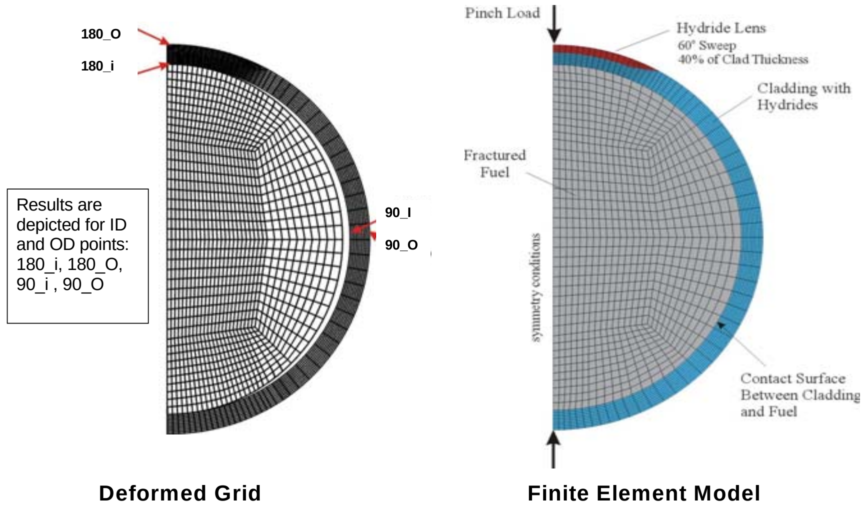
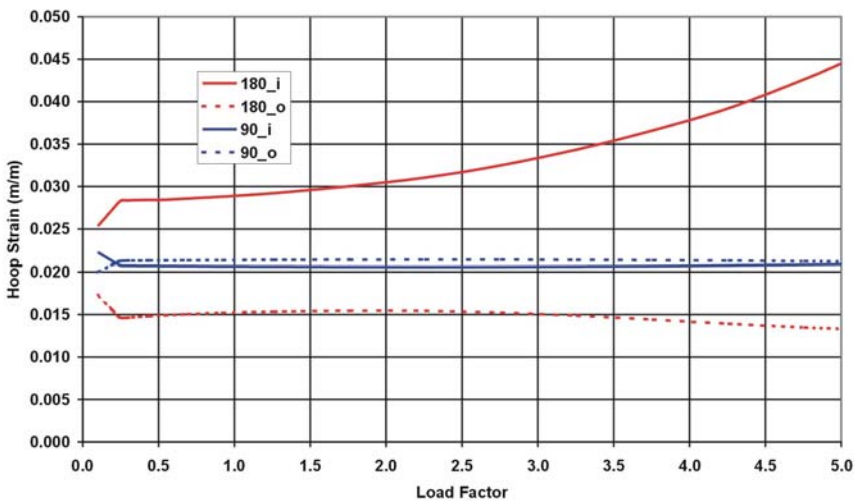
Fuel Damage Evaluation – Best-Estimate Approach



Fuel Damage Evaluation – Best-Estimate Approach





- 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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Recap

- Normal configuration of cask contents: k_{eff} <0.95
- Probability of criticality event during rail transportation accident: ~10^{-16}/shipment
  - Probability of accident
  - Conditional probability associated with accident severity and intrusion of moderator
  - Probability of one misloaded assembly in the cask
- Conservatisms
  - Multiple misloadings of severely under-burned or fresh fuel
  - Administrative controls (dedicated trains)
- 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

Conclusion

- No *credible* combination of rail transportation accident events and fuel misloading or reconfiguration can result in a critical configuration
- Overall transportation risks include non-radiological risks that are directly proportional to the number of shipments
  - Misallocation of regulatory requirements associated by radiological risks can lead to greater overall risks by overly restricting payloads
- High-capacity rail casks represent the lowest risk for transporting commercial spent nuclear fuel, regardless of the enrichment or burnup of the fuel