EPRI | ELECTRIC POWER RESEARCH INSTITUTE

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Session 1.1: Cladding Behavior for Regulatory Applications

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Spent Fuel Cladding Integrity – Opening Comments

- Normal and off-normal conditions: Managing fuel integrity is a key requirement
- Accident conditions: Precluding criticality is a key requirement
  - Cladding integrity: "Credible" assessment of cladding performance → feeds into criticality evaluation
  - Alternate approach: Choice of original geometry for evaluating subcriticality under *all* conditions → *no* fuel reconfiguration
    - Fuel burnup ≤45 GWd/MTU: OK
    - Fuel burnup >45 GWd/MTU: ???
  - Performance of the *confinement/containment* boundary: Key requirement (reflected in the existing regulations)

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Tractor-trailer Broadsided by a Train Locomotive Traveling at 80 miles per hour

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Transportation of Spent Fuel - Achieving Lowest Risk Levels

- Risk minimization drives to a reduction in the number of shipments
  - Use of large packages
    - Upper bound
  - Capacity optimization
    - Maximum number of spent fuel assemblies
- Transportation Risk Estimates
  - Criticality risks not included
    - Large body of work
  - Criticality risks
    - Limited body of work

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Risks in Transportation of Spent Fuel

	Normal Conditions	Accident Conditions
Criticality	§71.55(d) "Preclude"	§71.55(e) "Preclude"
Radiological	§71.47(d) §71.51(a)(1) "Small"	§71.55(d) §71.51(a)(2) "Very Small"[1]
Non-radiological	"---"	"Potential for fatal and nonfatal injury"

[1] Single shipment incident-free dose risks greatly exceed (>10^3-10^4) single shipment accident dose risks [Ref. NUREG/CR-6672, page E-6]

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Probability of a Criticality Event During Transportation of Spent Fuel

- Likelihood of a rail cask accident with >2% strain coupled with a concurrent submersion
  - "… this type of accident is estimated to occur once every ten million years." That is 10^{-7}/year.
    - Ref.: Rail shipping scenario of the Modal Study [NUREG/CR-4829]
  - "…relative to the Modal Study result, expected accident population dose risks for both rail and truck are further decreased by about two orders of magnitude"
    - Ref.: Reexamination of Spent Fuel Shipment Risk Estimates [NUREG/CR-6672]
- Likelihood of a critical configuration
  - Only possible by assuming misloadings of fresh fuel: estimated to be highly unlikely: ~10^{-6} to 10^{-10}/cask (actually, no fresh fuel assembly in the pool during cask loading campaign)
    - Refs.: EPRI 1003418 and unpublished NRC-sponsored work

Probability of a criticality event: <10^{-13}-10^{-17}/year!

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Maximum Increase in k_{eff} for Fuel Failure Scenario (from NUREG/CR-6835)

"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)

Scenario	GBC-32 (45 GWd/MTU)
Single missing rod	<0.0010
Multiple missing rod	0.0130
Cladding removed from all fuel rods	0.0349
Fuel rubble (no cladding)	0.0233
Assembly slips 8" above or below neutron poison panels	0.0435
Variation in pitch (without cladding)	Not calculated

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Spent Fuel Cladding Integrity – Closing Comments

- Risk information favors technologies that maximize transportation package capacity, and, thus, minimize the number of shipments
  - Moderator exclusion
  - Burnup Credit
  - Combination: Moderator exclusion, with a best-estimate burnup credit methodology for “defense-in-depth”
- Cladding integrity
  - Normal and off-normal conditions of storage and transportation
  - Accident conditions
    - What is the appropriate level of effort given:
      - Risk perspective: fine-tuning of regulations?
      - State-of-the-art cladding failure evaluation: engineering practice?
      - Learn from precedents and from others?

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