Spent Nuclear Fuel Transportation Casks Evaluation for Water In-Leakage

Mahendra J. Shah, Daniel T. Huang, Jack Guttmann
United States Nuclear Regulatory Commission (USNRC)

Nicholas A. Klymyshyn, Brian J. Koeppel, Harold E. Adkins
Pacific Northwest National Laboratory (PNNL)

Introduction

- Background / Objective
- Analytical Approach
- FEA Model
- Material Models
- Preliminary Results
- Current Status
- Conclusions

Background / Objective

- Spent nuclear fuel sub-criticality must be maintained at all times
- US Code of Federal Regulations, Title 10, Part 71[1] (10 CFR 71), section 71.55[1] requires assumption of water moderation under normal and accident conditions
  - defense-in-depth policy
  - Results in use of flux traps and/or neutron poisons

[1] Guidance featured in NUREG-1617, "Standard Review Plan for Transportation Packages for Spent Nuclear Fuel," and NUREG/CR-5661, "Recommendations for Preparing the Criticality Safety Evaluation of Transportation Packages”

Background / Objective (cont.)

- Quantify the level of conservatism or margin for spent nuclear fuel transportation packages resistance to water in-leakage

under normal and hypothetical accident conditions[2] (risk-informed).

[2] Per 10 CFR 71.71 & 71.73

Background / Objective (cont.)

- Ultimate goal - Quantify risk, Apply Risk-Insights in Regulatory Decisions, and Improve Transport Efficiency
  - Simplify basket construction
  - Increase physical space available
  - Enhance payload capacity (enrichment & burn-up)
- Fewer shipments = lower risk to public
- USNRC certified HI-STAR 100 & TN-68 considered for evaluation

HOLTEC HI-STAR 100 Cask

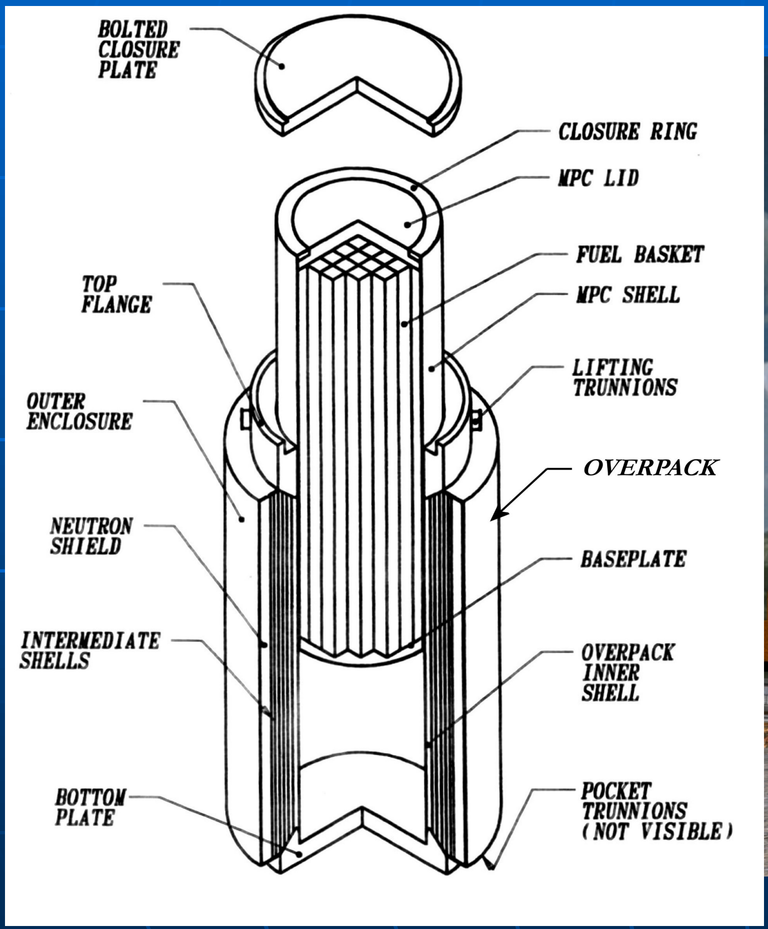
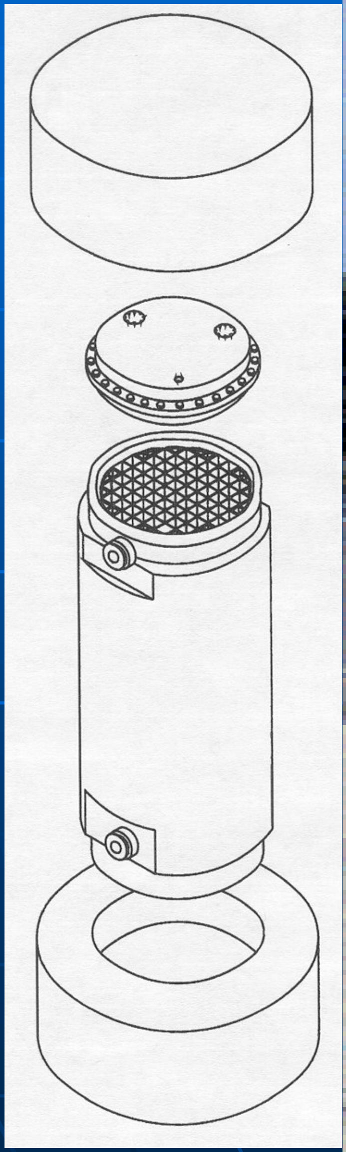


Image Courtesy of HOLTEC International

TN-68 Spent Fuel Cask



Analytical Approach

- Construct detailed Finite Element Analysis (FEA) models with ANSYS®
- Write to LS-DYNA™ input format
- Perform explicit evaluations using LS-DYNA™
- Perform drop evaluation(s) in accordance with 10 CFR 71.73 [30 ft (9 m) free drop impact onto an essentially unyielding surface]

Analytical Approach (cont.)

- A minimum of four drops analyzed for each transport system to determine worst orientation
  - Axial top-down drop
  - Side drop
  - CG-over-top corner drop
  - The slap-down to the top

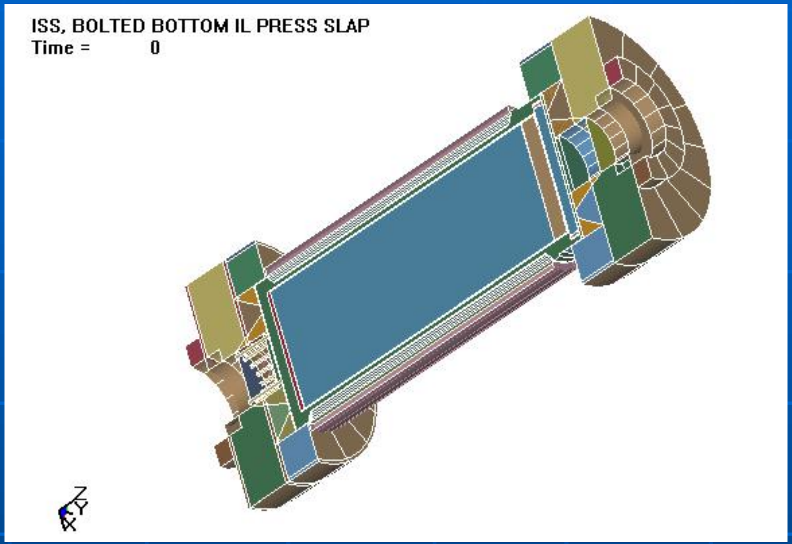
Analytical Approach (cont.)

- Other loadings considered
  - Bolt tension due to preload
  - Internal backfill pressure
  - Temperature dependent material strengths (PNNL thermal predictions utilized)
  - Residual stress due to fabrication
  - Non-linear plastic material behavior considered

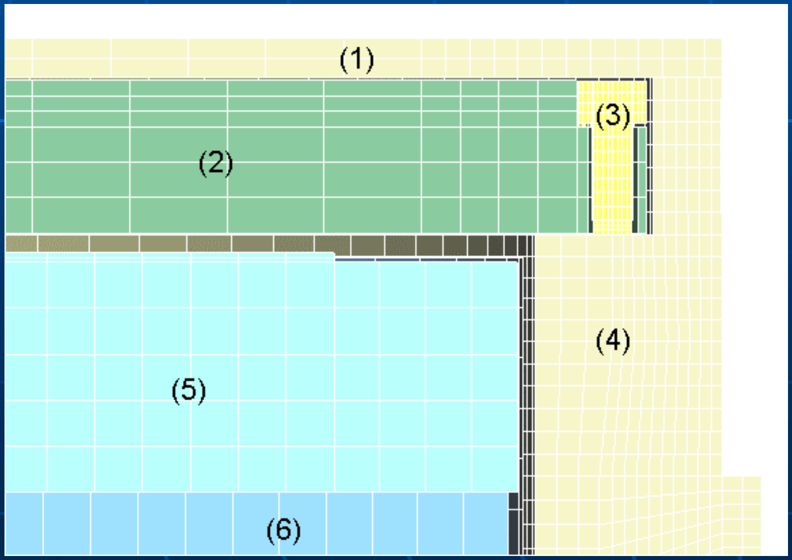
FEA Model

- 8-noded hexahedral element with full integration - main solid structural element (includes lid bolts & washers)
- 4-noded full-integrated shell elements - gamma & neutron shield layers, and impact limiter skin & sub-structure (less computational expense)
- Tiebreak connections - other non-complex loaded bolts
- Extreme detail in vicinity of lid and bolts - region of the greatest interest regarding containment

FEA Model (cont.)



FEA Model Geometry - HI-STAR 100



Top Portion of Cask w/o Limiter

- Impact Limiter Buttress Plate
- Bolted Closure Plate (Lid)
- Lid Bolt
- Top Flange
- MPC Lid
- Fuel Basket

Material Models

- Piecewise linear plastic material (LS-DYNA Type 24) - each solid steel & plate section
- Plastic bilinear material with kinematic hardening (LS-DYNA Type 3) - nickel alloy lid bolts
- Honeycomb material model (LS-DYNA Type 26) - aluminum impact limiter core
- Homogenized elastic material with representative density and modulus - basket and fuel assemblies

- Material examples for the HI-STAR 100 follow -

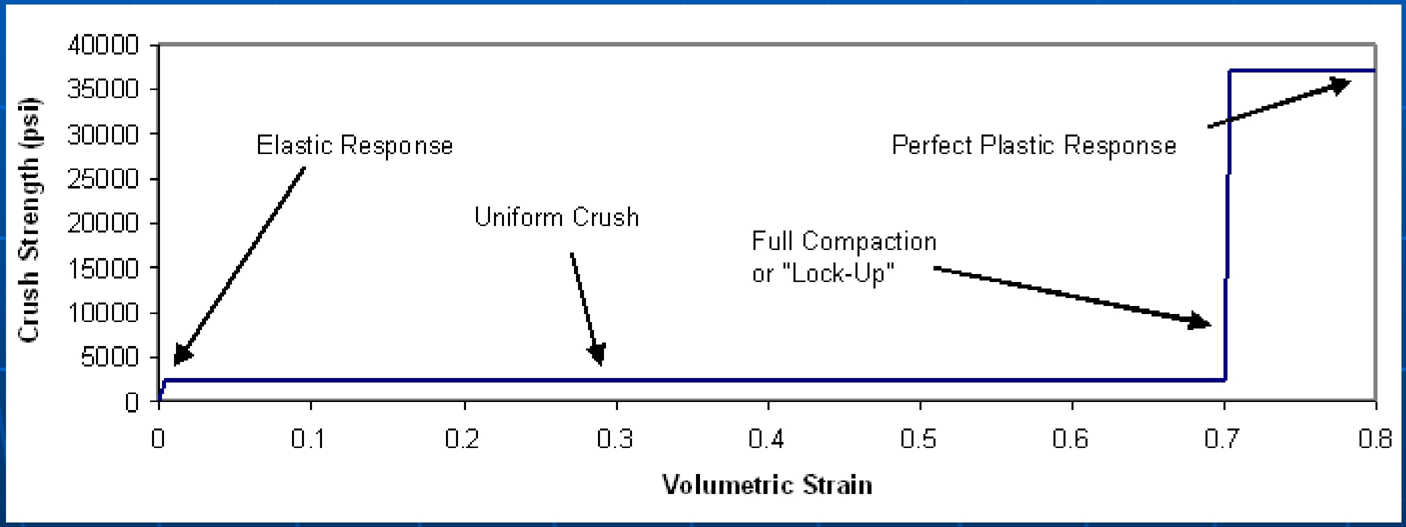
Material Models (cont.)

Hi-Star 100 Material Strengths

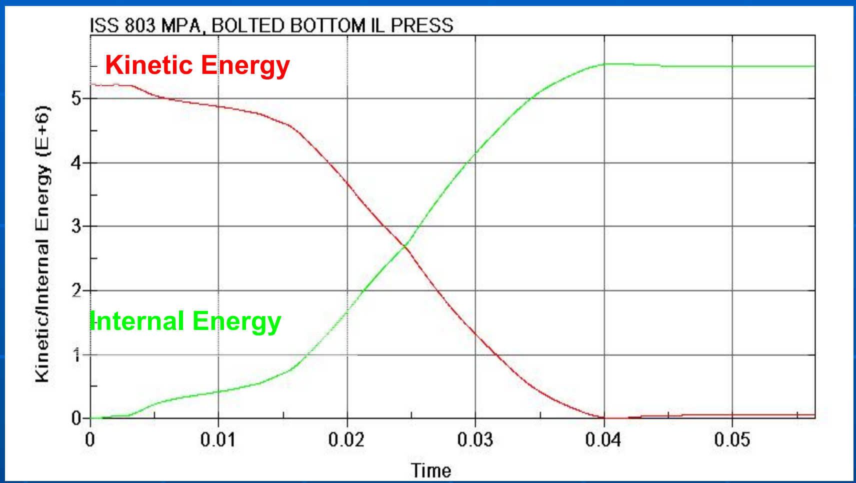
	Temperature (F)	Yield Strength (ksi)	Ultimate Strength (ksi)	Location
Alloy X	150	27.5	73.0	Impact Limiters Sub-structure
Alloy X	300	22.5	66.0	Top and Side Canister
Alloy X	450	20.0	64.0	Bottom Canister
SA350-LF	300	33.2	66.7	Cask Forging and Lid
SA515/516	225	34.4	70.0	Outer Cask
SA193-B8S	200	50.0	95.0	Bottom Impact Limiter Bolts
SB-637-N07718	225	150.0	185.0	Lid Bolts

Material Models (cont.)

Crush Strength vs. Volumetric Strain for HI-STAR 100
Aluminum Honeycomb Impact Limiter Material

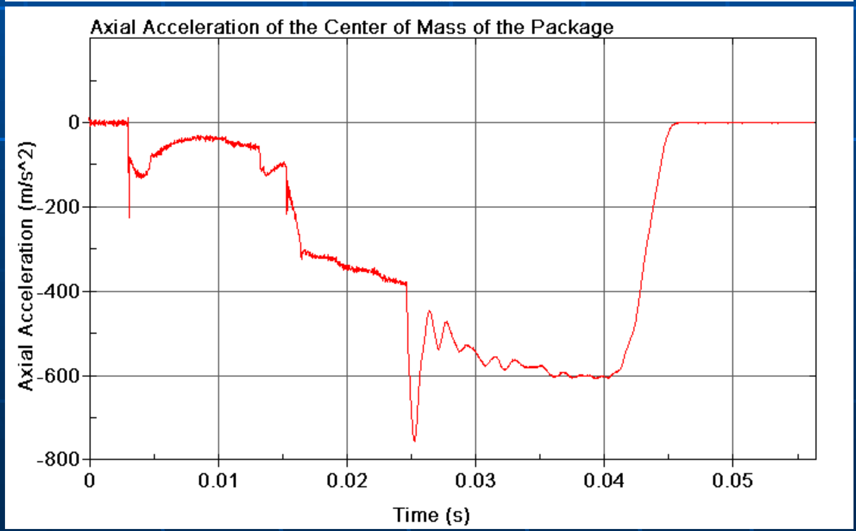


Preliminary Results



Kinetic and Internal Energy History

- Axial top-down drop
- Final version of the solution will only need to be run to 0.04s



Preliminary Acceleration History

- Behaving as expected in terms of maximum deceleration
- Testing showed 60 G deceleration under similar conditions
- Excluding 80G spike at 0.025s, peak deceleration approx. 60 G
- 80G spike coincides with canister striking cask lid due to initial gap

Current Status

- HI-STAR 100 analyses in their final stages
  - preliminary runs show contact surfaces, materials, and preloads are behaving satisfactorily
- TN-68 model is largely finished, and is following same build-up pattern
  - Implementation of bolt preloads, internal pressure, and wood impact limiter material properties remain

Conclusions

- Study could lead to quantification of risk to water intrusion in hypothetical accidents and risk-informed regulatory activities.
- Increased spent nuclear fuel transport efficiency.
- Initial results indicate the model features are working correctly.
- Preliminary acceleration results compare well with experimental data.
- Final structural results and evaluations are still forthcoming.

Questions ?