Demonstration of Safety in Nuclear Materials Transport

SAND2005-8001C

Seminar on Complex Technical Issues of Safety of Transport of Radioactive Material

International Atomic Energy Agency
January 11-12, 2006
Vienna, Austria

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Sandia National Laboratories

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Today's Presentation

International regulations ensure safe transport of nuclear materials

(Focus will be on Type B Spent Nuclear Fuel Casks)

- Safety Functions of Transport Casks
- Regulations
- Regulatory Tests
- Extra-Regulatory Tests and Analyses
- Current Technical Issues
- Conclusions

Safety Functions of SNF Transport Casks

- Transport casks are designed to address four principal safety functions:
  - **Containment** – cask must contain contents during normal and accident conditions
  - **Shielding** - cask must provide shielding from gamma and neutron radiation
  - **Criticality Control** - cask must prevent a nuclear chain reaction
  - **Heat Dissipation** - cask must dissipate heat from spent fuel assemblies

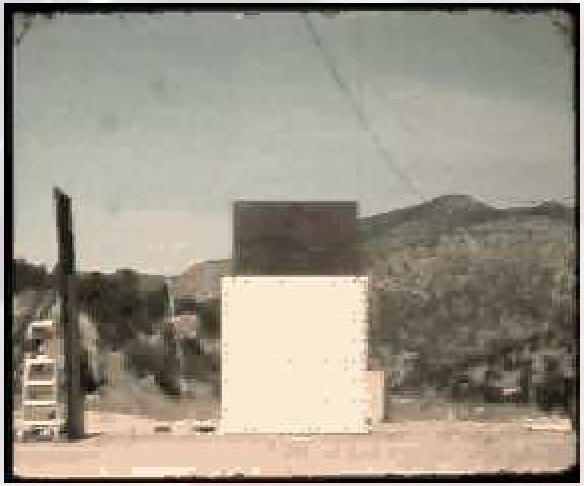
Regulatory Environment

- Transport in the public domain necessitates stringent requirements.
- The regulations are performance-based and define design requirements:
  - IAEA TS-R-1: Regulations for the Safe Transport of Radioactive Materials
    - Normal Conditions of Transport
    - Hypothetical Accident Conditions
      - Free drop
      - Puncture
      - Thermal
      - Immersion

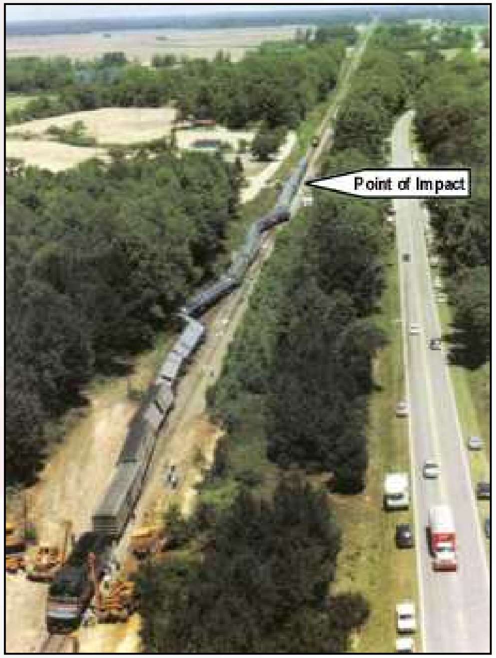
These test conditions envelope 99+% of all real accidents

Regulatory Testing Environments

- **Drop Test**
  - 9 meters = 48 kph (30 mph)
  - Unyielding target = 40 - 300g's
  - Cask oriented to cause maximum damage



3,000,000 lbs. of force present in this full-scale drop test

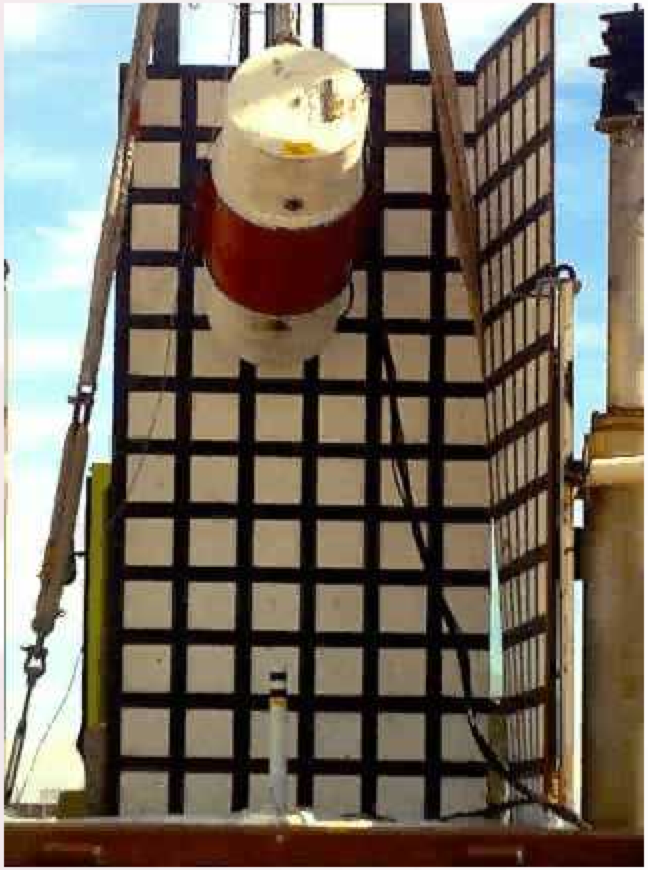


Train-Tractor/Trailer Impact: South Carolina, May 2, 1995

Less than 1,000,000 lbs. of force present in this real-life non-nuclear accident.

Regulatory Testing Environments

- **Puncture Test**
  - 1 meter = 16 kph (10 mph)
  - 15 cm (6″) ø steel pin welded to unyielding surface
  - Cask oriented to cause maximum damage



Regulatory Testing Environments

- **Thermal Test**
  - 30 minutes
  - Fully engulfing
  - 800°C (1475°F) minimum

Howard Street Tunnel Fire

Baltimore, Maryland July 18, 2001

- Peak Temperature ~1000C (1800F)
- Intense fire duration ~3 hours
- NRC analyses indicate that a Type B cask would have survived the fire environment without release of contents

Extra-Regulatory Testing

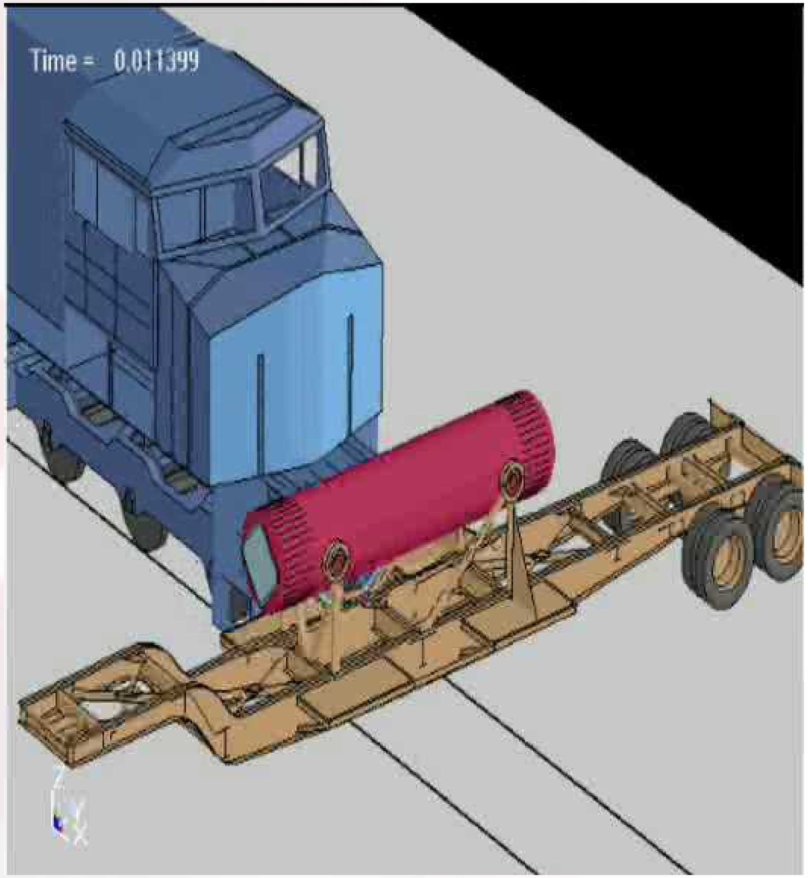
- **Full-Scale Rail Test at SNL**
  - A 74-ton cask on a railcar crashed into a 690-ton concrete block at 81 mph

Extra-Regulatory Testing

- **Full-Scale Railroad Grade Crossing Test at SNL**
  - A 25-ton cask on a semi-trailer was struck by a 120-ton diesel locomotive traveling at 81 mph
  - ~30 g loading

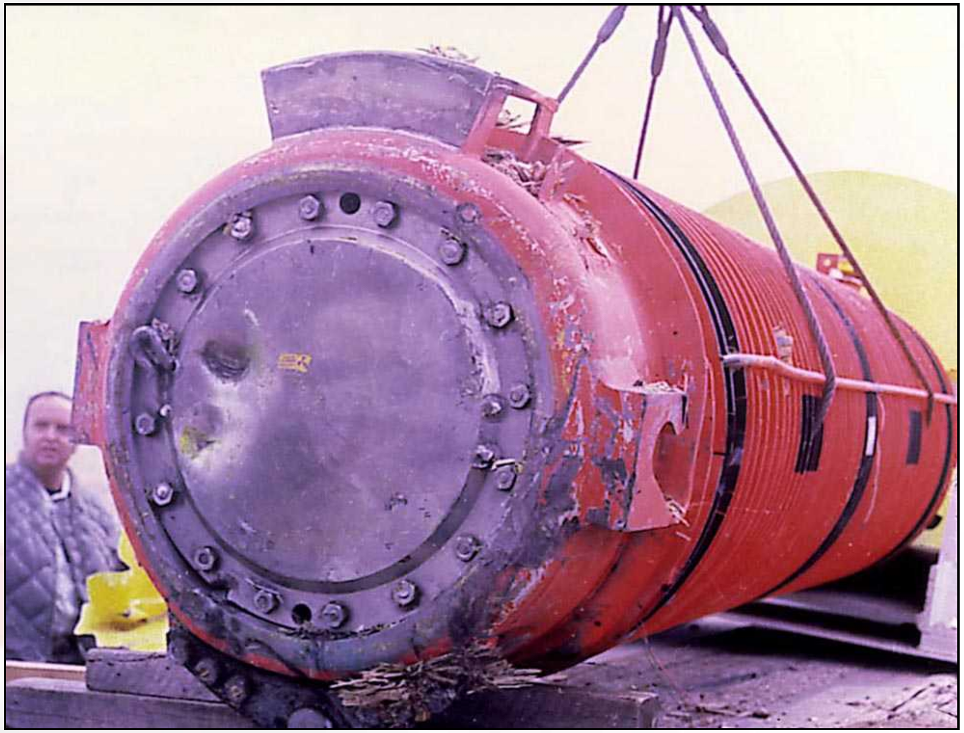
Extra-Regulatory Analysis

- Locomotive impact into a truck cask at a railroad grade crossing.
  - Analyses @ 70mph & 80mph
  - Limited plastic strains in bolts and localized plastic strain in the containment boundary
  - No failure in seal region or cask containment boundary



Extra-Regulatory Testing

- **Full-Scale Truck Testing at SNL**
  - A 22- ton cask on a flatbed semi-trailer crashed into a 690-ton concrete block at 84 mph
  - ~120 g loading



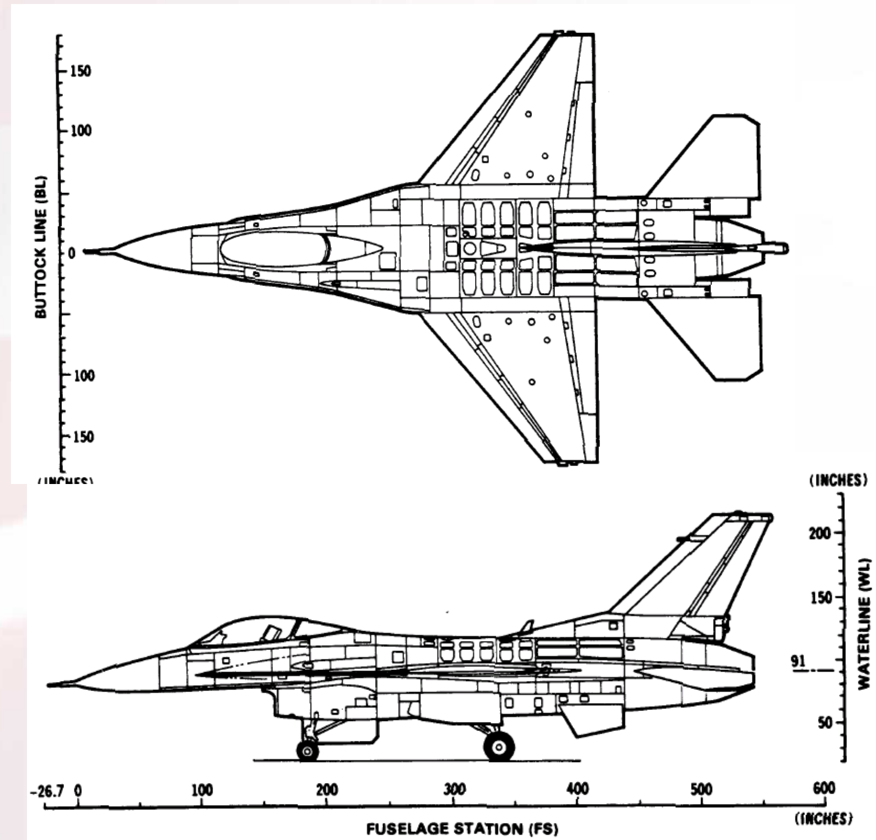
Aircraft Crash Test and Analysis

F-4 Crash Test

Velocity - 485 mph
Weight - 42,000 lbs

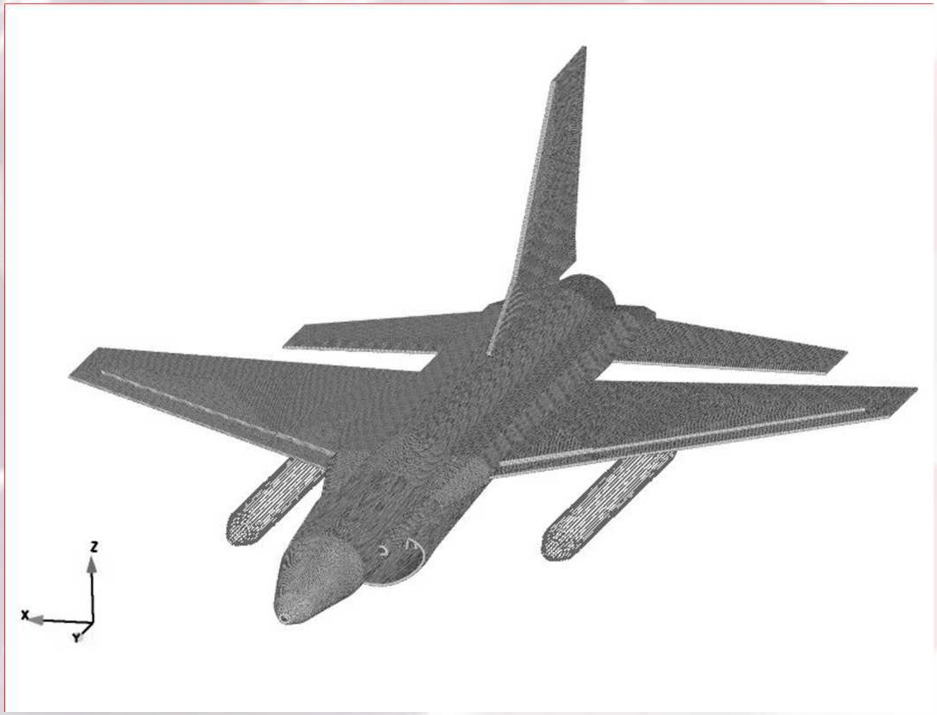
Aircraft Crash Test and Analysis

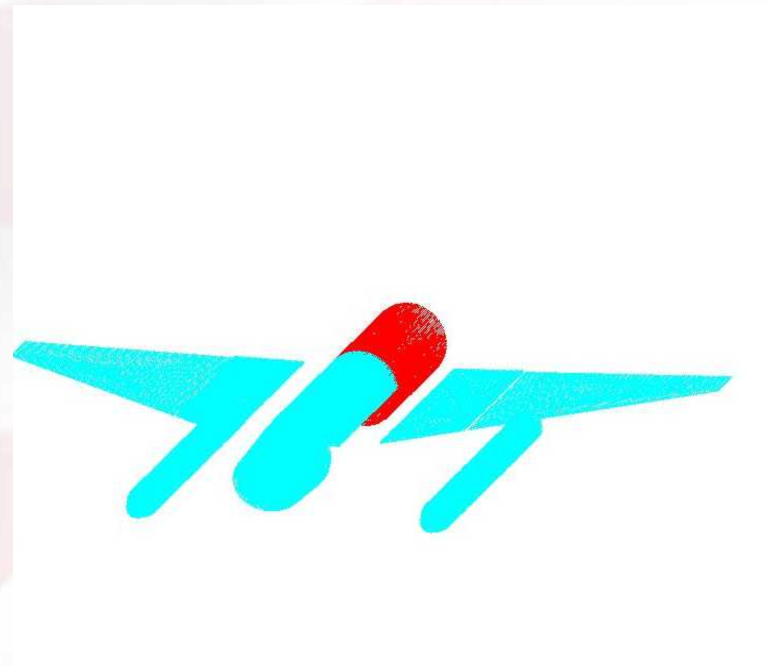
F-16 Aircraft Analysis



Estimated Weight 36,000lbs

Aircraft Crash Test and Analysis





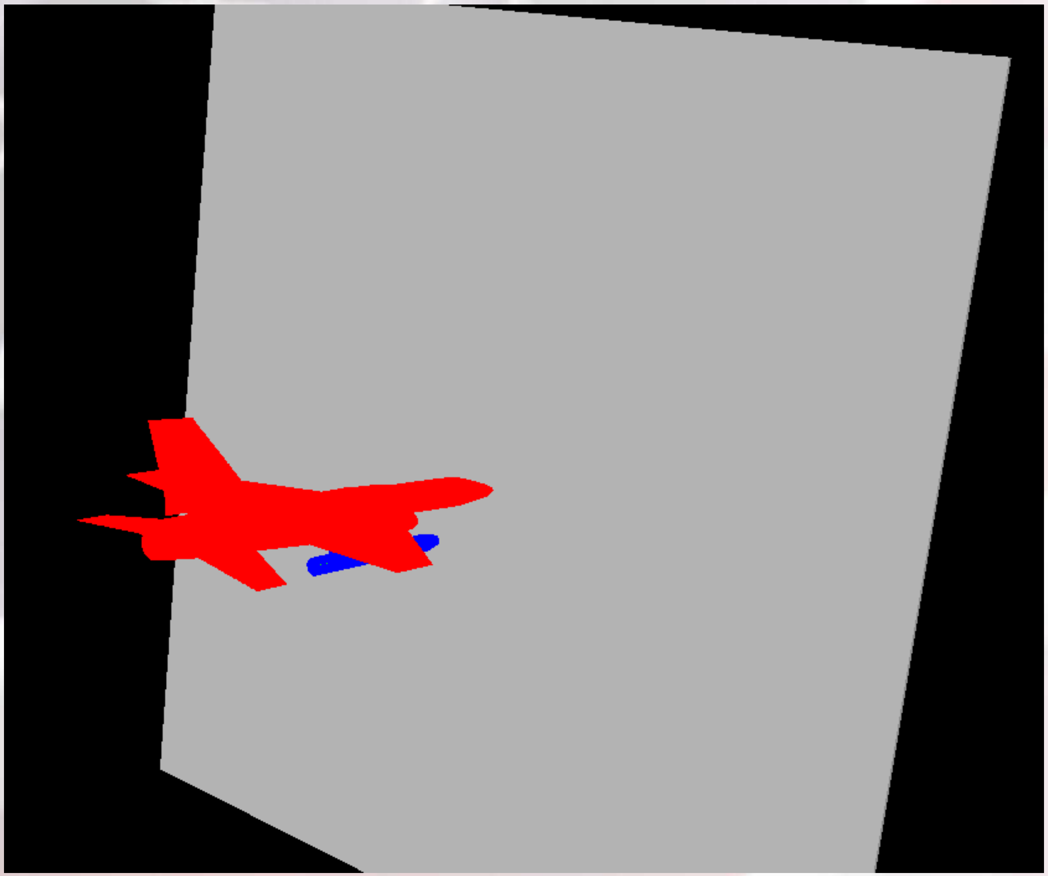
Smooth Particle Hydrodynamics (SPH) F-16 Model

(Mirrored for visualization purposes)
300,000 SPH elements in half-symmetry model

SPH F-16 Model Internals
Fuel Tanks and Engine

Aircraft Crash Test and Analysis

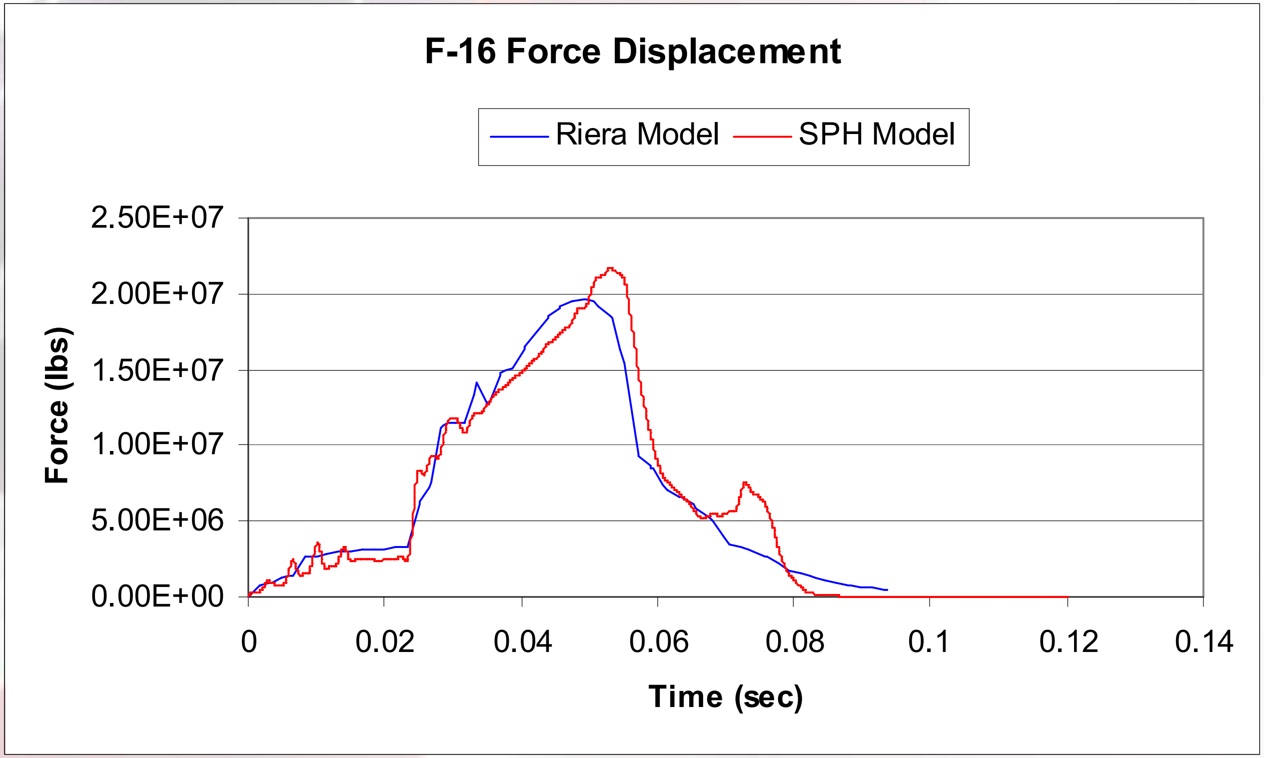
Model Verification



Aircraft Crash Test and Analysis

Model Verification
Force-Time-History Functions

Comparison of F-16 SPH Model and Riera Force-Time Functions



Benefits of Testing and Analysis

- The unyielding target produces very rigorous impact loading criteria relative to real-life accidents.
- The fully-engulfing fire produces very rigorous thermal loading criteria relative to real-life accidents.
- A significant amount of testing has been conducted that provides benchmark data for analytic verification.
- Benchmarked codes and analyses can then be used to evaluate many different scenarios without expensive testing.
- Testing provides insights into component response that may be missed in modeling and analysis.

Result: There will always be a need for some amount of testing, regardless of the sophistication of modeling and analyses

Current Complex Technical Issues

- **Full-scale testing is becoming important. Issues associated with these tests include:**
  - Large unyielding target (target mass is 10x test article mass)
  - Lifting test article
  - Temperature conditioning of the test article
  - Demonstration of scaling laws
    (U.K. Operation Smash Hit, 1983)

- **Fuel performance in an accident environment is not well understood.**
  - Little data on high burnup fuel cladding properties.
  - Little data or analyses on fuel response.
  - Canistered systems impact on cask performance.

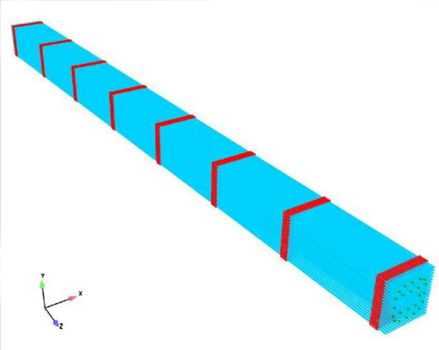
- **Energy transfer from external accident force to loading on fuel is not well understood.**
  - Compliance of cask systems in reducing energy inputs to fuel.

Current Complex Technical Issues

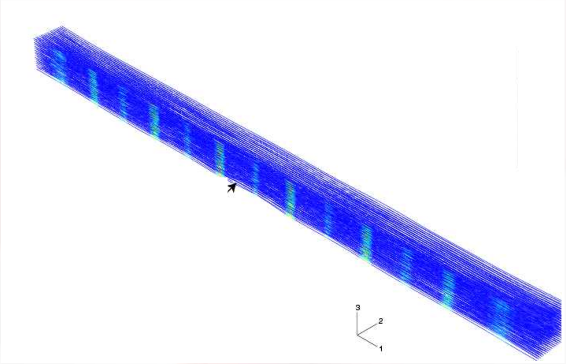
- **Full-scale Testing**
  - Scale model testing may not provide complete full-scale response characteristics (e.g. seals and welds).
  - Public comments in U.S. consistently ask for full-scale tests.

Current Complex Technical Issues

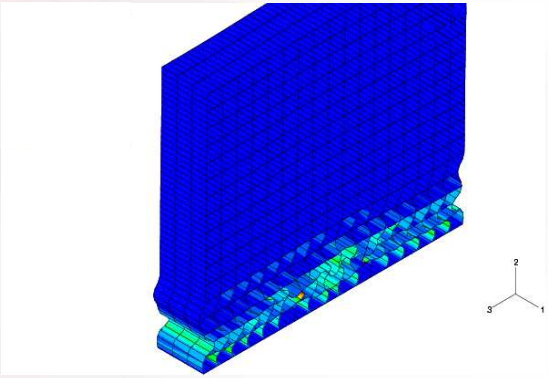
- **Fuel Performance**
  - Fuel performance is an important safety and operational issue.
  - Correct energy inputs, mechanical properties, and analyses provide quantifiable estimates of fuel behavior.



Finite element model of a PWR fuel assembly with spacer grids



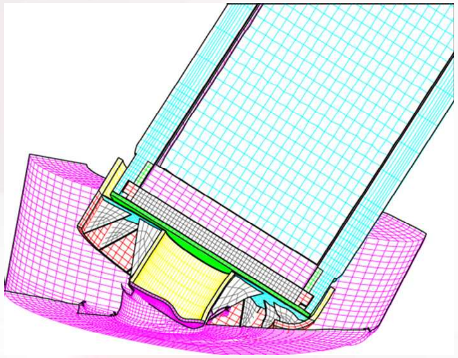
Side drop analysis of the PWR fuel rod



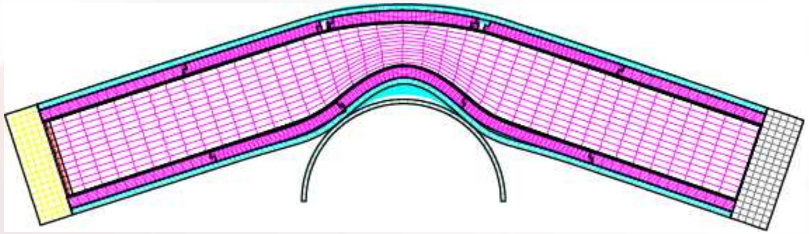
Side drop analysis of the spacer grid

Current Complex Technical Issues

- **Energy Transfer**
  - test data usually tracks rigid-body cask decelerations
  - analyses usually homogenizes fuel cavity only to simulate mass
  - certification testing and analyses provide little information on fuel response
  - energy transfer is dependent on;
    - cask design
    - impact orientation



Center-of-gravity over corner
9 meter drop test analysis



"Backbreaker" Analysis

Conclusions

- Testing has demonstrated that current regulations bound historical accident severities.
- Benchmarked analyses are very useful in comprehensively assessing cask response to a wide range of loading events.
- Resolution of identified technical issues will provide enhanced operational safety, increase understanding of how cask systems respond to accident environments, and increase public confidence.