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# Demonstration of Safety in Nuclear Materials Transport

## Presentation to UNM Engineering Class

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# Today’s Presentation

## International regulations ensure safe transport of nuclear materials

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

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

# Safety Functions of SNF Transport Packages

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

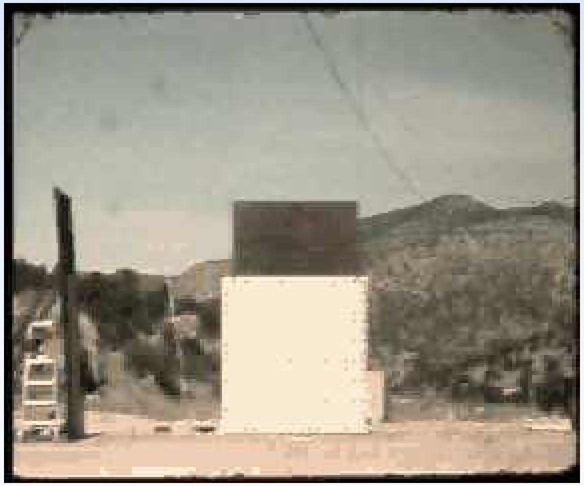
# Regulatory Environment

- 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

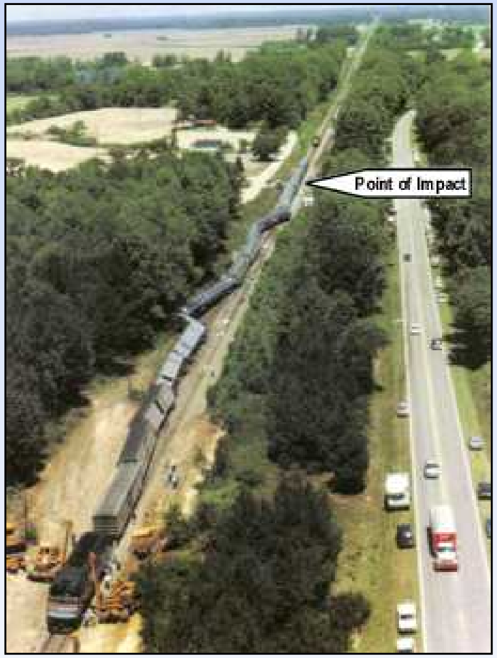
These test conditions envelope 99+% of all real accidents

# Regulatory Testing Environments

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



1,300,000 kgs (2,860,000 lbs.) of force present in this full-scale drop test




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

Less than 450,000 kgs (990,000 lbs.) of force present in this real-life non-nuclear accident.

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# Regulatory Testing Environments

- **Puncture Test**
  - 1 meter = 16 kph (10 mph)
  - 15 cm (6″) ø steel pin welded to unyielding surface
  - Package 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 package would have survived the fire environment without release of contents

# Extra-Regulatory Testing

- **Full-Scale Rail Test at SNL**
  - **A 74-ton package on a railcar crashed into a 690-ton concrete block at 130 kph (81) mph**

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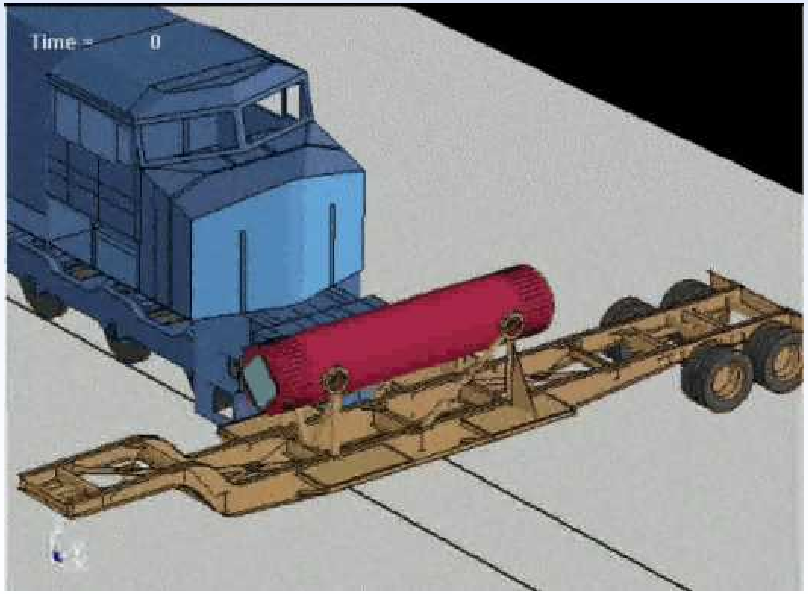
# Extra-Regulatory Testing

- **Full-Scale Railroad Grade Crossing Test at SNL**
  - **A 25-ton packaging on a semi-trailer was struck by a 120-ton diesel locomotive traveling at 130 kph (81 mph)**
  - **~30 g loading**

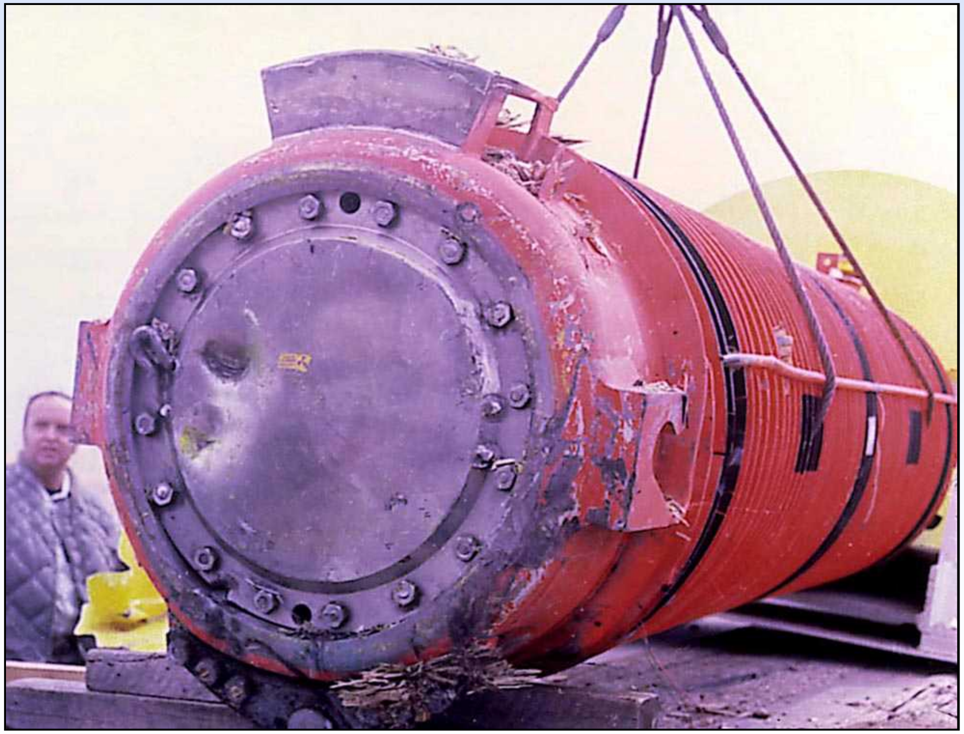
# Extra-Regulatory Analysis

- **Locomotive impact into a truck package at a railroad grade crossing.**
  - **Analyses at 113 kph (70mph) and 130 kph (80mph)**
  - **Limited plastic strains in bolts and localized plastic strain in the containment boundary**
  - **No failure in seal region or packaging containment boundary**



# Extra-Regulatory Testing

- **Full-Scale Truck Testing at SNL**
  - **A 22-ton package on a flatbed semi-trailer crashed into a 690-ton concrete block at 135 kph (84 mph)**
  - **~120 g loading**



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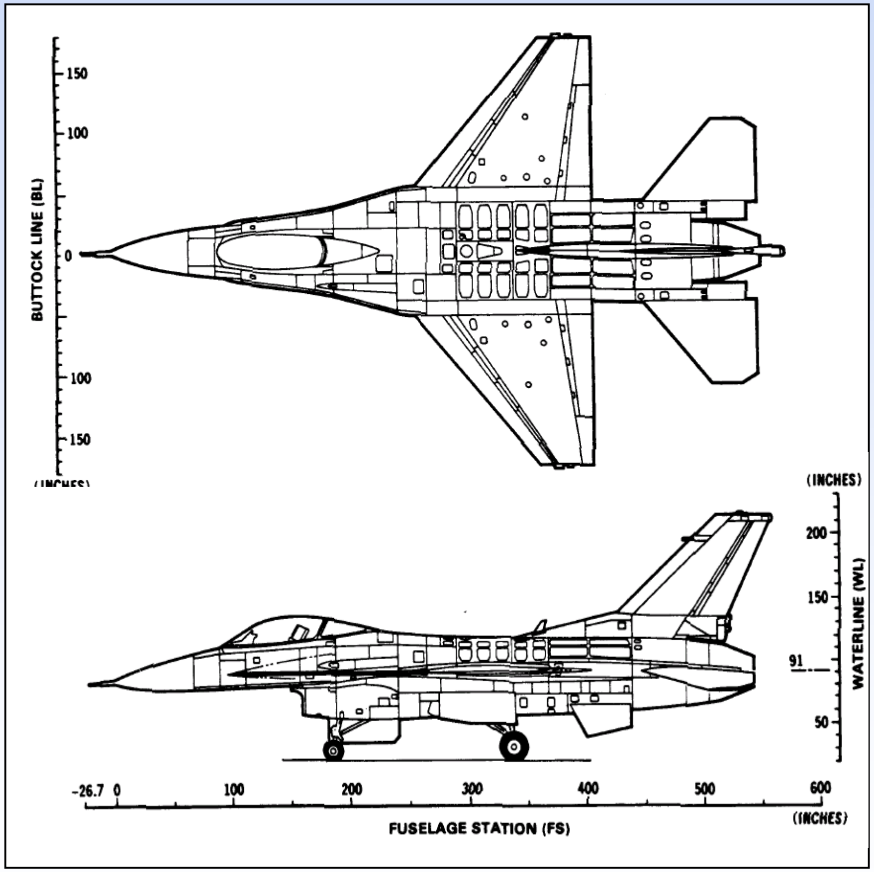
# Aircraft Crash Test and Analysis
## F-4 Crash Test

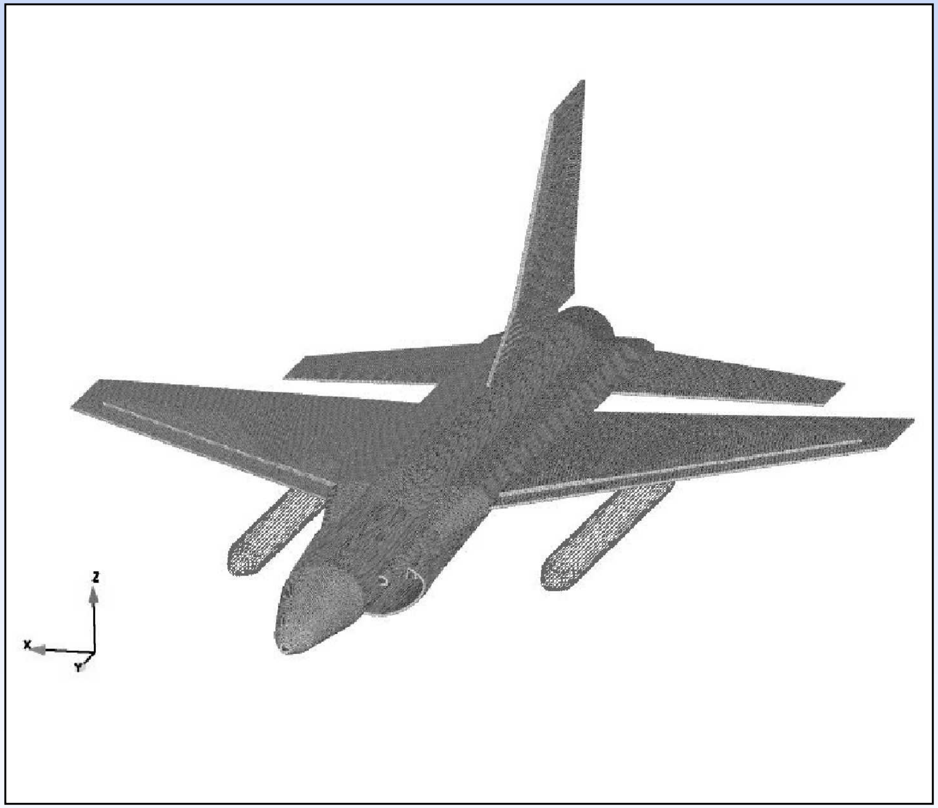
**Velocity – 780 kph (485 mph)**
**Weight – 18,750 kgs (41,250 lbs)**

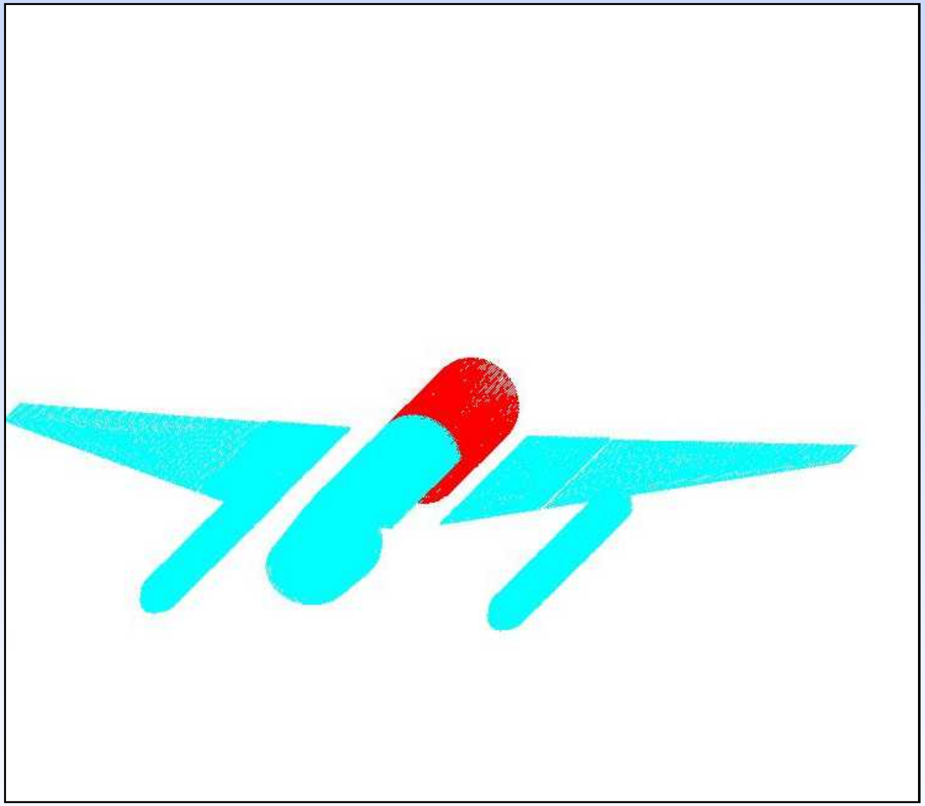
# Aircraft Crash Test and Analysis
## F-16 Aircraft Analysis

**Estimated Weight 16,100 kgs (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**

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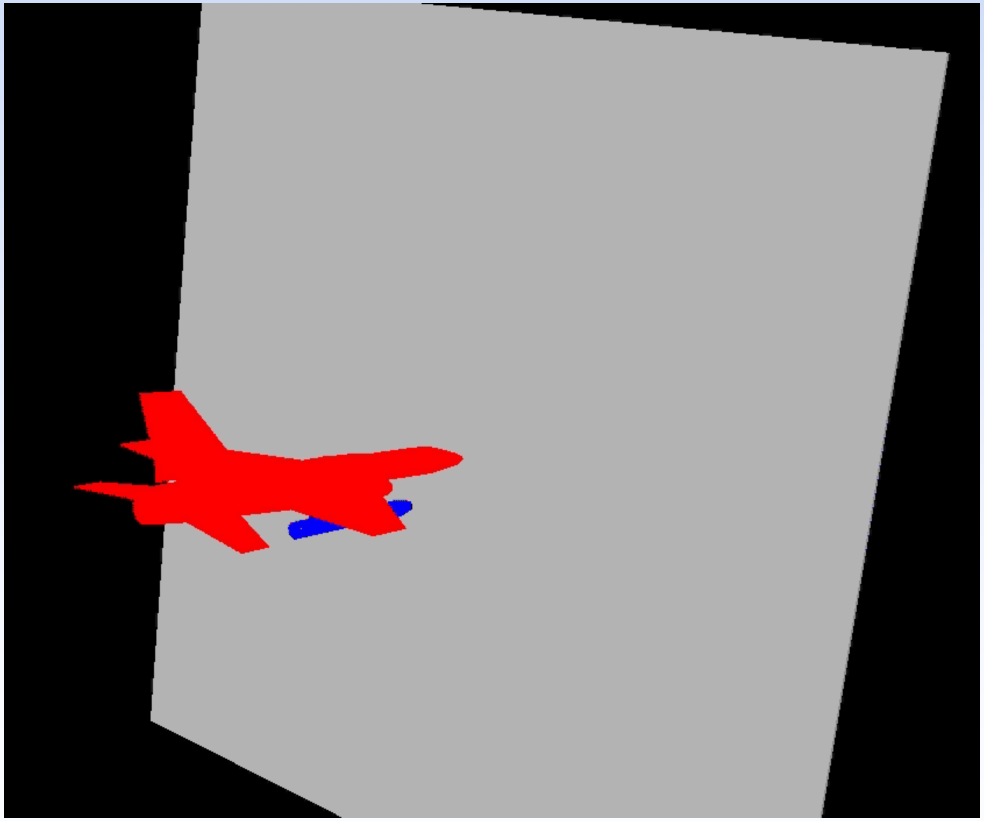
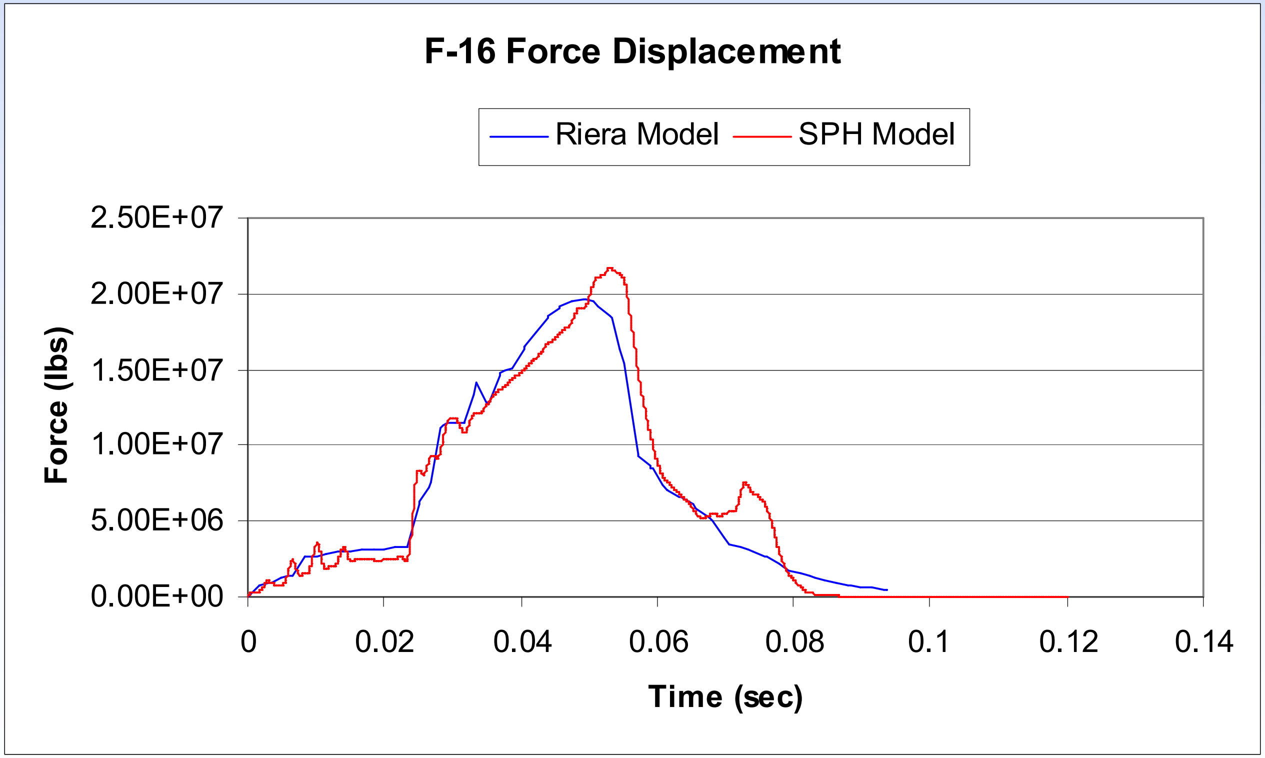
# Aircraft Crash Test and Analysis
## Model Verification



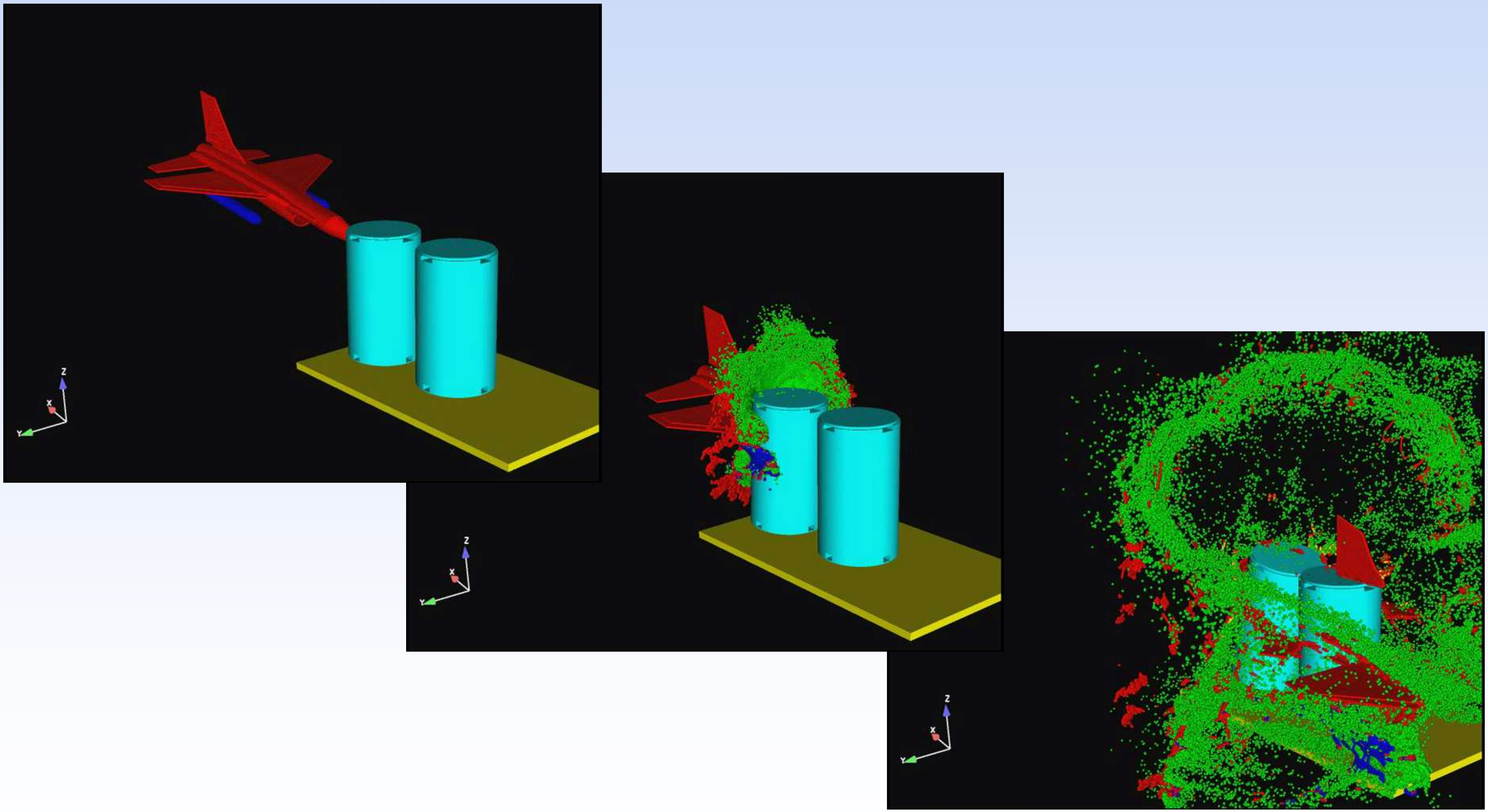
# Aircraft Crash Test and Analysis
## Model Verification
## Force-Time-History Functions

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



# Aircraft Crash Test and Analysis

## Model Analysis



# 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 package performance.**

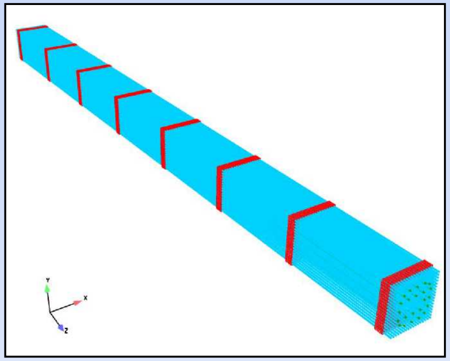
- **Energy transfer from external accident force to loading on fuel is design dependent.**
  - **Compliance of package systems in reducing energy inputs to fuel.**

# Current Complex Technical Issues

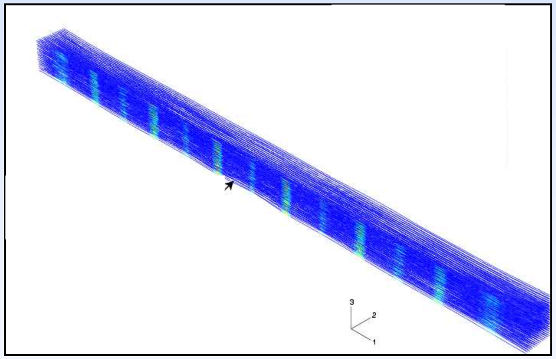
- **Full-scale Testing**
  - **Scale model testing may not provide complete full-scale response characteristics (e.g. seals and welds).**
  - **Public comments in U.S. consistently ask for full-scale tests.**

# Current Complex Technical Issues

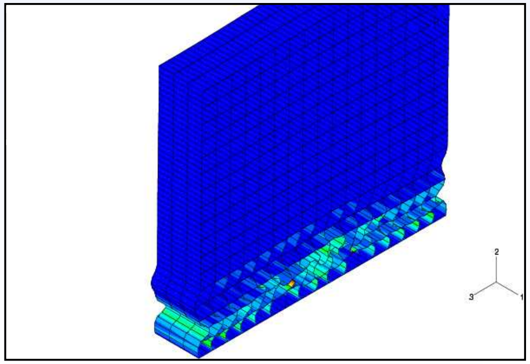
- **Fuel Performance**
  - Fuel performance is an important safety and operational issue.
  - Correct energy inputs, mechanical properties, and analyses provide quantifiable estimates of fuel behavior.



Finite element model of a PWR fuel assembly with spacer grids



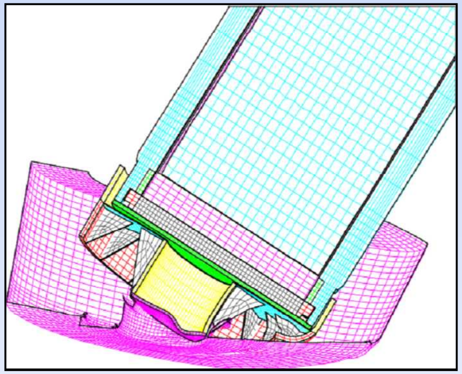
Side drop analysis of the PWR fuel rod



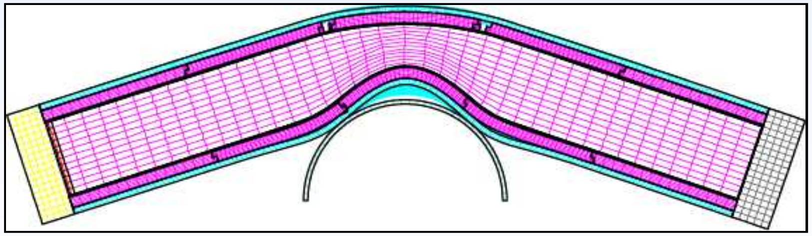
Side drop analysis of the spacer grid

# Current Complex Technical Issues

- **Energy Transfer**
  - test data usually tracks rigid-body package 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:
    - packaging 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 package response to a wide range of loading events.**
- **Resolution of identified technical issues will provide enhanced operational safety, increase understanding of how package systems respond to accident environments, and increase public confidence.**