SAND2007-3063P

Safety and Security in Nuclear Materials Transport

Study Tour for Chinese PUNT Delegation

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Ken B. Sorenson

Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

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Today's Presentation

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

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

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Safety Functions of SNF Transport Packages

- **Transport packages 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

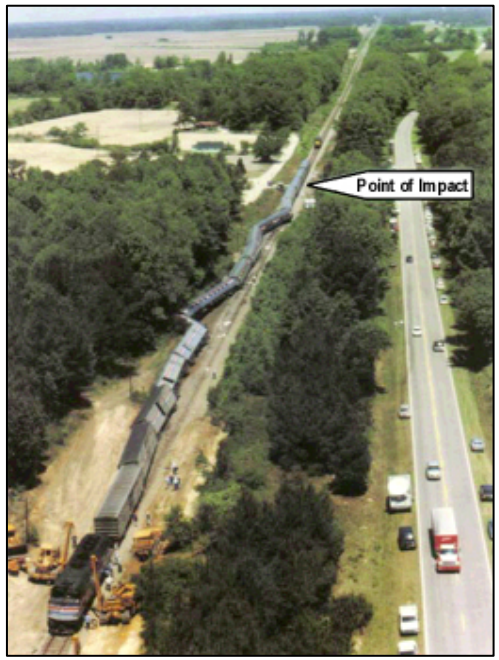
- **Transport in the public domain necessitates stringent requirements.**
- **The regulations are performance-based and define design requirements:**
  - **IAEA TS-R-1: Regulations for the Safe Transport of Radioactive Materials**
  - **Normal Conditions of Transport**
  - **Hypothetical Accident Conditions**
    - **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 (~3,000,000 lbs.) of force present in this full-scale drop test



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

Less than 450,000 kgs (~1,000,000 lbs.) of force present in this real-life non-nuclear accident.

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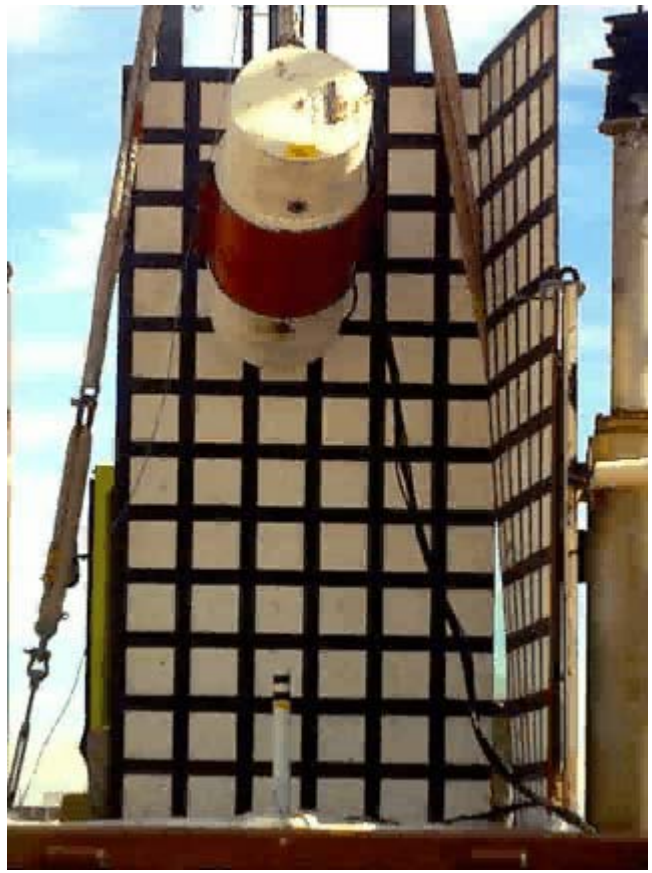
Regulatory Testing Environments

- **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**

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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**

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**

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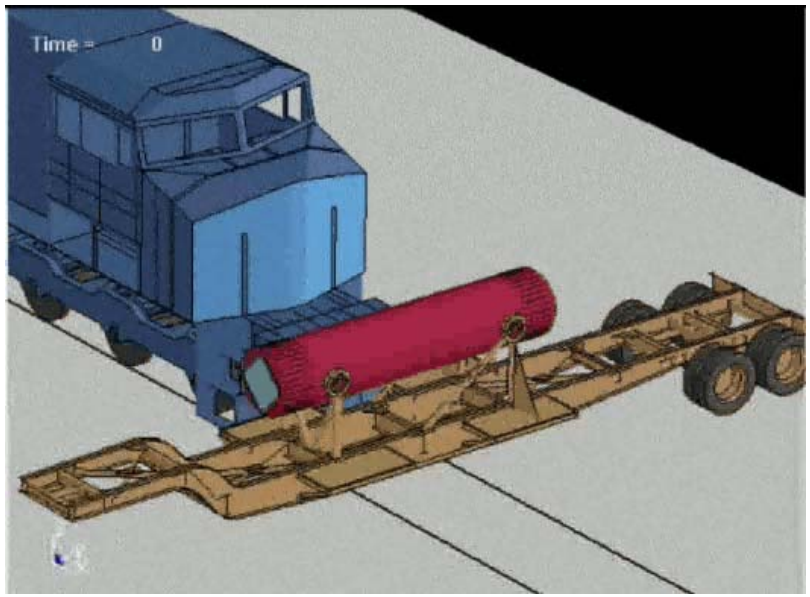
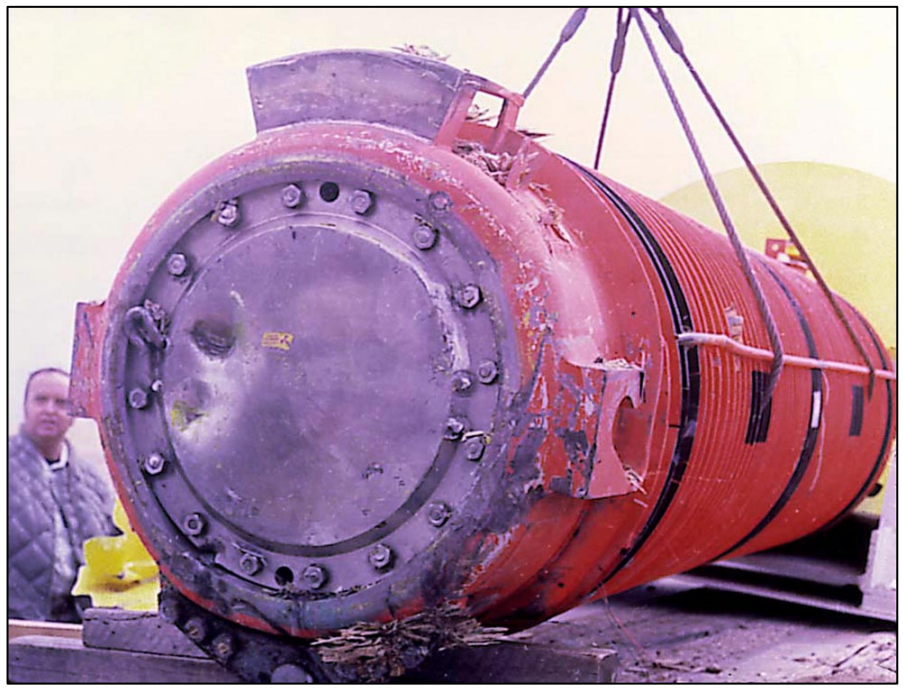
Extra-Regulatory Analysis

- **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-16 Crash Test

Velocity – 780 kph (485 mph)
Weight – 18,750 kgs (42,000 lbs)

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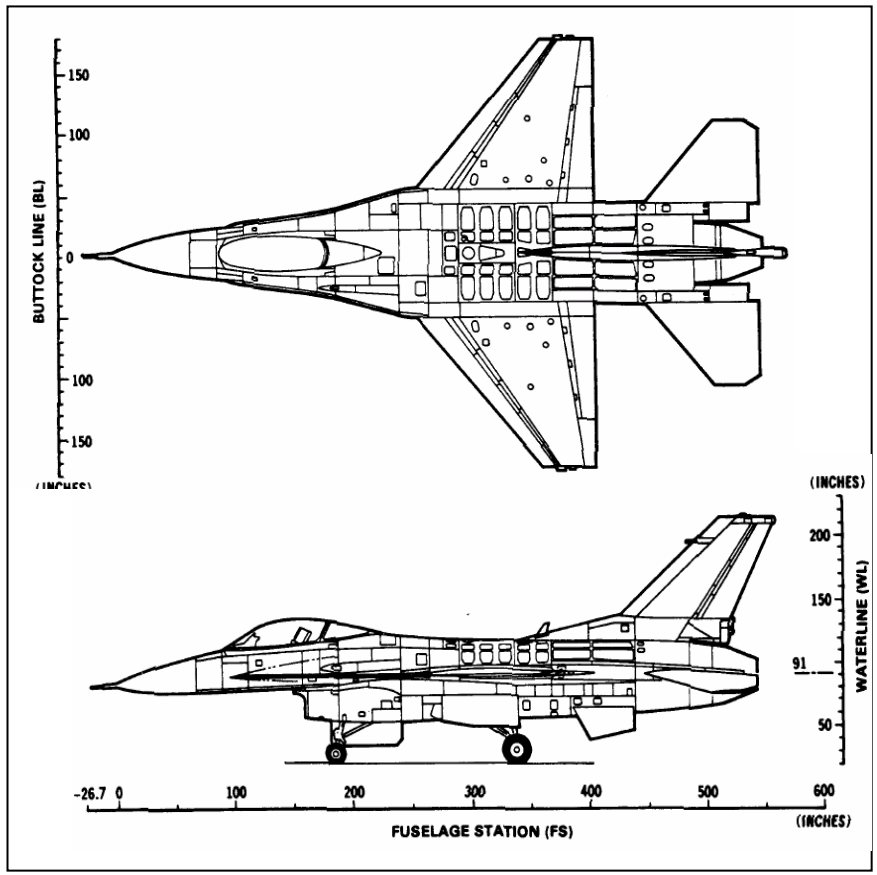
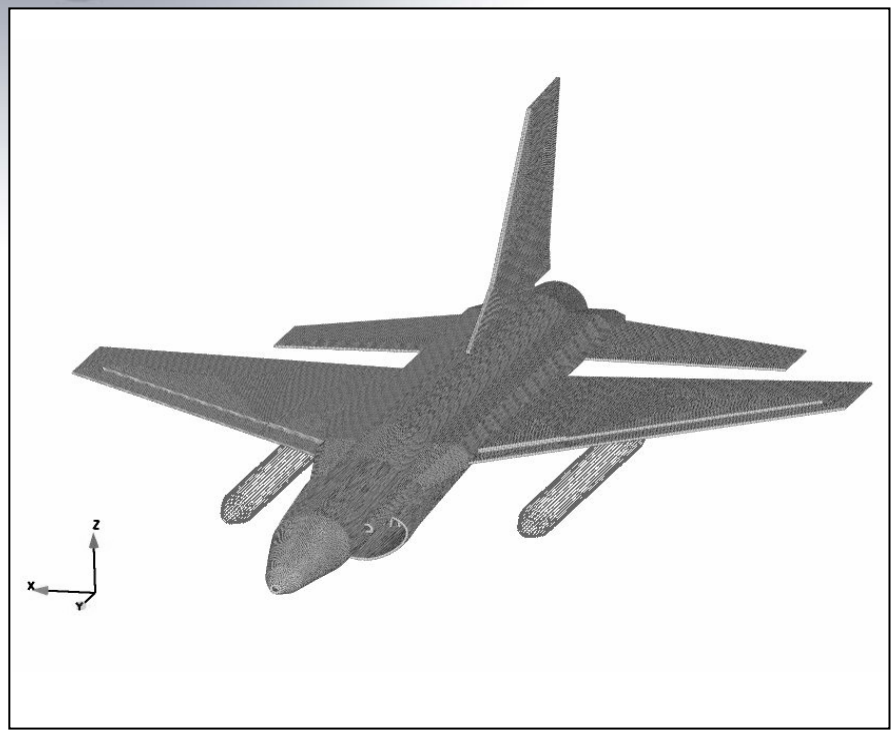
Aircraft Crash Test and Analysis

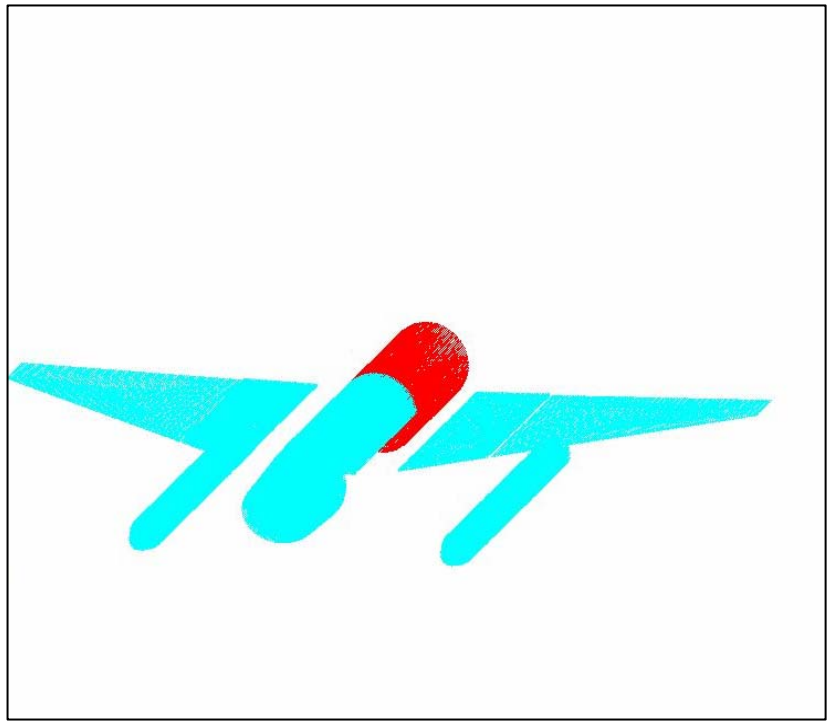
F-16 Aircraft Analysis

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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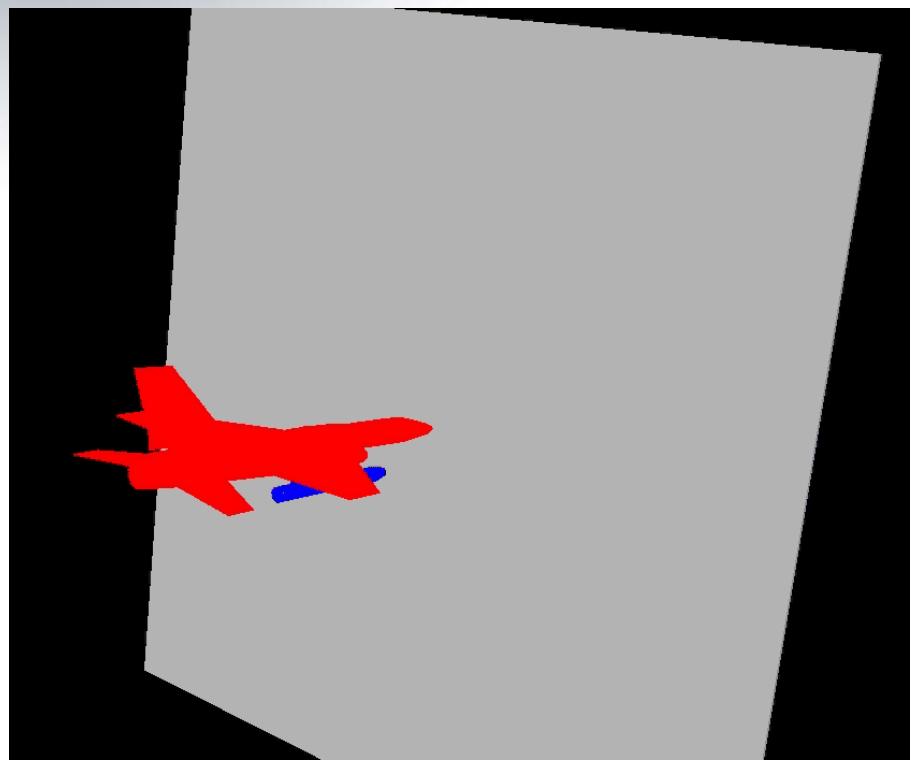
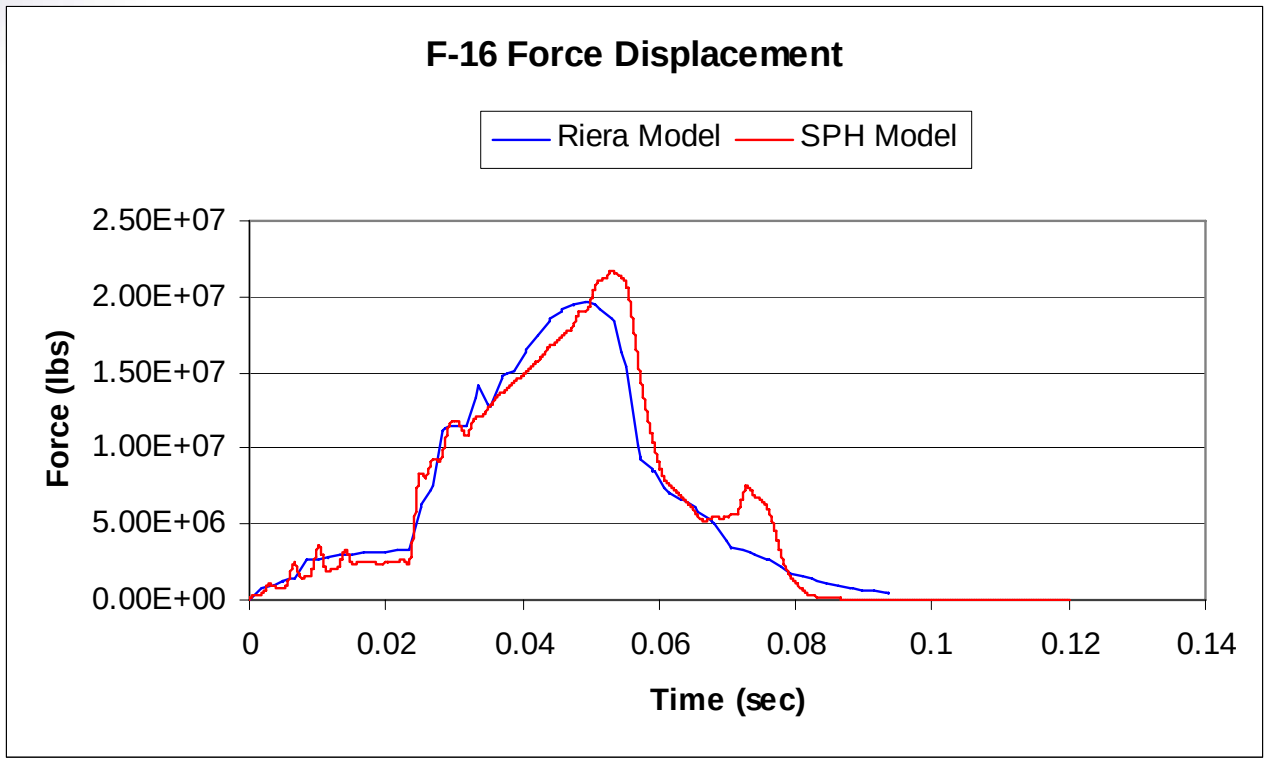
Aircraft Crash Test and Analysis
Model Verification

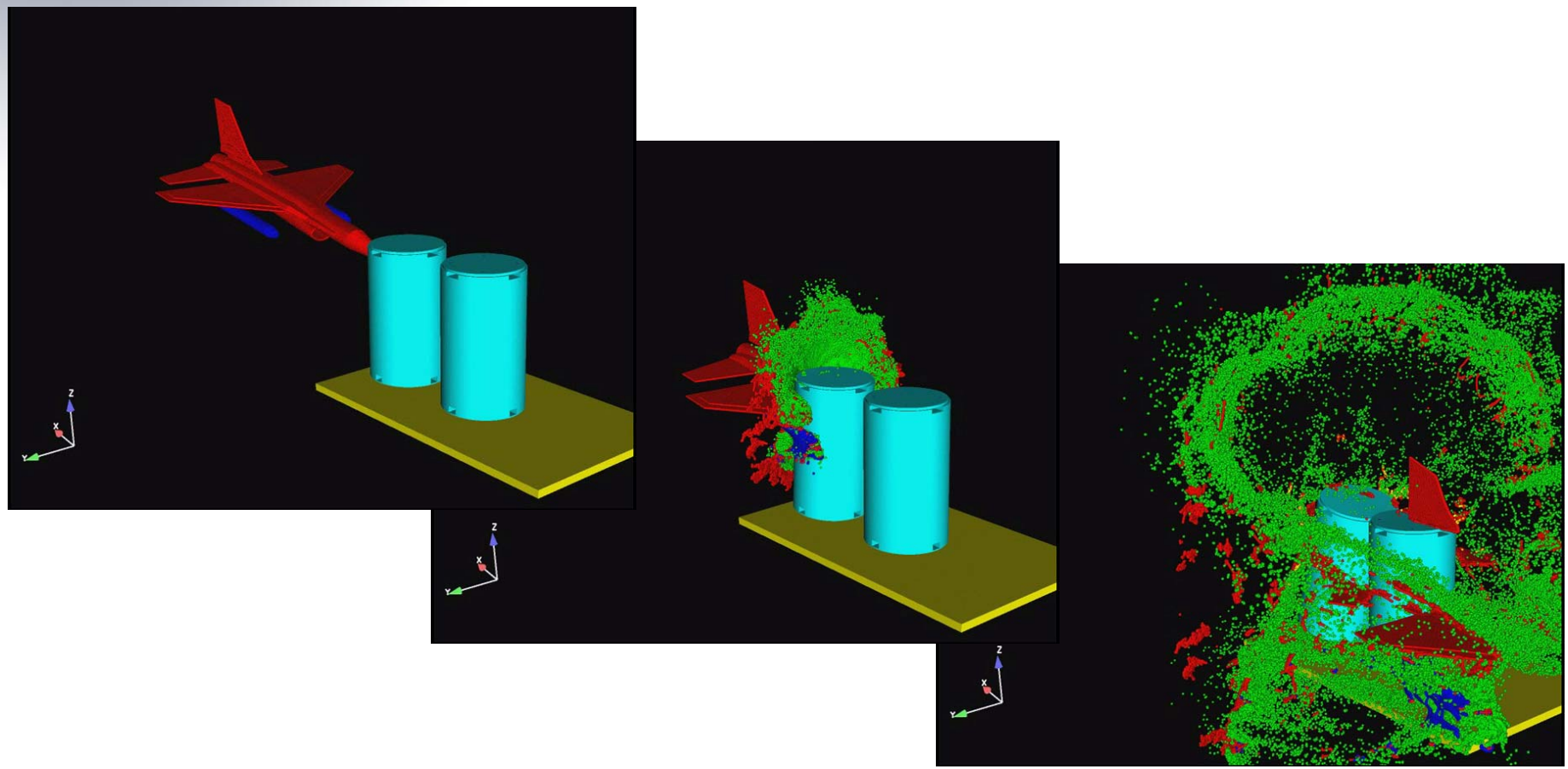


Aircraft Crash Test and Analysis
Model Verification
Force-Time-History Functions

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



Aircraft Crash Test and Analysis
Model Analysis



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.**

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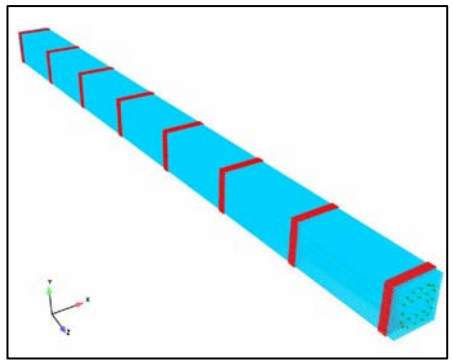
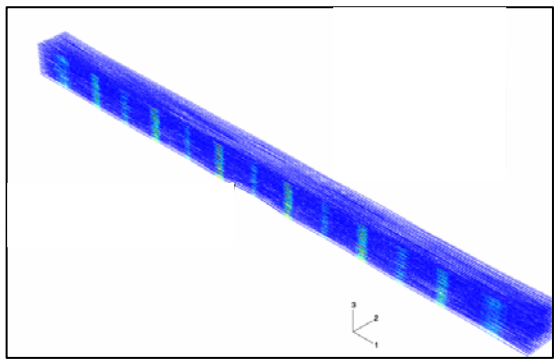
Current Complex Technical Issues

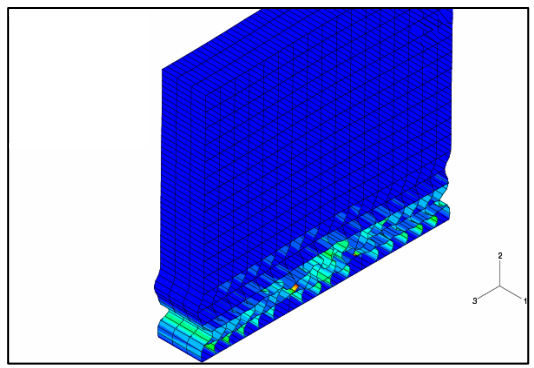
- **Fuel Performance**
  - **Fuel performance is an important safety and operational issue.**
  - **Correct energy inputs, mechanical properties, and analyses provide quantifiable estimates of fuel behavior**



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

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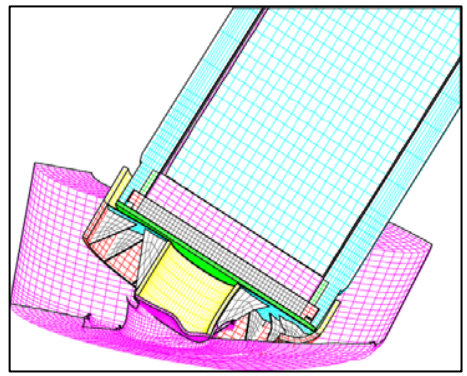
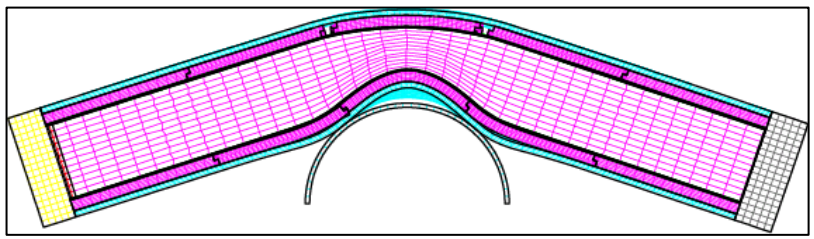
Current Complex Technical Issues

- **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.**

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