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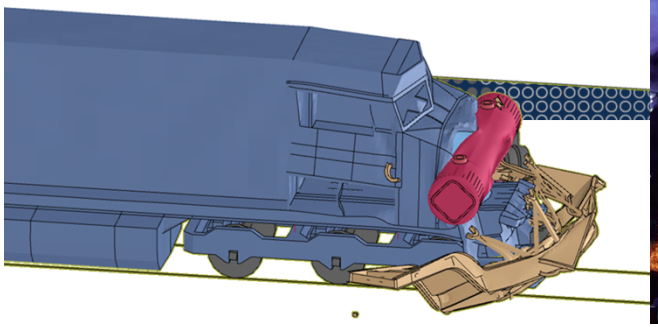

Testing and Certification for SNF Transportation Containers

Technical Workshop for the 2016 NTSF Meeting

Douglas J. Ammerman, Carlos Lopez

June 7-8, 2016

U.S. DEPARTMENT OF ENERGY NNSA

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Outline

- Accidents
- Transportation Regulations
- Regulatory Certification
  - Demonstration by Test
  - Demonstration by Analysis
- Risk Assessment/Extra-Regulatory Conditions
- Public Perception/Risk Communication
- Comparison to Real Accidents

Accidents do Happen – Impact

- Bridge Collapse – Schoharie Creek, 3 cars and a truck fell 80 ft from road deck to water
- Runaway Train – Cajon Pass, a runaway train struck a stopped train at ~45 MPH
- Viaduct Collapse – Cypress Street Viaduct, road segments fell onto lower deck
- Locomotive Impact at Grade Crossing – Ufton Nervet, passenger train impacted a stationary car at < 100 MPH

Accidents do Happen – Fire

- Weyauwega Wisc. – 14 propane tank cars derailed, various fires for 14 days
- Memphis BLEVE - propane tanker truck with 9500 gallons of gas
- Baltimore Tunnel Fire
- Freeland Michigan – rapid spill of naphtha from a rail tank car
- Akron Ohio - Butane fireball from a ruptured rail tanker

Radioactive Material Transportation Regulations

- Transportation of hazardous material is regulated by the Department of Transportation in the Code of Federal Regulations, Title 49, Parts 171-178 (49CFR171-178).
- For radioactive materials, regulations from the Nuclear Regulatory Commission (NRC) in 10CFR71 also apply.
- The regulations provide increasing levels of rigor depending on the form and quantity of material being transported.
- For large quantities (known as Type B), packages must be accident resistant.

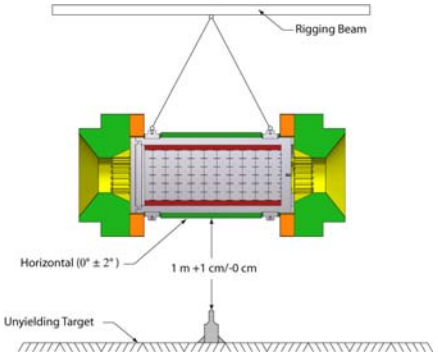
Regulatory Hypothetical Accidents
10 CFR 71.73

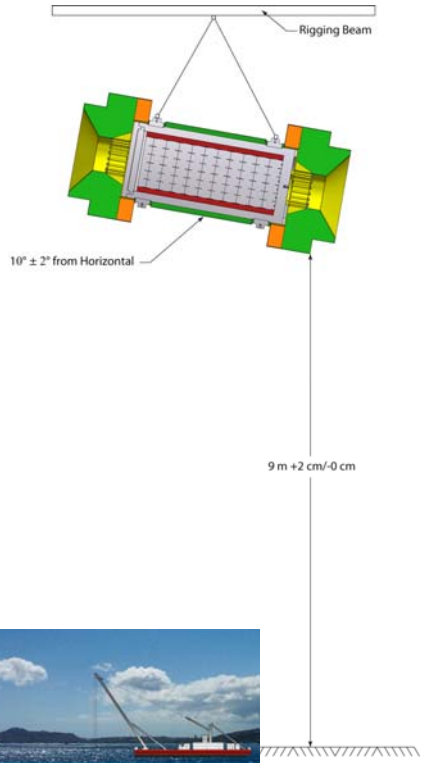
- Test sequence must be conducted so that the cumulative effect is the most damaging to the package.
- Individual tests are conducted with the package in the most damaging orientation.
- Test initial conditions regarding ambient temperature, internal heat load, and internal pressure must also be the most unfavorable.
- Following the accidents, the package must be leak tight, limit the external radiation dose rate, and be subcritical assuming the contents are in their most reactive credible configuration.

Regulatory Hypothetical Accidents

10 CFR 71.73

- Sequential Tests
  - A free drop from a height of 9 meters onto an essentially rigid target
  - A free drop from a height of 1 meter onto a 15-cm diameter puncture probe
  - A 30-minute engulfing hydrocarbon fuel fire
- Immersion under 200 meters of water



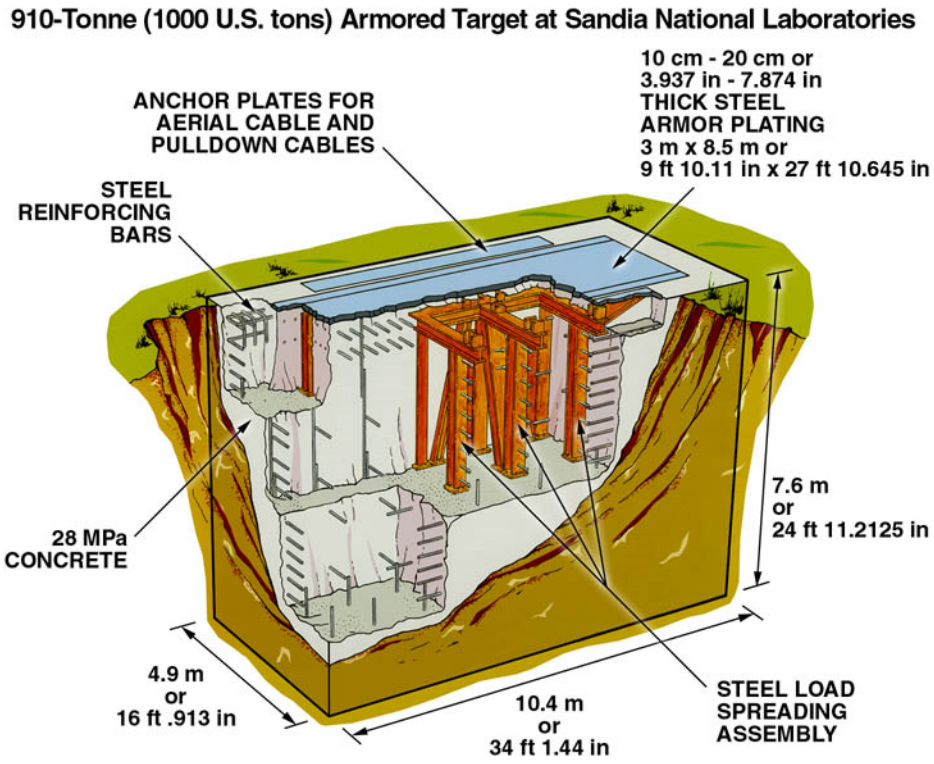


Demonstration by Test

- One way to achieve regulatory certification is to demonstrate that the package meets the hypothetical accident condition requirements through the use of physical testing.

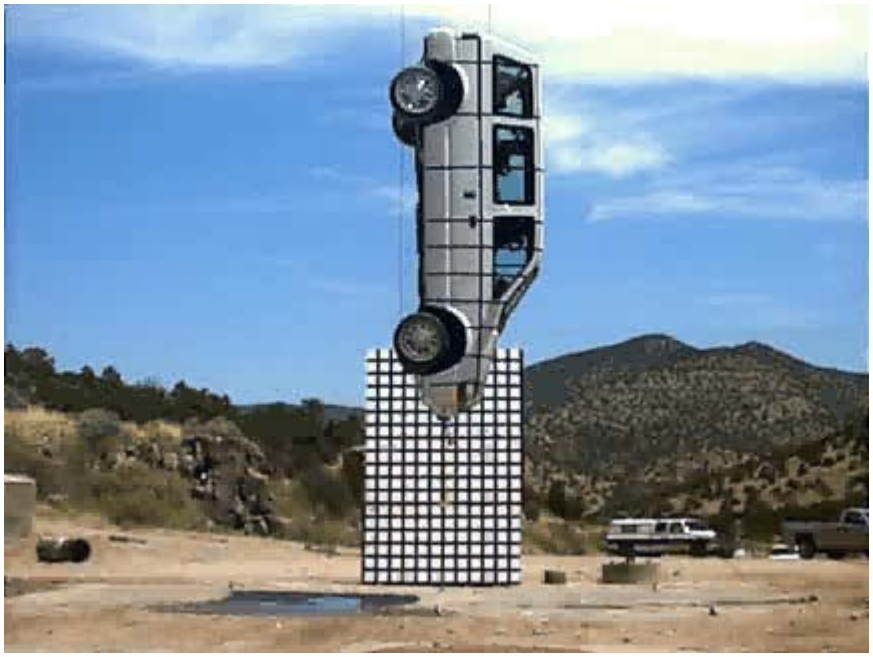
9-Meter Free Drop Test

- Essentially Rigid Target



Demonstration of Target Hardness

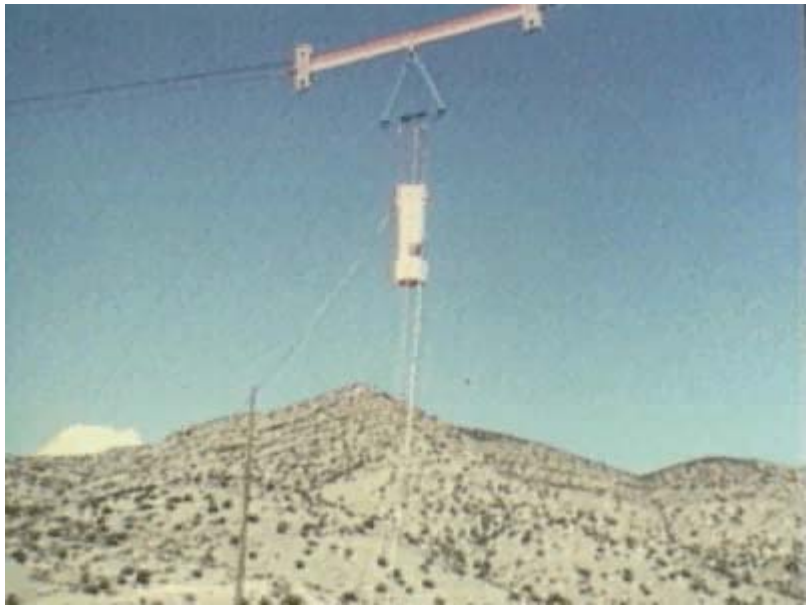
Impact onto an essentially rigid target



Impact onto a concrete target

Demonstration of Target Hardness

Impact onto an essentially rigid target



Impact onto a concrete target

Impact in the worst orientation

- Worst for one component/feature may be different for what is worst for another one.
- Generally this leads to a series of impact tests
  - Side
  - End
  - CG-over-Corner
  - Slapdown

- Requirement for worst-case initial temperature

Drop Test Examples

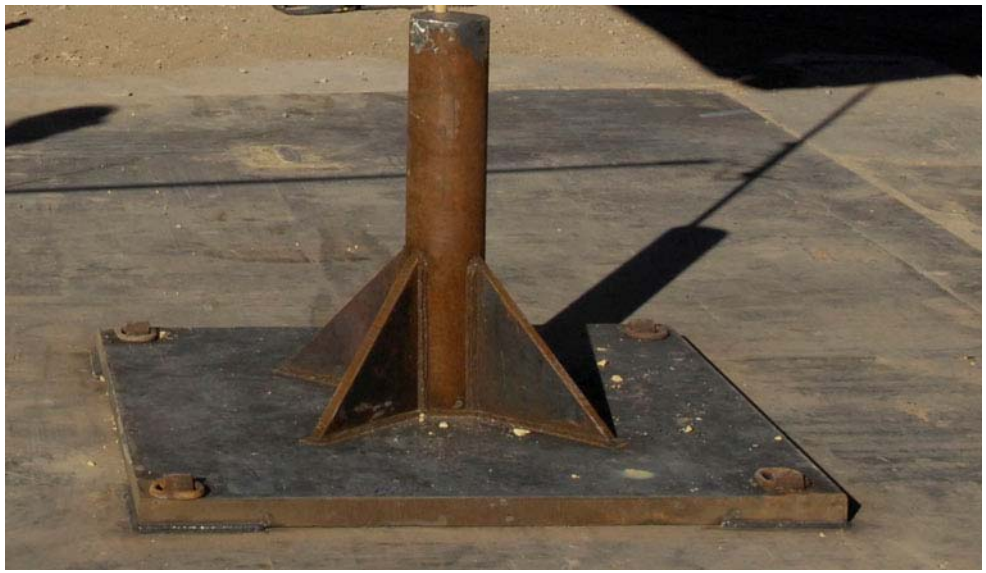
- TRUPACT-III (full scale)

- ENUN-32P (1/3-scale)

- ATR (full scale)

Puncture Test

- The puncture spike is required to be 15 cm in diameter and of a sufficient length to produce maximum damage, but not less than 20 cm.
- The spike is made from mild steel and attached to the essentially rigid target.
- Corner radius must not be more than 6 mm.

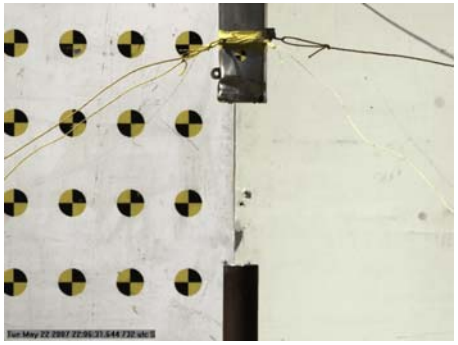


Puncture Test Examples

- MFFP

- TRUPACT-III

- ATR

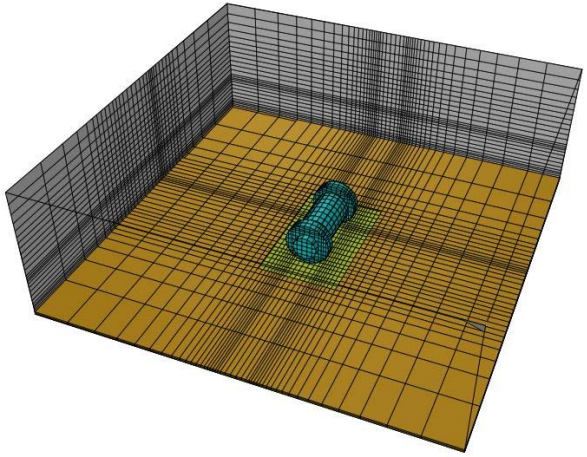


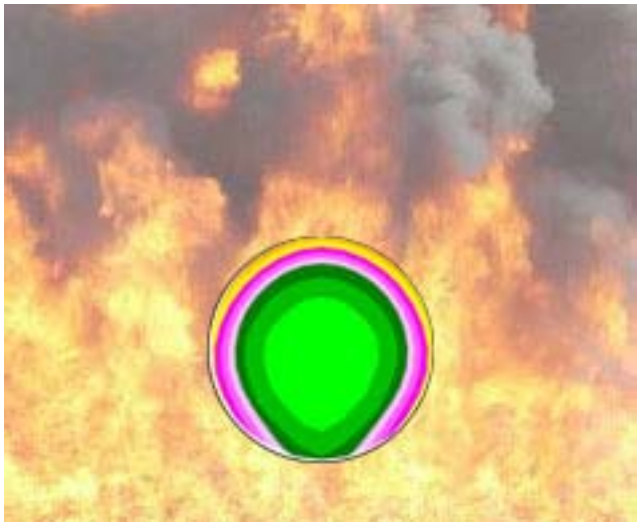
- ENUN-32P

Effect of Engulfing Fires

- The regulations require the package to be totally engulfed in flames. Fires that are even slightly offset provide much less heat input into the package.

Offset Fires for Spent Fuel Cask





- Cask is approximately 2 meters in diameter the fire is 6 X 10 meters.
- Having the cask at the edge of the greatly decreases the average internal temperature.
- Moving the cask over so the cask is just out of the fire reduces the peak internal temperature by 300° C.

Engulfing Fire Test

- Fire must extend from 1 meter to 3 meters beyond the edge of the package
- Average flame temperature is at least 800° C
- Fire must last for at least 30 minutes, which requires about 12 cm of jet aircraft fuel
- Fuel is floated on a layer of water to assure uniform depth and to protect the bottom of the pan from the heat

Immersion Test

- The preceding tests are all sequential on the same package.
- This test may be performed on an undamaged package (except fissile material packages must be subjected to an additional 0.9-m immersion after the other tests).
- For packages with more than 10,000 A_2, the immersion depth is 200 meters (2 MPa).

Demonstration by Analyses

- Another way to achieve regulatory certification is to demonstrate that the package meets the hypothetical accident condition requirements through the use of analytical techniques.

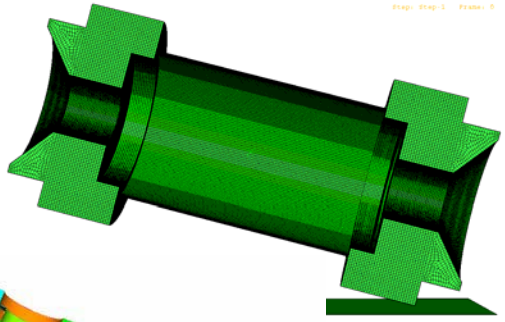
- In practice, most packages are certified by a combination of testing and analyses.

Finite Element Analysis of Impacts

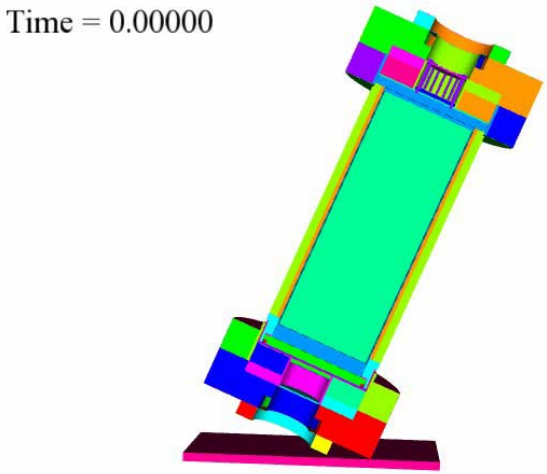
- Most packages are designed based upon the ASME Boiler and Pressure Vessel Code.
- Specifically, Section III, Division 3 is for the design of containments for transportation and storage of spent nuclear fuel and high level radioactive waste (although historically, most designers have used Section III, Div. 1, subsection NB).
- Analyses may be stress-based (allowable stress is some portion of yield or ultimate strength) or strain based (allowable strain is some portion of uniform elongation strain or failure strain).
- Demonstration of compliance by analyses gives some indication of margin of safety, where demonstration by test generally does not.

Examples of Impact Analyses

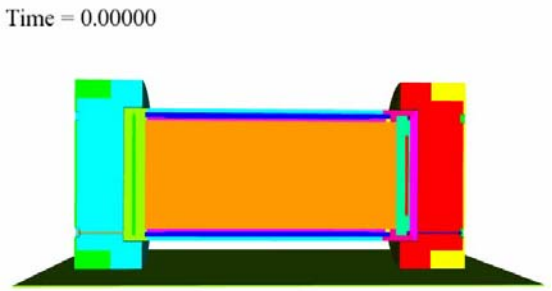
- ENSA Impact Limiter



- HI-STAR100

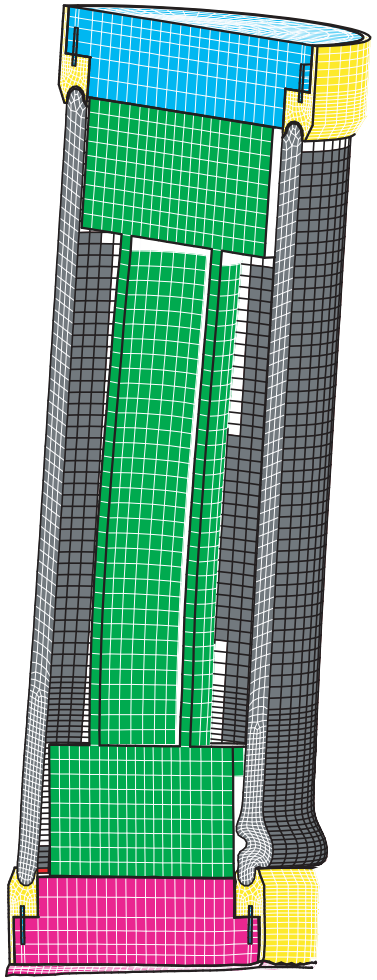


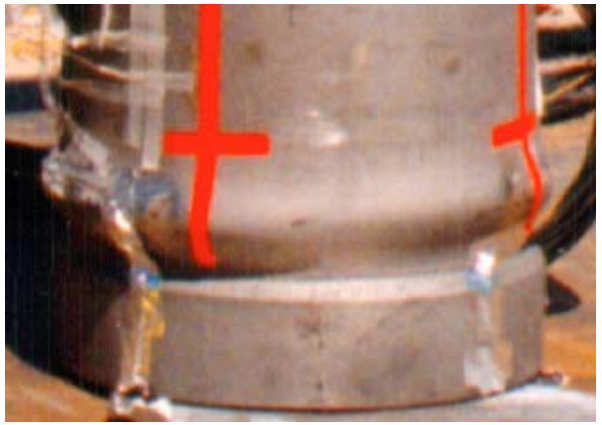
- NAC-STC

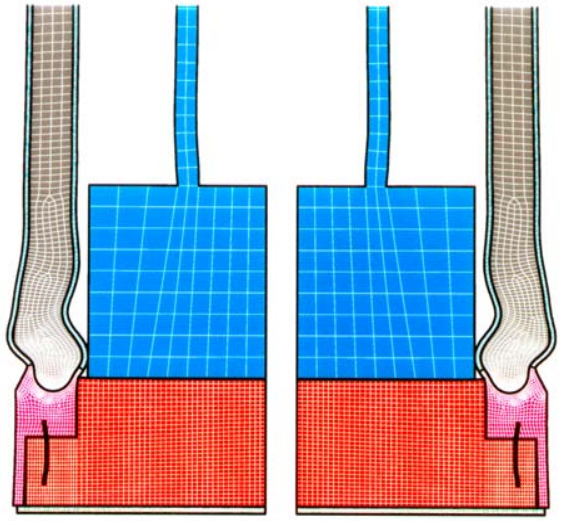


Validation Impact of Analyses

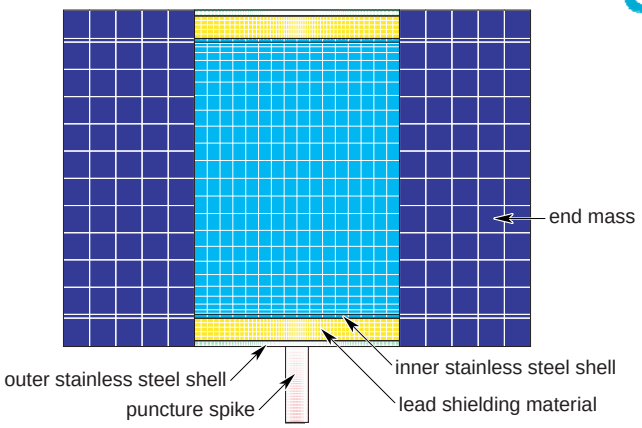
- Finite element analyses are compared to actual impact test to validate the models/analysis tools.

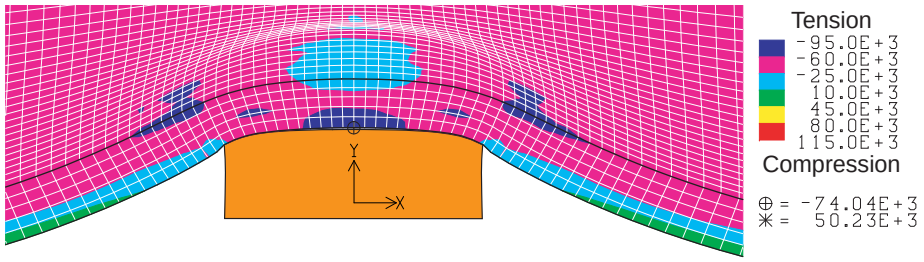


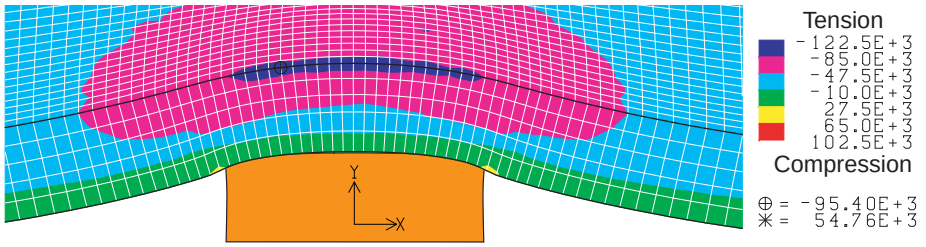


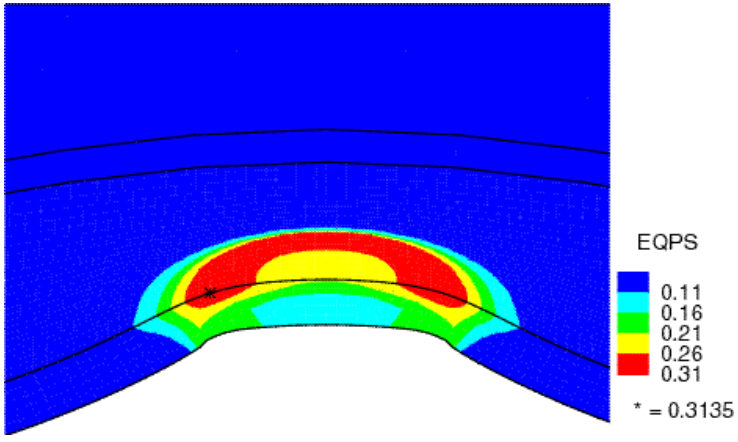


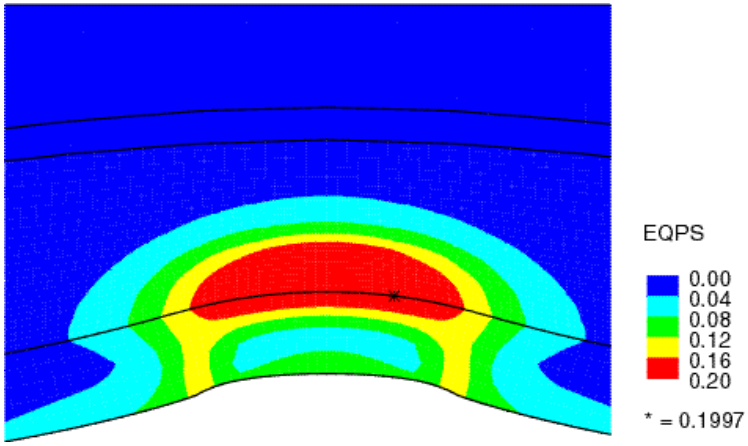
Analyses of Puncture







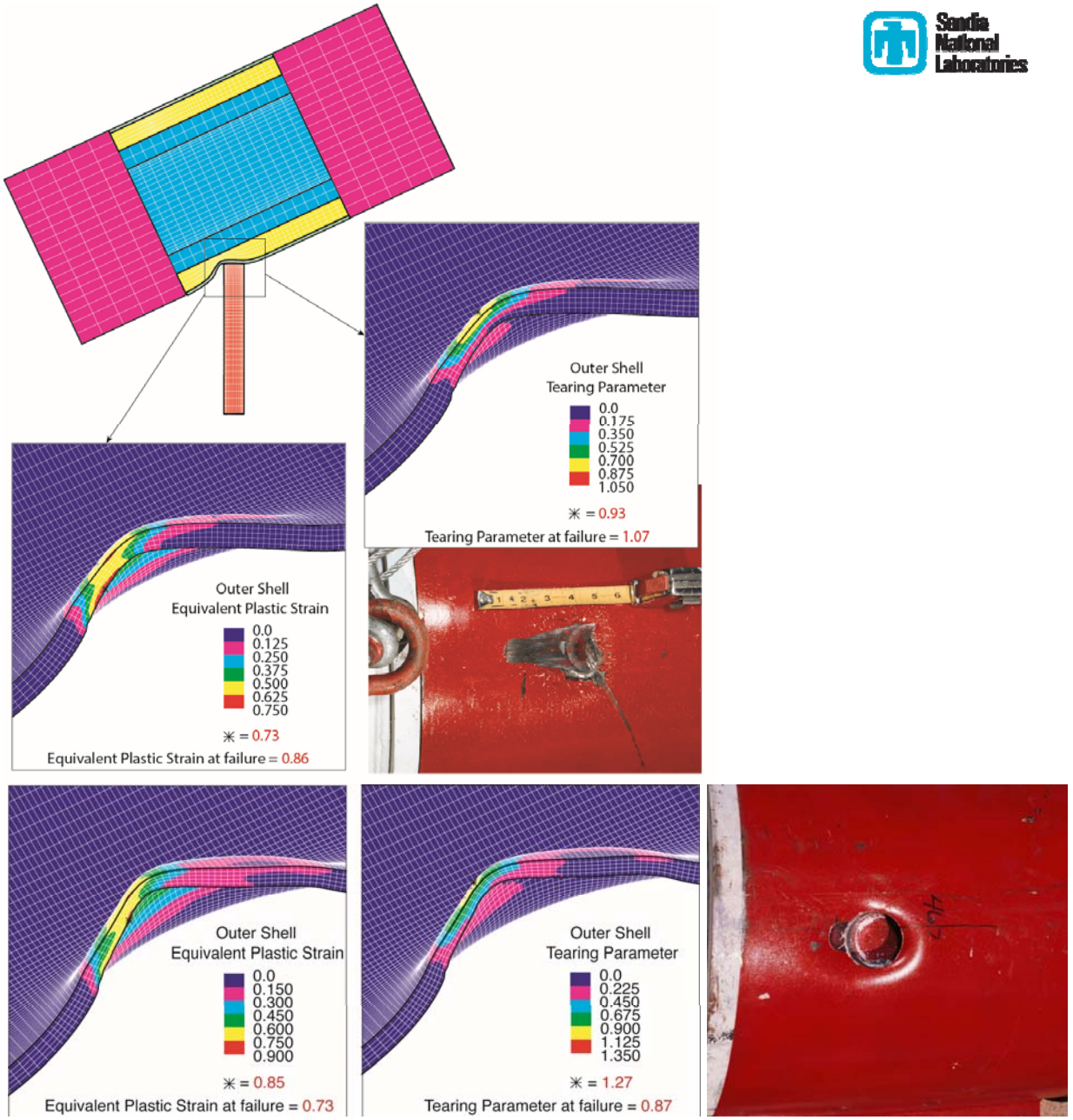




Failure ≈ 1.1

Validation of Puncture Analyses

- A test series with two different steel puncture panels and three different backing materials was conducted to determine the thickness of material required to prevent punch-through. 5/16” thick carbon steel prevented puncture, 1/4“ thick did not.

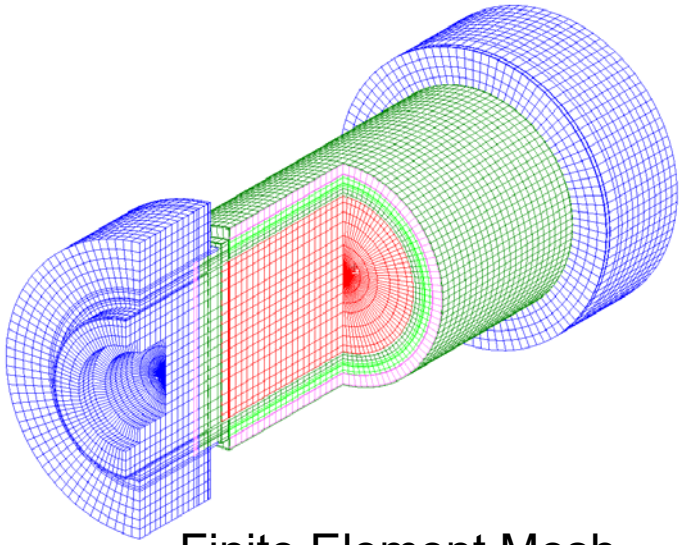


Analysis of Fires

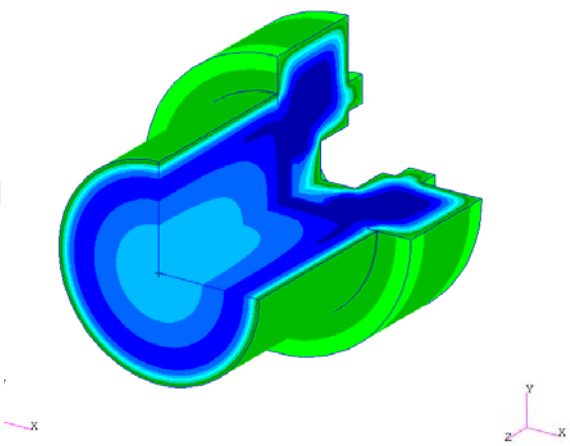
- Regulations allow analyses to be performed using a uniform thermal boundary condition with a temperature of 800° C, a flame emissivity of 0.9, a surface absorptivity of at least 0.8, and a convective coefficient appropriate to the engulfing fire environment.

- For comparison to test results, the actual fire environment must be simulated, which requires a coupled analysis—one calculation of the combustion/fluid dynamics/radiation and one of the heat transfer within the package.

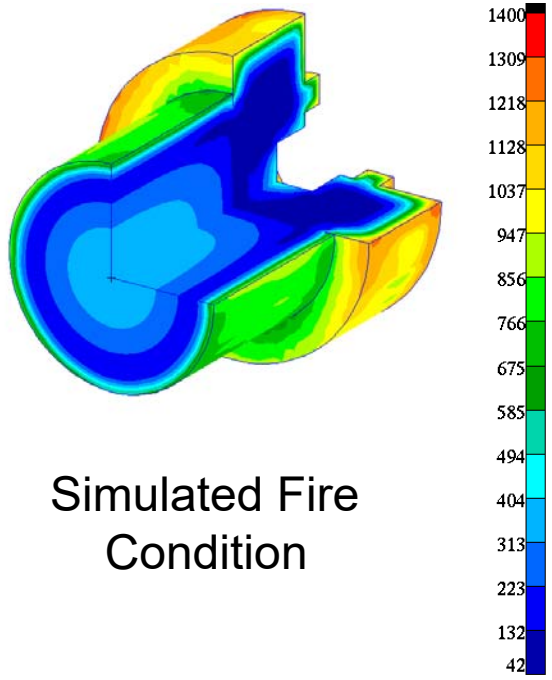
Example Fire Analyses



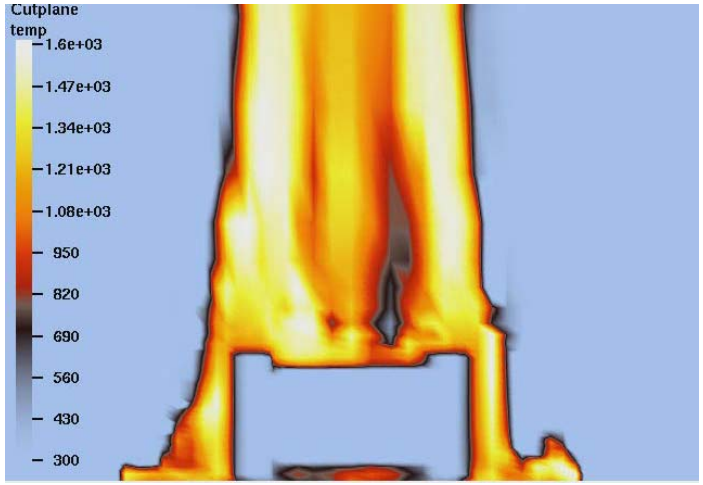
Finite Element Mesh



Uniform Boundary Condition

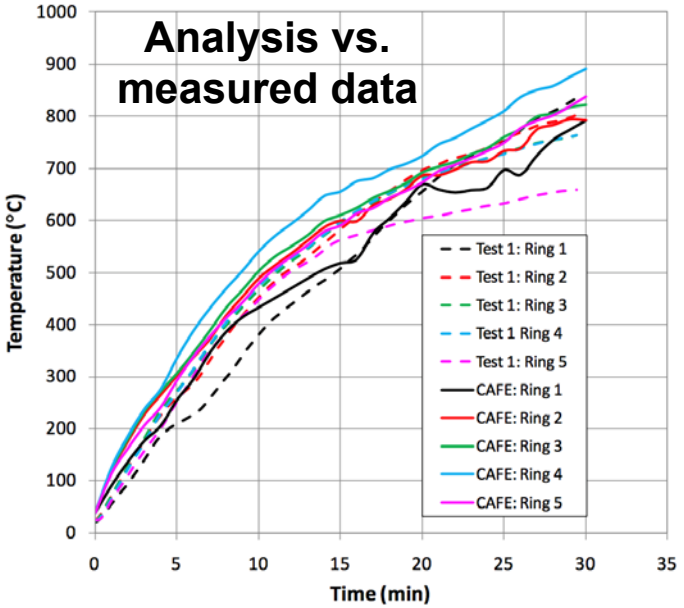


Simulated Fire Condition



Benchmark of Fire Analyses

- Modeling of a series of large calorimeter pool fires.
- Test unit was heavily instrumented to provide ample data for comparison to analysis results.
- Data provides both temporal and spatial variations.



Risk Assessment

- The NRC has conducted a number of generic risk assessments to evaluate the safety of spent fuel transportation:
  - NUREG-0170, Final Environmental Statement on the Transportation of Radioactive Material by Air and other Modes, published in 1977
  - NUREG/CR-4829, Shipping Container Response to Severe Highway and Railway Accident Conditions (The Modal Study), published in 1987
  - NUREG/CR-6672, Reexamination of Spent Fuel Shipment Risk Estimates, published in 2000
  - NUREG-2125, Spent Fuel Transportation Risk Assessment, published in 2014
- Each of these risk assessments has calculated a lower expected exposure to the public than the previous assessment.
- In addition, the DOE has conducted many transportation campaign specific risk assessments.

Response to Extra-Regulatory Events

- Transportation risk assessments consider what would happen in the extremely unlikely event that the package was involved in an accident more severe the regulatory hypothetical accidents.
- Impacts onto rigid targets at speeds greater than 30 mph have been analyzed.
- Engulfing fires with higher temperature and longer duration have also been analyzed.

Margin of Safety

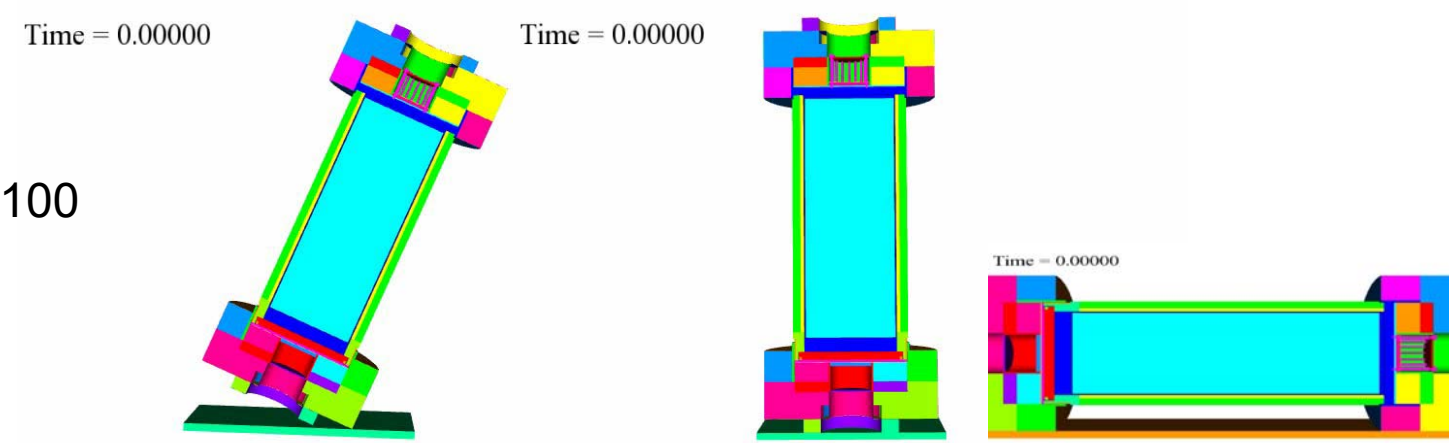
- The stringent acceptance criteria that the NRC requires packages to meet in order to be certified leads to designs that have a large margin of safety.

- Analyses and tests have shown that current package designs can survive impacts onto rigid targets at speeds much greater than that from the 9-meter drop without a release of contents.

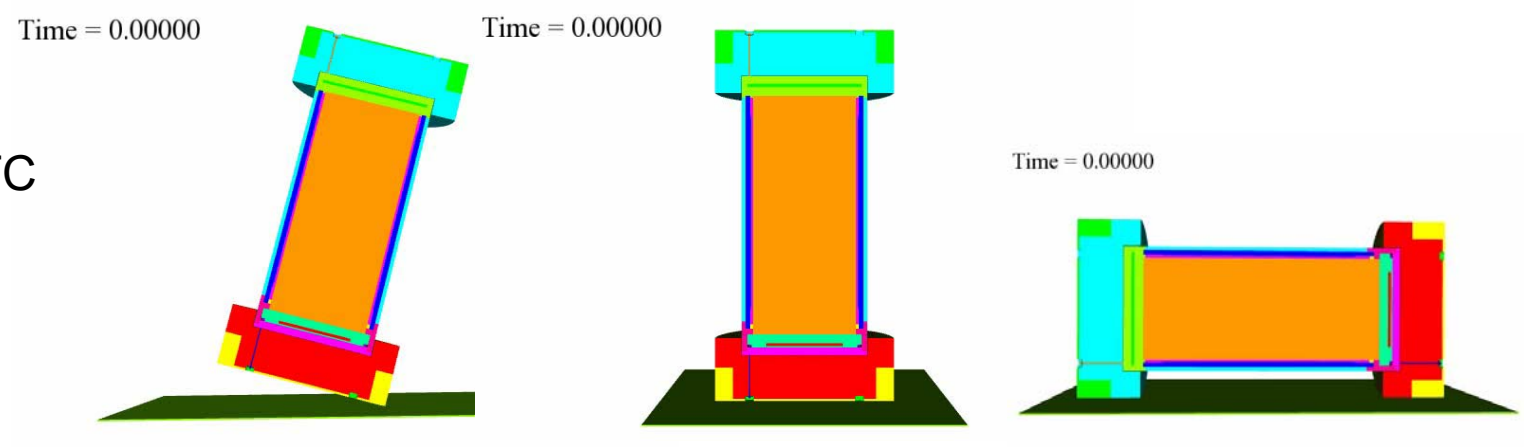
- Analyses have shown that current package designs can survive engulfing fires much longer than 30 minutes without a release of contents.

Extra-Regulatory Impacts (4x impact velocity)

HI-STAR 100

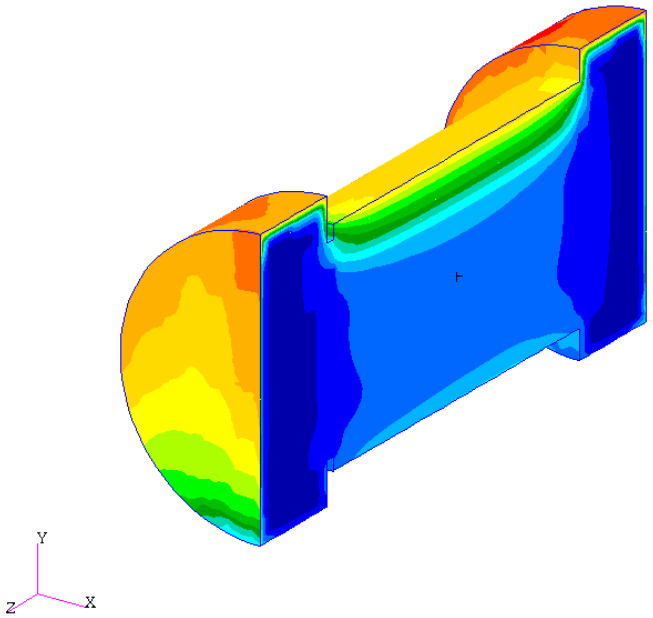


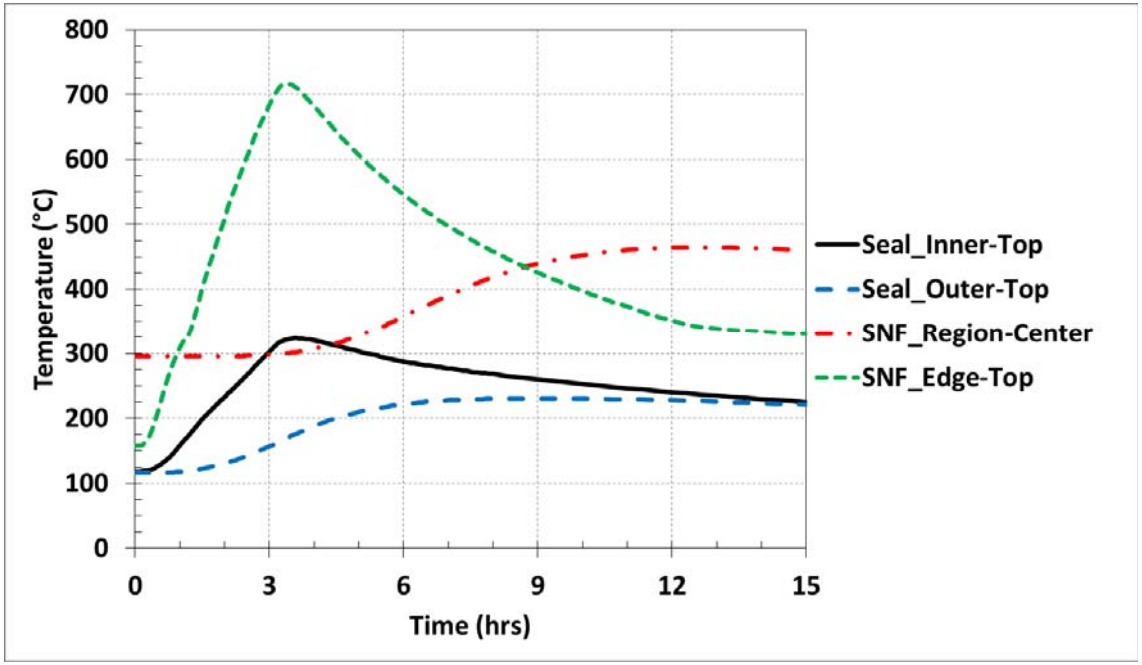
NAC-STC



Extra-Regulatory Fires

NAC-STC after 3-hour Concentric Fire





- Seal temperature is below its failure temperature of 350°C.
- Spent fuel temperature is below the rod-burst temperature of 750°C.

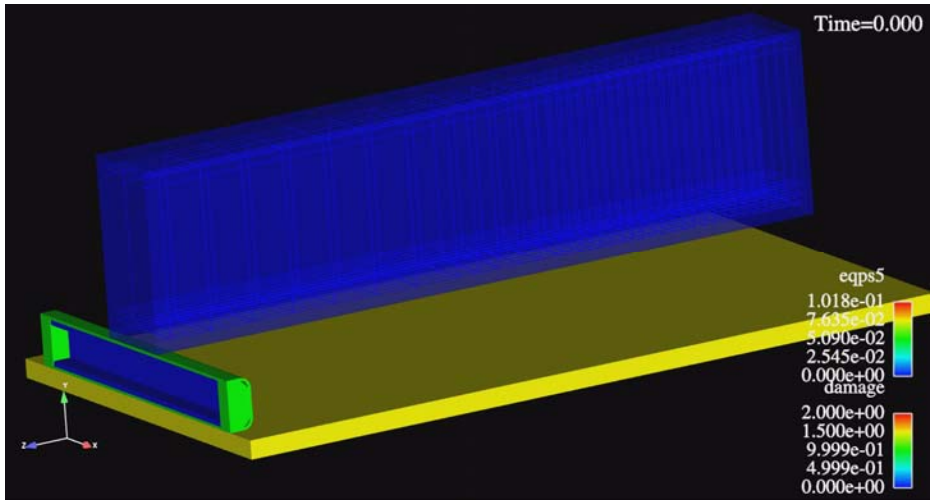
Real Accidents

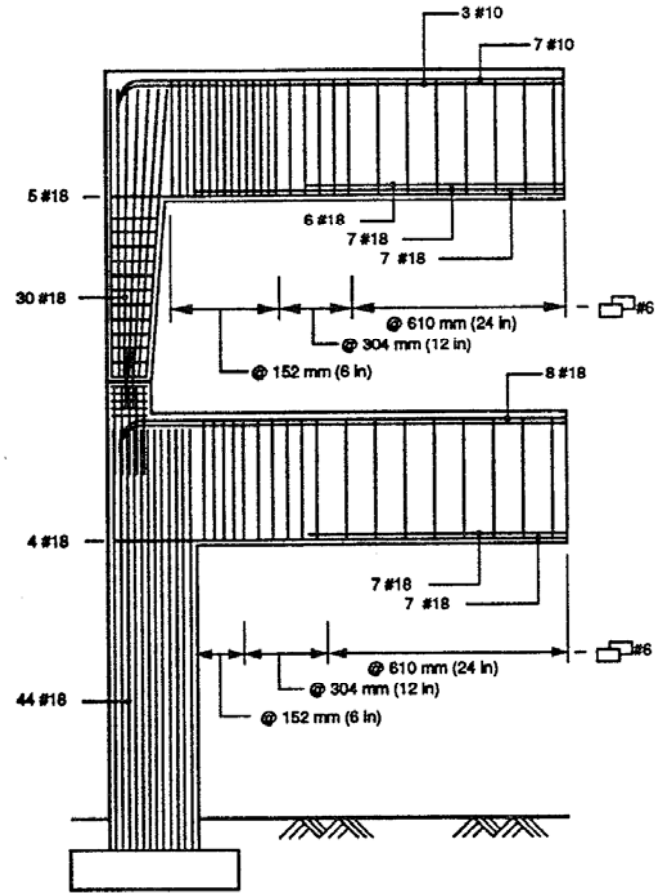
- The regulatory 9-meter drop test results in an impact velocity of 30 mph. Many accidents have initial speeds greater than this number, so there is concern that the regulatory impact does not envelop the severity of possible accidents.
  - Essentially rigid target (all the accident energy is absorbed by the package)
  - Impact velocity is perpendicular to the rigid target
  - Impact is in the worst orientation
  - Neglect the transport conveyance
- The regulatory fire burns for 30 minutes. Many accidents have fire durations longer than this, so there is concern that the regulatory fire does not envelop the severity of possible accidents.
  - Fully engulfing
  - No intervening structures

Consider the Accidents from the Beginning of this Presentation

- Schoharie Creek bridge collapse – 80-foot drop results in an impact velocity of 49 MPH—but the impact surface would not have been unyielding, an impact at 150 MPH onto water is required for similar damage as the regulatory impact.
- Cajon Pass runaway train – the impact velocity was ~45 MPH—but a locomotive is not an unyielding surface and an impact velocity of at least 150 MPH would be required for similar damage as the regulatory impact, neglecting any structure between the cask and the rear of the impacted train.

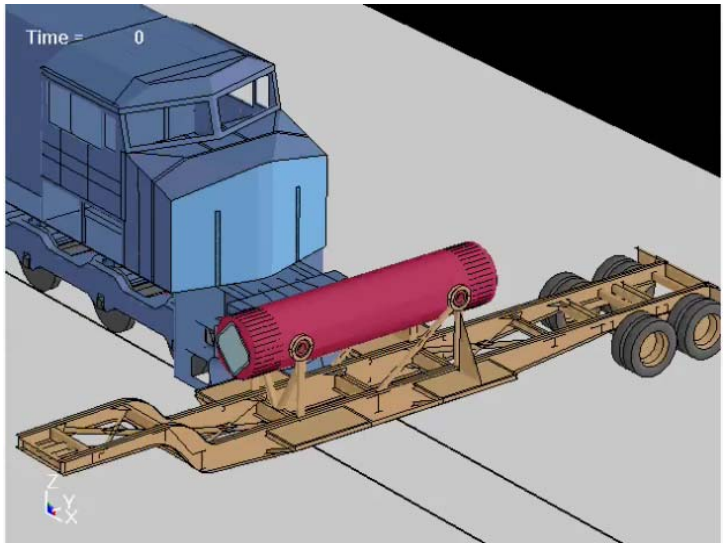
Viaduct Collapse during the Loma Prieta Earthquake





Result:
No release of radioactive material

Impact by a Locomotive



Test performed by CEGB, UK

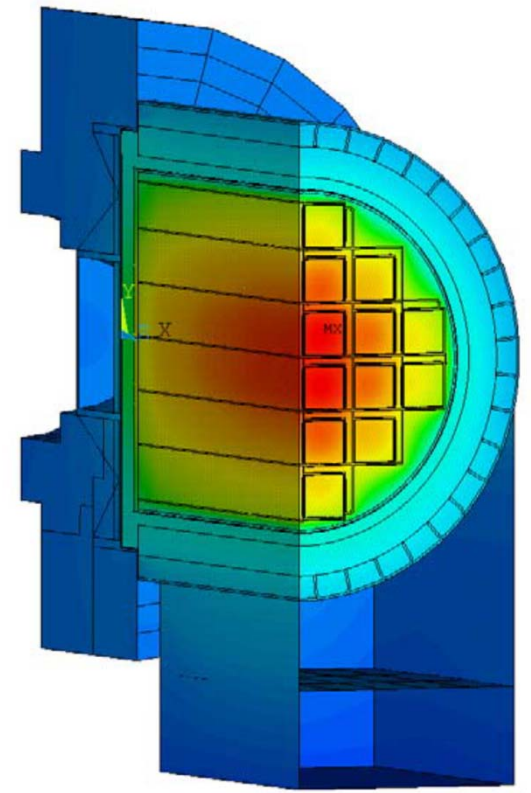
Truck Impact into a Rigid Wall

Propane Tank Explosion (possible in Weyauwega, actual in Memphis)

Test performed by BAM, Germany

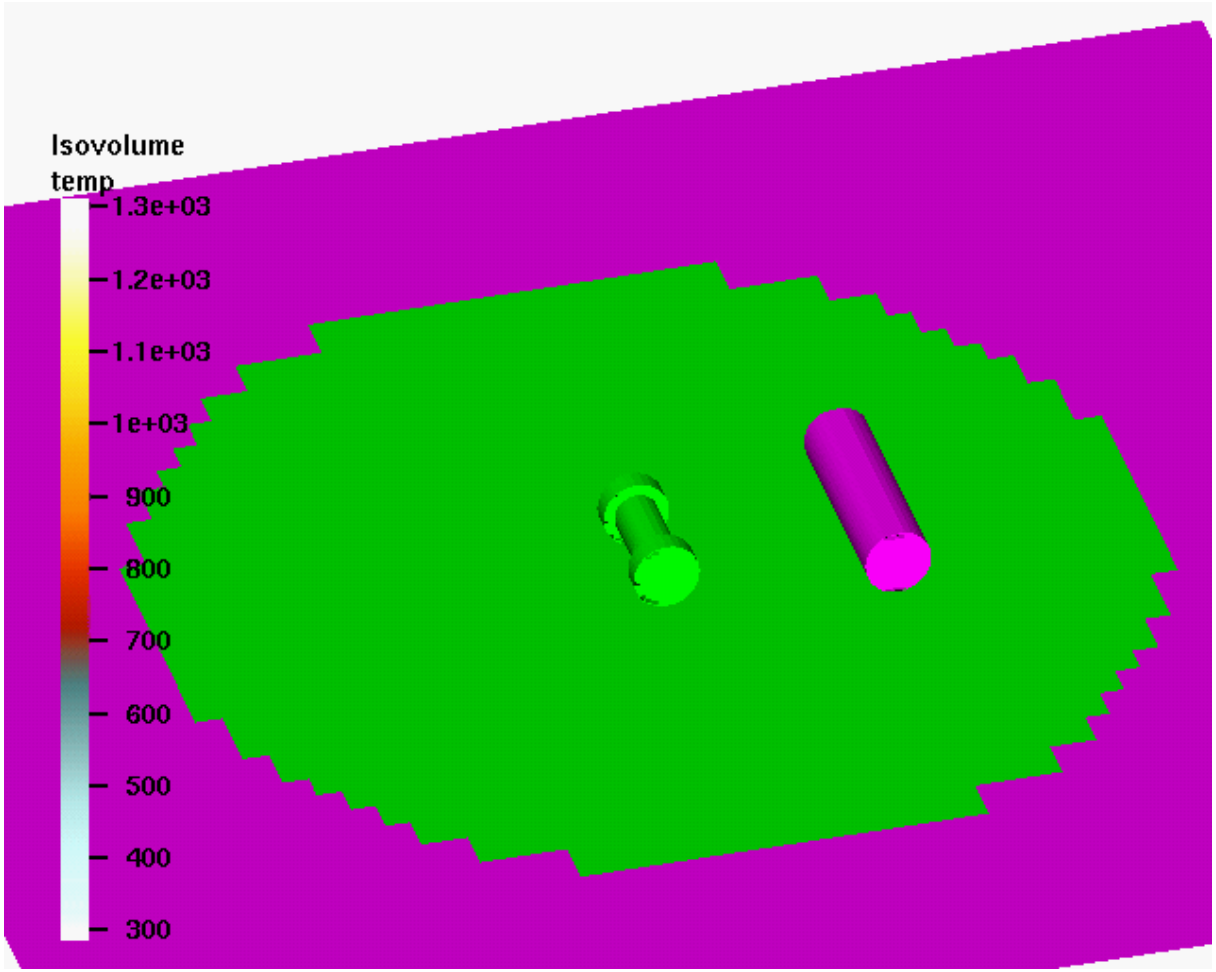
Baltimore Tunnel Fire

- NRC conducted analyses of this event making worst-case assumptions about the location of a spent fuel cask and its response.
- For a cask without an inner welded canister, there is the possibility of a small release of radioactive material (0.3 A_2), which is below regulatory limits.
- An accident of this severity occurs less than one-in-a-billion accidents.



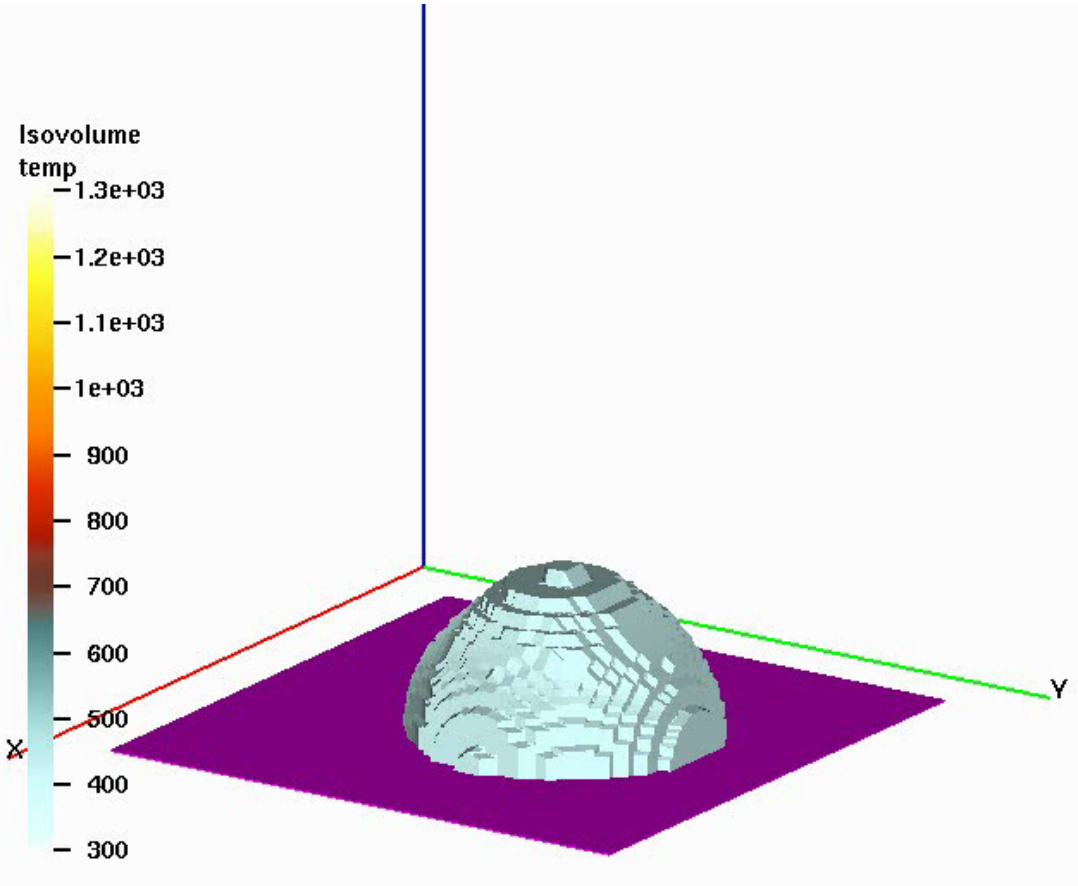
Freeland Michigan

- Naphtha car had a capacity of 27,000 gal, which could have produced an engulfing fire.
- 19 minute fire produced seal temperature rise of only a couple of degrees.



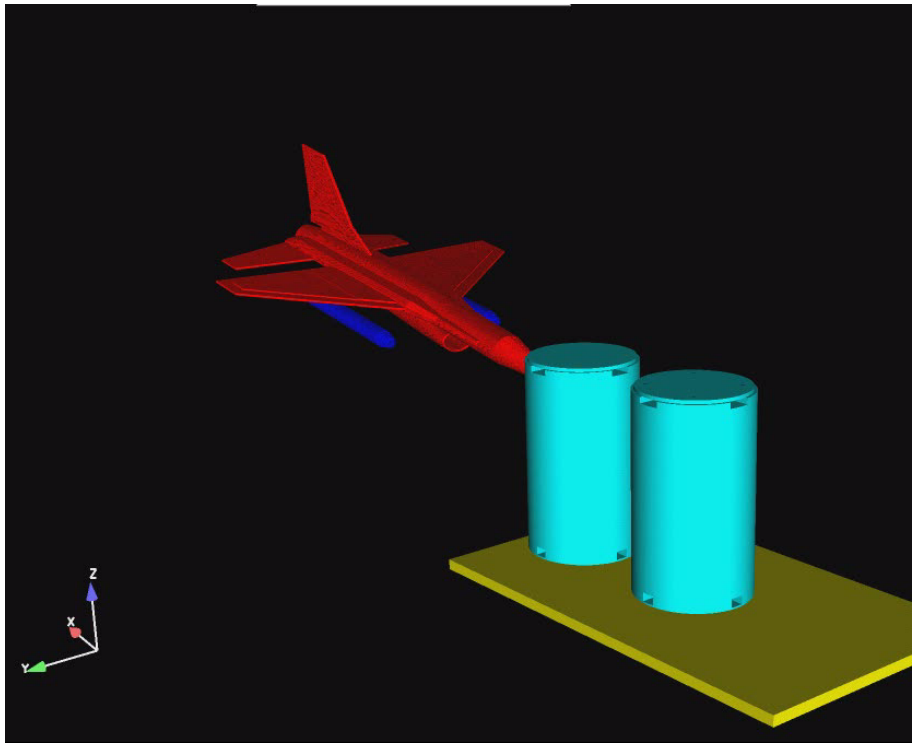
Akron Ohio Butane Fireball

- Gaseous fuel forming a 10m radius hemisphere prior to ignition
- Ignition occurred everywhere in the hemisphere
- Cask contents and seal region did not heat in an appreciable manner
  - Fire duration was very short
  - Thermal mass of the SNF cask is very large (250,000 lbs)



Consent-Based Siting

- For consent-based siting of an interim storage facility communities may be concerned with possible transportation accidents, but also with possible accidents at the storage facility, such as an airplane crash.



Risk Communication

- Hopefully, this workshop has helped you to see why the controls that are placed on the transportation of radioactive material make it a low-risk activity.
- Unfortunately, not all of the stakeholders regarding spent fuel transportation are in this room.
- It is up to us to facilitate public education on the safety of spent fuel transportation.

NRC Interactive DVD on Cask Basics

- Sandia produced an interactive DVD for the NRC that provides a background on radioactive material transportation regulations and safety.
- The NRC contact person is Dave Pstrak.

QUESTIONS?