Spent Fuel Accident Risk Investigation Analysis Plan

December 6, 2006

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E-28

Cask Selection

- Holtec HI-STAR 100 Rail Cask
  - Layered all-steel cask body
  - Welded canister with 24 PWR or 68 BWR assemblies
  - Aluminum honeycomb impact limiter
- NAC STC Rail Cask
  - Steel-lead-steel cask body
  - Direct loaded (26 PWR assemblies) or welded canister
  - Redwood/balsa impact limiter
- GA-4 Truck Cask
  - Steel-DU-steel cask body
  - Direct loaded (4 PWR assemblies)
  - Aluminum honeycomb impact limiter

Inclusion of a Different Canister

- **Both the rail casks are certified to transport spent fuel within a welded canister.**
- **It would be possible to analyze either of these casks with a different (currently uncertified) canister.**
  - One that meets the requirements document for the TAD

  or

  - A bolted canister that may be used for transportation to a temporary DOE surface storage facility

Structural Analysis

Analysis Overview

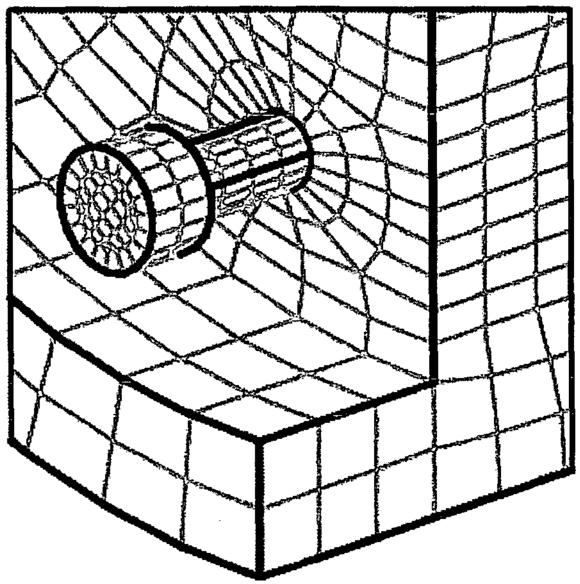
- Finite element calculations with PRESTO
- Three orientations
  - Closure end
  - Closure CG-over-corner
  - Flat side
- Four velocities
  - 30 MPH
  - 60 MPH
  - 90 MPH
  - 120 MPH
- All analyses will be for impacts onto a flat rigid target.

Why PRESTO?

- Sandia has available several explicit transient dynamic codes (PRESTO, PRONTO, LS-DYNA, ABAQUS-Explicit).
- All of these codes can produce good results for regulatory analyses.
- PRESTO and PRONTO have the ability to model failure using tearing parameter.
- PRESTO has an iterative contact algorithm that does a better job at preventing interpenetration of contact surfaces (especially when there is a large mismatch in element stiffness).

Modeling Detail

- One of the drawbacks of NUREG/CR-6672 was the level of modeling detail in the bolt region.
- This analysis will use a higher fidelity bolt model.



- Relative displacements between the lid and body will be tracked.

Modeling Detail (cont.)

- For the direct loaded casks, the basket will be explicitly included in the model.
- Fuel assemblies will be homogenized.
- Initially the contents of the canisters will be homogenized (if canister failure is seen this simplification will be evaluated).
- The impact limiters will be explicitly included.
  - The energy absorbing material will be modeled using the orthotropic crush material model in PRESTO.
  - Internal structural element will be modeled with shell and/or hex elements.
  - Impact limiter attachments may be included.

Structural Modeling Concerns

- These analyses will explore the region of incipient failure, the most difficult area to model.
- An accurate failure model (and material parameters for the model) is needed.
- Material data for modeling crushable materials at very high levels of crush and high strain rates is generally not available.
- Sandia will extrapolate available material data when possible, but some material testing may be necessary.
- Are 30, 60, 90, 120 MPH the appropriate impact speeds?

Specific Model Methodology – GA-4

- Impact limiter interior gussets and exterior skin modeled with shell elements
- Aluminum honeycomb modeled with orthotropic crush material model
- Material with holes modeled as equivalent solid
- Cask body (inner and outer shells and DU) modeled with hex elements
- Frictionless contact on all surfaces of DU segments
- Cask closure will include the tapered gap between the body and the lid
- Fuel support structure with B4C pellets modeled as equivalent homogenous shell

Specific Model Methodology – HI-STAR

- Impact limiter interior gussets and exterior skin modeled with shell elements
- Aluminum honeycomb modeled with orthotropic crush material model
- Impact limiter attachment bolts modeled with spot welds
- Cask body (inner layer and monolithic outer layers) modeled with hex elements
- Frictionless contact between these two layers
- Cask closure will include the gap between the lid and the cask and bolt preload
- Canister modeled with hex elements
- Weld stresses will be tracked – residual stresses not included (closure weld only)
- Basket and fuel homogenized
- Assume all fuel assemblies experience the same acceleration

Specific Model Methodology – NAC-STC

- **Impact limiter interior gussets and exterior skin modeled with shell elements**
- **Redwood and balsa wood modeled with orthotropic crush material model**
- **Impact limiter attachment bolts modeled with spot welds**
- **Cask body (inner and outer shells and lead) modeled with hex elements**
- **Frictionless contact between lead and shells**
- **Cask closure will include the gap between the lid and the cask and bolt preload**
- **Basket fuel tubes, structural disks, and heat transfer disks modeled with shell elements**
- **Tie rods modeled with hex elements**

Thermal Analysis

Analysis Overview

- Undamaged geometry
- 3D Heat transfer analyses with MSC P/Thermal
- 3D Fire analyses with CAFE
- Initial conditions based on steady-state for NCT (benchmarked against SAR data)
- ~21 thermal analyses (7/cask)
  - 800°C 30-minute P/Thermal fire
  - 1000°C 30-minute P/Thermal fire
  - 11 hour CAFE fire
  - Four P/Thermal cool-downs (starting at 1, 2, 3, and 11 hours)
- The thermal characteristics of the fuel region (including decay heat) will be homogenized

Why CAFE and P/Thermal?

- **Coupled CFD fire model and heat transfer code**
- **Fast running on desk-top workstation**
- **Commercial CFD codes such as Fluent and CFX can model the fire and heat transfer of objects within the fire, but require long runtimes on very large computers (uniform mesh for heat conduction and fluid flow)**
- **Other codes such as FDS simulate the fire but require uncoupled thermal analysis, somewhat ignoring the effect the heat-up of the cask has on the fire**

Thermal Modeling Concerns

- Fire duration
  - 11-hour fire analyzed in NUREG/CR-6672
  - Omitting it may seem like trying to hide bad results
  - Engulfing fires of this duration are extremely rare
- Location of pool relative to cask
  - Co-located, offset with constant wind blowing the flame onto the cask, or offset with other wind condition?
- Damaged cask and limiters
  - Damage from regulatory drop/punch, damage from extra-regulatory impact?
- Thermal properties of damaged materials
  - This data may not be available in the SAR or the literature
  - Material testing may be required

Source Term Analysis

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Analysis Overview

- PWR fuel (initially intact)
  - More prevalent
  - Less robust
  - NAC and GA casks are not certified for BWR fuel
- Fuel response will be based on finite element calculation of a generic assembly
- Structural and thermal analyses will be used to determine number of failed rods and containment hole size
- MELCOR calculation of one rail and one truck cask will determine cask blow-down
- Method from vulnerability analyses will be used to calculate the cask-to-environment release fraction

Risk Analysis

Accident Rates and Event Trees

- Rail accident rate from 5 years of FRA data and 30 years of HMIR data
- Truck accident rate from 5 years of state-by-state data and 30 years of HMIR data
- Accident rates for spent fuel shipments, WIPP shipments, and SGT shipments will be compared
- Event trees/branch point probabilities developed for PPS will be used
- Stop time as a result of an accident that doesn't damage the package is important

Routine Shipment Risk Analysis

- RADTRAN 6.0
- Routine exposure to the crew, workers, inspectors, and the general public (affected populations) calculated based on SAR exposure rates
- Routes selected using WebTRAGIS and broken down state-by-state for rural, suburban, and urban areas
- Some comparison to NUREG/CR-6672 routes
- Comparison of Reasonably Maximally Exposed Individual (RMEI) between RADTRAN 6.0 and RISKIND 2.0
- Distributions of input parameters will be discussed and importance determined using Incident-Free Importance Analysis Summary

Accident Risk Analysis

- Accident probabilities determined for scenarios that result in release
- Each scenario assigned a probability, release fraction, aerosolized fraction, and respirable fraction
- Vehicle speeds and other accident parameters necessary to achieve the scenario will be discussed
- Loss of shielding from lead slump or lead melt (or DU segment separation) dose and dose-risk calculated
- Routes same as incident free analysis

Accident PRA

- PRA conducted for each of the affected populations
- Input parameters distributed

1. Accidents resulting in release
2. Accidents resulting in LOS
3. Accidents that do not result in release or LOS but have extended stop time
4. Accidents that lead to a criticality event (there is no plan to perform a consequence analysis of this event)

- PRA results will be compared to NUREG/CR-6672 and NUREG-0170

Accident Consequence Analysis

- Consequence analyses will be conducted for each accident scenario that results in a release
- Use entire routes and also specific population zones
- Probabilities will be associated with each consequence calculation
- Results will be reported as collective dose, with the caveat that collective dose is only meaningful as a comparison, not in the absolute
- Should LCF be calculated?

Report Outline

NNSA
National Nuclear Security Administration

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Spent Fuel Accident Risk Investigation

Executive Summary/Brochure

1. Introduction
2. Probabilities
   - A. Incident Free – includes routes
   - B. Accident – includes event trees with branch point probabilities
3. Cask Description – includes payload
4. Structural Analysis
   - A. Finite element calculations
   - B. Target hardness evaluations
5. Thermal Analysis
   - A. Finite element calculations
   - B. Offset fires
6. Source Term and Condition of Fuel
   - A. Cladding failure
   - B. Fuel fines
   - C. Fuel-to-cask release fraction
7. Risk Analysis
   - A. Incident Free
   - B. Accident – includes release, LOS, stop, and criticality
   - C. Comparisons to NUREG-0170 and NUREG/CR-6672
8. Consequence Analysis
9. Summary and Conclusions