FESSP
Fission Energy and Systems Safety Program
Lawrence Livermore National Laboratory

Predicting Cask Performance in Accidents (Modal Study)

Panel on the Waste Management System
Nuclear Waste Technical Review Board

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Presentation Outline

- Summary of Modal Study
  - Objective
  - Description
  - Results / Conclusions

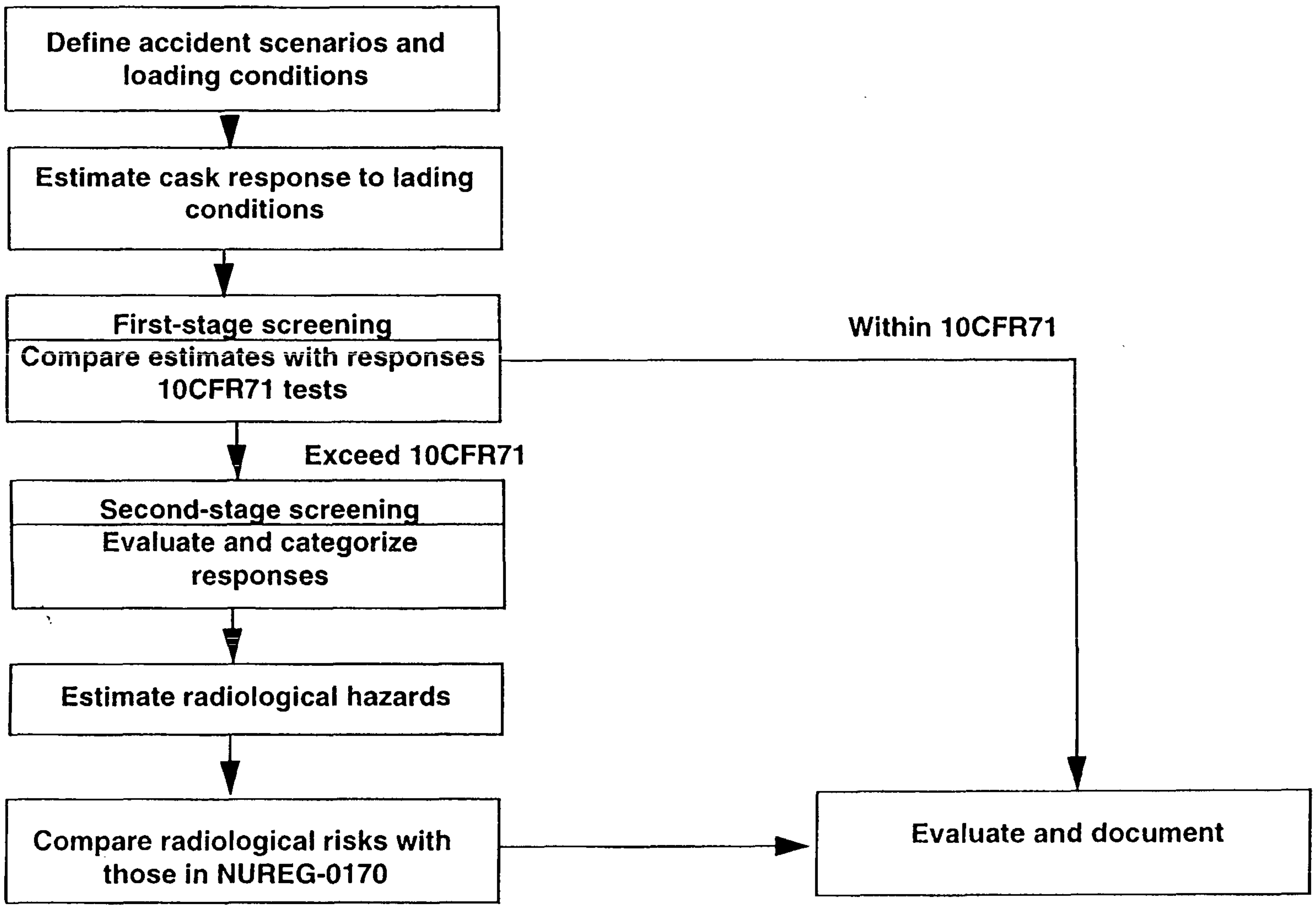
- Post Modal Study Calculations

- Improved Structural and Thermal Code Capabilities

Modal Study Objective

"The objective of this study, the Shipping Container Response to Severe Highway and Railway Accident Conditions, is to estimate the adequacy of radiological protection offered the public by the current NRC regulations when highway or railway accidents occur involving spent fuel shipments. The estimates are performed using data from real accident histories of similar types of vehicles and using models of cask designs that have a likelihood of meeting requirements for spent fuel shipments."

Two-stage screening process used in evaluating the regulations

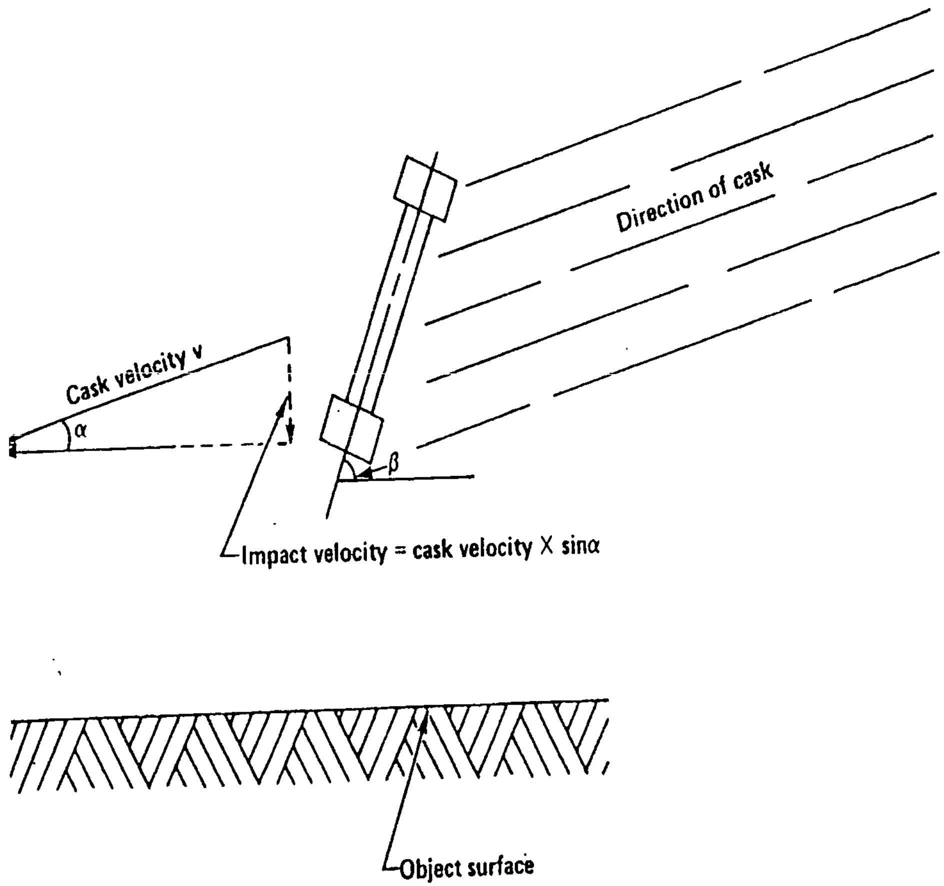


Accident Loads and Loading Parameters

Loading Parameter	Accident Loads					
	Mechanical Load Type			Thermal Load Type		
	Impact	Punch	Crush	Fire	Torch	Decay Heat [a/]
Object Hardness	X	X	X			
Impact Velocity	X	X				
Cask Orientation	X	X	X			
Object Weight	X	X	X			
Object Impact Area		X				
Flame Temperature				X	X	
Fire Duration				X	X	
Fire Location				X	X	
Flame Emissivity				X	X	
Convection Coefficient				X	X	
Surrounding Material						X

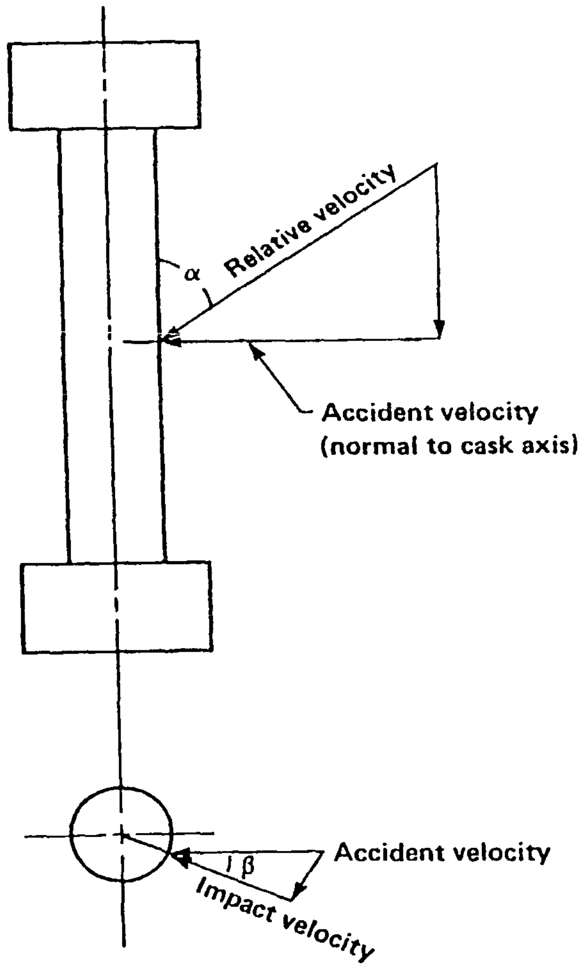
a/ Decay heat from spent fuel cargo

Three impact loading parameters considered response analysis for impacts on surface



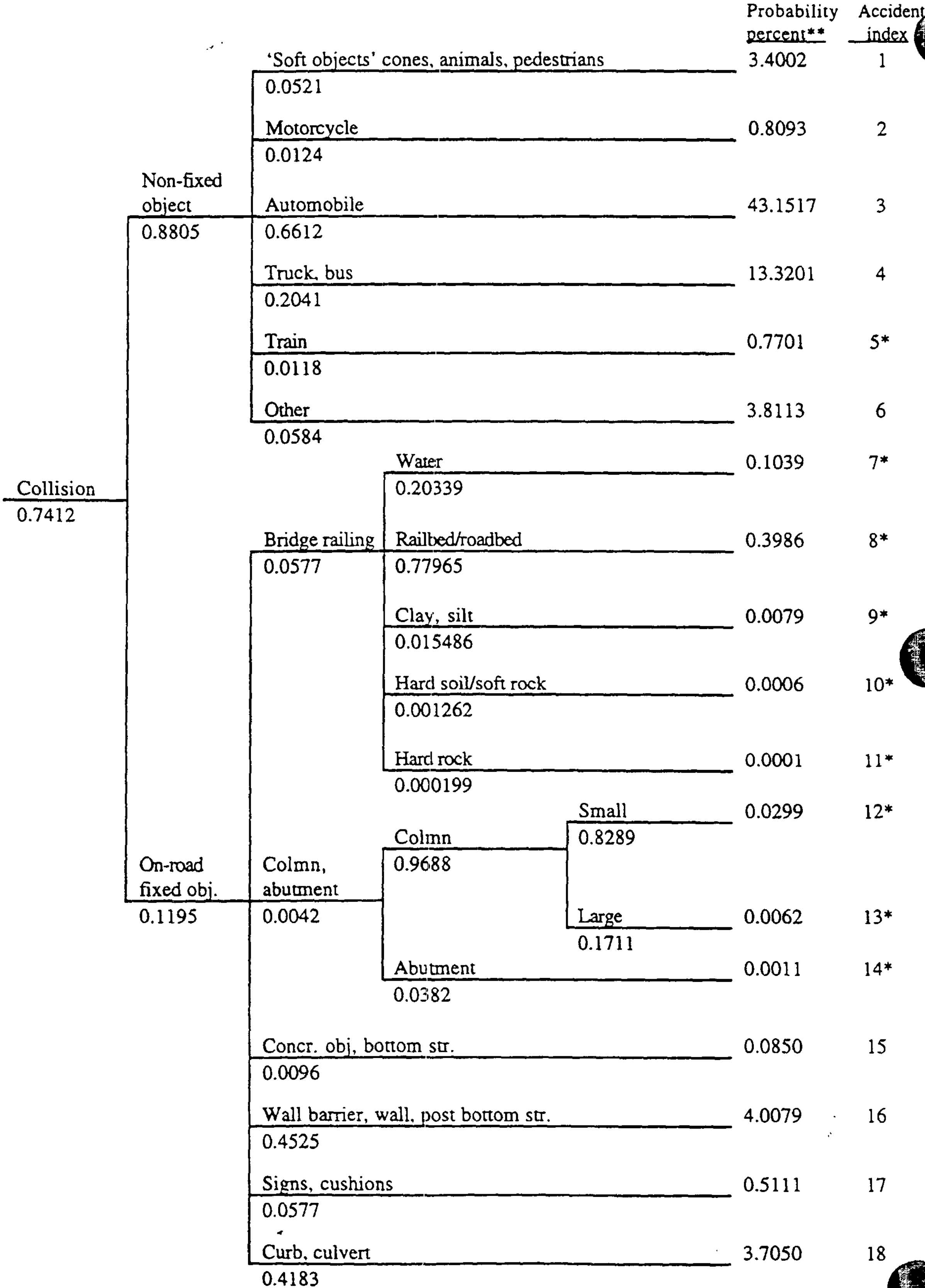
- Object surface hardness
- Impact velocity: Cask velocity component perpendicular to the surface
- Cask orientation is defined by angle β the angle between the cask longitudinal axis and the object's surface

Three impact loading parameters considered in the response analysis for impacts with objects such as train sills



- Object surface hardness
- Impact velocity: Relative velocity component perpendicular to cask surface
- Cask orientation angle, β : the angle between the accident velocity and impact velocity

Truck Collision Accident Scenarios - 6.4 x 10^{-6} per mile



*Potentially significant accident scenarios

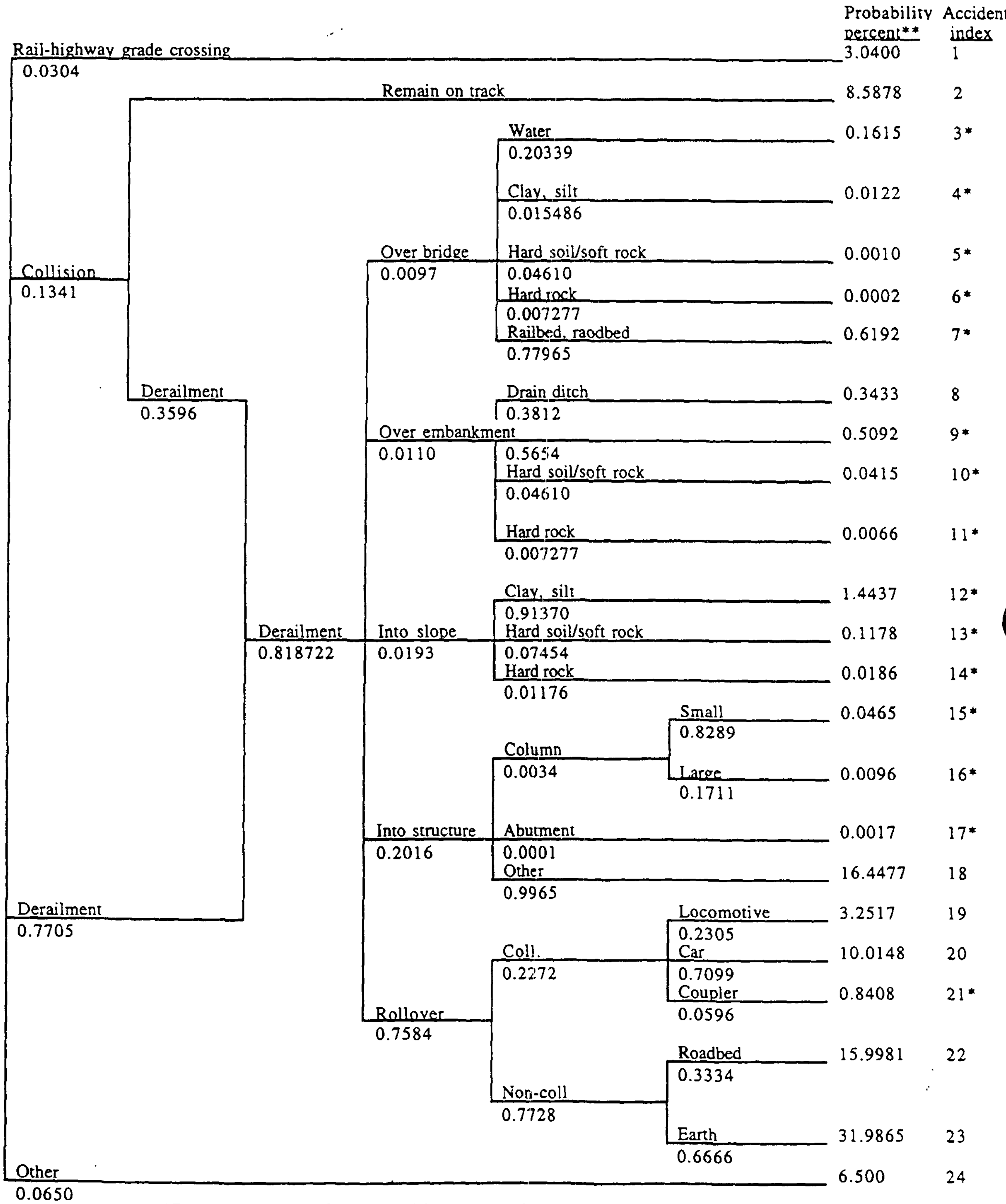
**Conditional probability which assumes an accident occurs

Truck Non-Collision Accident Scenarios - 6.4 x 10^{-6} per mile

				Probability percent**	Accident index
Non-collision 0.2588	Off road 0.3497	Into slope 0.2789	Clay, silt 0.91370	2.3063	19*
			Hard soil/soft rock 0.07454	0.1881	20*
			Hard rock 0.01176	0.0297	21*
		Over embankment 0.2578	Clay, silt 0.5654	1.3192	22*
			Hard soil/soft rock 0.0461	0.1076	23*
			Hard rock 0.007277	0.0170	24*
			Drain ditch 0.381223	0.8894	25
		Trees 0.1040		0.9412	26
		Other 0.3593		3.2517	27
	Impact roadbed 0.5336	Overturn 0.6046		8.3493	28
		Jackknife 0.3954		5.4603	29
	Other-involving mech. loading 0.0792			2.0497	30
	Fire only 0.0375			0.9705	31

*Potentially significant accident scenarios
**Conditional probability which assumes as accident occurs

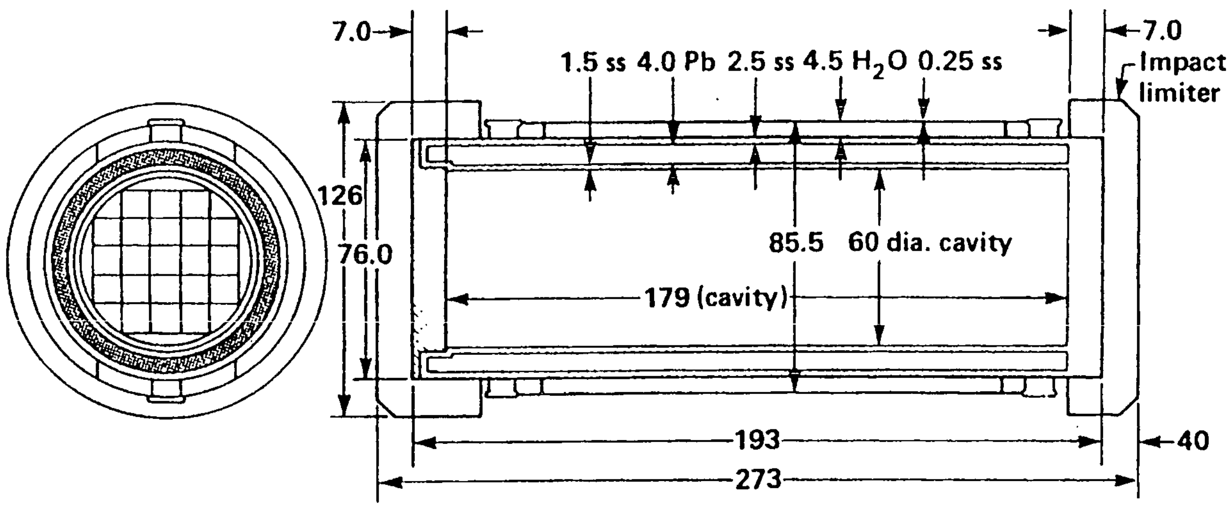
Train Accident Scenarios - 1.19 x 10^{-6} per mile



*Potentially significant accident scenarios

**Conditional probability which assumes an accident occurs

Representative rail cask design used for dynamic structural and thermal response studies



All dimensions in inches

Item	Weight, lbs
Body	122,500
Limiter	22,500
Contents	52,000
	197,000

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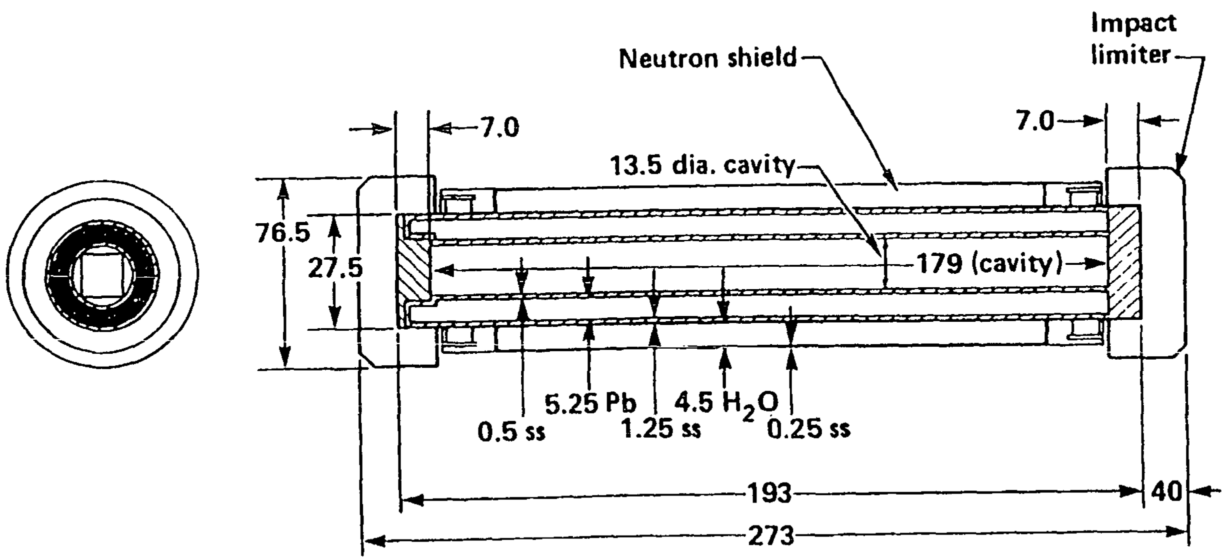
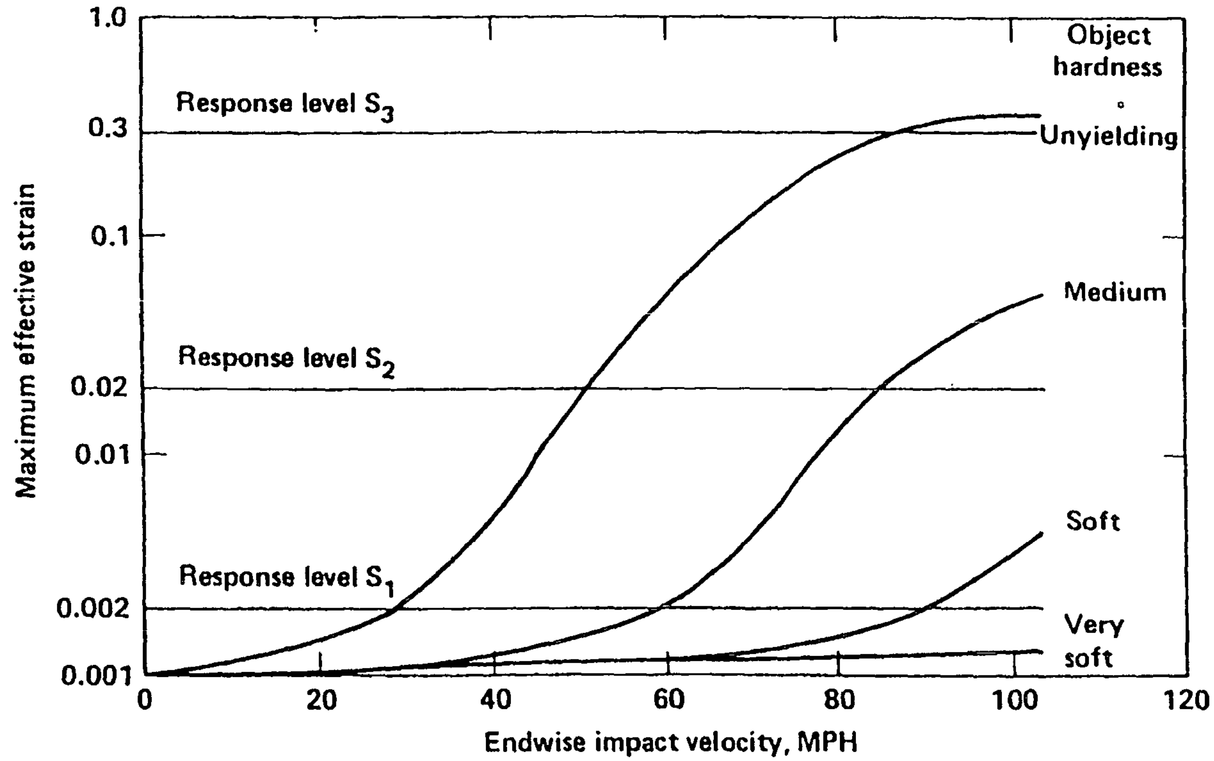
Representative truck cask design used for dynamic structural and thermal response studies



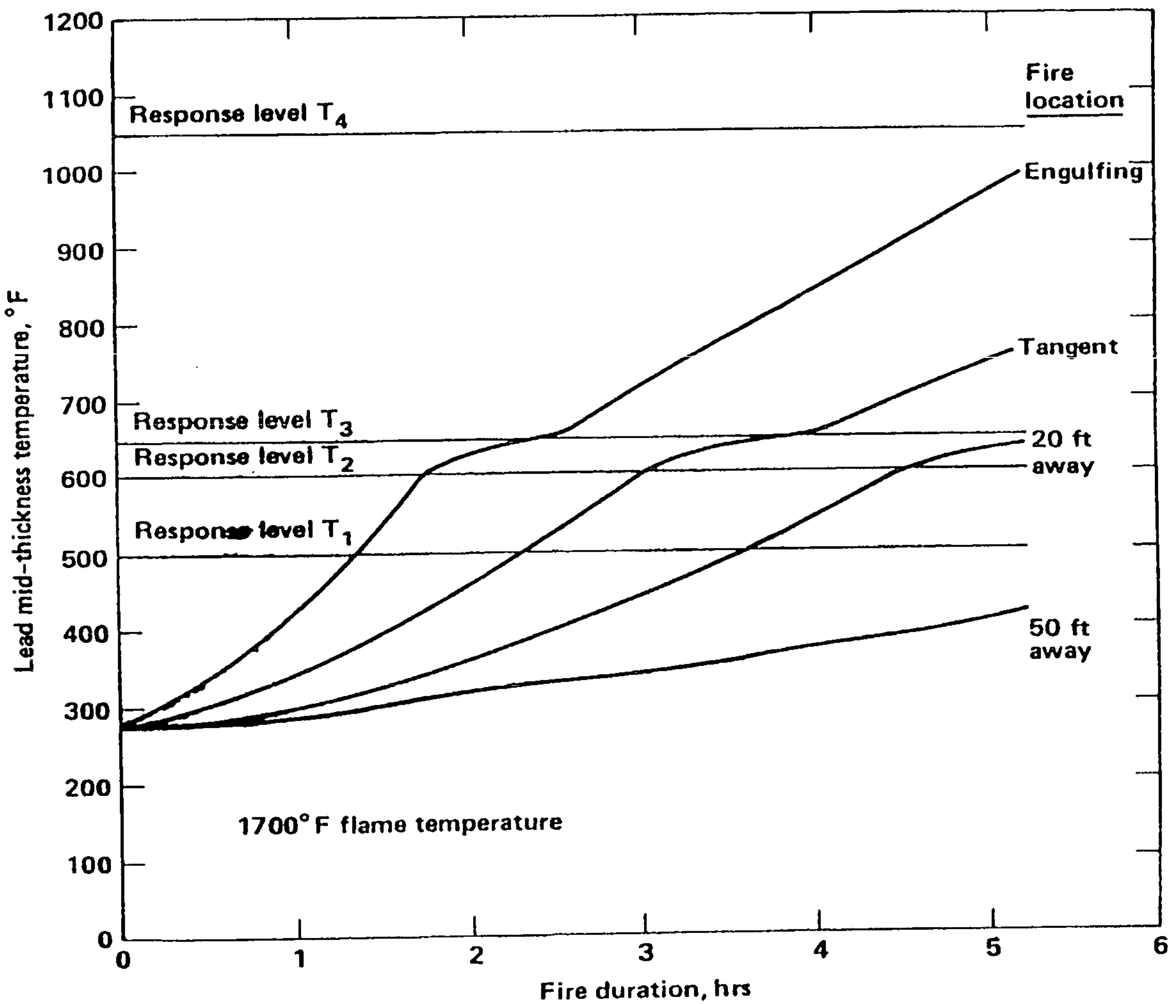
All dimensions in inches

Item	Weight, lbs
Body	32,000
Limiter	4,500
Contents	2,500
	39,000

Schematic representation of cask structural response for various surface hardness and impact velocities



Schematic representation of cask response for various fire locations and fire durations



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Matrix of cask response regions for combined mechanical thermal loads

Structural response (maximum strain on inner shell, %)

	R (4,1)	R (4,2)	R (4,3)	R (4,4)	R (4,5)
S_3 (30)					
	R (3,1)	R (3,2)	R (3,3)	R (3,4)	R (3,5)
S_2 (2)					
	R (2,1)	R (2,2)	R (2,3)	R (2,4)	R (2,5)
S_1 (0.2)					
	R (1,1)	R (1,2)	R (1,3)	R (1,4)	R (1,5)

T_1 (500) T_2 (600) T_3 (650) T_4 (1050)

Thermal response (lead mid-thickness temperature, •F)

Estimated Damage to the Cask

- Structural Damage
  - impacts evaluated for all significant accident scenarios
  - presented in terms of strain or inner wall versus impact velocity
  - "g" loads also calculated for evaluations
  - probability of occurrence estimated for exceeding strain levels
- Thermal Damage
  - all fire scenarios evaluated in terms of equivalent engulfing fires
  - presented in terms of lead mid-thickness temperature versus engulfing fire durations
  - Thermal loads calculated for evaluations
  - probability of occurrence estimated
- Combined Damage
  - regions defined for combined structural and thermal damage
  - joint probability of occurrence estimated

Fraction of truck accidents that could result in responses within each response region, assuming an accident occurs

Structural response (maximum strain on inner shell, %)

1.532E-7	3.926E-14	1.495E-14	7.681E-16	<E-16
1.7984E-3	1.574E-7	2.034E-7	1.076E-7	4.873E-8
3.8192E-3	2.330E-7	3.008E-7	1.592E-7	7.201E-8
0.994316	1.687E-5	2.362E-5	1.525E-5	9.570E-6

S_3 (30)
S_2 (2)
S_1 (0.2)

T_1 (500) T_2 (600) T_3 (650) T_4 (1050)

Thermal response (lead mid-thickness temperature, •F)

Note: $E + x = 10^x$

Source Term and Release Estimates

- Radioactive material release
  - failure of fuel rods related to "g" level and temperature
  - release from fuel rods into cask cavity estimated from ORNL test data
  - fuel road "g" level and temperature related to inner wall strain and lead mid-thickness temperature
  - Release from cask cavity related cask damage in terms of inner-wall strain (distortion) and lead mid-thickness temperature (seal temperature)
- Radiation levels
  - Estimated to lead slump due to impact and related to inner wall strain
  - Estimated to lead melting due to fire and related to lead mid-thickness temperature
  - Resultant radiation level expressed in terms of equivalent release to compare with NUREG-0170
- Criticality - physically unreasonable

Probability-hazard estimates in curies for the 20 truck cask response regions

Structural response (maximum strain on inner shell, %): S_3 (30), S_2 (2), S_1 (0.2)

(G)2.98E-4 (v)2.16E-5 (P)1.11E-8 (E)1.29E-5	7.65E-11 5.54E-12 2.83E-15 3.31E-12	2.91E-11 2.11E-12 1.08E-15 1.26E-12	1.49E-12 1.08E-13 5.54E-17 6.46E-14	~0 ~0 ~0 ~0
(G)1.83E+0 (v)2.54E-2 (P)1.30E-5 (E)1.51E-2	1.61E-4 2.22E-6 1.14E-9 1.32E-6	2.07E-4 2.87E-6 1.47E-9 1.71E-6	1.10E-4 1.52E-6 7.78E-10 9.07E-7	9.50E-4 6.87E-6 3.52E-9 4.10E-6
(G)3.90E-1 (V)5.36E-3 (P)2.76E-6 (E)1.37E-3	2.38E-5 3.29E-7 1.68E-10 8.39E-8	3.06E-5 4.24E-7 2.17E-10 1.14E-7	1.90E-4 2.24E-6 1.15E-9 6.05E-8	1.40E-4 1.02E-5 5.20E-9 6.60E-6
(G)~0 (V)~0 (P)~0 (E)~0	5.15E-4 7.14E-6 3.66E-9 ~0	7.20E-4 9.99E-6 5.13E-9 4.72E-7	1.83E-2 2.15E-4 1.10E-7 3.05E-7	1.87E-2 1.35E-3 6.90E-7 8.06E-4

T_1 (500) T_2 (600) T_3 (650) T_4 (1050)

Thermal response (lead mid-thickness temperature, °F)

(G)=Noble gases, curies
(V)=Vapors, curies
(P)=Particles, curies
(E)=Exposure, curies

Note: $E + x = 10^x$

Radiological hazards estimated for response regions for a representative truck cask

Structural response (maximum strain on inner shell, %)

	(G)1.95E+3 (v)1.41E+2 (P)7.22E-2 (E)8.60E+1	1.95E+3 1.41E+2 7.22E-2 8.60E+1	1.95E+3 1.41E+2 7.22E-2 8.60E+1	1.95E+3 1.41E+2 7.22E-2 8.60E+1	195E+3 1.41E+2 7.22E-2 8.60E+1
S_3 (30)	(G)1.02E+3 (v)1.41E+1 (P)7.22E-3 (E)8.40E+0	1.02E+3 1.41E+1 7.22E-3 8.40E+0	1.02E+3 1.41E+1 7.22E-3 8.60E+0	1.20E+3 1.42E+1 7.22E-3 8.60E+0	1.95E+3 1.41E+2 7.22E-2 8.60E+1
S_2 (2)	(G)1.02E+2 (V)1.41E+0 (P)7.22E-4 (E)3.60E-1	1.02E+2 1.41E+0 7.22E-4 3.60E-1	1.02E+2 1.41E+0 7.22E-4 5.60E-1	1.20E+3 1.42E+1 7.22E-3 5.60E-1	1.95E+3 1.41E+2 7.22E-2 8.60E+1
S_1 (0.2)	(G)~0 (V)~0 (P)~0 (E)~0	3.05E+1 4.23E-1 2.17E-4 ~0	3.05E+1 4.23E-1 2.17E-4 2.00E-1	1.20E+3 1.42E+1 7.22E-3 2.00E-1	1.95E+3 1.41E+2 7.22E-2 8.60E+1
		T_1 (500)	T_2 (600)	T_3 (650)	T_4 (1050)

Thermal response (lead mid-thickness temperature, °F)

(G)=Noble gases, curies
(V)=Vapors, curies
(P)=Particles, curies
(E)=Exposure, curies

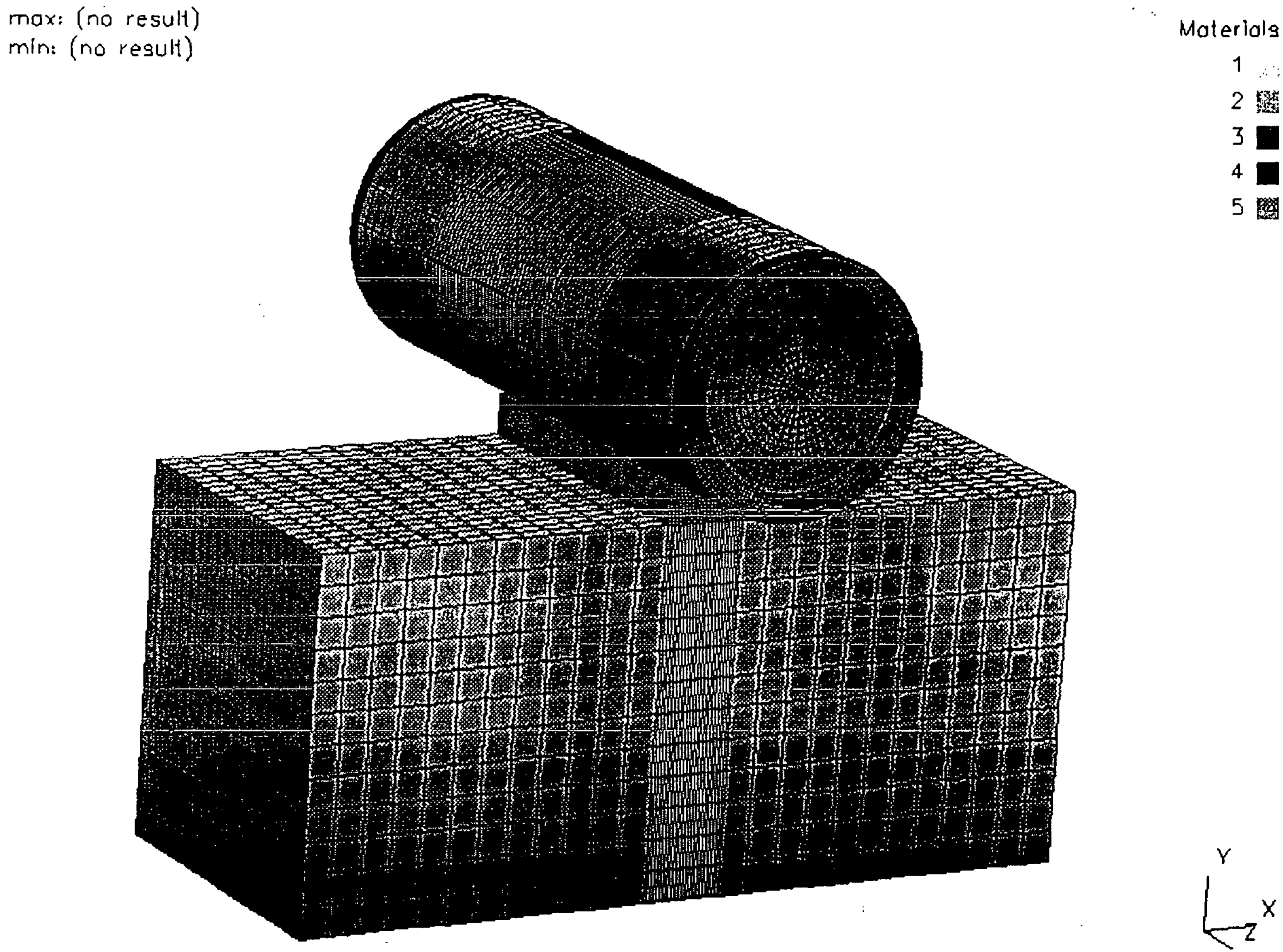
Note: E + x = 10^x

Results and Conclusions

- Estimated risk compared to NUREG-0170 is at least a factor of three less
- Human factors and uncertainties were not explicitly evaluated
- Assumes that cask meets all regulatory requirements including certification, proper maintenance and proper operation
- Study concluded that the 10CFR71 regulations are adequate

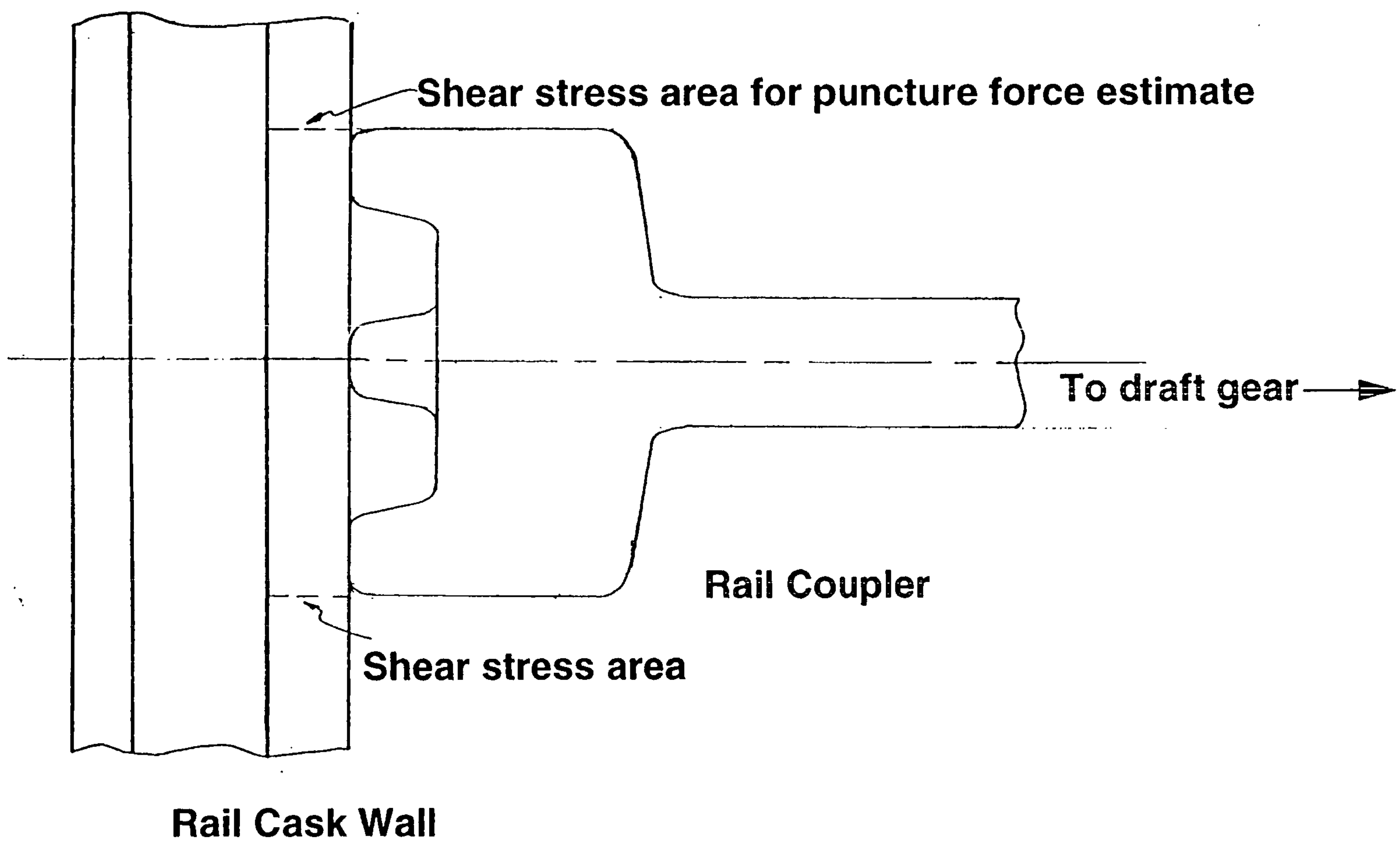
Additional Calculations to support Modal Study

- Cask Side drop onto uneven surface
- Coupler impact on rail cask wall
- Closure impact of rail cask on unyielding surface

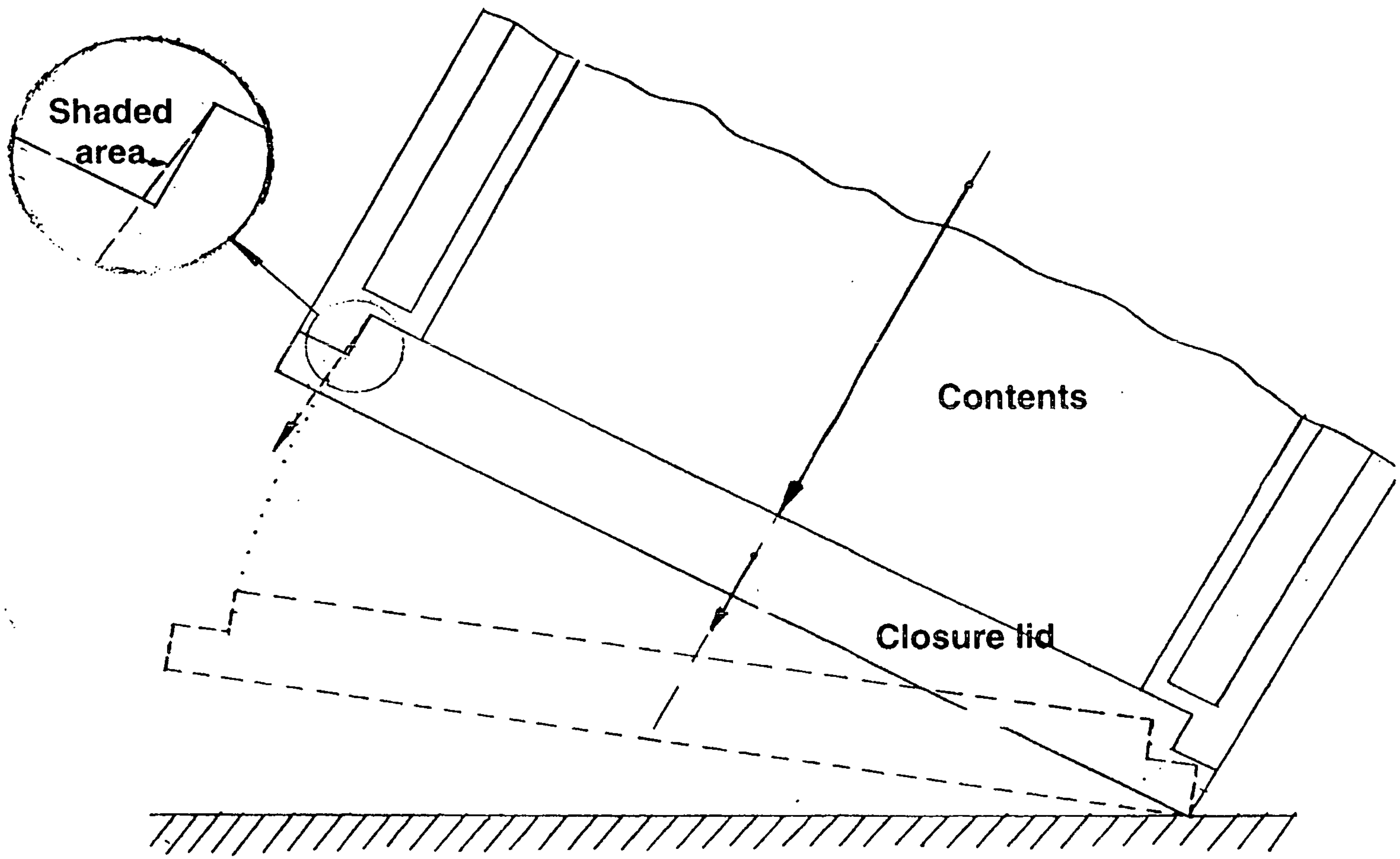


rail cask side drop on concret
t = 0.00000e+00

Coupler impact on representative rail cask wall



Closure impact of representative rail cask on unyielding surface



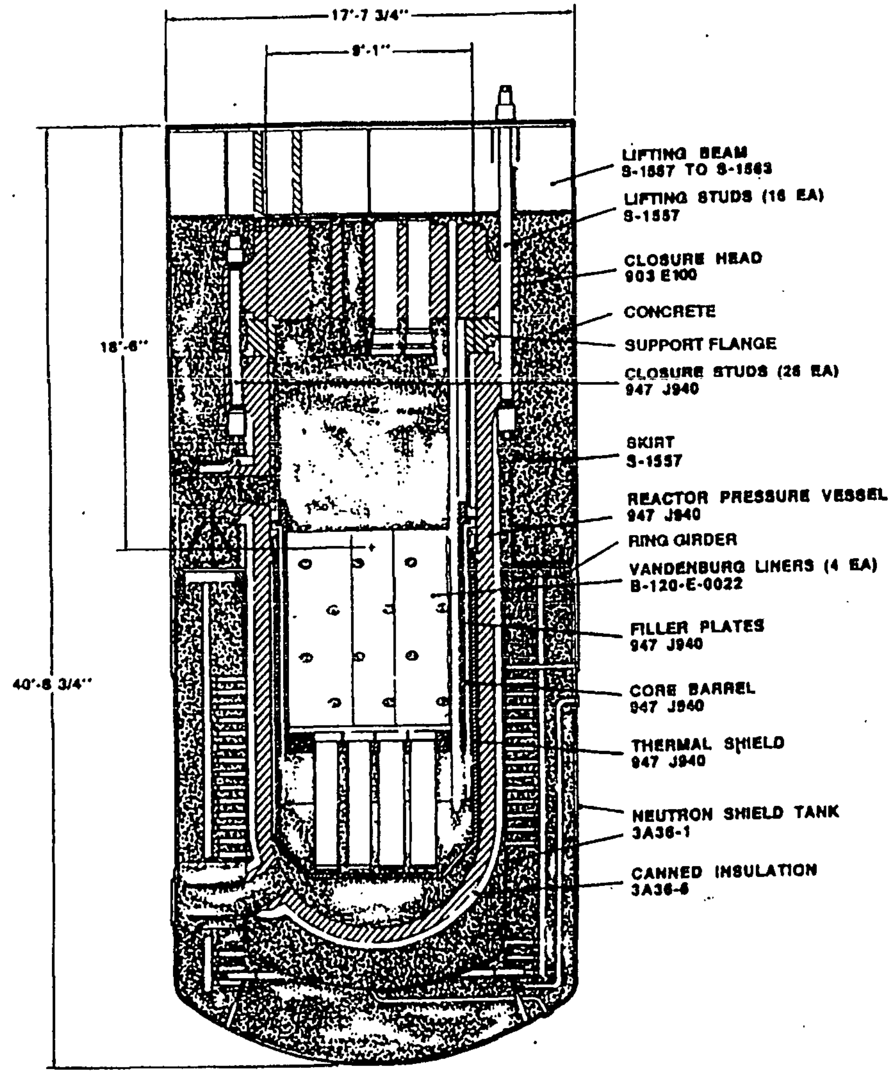
DYNA Benchmark Tests

- Shippingport Reactor Vessel and Neutron Shield Tank

- Plutonium air shipping package

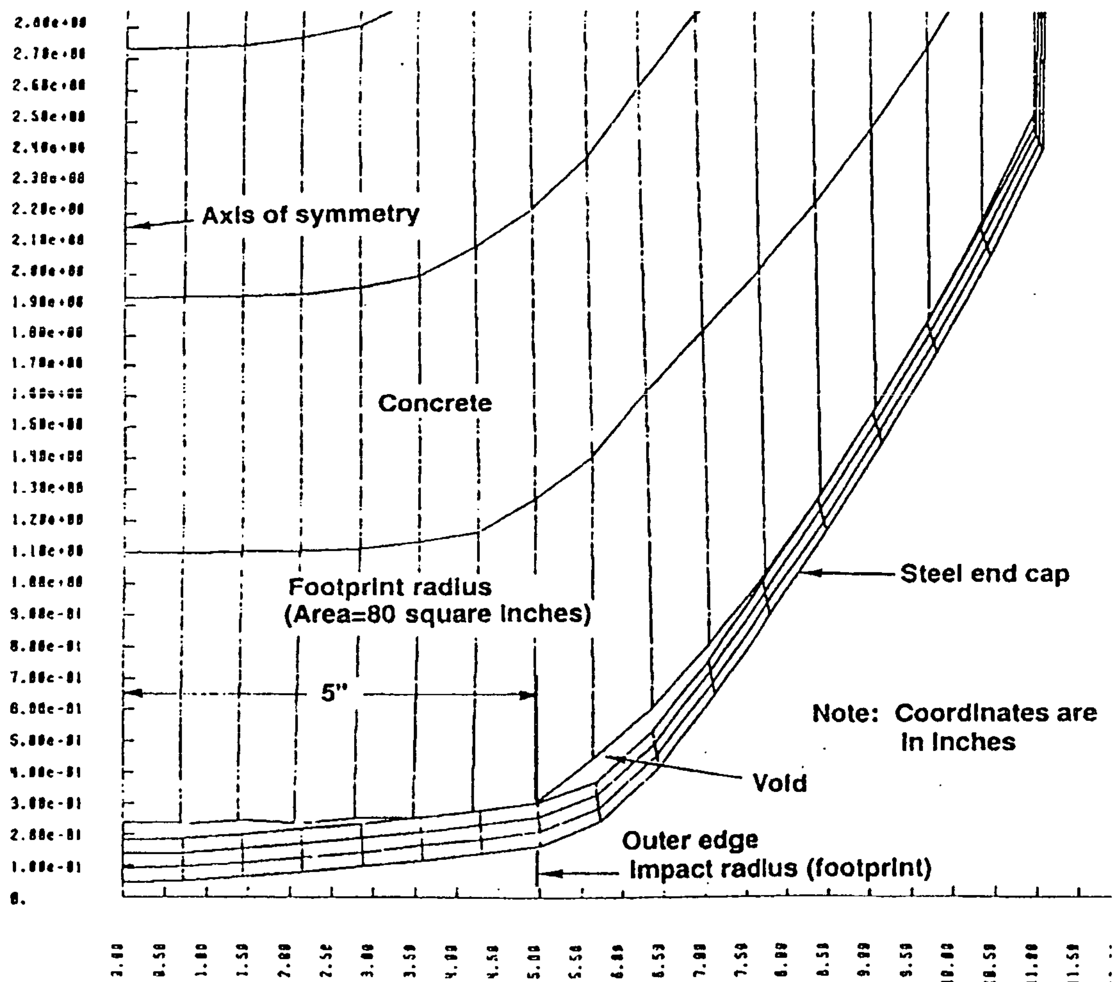
- Steel billet drop tests onto concrete pool

We performed stress and failure analysis and scale testing for Shippingport RPV/NST package



Footprint from 30 foot round end drop

Analytically predicted deformation using Dyna due to 30 ft round end drop



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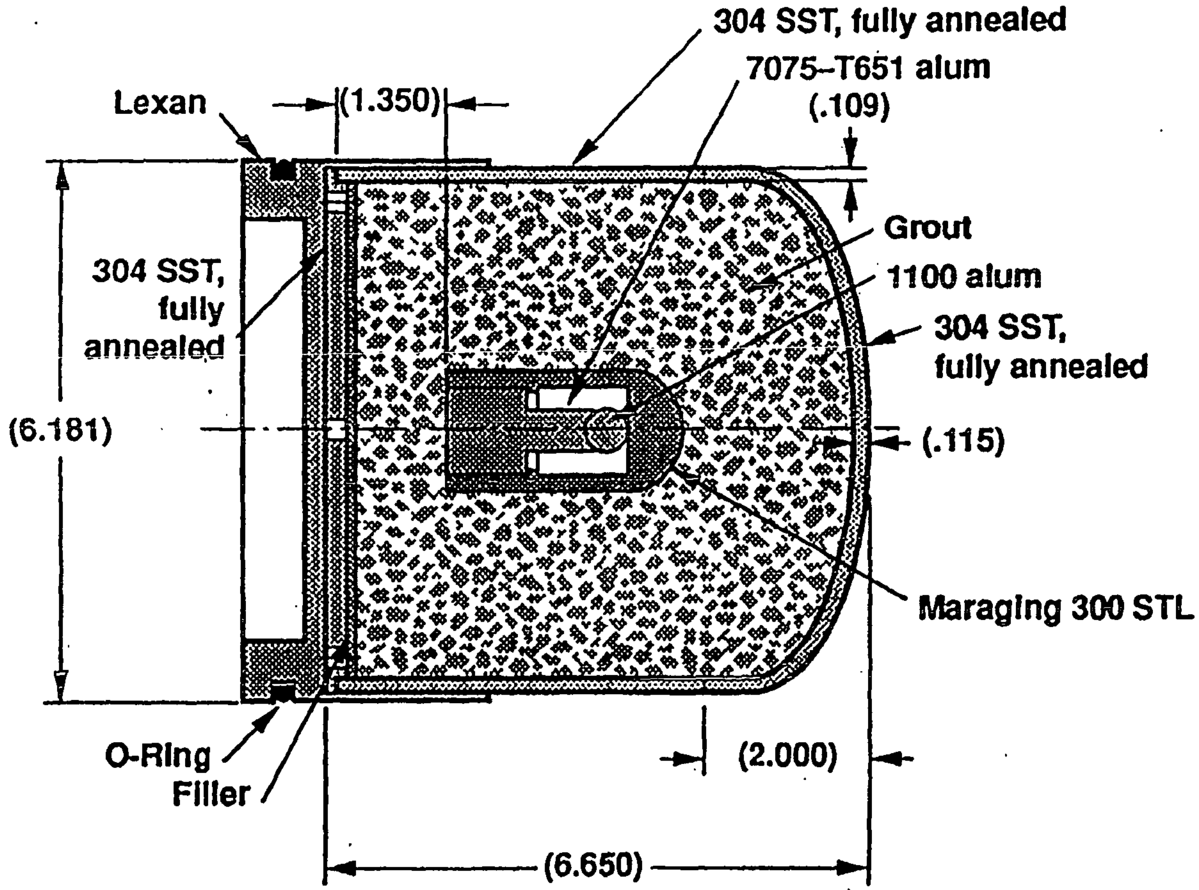
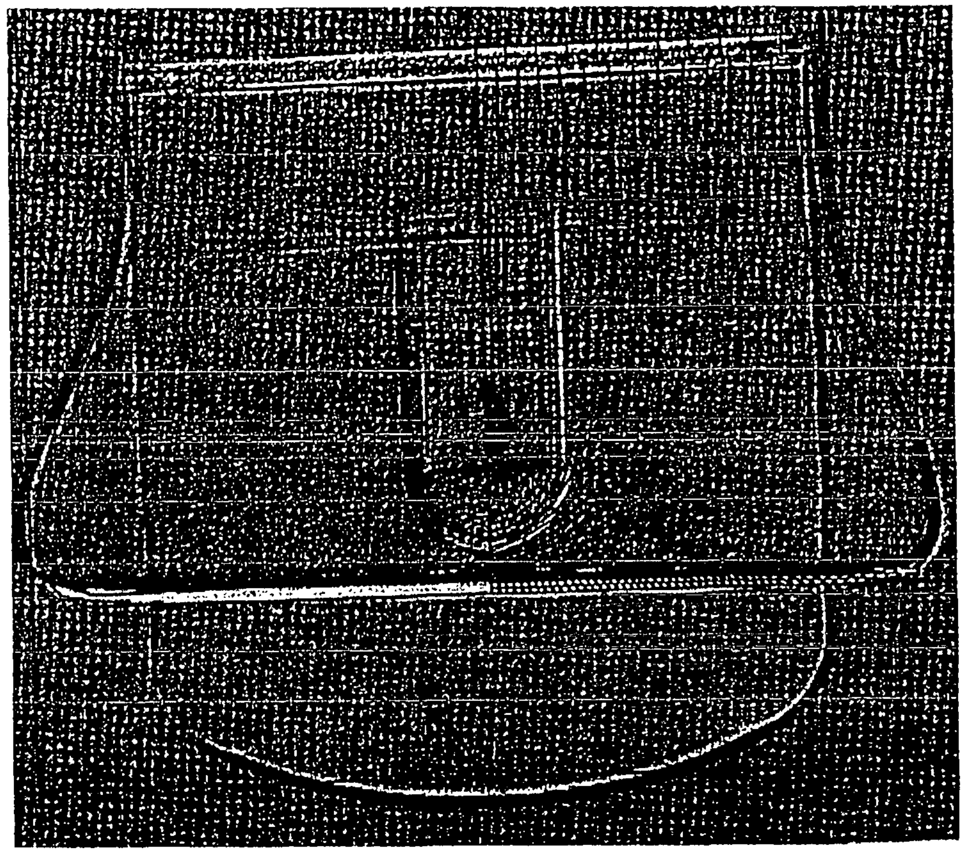
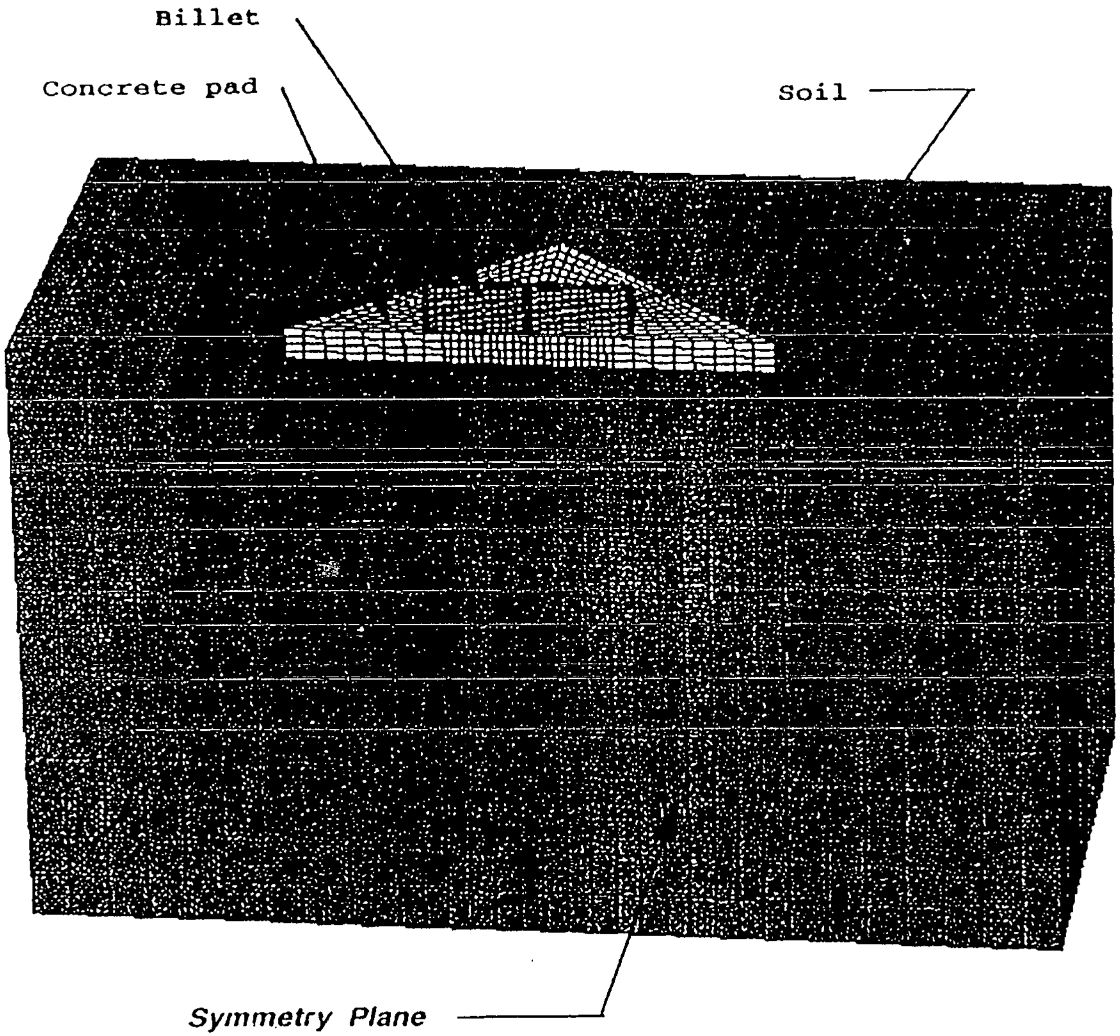
The scale model test design (Dimensions in inches)



Overlay of computer simulation on radiograph results of test package, impact on unyielding surface at 143.6 m/s



Finite element model of steel billet side drop and tipover onto concrete pad and soil



Maximum billet side drop acceleration test vs. simulation

Billet drop height	Test data from channel A3, filtered at 450 Hz	Finite element analysis simulation, filtered at 450 Hz
18 inches (Test #3)	108.2g	
18 inches (Test #5)	86.0g	94.5g
18 inches (Test #10)	125.5g	
36 inches (Test #4)	110.0g	
36 inches (Test #7)	not available	123.8g
36 inches (Test #9)	125.2g	
72 inches (Test #6)	206.7	
72 inches (Test #8)	197.0	173.3g

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