Design and Testing of the TN-Gemini Packaging

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Introduction

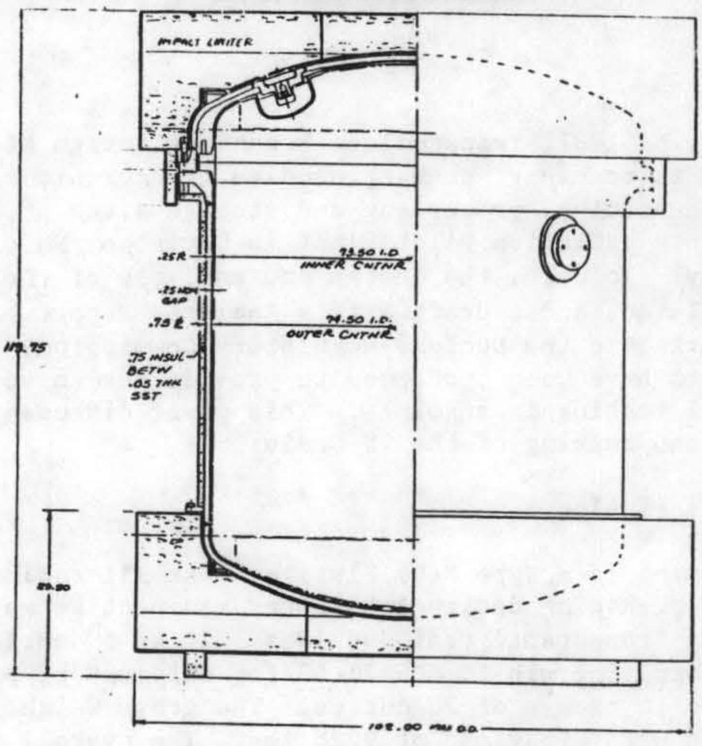
During May of 1987, Transnuclear began the design of the TN-Gemini, a packaging to transport contact handled transuranic radioactive waste between generating, processing and storage sites or from these sites to the Waste Isolation Pilot Plant in Carlsbad, NM or other repository. To date, the design and analysis of the packaging has been completed, and a draft Safety Analysis Report has been written for submittal to the Nuclear Regulatory Commission. Several scale model tests have been performed to provide design verification. Additional testing is ongoing . This paper discusses the design, analysis and testing of the TN-Gemini.

Design Description

The TN-Gemini is a Type B(U) Fissile Class III radioactive waste transport packaging designed to carry radioactive waste materials containing transuranic radionuclides. It is a double containment system, complying wih 10 CFR 71.63 for shipment of plutonium quantities in excess of 20 curies. The gross weight of the package is 27,000 lbs with a payload of 9225 lbs. The overall dimensions of the package are shown in Figure 1. The TN-Gemini consists of two stainless steel concentric right circular cylinders with torispherical top and bottom heads. Containment closure is accomplished with conventional bolting and double O-rings. The packaging is leaktight under normal conditions of transport and hypothetical accident conditions. The packaging includes a layer of thermal insulation encased in stainless steel around the exterior of the outer shell, and wood filled impact limiters covering the top and bottom ends. Four lifting lugs are provided on the outer lid which may be used for removing the outer lid and to lift the entire package with the top impact limiter removed. Four lifting lugs are provided on the inner lid which are designed to lift the inner lid only. Four trunnions welded to the outer shell are used to hold the package down during transport. Shear blocks on the trailer or rail car prevent the package from sliding horizontally during transport.

The cavity has a useable volume of about 180 ft^3 and carries fourteen 55 gallon drums, arranged in two layers of seven drums. Other waste containers which fit within the cavity may also be carried. The packaging is top loaded and is designed for truck or rail transport. For legal weight truck shipments, the TN-Gemini system has two casks per trailer. Table 1 provides additional information on the Gemini.

FIGURE 1
GENERAL ARRANGEMENT



TN GEMINI DESIGN FEATURES

Design Payload	
Weight	9225 lbs.
Heat Output	112 watts
Fissile Material	2100 grams Pu239
Alpha curies	3100 Ci
Maximum Operating Pressure	30 psig
Hydrogen Control	
Catalytic Recombiners and Hydrogen Getters	
Maximum Hydrogen Concentration	<5%
Sealing System	
Double O-Rings, Each Containment	
Leakage Rate	$<10^{-7}$ std. cc/sec of air

Analysis

The TN-Gemini has been designed and analyzed in compliance with NRC Regulatory Guides 7.6 and 7.8 and the U.S. Code of Federal Regulations, 10 CFR 71. The containment boundary has been designed in accordance with the rules for Class I components in the ASME B&PV Code, Section III, Subsection NB.

Three computer models are used to perform the structural evaluation of the TN-Gemini.

The computer program ADOC (Accelerations due to Drops on Covers) is used to determine the deformation of the impact limiters, the forces on the containment, and the packaging deceleration due to impact onto an unyielding surface. Analysis shows that the worst 30 ft drop orientation in terms of highest contact force is a 15 degree drop onto the top impact limiter.

An Ansys 2-D, elastic finite element model of the TN-Gemini inner and outer containments was constructed using axisymmetric structural solid elements in the flange area, and axisymmetric conical shell elements elsewhere. This model is used to determine the stresses and deformations in the containments during all normal conditions of transport, and all hypothetical accident conditions with the exception of the hypothetical puncture event. The stress intensities calculated for each loading combination are below the allowable stress intensity limits of Regulatory Guide 7.6 and the ASME Code.

A 3-D nonlinear finite element analysis was performed using axisymmetric conical shell elements for the hypothetical puncture event. Four areas of the container are analyzed:

- center of closure lid
- knuckle of closure head through center of gravity
- center of cylindrical shell
- lid flange

For the puncture analysis, energy absorption by the contents and the impact limiters are ignored. The analysis shows that the ductile stainless steel shells and heads of the containment vessels are capable of deforming under the punch loading to absorb the kinetic energy as strain energy (bending and stretching) without shear failure.

A buckling analysis of the inner container was performed in accordance with ASME Code Case N-284 for: maximum external pressure combined with minimum internal pressure and; immersion combined with minimum internal pressure. The results show that buckling will not occur.

The thermal analysis of the TN-Gemini for normal and hypothetical accident conditions was performed using ANSYS. A 2-D finite element model of a radial slice through the packaging and waste is modeled.

Only radial heat transfer is considered, so that all heat rejection occurs through the cylindrical portion of the package.

Transfer of heat through the packaging is limited to conduction while heat dissipation from the outer surface of the packaging is by radiation and natural conduction. The thermal analysis is based on a decay heat load of 112 watts. A 3-D solid model of the flange region is also analyzed for the thermal accident. A portion of the insulation is removed to simulate the damage from a puncture accident.

Shielding is not a limiting criterion, since the TN-Gemini is primarily designed for contact handled waste.

A series of criticality calculations were made for normal conditions, assuming 200 grams of Pu 239 in a sphere in each of 14 drums, and varying the drum contents and the H:Pu ratio of the spheres to find the maximum k_{eff}. Two accident models are analyzed. One assumes that the package is flooded and all fissile material is released from the drums and settles at one end of the packaging in an optimally moderated disc. The other is similar to the normal analysis except that the package is flooded. Criticality analyses establish the following restrictions on the quantity of Pu239 which assures subcriticality of the TN-Gemini:

200 grams Pu239 per drum
2100 grams Pu239 per package

For other fissile nuclides, the restrictions are based on fissile equivalent grams of Pu 239.

Testing

The TN-Gemini has undergone extensive scale model testing including static and dynamic puncture testing, static crush testing of the impact limiters and 30 foot drop testing. The results of each test series are briefly described below.

Static Punch Tests

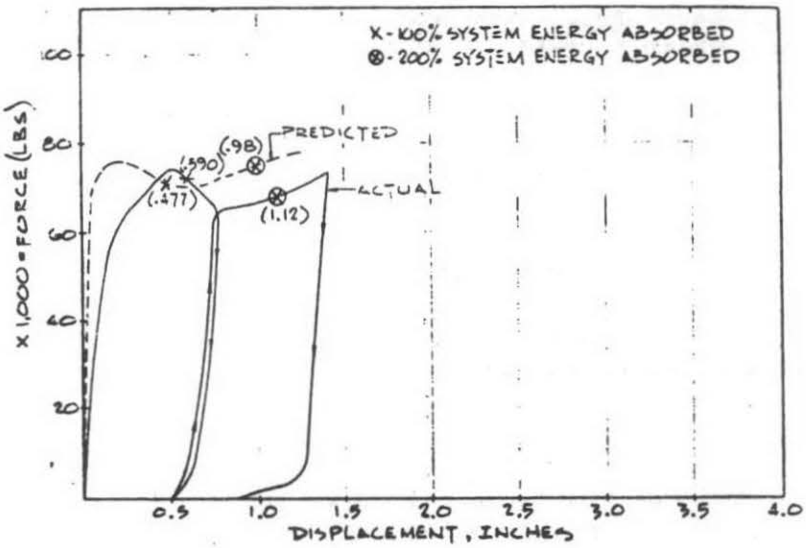
Static puncture tests were performed on one-third scale models of a one inch thick outer container. Puncture tests were performed at the following packaging locations:

- center of lid
- containment shell through the packaging center of gravity
- knuckle of the outer lid through the packaging center of gravity
- shell wall adjacent to flange
- directly onto flange

The tests were run using a calibrated Baldwin Compression Testing Machine with a capacity of 120,000 lbs. Continuous simultaneous measurements of vertical (axial) punch force and specimen deflection were recorded during each test on an x-y plotter.

The force-displacement curve for the puncture test into the knuckle of the outer lid is shown in Figure 2. The measured forces were slightly lower than predicted in the knuckle and center of lid puncture tests, but were higher than predicted in the center of the lid. This is most likely due to work hardening of the stainless steel during spinning of the head. All tests were conducted until at least 200% of the potential energy from a 40 inch drop was absorbed, indicating that the packaging had a large safety margin to failure.

FIGURE 2
STATIC PUNCTURE TESTING TO KNUCKLE OF LID



Dynamic Punch Tests

Dynamic Punch Tests were conducted on a one-third scale model of the outer cylinder with welded flat ends to investigate the effect of the angle between the puncture bar and shell on damage and impact force. Tests at 0° (shell perpendicular to puncture bar), 20° and 30° were performed. The model was dropped 40 inches onto an instrumented puncture bar. The impact force was measured using strain gages embedded in the puncture bar.

The 20° oblique drop was the most severe test, producing a force of 1.67 times that of the 0° drop. The 20° drop affected the least area, producing a shallow, localized dent. The 0° drop created a deeper and much longer dent. During the 30° drop the model skidded along the bar until it struck the closure flange.

Another test program was conducted using a one-third scale model of an entire outer container with a one inch wall thickness to help determine the packaging orientation which would cause the most damage during the puncture accident. The container was filled with Raschig rings to provide a weight of one-twenty seventh the full scale weight. Four orientations were tested:

- Puncture perpendicular on the end of the lid
- Puncture on the knuckle of the lid through the center of gravity
- Puncture on the lid flange through the center of gravity
- Puncture on the intersection of the shell and flange through the center of gravity

Force vs. deflection curves were generated for each of the tests, and compared with the static tests. In general, the static tests caused much larger deformations than the dynamic tests, but produced comparable peak forces. A comparison of the static vs. dynamic test results are shown in Table 2.

TABLE 2

COMPARISON OF STATIC AND DYNAMIC TEST RESULTS

	MAXIMUM FORCE (LBS.)		MAXIMUM DEFLECTION	
	Static	Dynamic	Static	Dynamic
Center of Lid	41,875	42,932	1.43	.419
Knuckle	76,250	73,094	.540	.045
Flange*	43,815	72,954	0.65	.040
Adj to Flange*	40,000	38,090	0.94	.285
Cylinder Wall	35,000	Not Tested	1.625	Not Tested

* The static and dynamic test results for flange testing are presented for information only, they are not comparable. Static tests were conducted with the load applied perpendicular to the flange. (Rotational effects were considered). The dynamic test load was applied at an angle to the flange but through the packagings center of gravity, rotation of the packaging did not occur.

Based on the results of the static and dynamic punch tests, it was determined that a thinner container would perform satisfactorily, since the damage was slight. Therefore the outer container wall thickness was reduced from 1 inch to 3/4 inch.

Impact Limiter Static Crush Tests

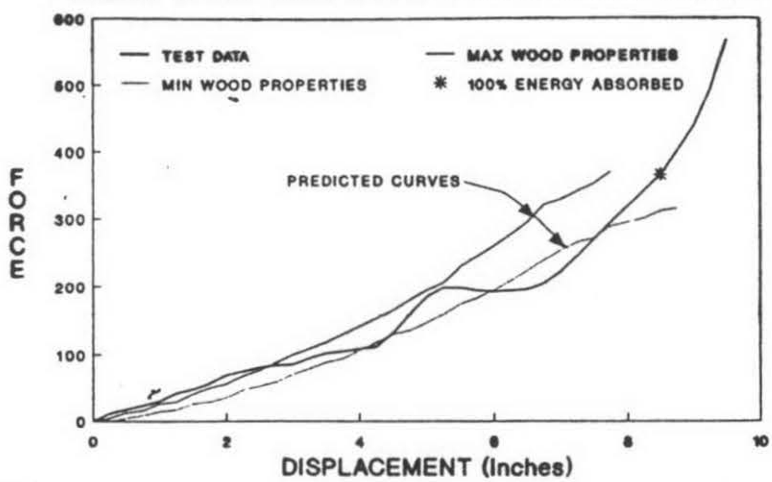
Three static crush tests of one-half scale TN-Gemini impact limiters were performed at Pittsburgh Testing Laboratories. The following impact angles were evaluated:

- load applied perpendicular to the exposed end
- load applied radially into the side of the impact limiter
- load applied into the corner directed towards the center of the packaging.

For each of the tests, the test article was loaded until at least 125% of the system's potential energy had been absorbed. No visible damage to the lid, lid bolts or sealing surface could be detected.

Load-deflection curves were obtained for each crush test. For each orientation, there was excellent correlation between test and analysis results. The force-deflection curve for the corner crush test is shown in Figure 3. The impact limiter attachment bolts withstood the loading during each test without failure.

FIGURE 3
CORNER CRUSH TEST FORCE DISPLACEMENT CURVES



FORCE in 1000's of lbs

Dynamic Drop Tests

A series of 30 foot drop tests and 40 inch drops onto a puncture bar were performed on a one-half scale model of the TN-Gemini. The model was filled with fourteen 7 gallon containers filled with concrete to provide the correct scaled weight of a fully loaded packaging.

The following tests were conducted:

1. 30 foot drop onto top end of the TN-Gemini
2. 40 inch drop onto puncture bar through the top impact limiter into a penetration in the outer lid.
3. 30 foot drop onto the bottom corner of the TN-Gemini through the packaging center of gravity.
4. 40 inch drop onto a puncture bar into the bottom knuckle of the TN-Gemini
5. 30 foot drop onto the side of the TN-Gemini
6. 30 foot drop onto the side of the TN-Gemini at a shallow angle
7. 40 inch drop onto a puncture bar through the packaging center of gravity hitting the shell directly below the flange at an oblique angle
8. 40 inch drop onto a puncture bar through the packaging center of gravity hitting the top outer flange.

The TN-Gemini Packaging is very durable and able to withstand 30 ft. drops and 40 inch puncture drops without damaging its integrity. The TN-Gemini impact limiters successfully absorb the energy during the 30 foot drop tests.

The maximum g loads and displacements predicted by the computer analysis are conservatively higher than those measured during the 30 foot drop tests.

The maximum forces measured during the 40 inch puncture drop tests were within 10% of the predicted forces.

REFERENCES

US Code of Federal Regulations - Title 10, Part 71, "Transportation of Radioactive Material", US NRC Washington, D.C., 1988.

Regulatory Guide 7.6, "Design Criteria for the Structural Analysis of Shipping Casks", US NRC Washington, D.C., Rev. 1, March, 1978.

Regulatory Guide 7.8, "Load Combinations for the "Structural Analysis of Shipping Casks", US NRC, Washington, D.C., Proposed Rev. 1, Sept., 1988.

ASME Boiler and Pressure Vessel Code, Section III, Subsection NB, 1986.