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IMPACT LIMITER TESTING FOR A TN-40 TRANSPORTATION PACKAGE

Steve Streutker
Transnuclear, Inc.(AREVA group) Columbia, MD, USA

Peter Shih
Transnuclear, Inc.(AREVA group) Columbia, MD, USA

ABSTRACT
Transnuclear, Inc. (TN) has designed a dual purpose TN-40 Cask which is currently licensed as a storage cask for spent nuclear fuel under the Nuclear Regulatory Commission (NRC) requirements of 10CFR Part 72. The TN-40 Cask is also designed as a transportation package under the NRC requirements of 10CFR Part 71. TN has submitted a transportation license application to the NRC for approval. The NRC requires an applicant to perform drop testing of the transportation package to verify that package can survive the accidental drops and also to provide data on the deformation and accelerations experienced by the package under these drop conditions which then can be used to verify and validate the analytical code models applied in the qualification of the transportation package. TN has performed the dynamic testing of a one-third scale model of the TN-40 Cask with impact limiters to demonstrate that it meets the requirements of 10CFR Part 71 under transportation drop conditions. The test program consisted of fabrication of a one-third scale model of the TN-40 Cask and impact limiters, including attachment tie rods, preparation of test procedures, testing facility with an unyielding impact surface, instrumentation, and data acquisition system. The drops are performed in the order of 0^o Side Drop, Center of Gravity (C.G.) over Corner Drop, 20^o Slap Down, and 90^o End Drop from a 30 foot drop height and a 90^o Drop onto a Puncture Bar from a height of 40 inches. New sets of impact limiters are used as necessary during these tests. Calibrated instrumentation was used to collect data and photographs of the test articles were taken before, during and after the test. The impact limiter used for the 90^o End Drop test was cooled for at least 24 hours at a temperature of -20^o F. The results of these tests demonstrated that the package survived the 10CFR Part 71 drop conditions successfully. The analyses of data collected during these tests confirmed the validity and verification of the analytical code models used in the qualification of the TN-40 Cask.

INTRODUCTION
Transnuclear, Inc. (TN) has designed a dual purpose TN-40 Cask which is currently licensed as a storage cask for spent nuclear fuel under the Nuclear Regulatory Commission (NRC) requirements of 10CFR Part 72. Several of these casks have been fabricated, and are currently being used to store spent nuclear fuel at the Prairie Island ISFSI located adjacent to the Prairie Island Nuclear Generating Station in Minnesota, USA. The TN-40 Cask is also intended to be used as a transportation package under the requirements of 10CFR Part 71. TN has submitted a transportation license application to the NRC for approval. The NRC requires an applicant to

demonstrate that the transportation package can survive required 30 foot drops as required by 10CFR 71.73. The test program described below was designed to provide data on the damage experienced by the impact limiters during impact and to measure accelerations experienced by the package under these drop conditions. The measured accelerations were compared with results of an in-house computer program, ADOC, which was used to determine impact accelerations subsequently used in the stress analyses of the transportation package. A discussion of the analysis and the drop testing program is provided below.

SUMMARY DESCRIPTION OF ADOC COMPUTER CODE

A computer code, ADOC (Acceleration due to Drop On Covers), has been written to determine the response of a packaging during impact. The cask body is assumed to be rigid and axisymmetric. Therefore, all of the energy absorption occurs in the impact limiters which are also assumed to have an axisymmetric geometry. Several assumptions are made in calculating the forces which develop in the limiters as they crush. Since the packaging is axisymmetric, its motion during impact will be planar. The vertical, horizontal, and rotational components of the motion of the packaging center of gravity (CG) are used to describe this planar motion.

TEST MODEL

The test article for the dynamic tests consists of a solid carbon steel test body with an impact limiter attached to either end. The test article, shown in Figure 1, is a $1/3^{rd}$ scale representation of the TN-40 cask. The test body is formed from a solid steel billet with external dimensions and weight scaled to match the full sized cask. The test article weighs approximately 10,100 lb (the total weight of the full-size package is 271,460 lb), and has maximum dimensions of approximately 87.0 inches long by 48.0 inches in diameter (The full size dimensions are 260.87 inches long and 144.0 inches in diameter).
The impact limiters are $1/3^{rd}$ scale replicas of the full-size design in order to provide accurate impact data that is used to predict the impact response of the full size TN-40 cask.
The impact limiters are attached to each other by thirteen 0.5 inch diameter threaded tie rods. Each limiter is also fastened to the test body with four 0.5 inch bolts. These impact limiter attachments are also $1/3^{rd}$ scale.

The impact limiters absorb energy during impact events by crushing of balsa and redwood. The size, location and orientation of each wood block are selected to provide maximum protection of the cask during all NCT and HAC drop events.

The top and bottom impact limiters are nearly identical. Each has an outside diameter of 48 inches and a height of 16.67 inches. The bottom impact limiter has pockets to accommodate the lower trunnions. The inner and outer shells are SA-240 Type 304 stainless steel joined by radial gussets of the same material. The metal structure positions, supports, confines and protects the wood energy absorption material. The metal structure also contributes to the energy absorbing capability of the impact limiter. However, the contribution to a side drop or oblique angles is negligible because contact starts at a single point with the unyielding surface (target) and initiates buckling of a single gusset. After the drop event is complete, relatively few gussets are buckled. The strength of the steel shell is conservatively omitted from the impact limiter analysis.

The region of the impact limiter which is adjacent to the cask ends is filled with balsa wood and redwood. The materials and grain orientations are selected to provide acceptably low deceleration to limit stresses in the cask during the 30 foot HAC impact end drop. A layer of balsa wood with the grain perpendicular to the axis of the cask is provided on the outer face of the impact limiter to minimize decelerations after a one foot NCT end drop.

A ring of redwood (consisting of 12 segments or blocks of wood) is located in the sides of the pie shaped compartments which surround the end of the cylindrical surface of the cask with the grain direction oriented radially. This ring of redwood absorbs most of the kinetic energy during a side drop. Redwood was selected for this portion of the impact limiter because of its high crush strength and hence the ability of a small amount of wood to absorb a large amount of energy in a relatively short crush distance.

The corners of the pie-shaped compartments are filled with redwood. A section of redwood is located around the outer corner of the impact limiter. The grain is oriented radially. The primary function of these redwood blocks is to absorp energy during a 30 foot corner drop. All wood blocks used in the impact limiters are composed of individual boards glued together. Therefore the boards or blocks of wood will not fail along the glue joints. The crush strength properties used cover the range of density and moisture content specified in the fabrication specification.

During the end drop, all of the wood in the central part of the impact limiter that is directly "backed-up" by the cask body will crush. The wood in the corners and sides of the limiter will tend to slide along the side of the cask since it is not supported or backed-up by the body and it will not crush or absorb energy as effectively as the wood that is backed-up. During the side or oblique drop the wood backed up by the cask will crush, while the wood beyond the end of the cask body will have a tendency to slide around the end of the cask. The analyses assume that the effectiveness of the portion of the wood that is not backed-up is 20%. Effectiveness is defined as the actual crush force developed at the target by this material divided by the theoretical force required to crush the material. The analysis also assumes a range of wood crush strengths. When determining maximum deceleration, the maximum crush strengths are used. When determining crush depth, the minimum wood crush strengths are used.

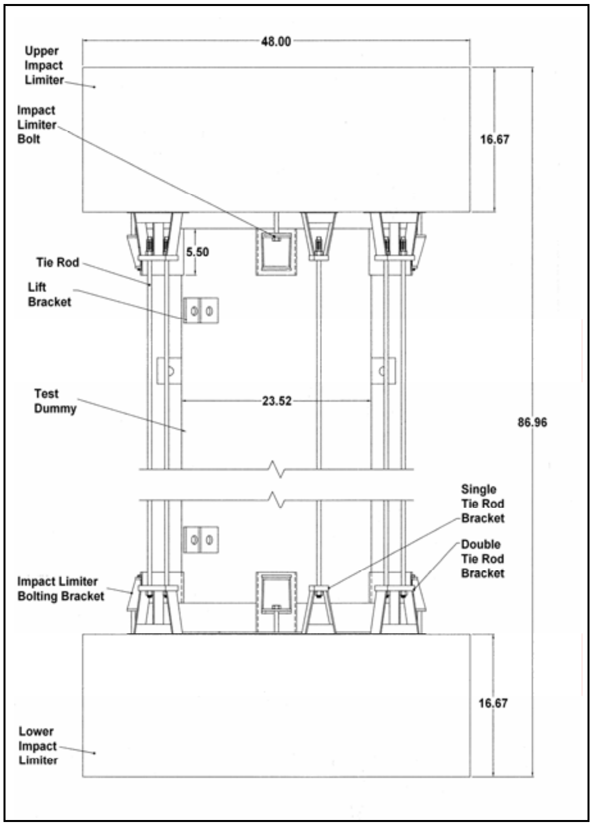

Figure 1 One-Third Scale Test Article

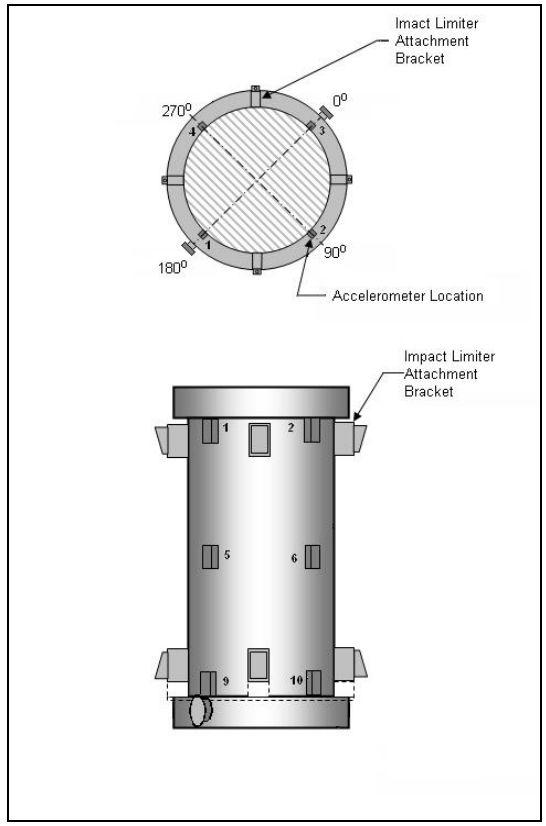

Figure 2 Accelerometer Locations

TEST DESCRIPTION

Equipment and Instrumentation

The drop testing was performed at the National Technical Systems (NTS) facility located at Acton, Massachusetts. The drop testing was performed in accordance with approved written procedures.

Lifting and dropping the test article was accomplished using a mobile crane. A quick release mechanism was used to initiate the drop. It consisted of a hydraulic piston that loaded a bolt to failure releasing a shackle supporting the test article via a rigging system. The rigging system consisted of nylon straps and padded shackles in order to minimize damage to the accelerometers installed on the test dummy.

An inclinometer was used to measure the initial angle (± 1°) of the test body longitudinal axis with respect to the drop pad (i.e., impact surface). A measured line, 30 feet long (+ 3.0, -0.0 inches), was attached to the lowest point on the test package in order to assure the proper drop height.

The impact surface was a 2 in. thick steel plate attached to a concrete block weighing approximately 250,000 lb. resting on bedrock. This configuration can be considered as an essentially unyielding surface.

A puncture bar made of cold-rolled steel was welded to the impact surface for the 40 in. puncture drop. The pin was scaled to match the test article resulting in a 2 in. diameter pin with the upper end edges rounded to a radius of approximately 0.083 in.

Accelerometers were used to measure the impact g load for all drops performed. Twelve PCB Piezotronics 353B18 accelerometers were attached to aluminum blocks which were bolted to the test body at 0°, 90°, 180°, and 270° orientations at three elevations: the approximate center of gravity location and adjacent to each impact limiter. The 12 accelerometer locations are shown in

Figure-2. PCB Model 353B18 quartz shear accelerometers were used to measure the test dummy response. These transducers have a measurement range of +/- 500 g, with a nominal frequency range of 1 – 10,000 Hz (+/- 5%). The accelerometers were connected to a Spectral Dynamics, Inc. Puma System signal analyzer. The accelerometer responses were recorded digitally and processed after completion of the test. The output signals were filtered using a 600Hz low pass filter to remove the higher frequencies present in the data.

Test Data and Results

For purposes of reviewing test results, it should be noted that the energy to be absorbed by the scale model is approximately 1/27 of the full scale TN-40 package energy. The acceleration of the model is approximately three times that of the full size cask, and the crush deformation of the model limiter is approximately one-third that of the full size limiter. The impact force applied to the model is determined by multiplying the mass by the rigid body acceleration (F = ma). The model force is 1/9 of the full scale force.

0° Side Drop Test

The first drop test performed was the 0° side drop. Impact limiters 1 and 2 were installed on the test dummy.

The accelerations measured during the side drop are higher than predicted by the ADOC computer program with the summary provided in Table 1.

After the first 0° side drop test, crush depths of the impact limiters were measured. There was evidence of both inside and outside crushing. The measured crush depths are slightly less that those predicted by the ADOC computer program.

It should also be noted that neither the neutron shield nor the trunnions would contact the impact surface during the impact.

Both impact limiters remained attached to the test dummy during and after the side drop impact. All of the tie rods and tie rod brackets remained intact, thus preventing separation of the impact limiters from the test dummy. In addition, the impact limiter attachment bolts remained in place, in spite of damage to two of the eight bolting brackets.

A single small opening in the stainless steel shell of each of the impact limiters was evident. Both openings consisted of a tear along the weld between two of the outer flat plates of the impact limiter.

64° CG over Corner Test

The second drop test performed was the 64° CG over corner test. Impact limiters 1 and 2 were again used. The test article was rotated about its longitudinal axis 180° so that an undamaged portion of the limiter was exposed to the impact surface.

The average acceleration of the accelerometers oriented parallel to the test dummy axis is 34 gs. The predicted acceleration is taken from ADOC results. Note that the predicted acceleration value is slightly less than the measured value.

The crush depths of the impact limiters were measured after the CG over corner drop. The measured crush depths are slightly less that those predicted by the ADOC computer program.

The primary purpose of the CG over corner drop test is to demonstrate that the impact limiter has sufficient material to protect the corner of the test dummy in this orientation and to demonstrate the adequacy of the impact limiter attachment design.

Both impact limiters remained attached to the test dummy during and after the CG over corner drop impact. All of the tie rods, and all but one of the tie rod brackets remained intact, thus preventing separation of the impact limiters from the test dummy. In addition, the impact limiter attachment bolts and brackets, although damaged, prevented the test dummy from separating from either impact limiter.

20° Slap Down Test
The 20° slap down drop test was performed using newly installed impact limiters 3 and 4.

The slap down event consists of two distinct impacts. The initial impact is the smaller of the two as it only stops the leading end of the test article and converts much of its kinetic energy from linear to rotational. The second impact is more severe in that the velocity of the second impact limiter is greater than that resulting from a 30 foot drop due to the added rotational velocity. The impact limiter attachment design is also exposed to unique loads due to the centrifugal forces caused by the test dummy rotation after the first impact.

The accelerations measured during the slap down drop test are low relative to the maximum predicted by the ADOC computer program.
After the slap down test, the impact limiter crush depths were measured. There was evidence of both inside and outside crushing. It should also be noted that neither the neutron shield nor the trunnions would contact the target during the impact. Both impact limiters remained attached to the test dummy during and after the slap down impact.
Considerable crushing from the inside occurred, resulting in significant failure of welds between the impact limiter inner cylinder to the inner base plate. However, since the test dummy remained attached to the limiters, no exposure of the wood to the post-drop fire accident would occur.

90° End Drop Test
The forth orientation tested was the 90° end drop. Impact limiters 3 and 4 were reused for this test with impact limiter 3 used for impacting the impact surface. In order to provide an extreme condition drop test, impact limiter 3 was chilled to -20 °F prior to the drop.

Consequently, the test was redone at a later date using impact limiters 2 and 4 that had been dropped previously. Impact limiter 2 was used for the impacting limiter because the wood in the end drop crush area was relatively undamaged due to the orientation of the prior drops. However, the second end drop was not done at a chilled temperature. The acceleration time history plots for the second 90° end drop test appeared qualitatively reasonable. The following table shows the axial acceleration measured by the accelerometers shown, during the 90° end drop, as well as the maximum axial acceleration predicted by ADOC.

After the initial end drop test the crush depths of the bottom impact limiter were measured. There was evidence of both inside and outside crushing. The relatively low crush depth measured after the initial 90° end drop, compared with predicted values can be attributed to the fact that the bottom impact limiter was chilled to -20 °F prior to the drop test.

Both impact limiters remained attached to the test dummy during and after the first end drop impact, and all impact limiter attachment bolts remained intact.
No openings in the stainless steel impact limiter external shell were evident, and no welds in the external shell failed.
90° Puncture Drop Test

The final drop test performed was the puncture drop. In order to simulate the proper sequence of accident events specified in 10 CFR 71.73, the impact limiters used for the first end drop test were left on the test dummy without adjustment or tightening of the attachment bolts. The puncture bar impacted impact limiter 3, which was previously crushed during the 90° end drop.

The puncture bar impacted the test package near the center of the outer flat surface of the impact limiter shell. The puncture bar cleanly punched through the outer shell of the impact limiter and was imbedded in the impact limiter wood. The test package came to rest in the vertical position, balanced on top of the puncture bar and then tilted to one side, bending the bar. No other sections of the impact limiter were damaged, and no welds on the impact limiter shell were broken. The impact limiter wood remained completely contained by the impact limiter shell, and no impact limiter wood could be seen at the puncture point. The puncture bar was stopped by a thin wedge of impact limiter wood that was compacted between the top of the puncture bar and the inner shell of the impact limiter. The puncture bar did not penetrate the inner stainless steel shell of the impact limiter.
Both impact limiters remained attached to the test dummy during the puncture drop event, and no additional impact limiter attachment bolts were damaged.

CONCLUSIONS

The results of the dynamic tests demonstrate that:
The loadings used in the basket and fuel rod cladding structural analyses bound the dynamic measured data.
The crush depths do not result in lockup of the wood in the limiters.
The crush depths for all the drop cases would not result in the neutron shield or trunnions impacting the target.
The impact limiter enclosure is structurally adequate in that it successfully confines the wood inside the steel shell.
The impact limiter attachment design is structurally adequate in that the impact limiters remain on the ends of the test dummy during and after all drop orientations.
A 40 inch drop onto a scaled six inch diameter puncture bar, per 10 CFR 71.73(c)(3), does not significantly damage the impact limiter nor are there any indications of damage to the test dummy.

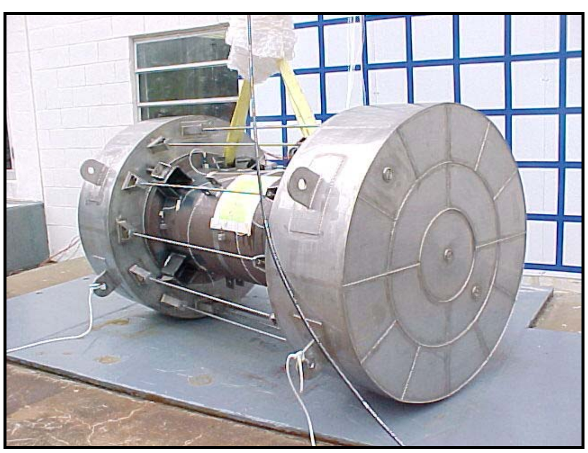

Figure 2. Test Article Prior to Drop

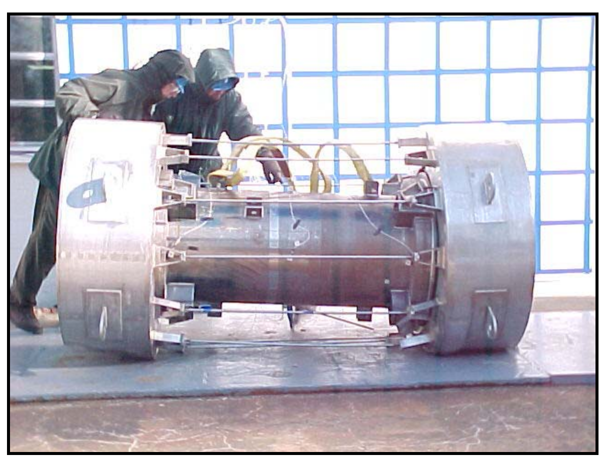

Figure 4. Test Article after 20° Slap Down

In summary, the results of these tests demonstrated that the package survived the 10CFR Part 71 drop conditions successfully. The analyses of data collected during these tests confirmed the validity and verification of the analytical code models used in the qualification of the TN-40 Cask.

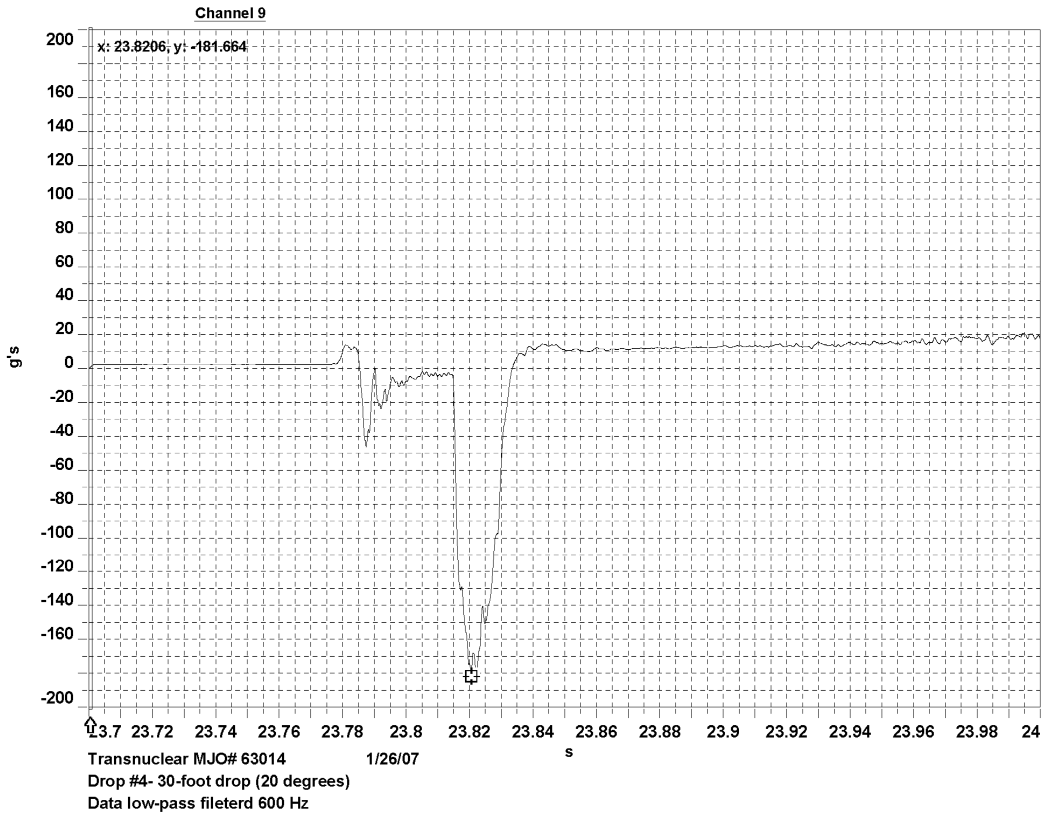

Figure-5 Acceleration Time History, 20° Slap Down Drop

Table 1. Comparison of Measured vs. Calculated g Loads

Drop Orientation	Measured g Load	Calculated g Load
90° End Drop	57g	49g
0° Side Drop	57g	51g
CG over Corner	34g	32g
20° Slap Down	61g	78g

REFERENCES

1. Title 10, Code of Federal Regulations, Part 71, "Packaging and Transportation of Radioactive Material."

Mok, Gerald C., et al., "Guidelines for Conducting Impact Tests on Shipping Packages for Radioactive Material," UCRL-ID-121673, September, 1995.

