Over-the-Road Testing of Radioactive Materials Packagings*

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INTRODUCTION

Sandia National Laboratories has an ongoing program to characterize the environments encountered during normal surface transport of radioactive materials. This effort consists of obtaining experimental data from both road simulator and over-the-road tests and of analyzing the data to obtain numerical models to simulate those environments (Glass and Gwinn, 1986, 1987, 1989; Gwinn et al., 1991).

These data and models have been used to define the design basis for resistance to shock and vibration and the requirements for tiedowns of truck-transported radioactive materials. This work is in conjunction with the American National Standards Institute (ANSI) standards development for radioactive materials transport.

This paper summarizes the data (Gwinn et al., 1991) from a series of over-the-road tests performed with Chem-Nuclear Systems, Inc. equipment near Barnwell, South Carolina. The data include packaging responses to driving over various road types as well as measurements of packaging and trailer responses to hard braking and turning events. The data also include the responses of both flexible and rigid tiedown systems. The results indicate that the tiedown forces for these tests were less than 0.06 g based on packaging weight.

EVENTS

Each test consisted of a trailer and packaging being subjected to nine separate events to determine both the acceleration and tiedown loads experienced during normal transport. Five types of roads (Gwinn et al., 1991) were used: (1) smooth asphalt primary, (2) rough asphalt primary, (3) rough concrete primary, (4) rough asphalt secondary, and (5) spalled asphalt secondary. The roads provided a vibrational environment for the packaging. To subject the packaging to shock environments, a railroad crossing and bridge approach were selected. Finally, to determine the package's response to maneuvering, a hard turn and hard stop were executed. The speed driven for each event was the lesser of either the posted legal speed limit or the fastest speed consistent with the safe operation of the tractor. The events for each packaging test are given in Table 1.

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Table 1. Events

Event	Primary Load Type	Description
1	Vibration	Smooth Asphalt Primary
2	Shock	Railroad Grade Crossing
3	Vibration	Rough Asphalt Primary
4	Shock	Bridge Approach
5	Vibration	Rough Concrete Primary
6	Rigid Body	Hard Turn
7	Rigid Body	Hard Stop
8	Vibration	Rough Asphalt Secondary
9	Vibration	Spalled Asphalt Secondary

PACKAGINGS

Two test packagings, the CNS 14-170 and CNS 3-55, were selected based on the weight and tiedown type. Test 1 used the CNS 14-170, a lead and steel Type A package used to ship dewatered or solidified waste materials. The package has an empty weight of 15,330 kg and a payload of 6350 kg. It is transported vertically and has a flexible tiedown system.

Test 2 used the CNS 3-55, a steel-encased lead-shielded Type B package. The packaging weight is 28,800 kg with a payload capacity of 4180 kg. The package is transported horizontally in a cradle representative of a rigid tiedown system.

INSTRUMENTATION

The primary roles of the instrumentation were to obtain the acceleration at various points on the trailer and package, and to either directly measure forces in the flexible tiedown, or to measure strains in the cradle which can be used to determine forces acting on the cradle tiedown. The locations and measurements obtained from each instrument are given in Table 2. Nine instruments were used in each test.

Table 2. Instrumentation Locations

Instrument	Test	Location	Measurement
1	1,2	Package Top	Transverse Acceleration
2	1,2	Package Top	Vertical Acceleration
3	1,2	Package Top	Longitudinal Acceleration
4	1,2	Trailer Center	Vertical Acceleration
5	1,2	Trailer Rear	Vertical Acceleration
6	1,2	Trailer Rear	Longitudinal Acceleration
7	1,2	Trailer Front	Vertical Acceleration
8	1	Front Tiedown	Separation Force
8	1	Rear Tiedown	Separation Force
9	2	Front Tiedown Strap	Vertical Strain
9	2	Rear Tiedown Strap	Vertical Strain

A triaxial accelerometer was placed on the package's center top to measure the package response along each axis. The package stiffness made this measurement representative of the entire package. At the same longitudinal location, an accelerometer measured the trailer's vertical acceleration. Longitudinal and vertical accelerometers were placed on the trailer bed over the rear axle, and a vertical accelerometer was placed on the trailer over the kingpin. The combination of vertical accelerometers at these three trailer locations allowed the bounce, pitch, and bending modes (Glass and Gwinn, 1986) to be detected. The longitudinal and transverse accelerometers were used to detect the effects of braking and turning.

The response of the tiedowns was determined from load cells in the links between attachment points on the CNS 14-170 and with strain gages mounted on the cradle straps for the CNS 3-55. The load cell was zeroed after preloading so that only transport-induced loads were measured. The strain gages were arranged in a bridge to remove the bending effects and hence measure only the strain in the direction of the strap.

TEST RESULTS

This section summarizes the results of the over-the-road tests. The complete data set is included in Gwinn et al., 1991. The data were obtained in the form of time histories which provide the mean-to-peak response at different locations. From these time histories, the auto spectral density (PSD) was generated for vibrational events. The PSD transforms the time history data into the frequency domain to relate how the response energy varies as a function of frequency. From this data, the vibration modes contributing to the overall response were determined, and the root-mean square (RMS) response was calculated. Figure 1 shows representative samples of time histories and the corresponding PSDs.

The railroad grade crossing and bridge approach shock events were not vibrational events and hence PSD calculations were not appropriate. Rigid body events, such as the hard turn and hard stop, were performed to determine the response magnitude only.

The time history shown in Figure 1a is the measured vertical acceleration of the rear trailer bed in response to the spalled asphalt event for Test 1. This figure shows a fairly severe vibrational environment, with two large transient events occurring 3 and 9 seconds into the run. Figure 1b shows the PSD of the same response in the frequency domain. The larger response at 1.5 Hz is due to the first bounce mode of the tractor/trailer combination (Glass and Gwinn, 1986). This vehicle bounce mode was caused by the structure bouncing in unison with the suspension system of the trailer. The next response at 4 Hz is the frequency of the vehicle's first pitching mode (Glass and Gwinn, 1986). This was caused by the kingpin/rear tractor front suspension deflecting. The high-frequency modes from 10 to 20 Hz are combinations of the trailer bending with the tractor pitching and bending.

Figures 1c and 1d show the comparable responses for the vertical accelerations at the top of the packaging. Note that the acceleration levels for the top of the packagings are approximately an order of magnitude smaller than those at the rear of the trailer. Also of note is that the first bounce mode dominated the packaging response whereas the response at the rear of the trailer was dominated by higher frequency modes.

Table 3 summarizes the peak acceleration results for each test. The RMS responses are presented in Table 4 and the tiedown responses are given in Table 5.

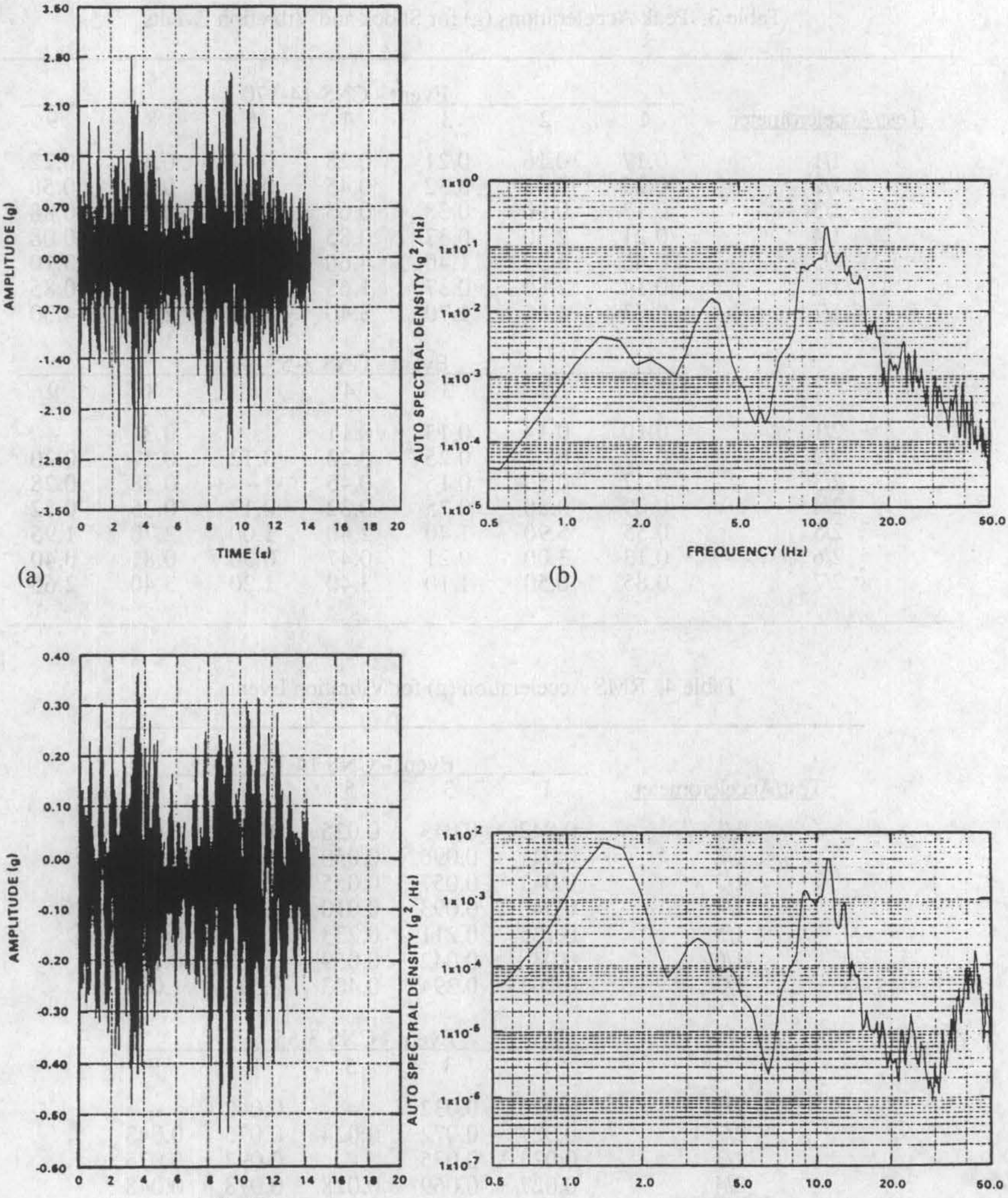

Figure 1. Comparative time histories and PSDs for the CNS 14-170 test of the spalled asphalt event: (a) time history, vertical acceleration, rear trailer bed; (b) PSD equivalent of (a); (c) time history, vertical acceleration, package top; and (d) PSD equivalent of (c).

Table 3. Peak Accelerations (g) for Shock and Vibration Events

	Event - CNS 14-170						
Test/Accelerometer	1	2	3	4	5	8	9
1/1	0.17	0.16	0.21	0.28	0.12	0.13	0.22
1/2	0.23	0.62	0.32	0.45	0.20	0.35	0.58
1/3	0.17	0.90	0.38	0.63	0.22	0.64	0.88
1/4	0.21	2.30	0.37	0.85	0.07	0.07	0.08
1/5	0.46	5.30	1.40	4.60	0.95	1.68	3.10
1/6	0.14	2.80	0.37	1.65	0.22	0.43	0.85
1/7	0.73	4.50	1.70	3.40	1.30	2.70	4.50
	Event - CNS 3-55						
	1	2	3	4	5	8	9
2/1	0.10	0.14	0.13	0.11	--	0.34	--
2/2	0.12	0.47	0.25	0.23	0.12	0.37	0.20
2/3	0.12	0.50	0.15	0.45	--	0.38	0.28
2/4	0.09	0.80	0.25	0.32	0.17	0.35	0.22
2/5	0.55	5.90	1.40	2.40	1.00	2.70	1.95
2/6	0.13	3.00	0.21	0.47	0.30	0.81	0.40
2/7	0.85	6.50	1.10	3.40	1.20	3.40	2.65

Table 4. RMS Acceleration (g) for Vibration Events

	Event - CNS 14-170				
Test/Accelerometer	1	3	5	8	9
1/1	0.042	0.043	0.025	0.027	0.054
1/2	0.041	0.096	0.050	0.066	0.125
1/3	0.041	0.057	0.055	0.143	0.227
1/4	0.040	0.093	0.010	0.011	0.011
1/5	0.135	0.211	0.233	0.401	0.718
1/6	0.030	0.042	0.059	0.088	0.180
1/7	0.201	0.294	0.403	0.571	1.030
	Event - CNS 3-55				
	1	3	5	8	9
2/1	0.020	0.032	--	0.042	--
2/2	0.027	0.072	0.024	0.075	0.043
2/3	0.023	0.035	--	0.097	0.075
2/4	0.027	0.069	0.028	0.078	0.048
2/5	0.280	0.230	0.240	0.650	0.530
2/6	0.028	0.042	0.058	0.110	0.096
2/7	0.102	0.220	0.320	0.770	0.630

Table 5. Peak Tiedown Loads (kg)

Test/Accelerometer	Event - CNS 14-170								
	1	2	3	4	5	6	7	8	9
1/8	195	317	263	180	99	360	284	158	207
1/9	99	293	162	135	68	248	216	126	293
	Event - CNS 3-55								
	1	2	3	4	5	6	7	8	9
2/8	855	--	918	--	509	432	--	927	756
2/9	1139	--	1058	918	702	648	--	1404	990

The test results can be normalized to indicate the dependence of the accelerometer response amplitude on both the type of event and the accelerometer location. The normalized vertical accelerations measured during the CNS 3-55 test at four locations for the shock and vibration events are given in Table 6. The data are normalized to the rail crossing acceleration at each accelerometer location. This approach to the data results in a comparison of relative severity of the events. The rail crossing responses are the most severe at each of the accelerometer locations. The secondary asphalt produces accelerations that range from 40 to 80% of the rail crossing results and the least severe event, the smooth asphalt, produces accelerations ranging from 10 to 26% of the rail crossing results. These results indicate that events that include vertical discontinuities in the road surface lead to the largest vertical accelerations.

Table 6. Event Dependence of Vertical Accelerometer Response Normalized with Respect to the Rail Crossing Response

	Trailer Rear	Package Top	Trailer Middle	Trailer Front
Smooth Asphalt	0.093	0.26	0.11	0.13
Rail Crossing	1.00	1.00	1.00	1.00
Rough Asphalt	0.24	0.53	0.31	0.16
Bridge Approach	0.41	0.49	0.40	0.52
Rough Concrete	0.17	0.26	0.21	0.18
Secondary Asphalt	0.46	0.79	0.44	0.52
Spalled Asphalt	0.33	0.43	0.28	0.41

The variation of the response as a function of accelerometer location is shown in Table 7. This table gives the data for the CNS 3-55 test normalized to the response of the trailer front. In all cases, the greatest response, even for this uniformly distributed load, is at the trailer front or trailer rear. The response on the package at the mid-point of the trailer is less than 20% of the peak response. These results indicate that care must be taken in evaluating the packaging response based on the trailer response.

Table 7. Spatial Dependence of Vertical Accelerometer Normalized with Respect to the Trailer Bed Front Response

	Trailer Rear	Package Top	Trailer Middle	Trailer Front
Smooth Asphalt	0.65	0.14	0.11	1.0
Rail Crossing	0.91	0.072	0.12	1.0
Rough Asphalt	1.33	0.24	0.24	1.0
Bridge Approach	0.71	0.068	0.094	1.0
Rough Concrete	0.83	0.10	0.14	1.0
Secondary Asphalt	0.79	0.11	0.10	1.0
Spalled Asphalt	0.74	0.075	0.083	1.0

The data also provide insight on the relative response of tiedown systems. Current regulations (49 CFR 393, "Parts and Accessories Necessary for Safe Operation") and the draft ANSI tiedown standard (ANSI, 1992) both relate the design of tiedowns to 1.5 times the weight of the packaging. To determine how the tiedowns responded with respect to these values, Table 8 presents the tiedown load divided by the weight of the packaging. The loads range from 0.004 to 0.024 of the weight of the packaging. The results for the CNS 3-55 range up to 0.055. These loads are far less than those derived from either the regulatory requirements or the draft ANSI standard.

Table 8. Tiedown Loads Divided by Packaging Weight

CNS 14-170	Front Tiedown	Rear Tiedown
Smooth Asphalt	0.013	0.007
Rail Crossing	0.021	0.019
Rough Asphalt	0.017	0.011
Bridge Approach	0.012	0.009
Rough Concrete	0.007	0.004
Hard Turn	0.024	0.016
Hard Stop	0.019	0.014
Secondary Asphalt	0.010	0.008
Spalled Asphalt	0.014	0.019

CONCLUSIONS

The data show the dependence of the accelerometer responses on both the type of event and location of the accelerometer. In particular, the greatest peak accelerations result from events that have surface discontinuities, such as the rail crossing and bridge approach.

The dependence of the accelerometer responses on accelerometer location shows that only select locations on the trailer correspond to packaging response. The center of the trailer, for example, corresponds reasonably well with the packaging response, but the extremities of the trailer experience much higher accelerations than the packaging. This indicates that the packaging response should be measured directly, if possible, and only extrapolated from trailer response where the correlation is well known.

Finally, the tiedown response data demonstrate that current regulations and proposed standards require tiedowns that are capable of withstanding much greater loads than those observed during these normal condition tests. This indicates that the current design standards are adequate to ensure that the package is retained on the trailer during normal transport.

REFERENCES

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