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DROP TEST EXPERIMENTAL RESULTS OF 1/3 SCALE MODEL FOR TK TYPE TRANSPORT AND STORAGE CASK

Jun Shimojo
Kobe Steel, LTD.
2-3-1, Araicho Shinhama,
Takasago, Hyogo 676-8670
JAPAN

Keisuke Umehara
Kobe Steel, LTD.
2-3-1, Araicho Shinhama,
Takasago, Hyogo 676-8670 JAPAN

Akito Oishi
Kobe Steel, LTD.
2-3-1, Araicho Shinhama,
Takasago, Hyogo 676-8670
JAPAN

Norihiro Kageyama
Transnuclear, Ltd.
1-18-16, Shinbashi, Minato-ku, Tokyo 105-0004 JAPAN

Hiroaki Taniuchi
Transnuclear, Ltd.
1-18-16, Shinbashi, Minato-ku, Tokyo 105-0004 JAPAN

Takao Shirakura
Transnuclear, Ltd.
1-18-16, Shinbashi, Minato-ku, Tokyo 105-0004 JAPAN

ABSTRACT

Dry storage system using spent fuel casks is focused on in these days and demand of storage using casks is expected to be strong increasingly. One of the most important design elements for safety of cask is its integrity under 9m drop tests. Drop tests using 1/3 scale model for TK type transport and storage cask were performed in order to confirm its structural integrity and establish suitable safety analysis method on 9m drop test conditions.

The height of drop tests is 9m and the drop tests were conducted with 4 different conditions such as horizontal, vertical, corner and slap-down. It is confirmed by these drop tests that the impact accelerations for all conditions are less than those of analysis conditions for 9m drop tests in the safety analysis of TK-69 and that the deformations of the shock absorbing covers are within the deforming limitation. The ratio of the maximum acceleration of the dummy content to the shell of 1/3 scale model is 0.97-1.04 for horizontal condition and 0.92-1.42 for vertical condition. The maximum acceleration of slap-down condition is a little larger than that of horizontal condition and the maximum ratio is 1.20 for the primary lid.

These drop tests result in the structural integrity of TK type cask. And these test results are used for confirming validity of the safety analysis procedures on 9m drop test conditions for TK type casks.

1. INTRODUCTION

In design requirements of transport and storage casks, 9m drop test condition is one of the most sever design conditions. In Japan, analysis methods are used for 9m drop test as the accident condition of transport. The validation of analysis methods is very important and to confirm it drop tests are usually conducted to obtain the necessary data such as acceleration and deformation of shock absorbing covers.

Recently the structural influence of delayed drop impact by contents such as fuel assemblies and basket for cask is focused. As for this event, Japan Nuclear Energy Safety Organization (JNES) preformed 9m drop test using actual size model cask and reported that the content made larger acceleration to the cask than its main shell affected by itself1). In addition, the structural influence for lids by slap-down drop test is also focused, but slap-down test had not conducted by JNES.

A series of 9m drop tests using 1/3 scale model of TK type cask are conducted including slap-down drop and the test results is reported here, and the validation of drop test analysis using them is performed by N. Kageyama, et al.2).

2. SPECIFICATION OF TK TYPE TRANSPOT AND STORAGE CASK

TK-69 and TK-52 are jointly designed for transport and storage of BWR spent fuels by Transnuclear, Ltd. and Kobe Steel, Ltd. A bird's-eye view of TK-69 is shown in Figure 1 and main specifications of these casks are shown in Table1. The design concepts of these casks are the same, but the loaded fuel specifications are different, i.e. fuel burnup of TK-52 is higher than that of TK-69 and cooling time of TK-52 is shorter than that of TK-69. Therefore the shielding thickness of shell for TK-52 is larger than that of TK-69, which results in that the margin of structural integrity for TK-52 is larger that that for TK-69.

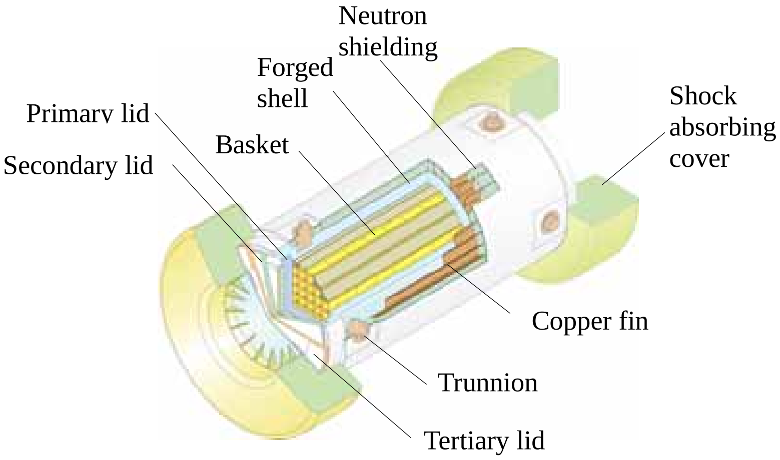


Figure 1. Bird's-eye view of TK-69

Table 1. Main specification of TK-69 and TK-52cask

Items	TK-69	TK-52
Weight and dimension		
- Total weight with SAC* / without SAC	Approx. 134 tons / 121 tons	Approx. 132 tons / 120 tons
- Length with SAC / without SAC	Approx. 6.8 m / 5.3 m	Approx. 6.8 m / 5.4 m
- Diameter with SAC / without SAC	Approx. ϕ3.5 m / ϕ2.5 m	Approx. ϕ3.4 m / ϕ2.4 m
Loading capacity	69 BWR fuel assemblies	52 BWR fuel assemblies
Materials		
- Body	Low alloy steel	Low alloy steel
- Neutron shielding	Resin	Resin
- Primary and Secondary lids	Low alloy steel	Low alloy steel
- Tertiary lid	Stainless steel	Stainless steel
- Basket	Borated aluminum alloy	Borated aluminum alloy
Sealing material	Double ring type metal gaskets	Double ring type metal gaskets

Note*) SAC means Shock Absorbing Covers.

3. SPECIFICATION OF 1/3 SCALE MODEL FOR TK-69

The 1/3 scale model is designed based on TK-69 because its weight of content is heaver than that of TK-52 and because the margin of structural integrity for TK-52 is larger than that for TK-69. The shape and dimensions, especially the space between flanges of lids and shell and between shell and dummy content are modeled in 1/3 scale as precise as possible. The dummy content is modeled to simulate dimension, weight and center of gravity. The trunnions are prepared only for handling this scale model. Main specifications of 1/3 scale model are shown in Table 2, and its cross section and outer view are shown in Figure 2 and Figure 3, respectively. In Figure 2, marks of G1 – G8 show the placements of each acceleration sensor.

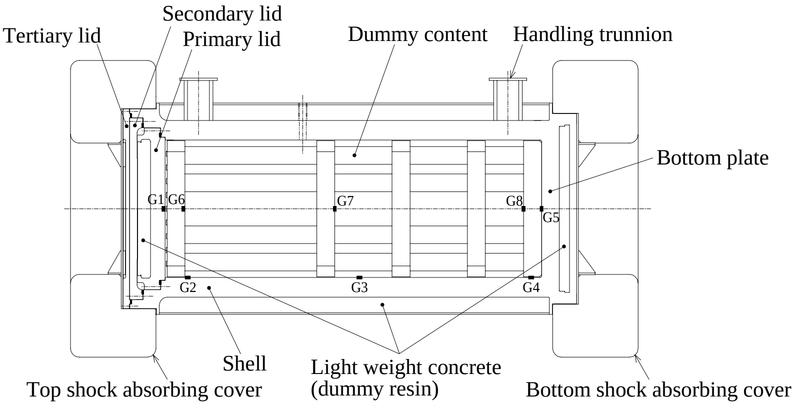


Figure 2. Cross section of 1/3 scale model

Figure 3. Outer view of 1/3 scale model

Table 2. Main specification of 1/3 scale model

Parts	Material	Scale ratio (actual size/scale size)	Weight (kg)
Shell **Neutron shielding** **Outer shell**	Low alloy steel (Light weight concrete)[*1] (Carbon steel)[*1]	Thickness of shell : 3 Outer dia. : 3 Length : 3	3,040
Primary lid	Low alloy steel	Thickness : 3 Outer dia. : 3 Cross sectional dia. of Gasket : 2.5 [*2]	210
Secondary lid	Low alloy steel	Thickness : 3 Outer dia. : 3 Cross sectional dia. of Gasket : 2.5 [*2]	120
Tertiary lid	Stainless steel	Thickness : 3 Outer dia. : 3 Cross sectional dia. of Gasket : 3.3	80
Shock absorbing cover	Stainless steel and Redwood	Outer dia. : 3 Length (top/ bottom) : 3	220 (top) 220 (bottom)
Dummy content	(Carbon steel)*	Outer dia : 3 Length : 3	980
--	--	--	Total 4,850

Note*1) Equivalent material simulating only weight
Note*2) Restriction of manufacturing

4. CONDITION OF DROP TESTS

4.1 Drop test target floor

The drop test target floor is made of reinforced concrete basement covered with carbon steel plate of which thickness is 42mm as shown in Figure 4. The total weight of basement is about 100 tons, which is more than 10 times heaver than that of the 1/3 scale model. Therefore, for drop tests of the scale model, this target satisfies the unyielding target specified by the IAEA Safety Standards TS-G-1.1[3].

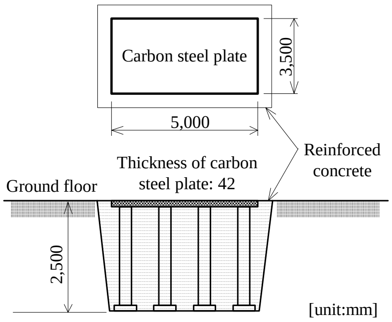


Figure 4. Drop test target floor

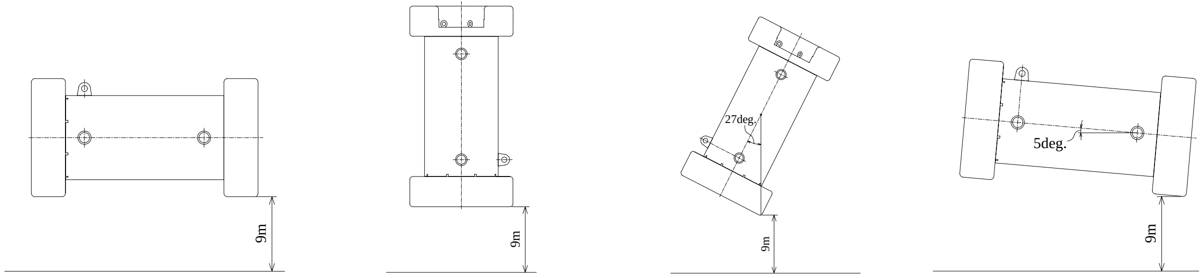
4.2 Drop test condition

The drop tests had been performed with 4 different conditions such as horizontal, vertical, corner and slap-down drop tests as shown in Figure 5. The height of drop tests is 9m which is from the lowest point of shock absorbing cover to the unyielding target of drop test facility.

For the vertical and corner drops, the scale model is dropped with its top side of cask on to the unyielding floor because lids' part is more important than bottom side on the containment point of view.

For the corner drop, the angle is set with a vertical axis to be the same line from the lowest corner of shock absorbing cover to the gravity center of scale model.

For slap-down drop, the angle is 5 degrees set with the longitudinal axis of the scale model and a horizontal line. This angle is selected in order to have the largest acceleration for lid part by preliminary dynamic drop analysis of actual scale cask model with LS-DYNA as shown in Table 3. Measuring items are accelerations, strains, axial force of lids bolts, opening displacements of lids and deformation of SAC. The detailed measuring specifications are shown in Table 4. The measurement of opening displacements of lid and the leak tests were performed only for reference because scale law is not strictly applicable.



(a) Horizontal drop (b) Vertical drop (c) Corner drop (d) Slap-down drop

Figure 5. Drop test conditions

Table 3. Preliminary dynamic analysis results

Angle	4°	5°	6°	10°
Acceleration of secondary lid	86.0 G	87.6 G	85.6 G	85.2 G

Table 4. Measuring specifications of 1/3 scale model

Measuring items	Measuring method	Measuring points
Acceleration	Acceleration sensor	- Primary lid: Center of inner surface - Shell: Top, middle and bottom points of inner surface - Bottom plate: Center of inner surface - Dummy content: Top, middle and bottom points of center axis
Strain	Strain gauge	- Primary lid : Center of outer surface - Secondary lid : Center of outer surface - Tertiary lid : Center of inner surface - Shell : Top, middle and bottom points of inner surface Top, middle and bottom points of outer surface - Bottom plate : Center of inner surface
Axial force of lids bolts	Strain gauge multiplied by elastic modulus and cross sectional area	- Primary lid : 4 orientations (0 ° / 90 ° / 180 ° / 270 °) - Secondary lid : 4 orientations(0 ° / 90 ° / 180 ° / 270 °) - Tertiary lid : 4 orientations (0 ° / 90 ° / 180 ° / 270 °)
Opening displacement of lids[*]	Eddy current displacement sensor	- Primary lid : 4 orientations (0 ° / 90 ° / 180 ° / 270 °) - Secondary lid : 4 orientations (0 ° / 90 ° / 180 ° / 270 °)
Deformation of SAC	Ruler	- Top and Bottom SAC : deforming region
Leak rates for lids[*]	He leak test	- Primary and Secondary lids
	Gas pressure rise leak test	- Tertiary lid

Note*) These tests were performed only for reference because scale law is not applicable.

5. RESULTS OF DROP TESTS

The drop tests were performed for each condition and the main results are summarized in Table 5. In the data analysis, 500 Hz of cut-off frequency is applied to the time history data of acceleration, strain, lid opening displacement and axial force of lid bolts. This cut-off frequency is set according to the IAEA Safety Standards TS-G-1.1 3). In this section, the important test results of acceleration, opening displacement of lids and deformation of SAC are mainly reported.

Table 5. Main results of drop tests

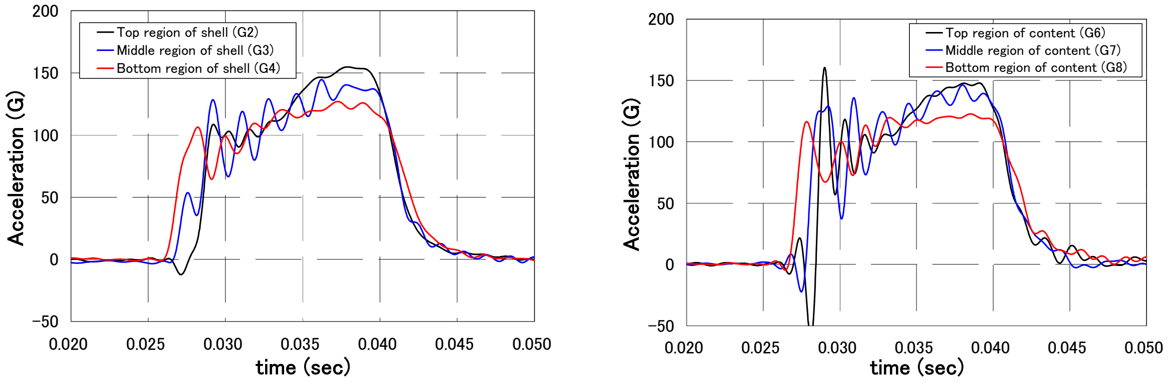
Items	Horizontal	Vertical	Corner	Slap-down
Maximum acceleration (G)				
- Target limitation [*1]	225	230	220	225
- Primary lid [*2]	152	182	94	182
- Shell (top / middle / bottom) [*2]	155 / 145 / 127	---	---	177 / 111 / 147
- Bottom [*2]	127	166	67	146
- Dummy content (top / middle / bottom) [*2]	161 / 146 / 123	167 / 200 / 235	92 / 85 / 71	171 / 122 / 133
Acceleration ratio of Dummy content to Shell(top / middle / bottom), Lid or Bottom	1.04 / 1.01 / 0.97	0.92 / - / 1.42	0.98 / - / 1.06	0.97 / 1.10 / 0.90
Maximum deformation of SAC (mm)				
- Target limitation [*1]	120	150	230	120
- Top	95	70	198	99
- Bottom	92	---	---	62
Maximum lid opening displacement (mm)				
- Primary lid[*3]	0.002	0.071	0.024	0.001
- Secondary lid[*3]	<0.001	0.025	0.009	0.012
Leak tightness difference between before and after drop test	No	No	No	No

Note*1) Target limitation is calculated with scale factor from actual size of cask.
Note*2) These are instantaneous maximum values.
Note*3) These are not permanent but instantaneous displacements.

5.1 Horizontal Drop

The time history of acceleration of each part of the scale model is shown in Figure 6. The ratio of the maximum acceleration's between the dummy content and the shell of each corresponding region is 0.97-1.04, this factor is smaller than that of the horizontal drop test conducted by the JNES[1], i.e.1.2. This multiplying factor is taken into consideration in safety analysis for TK type cask.

The maximum deformation of SAC is less than 100mm and this value is smaller than target limitation which is set from the distance between top surface of trunnion and outer surface of SAC. Therefore the trunnions are not hit on the target floor.

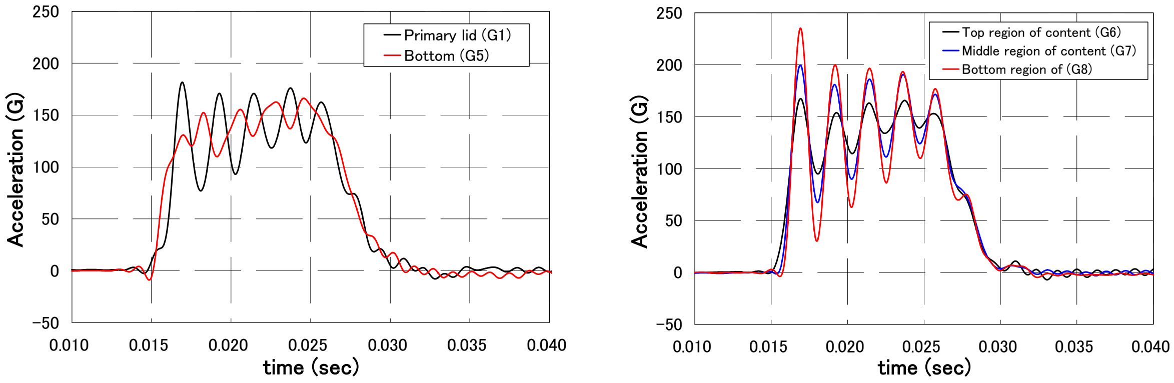


(a) Shell **(b) Dummy content**

Figure 6. Time history of acceleration of horizontal drop test

5.2 Vertical Drop

The time history of acceleration of each part of the scale model is shown in Figure 7. The maximum acceleration: 235G is larger than the target limitation, but this influence is separately taken into account for safety analysis. The ratio of the maximum acceleration's the dummy content to the primary lid or bottom is 0.92-1.42, which is smaller than that of the vertical drop test conducted by the JNES[1], i.e. 2.6. This multiplying factor is important because it is taken into consideration in safety analysis for TK type. The maximum deformation of SAC is about 70mm and this value is smaller than the target limitation.

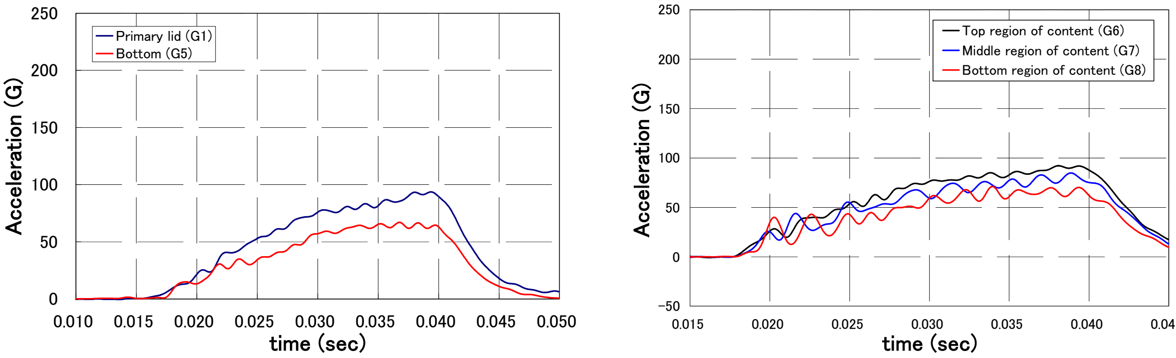


(a) Shell **(b) Dummy content**

Figure 7. Time history of acceleration of vertical drop test

5.3 Corner Drop

The time history of acceleration of each part of the scale model is shown in Figure 8. The maximum accelerations of the primary lid and the dummy content are 94G and 92G, respectively. These values are smaller than those of all other conditions. The ratio of the maximum acceleration of the dummy content to the primary lid or bottom is 0.98-1.06. The maximum deformation of SAC is less than 200mm and this value is smaller than the target limitation.



(a) Shell **(b) Dummy content**

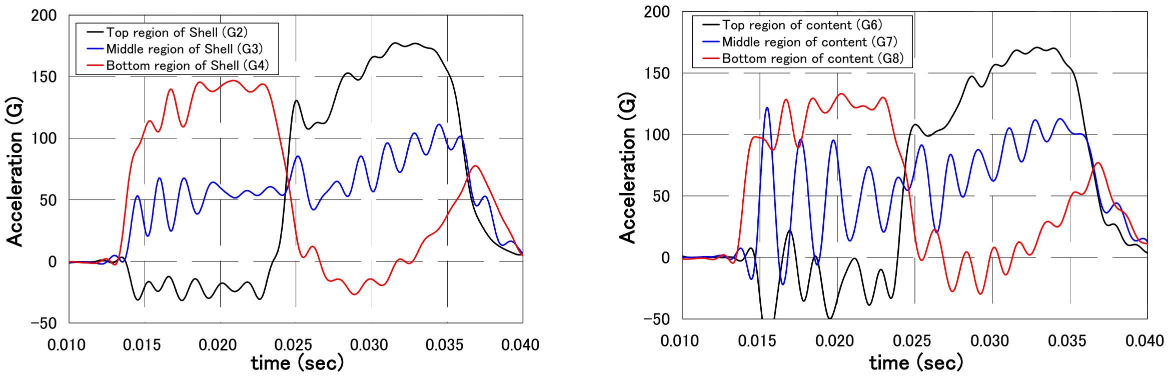
Figure 8. Time history of acceleration of corner drop test

5.4 Slap-down Drop

On the condition of slap-down test, the bottom SAC first hits on the target floor, and after the first impact, the top SAC has the second impact because the scale model is slightly inclined to the horizontal line. The maximum acceleration of the primary lid 182G is larger than 146G of the bottom. And the ratio of the maximum accelerations between the dummy content and the shell of each corresponding region is 0.90-1.10. The maximum deformation of the top SAC is 99 mm, and this is larger than 62 mm of the bottom SAC, which satisfy the target limitation. These results mean that the second impact for the top SAC is larger than the first one for the bottom SAC.

The time history of acceleration of each part of the scale model is shown in Figure 9. It shows that impact timing of each part is slightly delayed from bottom part to lid part of scale model due to the slightly incline of scale model with 5 degrees to the horizontal line.

The comparison of accelerations and of SAC deformations between the slap-down and horizontal drop tests are shown in Table 6. The acceleration ratios between each part are up to 1.20 and that the maximum factor is obtained at the primary lid.



(a) Shell **(b) Dummy content**

Figure 9. Time history of acceleration of slap-down drop test

Table 6. Comparison of main results between slap-down and horizontal drop tests

Items	Slap-down	Horizontal	Ratio (Slap-down/Horizontal)
Maximum acceleration (G)			
- Primary lid (G1)	182	152	1.20
- Shell			
top (G2)	177	155	1.14
middle (G3)	111	145	0.77
bottom (G4)	147	127	1.15
- Dummy Content			
top (G6)	171	161	1.06
middle (G7)	122	146	0.84
bottom (G8)	133	123	1.08
- Bottom (G5)	146	127	1.15

6. CONCLUSIONS

The 9m drop tests with 4 different conditions using 1/3 scale model of TK-69 cask were conducted and the structural integrity is confirmed. The necessary data such as acceleration, strain and deformation of SAC are obtained to validate structural analysis of 9m drop tests as the accident condition of transport. These data can be used validly for similar forging type casks such as TK-52, etc. The benchmark analysis results of TK-69 scale model are reported by the relevant paper2).

7. REFERENCES

[1] Japan Nuclear Energy Safety Organization, “Heisei 15, Corroborating Tests Report for Metal Cask Storage Technology”, (2004). (in Japanese)

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[3] International Atomic Energy Agency, “IAEA Safety Standards Advisory Material for the IAEA Regulations for the Safe Transport of Radioactive Material”, Safety Guide No. TS-G-1.1 (Rev. 1), (2008).