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Experimental evaluation of various packaging protection structures in the case of inclined pin-puncture drop test

Fabien Carteron[*1], Hélène Simon[*1]
[*1] CEA, DEN, DM2S, SEMT, BCCR, F-91191 Gif-sur-Yvette, France

Abstract

Within the framework of a technical investigation for packaging protection structures assessment, a series of inclined pin-puncture drop tests was performed on a model scale of 1:3 (pin diameter = 50 mm). Drop tests were performed at several heights between 1 m to 1.4 m, and two incident angle (22° and about 30°).
The following layers were disposed on a massive steel work piece, representative of the packaging body and mass: an inner wooden layer and a carbon or stainless steel layer. There was no outer wooden layer except for one variant. Two variants included a thin layer of glass fabric, PTFE coated, between wooden and steel layers.
The article presents the different tests with structures drawings and mechanical characteristics of materials. Drop parameters (height, angle, temperature) and results (damage, pin penetration) are reported. This experimental data is of interest for packaging project design and pin-puncture modelling validation.

Introduction

Packages tests requirements are imposed by the International Atomic Energy Agency (IAEA) regulations for the Safe Transport of Radioactive Material. In the AIEA Specific Safety Requirements document (No.SSR-6), one of the tests required for demonstrating ability to withstand accident conditions of transport, for type B and C packages, is a pin-puncture drop test. This test has to be performed onto a 15 cm diameter steel pin, at various drop angles and impact points.

Drop tests requirements are met by means of impact limiters at both ends of the packaging. Impact limiters structure usually consists of an inner steel wall in contact with the packaging body, an inner foam or wooden layer and a steel shield against pin-puncture, an outer foam or wooden layer as shock-absorbing material for the 9 meter drop case, and finally a steel thin envelop. This multi-layered configuration is designed to provide required protection with the minimum weight.

Within the framework of a technical investigation for packaging protection structures assessment, a series of inclined pin-puncture drop tests was performed on a model scale of 1:3 (pin diameter = 50 mm) for different sandwich wall designs and materials.

This work was performed with rigor and care, in a compatible way with a safety demonstration. Although this work arose from a targeted technical investigation and wasn't a research program, experimental data is of interest for packaging project design and pin-puncture modelling validation.

Test specimen and set-up

The test specimen consists in a massive body on which is installed the protection structure against pin-puncture. The massive body is representative of the packaging body and mass at a scale of 1:3. The test set-up consists in a steel pin anchored on a very massive and very rigid concrete slab. A new steel pin is provided for each drop test.

For every drop test, gravity center, impact point and steel pin are aligned on the same vertical line. The set is hanged and released without disturbance to the free fall under gravity by an electromagnet. The total mass of the specimen in fall has been measured: it equals 356 kg; the variation according to the configuration is lower than ± 0.5 kg.

Geometric, mounting and materials characteristics of the experimental set-up and specimen are reported on figure 1.

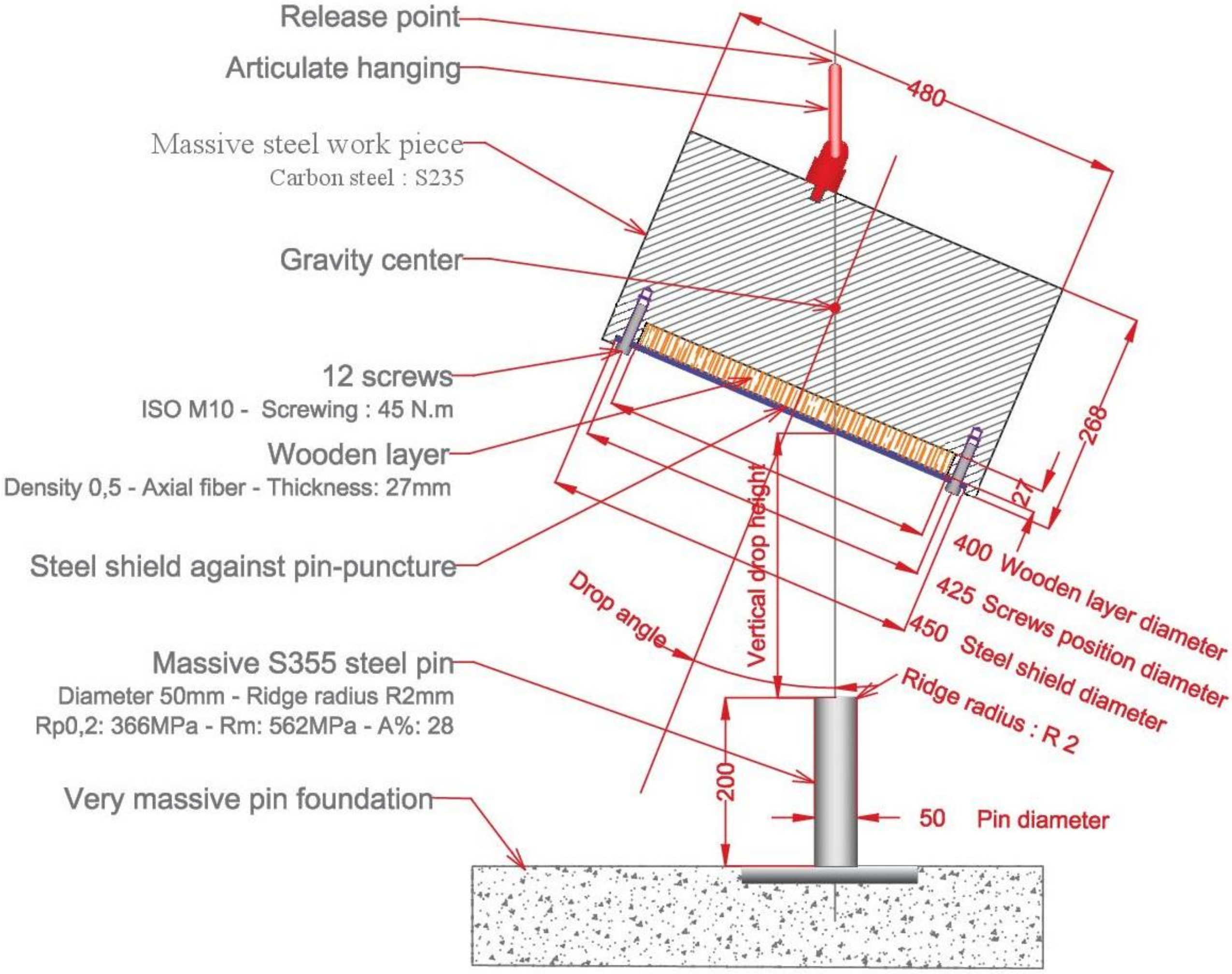


Figure 1 : experimental specimen and set-up

To simulate periods of maximal sunshine in normal conditions of transport, the outer surface of the protection structure is gradually warmed by a welding torch up to the desired temperature in a homogeneous way.

Description of tested protection structures

Table 1 shows a detailed description of the different tested protection structures which consist basically in an inner wooden layer and a carbon or stainless steel outer layer (also called shield plate in this article). Series 1xxx serves as reference, with a basic design and a common steel grade; the shield plate thickness is 6.6 mm. Between series 1xxx and series 2xxx, only the shield plate steel grade varies. In other series, the shield plate thickness is slightly reduced and resistance is enhanced by complementary elements, the specimen total mass being conserved: for series 3xxx and 6xxx, an additional layer of glass fabric and a thin steel sheet; for series 5xxx, an additional wooden layer; for series 4xxx, the unique shield plate is replaced by two 3 mm thick steel plates.

Table 1 lists steel grades and the main mechanical characteristics of each layer (measured values taken from test certificate 3.1 – EN 10204 European standard). As far as wood is concerned, mechanical characteristics are the one of basswood of density 0.5.

Pin-puncture drop tests results

The table 2 reports tests results. In each series the following parameters are varied:

- Drop height H
- Protection structure outer face temperature θ
- Drop angle

Observations of the damage are reported for each case. Deformation maximal depth D is measured, as defined in figure 2. For each series, representative pictures of the damage type are presented.

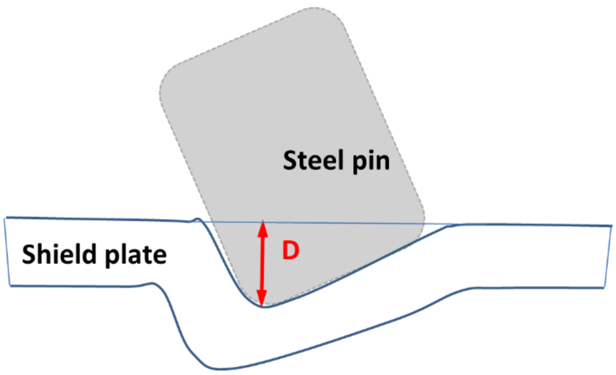


Figure 2: deformation maximal depth D

Figure 4 shows a graphical representation which combines the results for all series (except series 7xxx): the maximal depth of deformation is represented as a function of drop height.

Tableau 1 : different tested protection structures

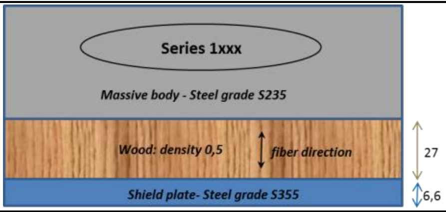
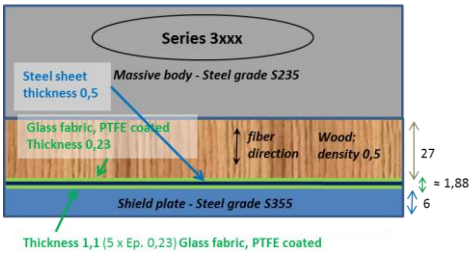
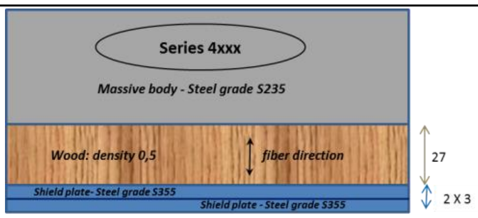
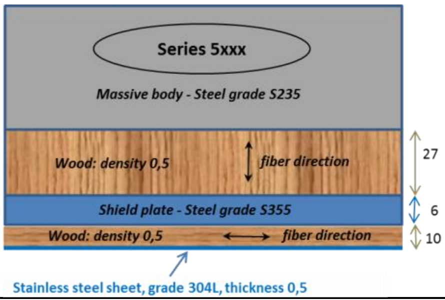
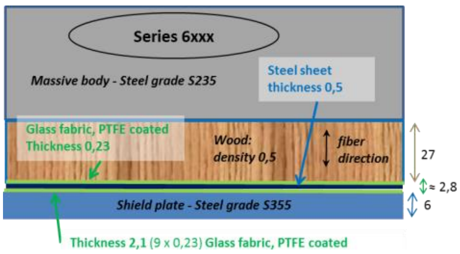
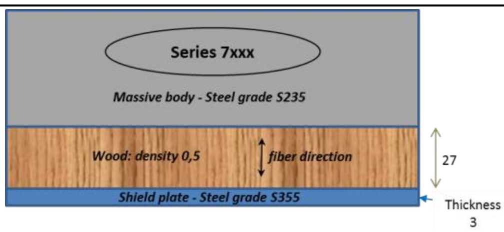
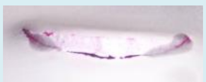
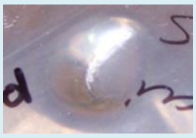
(Rp0,2 : yield strength at 0,2%) *(Rm : breaking point)* *(A% : percent elongation)*	Plate material characteristics				Additional elements characteristics			
Structures drawings	Steel grade - Thickness (mm)	Rp0,2 (Mpa)	Rm (Mpa)	A%	Steel grade - Thickness (mm) -	Rp0,2 (Mpa)	Rm (Mpa)	A%
	S355 - 6,6	367	515	31				
	1.4462 - 6,6	559	777	34				
	S355 - 6	382	534	30	C75S - 0,5	426	540	25
					Glass fabric, PTFE coated 470 g/m² Thickness (1 x 0,23) + (5 x 0,23)	Tensile strength (N /cm) Longitudinal X Transverse 500 x 360		
	S355 - 2 x 3	395	445	31				
	S355 - 6	382	534	30	(304L) 1.4307 - 0,5	661	288	60
	S355 - 6	382	534	30	C75S - 0,5	426	540	25
					Glass fabric, PTFE coated Thickness 0,23 470 g/m² (1 x 0,23) + (9 x 0,23)	Tensile strength (N /cm) Longitudinal X Transverse 500 x 360		
	S355 - 3	395	445	31				

Tableau 2 : pin-puncture tests results

	Drop test number	*H (m)*	*θ°C*	*Drop angle (°)*	*D (mm)*	*Observations about the shield plate and complementary indications*	
Series 1xxx	1c	1,05	110	22	10,6	Shear onset, no crack	 *1bis_b : outer face*
	1a	1,05	110	22	11,7	Shear onset, crack initiation	
	1b	1,10	105	22	11,13	Through crack	
	1d	1,10	110	22	12,3	Through crack	
	1bis_a	1,10	90	29,2	13,2	Through crack	
	1ter_a	1,15	102	22,6	12	Through crack	 *1bis_b : inner face*
	1bis_c	1,15	87	29,2	13,4	Through crack Beginning of appearance of the wood sublayer	
	1bis_b	1,15	87	29,2	15,9	Through crack Beginning of appearance of the wood sublayer	
Series 2xxx	2bis_b	1,05	85	28,5	6	Simple deformation No crack	  *2bis_d : outer and inner faces*
	2bis_a	1,05	87	23	7,5		
	2b	1,15	87	30	7,7		
	2ter_a	1,15	85	21	8,4		
	2a	1,15	87	29,6	8,7		
	2bis_c	1,20	86	27,7	8		
	2ter_b	1,30	85	21	8,5		
	2bis_d	1,30	85	29,8	8,9		
	2bis_e	1,40	85	29	8,2		
Series 3xxx	3d	1,10	85	30	12,5	Through crack of the shield plate Through crack of the thin steel sheet Torn glass fabric	 *3d : outer face of shield plate*
	3a	1,15	86	27,5	11,3	Shear onset of the shield plate Through crack of the thin steel sheet Torn glass fabric	
	3b	1,15	85	30	11,7	Through crack of the shield plate Through crack of the thin steel sheet Torn glass fabric	 *3d : thin steel sheet*
	3c	1,20	85	30	15,1	Through crack of the shield plate Through crack of the thin steel sheet Torn glass fabric Beginning of appearance of the wood sublayer	
Series 4xxx	4b	1,05	85	29,7	14,7	Both steel plates are cut through The wood sublayer is visible on a depth of 3,5 mm	 *4a : outer face*
	4a	1,15	85	29,8	23	Both steel plates are cut through The wood sublayer is visible on a depth of 11,5 mm	
Series 5xxx	5a	1,15	85	29,4	7,2	The upper protection layer is destroyed Simple deformation and no crack of the shield plate	 *5b : outer face of shield plate*
	5b	1,20	85	29,7	8,2	The upper protection layer is destroyed Simple deformation and no crack of the shield plate	 *5b: inner face of shield plate*
Series 6xxx	6b	1,05	85	29,9	11,6	Through crack of the shield plate No crack of the thin steel sheet Torn glass fabric	 *6d: outer face of shield plate*
	6a	1,15	85	30	12	Through crack of the shield plate No crack of the thin steel sheet Torn glass fabric	
	6c	1,20	85	27,8	11,7	Through crack of the shield plate No crack of the thin steel sheet Torn glass fabric	 *6d: thin steel sheet*
	6d	1,30	85	30,1	14	Through crack of the shield plate Through crack of the thin steel sheet Torn glass fabric Beginning of appearance of the wood sublayer	
Series 7xxx	7c	0,3	18	29,8	not measured	Through crack	  *7a: outer and inner faces*
	7b	0,45	18	28	not measured	Through crack The wood sublayer is very visible	
	7a	0,5	18	29,9	8,8	Through crack The wood sublayer is very visible	

 Impact zone on the outer surface of wood layer after a test 1xxx	 Pin after a test 1xxx (little or no matting of the edge)	 Impact zone on the outer surface of wood layer after a test 2xxx	 Pin after a test 2xxx (matting of the edge)

Figure 3: examples of damage on inner wood layer (thickness 27mm) and pin.

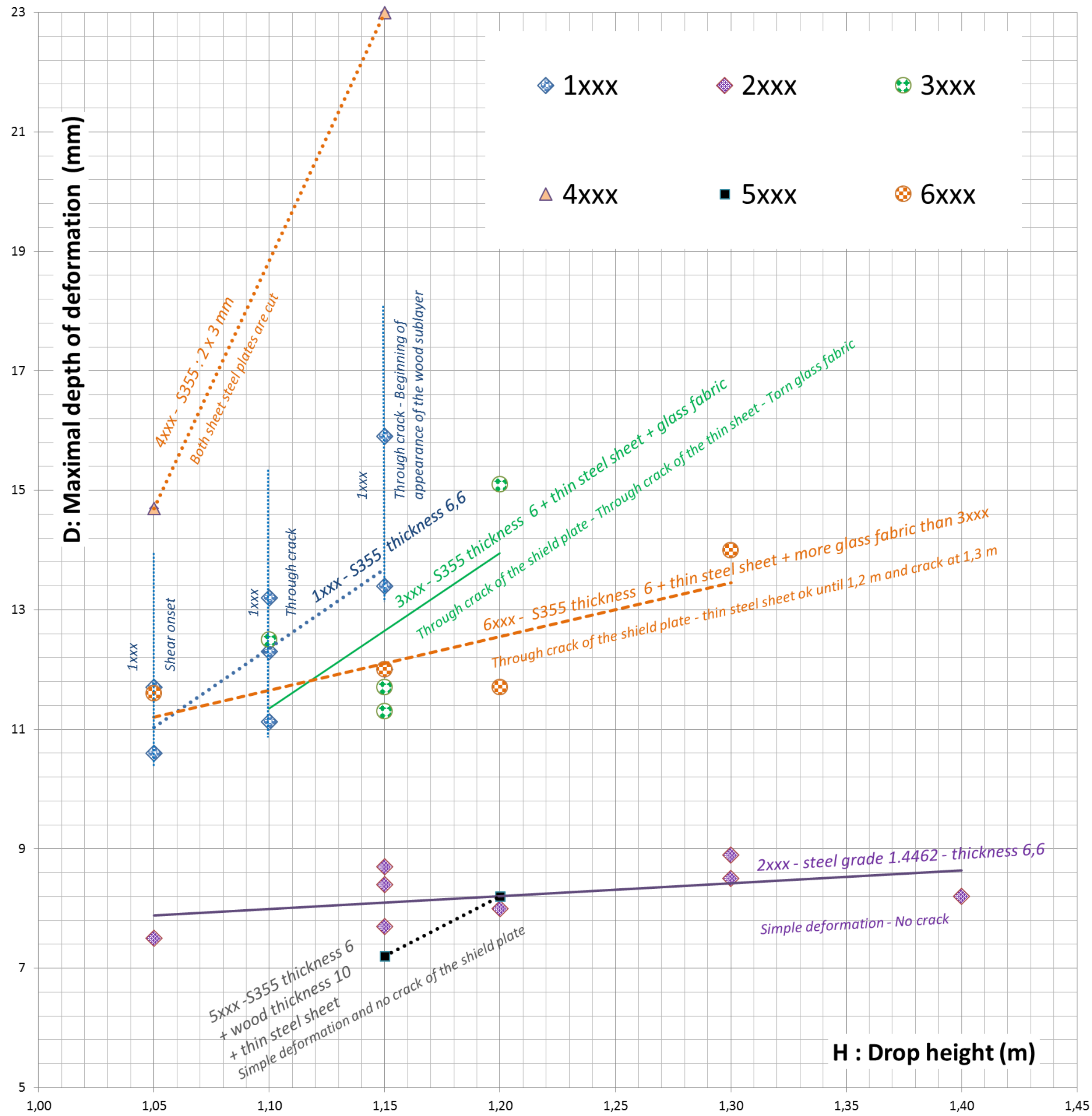


Figure 4 : Graphical overview of the results

Results analysis

We distinguish clearly the following main trends:

- The configuration 2xxx is the best design, the deformation depth is reduced of about a half compared with 1xxx, and there is no sign of crack of the shield plate,
- The configuration 5xxx is also successful, the deformation depth is reduced of about a half compared with 1xxx, and there is no sign of crack of the shield plate ; although only very few test points are recorded,
- The configurations 3xxx has a resistance more or less equivalent to 1xxx ; moreover, the glass fabric additional layers and thin steel additional layer are torn ; these additional layers are not efficient for maintaining a continuous shield against fire,
- The configuration 4xxx is the least successful; its resistance is appreciably lower than 1xxx.

The configuration 2xxx, with steel grade 1.4462 which has higher mechanical characteristics (Rm and $Rp_{0.2}$) than steel grade S355, shows a very good efficiency until heights clearly higher than 1xxx. A height greater than 1.4 m was not tested, so we do not know the limit height at which configuration 2xxx fails. We notice that deformation depth varies little over height range from 1.05 to 1.4 m.

The configuration 5xxx (with an additional wood layer and an additional thin steel sheet) is as efficient as 2xxx, as shown by both available test points. The multilayer design is more complex than 2xxx but it does not require a higher steel grade. The 10 mm wood layer yields puncture by distributing loads on the plate shield and avoids its cutting.

For the configuration 4xxx, superimposing two steel plates of 3 mm decreases the resistance compared with 1xxx. Both steel plates are clearly cut and the wood sublayer is clearly visible.

The configuration 6xxx with extra glass fabric sheets compared to 3xxx, shows an improvement in resistance: the increase of deformation depth with drop height is reduced and the thin steel sheet isn’t torn until a height of 1.2 m.

The results of 4xxx (S355 - 2 x 3 mm) may be compared to the ones of 7xxx (S355 - 1 x 3 mm). One can see that the deformation in the configuration 4b is almost equal to twice the deformation in 7a, for a height multiplied by two: the division into two plates shows no evidence of improving resistance compared to a single plate.

Conclusion

This article provides drop test data which can be used for studying of protection structures against pin-puncture. It shows clearly two leverages to improve resistance of protection structures from the basic sandwich wall with a S355 shield plate:

1. Use of steel with higher mechanical characteristics (while preserving a sufficient resilience),
2. Use of an additional wood outer layer which is efficient even with a small thickness.

Additional tests results with a direct incidence of the pin on the shield plate, for various thicknesses and steel grades would be necessary. It would allow to supply a database not attached to a specific model of packaging. It would be useful for design and safety analysis because direct incidence is a penalizing configuration compared to one with an upper layer protection which is often used on packagings. Furthermore, this database would allow to improve basic phenomena knowledge, modelling and tools for design.

References

- IAEA Safety Standards for protecting people and the environment - Regulations for the Safe Transport of Radioactive Material - 2012 Edition - Specific Safety Requirements No. SSR-6

- IAEA Safety Standards for protecting people and the environment - Advisory Material for the IAEA Regulations for the Safe Transport of Radioactive Material (2012 Edition) - Specific Safety Guide No. SSG-26