THE ENVIRONMENTAL CONDITIONS EXPERIENCED BY PACKAGES DURING ROUTINE TRANSPORT

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ABSTRACT

Packages carrying radioactive material experience a range of environmental conditions during routine transport including temperatures, pressures and shocks. This paper examines the current requirements in the IAEA Regulations for the safe transport of radioactive material (TS-R-1) and the associated guidance (TS-G-1.1), and outlines the need for a research project to confirm the validity of the current requirements and improve the existing guidance.

As for the mechanical loadings the packages are subjected to, the advisory material TS-G-1.1 indicates that, due to the differences in transport infrastructures and practices, the recommended acceleration factors, which represent the package inertial effects, could differ from one country to the other and that the package designer should confirm the acceptability of those factors.

In this context, the *Institut de radioprotection et de sûreté nucléaire* (IRSN) performed a bibliographical study relative to accelerations measured on packages or conveyances during transport. This study shows some variations with the acceleration factors mentioned in TS-G-1.1. It also highlights areas where data is missing. In these areas, further measurement campaigns should be performed.

The international project under the auspices of IAEA will provide opportunities for collecting a large set of results and facilitating the needed international consultation.

INTRODUCTION

The IAEA regulations for the safe transport of radioactive material (TS-R-1) [1], commonly called “The Regulations” have provided for safe transport for around 50 years. This has been supplemented by various guidance documents over the years, the main one being commonly called “The Advisory Material” TS-G-1.1 [2].

According to “The Regulations” [1] packages must be designed so that the package itself and its retention system do not break or yield in routine conditions of transport. The evaluation of the mechanical behaviour of the retention system is based on factors representing the effects of acceleration of inertia of the package. “The Advisory Material” [2] states that, given the differences in transport infrastructure and practices, acceleration factors, recommended by competent authorities, may differ from one country to another. However, this guide provides an order of magnitude for the acceleration factors that may be used in the safety analysis (see Table IV.1). It also gives values which can be applied to specific packages (see Table IV.2), but recommends that their validity be justified by the package designers.

Due to the lack of clarity about which acceleration levels are to be used, the French competent authority requested IRSN to provide recommendations.

To facilitate international transports, key issues are the harmonized adoption and the consistent interpretation of regulatory provisions between Member States. Failure to achieve harmony in application is a potential barrier to safe and efficient transport. The area has been the subject of multiple interventions by Member states during the process of reviewing and revising “The Regulations” [1] and “The Advisory Material” [2]. This is an indication that there is a need to consider whether harmonisation, or potentially studies, in this area is required. In addition, the IAEA General Conference has identified this as an area of concern, and requested additional work be carried out.

SURVEY FOR LEVELS OF ACCELERATIONS IN ROUTINE CONDITIONS

The IRSN survey is essentially based on the one hand on values recommended by norms, among which those indicated in the appendix IV of “The Advisory Material” [2] are considered the most relevant, on the other hand on available results from measurement campaigns, in particular those performed during actual campaigns of transport of packages transporting radioactive materials ([3], [4]). When no measurement result was found in the literature, an upper bound of the values recommended by norms or guides has been suggested. In that case, the suggested value can’t be considered as definitive. A more thorough research in the literature should be performed, and if no exploitable data were to be found, specific measurement campaigns are needed to fill the gap.

Results of the survey for levels of accelerations in routine conditions of transport

The accelerations depend on the transport mode (road, rail, air, sea or river), the direction of the acceleration (longitudinal, lateral or vertical), the conditions in which the transport is performed, the mass range of the package, and eventually special stowing provisions.

Road transport

The loadings encountered during road transport depend on many parameters such as:

- the state of the road, the way of driving and the speed of the vehicle;
- the nature of vehicle suspensions: acceleration values in case of air cushion suspension truck are lower than for leaf spring suspensions [8];
- the respective weights of the package and of the vehicle;
- the pressure and state of tyres.

The table 1 presents acceleration values collected for road transport.

Table 1. Acceleration values collected for road transport

References		Longitudinal[1]	Lateral	Vertical
Norms and guides	Guide TS-G-1.1 (table IV.1) [2]	2	1	2 up - 3 down
	EC [6]	- 0.5 /+ 1	0.5	± 1
	NTC, 2004 [7]	- 0.5 / + 0.8	0.5	0.2 up
Results of measurement campaigns	Pujet [3], Cory [4], NTL 8 (36 ton package)	1.8	1.8	± 2.2
	Pujet [3], NTL 11 (80 ton package)	1	1	± 1.4
	Prulhière [5], TN 12/2 (100 ton package)	0.15	0.5	± 0.4
	Singh [9]	0.51	0.85	± 2.26

1. In longitudinal direction : '-' is for backwards and '+' is for forwards

The definition of terms up and down for the package inertial static-equivalent forces acting on the tie-down systems as presented in "The Advisory Material" [2] appears ambiguous; in particular the interpretation of how to add the weight of the package (para. IV.10) is not clear. Then, the comparison with values collected from measurement campaigns that correspond to dynamic accelerations of the package, should be cautious.

In the case of longitudinal acceleration, considering the maximum value of 1.8 g measured on a 36 ton package (NTL 8), it is suggested to consider the value of 2 g, which is also recommended by "The Advisory Material" [2]. Dedicated measurement campaigns would be needed to check whether this 2 g level is appropriate for the tie-down loads applied to low mass packages.

In the case of lateral acceleration, the maximal value measured on the package NTL 8 (1.8 g) is greater than the value recommended in Table IV.1 of [2]. It is again suggested to consider a value of 2 g, envelope of the value measured on the package NTL 8 to cover lighter packages.

In the case of vertical acceleration, it is suggested to round up the maximal measured value (±2.26 g reported in [9]) to ±3 g, and to take into account the effect of gravity.

Rail transport

The table 2 presents acceleration values collected for rail transport.

Table 2. Acceleration values collected for rail transport

References		Longitudinal	Lateral	Vertical
Norms and guides	Guide TS-G-1.1 (table IV.1) [2]	5	2	±2
	Directives OMI [11]	4	0.8	-
	UIC [17]	4	0.5	0.3
Results of measurement campaigns	Pujet [3], NTL 11 (80 ton package)	1	1	± 1.4
	Prulhière [5], TN 12/2 (100 ton package)	0.6	0.4	± 0.5
	Singh [9]	5.56	3.5	± 3.36

For the marshalling of trains, the yard switching of wagons, conducted either by the "hump method" or "gravity method" leads to higher longitudinal acceleration. When the wagon is bearing Label n°15 defined in the RID [15], which prohibits these methods, it is accompanied by a low-speed motor coach. However, other parameters must be considered:

- the respective weights of the package, the wagon and the whole train;
- the damping properties of buffers located between wagons or between wagons and the motor coach. The requirement TE22 of RID, which recommends the use of wagons

equipped with special buffers designed to prevent yielding of the cargo, is not required for class 7 transports;
- Even at low speed, a longitudinal acceleration of 2.5 g was recorded during tests carried out in France by SNCF with a special wagon equipped with 4 bogies and long buffers (Domange-Jarret type) loaded with a NTL 11 package (80 tons); moreover, a LR 65 tank was damaged in 1998 at Sotteville (marshalling yard) station due to a rough operation [16].

There is a lack of experimental data for various kinds of wagons, of marshalling methods and of package masses. Additional dedicated campaigns of measurements are desirable.
Thus, it is suggested for longitudinal acceleration in case of heavy packages (more than 30 tons), a value of 2.5 g when hump yard or shunting by pushing off wagons is forbidden and long buffers are used. For lighter packages, a conservative value of 4 g, consistent with recommendation of UIC [17], is suggested. Finally, when Label n°15 of RID is not applied, a rounded up value of 6 g is suggested whatever the mass range of the package.
In the case of lateral acceleration, it is suggested a value of 4 g which is the rounded up maximal measured value (3.5 g in [9]).
In the case of vertical acceleration, the maximal measured value of 3.36 g mentioned in [9 is not confirmed by other results. So, for rail transport, it was preferred to round down to the value of ±3 g and to take into account the effect of gravity.

Sea transport
The tie-down loads applied on packages transported by sea depend on several parameters:
- the state of the sea, which could be characterized using the Beaufort Scale. IRSN considers that sea conditions up to degree 11 on the Beaufort Scale should be taken into account to cover violent storms, such as the one which lead to the sinking of the MSC Carla near the Azores;
- the nature of the sea: closed or open sea. In the case of an open sea, the prolonged action of the wind creates a swell whose amplitude is greater when the wind which generated it has regularly blown a long time on a large area. The wave period is also strongly dependent on the duration of prior action of the wind;
- the type of ship and its dimensions;
- the position of the package in the ship, and more precisely its distance to the rotation axes of the ship.

The table 3 presents acceleration values collected for sea transport.

Table 3. Acceleration values collected for sea transport

	References	Longitudinal	Lateral	Vertical
Norms and guides	Guide TS-G-1.1 (table IV.1) [2]	2	2	±2
	Directives OMI [11]	0.4	0.4	±0.8
	INF Code [12]	1.5	1.5	1 up / 2 down
Results of measurement campaigns	Cory [4] (Excellox 3B , Channel)	0.2	0.2	±0.4
	Rubertone [13]	0.3	0.3	±0.3
	Singh [14]	0.7	-	± 1.5[1] / ± 3.6[2] / ± 4.2[3]

1. Maximal value measured during a transport between Honduras and the USA, in a hold at the front of a ship used to transport fresh products (bananas) inside containers. The most frequently occurring value was 0.5 g.

2. Maximal value measured during a transport between Honduras and Germany, in a hold at the rear of a ship loaded with break-bulk shipment of fresh products (bananas), in conditions of severe roll (in adverse weather conditions). The most frequently occurring value was 0.7 g.
3. Maximal value measured during a transport between Honduras and Germany, in a hold at the front of a ship loaded with break-bulk shipment of fresh products (bananas), in conditions of severe pitch (in adverse weather conditions). The most frequently occurring value was 0.6 g.

The values presented in [4] could be considered representative of level 6 on the Beaufort scale. These values need to be extrapolated to level 11. In a first approach, it could be considered that the acceleration is proportional to the amplitude of swell ($H^{1/3}$) and the inverse square of its period (T).

Table 4. Corrective factor for extrapolation to level 11 on the Beaufort Scale

Level on Beaufort Scale	Significant wave height $H^{1/3}$ (m)	Period T (s)	Corrective factor	
			$H^{1/3}/T^2$	
6	2.9	6.5	0.069	2.2
11	13	9.2	0.154	

Regarding the influence of the position of the package in the ship, acceleration could be significantly amplified in case of pitching which could be characterized by the half length of the ship (the MSC Carla, which broke in two during a storm, was 280 m long). Nevertheless, for a given wave amplitude, this phenomenon is attenuated by the reduction of the angular velocity with the length of the ship.
Assuming large uncertainties on the performed extrapolation, it is suggested rounding up the corrective factor to at least 3, which leads to 0.6 g in longitudinal and lateral directions, and 1.2 g in vertical direction (corrected to take into account the effect of gravity).
It should be noted that vertical accelerations in the range of 4 g were measured during transports between Honduras, the USA and Germany in holds at the front or rear of cargo ships, but these values have not been correlated precisely to weather conditions ([14]). Such discrepancies on the accelerations show that more experimental data are needed.

Air transport

No specific data about air transports was found, which highlights the need for performing dedicated measurement campaigns for air transport.
Meanwhile, it is suggested to consider the values recommended by “The Advisory Material” [2], except the 6 g value mentioned for vertical inertial accelerations since it looks unrealistic for routine conditions.
For longitudinal acceleration, “The Advisory Material” [2] mentions two values: 1.5 g and 9 g, this latter value corresponding to the case of packages loaded in airplanes the cockpit of which is not protected against the shocks of the cargo in case of emergency landing. IRSN considers that this type of circumstance is not part of routine conditions of transport. Thus, the sole value of 1.5 g is suggested.

Summary of the values suggested by IRSN

Table 5. IRSN recommendations for maximum loads applied to packages by retention systems, for the various modes of transport

Direction	Value (unit m.g, with m mass of package and g = 9.81 m/s²)				
	Road	Rail	Sea	Air	All modes
Longitudinal	2	2.5 (1) 4 (2) 6 (3)	0.6	1.5	2.5 (1) 4 (2) 6 (3)
Lateral	2	4	0.6	1.5	4
Vertical	4 up - 2 down	4 up - 2 down	2.2 up - 0.2 down	? up - 1 down	4 up - 2 down

(1) For packages of more than 30 tons and transported in wagons bearing Label n°15 of RID and equipped with long buffers.

(2) For packages of less than 30 tons and transported in wagons bearing Label n°15 of RID and equipped with long buffers.

(3) Other cases

It is also to be noted that transit operations in airports or harbors are reported as generating high retention loads.

Perspectives and conclusion from IRSN work

The present study highlights the need for more experimental data and analyses to confirm the values that should be taken into account for dimensioning the tie-down package components and checking preservation of the package safety functions.
The experimental campaigns should cover the following operations:

- air transport (take-off, flight and landing) for different types of airplanes;
- rail transport, taking into account yard switching operations of wagons transporting:
  - small packages containing radioactive materials on standard wagons,
  - a heavy package (100 tons) on a wagon with specific equipments (long buffers);
- sea transport for various states of the sea, different positions of the package in the ship and for different ship lengths;
- road transport:
  - for a wide range of package mass: from 10 to 100 000 kg;
  - for different types of vehicles commonly used, from light commercial vehicles to special heavy ones, paying attention to the influence of suspension.

Such an extensive program would be facilitated by a partnership in view of sharing expertise and financial supports. Involvement of IAEA is desirable to make easier the mutualization of individual contributions.

THE WAY FORWARD

In 2008 the IAEA General Conference passed a resolution, GC(51)/RES/11 which said in paragraph B.(k) “Noting the changing global weather patterns and, in this regard, recognizing the important role of the Agency in continuing to ensure that such changes are addressed,” and went on in paragraph B.12 to “Calls upon the Agency to continue to take into account scientific evidence of changing global weather patterns, changes to infrastructure and changes to industry operations, in the ongoing review of the relevant Agency safety standards”.
In the following year, 2008, the IAEA General Conference again passed a similar resolution, GC(52)/RES/9 with the same preambular paragraph, but a slightly more detailed operative

paragraph (11) saying "Calls upon the Agency to continue to take into account scientific evidence of changing global weather patterns, changes to infrastructure and changes to industry operations in the ongoing review of the relevant Agency safety standards, and encourages the Secretariat to develop new fissile-excepted material requirements for the transport of radioactive materials". This was again followed in 2009 by resolution GC(53)/RES/10 with very similar wording.
The clear message is that "the Regulations" [1] and "The Advisory Material" [2] need to be living documents, having in place effective feedback mechanisms that take into account external changes that could affect them. There are several steps in taking forward these General Conference Resolutions. The first is to clearly establish and document each individual safety requirement, identifying its purpose and the standard it needs to meet. The second stage is to identify the variation in parameters that would indicate a need to change requirements or guidance. This work starts with a technical meeting in Paris on the week following the PATRAM conference. This will be followed by further related meetings. The output will be clearly specified safety criteria with documented justification, along with key parameters to guide the need to change.
As part of this work there may be areas where the technical meetings will identify the need to update the technical basis, as has recently taken place for both NORM and surface contamination. Such an area may be related to the environmental conditions of transport, such as temperature, pressures, insolation and acceleration. However it is essential to note that the environment that radioactive packages are exposed to is also the same environment that other dangerous goods are exposed to. While the involvement of IAEA has been identified as being desirable in relation to further work it is likewise important to ensure harmonisation through cooperative working with all other relevant UN bodies, and for the work to be carried out by experts that can command the respect of the Competent Authorities that will be required to implement the requirements in a harmonised manner.

CONCLUSION

Ensuring "The Regulations" [1] and "The Advisory Material" [2] remain sufficient to assure safety is an ongoing process. Ensuring they provide for a harmonised approach is essential to prevent barriers to shipment of radioactive material. Research, such as that provided by IRSN in this paper, form an essential part of the collaborative work required to validate the ongoing safety in the transport of radioactive material. The coordination of the work by IAEA in cooperation with other relevant UN bodies, and the consistent application in Member States is an essential tool in ensuring the harmonised application of standards and the mitigation of problems shipping radioactive material. A long term programme of work has been identified that will ensure the work is managed in an effective manner in order to respond to identified needs.

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