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Post-Fukushima complementary safety assessments extended to transport

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Baptiste LOUIS **Marie-Thérèse CAILLARD-LIZOT**
Gilles SERT **Marianne MOUTARDE**

Institut de Radioprotection et de Sûreté Nucléaire, Fontenay-aux-Roses, France

Abstract

Following the accident that occurred on the Fukushima Daiichi nuclear power plant on 11th March 2011, the ASN (French Competent Authority) required the French nuclear operators to perform Complementary Safety Assessments (CSAs) of their facilities. The CSAs evaluate the capacity of French nuclear facilities to withstand extreme situations beyond design basis assumptions.

During TRANSSC 24 in 2012, the 28 issues raised after the Fukushima accident were examined with regards to the IAEA SSR-6 transport regulations in order to draw lessons relevant for the transport of radioactive material. During the Technical Meeting on the Environment of Packages in transport, organized by the IAEA in July 2013 (TM 44891), it was underlined that emergency preparedness in transport was an urgent matter to be addressed.

In 2013, ASN extended the CSA concept to the transport of radioactive materials. In this framework, IRSN (French Technical Support Organization) was requested to analyse:

- the current state of knowledge on the behavior of packages facing hazards of extreme intensity or having characteristics different from the test conditions defined by the IAEA SSR-6 standards;
- the opportunity and means to complete this knowledge by identifying potential credible accident beyond regulatory limits in order to initiate reflections related to emergency preparedness.

IRSN considers that current regulatory requirements cover a large number of conceivable accidental situations. Nevertheless, there exist a limited number of scenarios that could lead, for some packages, to important radiological consequences. It was also concluded that potential risks induced by those scenarios could be reduced by implementing one of the following measures:

- a marginal strengthening of the regulations in particular cases;
- strengthening of local regulations in the case of specific infrastructures;
- operational measures such as excluding specific itineraries;
- special provisions for emergency response when above solutions are not suited to package design or to intended operations.

Introduction

In 2011, ASN required the French nuclear operators to perform Complementary Safety Assessments (CSAs) of their facilities. Those CSAs aim at drawing the first lessons of the Fukushima Daiichi accident by evaluating the capacity of French nuclear facilities to withstand extreme situations beyond design basis assumptions [1]. In 2013, ASN wished to extend the CSA concept to the transport of radioactive material. ASN then requested its technical support, IRSN, to examine:

- the state of knowledge on the behavior of approved packaging designs facing accident of higher intensity or with different characteristics than those defined in the IAEA Regulations [2], supporting the assessment at least on the references listed in the IAEA *Technical Basis Document*[1] (§10.4 and appendix 4) [3];
- the opportunity and means to complete this knowledge, especially by identifying possible accident scenarios out of the scope of the regulatory tests, with a view to preparing for emergency management.

Since 2012, IAEA has also engaged reflections on this matter. During the Technical Meeting 44891 held in July 2013, it was concluded that regulatory tests allow approved packages to be sufficiently dimensioned to resist possible accidents, but also that Regulations should be amended to make mandatory for the consignors and carriers the development of emergency plans, considered as the last line of defense in depth for the transport of radioactive materials [4]. France proposed such a modification of the IAEA Regulations (SSR-6) in 2015, and that proposal, accepted by the IAEA TRANSSC committee, will be implemented in the next edition of SSR-6. In France, ASN recently published a guide to address this matter [5].

Analysis of the *Technical Basis Document* and other available documents

First, IRSN reviewed available literature related to the technical origins of the IAEA series of accident tests and to the robustness of those tests regarding possible accident situations, especially those of higher severity.

Mechanical tests

Concerning the drop test on a planar surface, the regulatory unyielding target covers all soils and structures, more or less deformable, therefore bringing safety margins more or less quantifiable regarding decelerations and packaging damages. The 9-m height, rendering an impact at about 50 km/h, does not, however, present evident safety margins: shock speed or possible fall height may exceed those values (frontal crash, fall from a bridge, port handling at possible high heights, etc.). Eventually, it is the deformable nature of the impacted structure which is important. Consequently, the safety margins of a package are based on those of its damping structures after sustaining the drop tests.

[1] By the time the assessment was undertaken, the September-2014 version was considered. A new version was published in October 2015, after the end of the assessment.

Concerning the 1-m drop test on a bar, the shape of the bar and its mechanical properties seem to cover the majority of the possible targets encountered in the transport environment. However, the height of 1 m (impact speed of 16 km/h) cannot be representative of all real situations of impact on a blunt surface; moreover, we could not find evidence of justification of this height when the 1964 edition of the Regulations was published.

Concerning the dynamic crush test, there are few available studies. It is difficult to conclude that the regulatory test covers the majority of accident situations, especially those treated in the context of CSA. Regulations exempt many packages of the dynamic crush test: mass over 500 kg, “overall density” higher than 1, activity less than 1 000 A_2. Those choices are partly based on an analysis of the kinds of packages transported at the beginning of the 1980’s, which differ from the current situation. On construction sites or during handling in ports, it is conceivable that heavy objects weighing several tons fall on or collide with packages (beam of handling gear/equipment, 30-t ISO container, ground transportation frame, etc.); those objects can present protruding areas. For this test, the Regulations should be reviewed.

Thermal tests

All analyzed studies tend to show that the regulatory fire test is often more severe than thermal environment resulting from a real fire, partly because of his permanent engulfing nature with high emissivity and absorptivity characteristics. In addition, should the package lose its leak tightness following a severe fire, most studies conclude that, even if the regulatory thresholds are not met any more, there will be no cliff effect leading to a significant and sudden activity release. Fire alone might lead to a cliff effect *a priori* only for the transport of liquids (or phase-change materials like UF_6), especially due to the increase of the internal pressure which could lead to a sudden rupture of the containment system.

A package affected by a fire, even beyond regulatory one, may suffer damages (partial combustion of the shock absorbers, loosening of the screws, etc.) and cannot withstand shocks without potentially great damages. Accordingly, all measures must be taken to avoid such situations during the recovery phase of the package, during emergency management.

Immersion tests

All the studies considering failure of a package after immersion in water, conclude to low radiological consequences. However, their coarse modelling (e.g. [9]) does not always allow excluding the eventual need for specific protective measures, locally in the shipwreck area, such as the prohibition of fishing and/or retrieving of packages within a certain amount of time. It is desirable to consider such measures in emergency plans.

The risk of critical excursion cannot be ruled out in all cases: the current Regulations may consider only a limited quantity of water in the package, after immersion at a depth not below 15 m and not longer than 8 hours. The duration of the recovery operations are likely to be longer and depth lower. For this test, the Regulations should be reviewed.

<u>General conclusion on the regulatory tests</u>

Considering the requirements associated with the transport of radioactive materials requiring competent authority approval, we are confident that the current regulatory requirements cover a very broad spectrum of possible accident situations. Specific improvements and additional studies mentioned above could be undertaken. However, overstrengthening the design of the packages would lead to promote investment in package designs while this area is even less justified as occurrence probabilities of those situations are lower.. Consequently, we estimate that strengthening the requirements of design of the packages should only be marginal.

We identified two other areas for improvement:

- limiting the occurrence of degraded situations, either by operational arrangements (selection of routes to avoid high-height bridges or transit through tunnels, for example), or by regulating the transport co-activities (e.g. separation of the flow of radioactive material conveyances from other dangerous goods in tunnels, no handling at high height in ports);
- limiting the consequences of accident situations by implementing specific measures as part of the response to radiological emergencies.

For this latter context, knowing the potential state of a package, in case of a more severe accident situation than that resulting from the regulatory tests, would be essential. Indeed, typical accidents occurred in transport of radioactive material usually have fast kinetics; rescue teams and experts in charge of evaluating the situation do not have an immediate knowledge of the accident parameters. Consequently, we estimate it would be better to know the extent of the consequences of such situations in order to best prepare the equipment and human resources needed for emergency management.

Proposals for studies exceeding the severity of regulatory tests

<u>Feared situations</u>

Risks induced by an accident involving a package transporting radioactive material are:

- irradiation, in case of degradation of the radiological protection;
- dispersion resulting in contamination, in case of degradation of the containment system;
- criticality, in case of degradation of the confinement system.

Some materials transported (mainly UF_6 and uranyl nitrate) present significant chemical hazards. They are identified as substances with other risk than Class 7 (Class 8 corrosive essentially). The chemical toxicity of UF_6 (Class 6, due to hydrogen fluoride production in the presence of moisture in the air) was also discussed in international forums.

Scenarios possibly leading to feared situations

IRSN identified beyond-design scenarios based on considerations described hereafter.

Considering those scenarios can be done by different ways; it is possible by implementing operational measures to exclude the scenario or implementing emergency measures to limit the consequences. Possibilities are discussed below.

Enhanced dynamic crush

In ports, ISO containers weighing up to 30 t may be handled up to 50 m. **We recommend considering an « enhanced dynamic crush scenario » involving the fall of an ISO 20' container weighing 15 t, from a height of 25 m, on a package designed to transport radioactive material.**

Enhanced punching

Based on the previous scenario, it seems likely that rupture of the lifting points of the container will not occur at the same time, thus positioning the ISO container in a "punching position", one of its corners facing the package at the time of impact. Also the fork of lift trucks can damage packages. Such events are quite frequent.

We recommend considering the three following "enhanced punching scenarios":

- **fall of an ISO 20' container weighing 15 t, from a height of 25 m, on a package of radioactive material, impact with the corner of the container;**
- **fork blow of a lift truck, the mass of which is 1.5 times that of the impacted package, moving at more than 10 km/h;**
- **impact on specific metallic structures known to be part of the transport environment, at speeds consistent with the known conditions of the operations considered in the study.**

Air crash

Current regulations allow the air transport of type B packages, each containing up to 3 000 A_2 or 3 000 A_1 (limited to 10^5 A_2), with no particular restriction for the aircraft. **We recommend considering an air-crash scenario (impact at 90 m/s on an unyielding target).**

Enhanced delayed impact

The literature review presented above tends to show that the regulatory tests cover most surface accident situations of impact of packages on real targets (land, rail, sea). Nevertheless, none of the studies considered the possible effect of a delayed impact of the content on the closure system of the packages, whereas this phenomenon is nowadays considered as physically realistic, and that it is often taken into account in safety analyses (it shall also be described in the future SSG-26 edition [6]). **We recommend considering a fall from a height of 25 m (i.e. impact at about 80 km/h) on a real (yet conservative) target to be defined, taking into account the delayed impact of the content on the closure system.**

Burial and sinking

Obstructing passive cooling systems may result from the collapse of a (part of a) building on a package located nearby, due to an earthquake, or the burial in a soft ground. Hence, the induced rise in temperature may lead to loss of efficiency or the failure of the containment gaskets or of temperature sensible shields. **We recommend considering a complete burial/sinking scenario.**

Long-lasting or high-intensity fires

Fire in ship holds [7] or tunnels may last much longer than the regulatory duration of 30 minutes while occasionally exceeding the 800°C defined for the test.

Such fires could lead to various consequences, depending on the package design considered:

- failure of the containment gaskets (mainly elastomer-type);
- increase of the internal pressure, leading to the possible rupture of the containment system (especially liquids or UF_6);
- acceleration of the radiolysis and thermolysis phenomena, especially for hydrogenated materials (effluent, residual water, organic materials, etc.);
- thermal instability of particular contents (e.g. thermal runaway of bitumen).

We recommend studying long-lasting or high-intensity fires in order to be able to provide information on the potential package damages to emergency team.

Immersion in fishing zones

Packages submerged in sea are liable to lose their containment within a few months to a few years (mainly through local corrosion like pitting corrosion of stainless steel gasket seats [8]).

We recommend considering water immersion at any depth.

Methodology to define potential CSAs

We recommend the following methodology:

- identifying packages that could be submitted to the reference scenarios:
  - listing packages circulating in public space, their contents (quantity of A_2 really transported, physical/chemical forms in all conditions of transport), and their annual flows;
  - estimating the possibility of occurrence of a feared scenario (occurrence of air transport, of handling in ports, etc.)
  - estimating the potential consequences of the possible scenarios, to be compared with the trigger thresholds for actions of protection in emergency situations;
- defining, for the selected packages: operational measures if necessary, protection measures, emergency control means and radioactive material/packages recovery means in order to lower the possible consequences, as much as reasonably achievable;
- defining and considering potential aggravating situations.

Operational measures may be to avoid transport or handling through dangerous situations (long tunnels, high bridges, etc.).

Protection measures should then define:

- the safe time for packages subjected to fires until failure of containment (or shielding);
- the safe time for packages whose thermal heat dissipation capacity is affected, and the means needed to restore heat dissipation;
- the conditions for retrieval of immersed packages according to depth or define the extent of the fishing prohibition zone;
- the protection distance needed in case of a damaged containment system and the means needed to inspect and repair it;
- the protection distance needed in case of a damaged packaging component needed for radiation protection and the means needed to inspect it and repair it or provide additional shield on the accident scene;
- the means needed to retrieve and evacuate damaged packages.

CSA within the context of enhancing emergency preparedness – IAEA TS-G-1.2

International discussions

TRANSSC 32 (June 2016) approved the following changes to the Regulations No. SSR-6 [2]:

- 104. […] to ensure safety and to protect persons, property and the environment from the effects of radiation in the transport of radioactive material, [… the protection requirements are] **finally satisfied by making arrangements for planning and preparing emergency response in order to mitigate the consequences of potential events**.

- 304. […] **Consignors and carriers shall establish, in advance, arrangements for preparedness and response for emergencies that may occur during transport, in accordance with [10], that are coordinated with respective off-site response organizations.** Further guidance on emergency preparedness and response are found in [11], [12] and [13].

The consequences for this regulatory change would be the following:
- confirmation of users' duty to prepare emergency plans (TS-G-1.2 paras 3.10-3.15 and 4.4 [11]), and increased legitimacy for inspecting emergency plans of user;
- the emergency plans would be homogeneously applied in foreign countries the consignors and carriers are not from, which would reduce the uncertainties when an accident occurs;
- users' emergency plans should describe the reasonable measures they are able to take in view of limiting/reducing/preventing potential radiological consequences in accident situations;
- kinds of accident situations that might raise radiological issues should be identified;
- the expected gain is to increase efficiency of users' emergency plans.

Human factor

Human factor is the source of many abnormal events and could lead to difficulties. Thus, we recommend that human error be considered as an aggravating factor, to be taken into account in the evolution of emergency situations.

Conclusion

Current Regulations cover the main part of possible events. But a few scenarios could lead, for some packages, to great consequences, which should be under control. Some reinforcements of the packages may be possible. It is also possible to improve operational regulations to avoid some scenarios.

But we consider that, in most cases, emergency response has to be improved.

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