Proceedings of the 18th International Symposium on the Packaging and Transportation of Radioactive Materials
PATRAM 2016
September 18-23, 2016, Kobe, Japan

Paper No. 4027

IRSN's experience feedback list for the package design safety assessment

Benoit ECKERT **Marie-Thérèse CAILLARD-LIZOT** **Gilles SERT**
Olivier LOISEAU **Bernard MONNOT** **Igor LE BARS**
Institut de Radioprotection et de Sûreté Nucléaire (IRSN), Fontenay-aux-Roses, France

Abstract

Since more than 20 years, IRSN, the French Institute for radiation and nuclear safety, assesses the safety analysis reports in order to provide technical support to the French Nuclear authorities. In this context, IRSN has recorded the list of specific points most frequently encountered during the assessment of the safety demonstrations to which a special attention should be paid.

This experience feedback list has evolved over the last years to take into account the most recent evolutions of the regulations and the last technological knowledge.

It appears that some issues shall be taken into account in the first stages of a package development. In particular, IRSN put in the light the necessity to justify the mechanical behaviour of the package, during a 9 m free drop test simulating the accident conditions of transport (ACT), considering the delayed impact of the content and the internal arrangements onto the components of the closure system of the cavity.

Furthermore, some internal gaps, which could induce movements of the radioactive contents, should be minimized to justify notably that this phenomenon would not induce an external dose increase greater than 20 % in normal conditions of transport.

IRSN also highlighted that justifications relative to the transport of radioactive material under special form, such as sources, within the package cavity cannot be based only on the tests performed according the 2919 ISO norm. Complementary justifications have to be provided especially to conclude on the integrity of the source capsule during the regulatory ACT tests.

Furthermore, due to recent tests results, IRSN considers that a specific attention should be paid on the thermal behaviour of packaging made of polyurethane foam in case of fire exposure.

Finally, IRSN recommends to avoid the use of bolts with grade 14.9 due to the sensibility of the material to hydrogen embrittlement and the associated risk of fracture at ambient temperature. Concerning the bolts grades 10.9 and 12.9, IRSN considers that a specific attention shall be paid during manufacturing by introducing systematic hydrogen degassing. A relevant final control procedure has also to be put in place to guarantee the conformity of the bolts.

IRSN's experience feedback list for the transport package design is used as a guide by IRSN for the appraisals of the design safety reports and by applicants to improve their design safety reports.

Introduction

The Institute for Radiation Protection and Nuclear Safety (IRSN) is a national Technical Support Organization (TSO) to the French Competent authorities.

In the field of transport of radioactive material, IRSN's main mission is to carry out the assessment of the Safety Analysis Report (SAR) provided by the applicant in support to their approval request of a package design. Assessments may concern applications for approval of package designs, as well as modifications having an effect on the safety of already approved package designs.

Based on its feedback of safety analysis, on information relative to incidents or events, feedback from experience on use and maintenance of packagings and studies, IRSN has developed specific approaches and presented recommendations for assessing the safety cases [REF6]. The most recent developments are presented hereinafter.

In this context, IRSN has recorded a list of specific points most frequently not taken into account in the safety analysis reports.

This experience feedback list has evolved over the last years to take into account the most recent evolutions relative to the safety demonstrations, e.g. the consequences of a delayed impact of the content onto package components, the behaviour of special form materials during regulatory drop and fire tests, the thermal behaviour of packaging made of polyurethane foam in case of fire, the demonstrations provided to justify that the radiation level criteria under normal conditions of transport are met and also the manufacturing process.

Content of this experience feedback list is periodically sent to the French Competent authorities. The most recent topics are highlighted to update the French applicant guides ([REF4] and [REF5]) in order to improve the completeness of the safety analysis report.

Delayed impact of the content during ACT drop tests

According to the IAEA regulation [REF1], type B packages and packages used to transport fissile materials, must be submitted to the regulatory mechanical tests representative of the normal and accident conditions of transport including free drop from a height of 9 m onto unyielding target and drop from a height of 1 m onto a steel cylindrical bar.

In particular, during the puncture test and the free drop, it is specified in the IAEA regulation (paragraph 727 [REF1]) that the position of the specimen used to simulate the package shall be determined to induce the maximum damages. This requirement particularly applies to the packaging orientation and also the content location within the packaging cavity. During the test campaigns, the radioactive content is mostly simulated by dummies whose representativeness, generally in terms of mass and geometry, is justified by the applicants. Prior to the 9 m drop test, if no specific precautions are taken, the dummy content could be in some configurations in contact with the closure system inducing an impact of the dummies onto the components of the packaging at a time very close to the one of the impact of the specimen onto the target. Nevertheless, during a real accident, it is possible that the content and the internal arrangement would not be, before the impact, in contact with the closure components of the packaging cavity located in the upper part. In consequence, the impact of the loaded components within the packaging cavity will be delayed.

It has been proved by calculations and experiments that, for significant gaps between contents and cavity along the drop axis direction, this secondary impact could transfer an important amount of energy which shall be taken into account in the safety demonstrations. Indeed, the main issue is that a delayed impact of content onto the lid of the package could induce a loss of containment. In particular, this secondary impact mobilizes energy which may load lid screws beyond their elastic limit. In this regard, analyses of the mechanical behaviour of new package designs, taking into account the delayed impact of contents, have led some applicants to integrate complementary shock absorbers under the lid.

Due to the potential influence of a delayed impact of the content on the package design safety functions, the French applicant guide issued by the French competent authorities ([REF4] and [REF5]) introduced the necessity for the new package designs to consider in the safety demonstrations the most penalizing content position leading to the maximum damage during the regulatory 9 m free drop test simulating ACT.

In addition, the ASN applicant guide also mentioned that for the existing package designs [REF4], a specific analysis shall be transmitted in the application file for approval renewal.

Regulatory criteria for dose rate increase in normal conditions of transport

Regulation requires for industrial packages (IP-2 and IP-3) as well as for Type A packages, B(U), B(M) and C that, at the end of tests designed to demonstrate the ability of the package to withstand normal conditions of transport (NCT), the maximum radiation level at any external surface of the package shall not increase by more than 20%. It has to be noticed that this IAEA requirement exists since practically the origin of the transport regulation. Nevertheless, several modifications have been applied. This requirement, which concerned only the reduction of the shielding, has been enlarged to the industrial packages in 1985. Thereafter, in the 2005 edition of the transport regulation, the wording of the requirement was modified so that internal rearrangement of the content has to be considered in addition to shielding damage. The limit of dose rate increase, equal to 20 %, has been chosen to be consistent with the measurements uncertainties and to limit the dosimetric impact to workers that may handle and transport those packages after incidents, and to persons of the public.

The demonstrations provided by applicants to justify the respect of this criterion is generally based on calculations performed taking into account only the packaging damages resulting from the NCT regulatory drop test. However, during the NCT tests, gaps between the internal surfaces of the packaging cavity and the content could induce movement of the radioactive material.
Examples of packages concerned by this issue are those designed to transport bulk radioactive wastes, where internal movements of radioactive source could lead to a dose rate increase as presented in figure 1. In that case, the regulatory criterion is difficult to fulfil.

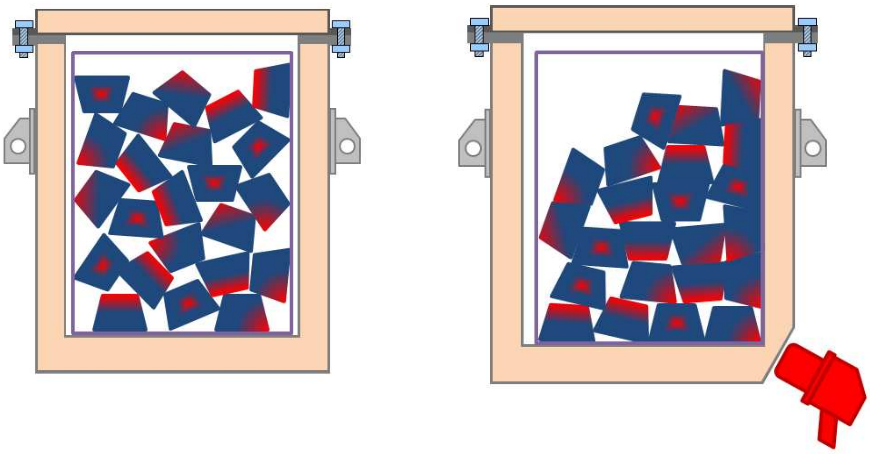

Figure 1: Example of content rearrangement and package damages inducing an increase of the dose rate

However, for some packages designed for low radiation levels, the limit of 20 % of increase of the radiation levels in normal conditions of transport could be relaxed and replaced by other requirements if needed. For example if the initial dose rate is almost zero (e.g. less than 5 microSv/h), higher increase factors than 20% would not lead to significant consequence on the annual dose.
The ALARA principle could be considered when proposing these requirements. Radiation protection programme requirements may also provide some preventive measures to cope with such circumstances whether detected or not.

In this context, IRSN considers that the aforementioned points could be discussed in an international working group. The proposed terms of reference of this working group are:

- Examine the + 20 % specification
    - Survey how it is assessed in different countries;
    - Identify the causes of increase, the possible range of increase factor and the design features that limit this range;
    - The associated safety issue;
    - The possibility of replacing this relative criterion (increase of 20 % of the irradiation level before departure) by an absolute criterion (limited irradiation level around the

    package in normal conditions of transport), in particular for least irradiating packages (categories I-WHITE or II-YELLOW);
  - The possibility of relaxing this criterion for packages of category III-YELLOW and the associated conditions;
  - Use of ALARA principle;
  - The consequences on radiation protection programs, on labelling and on segregation.
- Other alternatives may be examined concerning either design criteria or operational measures or both
  - Assess dose rates, use frequency of packages with high radiation level, package types, activity fields;
  - Assess the dosimetry induced by such packages;
  - Other measures.

Transport of the radioactive materials under special form

According to the IAEA regulation [REF1], a sealed source can be defined as a special form material meaning either an indispersible solid radioactive material or a sealed capsule containing radioactive material. In this regard, competent authority approval shall be required for the special form material. Then, it is mentioned that a sealed source must meet the specific IAEA requirements [REF1] which refer to ISO standards ([REF2] and [REF3]). The radioactive materials under special form shall be subjected to impact, percussion, bending and heat tests. Following each of them, the specimen shall be subjected to leak test to evaluate the integrity of the sealed capsule. It has to be noticed that a different specimen may be used for each of the tests which does not allow evaluating their combined effect on the radioactive source.

When radioactive materials are defined as special form materials, the radioactive material, notably the sealed capsule enclosing the radioactive material, may be considered as a component of the containment system.

In support to French applications for type B packages loaded with sealed sources, defined as special form material, applicants transmit safety demonstrations considering that the containment of the radioactive material is ensured by the capsule of the source and not by packaging components.

In this regard, applicants have to demonstrate the integrity of the sealed source after the sequence of the regulatory ACT tests required for the type B packages.

In some safety cases, the applicants considered that the integrity of the source loaded within the package, after the 9 m free drop, the puncture test and the 800°C fire test for 30 minutes was justified on the basis of the dedicated tests performed to qualify the radioactive material under special form.

Nevertheless, IRSN considers that this approach could not be sufficient. Indeed, during the qualification campaign required for the special form material, the sources are submitted to mechanical tests performed at 20°C using non active specimen. However, the temperature of the sealed capsule reached within the packaging cavity is mostly higher than 20°C due to:

- the source which is in general confined into the reduced volume of the packaging cavity which impacts significantly its heat dissipation. Based on the IRSN feedback, the external temperature of high activity source loaded within the packaging cavity could reach in normal conditions of transport temperatures ranging from 100°C to 400°C ;
- the regulatory ambient temperature, equal to 38°C, and the insolation conditions applied to the external surfaces of the packaging simulating the normal conditions of transport.

In consequence, IRSN considers that a higher temperature of the source could:

- decrease significantly the mechanical properties of the external capsule enclosing the radioactive material;
- increase the pressure within the cavity of the sealed source and create additional stress in the capsule.

Taking into account the aforementioned points, IRSN considers, in the absence of complementary justification, that the mechanical behaviour of the source loaded within a type B package submitted to the regulatory tests representative of the ACT could not be covered by those required to qualify the source as special form material. This is why IRSN considers that a specific analysis shall be transmitted by the applicant to justify the mechanical behaviour of the source loaded within a type B package.

Finally, the thermal behaviour of the source loaded within a package exposed to the ACT regulatory fire test applicable to the type B packages (800°C for 30 minutes) should generally be covered by the heat test required for the material under special form (800°C for 10 minutes as specified in [REF1]). Such assumption should nevertheless be based on specific justification to ensure that during the heat test required for the source, the temperature of the specimen was at least 800°C in all its volume. If this is not ensured, the internal temperature of the source, due to its thermal inertia, could be lower than 800°C.

Thermal behaviour of packaging made of polyurethane foam during fire test

Some new packaging designs are equipped with polyurethane foam present within their structure. The main objective of this material is to ensure a mechanical and thermal protection of the internal components of the package and the content during the applicable regulatory tests representative of the accident conditions of transport when required.

Recently, it has been observed by applicants an important burned thickness of the foam present within specimens which were exposed to the 30 minutes fire test. Examples of burned areas noticed,

after real fire tests, are presented in figure 2.
In particular, important internal temperature increases were measured in some areas located in front of the most important damages resulting from the regulatory drop tests performed previously and the areas of glue used for the foam blocks assembly.
In addition, it was put in the light that internal gaps between the polyurethane foam and the steel casing could increase the circulation of hot gases inside the packaging structure.

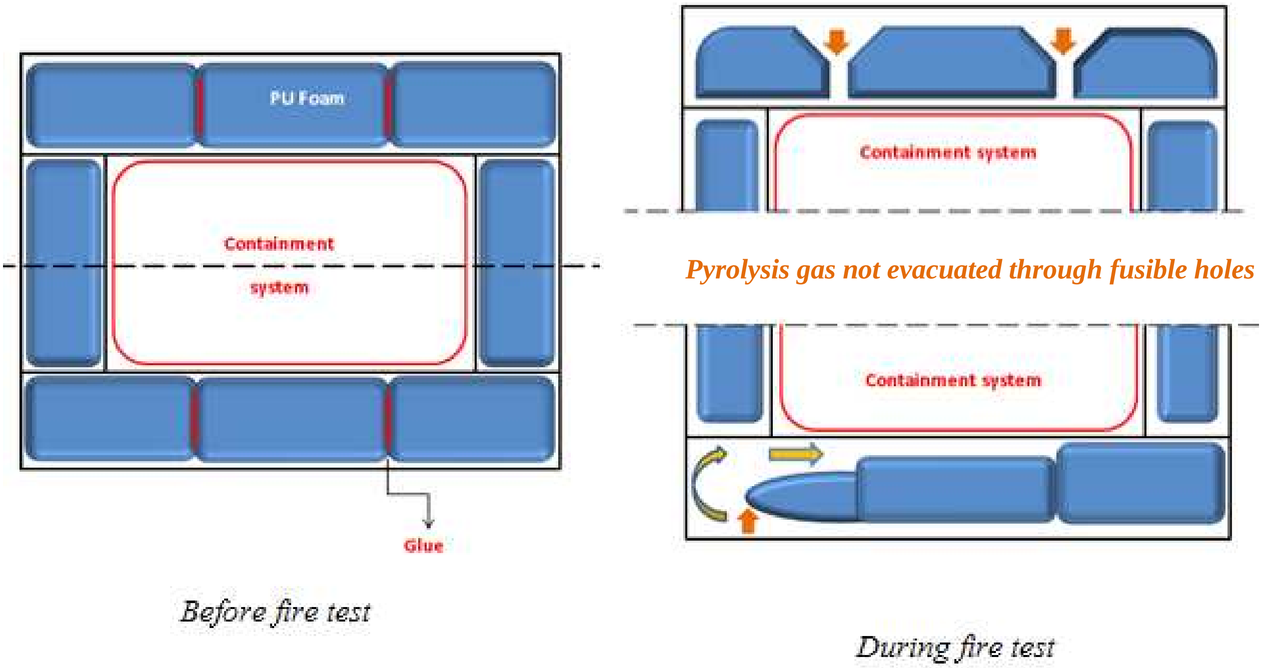

Figure 2: Examples of polyurethane foam blocks behaviour during fire test

These results highlight the necessity to evaluate precisely the pyrolysis effect of the polyurethane foam and the circulation of the associated hot gas. Such phenomena could significantly increase the temperature of the internal components of the package and question its safety level. Due to the complexity to simulate such effect, experimental approach should be considered.

Finally, IRSN underlines the importance of the number of fusible holes equipping the external shell of packagings which shall be sufficient to evacuate hot gas resulting from the combustion of the polyurethane foam. In addition, the leaktightness of these fusible plugs should be controlled during periodic inspection and at the end of manufacturing. This type of control should allow to prevent any moisture variation of the protective materials of the package design. For reminder, the humidity rate of these materials could influence their mechanical and thermal properties.

Specifications for the bolt supply and manufacturing

In order to guarantee the integrity of the package design safety functions, IRSN considers that a

specific attention should be paid on the bolted flange assemblies. One of their main duties is to ensure sufficient compression of the gaskets and maintain the leaktightness of the containment system.
During a regulatory drop, stress within components could lead to an opening between the lid and the lid flange of the package. This phenomenon has to be reduced especially in front of the grooves in which are accommodated gaskets.

The gasket seat opening has to be determined by the applicant to evaluate the decrease of the compression rate of the gaskets and to conclude on the integrity of the leaktighness of the closure system of the package cavity. The opening between the lid and its flange is mainly based on the mechanical behaviour of the fixing bolts. In this regard, IRSN considers that the bolts which are part of the containment system shall remain in their elastic domain. It means that the maximum equivalent stress within these bolts, calculated for all conditions of transport, shall be lower than their yield strength, including adequate safety margin. This criterion is in general deduced from the minimum value of the yield stress defined by the applicable standards for each « screw class property » considering their maximum temperature reached in NCT.
The characteristics of bolts and screws are defined in several standards including norms relative to dimensions, geometry, mechanical and chemical properties, surface treatment … For instance, ISO 898-1 [REF7], specifies minimum mechanical characteristics of the fixing screws made of carbon or alloy steel which are classified in several "class properties" associated to different performance levels as presented in figure 3.

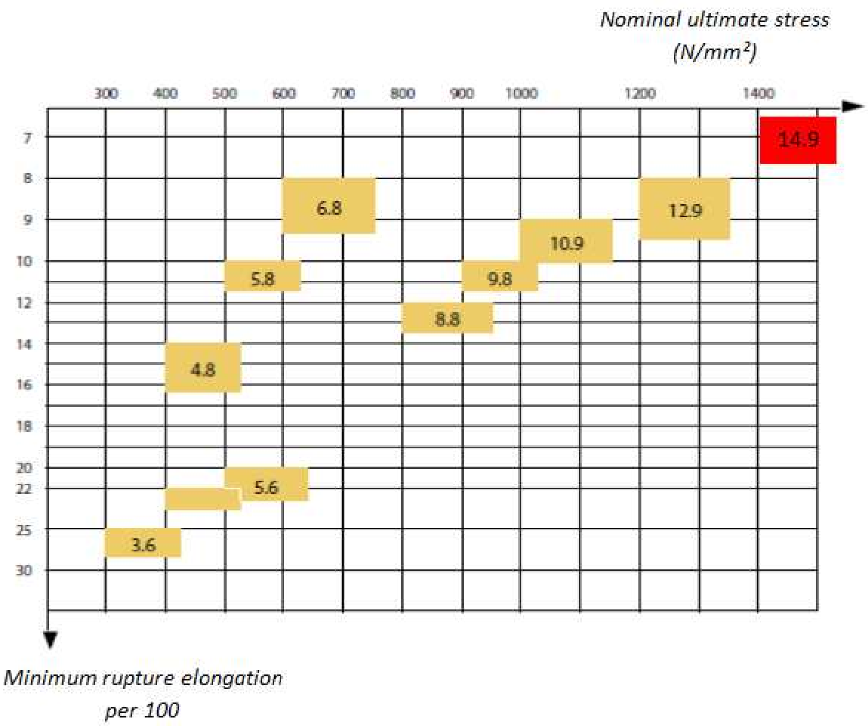

Figure 3: Main "class properties" screws

According to the figure 3, it can be noticed that the elongation capacity of the screws decreases in function of their class. In this regard, it appears that the modes of fracture of the screws are ductility for screw classes lower than 9.8 and brittle for screw classes higher than 10.9.

Nevertheless to guarantee the integrity of the components which are part of the containment system and notably the fixing screws of the closure components of the package cavity after the regulatory drop tests simulating the accident conditions of transport, package can be designed with high class properties screws higher than 10.9. According to IRSN this approach should not be considered due to:

- the ductility of screws, higher than 10.9 class, which is limited. In this case, the rupture elongation is in general lower than 10 %;
- the ultimate strength of such components is higher than 1 000 MPa meaning that there is a risk of hydrogen embrittlement due to the manufacturing process.

As a consequence, it is likely to observe damages or rupture of high class screws in situations leading to mechanical stress lower than those determined in the safety demonstrations. In this regard, several events have been declared in France concerning the rupture of high class screws during the loading operation when the operator applied the requested torque value. This is why IRSN recommends to exclude class 14.9 for screws in package design when such ones contribute to a safety function.

Concerning the classes 10.9 and 12.9 screws, IRSN considers that specific attention shall be paid to their manufacturing process. In this regard, to prevent the risk of hydrogen embrittlement, specific requirements should be applied including notably:

- a systematic degasing operation, for all screws whose ultimate strength is higher than 1 000 MPa, performed at least 3 hours after their thermal treatment ;
- the use of relevant method for their surface treatment, excluding, if possible, acid preparation.

Finally, IRSN recommends that a specific attention shall be paid to the supply of bolts and screws. In this regard, the applicants must put in place relevant control operations during different phases of the manufacturing of 10.9 and 12.9 class screws to limit the risk of hydrogen embrittlement. The procurement, performed under quality assurance, should also include a final control on a screws batch whose representativeness is justified.

Conclusions

The IRSN's experience feedback list, which is updated periodically by IRSN, is transmitted to the French Competent authorities to be included in their applicant guides. This list is therefore used as guidance for IRSN appraisals of the safety analysis reports and by applicants to update their justifications, or to even correct the package design, before applying for approval.

This approach allows to reduce the assessment duration, to improve the information exchange during assessments and to contribute to ensure a high level of safety in the radioactive material transportation activities.

References

[REF1] IAEA Regulation for the Safe Transport of Radioactive Material (2012 Edition)

[REF2] ISO standard 2919:2012 "Sealed radioactive sources - General requirements and classification"

[REF3] ISO standard 9978:1992 "Sealed radioactive sources - Leakage test methods"

[REF4] ASN Guide No. 7 "Applicant's guide related to applications for shipment approval and certificate of package design or radioactive materials for civil usage transported by public roads, by water or by railroad"

[REF5] ASND "Applicant's guide No. 1"

[REF6] Proceedings of the 15th International Symposium on the Packaging and Transportation of Radioactive Materials, PATRAM 2007, October 21-26, 2007, Miami, Florida, USA, "IRSN's Experience Feedback List for the Transport Package Design Safety Appraisals", Sophie LE MAO and al.

[REF7] ISO standard 898-1:2013 – Mechanical properties of fasteners made of carbon steel and alloy steel.