REVIEW OF MATERIAL REQUIREMENTS OF THE IAEA TRANSPORT REGULATIONS FOR LSA-II AND LSA-III

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ABSTRACT

In accordance with the safety concept of the IAEA Transport Regulations the package as combination of packaging and contained radioactive material has to provide required safety functions in all conditions of transport. Since Type IP-2 packages and Type IP-3 packages only have to protect against loss or dispersal of their contents under normal conditions of transport, IP packagings for LSA-II and LSA-III have only limited accident resistance. Consequently, the material properties required for LSA-II and LSA-III are mainly based on accident considerations and limitation of potential radiological consequences. Examples are:

- limiting the specific activity of LSA material to 10^{-4} A_2/g for solid LSA-II and to 2×10^{-3} A_2/g for LSA-III,
- homogeneity requirements regarding the distribution of radioactivity within the LSA material,
- for LSA-III only solid materials are allowed and powders are explicitly excluded,
- the requirement of a leaching test for LSA-III materials,
- the dose rate limit for the unshielded LSA-II or LSA-III material,
- conveyance activity limits for the transport of combustible LSA-II and LSA-III materials.

In the case of LSA-II material it is quite apparent by review of the historical development and current advisory material that the specific activity limit of 10^{-4} A_2/g was introduced regarding transport and handling accidents connected with airborne release. In contrast, the corresponding reasoning for the justification of the 20-fold higher specific activity limit of 2×10^{-3} A_2/g for LSA-III materials is not that evident since the leaching test examines a material property which has hardly any connection with the majority of accident sequences and with airborne release.

The LSA-II and LSA-III material requirements were introduced into the Regulations in the early 70s of last century. In the meantime much progress has been achieved internationally regarding knowledge of material characteristics of LSA-II and LSA-III and release behavior in accident conditions. It is shown that the factor of 20 in specific activity of LSA-III material compared to LSA-II has sufficient safety margins and results from other currently required material properties than those involved in the leaching test.

INTRODUCTION

For LSA-III material the IAEA Transport Regulations [1] require that the material is solid and has low solubility which must be demonstrated with a leaching test with test criteria which limit the leached activity expressed as fraction of the A_2 value. In this paper the justification for the leaching test is questioned and it is argued that similar as for LSA-II material the release behavior in accidents of land based transport is of prime importance regarding transport safety. For LSA-II material the specific activity limit of 10^{-4} A_2/g is clearly based on consideration of accident consequences resulting from airborne release following a transport accident with mechanical impact of the package. The original intention for requiring a leaching test was to introduce a material requirement in order to justify the factor of 20 higher specific activity limit for LSA-III material. By limiting the release of radioactivity from packages in accident conditions the IAEA Transport

Regulations aim to limit potential radiological consequences. Based on this overriding goal the following questions are discussed:

- Is the required leaching test for LSA-III material justified regarding its contribution to the limitation of radiological accident consequences? What level of radiation exposure could result in conceivable accident conditions without the current leaching test requirement?
- Are the arguments given in the current Advisory Material to explain the reasons for the leaching test and its performance requirements convincing?
- Given the current material requirements for LSA-III material but dropping the required leaching test can the factor of 20 higher specific activity limit for LSA-II be justified or would other LSA-III material requirements be needed?
- What kind of experimental and/or analytical data are available to quantify airborne release from packages with LSA-II and LSA-III material in severe transport and handling accidents and what levels of radiation exposure of persons in the vicinity of such an accident could result?

CURRENT REQUIREMENTS FOR THE TRANSPORT OF LSA-II AND LSA-III

Specification of LSA-II and LSA-III

For the transport of LSA-II and LSA-III materials industrial packages Type-2 or Type-3 are required which only have to provide sufficient protection to avoid loss or dispersal of radioactive contents in normal conditions of transport. The transport package as combination of packaging and radioactive contents is required to assure a high level of transport safety regarding accident conditions. A major emphasis is therefore laid onto the material properties of the LSA contents.

The most important material property is that the radioactive contents are distributed throughout the material in such a way that the activity concentration, i.e. the specific activity of the solid, liquid or gaseous LSA material, is limited to values which limit the potential intake of radioactive contents released in an accident.

This approach is quite evident when referring to solid LSA-II materials. The Transport Regulations [1] limit the specific activity of the LSA-II material to values of 10^{-4} A_2/g where the radionuclide-specific A_2 value is the non-special form content limit for Type A packages via a modeling approach known as Q-system. The radiological criterion applied in the derivation of A_1 and A_2 values is a limitation of the effective dose that a person in the vicinity of an accident site could receive via a number of exposure pathways. Generally, in cases where an accident results in an airborne release the most important pathway is inhalation of respirable radioactive material. In this case an intake by inhalation of 10^{-6} A_2 is equivalent to an effective dose of an adult person of 50 mSv.

The model applied to derive the specific activity limit for LSA-II material is rather simple by assuming that it is most unlikely that a person would remain long enough in a dusty atmosphere generated in an accident by an airborne release from a Type IP-2 or Type IP-3 package to inhale more than 10 mg of LSA-II material. The intake via inhalation is accordingly limited to 10^{-6} A_2 if the specific activity of the material is limited to 10^{-4} A_2/g.

The postulated upper limit of intake via inhalation of 10 mg generated dust implicitly combines assumptions on the airborne release in accident conditions, a resulting dust concentration at the location of a person close to the accident site, the breathing rate of this person and the time duration of intake via inhalation in such conditions. It is quite understandable that in the early 70s of last century a rather simple line of argumentation was used which involved intuitively plausible reasoning. This was due to the lack of data, e.g. on release fractions, and of detailed consequence assessment methods.

At this time a further category of low specific activity material with 20-fold higher specific activity limit was incorporated into the Transport Regulations which was later named LSA-III material. In para. 409 of the current TS-R-1 it is specified as

(c) LSA-III

Solids (e.g. consolidated wastes, activated materials), excluding powders, meeting the requirements of para. 601, in which:

(i) The radioactive material is distributed throughout a solid or a collection of solid objects, or is essentially uniformly distributed in a solid compact binding agent (such as concrete, bitumen, ceramic, etc.);

(ii) The radioactive material is relatively insoluble, or it is intrinsically contained in a relatively insoluble matrix, so that, even under loss of packaging, the loss of radioactive material per package by leaching when placed in water for seven days would not exceed 0.1 A_2; and

(iii) The estimated average specific activity of the solid, excluding any shielding material, does not exceed 2×10^{-3} A_2/g.

Accordingly, LSA-III material has to be solid, may not be in an easily dispersible form like powdery material and must be relatively insoluble. The latter attribute has to be demonstrated by a specified leaching test. By comparison with the material requirement for solid LSA-II it becomes evident that regarding release behavior in severe accidents with mechanical impact both the exclusion of powders and the leaching test are additional requirements to justify the higher specific activity limit.

For clarification it should be added that additional requirements are included in TS-R-1 [1] regarding accident conditions of transport for such materials by specifying conveyance activity limits for non-combustible LSA-II and LSA-III solids transported by inland waterway craft and for all conveyances when transporting LSA-II and LSA-III as combustible solids or liquids and gases as well as specifying the maximum external radiation level from the unshielded LSA material.

Arguments for the leaching test and the associated radiological criterion

The reasons for the leaching test and the associated radiological criterion are explained in the Advisory Material [2]. The wording used in para. 601.2 is essentially unchanged since the 70s of last century when the leaching requirement was introduced:

Taking as example the transport of LSA-III material conditioned in a block of cement which is packaged in a Type IP-2 or IP-3 packaging, the following sequence of events is postulated:

1. During normal conditions of transport a heavy rain results in penetration of water into the package interior.
2. The block of cement is thereby surrounded by water which leaches activity for a period of 7 days. (The test conditions require the volume of water to amount at least to 10 % of the volume of LSA-III material.)
3. During further transport operations a handling accident occurs which breaches the packaging and leads to loss of leaching water.
4. In order to establish a link to assumptions of the Q-system it is assumed that only 1 % of the leaching water is released from the damaged packaging.
5. As applied in the Q-system, e.g. for airborne release from a Type A package in an accident, it is assumed that 10^{-3} of the water escaping from the breached package is taken in by a person close to the location of the accident.
6. In order to limit with these assumptions the intake of a nearby person to 10^{-6} A_2 a limit for the absolute activity which may be in the leaching water of 10^{-1} A_2 is thereby derived and is applied as radiological criterion for the leaching test.

When evaluating the arguments to introduce the leaching test and to derive a leaching criterion of 0.1 A_2 in the (rain) water that is postulated to penetrate the Type IP-2 or Type IP-3 packaging and to leach radioactivity from the contents one can note that the associated assumptions are rather questionable:

- The sequence of postulated events – first penetrating rain, then exposure of the contents for a longer time period to leaching attack and then an accident which breaches the package and leads to loss of leaching water – is very improbable. To our knowledge no such type of event sequence has been reported worldwide during the last 40 years.
- It is not really convincing to postulate that only a very small fraction of 10^{-3} or 10^{-2} of the penetrated rain water would be released when such a package were involved in a transport or handling accident.
- If one would want to estimate potential radiological consequences following the loss of leaching water from such a package one would normally analyze by which pathways and to what extent an individual in the vicinity of the accident site could be exposed to radiation either externally or internally from activity intake. Instead, at the time of introducing the leaching test a rather artificial and weakly founded link to the Q-system was constructed by limiting the absolute activity in the leaching water to 0.1 A_2. In this way, an activity of 10^{-3} A_2 which is dissolved in water is released from the package when assuming a 1 % escape from the package following accidental impact. In connection with the further assumption that a person nearby to the accident site would incorporate a fraction of 10^{-3} of the activity released as applied in the Q-system for airborne release from a Type A package one arrives at an intake of 10^{-6} A_2.
- It can easily be shown that in reality an intake by inhaling airborne activity originating from dissolved activity in the released water would be many orders of magnitude lower than the assumed fraction of 10^{-3}. Accordingly, both the assumption of only 1 % loss of the postulated leaching rain water from a package involved in a transport or handling accident and the intake assumption of 10^{-3} of the dissolved activity released are not well founded and therefore not really adequate to specify a radiological leaching test criterion.
- A conceivable alternative – if one decides to postulate rain entering into the interior of a type IP-2 or Type IP-3 package during normal transport and a following transport accident breaching the packaging a few days later – could have been to assume a much higher release fraction of the leaching rain water and to limit the specific activity in the leaching water to e.g. 10^{-4} A_2/g. When LSA was introduced into the transport regulations this limit was judged as "inherently safe" for liquid LSA-II but to allow for conceivable effects of evaporation and associated increase of activity concentration during transport operations the limit was lowered to 10^{-5} A_2/g.

POTENTIAL ACCIDENT SCENARIOS INVOLVING LSA-II AND LSA-III PACKAGES

In order to judge whether the 20-fold higher specific activity limit of LSA-III compared to LSA-II material is supported regarding potential radiological consequences a spectrum of severe transport and handling accidents has been analyzed in detail. The majority of conceivable accidents during land transport involve mechanical impact which can result in a local breaching of the packaging and an airborne release of radioactive material. For such consequence analyses reliable data on airborne release fractions in the respirable particle size range < 10 µm as function of impact severity and material properties of the LSA-II or LSA-III package contents are needed to assess potential exposure of persons in the vicinity of an accident site via inhalation.

Data from extensive experimental programs to investigate the release behavior of powder type materials such as ashes as well as various representative brittle materials have been reported [3], [4]

which can be applied to estimate airborne release fractions as function of the severity, e.g. equivalent drop height, and the mass of representative LSA-II or LSA-III materials in a Type IP-2 or IP-3 packaging.
The spectrum of accident scenarios which have been analyzed (Table 1) has been chosen to represent rather severe conditions of mechanical impact to LSA-II and LSA-III packages and unfavorable exposure situations for persons close to the accident location. Since very dispersible materials like powders, e.g. ashes from waste incineration, are allowed as LSA-II material but excluded as LSA-III material this unfavorable material was assumed for LSA-II packages. As representative material for LSA-III a cement/concrete matrix material is assumed but other possible radioactive waste forms such as a collection of solid objects, e.g. pellets resulting from high pressure compactions of radioactive waste, are also considered. In all cases it is assumed that the specific activity of the LSA-II or LSA-III material is at the respective limit of 10^{-4} A_2/g and 2×10^{-3} A_2/g.

Table 1. Resulting activity intake from analyzed accidents

Type of accident	**equivalent drop height (m)**	**Volume of LSA material (m³)**	**Type of LSA material**	**airborne release fraction < 10 µm**	**intake as fraction of 10^{-6} A_2**
Handling accident small hall 300 m³ volume, 4/h air exchange, homogeneous mixing	3	0.2	LSA-II powder	2.1×10^{-5}	11.8 %
			LSA-III cement	6.7×10^{-8}	1.5 %
		1	LSA-II powder	7.2×10^{-6}	20.2 %
			LSA-III cement	3.4×10^{-8}	3.8 %
Handling accident large hall 3000 m³ volume, 4/h air exchange, homogeneous mixing	6	0.2	LSA-II powder	4.2×10^{-5}	2.4 %
			LSA-III cement	1.3×10^{-7}	0.3 %
		1	LSA-II powder	1.4×10^{-5}	3.9 %
			LSA-III cement	6.7×10^{-8}	0.8 %
		10	LSA-II powder	3.1×10^{-6}	8.7 %
			LSA-III cement	2.5×10^{-8}	2.8 %
Transport accident road or rail	9	0.2	LSA-II powder	6.3×10^{-5}	0.4 %
			LSA-III cement	2.0×10^{-7}	0.1 %
		1	LSA-II powder	2.2×10^{-5}	0.7 %
			LSA-III cement	1.0×10^{-7}	0.1 %
		10	LSA-II powder	4.6×10^{-6}	1.5 %
			LSA-III cement	3.8×10^{-8}	0.5 %

The main information regarding the analyzed accident scenarios and associated potential radiation exposure of a nearby reference person is summarized in Table 1.

<u>Accident Scenarios</u>

- The drop of a package when lifted and moved by a crane within a closed hall is assumed as a handling accident scenario. This kind of scenario is postulated in order to generate a link to a scenario applied in the original Q-system for Type A packages in which a handling accident is assumed to happen within a relatively small storeroom or cargo handling bay of 300 m³ free volume, e.g. crush of a Type A package overrun by a fork-lift truck. Due to the assumed small dimensions of such a hall, for example 10 m long, 6 m wide and 5 m high, only smaller packages like a 200 l drum or medium sized packages with 1 m³ inner volume are assumed to be dropped from a height of 3 m.

- Resulting from international developments in the treatment, conditioning and packaging of radioactive wastes nowadays a more frequent use of larger packages such as containers with sheet steel or concrete walls is observed. Therefore, also a handling accident in a larger storeroom with 3000 m³ free volume is analyzed with a drop height of 6 m.
- The third scenario is a severe road or rail transport accident in which a package is subjected to impact conditions equivalent to the 9 m drop test for Type B packages. In this case a 200 l drum, a medium sized package with 1 m³ inner volume and a large package with 10 m³ inner volume filled with LSA-II or LSA-III material are considered.

Package Definition

- As LSA-II material a highly dispersible powdery material such as ashes from the incineration of radioactive wastes is assumed which is explicitly excluded as LSA-III. Such highly dispersible material was used as LSA-II surrogate material in the mentioned experimental program to derive airborne release fractions [3], [4]. A package entirely filled with such a type of material is a very conservative assumption and it is hardly conceivable that a large package with 10 m³ inner volume is entirely filled with such a material without additional compaction or fixation.
- As representative LSA-III material a cement/concrete matrix material used as compact binding agent for radioactive waste is assumed and also served as surrogate material in the experimental program. From systematic small scale impact experiments with further types of brittle material it can be concluded that the derived release fractions would also be on the safe side regarding other LSA-III candidate materials [4], [5].

Assumptions

- In the frame of impact experiments to determine airborne release fractions a series of drop experiments onto an unyielding target was performed by systematically varying the volume of the LSA-type material up to 200 l volume. By comparing drops with the bare material and with cladding around the retention effect of the sheet steel packaging could be determined. As cautious approximation for drop heights up to 9 m it is assumed that the effect of the cladding is to reduce the airborne release by at least a factor of 10 compared to the bare, unprotected material. In Table 1 this reduction factor is included in the specified airborne release fraction with particle sizes < 10 µm.
- To determine the airborne aerosol concentration resulting from a drop of a package inside the small or large hall, as in the original Q-system an air exchange rate of 4 per hour is assumed and a resulting homogeneous dust concentration within the free hall atmosphere. As regards the potential exposure of a person that remains inside of the hall following the severe drop scenario it is assumed that the duration of exposure via inhalation is limited to 5 minutes. This is judged to be quite a conservative assumption when considering the prevailing circumstances and the fact that such a severe drop event would be immediately noticed by the personnel in the hall. The influence an initially inhomogeneous distribution of activity in the hall atmosphere and of longer exposure times has also been estimated.
- For a very severe impact accident of road or rail transport involving packages ranging from 200 l up to 10 m³ of inner volume potential activity intake has been determined with the following assumptions: A package containing LSA-II or LSA-III material at the respective

specific activity limit, impact severity equivalent to a 9 m drop onto an unyielding target, airborne release fractions as given in Table 1, a conservatively chosen time-integrated dispersion factor of 10^{-2} s/m³ at a downwind distance of about 50 to 100 m from the accident location, an inhalation rate of 3.3×10^{-4} m³/s for an adult person residing there. Due to turbulence induced by the assumed high speed impact of the affected package and associated kinematics of the release event time-integrated air concentrations of released radioactive dust would not be much higher for plausible closer exposure distances.

Supplementary accident scenarios with activity leaching

Two further scenarios have been investigated in order to quantify the potential contribution of the current leaching test to transport safety of LSA-III material. One accident scenario is similar to the scenario of the Advisory Material [2] as discussed above but assuming a high specific activity of 10^{-4} A_2/g in the leaching rain water and its complete release following drop in a storeroom. The other scenario is a ship collision on an inland waterway, with subsequent immersion of a damaged package in the river for 7 days. For the inland waterway immersion accident a volume flux of the navigable river of 100 m³/s is assumed and a high activity release to the river in one week of 10 A_2 (10 % of the conveyance limit of 100 A_2). For exposure calculation at downstream locations a drinking water consumption of 2 l/day is assumed.

RESULTS OF THE CONSEQUENCE ASSESSMENTS

Table 1 shows the calculated activity release fractions from different packages involved in the accident scenarios and the resulting potential activity intake expressed as multiple of 10^{-6} A_2. These fractions of an activity intake being equivalent to an effective dose of an adult person of 50 mSv are also depicted in figure 1.

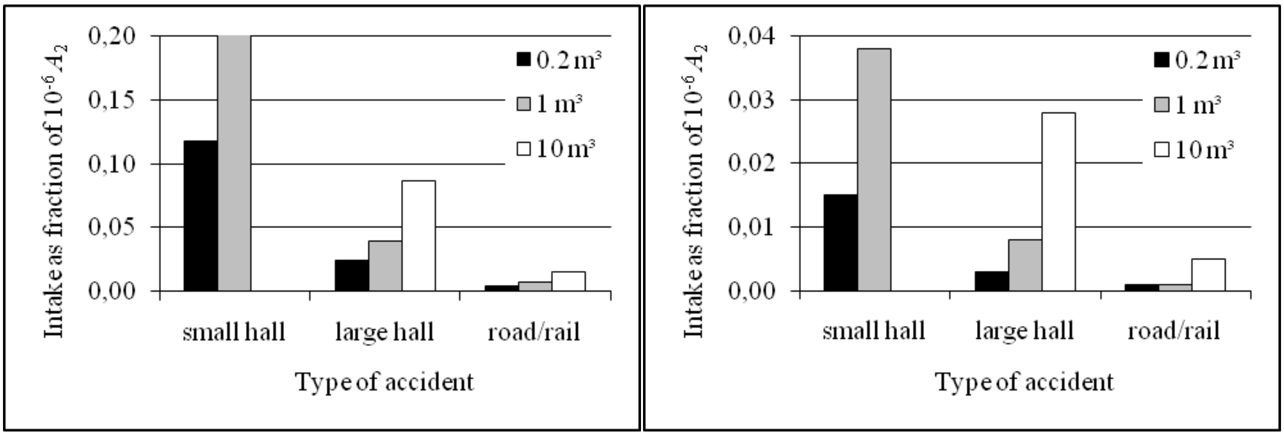

Figure 1. Resulting activity intake from analyzed accidents; left: LSA-II, right: LSA-III

A central question is whether the 20-fold higher specific activity limit for LSA-III material in comparison with LSA-II has a sound basis regarding potential accident consequences. This can be affirmed as in all analyzed severe accident scenarios airborne release fractions for LSA-III packages are lower by more than a factor of 50. But of overriding importance is whether one can conclude that even in the case of severe accident impact and unfavorable exposure conditions of individuals close to an accident site the 50 mSv exposure criterion for the effective dose is observed. This is indeed so because the assessed activity intakes remain below 10^{-6} A_2. It is quite reassuring to be able to conclude on the basis of these results that for LSA-II material even as highly dispersible powder

the specific activity limit of 10^{-4} A_2/g has safety reserves. For other solid LSA-II material forms this safety margin would be even more pronounced.
In the course of these analyses the influence of several parameters such as time development of the airborne activity distribution in the hall atmosphere, assumed unprotected residence times of personnel following the severe handling accident, quality of the functional relationship between release fractions and mass or volume of the LSA material, possible effects of homogeneity variations of the specific activity in the LSA-material have been investigated. These further considerations have not changed the conclusion that regarding LSA-III material properties activity intake remains below 10^{-6} A_2 and consequently the effective dose below 50 mSv.
The assessment of the very improbable sequence of 7 day activity leaching after massive rain penetration followed by a liquid release during a handling accident shows no exceedance of 10^{-6} A_2 even when the leaching of activity is far above the current limit of the leaching test. For the river immersion scenario the potential activity intake assuming consumption as drinking water 500 m downstream is at least two orders of magnitude below 10^{-6} A_2 and therefore also well below 1 mSv.

CONCLUSIONS

As regards packages with LSA-III material one can conclude on the ground of the performed analyses that for severe handling and land based transport accidents with mechanical impact the 50 mSv exposure criterion of the IAEA transport Regulations is clearly observed. It has to be emphasized that this conclusions is not at all connected with the currently required low solubility of the material and the associated leaching test. The contribution to transport safety of the low solubility of LSA-III material is negligible. The other material requirements for LSA-III – it has to be solid, the radioactive material has to be distributed throughout, powders are excluded – determine the relevant release behavior in accidents with mechanical impact. Therefore, the leaching test for LSA-III material could be omitted without a relevant influence on transport safety.

ACKNOWLEDGMENTS

This work was performed by GRS in the frame of a project granted by the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU) and the Federal Office for Radiation Protection (BfS).

REFERENCES

[1] International Atomic Energy Agency (IAEA): Regulations for the Safe Transport of Radioactive Material. Safety Standards, Safety Requirements No. TS-R-1, Vienna, 2009

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

[3] Nolte, O. et al.: Testing of Packages with LSA Materials in Very Severe Mechanical Impact Conditions with Measurement of Airborne Release. PATRAM 2007, Miami, FL., 2007

[4] F. Lange; R. Martens; O. Nolte; H. Lödding; W. Koch; E. Hörmann: Testing of packages with LSA materials in very severe mechanical impact conditions with measurement of airborne release. Packaging, Transport, Storage & Security of Radioactive Materials, Vol. 18, No. 2, pp 59-71, 2007.

[5] Sentuc, F.-N. et al.: Transportstudie Konrad 2009: Sicherheitsanalyse zur Beförderung radioaktiver Abfälle zum Endlager Konrad. Gesellschaft für Anlagen- und Reaktorsicherheit (GRS) mbH, GRS-256, April 2010