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# PROPOSAL TO SIMPLIFY LSA-III MATERIAL REQUIREMENTS OF IAEA TRANSPORT REGULATIONS

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## ABSTRACT

The LSA-II and LSA-III material requirements were introduced into the IAEA Transport regulations in the early 70s and revised in the 80s of last century. Meanwhile much progress has been achieved internationally regarding knowledge of material characteristics of LSA-II and LSA-III and their release behaviour under accident conditions of transport.

In particular in Germany comprehensive experimental and theoretical research work was performed in recent years to investigate the release behaviour of various LSA-II and LSA-III materials under different mechanical impact conditions and to use the results to assess the potential radiation exposure resulting from such materials under severe handling and transport accident conditions. Based on this research work a review of LSA-II and LSA-III requirements was performed which was mainly focusing on the need and the justification of the LSA-III leaching test which have often be questioned in the past.

For packages with LSA-III material it can be concluded that the achieved high level of transport safety is not connected with the currently required limited solubility of the material demonstrated by the leaching test but is resulting from the other required material properties. Therefore the performance of the leaching test for LSA-III material does not contribute to the requested safety level and can be omitted without decreasing the level of transport safety. This would help to simplify the Transport Regulations and to overcome difficulties regarding different interpretations and implementations of the leaching test in practice especially for radioactive waste.

The paper summarizes the research results, describes the justification and the proposed changes to the regulatory text to delete the leaching test and gives an outline on how this proposal will be introduced into the next review and revision cycle of the IAEA Regulations for the Safe Transport of Radioactive Material No. SSR-6 [1].

## INTRODUCTION

The transport of low specific activity (LSA) materials of the categories LSA-II and LSA-III in industrial packages (IP) of the categories IP-2 or IP-3 is an important segment of national and international shipments. A major part of these transports are waste materials from industrial, research and medical applications including nuclear power plants and associated facilities of the nuclear fuel cycle. Important destinations are waste treatment plants, interim storage facilities and final waste repositories.

Since the 1985 Edition of the IAEA Transport Regulations the requirements regarding material properties of solid LSA-II and LSA-III have remained unchanged apart from the exclusion of powdery materials for LSA-III in the 1996 Edition of the Transport Regulations.

For LSA-III material a leaching test is required of which the adequacy and justification has often been questioned. There were strong doubts whether a meaningful material property is assessed by this test which requires a substantial effort and poses problems to demonstrate compliance in practice. In the revision process for the 1996 Edition this was already a serious topic where the deletion of this test was proposed. But at that time the opinion prevailed that further work was needed in particular regarding experimental data on the release behaviour of LSA-II and LSA-III materials in accidents with mechanical impact in order to quantify the level of transport safety and to evaluate the validity of the leaching test.

In the time to follow substantial improvements by research work have been achieved internationally in the methods and database to assess transport safety. This includes in particular comprehensive data on the release behaviour of representative LSA-II and LSA-III materials in relation to the severity of a mechanical impact and the influence of the IP packaging on the resulting release of airborne particulate.

Based on these research results a critical review of the contribution of the leaching test to transport safety was performed. This work also included the question whether additional material requirements are needed when omitting the current leaching test for LSA-III material. In the following the main results of these investigations will be described starting with the safety concept for LSA-II/III material and concluding with proposed changes to the regulatory text of the IAEA Regulations for the Safe Transport of Radioactive Material No. SSR-6 [1].

## SAFETY CONCEPT FOR THE TRANSPORT OF LSA-II AND LSA-III MATERIAL AND ITS REVIEW

The safety concept for LSA material is mainly based on its limited specific activity. This material category has been introduced into the Transport Regulations because there are materials, the specific activity of which are so low that it is very unlikely that under any circumstances during transport, a sufficient mass of such material could be taken into the body to give rise to a significant radiation exposure [2]. It is important to emphasize at this point that the material must be in such a form that an average specific activity can be meaningfully assigned to it as stated clearly in para. 226 of SSR-6 [1].

The specific activity limit for LSA-II material had been derived from the simple model that it is most unlikely that a person would remain long enough in a dusty atmosphere to inhale more than 10 mg of material. According to the Q-system (see [2], Appendix I) the activity intake assumed to occur for a person involved in a transport accident must not exceed $10^{-6}$ $A_2$ which is equivalent to an effective dose of an adult person of 50 mSv. This limits the specific activity of LSA-II material to $10^{-4}$ $A_2$/g to meet this dose criterion of 50 mSv resulting from a material intake of 10 mg by inhalation.

Potential exposures of persons in the vicinity of an accident involving LSA-II or LSA-III material by other pathways are regulated by further requirements of the IAEA Transport Regulations which are

- A limitation of the external radiation level from the unshielded LSA material to 10 mSv/h at a distance of 3 m in case that the outer shielding of the material should be damaged or completely lost in an accident.
- A conveyance activity limit for combustible LSA-II and LSA-III material. By limiting the absolute activity within a conveyance when IP-2 or IP-3 packages containing combustible LSA-II and LSA-III packages are loaded the potential exposure of persons by inhalation of airborne activity being released in case of an accident with fire shall be limited to 50 mSv effective dose.

Due to this safety concept the inhalation of released material under accident conditions with mechanical impact is the main exposure pathway for LSA material to be considered for a review.

The main material property of LSA-II/III is a limitation of the specific activity expressed in the units $A_2$/g where $A_2$ is the radionuclide specific activity limit of a Type A package when the contents is in non-special form. For solid LSA-II materials the specific activity limit is $10^{-4}$ $A_2$/g and for LSA-III materials $2{\times}10^{-3}$ $A_2$/g.

These limits of the respective specific activity are associated with homogeneity requirements within the LSA material. For LSA-II it is required that "the activity is distributed throughout and the estimated average specific activity does not exceed $10^{-4}$ $A_2$/g for solids" [1]. For LSA-III it is required that "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 and ceramic)" [1]. This means that the homogeneity requirement is more constraining for LSA-III when the radioactive material is incorporated within a compact binding agent. In the associated Advisory Material TS-G-1.1 [2] methods of compliance with homogeneity requirements are specified in more detail.

For clarity the material requirements for solid LSA-II and LSA-III as described in para. 409 (b) and (c) in SSR-6 [1] are reproduced here:

*(b) LSA-II:*

*Other material in which the activity is distributed throughout and the estimated average specific activity does not exceed $10^{-4}$ $A_2$/g for solids.*

*(c) LSA-III:*

*Solids (e.g. consolidated wastes, activated materials), excluding powders, that meet 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 and ceramic).*

*(ii) The radioactive material is relatively insoluble, or 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 7 days would not exceed 0.1 $A_2$.*

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

As described above for LSA-II material it is evident that the major concern is the airborne particulate release of the material from an accident with mechanical impact of an IP package and the potential intake via inhalation by persons in the vicinity of the accident location.

The justification of the 20-fold higher specific activity limit of $2{\times}10^{-3}$ $A_2$/g for LSA-III material for which dispersible material such as powders are excluded was evidently more difficult lacking quantitative data on airborne release from such kind of solid materials at the time of its introduction into the IAEA transport Regulations. It was postulated that a leaching criterion for LSA-III material would support and justify among others the 20 times higher specific activity limit compared to LSA-II material. But no really plausible explanation was given in the Advisory Material how a limited leachability could be related to airborne particulate release following

mechanical impact of an IP package containing LSA-III material.
The example given in the Advisory Material of a block of cement inside an LSA-III package

- into which rain water is postulated to penetrate during normal transport operations
- which remains inside for 7 days, leading to a leaching attack
- and then is partially released in a following transport accident

is not a convincing argument especially within the Q-system approach to require a leaching test [3]. And it does not solve the problem to demonstrate that an airborne release from the LSA-III material would be sufficiently low that the potential exposure of persons in the vicinity of the accident location via inhalation would remain below the reference value of 50 mSv effective dose. Also the pass criterion of the leaching test which limits the activity content in the leaching water to 0.1 $A_2$ has no reasonable basis. It lacks a comprehensible relationship between activity content in water and potential exposure of individuals in the vicinity of the postulated accident with release of leaching water.
To investigate all these questions in particular the safety relevance of the leaching test the LSA-II/LSA-III concept for solids has been reviewed by using modern analyses tools and comprehensive experimental data on the release behaviour of representative LSA-II/III materials under mechanical accident conditions [4], [5]. For this purpose transport and handling accidents leading to severe mechanical impact of representative LSA-II and LSA-III packages have been analysed and potential radiation exposure of persons assumed to be in the vicinity of the accident location determined. Advanced assessment tools have been applied regarding the dispersion of released respirable particulates in the surrounding atmosphere after short term release of radioactive dust from a damaged package. Of fundamental importance are experimentally supported data on airborne release from LSA-II and LSA-III packages when subjected to severe mechanical impact. More information about important parts of this work can be found in [3].

## SUMMARY OF INVESTIGATIONS AND RESULTS

As covering transport accident scenario a road or rail accident is assumed which is so severe that the impact of an LSA-II or LSA-III package is equivalent to the 9 m drop onto an unyielding target as applied for testing of Type B packages. Also handling accidents happening inside a cargo handling and storage hall are considered because exposure conditions could be more adverse compared to an outdoor event. Such handling accident scenarios provide a link to the scenario in the original Q-system for Type A package in which a handling accident is assumed within a storeroom or cargo handling bay. To ensure covering conditions two types of halls were considered: a small hall with 300 $m^3$ free volume and a large hall with 3000 $m^3$ volume. As drop height onto the hard ground when lifting and moving a package 3 m is assumed in the small hall and 6 m in the large hall. In both cases an air exchange rate of 4 $h^{-1}$ is adopted.
Solid LSA-II material may be in indispersible but also in dispersible form such as ashes from incineration of combustible radioactive wastes. This latter highly dispersible powdery material form was assumed as most unfavourable LSA-II material because, as experimentally verified, the fractional airborne release from such material is much higher when impacting onto a hard surface compared to the other mentioned solid material forms.
For LSA-III powdery materials are explicitly excluded. Otherwise the same types of materials as for LSA-II could be LSA-III material. As representative matrix material for immobilized radioactive matter cement/concrete is chosen because of its brittle nature. With respect to airborne release upon impact this material is a conservative representative for other solid material types [6], [7].
As packaging for LSA-II and LSA-III materials industrial package Type 2 (Type IP-2) or Type 3 (Type IP-3) is required. Frequently such packagings are made of sheet steel but also more robust shell materials are in use. As representative industrial packages and sizes sheet steel drums with

inner volume of 0.2 m³ and sheet steel containers of 1 m³ and 10 m³ inner volumes were chosen. For accidents in the small hall only packages of 0.2 and 1 m³ volume were considered because the handling of a large container with 10 m³ inner volume seems to be unrealistic. In each case it was assumed that the package contains LSA-II or LSA-III material at the upper limit of average specific activity, i.e. $10^{-4}$ $A_2$/g or $2\times10^{-3}$ $A_2$/g, respectively. When applying the suggested procedure of the Advisory Material (paras 216.12 to 226.18) [2] in cases where the average specific activity reaches the allowed limit a volume portion of the entire LSA material may exceed this limit by a certain factor. Also this possibility has been considered in the consequence analyses by assuming that just this volume part with the maximum specific activity is impacted in the accident.

Impact tests with LSA materials to determine airborne release fractions as function of particle size have been performed by several international institutions, e.g. in the frame of research projects on transport safety of RAM shipments funded by the European Commission and in Germany funded by the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU) and the Federal Office for Radiation Protection (BfS). Results of this systematic research work have been published [3], [6], [8]. The experimental approach combined well-controlled and very reproducible impact experiments with small scale specimens and drop tests of larger scale specimens from different heights up to 27 m. In both cases the associated airborne release of particulate matter was determined by measuring the amount and aerodynamic particle size characteristics of released dust. The small scale tests revealed fundamental results on airborne release and particle size distribution In the large scale tests, volumes of specimens were varied systematically up to 200 L (0.2 m³) and the LSA material was contained either within a packaging or without protective packaging in order to determine the influence of the packaging on the airborne release and to be able to extrapolate to other configurations of package sizes and impact severities. For industrial packages and drop heights up to 9 m it can be assumed that the effect of the packaging cladding is to reduce the airborne release by at least a factor of 10 compared to the bare, unprotected material. The LSA surrogate materials were either cement/concrete used to immobilize radioactive wastes as representative brittle material, or appropriately chosen powders representing dispersible materials. On this basis airborne release fractions of respirable (< 10 µm aerodynamic diameter) particulate have been determined for the analysed accidents scenarios defined by

- volume and density of the LSA-II or LSA-III material inside the packaging (assumed densitiy of powders 1000 kg/m³ and of cement/concrete 2000 kg/m³),
- assumed drop height of 3 m (small hall), 6 m (large hall) and 9 m road or rail accident onto a hard/unyielding surface.

A road or rail transport accident in which an LSA-II or LSA-III package suffers an impact equivalent to the 9 m drop leads to an almost instant release of airborne respirable dust. A distance of about 50 to 100 m was adopted for a person residing in down-wind direction from the location where the severe accident happened. A conservatively determined time-integrated dispersion factor of $10^{-2}$ s/m³ was applied. Due to turbulence induced by the assumed high speed impact of the affected package and associated kinematics of the release event air concentrations of released radioactive dust would not be much higher for plausible closer exposure distances.

A severe handling accident inside a hall with a drop height of 3 m in a small and of 6 m in a large hall would not happen unnoticed by personnel present. Airborne released respirable particulate from the damaged package would gradually spread over the free air volume by the action of the ventilation system with assumed 4 air changes per hour. For the assessment of potential radiation exposure it was assumed that personnel in the hall would remain at most 5 minutes unprotected (e.g. use of a simple particle filtering half mask) in the generated dusty atmosphere.

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

**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 | $2.1\times10^{-5}$ | 11.8 % |
| | | | LSA-III cement | $6.7\times10^{-8}$ | 1.5 % |
| | | 1 | LSA-II powder | $7.2\times10^{-6}$ | 20.2 % |
| | | | LSA-III cement | $3.4\times10^{-8}$ | 3.8 % |
| **Handling accident large hall** 3000 m³ volume, 4/h air exchange, homogeneous mixing | 6 | 0.2 | LSA-II powder | $4.2\times10^{-5}$ | 2.4 % |
| | | | LSA-III cement | $1.3\times10^{-7}$ | 0.3 % |
| | | 1 | LSA-II powder | $1.4\times10^{-5}$ | 3.9 % |
| | | | LSA-III cement | $6.7\times10^{-8}$ | 0.8 % |
| | | 10 | LSA-II powder | $3.1\times10^{-6}$ | 8.7 % |
| | | | LSA-III cement | $2.5\times10^{-8}$ | 2.8 % |
| **Transport accident** road or rail | 9 | 0.2 | LSA-II powder | $6.3\times10^{-5}$ | 0.4 % |
| | | | LSA-III cement | $2.0\times10^{-7}$ | 0.1 % |
| | | 1 | LSA-II powder | $2.2\times10^{-5}$ | 0.7 % |
| | | | LSA-III cement | $1.0\times10^{-7}$ | 0.1 % |
| | | 10 | LSA-II powder | $4.6\times10^{-6}$ | 1.5 % |
| | | | LSA-III cement | $3.8\times10^{-8}$ | 0.5 % |

The resulting exposure of an individual in the vicinity of the accident event by inhalation is expressed as fraction of $10^{-6}$ $A_2$, being equivalent to an effective dose of 50 mSv. In all analysed accident scenarios involving LSA-II or LSA-III packages at the respective limit of specific activity calculated effective doses would be well below the reference limit of $10^{-6}$ $A_2$ [3], [9].
For an assumed severe transport accident of an LSA-III package potential exposure of a nearby person from inhalation of airborne released radioactive material would remain in the 1 % or lower range of $10^{-6}$ $A_2$. Higher potential doses in the range of a few percent and up about 20 % of this reference level would result in case of the assumed severe handling accidents inside a hall of an LSA-II package being completely filled with a highly dispersible powdery material inside a hall. This would leave room for further aggravating assumptions in the consequence analyses, e.g. that a package suffers an impact of the very volume element that exceeds the average specific activity limit by a factor in accordance with the homogeneity requirements as specified in the Advisory Material TS-G-1.1 or by assuming an initially inhomogeneous mixing of activity concentration in the air of the small or large hall. It is worth reminding in this context that the 50 mSv effective dose criterion is a reference value to judge transport safety and not intended as a hard limit in combination with severe and very conservative assumptions.
The following main conclusions can be drawn from these results:

- It is very reassuring that for LSA-III materials the 20-fold higher specific activity limit compared to LSA-II materials is well founded and in accordance with the safety concept of the IAEA Transport Regulations. The release behaviour of LSA-III packages when suffering the impact forces from a severe transport accident is sufficiently limited on the basis of the general material requirements for LSA-III. These results are independent from material requirements associated with the leaching test for LSA-III materials. The solubility of radioactive contents within material of limited specific activity has no or at most little influence on the generation and airborne release of particulates induced by a mechanical impact.

- It is also very reassuring on the ground of these analyses that the limiting specific activity of $10^{-4}$ $A_2$/g for LSA-II materials has a sound basis and that the 10 mg intake model in a dusty atmosphere following an accident is supported in this way.

- The currently required leaching test for LSA-III is accordingly not needed and not justified to demonstrate the requested safety level analog to the Q-system.

In addition to these investigations consistent with the Q-system concept of the IAEA Transport Regulations supplementary accident scenarios with activity leaching have been investigated in order to study the potential contribution of the current leaching test to transport safety of LSA-III material.

One scenario considers the postulated sequence of events as given in TS-G-1.1 [2] as explanation for the required leaching test and its pass criterion of 0.1 $A_2$ activity in the leaching water after seven days with the following assumed sequence of events:

Heavy rain fall during normal transport operation ➔ water penetrating into the packaging ➔ leaching attack during 7 days ➔ then accident which leads to partial loss of penetrated water ➔ resulting radiation exposure of a person nearby.

In contrast to the modeling approach of the Advisory Material [2] much more severe conditions are postulated by assuming a 100-fold higher activity content in the leaching water (10 $A_2$ instead of 0.1 $A_2$), complete loss instead of only 1 % of penetrated water following the handling accident (assumed drop from 3 m in small storage hall and from 6 m in large storage hall). The potential exposure of personnel in the hall is assessed by applying a well founded modeling approach and data regarding resulting airborne activity either after loss of water and evaporation from a resulting pool on the floor or by a spray release from the impacting package.

As second scenario an accident of an inland waterway craft on a small navigable river is considered which results in the submersion of an LSA-III package. Before recovery activity is released from the damaged package by leaching during 7 days. A 100-fold higher leaching rate of 10 $A_2$ in 7 days is assumed compared to the pass criterion of the leaching test (0.1 $A_2$/week). Neglecting retention and dilution effects from the usual bank filtration of drinking water a direct consumption of river water by a person downstream from the accident location is assumed and the resulting effective dose determined.

In both of these analysed accident scenarios a 100-fold higher leach rate from LSA-III compared to the 0.1 $A_2$/week as required by the leaching test was postulated. But even with this very conservative value and in combination with further covering assumptions in both cases radiation exposure of individuals most affected by the postulated accident event would remain substantially below the 50 mSv reference dose in case of an handling accident in the storage hall and in case of the scenario of a damaged package drowning in a river below 1 mSv.

Also these supplementary investigations confirm that the LSA-III leaching test does not substantially contribute to transport safety.

Since the current material requirements for LSA-II and LSA-III without the leaching test provide a high level of transport safety in accordance with the safety concept of the IAEA Transport Regulations it can further be concluded that no alternative or additional material requirements are needed.

## PROPOSED CHANGES TO SIMPLIFY THE REGULATIONS

The results of the LSA-II/III review have shown that the current requirements for LSA-II and LSA-III material are robust and that for LSA-III material the application of the leaching test is not needed. The remaining material requirements for LSA-III material are strong enough to guarantee the level of safety required within the IAEA Transport Regulations. This justifies the simplification of the Regulations by deletion of the leaching test requirement for LSA-III material. The changes to be made within SSR-6 [1] are quite limited. They can be summarized as followes:

a) Delete in para. 409 (c) "that meet the requirements of para. 601" and delete para. 409 (c) (ii) so that para. 409 (c) (iii) becomes para. 409 (c) (ii)
b) Delete para. 601 and the heading above para. 601
c) In para. 701 (a) delete in the first line: "LSA-III material, or"
d) In the heading above para. 703 delete: "LSA-III MATERIAL AND"

These changes to SSR-6 have been proposed by Germany within the current IAEA review process of SSR-6. Together with this change also additional text for TS-G-1.1 has been submitted to explain and justify the proposed change in SSR-6. The whole proposal is currently subject to IAEA member states review within the ongoing IAEA review process of SSR-6 and TS-G-1.1.

## SUMMARY AND CONCLUSIONS

The paper describes comprehensive research work performed in recent years to review the safety concept for transport of solid LSA-II and LSA-III materials including the consistency and adequacy of related requirements and in particular the need and justification for the LSA-III leaching test. In this work modern accident analyses methods have been applied and comprehensive experimental data on the release behaviour of such materials under mechanical accident conditions could be used. Transport and handling accidents leading to severe mechanical impact of representative LSA-II and LSA-III packages have been analysed and potential exposure of persons in the vicinity of the accident determined. As main results it can be concluded that the current LSA-II and LSA-III requirements for solids are well founded and that the leaching test for LSA-III material is not needed. For packages with LSA-III material it could be demonstrated that the achieved high level of transport safety is not connected with the currently required limited solubility of the material but is resulting from the other required material properties. Therefore the leaching test for LSA-III material does not contribute to the requested safety level and can be omitted without decreasing the level of transport safety. This would help to simplify the Transport Regulations and to overcome difficulties regarding different interpretations and implementations of the leaching test in practice especially for radioactive waste. A specific proposal to simplify the IAEA Transport Regulations SSR-6 by deletion of the LSA-III leaching test has been submitted to IAEA within the current review process.

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