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Review of the safety concept of the LSA-II and LSA-III material requirements of the IAEA Transport Regulations SSR-6

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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. Proposals to change these requirements were also part of the revision processes of the IAEA Transport Regulations in the 90s and in the first years after 2000, but there has never been available enough information to justify and to approve any change. Meanwhile much progress has been achieved internationally regarding the knowledge of material characteristics of LSA-II and LSA-III and their release behaviour under accident conditions of transport. This progress now allows a comprehensive review of these requirements, based on which justified changes to simplify and clarify the appropriate provisions can be derived.

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 caused by such materials under severe handling and transport accident conditions. Based on this research work a comprehensive review of LSA-II and LSA-III requirements was performed. It was mainly focusing on the safety concept these requirements are based on, in particular the need and the justification of the LSA-III leaching test, which has often been questioned in the past, and on improved guidance on how to demonstrate compliance with homogeneity requirements for the activity distribution throughout the LSA-II and LSA-III material.

The review leads to the conclusion that the whole LSA safety concept based on limitations of the average specific activities for LSA-II and LSA-III and the exclusion of powder from LSA-III material can be confirmed as being a well-founded and conservative system providing a high level of safety without the need to perform the leaching test for LSA-III material. Sensitivity studies based on empiric equations found in experiments confirmed this conclusion for different package volumes, drop heights and exposure times. In particular, it was demonstrated that for the most critical scenario of an indoor

accident the amount of inhalable material remains always below 10 mg, which is a very basic assumption of the original safety concept.

The paper summarizes the main research results, the main conclusions of the review of the safety concept including the sensitivity studies and the proposed changes to the IAEA Transport Regulations SSR-6 as well as to the Advisory Material SSG-26 and describes the status of these changes within the current IAEA Revision Process of SSR-6 and SSG-26.

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 is waste material from industrial, research and medical applications including nuclear power plants and associated facilities of the nuclear fuel cycle. Since the 1985 Edition of the IAEA Transport Regulations the requirements for LSA-II and LSA-III material have remained unchanged apart from the exclusion of powdery materials for LSA-III in the 1996 Edition of the Transport Regulations. These requirements were always a subject of discussion during the revision processes of the IAEA Transport Regulations in the 90s until the first years after 2000, but there has never been available enough information to justify and to approve any change. 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 in particular to evaluate the validity of the leaching test.

Meanwhile much progress has been achieved in this field. 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 comprehensive review of the LSA-II/LSA-III safety concept and its requirements was performed which will be discussed in this paper, including proposed changes to the IAEA Transport Regulations SSR-6 [1] and the associated Advisory Material SSG-26 [2].

Current safety concept and requirements

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 activities 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 hazard [2]. It is important to emphasize that the material must be in such a form that limits of estimated average specific activity apply and that an average specific activity can be meaningfully assigned to it as stated clearly in para. 226 of SSR-6 [1] and para. 409.1 of SSR-26 [2].

The main material property of LSA-II and LSA-III material is a limitation of the average 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 material this limit is 10^{-4} A_2/g and for LSA-III material 2×10^{-3} A_2/g.

These limits of the respective specific activity are associated with homogeneity requirements within the LSA material. Classification as LSA-II requires that "the activity is distributed throughout" the material [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 [2] methods on how to demonstrate compliance with homogeneity requirements are specified in more detail.

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 a person 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 (see paras 517 and 522 of SSR-6 [1]).

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.

Scope and approach of the review

The safety concept described above provides a quantitative justification for the maximum allowable average specific activity of 10^{-4} A_2/g for LSA-II material. However, such a quantitative justification could not be given so far for LSA-III material for which a 20-fold higher average specific activity is allowed which would for a 10 mg intake lead to a 20-fold exceeding of the 50 mSv effective dose limit. Instead of this, the following additional and more restrictive requirements for LSA-III material were introduced as compensation, but without a quantitative justification:

- Restricting such material to solids, excluding powders,
- Partially higher package standard and exclusive use conditions, and
- Leaching test to demonstrate limited solubility of the material.

In fact, the need and justification for the leaching test was always questioned because it has no relevance for the inhalation risk. In addition further inconsistencies and gaps exist in the Advisory Material related to LSA-II and LSA-III as described in [3].

To investigate all these problems a comprehensive review of LSA-II and LSA-III requirements has been performed focusing on

- the safety concept and the resulting material requirements for LSA-II and LSA-III with the aim to provide quantitative justifications,
- the need and the justification of the LSA-III leaching test, and
- improved guidance on how to demonstrate compliance with homogeneity requirements for the activity distribution throughout the LSA-II and LSA-III material.

This review was based on comprehensive experimental and theoretical research work, which was performed in recent years to investigate the release behaviour of various LSA-II and LSA-III materials under different mechanical impact conditions. The obtained results have been used to analyse transport and handling accidents leading to severe mechanical impact of representative LSA-II and LSA-III packages and to determine potential radiation exposures of persons assumed to be in the vicinity of the accident location. 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 packaged and unpackaged LSA-II and LSA-III materials when subjected to severe mechanical impact. More information about the research work can be found in [4], [5], [6], [7].

Results

Results have been obtained from analyses of severe transport and handling accidents scenarios as mentioned above and in addition from sensitivity analyses.

Analyses of severe transport and handling accident scenarios

Various covering transport and handling accident scenarios with conservative assumptions have been analysed and the resulting activity intake of an individual in the vicinity of the accident has been determined. These accident scenarios include

- road and rail accidents with impacts equivalent to the 9 m Type B drop test, with different packages sizes (0.2 m^3, 1 m^3 and 10 m^3) containing LSA-II material as powder (most conservative assumption) and LSA-III material as concrete being representative also for other brittle materials with maximum specific activities,
- handling accidents in a small and a large hall with drop heights of 3 m and 6 m, with different package sizes (0.2 m^3, 1 m^3 and 10 m^3) containing LSA-II material as powder (most conservative assumption) and LSA-III material as concrete with maximum specific activities and
- supplementary a river immersion accident with LSA-III material and an indoor handling accident leading to contaminated water spillage or spray from a LSA-III package when assuming a hypothetical pre-accident ingression of water into the IP-package to study the effect of leaching.

Detailed information about these scenarios and analyses can be found in [3].

The main results regarding the analysed accident scenarios and associated potential radiation exposure of a nearby person are summarized in Figure 1.

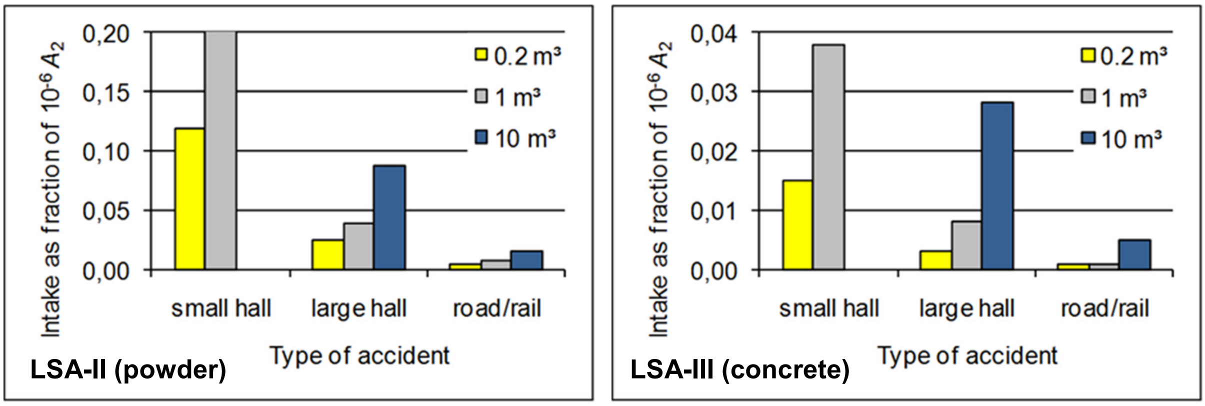

Figure 1 Resulting exposures due to inhalation intakes for various accident scenarios and package sizes for LSA-II and LSA-III material

In Figure 1 the resulting exposure of an individual in the vicinity of the accident by inhalation is expressed as fraction of 10^{-6} A_2, being equivalent to an effective dose of 50 mSv. For all scenarios the effective doses would be well below the reference limit of 10^{-6} A_2 [4], [8], [9].

The results show that due to the very much limited release of material from LSA-III packages under accident conditions of transport the resulting inhalation dose of a person close to the accident location is at least a factor of 20 below the limit of 50 mSv for the most critical scenario of an indoor accident with a midsize package. In case of outdoor road or rail accidents this dose would be still much lower (factor of about 100 below the limit of 50 mSv).

Figure 1 shows also that for all types of accidents the inhalation dose for LSA-II in powder form is higher than for LSA-III but still a factor of 5 below the 50 mSv limit. This confirms that the amount of released material significantly depends on the physical form of the material. The essential difference between LSA-II and LSA-III materials is that LSA-III is limited to solid material excluding powder. The investigations have shown that the amount of airborne released material leading to an inhalation dose under mechanical accident conditions of transport is at least by a factor of 100 lower for LSA-III solids than for LSA-II solids in powder form (see Figure 2). This much lower airborne release for LSA-III material due to its non-readily dispersible form compensates more than its allowable 20-fold increase in average specific activity compared to LSA-II solid in powder form. There is no need to take any credit from a leaching test to justify this allowable 20-fold increase in average specific activity between LSA-III and LSA-II.

Also these supplementary investigations mentioned above confirm that the LSA-III leaching test is not needed from a safety point of view [3]. Since the current material requirements for LSA-II and LSA-III without the leaching test provide the appropriate 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.

Sensitivity Analyses

As described above, many experiments have been performed to study the release behaviour of different types and sizes of LSA-II and LSA-III materials under various mechanical impact conditions. In such a way a comprehensive experimental database could be obtained based on which empiric equations have been derived to calculate the airborne release fraction from materials in dependence on material density, material volume and impact energy [5], [6], [7], [9]. They allow to perform sensitivity studies on the effect such important parameters may have on the airborne release fraction for LSA material which (together with the specific activity of the LSA material) determines finally the resulting inhalation exposure of persons in the vicinity of an accident.

LSA-III material as a solid (excluding powder) by definition can be considered to be a low dispersible material for which a material density of 2000 kg/m^3 (concrete) has been taken as a representative value for the sensitivity studies. Differently, LSA-II must be considered to be a high dispersible material because it can be a powder by definition. For LSA-II a material density of 1000 kg/m^3 (powdery material) has been applied. For all calculations a so called cladding factor of 0.1 has been introduced which takes into account that the airborne release is more than a factor of 10 lower for packaged LSA material compared to a severe impact of the bare material, as has been shown by experiments [7]. For these two representative material densities for LSA-II and LSA-III material the effect of the package volume and the drop height on the airborne release fraction has been studied. The influence of the package volume is shown in Figure 2 (left) for a drop height of 9 m. Smaller drop heights result in lower release fractions. Figure 2 (left) shows that the airborne release fraction (particles with a diameter less than 10 µm, i.e. respirable particles) is at least a factor of 100 lower for LSA-III material as compared to LSA-II material in powder form.

The effect of the drop height is shown in Figure 2 (right) for a 0.2 m^3 package volume. In this case the respirable release fractions for LSA-III are a factor of 300 lower than for LSA-II, which remains valid also for other package volumes.

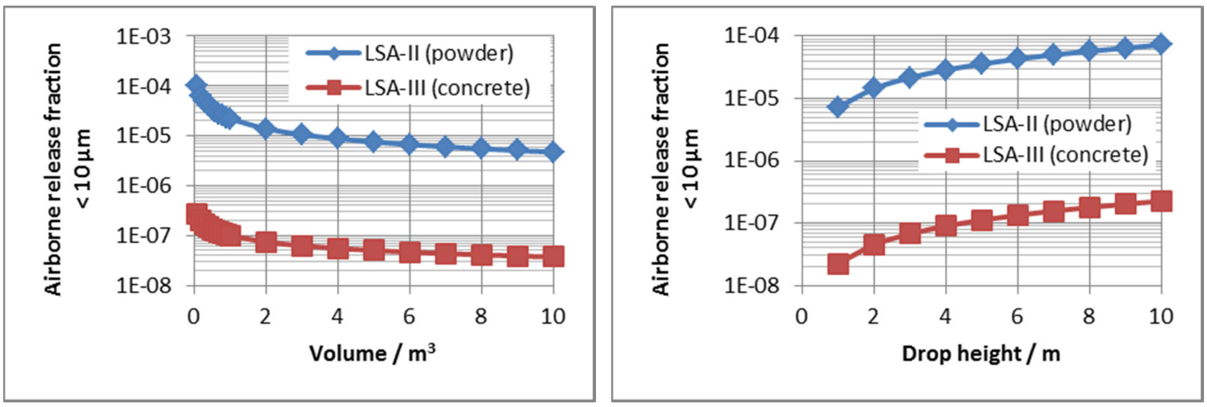

Figure 2 Influence of package volume (left) and drop height of a package (right) on airborne release fraction for LSA-II and LSA-III material

Another important parameter for the exposure by inhalation is the exposure time which is of concern for a handling accident inside a storage hall. Its effect is shown in Figure 3 for a small (300 m^3 volume) and a large (3000 m^3 volume) storage hall. In both cases an air exchange of 4 h^{-1} and a breathing rate of 3.3×10^{-4} m^3/s are assumed consistent with the Q-system (see [2], Appendix I). The results are presented for the package volume values of 1 m^3 for the small hall and 10 m^3 for the large hall, because among the values that have been studied these values lead to highest exposures (see Figure 1).

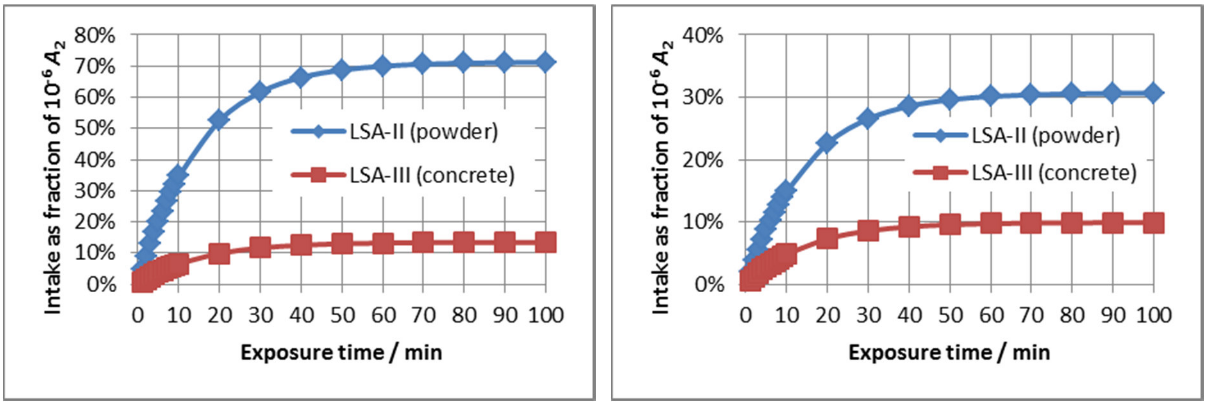

Figure 3 Influence of exposure time on intake fraction of released radionuclides for LSA-II and LSA-III material in a small (left) and large (right) storage hall

The results in Figure 3 confirm again that the resulting intakes for LSA-III are low in comparison with LSA-II. In particular they demonstrate further that for the most critical scenario of an accident with LSA-II powder material in a small hall the intake by inhalation remains below 10^{-6} A_2 also for extended exposure times. This means also that the amount of inhalable material remains always below 10 mg, which confirms by quantitative analyses that the original assumed 10 mg intake of the safety concept for LSA-II as described above is a conservative approach and justified. More details about the sensitivity analyses are given in [11], [12].

Proposed changes to SSR-6 and SSG-26

The results of the 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 by 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 are described in detail in [3]. These changes to SSR-6 have been proposed by Germany within the current IAEA revision process of SSR-6 together with additional text for SSG-26 to explain and justify the proposed changes in SSR-6. In addition all appropriate paragraphs for LSA-II and LSA-III in SSG-26 have been reviewed and revised to improve the guidance material on how to demonstrate compliance with the LSA-II and LSA-III requirements. It includes clarifications on

- the terms “distributed throughout” and “essentially uniformly distributed” ,
- the methods on how to demonstrate compliance with the homogeneity requirements for the activity distribution throughout the LSA-II and LSA-III material for all package volumes, and

- the options on how to consider objects which are contaminated and activated for being classified as LSA-II material.

All proposed changes to SSR-6 and SSG-26 have been accepted by the IAEA Transport Safety Standards Committee (TRANSSC) in June 2016 to be sent to IAEA member states review and comments within the so called 120 days commenting period as next step within the current IAEA revision process of SSR-6 and SSG-26.

Conclusions

The review of the LSA-II and LSA-III concept based on latest experimental and theoretical investigations leads to the conclusion that the limitations of the average specific activities to 10^{-4} A_2/g for LSA-II and $2x10^{-3}$ A_2/g for LSA-III and the exclusion of powder from LSA-III material assure that the 50 mSv effective dose criterion of the transport regulations is met with considerable safety margins. The results provide also a quantitative justification for the maximum allowable average specific activity of $2x10^{-3}$ A_2/g for LSA-III material, which was missing so far. It can be concluded further that the whole LSA-concept based on limitations of the average specific activities for LSA-II and LSA-III can be confirmed by recent experimental data and modern analyses methods as being a well-founded and conservative system providing a high level of safety. The leaching test requirement does not contribute to this safety level. It is therefore not necessary and not justified and should be deleted from LSA-III material requirements. This helps simplifying the transport regulations and overcoming unnecessary difficulties regarding different interpretations and implementations of the leaching test in practice, especially for radioactive waste transport. Appropriate changes to SSR-6 and SSG-26 have been proposed and have been accepted by the IAEA Transport Safety Standards Committee (TRANSSC) in June 2016. They are now part of the current IAEA revision process of SSR-6 and SSG-26.

References

[1] International Atomic Energy Agency (IAEA) (Ed.) (2012): Regulations for the Safe Transport of Radioactive Material 2012 Edition. Specific Safety Requirements. International Atomic Energy Agency (IAEA). Vienna (IAEA Safety Standards Series, No. SSR-6).

[2] International Atomic Energy Agency (IAEA) (Ed.) (2014): Advisory Material for the IAEA Regulations for the Safe Transport of Radioactive Material (2012 Edition). Specific Safety Guide. 2012 ed. Vienna (IAEA Safety Standards Series, No. SSG-26).

[3] Nitsche, Frank; Lange, Florentin; Büttner, Uwe (2013): Proposal to Simplify LSA-III Material Requirements of IAEA Transport Regulations. In Institute of Nuclear Materials Management (INMM) (Ed.): Proceedings PATRAM 2013. 17th International Symposium on the Packaging and Transportation of Radioactive Material. PATRAM 2013. San Francisco, CA, USA, August 18-23, 2013.

[4] Brücher, Wenzel; Büttner, Uwe; Lange, Florentin (2010): Review of Material Requirements of

the IAEA Transport Regulations for LSA-II and LSA-III. In Department for Transport (DfT) (Ed.): Proceedings PATRAM 2010. 16th International Symposium on the Packaging and Transportation of Radioactive Materials. PATRAM 2010. London, UK, 3-8 October 2010.

[5] Lange, Florentin; Martens, R.; Hörmann, E.; Koch, Wolfgang; Nolte, Oliver; Gray, I. et al. (2003): Improvement of the Radiological and Experimental Basis to Further Develop the Requirements of the IAEA Transport Regulations for LSA/SCO Materials. Final Report. Commission of the European Communities (Customer's Contract No: 4.1020/D/01-001).

[6] Lange, Florentin; Martens, R.; Hörmann, E.; Koch, Wolfgang; Nolte, Oliver; Malesys, P.; Hughes, J. S. (2004): Development of Methodologies and Small Scale Demonstration Tests for the Assessment of Aerosol-Borne Release of Radioactive Materials in Different Transport Situations. Final Report. Commission of the European Communities (Customer's Contract No: 4.1020/D/02-002).

[7] Lange, Florentin; Martens, R.; Nolte, Oliver; Lödding, H.; Koch, Wolfgang; Hörmann, E. (2007): Testing of packages with LSA materials in very severe mechanical impact conditions with measurement of airborne release. In Packaging, Transport, Storage & Security of Radioactive Material 18 (2), pp. 59–71. DOI: 10.1179/174651007X220186.

[8] Brücher, W.; Büttner, Uwe; Lange, Florentin; Sentuc, Florence (2011): Entwicklung eines Regeländerungsvorschlages für die Anforderungen in den IAEA-Transportvorschriften TS-R-1 zum Auslaugtest für LSA-III-Material. Abschlussbericht zum Vorhaben 3609R03320. Gesellschaft für Anlagen- und Reaktorsicherheit (GRS) mbH. Köln (GRS-A-3599) (in German).

[9] Nitsche, Frank; Lange, Florentin; Büttner, Uwe (2013): Proposal to simplify LSA-III material requirements of IAEA Transport Regulations. In *Packaging, Transport, Storage & Security of Radioactive Material* 24 (4), pp. 207–212. DOI: 10.1179/1746510914Y.0000000043

[10] Lange, Florentin; Fett, H.-J.; Hörmann, E.; Koch, Wolfgang; Martens, R.; Nolte, Oliver (2007): Assessment, Evaluation and further Development of the Safe Transport of Radioactive Material. Final Report of the Research Project SR 2479 (Working Area 4). Methods and Tools Applied for Radioactive Material Transport Risk Analysis Purposes. Gesellschaft für Anlagen- und Reaktorsicherheit (GRS) mbH. Köln (GRS-A-3378/IVe).

[11] Büttner, Uwe (2015): Review of Material Requirements for LSA-II and LSA-III. Summary of Main Results for Proposal Justification. Presentation, Workshop on Transport of Radioactive Material – LSA-III Material, Gesellschaft für Anlagen- und Reaktorsicherheit (GRS) gGmbH, Cologne, 15 April 2015.

[12] Sentuc, F.-N.; Endres, J.; Büttner, U.; Hartwig-Thurat, E. (2016): Bereitstellung von Verfahren zur Berechnung von Freistellungsgrenzwerten entsprechend der neuesten Transportvorschriften sowie von Daten zum Transportaufkommen in Deutschland. Zwischenbericht zum Vorhaben 3614R03371. Gesellschaft für Anlagen- und Reaktorsicherheit (GRS) gGmbH. Köln (draft, in German).