# Development of an Improved Radiological Basis and Revised Requirements for the Transport of LSA/SCO Materials

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## 1. Introduction

The IAEA Regulations for the Safe Transport of Radioactive Material [1] specify a range of package requirements that are dependent upon the activity and properties of the radioactive material being transported. For example, Type A packages can be used for the transport of material with an activity of up to one $A_1$ of special form material and one $A_2$ of other material. The $A_1$ and $A_2$ values are determined for over 350 radionuclides using the Q system in the advisory material [2]. This system models the following pathways in the event of a severe accident:

- External photon dose;
- External beta dose;
- Inhalation dose;
- Skin and ingestion dose due to contamination transfer;
- Submersion dose.

For the inhalation pathway, it is assumed that $10^{-6}$ of the contents of a Type A package, which equates to $10^{-6}$ $A_2$, would be inhaled by an individual in the event of a severe accident and that this would result in an effective dose to the individual of no more than 50 mSv.

Industrial packages can be used for the transport of low specific activity (LSA) material and surface contaminated objects (SCO) and the particular requirements for these types of materials are derived from a simplistic radiological model that is often referred to as the 10 mg inhalation model. This is because it is based on the assumption that, in a dusty environment, an individual would inhale no more than 10 mg in such a situation, although there is limited reliable information to justify this assumption.

If LSA-II material, which has specific activity limit of $10^{-4}$ $A_2$/g, were to be released from an industrial package, an intake of 10 mg would equate to $10^{-6}$ $A_2$. Hence, the 10 mg intake approach of the LSA-II limit corresponds to the intake model for Type A packages.

As well as the LSA material specific activity limits and the SCO surface contamination limits, the regulations impose some additional constraints, such as the limit on a conveyance for combustible material, in order to mitigate certain specific transport accidents.

However, the robustness of the radiological basis for the regulations governing the transport of LSA material and SCO and a Co-ordinated Research Programme has been managed by the IAEA in recent years to address this. Particular areas of weakness include the accident consequences not having been systematically assessed, and some potentially significant exposure pathways, such as exposure due to activity deposited on the ground, have not been considered. Modern modelling tools for transport accident analyses are available to provide a much improved radiological modelling basis for LSA material and SCO.

Furthermore, there are deficiencies in the specification of some of the material requirements for LSA/SCO material in the IAEA Transport Regulations [1]. Consequently, this can cause some difficulties for operators in complying with the regulations and to competent authorities in their compliance assurance role. Particular areas of difficulty include:

- It can be difficult to distinguish between LSA-type material and SCO-type;
- It is difficult to distinguish surface contamination from activity within the object, and between fixed and non-fixed contamination;

- In order to demonstrate compliance with SCO requirements, measurements of both accessible and non-accessible contamination are required, although it is not clear how compliance with the inaccessible contamination limit can be measured if it cannot be reached;
- Some terms, such as “distributed throughout”, are not well defined, and this makes it difficult to demonstrate unequivocal compliance with the regulatory requirements;
- The relevance of the leaching test for LSA-III material is not obvious, and the test is very difficult to perform in practice;
- Even trace quantities of materials that are forbidden can bring compliance into question.

There is consequently a need for improvements concerning the material specifications of the IAEA Transport Regulations [1] and for a radiological model that allows new activity limits to be derived in connection with an alternative system of requirements.

## 2. Previous Work

Within the frame of a previous study [3] that was funded by the European Union, a radiological consequence model was developed and this considered atmospheric releases following severe accident impact conditions. A new material grouping system was proposed, but this was at an early stage of development. This system included requirements with more precise material specifications than are currently defined for LSA material and SCO. From the material specifications and the radiological model, new package content activity limits were calculated. This system was envisaged as having the potential to replace the current requirements in the IAEA Transport Regulations for solid LSA-II, LSA-III, SCO-I and SCO-II. However, it was recognised that the system required development to cover LSA-I material, liquids and gases.

In a further study [4], the implications of classifying solid LSA/SCO type materials according to this new material grouping system were examined using data on the materials and packages that were transported or are planned to be transported in France, Germany and the United Kingdom. It was concluded that this system provided a suitable framework for regulation of all of the radioactive material that was assessed. However, there were aspects of the new material grouping system that were too complicated and needed to be developed further before a formal proposal for changes to the IAEA Transport Regulations could be submitted to the IAEA.

Therefore, additional further work was required to develop the proposed system and to extend it to LSA-I materials, liquids and gases. There was also a need to improve the robustness of the release fractions for the airborne release of radioactive material from LSA/SCO packages in accident conditions involving mechanical or thermal impacts. The package activity limits in the new material grouping system would then be based on these release fractions. These release fractions would need to be determined by an experimental programme designed to investigate the effect of both waste form and container interactions. However, thermal performance data could be obtained from review of published literature and research reports.

Details of the resultant work that is presented in the remainder of this paper are set out in a full report [5] that was prepared for the European Commission who funded the work. The work falls into three areas:

- Modelling approach;
- Release fractions;
- The New Grouping of Low Activity Material.

The organisations involved in this project were:

- Gesellschaft für Anlagen- und Reaktorsicherheit (GRS), Germany (Project co-ordinator);
- Nirex, UK;
- Nuclear Research & Consultancy Group (NRG), Netherlands;
- National Radiological Protection Board, UK;
- Fraunhofer Institute for Toxicology and Experimental Medicine, Germany;
- RM Consultants, UK;
- Ove Arup, UK;
- NSG Environmental, UK;
- KEMA, Netherlands;
- Centrale Organisatie Voor Radioactief Afval (COVRA), Netherlands;
- Independent consultants, France and Germany.

## 3. Modelling Approach

The fundamental basis of the new approach for LSA/SCO material is to clearly demonstrate that the effective dose for an individual exposed in the vicinity of a postulated transport accident site will be limited to 50 mSv. Consistent with the philosophy of the IAEA Transport Regulations severe accidents were considered which would lead to mechanical or thermal impacts that are equivalent to the Type B test conditions, i.e. a 9 m drop onto an unyielding target and a fully engulfing fuel fire of 800 °C and 30 minutes duration. As for the Type B test conditions, the fire environment is assumed to follow the mechanical impact. The test conditions defined in the Regulations represent the majority of transport accidents and are considered to be severe tests of a package. It is not intended to define the worst conceivable accident impact.

Under these accident conditions, depending on the quality of the packaging and the physical properties of the radioactive material (RAM) inside the package, a fraction of the radioactive inventory may be released to the environment. Concerning the release of particulate material following an accident with mechanical impact only the particle size range below 100 µm aerodynamic equivalent diameter (AED) is considered to be airborne and necessary to control. Atmospheric dispersion of larger particles is not of importance due to their high settling velocity. Regarding the inhalation dose only the respirable particle size range < 10 µm AED is relevant whereas the particle fraction > 10 µm AED only contributes to the dry or wet deposition. In the case of an accident involving a fire, only particles in the size range AED < 10 µm are produced by the thermal effect and need to be considered.

Persons in the vicinity may be exposed to the plume of released material, including subsequent exposure from ground-deposited material (ground-shine). It is assumed that the reference person is standing outdoors and within 50 m from the release point in downwind direction but does not have direct contact with the package or material. Under these conditions, the most relevant exposure pathways will be inhalation of the plume, skin dose from beta emitters in the plume (beta submersion dose), and gamma exposure from material deposited from the plume (ground-shine). While inhalation and submersion doses are received by the individual within a few seconds (when the cloud of airborne material passes the exposed individual), the external gamma dose from ground deposition is assumed to be received over a 1 year period to take account of residual contamination in an area that is regularly occupied. Ground-shine is only calculated for distances > 100 m from the site of the accident, because the near-distant area is assumed to be decontaminated within a short time or closed until decontamination is finished.

Starting with an initial volume of an aerosol cloud produced in an accident the resulting radioactivity concentration in a distance of 50 m and the amount of deposition 100 m away have to be calculated by an atmospheric dispersion model. Here a Lagrangian particle simulation model was used that enables a realistic description of the atmospheric dispersion process for short distances and near-ground-releases. By simulating a wide spectrum of weather situations (wind speed, rain intensity, stability classes) and applying their respective frequency of occurrence the time-integrated ground-level concentration were evaluated in a probabilistic way. For the purpose of deriving package activity limits, only representative single values of the airborne time-integrated ground-level concentration and of the deposition velocity were used. For the mechanical impact scenario a time-integrated ground-level concentration of $10^{-2}$ s/m³ at downwind source distances of 50 to 100 m and an effective dry deposition velocity of 2 x $10^{-2}$ m/s at 100 m have been evaluated for the relevant particle size range. In the fire scenario the thermal lift causes a much lower ground-level concentration; a value of $10^{-5}$ s/m³ has been evaluated at the downwind distance of highest impact. These adopted values cover 80 % of the atmospheric conditions and therefore are considered to give an appropriate conservative approach.

By applying effective dose coefficients recommended by the International Commission on Radiological Protection (ICRP) for the different pathways the dose per unit airborne release from a package can be calculated for each radionuclide of interest for the three main exposure pathways. The most restrictive pathway is used to derive the maximum allowable airborne release from a package for each radionuclide that leads to the accepted maximum dose limits (50 mSv effective dose or 500 mSv skin dose).

## 4. Release Fractions

An experimental programme was carried out to generate experimental data backing up the values chosen as release fractions in the overall modelling approach. Given the variety of LSA/SCO materials, package sizes and possible impact energies, this programme was designed to improve the general understanding of the release of airborne material upon mechanical energy input into solid matrix material (brittle material) but also to reveal some upper limit values based on a small number of full scale experiments with realistic packages. The target quantities were the fraction of the solid matrix material released into the airborne state (particles smaller than 100 µm aerodynamic diameter) as well as the aerodynamic size distribution.

The experiments were a combination of small scale experiments carried out with a variety of different solid brittle materials and a set of scaling experiments using one specific simulant material. Powder materials are treated in a separate experimental test programme. The small scale experiments (vertical direction) were aimed at revealing the influence of specific energy input, material properties, geometry, type of waste content, etc. on the release fraction. The large scale experiments were carried out to establish a database that enabled scaling parameters to be assessed and to estimate the possible influence of cladding on the release fractions of brittle and powder materials.

The small scale experiments were carried out at various impact speeds for each solid material in order to measure the parameters determining the relationship between the release fraction of airborne material and the specific energy input. Based on information available from previous projects and the open literature, a straight line was expected to represent this relationship and the corresponding parameters are its slope and offset. The large scale experiments were carried out as drop tests from heights of 9 m and 27 m, which correspond to impact velocities of 13.3 m/s and 23 m/s respectively.

In order to investigate the influence of waste composition and matrix materials a representative range of small scale waste forms was used to cover the following spectrum of typical LSA waste types:

- Ion exchange resin in cement;
- Ion exchange resin in polymer matrix;
- sludges/ concentrates in cement;
- sludges/ concentrates dried and compacted;
- sludges/ concentrates in borosilicate glass;
- solid waste covered with plain grout;
- powder.

The large scale samples were cementious grout, with some samples being clad in a steel drum and others being unclad. The specific samples were:

- 220 litre standard COVRA drum;
- 100 litre standard COVRA drum;
- 30 litre standard COVRA drum.

The results from these tests were assessed and combined with release fractions available from other test programmes and published in the literature to give the following release fractions that could be used in the radiological model described above to determine activity limits for the range of radionuclides in the IAEA Transport Regulations [1].

| Material Type | Airborne Release Fraction on Mechanical Impact | Airborne Release Fraction in Thermal Accident |
|---|---|---|
| Gases | 1 | $1^{(1)}$ |
| Liquids | $5 \times 10^{-3}$ | 1 |
| Solids, easily dispersible, e.g. powder, combustible with melting point less than 300ºC | $5 \times 10^{-3}$ | 1 |
| Solids, not easily dispersible, combustible with melting point greater than 300ºC | $5 \times 10^{-4}$ | $1 \times 10^{-2}$ |
| Immobilised solids (non-combustible matrix) | $5 \times 10^{-6}$ | $1 \times 10^{-4}$ |

Note: (1) This release fraction of 1 applies to gases and volatile elements.

## 5. The New Grouping of Low Activity Material

The aspects of different package qualities are met by dividing the current LSA/SCO material into four groups of so-called LAM (low active material) with the following characteristics:

- LAM-I ores, very low activity material; liquids of such materials;
- LAM-II solids and powders, liquids, gases;
- LAM-III solids in a not easily dispersible form, such as lumpy solid material or a collection of solids; it may contain some combustible material, but not with a melting point below 300 °C;
- LAM-IV solids by immobilisation of radioactive material in a non-combustible matrix.

These LAM groupings correspond to the different release fractions that are expected in the impact and thermal accidents. The airborne release fractions are as described above.

Combining the release fractions and dispersion conditions, it can be shown that for each material group the mechanical impact leads to exposures that are at least a factor of 5 higher than in the fire scenario. For this reason and because the maximum concentrations for thermal and mechanical releases are at different distances from the source, the calculation of radiological consequences and the derivation of activity limits were simplified to consider a mechanical release and neglecting the small contribution from the thermal event.

The application of this method to real packages has to take into account the different qualities of the packaging and the properties of the radioactive material itself. Often the radioactive inventory consists of a mixture of different radionuclides and, in such instances, the sum formula in Para 404 of the IAEA Transport Regulations [1] should be applied.

In deriving the new LAM grouping system based on a radiological consequence model, one fundamental requirement behind this new system was the use of the existing industrial package performance. However, the introduction of the new system is coupled with the following key issues that partially represent some major changes in requirements compared to the current system:

- activity limits are specified in terms of absolute activity within a package instead of specific activity within the radioactive material;
- surface contamination levels do not have to be assessed, as the key parameter is the total package activity;
- similarly, consideration does not have to be given to whether contamination is fixed or non-fixed, or whether contamination is on accessible or non-accessible surfaces;
- activated material with surface contamination can be readily transported in the new system by simply assessing the total activity;
- conveyance activity limits are not required;
- the leaching test is not required;
- the dose rate limit of 10 mSv/h at 3 m from the unshielded contents is retained;
- activity limits are reduced for content volumes less than 50 litres;
- liquids and powders can be present in LAM-III packages at a level of < 1%.

The changes needed to incorporate this new LAM System into the IAEA Transport Regulations [1] have been identified and a draft set of regulatory requirements has been developed in the full report [5]. These changes demonstrate that it is practical to make the necessary changes to establish a robust new regulatory system, although some further work is required to address:

- accidents during sea or river transport;
- specific consideration of the transport of tritiated water;
- statistical significance of the drop test results.

## 6. Comparison of New LAM System with LSA/SCO System

The following table shows the equivalence of the existing LSA/SCO and the new LAM material categories. It is intended to apply the existing package requirements (Type IP-1, Type IP-2, Type IP-3) equivalently to the new LAM groups.

| Existing Category | Proposed Category | Industrial Package Type | |
|---|---|---|---|
| | | Exclusive Use | Not under Exclusive Use |
| LSA-I solid material | LAM-I solid material | IP-1(1) | IP-1 |
| LSA-I liquids | LAM-I liquids | IP-1 | IP-2 |
| SCO-I | LAM-I solid material | IP-1 | IP-1 |
| LSA-II solid material | LAM-II solid material | IP-2 | IP-2 |
| LSA-II liquids | LAM-II liquids | IP-2 | IP-3 |
| LSA-II gases | LAM-II gases | IP-2 | IP-3 |
| SCO-II | LAM-II solid material | IP-2 | IP-2 |
| LSA-III | LAM-III and LAM-IV | IP-2 | IP-3 |

Note: (1) Under the conditions specified in Para 523 of the existing regulations [1], LAM-I solid material may be transported unpackaged.

Activity limits have been calculated for about 350 radioactive nuclides within the LAM-system. These absolute activity limits cannot be compared directly to the current LSA specific activity limits. However, the LAM-system effectively has a maximum specific activity as the activity limits for volumes less than 50 litres are reduced in proportion with the volume of the radioactive material for volumes less than 50 litres. For example, for a volume of 25 litres, the activity limits would be reduced by a factor of two but the specific activity (in terms of Bq/g) would be unchanged for the same density.

For volumes of radioactive material greater than 50 litres, the effective maximum permitted specific activity reduces with increased volume, as the maximum permitted total activity remains unchanged. The effective maximum permitted specific activity occurs at a volume of radioactive material of 50 litres. For example, for radioactive waste that has been grouted into a volume of 50 litres, giving a density of 2 kg/litre, a value for the effective maximum specific activity can be determined from the LAM activity limits by dividing by $10^5$ (= 50 litres x 2000 g/litre).

A comparison between the effective maximum specific activity values for LAM-II and the current specific activity values for LSA-II shows that about 12% of the nuclides have lower LAM-II values, while 59 % have LAM-II values that are higher by more than one order of magnitude. A similar comparison between LAM-IV and LSA-III shows that 99% of the nuclides have LAM-IV values that are higher by more than one order of magnitude. It must be taken into account that the specific LAM activity decreases with larger volumes, e.g. in a 500 l drum the specific activity is reduced by one order of magnitude compared with a 50 litre volume, but on the whole there is a trend for higher activities allowable in the LAM-system.

This trend is also seen when the LAM and the existing $A_2$ activity values are compared. In the LAM-II group, 99% of the nuclides have activity limits higher than $A_2$, 79% by more than one order of magnitude. The radionuclide with the lowest $A_2$ value is Ac-227, which has a value of $9 \times 10^{-5}$ TBq, compared with the LAM-II limit of $10^{-3}$ TBq. At the other end of the range, the highest LAM-II limit (Kr-81) is $5 \times 10^9$ TBq, compared with the $A_2$ value of 40 TBq, which is constrained by the cut-off for all radionuclides at that value, and so there is a much larger difference.

Analysis of surface contaminated objects show that the LAM-I approach and limits provide an effective alternative to the SCO-I criteria and the LAM-II approach proves to be an alternative to the SCO-II criteria.

The elimination of the leaching test for LSA-III material is considered to be a significant benefit, as it is not easy to demonstrate compliance with this performance requirement. Indeed, some material that could potentially be transported as LSA-III material in an industrial package is transported in a Type B package due to the difficulty of compliance demonstration. The removal of the total conveyance activity limits is also considered to be a benefit, as the radiological model shows that it is not necessary to have these limits and hence the elimination of them could result in a reduced number of shipments and a reduced overall risk.

For some large industrial packagings used in France for the transports of reprocessed uranyl nitrate, reprocessed $UF_6$ and enriched reprocessed $UF_6$ it has been evaluated that there are no problems to continue to use these packages under the conditions of the LAM system.

## 7. Conclusions

The proposed new LAM system:

- provides an improved radiological basis;
- addresses a number of operational problems;
- benefits operators and regulators in achieving compliance with the IAEA Transport Regulations.

A draft set of regulatory requirements has been developed and these demonstrate that it is practical to make the necessary changes to establish a robust new regulatory system.

## 8. References

[1] IAEA, *Requirements for the Safe Transport of Radioactive Material, 1996 Edition (Revised)*, TS-R-1 (ST-1, Revised).

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