**Proposed New Grouping Scheme and System of Requirements for the Transport of LSA-Type and SCO-Type Materials**

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## Introduction

Radioactive material in the form of low specific activity materials (LSA) and surface contaminated objects (SCO) can be carried by all modes of transport, but since these are generally bulky consignments they are predominantly carried by road or rail. The categories of LSA presently include ores, ore concentrates, and radioactive wastes. Most of the radioactive wastes from the decommissioning of nuclear facilities will be included in these categories of materials and are likely to be transported in considerable quantities in the future. The latest edition of the IAEA regulations (IAEA 1990) on the transport of radioactive materials allows for three categories of LSA materials (LSA I, II, and III) and two of SCO (SCO I and II). The lowest, least hazardous category of both forms can be carried with minimal or in some cases no packaging requirements. The higher categories require higher standards of packaging.

For the current LSA/SCO system a number of inadequacies have been identified, for example:

- SCO: Measurement of surface contamination and distinction from activity within objects is difficult, also the distinction between accessible and inaccessible surfaces and between fixed and non-fixed contamination poses problems.
- LSA: Terms such as "distributed throughout" or "combustible" are not well defined; the relevance of the leaching test for LSA-III is not obvious.
- LSA/SCO: The distinction between LSA- and SCO-materials is often difficult; for this and other reasons it is difficult to demonstrate compliance with requirements; also the conveyance limit for combustible materials induces problems.
- The radiological basis to derive limits of specific activity and of surface contamination is rather weak.

These disadvantages of the present LSA/SCO system have been noticed by many experts, notably in technical meetings at the IAEA. Uncertainties in the material definitions make it difficult, to demonstrate compliance with the current requirements. A need has therefore been identified to review the present LSA/SCO system and to seek improvements. The objective of a first study (Lange et al. 1994) was to examine possible alternatives, or amendments, to the existing system of classification and to suggest improvements. It is recognized that there are existing systems of transport and existing package designs and that many such materials are currently shipped with few problems. Any new system proposed needs to take into account present practices and future needs.

The main features of a new system of material definitions and of requirements have been developed and also a radiological consequence model to derive package content limits. At the moment only solid materials have been considered. It is suggested that the present categories LSA-II, LSA-III, SCO-I, and SCO-II be replaced by three material groups G1, G2, and G3. The system of this grouping scheme is linked to the fractional airborne release of radioactive matter in severe accidents. Apart from exposure via direct radiation from a damaged package the radiological consequence model includes the exposure pathways inhalation, β-submersion and γ-groundshine resulting from atmospheric dispersion and deposition of an airborne activity release.

The proposed system has been applied to derive radionuclide-specific activity content limits for the three material groups. It was the aim that most of the problems of the present system are avoided, that the new system is more adapted to present and future shipments of such materials, and that compliance and quality control are facilitated.

The present proposal is seen as a starting point, it definitely needs feedback from experts in this field and future improvements. The PATRAM conference is a very good opportunity to present the main features of this new approach to the transport community.

## Derivation of a System of Requirements

A system of requirements dealing with the transport of radioactive material such as LSA- or SCO-type has to specify

- required material properties,
- packaging requirements, and
- allowed package contents of radioactive material, taking into account differences in radiological hazard of different radionuclides.

As with the Q-system for Type A packages, requirements are based on considerations of potential radiological consequences in severe transport accidents in connection with the radiological criterion that radiation exposures of individuals, which could result from such an accident remain limited to 50 mSv effective dose. Potential radiation exposures following a transport accident can result essentially from

- reduction of shielding leading to enhanced radiation levels in the vicinity of a damaged package, and
- airborne release of radioactive material leading to radiation exposure of individuals via different exposure pathways.

In the LSA/SCO system of requirements of the current transport regulations the direct radiation hazard following an accident is limited by restricting the external radiation level at 3 m from the unshielded material to less than 10 mSv/h. This requirement is retained in the proposed new system.

Other exposure pathways are mainly influenced by:

- The severity of the accident impact which can either be mechanical, thermal, or both in combination.
- The properties of the packaging and of the radioactive material which determine the amount and physical/chemical characteristics of airborne released material.
- The activity release of radionuclides from a damaged package and the properties of the released material such as the particle size distribution which influences the inhalation by individuals and the deposition behavior of the material (e.g., groundshine pathway).

**Accident Severity**

Severe transport accidents can be associated with a variety of accidental impacts affecting a package. In order to base assumptions concerning release fractions on defined accident conditions severe accident impacts are assumed to be presented by the mechanical and thermal test conditions for Type B packages which are essentially:

- Drop from 9 m onto an unyielding surface.
- Fully engulfing fire of 800°C for 30 minutes following the mechanical impact

**Definition of Material Groups**

Presently only solid materials are considered. Special considerations will be necessary at a later stage in order to adequately treat liquids or gases. The current LSA-I category remains unchanged.

Three different groups of radioactive materials G1, G2, and G3 are defined which are proposed to replace the grouping presently used for solid materials of low specific activity (LSA-II and LSA-III) and for surface contaminated objects (SCO-I and SCO-II). The basis for defining material groups G1, G2, G3 is the release behavior in accident conditions. In some cases the release behavior is determined by a combination of material properties, other protective measures and the packaging. The three material groups are defined in a hierarchical order concerning material requirements and associated release fractions. To facilitate a general understanding of the grouping system, the proposed groups G1, G2, and G3 are introduced in general terms together with some basic requirements for the properties of the radioactive materials:

- G1 is the material group with the least requirements. This group would include material with high release fractions. If a fire is involved it is assumed that all the radioactivity is released.

- Group G2 is intended for materials with release fractions lower than for Group 1 and in an intermediate range. Therefore material requirements are more stringent than for G1. Materials that are not readily dispersible under mechanical impact and which, if in combustible form fulfill certain requirements concerning the melting point, are included in this Group.

- Group G3 is intended for materials with low release fractions under the specified mechanical and thermal conditions. It includes materials and objects homogeneously bound in a thermally stable cement/concrete block, or similar immobilizing material. If the radioactive material is protected by a thermally stable inactive layer, which retains its specified thermal protection following severe mechanical impact, then homogeneous distribution within a binding agent that may be combustible is not required, or alternatively immobilization is not required at all provided the material is not combustible, is not thermally decomposable, and not in powder form.

As a general requirement concerning all three groups a minimal volume of the radioactive material of 50 liters is introduced among other reasons because the assumptions on release fractions take into account the fact that the radioactive material has a larger volume than 50 liters. Material groups are defined by specifying or by excluding certain material properties. If certain material properties are excluded, this requires in general a specification of how to proceed if trace amounts of the excluded form are present. Exclusion of certain properties means, if not otherwise stated, that the material may only include less than 1% of the package activity limit in the excluded form (1% rule). In the more specific definitions of the three proposed material groups some attributes are written in italics to indicate that their meaning has been explicitly defined in the study.

**Group G1**: Solid materials with few regulatory requirements. This Group may include materials, such as powders, which are easily dispersible when subjected to mechanical impact or materials which are *combustible*. It may include SCO-type materials.

**Group G2:** Solid materials that are in a not easily dispersible form [e.g., no powders (1% rule)]. It may consist of lumpy solid materials or a collection of solid objects. It may include materials that are *combustible* or that can be *pyrolized*, i.e., thermally decomposed. It may not include (1% rule) *combustible* materials with a melting point below 300°C. Surface contaminated objects are included if they have the required properties.

**Group G3:** Properties of the radioactive material, e.g., immobilization in a cement/concrete matrix, or other technical means, such as certain properties of the packaging can result in high inherent safety, equivalent to a low fractional *release* from a package in severe accidents. Therefore, group G3 is subdivided into three alternative subgroups:

**Group 3a:** The radioactive material is *sufficiently homogeneously* distributed in one or several *mechanically and thermally stable bodies*. For example: one or several blocks of cement/concrete. The compressive strength of the stable bodies must exceed 5 $N/mm^2$.

**Group 3b**: The requirements that the radioactive materials are *sufficiently homogeneously* distributed within the binding agent, that the binding agent is *thermally stable*, and the *compressive strength* is > 5 N/mm$^2$ can be substituted by other safety measures which are equivalent concerning airborne release in accidents:

The radioactive contents are fixed in a *mechanically stable* body or are contained within an additional inner receptacle, e.g., a 200 liter drum, which is embedded in a *mechanically stable* matrix material. In addition, the radioactive contents are surrounded by an inactive material zone which is *thermally stable* and has a thermal resistance (ratio of material thickness and thermal conductivity) > 0.05 m$^2$ K/W, e.g., 5 cm of cement. The outer layer must retain its thermal protection if prior to a fire a mechanical impact equivalent to the 9-m drop test has occurred. It is also acceptable that the thermally stable outer layer with the required thermal resistance is provided by a packaging (container) which is made, for example, of concrete and which retains its thermal insulating properties after the 9-m drop test. The required thermal protection is essentially such that the inner wall temperature is limited to temperatures in the range of 100°C.

**Group 3c:** In the special case that the contents are noncombustible and not pyrolizable and also not in powder form, e.g., metallic objects and certain compacted wastes and surface contaminated objects, the radioactive materials need not be fixed in a thermally stable binding matrix. In this case the outer inactive layer with a thermal resistance > 0.05 m$^2$ K/W in connection with these required material properties is sufficient. Again, the thermally stable outer layer with the specified thermal resistance can be provided by the packaging. In either case the thermal protection must be retained following a severe accident equivalent to the impact of the 9-m drop test.

## Packaging

The packaging for the three material groups G1, G2, and G3 have to fulfill the requirements for industrial packages IP-2 or IP-3. In addition, for materials classified as G2 the material of the packaging should itself be noncombustible (for example, no polyethylene drum, cardboard, or wooden box). The reason for this requirement is the difference in release behavior of materials when they are directly exposed to the flames of a fire or when they are largely protected by the surrounding packaging. This is still valid even if the packaging has been locally damaged by prior mechanical impact. Combustible material that is no longer enclosed by the packaging will burn in an open flame and airborne release of material is comparatively large, whereas with remaining, albeit somewhat reduced, protection by the packaging temperatures of the material and oxygen access will be lower and the material could only thermally decompose on a much slower scale by pyrolysis. In the latter case release fractions are much lower. If the packaging is combustible and can burn it may no longer protect the radioactive material from exposure to open flames.

In the case of subgroups G3b and G3c of material Group 3 it is recognized that the radioactive contents are surrounded by an inactive material zone which retains its specified thermal protection following severe mechanical impact. This thermal and mechanical protection can also be provided by the packaging itself: some IP packagings, for example strong reinforced concrete containers, meet such conditions and are already widely available.

**Release Fractions**

Material properties and, in some cases, properties of additional protective material or of the packaging have been specified for the proposed three material groups G1 to G3. If these material requirements are met the following release fractions can be adopted as conservative upper values. Release fractions are given separately for accident conditions with high mechanical impact alone (equivalent to 9-m drop test conditions) and for thermal impact (equivalent to fully engulfing fire of 800°C, 30 min.) assuming a preceding mechanical impact. Explanatory material in support of the adopted release fractions is given in the study.

Table 1. Release Fractions

| | Release Fractions in Each Group | | |
|---|---|---|---|
| | G1 | G2 | G3 |
| Mechanical impact | $10^{-2}$ | $10^{-3}$ | $10^{-5}$ |
| Thermal impact | 1 | $10^{-2}$ | $10^{-4}$ * |

* in case of thermal impact, release fractions are generally higher for potentially volatile radionuclides/elements, e.g., H3, C14, halogens such as Cl, Br, and I, and noble gases physically or chemically fixed to solid material. As a conservative upper value, a release fraction of 1 is adopted. No practical limitations are expected to result from this assumption.

**Radiolgical Consequence Model**

The radiological criteria applied in the new system are the same as those for the current LSA/SCO classification: a limit of 50 mSv effective dose and of 500 mSv skin dose. A similar modeling approach as in the Q-system for Type A packages is used. However, LSA/SCO material is generally bulky material in large packages and this makes some pathways more important. In the calculations the main pathways considered have been the inhalation of plume aerosol, submersion and the direct gamma radiation from ground-deposited material. Other pathways have been considered, such as direct radiation from the plume of released material, but are not significant.

The inhalation pathway is modeled by adopting values for the time-integrated ground-level air concentration $\chi$ and for the breathing rate of individuals. In the case of mechanical impact leading to near ground-level release of radioactive material, a conservative value of $\chi = 5 \cdot 10^{-3}\ s \cdot m^{-3}$ was adopted for distances of 50 m to 100 m downwind from the location of an accident. If fire is involved, there will be thermal lift resulting in lower ground level air concentrations. A value of $\chi = 5 \cdot 10^{-5}\ s \cdot m^{-3}$ is therefore taken to be an appropriate value in those circumstances, for the region of highest air concentration.

The time-integrated air concentration can be used, in connection with an appropriate deposition velocity ($v_g$) to estimate groundshine from deposited gamma emitters. With the types of materials involved, mechanical impacts are likely to result in particles of larger aerodynamic equivalent diameter, and a reasonable choice of deposition velocity would be $2 \cdot 10^{-2}\ m \cdot s^{-1}$. As far as release from thermal impact is concerned a deposition velocity of

$10^{-3}$ m·s$^{-1}$ was adopted. Ground deposition could present problems during the clean-up phase, and doses could be received over a longer period. In order to properly take account of this pathway a period of one year was chosen for the calculations. Also in order to take account of the local shielding by effects such as ground roughness the external dose rate is multiplied by a factor f of 0.5.

**Activity Limits for Packages**

By employing the above mentioned dose limits and the radiological consequence models and on the basis of the release fractions of Table 1 radionuclide-specific package contents limits have been determined for the three material groups G1, G2, and G3. Activity limits for packages of some selected radionuclides are listed in Table 2 for the three material categories, along with the package limits A1 and A2 of Type A packages, for comparison. The activity limits for G2-material packages are a factor of 10 higher than the activity limits of G1-material packages because the release fraction is a factor of 10 lower. By the same reasoning the activity limits for G3-material packages are a factor of $10^3$ higher than for G1-material packages.

Table 2. Limits for Selected Radionuclides

| Radionuclide | $A_1$ [Bq] | $A_2$ [Bq] | $G_1/A_2$ | $G_1$ [Bq] | $G_2$ [Bq] | $G_3$ [Bq] |
|---|---|---|---|---|---|---|
| Co 60 | $4 \cdot 10^{+11}$ | $4 \cdot 10^{+11}$ | 2.5 | $1 \cdot 10^{+12}$ | $1 \cdot 10^{+13}$ | $1 \cdot 10^{+15}$ |
| Cs 134 | $6 \cdot 10^{+11}$ | $5 \cdot 10^{+11}$ | 4 | $2 \cdot 10^{+12}$ | $2 \cdot 10^{+13}$ | $2 \cdot 10^{+15}$ |
| Cs 137 | $2 \cdot 10^{+12}$ | $5 \cdot 10^{+11}$ | 12 | $6 \cdot 10^{+12}$ | $6 \cdot 10^{+13}$ | $6 \cdot 10^{+15}$ |
| Pu 238 | $2 \cdot 10^{+12}$ | $2 \cdot 10^{+08}$ | 250 | $5 \cdot 10^{+10}$ | $5 \cdot 10^{+11}$ | $5 \cdot 10^{+13}$ |
| Pu 241 | $4 \cdot 10^{+13}$ | $1 \cdot 10^{+10}$ | 200 | $2 \cdot 10^{+12}$ | $2 \cdot 10^{+13}$ | $2 \cdot 10^{+15}$ |
| Ra 226 | $3 \cdot 10^{+11}$ | $2 \cdot 10^{+10}$ | 50 | $1 \cdot 10^{+12}$ | $1 \cdot 10^{+13}$ | $1 \cdot 10^{+15}$ |
| Sr 90 | $2 \cdot 10^{+11}$ | $1 \cdot 10^{+11}$ | 80 | $8 \cdot 10^{+12}$ | $8 \cdot 10^{+13}$ | $8 \cdot 10^{+15}$ |
| Th 228 | $3 \cdot 10^{+11}$ | $4 \cdot 10^{+08}$ | 100 | $4 \cdot 10^{+10}$ | $4 \cdot 10^{+11}$ | $4 \cdot 10^{+13}$ |
| Th 232 | Unlimited | Unlimited | - | $1 \cdot 10^{+10}$ | $1 \cdot 10^{+11}$ | $1 \cdot 10^{+13}$ |
| U 238 | Unlimited | Unlimited | - | $1 \cdot 10^{+11}$ | $1 \cdot 10^{+12}$ | $1 \cdot 10^{+14}$ |

## Discussion

The grouping of materials is such that the requirements that the radioactive materials contents and to some extent the packaging have to meet increase from G1 to G3. Accordingly, the allowed radionuclide-specific activity limits of packages also increase from G1 to G3. As long as the activity content of a package does not exceed the activity limits of the lowest Group G1, all materials fulfilling the minimal requirements of this Group can be transported as G1 material. Otherwise the material would have to fulfill the higher requirements of Group G2 and could be shipped as such material provided that the activity limits for this Group are observed. Group G3 has the highest allowed activity limits along with more stringent material requirements than Group G2.

It is recognized that the new system requires further development. At present only solid materials have been covered in detail and no attempt has been made to alter the LSA-I category or the dose rate specification associated with the current LSA/SCO system. Such developments will come after feedback from operators and regulators on the initial phase of the new system. The advantages of the new system include:

- Improved material requirements directly related to airborne release and therefore to radiological consequences in an accident.
- Activity limits for packages are well defined and conveyance limits are not necessary.
- The problems with understanding and applying the definitions of LSA and SCO are removed, for example, distinctions between accessible and inaccessible surfaces or between fixed and non-fixed contamination.
- The new system facilitates compliance and quality control for regulators and operators.
- The new model is based on potential consequences in accident conditions, and this is in accordance with modern radiological protection philosophy.
- The new system is well suited to current and future transport operations, particularly those associated with decommissioning and wastes.

Further discussions with regulators and operators will help to develop the system into a format suitable for consideration in the next revision cycle of the transport regulations.

## References

IAEA Safety Series No. 6. *Regulations for the Safe Transport of Radioactive Material*, 1985 edition. (As amended 1990.)

Lange, F., Gründler, D., Hughes, J.S., Shaw, K.B., Lombard, J. *Radiological Criteria and Requirements for the Transport of LSA and SCO Materials* , a joint research study for CEC by GRS (G), CEA/IPSN (F) and NRPB (UK), October 1994