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4014 New Considerations on the Safety Basis for Shipment of Surface Contaminated Objects

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Abstract

Solid objects that are not radioactive by themselves but contaminated by radioactive material on their surface may be classified for transport as surface contaminated object (SCO). The safety basis for SCO as given in the Advisory Material for the IAEA Regulations for the Safe Transport of Radioactive Material SSG-26, paras 413.1-413.7, is based on an estimation of the dose due to intake of activity from resuspended contamination by a person present at an accident site. This estimation is based on reasonable assumptions about these processes.

During the last years, new experiments on the resuspension of surface contaminations after mechanical impact have been undertaken. Various surface materials, types of contamination and impact energies have been investigated. The number and size distribution of the resuspended particles have been measured. From these measurements fractions of resuspended and respirable particles and resulting inhalation doses have been calculated for SCO in packages under accident conditions of transport. The results that are presented in the paper show that the current limits for contamination on SCO include a reasonable safety margin regarding inhalation dose under accident conditions of transport.

Introduction

Solid objects that are not radioactive by themselves but contaminated by radioactive material on their surface may be classified for transport as SCO. The IAEA Transport Regulations SSR-6 [1] limit mainly the activity of contamination per surface area of the objects and the dose rate in their vicinity (Paras 413 and 414). For the subgroup SCO-II higher limits for specific contamination activity are allowed than for SCO-I, combined with more stringent packaging requirements (package Type IP-2 required). All these provisions aim at providing an equivalent level of safety for shipments of SCO as for shipments of Type A packages. Whereas for accident free transport of SCO-II no release of the radioactive contents is permitted and therefore the radiological impact is limited by the general dose rate rules applicable to all kinds of packages, under accident conditions the radiological consequences are dominated by inhalation of released activity and therefore depend in detail on release properties of the contents. In this paper the safety basis for SCO regarding radiological consequences of transport accidents is analysed specifically for SCO-II, taking into account new investigations about the release of activity in respirable form from SCO under accident conditions of transport [7].

The technical basis of SCO-II as given by SSG-26

Regarding severe transport accidents involving any type of package for transport of radioactive material the regulations aim on limiting the radiation exposure of a person staying in the vicinity of an accident site to 50 mSv effective dose or less, see SSG-26 [2].

For the SCO-II contamination limits in the regulations [1] an assessment of the inhalation dose of a person being close to the site of an accident with an industrial package containing SCO-II shows compliance with the 50 mSv criterion or the equivalent intake of 10^{-6} A_2 (see [2], paras 413.2 and 413.3). Assuming a contaminated accessible surface of 10 m^2 and a release of 4% of the fixed and 100% of the non-fixed contamination on this surface, the contamination limits lead to a release of an activity of 3.24 GBq within the package. Using a release fraction of 10^{-2} of this activity from the package, an intake by inhalation of 10^{-4} of the activity released from the package and assuming an A_2 value of the released activity of 0.02 TBq (as set in Table 3 of [1] for unknown β/γ emitters), the intake is obtained to be less than $0.2 \cdot 10^{-6}$ A_2. This meets the dose criterion.

But these safety considerations contain quite a lot of assumptions. These assumptions are evaluated in the following based on recent investigations. In such a way the technical basis can be strengthened by including more detailed information about the resuspension of the contamination under accident conditions of transport and about the activity release from the damaged package.

Resuspension of contamination as a consequence of an accident involving SCO

The airborne release of contamination on surfaces is generally called resuspension. Resuspension can be caused by forces affecting the surface such as airflow and induced vibrations, which can counteract the adhesive forces to the surface. Some general considerations about resuspension can be found in [3]. Of interest for inhalation of resuspended particulates are respirable particle sizes < 10 µm aerodynamic diameter. Adhesive forces for particulates on surfaces show pronounced particle size dependence: The resuspension processes for smaller particles, e.g. < 10 µm, are less effective compared to larger particles. On the other hand, due to gravity only particles less than around 100 µm diameter can become airborne and transported away from the surface. It is therefore important to have data from resuspension experiments that determine the size of particles that are being released airborne.

Resuspension rates are quite difficult to measure [3]. They depend significantly on characteristics of the resident surface material and surface condition (dry or wet), particle size, lifting events as mechanical impact (vibrations) and enhanced wind flow, and time since contamination. It is therefore important that the considered experiments represent, as close as possible, the conditions of the application case.

New experiments on the resuspension of contamination

Between 2009 and 2011 experiments have been carried out at Fraunhofer ITEM for measuring resuspension from various contaminated surfaces caused by air flow and mechanical impact ([4], report available in German language only, summary in English). The aim of the study had been to assess the radiation exposure of people operating in a contaminated site after a radiological emergency.

The resuspension rate of respirable particles (< 10 µm) and its dependence on time and influencing parameters have been measured. A sketch of the apparatus for resuspension measurement under defined conditions of airflow over a contaminated test surface is shown in Fig. 1:

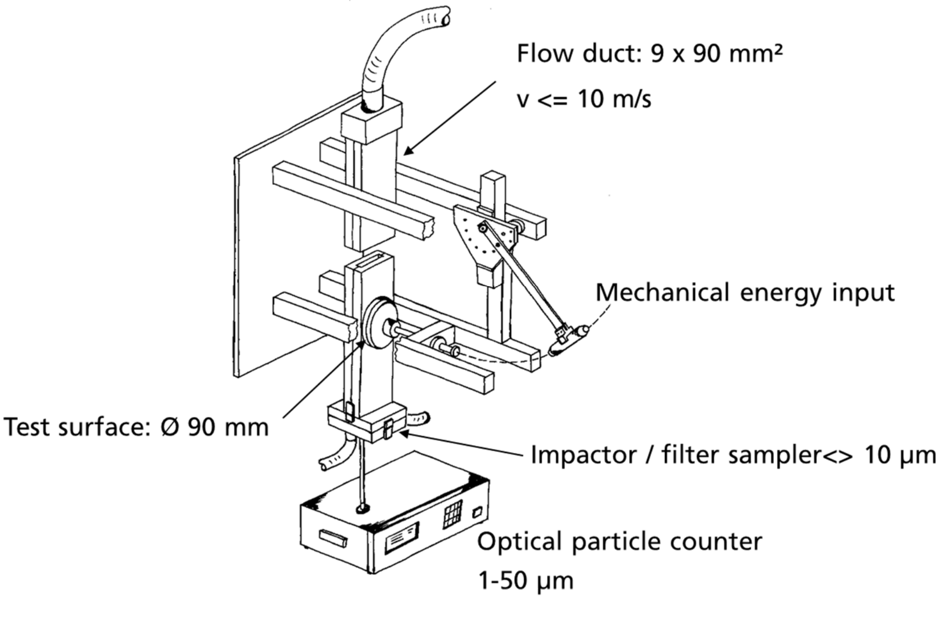

Fig. 1 Schematic representation of the resuspension apparatus for tests with model surfaces

In the experiments the airflow speed was varied. Various kinds of test surfaces were contaminated with different types of test powders and varying particle size distributions by controlled dry and wet deposition. Test surfaces were thin disks of tiles (some of them with smooth and some with coarse surface), of aluminium, of Tyvek fabric fixed to a metal plate and of various types of synthetic turf (similar to carpet material). Resuspended particles were recorded time-resolved by an optical particle counter with their particle size determined in the range from 1 to 50 µm. The apparatus is also equipped with a fall hammer by which a defined mechanical force is impacting onto the rear side of the contaminated circular disk. By varying the mass on the end of the shaft of the pendulum and/or its starting height the impacting force can be chosen.

Such impact tests were performed in the following way: A contaminated test disk was subjected to airflow and resuspended particles were recorded. In most cases a rather high wind speed of 6 m/s was chosen. But the airflow velocity was also varied in some experiments (2 m/s, 4 m/s, 6 m/s and 10 m/s). After an initial time period of typically 1 h a series of fall hammer impacts onto the rear of the contaminated plate was performed. Due to the vertical orientation of the flow channel with airflow from top to bottom all particles which become detached from the contaminated test surface are being recorded by the optical particle counter without any loss by redeposition. The choice of impact energies was to simulate situations where contaminated surfaces are subjected to mechanical impacts such as pedestrians walking or stamping or vibrations induced by passing vehicles, etc. Impact energies were not chosen to simulate dropping from larger heights, but the results can also be used in such a context.

Regarding resuspension of contamination on SCO under accident conditions of transport the main results of the study are:

- The resuspension rate R_R decreases with increasing time after contamination, following a power law $R_R = A \cdot t^{\kappa}$ with $\kappa \approx -1$. Resuspension rates increase with air flow velocity. In the case of combination of air flow and mechanical impact by the falling hammer pronounced short term resuspension bursts are induced, see Fig. 2.

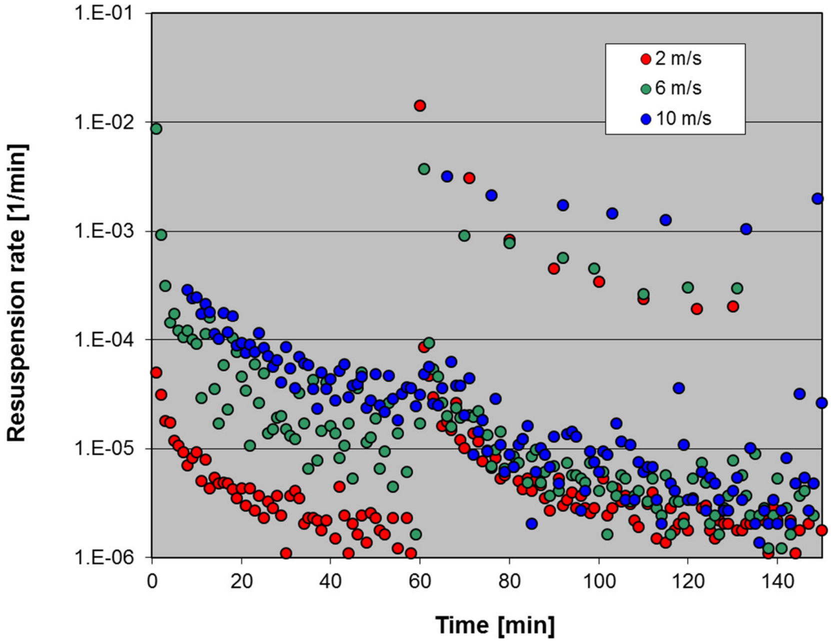

Fig. 2 Resuspension induced by repeated (7 or 8) transient energy inputs of 0.3 Joule (Nm) by impacting fall hammer under conditions of continuous airflow at different velocities (silver particles on smooth tile). Particle sizes 3 – 10 µm.

The fraction of the contamination which is being resuspended under conditions of continuous airflow within the minute following impact is defined as burst release. During the time period of about 10 minutes between impacts the wind resuspension is temporarily enhanced due to partial reduction of adhesion forces of deposited particles on the test surface induced by vibrations from the mechanical impact. This effect is most pronounced at low airflow velocities.

- In the case of Fig. 3 less than 1% of particles in the 3-5 µm size range are resuspended by the first impact and less than 1‰ from impact 4 and later. For the particle size range 20 – 30 µm about 10% are resuspended by the first impact and less than 1% by the second and further impacts.

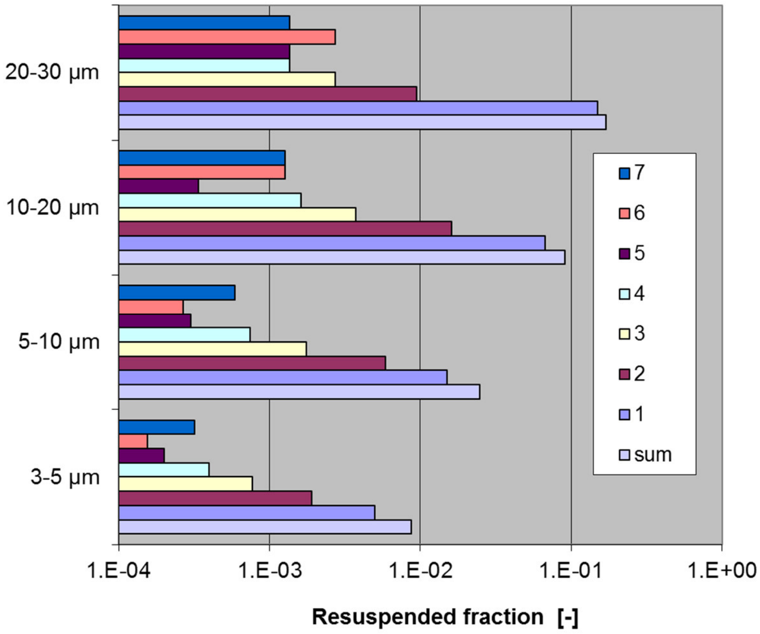

Fig. 3 Resuspended fraction of contamination caused by a series of mechanical impacts of 0.3 Joule to the rear of a test plate. Dry deposited CeO_2 particles on smooth ceramic tile. Released fractions are shown for different particle size intervals for 7 consecutive impacts - each about 10 min. apart - and the summed resuspension by all impacts.

- Measured resuspension rates for contamination from wet deposition are about a factor of 100 smaller compared to dry deposition. After wet deposition the contamination was dried before starting resuspension experiments. Resuspension results comparable to that after wet deposition were obtained when dry deposited particulates were subjected to spray with water or with a water/glycerine mixture and then dried again.

- For particles in the respirable size range 3 – 10 µm the results presented in Fig. 4 show a linear dependence of the airborne release fraction from impact energy. On this basis extrapolations to impacts with different impact energies are supported. According to Fig. 4 for the case of Tyvek cloth fixed to a metallic plate a mechanical impact of about 0.3 Joule would lead to a release fraction of about $4 \cdot 10^{-3}$ from the first impact. A linear relationship between impact energy and release fraction as shown in Fig. 4 was also observed for larger particle sizes (size intervals 10 – 20 µm, 20 – 30 µm and 30 – 50 µm). Due to the increasing adhesion forces experienced by smaller particles compared to larger ones particles below 3 µm size range would have a lower release fraction in comparison to the 3 - 5 µm interval.

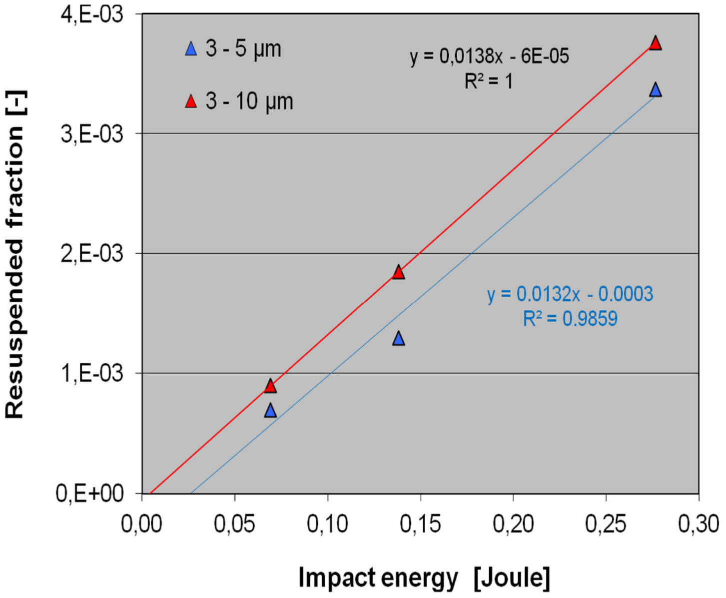

Fig. 4 Dependence of resuspended fraction (resuspension burst) from impact energy (0.08 J, 0.14 J and 0.28 J). CeO_2 particles dry deposited on Tyvek cloth fixed to a metal plate. Particle size intervals 3 – 5 µm and 3 – 10 µm.

Application of the new experimental results for evaluation of the safety basis for shipments of SCO-II

A hypothetical severe accident of an IP-2 or IP-3 package filled with objects in accordance with the SCO-II limits is considered. It is assumed that the package contains sheet steel objects (thickness 1 mm, density 7.8 g/cm³) contaminated on one side on 100 m² accessible surface area. This area is considered quite conservative since for release of resuspended activity from the package due to an impact all this surface would need to be connected by free and short flow paths to breaks in the packaging. Only contamination on accessible surfaces needs to be accounted for. The main argument for this is that inaccessible surfaces are understood to be surfaces in the inside of some more or less confined volume that would open to the outside of the package only by a very small portion.

For the resuspended contamination conservatively the following A_2 values of Table 3 of [1] are applied: 0.2 TBq for β/γ and low toxicity α emitters and $9 \cdot 10^{-5}$ TBq for all other α emitters.

A central issue for this consequence analysis is to assess the fraction of the non-fixed and fixed contamination on the 100 m² of sheet-steel that could be released from the damaged package as airborne particulate with particle sizes in the respirable size range below 10 µm aerodynamic equivalent diameter. A reasonable measure of energy input available for the induction of resuspension when the relatively thin disks are hit from the rear is the impact energy per contaminated surface area. An energy input of 0.3 Joule (most impact tests were at 0.3 Joule) to the 9 cm diameter test plate is equivalent to a specific surface energy of $4.7 \cdot 10^{-3}$ Joule/cm². On the other hand, a drop of the 0.1 cm thick steel sheet from a height of 9 m onto a hard surface is equivalent to a specific energy input into the contaminated surface of $6.9 \cdot 10^{-2}$ Joule/cm². This is a factor 15 higher than that in the experiments at 0.3 Joule. A linear extrapolation is considered reasonable based on the linear relationship between resuspended fraction and specific impact energy as shown in Fig. 4. In these measurements impact energy was varied by a factor of 4 (0.07 and 0.28 Joule). It is judged that extrapolation of impact energy by a further factor of 15 can be justified. It is therefore applied here, but an experimental verification at higher specific energy impact should still be performed in future.

Several impact experiments have been carried out with different types of contaminated test surfaces and types of dry deposited particulates at impact energies of 0.3 Joule. Results for an airflow velocity of 6 m/s acting on freshly deposited particulate are selected here. Very loosely attached particles are being removed before the first impact. The measured burst release fractions for different surfaces and particulates show relatively small variation about the average value. This average value of rounded $6 \cdot 10^{-3}$ for the first resuspension burst at an impact energy of 0.3 Joules is used to extrapolate to the resuspended burst fraction of respirable particles from contaminated sheet steel suffering a 9 m drop onto a hard target, leading to a value of about 10%. This value for the resuspended fraction is quite conservative because the experiments were performed with freshly deposited particles which were only being subjected to 1 hour of airflow at 6 m/s before the first impact. A release fraction of 10% is unrealistically high for contamination on surfaces which have already experienced some handling and treatment.

Regarding burst release fractions for fixed contamination, the experimental results for resuspension of wet deposited salts are considered. Wet deposited contamination showed a burst release fraction being a factor of about 100 lower compared to dry deposited contamination. These results justify to adopt an airborne release fraction of 10^{-3} for fixed contamination in case of a 9 m drop. The wet deposited contamination or contamination after treatment by a water or water/glycerine spray as used in the experiments show a much stronger attachment to surfaces compared to a fresh contamination by dry deposition, but such a contamination is still being removable by a common dry wipe. According to the explanations in SSG-26, para. 508.2 [2], fixed contamination should still be much less readily suspended.

Regarding release to the environment of resuspended particles entrainment in air and following transport by air flow to openings in the packaging generated by the accident impact are required. Only a fraction of local airflows induced inside the packaging will contribute to the airflow which leaves the breached packaging through openings. Also competing redeposition onto internal surfaces has a counteracting effect. On the basis of experiments with LSA type materials, e.g., [5], [6], and also supported by the above discussion of airborne release mechanisms to the outside of a breached packaging, it is assumed that only 10% of the generated respirable dust escapes from the interior to the atmosphere outside of the package (retention factor of 0.1 adopted for the packaging). By analysis in [5], [6] it was derived that a fraction of $3.3 \cdot 10^{-6}$ of the airborne release from a package as respirable particulate is inhaled by a person nearby in downwind direction from the site of a severe accident with mechanical impact involving an IP-2 or IP-3 package.

The intake, expressed by multiples of A_2, of a person close to an accident site from the considered severe accident is given by contamination level (A_2/cm²) · surface area (cm²) · resuspension release fraction (-) · retention factor of packaging (-) · inhaled fraction of airborne release to atmosphere (-).

Non-fixed and fixed β/γ contamination are assumed to be at the respective contamination limits at the same time. These two contributions to the exposure expressed by intake of multiples of A_2 are therefore added here. This holds also for non-fixed and fixed contamination by α emitters. Finally, from this analysis an intake from β/γ contamination of $6.6 \cdot 10^{-10}$ A_2 (non-fixed) + $1.3 \cdot 10^{-8}$ A_2 (fixed) = $1.4 \cdot 10^{-8}$ A_2 and from α contamination of $1.5 \cdot 10^{-10}$ A_2 + $2.9 \cdot 10^{-7}$ A_2 = $2.9 \cdot 10^{-7}$ A_2 is obtained.

In each case the intake remains well below 10^{-6} A_2 and accordingly below an effective dose of 50 mSv as safety criterion.

Conclusions

Recent experimental results on the resuspension of contamination due to mechanical impact and air flow in combination with data on retention properties of IP-2 and IP-3 packages support the safety basis for SCO-II.

Compared with the safety considerations in SSG-26, the new analysis

- Considers conservatively a ten times larger contaminated area,
- Takes into account in the calculation explicitly not only β/γ but also α emitters,
- Uses measurement based resuspension data,
- Uses measurement based package retention data.

The new assessment confirms that the activity intake by a person staying in the vicinity of an accident involving a transport package containing SCO-II remains below an effective dose of 50 mSv and therefore meets the safety criterion the regulations are based on.

The assessment contains quite some conservatism, but could still be improved by resuspension experiments designed especially for the case of SCO-II under accident conditions of transport, e.g. taking into account higher impact energies than in previous experiments.

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