Proceedings of the 19th International Symposium on the
Packaging and Transportation of Radioactive Materials
PATRAM 2019
August 4-9, 2019, New Orleans, LA, USA

EXPERIMENTAL DETERMINATION OF RESUSPENSION FROM SURFACE CONTAMINATED OBJECTS (SCO) IN SEVERE MECHANICAL ACCIDENT CONDITIONS AND CONCLUSIONS REGARDING TRANSPORT SAFETY

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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 SCO.

The contamination limits for SCO-II objects are derived from accident considerations requiring that the potential radiation exposure from inhalation of airborne released contamination of a person close to an accident location would remain below 50 mSv effective dose. Of central importance are accordingly quantitative data on the amount of respirable particulates that becomes airborne by resuspension from contaminated surfaces caused by accident impacts. Contamination limits distinguish between non-fixed and fixed contamination, a distinction which is not based on well-defined criteria. For practical purposes it is assumed that non-fixed contamination is removable by applying a wipe or smears with e.g. a dry cloth or filter paper.

An experimental set-up has been applied to measure release fractions from surfaces with defined contamination induced by impact forces simulating the drop of a package from e.g. 9 m onto a hard target.

Resuspension of particulates from contaminated surfaces depends on the distribution of adhesive forces to the surface and induced acceleration forces from surface vibrations caused by mechanical impact. Main features of the small scale apparatus are: The surface contamination of metallic plates is prepared in a defined way by deposited particulates, considering both fixed and non-fixed contamination. The induced surface vibrations and acceleration amplitudes from a variable fall hammer impact acting onto the contaminated plate are monitored by a small dynamic acceleration sensor (g-sensor) as used in drop tests of packages. The applied detection and size classification method for single particles released by vibration forces exceeding adhesions forces is very sensitive down to re-suspension fractions in the range of 10^{-7}.

Conservatively adopting impact forces leading to peak vibration amplitudes of 2000 g potential radiation exposure of a person close to an accident location has been analysed. Even under very cautious assumptions of an IP-2 package filled with 100 m² of metal sheets contaminated at the limits for SCO-II objects the exposure of an individual would remain substantially below the 50 mSv effective dose criterion of the IAEA Transport Regulations.

INTRODUCTION

According to the IAEA Transport Regulations SSR-6 [1] solid objects that are not radioactive by themselves but contaminated by radioactive material on their surface may be classified for transport as surface contaminated objects (SCO). For the subgroup SCO-II, being in the focus of this paper, limits apply for the activity of contamination per surface area of the objects and the dose rate in their vicinity (Paras 413 and 414). 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 a previous paper at PATRAM 2016 [2] experiments available at that time had been analysed regarding the release of surface contamination by mechanical impact. Later a new series of experiments was carried out [3] aiming on overcoming deficiencies of the older experiments regarding the maximum acceleration of the sample surface and the difficulties from classification of contamination being fixed or non-fixed.

In this paper the new experiments are described, their results are analysed and conclusions about the safety basis for SCO-II regarding radiological consequences of transport accidents are presented.

PREVIOUS INVESTIGATIONS ABOUT THE RESUSPENSION OF CONTAMINATION

The airborne release of contamination on surfaces is generally called resuspension. Inhalation of particles resuspended due to induced vibration is considered as the main contribution to the radiation dose to a person at the site of a transport accident involving shipment of SCO-II. Of interest for inhalation are respirable particles of sizes < 10 µm aerodynamic diameter. The adhesive forces for particles on surfaces show pronounced particle size dependence: The resuspension processes for smaller particles, e.g. < 10 µm, are less effective compared to larger particles. Resuspension rates further depend significantly on characteristics and condition of the resident surface material, time since contamination, parameters of the mechanical impact (vibrations) and other characteristics. It is therefore important that the considered experiments represent, as close as possible, the conditions of the application case.

Former investigations of resuspension have been designed for other purposes than analysing the release of radioactivity from packages containing SCO under accident conditions of transport. For instance, in a former project, reported at PATRAM in 2016 [2], the experimental set-up had been designed for analysing the resuspension by slow air flow and moderate impact. Obtaining results for accident conditions of transport from such experimental results had required significant extrapolation. The current experiments aim on overcoming these difficulties, at the same time taking into account the results of the former studies regarding the dependence of resuspension from the condition of the surface and the way of applying the contamination.

NEW INVESTIGATIONS – EXPERIMENTAL SET-UP AND CHALLEGES

For assessing the safety of transport packages the IAEA transport regulations define tests for analysing the damage to the package under accident conditions of transport. Since SCO-II is transported in industrial packages IP-2 and IP-3, the response of such packages to the regulatory 9 m drop test should define the conditions for determining the resuspension. The new experiments were set up for simulation a covering acceleration of 2000 g.

The experimental set-up is shown in Fig. 1.

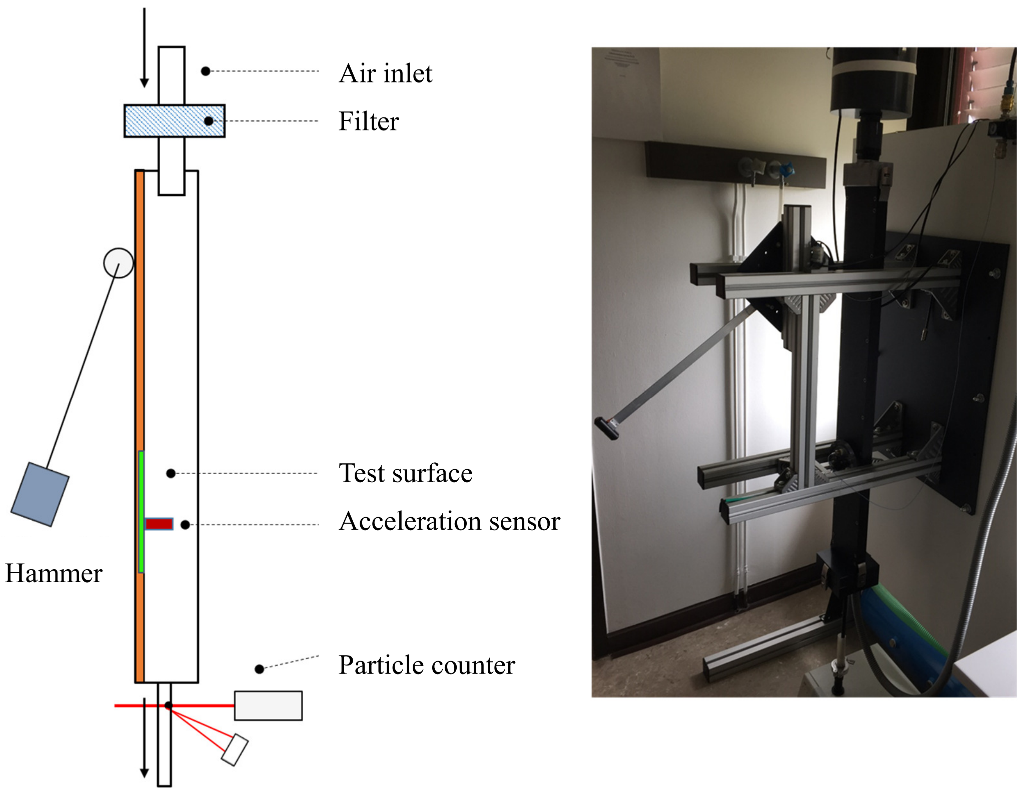

Fig. 1 Experimental set-up

It is well known that the resuspension of contamination strongly depends on the properties of the contaminated surface, the way the contamination has been put on the surface and the treatment of the surface after having been contaminated. One major aim of the new experimental studies was to find an upper value for resuspension of "fixed" contamination. For identifying proper conditions the results of the previous study [2] have been taken into account. A standard procedure has been defined for use in most of the experiments, accompanied by variations of this standard procedure.

In the standard procedure the test surface was contaminated by wet deposition of sprayed aqueous solutions of NaCl and in some cases CsCl. Then the test surfaces were dried at a temperature of 125 °C for 15 minutes and analysed immediately. The wet contamination led to elevated adhesion of the contamination compared to dry deposition of particles. This condition was selected in order to approach realistic conditions established by common handling procedures and decontamination measures applied to the real surfaces of contaminated objects prior to transportation leaving behind a contamination with stronger adherence (compared to the fresh contamination). On the other hand, this contamination is still representative for an upper resuspension ratio for fixed contamination, since variations of the procedure showed that less fresh contamination and higher humidity led to significantly lower resuspension rates.

The typical size of the particles of the contamination for all experiments was 5 µm.

The test surface consisted of round plates of a diameter of 9 cm.

A very sensitive aerosol measurement procedure was employed allowing for the quantification of the resuspended fraction in a regime above 10^{-7}.

NEW INVESTIGATIONS - RESULTS

There were carried out series of experiments with varying parameters: drop height (varied between 3.8 and 85.4 cm, acceleration spectra were measured showing equivalence to accelerations up to 2000 g), air humidity (45 %, 95 % relative humidity), duration and treatment after drying before impacting (wiping or not, impact immediately or after 15 min).

The experimental data generated in this study were used to calibrate a resuspension model. This model was subsequently used to extend the data base for the resuspended fraction into regions of the controlling parameter space that were not covered by the experiments. This concerned especially the extrapolation to the full range of respirable particles (up to 10 µm particle size).

Finally, for fixed contamination and 2000 g acceleration an upper limit of the resuspension fraction (mass of respirable particles per total mass of contamination) of $4 \cdot 10^{-4}$ was obtained. Due to the small number of particles counted in the experiments the uncertainty of the calculated resuspension fraction may reach 100 %. This result is in good agreement with the value for fixed contamination taken (after extrapolation over a wide range of impact energy) from the earlier study [2].

CONSIDERATIONS FOR THE SAFETY BASIS FOR SHIPMENTS OF SCO II

For assessing the safety of SCO-II under accident conditions of transport 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/cm^3) contaminated on one side on 100 m^2 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.

The contamination on the accessible surface is set conservatively to the limits set in para. 413 of SSR-6: 400 Bq/cm^2 for β/γ and low toxicity α emitters and 40 Bq/cm^2 for all other α emitters For the resuspended contamination conservatively the following A_2 values of Table 3 of SSR-6 are applied: 0.02 TBq for β/γ and low toxicity α emitters and $9 \cdot 10^{-5}$ TBq for all other α emitters. 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.

A central issue for this consequence analysis is to assess the fraction of the non-fixed and fixed contamination on the 100 m^2 of sheet-steel that could be released from the surface into the damaged packaging as airborne particulate with particle sizes in the respirable size range below 10 µm aerodynamic equivalent diameter. Data for non-fixed contamination are taken from a previous investigation [2], the resuspension fraction (mass of respirable particles per total mass of contamination) for non-fixed contamination is taken as 10^{-2}. For fixed contamination, as described above a resuspension fraction of $4 \cdot 10^{-4}$ is taken from the new experiments.

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., [4], [5], 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 [4], [5] 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 fraction (-) • retention factor of packaging (-) • inhaled fraction of airborne release to atmosphere (-).

Table 1 Inhaled activity from an accident involving a shipment of SCO-II based on the values derived in this study

Contamination [A_2 / cm²]	Surface of SCO-II [cm²]	Fraction of resuspended respirable particles	Fraction of resuspended particles released from the package	Inhaled fraction of release from the package	Inhaled Activity [A_2]
$2 \cdot 10^{-8}$ Non-fixed β/γ and low toxicity α	10^{6}	10^{-2}	10^{-1}	$3.3 \cdot 10^{-6}$	$6.6 \cdot 10^{-11}$
$4 \cdot 10^{-5}$ Fixed β/γ and low toxicity α	10^{6}	$4 \cdot 10^{-4}$	10^{-1}	$3.3 \cdot 10^{-6}$	$5.3 \cdot 10^{-9}$
$4.4 \cdot 10^{-7}$ Non-fixed α	10^{6}	10^{-2}	10^{-1}	$3.3 \cdot 10^{-6}$	$1.5 \cdot 10^{-9}$
$8.9 \cdot 10^{-4}$ Fixed α	10^{6}	$4 \cdot 10^{-4}$	10^{-1}	$3.3 \cdot 10^{-6}$	$1.2 \cdot 10^{-7}$

Each individual intake as well as the sum over all listed contributions remain well below 10^{-6} A_2 and accordingly below an effective dose of 50 mSv as safety criterion.

CONCLUSIONS

Experimental results on the resuspension of contamination due to mechanical impact [2,3] in combination with data on retention properties of IP-2 and IP-3 packages [4,5] support the safety basis for SCO-II regarding the dose for a person in the proximity of an accident site. The new experimental data took into account accelerations up to 2000 g and aimed in estimating an upper limit for resuspension of fixed contamination.

The assessment contains quite some conservatism that was identified in the study [2].

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