Experimental modeling of radioactive particle resuspension

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Abstract

Freshly fallen radionuclide material deposited after an energetic release from a Radiological Dispersal Device (RDD) or by a nuclear accident can be resuspended back into the air by the wind. Resuspension of radionuclide materials was investigated in a specially built wind tunnel. Resuspension factors at locations 52.5 cm and 165 cm downstream from the initial fallout were calculated to be 6.53E-04 ± 11.5% (1/m) and 1.51E-04 ± 15.62% (1/m) respectively. Experimental values of resuspension factors can vary by 2 to 3 orders of magnitude [1]. However resuspension factors found from this experiment were only 51% higher and 65% less compared to values found using a modified Garland relationship [2].

1. Introduction

The entrainment or suspension of particulate material into the atmosphere has long been of interest, and most of the early scientific work was concerned with erosion and soil transport. Since the advent of nuclear technologies, interest has also been on health aspects due to resuspension of deposited material from nuclear weapon test zones or areas that are affected by accidental releases from the nuclear industry [3]. Therefore, the phenomenon of resuspension of radioactive particles is not a new topic. However, this topic has hardly ever been viewed in the perspective of a terrorist attack such as an RDD event.

Particle resuspension is a very complex process and it is affected by numerous parameters such as wind shear, raindrop impact and mechanical disturbances. Most of these parameters can easily be controlled inside a wind tunnel compared to outdoor studies where one does not have control over some parameters such as wind shear. Even though numerous resuspension studies were done inside wind tunnels to study the resuspension process, a very little work has been done using radioactive material to study this process due to radioactive contamination problems. Studying the resuspension process using live-agents inside a wind tunnel helps to isolate and to control these parameters and to investigate countermeasures that will help to reduce the exposure due to the inhalation of resuspended radioactive materials after a Radiological Dispersal Device (RDD) event.

2. Resuspension experiment

Resuspension experiments were conducted in a 10 m long, open-ended wind tunnel located inside Wehrwissenschaftliches Institut für Schutztechnologien (WIS) facility located in Munster, Germany. The WIS facility was equipped with appropriate ventilation system to handle experiments with live-agent radioactive materials.

Figure 1 shows the layout of this wind tunnel experimental setup and the locations of contaminated plates. This wind tunnel was built exclusively for the purpose of radioactive resuspension experiments and it can generate winds at the test section up to 7 m/s using 3 fans (Fan1, Fan2 and Fan3) located at the end of the wind tunnel. Radiation monitoring devices (Mic.1, Mic. 2, Mic. 3 and Mic. 4) were placed under the floor of the wind tunnel. These detectors were shielded using lead bricks in-between them.

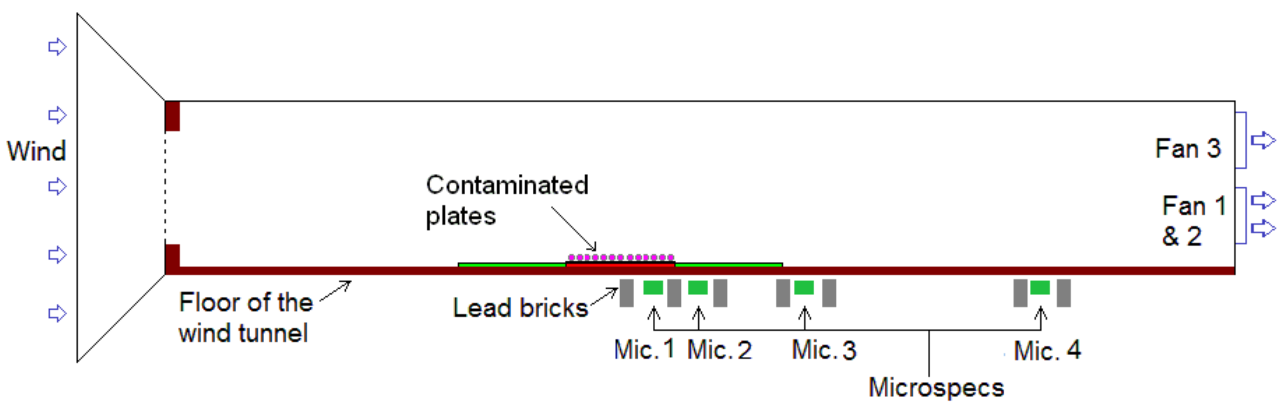

Figure 1: General layout of the open channel wind tunnel

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Radioactive ^{140}La has a relatively short half-life at 1.679 days (± 0.01%) [4], hence mixture of radioactive and non-radioactive La_2O_3 was used as contamination material to study the radioactive particle resuspension inside the WIS facility wind tunnel. Radioactive $^{140}La_2O_3$ powder was produced in a research reactor facility near Hamburg, Germany, by irradiating 1.0 ± 0.0005 g of non-radioactive La_2O_3 power in a high-flux thermal neutron field. The nominal activity of 2 Ci was achieved during the day of active resuspension experiment after mixing a measured amount of radioactive powder with non-radioactive La_2O_3 powder to achieve a total starting mass of 30.0 ± 0.0005 g.

The La_2O_3 powder mixture was dispersed inside an environmentally controlled contamination chamber at the WIS facility, simulating a high-energy dispersion by a RDD event. After 8 hours of gravitational settling, La_2O_3 powder was collected onto 50 ± 0.5 cm square painted smooth sample plates. These contaminated plates were carefully brought into the wind tunnel and placed on the floor of the test section.

2.1 Radiation measurements during resuspension experiment

Radioactive $^{140}La_2O_3$ emits both beta and gamma radiation during its decay process. Decay of ^{140}La, initially emits 100% beta radiation, some of the ^{140}La reaches stable ^{140}Ce via direct beta decay while the others will release gamma rays before reaching stable ^{140}Ce [5] . One can measure the beta count rate with a large area contamination monitor placed above the contamination plates inside the wind tunnel as a marker for number of radioactive atoms present in La_2O_3 powder mixer. Having an area contamination monitor inside the wind tunnel will disturb the aerodynamic properties of the test chamber; therefore, the radiation monitoring system was placed under the wind tunnel floor to measure the instantaneous radiation fields inside the wind tunnel during particle resuspension process. Mobile Microspecs manufactured by Bubble Technology Industries (BTI) with 4"x4"x16" NaI(Tl) crystals were selected as a suitable candidate for monitoring this penetrating gamma[6]. The efficiencies of the detectors for the configuration shown in the experimental setup were calculated performing shielding calculations using the Monte Carlo N-Particle eXtended (MCNPX) software [7].

Table 1 summarizes the background and decay corrected counts per second (cps) measurements of Mobile Microspecs readings immediately before (***Before wind)*** and after (***After wind)*** plates were exposed to the wind, and their corresponding errors due to measurements and calculations.

Table 1: Background and decay corrected cps and corresponding uncertainties of Mobile Microspec readings

	Before wind		***After wind***	
	cps	**% error**	**cps**	**% error**
Mic.1	696538	7.5%	679839	7.5%
Mic.2	28362	7.5%	35795	7.5%
Mic.3	0	-	526	7.6%
Mic.4	43	7.6%	165	7.6%

2.2 Resuspension factor

Activity based resuspension factors (K_A) for the locations downstream of contaminated plates were calculated using Equation (1), by dividing the decay corrected accrued activity/m^3 (ΔN) of deposited La_2O_3 powder on the plates and in the air after wind by the decay corrected initial activity/m^2 ($N_{Mic.1}$) of the contaminated plates measured prior to the wind during resuspension experiment.

$$K_A = \frac{\text{Decay corrected acccrued activity on the plate and the air after wind } (\Delta N)}{\text{Decay corrected absolute CPS of contaminated plate before wind } (N_{Mic.1})} \quad (1)$$

The corresponding resuspension factors at locations 52.5 cm and 165 cm downstream from the initial fallout were calculated to be 6.53E-04 ± 11.5% (1/m) and 1.51E-04 ± 15.62% (1/m) respectively. These resuspension factor values were compared against the values found from the modified Garland equation as given in Equation (2).

$$K_G(t) = \left(\frac{1.2\times10^{-6}}{t} + 10^{-9} \right) e^{-\lambda \cdot t} \tag{2}$$

Here K_G is the empirically derived resuspension factor for wind driven resuspension for climates typical to the United Kingdom, t is the time after deposition in days and λ is the radioactive decay constant measured in 1/days. The corresponding K_G for the WIS facility resuspension experiment for ^{140}La after 4 minutes of wind driven resuspension was calculated to be 4.32E-04 ± 3.2% (1/m). Table 2 tabulates the activity based resuspension factors found using radiation measurements at the locations 52.5 cm and 165 cm downstream and the comparison of these results against modified Garland equation.

Table 2: Comparison of activity based resuspension factor values against the modified Garland Equation

Locations of interest downstream of initial fall out	K_A (1/m)	% difference compared to modified Garland equation
52.5 cm	7.55E-04 ±11.5%	52% higher
165 cm	1.51E-04 ± 15.6%	65% less

Usually experimental values of resuspension factors can vary by 2 to 3 orders of magnitude [1]. These results show that activity based resuspension factor values found using the Garland model matches very well with the experimental resuspension factor values.

3. Conclusion and future studies

The research has demonstrated that it is possible to successfully model the wind driven radioactive resuspension experiments inside a controlled wind tunnel without having to conduct expensive field exercises. The cumulative wind driven radioactivity based resuspension factors do not provide adequate information about the particle size distribution and what fraction of these particles can get into human respiratory track. In future studies the cumulative resuspension factor found using these experiments will be divided into bin-by-bin particle size resuspension factors. The bin-by-bin particle resuspension factor will be able to use to find the effect of resuspended particles in the human respiratory track since particles with different sizes deposit different regions of respiratory track imposing health hazard for people living in the vicinity and the downstream of the RDD fall out.

4. Acknowledgments

Funding for this work was provided by the Chemical, Biological, Radiological, Nuclear and Explosive (CBRNE) Research and Technology Initiative, under project CRTI 05-0014RD. The authors wish to express gratitude to Dr. Tom Cousins, Dr. Nikolaus Schneider, Mr. Jonathan Hill, Mr. Ronald Rambousky, Dr. Joe Shinn, Mr. Marc Desrosiers, Mr. Trevor Jones, Mr. Jason Brown, and Mr. Joe Chaput for their assistance with the experiments, and Mr. Ragu Satgunanathan for assistance with the literature review.

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