Measuring Concentrations of Particulate ^{140}La in the Air

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Abstract

Air sampling systems were deployed to measure the concentration of radioactive material in the air during the Full-Scale Radiological Dispersal Device experiments. The air samplers were positioned 100-600 meters downwind of the release point. The filters were collected immediately and analyzed in a field laboratory. Quantities for total activity collected on the air filters are reported along with additional information to compute the average or integrated air concentrations.

Keywords:

Radioactivity, airborne; Air sampling; Inhalation; Emergency planning

Introduction

During an incident where radioactive material may be released to the atmosphere, air samplers can be used to assess the concentration of airborne radioactivity. These measurements can confirm the release of radioactivity and can aid in estimating the dose that an impacted population received as a consequence of inhaling the material either during the passage of the plume, or from deposited material that has been resuspended. Different techniques are employed depending on whether the material is a gas or airborne particulate. Only particulate sampling techniques were employed here because the design of the experiment produced radioactive particulates, but no radioactive gases.

Airborne concentrations of radioactive material are often measured and compared to a Derived Air Concentrations (DACs) which are frequently present in regulatory guidelines. A DAC will exist for an individual radionuclide, and is calculated based on an Annual Limit on Intake (ALI) (IAEA 1999) for the radionuclide of interest. The DAC assumes that an individual will be working for 2000 hours in the environment where the concentration of the radionuclide in the air is constant and that the person is breathing at an easy rate. In Canada, the ALI is calculated based on a committed effective dose (CED) of 20 mSv (CNSC 2010), while the US uses the higher dose of 50 mSv (US CFR 2015). While these regulations are written for occupational exposure situations, DACs and ALIs, and the calculations of CED can also be found in documents related to radiological emergency response planning (FRMAC 2010).

This paper reports on air sampling performed in support of the Defense Research and Development Canada (DRDC) Full-Scale Radiological Dispersal Device Experiments and Models (FSRDD) project trials in June of 2012. On June 6 and 12, approximately 31.3 GBq and 36.3 GBq, respectively, of ^{140}La was explosively released (Green 2016). The ^{140}La was in the form of lanthanum oxide powder with particle sized of 2-6 µm. For this experiment, the air concentration measurements were performed primarily for checking the performance of the dispersion models. The major focus of these measurements was to sample the air during the time covering the passage of the debris cloud over the area. A smaller number of samples were collected to examine resuspension of the deposited radioactive material while measurement activities were carried out in the contamination field.

Materials and Methods

The air sampling was performed by two groups operating at different distance scales and flow rates. The two measurement efforts will be referred to as “near-field” and “far-field.”

Near-field Air Samples

For the near-field air sampling, equipment was borrowed from a cache maintained by the Federal Radiological Monitoring and Assessment Center (FRMAC) for use in the event of a large scale radiological or nuclear incident in the United States. The sampling was performed with Staplex model TFIA High Volume air samplers (Staplex, Brooklyn, New York, USA). A 10 cm diameter glass fiber filter was used on the front of the air sampler to collect the airborne particulate. The filters have a stated efficiency of 99.98% for particles larger than 0.3 μm, providing high collection efficiency for a majority of the post-dispersal particle size distribution.

Staplex air samplers have flow rate meters and run time counters to assist in determination of the total volume drawn through a filter. In the days preceding the first release, the flow rate of each sampler was measured at the testing range using the Staplex calibration kit and the flow rate meters were adjusted to reflect the correct value.

The air samplers were positioned at 19 locations 100, 150 or 250 meters from the release site, and in a wedge covering 90° toward the northeast. At each location, a sampler was set at a height of 1.5 meters above the ground. Additional samplers were placed atop two 10 meter tall towers at 100 meters from the release site. The locations and flow rates of the near-field samplers are shown in Table 1. The air samplers require 120V AC to operate; portable gasoline-operated generators were brought to the test range to provide the needed power. A single generator was typically used to run 2-3 air samplers.

When collecting an air sample, a filter is placed in the air sampler and the pump is started. Some relevant information about the sample site (sample location, start time, start flow rate, run time counter at start) is recorded on a sealable plastic bag that is attached to the pump. The plastic bag is used to collect the filter for analysis. When a filter is collected, it is placed in the plastic bag and additional information is recorded (stop time, stop flow rate, run time counter at stop). Depending on the sample, the generator may have run out of fuel before the collection team arrived, thus the information from the run time counter was used to compute the total air volume drawn through the filters. Each filter was placed in a second sealable plastic bag as it came through the personnel decontamination station.

Some of the filters were not collected following the second release. This was a consequence of warmer temperatures which limited the working time of the collection teams, and a reduction in the number of people available to enter the contaminated area.

In some instances new air filters were installed and the pumps restarted. These filters were intended for use in examining the resuspension of the radioactivity as a result of the weather or measurement activities in the freshly contaminated area.

Far-field Air Samples

The far-field air samplers were only operated during the first release. These samplers were of two designs developed by Pacific Northwest National Laboratory (PNNL) using a previously designed filter holder. One design was based upon a gasoline-powered "Little Wonder" (LW) leaf blower. The LW air sampler, as fitted with an aftermarket six gallon gasoline tank, has an estimated endurance of approximately twelve hours. The other design was based upon a blower turned by a 24 VDC Scott Motor (SC). Power for the DC motors was supplied by six deep cycle marine batteries. At the highest rotational speed, these batteries can power the blower for 40 minutes to one hour. The two models for the far-field air samplers are displayed in Figure 1.

Both air sampler designs drew air in through a vertical 20 cm (8 in) inner diameter perforated cylindrical filter holder. The air filters, made from 3M^{TM} electrostatic filter paper, were approximately 56 cm (22 in) in width by 80 cm (32 in) in length. The air filters were held by O-rings at the top and bottom to the cylinders. Both air sampler designs used 2.13 m (7 foot) long PVC exhaust pipes with propeller anemometers mounted near the exit. The gasoline systems were preset to 28317 Lpm (1000 cfm) and operated from about half an hour before the release until the filters were collected several hours after the release. The electric air samplers were started remotely a few minutes before the release and shut down remotely approximately 10 minutes after the release. The anemometers measured both electric systems at approximately 24777 Lpm (875 cfm). The locations and flow rates of the different systems are shown in Table 2.

When the filters for the far-field samplers were collected, they were folded to encapsulate any material collected on them. The folded filter was placed into a 500 mL plastic beaker with a screw top cap. The beaker was placed into a sealable plastic bag.

Sample Analysis

The air filters were analyzed with a Detective-EX high-purity germanium (HPGe) detector from ORTEC (801 South Illinois Avenue, Oak Ridge, Tennessee, 37830, USA). The Detective-EX has an efficiency of approximately 14% relative to a 7.62 cm diameter, 7.62 cm long sodium iodide detector. The Detective-EX was placed with the detector pointing up. A 6mm sheet of lead was formed into a collimator to reduce some of the contribution from the natural background radioactivity. A wire mesh with 2.5cm grid spacing was used to offset the samples from the detector endcap by 5 cm. An example of the gamma ray spectrum from a filter is shown in Figure 2.

The near-field filters were counted inside the sealed plastic bags and the far-field filters were counted inside the beaker and plastic bag combination. The efficiencies for the detector were measured for these sample geometries in the laboratory 1 month prior to the first Trial. Periodic background spectra were collected, and no evidence of contamination in the counting area was shown. Typical acquisition times of 300 s were used when analyzing the near-field samples to accommodate the short half-life of ^{140}La and to be able to measure all of the samples on the day they were received. Longer count times were used for the far-field samples.

Results and Discussion

Near-field air filter activities

The gamma ray spectra collected for the air filters were analyzed for total ^{140}La activity. For the air filters which were exposed to the radioactive debris cloud, the activities were corrected for radioactive decay back to the time of the release. These values are reported in Table 3 and Table 4. Many of the filters away from the centers of the plumes showed no detectable ^{140}La activity. The narrowness of the plumes are apparent from the fact that, even with a relatively dense array, only the samplers closest to the center of the plumes recorded significant activity.

Far-field air filter activities

The gamma ray spectra collected for the air filters were analyzed for total ^{140}La activity. The counting time varied with longer counts being performed on filters with less activity. The counting time varied from 30 minutes to 17.8 hours. The results are shown in Table 5.

Inhalation dose

The activity on the filter can be used to estimate the inhalation dose an individual would have received if they had been standing at the sampler location as the cloud passed. The activity concentrations of the air has not been interpolated or extrapolated between the sample locations. The committed effective dose considers the breathing rate (*B*), exposure time (*T*) and the concentration of radioactivity in the air (*C*) to determine the amount of activity that ended up being available for absorption into the body. The amount of activity is combined with an effective dose coefficient (*e*) to determine the likely dose.

$$CED = B[m^3\ h^{-1}] \times C[B\ m^{-3}] \times T[h] \times e[Sv\ Bq^{-1}]$$

The highest activity on a near-field air filter was 3.85x10^4 Bq which occurred in the second trial at 100 m and 67.5°. From ICRP 119, Table A.1 (ICRP 2012) the dose coefficient for inhalation of ^{140}La (Type M – moderate rate of absorption, 5 µm activity mean aerodynamic diameter (AMAD)) for an individual working in the environment is 1.5x10^{-9} Sv Bq^{-1}. The Breathing rate for light activity is 1.2 m^3 h^{-1} from ICRP 66 (ICRP 1994). Using these values, the highest inhalation dose that would have been received at this location by the passing cloud is:

$$CED = 1.2\ m^3\ h^{-1} \times \frac{38{,}500\ Bq}{85.2\ m^3} \times 5160\ s\ \times \frac{1\ h}{3600\ s}\ \times\ 1.5 \times 10^{-6}\ mSv\ Bq^{-1} = 1.2 \times 10^{-3}\ mSv.$$

The highest activity collected on a far-field air filter, was 5.87x10^5 Bq, collected in the first trial at 600 m and 37.5°. Using the same assumptions described above, the highest observed CED at 600 meters downwind is:

$$CED = 1.2\ m^3\ h^{-1} \times \frac{587{,}000\ Bq}{248\ m^3} \times 600\ s\ \times \frac{1\ h}{3600\ s}\ \times\ 1.5 \times 10^{-6}\ mSv\ Bq^{-1} = 7.1 \times 10^{-4}\ mSv.$$

The regulatory guidelines in Canada calculate the Annual Limit on Intake based on a CED of 20 mSv. This corresponds to a DAC for ^{140}La of $5.56 \times 10^3\ Bq\ m^{-3}$. The activity concentrations seen in these measurements are well below the DAC.

Debris cloud concentration of radioactivity

The concentration of radioactivity in the air rather than the amount of activity on the filter is of more interest for comparison with atmospheric dispersion models. To determine the concentration, a better estimate of the time required for the cloud to pass by the samplers is needed. The second-by-second count rate information from the array of Thermo RadEye detectors (Thermo Scientific, 27 Forge Parkway, Franklin, MA, 02038, USA) (Green 2016) was used to estimate when the cloud was present at the different stations. Deviations from the average count rates calculated for the minutes preceding and following the event were used to define the cloud transit time (see Figure 3). The times from the RadEye detectors centered along the wind direction were used to produce empirical fits to the cloud durations as a function of distance from the detonation site (Figure 4). These times and the activities listed in Table 3 and Table 4 provide the necessary information to calculate average radioactivity concentrations in air at the sampling locations. The average concentrations are useful for comparison to atmospheric dispersion model results (Neuscamman 2016; Purves 2016).

Resuspended radioactivity

Additional air samples were collected following the first trial during the time that experimenters were active in the contaminated area to collect samples, perform surveys, etc. These measurements are used to examine the amount of the activity that was deposited on the ground during the experiment that is resuspended into the air. The air concentrations were calculated according to the equations given below. Resuspension is a complicated process which can depend upon the properties of the deposited material, the weather, the surface type and the physical activities occurring in the area. For this study, it is necessary to simplify the model and assume that the exchange of material between the ground and the breathing zone (first few meters above the ground) is a steady state process. In this way, we can assume there is a fixed air mass, and that radioactive decay is the only change which occurs.

$$A = e^{-t_{spec}/\tau} \int_{t_{start}}^{t_{stop}} F C_0 e^{-t/\tau} dt$$

$$C_0 = \frac{A e^{t_{spec}/\tau}}{F\tau\left[1 - e^{-t_{stop}/\tau}\right]}$$

A	Activity on the air filter (Bq)
t_{spec}	Time from the end of the air sample to the collection of the HPGe spectrum (h)
t_{start}	Start time for the air sample (h): $t_{start} = 0$
t_{stop}	Stop time for the air sample (h)
τ	Decay time for the radioactive material (h): $\tau = t_{1/2} / ln(2)$ = 58.2 hours
F	Air sample pump flow rate ($m^3\ h^{-1}$)
C_0	Air concentration at the start of the sample collection (Bq m^{-3})

The analysis of the air filters result in the amount activity at the time of the analysis. These activities are corrected back to the time the air sample was collected. The corrections also account for the radioactive decay while the sample was collected. The final concentration of resuspended material reported is the

effective air concentration at the start of the sample collection time. The results are shown in Table 6 and Table 7. The results indicate that resuspended ^{140}La activity was observed in several instances; locations where the highest levels of resuspended activity were collected are consistent with the axis of the plume.

Conclusions

Equipment intended for the measurement of airborne concentrations of radioactivity in response to a radiological or nuclear emergency were successfully employed during a Radiological Dispersal Device experiment. The analyses of the samples in the field were accomplished with sufficient sensitivity so that immediate questions regarding potential inhalation doses due to the radioactive debris cloud could be addressed.

The far-field air samplers were new configurations, and this experiment demonstrated their suitability for this task. Both types of air samplers functioned correctly in the field. The electric system has the advantage that it could be started and stopped remotely, allowing the system to be started just prior to the release and shut down shortly after the plume passage. As configured, the gasoline powered air samplers must be started with a pull cord prior to the release and manually shut down after re-entry was permitted. However, the aftermarket gasoline tank allowed for an extended operation that would be useful if monitoring for a release where the likely release time is poorly defined beforehand.

Air sampling to investigate the air concentrations resulting from resuspension of the radioactive material was performed. Weak positive collections were observed, primarily in samples collected near the plume axis. Previous studies of resuspension (Maxwell and Anspaugh 2011) indicated that the low air concentrations observed were expected.

For these experiments, a fairly heavy density of instruments was employed. The design of the experiment also allowed for selection of acceptable weather conditions so that good instrument coverage would be assured. In an actual emergency, pre-deployed samplers are likely to be a sparse array. These sparse data, along with validated meteorological dispersion models, will likely be relied upon for plume reconstruction. Dose reconstructions will also rely upon deposition, and potentially utilize unconventional air samplers (e.g. home or vehicle air filters, etc). In some scenarios, it may be possible to deploy portable, field-capable samplers into the path of the plume.

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Figures

Figure 1: The image on the left shows the gasoline powered air sampler adapted from a leaf blower. The image on the right shows the air sampler adapted from a blower which is actuated by a DC electric motor. Note that in these images, the frame for the air filter is installed on the gasoline powered air sampler, but has not yet been placed on the electric air sampler.

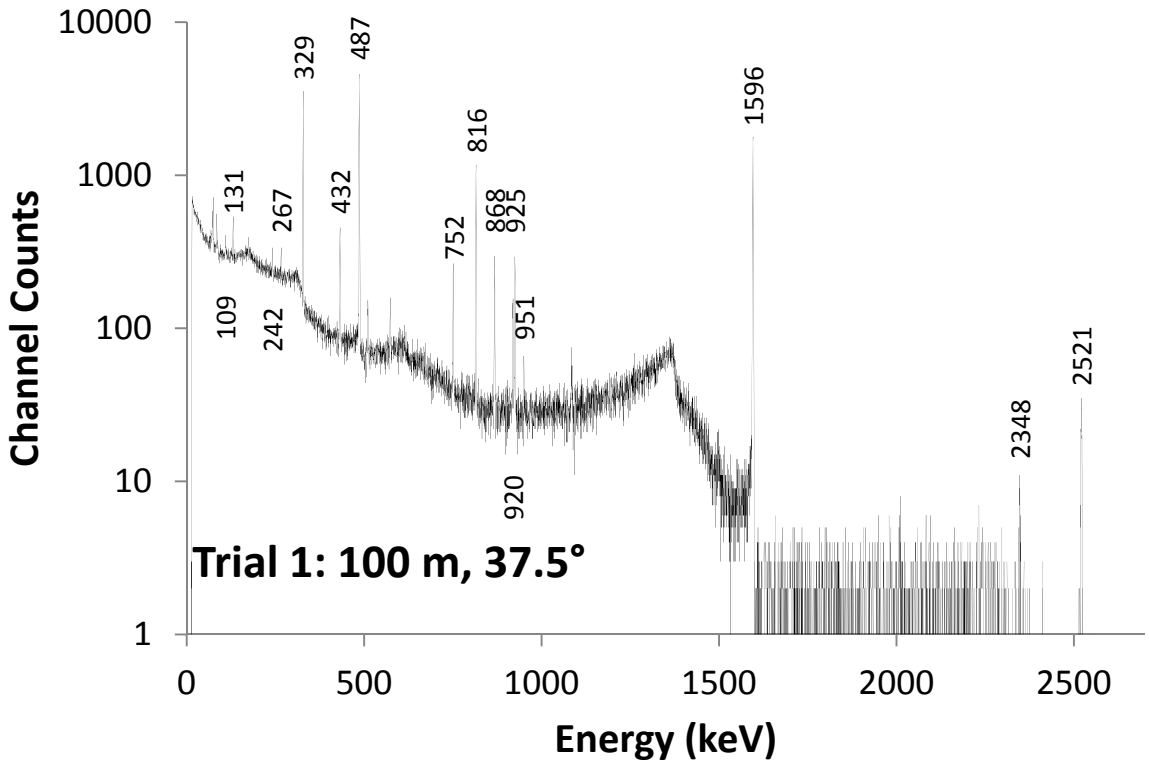

Figure 2: Gamma-ray spectrum for an air filter that sampled during the cloud passage. The gamma rays for ^{140}La are labeled with their energies. This filter was from the first Trial at a height of 1.5 m, distance of 100 m and angle of 37.5°.

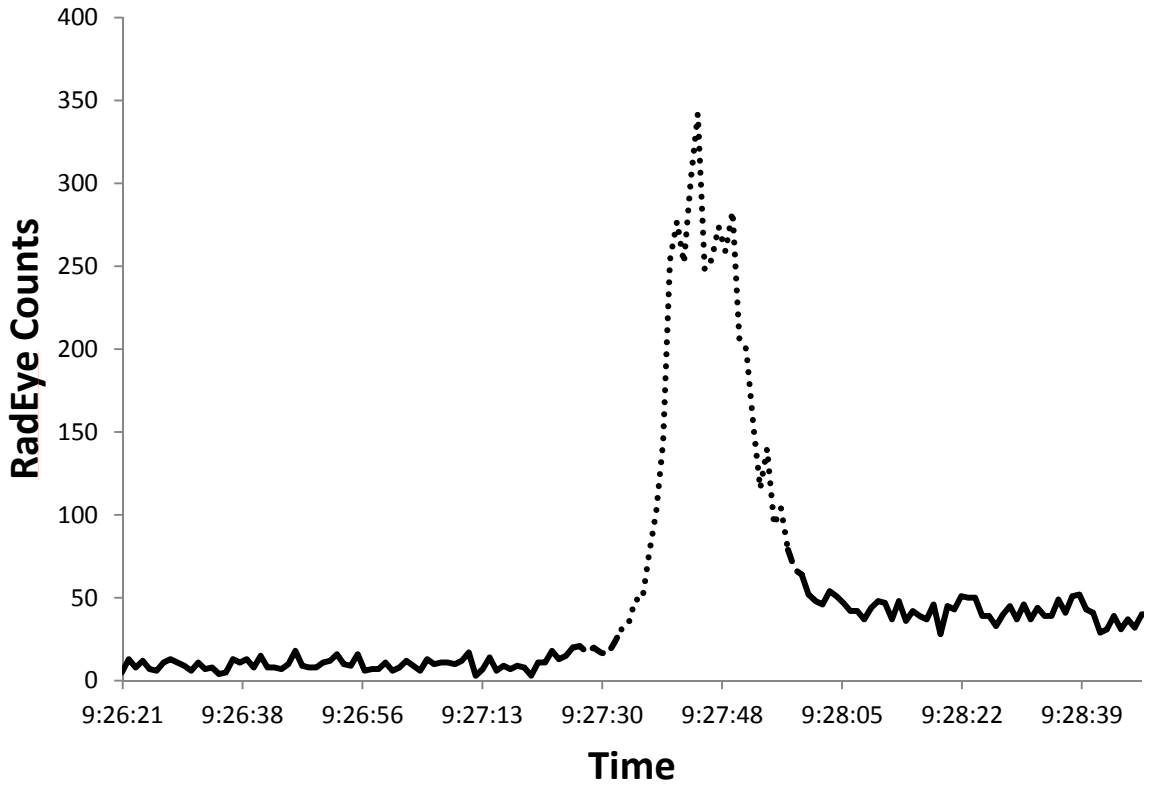

Figure 3: Example count rate plot for one of the RadEye detectors. The dashed portion of the plot indicates the time assumed for the passage of the radioactive cloud by the detector. The cloud time is estimated by identifying when the counts exceed the pre- and post-event rates by 5σ.

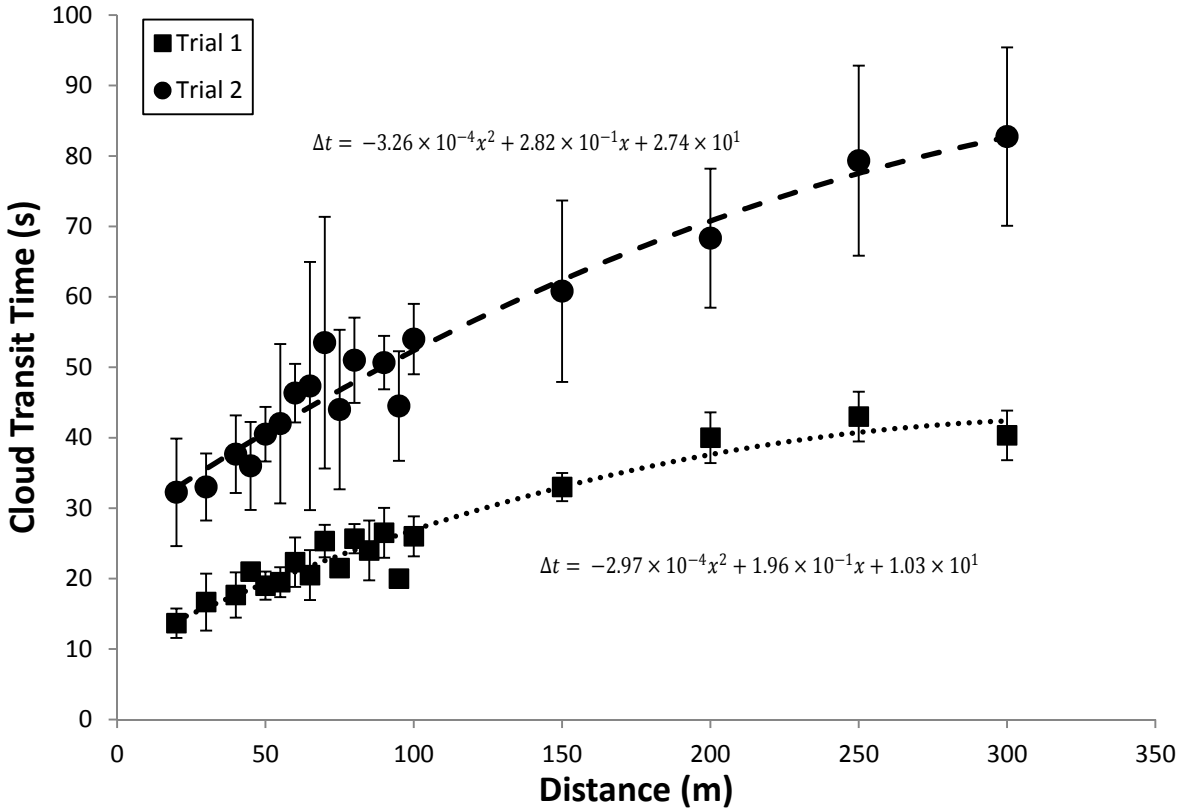

Figure 4: Duration of the passage of the radioactive cloud by the RadEye detectors as a function of the distance to the detonation site. Each point is an average of the times identified at a given distance. The error bars are the square roots of the variances among the times at a given distance. The dotted line is a fit to the data with a quadratic curve.

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Table 1: Near-field high volume air sample locations and flow rates. The samplers positioned at 10 m above the ground are shown in bold italics for emphasis.

Distance (m)	Array Angle	Height (m)	Easting (UTM zone 12)	Northing (UTM zone 12)	Latitude (degrees)	Longitude (degrees)	Flowrate (Lpm)
100	15	1.5	509450	5573766	50.31592	-110.86751	1020
100	37.5	1.5	509487	5573752	50.31580	-110.86675	1050
100	***37.5***	***10***	***509487***	***5573752***	***50.31580***	***-110.86675***	***990***
100	52.5	1.5	509507	5573736	50.31565	-110.86647	1020
100	67.5	1.5	509522	5573714	50.31546	-110.86626	990
100	82.5	1.5	509531	5573690	50.31524	-110.86613	1100
100	***82.5***	***10***	***509531***	***5573690***	***50.31524***	***-110.86613***	***1050***
100	105	1.5	509531	5573651	50.31489	-100.86613	1020
150	15	1.5	509459	5573816	50.31637	-110.86714	1020
150	30	1.5	509496	5573804	50.31627	-110.86662	1100
150	45	1.5	509529	5573783	50.31608	-110.86616	1050
150	60	1.5	509556	5573754	50.31581	-110.86578	1130
150	75	1.5	509574	5573719	50.31550	-110.86553	1130
150	90	1.5	509582	5573681	50.31516	-110.86542	1130
150	105	1.5	509581	5573642	50.31481	-110.86543	1100
250	22.5	1.5	509508	5573906	50.31718	-110.86645	1130
250	37.5	1.5	509567	5573879	50.31694	-110.86562	1020
250	52.5	1.5	509617	5573837	50.31656	-110.86492	1130
250	67.5	1.5	509655	5573783	50.31607	-110.86439	1130
250	82.5	1.5	509677	5573722	50.31552	-110.86408	1020
250	97.5	1.5	509683	5573657	50.31494	-110.86400	1100

Table 2. Far-field air sampler locations and flow rates

Distance (m)	Array Angle	Type	Easting (UTM zone 12)	Northing (UTM zone 12)	Latitude (degrees)	Longitude (degrees)	Flowrate (Lpm)
600	22.5	gasoline	509663	5574222	50.320022	-110.864265	28300
600	37.5	electric	509798	5574144	50.319318	-110.862371	24800
600	52.5	gasoline	509909	5574033	50.318318	-110.860814	28300[a]
600	67.5	gasoline	509987	5573898	50.317103	-110.859722	28300
600	82.5	electric	510028	5573746	50.315735	-110.859151	24800
600	97.5	gasoline	510028	5573590	50.314332	-110.859155	28300

[a] The system for recording the flowrate failed for this instrument. The rate is inferred from behavior of the other gasoline systems and the preset rate of 1000 cfm (28317 lpm).

Table 3: Near-field air sample results for Trial 1. The reported activities are for the time of the detonation. The Total Time and Total Volume reflect the air sample collection from the detonation time until the sample pump stopped. The bold-faced entries are at 10 m above the ground. ND=not detected.

Distance (m)	Array Angle	Height (m)	^{140}La Activity[a] (Bq)	MDA (Bq)	Total Time[b] (s)	Tot. Vol.[b] (m^3)	Flowrate (Lpm)
100	15	1.5	4.6±1.1	10.7	5520	93.8	1020
100	37.5	1.5	28400±561	163	9120	159.3	1050
100	***37.5***	***10***	***29700±585***	***136***	***9660***	***159.6***	***990***
100	52.5	1.5	66.0±4.3	10.6	4380	74.4	1020
100	67.5	1.5	ND	10.6	4020	66.4	990
100	82.5	1.5	9.2±1.5	10.7	10800	198.8	1100
100	***82.5***	***10***	***ND***	***10.7***	***10680***	***186.4***	***1050***
100	105	1.5	4.6±1.1	10.8	6420	109.1	1020
150	15	1.5	ND	15.7	720	12.2	1020
150	30	1.5	13.9±1.9	10.8	6300	116.0	1100
150	45	1.5	8470±171	54.8	12840	224.2	1050
150	60	1.5	ND	10.9	13140	248.1	1130
150	75	1.5	ND	15.7	13620	257.1	1130
150	90	1.5	ND	15.7	14520	274.1	1130
150	105	1.5	ND	15.8	14880	273.9	1100
250	22.5	1.5	ND	15.4	15960	301.3	1130
250	37.5	1.5	960±26.5	15.5	16200	275.2	1020
250	52.5	1.5	ND	15.5	16380	309.2	1130
250	67.5	1.5	ND	15.6	11640	219.7	1130
250	82.5	1.5	ND	15.4	180	3.1	1020
250	97.5	1.5	ND	15.6	12300	226.4	1100

[a] The activities have been decay corrected to the detonation time.

[b] The reported time and air volume is for the sample time after the detonation.

Table 4: Near-field air sample results for Trial 2. The reported activities are for the time of the detonation. The Total Time and Total Volume reflect the air sample collection from the detonation time until the sample pump stopped. The bold-faced entries are at 10 m above the ground. ND=not detected; blank fields indicate air samples not collected.

Distance (m)	Array Angle	Height (m)	^{140}La Activity[a] (Bq)	MDA (Bq)	Total Time[b] (s)	Tot. Vol.[b] (m^3)	Flowrate (Lpm)
100	15	1.5	65.1±12.9	10.8	5400	91.7	1020
100	37.5	1.5	10.8±3.5	5.1	4320	74.4	1050
100	***37.5***	***10***	***23.0±5.2***	***5.1***	***4380***	***72.3***	***990***
100	52.5	1.5	25.3±7.8	10.7	4920	83.6	1020
100	67.5	1.5	38500±2270	186	5160	85.2	990
100	82.5	1.5	101±12.0	5.1	1620	29.8	1100
100	***82.5***	***10***	***107±12.5***	***5.14***	***1500***	***26.2***	***1050***
100	105	1.5	--	--	--	--	1020
150	15	1.5	ND	10.9	4560	77.5	1020
150	30	1.5	ND	10.9	4560	83.9	1100
150	45	1.5	ND	10.9	7140	124.7	1050
150	60	1.5	18.8±6.8	11.0	9420	177.8	1130
150	75	1.5	4330±272	25.7	9420	177.8	1130
150	90	1.5	7.1±4.1	11.0	9300	175.6	1130
150	105	1.5	--	--	--	--	1100
250	22.5	1.5	4.7±3.4	11.0	7920	149.5	1130
250	37.5	1.5	ND	14.9	7500	127.4	1020
250	52.5	1.5	--	--	--	--	1130
250	67.5	1.5	--	--	--	--	1130
250	82.5	1.5	--	--	--	--	1020
250	97.5	1.5	--	--	--	--	1100

[a] The activities have been decay corrected to the detonation time.

[b] The reported time and air volume is for the sample time after the detonation.

Table 5. Far-field air sample results for Trial 1.

Distance (m)	Array Angle	Height (m)	^{140}La Activity[a] (Bq)	MDA (Bq)	Total Time[b] (s)	Tot. Vol.[b] (m^3)	Flowrate (Lpm)
600	22.5	1.5	301±5.6	2.73	10800	5094	28300
600	37.5	1.5	587000±1870	37.4	600	248	24800
600	52.5	1.5	42.1±1.1	1.46	10800	5094	28300
600	67.5	1.5	21.9±1.1	1.41	10800	5094	28300
600	82.5	1.5	24.8±5.8	7.26	600	248	24800
600	97.5	1.5	28.2±6.3	7.76	10800	5094	28300

[a] The activities have been corrected for decay, including decay during the measurements of the filters, to the detonation time.

[b] The reported time and air volume is for the sample time after the detonation.

Table 6: Measurements of resuspended radioactivity performed shortly after the dispersion.

Distance (m)	Array Angle	Start/Stop after release (m)	^{140}La Activity[a] (Bq)	MDA (Bq)	Tot. Vol. (m^3)	Air Conc. (Bq m^{-3})	Air Conc. MDC (Bq m^{-3})
100	37.5	157 – 1480	217±25	9.9	1386	$1.4x10^{-1}$±$1.6x10^{-2}$	$6.3x10^{-3}$
100	82.5	183 – 1494	6.4±3.7	9.9	1448	$3.9x10^{-3}$±$2.3x10^{-3}$	$6.0x10^{-3}$
150	45	216 – 1507	2.85±0.87	0.02	1353	$1.8x10^{-3}$±$5.6x10^{-4}$	$1.1x10^{-5}$
150	75	247 – 313	8.5±4.3	9.9	75	$1.2x10^{-1}$±$6.0x10^{-2}$	$1.4x10^{-1}$
250	37.5	272 – 1532	11.4±8.7	1.2	1284	$7.7x10^{-3}$±$5.9x10^{-4}$	$7.9x10^{-4}$
250	52.5	276 – 1044	8.5±4.3	9.9	870	$9.1x10^{-3}$±$4.6x10^{-3}$	$1.1x10^{-2}$
250	67.5	303 – 675	4.3±3.0	9.9	421	$9.9x10^{-3}$±$7.0x10^{-3}$	$2.3x10^{-2}$

[a] The sample activities are for the analysis time.

Table 7: Resuspension measurements of filters exposed the day following the dispersion.

Distance (m)	Array Angle	Start/Stop after release (m)	^{140}La Activity[a] (Bq)	MDA (Bq)	Tot. Vol. (m^3)	Air Conc. (Bq m^{-3})	Air Conc. MDC (Bq m^{-3})
100	15	1552 – 1855	8.5±7.5	3.3	309	$9.5x10^{-2}$±$8.4x10^{-2}$	$3.7x10^{-2}$
100[b]	37.5	1482 – 1882	50.3±20	3.3	419	$4.1x10^{-1}$±$1.6x10^{-1}$	$2.7x10^{-2}$
100	52.5	1554 – 1942	4.3±5.3	3.3	396	$3.7x10^{-2}$±$4.6x10^{-2}$	$2.9x10^{-2}$
150	15	1546 – 1738	ND	3.3	196	ND	$5.8x10^{-2}$
150	30	1546 – 1738	3.5±4.8	3.3	212	$5.8x10^{-2}$±$7.9x10^{-2}$	$5.4x10^{-2}$
150	45	1508 – 1979	6.4±6.5	3.3	493	$4.5x10^{-2}$±$4.5x10^{-2}$	$2.3x10^{-2}$
250	22.5	1526 – 2036	1.4±3.0	3.3	578	$8.5x10^{-3}$±$1.8x10^{-2}$	$2.0x10^{-2}$
250	37.5	1534 – 2131	19±12	3.3	609	$1.1x10^{-1}$±$6.4x10^{-2}$	$1.8x10^{-2}$
250	52.5	1540 – 1750	5.7±6.1	3.3	238	$8.3x10^{-2}$±$8.9x10^{-2}$	$4.8x10^{-2}$

[a] The sample activities are for the analysis time.

[b] This sample was dropped onto the ground after it was encased in the collection bag. Additional external contamination may have resulted.