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Results of the 2018 PHE Intercomparison of Passive Radon Detectors

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Results of the 2018 PHE Intercomparison of Passive Radon Detectors

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ABSTRACT

Intercomparison exercises for passive radon detectors have been held regularly by PHE and its predecessor organisations over many years. In 2018, a total of 26 laboratories from 12 countries took part in the exercise. Some laboratories submitted more than one set of detectors. A total of 30 sets of detectors were exposed in the PHE radon chamber.

The detectors were exposed to five different radon concentrations ranging between 137 and 2180 kBq m^{-3} h. After exposure, the detectors were returned to the originating laboratories for processing. Each participant was asked to return results for each detector in terms of integrated exposure to radon. A parameter referred to as measurement error was used to evaluate the performance for each exposure separately and to classify results. Results have been reported to individual participants and are presented here.

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EXECUTIVE SUMMARY

Radon is the largest and most variable contributor of radiation dose to the general population. For more than 20 years, countries in Europe and elsewhere have carried out surveys in order to determine both individual and average exposures and to identify where excessive exposures might occur. Most of these measurements have been carried out using passive etched track radon detectors exposed for periods of months. Activated charcoal and electret radon detectors have also been used, mainly for shorter term measurements. In addition, all three types of detector are used for experimental and research work.

Intercomparisons provide information about the accuracy of measurements. By allowing different detectors to be compared side by side, an objective assessment of the accuracy of measurements can be made. The results of intercomparisons have been used by individual laboratories to identify and rectify problems, as well as providing calibrations for their detectors traceable to international standards.

The Centre for Radiation, Chemical and Environmental Hazards of Public Health England (CRCE) carries out international intercomparisons of passive radon detectors each year. For this intercomparison, laboratories were invited to submit sets of detectors that were randomised into six groups at CRCE. Five of these groups were exposed in the CRCE radon chamber to five different radon concentrations ranging from 137 to 2180 kBq m^{-3} h and the sixth group was used to determine transit exposures. The detectors were then returned to the laboratories who were asked to report the integrated exposure result for each detector. The laboratories were not informed of the details of the exposures or which detectors were in which group until all the results had been submitted.

This report considers the results for the intercomparison carried out in 2018, for which a total of 26 laboratories from 12 countries submitted 30 sets of detectors. One laboratory withdrew their results, so the report only covers 25 laboratories and 29 sets of detectors in total. Analysis of the results allows each exposure group in each set to be classified from A (lowest measurement error %) to F (highest measurement error %). On this occasion, some of the etched track and all of the electret detectors can be found in the lower classes, demonstrating that stringent quality assurance is vital, as is consideration of the equipment used and the measurement technique.

Some laboratories reported their results to one or two decimal places - these results were rounded to the nearest whole number for this report.

CONTENTS

1 INTRODUCTION

Passive detectors, of varying designs, have been used for many years to make measurements of integrated radon exposures. The three most common methods are outlined below.

- Etched track detectors are referred to as such because alpha particles from the decay products of radon damage the surface of the plastic detection medium, producing microscopic tracks. These tracks are subsequently made visible by chemical or electrochemical etching. The most popular etched track materials are cellulose nitrate (LR-115), polycarbonate (Makrofol) and polyallyl diglycol carbonate (CR-39). In the open type of etched track detector, the plastic material is exposed to the ambient atmosphere. Open etched track detectors record alpha particles originating from radon decay products and from radon isotopes. For these open detectors, the radioactive decay equilibrium factor, *F*, for Rn-222 has to be taken into account to estimate the proportion of alpha particles that arise from radon-222 decay. In the closed type, the detection material is enclosed in a chamber that excludes entry of ambient radon decay products and only allows entry of radon gas by diffusion.
- Activated charcoal detectors work by retaining adsorbed radon in a charcoal volume. The radon is subsequently measured in the originating laboratory.
- Electret detectors consist of an air chamber above an electret. Ionisation of air in the chamber by radon gradually discharges the electret. Measurement of the charge on the electret by the laboratory before and after radon exposure allows the average radon concentration during exposure to be calculated.

Passive radon detectors are quite simple to produce and process, but each is subject to sources of error. It is therefore appropriate for laboratories that use these detectors to undertake regular checks against reference exposures carried out in relevant radon exposure facilities. The present laboratory intercomparison programme, which was developed with broad international participation, following standard and agreed test and interpretation protocols, has been designed to provide participants with a routine benchmark performance standard. The intercomparison programme was established by the National Radiological Protection Board (NRPB)*, now the PHE Centre for Radiation, Chemical and Environmental Hazards (CRCE), and has operated regularly since 1982.

Operational procedures and equipment have been described previously (Howarth, 2009).

* The NRPB was subsequently incorporated into the Health Protection Agency (HPA). On 1 April 2013 the HPA was abolished and its functions transferred to Public Health England.

2 LABORATORY EXPOSURE AND MEASUREMENT FACILITIES

The exposures in this intercomparison were carried out in the CRCE radon chamber. This 43 m^3 walk-in chamber is of the static type, in which radon is continuously released from dry radium-226 radon sources. There is no air flow through the chamber during operation.

The radon atmosphere in the chamber can be varied from around 200 to 8000 Bq m^{-3}. Table 1 shows the parameters measured and controlled in the chamber.

The radon concentration in the chamber was continuously monitored using an ATMOS 12 DPX ionisation chamber and with an Alphaguard ionisation chamber as a second primary transfer standard. A daily cross-calibration between the Atmos12 DPX and Alphaguard was carried out throughout the intercomparison exercise. Both instruments are calibrated regularly using a radon gas source supplied by either Physikalisch Technische Bundesanstalt (PTB), Germany, or CHUV Institut de Radiophysique, Switzerland.

During exposures, radon decay products were sampled approximately four times per day onto a Millipore AA filter and their concentrations determined using an alpha spectrometry system. All chamber-monitored data were automatically transferred to a database. Radon and radon decay product exposures were calculated subsequently.

3 LOGISTICAL ARRANGEMENTS

In total, 26 laboratories from 12 countries took part in the 2018 PHE intercomparison. Some laboratories submitted more than one set of detectors, so 30 sets of detectors were exposed in the radon chamber. Following exposure, the detectors were returned to the originating laboratories for processing. Each participant was asked to return results for each detector in terms of integrated exposure to radon. Participants were not told any details of the exposures delivered in the exercise until after the results had been received from all participating laboratories.

4 RADON EXPOSURES

Appropriate conditions for typical domestic radon exposure were established in the chamber before introducing the detectors. An equilibrium factor, *F*, of about 0.40 between radon and its decay products was maintained in the chamber for the five intercomparison exposures. The chamber exposures were calculated after the deadline for return of results by participants and are shown with exposure durations in Table 1. Radon and EER (equilibrium equivalent of radon) concentrations during the exposures are shown in Figures 1–5.

The radon concentration in the laboratory outside the exposure chamber was monitored during the exposures using an Alphaguard ionisation chamber. The daily average concentrations ranged from 16 to 36 Bq m^{-3}, with an overall average of 25 Bq m^{-3}. The estimated additional exposure of the detectors caused by leaving them exposed in the laboratory for a minimum of three days to allow radon to diffuse out of them was less than 1% of the exposure in the chamber in all cases and this value was excluded when calculating the reference exposures. Transit detectors were used to monitor radon exposure received in transit.

We identified a flaw in our system which resulted in one laboratory only receiving three different exposures, instead of five. For two of the exposures, two different detector groups were given the same exposure. The laboratory was informed. We are reviewing our procedures and a more robust mechanism for detector checks will be instigated for the 2019 intercomparison, to prevent this kind of error from occurring in future.

5 PERFORMANCE CLASSIFICATION SCHEME

A performance classification scheme was introduced in 2011 based on the following parameters (Daraktchieva et al, 2012):

- percentage biased error, which measures the bias of the measurement;
- percentage precision error, which measures the precision of the measurement; and
- percentage measurement error, which takes into account their combined effect.

The measured mean is obtained by subtracting the mean transit exposure from the mean reported exposure.

The parameters are given below:

$$\%\ \text{biased error} = \frac{(\text{Measured mean} - \text{Reference value})}{\text{Reference value}} \times 100$$

where the reference value is the reference radon exposure,

$$\%\ \text{precision error} = \frac{\text{Standard deviation}}{\text{Measured mean}} \times 100$$

$$\%\ \text{measurement error} = \sqrt[2]{(\%\ \text{biased error}^2 + \%\ \text{precision error}^2)}$$

Since the percentage measurement error combines the biased error and precision error, a result can have low measurement error only if both bias and precision errors are low. Measurement errors are reflected as a performance classification from A (lowest measurement error %) to F (highest measurement error %) for each exposure separately. Each participating laboratory is assigned a classification, between A and F, for each exposure. The criteria for each of the classification groups are given below.

Range of measurement error (%)	Performance classification
< 10%	A
≥ 10% and < 20%	B
≥ 20% and < 30%	C
≥ 30% and < 40%	D
≥ 40% and < 50%	E
≥ 50%	F

6 RESULTS AND DISCUSSION

The results reported by the laboratories are given in Table 2. One of the participating laboratories withdrew their results, so the tables show the results for 25 laboratories and 29 sets of detectors. In these tables, the 'mean' is the mean result of ten exposed detectors (five for electret) after subtracting the mean transit exposure. The standard deviation, '1 SD', is for ten reported results (five for electrets). Results for % biased error, % precision error and % measurement error are also provided.

The mean results and their standard deviations, as reported by participants, are depicted in Figures 6–10. The mean of all transit exposures is shown in Figure 11.

The mean, μ, and standard deviation, σ, of all reported results, calculated for each exposure, are given in Table 3. The distributions of the mean exposure results given in Table 3 are depicted in Figure 12.

The characteristics of the detectors such as material, detector holder design, detector type and material supplier are provided in Table 4.

The mean of all transit exposures (Figure 11) is 35 kBq m^{-3} h. Most of the reported transit exposures were below 50 kBq m^{-3} h, three laboratories reported a value between 50 and 100 kBq m^{-3} h, a further four laboratories reported values above 100 kBq m^{-3} h. This is a further increase from 2017 and suggests that there might be problems with the 'radon-proof' transit packaging used by some laboratories, or perhaps there has been some change in the way that cargo is scanned at some airports?

Results, using the performance classification scheme, are given in Table 4. This table is sorted according to performance classification with the first order of sort being the lowest exposure. The position of a laboratory in the table reflects the performance classification of the different exposures and should not be interpreted as a criterion of their total performance. The results in the table are informative and can be used by laboratories to review their procedures and to identify problems at different exposure levels.

Six laboratories achieved class A results for all five exposures, meaning that they have a measurement error of under 10% for all five exposures. This includes one laboratory which participated with two different types of detector sets. This is an increase compared to 2017. Approximately 66% of all sets of detectors achieved class A for at least 3 exposures – much improved from 2017. For the lowest exposure measurement (137 kBq m^{-3} h), only 28% of laboratories achieved class A, a lower score than in 2017. For the second lowest exposure (307 kBq m-3 h), 45% of laboratories achieved class A.

It should be noted that the laboratories participating with the same type of detectors and detector material can achieve quite different performance classifications, possibly reflecting each laboratory's own quality assurance (QA) protocols and staff experience.

In order to identify sources of errors, the laboratories should take into account changes in various parameters such as: calibration factor, sensitivity and background. Reviews of sources of errors for etched track detectors are given in Ibrahimi et al (2009), Hanley et al (2008) and Hardcastle and Miles (1996). Constant monitoring of detector performance and strict QA protocols should be established and maintained to identify and manage the above sources of errors.

The proportion of sets achieving each performance classification (A-F) is given in Figure 13.

7 CONCLUSION

In total, 26 laboratories from 12 countries participated in the 2018 PHE intercomparison of passive radon detectors. One laboratory withdrew their results – so this report is of 25 laboratories and 29 sets of detectors. A six-band (A-F) classification scheme was used to evaluate the performance of the detectors across a range of exposures. Five laboratories achieved five class A ratings, the same as in the 2017 intercomparison. One laboratory only had three exposures due to a logistical error by PHE – they received three class A ratings.

8 ACKNOWLEDGEMENTS

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10 LIST OF PARTICIPANTS SUBMITTING RESULTS

Contact person	Organisation	Country
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11 TABLES AND FIGURES

TABLE 1 Exposure parameters

Etched track detectors

Exposure	1	2	3	4	5
Duration (h)	359.4	115.75	233.17	52.33	24.37
Radon exposure (kBq m^{-3} h)	2180	749	1354	307	137
Uncertainty (%) at 68% CL	3.0	3.0	3.0	3.0	3.0
EER exposure (kBq m^{-3} h)	981	315	623	138	64.4
Uncertainty (%) at 68% CL	7.0	7.0	7.0	7.0	7.0
F, equilibrium factor	0.45	0.42	0.46	0.45	0.47

Notes

EER is equilibrium equivalent of radon.

CL is the confidence level.

TABLE 2 Analysis of all reported results

Exposure 1 2180 kBq m^{-3} h

Set ID	Mean (kBq m^{-3} h)	1 SD (kBq m^{-3} h)	% biased error	% precision error	% measurement error
1-1	2225.1	29.7	2.1	1.3	2.5
12-1	2359.2	93.7	8.2	4.0	9.1
12-2	2217.1	163.9	1.7	7.4	7.6
13-1	2141.9	111.1	-1.7	5.2	5.5
13-2	2131.6	83.7	-2.2	3.9	4.5
14-1	2059.7	93.9	-5.5	4.6	7.2
16-1	2186.3	75.8	0.3	3.5	3.5
19-1	2250.3	70.4	3.2	3.1	4.5
20-1	2284.4	74.8	4.8	3.3	5.8
23-1	2081.8	95.8	-4.5	4.6	6.4
25-1	2532.3	30.3	16.2	1.2	16.2
25-2	2490.5	124.8	14.2	5.0	15.1
32-1	2236.6	88.6	2.6	4.0	4.7
40-1	2166.8	383.0	-0.6	17.7	17.7
45-1	2411.2	588.1	10.6	24.4	26.6
54-1	2006.0	40.8	-8.0	2.0	8.2
62-1	2249.5	283.3	3.2	12.6	13.0
141-1	2200.0	29.6	0.9	1.3	1.6
144-1	1936.7	631.6	-11.2	32.6	34.5
156-1	1837.8	669.5	-15.7	36.4	39.7
160-1	2017.9	32.7	-7.4	1.6	7.6
163-1	1601.4	112.9	-26.5	7.1	27.5
163-2	1366.0	253.3	-37.3	18.5	41.7
171-1	2901.9	297.9	33.1	10.3	34.7
173-1	2125.7	68.0	-2.5	3.2	4.1
174-1	2037.8	38.2	-6.5	1.9	6.8
177-1	2075.3	236.0	-4.8	11.4	12.3
179-1	2170.4	36.2	-0.4	1.7	1.7
186-1	2014.5	62.7	-7.6	3.1	8.2

TABLE 2 Analysis of all reported results *(continued)*

Exposure 2 749 kBq m^{-3} h

Set ID	Mean (kBq m^{-3} h)	1 SD (kBq m^{-3} h)	% biased error	% precision error	% measurement error
1-1	766.5	11.7	2.3	1.5	2.8
12-1	802.5	37.3	7.1	4.6	8.5
12-2	805.8	50.9	7.6	6.3	9.9
13-1	719.7	26.9	-3.9	3.7	5.4
13-2	725.8	22.2	-3.1	3.1	4.4
14-1	685.3	29.1	-8.5	4.2	9.5
16-1	700.3	48.3	-6.5	6.9	9.5
19-1	782.0	24.4	4.4	3.1	5.4
20-1	769.2	23.1	2.7	3.0	4.0
23-1	695.5	22.1	-7.1	3.2	7.8
25-1	751.6	31.8	0.3	4.2	4.2
25-2	751.8	42.1	0.4	5.6	5.6
32-1	747.2	34.0	-0.2	4.6	4.6
40-1	676.7	111.9	-9.7	16.5	19.1
45-1	687.6	178.2	-8.2	25.9	27.2
54-1	683.7	22.6	-8.7	3.3	9.3
62-1	796.3	31.3	6.3	3.9	7.4
141-1	720.0	24.7	-3.9	3.4	5.2
144-1	741.4	38.9	-1.0	5.2	5.3
156-1	711.3	48.9	-5.0	6.9	8.5
160-1	682.5	16.2	-8.9	2.4	9.2
163-1	572.7	71.6	-23.5	12.5	26.7
163-2	396.2	21.4	-47.1	5.4	47.4
171-1	668.1	139.5	-10.8	20.9	23.5
173-1	750.9	18.3	0.3	2.4	2.5
174-1	692.8	31.9	-7.5	4.6	8.8
177-1	667.4	59.0	-10.9	8.8	14.0
179-1	743.9	14.3	-0.7	1.9	2.0
186-1	678.6	31.5	-9.4	4.6	10.5

TABLE 2 Analysis of all reported results *(continued)*

Exposure 3 1354 kBq m^{-3} h

Set ID	Mean (kBq m^{-3} h)	1 SD (kBq m^{-3} h)	% biased error	% precision error	% measurement error
1-1	1366.7	46.4	0.9	3.4	3.5
12-1	1455.2	75.3	7.5	5.2	9.1
12-2	1349.4	53.9	-0.3	4.0	4.0
13-1	1353.8	51.9	0.0	3.8	3.8
13-2	1319.8	27.7	-2.5	2.1	3.3
14-1	1244.5	59.4	-8.1	4.8	9.4
16-1	1307.0	103.3	-3.5	7.9	8.6
19-1	1371.3	36.2	1.3	2.6	2.9
20-1	1418.8	51.6	4.8	3.6	6.0
23-1	1252.3	27.5	-7.5	2.2	7.8
25-1	1498.0	68.6	10.6	4.6	11.6
25-2	1401.2	69.9	3.5	5.0	6.1
32-1	1348.6	51.6	-0.4	3.8	3.8
40-1	1259.3	248.2	-7.0	19.7	20.9
45-1	1333.2	330.8	-1.5	24.8	24.9
54-1	1215.6	58.8	-10.2	4.8	11.3
62-1	1564.9	297.2	15.6	19.0	24.6
141-1	1344.9	50.4	-0.7	3.7	3.8
144-1	1304.5	68.0	-3.7	5.2	6.4
156-1	1241.4	61.4	-8.3	4.9	9.7
160-1	1241.7	39.3	-8.3	3.2	8.9
163-1	999.2	131.2	-26.2	13.1	29.3
163-2	739.6	23.9	-45.4	3.2	45.5
171-1	1384.3	364.9	2.2	26.4	26.5
173-1	1337.4	48.3	-1.2	3.6	3.8
174-1	1260.3	29.8	-6.9	2.4	7.3
177-1	1230.9	93.9	-9.1	7.6	11.9
179-1	1346.6	42.6	-0.5	3.2	3.2
186-1	1203.3	44.6	-11.1	3.7	11.7

TABLE 2 Analysis of all reported results *(continued)*

Exposure 4 307 kBq m^{-3} h

Set ID	Mean (kBq m^{-3} h)	1 SD (kBq m^{-3} h)	% biased error	% precision error	% measurement error
1-1	318.6	4.7	3.8	1.5	4.1
12-1	346.2	29.8	12.8	8.6	15.4
12-2	327.1	25.1	6.5	7.7	10.1
13-1	307.9	17.5	0.3	5.7	5.7
13-2	317.2	8.6	3.3	2.7	4.3
14-1	301.7	22.5	-1.7	7.5	7.7
16-1	313.2	16.8	2.0	5.4	5.7
19-1	331.8	35.7	8.1	10.8	13.5
20-1	323.7	10.7	5.4	3.3	6.4
23-1	282.3	26.7	-8.0	9.5	12.4
25-1	305.6	26.7	-0.5	8.7	8.7
25-2	279.6	10.7	-8.9	3.8	9.7
40-1	319.5	48.9	4.1	15.3	15.8
45-1	270.5	77.4	-11.9	28.6	31.0
54-1	280.2	22.9	-8.7	8.2	12.0
62-1	326.7	15.5	6.4	4.7	8.0
141-1	314.6	12.7	2.5	4.0	4.7
144-1	300.1	14.3	-2.2	4.8	5.3
156-1	293.0	86.9	-4.6	29.7	30.0
160-1	275.3	18.0	-10.3	6.5	12.2
163-1	256.4	49.1	-16.5	19.1	25.3
163-2	164.4	9.8	-46.4	6.0	46.8
171-1	335.8	26.3	9.4	7.8	12.2
173-1	353.5	16.0	15.1	4.5	15.8
174-1	302.6	10.1	-1.4	3.3	3.6
177-1	279.5	33.4	-9.0	11.9	14.9
179-1	305.4	14.5	-0.5	4.7	4.8
186-1	263.9	20.8	-14.0	7.9	16.1

TABLE 2 Analysis of all reported results *(continued)*

Exposure 5 137 kBq m^{-3} h

Set ID	Mean (kBq m^{-3} h)	1 SD (kBq m^{-3} h)	% biased error	% precision error	% measurement error
1-1	147.8	5.7	7.9	3.9	8.8
12-1	163.1	6.0	19.1	3.7	19.4
12-2	158.0	14.7	15.3	9.3	17.9
13-1	138.3	9.6	0.9	6.9	7.0
13-2	142.1	12.1	3.7	8.5	9.3
14-1	138.4	9.2	1.0	6.6	6.7
16-1	145.4	14.2	6.1	9.8	11.5
19-1	153.1	15.4	11.8	10.1	15.5
20-1	153.5	5.6	12.0	3.6	12.6
23-1	139.2	18.6	1.6	13.4	13.5
25-1	134.0	10.6	-2.2	7.9	8.2
25-2	129.1	14.0	-5.8	10.8	12.3
40-1	138.0	23.6	0.7	17.1	17.1
45-1	125.8	36.9	-8.2	29.3	30.5
54-1	124.9	13.4	-8.8	10.7	13.9
62-1	151.8	14.7	10.8	9.7	14.5
141-1	150.7	9.0	10.0	6.0	11.6
144-1	346.9	653.9	153.2	188.5	242.9
156-1	103.0	20.1	-24.8	19.5	31.6
160-1	125.6	6.1	-8.3	4.9	9.6
163-1	114.2	22.4	-16.6	19.6	25.7
163-2	60.6	6.4	-55.8	10.6	56.8
171-1	160.0	21.9	16.8	13.7	21.7
173-1	173.4	8.9	26.6	5.1	27.1
174-1	133.1	7.0	-2.8	5.3	6.0
177-1	112.4	39.4	-18.0	35.1	39.4
179-1	136.1	6.2	-0.7	4.6	4.6
186-1	118.8	15.0	-13.3	12.6	18.3

TABLE 2 Analysis of all reported results *(continued)*

Transit controls

Set ID	Mean (kBq m^{-3} h)	1 SD (kBq m^{-3} h)	Set ID	Mean (kBq m^{-3} h)	1 SD (kBq m^{-3} h)
1-1	**3.7**	2.2	54-1	**89.6**	4.5
12-1	**7.7**	2.8	62-1	**3.1**	1.2
12-2	**9.9**	4.9	141-1	**130.2**	18.7
13-1	**5.6**	2.0	144-1	**12.5**	6.1
13-2	**5.3**	2.5	156-1	**65.0**	93.6
14-1	**13.9**	3.2	160-1	**155.3**	13.8
16-1	**21.1**	12.3	163-1	**16.4**	10.5
19-1	**5.4**	4.3	163-2	**50.6**	25.4
20-1	**1.4**	5.6	171-1	**17.9**	3.6
23-1	**47.4**	8.4	173-1	**1.8**	1.8
25-1	**30.0**	0.0	174-1	**3.7**	3.8
25-2	**30.0**	0.0	177-1	**10.6**	48.7
32-1	**10.1**	3.2	179-1	**121.8**	9.4
40-1	**10.4**	2.4	186-1	**102.8**	8.4
45-1	**30.8**	6.4			

TABLE 3 Statistical analysis of all reported results given in Table 2

Exposure	Mean (μ) of all reported results (kBq m^{-3} h)	Standard deviation (σ) of all reported results (kBq m^{-3} h)
1 (2180 kBq m^{-3} h)	2149	277
2 (749 kBq m^{-3} h)	709	79
3 (1354 kBq m^{-3} h)	1300	150
4 (307 kBq m^{-3} h)	300	36
5 (137 kBq m^{-3} h)	144	46

TABLE 4 Performance classification scheme based on measurement error

	Performance classification in each exposure									
	5	4	2	3	1					
Set ID	137 kBq m^{-3} h	307 kBq m^{-3} h	749 kBq m^{-3} h	1354 kBq m^{-3} h	2180 kBq m^{-3} h	Detector type	Filter	Holder	Detector material	Detector material supplier
1-1	A	A	A	A	A	Closed	-	NRPB	CR39	MiNet(UK)
13-1	A	A	A	A	A	Closed	y	Own design	CR39	RTP Company
13-2	A	A	A	A	A	Closed	y	NRPD/SSI	CR39	RTP Company
14-1	A	A	A	A	A	Closed	-	NRPB/SSI	CR39	TASL
174-1	A	A	A	A	A	Closed	-	TASL	CR39	TASL
179-1	A	A	A	A	A	Closed	-	TASL	CR39	TASL
32-1	-	-	A	A	A	Closed	-	NRPB	CR39	TASL
16-1	B	A	A	A	A	Closed	-	Radosys	CR39	Radosys
20-1	B	A	A	A	A	Closed	-	TASL	CR39	TASL
141-1	B	A	A	A	A	Closed	-	TASL, black	CR39	TASL
160-1	A	B	A	A	A	Closed	n	TASL	CR39	TASL
12-1	B	B	A	A	A	Closed	-	Own design	CR39	GM Scien
12-2	B	B	A	A	A	Closed	-	NRPB/SSI	CR39	GM Scien
19-1	B	B	A	A	A	Closed	-	ARPA	CR39	TASL

23-1	B	B	A	A	A	Closed	-	NRPB/SSI	CR39	TASL
25-1	A	A	A	B	B	Open	-	Open	LR115	Algade/Dosirad
25-2	B	A	A	A	B	Closed	-	Own design, yellow	LR115	Algade/Dosirad
54-1	B	B	A	B	A	Closed	-	Own design, black	CR39	TASL
186-1	B	B	B	B	A	Closed	-	TASL	CR39	TASL
62-1	B	A	A	C	B	Closed	-	Own design, black	Makrofol Polycarbonate	Covestro GmbH
173-1	C	B	A	A	A	Closed	-	TASL	CR39	TASL
40-1	B	B	B	C	B	Closed	-	NRPB, yellow	CR39	Instrument Plastics
163-1	C	C	C	C	C	Closed	-	Own design, black	CR39	-
156-1	D	D	A	A	D	Closed	-	Radosys	CR39	Radosys
177-1	D	B	B	B	B	Closed	-	TASL	-	TASL
171-1	C	B	C	C	D	Closed	-	Own design	LR115	Dosirad
45-1	D	D	C	C	C	Closed	y	Own design, black	LR115	-
144-1	F	A	A	A	D	Closed	-	Radosys	CR39	Radosys
163-2	F	E	E	E	E	Closed	-	Electrets	-	-

Notes to Tables 2 and 4 – see overleaf

1. *The results for two detectors in set 62-1 were incorrectly assigned by the reporting laboratory. When the correct values are applied, the classification for group* 1 (2180 kBq m^{-3} h chamber exposure) changes from B to A and for group 3 (1354 kBq m^{-3} h chamber *exposure) changes from C to A. This means that their classification would be B A A A A.*
2. *The results for two detectors in set 144-1 were incorrectly assigned by the reporting laboratory. When the correct values are applied, the classification for group 1* (2180 kBq m^{-3} h chamber exposure) *changes from F to A, and for group 5 (*137 kBq m^{-3} h *chamber exposure) from D to B. This means that their classification would be A A A A B.*
3. *The results for two detector groups in set 32-1 were not reported due to an administrative error by PHE.*

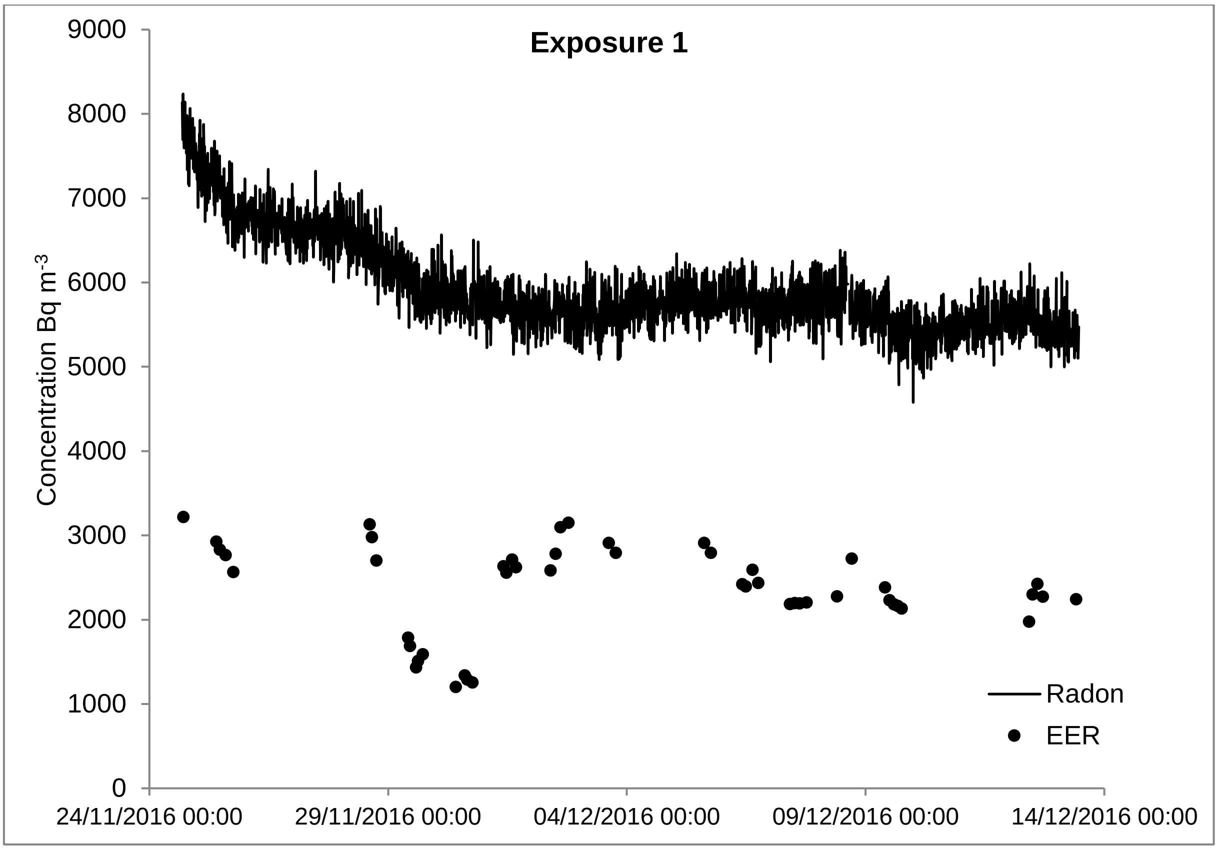


FIGURE 1 Radon and EER concentrations for exposure 1

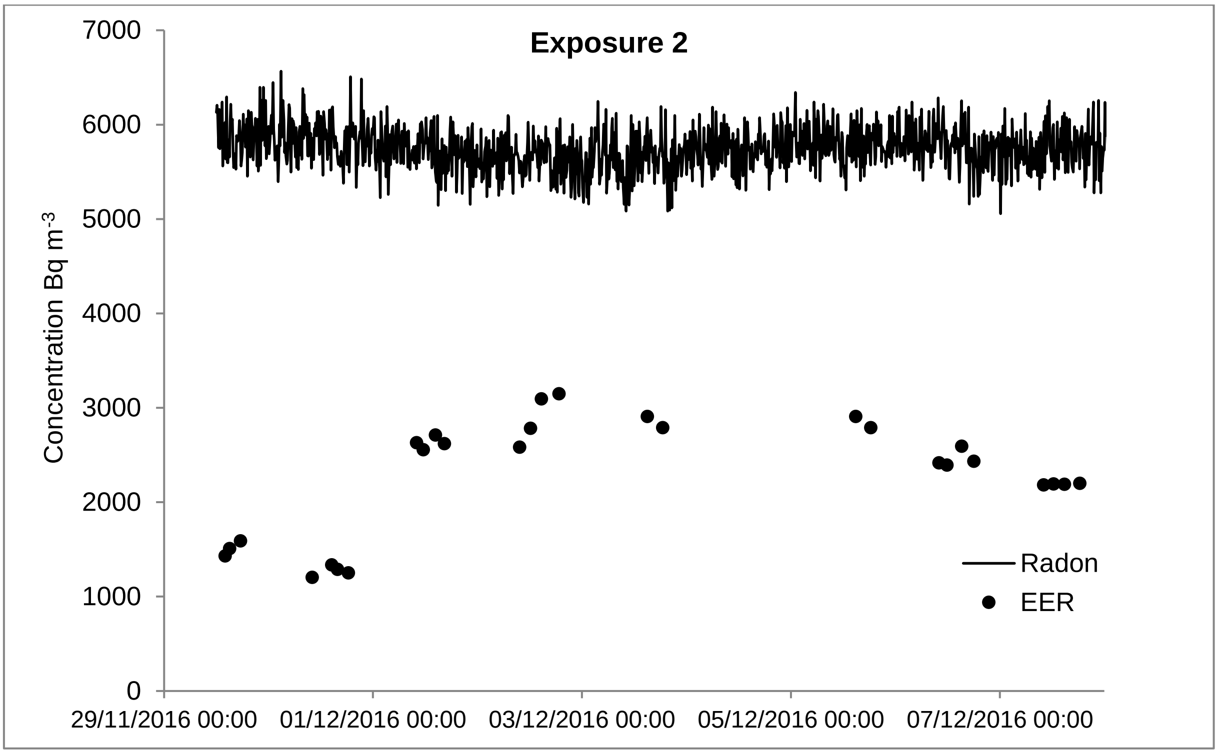


FIGURE 2 Radon and EER concentrations for exposure 2

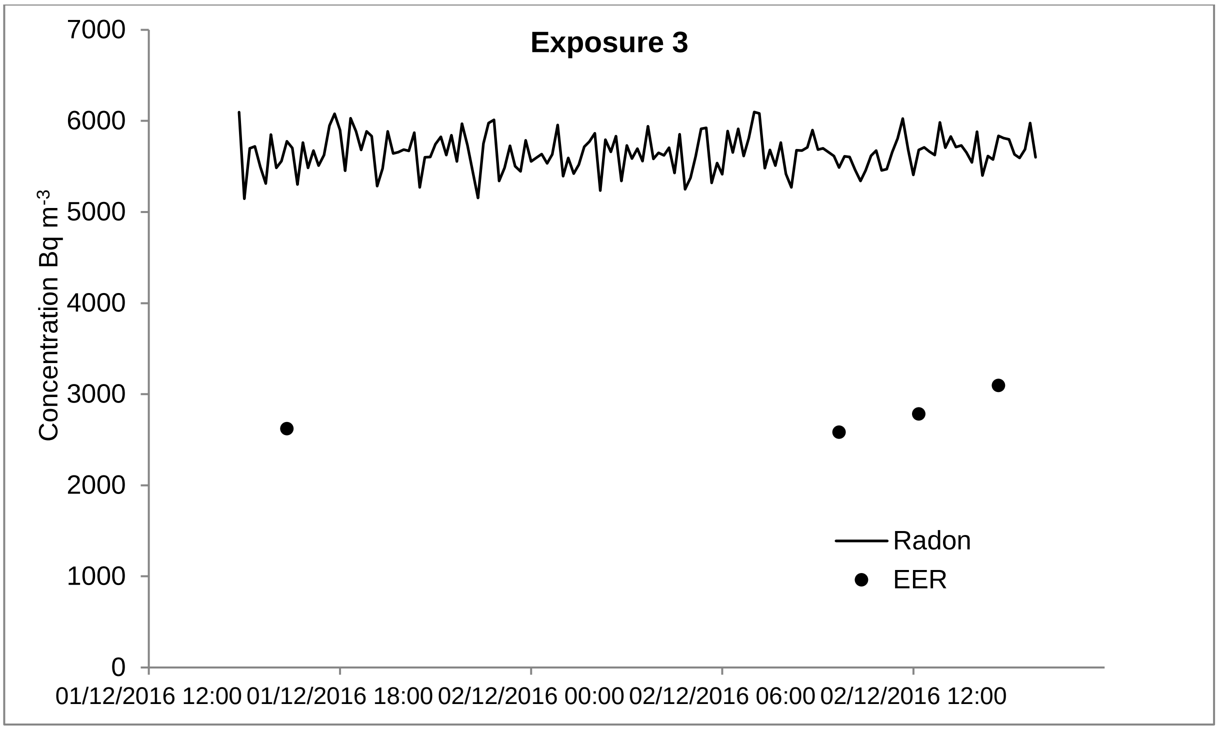


FIGURE 3 Radon and EER concentrations for exposure 3

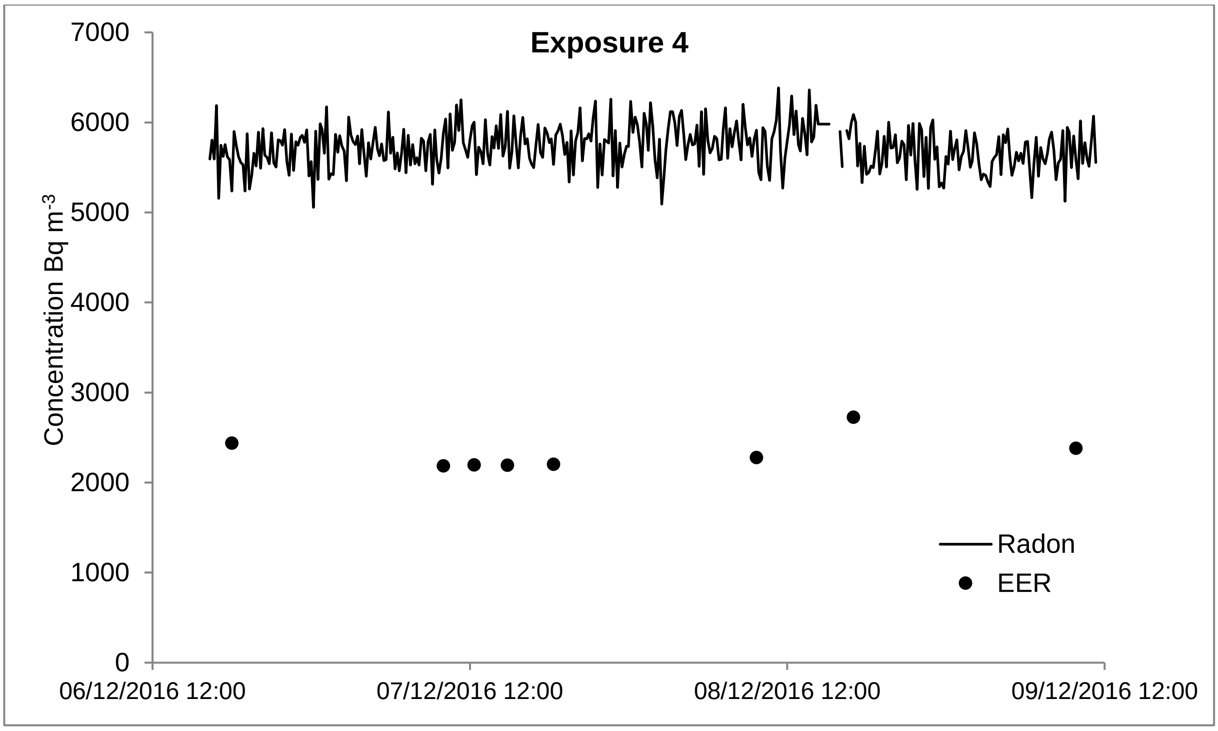


FIGURE 4 Radon and EER concentrations for exposure 4

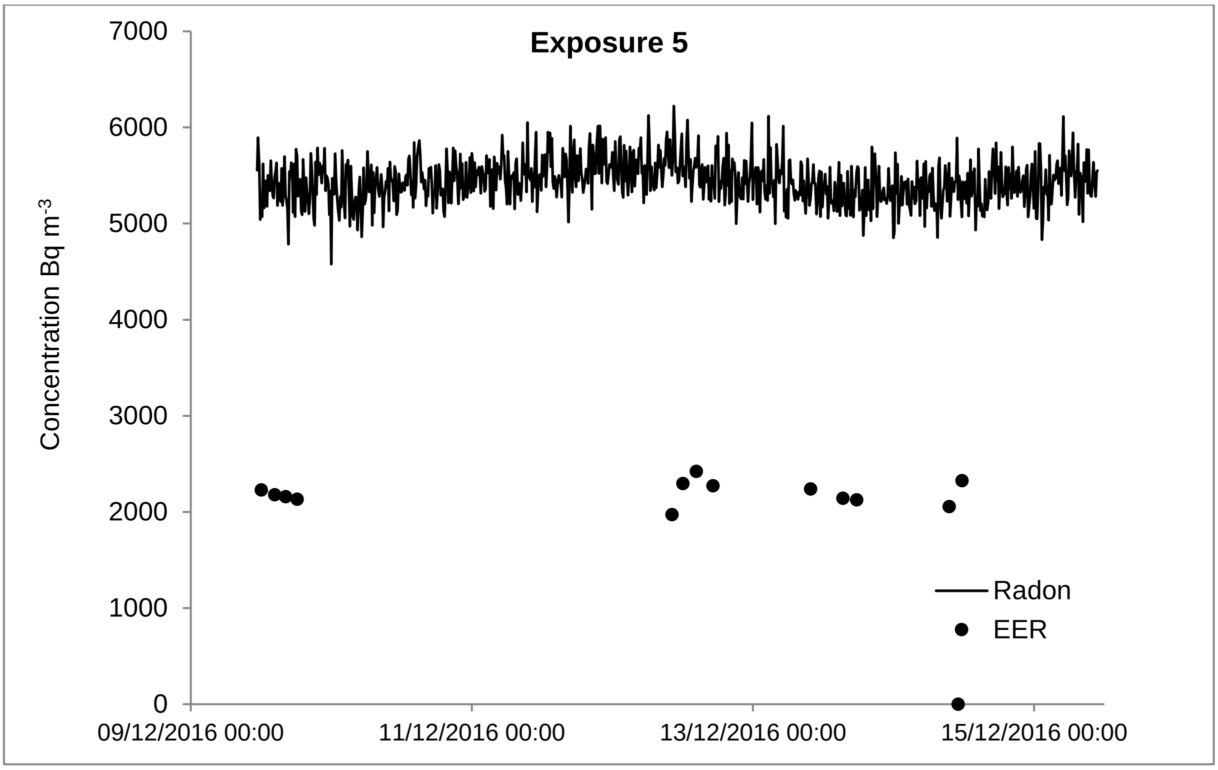


FIGURE 5 Radon and EER concentrations for exposure 5

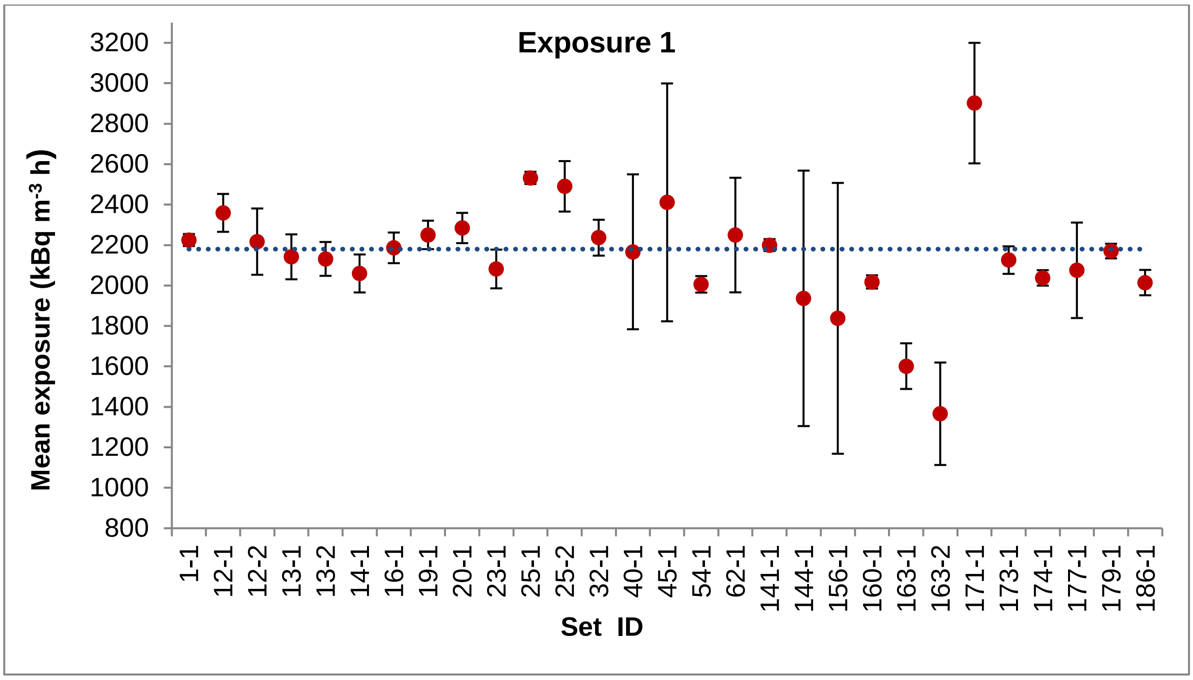


FIGURE 6 Results as reported by participants for exposure 1

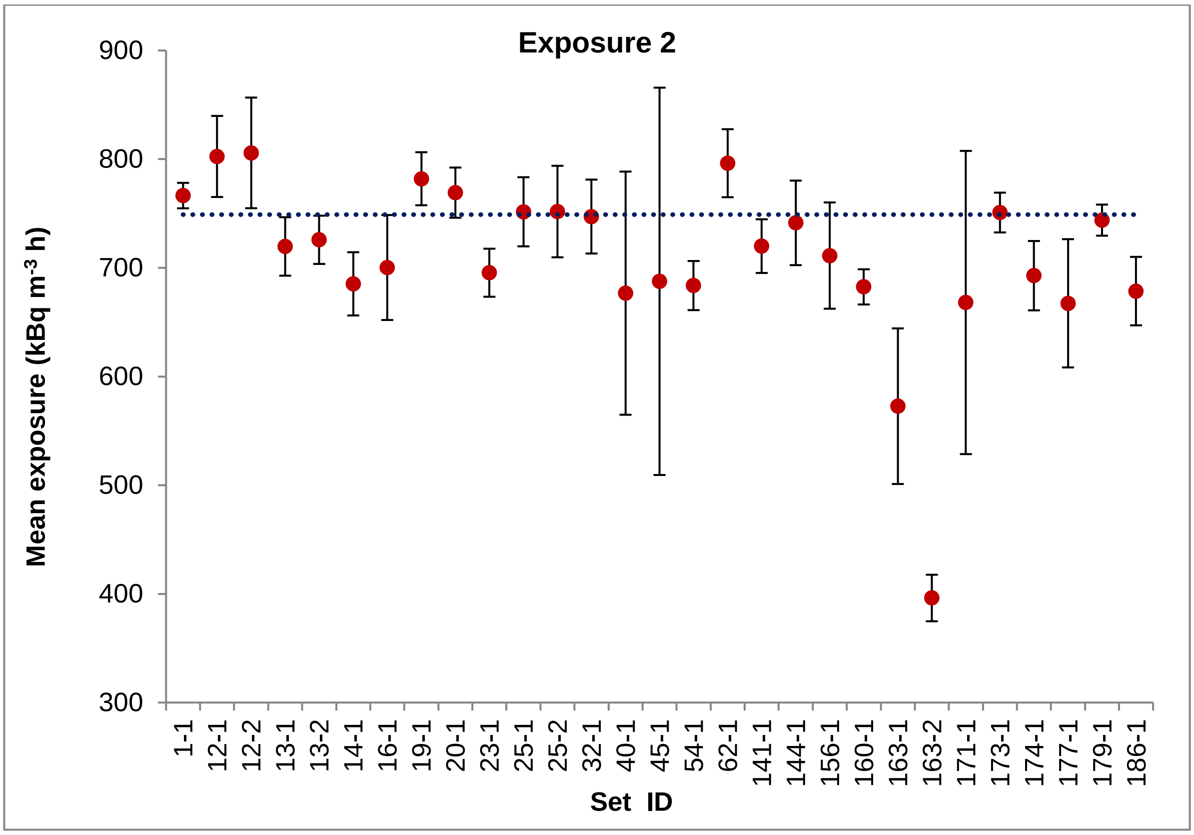


FIGURE 7 Results as reported by participants for exposure 2

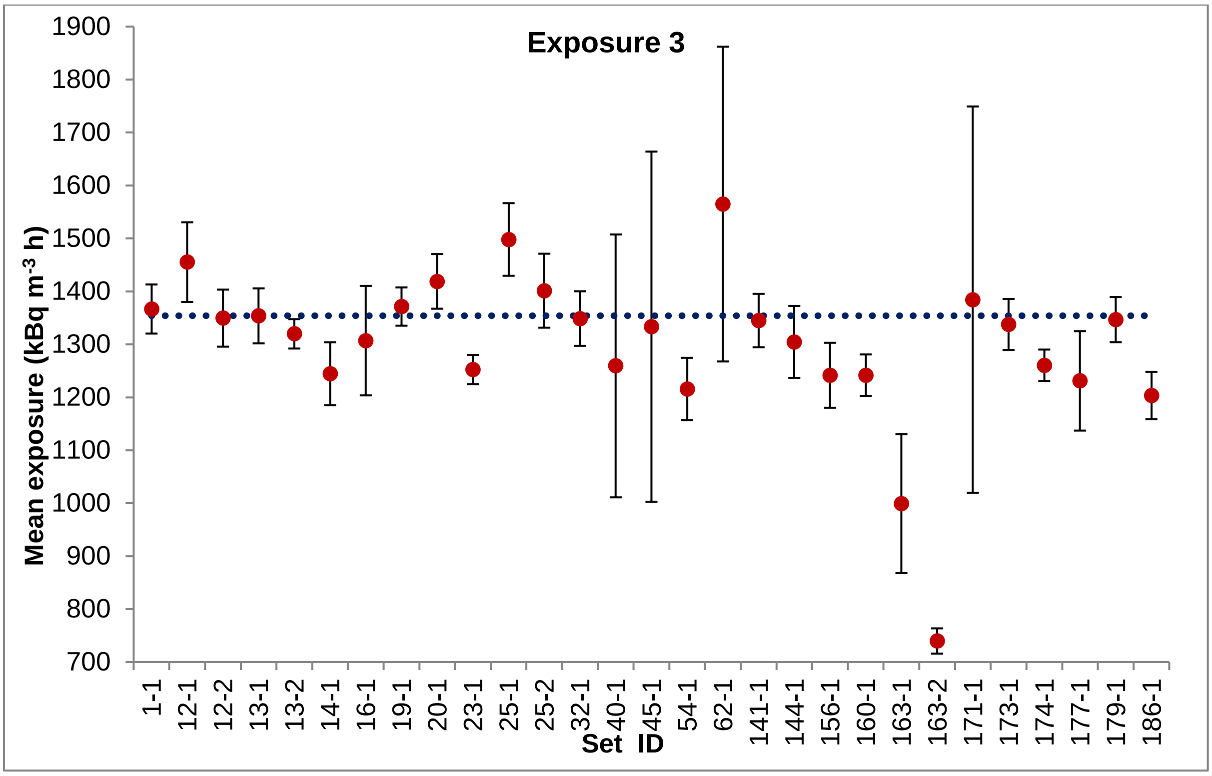


FIGURE 8 Results as reported by participants for exposure 3

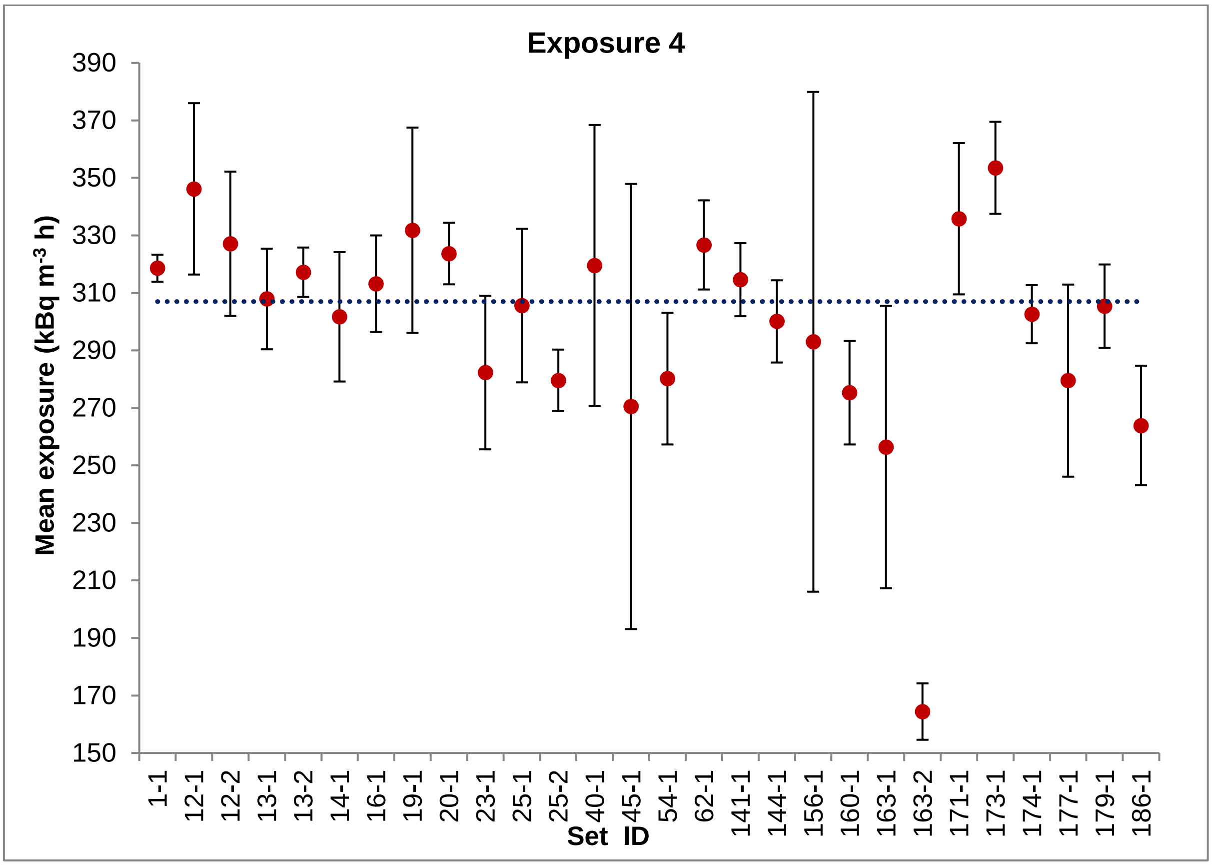


FIGURE 9 Results as reported by participants for exposure 4

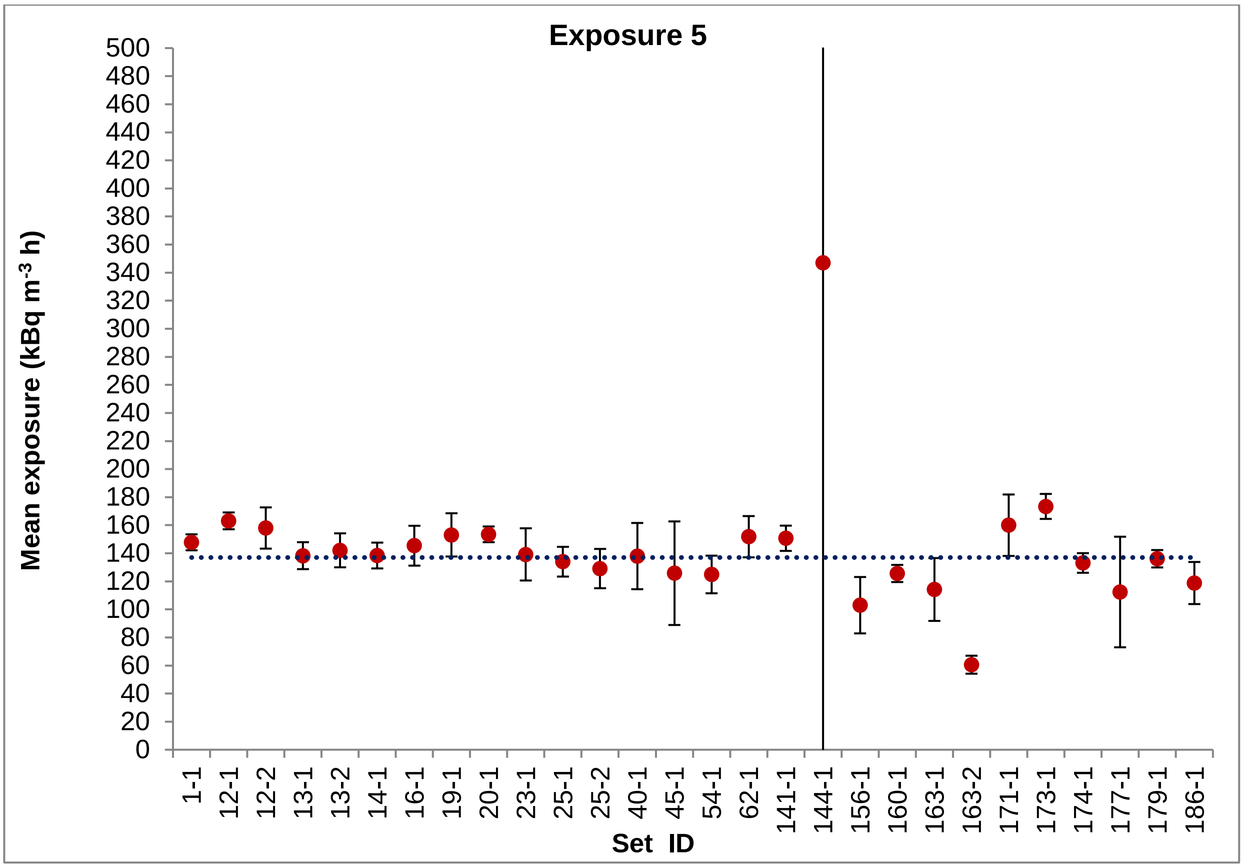


FIGURE 10 Results as reported by participants for exposure 5

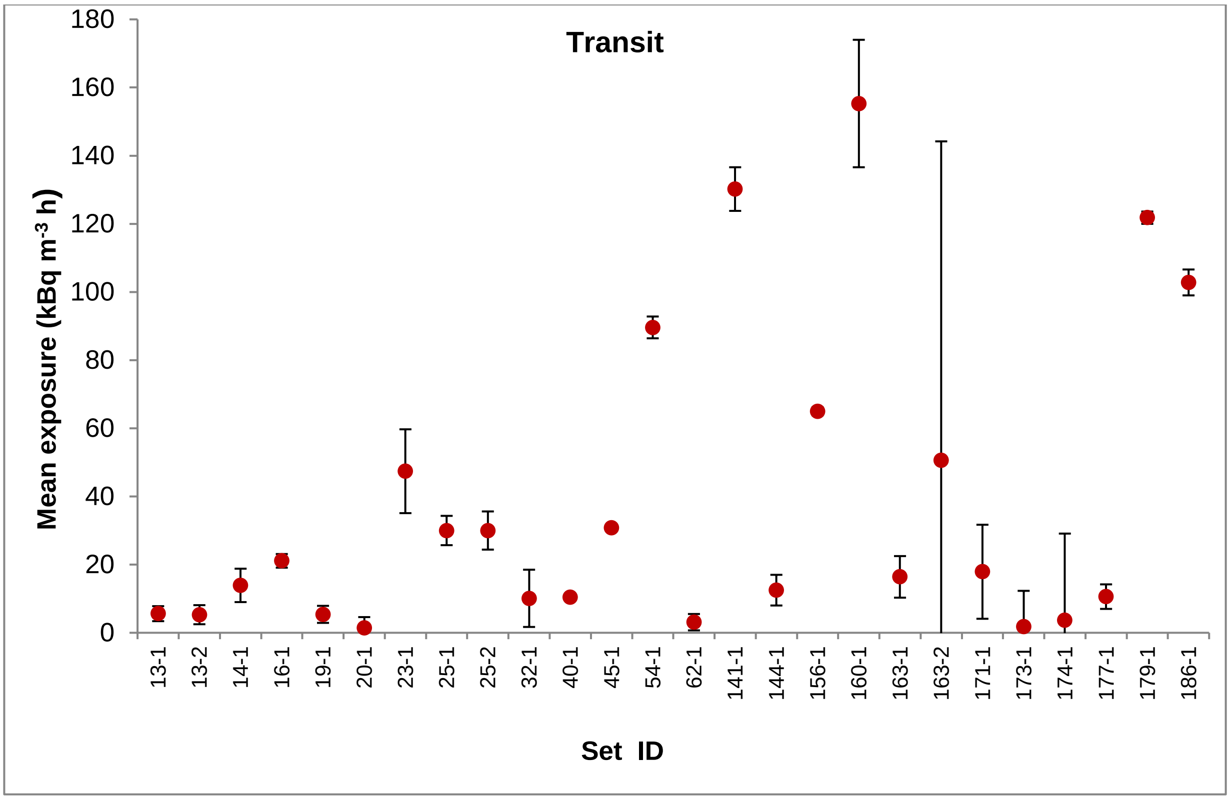
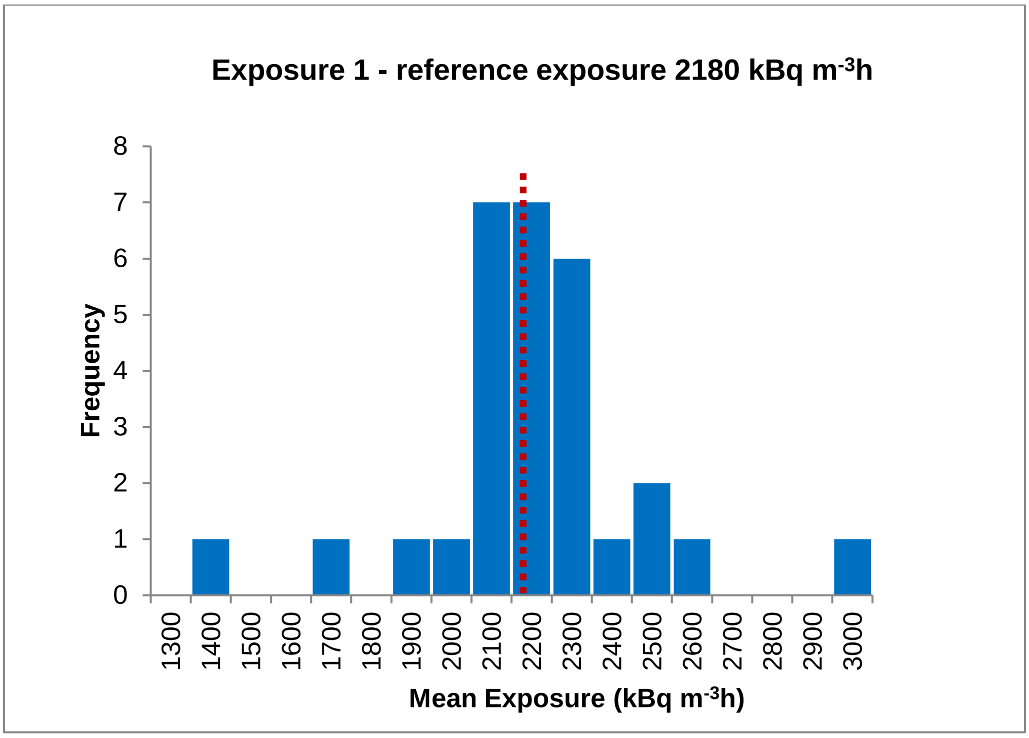
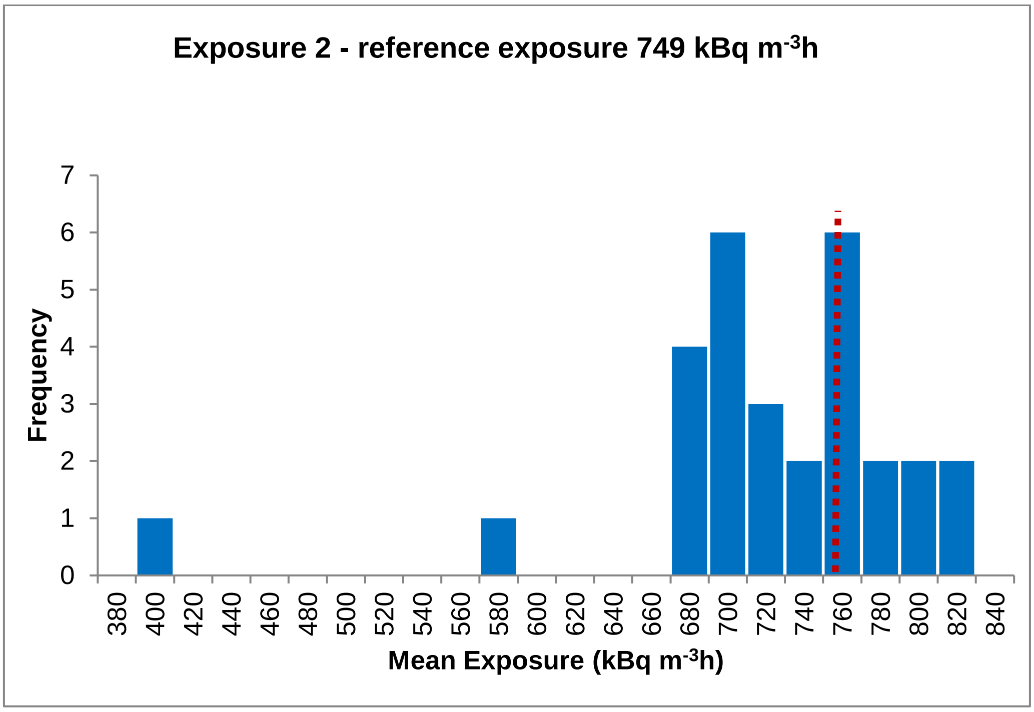
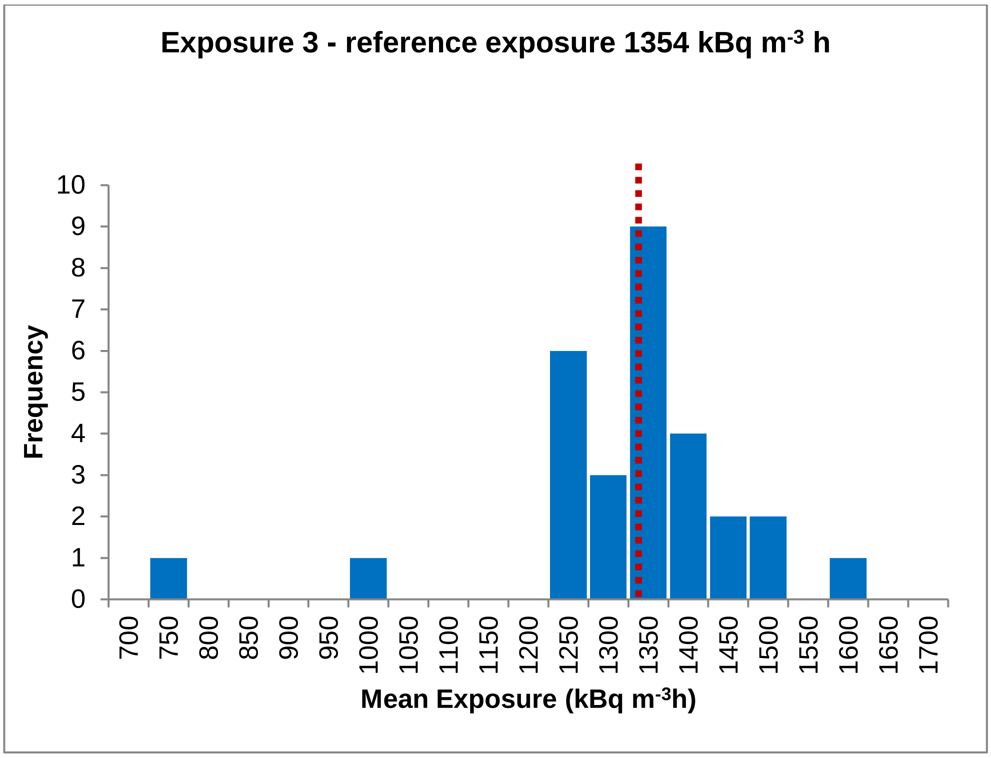
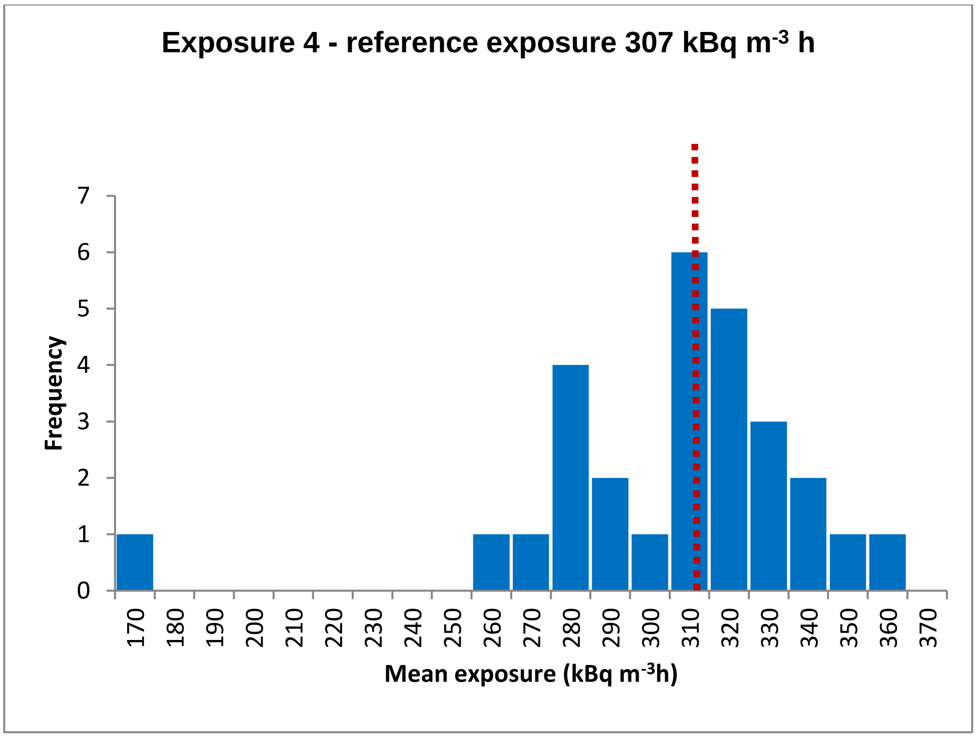


FIGURE 11 Results as reported by participants for transit exposure


Exposure 1 - reference exposure 2180 kBq m-3h
Frequency
0
1
2
3
4
5
6
7
8
1300
1400
1500
1600
1700
1800
1900
2000
2100
2200
2300
2400
2500
2600
2700
2800
2900
3000
Mean Exposure (kBq m-3h)


Exposure 2 - reference exposure 749 kBq m-3h
Frequency
0
1
2
3
4
5
6
7
380
400
420
440
460
480
500
520
540
560
580
600
620
640
660
680
700
720
740
760
780
800
820
840
Mean Exposure (kBq m-3h)


Exposure 3 - reference exposure 1354 kBq m-3 h
Frequency
0
1
2
3
4
5
6
7
8
9
10
700
750
800
850
900
950
1000
1050
1100
1150
1200
1250
1300
1350
1400
1450
1500
1550
1600
1650
1700
Mean Exposure (kBq m-3h)


Exposure 4 - reference exposure 307 kBq m-3 h
Frequency
0
1
2
3
4
5
6
7
170
180
190
200
210
220
230
240
250
260
270
280
290
300
310
320
330
340
350
360
370
Mean exposure (kBq m-3h)

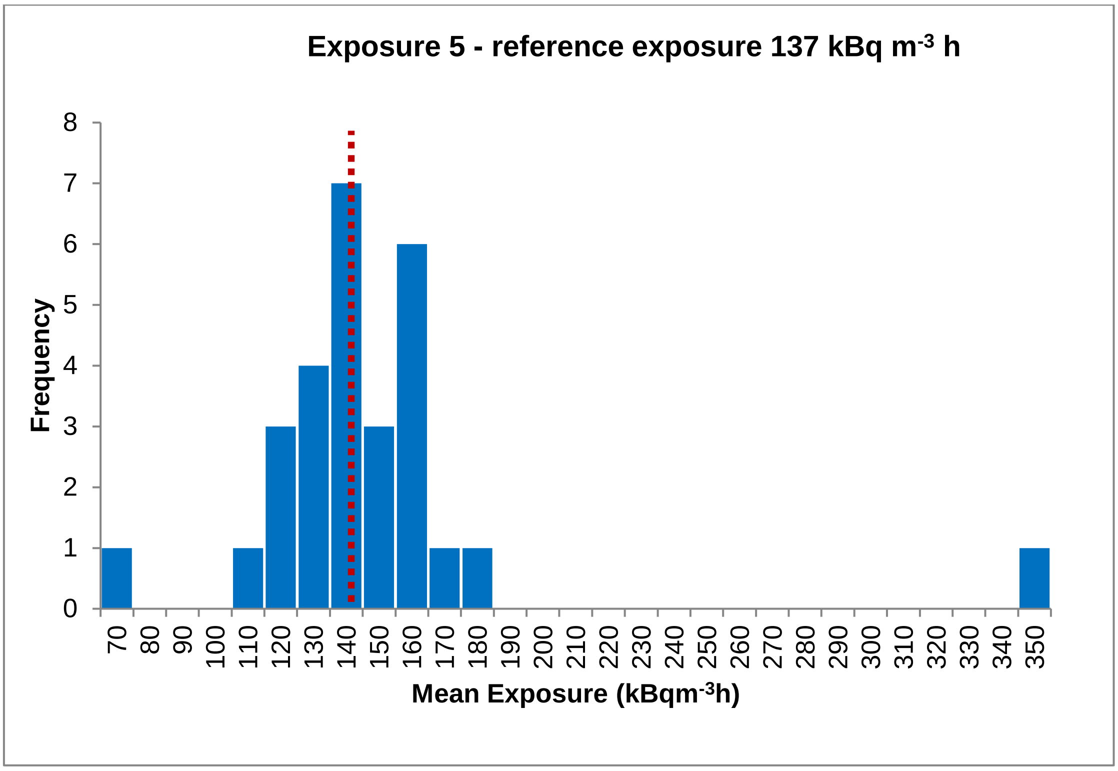


FIGURE 12 Distribution of mean exposure results given in Table 3

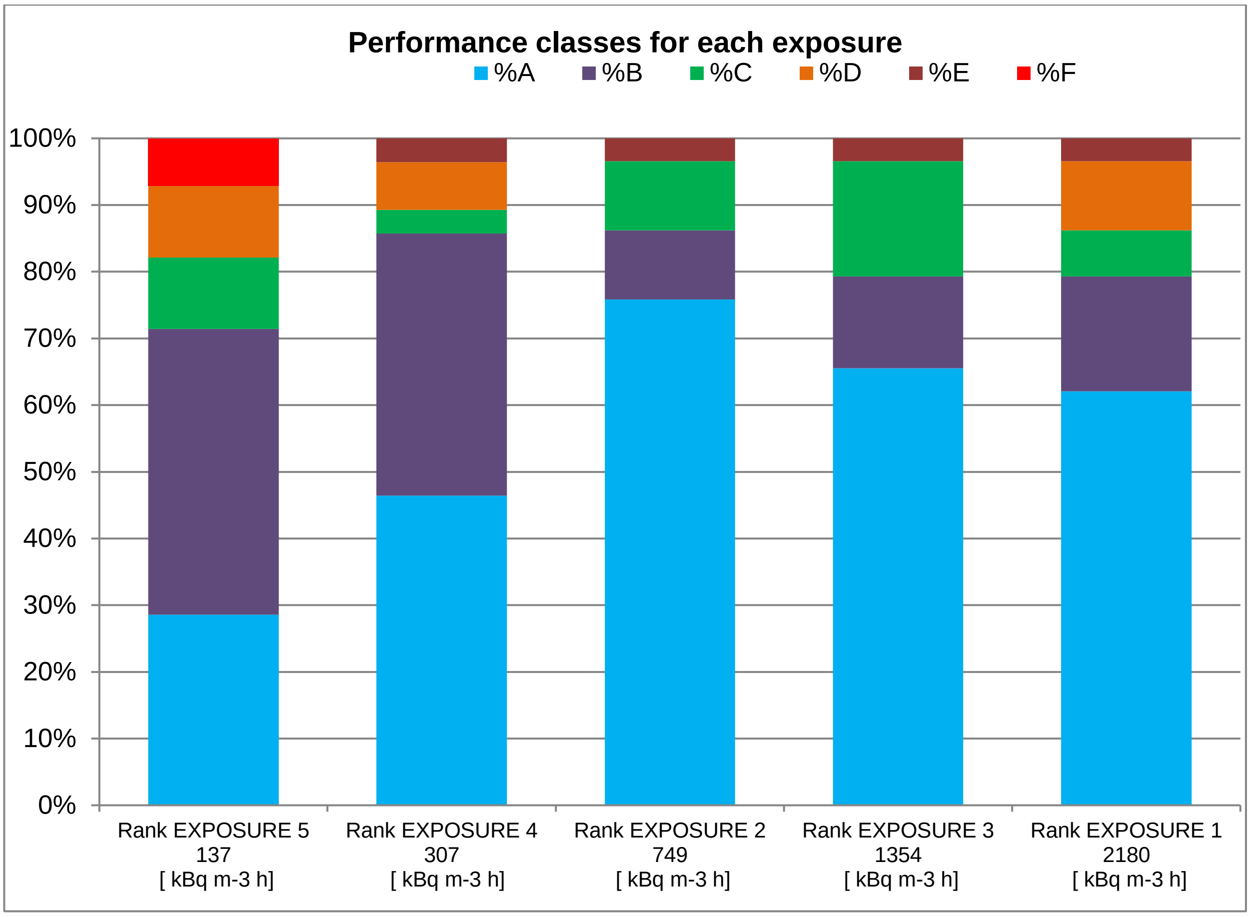


FIGURE 13 Proportions of sets achieving different performance classes for each exposure