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Results of the 2014 PHE Intercomparison of Passive Radon Detectors

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Results of the 2014 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 2014, 22 laboratories from 10 countries, took part in the exercise. Some laboratories submitted more than one set of detectors. A total of 27 sets of detectors were exposed in the PHE radon chamber.

The detectors were exposed to five different radon concentrations ranging from 50 to 3000 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 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. Countries in Europe and elsewhere have carried out surveys in order to determine both individual and average exposures and 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 PHE radon chamber to five different radon concentrations ranging from 50 to 3000 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 2014, for which a total of 22 laboratories from 10 countries submitted 27 sets of detectors. Analysis of the results allows each exposure group in each set to be classified from A (best) to F (worst). All types of detector, whether etched track or electret, can be found in each class, demonstrating the point that, in measuring radon, stringent quality assurance is vital irrespective of the measurement technique.

Contents

Abstract i
Executive Summary iii
1 Introduction 1
2 Laboratory Exposure and Measurement Facilities 2
3 Logistical Arrangements 2
4 Radon Exposures 2
5 Performance classification Scheme 3
6 Results and Discussion 4
7 Conclusion 5
8 Acknowledgements 5
9 References 5
10 List of Participants 6
11 Tables and Figures 7

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.

a 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 detectors, the radioactive decay equilibrium factor, *F*, for radon-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

b Activated charcoal detectors work by retaining adsorbed radon in a charcoal volume. The radon is subsequently measured in the originating laboratory

c 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)* and has operated since 1982. It is now run by the PHE Centre for Radiation, Chemical and Environmental Hazards (CRCE).

Operational procedures and equipment have been described previously (Daraktchieva et al, 2014).

* 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 PHE 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 ATMOS 12 DPX and AlphaGUARD was carried out throughout the intercomparison exercise. Both instruments are calibrated regularly using a radon gas source supplied by Physikalisch Technische Bundesanstalt (PTB), Germany.

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

3 Logistical Arrangements

In total, 22 laboratories from 10 countries, took part in the 2014 PHE intercomparison. Some laboratories submitted more than one set of detectors, so 27 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 exposure to radon. Participants were not told any details of the exposures delivered in the exercise. Results were not reported for some sets, so the results for 21 sets of detectors from 20 laboratories are presented in this report.

4 Radon Exposures

Appropriate conditions were established in the chamber before introducing the detectors. An equilibrium factor, *F*, of about 0.45 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. There is an incomplete data set for exposure 5. This is because of a failure of the data logging system for the radon chamber which occurred over the weekend that the detectors were exposed. The exposure was estimated from the extrapolated data of the days before and after assuming that the atmospheric conditions in the chamber were stable during the weekend.

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 2 to 45 Bq m^{-3}, with an overall average of 31 Bq m^{-3}. The estimated additional exposure of the detectors caused by leaving them exposed in the laboratory for three days to allow radon to diffuse out of them was less than 1% of the exposure in the chamber in all cases and the values were neglected for the purpose of calculating the reference exposures. Transit detectors were used to monitor radon exposure received in transit.

5 Performance Classification Scheme

A performance classification scheme was introduced in 2011 based on the following three parameters:

a percentage biased error, which measures the bias of the measurement

b percentage precision error, which measures the precision of the measurement

c 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,

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

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

The percentage measurement error combines the biased error and precision error, so 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 (best) to F (worst) for each exposure separately. Each participating laboratory is assigned a classification, between A and F, for each exposure. The criteria for 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. In this set of tables, the ‘mean’ is the mean result of ten exposed detectors (five for electrets) 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 provided as well.

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 this table 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 is 33 kBq m^{-3} h (Figure 11). Most of the reported transit exposures were below 50 kBq m^{-3} h, one laboratory reported a value between 50 and 100 kBq m^{-3} h, while two laboratories reported values above 100 kBq m^{-3} h.

Results, using the performance classification scheme, are given in Table 5. 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 overall 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.

Five laboratories participating with five sets of detectors achieved five class A results, meaning that they have a measurement error of under 10% for all five exposures. Moreover, about 60% of all sets of detectors achieved class A for exposures 1, 3, 4 and 5 – an improvement over the results achieved in 2011 and 2012 and equivalent to those achieved in 2013. There was comparable performance at measuring the lowest exposure (132 kBq m^{-3} h): 24% of laboratories achieved class A, the same proportion as in 2013.

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, 22 laboratories from 10 countries participated in the 2014 PHE intercomparison of passive radon detectors. A six-band (A–F) classification scheme was used to evaluate the performance of the detectors across a range of exposures.

8 Acknowledgements

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9 References

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10 List of Participants

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F Sarradin	Dosirad	France
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T Rönnqvist	Gammadata Landauer	Sweden
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S Crust	Kingston University	UK
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D Langridge	DSTL Radiological Protection Services	UK
J Wasikiewicz	Public Health England	UK

11 Tables and Figures

Table 1: Exposure parameters

Exposure	1	2	3	4	5
Duration (h)	336.4	18.2	215.4	48.1	95.1
Radon exposure (kBq m^{-3} h)	2382	132	1477	327	630
Uncertainty (%) at 68% CL	3.0	3.0	3.0	3.0	3.0
EER exposure (kBq m^{-3} h)	1072	58	650	147	284
Uncertainty (%) at 68% CL	7.0	7.0	7.0	7.0	7.0
F, equilibrium factor	0.45	0.44	0.44	0.45	0.45

Notes
EER is equilibrium equivalent of radon.
CL is the confidence level.

Notes to Table 2 and 5

The results for two detectors in set 23-1 were incorrectly assigned by the reporting laboratory. When the corrected results were supplied, the results for the mean of exposures 1, 2, 3, 4 and 5 were 2161.3, 119.2, 1367.4, 303.0 and 603.0 kBq m^{-3} h, respectively. The measurement errors for exposures 1– 5 when corrected were 11.62%, 12.71%, 9.50%, 11.19% and 7.50%, respectively. The ranks for exposures 1–5 when corrected were B, B, A, B and A, respectively.

Table 2: Analysis of all reported results
Exposure 1: 2382 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	2393.1	84.9	0.5	3.5	3.6
7-1	2291.7	82.3	–3.8	3.6	5.2
12-1	2252.5	55.0	–5.4	2.4	6.0
13-1	2253.1	53.6	–5.4	2.4	5.9
14-1	2239.7	93.9	–6.0	4.2	7.3
19-1	2412.5	31.3	1.3	1.3	1.8
20-1	2457.0	78.8	3.1	3.2	4.5
23-1	1771.2	703.9	–25.6	39.7	47.3
28-1	2819.2	75.9	18.4	2.7	18.6
32-1	2331.7	60.0	–2.1	2.6	3.3
40-1	2233.0	280.2	–6.3	12.5	14.0
62-1	2471.7	105.0	3.8	4.2	5.7
129-1	2285.2	103.1	–4.1	4.5	6.1
141-1	2291.4	55.0	–3.8	2.4	4.5
160-1	2291.8	118.8	–3.8	5.2	6.4
160-2	2307.1	71.9	–3.1	3.1	4.4
161-1	2460.5	73.0	3.3	3.0	4.4
163-1	2397.6	156.5	0.7	6.5	6.6
171-1	2823.7	152.3	18.5	5.4	19.3
174-1	2451.3	71.2	2.9	2.9	4.1
178-1	2425.4	48.1	1.8	2.0	2.7

Table 2: Analysis of all reported results *(continued)*
Exposure 2: 132 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	135.0	3.6	2.3	2.7	3.5
7-1	132.0	23.6	0.0	17.9	17.9
12-1	127.2	6.2	–3.6	4.9	6.1
13-1	133.7	5.3	1.3	4.0	4.2
14-1	116.3	10.1	–11.9	8.7	14.7
19-1	134.6	18.2	2.0	13.5	13.7
20-1	120.8	16.0	–8.5	13.2	15.7
23-1	–75.8	9.8	–157.4	–12.9	158.0
28-1	127.3	12.9	–3.6	10.1	10.7
32-1	133.2	6.8	0.9	5.1	5.2
40-1	144.8	25.0	9.7	17.3	19.8
62-1	144.3	8.4	9.3	5.8	11.0
129-1	126.1	13.6	–4.5	10.8	11.7
141-1	145.0	6.0	9.8	4.1	10.7
160-1	133.2	10.4	0.9	7.8	7.9
160-2	89.1	10.4	–32.5	11.7	34.5
161-1	147.6	21.9	11.8	14.8	19.0
163-1	64.0	11.5	–51.5	18.0	54.6
171-1	181.2	39.7	37.3	21.9	43.2
174-1	146.3	15.3	10.8	10.5	15.1
178-1	162.4	5.0	23.0	3.1	23.2

Table 2: Analysis of all reported results *(continued)*

Exposure 3: 1477 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	1518.2	43.5	2.8	2.9	4.0
7-1	1406.7	92.4	–4.8	6.6	8.1
12-1	1450.7	51.9	–1.8	3.6	4.0
13-1	1435.5	24.9	–2.8	1.7	3.3
14-1	1358.4	37.8	–8.0	2.8	8.5
19-1	1508.8	11.7	2.2	0.8	2.3
20-1	1524.0	70.1	3.2	4.6	5.6
23-1	1172.4	81.1	–20.6	6.9	21.8
28-1	1668.3	164.5	13.0	9.9	16.3
32-1	1420.3	52.9	–3.8	3.7	5.3
40-1	1475.7	198.8	–0.1	13.5	13.5
62-1	1442.9	71.0	–2.3	4.9	5.4
129-1	1412.9	97.8	–4.3	6.9	8.2
141-1	1422.2	29.2	–3.7	2.1	4.2
160-1	1368.7	50.7	–7.3	3.7	8.2
160-2	1397.4	54.3	–5.4	3.9	6.6
161-1	1515.1	84.8	2.6	5.6	6.2
163-1	1526.6	94.5	3.4	6.2	7.0
171-1	1658.2	244.5	12.3	14.7	19.2
174-1	1513.7	45.5	2.5	3.0	3.9
178-1	1451.4	31.1	–1.7	2.1	2.8

Table 2: Analysis of all reported results *(continued)*
Exposure 4: 327 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	335.6	11.2	2.6	3.3	4.2
7-1	317.4	24.5	–2.9	7.7	8.3
12-1	313.3	27.1	–4.2	8.6	9.6
13-1	338.1	10.3	3.4	3.0	4.6
14-1	304.1	16.1	–7.0	5.3	8.8
19-1	342.7	7.7	4.8	2.2	5.3
20-1	338.9	21.2	3.6	6.3	7.2
23-1	108.0	25.5	–67.0	23.6	71.0
28-1	309.6	20.3	–5.3	6.6	8.4
32-1	342.9	10.5	4.9	3.1	5.7
40-1	341.7	49.9	4.5	14.6	15.3
62-1	354.0	15.8	8.3	4.5	9.4
129-1	311.9	31.0	–4.6	9.9	11.0
141-1	330.5	13.3	1.1	4.0	4.2
160-1	331.4	22.4	1.3	6.8	6.9
160-2	282.1	22.8	–13.7	8.1	15.9
161-1	356.7	24.6	9.1	6.9	11.4
163-1	350.0	132.1	7.0	37.7	38.4
171-1	444.7	92.3	36.0	20.8	41.5
174-1	347.9	25.7	6.4	7.4	9.8
178-1	346.6	20.2	6.0	5.8	8.4

Table 2: Analysis of all reported results *(continued)*
Exposure 5: 630 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	664.1	17.1	5.4	2.6	6.0
7-1	661.1	53.7	4.9	8.1	9.5
12-1	641.8	18.1	1.9	2.8	3.4
13-1	676.8	27.1	7.4	4.0	8.4
14-1	593.2	20.8	–5.8	3.5	6.8
19-1	697.1	18.2	10.7	2.6	11.0
20-1	619.0	39.3	–1.7	6.3	6.6
23-1	408.0	37.5	–35.2	9.2	36.4
28-1	720.2	122.7	14.3	17.0	22.3
32-1	648.7	19.9	3.0	3.1	4.3
40-1	718.3	106.4	14.0	14.8	20.4
62-1	623.9	42.0	–1.0	6.7	6.8
129-1	630.8	35.8	0.1	5.7	5.7
141-1	645.5	24.5	2.5	3.8	4.5
160-1	663.8	41.1	5.4	6.2	8.2
160-2	600.8	31.3	–4.6	5.2	7.0
161-1	709.1	33.6	12.6	4.7	13.4
163-1	667.2	33.8	5.9	5.1	7.8
171-1	843.6	113.5	33.9	13.5	36.5
174-1	688.1	18.6	9.2	2.7	9.6
178-1	682.3	29.6	8.3	4.3	9.4

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	7.8	4.5	62-1	8.5	1.4
7-1	43.2	16.8	129-1	21.4	18.6
12-1	5.4	2.8	141-1	0	0.0
13-1	3	2.2	160-1	22.6	3.9
14-1	17	6.1	160-2	141.8	12.8
19-1	20.7	8.3	161-1	31.1	5.7
20-1	1.5	3.3	163-1	127	131.3
23-1	207.2	616.1	171-1	20.3	7.9
28-1	13.8	8.2	174-1	5.7	5.7
32-1	6.2	1.5	178-1	24.6	3.1
40-1	56.4	45.4			

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 (2382 kBq m^{-3} h)	2342	189
2 (132 kBq m^{-3} h)	122	51
3 (1477 kBq m^{-3} h)	1459	104
4 (327 kBq m^{-3} h)	326	59
5 (630 kBq m^{-3} h)	657	78

Table 4: Detector characteristics

Set ID	Detector type	Filter	Holder	Detector material	Detector material supplier
1-1	Closed	–	NRPB/SSI	CR39	Mi-Net
7-1	Closed	–	TASL	CR39	TASL
12-1	Closed	–	NRPB/SSI	CR39	TASL
13-1	Closed	–	NRPB/SSI	CR39	Intercast
14-1	Closed	–	NRPB/SSI	CR39	TASL
19-1	Closed	–	Own	CR39	Intercast
20-1	Closed	–	TASL	CR39	TASL
23-1	Closed	–	NRPB/SSI	CR39	TASL
28-1	Closed	–	Radosys	CR39	Radosys
32-1	Closed	–	NRPB/SSI	CR39	TASL
40-1	Closed	–	NRPB/SSI	CR39	Mi-Net
62-1	Closed	–	Own	Makrofol	Bayer
129-1	Closed	–	Own	CR39	Intercast
141-1	Closed	–	TASL	CR39	TASL
160-1	Closed	–	NRPB/SSI	CR39	TASL
160-2	Closed	–	TASL	CR39	TASL
161-1	Closed	–	Radosys	CR39	Radosys
163-1	Closed	–	E Perm S	Electret	N/A
171-1	Closed	–	E Perm S	Electret	N/A
174-1	Closed	–	TASL	Cr39	TASL
178-1	Closed	–	TASL	CR39	TASL

Table 5: Performance classification scheme based on measurement error

	Performance classification in each exposure				
	2	4	5	3	1
Set ID	132 kBq m^{-3} h	327 kBq m^{-3} h	630 kBq m^{-3} h	1477 kBq m^{-3}	2432 kBq m^{-3} h
1-1	A	A	A	A	A
12-1	A	A	A	A	A
13-1	A	A	A	A	A
32-1	A	A	A	A	A
160-1	A	A	A	A	A
7-1	B	A	A	A	A
14-1	B	A	A	A	A
20-1	B	A	A	A	A
62-1	B	A	A	A	A
141-1	B	A	A	A	A
174-1	B	A	A	A	A
19-1	B	B	A	A	A
129-1	B	A	A	B	A
161-1	B	B	A	B	A
178-1	C	A	A	A	A
28-1	B	C	B	A	B
40-1	B	C	B	B	B
160-2	D	A	A	B	A
171-1	E	D	B	E	B
163-1	F	A	A	D	A
23-1	F	D	C	F	E

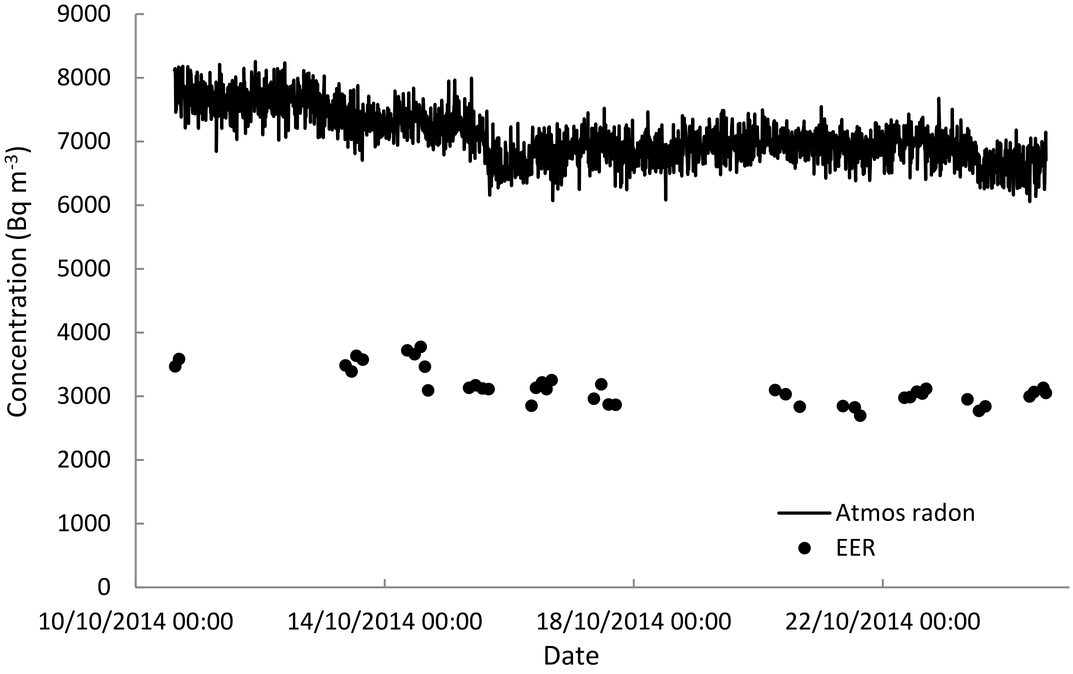


Figure 1: Radon and EER concentrations for exposure 1

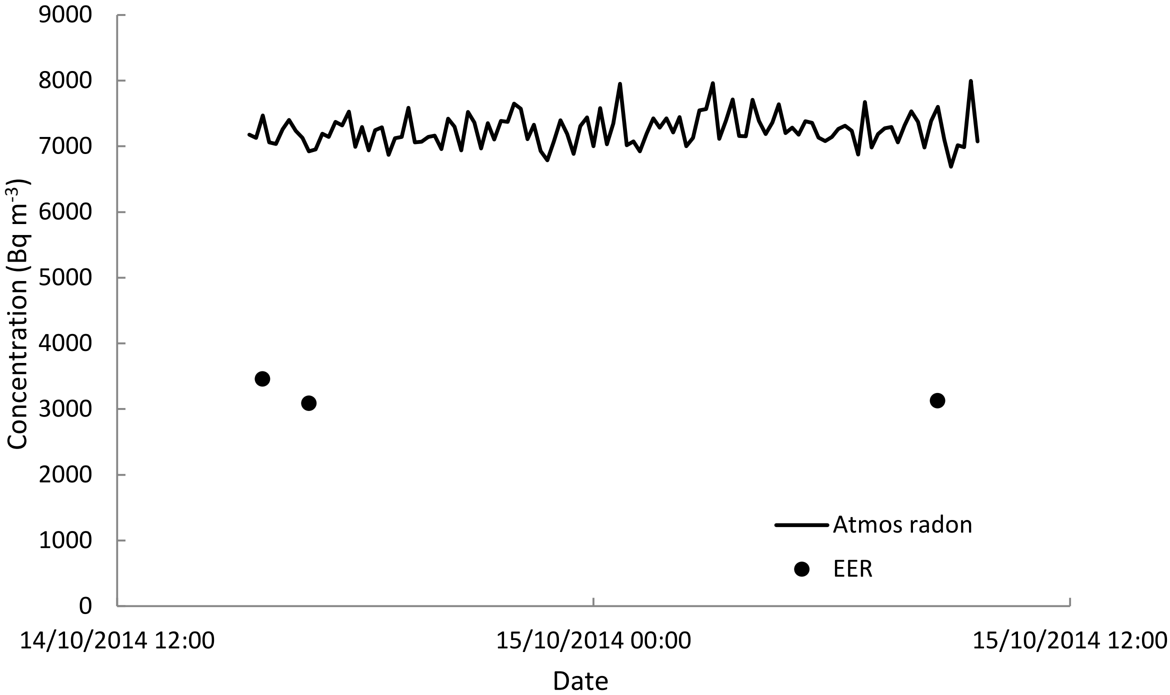


Figure 2: Radon and EER concentrations for exposure 2

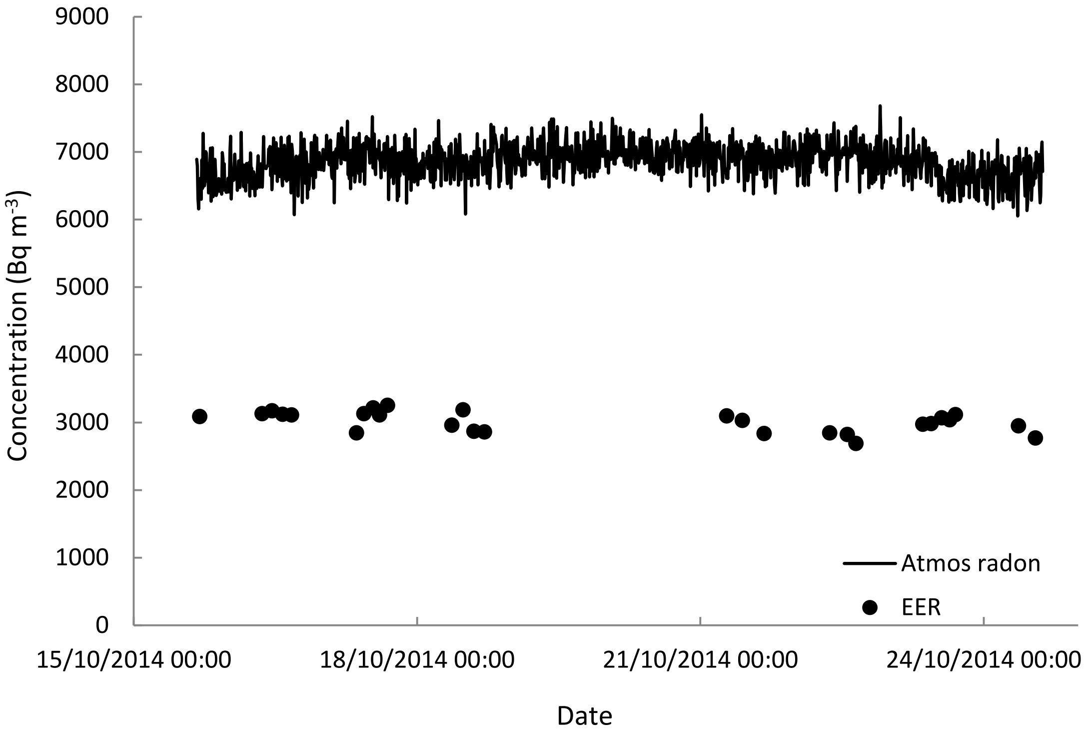


Figure 3: Radon and EER concentrations for exposure 3

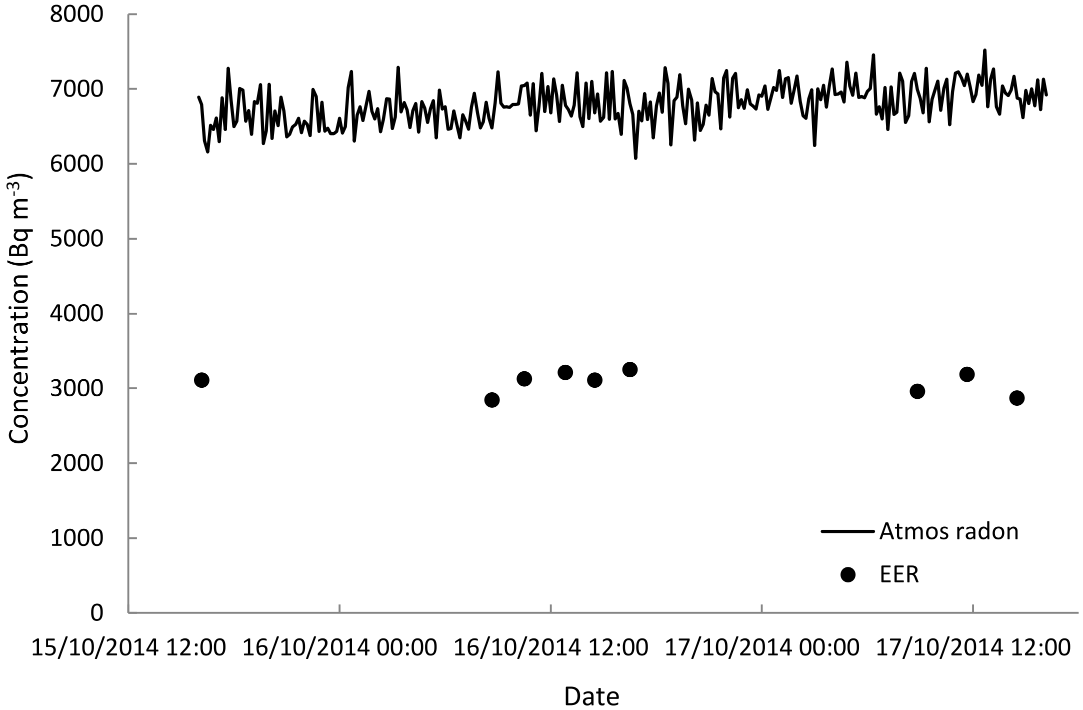


Figure 4: Radon and EER concentrations for exposure 4

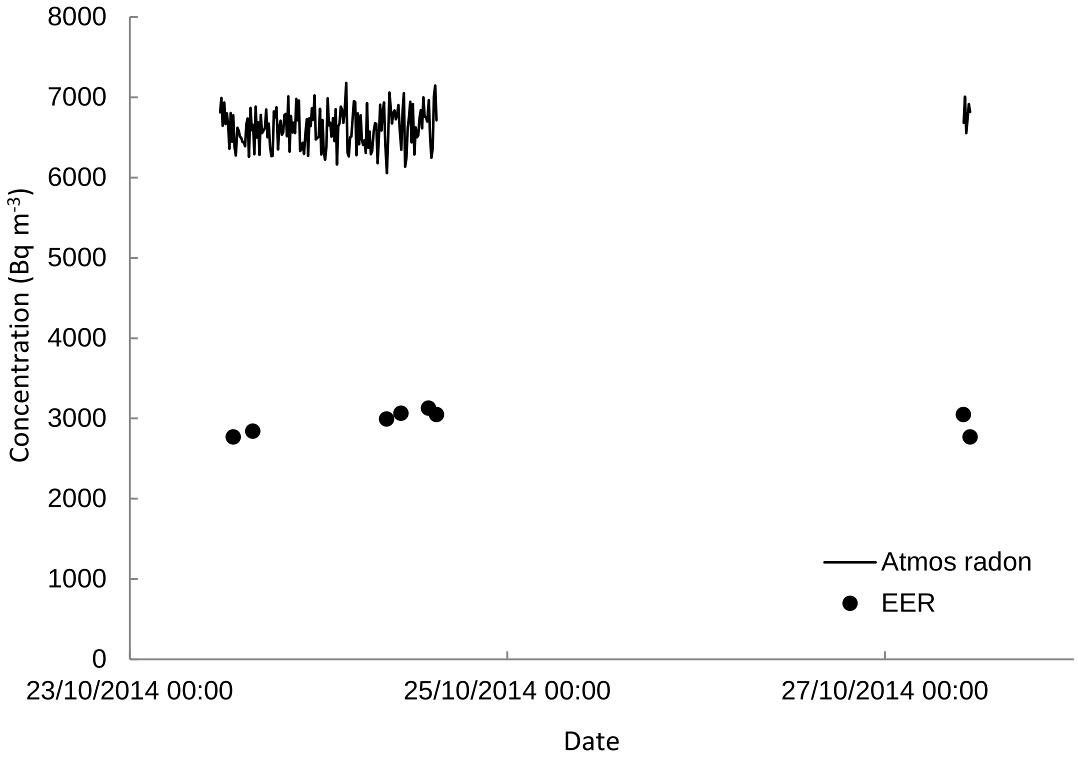


Figure 5: Radon and EER concentrations for exposure 5

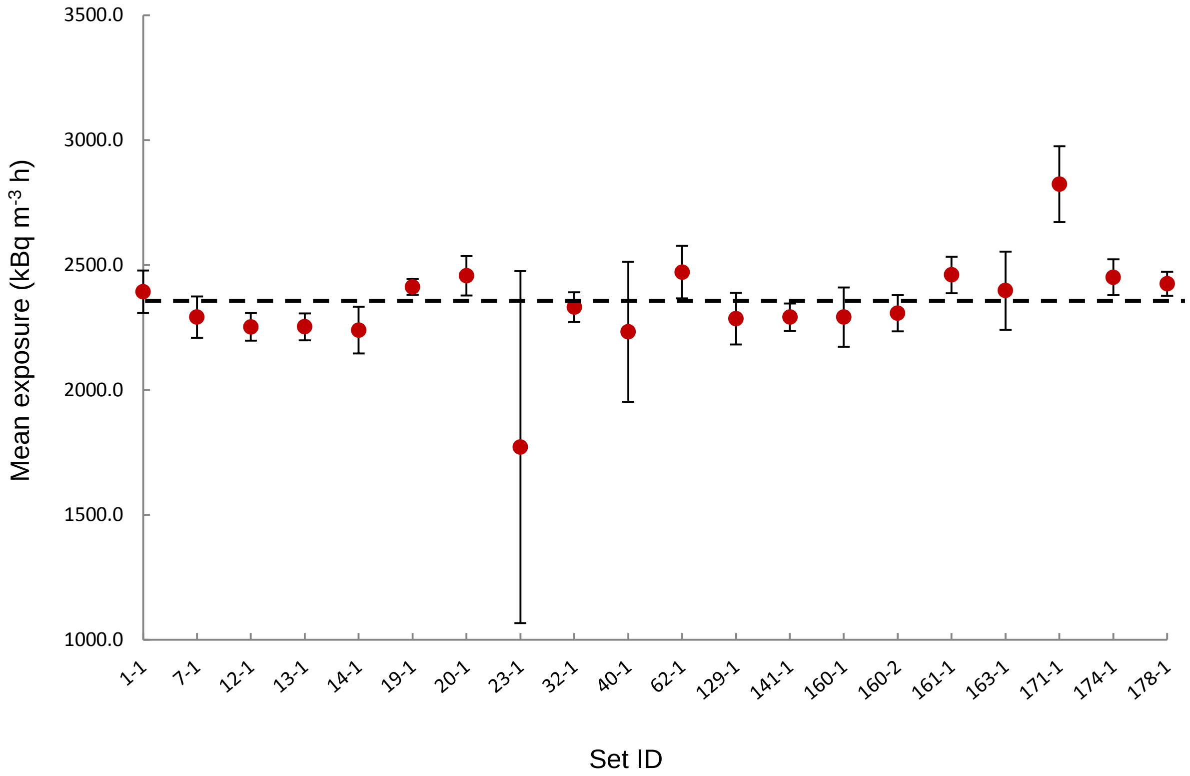


Figure 6: Results as reported by participants for exposure 1

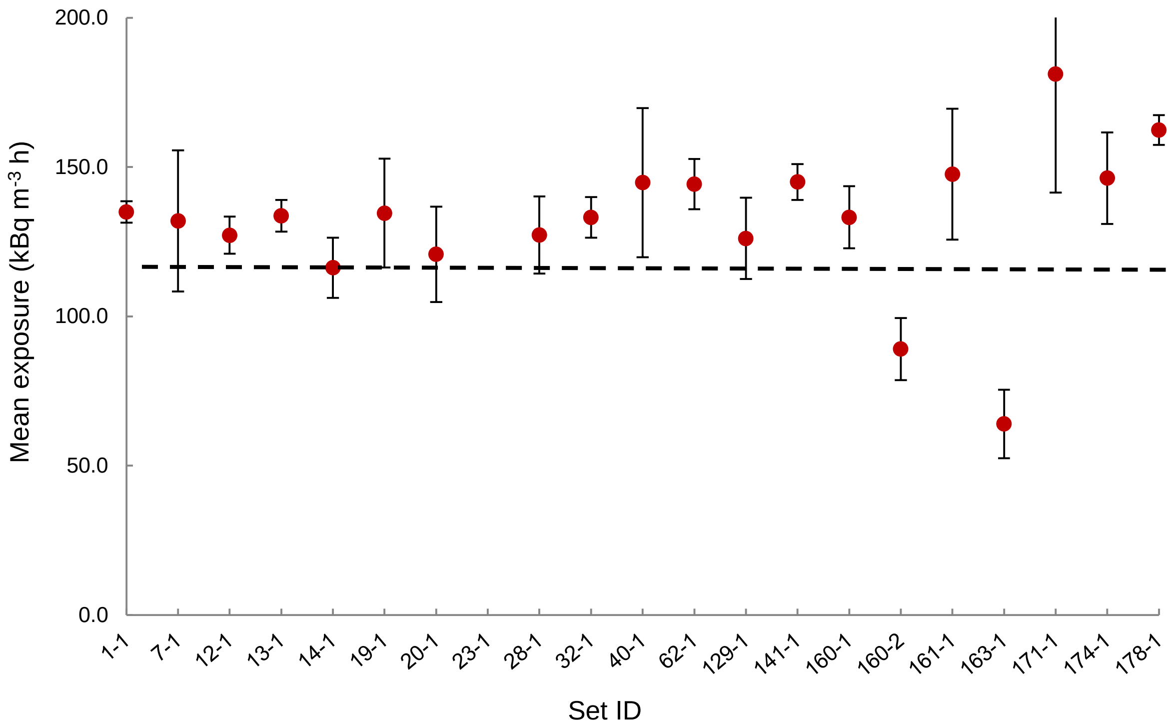


Figure 7: Results as reported by participants for exposure 2

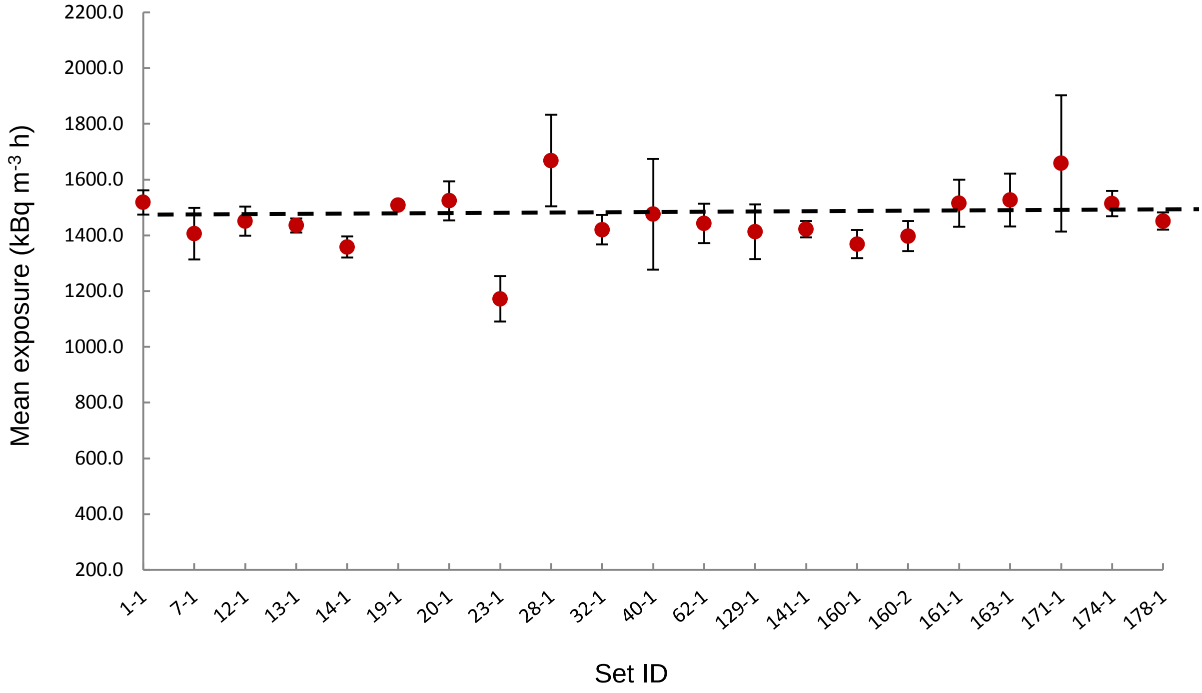


Figure 8: Results as reported by participants for exposure 3

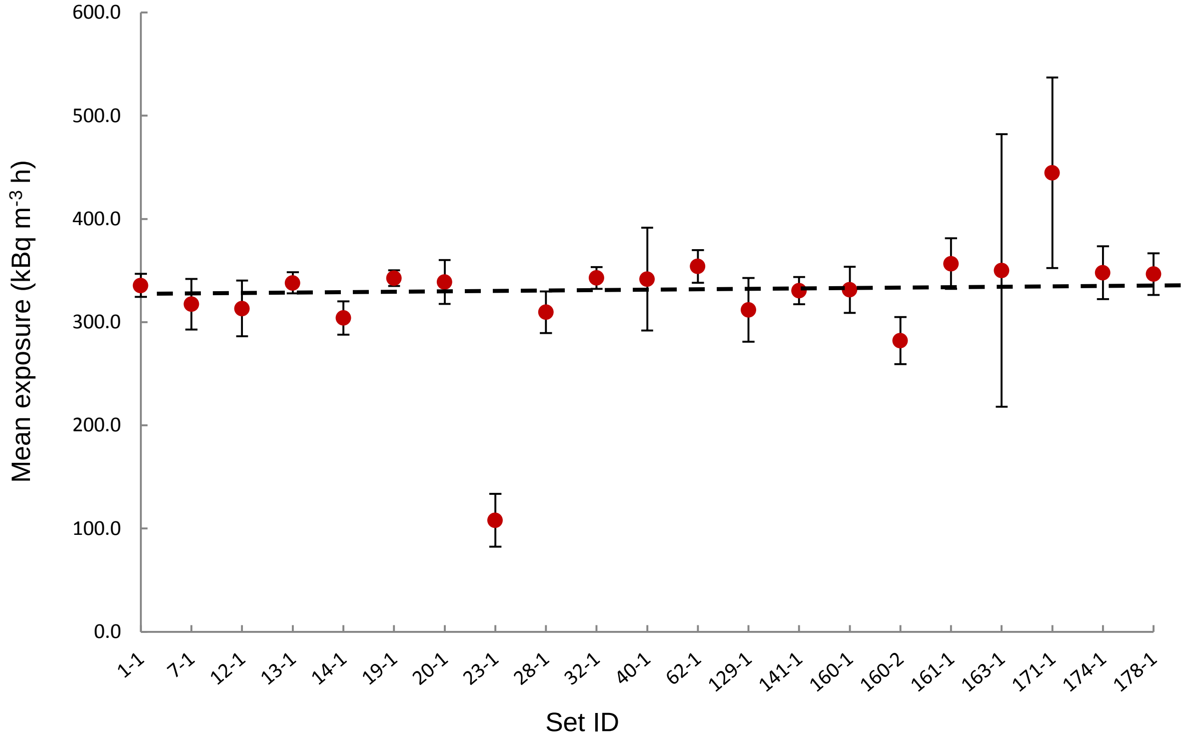


Figure 9: Results as reported by participants for exposure 4

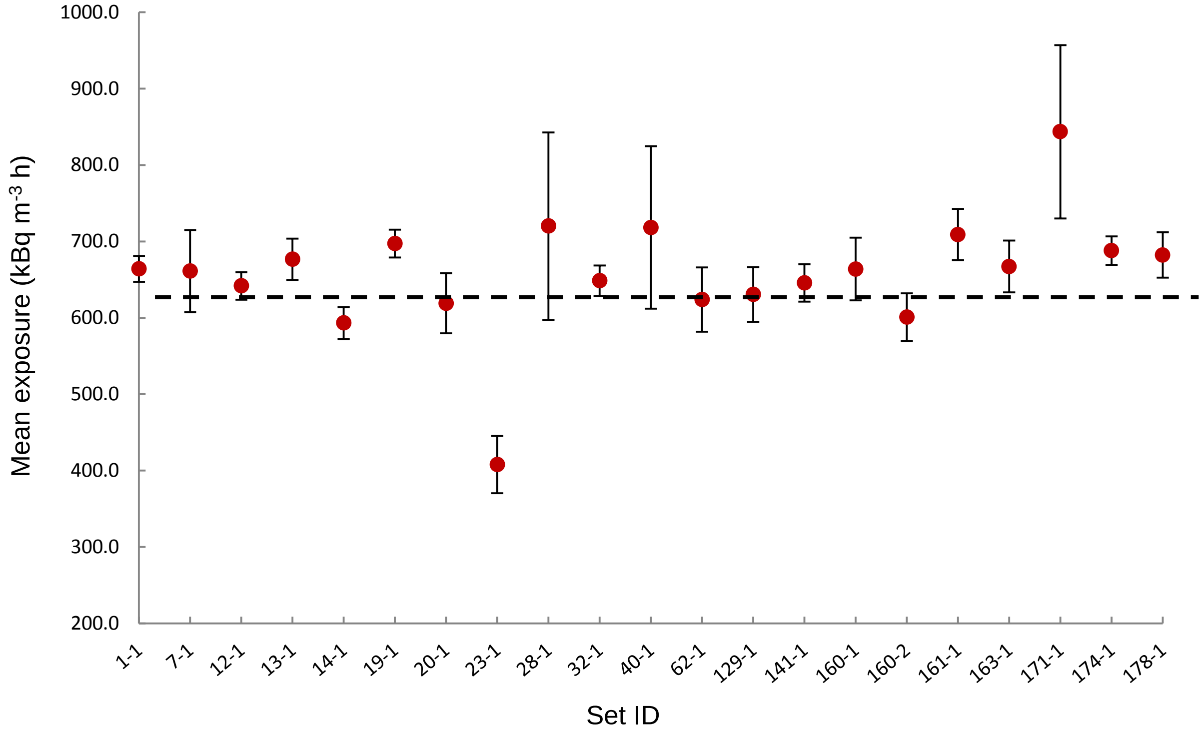


Figure 10: Results as reported by participants for exposure 5

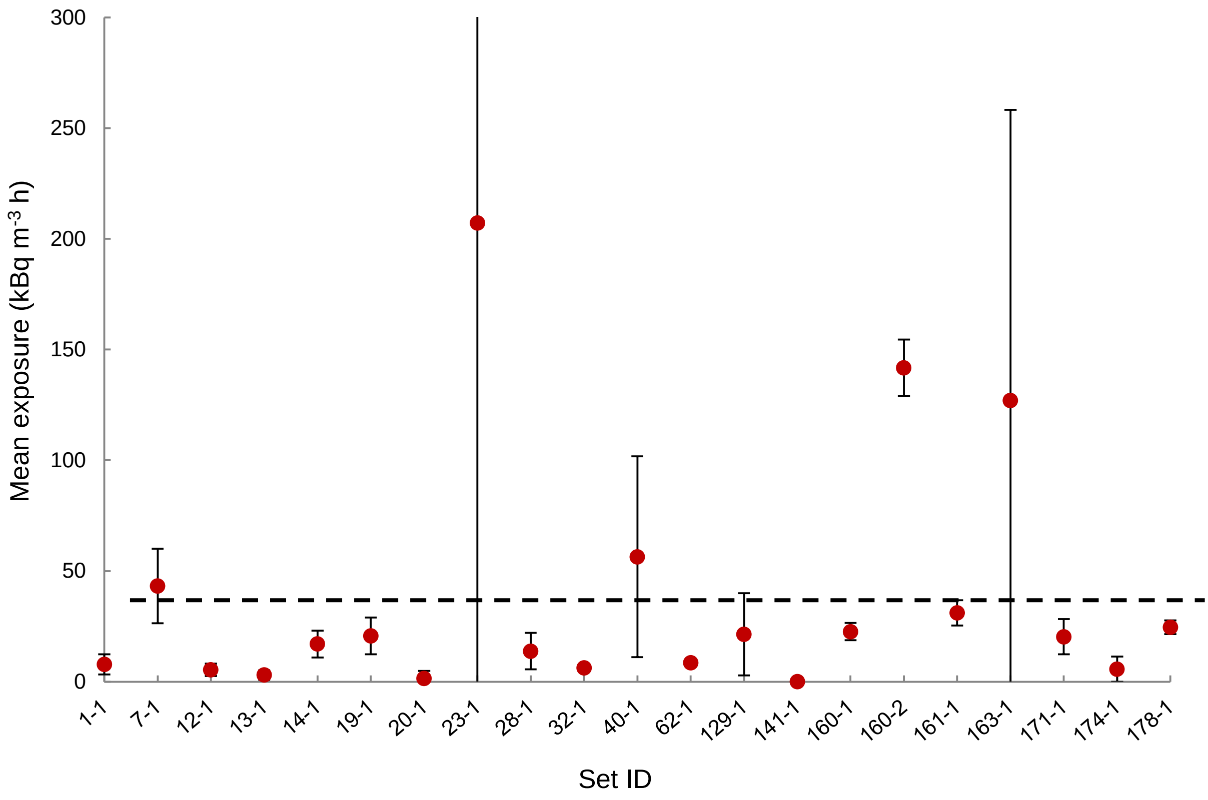
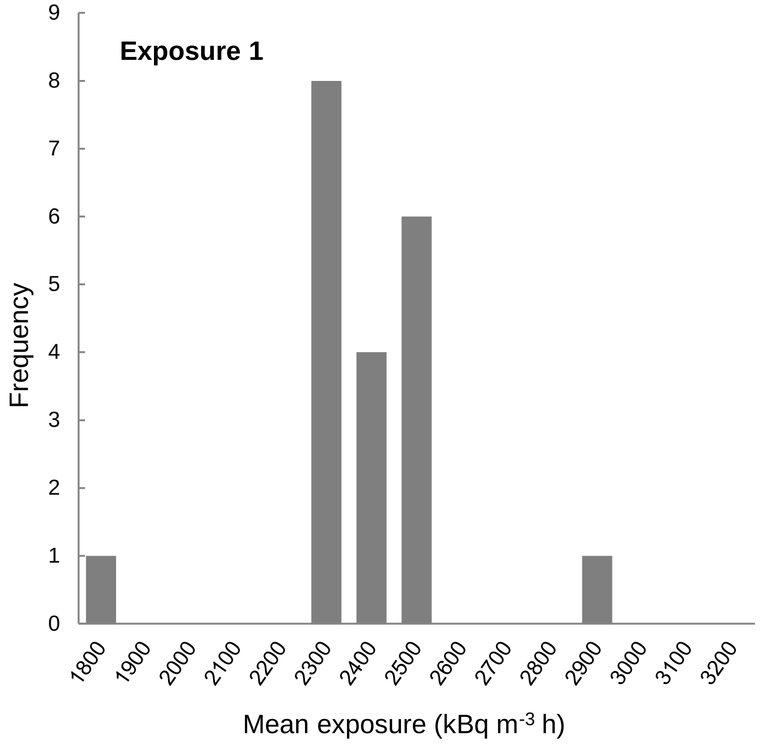


Figure 11: Results as reported by participants for transit exposure



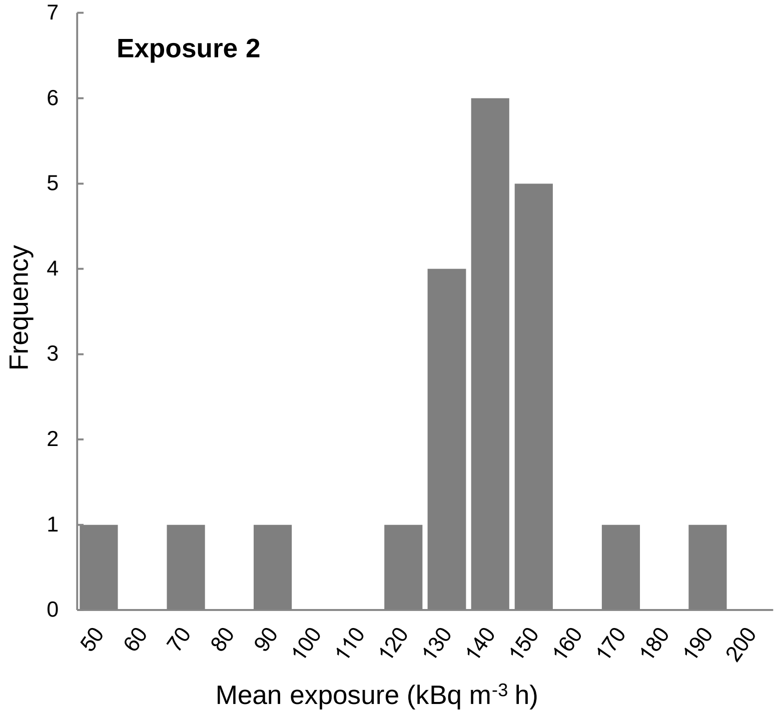
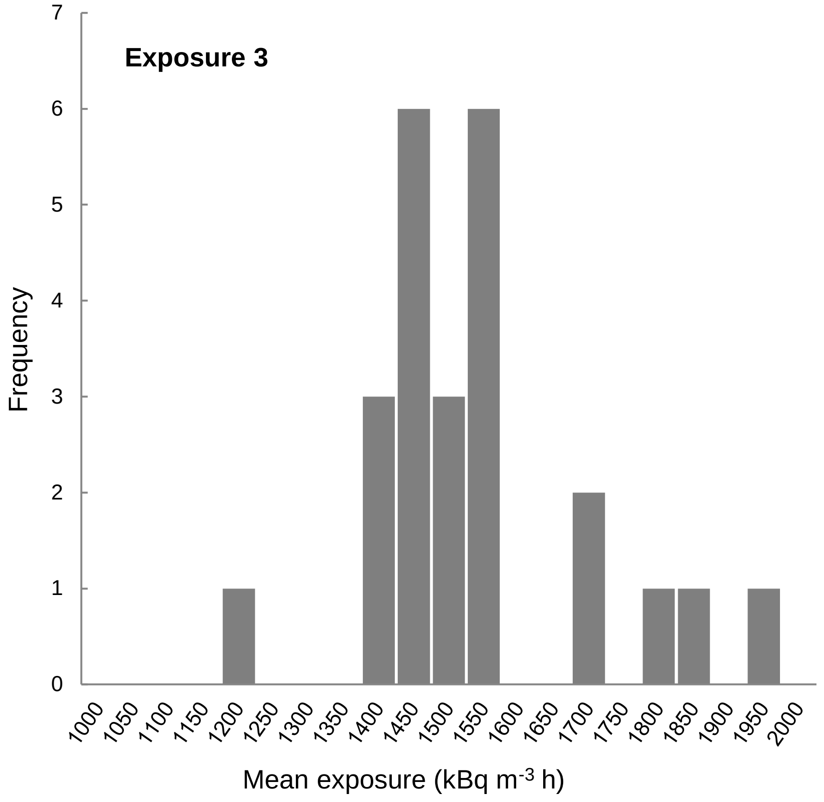


Figure 12: Distribution of mean exposure results given in Table 3



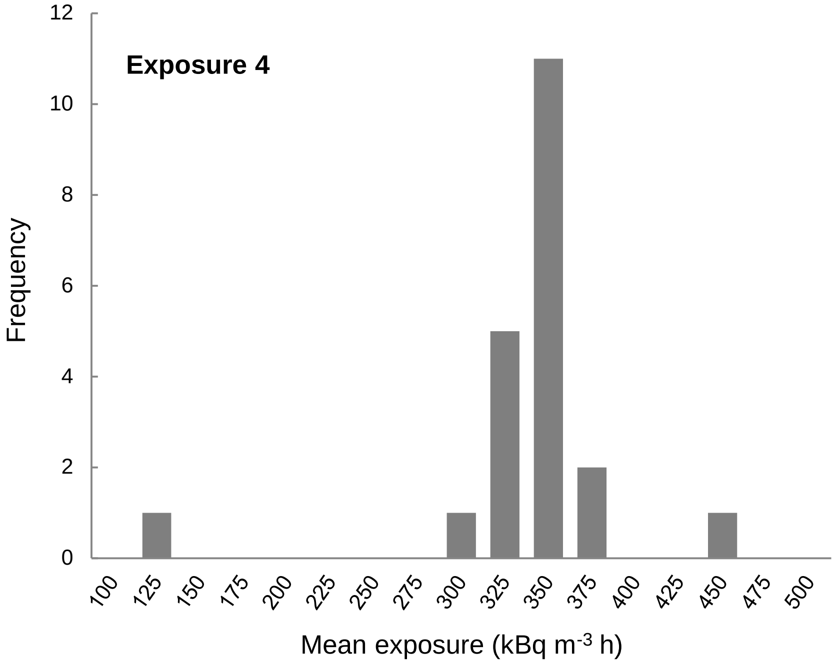


Figure 12: Distribution of mean exposure results given in Table 3 *(continued)*

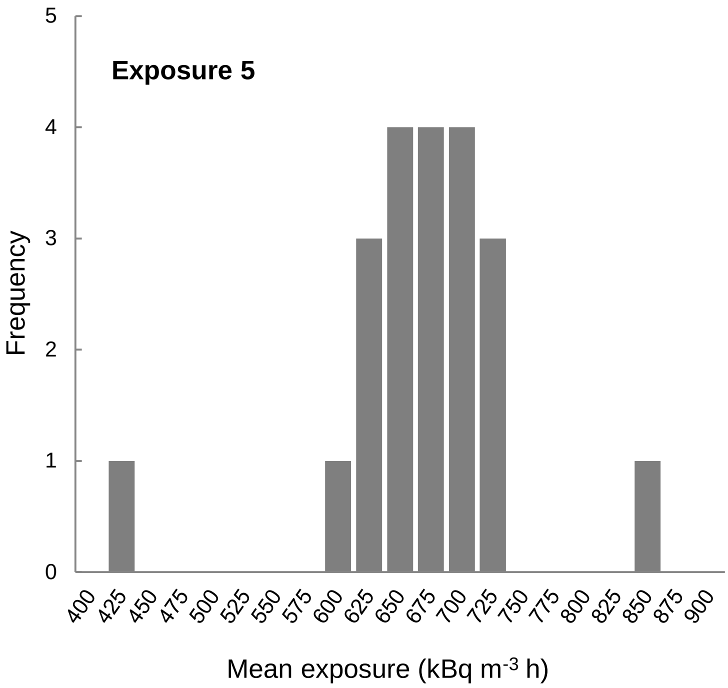


Figure 12: Distribution of mean exposure results given in Table 3 *(continued)*

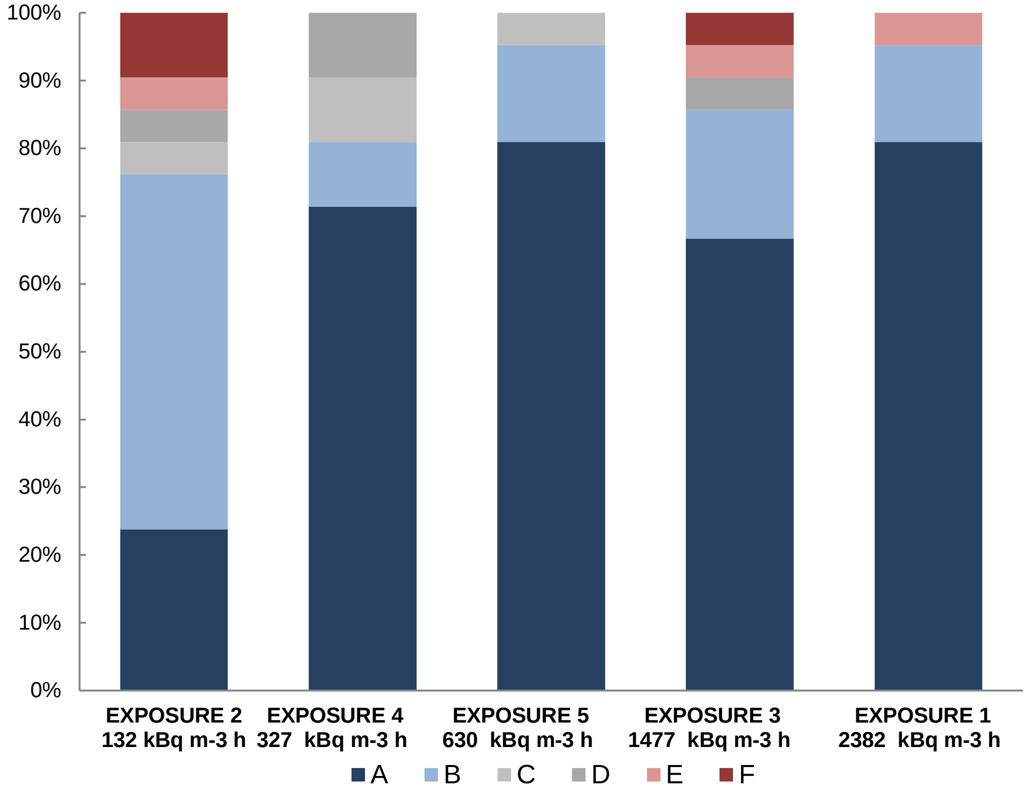


Figure 13: Proportions of sets achieving different performance classes for each exposure