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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 for many years. In 2018, a total of 26 laboratories from 12 countries took part in the exercise. As some laboratories submitted more than 1 set of detectors, a total of 30 sets of detectors were exposed in the PHE radon chamber.

The detectors were exposed to 5 different radon concentrations ranging between 100 and 2,200 kBq m^{-3} h. After exposure, the detectors were returned to the originating laboratories for processing. Participants were 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. The 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 3 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 (CRCE) of Public Health England 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 6 groups at CRCE. Five of these groups were exposed in the CRCE radon chamber to radon exposures ranging from 100 to 2,200 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 (best) to F (worst). This year, 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 1 or 2 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 3 most common methods are outlined below.

- **Etched track detectors** are referred to as such because alpha particles from radon and its decay products 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 radon-222 (^{222}Rn) has to be taken into account to estimate the proportion of alpha particles that arise from ^{222}Rn 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. The response of closed detectors is not affected by the equilibrium factor (F).
- **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. A filter in the chamber excludes radon decay products, so the response is unaffected by F.

Passive radon detectors are quite simple to produce and to 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 annually 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 (^{226}Ra) 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 8,000 Bq m^{-3}. Table 3 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 either Physikalisch Technische Bundesanstalt (PTB), Germany or CHUV Institut de Radiophysique, Switzerland.

During exposures, radon decay products were sampled approximately 4 times per day on to 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 1 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. Participants were asked to return results for each detector in terms of integrated exposure to radon. The participants were not told any details of the exposures delivered in the exercise until after the results had been received from all participating laboratories. One laboratory withdrew their results, so this report is of 25 laboratories and 29 sets of detectors.

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 5 intercomparison exposures. The chamber exposures were calculated after the deadline for return of results by participants and are shown with exposure durations in Table 3. 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

3 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 for the purpose of calculating the reference exposures. Transit detectors were used to monitor radon exposures received in transit.

We identified a flaw in our system which resulted in 1 laboratory only receiving 3 different exposures, instead of 5. For 2 of the exposures, 2 different detector groups were given the same exposure. The laboratory was informed. We have reviewed our procedures and a more robust mechanism for detector checks has been 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, (Daraktchieva et al, 2012), based on the following parameters:

- 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 (best) to F (worst) for each exposure separately. Each participating laboratory was 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

TABLE 1 Performance classification

6 RESULTS AND DISCUSSION

The results reported by the laboratories are given in Table 4. 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 10 exposed detectors (5 for electrets) after subtracting the mean transit exposure. The standard deviation, '1 SD', is for 10 reported results (5 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 5. The distributions of the mean exposure results given in Table 5 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 6.

The mean of all transit exposures was 35 kBq m^{-3} h (Figure 11). Most of the reported transit exposures were below 50 kBq m^{-3} h, 3 laboratories reported a value between 50 and 100 kBq m^{-3} h, and a further 4 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 pre-intercomparison storage of detectors or the 'radon-proof' transit packaging used by some laboratories.

The results, using the performance classification scheme, are given in Table 6. 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 5 exposures in a set, meaning that they have a measurement error of under 10% for all 5 exposures. This includes 1 laboratory which participated with 2 different types of detectors. This is a 4% increase compared to 2017. Approximately 66% of all sets of detectors achieved class A for at least 3 exposures – much improved from 2017, see Howarth (2019). 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 for 25 laboratories and 29 sets of detectors. A 6-band (A-F) classification scheme was used to evaluate the performance of the detectors across a range of exposures. Six laboratories achieved 5 class A ratings, an improvement on the 2017 intercomparison. One laboratory only had 3 exposures due to a logistical error by PHE – they received 3 class A ratings.

8 ACKNOWLEDGEMENTS

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9 REFERENCES

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10 TABLES AND FIGURES

TABLE 2 Participating laboratories

Contact person	Organisation	Country
Dr N C da Silva	Brazilian Commission for Nuclear Energy – LAPOC	Brazil
Renato Falcomer	Health Canada National Radon Laboratory	Canada
Tiina Oinas	STUK	Finland
Pierre Filleul	ALGADE	France
Nicolas Tharaud	ALGADE / DOSIRAD	France
Vincent Delpech	Pearl-SAS	France
Erik Hulber	Radosys, Ltd.	Hungary
Michael Murray	Environmental Protection Agency	Ireland
Enrico Chiaberto	ARPA Piemonte, Dip. Ivrea	Italy
Dr M Moroni	GEOEX srls	Italy
Dr L Baldassarre	L.B. Servizi per le Aziende s.r.l.	Italy
Ing. G Troiano	Niton srl	Italy
Dr D Bonamini	Tecnorad s.u.r.l.	Italy
Paola Gozzelino	Tointech Srl	Italy
Dr M Rossetti	U-Series Srl	Italy
Karin Pier	Ministère de la Santé, Division de la Radioprotection	Luxembourg
Trine Kolstad	DSA (Norwegian Radiation and Nuclear Safety Authority), formerly NRPA.	Norway
Marius Strauss	Parc RGM	South Africa
Monika Nordqvist	Eurofins	Sweden
Prof. G Jönsson	RADONANALYS GJAB	Sweden
Dr T Rönnqvist	Radonova	Sweden
David Andrews	DSTL	United Kingdom
Sean Baker	PHE Personal Dosimetry Services	United Kingdom
Dr J Wasikiewicz	PHE Radon Dosimetry Team	United Kingdom
Dr P Fews	TASL	United Kingdom

TABLE 3 Exposure parameters

Etched track detectors

Exposure	1	2	3	4	5
Duration (h)	359.4	115.8	233.2	52.3	24.4
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
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 4 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 4 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 4 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 4 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 4 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 4 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 5 Statistical analysis of all reported results given in Table 4

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 6 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	NRPB/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[(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[(2)]	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[(3)]	F	A	A	A	D	Closed	-	Radosys	CR39	Radosys
163-2	F	E	E	E	E	Closed	-	Electrets	-	-

Notes to Table 6 above:

(1) *The results for 2 detector groups in **set 32-1** were not reported due to an administrative error by PHE.*

(2) *The results for 2 detectors in set **62-1** were incorrectly assigned by the reporting laboratory. When the correct values are applied, the classification for 1354 kBq m–3 h chamber exposure (group 3) changes from C to A and for 2180 kBq m–3 h chamber exposure (group 1) changes from B to A. This means that their classification would be B A A A A.*

(3) *The results for 2 detectors in set **144-1** were incorrectly assigned by the reporting laboratory. When the correct values are applied, the classification for 137 kBq m–3 h chamber exposure (group 5) changes from F to A and for 2180 kBq m–3 h chamber exposure (group 1) changes from D to A. This means that their classification would be A A A A A.*

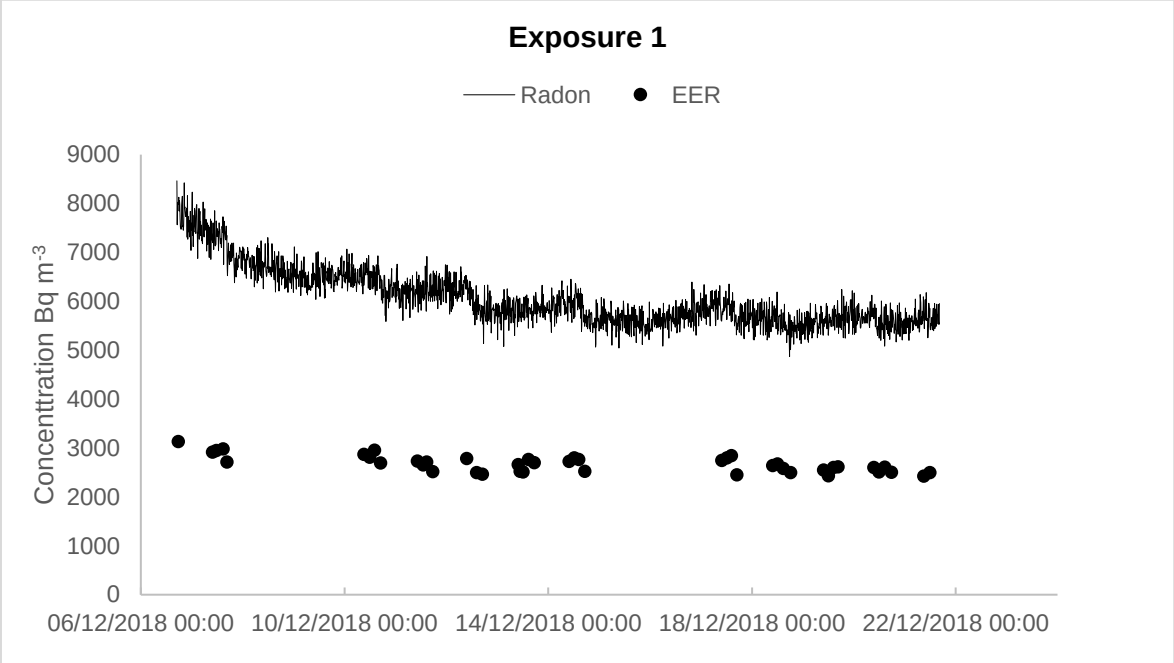


FIGURE 1 Radon and EER concentrations for exposure 1

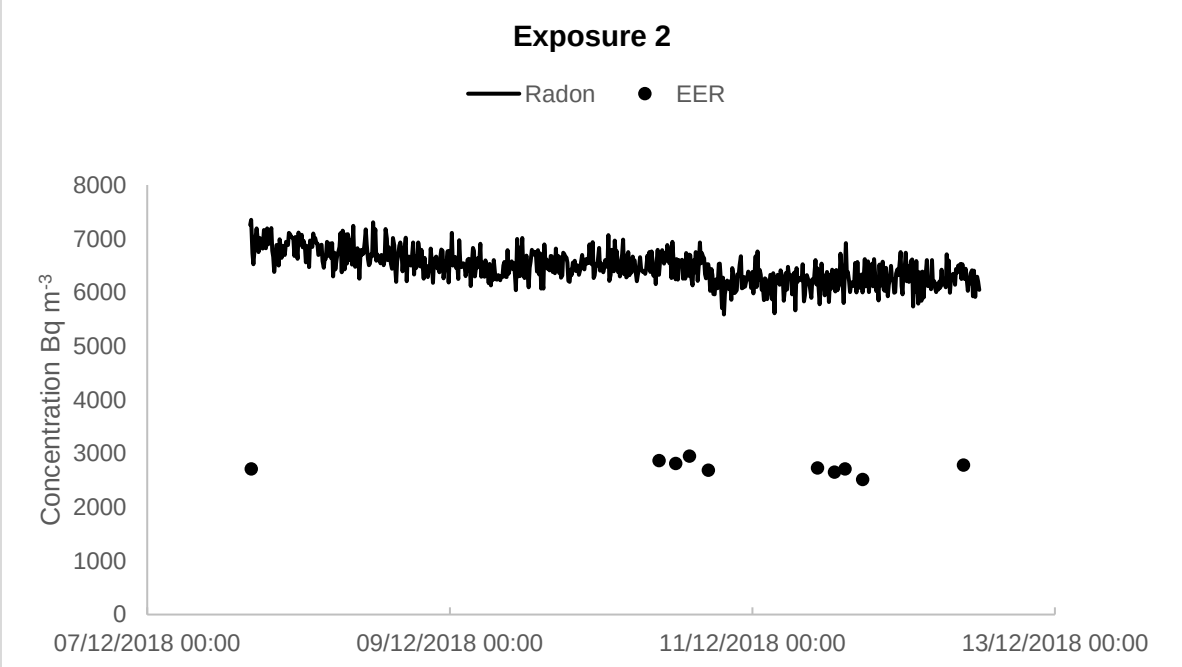


FIGURE 2 Radon and EER concentrations for exposure 2

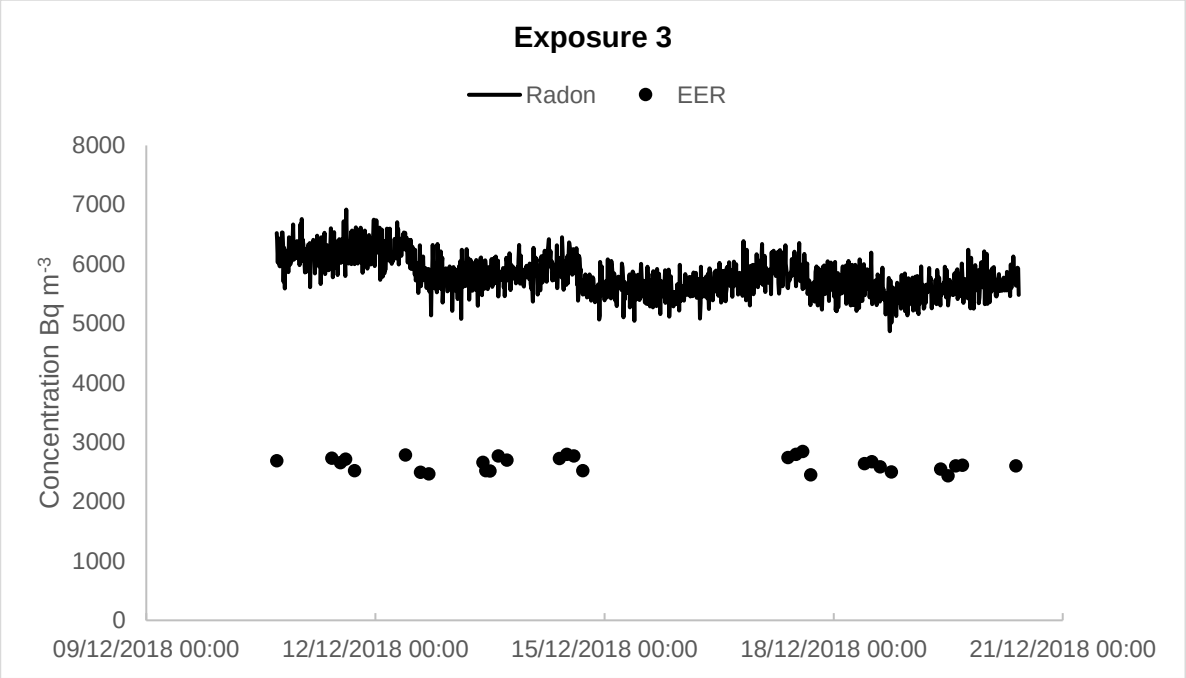


FIGURE 3 Radon and EER concentrations for exposure 3

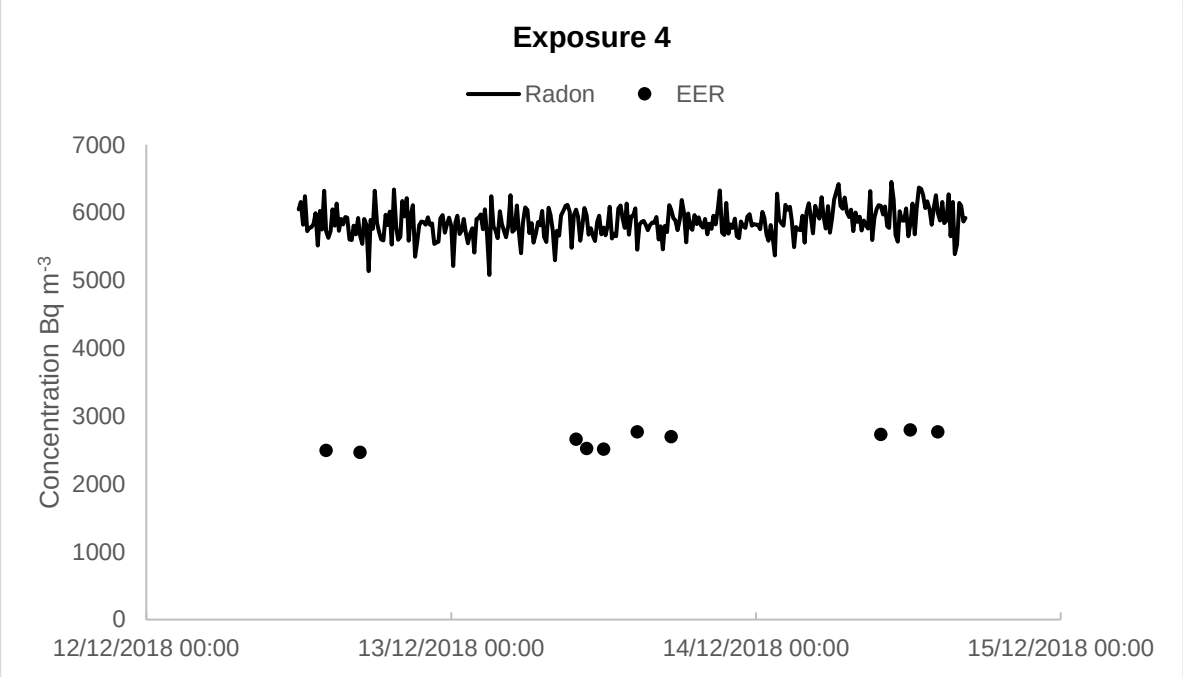


FIGURE 4 Radon and EER concentrations for exposure 4

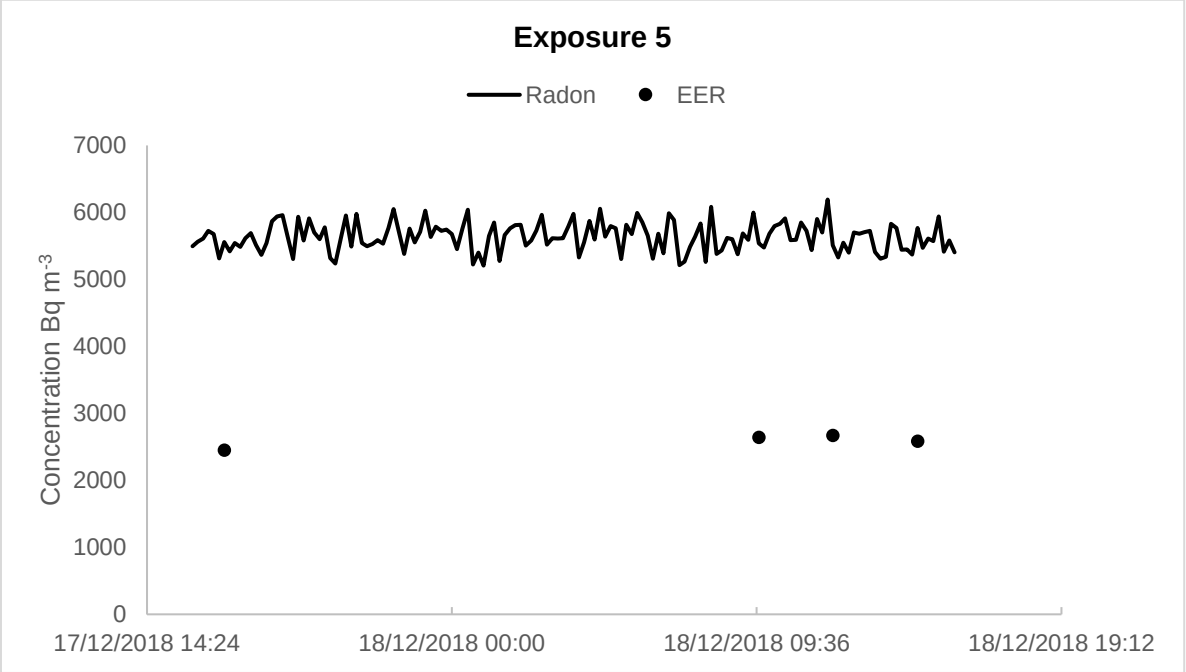


FIGURE 5 Radon and EER concentrations for exposure 5

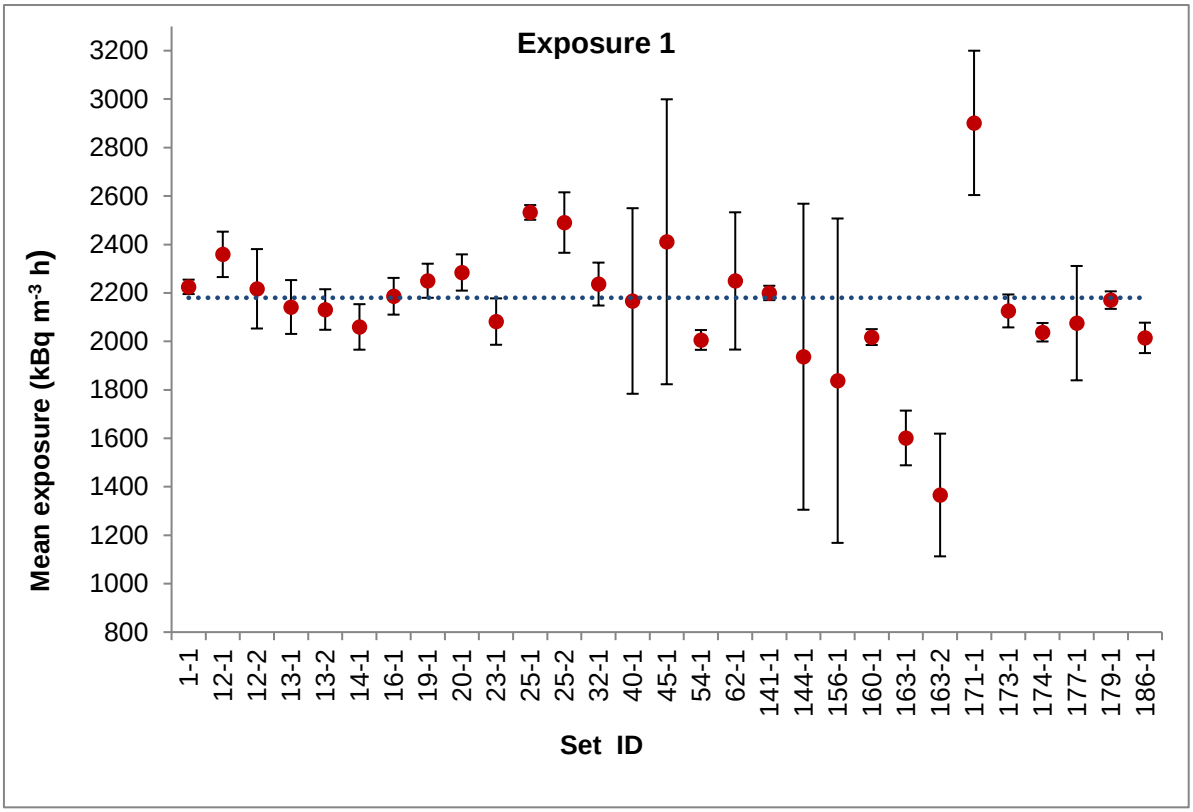


FIGURE 6 Results as reported by participants for exposure 1

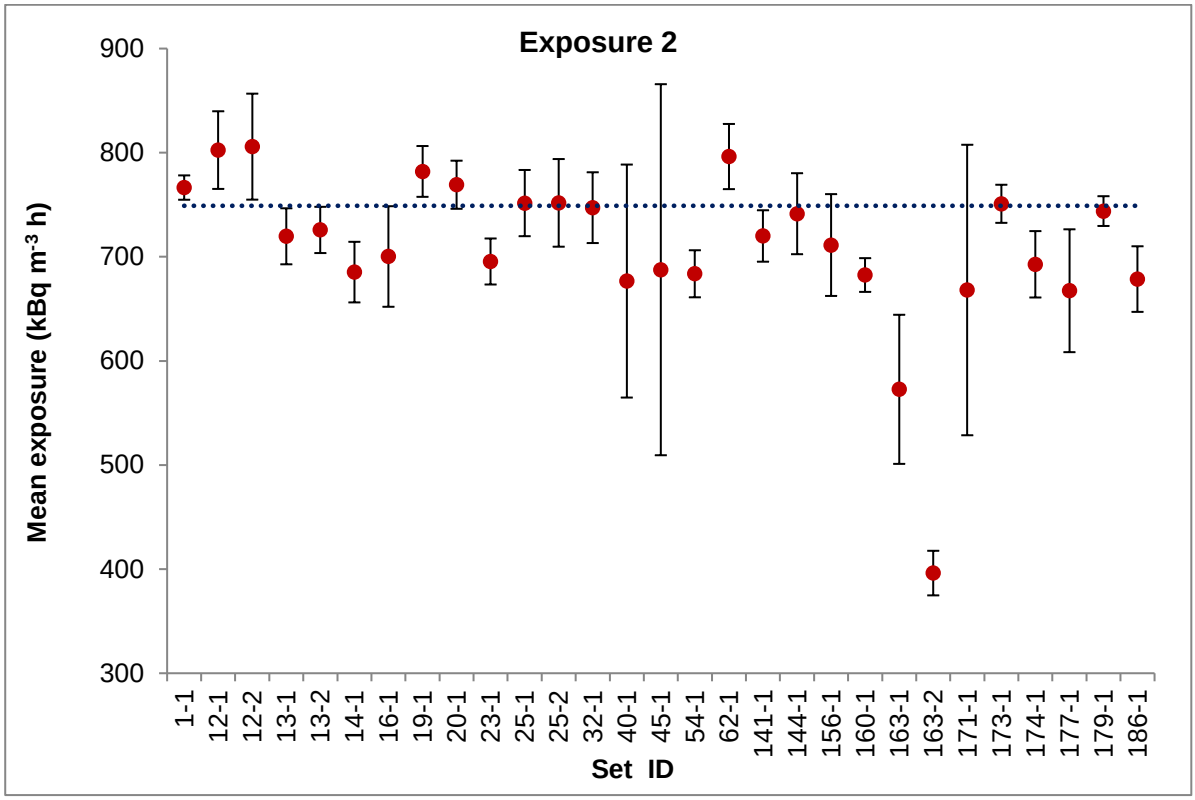


FIGURE 7 Results as reported by participants for exposure 2

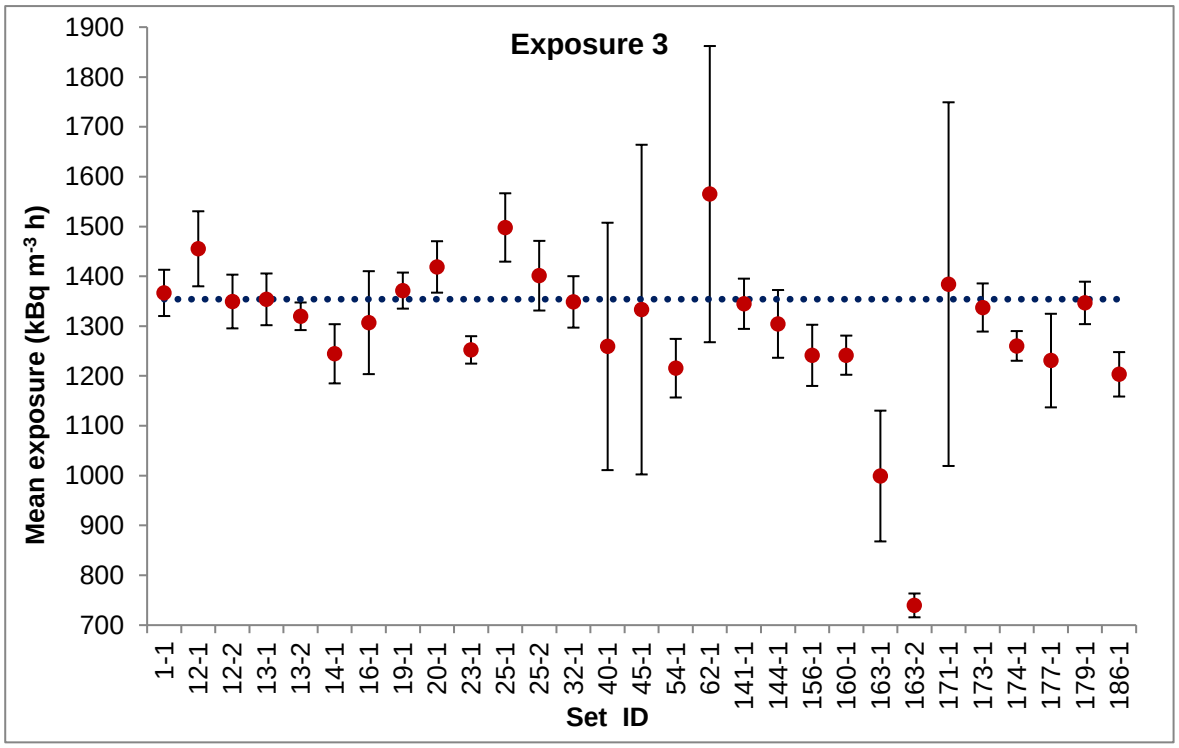


FIGURE 8 Results as reported by participants for exposure 3

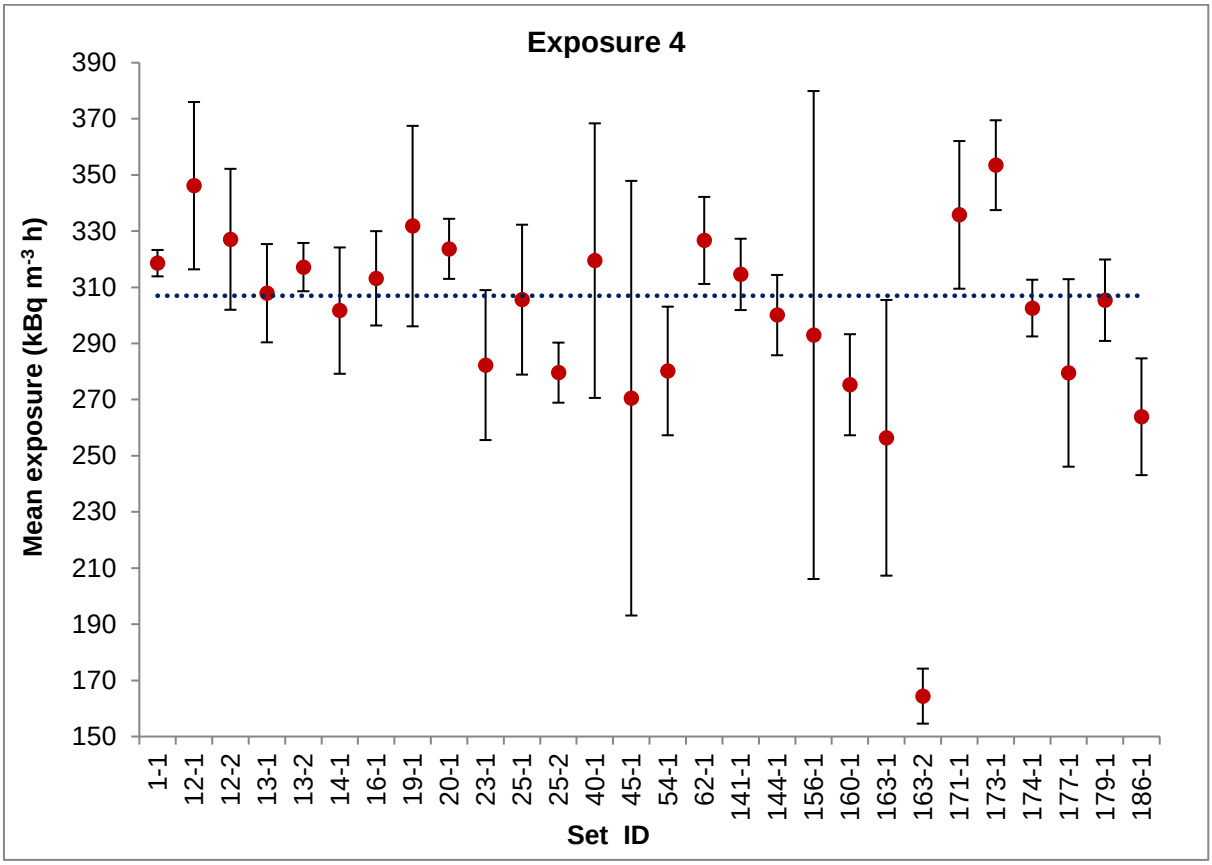


FIGURE 9 Results as reported by participants for exposure 4

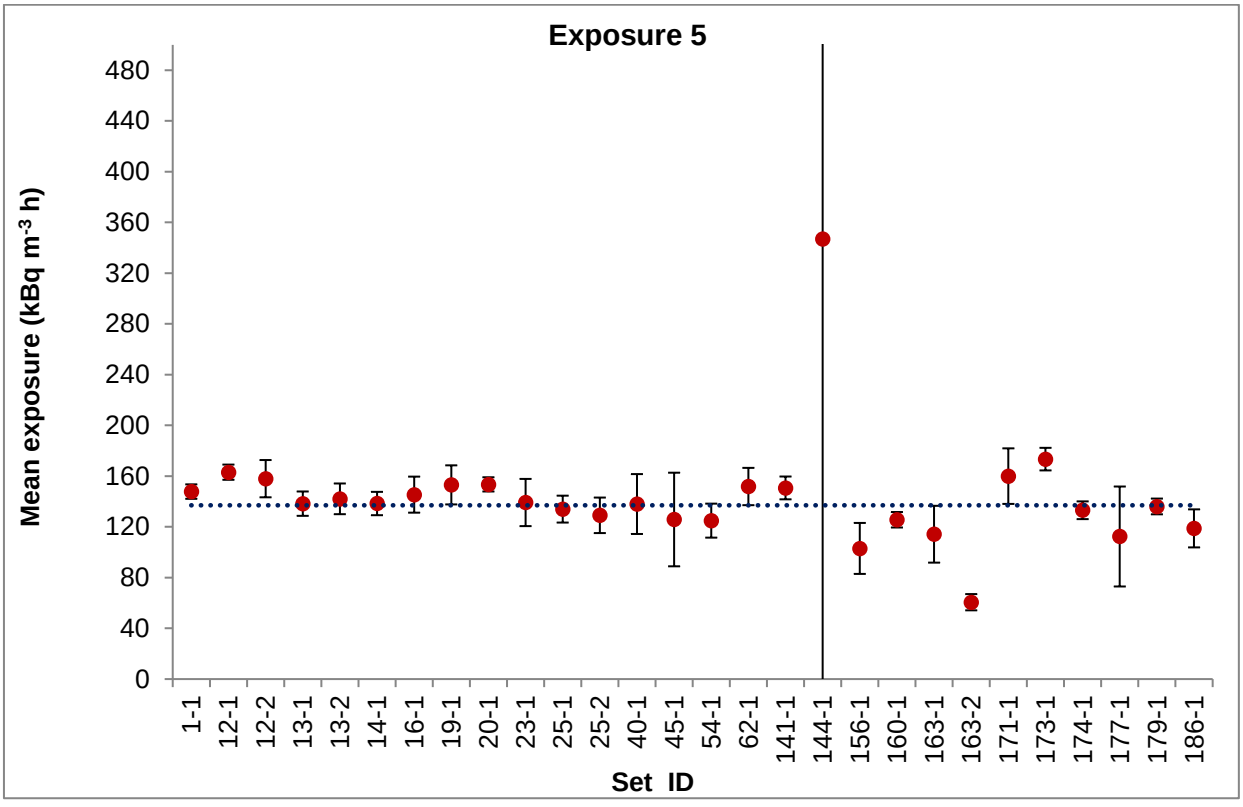


FIGURE 10 Results as reported by participants for exposure 5

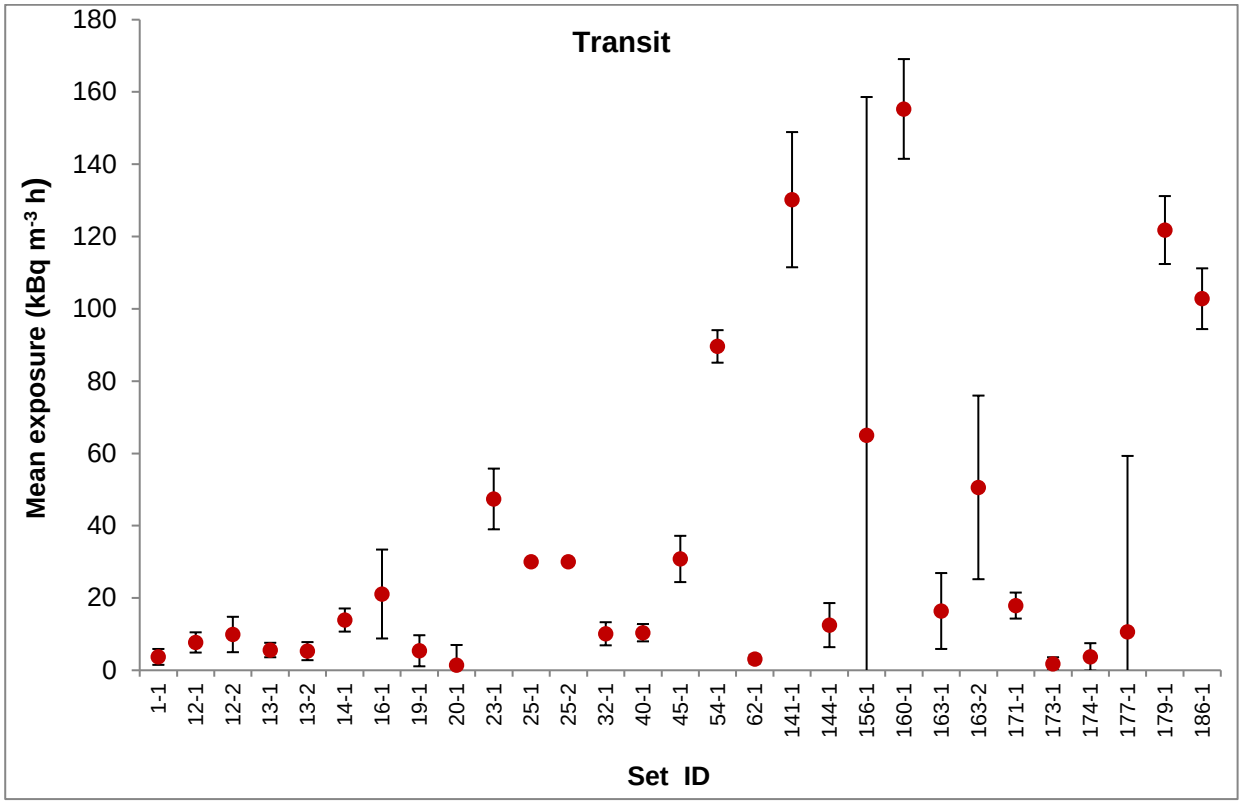


FIGURE 11 Results as reported by participants for transit exposure

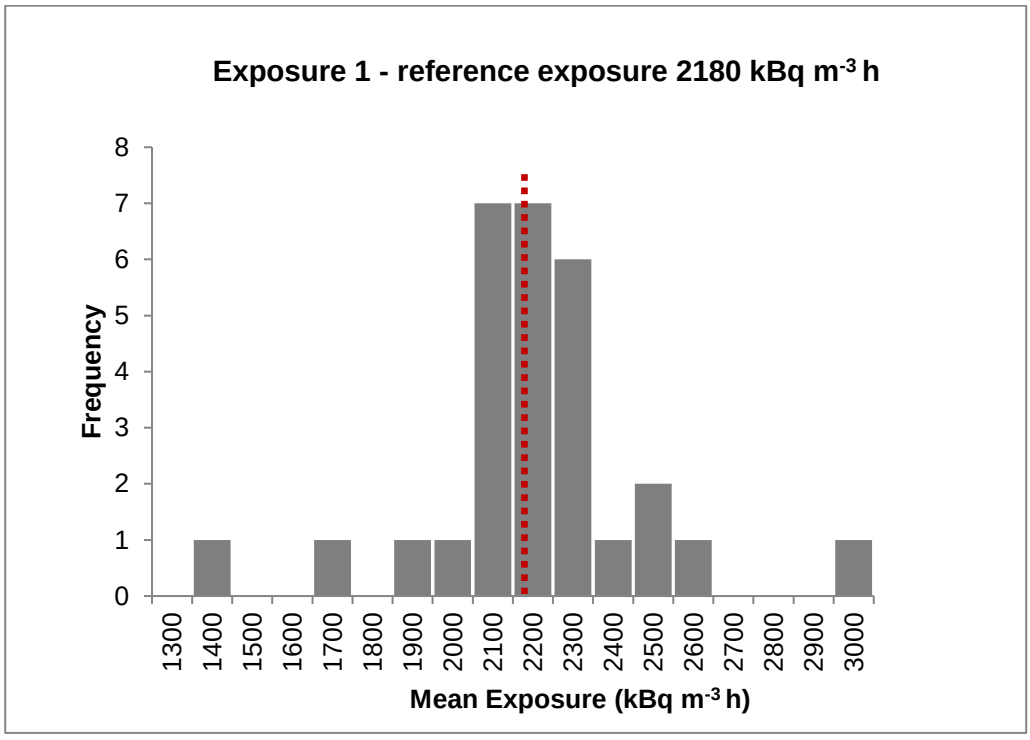


FIGURE 12a Distribution of mean exposure results given in Table 5

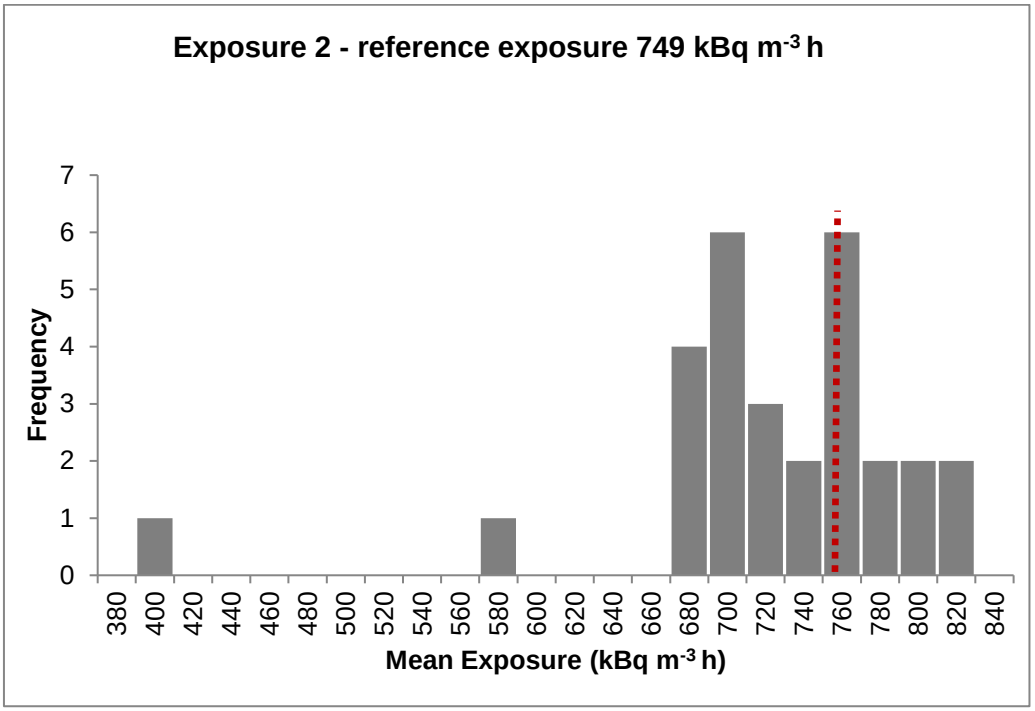


FIGURE 12b Distribution of mean exposure results given in Table 5

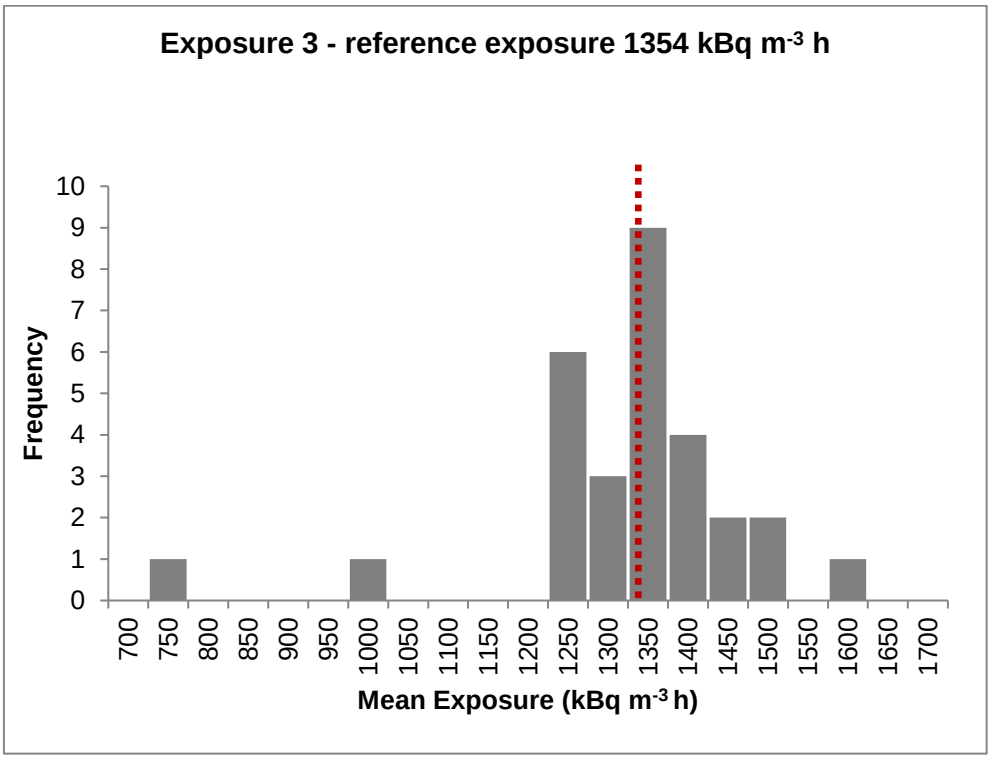


FIGURE 12c Distribution of mean exposure results given in Table 5

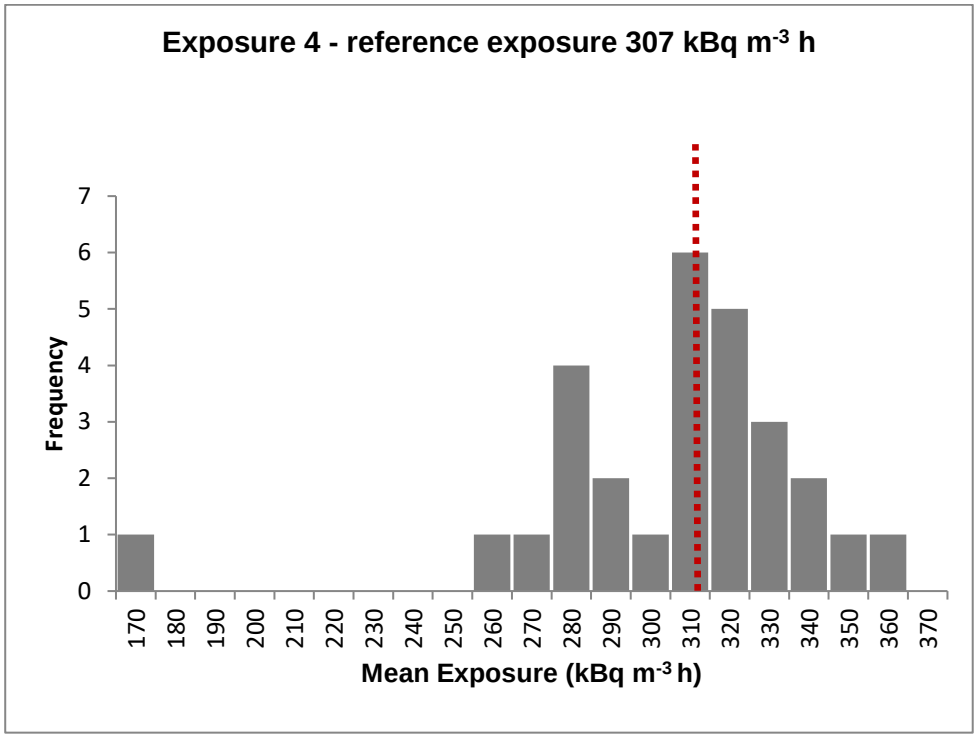


FIGURE 12d Distribution of mean exposure results given in Table 5

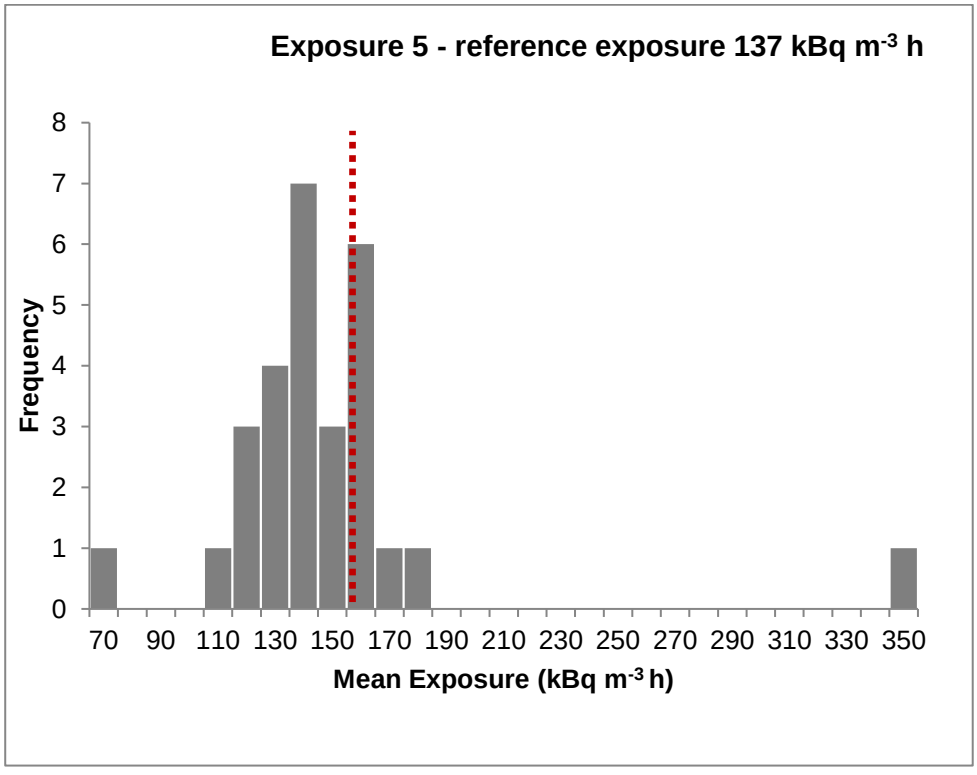
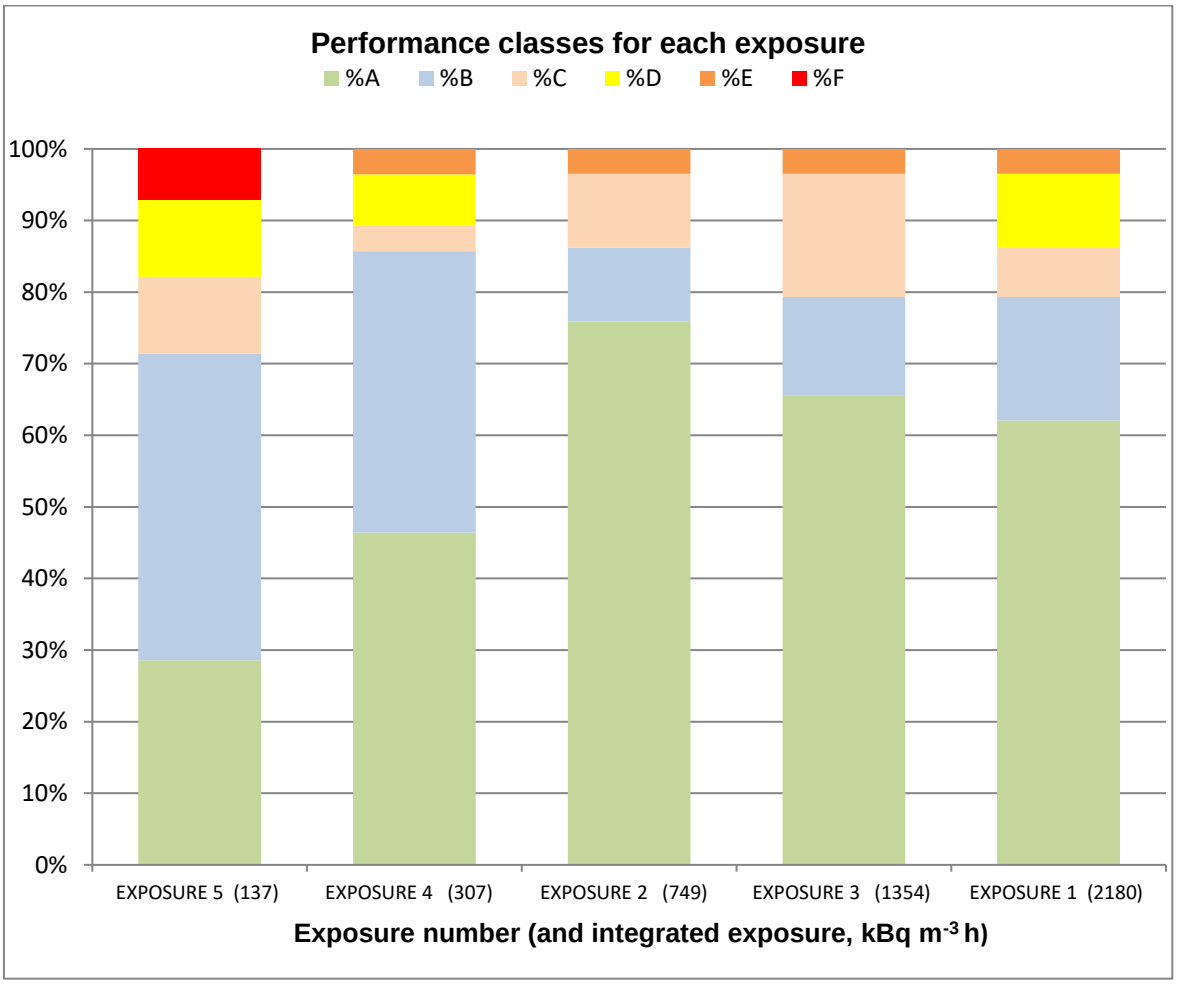


FIGURE 12e Distribution of mean exposure results given in Table 5


Performance classes for each exposure
%A
%B
%C
%D
%E
%F
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
EXPOSURE 5 (137)
EXPOSURE 4 (307)
EXPOSURE 2 (749)
EXPOSURE 3 (1354)
EXPOSURE 1 (2180)
Exposure number (and integrated exposure, kBq m-3 h)