



Public Health
England

Results of the 2017 PHE Intercomparison of Passive Radon Detectors

About Public Health England

Public Health England's mission is to protect and improve the nation's health and to address inequalities through working with national and local government, the NHS, industry and the voluntary and community sector. PHE is an operationally autonomous executive agency of the Department of Health.

Public Health England
133–155 Waterloo Road
Wellington House
London SE1 8UG
T: 020 7654 8000

www.gov.uk/phe

Twitter: [@PHE_uk](https://twitter.com/PHE_uk)

Facebook: www.facebook.com/PublicHealthEngland



© Crown copyright 2019

You may re-use this information (excluding logos) free of charge in any format or medium, under the terms of the Open Government Licence v2.0. To view this licence, visit OGL or email psi@nationalarchives.gsi.gov.uk. Where we have identified any third party copyright information you will need to obtain permission from the copyright holders concerned.

Any enquiries regarding this publication should be sent to

Press and Information
Centre for Radiation, Chemical and Environmental Hazards
Public Health England
Chilton, Didcot, Oxfordshire OX11 0RQ
Email: ChiltonInformationOffice@phe.gov.uk

Published November 2019

PHE publications gateway number: GW-893

PHE supports the UN

Sustainable Development Goals



Results of the 2017 PHE Intercomparison of Passive Radon Detectors

C B Howarth

ABSTRACT

Intercomparison exercises for passive radon detectors have been held regularly by PHE and its predecessor organisations over many years. In 2017, 26 laboratories from 13 countries took part in the exercise. Some laboratories submitted more than one set of detectors. A total of 29 sets of detectors were exposed in the PHE radon chamber.

The detectors were exposed to 5 different radon concentrations ranging between 50 to 3000 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 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.

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 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 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 6 groups at CRCE. Five of these groups were exposed in the CRCE radon chamber to radon exposures 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 2017, for which a total of 26 laboratories from 13 countries submitted 29 sets of detectors. Analysis of the results allows each exposure group in each set to be classified from A (best) to F (worst). Both etched track and electret detectors can be found in each class, demonstrating the point that, in measuring radon, stringent quality assurance is vital irrespective of the measured 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	3
7 Conclusion	5
8 Acknowledgements	5
9 References	5
10 Tables and Figures	6

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 detectors, the radioactive decay equilibrium factor, F , for ^{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. Therefore the response of these 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 again unaffected by F .

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 m³ 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 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 Atmos12 DPX and Alphaguard was carried out throughout the intercomparison exercise. Both instruments are calibrated annually using a radon gas source supplied by Physikalisch Technische Bundesanstalt (PTB), Germany.

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 was automatically transferred to a database. Radon and radon decay product exposures were calculated subsequently.

3 LOGISTICAL ARRANGEMENTS

In total, 26 laboratories from 13 countries took part in the 2017 PHE intercomparison. Some laboratories submitted more than one set of detectors, so 29 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 exposure to radon. Participants were not told any details of the exposures delivered in the exercise. Results were not reported by the originating laboratory for one set, so the results for 28 sets of detectors from 25 laboratories are presented in this report.

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 18 to 34 Bq m⁻³, with an overall average of 24 Bq m⁻³. The estimated additional exposure of the detectors caused by leaving them exposed in the laboratory for 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 exposure received in transit.

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,

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

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

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. In these tables, the ‘mean’ is the mean result of 10 exposed detectors (5 for electret) 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 4. The distributions of the mean exposure results given in Table 4 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 37 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, while 3 laboratories reported values above 100 kBq m⁻³ h.

The 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 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.

Five laboratories participating with 5 sets of detectors (10%) achieved 5 class A results, meaning that they have a measurement error of under 10% for all 5 exposures. This is similar to previous years. 57% of all sets of detectors achieved class A for at least 3 exposures— a figure similar to that seen in recent intercomparisons. There was also similar performance to 2016 at measuring the lowest exposure (138 kBq m⁻³ h): 32% of laboratories achieved class A.

It should be noted that different 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 Ibrahim *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 13 countries participated in the 2017 PHE intercomparison of passive radon detectors. One laboratory failed to submit results. A 6-band (A-F) classification scheme was used to evaluate the performance of the detectors across a range of exposures. Five laboratories achieved 5 class A ratings, an improvement on 2016.

8 ACKNOWLEDGEMENTS

The author would like to thank Catherine Miller and David Wright who provided valuable assistance in the radon exposure of the detectors.

9 REFERENCES

- Daraktchieva Z, Howarth C, Algar R . (2012). Results of the 2011 HPA Intercomparison of Passive Radon Detectors. Chilton. HPA-CRCE-033.
- Hanley O, Gutierrez-Villanueva JL, Currihan L and Pollard D (2008). Assessment of the uncertainties in the Radiological Protection Institute of Ireland (RPII) radon measurements service. *Journal of Environmental Radioactivity*, **99**, 1578–82.
- Hardcastle GD and Miles JCH (1996). Ageing and fading of alpha particle tracks in CR-39 exposed to air. *Radiation Protection Dosimetry*, **67**(4), 295–8.
- Howarth CB (2009). Results of the 2007 HPA Intercomparison of Passive Radon Detectors. Chilton, HPA-RPD-060.
- Howarth CB (2018). Results of the 2016 HPA Intercomparison of Passive Radon Detectors. Chilton, HPA-CRCE-042.
- Ibrahimi Z-F, Howarth CB, Miles JCH (2009). Sources of error in etched-track radon measurements and a review of passive detectors using results from a series of radon intercomparisons. *Radiation Measurements*, **44**, 750–54.

10 TABLES AND FIGURES

TABLE 2 Participating laboratories

Contact person	Organisation	Country
N C da Silva	LAPOC	Brazil
Prof D Pressyanov	Sofia University	Bulgaria
Kremena Ivanova	NCRRP	Bulgaria
Renato Falcomer	Health Canada National Radon Laboratory	Canada
Vincent Delpech	Pearl-SAS	France
A Vauchamp	ALGADE	France
F Sarradin	Dosirad	France
Eric Hulber	Radosys, Ltd.	Hungary
Mr M Murray	Environmental Protection Agency	Ireland
David Doyle	Alpharadon Teo	Ireland
Annamaria Sotgiu	ISPRA	Italy
Claudia Marchesoni	APPA Bolzano	Italy
Dr M Rossetti	U-Series Srl	Italy
M Magnoni	ARPA Piemonte. Dip. Ivrea	Italy
Dr C Cazzato	Laboratorio RADONGAS del Dott. Claudio Cazzato	Italy
Dr D Bonamini	Tecnorad S.r.l.	Italy
Dr L Baldassarre	L.B. Servizi per le Aziende s.r.l.	Italy
Karin Pier	Division de la Radioprotection Laboratoire	Luxembourg
A K Kolstad	Norwegian Radiation Protection Authority	Norway
L Neves	Universidade de Coimbra	Portugal
Tryggve Rönqvist	Radonova	Sweden
Professor Gilbert Jönsson	RADONANALYS GJAB	Sweden
Berna Ataksor	CNAEM	Turkey
Darren Langridge	DSTL	United Kingdom
Jaroslav Wasikiewicz	Public Health England	United Kingdom

TABLE 3 Exposure parameters**Etched track detectors**

Exposure	1	2	3	4	5
Duration (h)	114.7	192.4	385.2	22.9	66.0
Radon exposure (kBq m ⁻³ h)	751	1184	2415	138	394
Uncertainty (%) at 68% CL	3.0	3.0	3.0	3.0	3.0
EER exposure (kBq m ⁻³ h)	353	497	990	52	158
Uncertainty (%) at 68% CL	7.0	7.0	7.0	7.0	7.0
<i>F</i> , equilibrium factor	0.47	0.42	0.41	0.38	0.40

Notes

EER is equilibrium equivalent of radon.

CL is the confidence level.

TABLE 4 Analysis of all reported results
Exposure 1 751 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	753.1	9.9	0.3	1.3	1.3
7-1	750.5	31.6	-0.1	4.2	4.2
12-1	699.0	12.9	-6.9	1.8	7.2
13-1	788.8	26.2	5.0	3.3	6.0
14-1	701.0	32.7	-6.7	4.7	8.1
16-1	847.0	38.4	12.8	4.5	13.6
16-2	793.0	60.2	5.6	7.6	9.4
19-1	784.7	57.2	4.5	7.3	8.6
23-1	687.8	13.7	-8.4	2.0	8.6
25-1	782.0	45.1	4.1	5.8	7.1
25-2	790.3	72.7	5.2	9.2	10.6
28-1	886.0	45.0	18.0	5.1	18.7
32-1	699.0	12.9	-6.9	1.8	7.2
45-1	851.0	89.7	13.3	10.5	17.0
136-1	761.7	29.9	1.4	3.9	4.2
141-1	794.6	30.4	5.8	3.8	7.0
144-1	813.3	62.4	8.3	7.7	11.3
156-1	757.8	72.7	0.9	9.6	9.6
159-1	680.4	122.1	-9.4	17.9	20.3
160-1	760.1	38.7	1.2	5.1	5.2
163-1	773.3	6.8	3.0	0.9	3.1
166-1	797.5	39.9	6.2	5.0	8.0
171-1	684.2	47.0	-8.9	6.9	11.2
172-1	400.8	49.6	-46.6	12.4	48.2
174-1	759.9	17.1	1.2	2.3	2.5
177-1	647.3	29.8	-13.8	4.6	14.6
178-1	931.1	177.8	24.0	19.1	30.7
181-1	676.8	27.9	-9.9	4.1	10.7

TABLE 4 Analysis of all reported results (continued)

Exposure 2 1184 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	1184.8	15.5	0.1	1.3	1.3
7-1	1223.1	49.5	3.3	4.0	5.2
12-1	1106.7	19.7	-6.5	1.8	6.8
13-1	1230.9	43.6	4.0	3.5	5.3
14-1	1117.8	45.7	-5.6	4.1	6.9
16-1	1339.3	67.7	13.1	5.1	14.1
16-2	1264.5	46.1	6.8	3.6	7.7
19-1	1232.7	29.5	4.1	2.4	4.8
23-1	1046.4	44.8	-11.6	4.3	12.4
25-1	1266.5	48.4	7.0	3.8	7.9
25-2	1241.4	88.3	4.8	7.1	8.6
28-1	1270.3	28.5	7.3	2.2	7.6
32-1	1106.7	19.7	-6.5	1.8	6.8
45-1	1411.8	141.0	19.2	10.0	21.7
136-1	1167.7	22.8	-1.4	2.0	2.4
141-1	1227.8	45.7	3.7	3.7	5.2
144-1	1214.7	54.8	2.6	4.5	5.2
156-1	1133.6	87.8	-4.3	7.7	8.8
159-1	1077.1	150.7	-9.0	14.0	16.7
160-1	1233.4	31.9	4.2	2.6	4.9
163-1	1200.1	31.8	1.4	2.6	3.0
166-1	1205.9	101.4	1.8	8.4	8.6
171-1	1457.8	109.9	23.1	7.5	24.3
172-1	235.3	30.8	-80.1	13.1	81.2
174-1	1188.9	20.8	0.4	1.7	1.8
177-1	1059.7	45.5	-10.5	4.3	11.3
178-1	1369.7	171.2	15.7	12.5	20.1
181-1	1061.2	39.9	-10.4	3.8	11.0

TABLE 4 Analysis of all reported results (continued)
Exposure 3 2415 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	2368.7	47.3	-1.9	2.0	2.8
7-1	2430.1	66.0	0.6	2.7	2.8
12-1	2273.5	53.9	-5.9	2.4	6.3
13-1	2539.9	81.9	5.2	3.2	6.1
14-1	2311.3	95.6	-4.3	4.1	6.0
16-1	2761.6	251.5	14.4	9.1	17.0
16-2	2499.9	165.3	3.5	6.6	7.5
19-1	2501.0	36.5	3.6	1.5	3.8
23-1	2196.6	102.8	-9.0	4.7	10.2
25-1	2672.4	71.2	10.7	2.7	11.0
25-2	2508.3	190.5	3.9	7.6	8.5
28-1	2373.8	93.2	-1.7	3.9	4.3
32-1	2273.5	53.9	-5.9	2.4	6.3
45-1	2776.0	270.8	14.9	9.8	17.8
136-1	2411.7	53.3	-0.1	2.2	2.2
141-1	2458.5	51.2	1.8	2.1	2.8
144-1	2516.7	76.1	4.2	3.0	5.2
156-1	2294.7	115.9	-5.0	5.1	7.1
159-1	1982.1	120.7	-17.9	6.1	18.9
160-1	2558.2	40.0	5.9	1.6	6.1
163-1	2280.4	75.6	-5.6	3.3	6.5
166-1	2171.0	125.3	-10.1	5.8	11.6
171-1	2540.2	93.1	5.2	3.7	6.3
172-1	849.7	55.2	-64.8	6.5	65.1
174-1	2473.8	44.5	2.4	1.8	3.0
177-1	2257.0	81.7	-6.5	3.6	7.5
178-1	2994.9	19.0	24.0	0.6	24.0
181-1	2128.0	105.7	-11.9	5.0	12.9

TABLE 4 Analysis of all reported results (continued)

Exposure 4 138 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	142.1	4.1	3.0	2.9	4.1
7-1	145.7	19.0	5.6	13.0	14.2
12-1	130.4	3.4	-5.5	2.6	6.1
13-1	148.5	8.7	7.6	5.9	9.6
14-1	138.0	9.6	0.0	7.0	7.0
16-1	157.6	16.2	14.2	10.3	17.5
16-2	153.9	8.4	11.5	5.5	12.7
19-1	158.6	14.6	14.9	9.2	17.5
23-1	128.3	10.2	-7.0	8.0	10.6
25-1	128.8	6.0	-6.7	4.7	8.1
25-2	133.4	9.4	-3.3	7.0	7.8
28-1	185.0	21.5	34.1	11.6	36.0
32-1	130.4	3.4	-5.5	2.6	6.1
45-1	167.9	19.2	21.7	11.4	24.5
136-1	104.1	5.2	-24.6	5.0	25.1
141-1	138.7	10.3	0.5	7.4	7.4
144-1	145.6	41.5	5.5	28.5	29.0
156-1	152.2	15.9	10.3	10.4	14.7
159-1	149.2	100.5	8.1	67.4	67.8
160-1	132.3	14.4	-4.1	10.9	11.6
163-1	163.6	4.1	18.6	2.5	18.7
166-1	145.0	19.8	5.1	13.7	14.6
171-1	155.4	33.3	12.6	21.4	24.9
172-1	44.7	8.8	-67.6	19.7	70.4
174-1	144.5	9.5	4.7	6.6	8.1
177-1	108.0	17.6	-21.7	16.3	27.2
178-1	117.5	46.2	-14.9	39.3	42.0
181-1	140.7	46.6	2.0	33.1	33.2

TABLE 4 Analysis of all reported results (continued)

Exposure 5 394 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	384.6	8.2	-2.4	2.1	3.2
7-1	390.0	30.9	-1.0	7.9	8.0
12-1	350.0	5.8	-11.2	1.7	11.3
13-1	422.7	18.5	7.3	4.4	8.5
14-1	369.1	18.5	-6.3	5.0	8.1
16-1	458.0	34.7	16.2	7.6	17.9
16-2	406.0	20.5	3.0	5.0	5.9
19-1	412.9	22.3	4.8	5.4	7.2
23-1	352.6	13.0	-10.5	3.7	11.1
25-1	379.8	14.6	-3.6	3.8	5.3
25-2	364.5	22.3	-7.5	6.1	9.7
28-1	585.7	285.0	48.7	48.7	68.8
32-1	350.4	5.8	-11.1	1.7	11.2
45-1	467.7	68.4	18.7	14.6	23.7
136-1	395.7	7.0	0.4	1.8	1.8
141-1	402.6	18.6	2.2	4.6	5.1
144-1	397.6	43.2	0.9	10.9	10.9
156-1	369.1	23.0	-6.3	6.2	8.9
159-1	354.1	118.1	-10.1	33.4	34.9
160-1	391.4	21.1	-0.7	5.4	5.4
163-1	454.7	8.3	15.4	1.8	15.5
166-1	411.8	42.0	4.5	10.2	11.2
171-1	385.5	37.2	-2.2	9.6	9.9
172-1	123.6	25.8	-68.6	20.9	71.7
174-1	388.4	14.8	-1.4	3.8	4.1
177-1	332.4	32.9	-15.6	9.9	18.5
178-1	432.3	6.1	9.7	1.4	9.8
181-1	359.6	23.4	-8.7	6.5	10.9

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	5.8	1.1	136-1	52.3	9.3
7-1	25.3	11.3	141-1	195.4	12.0
12-1	11.7	1.7	144-1	115.3	33.7
13-1	5.6	1.5	156-1	17.5	8.2
14-1	14.9	4.2	159-1	90.7	89.1
16-1	26.8	13.5	160-1	150.2	11.0
16-2	12.8	4.7	163-1	13.7	1.6
19-1	20.0	7.8	166-1	52.9	5.2
23-1	28.9	5.4	171-1	18.0	4.4
25-1	16.0	0.0	172-1	15.9	3.9
25-2	30.0	0.0	174-1	9.9	2.7
28-1	-1.5	12.2	177-1	0.0	17.5
32-1	11.7	1.7	178-1	21.3	45.2
45-1	28.6	2.9	181-1	36.4	26.1

TABLE 5 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)
1 751 kBq m ⁻³ h	752	95
2 1184 kBq m ⁻³ h	1174	211
3 2415 kBq m ⁻³ h	2371	367
4 138 kBq m ⁻³ h	139	25
5 394 kBq m ⁻³ h	389	72

TABLE 6 Performance classification scheme based on measurement error

Set ID	Performance classification in each exposure					Detector type	Filter	Holder	Detector material	Detector material supplier
	4	5	1	2	3					
	138 kBq m ⁻³ h	394 kBq m ⁻³ h	751 kBq m ⁻³ h	1184 kBq m ⁻³	2415 kBq m ⁻³ h					
1-1	A	A	A	A	A	Closed		NRPB/SSI	CR39	Mi-Net
13-1	A	A	A	A	A	Closed		NRPB/SSI	CR39	Intercast
14-1	A	A	A	A	A	Closed		NRPB/SSI	CR39	TASL
141-1	A	A	A	A	A	Closed		TASL	CR39	TASL
174-1	A	A	A	A	A	Closed		TASL	CR39	TASL
7-1	B	A	A	A	A	Closed		TASL	CR39	TASL
12-1	A	B	A	A	A	Closed		NRPB/SSI	CR39	–
16-2	B	A	A	A	A	Closed		Radosys	CR39	Radosys
19-1	B	A	A	A	A	Closed		Own	CR39	Intercast
25-1	A	A	A	A	B	Closed		Own	LR115	Dosirad
25-2	A	A	B	A	A	Open		Own	LR115	Dosirad
32-1	A	B	A	A	A	Closed		NRPB/SSI	CR39	TASL
156-1	B	A	A	A	A	Closed		Radosys	CR39	Radosys
160-1	B	A	A	A	A	Closed		TASL	CR39	TASL

163-1	B	B	A	A	A	Closed		TASL	CR39	TASL
166-1	B	B	A	A	B	Closed		DVD	Polycarbonate	DVD
23-1	B	B	A	B	B	Closed		NRPB/SSI	CR39	Mi-Net
16-1	B	B	B	B	B	Closed		Radosys	CR39	Radosys
136-1	C	A	A	A	A	Closed		TASL	CR39	TASL
144-1	C	B	B	A	A	Closed		TASL	CR39	TASL
177-1	C	B	B	B	A	Closed		TASL	CR39	TASL
171-1	C	A	B	C	A	Closed		Own	LR115	Dosirad
45-1	C	C	B	C	B	Closed	Yes	Own	LR115	Dosirad
181-1	D	B	B	B	B	Closed		Radosys	CR39	Radosys
178-1	E	A	D	C	C	Closed		TASL	CR39	TASL
28-1	D	F	B	A	A	Closed		Radosys	CR39	Radosys
159-1	F	D	C	B	B	Closed		Radosys	CR39	Radosys
172-1	F	F	E	F	F	Closed		Radosys	CR39	Radosys

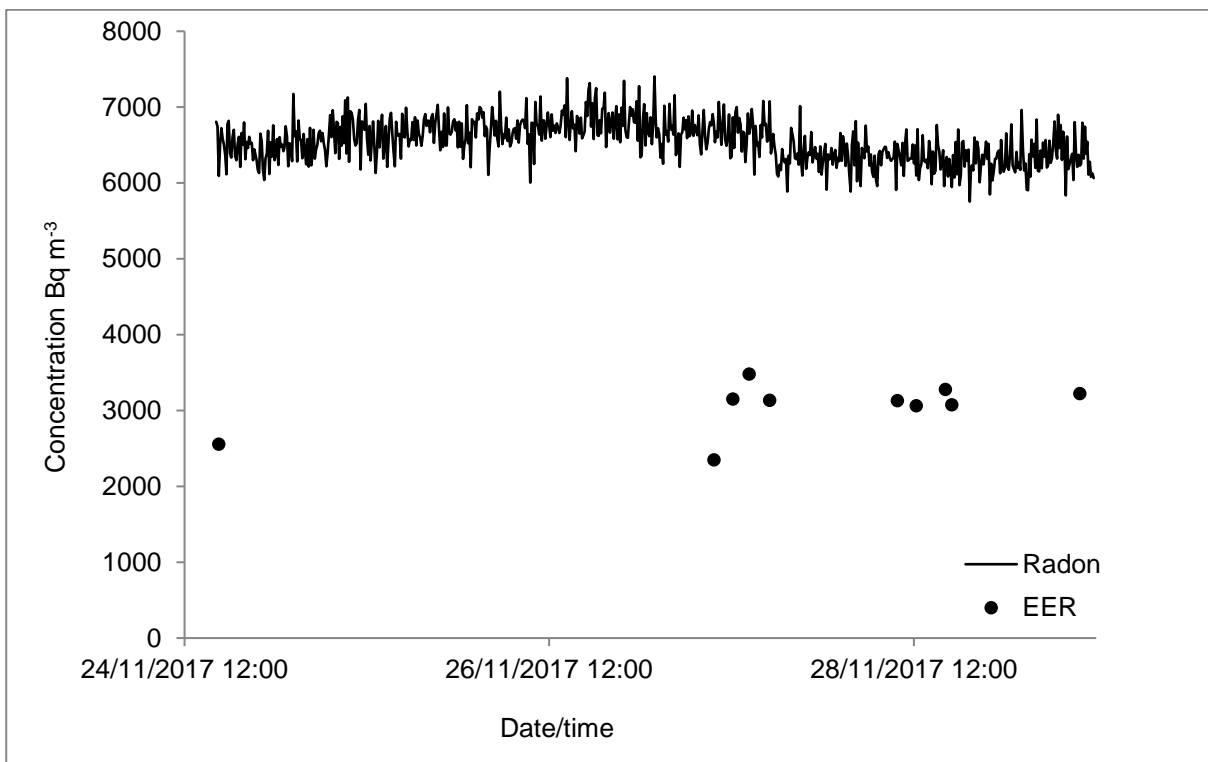


FIGURE 1 Radon and EER concentrations for exposure 1

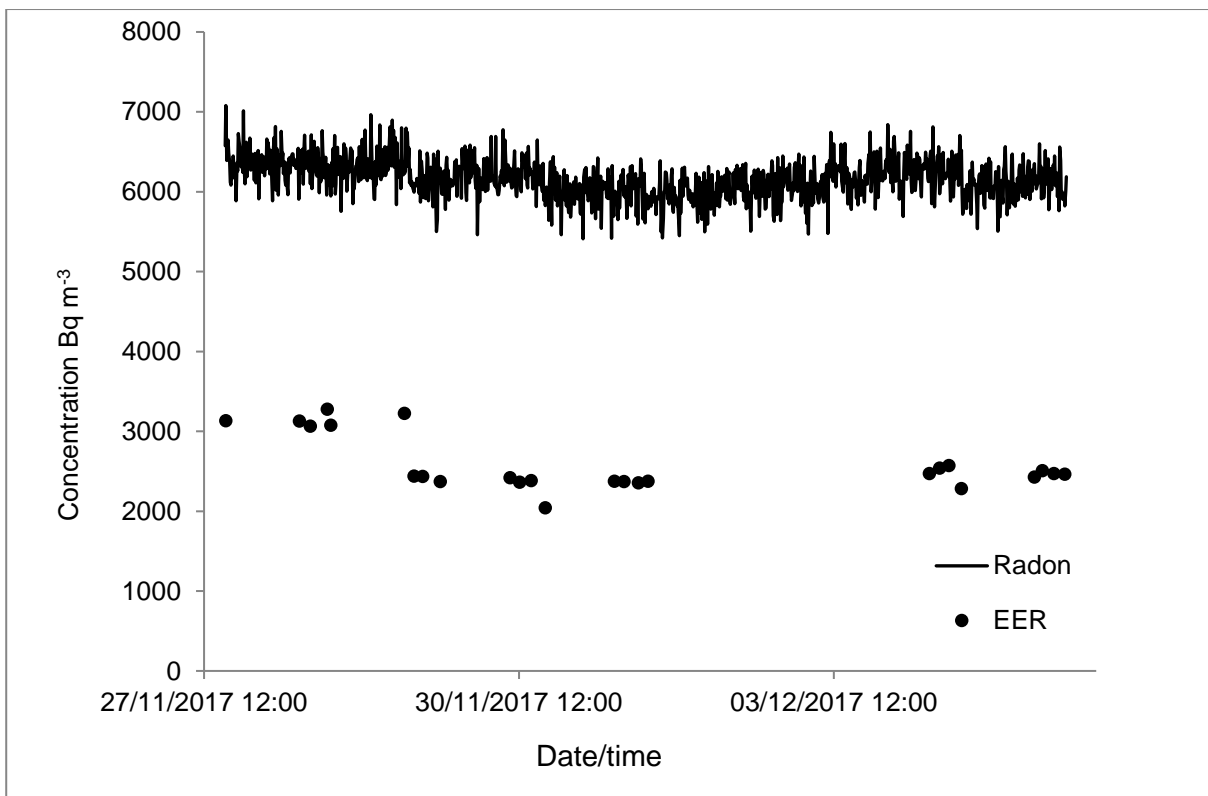


FIGURE 2 Radon and EER concentrations for exposure 2

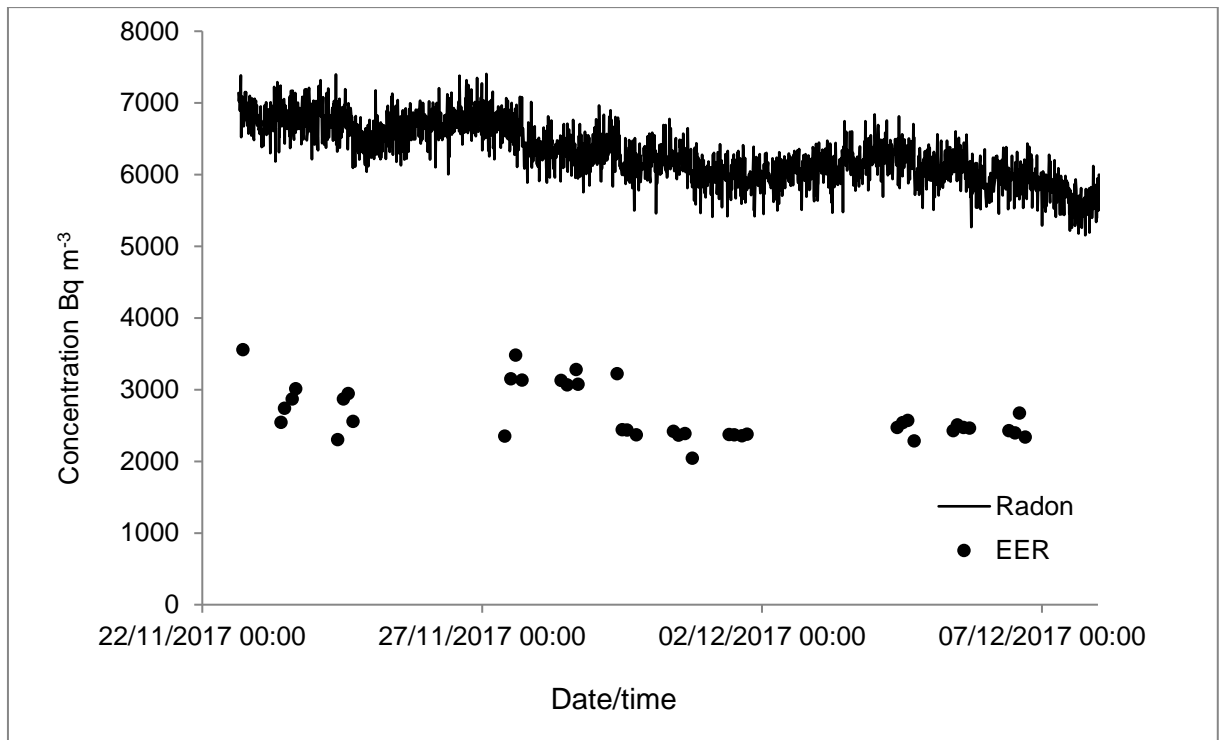


FIGURE 3 Radon and EER concentrations for exposure 3

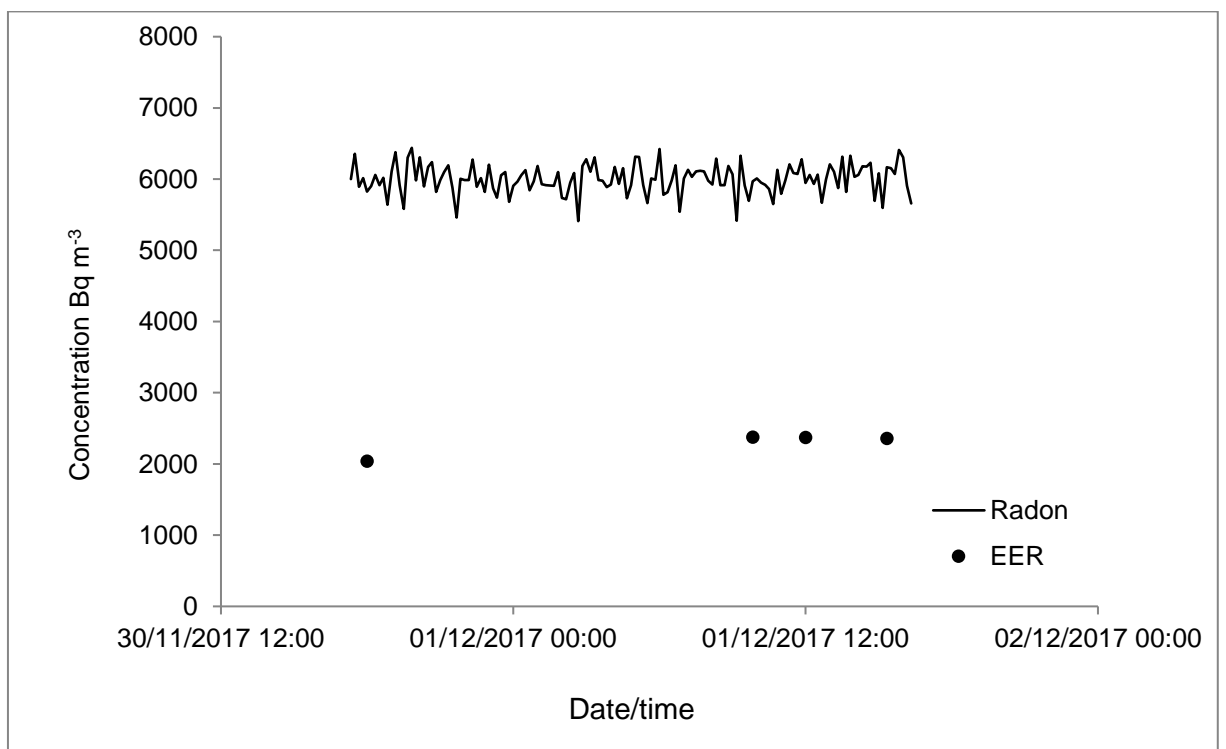


FIGURE 4 Radon and EER concentrations for exposure 4

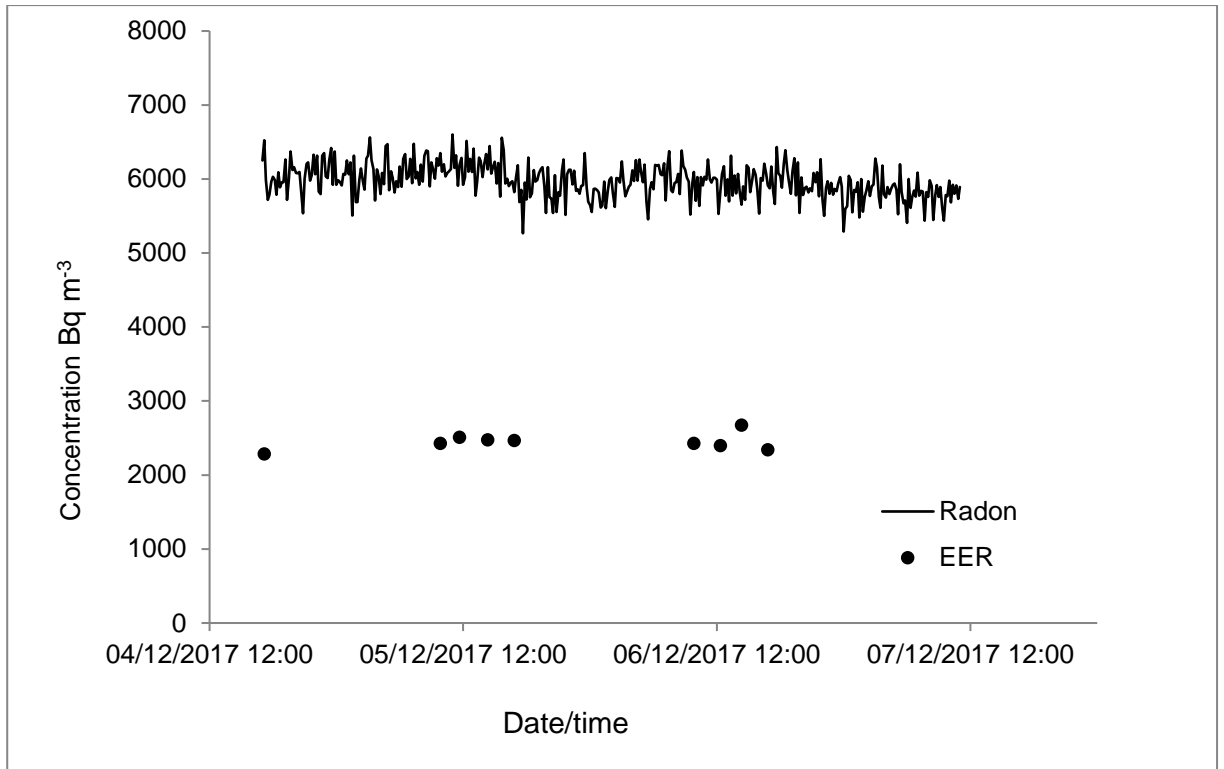


FIGURE 5 Radon and EER concentrations for exposure 5

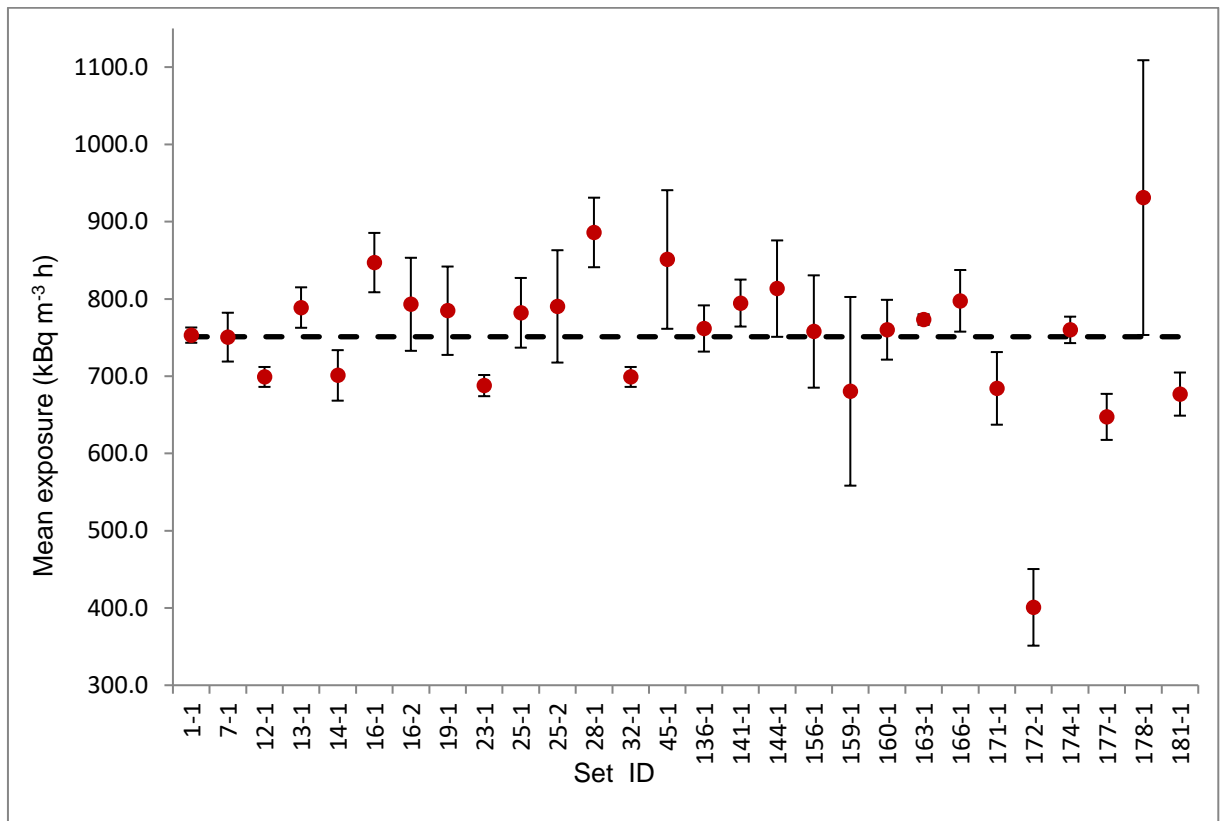


FIGURE 6 Results as reported by participants for exposure 1

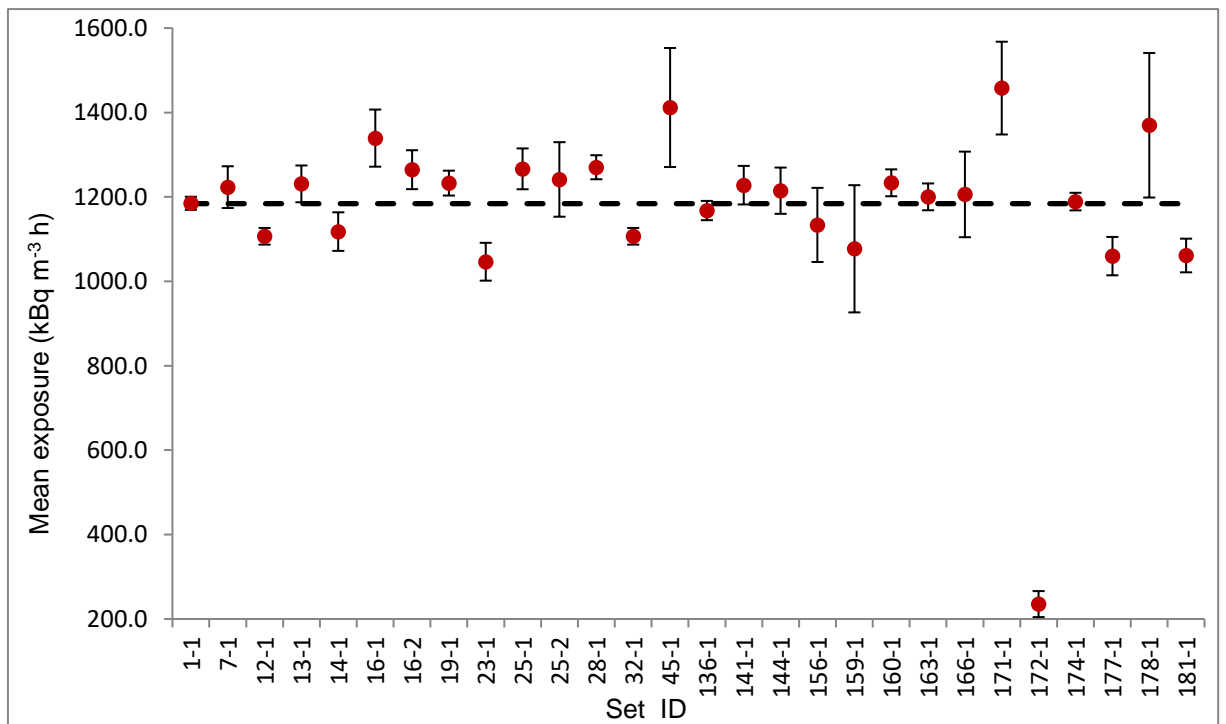


FIGURE 7 Results as reported by participants for exposure 2

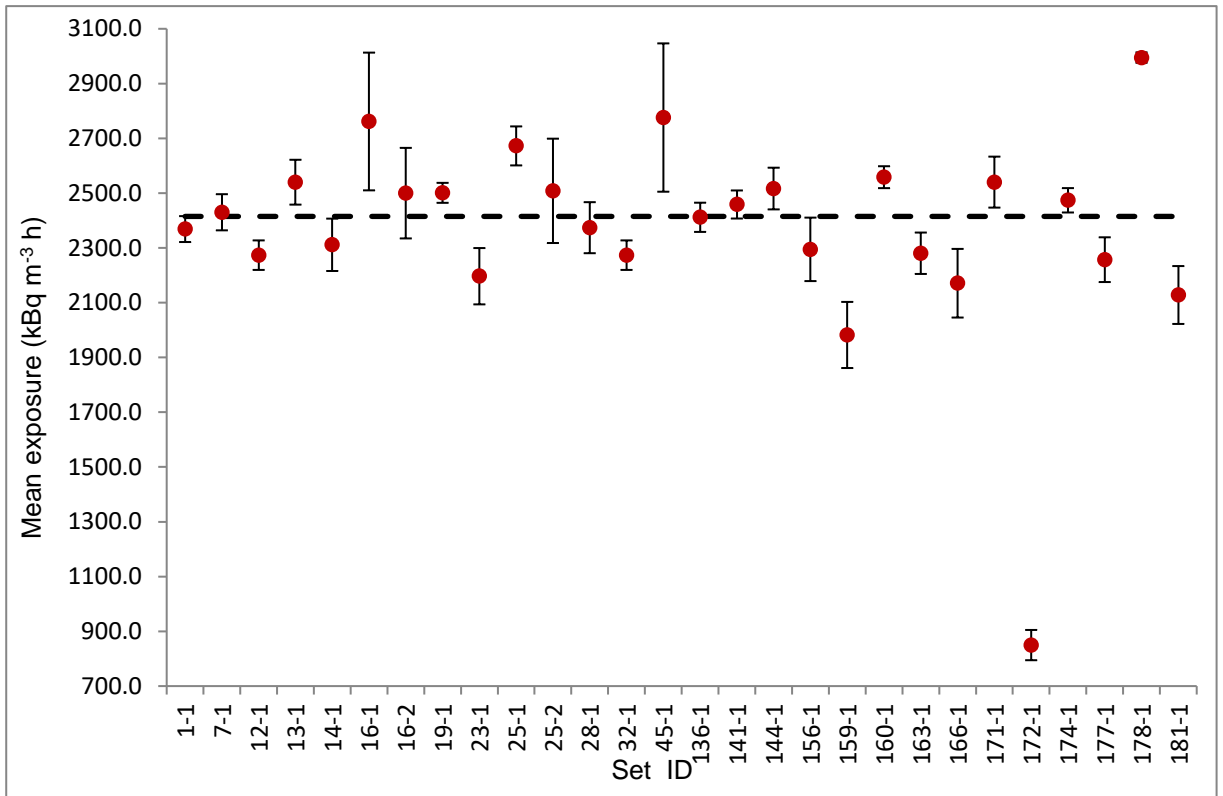


FIGURE 8 Results as reported by participants for exposure 3

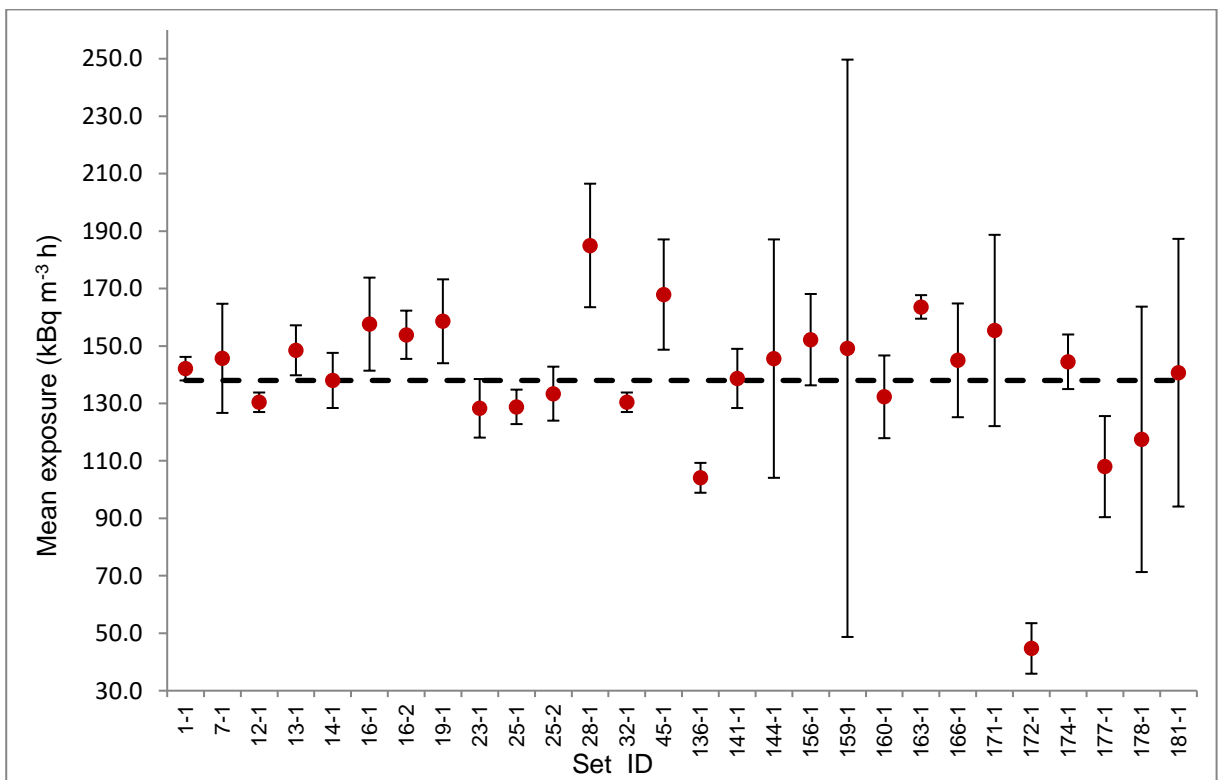


FIGURE 9 Results as reported by participants for exposure 4

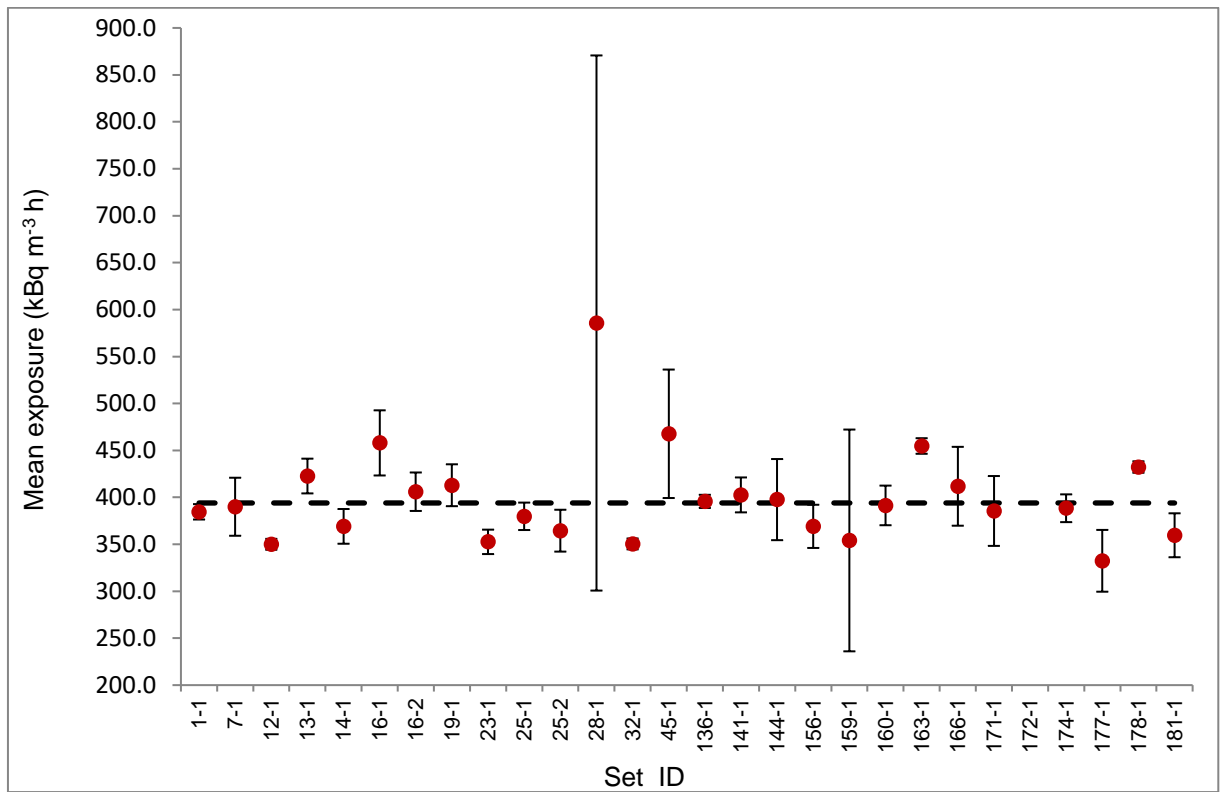


FIGURE 10 Results as reported by participants for exposure 5

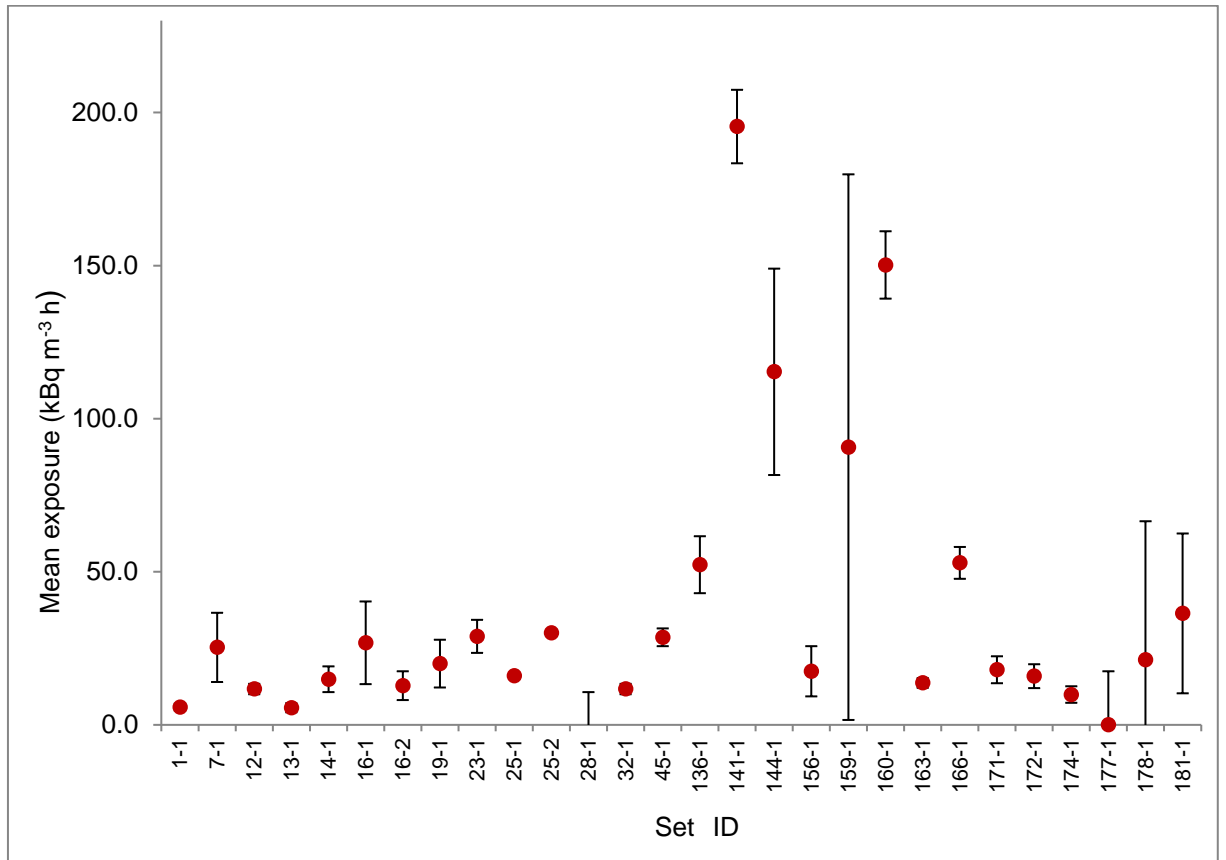


FIGURE 11 Results as reported by participants for transit exposure

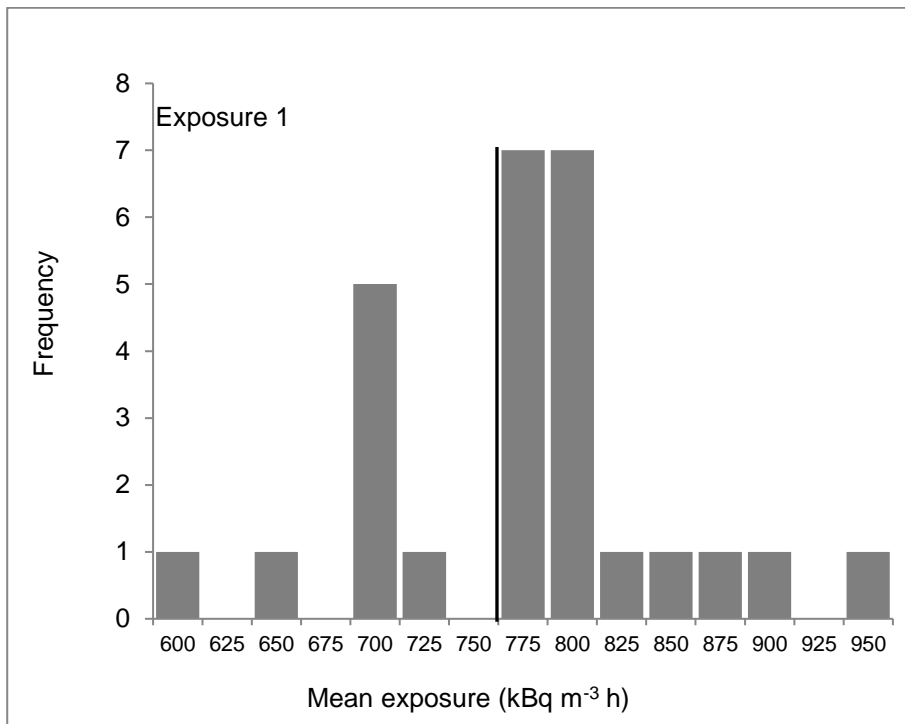


FIGURE 12a Distribution of mean exposure results given in Table 3

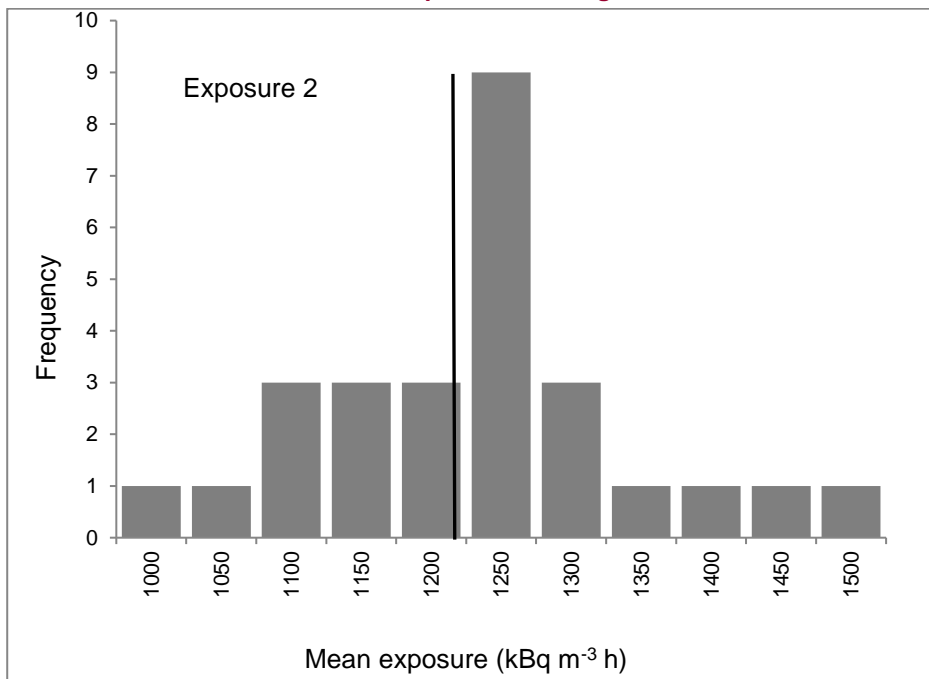


FIGURE 12b Distribution of mean exposure results given in Table 3

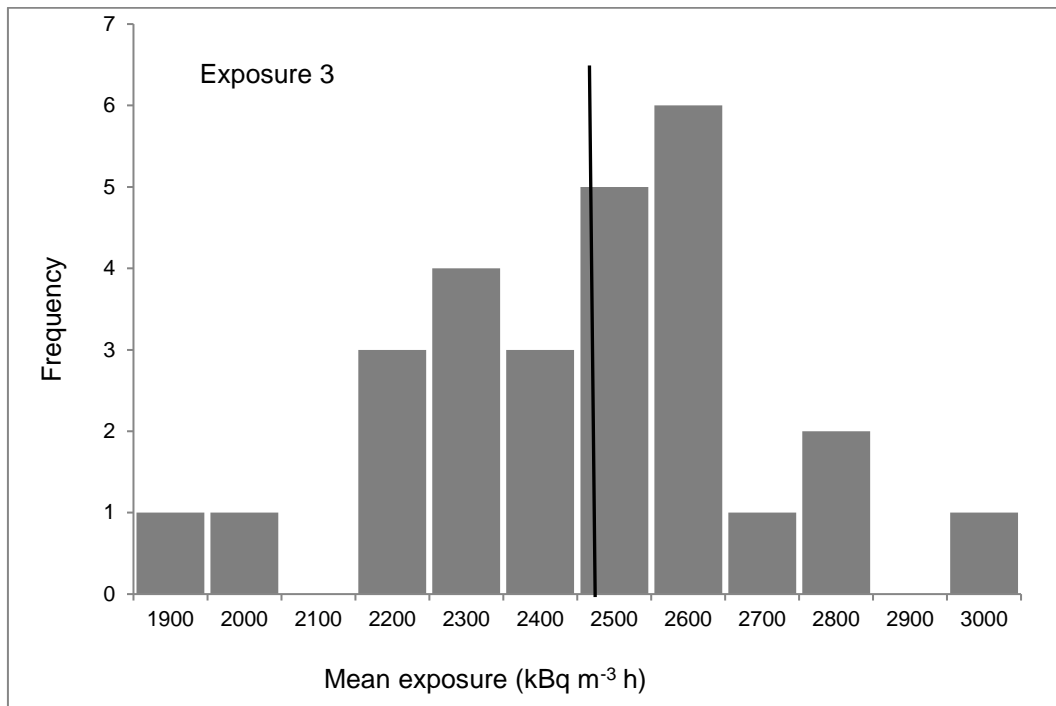


FIGURE 12c Distribution of mean exposure results given in Table 3

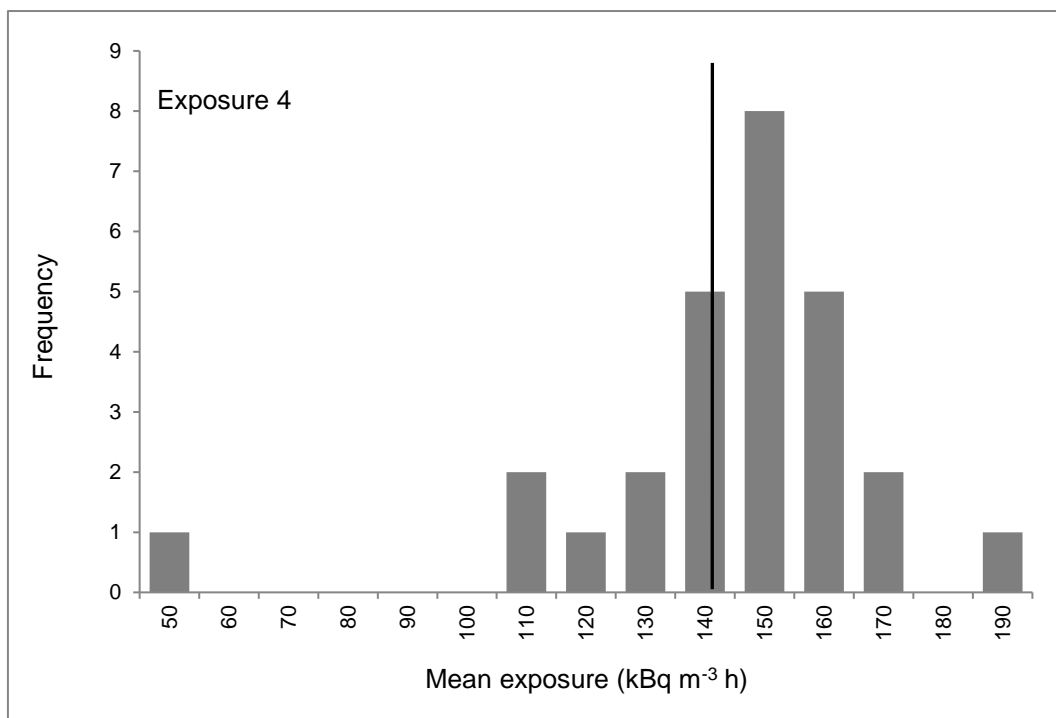


FIGURE 12d Distribution of mean exposure results given in Table 3

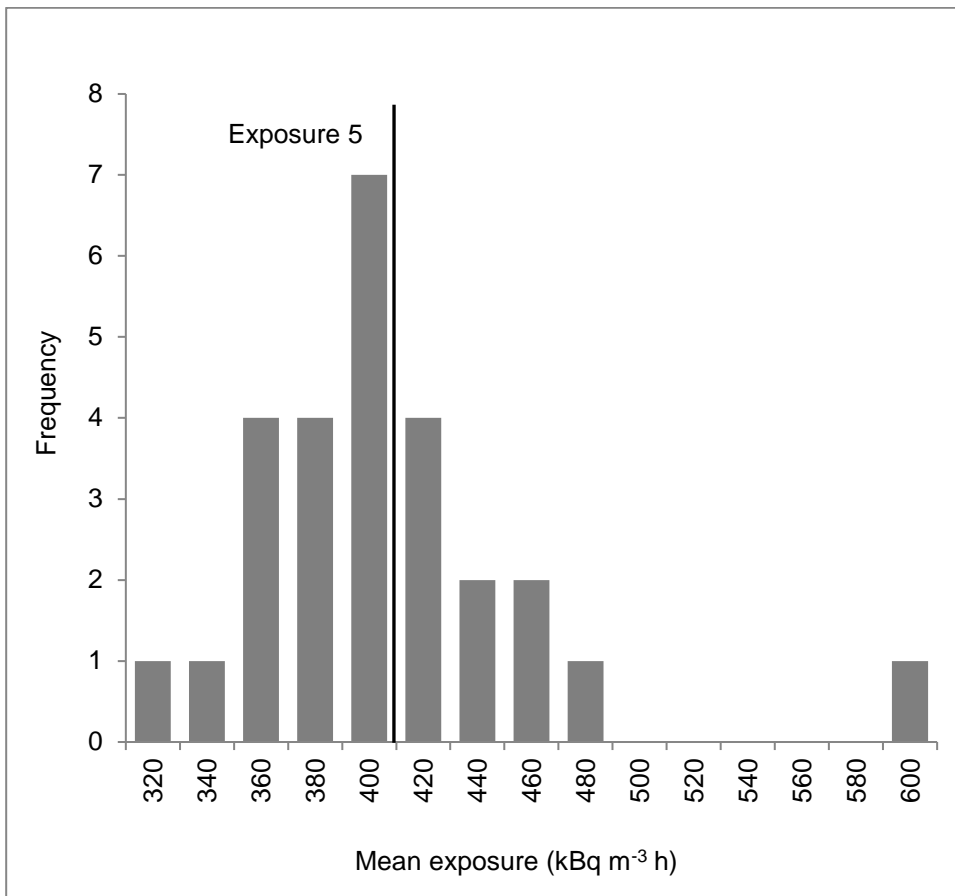


FIGURE 12e Distribution of mean exposure results given in Table 3

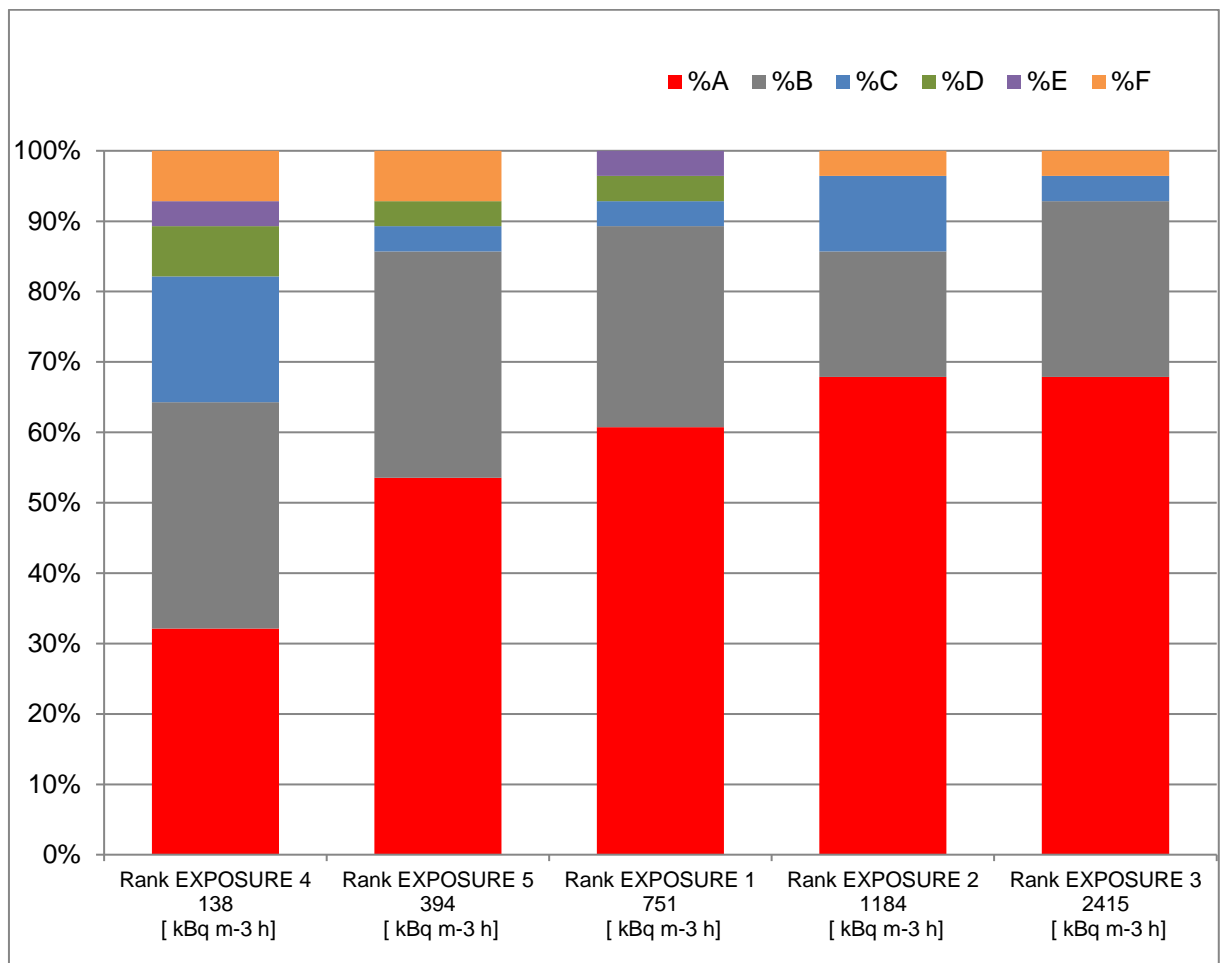


FIGURE 13 Proportions of sets achieving different performance classes for each exposure