Public Health England

Protecting and improving the nation's health

Results of the 2019 intercomparison of passive radon detectors

About Public Health England

Public Health England exists to protect and improve the nation's health and wellbeing, and reduce health inequalities. We do this through world-leading science, research, knowledge and intelligence, advocacy, partnerships and the delivery of specialist public health services. We are an executive agency of the Department of Health and Social Care, and a distinct delivery organisation with operational autonomy. We provide government, local government, the NHS, Parliament, industry and the public with evidence-based professional, scientific and delivery expertise and support.

Public Health England
Wellington House
133-155 Waterloo Road
London SE1 8UG
Tel: 020 7654 8000
www.gov.uk/phe
Twitter: @PHE_uk
Facebook: www.facebook.com/PublicHealthEngland

Prepared by: C A Miller, Project Scientist, Radon Dosimetry Team

For queries relating to this document, please contact:
Centre for Radiation, Chemical and Environmental Hazards
Public Health England
Chilton, Didcot, Oxfordshire OX11 0RQ
E: Radon@phe.gov.uk

Published November 2020
PHE publications
gateway number: GW-1624

PHE supports the UN
Sustainable Development Goals

Contents

Executive summary

Radon is the largest and most variable contributor of radiation dose to the general population. For more than 30 years, countries in Europe and elsewhere have carried out measurement 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 to reference radon exposures, 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 2,400 kBq m^{-3} h and the sixth group was used to determine transit exposures. The detectors were then returned to the laboratories, which 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 2019, for which a total of 25 laboratories from 13 countries submitted 29 sets of detectors. One laboratory did not receive their exposed detectors due to a courier/customs problem, so the report covers 24 laboratories and 28 sets of detectors from 12 countries. Analysis of the results allows each exposure group in each set to be classified from A (best) to F (worst). 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.

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)[1], 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).

[1] 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.

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 continually released from dry radium-226 (^{226}Ra) radon sources. There is no air flow through the chamber during operation.

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.

Logistical arrangements

In total, 25 laboratories from 13 countries took part in the 2019 PHE intercomparison. Some laboratories submitted more than 1 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. One laboratory did not receive their exposed detectors due to a courier/customs problem, so the report covers 24 laboratories and 28 sets of detectors from 12 countries. 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.

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 the 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 laboratory daily average concentrations ranged from 15 Bq m^{-3} to 27 Bq m^{-3}, with an overall average of 22 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 2% of the exposure in the chamber for the lowest exposure and less than 1% for the other exposures. This value was excluded for the purpose of calculating the reference exposures. Transit detectors were used to monitor radon exposures received in transit.

Between 6 November and 11 November 2019, 120 hours of data were lost by the automatic radon concentration logging system. During this period the logging system was ostensibly working, but failed to record any data at all. This included the data for the ATMOS instrument and the spectrometry samples. This period occurred during exposures 4 and 5, which were the 2 longest exposures. Subsequent cross-calibration checks with the AlphaGUARD back up instrument showed a difference between the ATMOS and AlphaGUARD of less than 1%, so data retrieved from the AlphaGUARD was used to calculate the radon exposures for exposures 4 and 5. The data for the spectrometry samples taken during this period could not be retrieved and the results were lost. This can be seen from the gaps in the data in Figures 4 and 5. Once the failure in the system was identified, the system was restarted and thereafter worked correctly. For the sake of consistency, the AlphaGUARD was also used to calculate the exposures for the other 3 exposure groups. This data transfer problem also illustrates the benefit of having a reliable second primary transfer standard as a backup.

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;
- 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.

Table 1. Performance classification

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

The participating laboratories are set out in Table 2.

Results and discussion

The results reported by the laboratories are given in Table 4. One of the participating laboratories did not receive their exposed detectors, so the tables show the results for 24 laboratories and 28 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 Figures 12a -12e.

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 23 kBq m^{-3} h (Figure 11). Most of the reported transit exposures were below 30 kBq m^{-3} h, 3 laboratories reported a value between 40 and 100 kBq m^{-3} h, and one laboratory reported a value above 100 kBq m^{-3} h. Overall this is an improvement from 2018, however for the laboratory with a reported transit value above 100 kBq m^{-3} h, this is a significant increase compared to their mean transit value from the 2018 intercomparison. This problem is being investigated by the participant.

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.

Five 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 one laboratory which participated with 2 different types of detectors. This is a slight decrease from 2018. Approximately 43% of all sets of detectors achieved class A for at least 3 exposures – which is a decrease from 2018, see Miller and Howarth (2020). For the lowest exposure measurement (116 kBq m^{-3} h), 36% of laboratories achieved class A, an improvement from 2018. For the second lowest exposure (363 kBq m^{-3} h), 39% of laboratories achieved class A, a lower score than in 2018.

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.

For the electret detectors, the participating laboratory had selected an electret combination with high sensitivity, which meant that while the lower exposures were very accurate, the higher exposures were not recorded correctly – the electrets were totally discharged. This is an intrinsic characteristic of electrets in that the chosen combination will be a balance between the sensitivity and the maximum recordable exposure.

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.

Conclusion

In total, 25 laboratories from 13 countries participated in the 2019 PHE intercomparison of passive radon detectors. One laboratory did not receive their exposed detectors, so this report is for 24 laboratories and 28 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 5 class A ratings, a slight decrease from the 2018 intercomparison.

Acknowledgements

The author would like to thank Chris Howarth who provided valuable assistance in the radon exposure of the detectors. Other members of the PHE Radon Dosimetry team provided logistical support with the handling of the detectors.

References

Daraktchieva Z, Howarth C B, Algar R (2012) Results of the 2011 HPA Intercomparison of Passive Radon Detectors. Chilton, HPA-CRCE-033.

Hanley O, Gutierrez-Villanueva JL, Currivan 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.

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.

Miller CA, Howarth CB (2020). Results of the 2018 PHE Intercomparison of Passive Radon Detectors. Chilton, PHE-CRCE-058.

Tables and figures

Table 2. Participating laboratories

Contact person	Organisation	Country
Kremena Ivanova	NCRRP	Bulgaria
Tiina Oinas	STUK	Finland
Pierre Filleul	ALGADE	France
Nicolas Tharaud	ALGADE / DOSIRAD	France
Vincent Delpech	Pearl-SAS	France
Erik Hülber	Radosys, Ltd.	Hungary
David Doyle	AlphaRadon Teo	Ireland
Enrico Chiaberto	ARPA Piemonte	Italy
Dr. M Guazzini	ARPAT Toscana	Italy
Ing. G Troiano	Niton Srl	Italy
Dr. C Cazzato	Radongas Srl	Italy
Dr. G Dalle Mulle	X-GAMMAGUARD di Laura Pini	Italy
Dr. M Rossetti	U-Series Srl	Italy
Trine Kolstad	DSA (was NRPA)	Norway
Marius Strauss	Parc RGM	South Africa
Raquel Sorribas	Labs & Technological Services Agq Sl	Spain
José Diaz Medina/ Vanesa Delgado	Laboratorio de Radiactividad Ambiental, Universidad de Valencia	Spain
Monika Nordqvist	Eurofins	Sweden
Prof. G Jönsson	RADONANALYS GJAB	Sweden
Dr. T Rönnqvist	Radonova	Sweden
Berna Ataksor	TAEK	Turkey
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)	170	37.4	96.8	624.6	329.3
Radon exposure (kBq m^{-3} h)	639	116	363	2393	1278
Uncertainty (%) at 68% CL	3.0	3.0	3.0	3.0	3.0
EER exposure (kBq m^{-3} h)	230	41	127	885	486
Uncertainty (%) at 68% CL	7.0	7.0	7.0	7.0	7.0
F, equilibrium factor	0.36	0.35	0.35	0.37	0.38

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

Table 4. Analysis of all reported results

Exposure 1 639 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	657.6	8.7	2.9	1.3	3.2
5-1	588.6	33.0	-7.9	5.6	9.7
12-1	582.3	32.3	-8.9	5.5	10.5
13-1	593.2	15.2	-7.2	2.6	7.6
13-2	595.6	32.6	-6.8	5.5	8.7
16-1	613.7	34.6	-4.0	5.6	6.9
16-2	577.9	33.3	-9.6	5.8	11.2
19-1	635.2	21.6	-0.6	3.4	3.5
20-1	663.1	21.9	3.8	3.3	5.0
25-1	676.0	51.7	5.8	7.6	9.6
25-2	715.6	82.7	12.0	11.6	16.7
32-1	525.2	19.2	-17.8	3.7	18.2
40-1	655.6	63.5	2.6	9.7	10.0
45-1	539.0	105.0	-15.6	19.5	25.0
54-1	552.5	23.0	-13.5	4.2	14.2
62-1	681.0	24.9	6.6	3.7	7.5
81-1	320.7	2.3	-49.8	0.7	49.8
136-1	675.9	21.8	5.8	3.2	6.6
136-2	601.6	16.3	-5.9	2.7	6.4
141-1	586.8	12.7	-8.2	2.2	8.5
171-1	546.7	65.2	-14.4	11.9	18.7
175-1	536.9	31.8	-16.0	5.9	17.0
177-1	459.4	23.1	-28.1	5.0	28.6
178-1	530.9	6.2	-16.9	1.2	17.0
181-1	686.2	26.0	7.4	3.8	8.3
186-1	582.9	20.6	-8.8	3.5	9.5
187-1	534.1	75.8	-16.4	14.2	21.7
191-1	554.7	55.5	-13.2	10.0	16.6

Table 4. Analysis of all reported results (continued)

Exposure 2 116 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	123.0	3.7	6.0	3.0	6.7
5-1	115.1	14.8	-0.8	12.9	12.9
12-1	105.7	3.9	-8.9	3.7	9.6
13-1	115.4	6.9	-0.5	6.0	6.0
13-2	122.6	10.0	5.7	8.2	9.9
16-1	112.5	11.4	-3.0	10.1	10.6
16-2	118.4	14.6	2.1	12.3	12.5
19-1	120.0	16.6	3.4	13.8	14.3
20-1	115.1	9.5	-0.8	8.3	8.3
25-1	109.8	10.6	-5.3	9.7	11.0
25-2	141.0	25.1	21.6	17.8	28.0
32-1	109.7	5.4	-5.4	4.9	7.3
40-1	138.1	18.5	19.1	13.4	23.3
45-1	126.5	32.9	9.1	26.0	27.5
54-1	95.6	18.4	-17.6	19.2	26.1
62-1	121.4	10.4	4.7	8.6	9.7
81-1	114.4	5.6	-1.4	4.9	5.1
136-1	124.9	2.5	7.7	2.0	7.9
136-2	119.5	3.4	3.0	2.8	4.1
141-1	104.7	4.9	-9.7	4.7	10.8
171-1	129.0	17.2	11.2	13.3	17.4
175-1	97.0	11.1	-16.4	11.4	20.0
177-1	88.8	9.7	-23.4	10.9	25.9
178-1	94.2	1.8	-18.8	1.9	18.9
181-1	131.1	8.0	13.0	6.1	14.4
186-1	105.2	8.9	-9.3	8.5	12.6
187-1	68.1	57.1	-41.3	83.8	93.5
191-1	106.7	24.8	-8.0	23.2	24.6

Table 4. Analysis of all reported results (continued)

Exposure 3 363 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	369.1	6.0	1.7	1.6	2.3
5-1	331.3	24.0	-8.7	7.2	11.3
12-1	321.2	14.7	-11.5	4.6	12.4
13-1	338.8	12.2	-6.7	3.6	7.6
13-2	344.1	20.2	-5.2	5.9	7.8
16-1	336.2	26.3	-7.4	7.8	10.8
16-2	342.7	18.6	-5.6	5.4	7.8
19-1	363.2	17.2	0.1	4.7	4.7
20-1	361.7	17.2	-0.4	4.8	4.8
25-1	370.9	32.4	2.2	8.7	9.0
25-2	364.6	42.0	0.4	11.5	11.5
32-1	311.3	14.4	-14.2	4.6	15.0
40-1	387.1	38.8	6.6	10.0	12.0
45-1	275.5	75.0	-24.1	27.2	36.4
54-1	302.9	27.0	-16.6	8.9	18.8
62-1	392.9	30.2	8.2	7.7	11.3
81-1	316.4	6.5	-12.8	2.1	13.0
136-1	387.4	11.0	6.7	2.8	7.3
136-2	380.9	8.8	4.9	2.3	5.4
141-1	344.2	12.2	-5.2	3.5	6.3
171-1	357.4	55.2	-1.5	15.4	15.5
175-1	299.8	27.5	-17.4	9.2	19.7
177-1	264.2	13.8	-27.2	5.2	27.7
178-1	306.7	2.1	-15.5	0.7	15.5
181-1	406.9	18.0	12.1	4.4	12.9
186-1	341.1	7.6	-6.0	2.2	6.4
187-1	297.7	61.4	-18.0	20.6	27.4
191-1	312.5	53.1	-13.9	17.0	22.0

Table 4. Analysis of all reported results (continued)

Exposure 4 2393 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	2404.6	45.2	0.5	1.9	1.9
5-1	2183.3	40.2	-8.8	1.8	9.0
12-1	2074.7	42.3	-13.3	2.0	13.5
13-1	2214.3	36.4	-7.5	1.6	7.6
13-2	2111.6	137.1	-11.8	6.5	13.4
16-1	2224.2	109.7	-7.1	4.9	8.6
16-2	2183.7	114.2	-8.7	5.2	10.2
19-1	2300.7	42.5	-3.9	1.8	4.3
20-1	2352.1	27.2	-1.7	1.2	2.1
25-1	2779.9	72.4	16.2	2.6	16.4
25-2	2930.9	106.1	22.5	3.6	22.8
32-1	2035.7	110.4	-14.9	5.4	15.9
40-1	2072.3	176.1	-13.4	8.5	15.9
45-1	2428.0	387.3	1.5	16.0	16.0
54-1	2089.0	32.1	-12.7	1.5	12.8
62-1	2618.0	110.5	9.4	4.2	10.3
81-1	318.1	2.8	-86.7	0.9	86.7
136-1	2451.9	57.7	2.5	2.4	3.4
136-2	2212.6	103.4	-7.5	4.7	8.9
141-1	2284.9	59.5	-4.5	2.6	5.2
171-1	1929.0	134.8	-19.4	7.0	20.6
175-1	1918.5	43.6	-19.8	2.3	20.0
177-1	1734.9	26.5	-27.5	1.5	27.5
178-1	2101.7	8.1	-12.2	0.4	12.2
181-1	2548.3	65.3	6.5	2.6	7.0
186-1	2236.0	37.5	-6.6	1.7	6.8
187-1	2002.4	704.4	-16.3	35.2	38.8
191-1	2144.8	72.5	-10.4	3.4	10.9

Table 4. Analysis of all reported results (continued)

Exposure 5 1278 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	1293.2	27.4	1.2	2.1	2.4
5-1	1181.9	31.6	-7.5	2.7	8.0
12-1	1104.1	33.5	-13.6	3.0	13.9
13-1	1201.3	34.3	-6.0	2.9	6.6
13-2	1179.0	42.1	-7.7	3.6	8.5
16-1	1182.1	73.2	-7.5	6.2	9.7
16-2	1155.0	26.1	-9.6	2.3	9.9
19-1	1242.6	22.9	-2.8	1.8	3.3
20-1	1287.9	29.6	0.8	2.3	2.4
25-1	1532.1	89.8	19.9	5.9	20.7
25-2	1417.3	95.8	10.9	6.8	12.8
32-1	1071.7	17.7	-16.1	1.7	16.2
40-1	1153.3	407.9	-9.8	35.4	36.7
45-1	1292.6	277.4	1.1	21.5	21.5
54-1	1122.9	33.8	-12.1	3.0	12.5
62-1	1376.2	58.2	7.7	4.2	8.8
81-1	319.1	4.3	-75.0	1.3	75.0
136-1	1374.4	41.5	7.5	3.0	8.1
136-2	1166.5	23.1	-8.7	2.0	8.9
141-1	1201.1	27.1	-6.0	2.3	6.4
171-1	1278.4	65.6	0.0	5.1	5.1
175-1	1036.8	39.0	-18.9	3.8	19.2
177-1	947.3	37.4	-25.9	3.9	26.2
178-1	1128.3	7.0	-11.7	0.6	11.7
181-1	1406.2	42.6	10.0	3.0	10.5
186-1	1183.1	33.3	-7.4	2.8	7.9
187-1	1165.7	51.0	-8.8	4.4	9.8
191-1	1107.3	45.6	-13.4	4.1	14.0

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	639 kBq m^{-3} h	588	81
2	116 kBq m^{-3} h	113	16
3	363 kBq m^{-3} h	340	36
4	2393 kBq m^{-3} h	2175	447
5	1278 kBq m^{-3} h	1182	211

Table 6. Performance classification scheme based on measurement error

Performance classification in each exposure:

	Exposure 2	Exposure 3	Exposure 1	Exposure 5	Exposure 4					
Set ID	116 kBq m^{-3} h	363 kBq m^{-3} h	639 kBq m^{-3} h	1278 kBq m^{-3} h	2393 kBq m^{-3} h	Detector type	Filter	Holder	Detector material	Detector material supplier
1-1	A	A	A	A	A	Closed		NRPB	CR-39	MiNet (UK)
13-1	A	A	A	A	A	Closed	yes	NRPB/SSI	CR-39	RTP Company
20-1	A	A	A	A	A	Closed		TASL	PADC	TASL
136-1	A	A	A	A	A	Closed		NRPB / SSI	PADC	TASL
136-2	A	A	A	A	A	Closed		Film badge	PADC	TASL
13-2	A	A	A	A	B	Closed	yes	Duotrak	CR-39	RTP Company
19-1	B	A	A	A	A	Closed		ARPA	CR-39	TASL
141-1	B	A	A	A	A	Closed		Radosure	TASTRAK	TASL
186-1	B	A	A	A	A	Closed		TASL	TASTRAK PADC	TASL
5-1	B	B	A	A	A	Closed		TASL	CR-39	TASL
16-1	B	B	A	A	A	Closed		RSK cylindrical	PADC (CR-39)	Radosys
62-1	A	B	A	A	B	Closed		Own design	Polycarbonate Makrofol	Covestro GmbH
16-2	B	A	B	A	B	Closed		RSX pentagonal	PADC (CR-39)	Radosys
181-1	B	B	A	B	A	Closed		Radosys	PADC (CR-39)	Radosys
25-1	B	A	A	C	B	Open			LR115	Algade/Dosirad

	Exposure 2	Exposure 3	Exposure 1	Exposure 5	Exposure 4				
	116 kBq m^{-3} h	363 kBq m^{-3} h	639 kBq m^{-3} h	1278 kBq m^{-3} h	2393 kBq m^{-3} h				
12-1	A	B	B	B	B	Closed		CR-39	GM Scientific
32-1[1]	A	B	B	B	B	Closed	NRPB/SSI (black)	CR-39/PADC	TASL
81-1[2]	A	B	E	F	F	Closed	E-Perm (S)	Rad Elec E-Perm System X	
171-1	B	B	B	A	C	Closed	Own design	LR115	Dosirad
187-1[3]	F	C	C	A	D	Closed		PADC / CR-39	Radosys
175-1	B	B	B	B	B	Closed		CR-39	Radosys
178-1	B	B	B	B	B	Closed	none TASL	CR-39	TASL
54-1	C	B	B	B	B	Closed	Own design	CR-39	TASL UK
25-2	C	B	B	B	C	Closed	Own design	LR115	Algade/Dosirad
191-1	C	C	B	B	B	Closed	RadOut™	CR-39	GM Scientific
40-1	C	B	B	D	B	Closed	NRPB (yellow)	PADC	Instrument plastics
45-1	C	D	C	C	B	Closed	Own design	LR115	
177-1	C	C	C	C	C	Closed	TASL	TASL	TASL

Notes to Table 6 above:

(1) *32-1 - The laboratory acknowledged that they had used an incorrect sensitivity factor in their result calculations; with the correct factor the results would have been: A A B A A.*

(2) *81-1 - The electret / holder combination was too sensitive for the range of exposures used in the intercomparison so 4 of the detectors were fully discharged.*

(3) *187-1 - An administrative error by the participant resulted in PHE detector numbers being incorrectly recorded.*

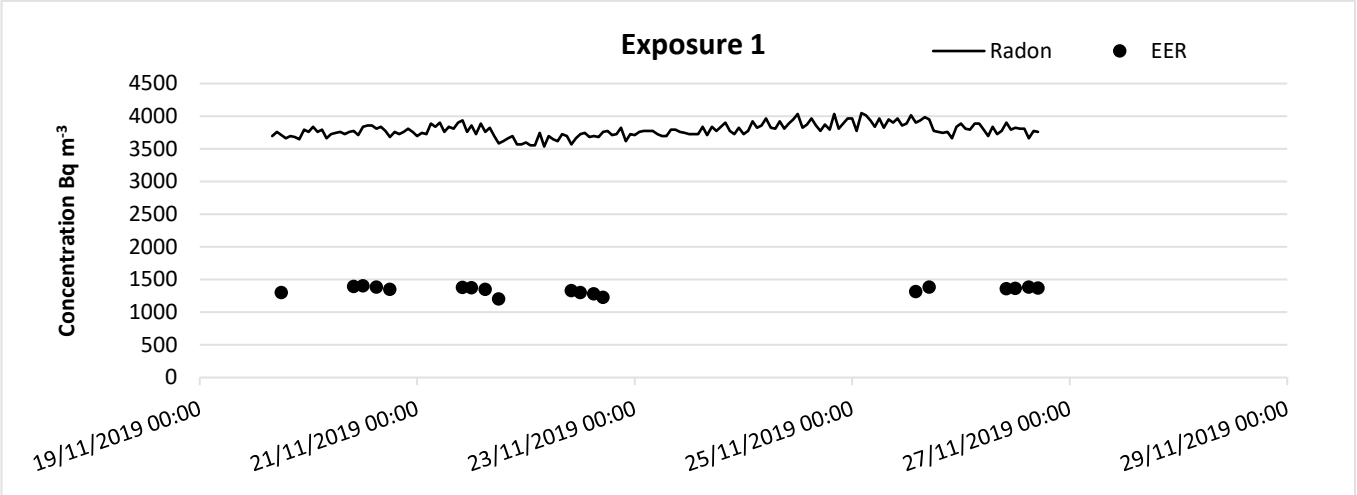

Figure 1. Radon and EER concentrations for exposure 1

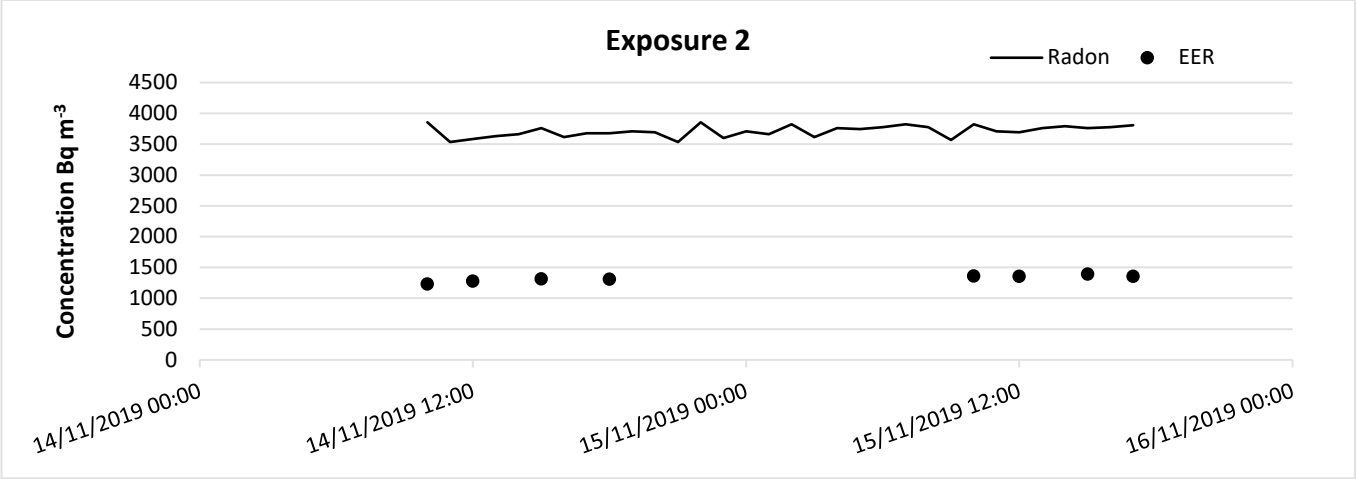

Figure 2. Radon and EER concentrations for exposure 2

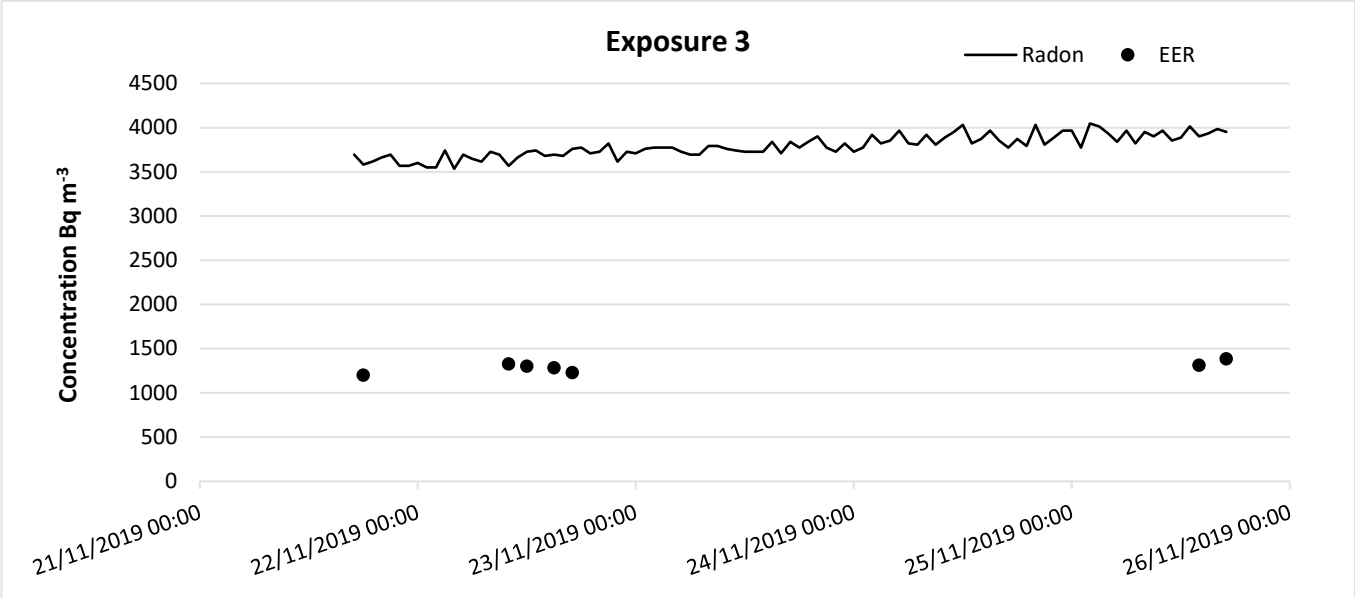

Figure 3. Radon and EER concentrations for exposure 3

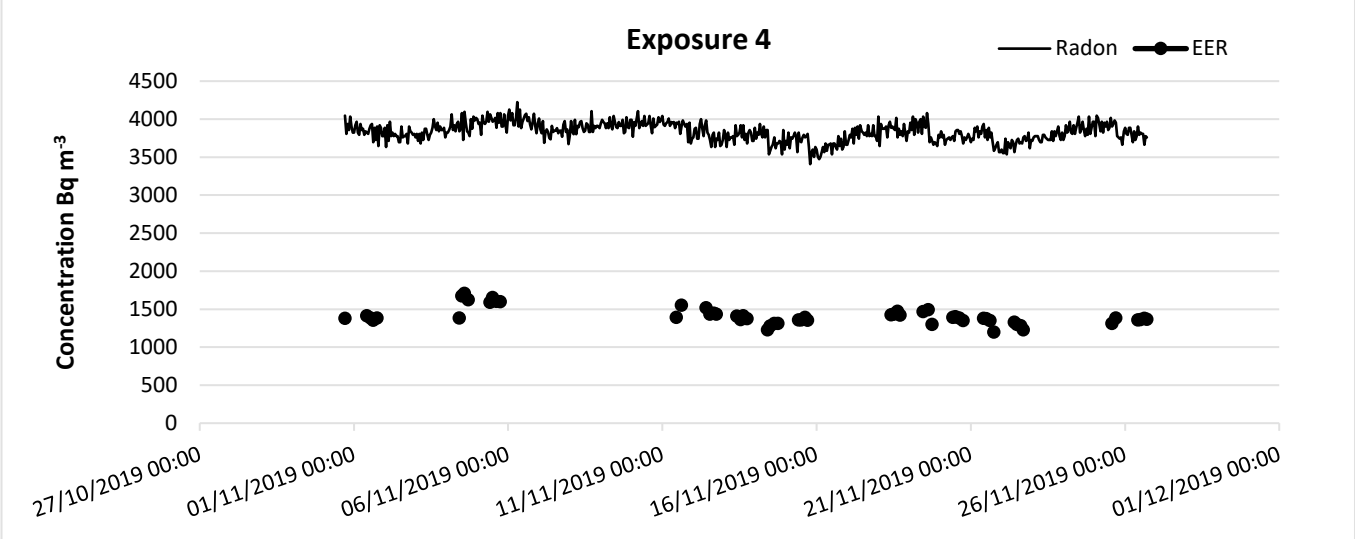

Figure 4. Radon and EER concentrations for exposure 4

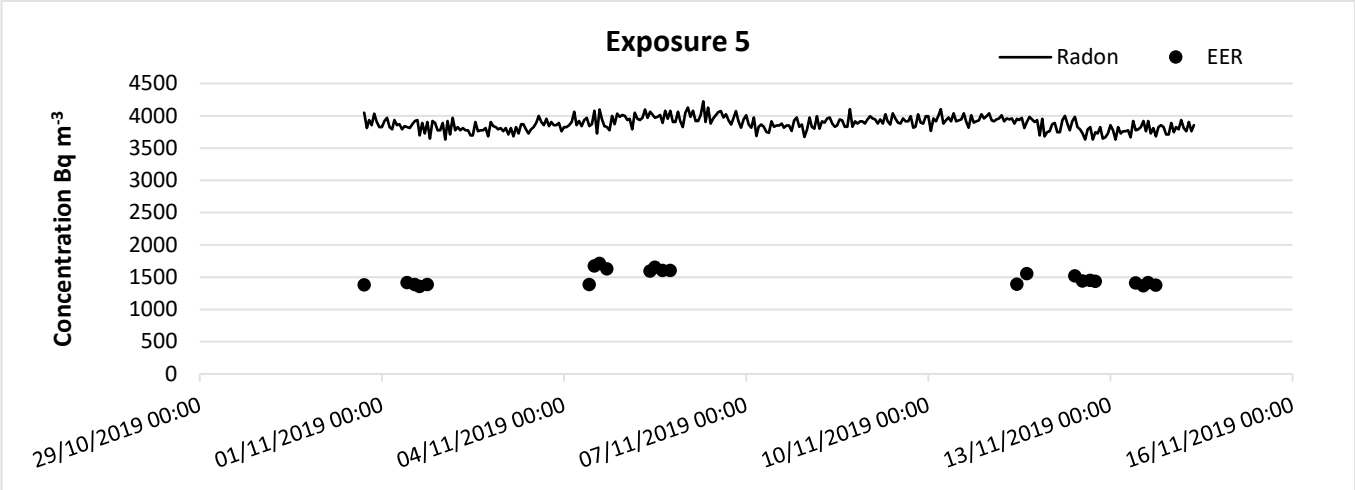

Figure 5. Radon and EER concentrations for exposure 5

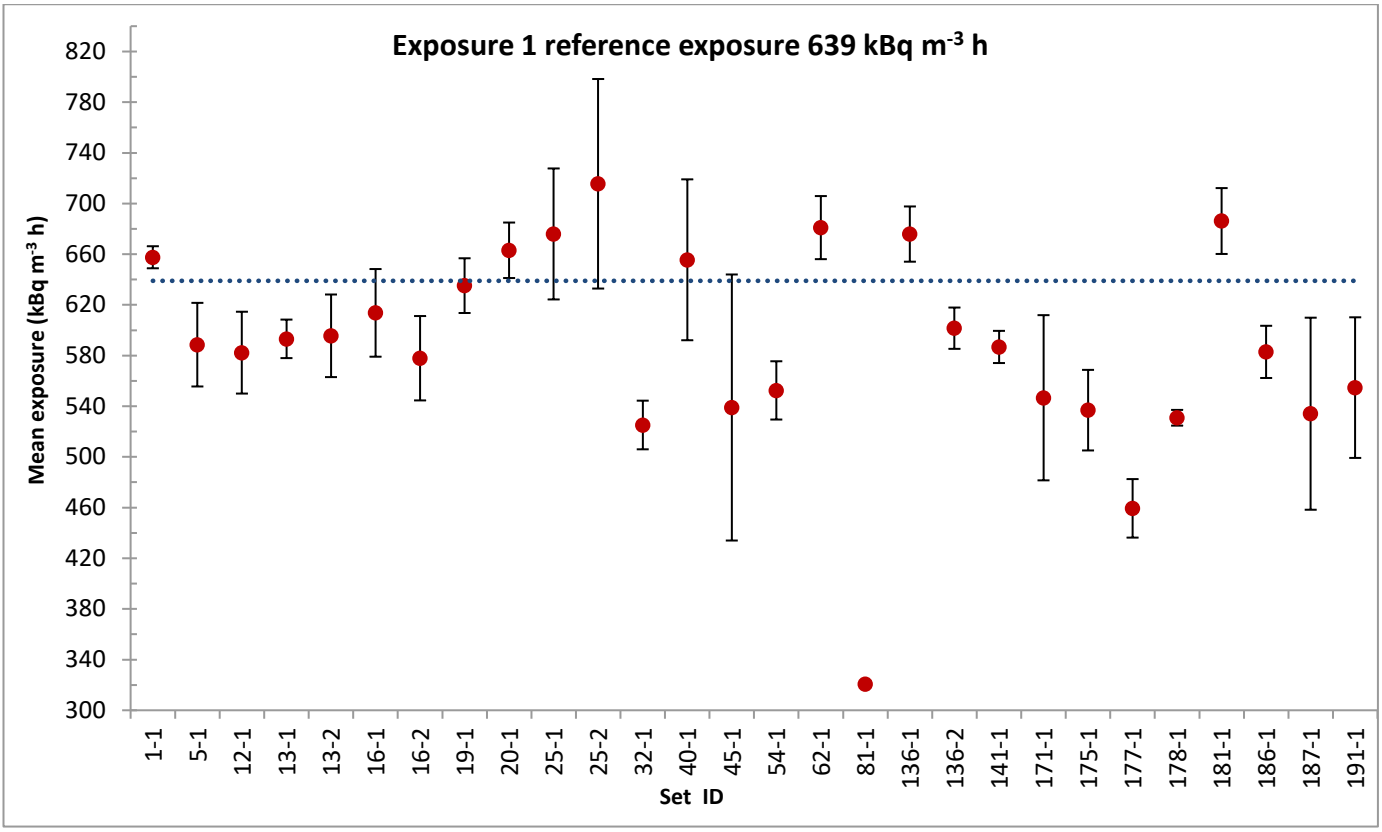

Figure 6. Results as reported by participants for exposure 1

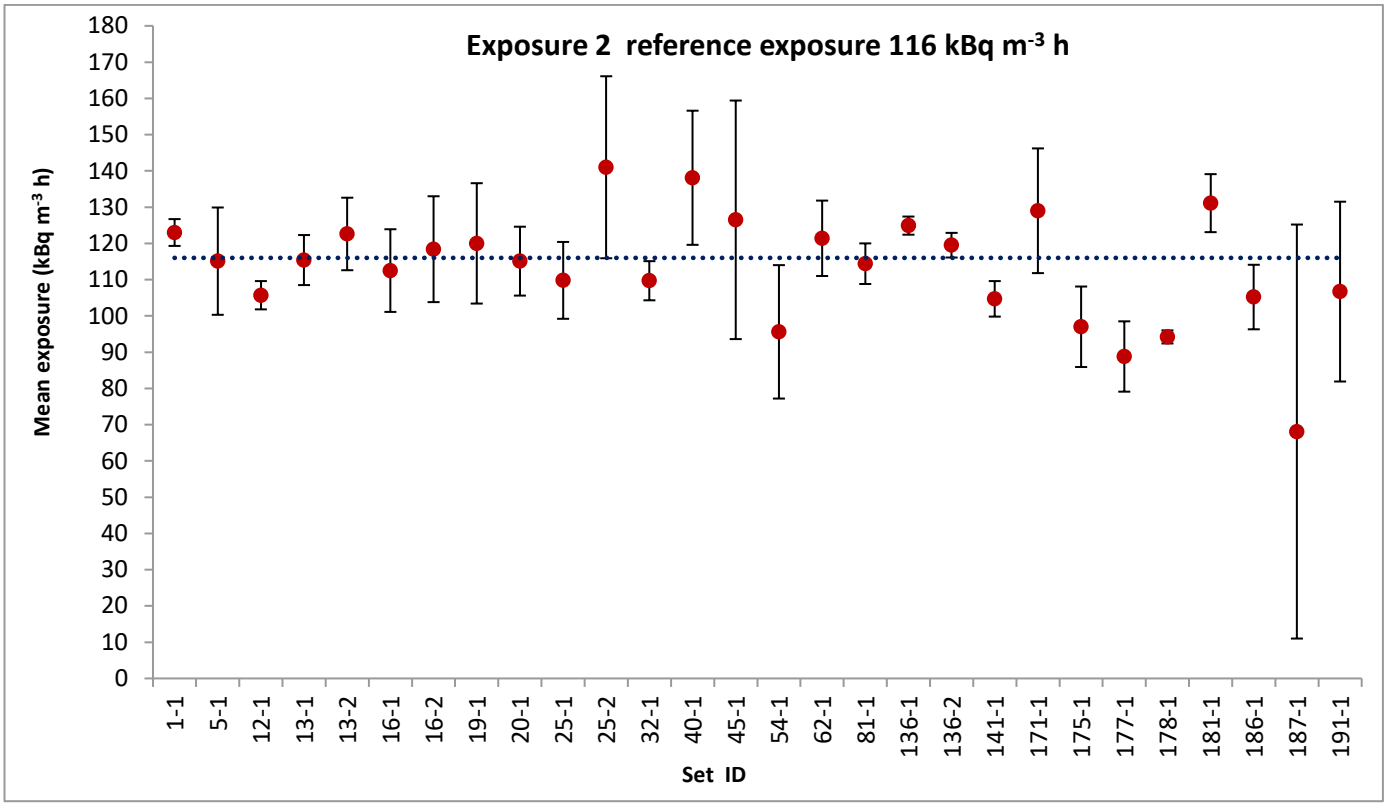

Figure 7. Results as reported by participants for exposure 2

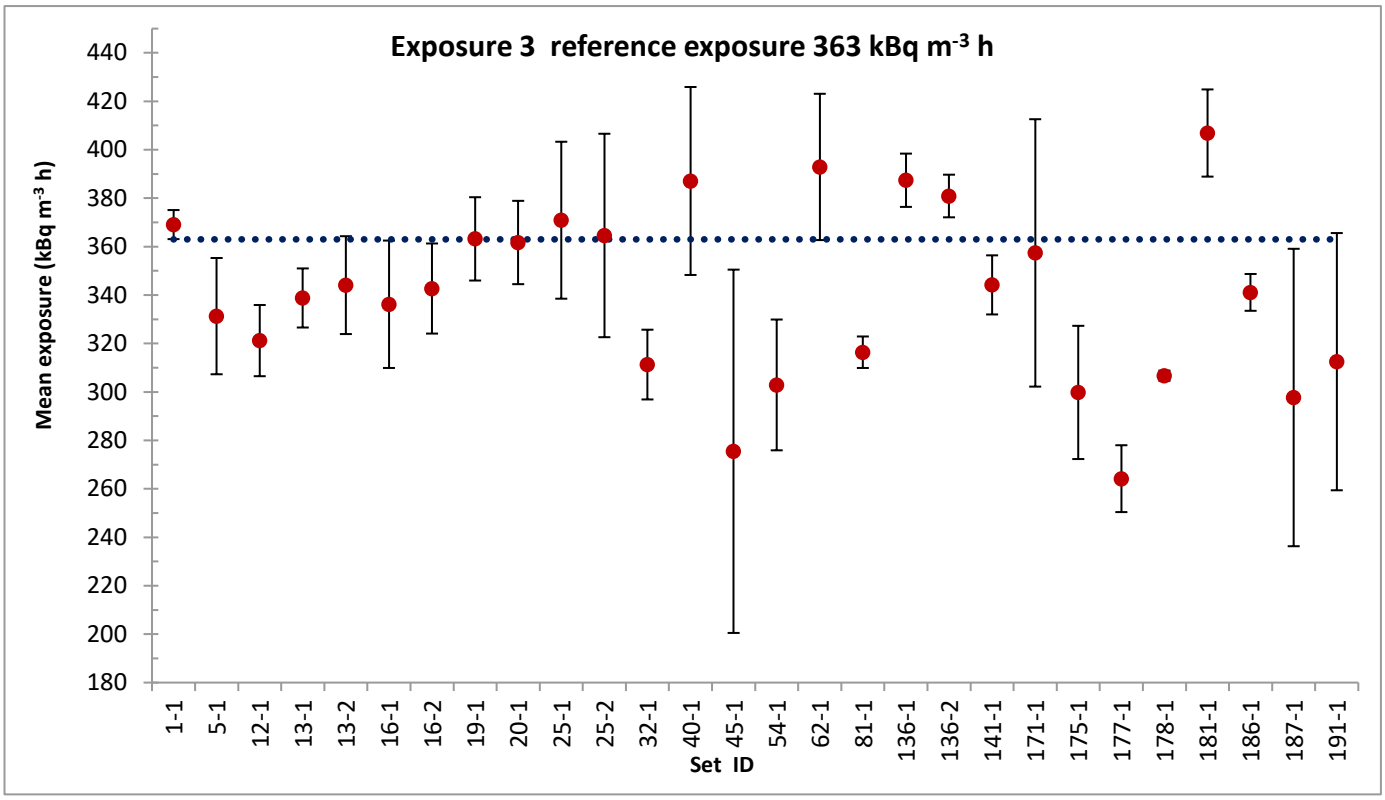

Figure 8. Results as reported by participants for exposure 3

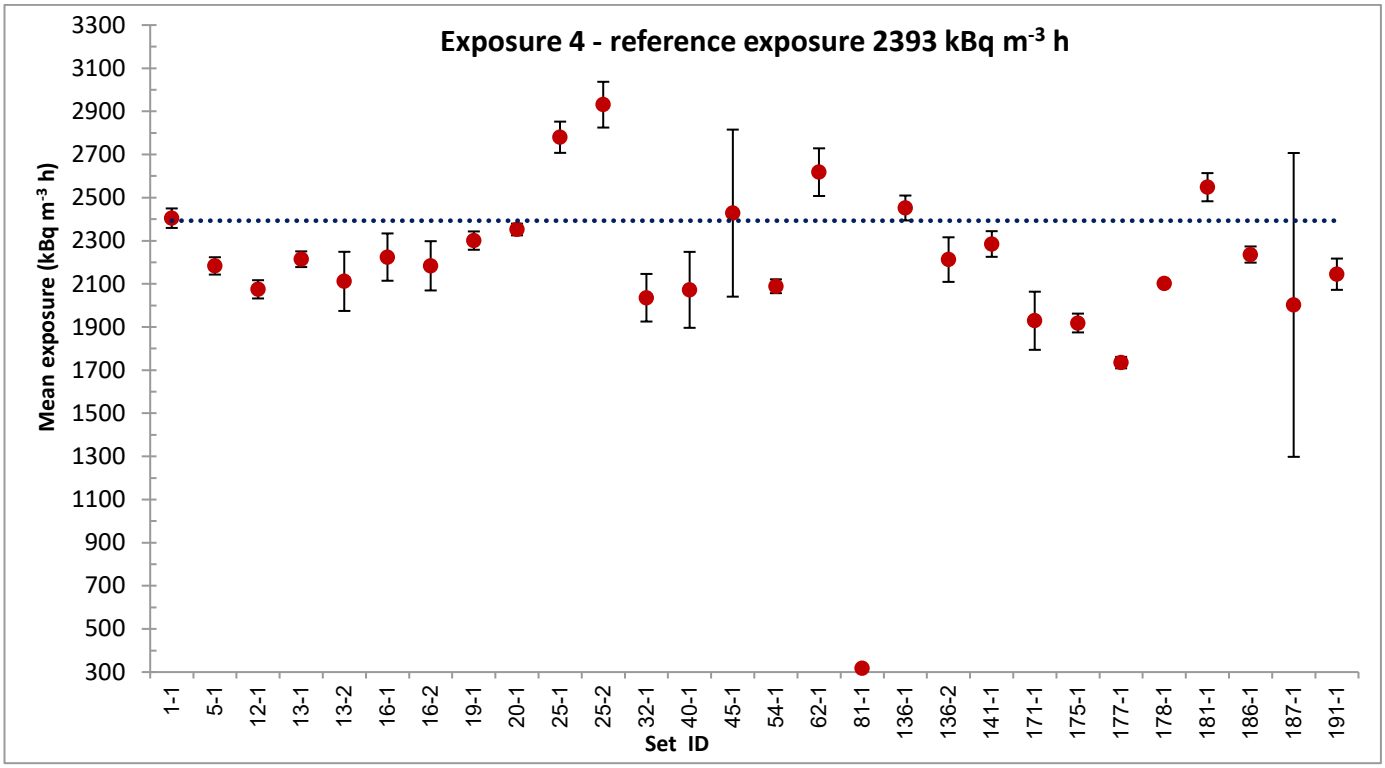

Figure 9. Results as reported by participants for exposure 4

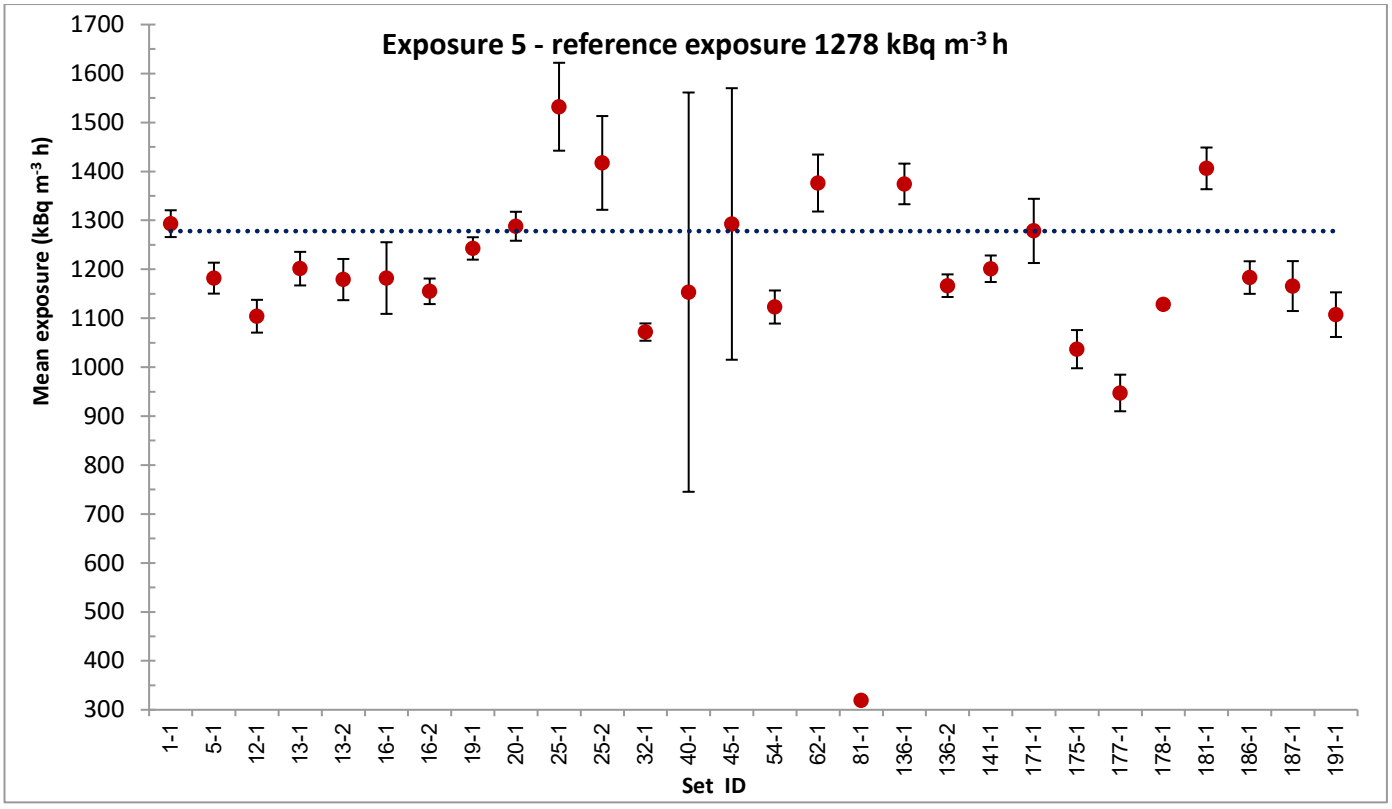

Figure 10. Results as reported by participants for exposure 5

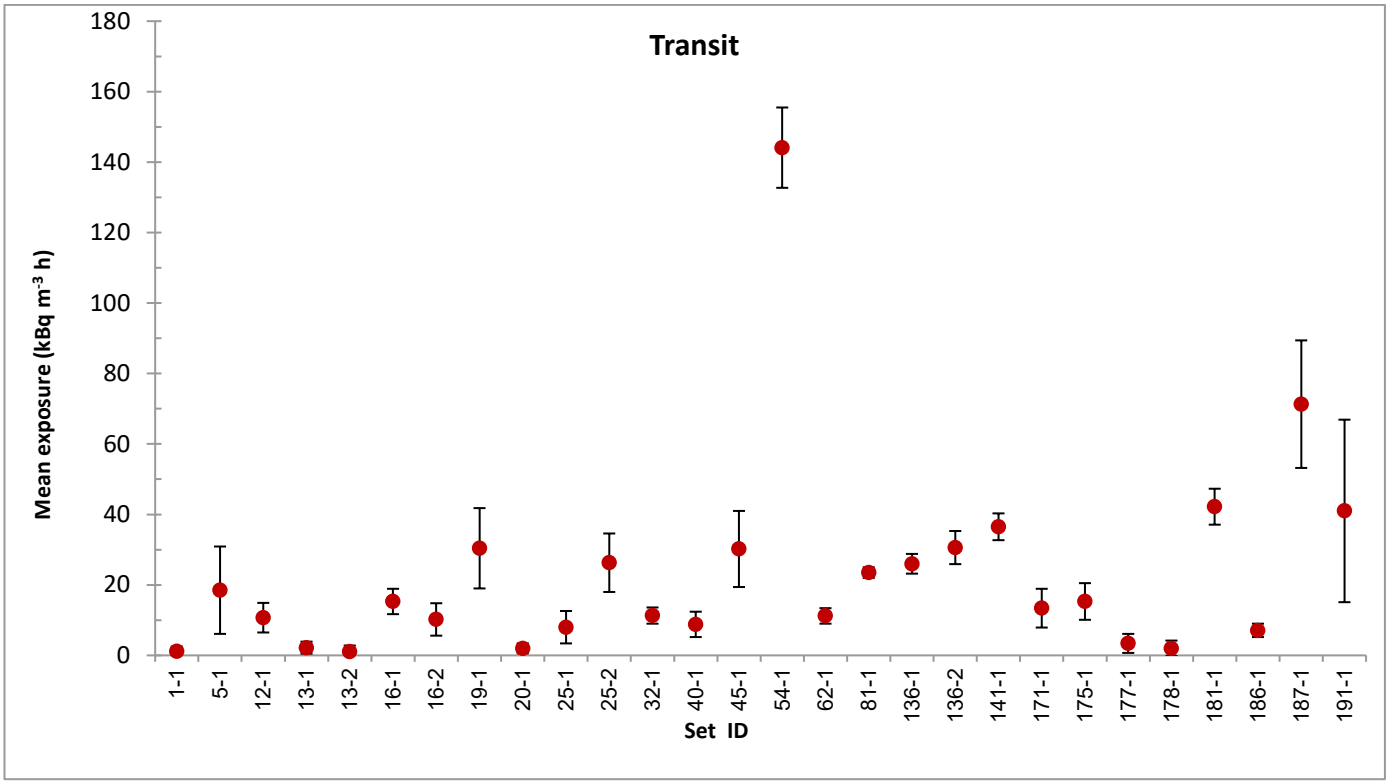

Figure 11. Results as reported by participants for transit exposure

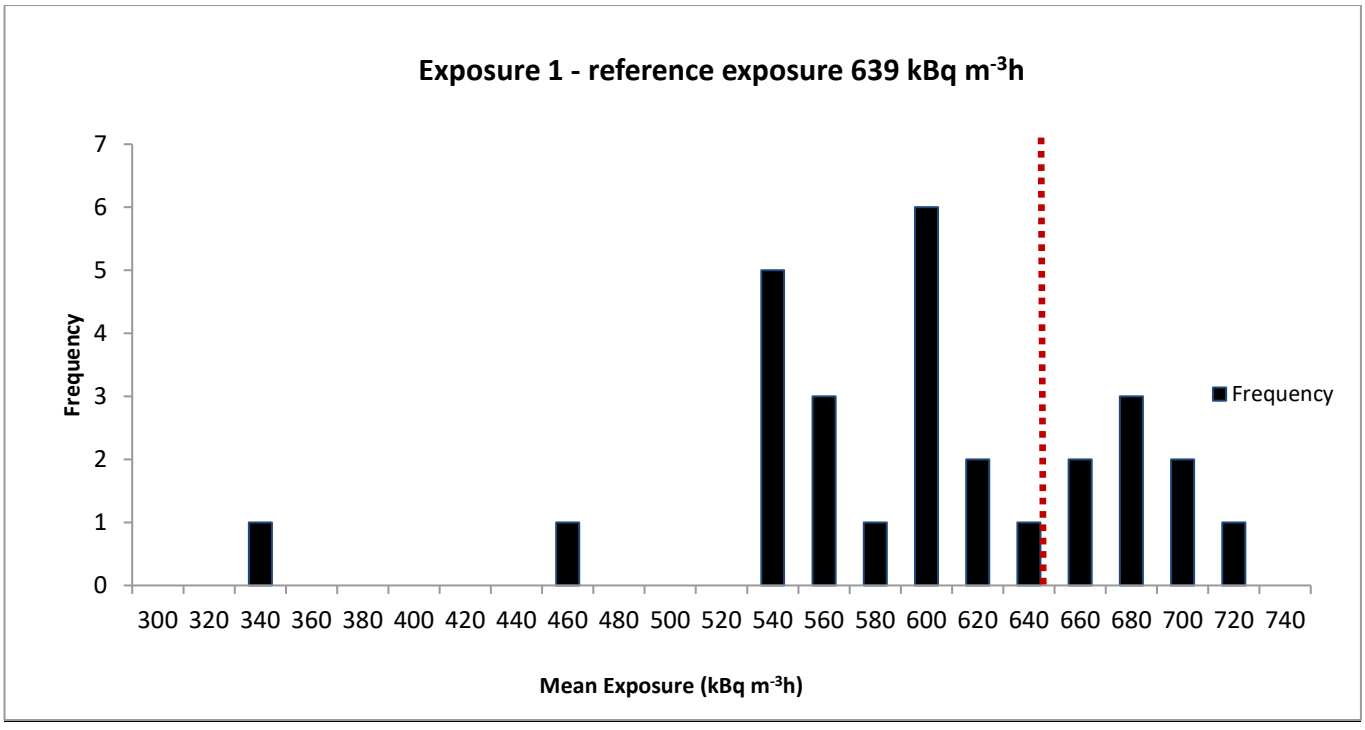

Figure 12a. Distribution of mean exposure results given in Table 5 – exposure 1

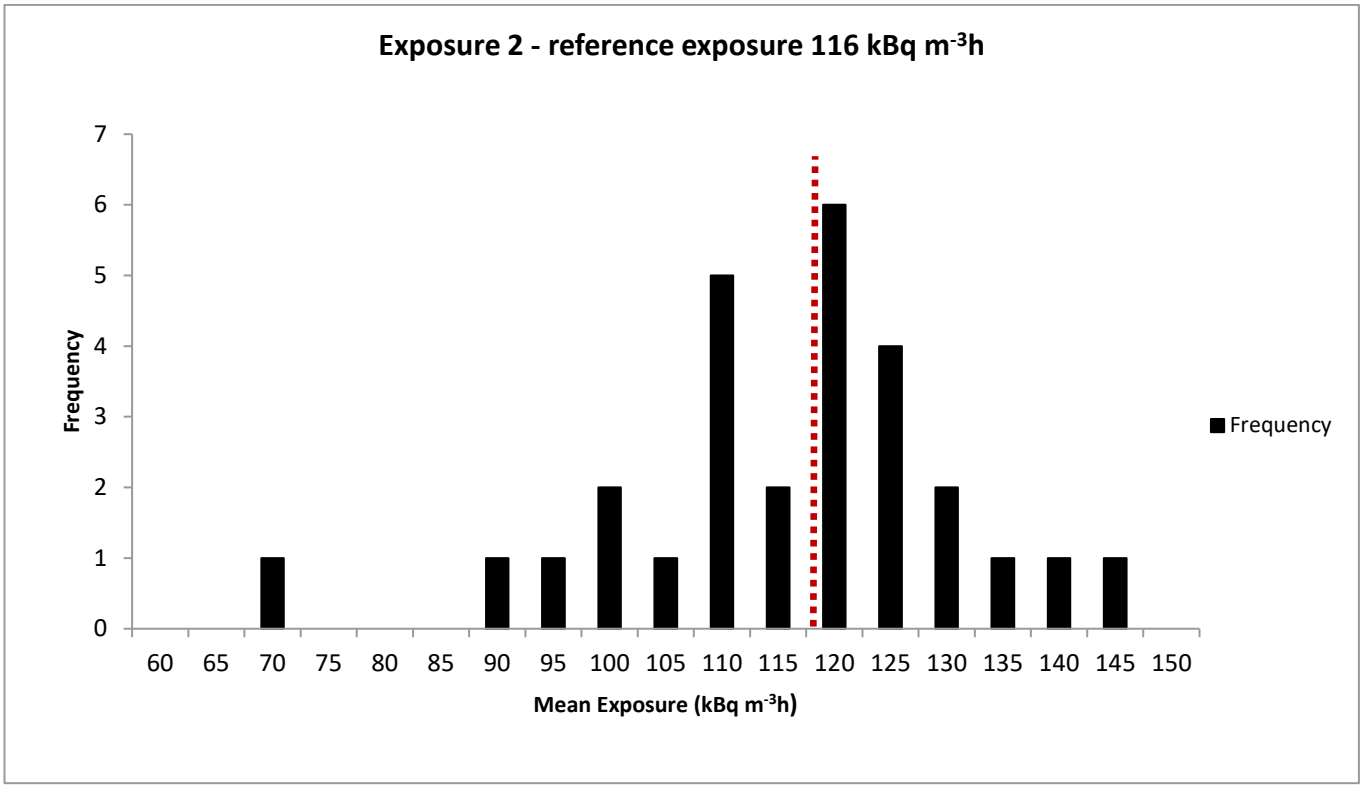

Figure 12b. Distribution of mean exposure results given in Table 5 – exposure 2

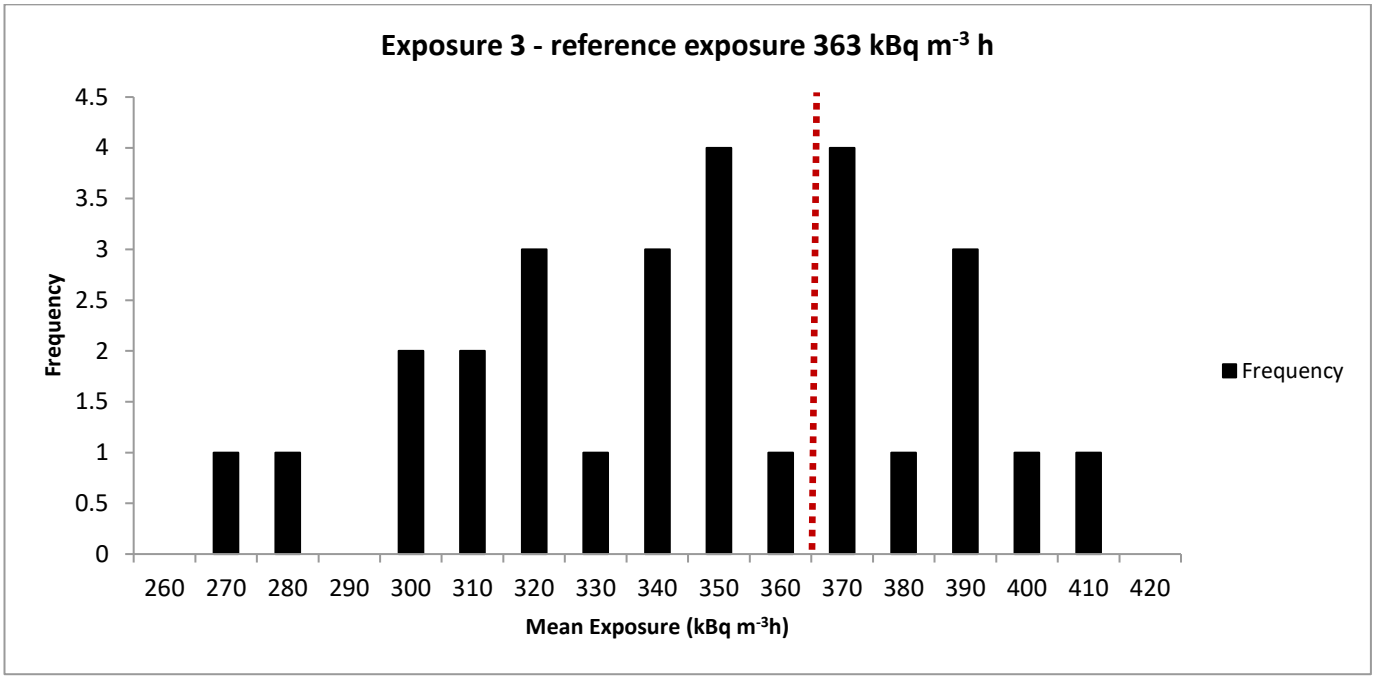

Figure 12c. Distribution of mean exposure results given in Table 5 – exposure 3

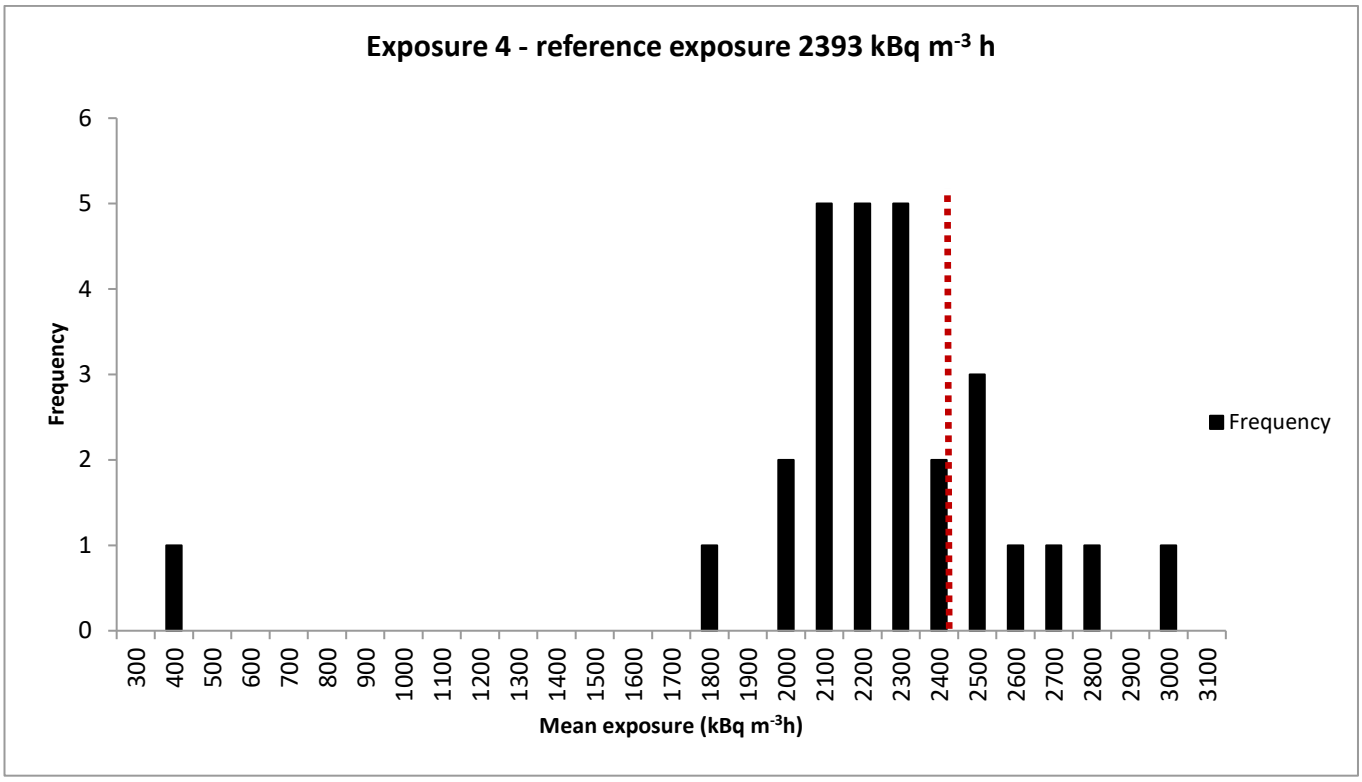

Figure 12d. Distribution of mean exposure results given in Table 5 – exposure 4

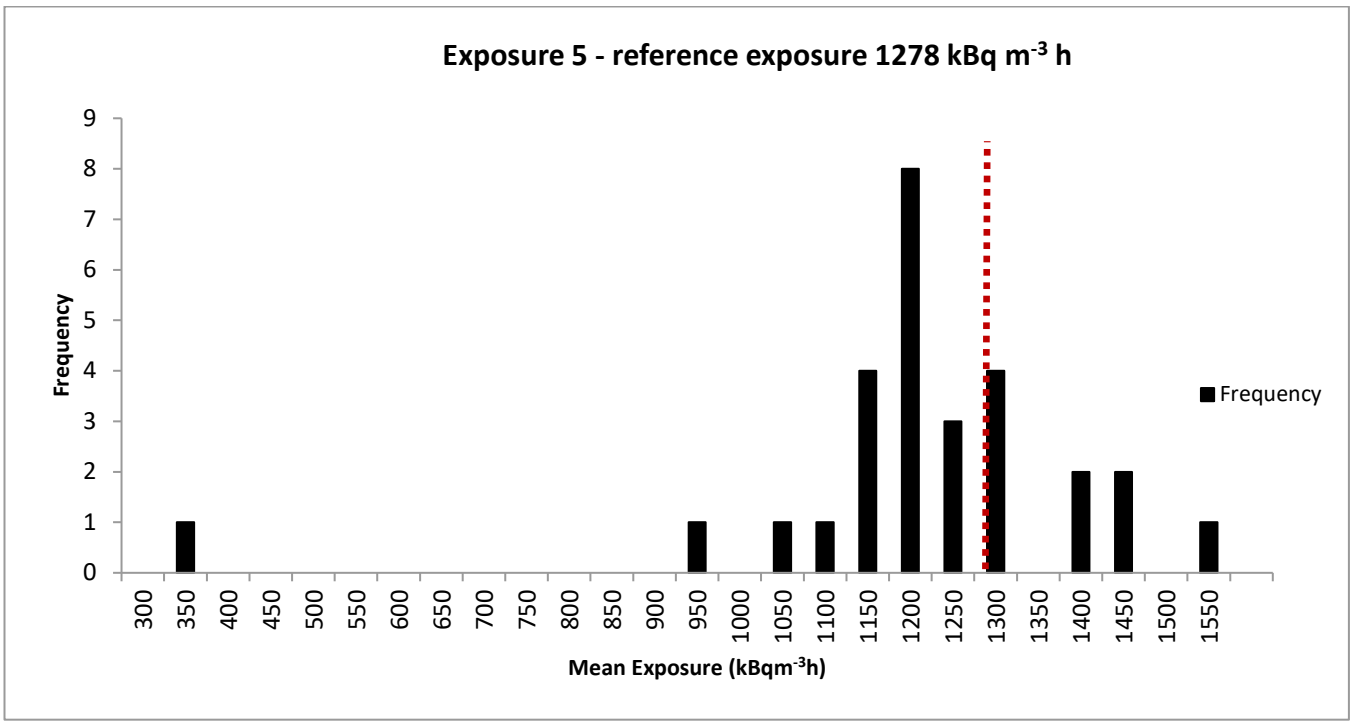

Figure 12e. Distribution of mean exposure results given in Table 5 – exposure 5

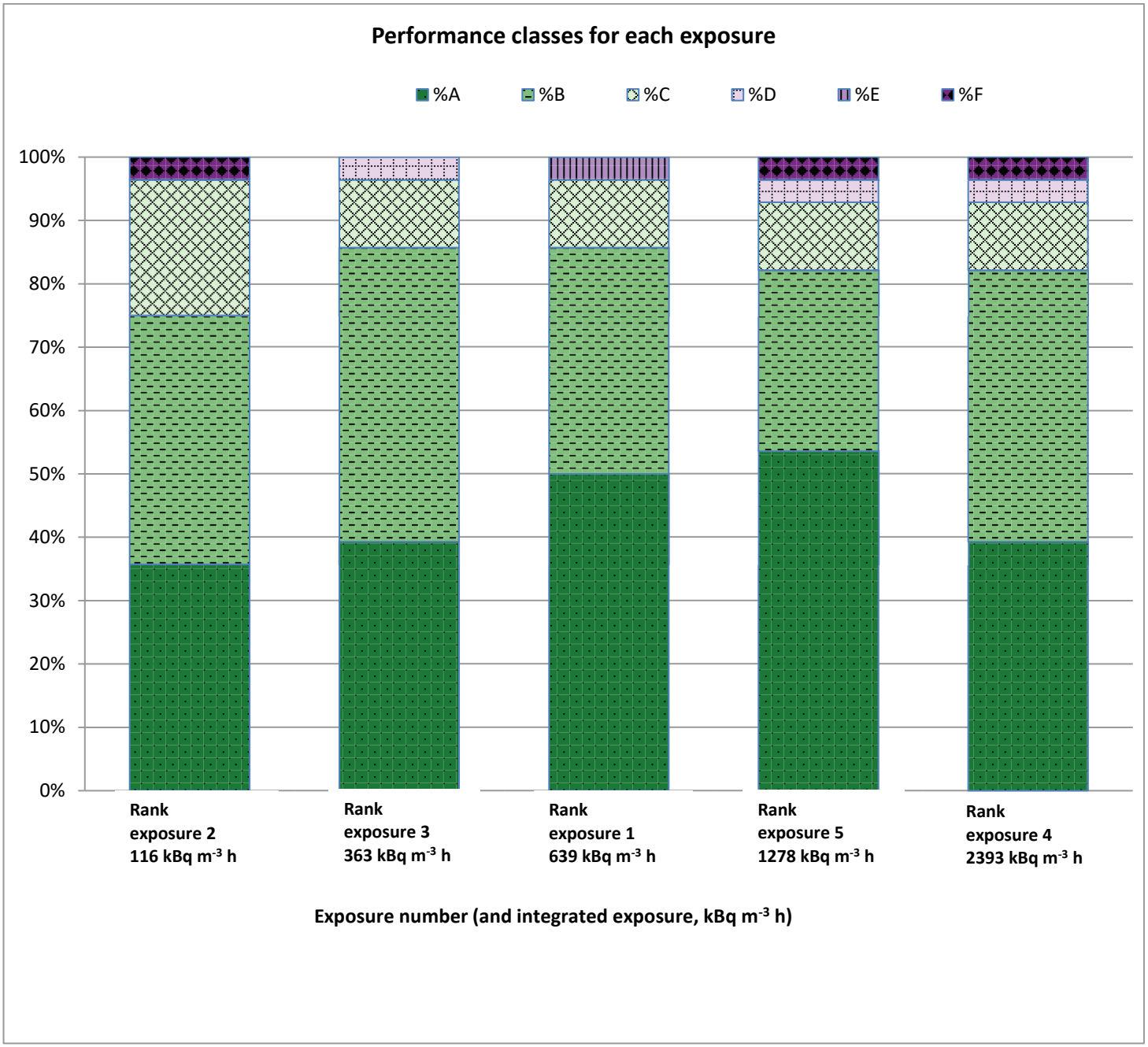

Figure 13. Performance classes for each exposure