Public Health England

Protecting and improving the nation's health

Results of the 2020 intercomparison of passive radon detectors

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 and precision of measurements. By allowing different detectors to be compared side by side to reference radon exposures, an objective assessment 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 (PHE) carries out international intercomparisons of passive radon detectors each year. For this intercomparison, laboratories were invited to submit sets of etched track and electret detectors that were randomised into 6 groups at CRCE. Five of these groups were exposed in the CRCE radon chamber to radon gas exposures ranging from 100 kBq m^{-3} h to 2,700 kBq m^{-3} h; the 6th group was used to determine transit exposures. In addition, laboratories were invited to submit sets of activated charcoal detectors that were randomised into 3 groups at CRCE. All 3 groups were exposed in the CRCE radon chamber to radon gas exposures ranging from 500 kBq m^{-3} h to 1,200 kBq m^{-3} h.

The detectors were then returned to the participating laboratories, which were asked to report the integrated radon gas exposure result for each detector. The laboratories were not informed of the details of the exposures nor which detectors were in which group until all the results had been submitted.

This report considers the results for the intercomparison carried out in 2020, for which a total of 31 laboratories from 14 countries submitted 39 sets of detectors. One laboratory was unable to process their exposed detectors due to a building fire, so the report covers 30 laboratories and 38 sets of detectors from 14 countries. The 38 sets of detectors comprise 37 sets of etched track and electret detectors, plus 1 set of activated charcoal detectors, which were exposed separately for logistical reasons and for which the results are given separately within this report. 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 have been 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:

1. 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).

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

3. 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 are subject to various sources of error during production, storage and processing. 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 annually using a radon gas source, most recently supplied by CHUV Institut de Radiophysique, Switzerland.

During the etched track and electret 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, 31 laboratories from 14 countries took part in the 2020 PHE intercomparison. Some laboratories submitted more than 1 set of detectors, so 39 sets of detectors were exposed in the radon chamber. Following exposure, the detectors were returned to the originating laboratories for processing.

One laboratory was unable to process their exposed detectors due to a building fire, so this report covers 30 laboratories and 38 sets of detectors from 14 countries. The 38 sets of detectors are 37 sets of etched track and electret detectors, plus 1 set of activated charcoal detectors, which were exposed separately and for which the results are given separately within this report.

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 etched track and electret detectors. An equilibrium factor, F, of approximately 0.40 to 0.50 between the radon and its decay products was maintained in the chamber for all 5 etched track and electet detector intercomparison exposures. The equilibrium factor was not monitored during the activated charcoal detector exposures.

The chamber exposures were calculated after the deadline for return of results by participants and are shown with exposure durations in Tables 3 and 3A. Radon and EER (equilibrium equivalent of radon) concentrations during the etched track and electret detector exposures are shown in Figures 1 to 5.

The radon level was increased during exposure 5 in order to shorten its duration. This has no effect on the performance of an integrating radon detector.

The radon concentration in the laboratory outside the exposure chamber was monitored during the exposures using an AlphaGUARD ionisation chamber. The laboratory daily average corrected concentrations ranged from 5 Bq m^{-3} to 44 Bq m^{-3}, with an overall average of 19 Bq m^{-3}. The estimated additional exposure of the etched track and electret detectors caused by leaving them exposed in the laboratory for a minimum of 3 days to allow radon to diffuse out 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.

The activated charcoal detectors were returned to the participating laboratory on removal from the radon chamber. As the detectors were sealed before and after exposure, there was no period of diffusion and there were no transit detectors.

Performance classification scheme

A performance classification scheme was introduced in 2011, (Daraktchieva, and others, 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
less than 10%	A
greater than or equal to 10% and less than 20%	B
greater than or equal to 20% and less than 30%	C
greater than or equal to 30% and less than 40%	D
greater than or equal to 40% and less than 50%	E
greater than or equal to 50%	F

The participating laboratories are set out in Table 2.

Results and discussion

The results reported by the laboratories for the etched track and electret detectors are given in Tables 4.1 to 4.6. One of the participating laboratories was unable to analyse their exposed detectors, so the tables show the results for 30 laboratories and a total of 37 sets of detectors.

In Tables 4.1 to 4.5, 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 to 10; the reference exposures are indicated by dotted lines. The mean of all transit exposures is shown in Figure 11.

The mean and standard deviation 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 to 12f. For Figures 12a to 12e, the reference exposures are indicated by vertical dotted lines.

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 27 kBq m^{-3} h (Figure 11). Most of the reported transit exposures were below 30 kBq m^{-3} h, 13 reported transit exposures between 30 kBq m^{-3} h and 90 kBq m^{-3} h, but 8 of these were above 40 kBq m^{-3} h. This is a narrower range of results than in 2019 where 10 from a total of 28 reported transit exposures were between 30 kBq m^{-3} h and 145 kBq m^{-3} h, but of which only 2 were above 45 kBq m^{-3} h.

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.

Four 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 is a slight decrease from 2019. Approximately 41% of all sets of detectors achieved class A for at least 3 exposures, which is a decrease from 2019, see Miller (2020). For the lowest exposure measurement (144 kBq m^{-3} h), 24% of laboratories achieved class A, a decrease from 2019. For the second lowest exposure (378 kBq m^{-3} h), 46% of laboratories achieved class A, an improvement from 2019.

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, and others (2009), Hanley, and others (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 to F) is given in Figure 13.

The results for the activated charcoal detectors reported by the laboratory are given in Table 4A. In this table, the 'mean' is the mean result of 5 exposed detectors. There is no transit exposure. The standard deviation, '1 SD', is for 5 reported results. Results for % biased error, % precision error and % measurement error are also provided. The characteristics of the detectors such as material, detector holder design, detector type and material supplier are provided in Table 6A.

Conclusion

In total, 31 laboratories from 14 countries participated in the 2020 PHE intercomparison. One laboratory was unable to process their exposed detectors due to a building fire, so this report is for 30 laboratories and 38 sets of detectors from 14 countries. The detectors were 37 sets of etched track and electret detectors, plus 1 set of activated charcoal detectors. The activated charcoal detectors were exposed separately and the results are given in separate tables within this report.

A 6-band (A to F) classification scheme was used to evaluate the performance of the detectors across a range of exposures. Four laboratories achieved 5 class A ratings, a slight decrease from the 2019 intercomparison.

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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 (2020). Results of the 2019 PHE Intercomparison of Passive Radon Detectors. Chilton, PHE-CRCE-060.

Tables and figures

Table 2. Participating laboratories

Contact person	Organisation	Country
Nivaldo Carlos da Silva, Danila Carrijo S. Dias	LAPOC, CNEN	Brazil
Kremena Ivanova	NCRRP	Bulgaria
Salla Rantanen	STUK	Finland
Roselyne Ameon	ALGADE	France
Nicolas Tharaud / Frédéric Sarradin	ALGADE / DOSIRAD	France
David Delage	Pearl-SAS	France
Erik Hülber, Tímea Hülber	Radosys, Ltd.	Hungary
David Doyle	AlphaRadon Teo	Ireland
Enrico Chiaberto, Mauro Magnoni, Elena Serena	ARPA Piemonte	Italy
Dr. Massimo Guazzini / Gabriele Pratesi	ARPAT Toscana	Italy
Dr. Silvia Penzo, Dr. Fabio Alessio Vittoria	ENEA Radon Service	Italy
Dr. Massimo Moroni	Geoex srls	Italy
Leonardo Baldassarre, Oliviero Tito Sandri	L.B. Servizi per le Aziende s.r.l.	Italy
Ing. Gianluca Troiano	Niton Srl	Italy
Dr. Daniele Bonamini, Dr. Marco Zanoli, Alessandro Pontirolli	Tecnorad s.u.r.l.	Italy
Dr. Marta Rossetti	U-Series Srl	Italy
Karin Pier	Ministère de la Santé	Luxembourg
Trine Kolstad	DSA	Norway
Prof. Alcides Pereira	Laboratório de Radioatividade Natural – Universidade de Coimbra	Portugal
Mário Reis	Laboratório de Proteção e Segurança Radiológica (LPSR), IST, Lisboa	Portugal

Peter Jovanovič	ZVD Zavod za varstvo pri delu d.o.o.	Slovenia
Prof. José Díaz, Ms Vanesa Delgado	Laboratorio de Radiactividad Ambiental, Universidad de Valencia	Spain
Daniel Rábago	Laboratorio de Radiactividad Ambiental, Universidad de Cantabria (LaRUC)	Spain
Hanna Malmström	Eurofins	Sweden
Prof. Gilbert Jönsson	RADONANALYS GJAB	Sweden
Dr. Tryggve Rönnqvist	Radonova	Sweden
Kinga Zmijewska, Richard Burkett	PHE Personal Dosimetry Services	United Kingdom
Dr. J Wasikiewicz	PHE Radon Dosimetry Team	United Kingdom
Denis Henshaw, Dr. Peter Fews	TASL	United Kingdom
Julie Cowlin	Testair	United Kingdom

Table 3. Exposure parameters – etched track and electret detectors

Exposure	1	2	3	4	5
Duration (h)	21.6	93.6	207.8	22.7	409.7
Radon exposure (kBq m^{-3} h)	378	602	1640	144	2718
Uncertainty (%) at 68% CL	3.0	3.0	3.0	3.0	3.0
EER exposure (kBq m^{-3} h)	174	271	754	65	1250
Uncertainty (%) at 68% CL	7.0	7.0	7.0	7.0	7.0
F, equilibrium factor	0.46	0.45	0.46	0.45	0.46

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

Table 3A. Exposure parameters – activated charcoal detectors

Exposure	1	2	3
Duration (h)	167.5	121	72.6
Radon exposure (kBq m^{-3} h)	1215	871	494
Uncertainty (%) at 68% CL	3.0	3.0	3.0

Notes:
F was not monitored
CL is the confidence level

Table 4.1. Analysis of all reported results for etched track and electret detectors: Exposure 1, 378 kBq m^{-3} h, etched track and electret detectors

Set ID	Mean (kBq m^{-3} h)	1 SD (kBq m^{-3} h)	% biased error	% precision error	% measurement error
1-1	369.0	9.7	-2.4	2.6	3.5
1-2	364.9	8.5	-3.5	2.3	4.2
5-1	335.1	36.2	-11.3	10.8	15.7
5-2	343.4	27.0	-9.2	7.9	12.1
12-1	350.1	11.5	-7.4	3.3	8.1
13-1	324.0	15.9	-14.3	4.9	15.1
13-2	312.1	14.7	-17.4	4.7	18.1
16-1	380.2	20.1	0.6	5.3	5.3
16-2	379.6	32.6	0.4	8.6	8.6
19-1	295.0	27.7	-22.0	9.4	23.9
20-1	347.8	21.3	-8.0	6.1	10.1
21-1	346.7	20.2	-8.3	5.8	10.1
25-1	385.1	25.2	1.9	6.5	6.8
25-2	361.7	32.4	-4.3	9.0	9.9
32-1	362.6	23.7	-4.1	6.5	7.7
40-1	343.9	47.4	-9.0	13.8	16.5
45-1	436.4	49.9	15.4	11.4	19.2
49-1	410.1	21.5	8.5	5.2	10.0
62-1	404.8	17.1	7.1	4.2	8.3
81-1	422.2	36.4	11.7	8.6	14.5
141-1	366.5	5.4	-3.0	1.5	3.4
144-1	371.6	24.5	-1.7	6.6	6.8
144-2	392.0	16.7	3.7	4.3	5.6
156-1	348.6	24.8	-7.8	7.1	10.5
159-1	380.8	29.8	0.7	7.8	7.9
160-1	375.0	23.3	-0.8	6.2	6.3
163-1	375.8	115.4	-0.6	30.7	30.7
163-2	339.4	25.5	-10.2	7.5	12.7
171-1	420.8	39.8	11.3	9.5	14.8
173-1	373.2	10.2	-1.3	2.7	3.0
177-1	357.7	58.0	-5.4	16.2	17.1
178-1	292.6	9.8	-22.6	3.3	22.8
181-1	319.1	28.6	-15.6	9.0	18.0
186-1	348.3	14.9	-7.9	4.3	8.9
195-1	427.0	62.6	13.0	14.7	19.6
196-1	319.1	19.3	-15.6	6.0	16.7
197-1	334.7	26.3	-11.5	7.9	13.9

Table 4.2. Analysis of all reported results for etched track and electret detectors: Exposure 2, 602 kBq m^{-3} h, etched track and electret detectors

Set ID	Mean (kBq m^{-3} h)	1 SD (kBq m^{-3} h)	% biased error	% precision error	% measurement error
1-1	575.0	10.7	-4.5	1.9	4.9
1-2	578.0	10.5	-4.0	1.8	4.4
5-1	565.2	19.8	-6.1	3.5	7.0
5-2	563.0	19.9	-6.5	3.5	7.4
12-1	551.9	19.7	-8.3	3.6	9.1
13-1	503.4	17.1	-16.4	3.4	16.7
13-2	474.1	17.1	-21.2	3.6	21.5
16-1	565.6	32.9	-6.0	5.8	8.4
16-2	614.1	45.9	2.0	7.5	7.7
19-1	483.1	24.0	-19.8	5.0	20.4
20-1	559.4	13.3	-7.1	2.4	7.5
21-1	542.2	41.3	-9.9	7.6	12.5
25-1	566.4	56.5	-5.9	10.0	11.6
25-2	553.4	72.5	-8.1	13.1	15.4
32-1	553.6	49.0	-8.0	8.9	12.0
40-1	558.0	96.4	-7.3	17.3	18.8
45-1	715.8	76.1	18.9	10.6	21.7
49-1	657.8	40.2	9.3	6.1	11.1
62-1	624.0	25.4	3.7	4.1	5.5
81-1	622.6	16.4	3.4	2.6	4.3
141-1	575.0	12.6	-4.5	2.2	5.0
144-1	587.0	37.7	-2.5	6.4	6.9
144-2	624.8	21.1	3.8	3.4	5.1
156-1	533.0	33.9	-11.5	6.4	13.1
159-1	631.9	70.8	5.0	11.2	12.3
160-1	592.4	26.8	-1.6	4.5	4.8
163-1	555.4	30.9	-7.7	5.6	9.5
163-2	538.2	19.0	-10.6	3.5	11.2
171-1	693.1	55.6	15.1	8.0	17.1
173-1	596.7	15.3	-0.9	2.6	2.7
177-1	536.1	23.8	-10.9	4.4	11.8
178-1	541.1	7.6	-10.1	1.4	10.2
181-1	467.3	34.8	-22.4	7.4	23.6
186-1	546.8	21.6	-9.2	4.0	10.0
195-1	705.3	59.4	17.2	8.4	19.1
196-1	531.5	29.8	-11.7	5.6	13.0
197-1	515.3	22.9	-14.4	4.4	15.1

Table 4.3. Analysis of all reported results for etched track and electret detectors: Exposure 3, 1640 kBq m^{-3} h, etched track and electret detectors

Set ID	Mean (kBq m^{-3} h)	1 SD (kBq m^{-3} h)	% biased error	% precision error	% measurement error
1-1	1499.3	30.1	-8.6	2.0	8.8
1-2	1469.4	20.0	-10.4	1.4	10.5
5-1	1354.1	150.6	-17.4	11.1	20.7
5-2	1426.8	79.7	-13.0	5.6	14.1
12-1	1439.1	34.0	-12.3	2.4	12.5
13-1	1315.6	26.4	-19.8	2.0	19.9
13-2	1253.7	41.1	-23.6	3.3	23.8
16-1	1465.0	40.5	-10.7	2.8	11.0
16-2	1491.1	65.3	-9.1	4.4	10.1
19-1	1202.3	62.2	-26.7	5.2	27.2
20-1	1422.6	46.3	-13.3	3.3	13.6
21-1	1395.3	102.8	-14.9	7.4	16.6
25-1	1597.6	107.9	-2.6	6.8	7.2
25-2	1381.8	144.8	-15.7	10.5	18.9
32-1	1389.5	59.9	-15.3	4.3	15.9
40-1	1459.6	261.0	-11.0	17.9	21.0
45-1	1715.2	151.6	4.6	8.8	10.0
49-1	1539.7	63.4	-6.1	4.1	7.4
62-1	1692.2	46.2	3.2	2.7	4.2
81-1	1565.6	80.9	-4.5	5.2	6.9
141-1	1492.3	13.7	-9.0	0.9	9.1
144-1	1492.5	47.6	-9.0	3.2	9.5
144-2	1569.0	33.9	-4.3	2.2	4.8
156-1	1350.2	56.4	-17.7	4.2	18.2
159-1	1738.0	93.7	6.0	5.4	8.0
160-1	1550.8	46.4	-5.4	3.0	6.2
163-1	1377.5	54.0	-16.0	3.9	16.5
163-2	1348.8	26.2	-17.8	1.9	17.9
171-1	1601.7	190.1	-2.3	11.9	12.1
173-1	1541.3	56.0	-6.0	3.6	7.0
177-1	1355.7	67.3	-17.3	5.0	18.0
178-1	1501.9	15.7	-8.4	1.0	8.5
181-1	1247.4	81.5	-23.9	6.5	24.8
186-1	1423.0	56.1	-13.2	3.9	13.8
195-1	1852.8	162.2	13.0	8.8	15.7
196-1	1347.6	39.4	-17.8	2.9	18.1
197-1	1391.0	50.8	-15.2	3.7	15.6

Table 4.4. Analysis of all reported results for etched track and electret detectors: Exposure 4, 144 kBq m^{-3} h, etched track and electret detectors

Set ID	Mean (kBq m^{-3} h)	1 SD (kBq m^{-3} h)	% biased error	% precision error	% measurement error
1-1	142.1	5.5	-1.3	3.9	4.1
1-2	144.3	3.6	0.2	2.5	2.5
5-1	133.8	16.9	-7.1	12.6	14.5
5-2	143.7	25.5	-0.2	17.7	17.7
12-1	126.1	7.8	-12.4	6.2	13.9
13-1	123.9	7.4	-14.0	6.0	15.2
13-2	123.6	11.5	-14.2	9.3	16.9
16-1	158.0	13.8	9.7	8.7	13.1
16-2	163.3	31.0	13.4	19.0	23.2
19-1	118.1	17.3	-18.0	14.6	23.2
20-1	144.3	9.8	0.2	6.8	6.8
21-1	140.7	15.5	-2.3	11.0	11.3
25-1	131.6	13.9	-8.6	10.6	13.6
25-2	123.5	13.9	-14.2	11.3	18.1
32-1	145.3	8.6	0.9	5.9	6.0
40-1	136.9	21.6	-4.9	15.8	16.5
45-1	179.6	26.2	24.7	14.6	28.7
49-1	173.7	34.5	20.6	19.9	28.6
62-1	153.0	15.2	6.3	9.9	11.7
81-1	156.0	12.4	8.3	7.9	11.5
141-1	137.7	4.1	-4.4	3.0	5.3
144-1	154.1	15.3	7.0	9.9	12.2
144-2	153.8	4.7	6.8	3.1	7.5
156-1	178.9	72.5	24.2	40.5	47.2
159-1	155.4	24.8	7.9	16.0	17.8
160-1	145.5	16.7	1.0	11.5	11.5
163-1	122.0	34.5	-15.3	28.3	32.1
163-2	114.0	25.4	-20.8	22.3	30.5
171-1	181.8	20.3	26.3	11.2	28.5
173-1	134.8	4.0	-6.4	3.0	7.0
177-1	138.9	11.2	-3.5	8.1	8.8
178-1	111.2	3.5	-22.8	3.1	23.0
181-1	138.1	16.8	-4.1	12.2	12.8
186-1	137.9	5.8	-4.2	4.2	6.0
195-1	186.8	53.7	29.7	28.7	41.3
196-1	135.6	12.4	-5.8	9.1	10.8
197-1	134.5	15.3	-6.6	11.4	13.2

Table 4.5. Analysis of all reported results for etched track and electret detectors: Exposure 5, 2718 kBq m^{-3} h, etched track and electret detectors

Set ID	Mean (kBq m^{-3} h)	1 SD (kBq m^{-3} h)	% biased error	% precision error	% measurement error
1-1	2632.8	43.7	-3.1	1.7	3.5
1-2	2576.4	34.9	-5.2	1.4	5.4
5-1	2506.6	91.9	-7.8	3.7	8.6
5-2	2509.1	73.9	-7.7	2.9	8.2
12-1	2548.9	47.4	-6.2	1.9	6.5
13-1	2268.2	66.2	-16.5	2.9	16.8
13-2	2179.2	25.8	-19.8	1.2	19.9
16-1	2637.1	58.3	-3.0	2.2	3.7
16-2	2769.9	285.4	1.9	10.3	10.5
19-1	2088.6	61.2	-23.2	2.9	23.3
20-1	2514.6	67.1	-7.5	2.7	7.9
21-1	2392.7	53.5	-12.0	2.2	12.2
25-1	3101.9	207.9	14.1	6.7	15.6
25-2	2504.9	96.8	-7.8	3.9	8.7
32-1	2601.2	105.9	-4.3	4.1	5.9
40-1	2614.0	339.2	-3.8	13.0	13.5
45-1	2990.2	282.5	10.0	9.4	13.8
49-1	2585.9	146.4	-4.9	5.7	7.5
62-1	2827.5	87.2	4.0	3.1	5.1
81-1	2879.8	214.5	6.0	7.4	9.5
141-1	2582.7	28.4	-5.0	1.1	5.1
144-1	2545.2	60.6	-6.4	2.4	6.8
144-2	2755.2	62.4	1.4	2.3	2.6
156-1	2381.6	58.3	-12.4	2.4	12.6
159-1	3425.5	126.8	26.0	3.7	26.3
160-1	2797.0	77.0	2.9	2.8	4.0
163-1	2262.8	56.3	-16.7	2.5	16.9
163-2	2279.3	56.6	-16.1	2.5	16.3
171-1	3161.0	130.8	16.3	4.1	16.8
173-1	2755.5	69.1	1.4	2.5	2.9
177-1	2370.8	51.7	-12.8	2.2	13.0
178-1	2669.3	28.2	-1.8	1.1	2.1
181-1	2236.2	92.8	-17.7	4.1	18.2
186-1	2501.8	52.4	-8.0	2.1	8.2
195-1	3202.6	176.2	17.8	5.5	18.7
196-1	2418.4	30.1	-11.0	1.2	11.1
197-1	2385.5	79.4	-12.2	3.3	12.7

Table 4.6. Analysis of all reported results for etched track and electret detectors: Transit exposure, etched track and electret detectors

Set ID	Mean (kBq m^{-3} h)	1 SD (kBq m^{-3} h)
1-1	4.1	3.0
1-2	2.1	2.2
5-1	28.3	11.5
5-2	21.9	13.1
12-1	33.6	8.2
13-1	6.7	3.0
13-2	9.3	2.7
16-1	15.2	7.0
16-2	20.2	7.7
19-1	38.8	13.4
20-1	1.2	2.6
21-1	17.1	4.7
25-1	9.5	3.8
25-2	22.5	12.6
32-1	21.4	5.1
40-1	14.0	5.0
45-1	68.5	9.3
49-1	28.9	7.7
62-1	17.2	1.8
81-1	43.4	13.5
141-1	25.5	5.4
144-1	12.5	6.2
144-2	41.0	8.9
156-1	47.3	22.7
159-1	9.9	8.0
160-1	89.1	10.9
163-1	74.9	60.8
163-2	87.1	28.9
171-1	31.5	7.8
173-1	1.0	0.7
177-1	2.9	1.6
178-1	4.6	1.0
181-1	36.3	5.9
186-1	9.7	4.8
195-1	44.1	27.6
196-1	6.7	5.7
197-1	34.2	13.0

Table 4A. Analysis of all reported results for activated charcoal detectors: Set ID 49-2, activated charcoal detectors

	Exposure ($kBq\ m^{-3}\ h$)	Mean ($kBq\ m^{-3}\ h$)	1 SD ($kBq\ m^{-3}\ h$)	% biased error	% precision error	% measurement error
1	1215	1085.0	37.2	-10.7	3.4	11.2
2	871	854.4	39.6	-1.9	4.6	5.0
3	494	435.8	5.3	-11.8	1.2	11.9

Table 5. Statistical analysis of all reported results given in Tables 4.1 to 4.5

	Exposure	Mean of all reported results ($kBq\ m^{-3}\ h$)	Standard deviation of all reported results ($kBq\ m^{-3}\ h$)
1	378 $kBq\ m^{-3}\ h$	362.6	35.2
2	602 $kBq\ m^{-3}\ h$	572.9	58.1
3	1640 $kBq\ m^{-3}\ h$	1466.4	139.9
4	144 $kBq\ m^{-3}\ h$	143.9	19.1
5	2718 $kBq\ m^{-3}\ h$	2607.0	297.4

Table 6. Performance classification scheme based on measurement error

	Performance classification in each exposure									
	Exposure 4	Exposure 1	Exposure 2	Exposure 3	Exposure 5					
Set ID	144 kBq m^{-3} h	378 kBq m^{-3} h	602 kBq m^{-3} h	1640 kBq m^{-3} h	2718 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)
141-1	A	A	A	A	A	Closed	No	Radosure	Tastrak	TASL
144-2	A	A	A	A	A	Closed – Electrect	Yes	S-Chamber Long term Electret	Teflon	Rad Elec
173-1	A	A	A	A	A	Closed – Radonalpha-C	Yes	TASL	CR-39	TASL
1-2	A	A	A	B	A	Closed		NRPB	CR-39	GM Scientific
62-1	B	A	A	A	A	Closed – alpha track	No	STUK (Sensitive volume 79mL)	Makrofol	Covestro
144-1	B	A	A	A	A	Closed – SSNTD	Yes	RSKS Radosys chamber	CR-39	Radosys Ltd.
160-1	B	A	A	A	A	Closed	No		CR-39	TASL

	Performance classification in each exposure									
	Exposure 4	Exposure 1	Exposure 2	Exposure 3	Exposure 5					
Set ID	**144 kBq m^{-3} h**	**378 kBq m^{-3} h**	**602 kBq m^{-3} h**	**1640 kBq m^{-3} h**	**2718 kBq m^{-3} h**	**Detector type**	**Filter**	**Holder**	**Detector material**	**Detector material supplier**
186-1	A	A	A	B	A	Closed	No	TASL	Tastrak PADC/ CR-39	TASL
12-1	B	A	A	B	A	Closed	Yes	Eurofins	CR-39	GM Scientific
16-1	B	A	A	B	A	Closed – RSK	'gap filter'	cylindrical	CR-39	Radosys Ltd.
20-1	A	B	A	B	A	Closed	No	ASL	PADC	TASL
32-1	A	A	B	B	A	Closed	No	NRPB/SSI	CR	TASL
81-1	B	B	A	A	A	Closed – Electret	No	S-Chamber Long term Electret	Teflon	Rad Elec
49-1	C	A	B	A	A	Closed – Electret	No	Radosys	CR-39	Radosys Hungary
5-2	B	B	A	B	A	Closed – SSNTD	Yes	TASL	CR-39	TASL
25-1	B	A	B	A	B	Open – Kodalpha	No	Algade	LR115	Algade

	Performance classification in each exposure									
	Exposure 4	Exposure 1	Exposure 2	Exposure 3	Exposure 5					
Set ID	144 kBq m^{-3} h	378 kBq m^{-3} h	602 kBq m^{-3} h	1640 kBq m^{-3} h	2718 kBq m^{-3} h	Detector type	Filter	Holder	Detector material	Detector material supplier
25-2	B	A	B	B	A	Closed – DPR	No	Algade	LR115	Algade
5-1	B	B	A	C	A	Closed – SSNTD	Yes	TASL	CR-39	TASL
16-2	C	A	A	B	B	Closed – RSXA	'gap filter'	Pentagonal	CR-39	Radosys Ltd.
159-1	B	A	B	A	C	Closed		Radosys	CR-39	Radosys
178-1	C	C	B	A	A	Closed	No	TASL	CR-39	TASL
177-1	A	B	B	B	B	Closed	No	TASL	CR-39	TASL
45-1	C	B	C	A	B	Closed	Yes	DPR3	LR115	Algade
163-1	D	D	A	B	B	Closed – SSNTD	No	Cylinder	CR-39	Grilon TSC-10/4 EC
13-1	B	B	B	B	B	Closed – Radtrak2	Yes	NRPB/SSI	CR-39	RTP Company
21-1	B	B	B	B	B	Closed – SSNTD	No	ENEA	CR-39	TASL
196-1 (1)	B	B	B	B	B	Closed	No	Radout (Miam Italy)	CR-39	GM Scientific

	Performance classification in each exposure									
	Exposure 4	Exposure 1	Exposure 2	Exposure 3	Exposure 5					
Set ID	**144 kBq m^{-3} h**	**378 kBq m^{-3} h**	**602 kBq m^{-3} h**	**1640 kBq m^{-3} h**	**2718 kBq m^{-3} h**	**Detector type**	**Filter**	**Holder**	**Detector material**	**Detector material supplier**
197-1	B	B	B	B	B	Closed – SSNTD	Yes	RSKS	CR-39	Radosys
40-1	B	B	B	C	B	Closed – SSNTD	No	NRPB – yellow	PADC	MiNet Technology Ltd. (Instrument Plastics)
171-1	C	B	B	B	B	Closed – LR115	Yes	Radonanalys	LR115	Radonanalys
163-2	D	B	B	B	B	Closed – Electret	No	S-Chamber Long term Electret		
156-1	E	B	B	B	B	Closed – DSTN	No		PADC/ CR-39	Radosys (Hungary)
195-1	E	B	B	B	B	Closed	Yes	ANPA (Italian holder design)	LR115	Dosirad
13-2	B	B	C	C	B	Closed – Radtrak3	Yes	Radtrak3	CR-39	RTP Company

	Performance classification in each exposure									
	Exposure 4	Exposure 1	Exposure 2	Exposure 3	Exposure 5					
Set ID	**144 kBq m^{-3} h**	**378 kBq m^{-3} h**	**602 kBq m^{-3} h**	**1640 kBq m^{-3} h**	**2718 kBq m^{-3} h**	**Detector type**	**Filter**	**Holder**	**Detector material**	**Detector material supplier**
181-1	B	B	C	C	B	Closed – RSKS	Yes	Radosys Ltd. Hungary	PADC/ CR-39	Radosys Ltd. Hungary
19-1	C	C	C	C	C	Closed – SSNTD	Yes	Radout	CR-39	GM

Notes to Table 6 above: (1) Set ID 196-1 – an error by PHE resulted in one of the transit detectors being exposed – this detector result was excluded when calculating the mean transit value.

Table 6A. Performance classification scheme based on measurement error

Performance classification in each exposure								
	Exposure 3	Exposure 2	Exposure 1					
	494 kBq m^{-3} h	871 kBq m^{-3} h	1215 kBq m^{-3} h	Detector type	Filter	Holder	Detector material	Detector material supplier
49-2	B	A	B	Charcoal Adsorber	No	Metal cylinder	Charcoal	

Text alternatives for graphs can be found on the Results of the 2020 intercomparison of passive radon detectors webpage.

Figure 1. Radon and EER concentrations for exposure 1

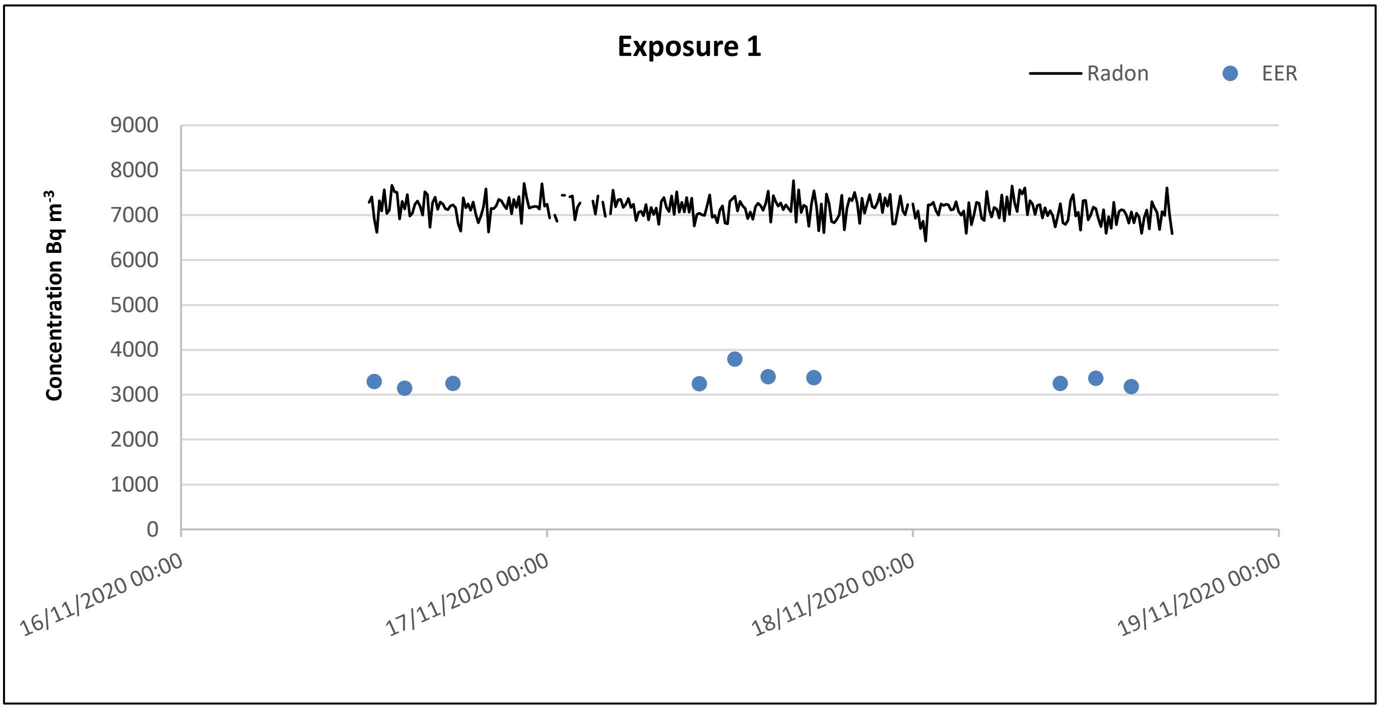


Figure 2. Radon and EER concentrations for exposure 2

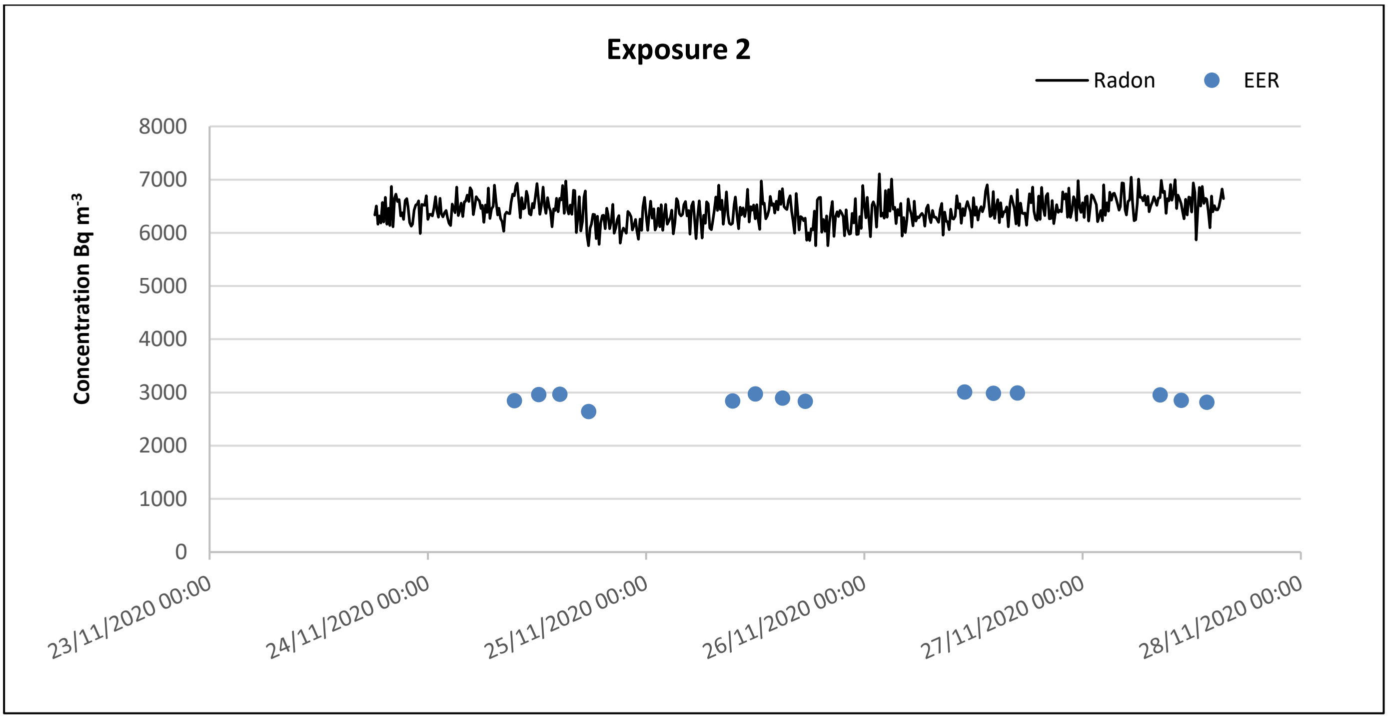


Figure 3. Radon and EER concentrations for exposure 3

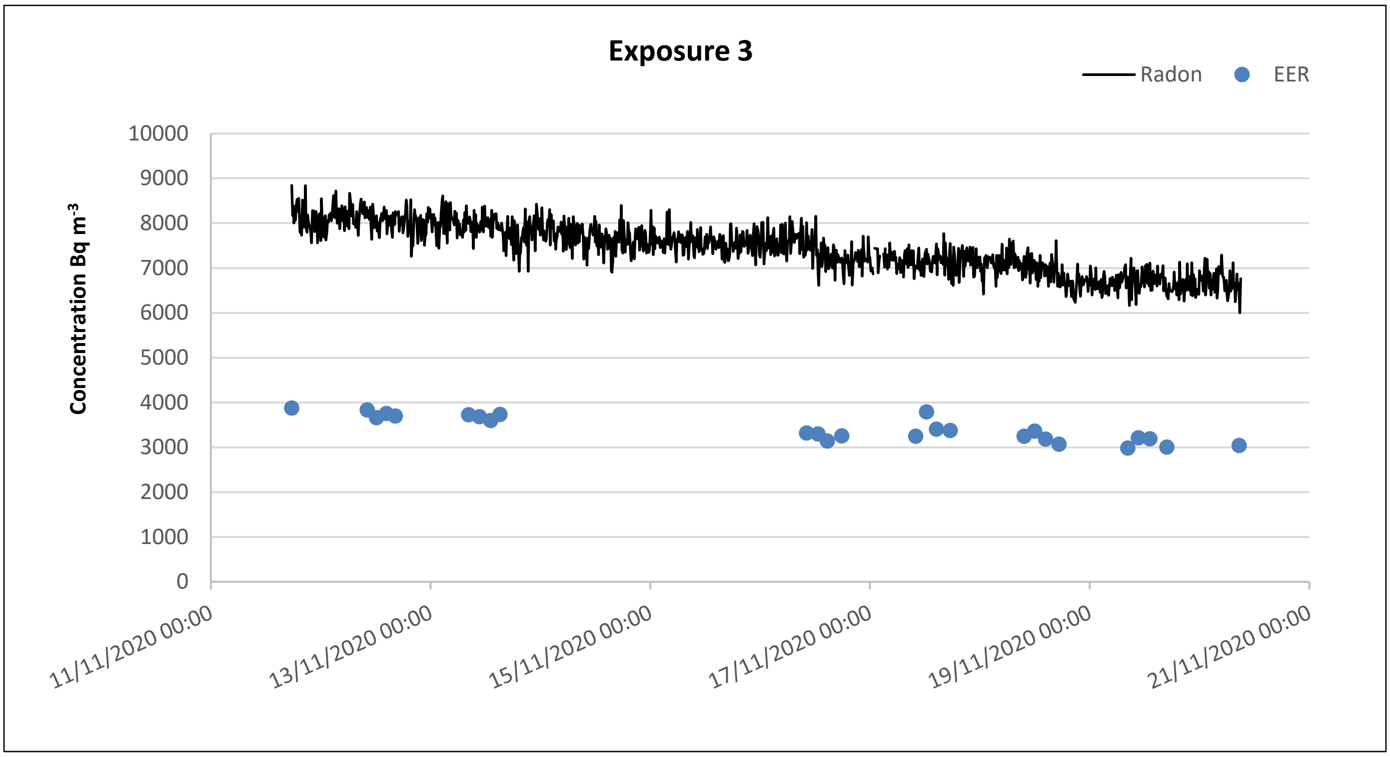


Figure 4. Radon and EER concentrations for exposure 4

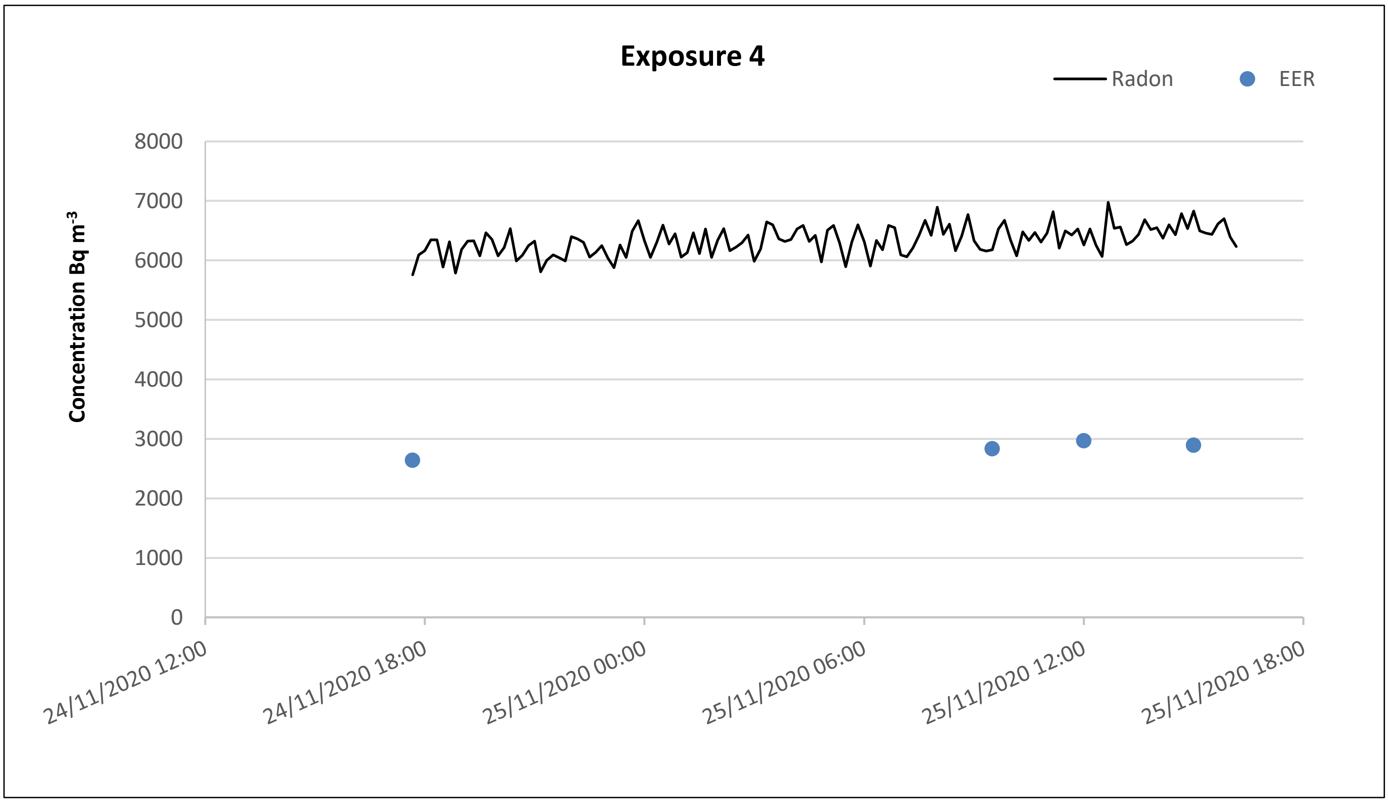


Figure 5. Radon and EER concentrations for exposure 5

The radon level was increased in order to shorten the duration of the exposure.

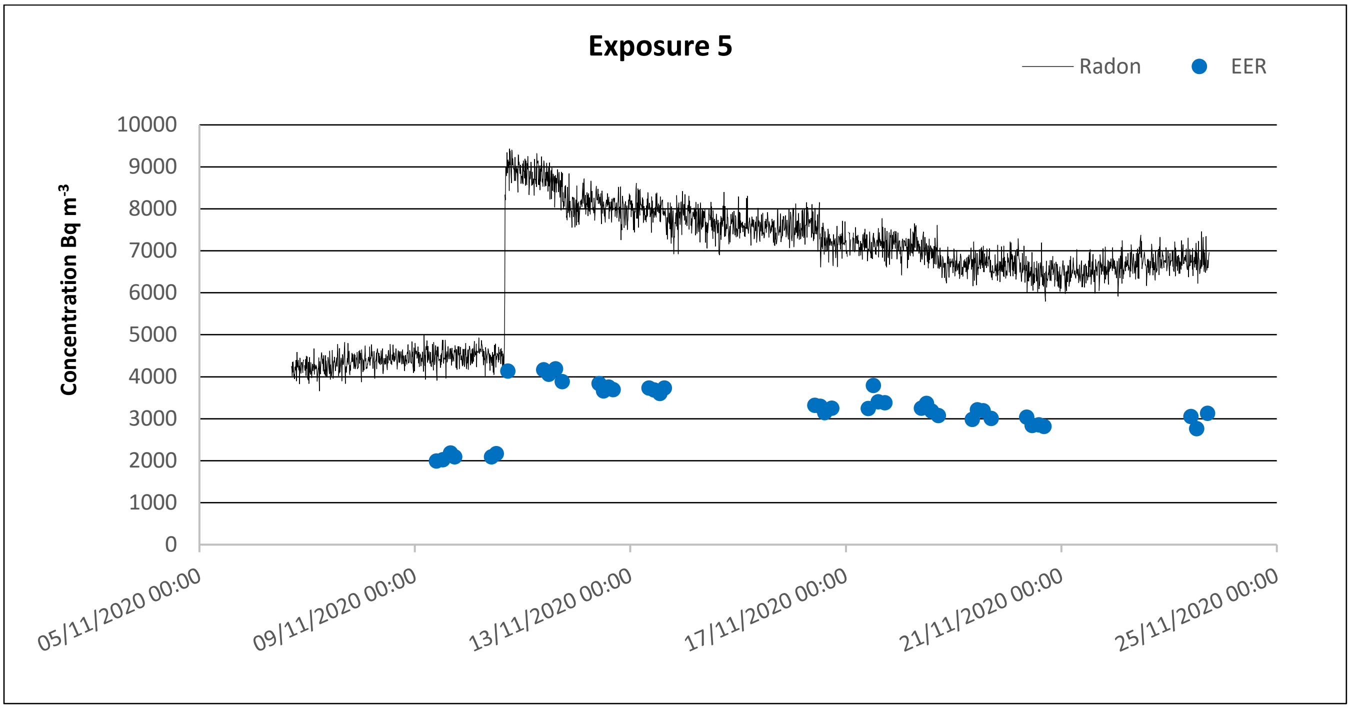


Figure 6. Results as reported by participants and given in Table 4.1, for exposure 1

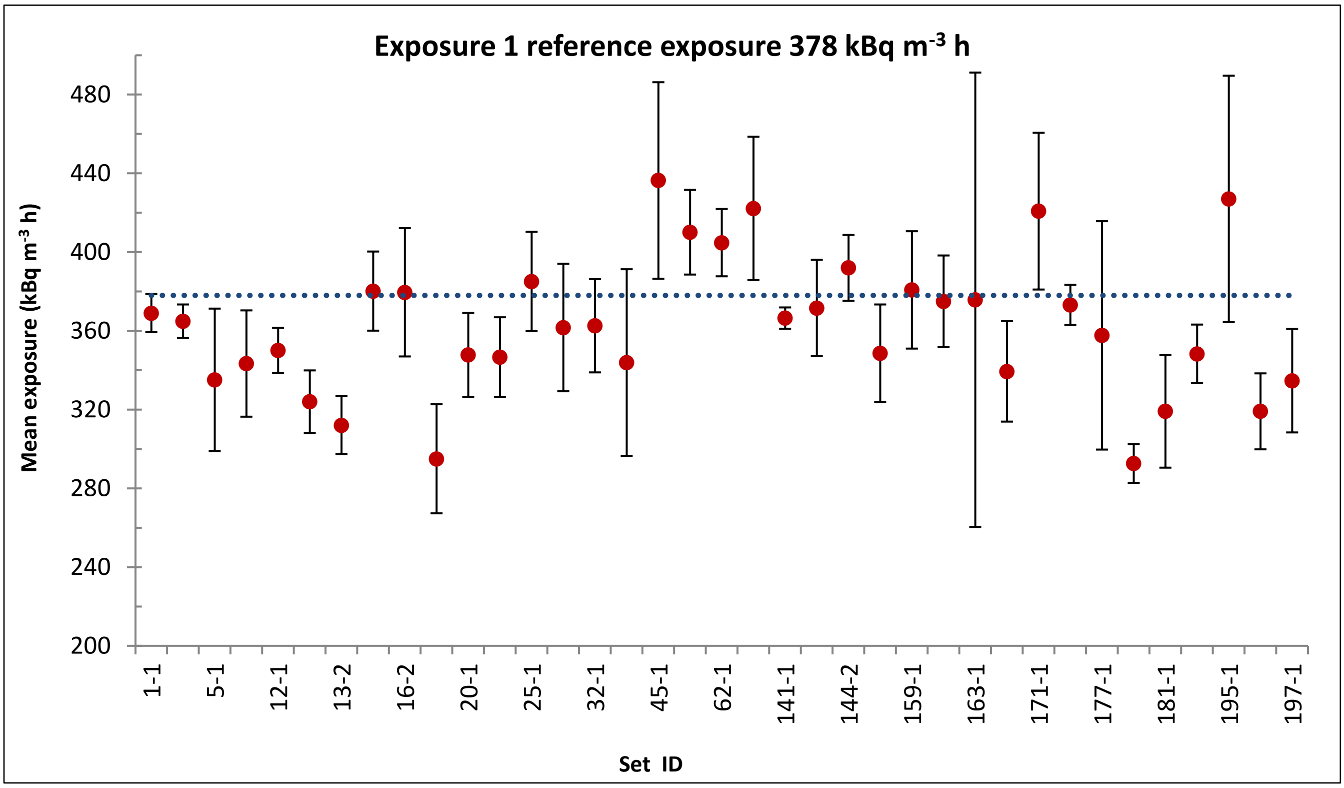


Figure 7. Results as reported by participants and given in Table 4.2, for exposure 2

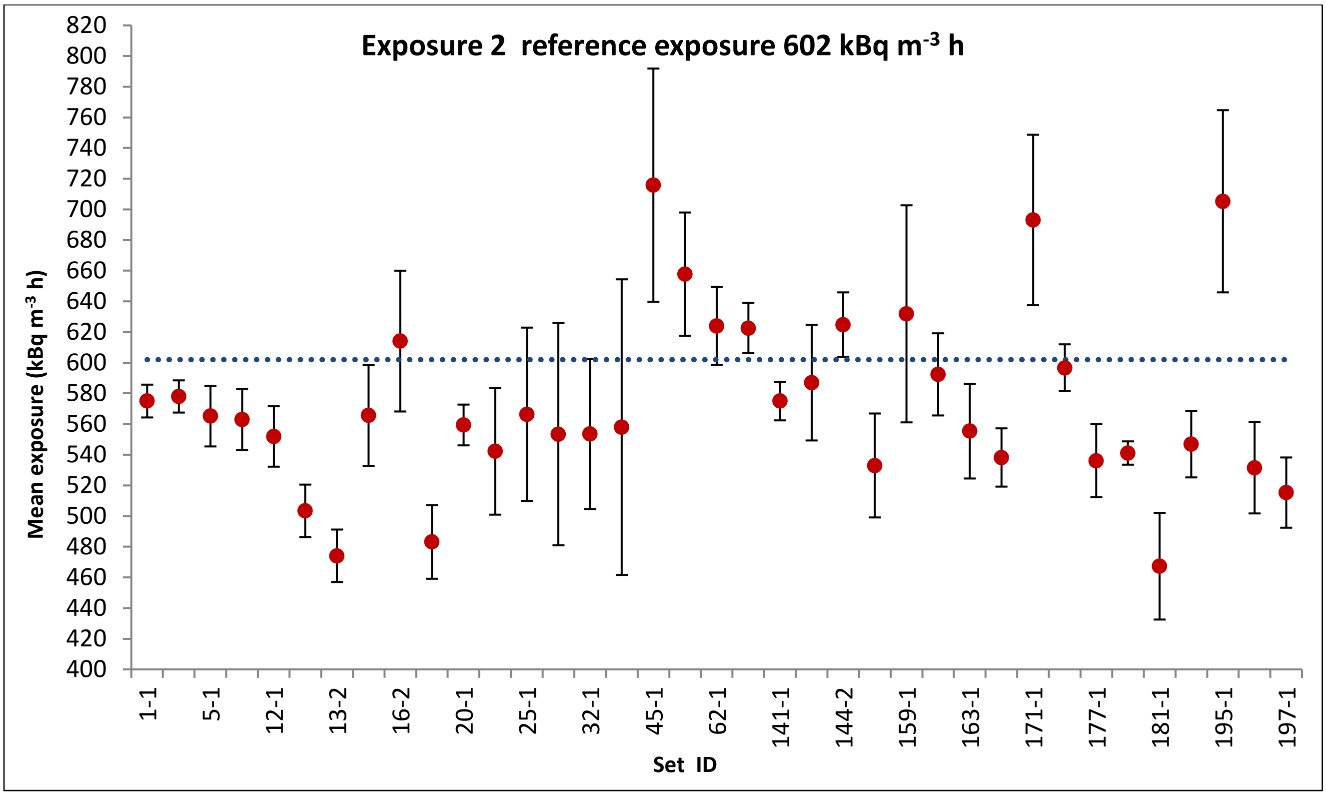


Figure 8. Results as reported by participants and given in Table 4.3, for exposure 3

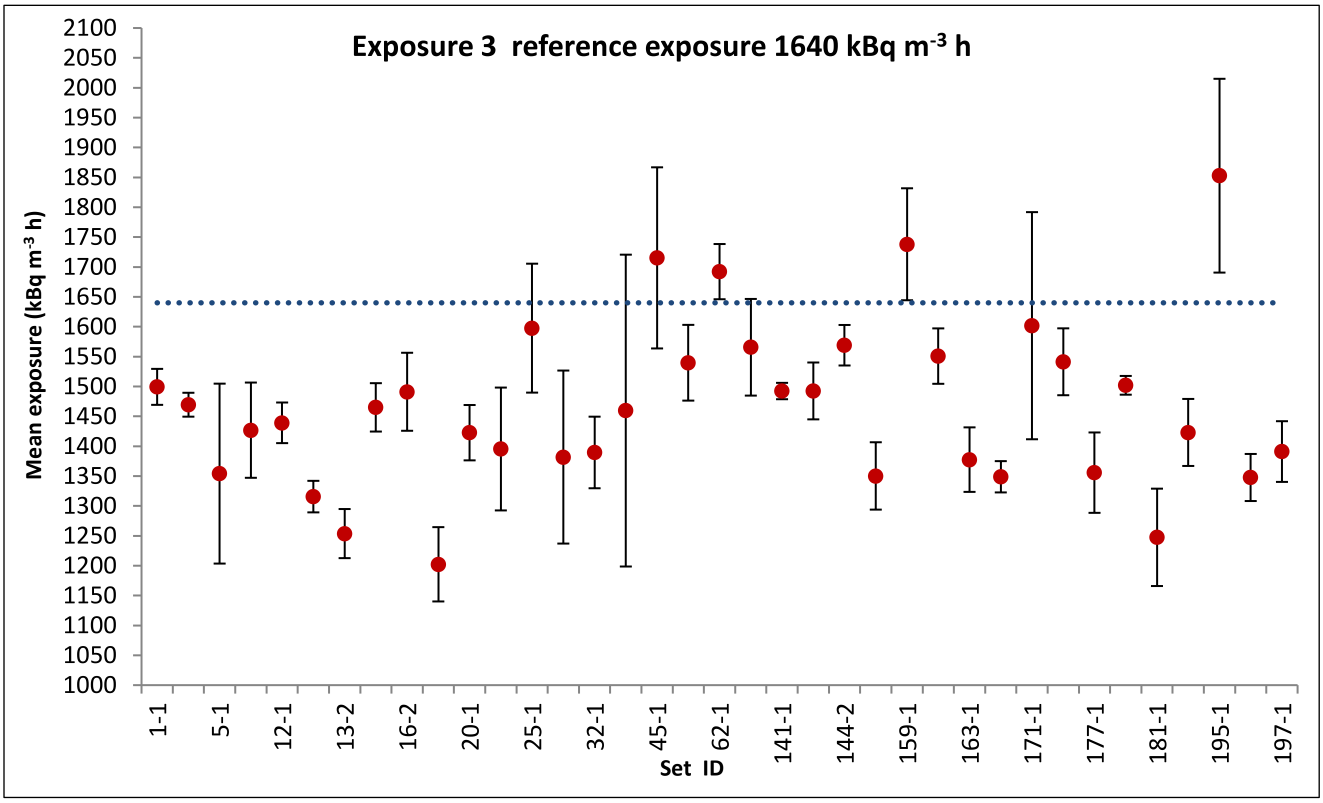


Figure 9. Results as reported by participants and given in Table 4.4, for exposure 4

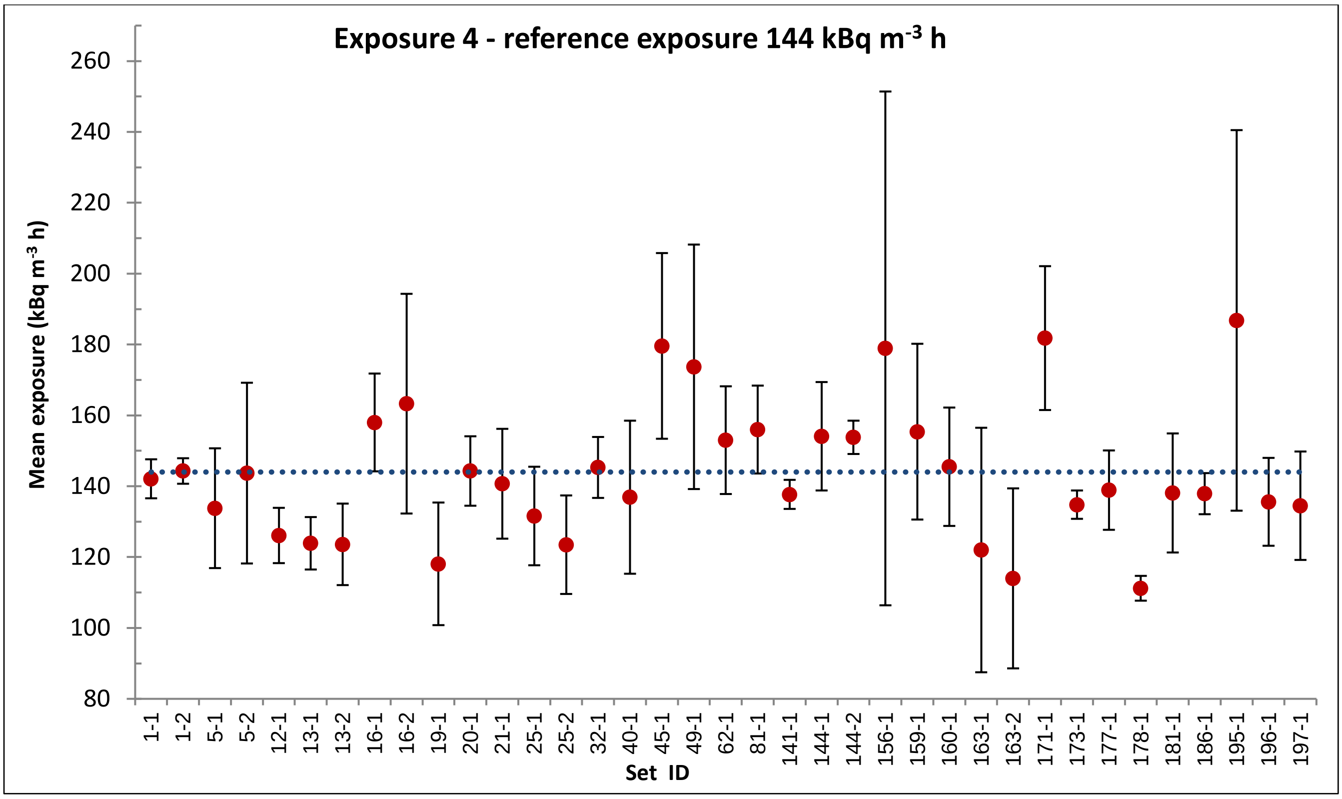


Figure 10. Results as reported by participants and given in Table 4.5, for exposure 5

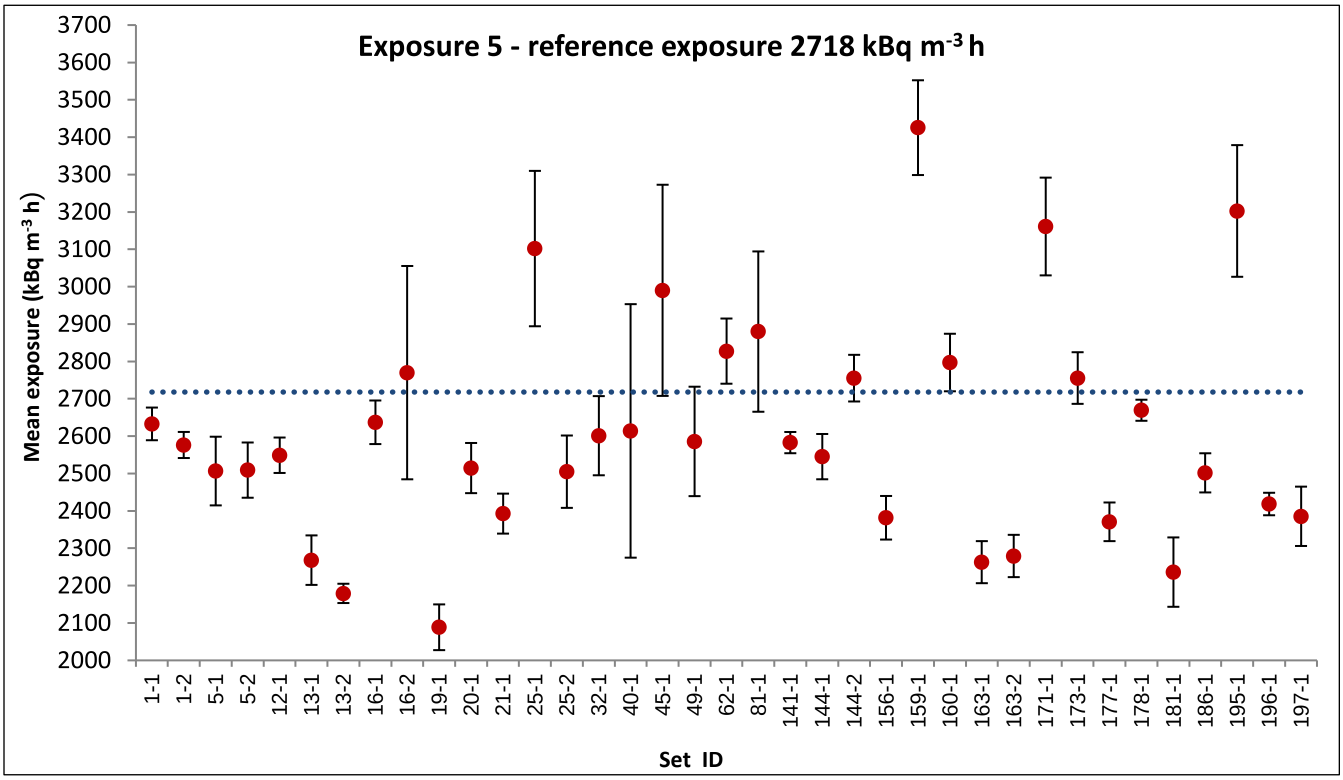


Figure 11. Results as reported by participants and given in Table 4.6, for transit exposure

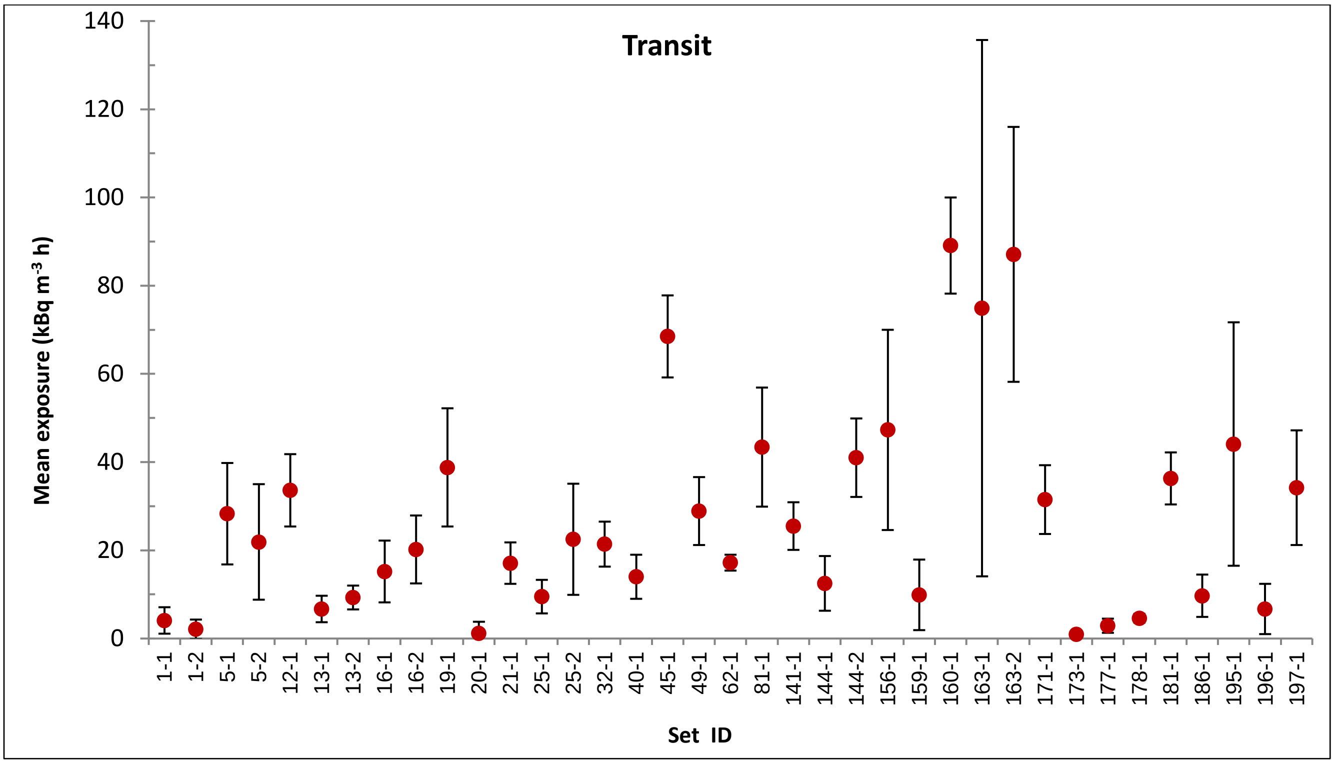


Figure 12a. Distribution of mean exposure results given in Table 5 – exposure 1

The vertical dotted line indicates the reference exposure.

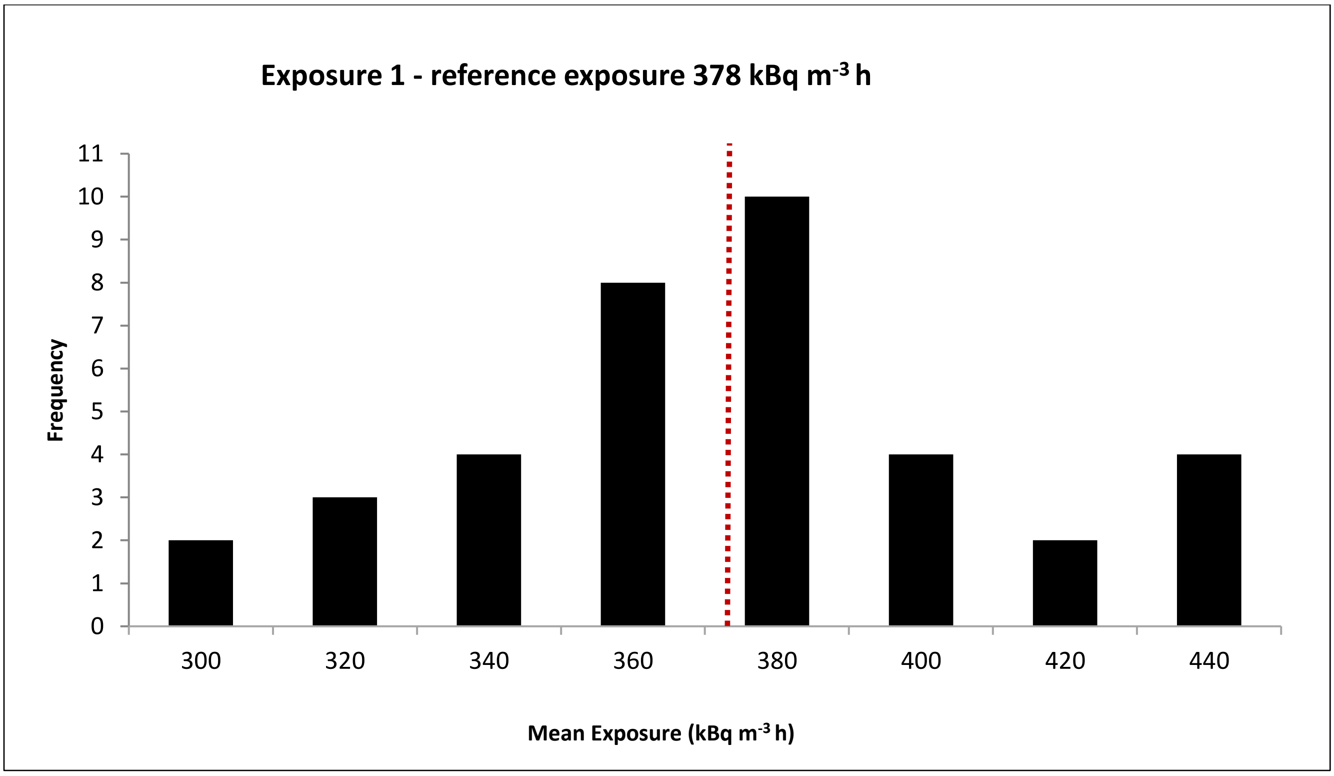


Figure 12b. Distribution of mean exposure results given in Table 5 – exposure 2

The vertical dotted line indicates the reference exposure.

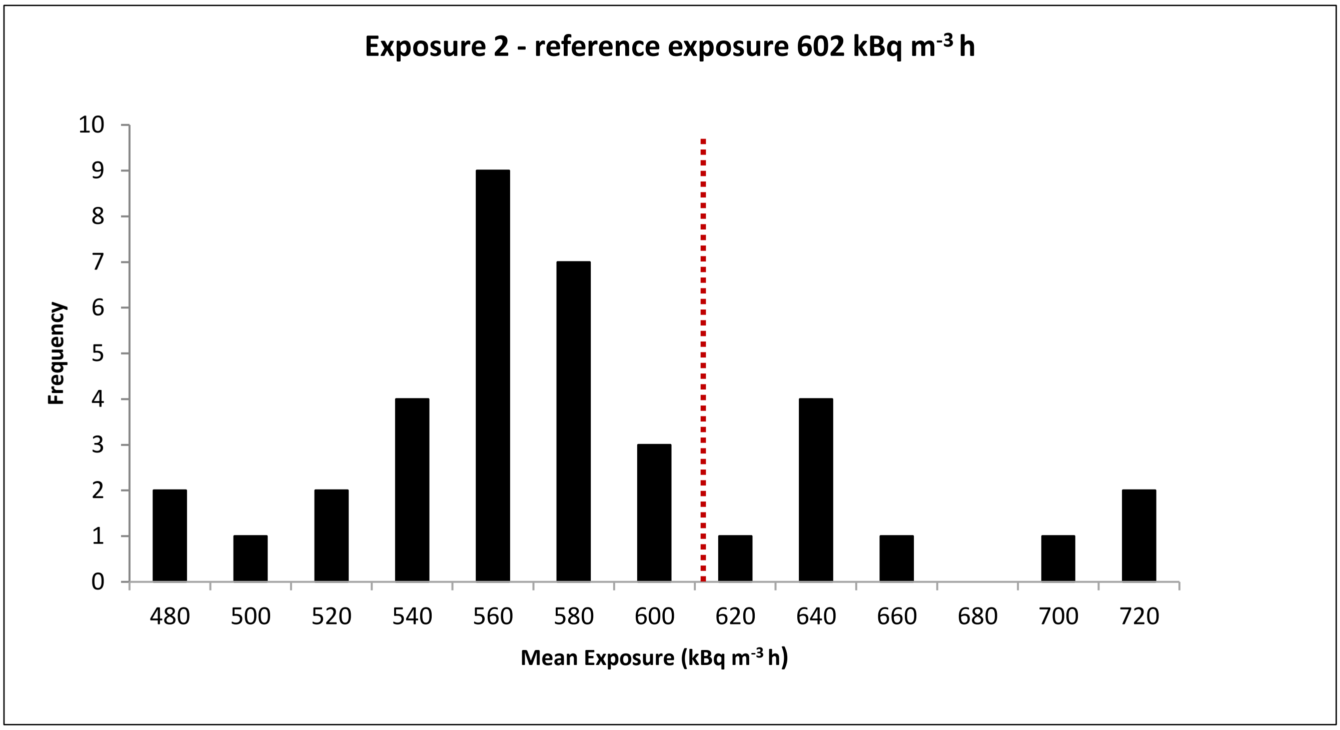


Figure 12c. Distribution of mean exposure results given in Table 5 – exposure 3

The vertical dotted line indicates the reference exposure.

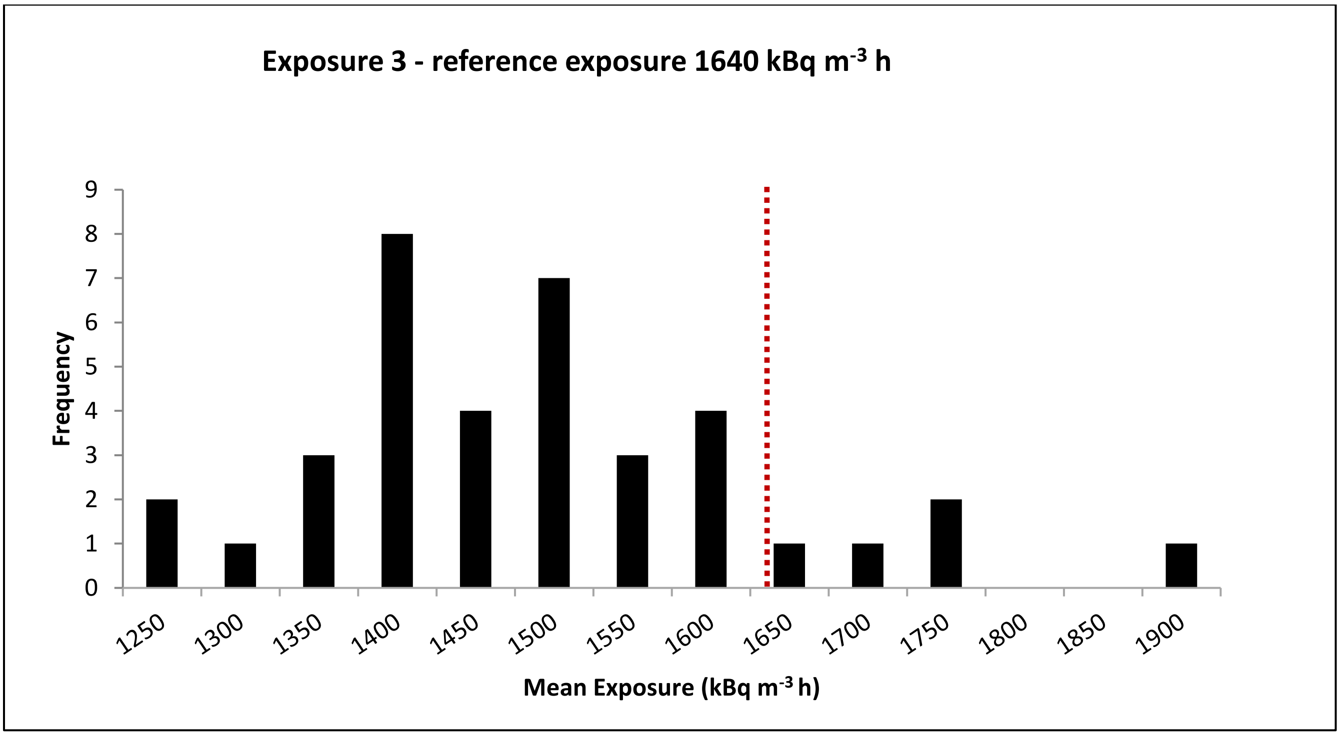


Figure 12d. Distribution of mean exposure results given in Table 5 – exposure 4.

The vertical dotted line indicates the reference exposure.

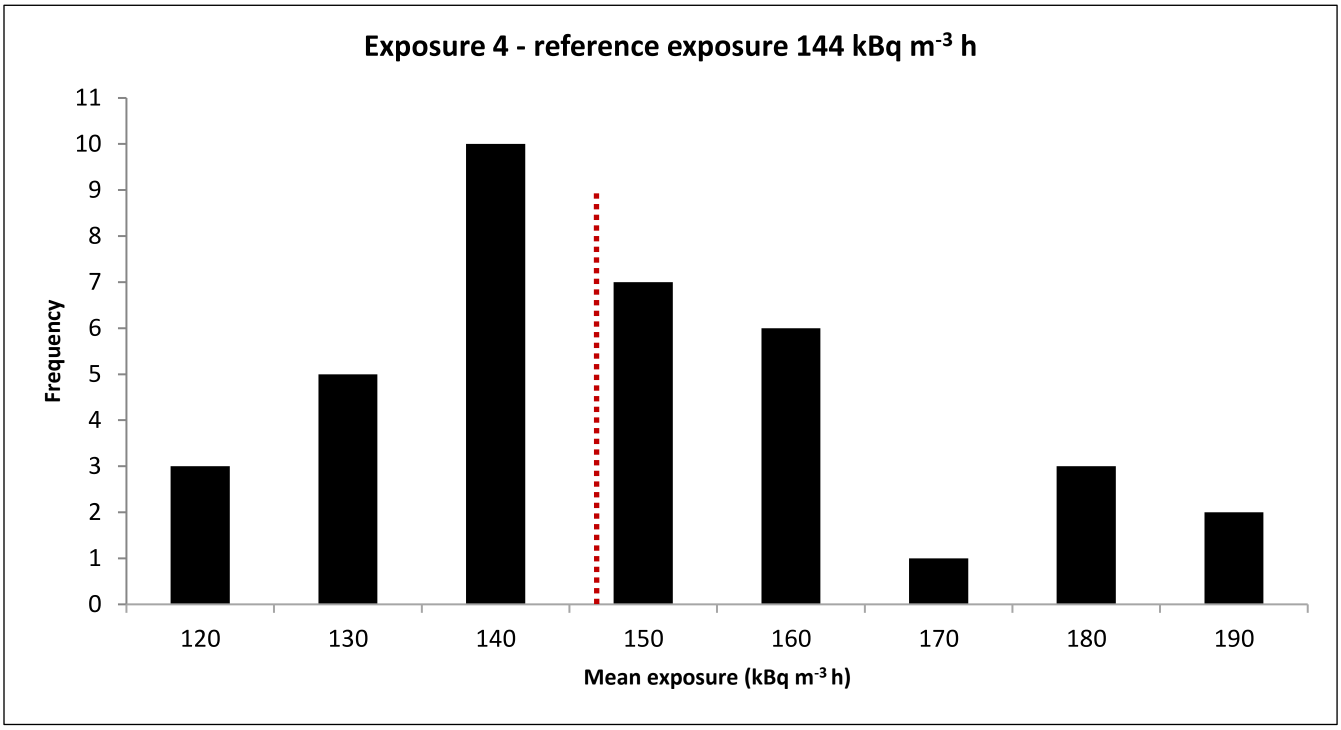


Figure 12e. Distribution of mean exposure results given in Table 5 – exposure 5

The vertical dotted line indicates the reference exposure.

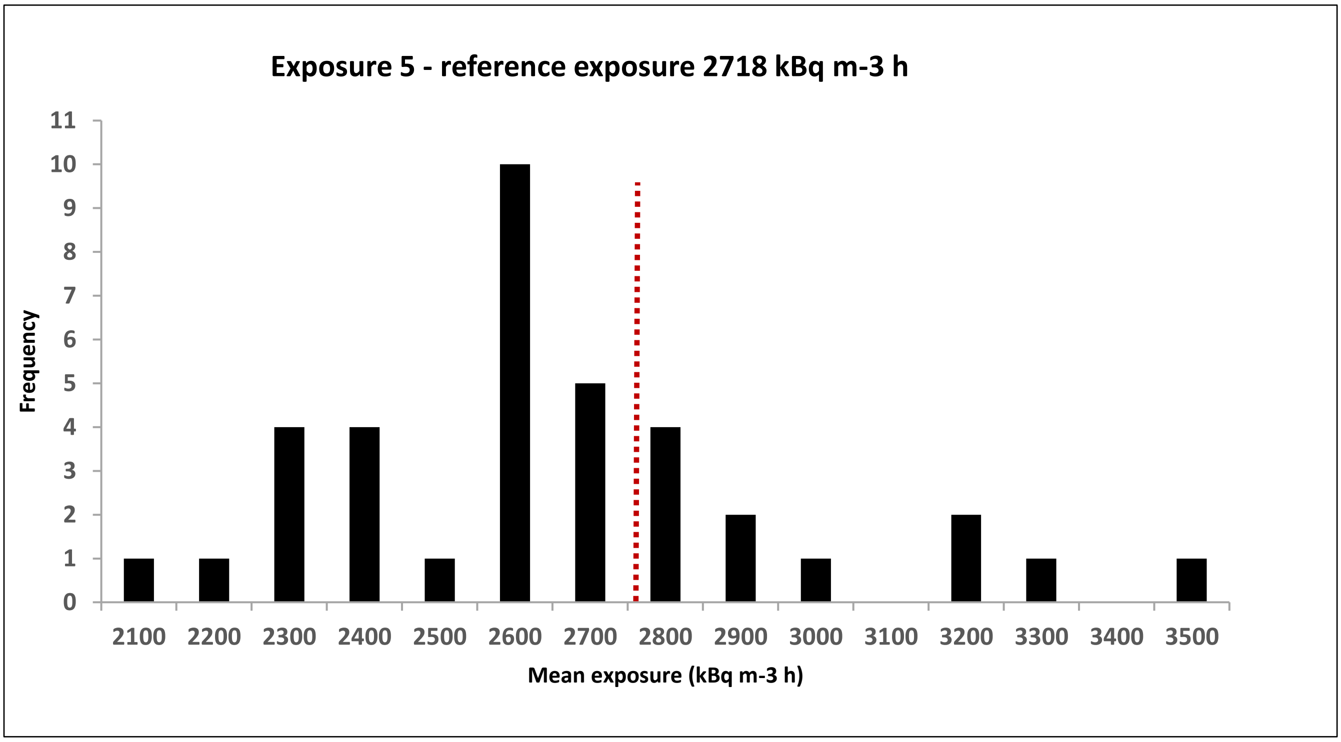


Figure 12f. Distribution of mean exposure results given in Table 5 – Transit exposure

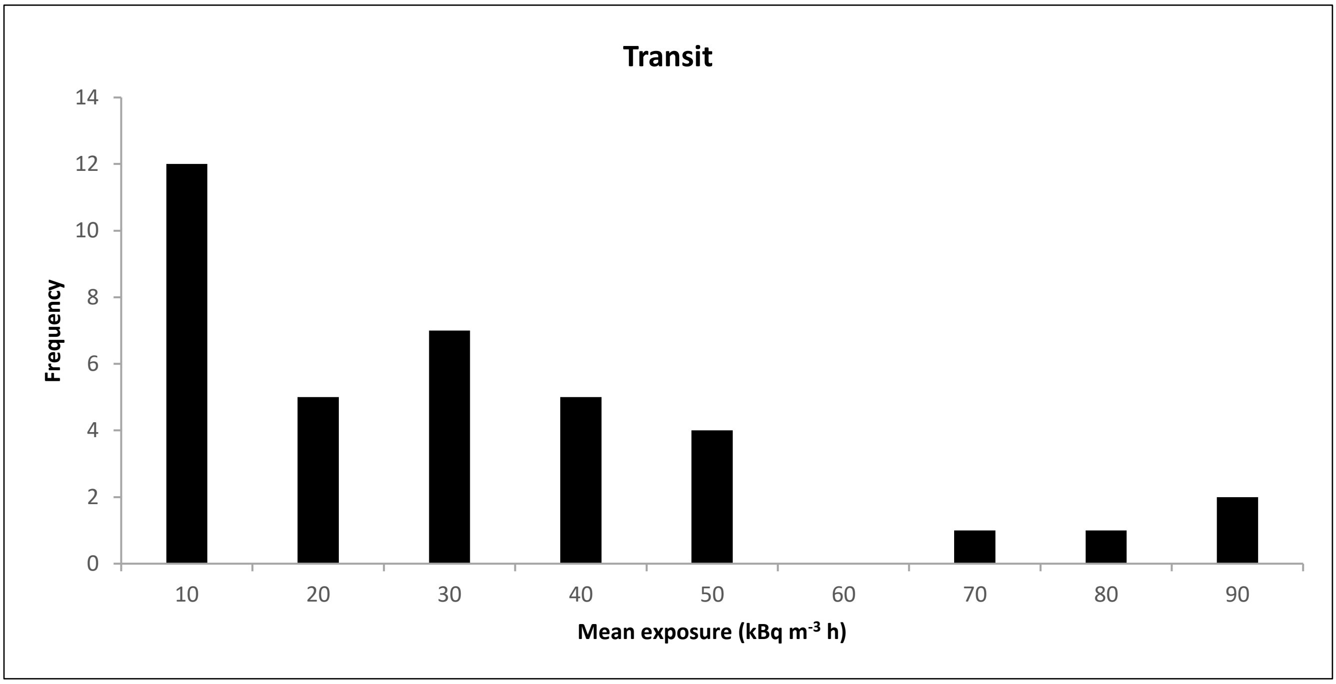
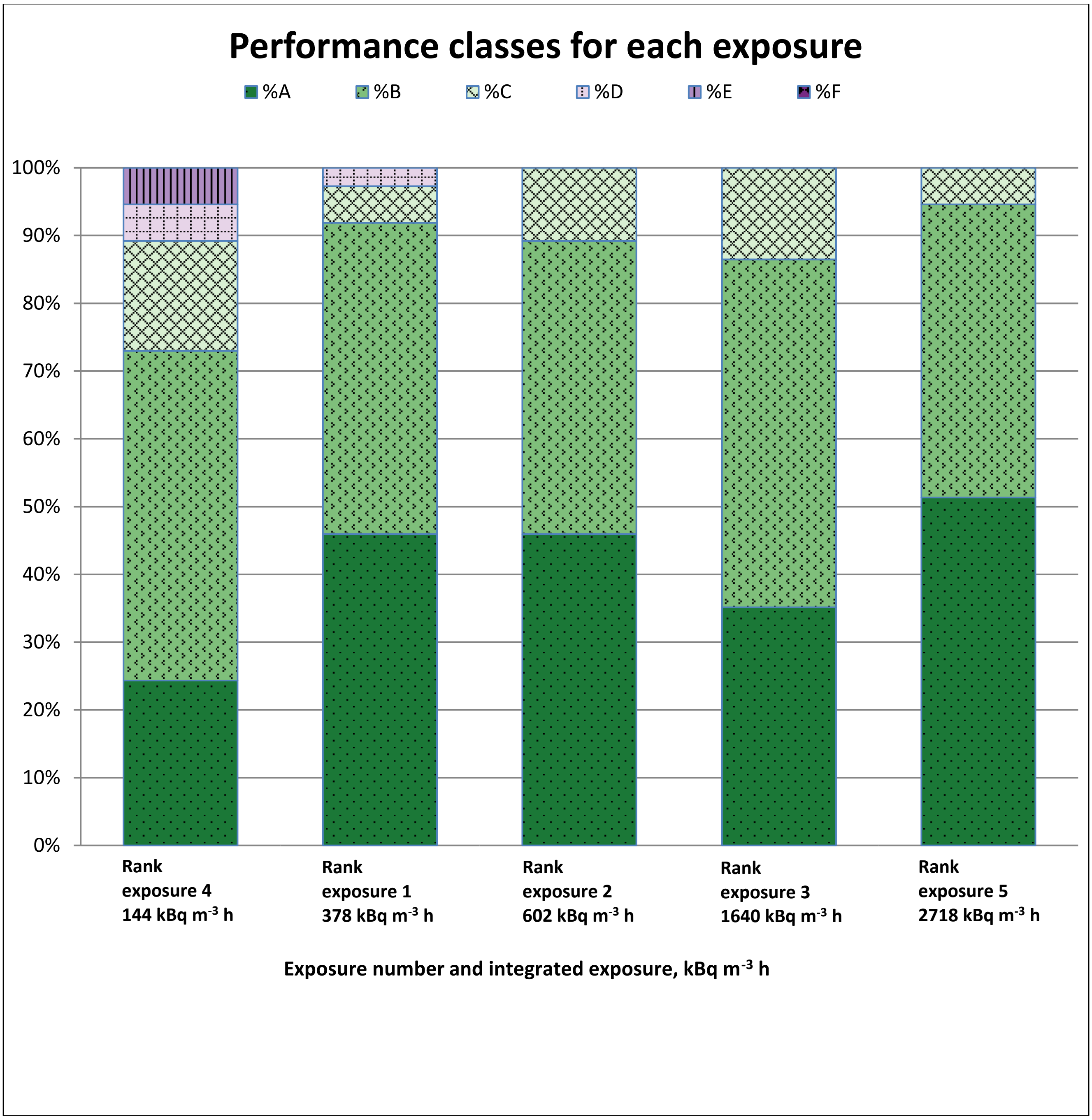


Figure 13. Performance classes for each exposure



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