Results of the 2011 HPA Intercomparison of Passive Radon Detectors

Z Daraktchieva, C B Howarth and R Algar

ABSTRACT

In total, 34 laboratories from 13 countries, took part in the 2011 HPA Intercomparison. Some laboratories submitted more than one set of detectors, so 39 sets of detectors were exposed together in the radon chamber. The detectors were exposed to five different radon concentrations in the range of 50 kBq m^{-3} h to 2500 kBq m^{-3} h. After the exposures the detectors were returned to the originating laboratories for processing. Each participant was asked to return results for each detector in terms of kBq m^{-3} h exposure of radon. In total, 33 laboratories reported results for 38 sets. A new exposure scheme was introduced to provide a better measure of the detectors response over specified range. A new parameter, measurement error, was introduced for a better overall evaluation of the results in terms of precision and accuracy. The measurement error was used in the new ranking system, which evaluates the performance for each exposure separately.

Centre for Radiation, Chemical and Environmental Hazards
Chilton, Didcot
Oxfordshire OX11 0RQ

Approval: April 2012
Publication: May 2012
£15.00
ISBN 978-0-85951-715-7

This report from the HPA Centre for Radiation, Chemical and Environmental Hazards reflects understanding and evaluation of the current scientific evidence as presented and referenced in this document.

EXECUTIVE SUMMARY

Radon is the largest and most variable contributor of radiation dose to the general population. For more than twenty 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 three types of detector are used for experimental and research work.

Intercomparisons provide information about the accuracy of measurements. By allowing different detectors to be compared side by side an objective assessment of the accuracy of measurements can be made. The results of intercomparisons have been used by individual laboratories to identify and rectify problems, as well as providing calibrations for the detectors traceable to international standards.

The Centre for Radiation, Chemical and Environmental Hazards of the Health Protection Agency (HPA-CRCE) carries out international intercomparisons of passive radon detectors each year. In this intercomparison laboratories were invited to submit sets of detectors which were randomised into six groups at HPA-CRCE. Five of these groups were exposed in the HPA-CRCE radon chamber to five different radon concentrations in the range of 50 kBq m^{-3} h to 2500 kBq m^{-3} h and the sixth group were used to determine transit exposures. Detectors were then returned to the laboratories who were asked to report the integrated exposure result for each detector. Laboratories are not informed of the details of the exposures or which detectors were in which group until all results have been submitted.

This report considers the results for the intercomparison carried out in 2011, for which a total of 34 laboratories from 13 countries submitted 39 sets of detectors. Analysis of the results allows each exposure group in each set to be ranked from A (best) to E (worst). All types of detector whether etched track, charcoal or electret can be found in each class, demonstrating the point that in measuring radon stringent quality assurance is vital irrespective of the measured technique.

International passive radon detector intercomparisons remain popular, with new laboratories joining each year. It is intended to continue these exercises on an annual basis as long as demand for them continues.

CONTENTS

1 INTRODUCTION

Passive radon detectors have been employed for years for integrated measurements of radon concentrations using a variety of detectors designs.

Passive detectors employing plastic as the detector material are called etched track detectors. The alpha particles from the decay products of radon damage the surface of the plastic material and produce tiny tracks. These tracks are 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). There are two types of etched track detectors: open (the material is exposed to the ambient atmosphere) and closed (the material is enclosed in a container). The open etched track detectors record alpha particles originated from radon decay products and from all radon isotopes. Therefore the equilibrium factor F should be taken into account to estimate the alphas only from radon decay. The closed etched track detectors allow only radon to diffuse into the closed chamber and, therefore, exclude radon daughters.

Activated charcoal detectors and electrets chambers do not rely on etched tracks. The charcoal detectors rely on retaining adsorbed radon for measurement in the laboratory. Electret radon 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 exposure to radon allows the average radon concentrations during exposure to be calculated.

Although the passive radon detector technology is quite simple to produce and process, there are sources of errors that should be monitored closely. Therefore regular checks are needed against reference exposures in relevant radon exposure facilities. The laboratory intercomparison programme has been intended to provide participants with a routine benchmark performance standard, developed with broad international participation following standard and agreed test and interpretation protocols. The Intercomparison programme was established by NRPB (now part of the Health Protection Agency) in 1982 and has operated regularly since then.

2 LABORATORY EXPOSURE AND MEASUREMENT FACILITIES

HPA maintains a 43 m^3 walk-in radon chamber. The chamber is of the static type: radon is continuously released inside the chamber by radon sources, so there is no need to ventilate the chamber. All of the exposures in this intercomparison were carried out in this chamber.
The chamber contains a radon atmosphere which can be varied from around 200 Bq m^{-3} to 8000 Bq m^{-3}, depending on the use of various dry Ra-226 sources. In 2010 the radon chamber was fully refurbished and upgraded with a new aerosol generator. Table 1 shows the parameters measured and controlled in the chamber. An equilibrium factor (F) of about 0.4 between radon and its decay products was maintained for the five laboratory exposures during the intercomparison.

The radon concentration in the chamber was continuously monitored using an ATMOS 12 ionisation chamber. From May 2011 the monitoring of the radon concentration inside the chamber was optimised by introducing an Alphaguard ionisation chamber as a second primary instrument. A daily cross calibration between the Atmos12 DPX and Alphaguard was carried out throughout the intercomparison exercise. Both instruments are calibrated regularly using a radon gas source supplied by Physikalisch Technische Bundesanstalt (PTB), Germany.

During exposures radon decay products were sampled five times per day onto 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 later.

3 LOGISTICAL ARRANGEMENT

In 2011 the format of the inter-laboratory comparison of passive radon detectors was modified:

a) The detectors were exposed to five radon concentrations in the range of

50 kBq m^{-3} h to 2500 kBq m^{-3} h.

b) Laboratories were invited to send a set of 60 etched track detectors including 10 transit controls, a set of 30 identical electrets detectors (including 5 transit controls) or a set of 15 identical charcoal detectors.

c) The exposures took place in October 2011.

d) A new ranking system was introduced, which provides a better measure of precision for each exposure

e) The detectors were randomly separated into six groups: five exposed and one transit.

f) The detectors in the five exposure groups were given five different integrated radon exposures in the radon chamber; the detectors in the sixth group were not exposed but sealed in radon-resistant bags for the duration of the exposures.

Operational procedures and equipment are described fully in the reports of previous intercomparisons (Howarth 2009).

In total, 34 laboratories from 13 countries, took part in the 2011 HPA Intercomparison. Some laboratories submitted more than one set of detectors, so 39 sets of detectors were exposed side by side in the radon chamber. After the end of exposures the detectors were returned to the originating laboratories for processing. Each participant was asked to return results for each detector in terms of kBq m-3 h exposure of radon. In total, 33 laboratories reported results for 38 sets. Participants did not know which detectors were exposed together. The exposures given in the intercomparison were not calculated until the results for the deadline for return of all results had been passed. The exposure durations and magnitudes are given in Table 1.

4 NEW RANKING SCHEME

In 1997 a laboratory ranking scheme was introduced for the first time. Two parameters were monitored. The first parameter was the percentage difference and the second parameter was the percentage standard deviation. The percentage difference is the difference between the mean of the reported results and the reference value divided by the reference value, expressed as percentage. The percentage standard deviation is the ratio of the standard deviation and mean of the reported results expressed as percentage.

In 2011 a new ranking scheme was introduced with the following parameters:

- The percentage biased error (previously known as the percentage difference) measures the accuracy of the results, i.e. what the bias of the measurement is. The parameter is calculated as absolute value (modulus) and is given by:

$$\%\ Biased\ error = \left|\frac{Measured\ Mean - Reference\ Value}{Reference\ Value}\right| \times 100$$

The reference value is the reference radon exposure.

- The percentage precision error (previously known as the percentage standard deviation) measures the precision of the measurement. The parameter is given by:

$$\%\ Precision\ error = \frac{Standard\ Deviation}{Measured\ Mean} \times 100$$

- A new parameter, percentage measurement error, was introduced which is given by:

$$\%\ \text{Measurement error} = \sqrt[2]{\%Biased\ error^2 + \%Precision\ error^2}$$

Note that the percentage measurement error combines the biased error and precision error, and therefore provides a better evaluation of the measurement error. A result can have low measurement error only if both bias and precision errors are low. The measurement error is used in the new ranking system, which evaluates the performance for each exposure separately. Therefore a laboratory can achieve five ranks, i.e. one rank for each exposure.

The new ranks based on the measurement error are:

- If the measurement error is < 10% the rank is A
- If the measurement error is between ≤10% and < 20% the rank is B

- If the measurement error is between ≤20% and < 30% the rank is C
- If the measurement error is between ≤30% and < 40% the rank is D
- If the measurement error is between ≤40% and < 50% the rank is E
- If the measurement error is ≥50% and < 100% the rank is F

5 RESULTS AND DISCUSSION

The results reported by customers are given in Table 2. In this table, “Mean” is the mean result of ten (five for electrets) exposed detectors after subtracting the mean transit exposure. “1SD” is the standard deviation of ten (five for electrets) reported results. Results for % Biased error, % Precision error and % Measurement error are provided as well.

The mean results and their standard deviations, as reported by participants, are depicted in Figures 1-5. The analysis shows that the reported results are nearly normally distributed for all five exposures. The mean, μ, and standard deviation, σ, of all reported results, calculated for each exposure, are given in Table 3.

Most of the mean transit exposures are below 50 kBq m^{-3} h (see Figure 6). Note that one laboratory reported a mean transit exposure of 158 kBq m^{-3} h, which was a result of administrative error by the reporting laboratory.

The new ranking scheme based on measurement error is given in Table 4. The exposures are ascending in the headings of the columns of Table 4. The laboratories are sorted according to the ranks from A to F, from left to right. The position of the laboratories in the table is according to the ranks of the different exposures and it should not be interpreted as a criterion of their total performance. The total single rank used previously to evaluate laboratories was removed because it does not provide enough information on how a laboratory is performing at different radon exposures. Therefore, the results in the table are more informative and the laboratories can use them to review their procedures. The characteristics of the detectors such as material, detector holder design, detector type and coded material supplier are provided in Table 4. Three laboratories achieved a ranking of five ‘A’s meaning that they have less than 10 % measurement error for all five exposures. Three other laboratories have four ‘A’s and one ‘B’, ‘C’, ‘D’ or ‘F’ in exposure 2. This shows that these laboratories may have issues with the low exposure measurements. The lowest exposure was the most difficult to measure with only 5 laboratories managing to achieve A. One factor that may contribute to the deterioration of precision for the low exposure range is the material background. So called “false tracks” can be mistaken as real alpha tracks and the background contribution can either be overestimated or underestimated. The exposure 5 and exposure 1 were measured with the greatest precision – 18 and 16 laboratories achieved ‘A’, respectively. It should also be noted that laboratories participating with the same type of detectors and detector material can achieve quite different ranks which reflects each laboratory’s own Quality Assurance (QA) protocols.

Therefore it should be stressed again that while etch track technology is quite simple without constant monitoring and strict QA protocols, every laboratory can experience some deterioration in performance.

6 CONCLUSION

In total, 34 laboratories from 13 countries participated in the 2011 HPA Intercomparison. A new exposure scheme was introduced to provide a better measure of the detectors' response across the range of exposures that a laboratory is likely to measure. A new parameter, measurement error, was introduced to provide a better overall evaluation of the detectors' performance in terms of precision and accuracy. The old single rank scheme was removed and a new scheme was introduced with ranking for each exposure.

7 ACKNOWLEDGEMENTS

The authors would like to thank Carly Dyson and Zeinub-Ferozan Ibrahimi who provided valuable assistance in the radon exposure of the detectors.

8 REFERENCES

Howarth CB (2009). Results of the 2007 NRPB intercomparison of passive radon detectors. Chilton, HPA-RPD-060.

9 TABLES AND FIGURES

TABLE 1 Exposure durations and magnitudes

Exposure	1	2	3	4	5
Duration (h)	581.78	29.03	102.35	405.95	239.08
Radon exposure (kBq m^{-3} h)	2174	112	382	1516	902
Uncertainty (%) at 68 % CL	3.0	3.0	3.0	3.0	3.05
EER exposure (kBq m^{-3} h)	826	45	149	576	325
Uncertainty (%) at 68 % CL	7.0	7.0	7.0	7.0	7.0

Notes to Table 1

EER is equilibrium equivalent of radon.

CL is the confidence level.

Notes to Tables 2 and 4

Due to an administrative error, the results for five detectors in set 14-1 were incorrectly assigned by the reporting laboratory. When the corrected results were supplied the results for the Mean for Exposures 1,3, 4 and 5 were 1927.7, 336.4, 1354.3 and 790.6 kBq m^{-3} h respectively. The measurement errors in exposures 1, 3, 4 and 5 when corrected were 11.5%, 14.5%, 10.8% and 12.8% respectively.The ranks for exposures 1, 2, 4 and 5 when corrected were B, B ,B and B respectively.

Due to an administrative error, the results for two detectors in set 13-1 were incorrectly assigned by the reporting laboratory. When the corrected results were supplied the results for the Mean for Exposures 2 and 3 were 124.9 and 389.1 kBq m^{-3} h respectively. The measurement errors in exposures2 and 3 when corrected were12.6 % and 3.1 % respectively.The ranks for exposures 2 and 3 when corrected were B and A respectively.

TABLE 2 Analysis of all reported results

	EXPOSURE 1 2174 (kBq m^{-3} h)					EXPOSURE 2 112 (kBq m^{-3} h)				
SET ID	Mean (kBq m^{-3} h)	1SD (kBq m^{-3} h)	% Biased error	% Precision error	% Measurem□nt error	Mean (kBq m^{-3} h)	1SD (kBq m^{-3} h)	% Biased error	% Precision error	% Measurement error
1-1	2157.6	112.6	0.8	5.2	5.3	119.9	22.1	7.1	18.4	19.7
1-2	2071.9	75.9	4.7	3.7	6.0	116.7	7.3	4.2	6.3	7.5
7-1	1876.7	46.9	13.7	2.5	13.9	103.7	16.1	7.4	15.5	17.2
12-1	2307	41.2	6.1	1.8	6.4	117.8	8.7	5.2	7.4	9.0
13-1	2087.7	49.2	4.0	2.4	4.6	151.9	86.9	35.6	57.2	67.4
14-1	1822.6	358.4	16.2	19.7	25.5	102.6	7.9	8.4	7.7	11.4
16-1	1940.9	64.5	10.7	3.3	11.2	106.7	10.1	4.7	9.5	10.6
16-2	2341.2	249.2	7.7	10.6	13.1	115.4	12.8	3.0	11.1	11.5
19-1	2179.7	110.1	0.3	5.1	5.1	120.4	13.3	7.5	11.0	13.4
20-1	1381.2	32.3	36.5	2.3	36.5	61.3	3.8	45.3	6.2	45.7
25-1	2162	55.2	0.6	2.6	2.6	101.9	10.5	9.0	10.3	13.7
25-2	2095.1	199.0	3.6	9.5	10.2	107.5	10.0	4.0	9.3	10.1
28-1	1583.2	73.2	27.2	4.6	27.6	85.6	24.3	23.6	28.4	36.9
30-1	2307.2	153.8	6.1	6.7	9.1	135.9	29.3	21.3	21.6	30.3
40-1	1978.3	103.6	9.0	5.2	10.4	129.6	12.4	15.7	9.6	18.4
45-1	1862.5	138.4	14.3	7.4	16.1	50.7	15.4	54.7	30.4	62.6
50-1	2070.3	92.9	4.8	4.5	6.5	115.7	22.3	3.3	19.3	19.6
59-1	N/A	N/A	N/A	N/A	N/A	178.1	54.6	59.0	30.7	66.5
78-1	432.3	238.5	80.1	55.2	97.3	N/A	N/A	N/A	N/A	N/A
94-1	2155.7	112.3	0.8	5.2	5.3	105.8	24.8	5.5	23.4	24.1
119-1	1938.3	125.0	10.8	6.4	12.6	122.5	15.2	9.4	12.4	15.6
122-1	1872.7	30.0	13.9	1.6	14.0	110.4	3.9	1.4	3.5	3.8
122-2	1858.4	27.0	14.5	1.5	14.6	114.8	4.3	2.5	3.7	4.5

	EXPOSURE 1 (continued) 2174 (kBq m^{-3} h)					EXPOSURE 2 (continued) 112 (kBq m^{-3} h)				
SET ID	Mean (kBq m^{-3} h)	1SD (kBq m^{-3} h)	% Biased error	% Precision error	% Measurement error	Mean (kBq m^{-3} h)	1SD (kBq m^{-3} h)	% Biased error	% Precision error	% Measurement error
125 -1	2037.9	281.0	6.3	13.8	15.1	101.5	16.9	9.4	16.7	19.1
125 -2	2084.1	198.0	4.1	9.5	10.4	111.3	13.0	0.6	11.7	11.7
129-1	2248.5	72.9	3.4	3.2	4.7	113.1	10.6	1.0	9.4	9.4
130-1	1800.0	146.1	17.2	8.1	19.0	93.1	14.2	16.9	15.3	22.7
141-1	2160.2	86.8	0.6	4.0	4.1	138.5	12.6	23.7	9.1	25.3
144-1	2335.3	126.6	7.4	5.4	9.2	126.0	19.1	12.5	15.2	19.6
146-1	1932.3	80.4	11.1	4.2	11.9	124.8	20.9	11.4	16.7	20.3
152-1	2048.6	55.5	5.8	2.7	6.4	120.2	9.3	7.3	7.7	10.7
158-1	2188.3	97.8	0.7	4.5	4.5	109.8	11.4	2.0	10.4	10.6
160-1	1989.5	57.1	8.5	2.9	9.0	125.0	78.5	11.6	62.8	63.9
161-1	2453.7	164.8	12.9	6.7	14.5	117.5	21.7	4.9	18.5	19.1
163-1	1944.0	31.4	10.6	1.6	10.7	96.0	7.7	14.3	8.0	16.4
168-1	1711.0	55.4	21.3	3.2	21.5	121.3	11.7	8.3	9.6	12.7
171-1	2504.2	149.7	15.2	6.0	16.3	86.3	23.0	22.9	26.7	35.2
172-1	2035.9	88.6	6.4	4.4	7.7	100.1	3.6	10.6	3.6	11.2

	EXPOSURE 3 382 (kBq m^{-3} h)					EXPOSURE 4 1516 (kBq m^{-3} h)				
SET ID	Mean (kBq m^{-3} h)	1SD (kBq m^{-3} h)	% Biased error	% Precision error	% Measurement error	Mean (kBq m^{-3} h)	1SD (kBq m^{-3} h)	% Biased error	% Precision error	% Measurement error
1-1	404.6	18.6	5.9	4.6	7.5	1663.5	78.7	9.7	4.7	10.8
1-2	379.1	6.3	0.8	1.7	1.8	1463.0	51.1	3.5	3.5	4.9
7-1	333.1	26.6	12.8	8.0	15.1	1308.7	42.3	13.7	3.2	14.1
12-1	381.3	10.3	0.2	2.7	2.7	1564.9	35.2	3.2	2.2	3.9
13-1	362.1	82.6	5.2	22.8	23.4	1482.6	42.0	2.2	2.8	3.6
14-1	383.3	147.4	0.3	38.5	38.5	1250.8	325.7	17.5	26.0	31.4
16-1	375.4	48.7	1.7	13.0	13.1	1442.8	82.9	4.8	5.7	7.5
16-2	418.2	39.0	9.5	9.3	13.3	1645.2	181.3	8.5	11.0	13.9
19-1	381.4	48.3	0.2	12.7	12.7	1585.9	35.7	4.6	2.3	5.1
20-1	228.1	10.8	40.3	4.7	40.6	945.9	30.2	37.6	3.2	37.7
25-1	338.5	15.9	11.4	4.7	12.3	1436.2	31.3	5.3	2.2	5.7
25-2	353.8	46.4	7.4	13.1	15.0	1458.4	139.2	3.8	9.5	10.3
28-1	293.4	12.9	23.2	4.4	23.6	1091.2	131.1	28.0	12.0	30.5
30-1	394.9	16.7	3.4	4.2	5.4	1499.2	262.8	1.1	17.5	17.6
40-1	369.7	38.4	3.2	10.4	10.9	1427.2	72.5	5.9	5.1	7.8
45-1	271.1	44.7	29.0	16.5	33.4	1319.4	203.2	13.0	15.4	20.1
50-1	321.5	15.3	15.8	4.8	16.5	1316.1	193.0	13.2	14.7	19.7
59-1	413.8	80.2	8.3	19.4	21.1	586.0	249.0	61.3	42.5	74.6
78-1	238.2	210.1	37.6	88.2	95.9	563.3	263.8	62.8	46.8	78.4
94-1	389.8	30.0	2.0	7.7	8.0	1457.6	67.4	3.9	4.6	6.0
119-1	344.7	42.1	9.8	12.2	15.6	1398.8	126.2	7.7	9.0	11.9
122-1	345.5	9.0	9.6	2.6	9.9	1319.8	15.8	12.9	1.2	13.0
122-2	353.7	8.4	7.4	2.4	7.8	1333.0	20.7	12.1	1.6	12.2

	EXPOSURE 3 (continued) 382 (kBq m^{-3} h)					EXPOSURE 4 (continued) 1516 (kBq m^{-3} h)				
SET ID	Mean (kBq m^{-3} h)	1SD (kBq m^{-3} h)	% Biased error	% Precision error	% Measurement error	Mean (kBq m^{-3} h)	1SD (kBq m^{-3} h)	% Biased error	% Precision error	% Measurement error
125-1	368.9	63.3	3.4	17.2	17.5	1477.9	177.3	2.5	12.0	12.3
125-2	381.4	81.1	0.2	21.3	21.3	1487.5	248.8	1.9	16.7	16.8
129-1	379.2	20.5	0.7	5.4	5.5	1550.7	34.1	2.3	2.2	3.2
130-1	341.5	27.8	10.6	8.1	13.4	1363.3	116.1	10.1	8.5	13.2
141-1	434.8	20.8	13.8	4.8	14.6	1530.6	39.9	1.0	2.6	2.8
144-1	429.9	14.4	12.5	3.3	13.0	1698.2	124.5	12.0	7.3	14.1
146-1	382.5	23.7	0.1	6.2	6.2	1386.9	41.9	8.5	3.0	9.0
152-1	387.5	18.3	1.4	4.7	4.9	1467.1	53.3	3.2	3.6	4.9
158-1	410.5	28.0	7.5	6.8	10.1	1715.0	130.9	13.1	7.6	15.2
160-1	359.9	19.4	5.8	5.4	7.9	1435.9	80.1	5.3	5.6	7.7
161-1	440.5	64.0	15.3	14.5	21.1	1789.4	126.6	18.0	7.1	19.4
163-1	343.4	23.3	10.1	6.8	12.2	1344.8	34.4	11.3	2.6	11.6
168-1	351.2	20.4	8.1	5.8	9.9	1223.8	49.0	19.3	4.0	19.7
171-1	342.3	34.5	10.4	10.1	14.5	1575.3	157.5	3.9	10.0	10.7
172-1	337.9	24.4	11.5	7.2	13.6	1377.8	52.5	9.1	3.8	9.9

	EXPOSURE 5 902 (kBq m^{-3} h)					TRANSIT CONTROLS	
SET ID	Mean (kBq m^{-3} h)	1SD (kBq m^{-3} h)	% Biased error	% Precision error	% Measurement error	Mean (kBq m^{-3} h)	1 SD (kBq m^{-3} h)
1-1	957.0	43.4	6.1	4.5	7.6	22.3	12.2
1-2	894.3	24.3	0.9	2.7	2.8	16.4	3.6
7-1	774.2	35.5	14.2	4.6	14.9	30.7	17.8
12-1	925.7	25.5	2.6	2.8	3.8	21.0	3.5
13-1	888.1	28.1	1.5	3.2	3.5	4.5	3.1
14-1	952.3	366.9	5.6	38.5	38.9	18.5	5.4
16-1	908.7	33.5	0.7	3.7	3.8	25.8	18.0
16-2	937.3	153.1	3.9	16.3	16.8	45.3	21.9
19-1	915.8	55.2	1.5	6.0	6.2	31.4	17.4
20-1	553.7	25.8	38.6	4.7	38.9	9.3	3.5
25-1	835.5	44.3	7.4	5.3	9.1	5.0	0.0
25-2	842.0	50.4	6.7	6.0	8.9	10.3	1.5
28-1	687.0	47.8	23.8	7.0	24.8	43.0	9.7
30-1	966.2	89.2	7.1	9.2	11.7	26.0	11.6
40-1	835.8	42.5	7.3	5.1	8.9	15.6	4.7
45-1	803.9	69.5	10.9	8.6	13.9	45.0	0.0
50-1	800.0	70.8	11.3	8.9	14.4	31.6	6.8
59-1	669.3	93.1	25.8	13.9	29.3	65.0	18.9
78-1	360.0	252.3	60.1	70.1	92.3	169.0	157.9
94-1	885.9	57.7	1.8	6.5	6.8	63.6	19.4
119-1	806.2	46.3	10.6	5.7	12.1	27.9	6.1
122-1	820.4	15.1	9.0	1.8	9.2	12.0	2.2
122-2	831.7	9.8	7.8	1.2	7.9	12.0	3.8

	EXPOSURE 5 (continued) 902 (kBq m^{-3} h)					TRANSIT CONTROLS (continued)	
SET ID	Mean (kBq m^{-3} h)	1SD (kBq m^{-3} h)	% Biased error	% Precision error	% Measurement error	Mean (kBq m^{-3} h)	1 SD (kBq m^{-3} h)
125-1	918.8	174.2	1.9	19.0	19.1	3.8	3.2
125-2	874.4	133.8	3.1	15.3	15.6	4.8	2.9
129-1	916.6	50.8	1.6	5.5	5.8	6.4	4.3
130-1	722.3	60.7	19.9	8.4	21.6	4.4	3.0
141-1	908.8	44.5	0.8	4.9	5.0	11.2	4.8
144-1	1050.2	50.2	16.4	4.8	17.1	23.5	4.3
146-1	843.0	19.8	6.5	2.3	6.9	29.2	8.6
152-1	875.8	30.5	2.9	3.5	4.5	13.2	2.8
158-1	1033.5	78.3	14.6	7.6	16.4	5.4	4.1
160-1	840.6	31.5	6.8	3.7	7.8	50.4	19.5
161-1	1060.7	80.1	17.6	7.6	19.1	9.8	6.5
163-1	909.2	253.2	0.8	27.8	27.9	20.8	5.0
168-1	777.1	31.4	13.8	4.0	14.4	6.6	4.5
171-1	866.6	125.0	3.9	14.4	14.9	11.7	8.4
172-1	819.7	32.7	9.1	4.0	9.9	15.7	2.6

TABLE 3 Analysis of all reported results

Reference exposures	Mean μ of all reported results, (kBq m^{-3} h)	Standard deviation σ of all reported results (kBq m^{-3} h)	Excluded outliers
Exposure 1 2174 (kBq m^{-3} h)	2042	231.7	1
Exposure 2 112 (kBq m^{-3} h)	113	22	2
Exposure 3 382 (kBq m^{-3} h)	363	47	-
Exposure 4 1516 (kBq m^{-3} h)	1439	168	2
Exposure 5 902 (kBq m^{-3} h)	861	103	1

TABLE 4 New ranking scheme based on the measurement error

SET ID	Rank EXPOSURE 2 112 (kBq m^{-3} h)	Rank EXPOSURE 3 382 (kBq m^{-3} h)	Rank EXPOSURE 5 902 (kBq m^{-3} h)	Rank EXPOSURE 4 1516 (kBq m^{-3} h)	Rank EXPOSURE 1 2174 (kBq m^{-3} h)	Detector Type	Filter	Holder	Detector material	Detector material supplier
1-2	A	A	A	A	A	Closed		NRPB/SSI	CR-39	I
12-1	A	A	A	A	A	Closed	Yes	NRPB/SSI	CR-39	Unknown
129-1	A	A	A	A	A	Closed		Own	CR-39	II
152-1	B	A	A	A	A	Closed		TASL	CR-39	II
94-1	C	A	A	A	A	Closed		Radosys	CR-39	III
160-1	F	A	A	A	A	Closed		NRPB/SSI	CR-39	IV
19-1	B	B	A	A	A	Closed		ARPA	CR-39	II
25-1	B	B	A	A	A	Open		Dosirad	LR115	V
172-1	B	B	A	A	A	Closed		Radosys	CR-39	III
141-1	C	B	A	A	A	Closed		TASL	CR-39	IV
13-1	F	C	A	A	A	Closed		NRPB/SSI	CR-39	II
1-1	B	A	A	B	A	Closed		NRPB/SSI	CR-39	VI
30-1	D	A	B	B	A	Closed		KfK FN	Makrofol	VII
50-1	B	B	B	B	A	Open			LR115	VII
144-1	B	B	B	B	A	Closed		Radosys RSKS	CR-39	III
158-1	B	B	B	B	A	Closed		TASL	CR-39	IV
16-1	B	B	A	A	B	Closed	Yes	Radosys RSG	CR-39	III
40-1	B	B	A	A	B	Closed		NRPB/SSI	CR-39	I

TABLE 4 (continue) New ranking scheme based on the measurement error

SET ID	Rank EXPOSURE 2 112 (kBq m^{-3} h)	Rank EXPOSURE 3 382 (kBq m^{-3} h)	Rank EXPOSURE 5 902 (kBq m^{-3} h)	Rank EXPOSURE 4 1516 (kBq m^{-3} h)	Rank EXPOSURE 1 2174 (kBq m^{-3} h)	Detector Type	Filter	Holder	Detector material	Detector material supplier
146-1	C	A	A	A	B	Closed		NRPB/SSI	CR-39	III
122-1	A	A	A	B	B	Closed		TASL	CR-39	III
122-2	A	A	A	B	B	Closed		TASL	CR-39	III
25-2	B	B	A	B	B	Closed		ALGADE	LR115	V
7-1	B	B	B	B	B	Closed		TASL	CR-39	IV
16-2	B	B	B	B	B	Closed	Yes	Radosys RSK	CR-39	III
119-1	B	B	B	B	B	Closed		TASL	CR-39	IV
125-1	B	B	B	B	B	Closed	Yes	Radosys RSK	CR-39	III
171-1	D	B	B	B	B	Closed		Own	LR115-2	Unknown
161-1	B	C	B	B	B	Closed	Yes	Radosys RSK	CR-39	III
125-2	B	C	B	B	B	Closed	Yes	Radosys	CR-39	III
163-1	B	B	C	B	B	Closed		Eperm S	Electret	-
130-1	C	B	C	B	B	Closed		Radosys	CR-39	III
45-1	F	D	B	C	B	Closed	Yes	Own	LR115	Unknown
168-1	B	A	B	B	C	Closed		NRPB/SSI	CR-39	IV
28-1	D	C	C	D	C	Closed		Radosys RSK	CR-39	III
14-1	B	D	D	D	C	Closed		NRPB/SSI	CR-39	IV
20-1	E	E	D	D	D	Closed		TASL	CR-39	IV
78-1	N/A	F	F	F	F	Closed		NRPB/SSI	CR-39	VI
59-1	F	C	C	F	N/A	Closed		Karlsruhe	Makrofol	IX

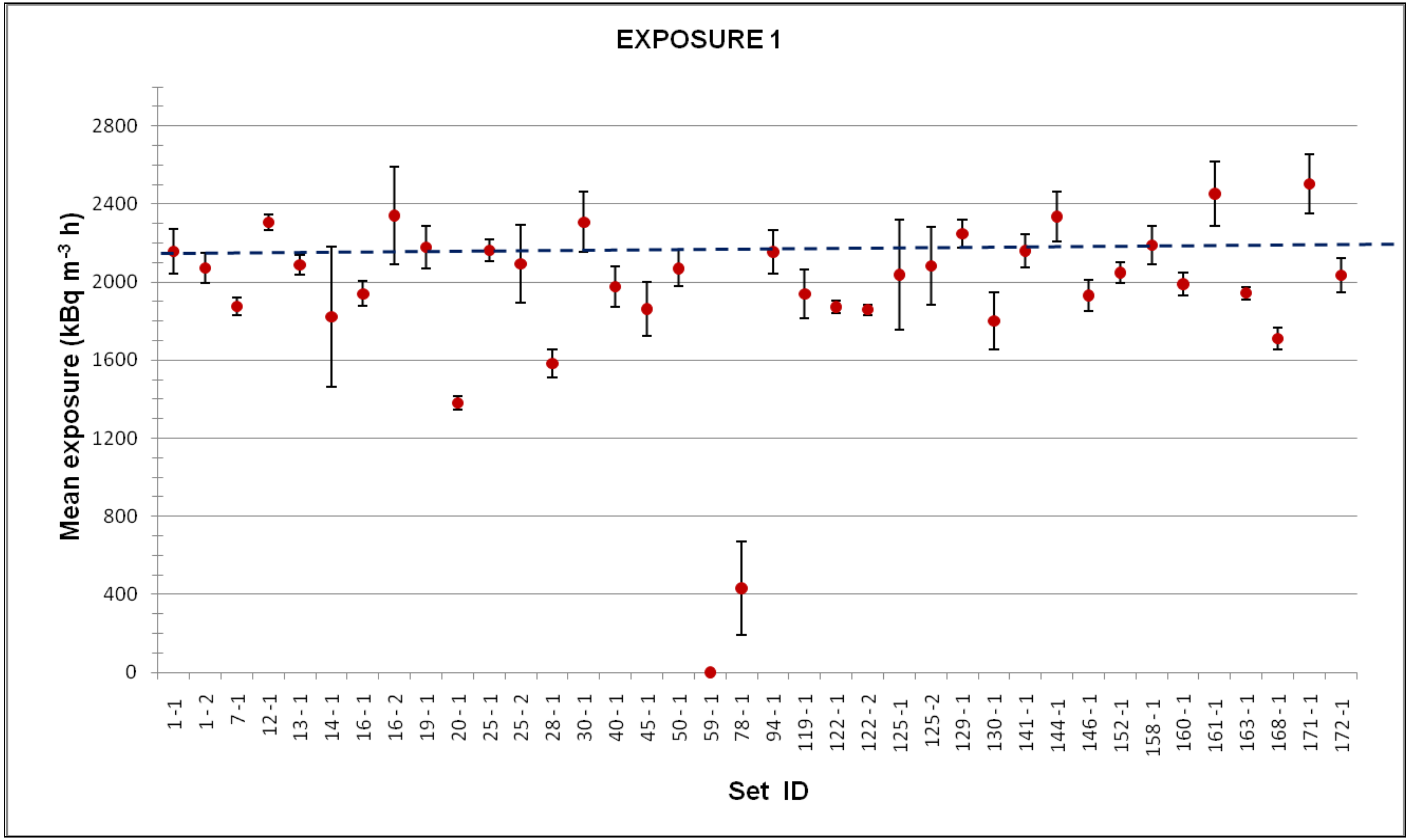

FIGURE 1 Results as reported by participants for exposure 1

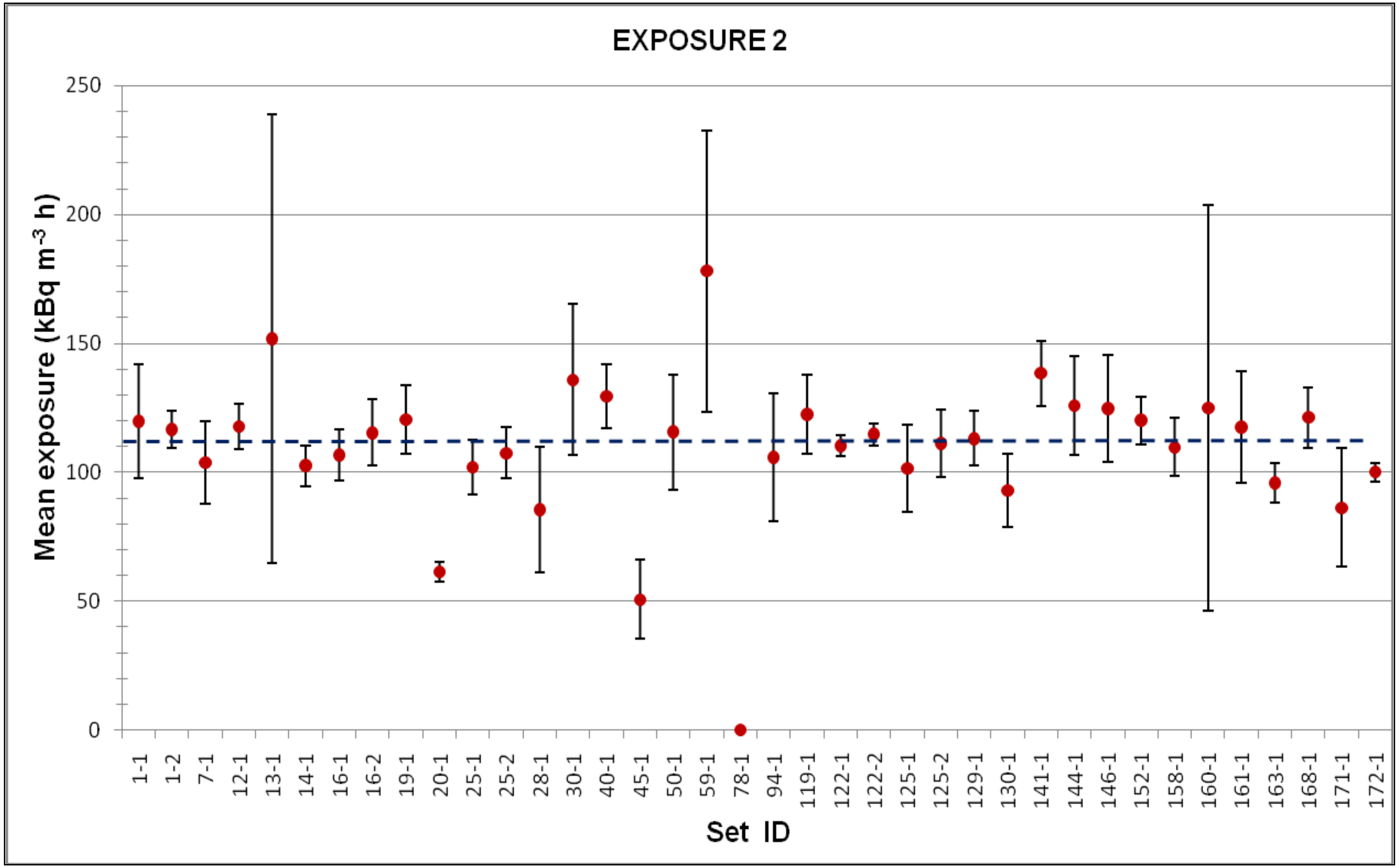

FIGURE 2 Results as reported by participants for exposure 2

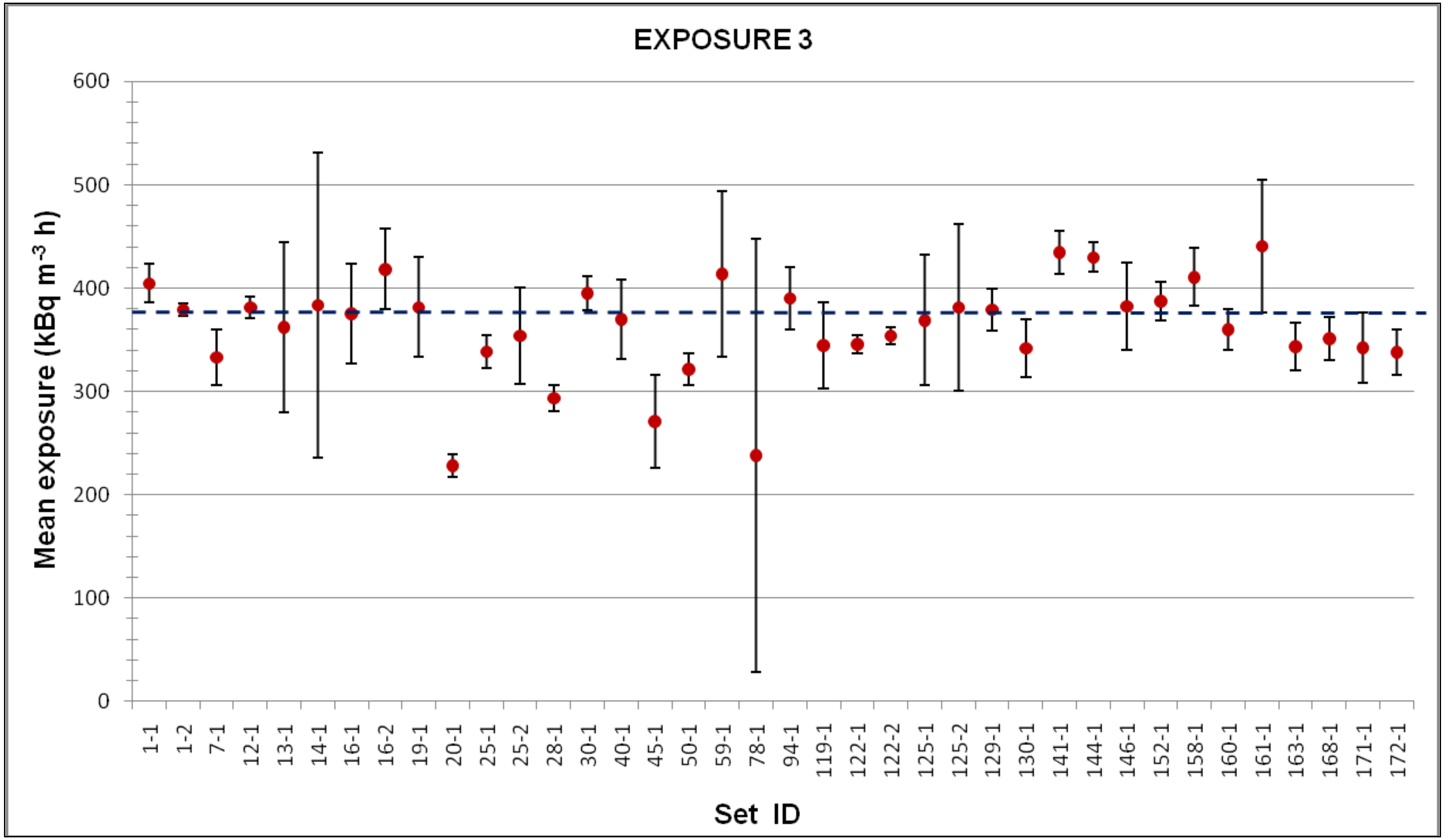

FIGURE 3 Results as reported by participants for exposure 3

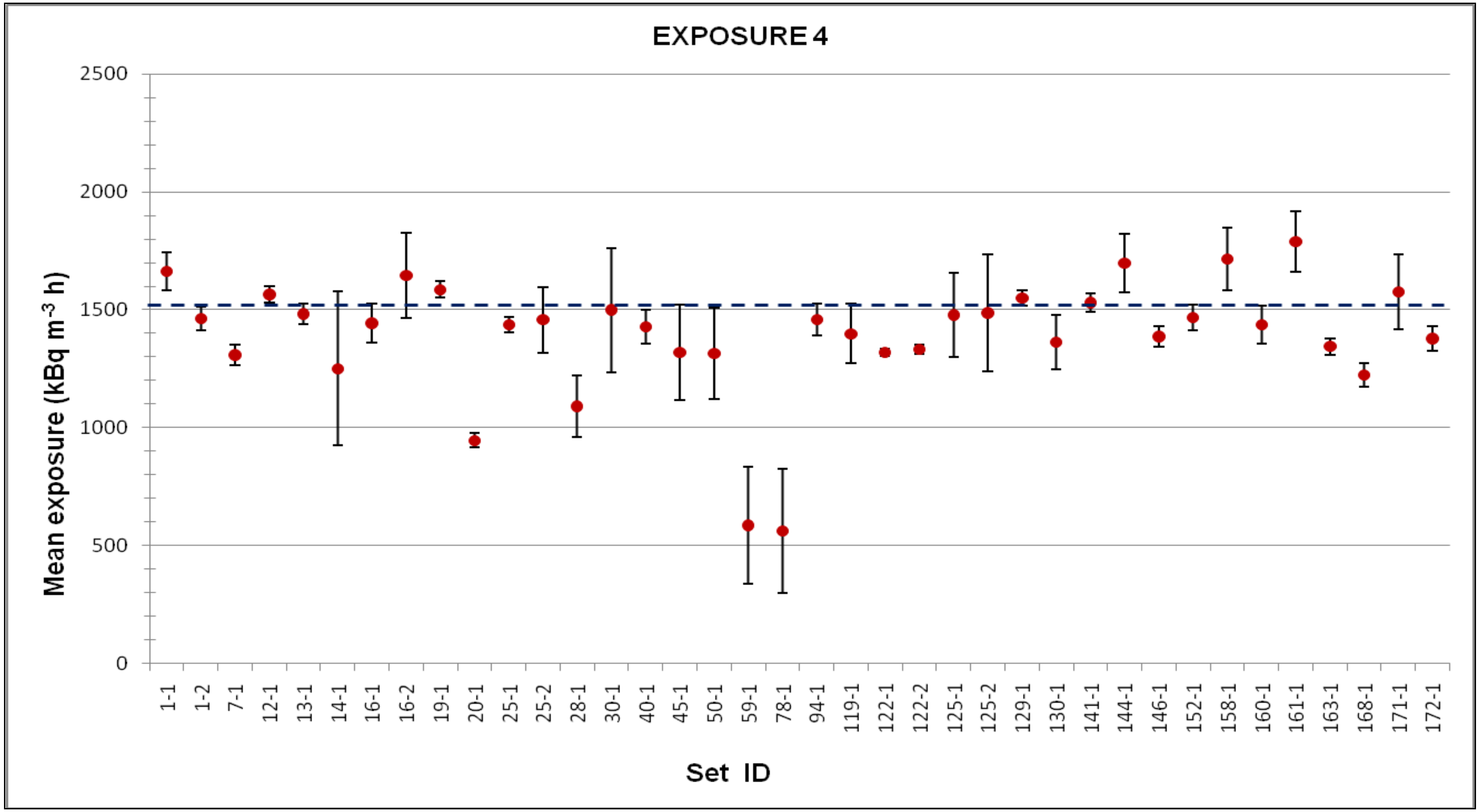

FIGURE 4 Results as reported by participants for exposure 4

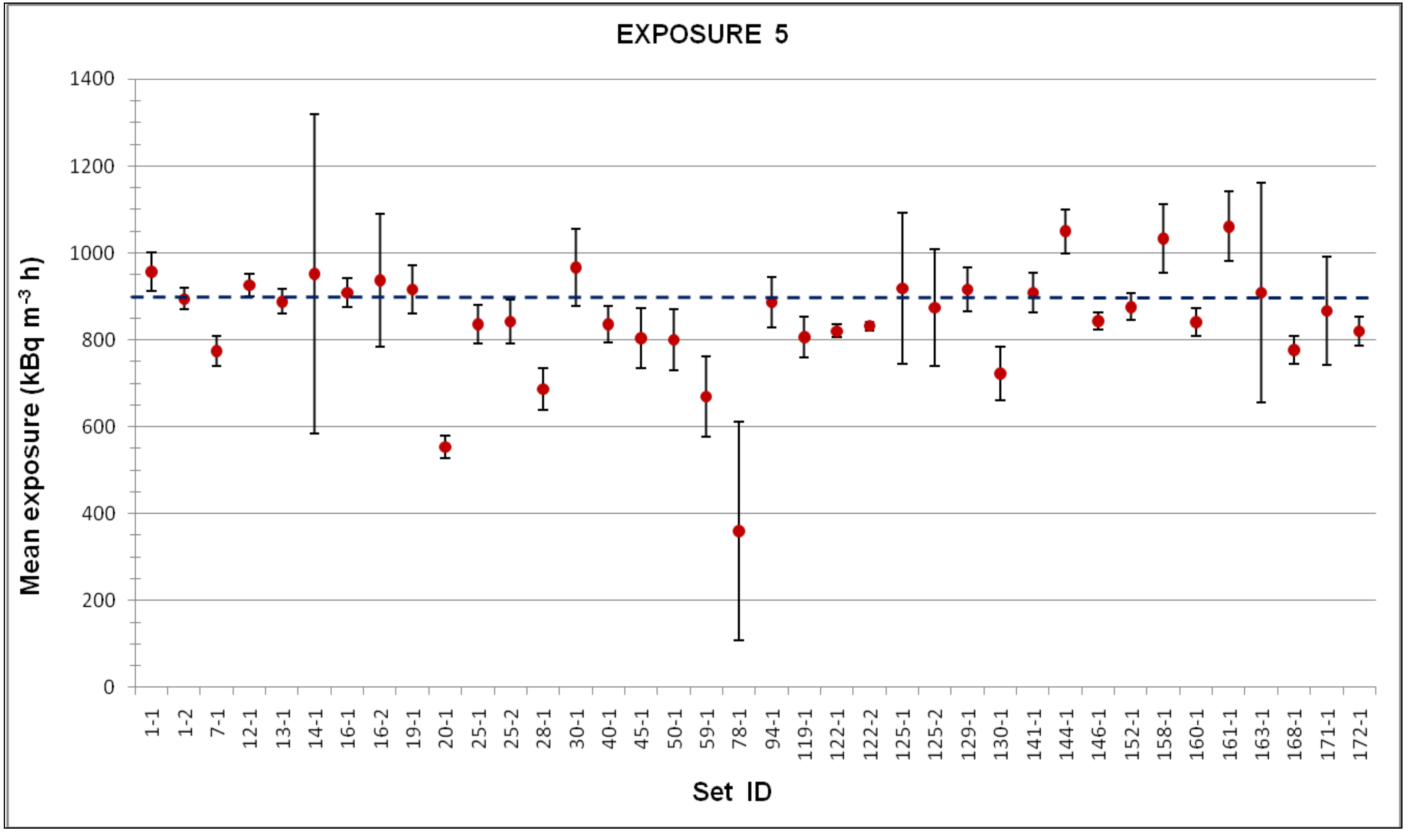

FIGURE 5 Results as reported by participants for exposure 5

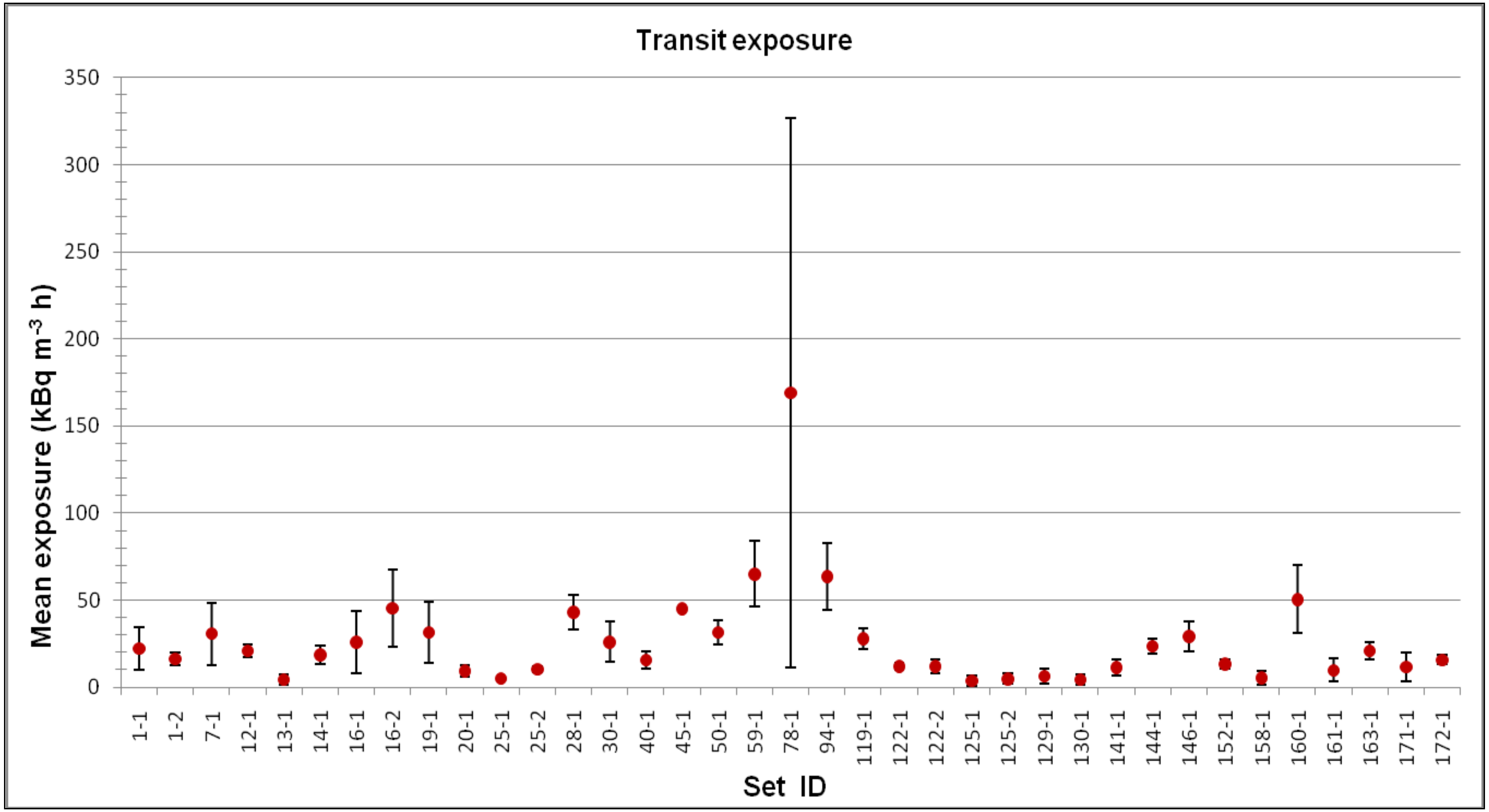

FIGURE 6 Results as reported by participants for transit exposure