Results of the 2006 Health Protection Agency Intercomparison of Passive Radon Detectors

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ABSTRACT

As in previous years, an intercomparison of passive radon detectors was held at the Radiation Protection Division of the Health Protection Agency in 2006. Thirty-two laboratories submitted 38 sets of passive detectors to this intercomparison. The exercise included three exposures to radon and its decay products at different equilibrium factors. After exposure, the detectors were returned to their originating laboratories for assessment. Participants reported the estimated exposure for each detector before they were notified of the exposures given to the detectors. The results obtained by participating laboratories were classified according to the spread of results from detectors exposed together and by the difference between the mean result of each group and the actual exposure given. Fifty three per cent of the laboratories achieved the highest classification for accuracy, while 22% were in the lowest category. The proportion of laboratories achieving very good results is broadly in line with that seen in recent intercomparisons. Each year there is a number of laboratories introducing new detector systems which often results in initially less successful performance. As experience is gained it is expected that results from laboratories operating such systems will improve.

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The following amendments have been made to this report since its first publication (April 2009)

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The results for Set 152 – 1 have been updated to the correct values. Tables 5 and 6 have been updated, together with Figures 9, 10 and 11. Suitable amendments have made to the text, where necessary.

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 average exposures and identify where excessive exposures 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 are essential to ensure that the results of measurements are accurate. 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 to identify and rectify problems, as well as providing calibrations for the detectors traceable to international standards.

The Radiation Protection Division of the Health Protection Agency (HPA-RPD), formerly the National Radiological Protection Board (NRPB) carries out international intercomparisons of passive radon detectors each year. Typically around 40 laboratories take part. In each intercomparison laboratories are invited to submit sets of detectors which are randomised into four groups at HPA-RPD. Three of these groups are exposed in the HPA-RPD radon chamber and the fourth group is used to determine transit exposures. Detectors are then returned to the laboratories who are asked to report the 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 2006, for which a total of 32 laboratories from 14 countries submitted 38 sets of detectors. Analysis of the results allows each set to be ranked from A (best) to E (worst). Some sets of etched track, charcoal and electret detectors can be found in each class, demonstrating the point that in measuring radon stringent quality assurance is vital. It is encouraging that a general trend throughout the history of these exercises towards improved results has continued.

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

Radon is the largest contributor to the radiation dose to the public and is highly variable. Surveys of radon levels in homes and other buildings have been carried out throughout Europe to determine the magnitude of average exposures and to identify situations where excessive exposures occur. The great majority of these surveys have been carried out using passive etched-track detectors exposed over long periods to take account of the short-term variations in radon levels. Some surveys have been carried out using charcoal detectors exposed over periods of a few days, and some have used electrets which may be exposed over periods from days to months.

In order to ensure the quality of these measurements, it is important to compare different detectors exposed side by side. Although passive radon measurement techniques are simple in principle, it has been found that it is difficult in practice to maintain good quality control. The Radiation Protection Research Programme of the European Commission provided funds for intercomparisons of active and passive radon and radon decay product measurement techniques in 1982, 1984 and 1987 (Miles, 1988). More limited exercises were held in 1989 (Miles, 1990), 1991 (Whysall, 1996) and 1995 (Miles, 1996) for passive radon detectors only. Since 1997 these exercises have been conducted on an annual basis (Naismith et al, 1998; Howarth and Miles, 2000a,b, 2002a,b, 2003, 2007; Howarth 2007, 2008). Many laboratories regard such an exercise as an important check on the international comparability of radon measurement results and on their quality control procedures.

In 1996 agreement was obtained from the European Commission to sponsor a series of three annual intercomparisons to be held at NRPB. The contract also provided for a steering meeting to be held before the first intercomparison and a final meeting open to all participants to be held after the last of the three. The steering meeting took place in early 1997, followed by intercomparisons in 1997, 1998 and 1999. The final meeting, to which all participants in the intercomparisons were invited was held at NRPB in May 1999.

Participants in the final meeting were invited to complete a questionnaire about future intercomparisons, approximately half of whom did so. The original meeting had decided that the intercomparisons should have two similar exposures and one very different one. The purpose of having two similar exposures was to make the intercomparison more ‘blind’- if three very different exposures are used it is easier for participants to identify which detectors were exposed together. A majority of respondents to the final questionnaire were in favour of having three very different exposures as this would enable participants to use them as a linearity check. This was therefore the format adopted for subsequent intercomparisons.

Thirty-two laboratories submitted 38 sets of passive detectors to this intercomparison. After exposure to radon and its decay products, the detectors were returned to their originating laboratories for assessment. Participants reported the estimated exposure for each detector before they were notified of the exposures given to the detectors. The intercomparison included three laboratory exposures at different equilibrium factors.

2 EXPOSURE AND MEASUREMENT FACILITIES

HPA-RPD maintains a 43 m^3 walk-in radon chamber (Miles and Strong, 1989) shown in Figure 1. 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 were carried out in this chamber.

The chamber contains a radon atmosphere which can be varied (and held stable) from around 200 Bq m^{-3} to 8000 Bq m^{-3}, depending on the use of various dry and liquid radium-226 sources. A radon concentration of about 4000 Bq m^{-3} is normally maintained in the chamber, and the concentrations of radon and its decay products are continuously monitored. The aerosol conditions and the equilibrium factor in the chamber are altered as required for different studies and calibrations. Table 1 shows the parameters measured and controlled in the chamber.

Three different values of the equilibrium factor (F) between radon and its decay products were obtained for the three laboratory exposures in the intercomparison. To obtain a high value of F in the chamber, the aerosol generator was used to maintain a high aerosol concentration. This reduces the plate-out of radon decay products onto room surfaces. A low equilibrium factor was obtained by running an electrostatic precipitator to remove aerosols and decay products. By running the precipitator fan at low speed an intermediate equilibrium factor was obtained.

The radon concentration in the chamber was continuously monitored using an ATMOS 12 ionisation chamber. This instrument is normally calibrated every 6 months using a radon gas source obtained from the UK National Physical Laboratory (NPL) or the Physikalisch - Technische Bundesanstalt (PTB), Germany.

An Alphaguard ionisation chamber was used as a backup radon monitoring instrument. Radon decay products were sampled onto a Millipore AA filter and their concentrations determined using an alpha particle spectrometry system (Cliff, 1990). All monitored data was automatically transferred to a database. Radon and radon decay product exposures were calculated later.

The total ambient aerosol concentration and size distribution within the radon chamber were monitored using a TSI 3025 condensation nucleus counter connected to a TSI 3040 serial diffusion battery via a TSI 3042 switching valve. The equipment was mounted outside the chamber and the aerosol was sampled inside the chamber at a distance of 30 cm from the wall in order to minimise any plate-out effects. Measurements were carried out twice a day during the exposures, each measurement consisting of four samples, the results being averaged. These average values were then used to calculate the aerosol size distribution using a program developed at NRPB based on the Twomey (Twomey, 1975) method.

3 PASSIVE RADON DETECTORS

Two types of passive etched track radon detector are commonly used, one consisting of a track detector within a closed container, which allows radon-222 to diffuse into it (closed) and the other which consists of naked track-detecting material exposed to the ambient atmosphere (open). The closed detector excludes radon decay products which are present in the ambient atmosphere, and records only those alpha particles generated by the radon entering the container and the decay products formed from it. This form of detector therefore provides a result which is related to the true average radon gas concentration during the time of exposure. In recent years a small number of etched track detector designs which have proven successful have been adopted by laboratories other than those which first developed them, often with some modification. In addition there are now commercial suppliers of complete etched track detector systems, and many laboratories find it simpler to purchase one of these rather than develop their own system.

The open detectors, however, record alpha particles originating from both radon and its decay products in the ambient atmosphere. Their response to radon and its decay products as a function of equilibrium factor, F, depends on the detector material used. Open detectors made from Kodak LR-115 have a sensitivity as a function of F which is intermediate between that of a true radon gas detector and a true Equilibrium Equivalent Radon (EER) detector, being closer to the true radon gas response. Bare CR-39 detectors have a response which depends strongly on F, and are not recommended.

Two types of detector which do not rely on etched tracks were submitted by some laboratories: activated charcoal detectors and electret chambers. The charcoal detectors rely on retaining adsorbed radon for measurement in the originating laboratory. As they must be assessed before the radon they adsorb decays or desorbs, each set was returned at the end of an exposure. 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 issuing laboratory before and after exposure to radon allows the average radon during exposure to be calculated. Because electret radon detectors are also sensitive to gamma and cosmic rays, they are sometimes accompanied by additional detectors sealed in radon-proof bags to allow the gamma and cosmic ray dose-rate to be estimated separately. If such extra detectors are not supplied, the combined gamma and cosmic ray dose rate is estimated on the basis of average gamma ray dose rates and the elevation of the measurement point above sea level.

Thirty-six sets of closed etched track detectors were submitted to the intercomparison. In addition, one set of charcoal detectors and one set of electrets were submitted. The laboratories participating in the intercomparison are listed in Table 2, and the characteristics of the detectors submitted are shown in the appendix.

4 LOGISTICAL ARRANGEMENTS

Participating laboratories were sent sets of 40 labels to attach to their detectors and were asked to send the detectors to HPA-RPD in radon-proof bags if possible. Each label carried a detector number from 1 to 40 and a set number. HPA-RPD assigned the detector numbers 16 to 20 and 36 to 40 to the transit control group and the other 30 numbers at random to one of the three measurement groups. Charcoal and electret detectors were submitted in groups of 15, 20 or 30 rather than 40, using 5 or 10 detectors for each measurement group. No transit controls were used for charcoal detectors. Two laboratories submitting sets of electret detectors provided extra detectors to measure gamma and cosmic ray dose rates.

When a set of detectors was received by HPA-RPD, the detectors were divided up among the four groups and stored in radon-proof bags. The handling of the passive radon detectors during the intercomparison was as follows:

a Sets of 40, 15 or 20 detectors were received from participants.

b If they were not already properly labelled, labels were attached.

c Each set was split into 4 groups of 10 (3 or 4 groups of 5 for charcoal and electret).

d Each group of detectors was sealed in a radon proof bag, which was then sealed inside another radon-proof bag (referred to as double bagging below).

e All bags for exposure 1 were put in a large box, similarly for exposure 2, etc.

f Boxes 1-3 and the box of background detectors were stored in the laboratory, in an average radon concentration of 18 Bq m^{-3}.

g The conditions for exposure 1 were obtained in the chamber.

h The detectors for exposure 1 were taken from the box and set up in plastic trays. Detectors which needed to be mounted on supports were mounted outside the exposure chamber.

i The mounted detectors and those in the trays were taken into the exposure chamber and the detectors set out on two tables in the centre of the chamber over a period of approximately 5 minutes.

j At the end of the exposure the detectors were taken out of the chamber within approximately 5 minutes and set out on benches in the laboratory to allow radon to diffuse out, except for charcoal detectors which were returned to the originating laboratory immediately, and open detectors which were double-bagged.

k After 3 days the detectors were grouped into sets and double-bagged.

l The procedure was repeated for exposures 2 and 3.

m Three days after the third exposure all of the bags of detectors were collected together and grouped according to the originating laboratory. The bags were opened and each group of detectors was double-bagged, all in together if possible.

5 EXPOSURES

The radon exposures were carried out in the radon exposure chamber at HPA-RPD. The appropriate conditions were obtained in the chamber before introducing the detectors. Detectors were placed on or above a table in the centre of the radon chamber (see Figure 2).

The exposures are summarised in Tables 3 and 4 and Figures 3–5. The first exposure was at a high equilibrium factor and lasted 240.7 hours. The second exposure was at a low equilibrium factor for 92.9 hours and the third at an intermediate equilibrium factor for 66.8 hours. The radon and EER concentrations during the exposures are shown in Figures 3–5. The continuously emanating dry sources did not emanate enough radon to achieve a high exposure in a reasonable time, so an additional flow through dry source was used, in conjunction with a pump operating at a flow rate of 1 litre per minute. Because the second exposure continued for longer than charcoal detectors are normally exposed, they were removed from the chamber after 5 days and returned to the originating laboratory.

During the exposures the radon level was monitored continuously by the ATMOS 12 instrument. Measurements of radon decay products were made using the alpha particle spectrometric method on 42 occasions during the first exposure, 21 occasions during the second and 15 during the third. The radon concentration in the laboratory outside the exposure chamber was monitored during the exposures using an Alphaguard Professional monitor. The daily average concentrations ranged from 14 to 23 Bq m^{-3}, with an overall average of 18 Bq m^{-3}. The estimated additional exposure of the detectors caused by leaving them exposed in the laboratory for 3 days to allow radon to diffuse out of them was less than 1% of the exposure in the chamber in all cases and was neglected.

Thoron decay product concentrations were estimated by recounting some of the filter papers overnight, 24 hours after sampling. The highest thoron decay product concentration was found to be <1 Bq m^{-3} equilibrium equivalent thoron during exposure 3.

Temperature and humidity did not vary greatly during the exposures. Figure 6 gives the variation during exposure 2 as an example. The distribution of aerosol sizes for the three exposures is shown in Figure 7. The median thermodynamic diameters of the aerosols during exposure 1 was 116 nm, during exposure 2 was 97 nm and during exposure 3 was 98 nm.

6 RESULTS AND DISCUSSION

Each participant was asked to return results for each detector in terms of kBq m^{-3} h exposure of radon. The results were received by HPA-RPD before the participants were informed of the exposures given. With the exception of the charcoal detectors (which had to be returned immediately at the end of an exposure), participants did not know which detectors were exposed together. To ensure that the results submitted by HPA-RPD (as a participant in the intercomparison) were reported blind as well, they were routed through a third party who renumbered the detectors. The exposures given in the intercomparison were not calculated until after the results for HPA-RPD detectors had been returned and the deadline for return of all results had been passed.

Results were submitted for 30 out of the 38 sets of detectors. Results for eight sets were not received for a variety of reasons, mainly to do with doubts regarding calibrations. A summary of the results is given in Table 5 and Figures 8–11. The mean of the transit exposure results for a set of detectors was subtracted from all other results for that set before calculating the means and standard deviations. Note that in the tables, standard deviations are given as a measure of the spread of a set of results. In the figures the error bars shown are standard errors on each set of results to show whether differences between mean results and the reference levels can be accounted for by variations within a set.

As in previous intercomparisons, the sets of detectors were ranked in an additional table (Table 6). The mean absolute percentage difference and the mean standard deviation between the reported result and the reference value were calculated separately for each set. Sets which recorded <10% for both difference and SD were ranked as category A, sets <15% for both as category B, sets <20% as category C, sets <25% as category D and others as category E. Within each category, sets are ordered using the sum of the mean percentage difference from the reference exposure and the mean percentage standard deviation.

Seventeen sets of etched track detectors achieved the category A rating. All of the sets of etched track detectors in category A are closed, and most use one of the standard designs of holder. The general trend of improvement in the results observed since the 1997 intercomparisons seems to have reached a plateau. A comparison of this table with the equivalent in the reports of recent intercomparisons shows that the number of laboratories achieving results in the top category, A, seems to have stabilised in the region of 40%. However, the number getting results in the lowest category has decreased from 28% to 22% compared to 2005. The median values of the absolute percentage differences and percentage standard deviations found in the three exposures were: for the lowest exposure 11 and 10; for the next exposure 11 and 7; and for the highest exposure 8 and 4. This is broadly in line with previous intercomparisons.

Two additional conclusions can be drawn from the data, though not obvious from the tables. Almost all of the best etched track detector results were obtained using small detector holders (about 2 cm high) and most used electrically conducting holders to prevent electrostatic charges on the holder from affecting the deposition of decay products. It is therefore encouraging that during recent intercomparisons there has been a marked trend towards the use of standard small closed conducting holders among the participants.

It should be noted that errors of bias can in principle be corrected by more accurate calibration, but if there is a large standard deviation on a set of detectors exposed simultaneously this indicates problems which may be more difficult to identify and correct. There are many potential sources of error on individual results, including the effects of shock in partially discharging electrets and problems of proper recognition of etched tracks by automatic image analysers.

Table 7 shows the minimum standard deviations achieved by each of the common detector types, taking the last nine (1997 – 2005) intercomparisons together. These results serve as reference points for each of the detector types. In all cases there were other laboratories using the same combination of holder and detector material which produced much higher standard deviations. The results demonstrate that many laboratories are not achieving the best possible results from their detectors. They also appear to show differences between the best possible results obtainable from each detector type.

As can be seen from Table 2, large numbers of European and other laboratories continue to take part in these passive detector intercomparisons. There has been a general trend of improvement in results which it is hoped will continue. These improvements can be attributed to several factors. One of the most important is for participants to see their results ranked alongside those from other laboratories, so that they can tell immediately whether they are performing better or worse than others. Poor performance provides a strong incentive for improvement. Also the nature of the errors shown by the results allows a participant to identify what may be going wrong. For instance, high standard deviations indicate poor quality control, and possibly electrostatic effects. Consistent deviations from the reference value indicate a calibration error. Variable deviations from the reference value may indicate non-linearity of response. Hence participation in an intercomparison like the one reported here allows a scientist to identify and correct sources of error.

7 ACKNOWLEDGEMENTS

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9 TABLES AND FIGURES

TABLE 1 Parameters measured and controlled in the Health Protection Agency radon chamber

Parameter	Control	Measurement
Temperature	None	Platinum resistance thermometer
Humidity	Humidifier and dehumidifier controlled by humidistats	Capacitive sensor
Aerosol concentration	Carnauba wax aerosol generator, electrostatic precipitator	Ultrafine condensation nucleus counter (TSI 3025)
Aerosol size distribution	Aerosol about 100 nm produced by aerosol generator	Diffusion battery with switching valve
Radon concentration	Dry and liquid radium sources	Ionisation chambers (Atmos 12 DPX and Alphaguard Professional)
Radon decay product concentrations	Use of aerosol generator, electrostatic precipitator with variable speed fan and mixing fans	Sampling on Millipore AA filter, spectrometry using Nazaroff method
Unattached fraction	As for radon decay product concentrations	Sampling on wire screen

TABLE 2 Laboratories participating in the intercomparison

Name	Organisation	Country
H Reisbacka	STUK	Finland
J Andru	Dosirad	France
T R Beck	BfS	Germany
S Nagels	Karlsruhe Research Centre	Germany
E Hulber	Radosys, Ltd.	Hungary
Ms L Currivan	RPII	Ireland
A Parravicini	MI.AM srl	Italy
Dr L Verdi	Agenzia Provinciale Protezione Ambiente	Italy
Dr M Esposito	U-Series Srl	Italy
Dr R Milanesi	Tecnorad S.r.l.	Italy
Dr S Rullo	GAIA Consulting and technologies S.r.l.	Italy
G Torri	APAT	Italy
I Peroni	APPA Tuscany	Italy
M Calamosca	ENEA IRP	Italy
M Magnoni	ARPA Piemonte. Dip. Ivrea	Italy
Dr N Kanno	Japan Chemical Analysis Centre	Japan
M Lecomte	Division de la Radioprotection	Luxembourg
Dr Bente Fjerdingen	Rödmyr Miljösenter	Norway
Dr L Neves	Universidade de Coimbra	Portugal
Ian Donald	Parc RGM	South Africa
V Moreno	Universitat Autònoma de Barcelona	Spain
Dr A Diebitsch	Independia Control AB	Sweden
Per-Arne Svanberg	Pasela miljosupport ab	Sweden
B H Ahern	Radon - One (UK) Ltd	United Kingdom
Chris Perks	Landauer	United Kingdom
Roger Stokes	DRPS	United Kingdom
J Miles	HPA - RPD	United Kingdom
Phil Gilvin	HPA Personal Monitoring Services	United Kingdom

TABLE 3 Air treatment during laboratory exposures

Exposure	1	2	3
Mixing fan	On	On	On
Aerosol generator	On	On	On
Electrostatic precipitator	Low	Off	High

TABLE 4 Exposure durations and magnitudes

Exposure	1	2	3
Duration (h)	240.67	92.92	68.83
Radon exposure (kBq m^{-3} h)	1719	320	177
Uncertainty (%)*	5	5	5
EER exposure (kBq m^{-3} h)	1375	54	74
Uncertainty (%)*	7	7	7
F	0.80	0.17	0.42

* Estimated uncertainty at 68% confidence level. For radon gas exposure this is estimated from the contributions to uncertainty on measurements with the Atmos 12 instrument: volume of calibration vessel, 3.1%, counting statistics, 3%, radon gas source, 1.5%. Using the standard method of combining these uncertainties yields a total uncertainty of 4.6% rounded to 5%. The method of estimating uncertainty on radon decay product measurements is given by Cliff (1990).

Notes to Tables 5, 6 and 7

a The results for Set 48 – 1 are for charcoal detectors which were exposed separately for exposure 2. The reference result for these detectors is 827 kBq m^{-3} h. In Figure 11 these results are normalised to a reference value of 1719, for comparison with other detector sets.

b The set numbers were chosen randomly and do not follow the order of laboratories in Table 2.

c The transit group is the group of 10 detectors returned unexposed.

d The mean result for exposed detectors is the mean after subtracting the mean transit exposure.

e % SD is the percentage standard deviation.

f % Diff is the percentage difference between the reference value and the mean reported.

g In Table 6 the Mean % diff and Mean % SD are the means of the three absolute values given for a set in Table 5.

h In Table 6, 'Sum' is the sum of Mean % diff and Mean % SD.

i There are no results for exposure 1 and for set 159 - 1. This is because this set was received after the start of the exposures.

TABLE 5 Radon results from passive detectors

	Transits		Exposure 1			Exposure 2			Exposure 3		
Set ID	Mean	SD	Mean	% Diff	%SD	Mean	% Diff	%SD	Mean	% Diff	%SD
1 - 1	11.10	3.87	1749.3	1.76	2.85	326.30	1.97	2.85	176.60	-0.23	3.49
7 - 1	16.80	9.27	1627.7	-5.31	3.09	300.60	-6.06	6.94	162.60	-8.14	12.90
10 - 1	0.00	0.00	1462.3	-14.93	2.62	247.80	-22.56	5.24	105.50	-40.40	8.35
14 - 1	36.30	7.06	1518.3	-11.68	4.60	312.20	-2.44	12.24	149.70	-15.42	8.16
15 - 1	8.60	7.86	1660.6	-3.40	2.60	316.70	-1.03	5.06	174.80	-1.24	9.79
15 - 2	16.67	11.54	1721.1	0.12	5.10	326.03	1.89	5.10	182.93	3.35	9.49
16 - 1	11.10	3.35	1737.2	1.06	2.79	359.60	12.38	4.99	183.20	3.50	8.92
17 - 1			1420.9	-17.34	1.86	209.70	-34.47	7.18	115.20	-34.92	8.35
19 - 1	50.90	26.21	1402.5	-18.41	3.81	253.40	-20.81	4.40	141.30	-20.17	10.51
23 - 1	33.40	7.01	1896.7	10.34	2.46	355.50	11.09	5.51	193.20	9.15	9.63
25 - 1	160.90	17.22	1494.9	-13.04	3.02	249.00	-22.19	9.04	145.20	-17.97	13.87
26 - 3	50.60	13.38	1941.2	12.93	3.88	364.50	13.91	36.01	195.10	10.23	13.84
28 - 1	284.20	21.01	2060.8	19.88	4.32	362.30	13.22	38.34	221.40	25.08	25.58
28 - 2	23.90	15.80	1798.1	4.60	33.08	362.10	13.16	18.14	196.50	11.02	17.17
30 - 1	15.80	7.89	1473.9	-14.26	6.23	316.40	-1.13	8.70	170.10	-3.90	15.11
40 - 1	7.60	1.51	1739.7	1.20	13.27	309.50	-3.28	9.28	170.00	-3.95	7.11
48 - 1			848.60	2.61	1.48	345.40	7.94	2.44	185.60	4.86	1.73
54 - 1	120.10	72.60	2292.0	33.33	9.46	428.70	33.97	9.58	250.40	41.47	23.60
62 - 1	13.20	4.85	1745.2	1.52	4.62	372.00	16.25	5.46	196.30	10.90	4.69
125 - 1	24.70	6.40	1811.8	5.40	3.74	321.40	0.44	11.37	195.20	10.28	9.56
129 - 1	15.60	6.67	1677.0	-2.44	4.50	284.00	-11.25	6.99	159.00	-10.17	10.09
129 - 2	20.80	17.22	1637.8	-4.72	4.21	282.50	-11.72	7.69	150.00	-15.25	5.56
134 - 1			1503.4	-12.54	10.06	379.00	18.44	11.19	292.80	65.42	41.85
139 - 1	4.40	1.78	1494.4	-13.06	2.00	291.90	-8.78	8.60	165.00	-6.78	7.77
141 - 1	0.00	0.00	1634.9	-4.89	3.39	291.00	-9.06	2.66	155.50	-12.15	5.19
144 - 1	29.50	4.86	1820.1	5.88	2.43	326.40	2.00	5.67	180.50	1.98	8.24
152 - 1	0.00	0.00	1680.40	-2.25	3.84	312.60	-2.31	3.90	167.10	-5.59	7.86
156 - 1	21.70	5.42	1110.3	-35.41	5.11	247.10	-22.78	12.53	142.80	-19.32	7.49
157 - 1	20.50	3.41	1663.90	-3.21	7.55	302.30	-5.53	9.59	171.10	-3.33	9.34
157 - 2	20.10	4.56	1746.50	1.60	7.08	321.30	0.41	7.93	164.80	-6.89	12.01
158 - 1	2.80	2.30	931.60	-45.81	4.31	164.50	-48.59	5.84	96.10	-45.71	10.56
159 - 1	32	10.5							15.00	-35.03	17:00
Reference value:			1719			320			177		

Note: All reference values and mean values for exposure groups are in units of kBq m^{-3} h.

TABLE 6 Results ranked by category

Rating	Set ID	Mean % diff	Mean % SD	Sum	Holder type	Filter	Detector type	Detector material
A	1 - 1	1.32	3.06	4.4	Closed		NRPB/SSI	CR39
A	48 - 1	5.14	1.89	7.02	Open		Canister	Charcoal
A	15 - 1	1.89	5.82	7.71	Closed		TASL	CR39
A	15 - 2	1.79	6.56	8.35	Closed		ANPA	LR115
A	152 - 1	3.38	2.20	8.58	Closed		TASL	CR39
A	144 - 1	3.29	5.45	8.73	Closed		Radosys	CR39
A	16 - 1	5.65	5.57	11.2	Closed		Radosys	CR39
A	157 - 2	2.97	9.01	12.0	Closed	Yes	KfK FN	Makrofol
A	141 - 1	8.70	3.74	12.4	Closed		TASL	CR39
A	40 - 1	2.81	9.89	12.7	Closed		NRPB	CR39
A	157 - 1	4.02	8.82	12.8	Closed	Yes	KfK FN	Makrofol
A	125 - 1	5.37	8.23	13.6	Closed		Radosys	CR39
A	7 - 1	6.50	7.64	14.1	Closed		TASL	CR39
A	62 - 1	9.56	4.92	14.4	Closed	Yes	Own	CR39
A	129 - 1	7.95	7.19	15.1	Closed		Own	CR39
A	139 - 1	9.54	6.12	15.6	Closed		Radosys	CR39
A	14 - 1	9.85	8.33	18.1	Closed		NRPB/SSI	CR39
B	23 - 1	10.19	5.87	16.0	Closed		NRPB/SSI	CR39
B	129 - 2	10.57	5.82	16.3	Closed		Own	CR39
B	30 - 1	6.43	10.01	16.4	Closed	Yes	KfK FN	Makrofol
C	19 - 1	19.80	6.24	26.0	Closed		ANPA	LR115
C	25 - 1	17.73	8.65	26.3	Closed		Own	LR115
C	26 - 3	12.35	17.91	30.2	Closed	Yes	Own	Makrofol
D	28 - 2	9.59	22.80	32.3	Closed		ANPA	LR115
D	28 - 1	19.40	22.74	42.1	Closed		Radosys	CR39
E	10 - 1	25.96	5.40	31.3	Closed		NRPB/SSI	CR39
E	156 - 1	25.84	8.38	34.2	Closed	Yes	KfK FN	Makrofol
E	17 - 1	28.91	5.80	34.7	Closed	Yes	Own	CR39
E	54 - 1	36.26	14.21	50.4	Closed		Own	CR39
E	159 - 1	35.03	17.00	52.0	Closed		Radosys	CR39
E	134 - 1	32.13	21.03	53.1	Closed		E-perm (L)	Electret
E	158 - 1	46.70	6.90	53.6	Closed		TASL	CR39

Note: The holder design refers to the company or organisation which first designed the detector. Some designs are used by several laboratories. The name of some organisations has changed since the detectors were first designed. The name used for the holder design has not been updated (eg HPA for NRPB) to ensure consistency with previous intercomparison reports.

TABLE 7 Minimum standard deviations achieved by different common detector types in all intercomparisons since 1997

Holder design	Detector material	Minimum mean % SD
Canister	Activated charcoal	1.0
E-Perm L	Electret	2.3
NRPB/SSI	CR-39/PADC	2.7
Karlsruhe FN	Polycarbonate	4.3
NRPB	CR-39/PADC	4.6
ANPA	Cellulose nitrate	4.7

Note: Measuring laboratories were not aware which detectors were exposed together to the same radon level, except in the case of activated charcoal detectors, which had to be returned immediately at the end of each exposure to avoid excessive loss of absorbed radon by decay.

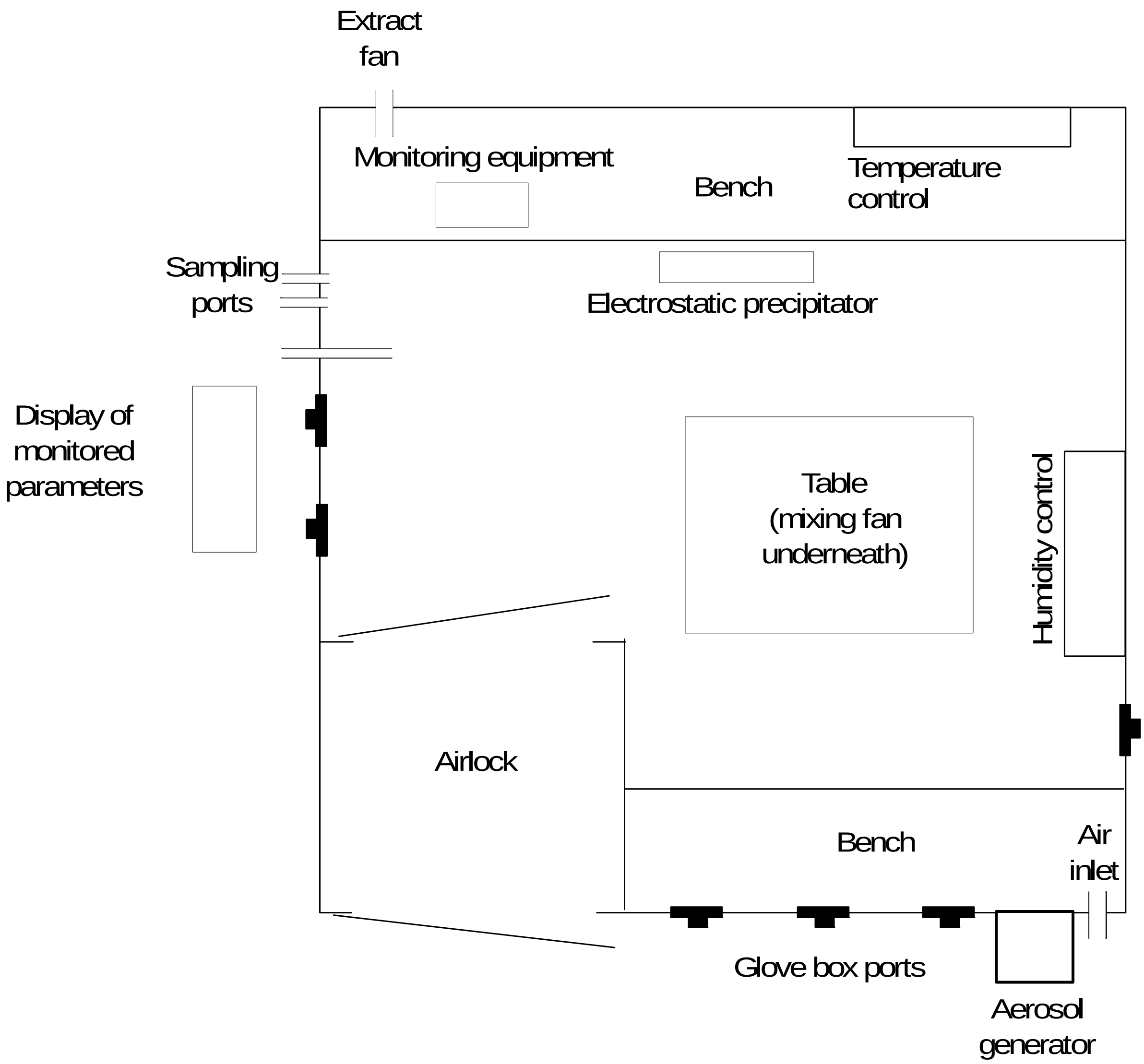


FIGURE 1 The Health Protection Agency radon chamber

FIGURE 2 Detectors during an exposure

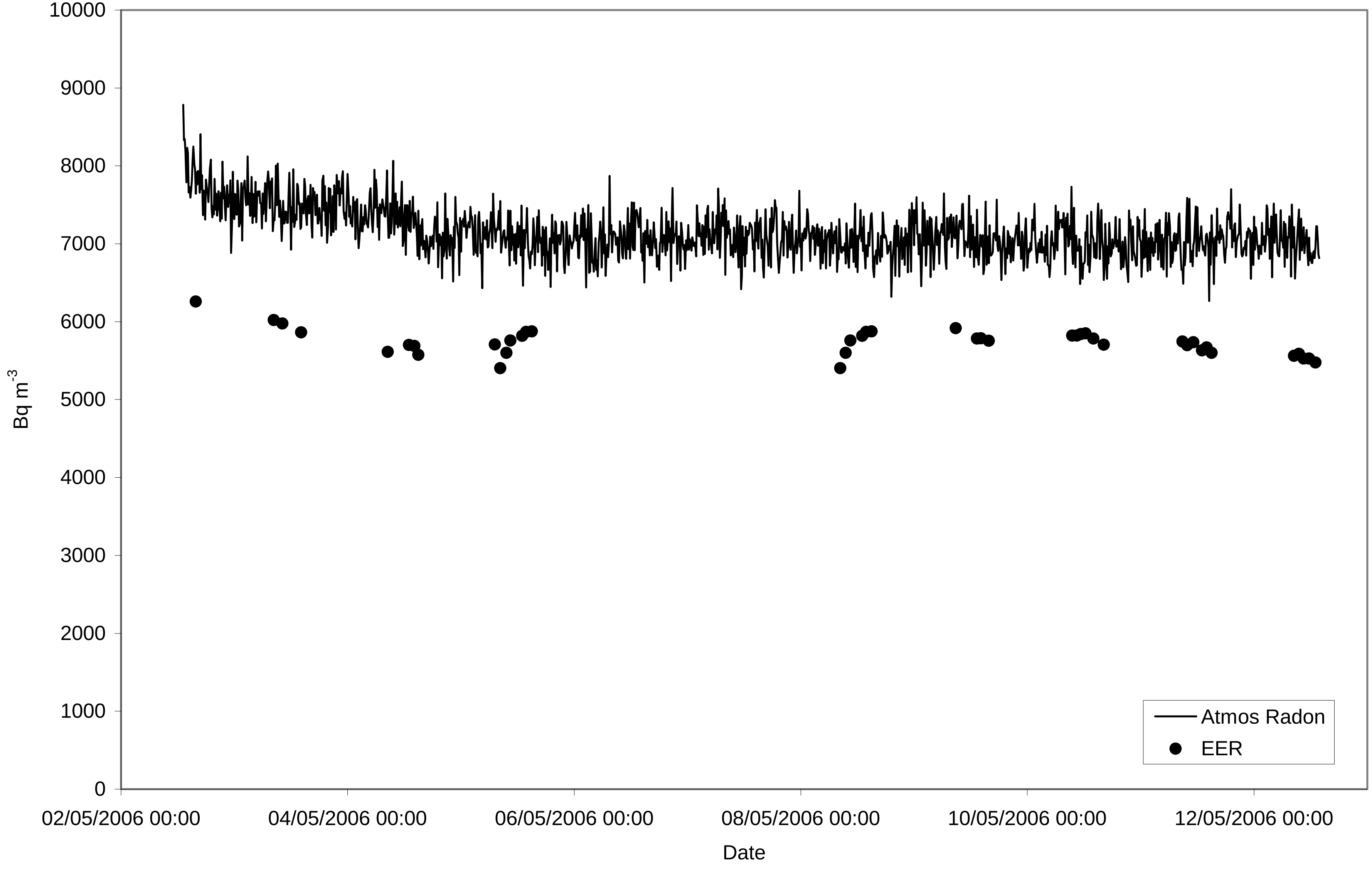


FIGURE 3 Radon and EER concentrations exposure 1

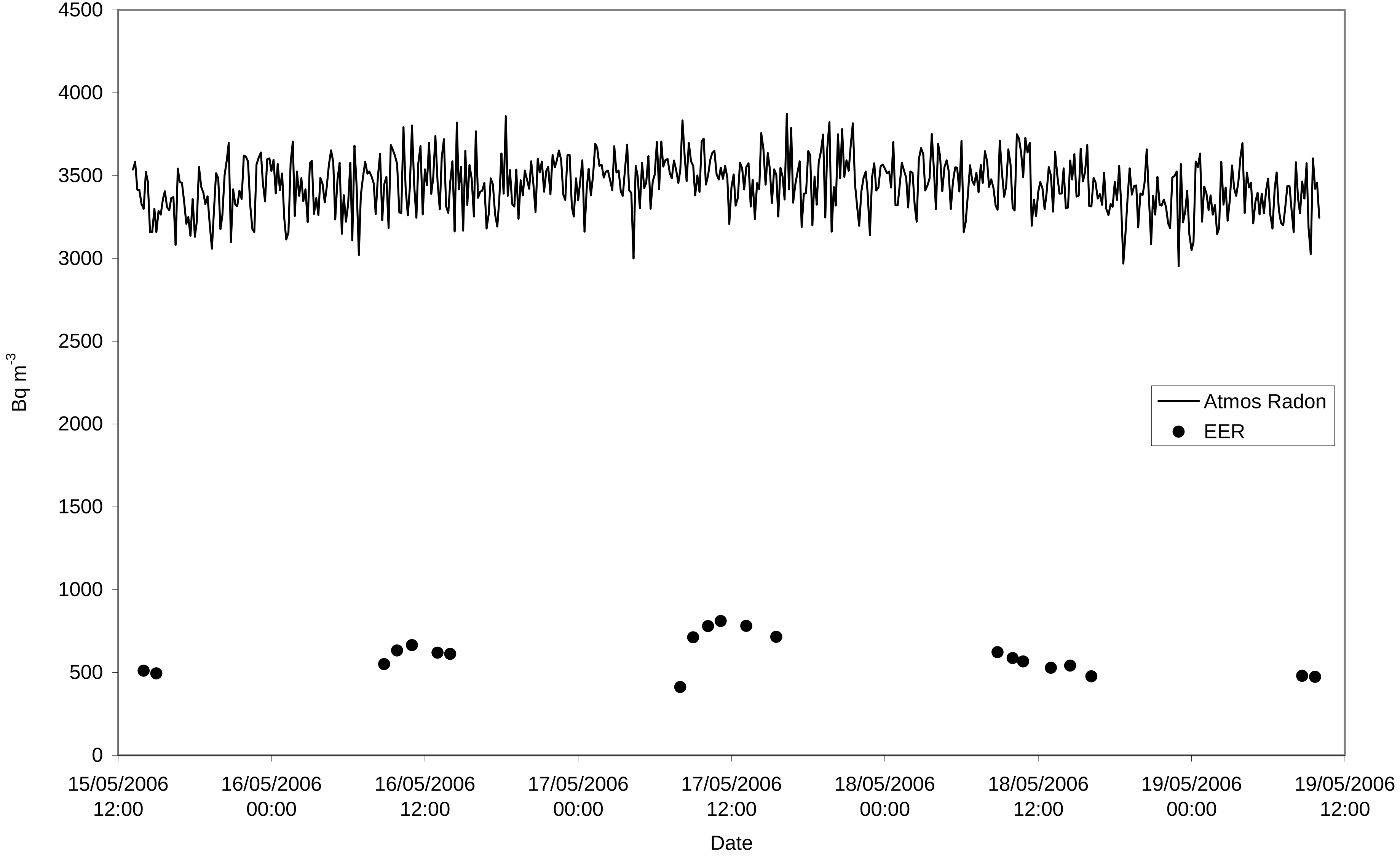


FIGURE 4 Radon and EER concentrations exposure 2

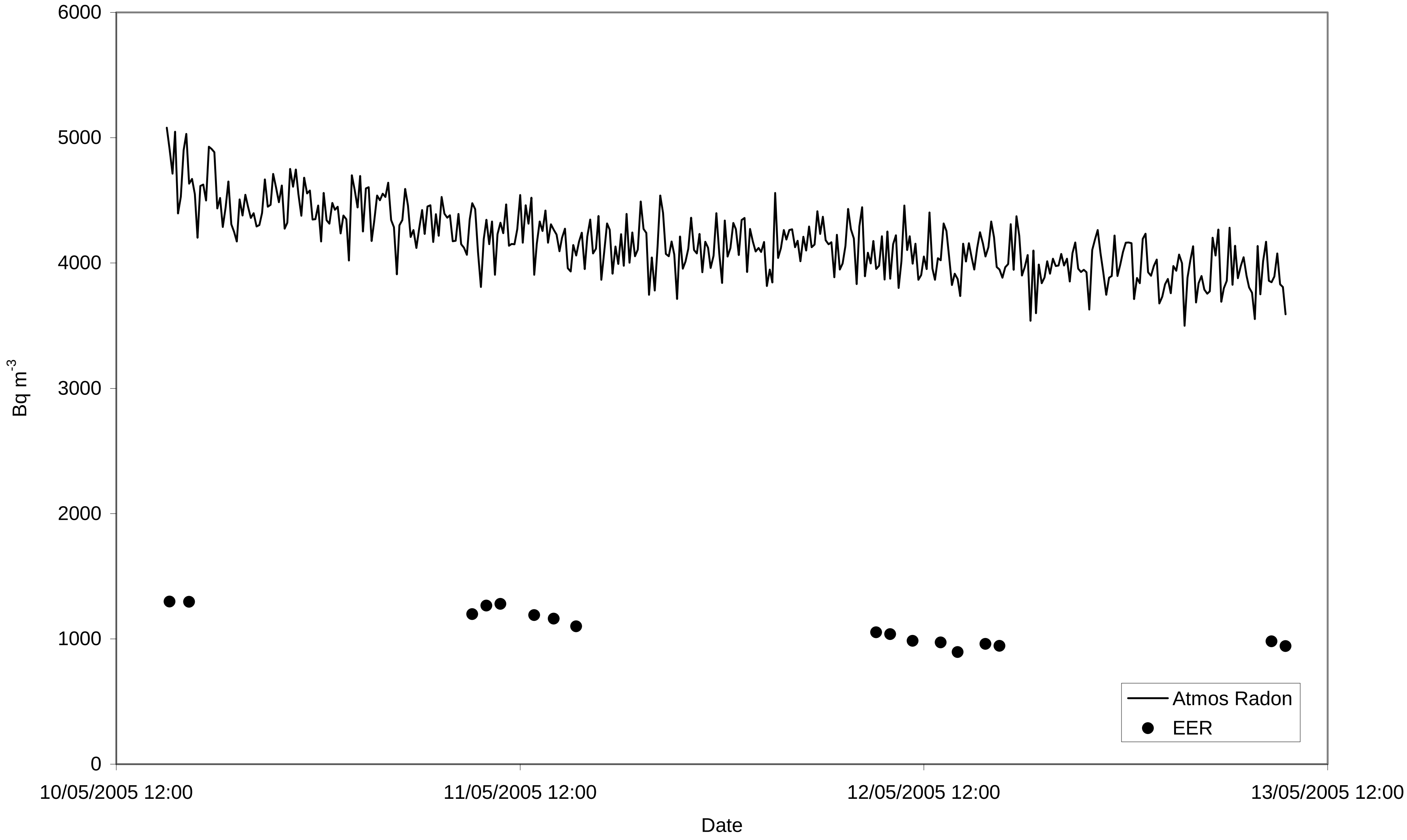


FIGURE 5 Radon and EER concentrations exposure 3

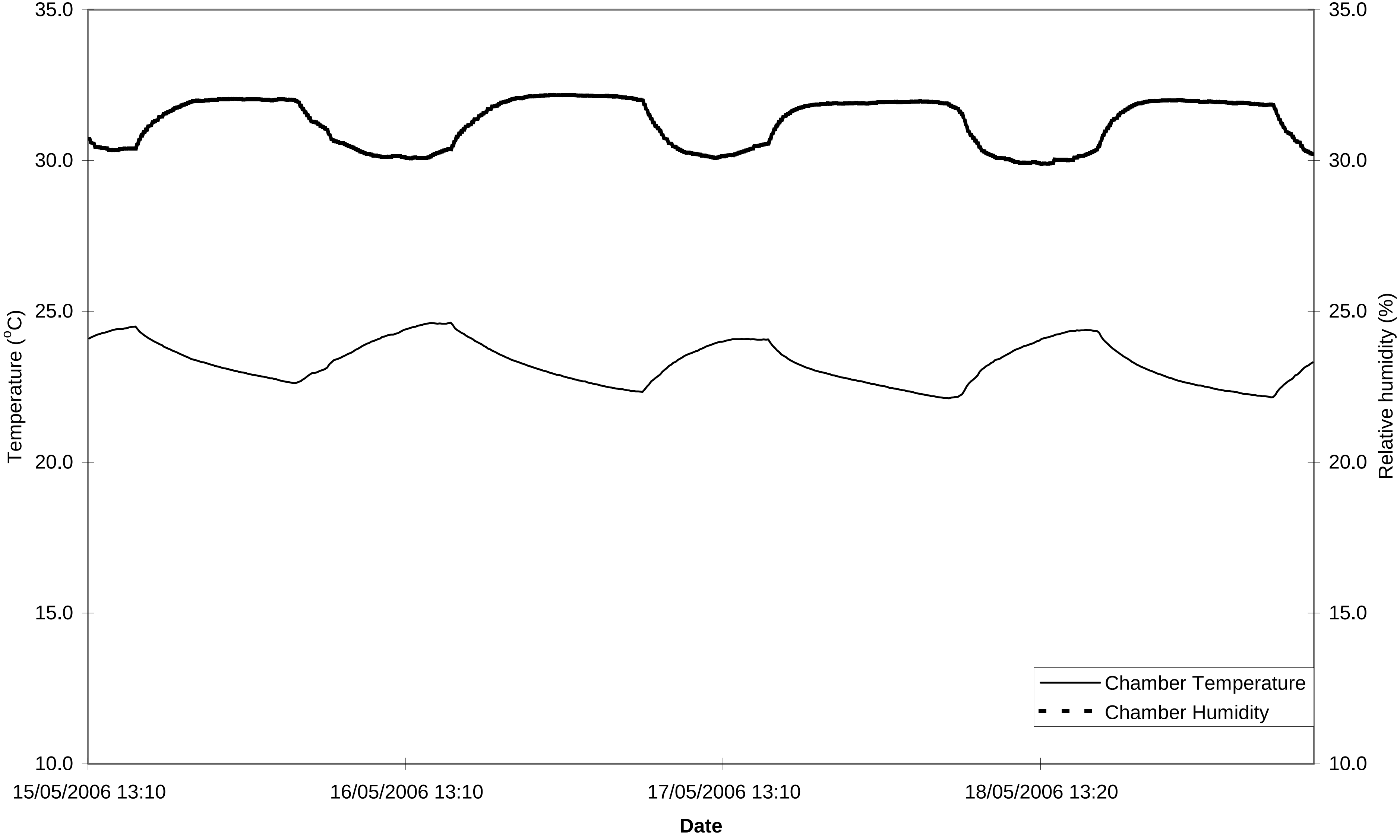


FIGURE 6 Temperature and relative humidity in the chamber during exposure 3

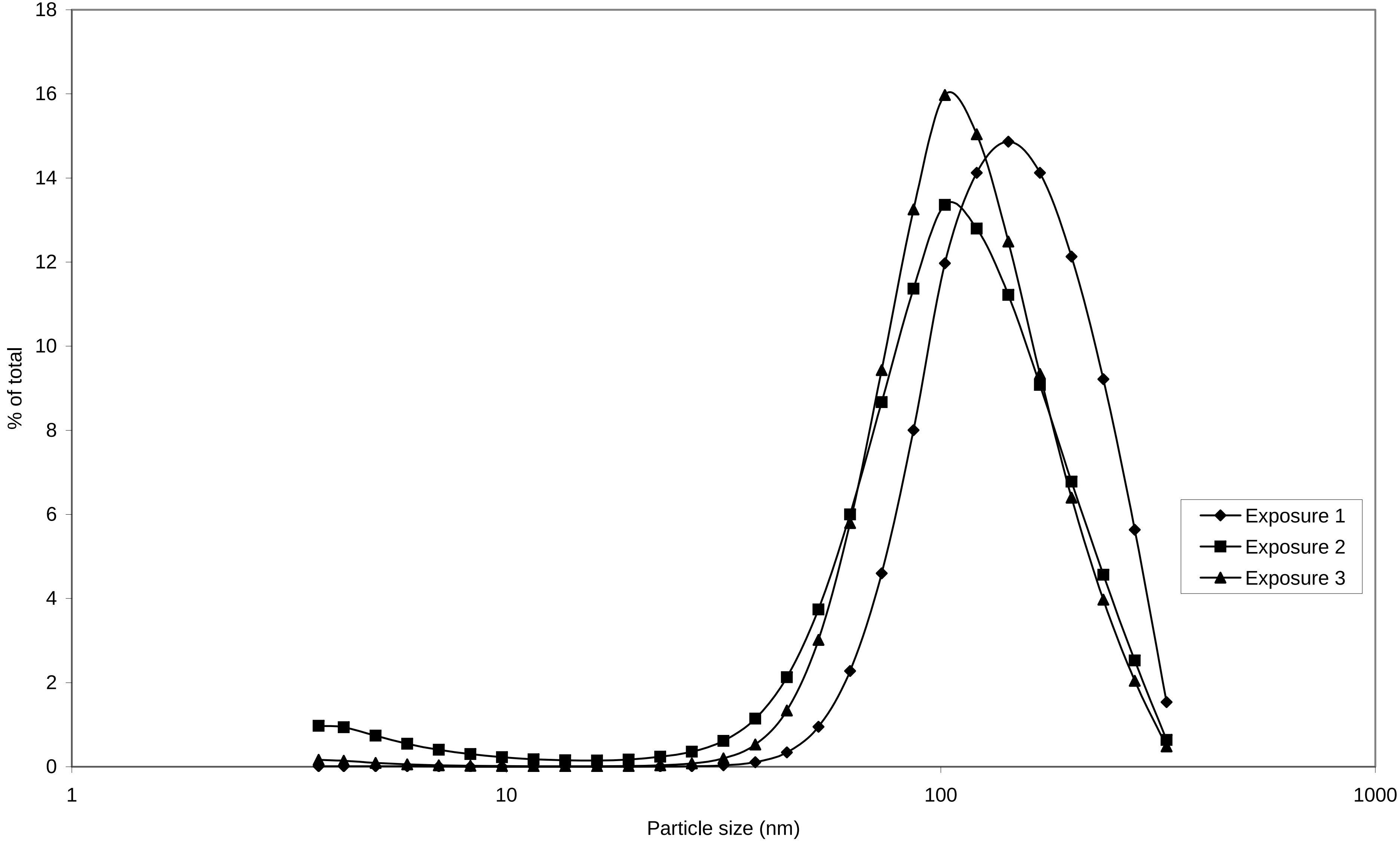


FIGURE 7 Ambient aerosol size distributions during exposures 1, 2 and 3

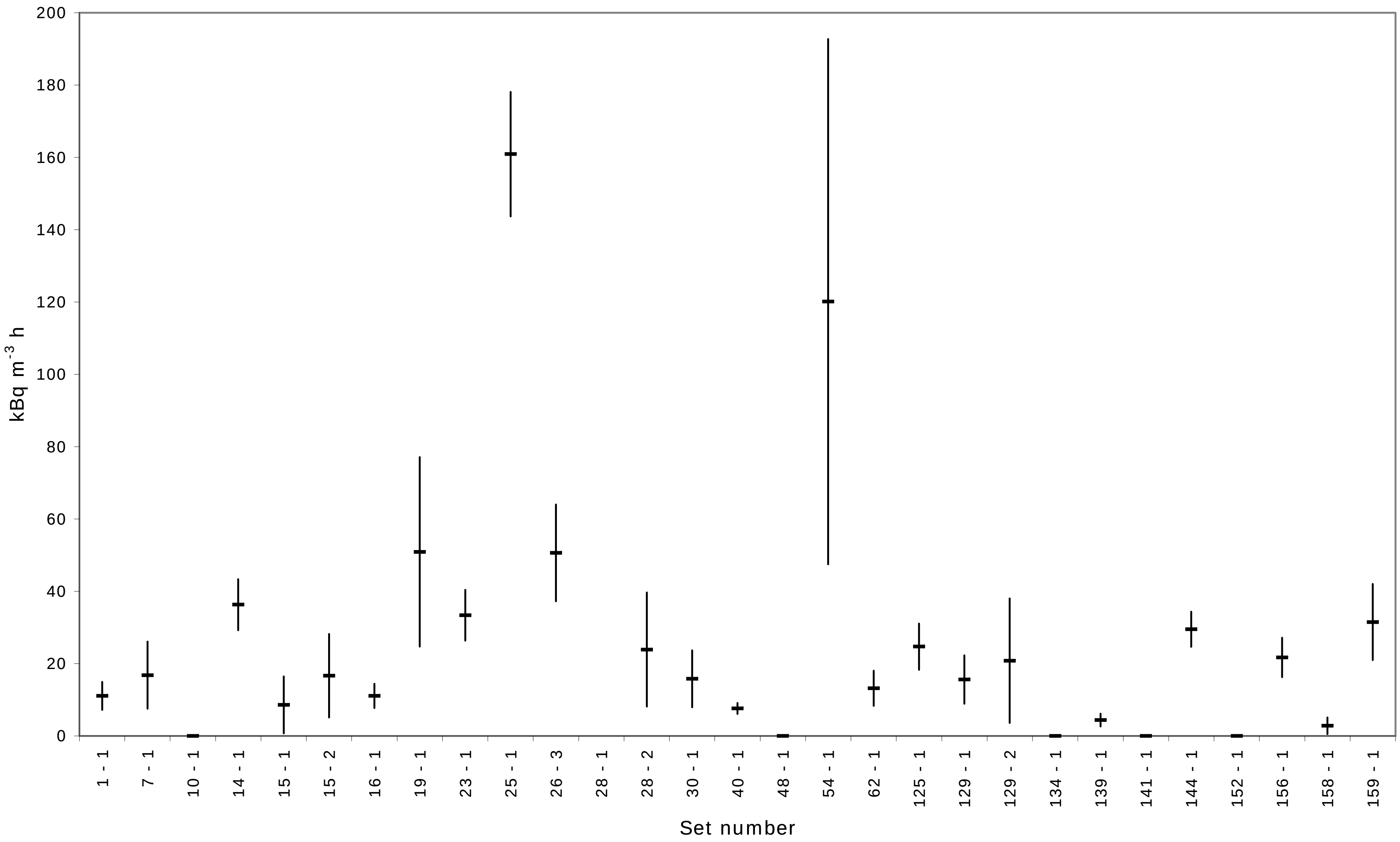


FIGURE 8 Results for transit detectors

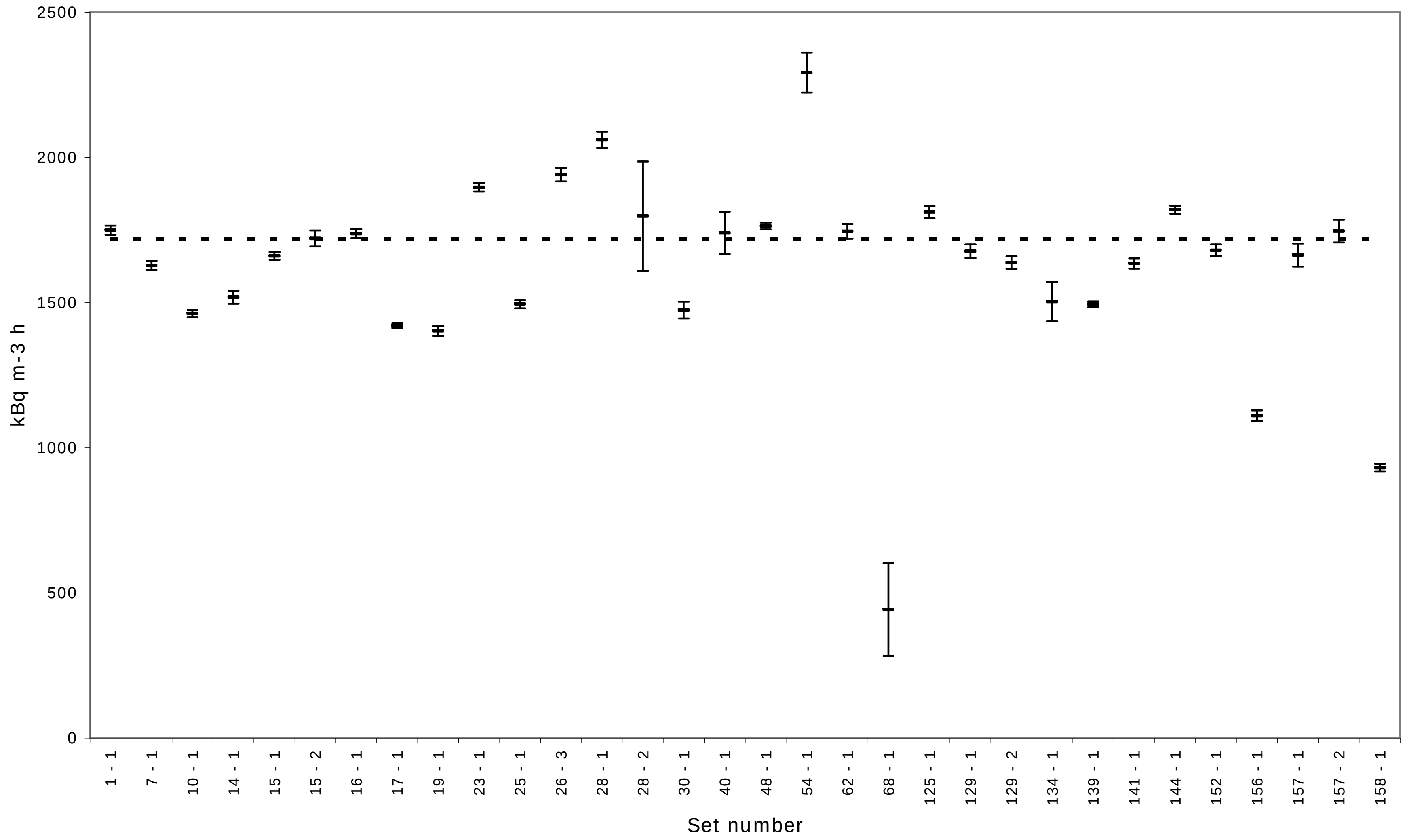


FIGURE 9 Detector results with standard error exposure 1

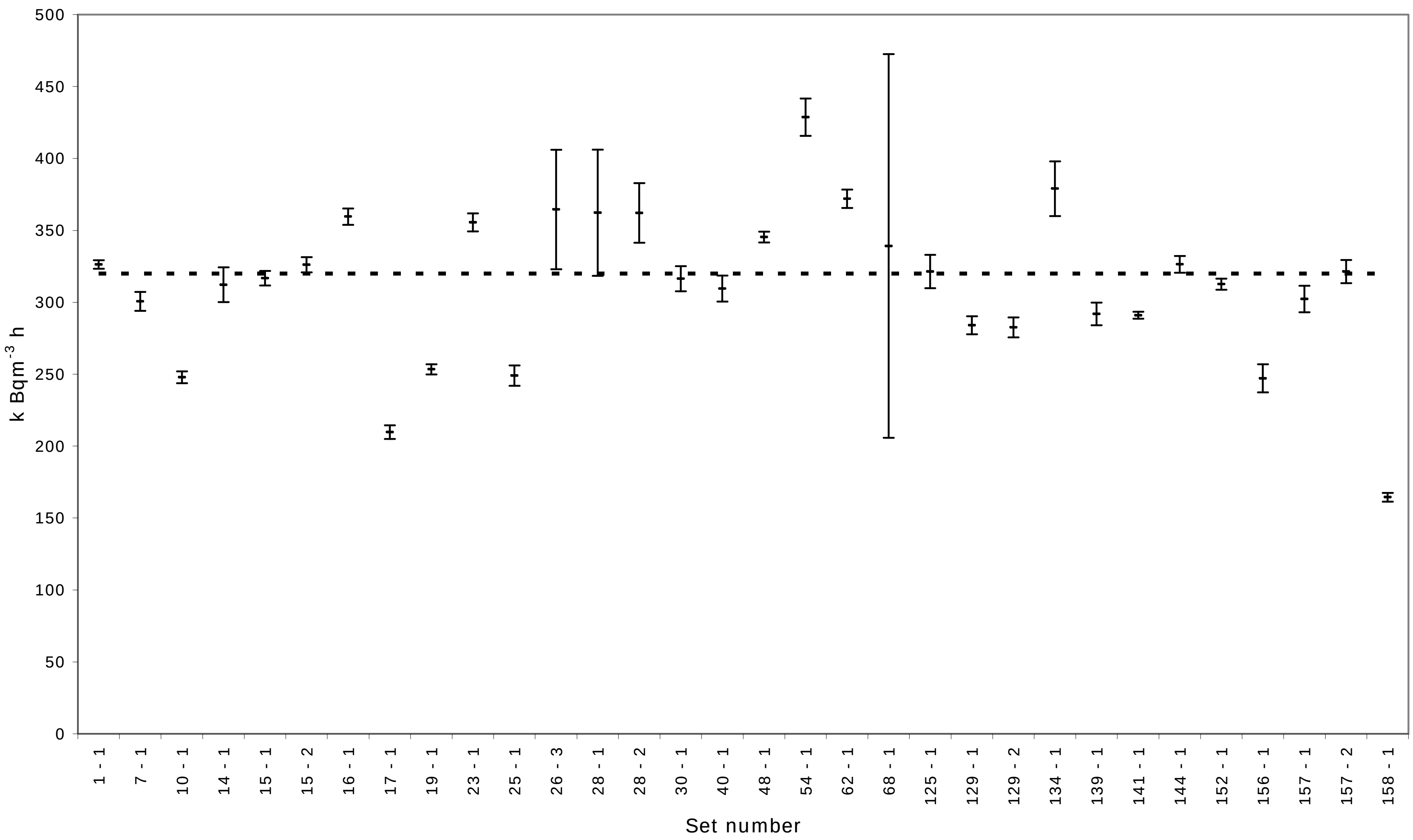


FIGURE 10 Detector results with standard error exposure 2

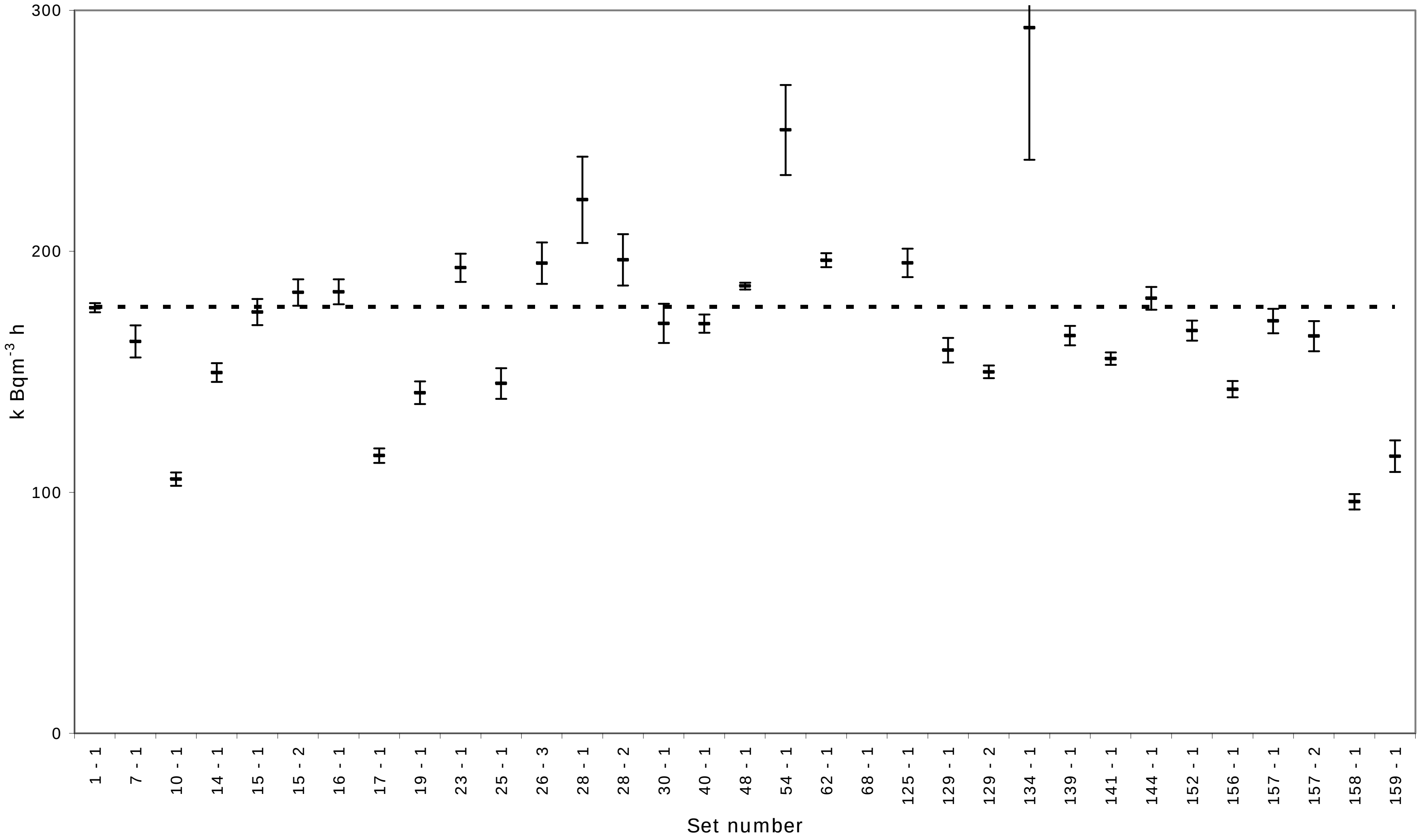


FIGURE 11 Detector results with standard error exposure 3

APPENDIX

Characteristics of detectors used in the intercomparison

Laboratory:
Dosirad
Villa Parc, Le chene
rue Lech Walesa
F - 77185 Lognes
France

Scientists:	Jean Andru
Contact:	Jean Andru
Telephone:	+33 1 60 17 92 13
Fax:	+33 1 60 17 91 96
Email:	dosirad@wanadoo.fr

Calibration and exposure:	
Calibration method:	Simulated radon source
Typical calibration exposure (kBq h-m^{-3})	1000
Normal exposure duration (days)	
Normal exposure range (kBq h m^{-3})	60 - 40 000
Quoted uncertainty in this range	<15%
Basis of uncertainty (eg 95% CL)	1.35 * SD

Detector application:	
Used for dwellings?	Yes
Used for workplaces?	Yes
Used for mines/caves?	Yes
Used for outdoor?	Yes
Used for soil?	
Routine/experimental?	Experimental

Characteristics:	
Holder type	Closed without filter
Holder design	Own
Holder antistatic measures	Conducting holder
Detector antistatic measures	None

Detector characteristics:	
Detector material	LR 115
Detector thickness (mm)	12 µm
Detector size (mm^{-2})	100

Etching	Chemical/ pre-etch	Electro-chemical
Time (h)	1h 30min	
Solution	NaOH	
Strength (%)	10%	
Temperature ^{o}C	60	
Chemical stirring?	Yes	
Field (kV cm^{-1})		
Frequency (kHz)		

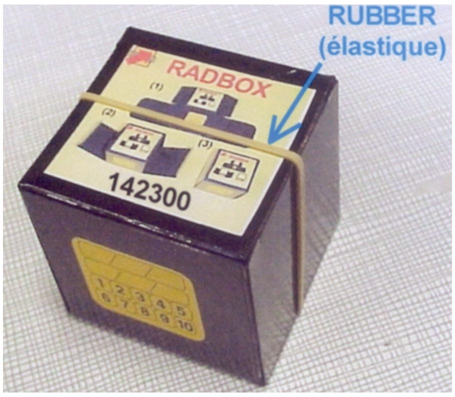
Detector performance:	
Sensitivity (tracks/cm^{2}/kBq h m^{-3})	1.50
Typical background (kBq h m^{-3})	4
SD on background (kBq h m^{-3})	3
Saturation (MBq h m^{-3})	60

Track counting:	
Manual (M) or Automatic (A):	
Area of one counting field (mm^{-2}):	
Number of fields counted per detector:	
OR minimum number of tracks counted:	
Autofocus:	
Correction for non-linearity:	

Light level stabilisation for automatic counters:	
Constant voltage:	
Constant current:	
Constant light output:	
Regular check of reference detector:	

Reference:

Detector:



Laboratory:
BfS
Dienststelle Berlin
Köpernicker Allee 120 - 130
10318 Berlin
Germany

Scientists:	Dr T Beck
Contact:	E Foerster
Telephone:	+49 1888 333 4221
Fax:	+49 1888 333 4215
Email:	efoerster@bfs.de

Calibration and exposure:	
Calibration method:	Radon calibration chamber
Typical calibration exposure (kBq h m^{-3})	50 - 60 000
Normal exposure duration (days)	90 - 180
Normal exposure range (kBq h m^{-3})	50 - 60 000
Quoted uncertainty in this range	<20%
Basis of uncertainty (eg 95% CL)	95% CL

Detector application:	
Used for dwellings?	Yes
Used for workplaces?	Yes
Used for mines/caves?	No
Used for outdoor?	Yes
Used for soil?	No
Routine/experimental?	Routine

Characteristics:	
Holder type	Closed with filter
Holder design	Own
Holder antistatic measures	Conducting holder
Detector antistatic measures	None

Detector characteristics:	
Detector material	Makrofol
Detector thickness (mm)	0.3
Detector size (mm^{-2})	1000

Etching	Chemical/ pre-etch	Electro-chemical
Time (h)		1.5/0.75
Solution		KOH/EtOH
Strength (%)		40:60
Temperature ^oC		
Chemical stirring?		
Field (kV cm^{-1})		4
Frequency (kHz)		100 - 3000

Detector performance:	
Sensitivity (tracks/cm^2/kBq h m^{-3})	1.6
Typical background (kBq h m^{-3})	25
SD on background (kBq h m^{-3})	6
Saturation (MBq h m^{-3})	6

Track counting:	
Manual (M) or Automatic (A):	Automatic
Area of one counting field (mm^{-2}):	
Number of fields counted per detector:	
OR minimum number of tracks counted:	0
Autofocus:	No
Correction for non-linearity:	Yes

Light level stabilisation for automatic counters:	
Constant voltage:	
Constant current:	
Constant light output:	
Regular check of reference detector:	

Reference:

Detector:

Laboratory:
Radosys, Ltd.
Vegyesz U. 17-25
H-1116 Budapest
Hungary

Scientists:	E. Hulber, D. Selmeczi
Contact:	E. Hulber
Telephone:	++36 1 2030878
Fax:	++36 1 2030879
Email:	ehulber@radosys.com

Calibration and exposure:	
Calibration method:	detectors returned at intercomparison
Typical calibration exposure (kBq h m^{-3})	300
Normal exposure duration (days)	50 to 100
Normal exposure range (kBq h m^{-3})	100 to 5000
Quoted uncertainty in this range	below 20%
Basis of uncertainty (eg 95% CL)	

Detector application:	
Used for dwellings?	Yes
Used for workplaces?	Yes
Used for mines/caves?	
Used for outdoor?	
Used for soil?	
Routine/experimental?	Routine

Characteristics:	
Holder type	Closed without filter
Holder design	Radosys
Holder antistatic measures	Conducting holder
Detector antistatic measures	Dip in antistatic solution

Detector characteristics:	
Detector material	CR39
Detector thickness (mm)	1
Detector size (mm^{-2})	100

Etching	Chemical/ pre-etch	Electro-chemical
Time (h)	4	
Solution	NaOH	
Strength (%)	25	
Temperature ^{o}C	90	
Chemical stirring?	Yes	
Field (kV cm^{-1})		
Frequency (kHz)		

Detector performance:	
Sensitivity (tracks/cm^2/kBq h m^{-3})	2.1
Typical background (kBq h m^{-3})	19
SD on background (kBq h m^{-3})	8
Saturation (MBq h m^{-3})	6.5

Track counting:	
Manual (M) or Automatic (A):	
Area of one counting field (mm^{-2}):	
Number of fields counted per detector:	
OR minimum number of tracks counted:	0
Autofocus:	Yes
Correction for non-linearity:	No

Light level stabilisation for automatic counters:	
Constant voltage:	No
Constant current:	No
Constant light output:	Yes
Regular check of reference detector:	Yes

Reference:

Detector:

Laboratory:
R.P.I.I
3 Clonskeagh Square
Clonskeagh Road
Dublin 14
Ireland

Scientists:	Mairin O'Colmain, Olwyn Hanley
Contact:	Lorraine Currivan
Telephone:	++353 1 2697766
Fax:	
Email:	lcurrivan@rpii.ie

Calibration and exposure:	
Calibration method:	RPII Radon Chamber
Typical calibration exposure (kBq h m^{-3})	500
Normal exposure duration (days)	90 to 270
Normal exposure range (kBq h m^{-3})	30 to 7000
Quoted uncertainty in this range	15
Basis of uncertainty (eg 95% CL)	1 SD

Detector application:	
Used for dwellings?	Yes
Used for workplaces?	Yes
Used for mines/caves?	Yes
Used for outdoor?	
Used for soil?	
Routine/experimental?	Routine

Characteristics:	
Holder type	Closed without filter
Holder design	NRPB/SSI
Holder antistatic measures	Conducting holder
Detector antistatic measures	Antistatic dip

Detector characteristics:	
Detector material	Cr39
Detector thickness (mm)	1
Detector size (mm^{-2})	481

Etching	Chemical/ pre-etch	Electro-chemical
Time (h)	8	
Solution	NaOH	
Strength (%)	25	
Temperature ^{o}C	75	
Chemical stirring?	No	
Field (kV cm^{-1})		
Frequency (kHz)		

Detector performance:	
Sensitivity (tracks/cm^2/kBq h m^{-3})	2.7 - 2.9
Typical background (kBq h m^{-3})	11
SD on background (kBq h m^{-3})	6
Saturation (MBq h m^{-3})	27

Track counting:	
Manual (M) or Automatic (A):	
Area of one counting field (mm^{-2}):	
Number of fields counted per detector:	
OR minimum number of tracks counted:	0
Autofocus:	Yes
Correction for non-linearity:	Yes

Light level stabilisation for automatic counters:	
Constant voltage:	Yes
Constant current:	No
Constant light output:	No
Regular check of reference detector:	Yes

Reference:

Detector:

Laboratory:
ENEA ION-IRP
V. dei Colli 16
40136 Bologna -BO
Italy

Scientists:	M. Calamosca, S. Penzo
Contact:	M. Calamosca
Telephone:	++39-051-6098361
Fax:	++39-051-6098003
Email:	Radon@bologna.enea.it

Calibration and exposure:	
Calibration method:	NRPB radon chamber
Typical calibration exposure (kBq h m^{-3})	200 - 600 - 2000
Normal exposure duration (days)	30 to 180
Normal exposure range (kBq h m^{-3})	0 to 10000
Quoted uncertainty in this range	<10
Basis of uncertainty (eg 95% CL)	68% C L

Detector application:	
Used for dwellings?	Yes
Used for workplaces?	Yes
Used for mines/caves?	Yes
Used for outdoor?	Yes
Used for soil?	
Routine/experimental?	Routine

Characteristics:	
Holder type	Closed without filter
Holder design	Own
Holder antistatic measures	Conducting holder
Detector antistatic measures	Aluminised foil

Detector characteristics:	
Detector material	CR39
Detector thickness (mm)	1.4
Detector size (mm^{-2})	900

Etching	Chemical/pre-etch	Electro-chemical
Time (h)	6	
Solution	NaOH	
Strength (%)	20.8	
Temperature ^{o}C	70	
Chemical stirring?	Yes	
Field (kV cm^{-1})		
Frequency (kHz)		

Detector performance:	
Sensitivity (tracks/cm^2/kBq h m^{-3})	4.26 ±0.04
Typical background (kBq h m^{-3})	6.9
SD on background (kBq h m^{-3})	1.4
Saturation (MBq h m^{-3})	22

Track counting:	
Manual (M) or Automatic (A):	Automatic
Area of one counting field (mm^{-2}):	
Number of fields counted per detector:	
OR minimum number of tracks counted:	0
Autofocus:	Yes
Correction for non-linearity:	Yes

Light level stabilisation for automatic counters:	
Constant voltage:	Yes
Constant current:	No
Constant light output:	Yes
Regular check of reference detector:	Yes

Reference:
M. Calamosca, S. Penzo and G. Gualdrini "The features of the new radon gas CR-39 dosemeter developed at the ENEA Institute of Radioprotection" Radiat. Meas. 36 (2003) 221 – 224

Detector:

Laboratory:	
ENEA ION-IRP	
V. dei Colli 16	
40136 Bologna -BO	
Italy	

Scientists:	M. Calamosca, S. Penzo
Contact:	M. Calamosca
Telephone:	++39-051-6098361
Fax:	++39-051-6098003
Email:	Radon@bologna.enea.it

Calibration and exposure:	
Calibration method:	NRPB radon chamber
Typical calibration exposure (kBq h m^{-3})	200 - 600 - 2000
Normal exposure duration (days)	30 to 180
Normal exposure range (kBq h m^{-3})	0 to 10000
Quoted uncertainty in this range	<10
Basis of uncertainty (eg 95% CL)	68% C L

Detector application:	
Used for dwellings?	Yes
Used for workplaces?	Yes
Used for mines/caves?	Yes
Used for outdoor?	Yes
Used for soil?	
Routine/experimental?	Routine

Characteristics:	
Holder type	Closed without filter
Holder design	Own
Holder antistatic measures	Conducting holder
Detector antistatic measures	Aluminised foil

Detector characteristics:	
Detector material	CR39
Detector thickness (mm)	1.4
Detector size (mm^{-2})	900

Etching	Chemical/pre-etch	Electro-chemical
Time (h)	6	
Solution	NaOH	
Strength (%)	20.8	
Temperature ^{o}C	70	
Chemical stirring?	Yes	
Field (kV cm^{-1})		
Frequency (kHz)		

Detector performance:	
Sensitivity (tracks/cm^2/kBq h m^{-3})	4.26 ±0.04
Typical background (kBq h m^{-3})	6.9
SD on background (kBq h m^{-3})	1.4
Saturation (MBq h m^{-3})	22

Track counting:	
Manual (M) or Automatic (A):	Automatic
Area of one counting field (mm^{-2}):	
Number of fields counted per detector:	
OR minimum number of tracks counted:	0
Autofocus:	Yes
Correction for non-linearity:	Yes

Light level stabilisation for automatic counters:	
Constant voltage:	Yes
Constant current:	No
Constant light output:	Yes
Regular check of reference detector:	Yes

Reference:

M. Calamosca, S. Penzo and G. Gualdrini "The features of the new radon gas CR-39 dosemeter developed at the ENEA Institute of Radioprotection" Radiat. Meas. 36 (2003) 221 – 224

Detector:

Laboratory:
ARPAT - Dept Florence
Via Del Ponte Alle Mosse, 211
I- 50144 Florence
Italy

Scientists:	S Bucci, S Gambi
Contact:	I Peroni
Telephone:	+39 055 3206029
Fax:	+39 055 3206218
Email:	I.peroni@arpat.toscana.it

Calibration and exposure:	
Calibration method:	Radon chamber exposure
Typical calibration exposure (kBq h m^{-3})	100 - 2200
Normal exposure duration (days)	90 - 180
Normal exposure range (kBq h m^{-3})	100 - 2000
Quoted uncertainty in this range	20 - 35
Basis of uncertainty (eg 95% CL)	95% CL

Detector application:	
Used for dwellings?	Yes
Used for workplaces?	Yes
Used for mines/caves?	
Used for outdoor?	
Used for soil?	
Routine/experimental?	Routine

Characteristics:	
Holder type	Closed without filter
Holder design	TASL
Holder antistatic measures	Conducting holder
Detector antistatic measures	Antistatic dip

Detector characteristics:	
Detector material	CR 39
Detector thickness (mm)	
Detector size (mm^{-2})	

Etching	Chemical/ pre-etch	Electro-chemical
Time (h)	1:00	
Solution	NaOH	
Strength (%)	25	
Temperature ^{o}C	98	
Chemical stirring?	Yes	
Field (kV cm^{-1})		
Frequency (kHz)		

Detector performance:	
Sensitivity (tracks/cm^2/kBq h m^{-3})	1.8
Typical background (kBq h m^{-3})	12
SD on background (kBq h m^{-3})	7
Saturation (MBq h m^{-3})	20

Track counting:	
Manual (M) or Automatic (A):	
Area of one counting field (mm^{-2}):	
Number of fields counted per detector:	
OR minimum number of tracks counted:	
Autofocus:	
Correction for non-linearity:	

Light level stabilisation for automatic counters:	
Constant voltage:	
Constant current:	
Constant light output:	
Regular check of reference detector:	

Reference:

Detector:

Laboratory:
Lab. Chimica Fisica
Agenzia Provinciale per l'Ambiente
Via Amba Alagi, 5
I - 39100 Bolzano
Italy

Scientists:	Dr. Luca Verdi
Contact:	Dr. Luca Verdi
Telephone:	++39 0471 291202
Fax:	++39 0471 291202
Email:	luca.verdi@provincia.bz.it

Calibration and exposure:	
Calibration method:	By detector supplier based on previous intercomparison
Typical calibration exposure (kBq h m^{-3})	300
Normal exposure duration (days)	2 - 200
Normal exposure range (kBq h m^{-3})	20 - 6000
Quoted uncertainty in this range	20
Basis of uncertainty (eg 95% CL)	

Detector application:	
Used for dwellings?	Yes
Used for workplaces?	Yes
Used for mines/caves?	Yes
Used for outdoor?	No
Used for soil?	No
Routine/experimental?	Routine

Characteristics:	
Holder type	Closed, without filter
Holder design	Radosys
Holder antistatic measures	Conducting holder
Detector antistatic measures	Antistatic dip

Detector characteristics:	
Detector material	CR39
Detector thickness (mm)	1
Detector size (mm^{-2})	100

Etching	Chemical/pre-etch	Electro-chemical
Time (h)	4	
Solution	NaOH	
Strength (%)	20	
Temperature °C	90	
Chemical stirring?	Yes	
Field (kV cm^{-1})		
Frequency (kHz)		

Detector performance:	
Sensitivity (tracks/cm^2/kBq h m^{-3})	2.9
Typical background (kBq h m^{-3})	19
SD on background (kBq h m^{-3})	8
Saturation (MBq h m^{-3})	6.5

Track counting:	
Manual (M) or Automatic (A):	Automatic
Area of one counting field (mm^{-2}):	0.35
Number of fields counted per detector:	144
OR minimum number of tracks counted:	0
Autofocus:	Yes
Correction for non-linearity:	No

Light level stabilisation for automatic counters:	
Constant voltage:	No
Constant current:	No
Constant light output:	Yes
Regular check of reference detector:	Yes

Reference:
RadoSys 2000 system produced by Radosys Co., Ltd - Hungary

Detector:

Laboratory:
Lab. Chimica Fisica
Agenzia Provinciale per l'Ambiente
Via Amba Alagi, 5
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Email:	luca.verdi@provincia.bz.it

Calibration and exposure:	
Calibration method:	Radon chamber with certified exposure
Typical calibration exposure (kBq h m^{-3})	200 - 1000
Normal exposure duration (days)	2 - 200
Normal exposure range (kBq h m^{-3})	20 - 6000
Quoted uncertainty in this range	30%
Basis of uncertainty (eg 95% CL)	95% CL

Detector application:	
Used for dwellings?	Yes
Used for workplaces?	Yes
Used for mines/caves?	Yes
Used for outdoor?	No
Used for soil?	Yes
Routine/experimental?	Routine

Characteristics:	
Holder type	Closed without filter
Holder design	ANPA
Holder antistatic measures	None
Detector antistatic measures	Aluminised film

Detector characteristics:	
Detector material	LR115
Detector thickness (mm)	0.012
Detector size (mm^{-2})	25x34

Etching	Chemical/ pre-etch	Electro-chemical
Time (h)	1h 50	
Solution	NaOH	
Strength (%)	10	
Temperature ^{o}C	60	
Chemical stirring?	No	
Field (kV cm^{-1})		
Frequency (kHz)		

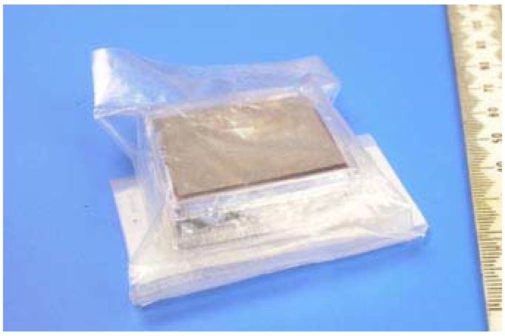
Detector performance:	
Sensitivity (tracks/cm^2/kBq h m^{-3})	0.9
Typical background (kBq h m^{-3})	11
SD on background (kBq h m^{-3})	2
Saturation (MBq h m^{-3})	7 - 8

Track counting:	
Manual (M) or Automatic (A):	Automatic
Area of one counting field (mm^{-2}):	100
Number of fields counted per detector:	1 - 2
OR minimum number of tracks counted:	0
Autofocus:	No
Correction for non-linearity:	Yes

Light level stabilisation for automatic counters:	
Constant voltage:	No
Constant current:	No
Constant light output:	No
Regular check of reference detector:	No

Reference:
F Bochicchio et al., Rad. Prot. Dos. 45 (1992) 459

Detector:



Laboratory:
Tecnorad
Via Schiaperelli, 15
37135 Verona
Italy

Scientists:	Dr Michele Marinaro
Contact:	A Sacchetto, R Milanesi
Telephone:	+39 045 8201066
Fax:	+39 045 8202451
Email:	radon@tecnorad.it

Calibration and exposure:	
Calibration method:	Primary/secondary detector samples
Typical calibration exposure (kBq h m^{-3})	180 per 3 days
Normal exposure duration (days)	1 - 3
Normal exposure range (kBq h m^{-3})	180 - 1800
Quoted uncertainty in this range	± 10%
Basis of uncertainty (eg 95% CL)	95% CL

Detector application:	
Used for dwellings?	Yes
Used for workplaces?	Yes
Used for mines/caves?	Yes
Used for outdoor?	
Used for soil?	
Routine/experimental?	Routine

Characteristics:	
Holder type	Closed without filter
Holder design	RAD
Holder antistatic measures	Antistatic dip
Detector antistatic measures	Antistatic dip

Detector characteristics:	
Detector material	CR39
Detector thickness (mm)	1 mm
Detector size (mm^{-2})	100

Etching	Chemical/ pre-etch	Electro-chemical
Time (h)	4.0	
Solution	NaOH	
Strength (%)	25%	
Temperature ^{o}C	90	
Chemical stirring?	Yes	
Field (kV cm^{-1})		
Frequency (kHz)		

Detector performance:	
Sensitivity (tracks/cm^2/kBq h m^{-3})	2.9
Typical background (kBq h m^{-3})	20
SD on background (kBq h m^{-3})	10
Saturation (MBq h m^{-3})	8

Track counting:	
Manual (M) or Automatic (A):	Automatic
Area of one counting field (mm^{-2}):	
Number of fields counted per detector:	
OR minimum number of tracks counted:	
Autofocus:	
Correction for non-linearity:	

Light level stabilisation for automatic counters:	
Constant voltage:	
Constant current:	
Constant light output:	
Regular check of reference detector:	

Reference:

Detector:

Laboratory:
Division De La Radioprotection
Villa Louvigny
Alleé Marconi
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Luxembourg

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Calibration and exposure:	
Calibration method:	Exposure in PTB chamber
Typical calibration exposure (kBq h m^{-3})	100/500/1000
Normal exposure duration (days)	30 - 90
Normal exposure range (kBq h m^{-3})	20 - 2000
Quoted uncertainty in this range	<20%
Basis of uncertainty (eg 95% CL)	95% CL

Detector application:	
Used for dwellings?	Yes
Used for workplaces?	Yes
Used for mines/caves?	
Used for outdoor?	
Used for soil?	
Routine/experimental?	Routine

Characteristics:	
Holder type	Closed with filter
Holder design	KfK FN
Holder antistatic measures	Conducting Holder
Detector antistatic measures	Aluminised film

Detector characteristics:	
Detector material	Makrofol
Detector thickness (mm)	0.3
Detector size (mm^{-2})	350

Etching	Chemical/ pre-etch	Electro-chemical
Time (h)	3:45	1:45
Solution	6.5 N KOH +EtOH	6.5 N KOH +EtOH
Strength (%)	50%	50
Temperature ^{o}C	35	
Chemical stirring?	No	
Field (kV cm^{-1})		35
Frequency (kHz)		3

Detector performance:	
Sensitivity (tracks/cm^2/kBq h m^{-3})	0.840
Typical background (kBq h m^{-3})	5
SD on background (kBq h m^{-3})	2
Saturation (MBq h m^{-3})	2

Track counting:	
Manual (M) or Automatic (A):	
Area of one counting field (mm^{-2}):	
Number of fields counted per detector:	
OR minimum number of tracks counted:	
Autofocus:	
Correction for non-linearity:	

Light level stabilisation for automatic counters:	
Constant voltage:	
Constant current:	
Constant light output:	
Regular check of reference detector:	

Reference:

Detector:

Laboratory:
LabNett
Postboks 2502
3702 Skein
Norway

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Contact:	Bente Fjerdingen
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Fax:	++35505620
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Calibration and exposure:	
Calibration method:	Check of reference detector
Typical calibration exposure (kBq h m^{-3})	500
Normal exposure duration (days)	60 - 90
Normal exposure range (kBq h m^{-3})	100 - 1000
Quoted uncertainty in this range	<20%
Basis of uncertainty (eg 95% CL)	95% CL

Detector application:	
Used for dwellings?	Yes
Used for workplaces?	No
Used for mines/caves?	No
Used for outdoor?	No
Used for soil?	No
Routine/experimental?	

Characteristics:	
Holder type	Closed without filter
Holder design	NRPB/SSI
Holder antistatic measures	Conducting holder
Detector antistatic measures	Antistatic dip

Detector characteristics:	
Detector material	CR39
Detector thickness (mm)	1
Detector size (mm^{-2})	

Etching	Chemical/ pre-etch	Electro-chemical
Time (h)	17	
Solution	NaOH	
Strength (%)	25	
Temperature ^oC	70	
Chemical stirring?	No	
Field (kV cm^{-1})		
Frequency (kHz)		

Detector performance:	
Sensitivity (tracks/cm^2/kBq h m^{-3})	2.0
Typical background (kBq h m^{-3})	20
SD on background (kBq h m^{-3})	
Saturation (MBq h m^{-3})	

Track counting:	
Manual (M) or Automatic (A):	Automatic
Area of one counting field (mm^{-2}):	
Number of fields counted per detector:	
OR minimum number of tracks counted:	0
Autofocus:	No
Correction for non-linearity:	No

Light level stabilisation for automatic counters:	
Constant voltage:	No
Constant current:	No
Constant light output:	No
Regular check of reference detector:	Yes

Reference:
B. Majborn, 1986. T.Strand, SIS, 1989:5

Detector:

Laboratory:
Radonlab Ltd
Akersveien, 24c
0177 Oslo
Norway

Scientists:	Aleksandar Birovljev
Contact:	Aleksandar Birovljev
Telephone:	+47 9512 9366
Fax:	++47 9043 3880
Email:	post@radonlab.net

Calibration and exposure:	
Calibration method:	Exposure at accredited lab
Typical calibration exposure (kBq h m^{-3})	200, 400, 800, 1600
Normal exposure duration (days)	60 - 90
Normal exposure range (kBq h m^{-3})	50 - 2000
Quoted uncertainty in this range	4 - 10%
Basis of uncertainty (eg 95% CL)	95% CL

Detector application:	
Used for dwellings?	Yes
Used for workplaces?	No
Used for mines/caves?	No
Used for outdoor?	Yes
Used for soil?	No
Routine/experimental?	Routine

Characteristics:	
Holder type	Closed without filter
Holder design	Radosys
Holder antistatic measures	Antistatic dip/conducting holder
Detector antistatic measures	Antistatic dip

Detector characteristics:	
Detector material	CR39
Detector thickness (mm)	1
Detector size (mm^{-2})	0.5

Etching	Chemical/ pre-etch	Electro-chemical
Time (h)	4	
Solution	NaOH	
Strength (%)	25	
Temperature ^{o}C	90	
Chemical stirring?	Yes	
Field (kV cm^{-1})		
Frequency (kHz)		

Detector performance:	
Sensitivity (tracks/cm^{2}/kBq h m^{-3})	0.4
Typical background (kBq h m^{-3})	10
SD on background (kBq h m^{-3})	15
Saturation (MBq h m^{-3})	0.1

Track counting:	
Manual (M) or Automatic (A):	Automatic
Area of one counting field (mm^{-2}):	
Number of fields counted per detector:	
OR minimum number of tracks counted:	0
Autofocus:	Yes
Correction for non-linearity:	Yes

Light level stabilisation for automatic counters:	
Constant voltage:	No
Constant current:	No
Constant light output:	No
Regular check of reference detector:	Yes

Reference:

Detector:

Laboratory:
Universitat Autònoma de Barcelona
Grup de Fisica de les Radiacions
Departament de Frisica. Edific Cc.
08193 Bellaterra
Spain

Scientists:	C Baixeras, Ll Font, V Moreno
Contact:	Victòria Moreno
Telephone	++34 93 5811364
Fax:	++34 93 5812155
Email:	Victoria.Moreno@uab.es

Calibration and exposure:	
Calibration method:	Exposure in NRPB radon chamber
Typical calibration exposure (kBq h m^{-3})	50 - 2000
Normal exposure duration (days)	60 - 120
Normal exposure range (kBq h m^{-3})	60 - 1500
Quoted uncertainty in this range	10 - 40
Basis of uncertainty (eg 95% CL)	

Detector application:	
Used for dwellings?	Yes
Used for workplaces?	Yes
Used for mines/caves?	Yes
Used for outdoor?	
Used for soil?	
Routine/experimental?	Both

Characteristics:	
Holder type	Closed with filter
Holder design	KfK FN
Holder antistatic measures	Conducting holder
Detector antistatic measures	Aluminised film

Detector characteristics:	
Detector material	Makrofol
Detector thickness (mm)	0.5
Detector size (mm^{-2})	314

Etching	Chemical/pre-etch	Electro-chemical
Time (h)	4	1.5
Solution	KOH	KOH
Strength (%)	50	50
Temperature ^oC	40	
Chemical stirring?	No	
Field (kV cm^{-1})		31
Frequency (kHz)		3

Detector performance:	
Sensitivity (tracks/cm^2/kBq h m^{-3})	0.67
Typical background (kBq h m^{-3})	12
SD on background (kBq h m^{-3})	6
Saturation (MBq h m^{-3})	1.8

Track counting:	
Manual (M) or Automatic (A):	
Area of one counting field (mm^{-2}):	
Number of fields counted per detector:	
OR minimum number of tracks counted:	0
Autofocus:	Yes
Correction for non-linearity:	Yes

Light level stabilisation for automatic counters:	
Constant voltage:	
Constant current:	
Constant light output:	
Regular check of reference detector:	

Reference:
Baixeras C., Garcia I., Fernández F., Domingo C., Vidal-Quadras A. and Piesch E. (1991) "Indoor radon concentration measurements in some Spanish houses and dwelling with nuclear track detector" Nucl. Tracks Radiat. Meas. 19, pp. 279-282

Detector:

Laboratory:
Pasela Miljösupport ab
PO Box 5093
Se - 426 05 V. Frölunda
Sweden

Scientists:	Per - Arne Svarnberg
Contact:	Per - Arne Svarnberg
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Calibration and exposure:	
Calibration method:	Exposure in SSI radon room
Typical calibration exposure (kBq h m^{-3})	200 - 2000
Normal exposure duration (days)	60 - 90
Normal exposure range (kBq h m^{-3})	50 - 2000
Quoted uncertainty in this range	10%
Basis of uncertainty (eg 95% CL)	1 - 2 SD

Detector application:	
Used for dwellings?	Yes
Used for workplaces?	Yes
Used for mines/caves?	Yes
Used for outdoor?	Yes
Used for soil?	Yes
Routine/experimental?	Routine

Characteristics:	
Holder type	Closed without filter
Holder design	TASL
Holder antistatic measures	Conducting holder
Detector antistatic measures	Antistatic dip

Detector characteristics:	
Detector material	CR 39
Detector thickness (mm)	1 mm
Detector size (mm^{-2})	

Etching	Chemical/pre-etch	Electro-chemical
Time (h)		
Solution		
Strength (%)		
Temperature °C		
Chemical stirring?		
Field (kV cm^{-1})		
Frequency (kHz)		

Detector performance:	
Sensitivity (tracks/cm^2/kBq h m^{-3})	2.6
Typical background (kBq h m^{-3})	10 - 15
SD on background (kBq h m^{-3})	
Saturation (MBq h m^{-3})	

Track counting:	
Manual (M) or Automatic (A):	Automatic
Area of one counting field (mm^{-2}):	
Number of fields counted per detector:	
OR minimum number of tracks counted:	
Autofocus:	
Correction for non-linearity:	

Light level stabilisation for automatic counters:	
Constant voltage:	
Constant current:	
Constant light output:	
Regular check of reference detector:	

Reference:
H Mellander and A Enflo. The alpha track method used in the Swedish radon epidemiological study. Radiation Protection Dosimetry, Vol 45 No.1/4 pp 65 - 71 (1992)

Detector:

Laboratory:
DSTL Radiological Protection Services
Institute of Navel Medicine
Cresent Rd, Alverstoke
Gosport, Hants PO12 2DL
U.K

Scientists:	Roger Stokes, Laurence Jones
Contact:	Roger Stokes
Telephone:	++44 (0)23 92 768294
Fax:	++44 (0)23 92 768150
Email:	rpstokes@dstl.gov.uk

Calibration and exposure:	
Calibration method:	NRPB Radon Exposure Chamber
Typical calibration exposure (kBq h m^{-3})	500
Normal exposure duration (days)	30 to 100
Normal exposure range (kBq h m^{-3})	20 to 2500
Quoted uncertainty in this range	±20%
Basis of uncertainty (eg 95% CL)	95% C L

Detector application:	
Used for dwellings?	Yes
Used for workplaces?	Yes
Used for mines/caves?	Yes
Used for outdoor?	No
Used for soil?	No
Routine/experimental?	Routine

Characteristics:	
Holder type	
Holder design	NRPB/SSI
Holder antistatic measures	Conducting holder
Detector antistatic measures	None

Detector characteristics:	
Detector material	CR39
Detector thickness (mm)	1.5
Detector size (mm^{-2})	500

Etching	Chemical/ pre-etch	Electro-chemical
Time (h)	6	
Solution	NaOH	
Strength (%)	25	
Temperature °C	70	
Chemical stirring?	Yes	
Field (kV cm^{-1})		
Frequency (kHz)		

Detector performance:	
Sensitivity (tracks/cm^2/kBq h m^{-3})	2.0
Typical background (kBq h m^{-3})	10
SD on background (kBq h m^{-3})	2.5
Saturation (MBq h m^{-3})	>5

Track counting:	
Manual (M) or Automatic (A):	
Area of one counting field (mm^{-2}):	
Number of fields counted per detector:	
OR minimum number of tracks counted:	0
Autofocus:	Yes
Correction for non-linearity:	Yes

Light level stabilisation for automatic counters:	
Constant voltage:	Yes
Constant current:	Yes
Constant light output:	Yes
Regular check of reference detector:	Yes

Reference:
Internal DSTL Report

Detector:

Laboratory:
Landauer
12 North Oxford Business Centre
Lakesmere Close, Kidlington
Oxford, OX5 1LG
United Kingdom

Scientists:	Ryan Ford, Chris Perks
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Calibration and exposure:	
Calibration method:	Radon exposures in standard chamber
Typical calibration exposure (kBq h m^{-3})	44 - 1780
Normal exposure duration (days)	90 - 365
Normal exposure range (kBq h m^{-3})	27 - 10 000
Quoted uncertainty in this range	± 10%
Basis of uncertainty (eg 95% CL)	1 SD

Detector application:	
Used for dwellings?	Yes
Used for workplaces?	Yes
Used for mines/caves?	Yes
Used for outdoor?	Yes
Used for soil?	Yes
Routine/experimental?	Routine

Characteristics:	
Holder type	Closed with filter
Holder design	Landauer
Holder antistatic measures	Conducting holder
Detector antistatic measures	None

Detector characteristics:	
Detector material	CR39
Detector thickness (mm)	0.8
Detector size (mm^{-2})	171

Etching	Chemical/ pre-etch	Electro-chemical
Time (h)	15.5	
Solution	NaOH	
Strength (%)	5.5N	
Temperature ^{o}C	70	
Chemical stirring?	No	
Field (kV cm^{-1})		
Frequency (kHz)		

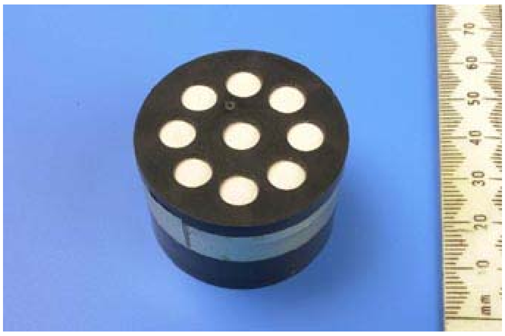
Detector performance:	
Sensitivity (tracks/cm^2/kBq h m^{-3})	2.82
Typical background (kBq h m^{-3})	11.4
SD on background (kBq h m^{-3})	4.3
Saturation (MBq h m^{-3})	88.8

Track counting:	
Manual (M) or Automatic (A):	
Area of one counting field (mm^{-2}):	
Number of fields counted per detector:	
OR minimum number of tracks counted:	0
Autofocus:	No
Correction for non-linearity:	Yes

Light level stabilisation for automatic counters:	
Constant voltage:	Yes
Constant current:	No
Constant light output:	Yes
Regular check of reference detector:	Yes

Reference:

Detector:



Laboratory:
HPA
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Calibration and exposure:	
Calibration method:	Radon chamber
Typical calibration exposure (kBq h m^{-3})	450 - 500
Normal exposure duration (days)	90
Normal exposure range (kBq h m^{-3})	0 - 1550
Quoted uncertainty in this range	20%
Basis of uncertainty (eg 95% CL)	95% CL

Detector application:	
Used for dwellings?	Yes
Used for workplaces?	Yes
Used for mines/caves?	Yes
Used for outdoor?	No
Used for soil?	No
Routine/experimental?	Routine

Characteristics:	
Holder type	Closed without filter
Holder design	NRPB/SSI
Holder antistatic measures	Conducting holder
Detector antistatic measures	Antistatic dip

Detector characteristics:	
Detector material	CR39
Detector thickness (mm)	1
Detector size (mm^{-2})	1040

Etching	Chemical/ pre-etch	Electro-chemical
Time (h)	18	
Solution	NaOH	
Strength (%)	20%	
Temperature ^{o}C	81	
Chemical stirring?	No	
Field (kV cm^{-1})		
Frequency (kHz)		

Detector performance:	
Sensitivity (tracks/cm^{2}/kBq h m^{-3})	2.7
Typical background (kBq h m^{-3})	16
SD on background (kBq h m^{-3})	4
Saturation (MBq h m^{-3})	

Track counting:	
Manual (M) or Automatic (A):	Automatic
Area of one counting field (mm^{-2}):	
Number of fields counted per detector:	
OR minimum number of tracks counted:	0
Autofocus:	No
Correction for non-linearity:	Yes

Light level stabilisation for automatic counters:	
Constant voltage:	No
Constant current:	No
Constant light output:	No
Regular check of reference detector:	No

Reference:

Detector: