EML-585

INTERCOMPARISON OF ACTIVE, PASSIVE AND CONTINUOUS INSTRUMENTS FOR RADON AND RADON PROGENY MEASUREMENTS IN THE EML CHAMBER AND TEST FACILITY

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October 1996

ABSTRACT

Results are presented from the Fifth Intercomparison of Active, Passive and Continuous Instruments for Radon and Radon Progeny Measurements conducted in the EML radon exposure and test facility in May 1996. In total, thirty-four government, private and academic facilities participated in the exercise with over 170 passive and electronic devices exposed in the EML test chamber. During the first week of the exercise, passive and continuous measuring devices were exposed (usually in quadruplicate) to about 1280 Bq m^{-3} ^{222}Rn for 1-7 days. Radon progeny measurements were made during the second week of the exercise. The results indicate that all of the tested devices that measure radon gas performed well and fulfill their intended purpose. The grand mean (GM) ratio of the participants' reported values to the EML values, for all four radon device categories, was 0.99 ± 0.08. Eighty-five percent of all the radon measuring devices that were exposed in the EML radon test chamber were within ± 1 standard deviation (SD) of the EML reference values. For the most part, radon progeny measurements were also quite good as compared to the EML values. The GM ratio for the 10 continuous PAEC instruments was 0.90 ± 0.12 with 75% of the devices within 1 SD of the EML reference values. Most of the continuous and integrating electronic instruments used for measuring the PAEC underestimated the EML values by about 10-15% probably because the concentration of particles onto which the radon progeny were attached was low (1200 - 3800 particles cm^{-3}). The equilibrium factor at that particle concentration level was 0.10 - 0.22.

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INTRODUCTION

The Fifth Intercomparison of Active, Passive and Continuous Instruments for Radon and Radon Progeny Measurements was conducted at EML to determine the performance and suitability of these devices to assess human radiation exposure from radon and radon progeny. This intercomparison exercise was mandated by the U. S. Department of Energy (DOE), Office of Health and Environmental Research (OHER), and is recommended by the Co-ordinated Research Program (CRP) of the International Atomic Energy Agency (IAEA), in cooperation with the Commission of European Communities (CEC). In 1992, the International Radon Metrology Program (IRMP) was established to provide the scientific community and the users of these instruments with a network of reference calibration centers where they can obtain high quality assurance standards in the area of radon metrology. EML is the reference calibration facility for North America and as such provides support to participants from the U. S., Canada and South America. The success and usefulness of this program is indicated by the participation of researchers from Europe and Asia who are seeking a means to ensure consistency of radon measurements on a global scale.

This program is different from the U. S. Environmental Protection Agency (EPA) sponsored Radon Measurement Proficiency Program (RMP), and is separate from EML's sponsored National Radon Intercomparison Program (Fisenne, 1995). The purpose of this intercomparison exercise is to evaluate the performance of different types of devices which are used to measure environmental radon and radon progeny. Previously, similar exercises were conducted by EML in 1990, 1992 , 1994 and 1995 (George et al., 1995a,b).

EXPOSURE AND TEST FACILITY

The intercomparison tests were conducted in EML's 30 m^3 radon, thoron and progeny test facility from April 29 through May 10, 1996. The chamber provides a well-controlled, airtight and uniform environment. It is the primary test facility at EML in which a large number and diverse types of monitoring instruments can be accommodated for calibration, evaluation and intercomparison purposes (Fisenne and Cavallo, in press). The test chamber is environmentally controlled for temperature and humidity. Monodispersed or polydispersed aerosols are generated to study radon and thoron progeny attachment and behavior, and to investigate instrument performance under different conditions of exposure. Also, particle size measurements are performed to develop techniques for the assessment of the health risk from inhalation of radon and thoron progeny.

Radon exposures were extended over periods of from 1 to 7 days in order to accommodate devices with different exposure protocols and different sensitivity limits when used in field applications. In all, there were more than 30 participants (consisting of: U. S. government laboratories, universities and private firms, and several foreign government agencies and universities) that conduct radon and radon progeny measurements and research studies.

Temperature and humidity were controlled and ranged from 19 - 21°C and 48 - 52% relative humidity, respectively. The concentration of radon in the test chamber was maintained at about 1280 ± 50 Bq m^{-3}. During testing of active devices for radon progeny, concentrations ranging from 40 - 2,700 nJ m^{-3} were obtained by varying the concentration of particles generated from Carnauba wax. The wax particles were generated by two TSI condensation aerosol generators Models 3470 and 3472, and the particle concentration was measured continuously with a condensation nuclei counter. The gamma background exposure inside the chamber was nearly constant at 0.08 μSv h^{-1}.

During testing, all instruments and radon devices were placed inside the EML test chamber 0.5 - 1.5 m above the floor. Grab sampling for radon progeny was conducted during the second week of the exercise from an adjacent room by taking samples from inside the test chamber through sampling ports. Analysis of the radon progeny activity inside the chamber was conducted using the Thomas method (Thomas, 1972), and the least squares method (Raabe and Wrenn, 1969). One participant used the Rolle method (Rolle, 1972). The particle size of the airborne radon progeny measured with a particle size analyzer ranged from 90 nm to 125 nm geometric mean diameter (GMD), corresponding to 100 nm to 200 nm activity median diameters (AMDs).

QUALITY ASSURANCE

Radon concentrations inside the test chamber were determined by measuring it continuously with a flow-through scintillation cell monitor that was calibrated against EML's pulse ionization chambers (PICs). These chambers are calibrated against a radium solution traceable to the National Institute of Standards and Technology (Fisenne and Keller, 1985). The concentrations of ^{222}Rn and progeny inside the test chamber were monitored continuously using a 3.0 L scintillation cell monitor (Eberline RGM3) and a quasi-continuous radon progeny monitor (Alpha Nuclear 770B), respectively. All chamber data were downloaded daily into a Minitab spreadsheet for averaging. Random daily grab samples (four samples per day) were obtained from within the radon test chamber and measured in EML's PICs to verify the daily averages obtained using the Eberline RGM3 cell. As a spot check, grab samples were also obtained using three Rocky Mountain scintillation cells. These cells were then alpha counted for 1 h each. A summary of the radon and progeny data during the 2 week exercise are provided in the Appendix as Figures A1 and A2, respectively.

The total uncertainty in the EML radon value is less than 5%. Radon progeny measurements made with EML instruments and methods are accurate to within 3% at the concentration levels tested. Their accuracy was verified on numerous occasions during past intercomparisons with several reference laboratories throughout the world.

RADON AND RADON PROGENY INSTRUMENTS

The participants and methods used for radon and progeny measurements are listed in Table 1. The passive integrating devices for radon included: 1) several types of open-faced and diffusion barrier activated carbon collectors; 2) two types of electret/ionization chambers (E-Perm and Ra Dome); 3) several types and different configurations of nuclear alpha track detectors (ATDs); 4) pulse ionization chambers; and 5) scintillation cell monitors. The active instruments for radon included scintillation cell and solid-state detection monitors. The active instruments for measuring radon or thoron progeny included grab, integrating and continuous monitors by sampling on filters that are counted by solid-state and scintillation detectors or by registration of nuclear alpha tracks in solid-state materials. A thorough review of these instruments and vendor addresses has been published by George (1996).

RESULTS AND DISCUSSION

EML values were used as the reference against which all other measurements were compared. To maintain participant confidentiality, the reported values are listed with each facility's code number. For comparison purposes, the different types of radon measuring devices were grouped separately into four categories consisting of:
1) passive activated carbon collectors, 2) nuclear alpha track detectors,
3) electret/ionization chambers, and 4) continuous active and passive electronic devices.

RADON GAS MEASUREMENTS

The range, the mean and SD of each participant's data set are compared with the mean reference value obtained by EML during the same exposure period. The ratios (participant/EML) and the associated propagated errors are listed in the last column of Table 2 and are also shown in Figure 1. Both the table and the figure include the GM ratios and their SDs for the four device categories which do not include EML measurements.

The GM ratio and SD for the 12 participants who used charcoal monitors was 0.99 ± 0.07. More than 80% of the participants using activated carbon collectors obtained values that were within 10% of the EML reference value. All were within 20% of the EML value, with one outlier. One participant's ratio was markedly different than the EML reference value and was not included in the averaging. When compared with the last two intercomparisons (George, 1995a,b), with a mean ratio of 1.04 ± 0.10 and 1.02 ± 0.07, respectively, both open-faced and diffusion barrier carbon collectors performed very well, indicating proper calibration with the maintenance of good quality control procedures.

The number of participants using short-term (2 day) and long-term (7 day) electret/ionization chambers was eight, about the same as in the 1995 intercomparison. Most of the 1996 participants used the RAD Elec type (E-Perm), whereas one was a Ra Dome type. The mean ratio and SD of the eight participants (0.97 ± 0.03) compared very favorably with 0.97 ± 0.03 and 0.99 ± 0.14 from the last two intercomparisons.

The mean ratio of the nine sets of nuclear alpha track detectors was 0.97 ± .16, identical to last year's value of 0.97 ± 0.18. These devices exhibited the largest variation as compared to both the activated charcoal and electret type devices. For this exercise, the range of the ratios of the mean values was 0.74 - 1.23, as compared to 0.81 - 1.10 and 0.69 - 1.25 in the 1994 and 1995 intercomparisons, respectively.

The results of the 13 continuous electronic devices that measure radon gas are shown in Table 3 and Figure 2. The data show that these active radon instruments performed very well. The mean ratio and SD is 1.00 ± 0.05, as compared to 1.01 ± 0.05 and 0.98 ± 0.04 from the 1994 and 1995 intercomparisons, respectively.

The overall mean ratio for all four passive device categories (excluding EML) is 0.99 ± 0.08. Eighty-five percent of all 150 passive radon measuring devices that were exposed in the EML radon test chamber were within ± 1 SD of the EML reference value.

RADON PROGENY GRAB SAMPLING

Grab sampling was performed during the second week of the exercise, from May 6 to May 9, 1996. The radon concentration during that period was maintained at about 1300 Bq m^{-3}. During the first day of grab sampling (Interval 1), the aerosol particle concentration was 1200-2800 particles cm^{-3} and was increased to 3800 cm^{-3} on May 7 (Interval 2). Using the data in Figures A1 and A2, the equilibrium factors (F) during the two test intervals were calculated as 10% and 22%, respectively. Six continuous integrating working level (WL) monitors were also exposed in the EML radon test chamber during the low test intervals, while three monitors were exposed during a third test interval.

Particle concentrations in residential buildings drop below 5,000 cm^{-3} at night when indoor activity ceases. Therefore, it was necessary to find out how some of the continuous and integrating PAEC instruments perform under such conditions. The measurement results for the individual radon progeny concentrations (i.e., RaA, RaB, RaC) and PAECs obtained by the four visiting participants are listed in Table 4 and compared in Figure 3. Table 4 lists the participant's individual radon progeny and PAEC ratios to that of the EML reference value during simultaneous grab sampling. The last column gives the concentration of the reference radon progeny atmosphere shown in the Appendix as Figure A2. The uncertainty of the PAEC ratio values were calculated and reported based on counting statistics alone.

In Table 4, the mean ^{218}Po, ^{214}Pb and ^{214}Bi ratios for the four visiting participants ranged from 0.89 to 1.22 with an overall GM ratio of 0.98 ± 0.13, indicating good agreement with the EML reference value and with the other participants. However the SDs for ^{214}Pb and ^{214}Bi were large, ranging from 16% - 24%. The mean ratios for the PAECs, using the modified Tsivoglou method, were in very close agreement with EML's reference value and with each other, with an overall GM ratio of 0.96 ± 0.04. The airborne radon progeny were collected on 2.54 cm Gelman Metricel filters (0.8 µm) by all of the participants (Knutson 1996). The data in Figure 3 show that even at low concentrations of condensation nuclei all of the participants performed well. The counting efficiencies and the air flow rates used by each participant were checked daily during the intercomparison and were found to be accurate.

The results of the continuous PAEC instruments are listed in Table 4 and are compared in Figures 4 and 5. The error for each participant's ratio was not propagated because the progeny and particle concentrations changed during sampling, yielding large variations from the average (integrated) value. The overall GM ratios for all 10 continuous PAEC devices ranged from 0.77-1.28 with a mean and SD of 0.90 ± 0.12. One device failed and was not used in averaging the GM ratio. By comparison, in the last intercomparison (George et al., 1995a,b), the overall GM ratios ranged from 0.57-1.03 with a mean and SD of 0.81 ± 0.16. In the present intercomparison, 79% of the measured PAEC values for both particle concentration exposure intervals were within ± 1 SD of the EML reference values. There does not appear to be any appreciable difference in instrument responses when exposed to a particle concentration of 1200 or 3800 particles cm^{-3}. The mean ratios of the six instruments exposed at those concentration levels was 0.84 ± 0.04 and 0.90 ± 0.07, respectively.

SUMMARY AND CONCLUSIONS

The instruments and methods used by the participants in this intercomparison for the measurement of radon were found to fulfill their intended purpose. About 10 facilities submitted more than one type of radon/progeny measuring device. A total of 206 measurements were reported by 34 participants; 32% of the measurements made utilized activated charcoal monitors, 22% ATDs, 19% E-Perms and 11% continuous radon/PAEC devices. Passive radon devices comprised 73% of all measurements. In total, more than 170 monitors were submitted for radon and/or progeny measurements with the balance (36) being progeny grab samples. A summary of the GM ratios for all reported data and for each type of measuring device exposed at EML is shown in Figure 6. The GM ratios are: a) activated carbon collectors = 0.99 ± 0.07; b) nuclear alpha track detectors = 0.97±0.16; c) electret/ionization chambers = 0.97 ± 0.03; and d) continuous electronic radon monitors = 1.00 ± 0.05. Monitors for passive or active radon measurements performed very well, indicating proper calibration and continuous maintenance by both the manufacturer and the user. All four participants that used grab sampling for PAEC measurements by the Tsivoglou method, which is considered their primary or standard method for measuring radon progeny, did very well (GM = 0.96 ± 0.04) indicating that their instruments are properly calibrated and maintained and that the operators are well trained in their use. As in the last intercomparison, this exercise demonstrated that active, passive, integrating, continuous or grab sampling instruments for radon are still in very good standing. Most of the commercial electronic instruments for radon progeny performed satisfactorily in environments where the concentration of airborne particles ranged from 1200 - 3800 cm^{-3}. Some instruments for measuring the PAEC or WL in low particle concentration environments may wish to adjust their instrument calibration factors (i.e., counts min^{-1} WL^{-1}) since this or progeny plate out are the most probable causes for underestimation of radon progeny concentration levels.

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TABLE 1
DEVICES SUBMITTED BY PARTICIPANTS FOR RADON AND PROGENY MEASUREMENTS

Participant	Device/Instrument/Method
AECL-Low Level Radioactive waste Ottawa, Ontario, Canada	Electret/ionization chamber Scintillation cell monitor
ALTRAC Berlin, Germany	Nuclear alpha track detectors
Atomic Energy for Peace Bangkok, Thailand	Activated carbon collectors (OF)
Bowser/Morner Dayton, OH	Activated carbon collectors (OF), Femto-Tech R210F (CRM), Alpha Nuclear-100 WL Monitor
Enviroserv, Inc Morristown, NJ	Activated carbon collectors (OF)
FERMCO Fernald, OH	Nuclear alpha track detectors Alpha Nuclar Prism-PAD WLM1A, WLx, WLM-30, AB5
Femto-TECH Inc. Carlisle, OH	Pulse ionization chamber (CRM-510)
Gemini Research Timonium, MD	Nuclear alpha track detectors (NYU type)
Health and Welfare of Canada Ottawa, Ontario, Canada	Electret/ionization chamber (E-Perm)
Hebrew University of Jerusalem Jerusalem, Israel	Activated carbon collectors, (liquid scintillation)
Japan Chemical Analysis Center Chiba, Japan	Nuclear alpha track detector (SSNTD type)
Institute of Nuclear Sciences Vinca, Yugoslavia	Nuclear alpha track detectors (ATD)
Kearney and Associates Fort Collins, CO	Activated charcoal (DB)
Landauer Inc. Glenwood, IL	Nuclear alpha track detectors

TABLE 1 (Cont'd)

Participant	Device/Instrument/Method
National Institute of Env. Sciences Aomori, Japan	Nuclear alpha track detectors (ATD)
New York University New York, NY	Nuclear alpha track detectors (ATD)
	Activated charcoal (liquid scintillation) Rad-7 Monitor
Niton Corporation Bedford, MA	
Northeast Laboratory Services Waterville, Maine	Activated charcoal (liquid scintillation)
Pennsylvania DER Harrisburg, PA	Activated charcoal scintillation cell (RGM3) scintillation cell (Gemini Certifier II) solid-state alpha spectometry (RAD-7)
Paul Scherrer Institut Switzerland	Nuclear alpha track detectors (ATD)
Pylon Electronics, Inc. Ottawa, CANADA	Pylon AB5-CPC, AB5-CPRD Pylon WLx
Rad Elec. Inc. Frederick, MD	Electret/ionization chamber (E-Perms), short-term and long-term types
Radon Testing Corporation of America Irvington, NY	Activated carbon collectors, (OF) and (DB) Electet/ionization chamber (RaDome)
RSSI Morton Grove, IL	Activated charcoal (DB)
St. Johns University Collegeville, MN	Nuclear alpha track detectors (ATD)
Teledyne Environmental Services Westwood, NJ	Activated carbon collectors (OF)
Thompson and Nielson Electronics Ltd. Ontario, CANADA	TN-IR-21, TN-WL02
United Radon Sciences Rockville, MD	Alpha Nuclear Guard (CRM)

TABLE 1 (Cont'd)

Participant	Device/Instrument/Method
U. S. EPA Montgomery, AL	Activated carbon collectors (DB)
Wilkes Barre University Wilkes Barre, PA	Activated carbon collectors (DB) Electret/ionization chambers Scintillation cell (RGM-3) AB5-PRD, WLR1A

ATD = alpha track detector
CRM = continuous radon monitor
DB = diffusion barrier
OF = open faced
SSNTD = solid state nuclear track detector
WL = working level

TABLE 2

RESULTS OF THE RADON INTERCOMPARISON MEASUREMENTS
FOR PASSIVE DIVICES
(Radon Concentration, Bq m^{-3})

Participant ID No.	Participant		EML Value, Mean ± σ_2	Ratio to EML ± σ_g
	Range*	Mean ± σ_1		
Charcoal				
5*	1453 - 1528	1513 ± 70	1278 ± 47	1.18 ± .07
6	400 - 568	466 ± 93	1278 ± 47	0.37 ± .07*
7	1236 - 1343	1269 ± 48	1278 ± 47	0.99 ± .05
12	1288 - 1436	1351 ± 137	1278 ± 47	1.06 ± .11
14*	1196 - 1288	1226 ± 5	1278 ± 47	0.96 ± .04
16	1153 - 1222	1201 ± 33	1310 ± 20	0.92 ± .04
22	1029 - 1154	1094 ± 58	1278 ± 47	0.86 ± .06
25	1206 - 1277	1240 ± 30	1278 ± 47	0.97 ± .04
29	1173 - 1310	1247 ± 66	1278 ± 47	0.98 ± .06
30	1228 - 1280	1262 ± 63	1278 ± 47	0.99 ± .06
32	1272 - 1306	1299 ± 10	1278 ± 47	1.02 ± .04
32	1080 - 1328	1221 ± 12	1278 ± 47	0.98 ± .04
32	1121 - 1346	1232 ± 13	1278 ± 47	0.99 ± .04
32	1121 - 1310	1243 ± 28	1278 ± 47	0.97 ± .04
34	1272 - 1399	1352 ± 44	1340 ± 30	1.01 ± .04
34	1311 - 1520	1369 ± 89	1340 ± 30	1.02 ± .07
				GM = 0.99 ± .07
Nuclear Track				
2	1181 - 1317	1252 ± 63	1278 ± 47	0.98 ± .06
8	899 - 944	939 ± 34	1278 ± 47	0.74 ± .04
9	1500 - 1664	1584 ± 82	1278 ± 47	1.23 ± .08
11	1190 - 1340	1240 ± 74	1278 ± 47	0.97 ± .07
19	1316 - 1450	1388 ± 55	1278 ± 47	1.09 ± .06
20	1083 - 1452	1292 ± 184	1278 ± 47	1.01 ± .15
21	842 - 1057	961 ± 35	1278 ± 47	0.75 ± .04
23	1110 - 1240	1165 ± 66	1278 ± 47	0.92 ± .06
31	1332 - 1391	1354 ± 27	1278 ± 47	1.06 ± .05
				GM = 0.97 ± .16

TABLE 2 (Cont'd)

Participant ID No.	Participant		EML Value, Mean ± σ_2	Ratio to EML ± σ_g
	Range*	Mean ± σ_1		
Electret/Ionization Chamber				
3	1214 - 1280	1240 ± 30	1278 ± 47	0.97 ± .04
3	1191 - 1254	1236 ± 30	1278 ± 47	0.97 ± .04
7	1228 - 1391	1291 ± 78	1278 ± 47	1.01 ± .07
22	1169 - 1206	1184 ± 16	1278 ± 47	0.93 ± .03
24	1192 - 1267	1227 ± 32	1278 ± 47	0.96 ± .04
28	1206 - 1354	1252 ± 60	1278 ± 47	0.98 ± .06
29	1135 - 1254	1195 ± 52	1278 ± 47	0.94 ± .06
32	1145 - 1265	1280 ± 74	1278 ± 47	1.00 ± .07
				GM = 0.97 ± .03

* Liquid scintillation counting.

TABLE 3

RESULTS OF THE RADON INTERCOMPARIS MEASUREMENTS
FOR ELECTRONIC DEVICES*
(Radon Concentration, Bq m^{-3})

Identification No.	Device/Unit Type	^{222}Rn (Bq $m^{-3} \pm \sigma_1$)	EML value (Bq $m^{-3} \pm \sigma_{2}$)	Ratio to EML $\pm \sigma_g$*
4	Pylon AB5-CPRD	1195 ± 48	1310 ± 20	0.91 ± .04
	Pylon AB5-CPC	1213 ± 51	1310 ± 20	0.93 ± .04
7	Eberline RGM-3	1320 ± 6	1310 ± 20	1.01 ± .02
	Niton RAD-7	1291 ± 8	1310 ± 20	0.99 ± .02
	Gemini GRI-1100	1310 ± 1	1310 ± 20	1.00 ± .02
16	Femto-Tech R210F	1364 ± 8	1310 ± 20	1.04 ± .02
17	CRM-510	1265 ± 15		
	CRM-510	1275 ± 12	1278 ± 47	0.99 ± .02
				1.00 ± .02
28	Pylon AB5	1232 ± 12	1310 ± 20	0.95 ± .02
29	Pylon AB5	1422 ± 57	1310 ± 20	1.08 ± .06
	Eberline RGM-3	1351 ± 26	1310 ± 20	1.02 ± .06
33	Pylon AB5	1339 ± 30	1278 ± 47	1.04 ± .05
34	Niton Rad-7	1306 ± 68	1337 ± 40	0.98 ± .03
				GM = 1.00 ± .05

*The error associated with the participant's average value is the total error of the measurement: σ_g = Sqrt [CV_1^2 + CV_2^2], where CV = coefficient of variation of participant and reference facility.

TABLE 4

RADON PROGENY INTERCOMPARISON MEASUREMENTS
GRAB SAMPLING

Participant and Sample No.	Cond. Nucl. Particles x 10^3 (cm^{-3})	Ratio of Participants/EML ^{218}Po	^{214}Pb	^{214}Bi	PAEC** Ratio	Reference PAEC ($nJ\ m^{-3}$)
16-1	1.2	1.16	0.93	0.66	0.97	695 ± 16
16-2	1.2	0.86	0.55	1.15	0.82	584 ± 15
16-3	2.6	1.16	1.19	0.79	1.08	844 ± 17
16-4	2.6	0.99	0.90	1.03	0.95	711 ± 14
16-5	2.6	1.00	1.21	0.78	1.02	926 ± 8
16-6	2.6	*	*	*	1.10	811 ± 20
16-7	21.0	1.02	0.96	0.94	0.96	2372 ± 35
16-8	21.0	0.98	0.96	1.06	0.95	2499 ± 35
16-9	19.0	0.96	1.05	0.83	0.98	2475 ± 35
Mean and σ_g:		(1.00 ±.09)	(0.96 ± .22)	(0.91 ± .17)	(0.98 ± .08)	
28-1	1.2	1.26	1.39	0.55	1.16	695 ± 16
28-2	1.2	1.13	1.51	0.78	1.17	584 ± 15
28-3	2.6	1.29	1.40	0.64	1.14	844 ± 17
28-4	2.6	1.12	0.92	1.17	1.03	711 ± 14
28-5	2.6	1.09	1.29	0.90	1.11	926 ± 8
28-6	2.6	*	*	*	1.22	811 ± 20
28-7	21.0	1.26	1.05	1.00	1.09	2372 ± 35
28-8	21.0	0.97	0.97	1.16	1.00	2499 ± 35
Mean and σ_g:		(1.16 ± .12)	(1.22 ± .24)	(0.89 ± .24)	(1.12 ± .07)	
4-1	1.2	0.95	0.90	0.62	0.86	695 ± 16
4-2	1.2	0.86	1.00	1.00	0.91	584 ± 15
4-3	2.6	0.82	0.62	0.92	0.83	844 ± 17
4-4	2.6	----	----	----	0.94	711 ± 14
4-5	2.6	0.83	1.16	0.86	0.94	926 ± 8
4-6	2.6	*	**	**	1.07	811 ± 20
4-7	21.0	0.98	0.96	0.86	0.93	2372 ± 35
4-8	21.0	0.70	0.83	1.08	0.86	2499 ± 35
Mean and σ_g:		(0.86 ± .10)	(0.91 ± .18)	(0.89 ± .16)	(0.92 ± 0.07)	
10-3	2.6	-	-	-	0.83	844 ± 17
10-4	2.6	-	-	-	0.93	711 ± 14
10-5	2.6	-	-	-	0.93	926 ± 8
10-6	2.6	-	-	-	0.91	811 ± 20
10-7	21.0	-	-	-	0.93	2372 ± 35
10-8	21.0	-	-	-	0.88	2499 ± 35
10-9	21.0	-	-	-	0.99	2475 ± 32
				Mean and σ_g:	(0.93 ± .05)	
	Overall avg.:	(1.01 ± 0.15)	(1.03 ± 0.17)	(0.90 ± 0.01)	(0.96 ± 0.04)	

*No data because EML filter sample was damaged during sampling.
**Obtained by the modified Tsivoglou method.

TABLE 5

RESULTS OF CONTINUOUS WL MONITORS*

Identification No., Exposure Dates**	Device Type	PAEC (nJ m^{-3}) ± σ_1	EML value† (nJ m^{-3}) ± σ_2	Ratio to EML
EML 5/6	Alpha Smart 770			
5/7		687 ± 120	687 ± 120	1.00
		1586 ± 826	1586 ± 826	1.00
EML 5/6	Grab Samples	640 ± 50	648 ± 90	0.99
5/7	(Raabe/Wrenn)	828 ± 107	863 ± 126	0.96
(4) 5/6	Pylon WLx-125	517 ± 76	687 ± 120	0.86
5/7		1530 ± 880	1586 ± 826	0.97
(4) 5/6	Pylon WLx-126	538 ± 153	687 ± 120	0.78
5/7		1523 ± 926	1586 ± 826	0.96
(4) 5/6	Pylon AB5-407	675 ± 80	687 ± 120	0.84
5/7		1417 ± 842	1586 ± 826	0.89
(4) 5/6	Pylon AB5-1015	678 ± 67	687 ± 120	0.84
5/7		1414 ± 839	1586 ± 826	0.89
(10) 5/6-5/7	TN-WL02			
(16) 5/6-5/8		618 ± 20	687 ± 120	0.90
(29) 5/6-5/7	Alpha-Nuclear 100	627 ± 85	687 ± 120	0.91
5/7-5/8		1611 ± 1049	1586 ± 826	1.02
(33) 5/9-5/10	Eberline WLM	545 ± 41	687 ± 120	0.80
		1220 ± 768	1586 ± 826	0.77
(33) 5/9-5/10	Alpha-Nuclear	64 ± 17	50 ± 15	1.28
	PAD	41 ± n.d.	50 ± 15	0.82
(33) 5/6	Scintrex WLM	187 ± 23	687 ± 120	0.27‡
5/7	Eberline WLM1A	314 ± 140	1586 ± 826	0.20‡
(33) 5/7	Pylon WLx	1378 ± 735	1586 ± 826	0.90
			GM: 0.90 ± .12	

*See Figure 4 for comparitive continuous data.
**DST time intervals are 1300 on 5/6/96 to 0700 on 5/7/96; 0800 on 5/7/96 to 0100 5/8/96 and 0200-2400 EST on 5/8/96.
†EML reference PAEC values using continuous Alpha Smart-770 WL for same sampling times.
‡Not averaged.
n.d.= no data reported

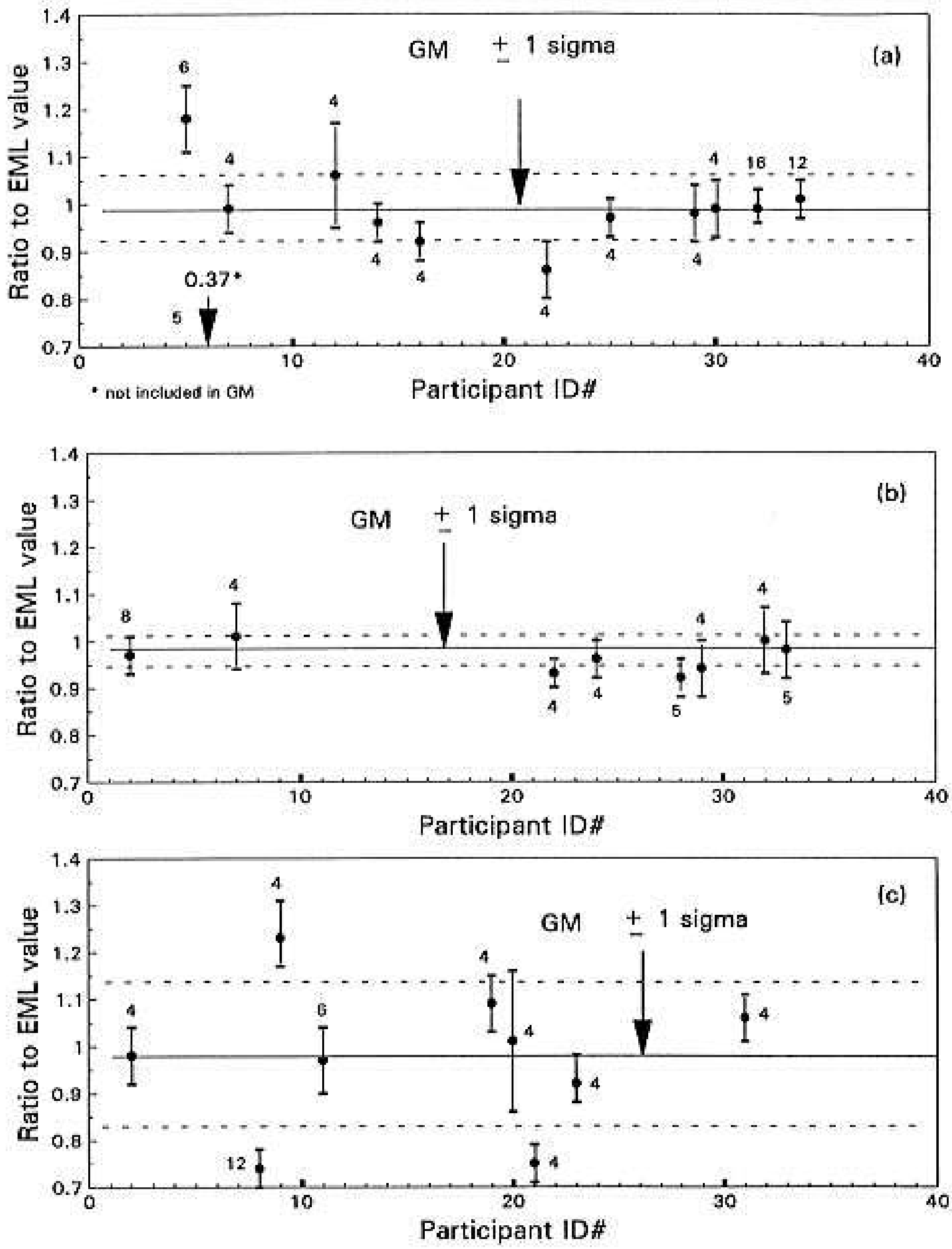

Figure 1. Results of 5th Radon/Progeny Intercomparison.
Passive Radon-222 devices: (a) activated charcoal;
(b) E-Perms; (c) ATDs/SSNTDs;

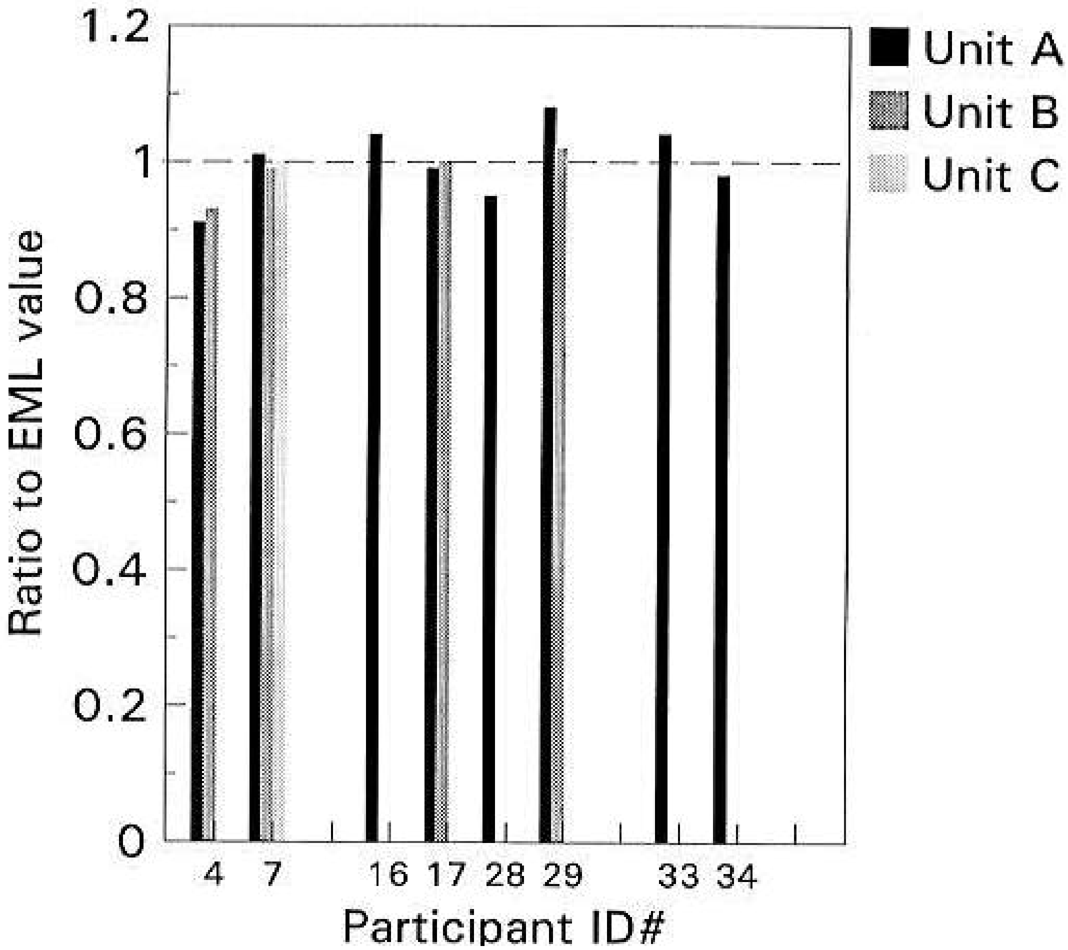

Figure 2. Continuous radon measuring devices in Table 3.

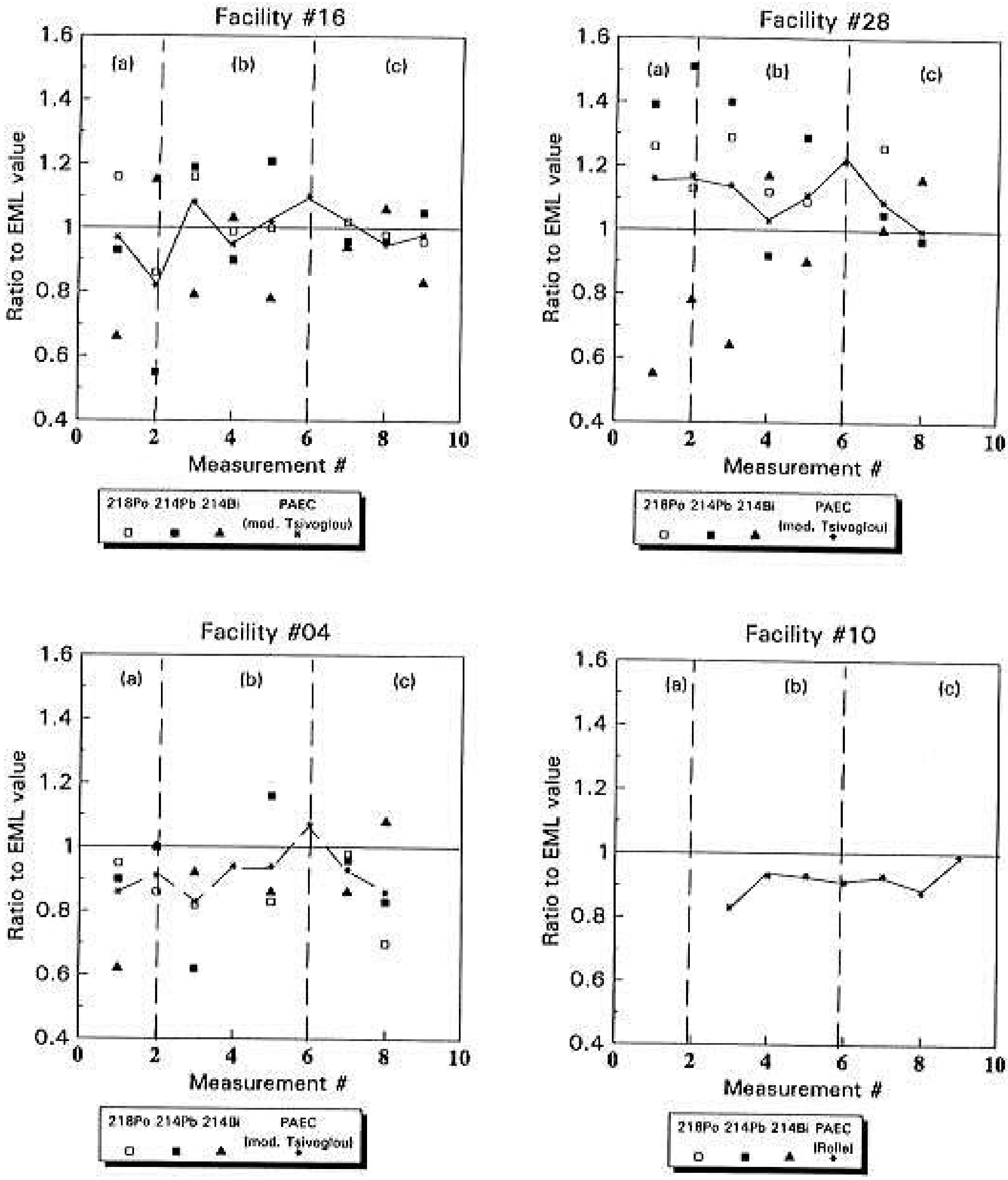

Figure 3. Results of 5th Radon/Progeny Intercomparison: Grab Sampling:
^{222}Rn = 1311-1448 Bq m^{-3} ; T = 20^{O} C, RH = 50% ;
(a) CN = 1200 cm^{-3} : F = 10%, (b) CN = 2600 cm^{-3} : F = 10%,
(c) CN = 21,000 cm-3 : F = 22%

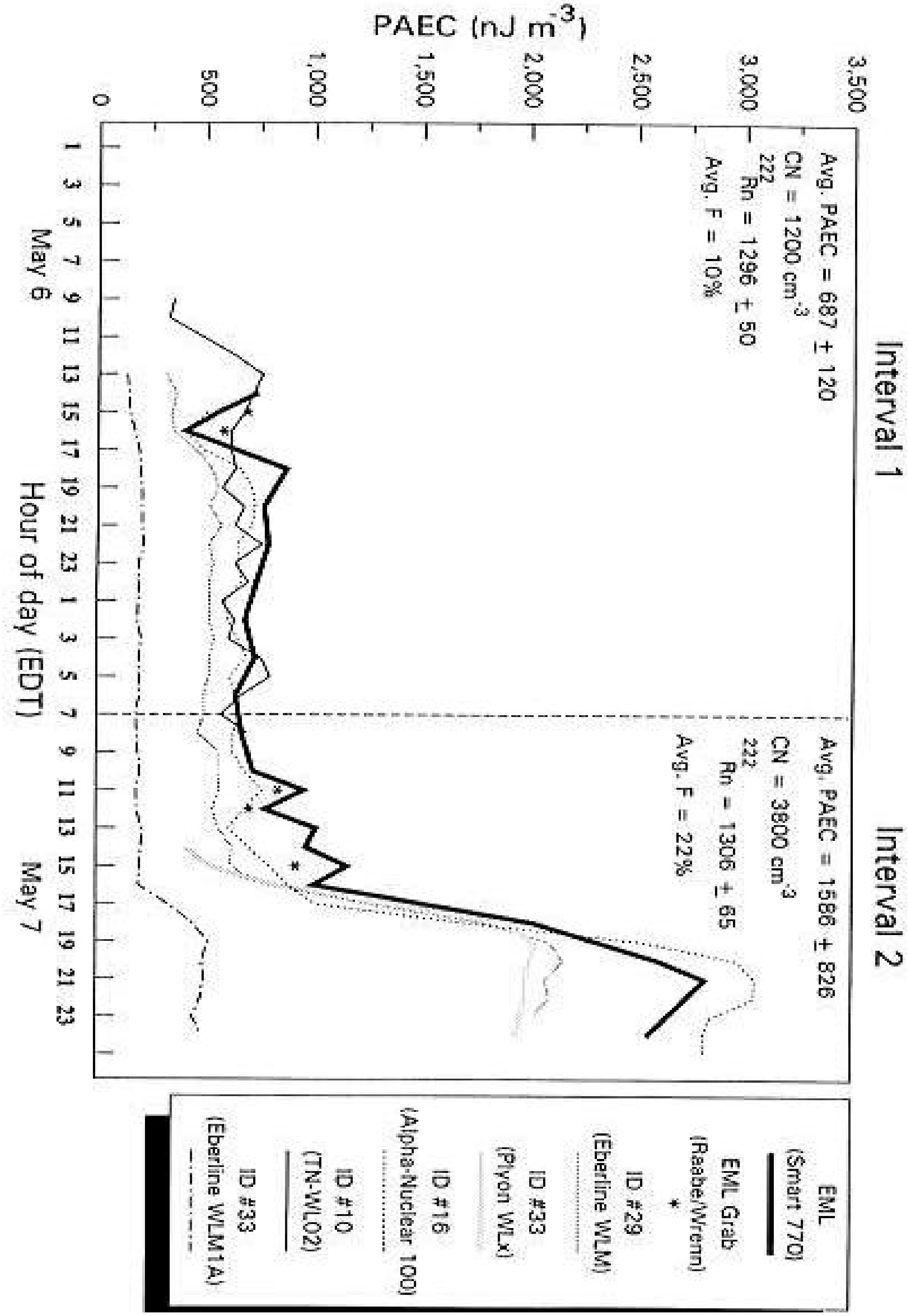

Figure 4. Radon progeny data summary for continuous PAEC monitors.
F = equilibrium factor = [(PAEC nJ m^{-3} / 2.08 E-5 J m^{-3}) x 3700] / ^{222}Rn (Bq m^{-3})

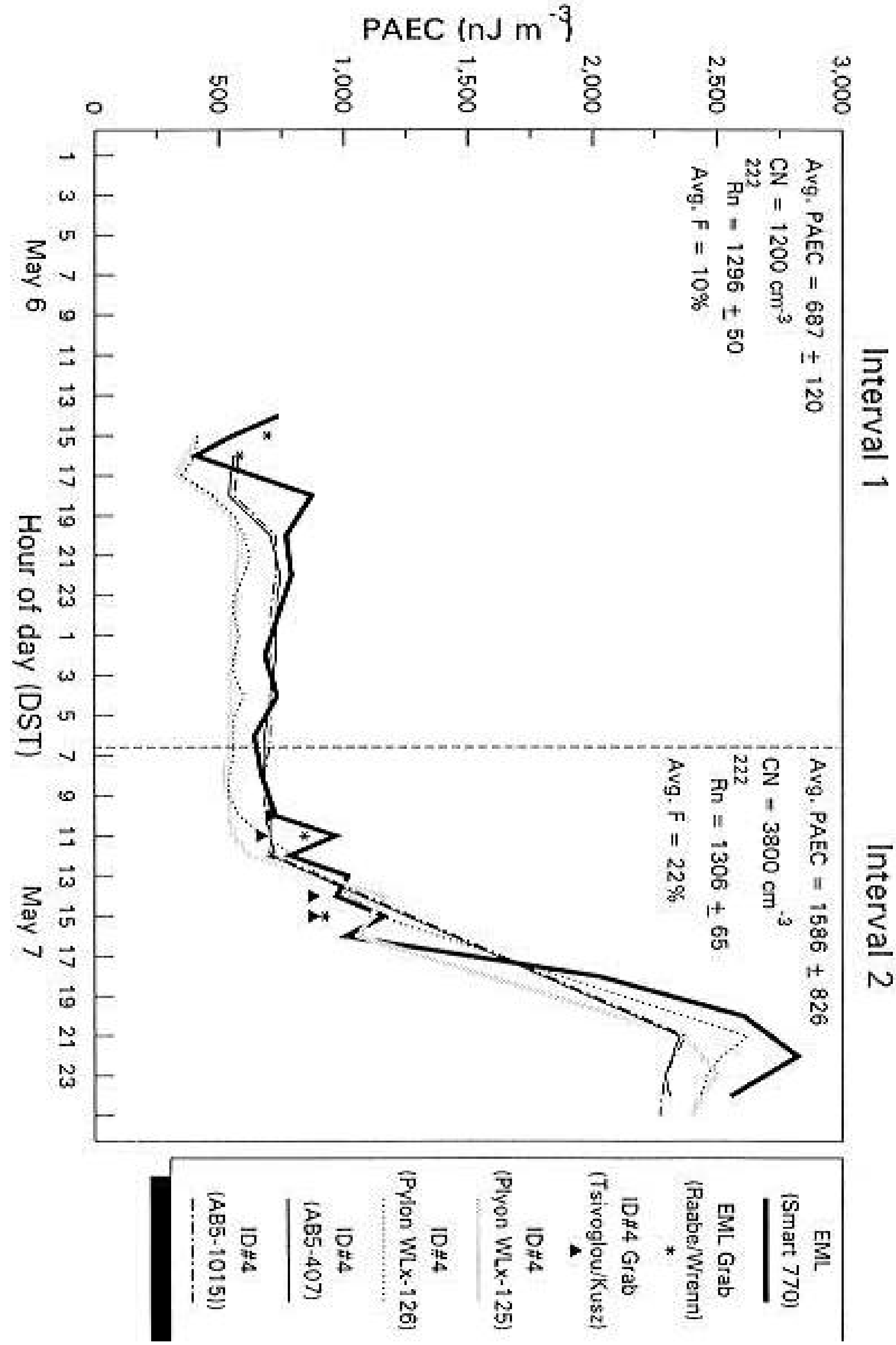

Figure 5. Radon progeny data summary for PAEC monitors: Facility #4.
F = equilibrium factor = [(PAEC nJ m^{-3} / 2.08 E-5 J m^{-3}) x 3700] / ^{222}Rn (Bq m^{-3})

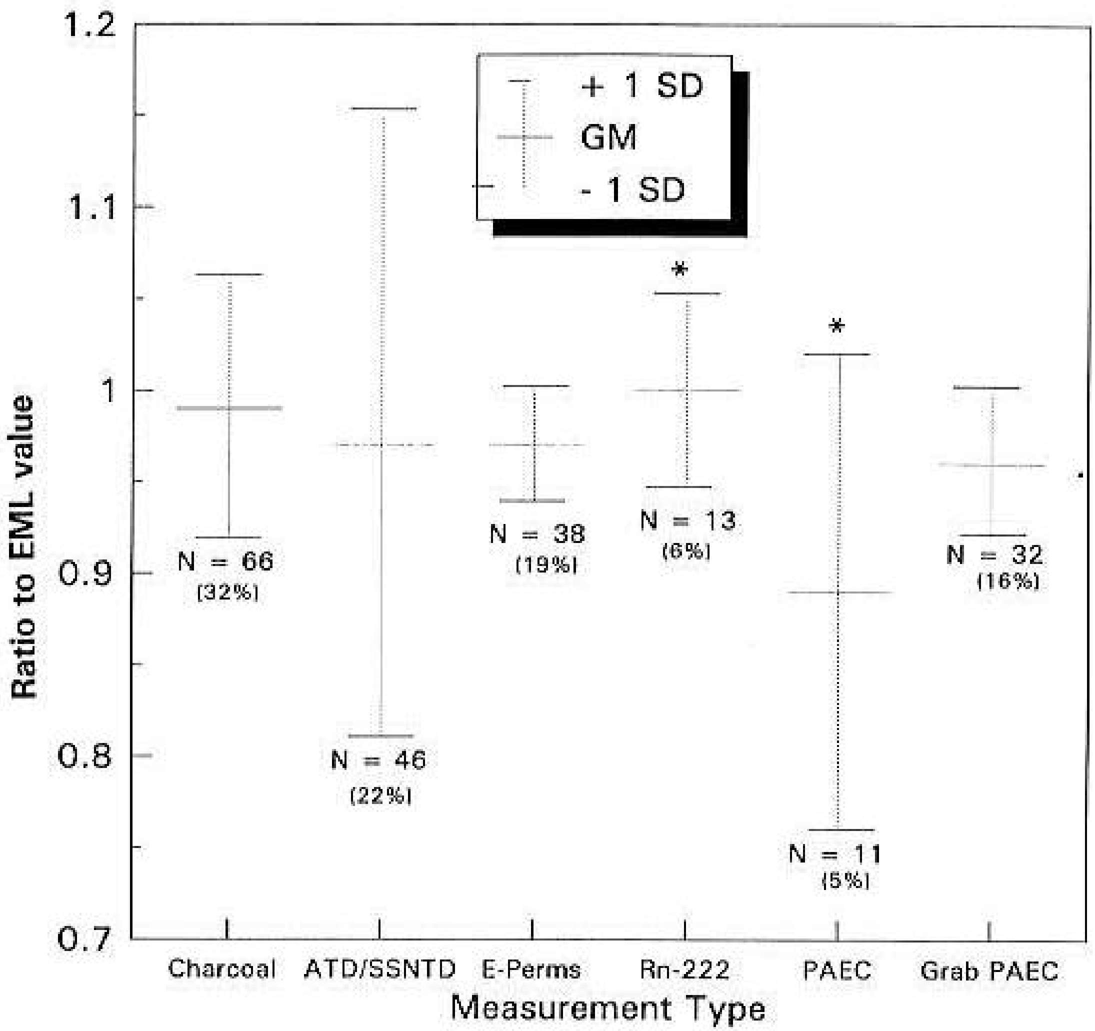

Figure 6. Data summary of 5th Radon/Progeny Intercomparison.

N = # of measurements or devices (excluding EML);
* = continuous measuring devices in Table 2d and Table 4;.
(%) = percentage of total (N=206) measurements reported.

APPENDIX

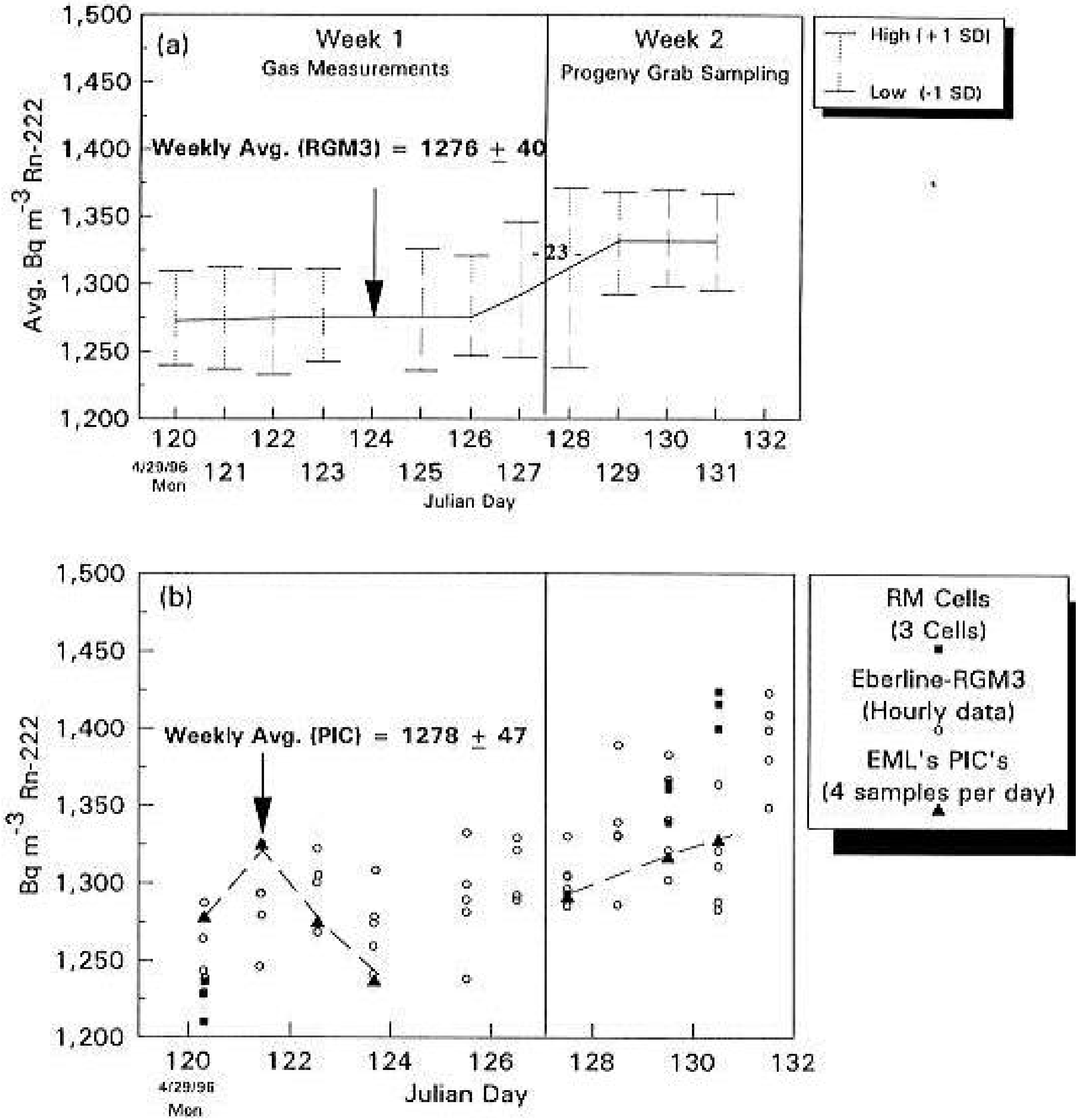

Figure A1. ^{222}Rn data. (a) daily Averages in EML radon chamber using Eberline RGM3 scintillation cell. (b) data during random grab sampling using EML's PICs and RM scintillation cells.

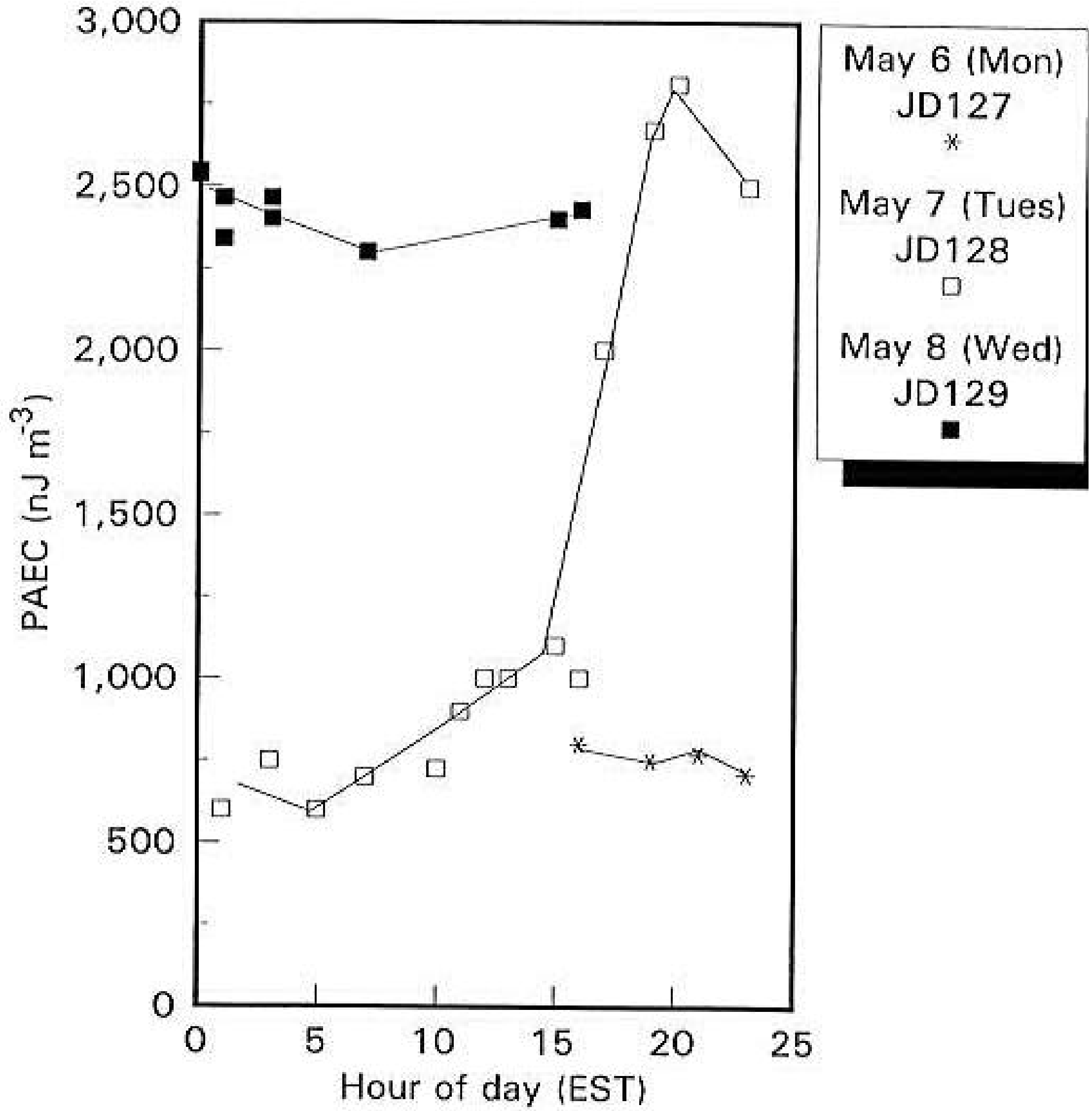

Figure A2. Radon progeny data summary during grab sampling.
Alpha Nuclear Smart-770; JD = Julian day #.