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NIST TRACEABLE RADON CALIBRATION SYSTEM FOR CALIBRATING TRUE INTEGRATING RADON MONITORS - E-PERM®*

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ABSTRACT

The NIST (National Institute of Standards and Technology) has recently made available ^{222}Rn emanation standards for test and evaluation. The NIST certified parameters include the ^{226}Ra strength and the emanation coefficient. When such a source is loaded into a radon leak tight enclosure of a known volume, ^{222}Rn accumulates over time and it is possible to calculate precisely the time integrated average radon concentration after any given accumulation time. For example, if 25 Bq(676pCi) NIST source is loaded into a jar with an air volume of 3.72 liter, the time integrated average radon concentration is 973 Bq m^{-3} (26.3 pCi L^{-1})after an accumulation time of exactly two days. If the radon detector placed in the jar is non-radon absorbing and a true integrator, the radon detector must yield the theoretically predicted results. The paper describes a study involving 30 randomly chosen E-PERM®S and 15 NIST sources in 15 different calibration jars. The study indicated that E-PERM®S give results within about 5 % of the predicted results. The study also shows how a NIST source can be used in practice. The availability of NIST sources in the future with precisely known radon emanation characteristics is considered to be a major advancement in radon metrology.The methodology is within the reach of any quality conscious radon measurement laboratory.

KEY WORDS : electret, ion chamber, radon, radon emanation standards

INTRODUCTION

The NIST (National Institute of Standards and Technology) has recently made available ^{222}Rn emanation standards for test and evaluation (Collé et al. 1993). The NIST certified parameters include the ^{226}Ra strength and the emanation coefficient. When such a source is loaded into a radon leak tight jar of a known volume, ^{222}Rn will accumulate over time. It is possible to calculate precisely the time integrated average radon concentration after any given accumulation time. For example, if a NIST source of a small strength, 25 Bq (676 pCi), is loaded into a jar with an air volume of 3.72 liter, the time integrated average radon concentration is 26.3 pCi/L (973 Bq m^{-3} after an accumulation time of exactly two days. If the radon detector present in the jar is non-radon absorbing and a true integrator, this radon detector must yield the theoretically predicted results. If there is some consistent difference, a suitable NIST traceable calibration corrections can be derived. A detailed theory and practice of this concept of using NIST traceable sources for calibration of E-PERM® (electret passive environmental radon monitors (Kotrappa et al 1988 and 1990) is in the process of publication in Health Physics Journal (Colle` et al. 1993). The current study involves 30 randomly chosen E-PERM®S and 15 NIST sources in 15 different calibration jars. The study indicated that E-PERM®S give results within about 5 % of the predicted results. The study also showed how a NIST source can be used in practice. The availability of NIST sources with precisely known radon emanation characteristics is considered to be a major advancement in radon metrology. The methodology is within the reach of any quality conscious radon measurement laboratory.

* E-PERM® is a registered trade mark of the electret ion chamber system patented and manufactured by Rad Elec Inc., 5714-C Industry Lane, Frederick, MD 21701

MATERIALS AND METHODS

The recently developed ^{222}Rn emanation standards that are based on polyethylene-encapsulated ^{226}Ra solutions (Colle` et al. 1993) are used in the present study. These sources are certified by NIST in terms of ^{226}Ra content and the ^{222}Rn emanation fraction. These have been demonstrated to emanate a well-characterized and known quantity of ^{222}Rn when employed in "accumulation mode". Fifteen such sources with 226Ra content ranging from 23.38 Bq to 26.57 Bq with emanation fraction of 0.888 were made available by NIST for this study under the on-going CRADA (cooperative research and development agreement between NIST and REI) program. Specially prepared glass jars with a capability of being made radon leak tight were used as accumulators. These were simply the jars routinely used for measurement of radon in water (Kotrappa et al 1993). The radon detectors used were the standard commercially available E-PERM® (Kotrappa et al 1988,1990) 210 mL volume "S" chamber configured with either a short term (ST) or a long term (LT) electrets. The 50 mL ion chamber "L" chmber configured either with ST or LT electret has also been used.

THEORETICAL CALCULATIONS OF ^{222}Rn IN AN ACCUMULATOR

Equation (1) gives the radon concentration in the accumulator after an accumulation time T_A. This is the maximum radon concentration seen by the detector in the accumulator. The ^{222}Rn concentration varies from zero at the start of the experiment to the concentration given by equation(1) at the end of the accumulation time of T_A days.

$$A_{Rn} = \frac{f A_{Ra}(1 - e^{-\lambda_{Rn} T_A})}{V_A} \qquad (1)$$

Time integrated concentration of radon is obtained by integrating equation (1) from time zero to T_A. Further, if one divides the time integrated ^{222}Rn is divided by the accumulation time T_A, we arrive at the average concentration over the time T_A. Equation (2) gives the result.

AIR VOLUME OF THE ACCUMULATOR

Air volume of the accumulator depends upon the number and the type of E-PERM® used in the accumulator jar. The different air volumes to be used are given in Table-1. These were determined experimentally by carefully measuring the volume of the empty jar and the volume of the jar when respective number of detectors were loaded into the jar by filling the jar with distilled water and weighing the water needed to fill the jar. The difference in the volume gives the air volume of the jar when respective number of detectors were loaded. Experiments were repeated at least 10 times and the values reported in the table have an error of less than 3 %.

Depending upon how many E-PERMS are inside the accumulator, appropriate air volume (V_A) given by the Table-1 should be used. For example, if 2 SST (or SLT) are used in the accumulator, appropriate value for V_A to be used is 3720 mL. Please see Table-1 for appropriate value to be used when different number of detectors are used in the accumulator.

Equation (2) gives the time averaged concentration of radon in the accumulator after the stated accumulation time. This is always smaller than the maximum concentration given by equation (1) since the chamber starts with 0 concentration and builds up to the maximum.

$$C_{Rn} = \frac{f A_{Ra}}{V_A}\left(1 - \frac{1 - e^{-\lambda_{Rn} T_A}}{\lambda_{Rn} T_A}\right) \quad (2)$$

f = fraction of radon released

A_{Ra} = RA-226 activity

V_A = volume of the accumulator

λ_{Rn} = decay constant of Rn

A_{Rn} = radon concentration at time T_A

C_{Rn} = average radon concentration after time T_A

The radium concentration is in Bq units, f is the emanation coefficient and is determined by NIST as 0.888, volume of the jar should be in units of cubic meters (3720 mL =.00372 m^3), time is in units of days and decay constant of radon is in units of day^{-1} (0.1812), then radon concentration is in units of Bq per m^3. This is divided by 37 to get the radon concentration in pCi per liter.

Table-2 gives the calculated radon concentrations when a source of 25 Bq (676 pCi) and 2 SST (or SLT) units are present in the accumulator. Figure-1 is a graphical representation of the Table-2. The top curve gives the maximum radon concentration seen by the detector (equation 1) and lower curve gives the time averaged radon concentration (equation 2) seen by the detector. If the detector is a true integrator, the response should be in accordance with lower curve.

EXPERIMENTS AND RESULTS

Each source was fixed inside each jar using the clip arrangement. The NIST serial number was marked on each jar. NIST instructions require that the source should be open to the atmosphere for at least 24 hours prior to the use of the source in the accumulator mode.(Colle` et al 1993). This was achieved by keeping the lid of the jars open for at least 24 hours. The jars were also left in low radon area (outside environment) so as to satisfy the requirement of near zero radon concentration before starting the accumulation. A pair of premeasured E-PERMS (initial voltage IV) were loaded into each ja,the lids closed, the collars ightened and the time noted. Please see Figure-2 and Figure-3. This is a start of an experiment. Exactly after 2 days, the E-PERMS were taken out and the final voltage readings of the electrets were taken (FV). E-PERMS were left in low radon area in "on" position for a period of 3 hours before taking the final readings. In the normal usage of E-PERMS the final reading is taken immediately after the termination of a measurement. The reasons for taking a delayed final reading in the present case warrant additional discussions. In the accumulator mode the radon concentration changes from zero at the beginning to a maximum concentration at the end of the experiment. The radon and associated progeny signal at the beginning and at the end are very different. In the normal usage the concentration remains reasonably constant over the entire period of measurement. The end effect is compensated by leaving the E-PERMS in a low radon area for about 3 hours before taking the final reading of the electrets. By following this procedure we have found that the measurements can be extended to as short an interval as 6 hours. Radon concentration was calculated by the standard procedure using the calibration supplied by the manufacturers. Results are listed in Table-3. The sixth column gives the calculated radon concentration using equation (2) and is termed as NIST pCi/L. Column 10 gives the radon concentration as measured by E-PERMS. The column 11 gives the ratio of E-PERM measured to the NIST theoretically expected radon concentrations. The column 12 gives the average ratio taking into account the two sets of values for each source. The last row gives the grand average ratio of 0.9833. Ideally it should be 1.00. Five additional 2 day accumulation experiments were conducted following the exactly identical procedures, but same E-PERMS were successively used until the final voltages were about 150 volts. Final results of grand average ratios varied from 0.95 to 1.01. Experiments done for accumulating times from 6 hours to 5 days also gave similar results. The experiments done with SLT and LST configurations over periods from 5 to 10 days also gave similar results.

DISCUSSION OF RESULTS

Table-3 gives the results for a 2 day accumulation test for 30 randomly chosen E-PERMS, 15 randomly chosen jars and 15 sources supplied by NIST. Results are an indication that calibration equation used for making measurement of radon using E-PERMS is within 5 % of the theoretically expected results over the entire operating voltages of E-PERMS. This is within the accuracy expected from E-PERMS (Kotrappa et al 1988,1990). The procedure developed in this study is demonstrated to be usable for different accumulation times, for different E-PERM configurations and for sources of different strengths. E-PERMS were clearly demonstrated as truly integrating radon measuring units integrating from near zero concentrations to the highest concentrations encountered in the study.

Before using a certain configuration of E-PERM with a source of certain strength, one should do a theoretical analysis so as not to discharge the electret beyond the operating voltages of electrets.

CONCEPT OF TRANSFER STANDARD

If an E-PERM shows 5 % lower than what is predicted by the NIST source, the results of the measurements made by using this unit should be divided by 0.95 to get the correct results. Using a portion (say from 700 to 650 volts) it is possible to calibrate an E-PERM to NIST traceability. This still has a large range of usable voltage range. This now is an individually calibrated E-PERM and can be used as reference E-PERM or as transfer standard for calibrating continuous radon monitors used in radon test chambers. This concept is being developed by NIST for use in practice.

ACKNOWLEDGEMENTS

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TABLE-1

Air volume of the accumulator when E-PERM(R)S are used in the accumulator.

E-PERM(R) Configuration	Air volume of the accumulator in mL ± 3 %
1 SST or SLT	3843
2 SST or SLT	3720
3 SST or SLT	3597
1 LST or LLT	3920
2 LST or LLT	3873
3 LST or LLT	3827
4 LST or LLT	3780

TABLE - 2

Radon concentration in the accumulator at any time t days.

Accumulator volume : 3.717 L or 0.003717 m3. Source strength is 25 Bq or 676 pCi. f =0.888

days	Ra Bq	Rn Bq	Rn Bq/m3	Rn pCi/L	Rn Av Bq	Rn Av Bq/m3	Rn Av pCi/L
1	25	3.679517	989.9159	26.75448	1.895146	509.859	13.77997
2	25	6.749177	1815.759	49.07457	3.577723	962.5297	26.01432
3	25	9.310058	2504.724	67.69524	5.074396	1365.186	36.89692
4	25	11.44649	3079.497	83.22964	6.408273	1724.044	46.59579
5	25	13.22882	3559.004	96.18931	7.599397	2044.497	55.25669
6	25	14.71574	3959.037	107.001	8.665172	2331.227	63.00614
7	25	15.95621	4292.766	116.0207	9.620723	2588.303	69.95414
8	25	16.99108	4571.181	123.5454	10.47921	2819.266	76.19637
9	25	17.85443	4803.451	129.823	11.2521	3027.198	81.81617
10	25	18.57468	4997.224	135.0601	11.94937	3214.789	86.8862
11	25	19.17556	5158.88	139.4292	12.57976	3384.386	91.46989
12	25	19.67684	5293.742	143.0741	13.15089	3538.039	95.62267

TABLE - 3

Start date:3/8/93 Start time:14:16 SST End date:3/10/93

Ser #	Source #	vol L	NIST Ra Bq	NIST Rn Bq/m3	NIST Rn pCi/L	Electret #	IV	FV	EPERM pCiL-1	EPERM/ NIST	Av ratio
1	124	3720	26.67	1022.15	27.63	SK1259	767.00	631.00	26.35	0.953902	
	124	3720	26.67	1022.15	27.63	SK1235	762.00	626.00	26.61	0.963162	0.96
2	125	3720	26.3	1011.76	27.34	SK1117	766.00	627.00	27.02	0.98794	
	125	3720	26.3	1011.76	27.34	SK1224	769.00	637.00	25.46	0.931246	0.96
3	127	3720	25.36	976.60	26.37	SK1177	733.00	599.00	28.29	1.072979	
	127	3720	25.36	976.60	26.37	SK1317	761.00	638.00	25.67	0.973485	1.02
4	128	3720	24.94	959.45	25.93	SK1276	743.00	615.00	26.89	1.037175	
	128	3720	24.94	959.45	25.93	SK1281	762.00	634.00	26.75	1.031644	1.03
5	129	3720	24.96	960.21	25.95	SK1189	760.00	626.00	25.97	1.000577	
	129	3720	24.96	960.21	25.95	SK1220	748.00	624.00	25.66	0.984839	0.99
6	130	3720	25.98	999.45	27.01	SK1151	760.00	641.00	24.50	0.918255	
	130	3720	25.98	999.45	27.01	SK1120	763.00	638.00	26.09	0.965853	0.94
7	131	3720	26.49	1019.07	27.54	SK1216	758.00	630.00	26.36	0.957052	
	131	3720	26.49	1019.07	27.54	SK1268	754.00	630.00	25.94	0.941725	0.95
8	133	3720	24.86	956.37	25.85	SK1202	740.00	614.00	26.48	1.024412	
	133	3720	24.86	956.37	25.85	SK1144	764.00	638.00	24.63	0.952607	0.99
9	136	3720	26.44	1017.15	27.49	SK1316	749.00	615.00	28.16	1.024514	
	136	3720	26.44	1017.15	27.49	SK1296	747.00	618.00	27.08	0.985202	1.00
10	137	3720	23.67	910.59	24.61	SK1143	767.00	645.00	23.30	0.946788	
	137	3720	23.67	910.59	24.61	SK1302	768.00	635.00	25.27	1.026726	0.99
11	138	3720	24.22	931.76	25.18	SK1249	755.00	631.00	25.93	1.029697	
	138	3720	24.22	931.76	25.18	SK1129	767.00	631.00	26.35	1.046457	1.04
12	139	3720	25.94	997.92	26.97	SK1287	751.00	625.00	25.74	0.9544	
	139	3720	25.94	997.92	26.97	SK1106	764.00	628.00	26.16	0.969792	0.96
13	141	3720	24.46	940.69	25.42	SK1149	748.00	635.00	23.68	0.92749	
	141	3720	24.46	940.69	25.42	SK1211	762.00	633.00	24.86	0.977916	0.95
14	142	3720	25.24	970.99	26.24	SK1270	763.00	646.00	24.35	0.927802	
	142	3720	25.24	970.99	26.24	SK1283	760.00	635.00	24.00	0.914573	0.92
16	143	3720	23.36	899.43	24.31	SK1125	763.00	640.00	23.64	0.96857	
	143	3720	23.36	899.43	24.31	SK1218	769.00	633.00	26.34	1.083446	1.03
										AVG	0.983335

Fig.1 Radon concentration in an accumulator with a source of 25 Bq (676 pCi).

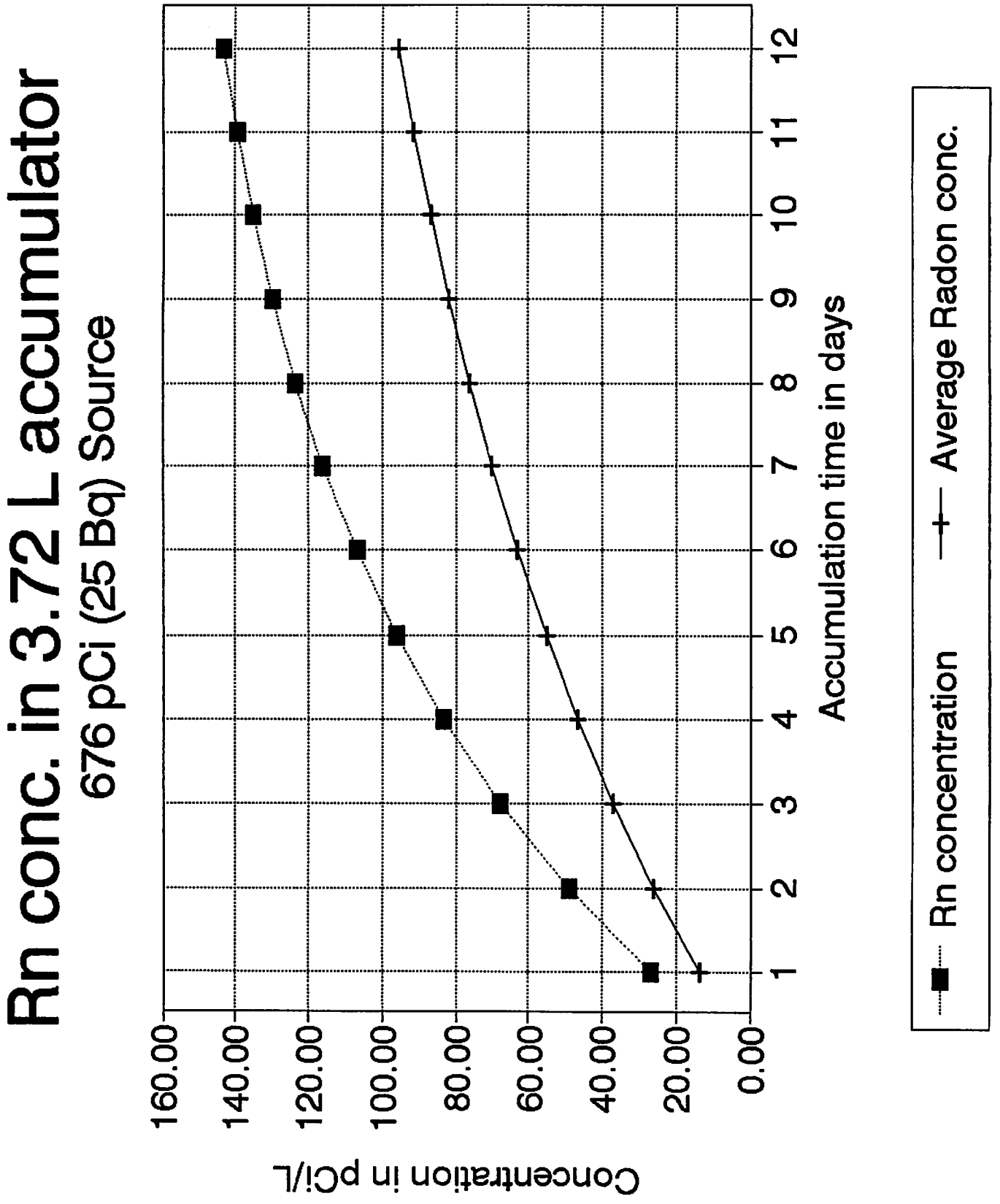
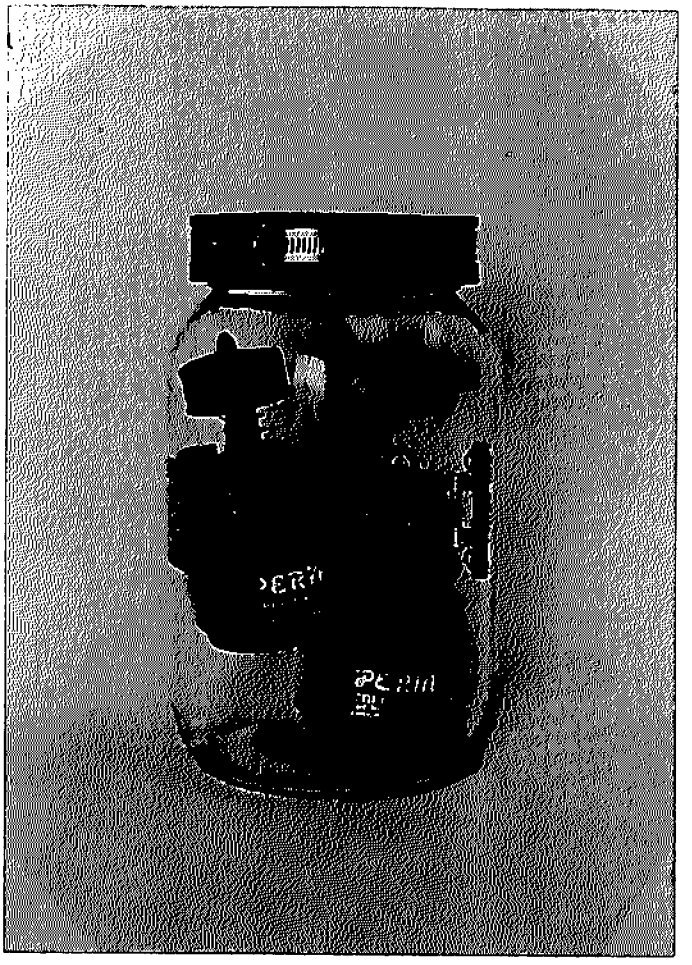


Fig.2 Photograph of experimental arrangement



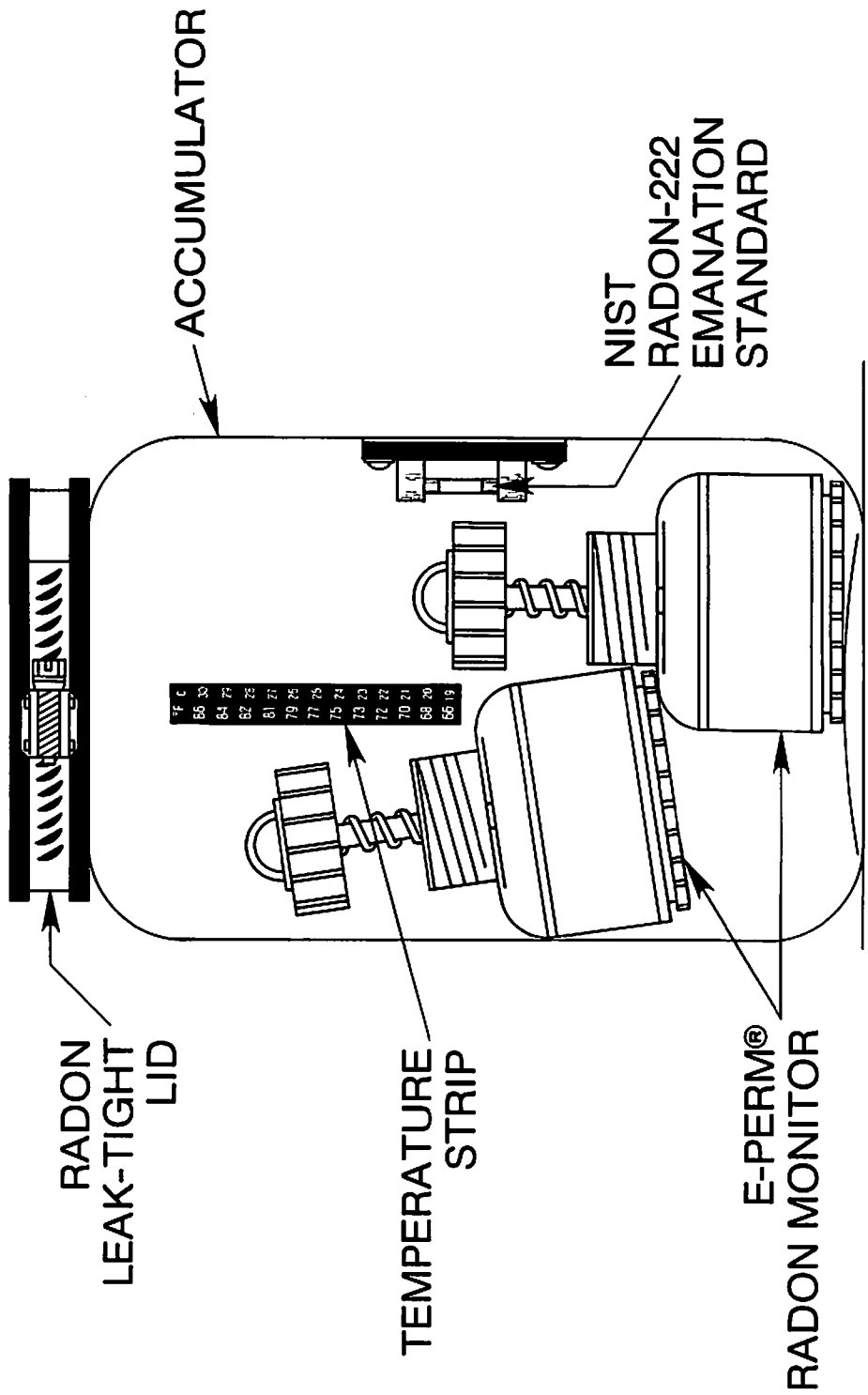


Fig.3 Line drawing of the experimental arrangement