EVALUATION OF ELECTRET ION CHAMBER FOR TRITIUM MEASUREMENT

R. A. Surette and M. J. Wood*

Abstract—**Commercial E-PERM® radon-in-air monitors modified to detect tritium in air have been evaluated. Each monitor consists of a small ion chamber with access holes around the sides to allow the air to diffuse into the chamber, and an electret at the bottom to establish an electrostatic potential. Radioactive gas inside the volume generates ions, which are collected by the electret. The reduction of charge (and subsequent reduction in surface potential) on the electret is a measure of the integrated exposure. Two types of detectors, a 50 cm^3 model and a 200 cm^3 model, were tested for tritium-in-air concentrations from 1 to 60 MBq m^{-3}, and gamma-absorbed dose rates from background levels to 50 μGy h^{-1}. The HTO-in-air response of the modified E-PERM® monitors was 3.3 ± 0.3 V MBq^{-1} m^3 h^{-1} for the 200 cm^3 and 0.8 ± 0.2 V MBq^{-1} m^3 h^{-1} for the 50 cm^3 monitor. For external gamma radiation (^{226}Ra), the 200 cm^3 chamber gave a response of 7.6 ± 1.8 V μGy^{-1} and the 50 cm^3 chamber 1.8 ± 0.5 V μGy^{-1}. The detection limit was about 3.6 and 15.2 MBq m^{-3} h for the 200 and 50 cm^3 chambers, respectively. The accuracy and limit of detection of the electret detectors are limited by the accuracy in measuring the surface potential on the electret.**

Health Phys. 65(4):418–421; 1993

Key words: tritium; ionization chambers; electrets; monitoring, air

INTRODUCTION

AN ELECTRET is a dielectric material that can retain an electrical charge almost indefinitely. With the development of high dielectric fluorocarbon polymers such as Teflon®†, electrets have become reliable and are capable of maintaining a constant electrostatic field even under high temperature and humidity conditions. Several other monitors using electrets to measure photon radiation (Bauser and Ronge 1978; Gupta et al. 1985; Dorschel and Pretzsch 1986; Pretzsch and Dorschel 1986) and tritium-in-air concentration (Miki et al. 1984; Pretzsch et al. 1986) have been developed.

The electret ion chambers evaluated were modified environmental ^{222}Rn dosimeters (Kotrappa et al. 1988; Kotrappa et al. 1990) manufactured by Rad Elec Inc.‡ Two types of electret ion chambers (200 cm^3 standard-volume "S" ion chambers and small-volume "L" 50 cm^3 personnel dosimeters) were evaluated for HTO response from 1 MBq m^{-3} to 60 MBq m^{-3} (27 μCi m^{-3} to 1.6 mCi m^{-3}), and for sensitivity to gamma fields from background to 50 μGy h^{-1} (5 mrad/h).

The modification to both types of chambers include 2 cm access holes cut in the side of the chambers to allow room air to freely defuse into and out of the units. The holes were covered with a filter to minimize the effects of air current. These modifications were done by the manufacturer before the units were received

Conventional ion chambers use batteries or a power supply to establish an electrostatic field. Ions created by the interactions of radiation with the gas in the chamber volume are collected by the electrodes. The charge collected is proportional to the radiation exposure. The operating principle of an electret dosimeter is that of a common ionization chamber, in which the bias electrode has been replaced by a charged electret.

In the electret ion chambers evaluated, the electrostatic field is established by an E-PERM®§ Teflon® electret and the walls of the ionization chamber are constructed out of conductive plastic. The E-PERM® electrets have been treated to hold a positive charge and attract negative ions. The ions collected on the electret surface slowly discharge the surface charge and thus reduce the electrostatic potential. The surface potential is measured before and after exposure. The difference in this surface potential is proportional to the total radiation exposure. A special surface potential reader is required to measure the voltage on the electret without disturbing the surface charge.

Electret dosimeters are compact, lightweight and require no batteries or external power source. In addition, the electret's surface charge is not affected by the reading of the surface potential. One disadvantage is that after prolonged use in a radiation field, the electret charge may become fully depleted, and the dosimeter then ceases to function. The electret then has to be

* AECL Research, Health Physics Branch, Chalk River Laboratories, Chalk River, Ontario, KOJ 1JO.

† Teflon is a registered trademark of E.I. DuPont de Nemours & Company Inc., Wilmington, DE 19898.

(*Manuscript received* 17 *December* 1992; *revised manuscript received* 23 *April* 1993, *accepted* 26 *May* 1993)

0017-9078/93/ $3.00/0

‡ Rad Elec Inc., 5330J Spectrum Drive, Frederick, MD 21701.

§ E-PERM is a registered trademark of the product patented and manufactured by Rad Elect Inc., Frederick, MD 21701.

replaced with a new one. Fortunately, these electrets are relatively inexpensive.

HTO-IN-AIR RESPONSE OF E-PERM® MONITORS

The electret ionization chambers to be tested were placed in an exposure chamber through which tritiated (HTO) air was flowed at a rate of 3 L min^{-1} (Fig. 1). The tritium concentration in the exposure chamber was measured using a Scintrex 275 tritium-in-air monitor[‖] and recorded. Background radiation was monitored with both an E-PERM® radon monitor and modified 50 and 200 cm^3 monitors located outside of the exposure chamber.

The different tritium-in-air concentrations were obtained by circulating air through a bubbler (gas washing bottle) containing HTO. By controlling the temperature of the bubbler, and therefore the relative humidity, the tritium-in-air concentration could be controlled.

GAMMA RESPONSE OF E-PERM® MONITORS

To measure the gamma response, a gamma field was established using a ^{226}Ra source. Different exposure rates were achieved by adjusting the distance between the source and the monitors tested. The radiation field was calculated for each distance and verified with a survey meter.

The electrets were measured before and after each series of exposures using a Surface Potential Electret Reader (SPER-1) Electret Voltage Reader.[‡] A set of long-term "E-PERM® Reference Electrets" provided measurement checks for assuring the performance of the SPER-1 electret voltage reader.

RESULTS

Fig. 2 shows the response of the 200 cm^3 "S" chamber with HTO-in-air concentrations from 1 MBq m^{-3} to 6 MBq m^{-3}. This graph shows that the two chambers tested have a response of about 3.3 ± 0.3 volts per MBq m^{-3} h. The SPER-1 electret reader sensitivity is ± 1 volt, and therefore would require a voltage reading of about 2 volts to obtain an unambiguous reading above background. This is equivalent to a tritium-in-air exposure (concentration × time) of about 0.6 MBq m^{-3} h.

Fig. 3 demonstrates the response of the 50 cm^3 personnel monitor over the same tritium-in-air exposure. The response of this monitor is about 0.8 ± 0.1 volts per MBq m^{-3} h. A one-hour exposure at 4 MBq m^{-3} would be required to obtain a statistically meaningful reading. These results are consistent with similar measurements at Ontario Hydro.[¶]

Figs. 4 and 5, respectively show the 200 cm^3 and

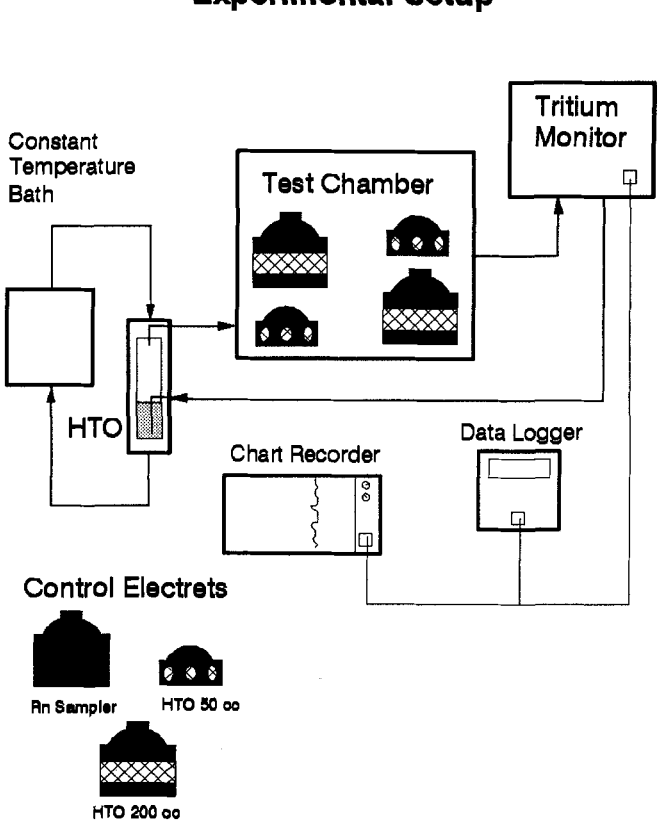

Fig. 1. Experimental setup for determination of HTO-in-air response of electret-based ionization chambers.

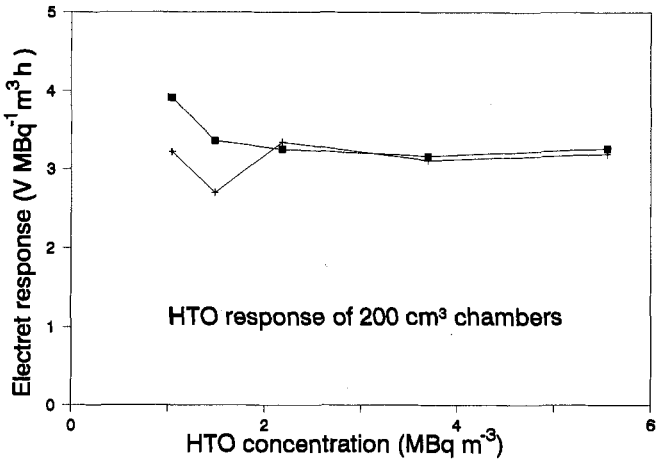

Fig. 2. Response of modified 200 cm^3, "S", ionization chambers to HTO in air.

[‖] Scintrex Nuclear Instrumentation, 222 Snidercroft Road, Concord, Ontario, L4K 1B5.

[¶] Lopez, S. Unpublished work, private communication. Ontario Hydro Safety Service Division, Ontario Hydro, Pickering, Ontario, 1991.

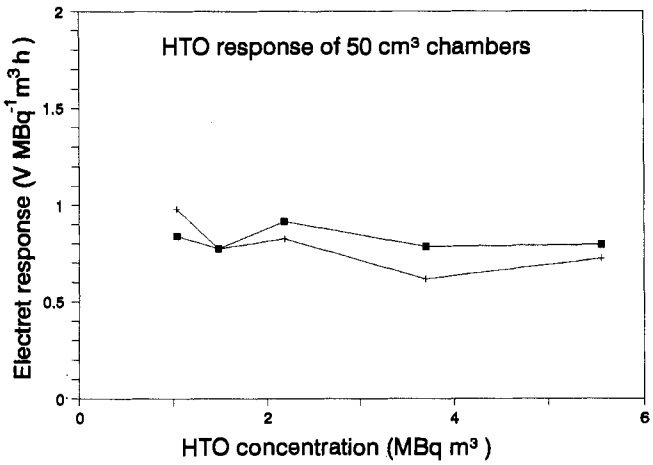

Fig. 3. Response of modified 50 cm³, "L", ionization chambers to HTO in air.

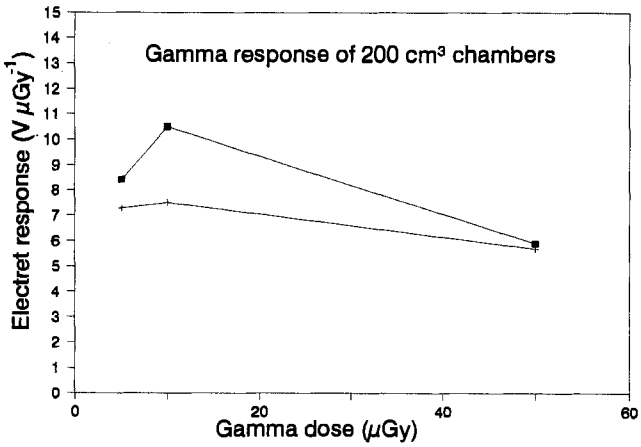

Fig. 4. 200 cm³ "S" electret ionization chambers response to external gamma exposure (^{222}Rn source).

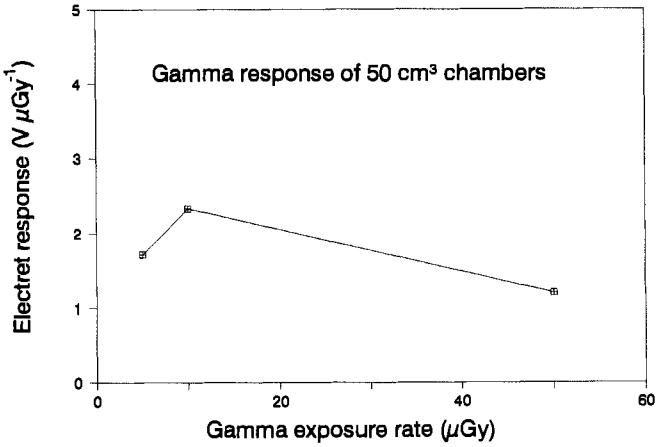

Fig. 5. 50 cm³ "L" electret ionization chambers response to external gamma exposure (^{222}Rn source).

Table 1. Electret ionization chamber response.

	UNIT TESTED			
HTO MBq m^{-3}	PS1[a]	PS2[b] (V MBq^{-1} m^3 h^{-1})	200a[c]	200b[d]
1.0	0.84	0.98	3.92	3.22
1.5	0.77	0.77	3.36	2.70
2.2	0.92	0.82	3.25	3.34
3.7	0.78	0.62	3.16	3.11
5.6	0.79	0.72	3.26	3.19
Average response[e]	0.8 ± 0.1		3.3 ± 0.3	
PHOTON μGy/h	(V μGy^{-1})			
5	1.71	1.71	8.42	7.29
10	2.33	2.33	10.50	7.50
50	1.20	1.20	5.90	5.70
Average response[e]	1.8 ± 0.5		7.55 ± 1.8	

[a] 50 cm³ chamber #1.
[b] 50 cm³ chamber #2.
[c] 200 cm³ chamber #1.
[d] 200 cm³ chamber #2.
[e] Average response of both units tested.

50 cm³ electret chambers' response to external gamma radiation. The background radiation field at this location can change by one order of magnitude, depending on the operation of the on-site reactors and the weather conditions. During these tests, the background fluctuated from under 0.1 μGy h^{-1} to 1.0 μGy h^{-1}. The background was measured at the start and end of the tests. The test electret chambers' readings were corrected for background, as indicated by the control electret chambers kept outside of the exposure area. See also Kotrappa and Stieff (1992) for information on atmospheric pressure corrections.

Table 1 summarizes the response of the electret ionization chambers to both tritium and photons.

The electrets, as supplied by the manufacturer, have a surface potential of about 700 volts. Because the surface potential is reduced as the electret is exposed to ionizing radiation, the electret has a finite life. The manufacturer suggests that the electret not be used if the surface potential is less than 200 volts. At lower potentials, the ion collection efficiency may be less than optimum and, therefore, a lower signal will result. Within the 700 to 200 volt range, the electrets may be reused as often as the charge reduction permits. For example, if the 200 cm³ chambers were exposed to 1 MBq m^{-3} for 8 h every day, the useful life would be about 20 d. The useful life of the same electret in the 50 cm³ chamber would be about 3 mo.

The electrets come in a holder with a screw-cap "keeper"; although they are very rugged, care must be taken when installing the electrets into the chambers. The surface of the electret is very sensitive and must

not be touched or come in contact with any object. Neutralization of the electrostatic field and inaccurate readings would result.

During these tests, the measurement of the reference electrets was variable. It was later found that the electret reader was not stable. It was replaced and the measurements were repeated. The data obtained with the unstable reader are not used in this discussion and are only mentioned to indicate one of the problems encountered. The electret reader is sensitive to humidity and dust, and must be kept in its storage case when not in use.

The electret ionization chambers were exposed to 60 MBq m^{-3} for about 1 h. This exposure resulted in depletion of the 200 cm^3 chamber electret surface charge to less than 100 volts; therefore, the readings were not dependable. The response of the 50 cm^3 chamber to this exposure was 0.4 V MBq^{-1} m^3 h^{-1}, which is consistent with the other observations. It is expected that the chambers' (200 cm^3 or 50 cm^3) response to high concentrations would remain linear as long as the electret surface potential is above 200 V.

CONCLUSIONS

The modified 200 cm^3 chambers can be used to effectively monitor a tritium-in-air exposure in the range of 1 MBq m^{-3} h–100 MBq m^{-3} h and the 50 cm^3 chambers can be used for exposures in the range of 4 MBq m^{-3} h–400 MBq m^{-3} h. The measurements are very dependent on the stability of the electret reader. A gamma absorbed dose of 4 μGy will give rise to a signal comparable to that from a 13 MBq m^{-3} h HTO tritium exposure. Thus, on an equal radiological hazard basis, these devices are about two orders of magnitude more sensitive to photons than to tritium.

Both the 50 cm^3 and 200 cm^3 chambers tested can be used for monitoring persons working in a tritium environment in the absence of external gamma fields. The use of these monitors is complementary to a bioassay program. While they cannot replace the bioassay program, in some instances they may reduce the number of bioassay samples required.

The 200 cm^3 chamber may be a cost-effective alternative to active-area monitors or passive-sampling and liquid-scintillation counting in facilities where the ambient gamma background is low. Both the initial and operating costs of the electret-based monitors are relatively low. In nuclear power plants, the radiation fields may be too high to allow for personnel monitoring with the electret ionization chambers described. For example, the signal due to a 1 μGy h^{-1} (100 μrad h^{-1}) gamma field over a one-hour period is the same magnitude as that due to tritium at 2.3 MBq m^{-3} for the same period.

No humidity effects were observed as long as the relative humidity was not condensing. No adverse effects were observed after the electret ion chambers were exposed to 95% RH for about four hours.

The electret ionization chambers tested were very rugged. The electrets are not susceptible to mechanical shock or vibration, but their active surfaces require special care. Any contact with, or foreign substance on, the electret surface can degrade the surface charge and give rise to false readings. As previously indicated, the SPER-1 reader also requires special care in handling and storage.

The ionization chamber and electrets are relatively inexpensive. With normal precautions and handling procedures outlined by the manufacturer, the 50 cm^3 samplers could be a useful addition to a monitoring program. It would supplement, but not replace, the need for regular bioassay.

REFERENCES

Bauser, H.; Ronge, W. The electret ionization chamber: a dosimeter for long-term personnel monitoring. Health Phys. 34:97–102; 1978.

Dorschel, B.; Pretzsch, G. Properties of an electret ionization chamber for individual dosimetry in photon radiation fields. Radiat. Prot. Dosim. 12:339–343; 1986.

Gupta, P. C.; Kotrappa, P.; Dua, S. K. Electret personnel dosimeter. Radiat. Prot. Dosim. 11:107–122; 1985.

Kotrappa, P.; Dempsey, J. C.; Hickey, J. R.; Stieff, L. R. An electret passive environmental ^{222}Rn monitor based on ionization measurement. Health Phys. 54:47–56; 1988.

Kotrappa, P.; Dempsey, J. C.; Ramsey, R. W.; Stieff, L. R. A practical E-PERM (passive environmental radon monitor) system for indoor radon measurements. Health Phys. 58:461–467; 1990.

Kotrappa, P.; Stieff, L. R. Elevation correction factors for E-PERM radon monitors. Health Phys. 62:82–86; 1992.

Miki, T.; Ikeya, M.; Matsuyama, M.; Watanabe, K. Tritium detection using electret dosimeter. Jpn. J. Appl. Phys. 23:931–934; 1984.

Pretzsch, G.; Dorschel, B. A reusable electret dosimeter. Radiat. Prot. Dosim. 12:351–354; 1986.

Pretzsch, G.; Dorschel, B.; Seifert, H.; Streil, T.; Seeliger, D. Measurement of tritium activity concentration in air by means of the electret ionization chamber. Radiat. Prot. Dosim. 12:345–349; 1986.

■ ■