Fermilab

September, 1979
TM-894
1183.00

PRECISION OF BEAM CALIBRATION: CONSTANCY OF CALIBRATION OF IONIZATION CHAMBERS*

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Introduction

Various factors appear in the formula that allows interpretation of the charge collected by an ionization chamber as a dose. Some of these factors affect the accuracy and others the precision of dose measurement. In particular, the calibration factor for the ionization chamber may not be a constant thus affecting both the precision and accuracy of dose determination.

At Fermilab, a ^{137}Cs source has been mounted in a holder ("jig") that allows reproducible mountings of EG&G, IC-17, 1 cc and modified EXRADIN ½ cc ionization chambers. This jig and the use of a computer[1] to perform calibrations have made it possible to study short term and long term stability as well as azimuthal variations in sensitivity and hysteresis of ionization charge collection efficiency versus applied high voltage. Some experiences gained at other USA facilities are also quoted.

Long Term Stability of EG&G IC-17 Ionization Chambers

Two EG&G model IC-17 TE-wall 1 cc ionization chambers were found which had been in continuous use for 2 or more years.

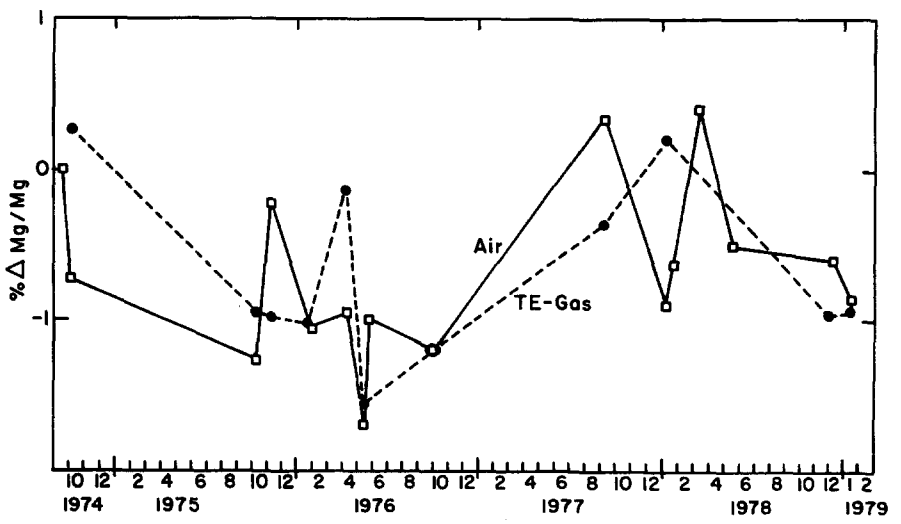


Figure 1. $\%\Delta M_g/M_g$ versus date for 57TG ion chamber

Figure 1 shows the relative changes in gas mass for 57TG versus date.

*This work was partly supported by NCI Grant # 5P01 CA18081.

Relative mass changes %(ΔM/M) are shown for both air and TE-gas fillings

$$M_{air} = (1.266 \pm 0.007) \times 10^{-6} \text{ kg}, (\pm.6\%)$$

$$M_{TE} = (1.129 \pm 0.006) \times 10^{-6} \text{ kg}, (\pm.6\%).$$

The uncertainties are one standard deviation. The TE gas %(ΔM/M) data was arbitrarily renormalized to the air curve in October, 1976, after two years of use. This chamber belongs to the Texas A&M Variable Energy Cyclotron group.

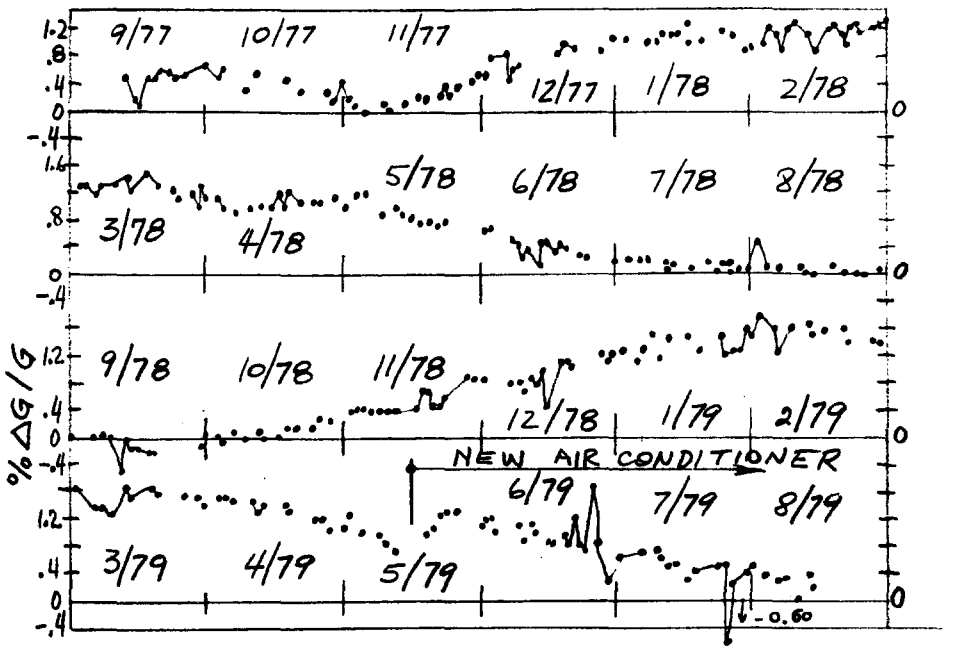


Figure 2. %ΔG/G versus date for 117TG ionization chamber

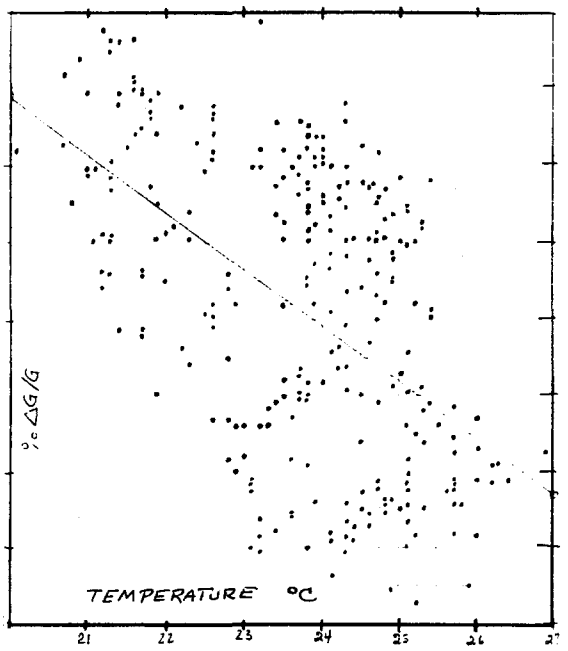
Figure 2 shows a similar graph for the relative changes of the calibrating factor G[R/C] of chamber 117TG in use at Fermilab. The peak-to-peak variations of both chambers are comparable (∿1.6% for TAMVEC's chamber and 1.8% for Fermilab's). An interesting winter-summer effect appears in this figure. A correlation study between (ΔG/G) versus temperature was made, where T is the temperature (^{o}C) of the system in which the chamber is recalibrated daily before calibrating the neutron beam. Figure 3 shows a scatter plot of %(ΔG/G) vs. T. A least square fit to a straight line was made, $\% \left(\frac{\Delta G}{G}\right) = -0.19T + 5.2$. The correlation factor was -0.51,for 290 points. A similar study relating G vs temperature-pressure correction factor yielded a correlation factor of -0.27, for 255 points. Although this effect is not yet fully understood by us, a correction factor for the chamber calibration is suggested,

$$G(T) = G(To) \times \left[1-0.0019\ (T-To)\right], \text{ where}$$

T is the temperature of the chamber in ^{o}C, and

To is the temperature of the chamber at the time of calibration.

Figure 3.
Scatter plot of %ΔG/G versus temperature for 117TG ionization chamber. The straight line is
$\% \frac{\Delta G}{G} = -0.19T+5.2$



At best, this formula is a zero order approximation to the changes in sensitivity of the ionization chamber itself. If the coefficient 0.0019 is taken to be the coefficient of volume expansion of A-150 plastic, then the coefficient of linear expansion would be approximately equal to $.0019/3 = 0.63 \times 10^{-3}\ {}^{o}C^{-1}$. This number is close to those for nylon and polyethylene at room temperature[2] (0-08 to $0.1 \times 10^{-3}\ {}^{o}C^{-1}$ and 0.15 to $0.3 \times 10^{-3}\ {}^{o}C$, respectively).

Hysteresis in Charge Collecting Efficiency

Both the EG&G 1 cc and Exradin ½ cc ionization chambers show hysteresis when plotting collected current versus polarizing field at constant exposure rate. Figure 4 shows this hysteresis for two chambers and positive H.V. The ordinates on the left hand side, $100 \times [Q(V)/Q(+600)]$ represent the charge collection efficiency for ^{137}Cs photons at an exposure rate of ∿0.8 R/sec. 149TG is an EG&G IC-17 chamber. The Exradin is a ½ cc chamber. The plots are versus V^{-2}, bottom abscissa. The ordinates on the right hand side represent current collection efficiency for the EG&G chamber in a neutron beam of dose rate ∿ 10 rad/min and a duty cycle of approximately 5×10^{-5}. The plot is versus V^{-1}, top abscissa. The points were recorded after the ionization chambers had stabilized themselves at each new polarizing voltage. Some points required up to 1½ hours before acceptable stability was reached. Similar behavior was

found in other EG&G IC-17 chambers, for both positive and negative voltages, for photons and for pulsed neutron beams. The EG&G parallel plate extrapolation chamber was the only ionization chamber which showed almost no hysteresis.

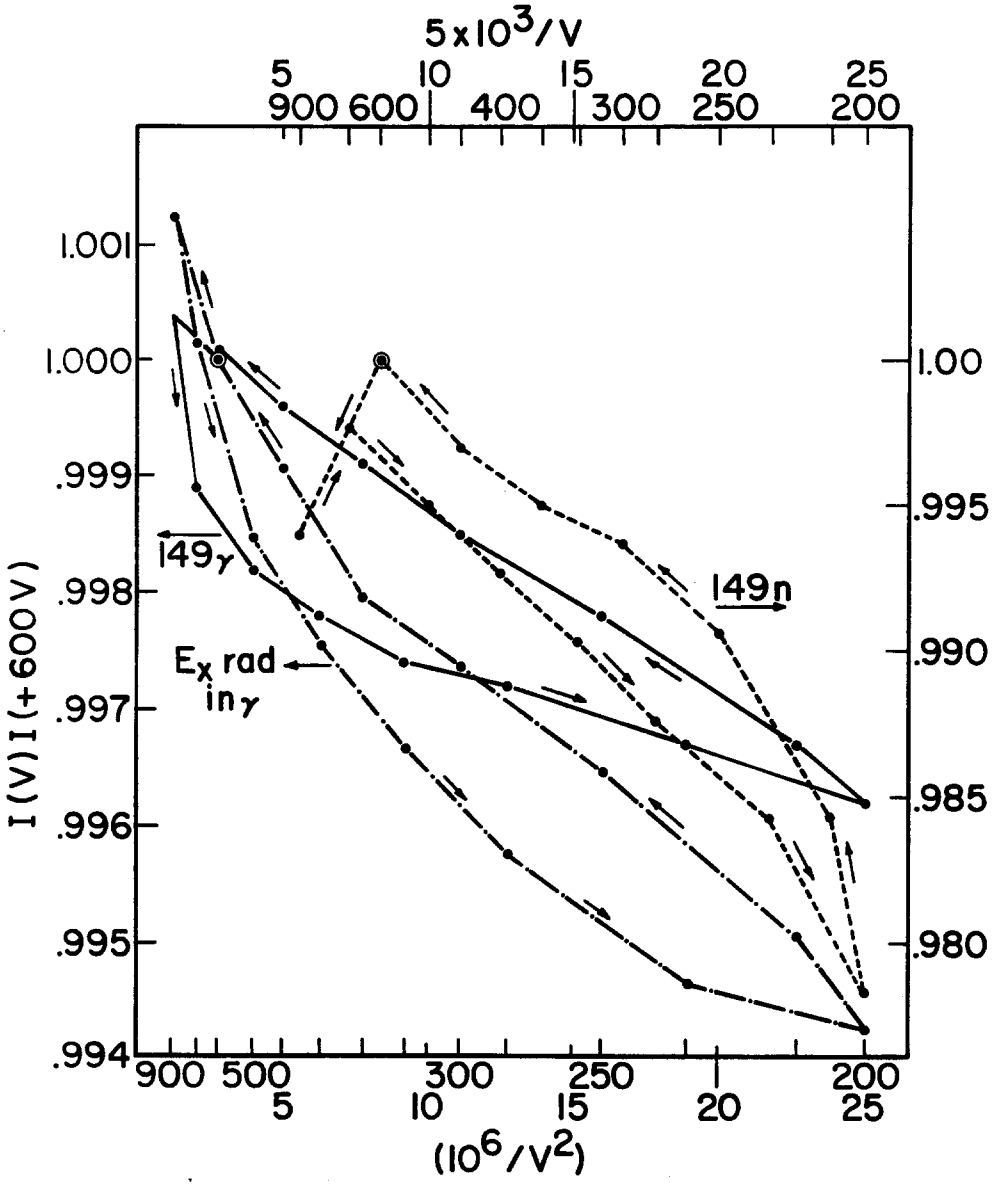


Figure 4. Hysteresis curves for two ionization chambers.

Gas Flow and Moisture Condensation

Problems have been encountered at Fermilab when operating EG&G ionization chambers in the TE-liquid phantom even though the chambers were inside one condom. The use of three condoms reduced problems considerably. In these

circumstances, the use of a continuous flow of dry air did not always prevent noise and unstable operation. When this occurred, it was necessary to disassemble the ionization chambers, blow dry air, and reassemble them. Satisfactory operation followed for many hours. The need to disassemble the chambers to blow dry air is interpreted as a manifestation of unsuccessful air flow in the chamber and its stem. The Exradin chamber is very good in this respect because it is possible to monitor the gas outflow. At the University of Chicago, where most in-phantom dosimetry is done with Exradin chambers, moisture problems have not appeared.

At TAMVEC, continuous gas flow is used in their EG&G, IC-17 chamber if it is filled with TE gas. Plotting current output versus gas flow, they found maximum stability for a gas flow of 16 ± 4 cc/min. At the University of Chicago, Kuchnir found that pressures of 30 cm of oil for the IC-17 and 2 cm of oil for the Exradin chamber were needed to achieve a flow of 0.2 to 2 cc/min. This difference may be explained by the different techniques used to monitor gas flow: Kuchnir measures gas outflow, while at TAMVEC they measure gas flow to the chamber. At Fermilab, all dosimetry is done with air filled chambers.

Azimuthal Variation of the Ionization Chamber Sensitivity

Using the ^{137}Cs jig at Fermilab, the azimuthal variation of sensitivity of various EG&G 1 cc and one ½ cc Exradin ionization chambers to a ^{137}Cs beam was studied. One chamber was also studied in a ^{60}Co beam. The results of these studies are given in Table 1 as percent deviation from the average

Table 1. Azimuthal Variation in Sensitivity for Various Ionization Chambers

Source	^{137}Cs	id	id	id	id	id	id	id	^{60}Co
Chamber ID	173TG	191TG	117TG	117TG	120TG	149TG	149TG	145XR	149TG
Position 1	+.2%	-.2%	-.2%	-.2%	-.2%	+.0%	+.0%	-.0%	+.0%
2	+.1%	-.1%	-.1%	-.1%	-.0%	-.3%	-.3%	+.0%	-.1%
3	-.2%	+.1%	+.2%	+.3%	-.2%	-.0%	-.0%	-.3%	-.0%
4	-.1%	+.1%	+.1%	+.1%	+.0%	+.2%	+.2%	+.3%	+.1%
1	+.3%	-.1%	-.2%	-.1%	-.0%	+.1%	+.1%	-.1%	+.0%
p-p	.5%	.3%	.4%	.5%	.4%	.5%	.5%	.6%	.2%
Av Sens*	3.262	3.381	3.714	3.742	3.601	3.402	3.407	6.166	3.407
Date	12/14/77	12/14/77	12/14/77	3/23/79	3/23/79	12/14/77	3/23/79	id	id
Owner	GLANTA	MANTA	Fermilab	id	id	id	id	id	id

*Average sensitivity in units of 10^9 R/C

value. Positions 1, 2, 3, and 4 represent successive 90° rotation of the chambers. No azimuthal variation in sensitivity to neutrons was found at Fermilab when similar measurements were made with an EG&G 1 cc chamber in a 16 x 16 x 18 cm^3 solid mini-phantom.[1]

The conclusions are that a record should be kept of the direction of the incident photon beam at the time of chamber calibration. This direction should then be used during subsequent photon beam calibration.

Chamber Stabilization Time

The procedure normally followed before dosimetry measurements is to stabilize the ionization chambers in the radiation field with the polarizing voltage to be used during measurements.

If this voltage is always the same, the time constant for stabilization of the collected current is relatively short. The charge collection per unit time of three EG&G 1 cc and three Exradin ½ cc chambers were followed with the computer for some time after being inserted in the ^{137}Cs jig. Two of the EG&G chambers had been used on and off for years, the third one was used for daily beam calibrations. The Exradin chambers were almost virgins. For this study, one chamber of each type was calibrated monthly, another pair weekly, and a third pair daily. The variation of current versus time was least-squares fitted to an algorithm of the form,

$$[I(t)/I(o)] = 1-a[1-\exp(-t/b)]$$

The results may be summarized as follows:

	EG&G IC-17	Exradin ½ cc
parameter a	$-(4 \text{ to } 6) \times 10^{-2}$	$(2 \text{ to } 4) \times 10^{-3}$ just as often + as -
parameter b		
daily	(2.6 ± 1.3) min	(6.2 ± 3.1) min
weekly	½ to 1½ min	∿ 3 min
monthly	3 to 4 min	5 to 6 min

For stability of the order of ½%, one should wait about 5 time constants. This seems to be a function of the individual ionization chamber and its prior radiation history. For chambers in frequent use, it seems that 15 minutes wait is adequate.

When chambers undergo a change in polarizing voltage, as when making the hysteresis studies in figure 4, the time needed to achieve adequate stability (two successive calibrations agreeing within 0.1%) varied between 20 minutes and 90 minutes.

Reference

1. Awschalom, M. and Rosenberg, I, Fermilab TM-834, December, 1978.
2. Handbook of Chemistry and Physics, 51st ed.