AN EXPERIMENTAL STUDY OF THE PERFORMANCE OF A CAVITY TYPE IONIZATION CHAMBER

G. H. Jenks, W. M. Breazeale and J. J. Hairston

Oak Ridge National Laboratory

Oak Ridge, Tennessee

Abstract

Comparisons between calorimetric and ionization chamber measurements of the power generated in graphite by absorption of energetic gamma rays have been carried out. The results serve as a calibration of the chamber. They also serve to test the consistency between the theoretical performance of this type of chamber and previously determined values for the factors which relate ionization in the chamber to energy absorption in the walls. (auth)

Small ionization chambers, frequently called cavity type chambers, have been used extensively for some time to measure the quantity of gamma ray energy absorbed in various liquids and solids under irradiation. This method of measurement is based on Gray's fundamental relation between the rate at which electronic energy is dissipated at a point in a medium and the ionization which is produced in a gas which replaces the medium at the given point[1, 2]. The relationship is expressed by the equation:

$$E = WJ\rho$$

where E is the energy absorbed per unit mass in the medium, J is the ionization per unit mass in the gas, W is the average energy expended by electrons in producing a pair of ions in the gas, and ρ is the mass stopping power for electrons in the medium relative to that in the gas. To date, very few absolute experimental verifications of the method have been made, and under given experimental conditions the energy absorption values computed from the measured ionization may be uncertain[3].

The study carried out consisted mainly of comparisons between the ionization occurring in CO_2-filled graphite chambers under pile irradiation and the power generated in surrounding graphite as determined calorimetrically. The relative amounts of ionization resulting when helium and dry air respectively were substituted for carbon dioxide were also determined. Measurements of the latter type were also carried out using cobalt-60 (1.2 and 1.3 Mev gamma rays) instead of the reactor as the source of gamma rays. Argon was included among the gases measured in this source.

Details of the equipment, procedure, and experimental results are given in another paper;[4] hence only a brief description will be given here. The power generated in a graphite sample in the reactor was determined by placing the sample in a liquid nitrogen calorimeter similar to one recently described by one of the authors[5]. As before, the calorimeter operated isothermally, and the power generated in the sample was determined by the rate of vaporisation of liquid nitrogen in contact with the sample. The sample itself was a thick-walled graphite cylinder which weighed 33.4 grams. A thin-walled stainless steel container fitted into the center of the cylinder and held the liquid nitrogen which comprised the thermal measuring element of the calorimeter. The vacuum jacket surrounding the sample was lined with 6 mm of graphite in order to prevent recoil electrons originating in the steel walls of the jacket from reaching the sample. Calibration of the calorimeter was carried out using a small carbon resistance heater imbedded in the sample to produce precisely known power levels within the sample. The calorimeter was sufficiently sensitive

to detect changes in power input of about 3 microwatts when the measurement extended over a period of an hour.

The graphite ionization chamber studied had a gas volume of 10.3 ml. Its wall thickness was adjusted to be greater than the range of most of the secondary electrons encountered in the measurements. The sources of gases used in the chamber were tank supplies in all cases. During measurements the gases were passed through the chamber at an approximate rate of 2 cu. ft. per hour. For the measurements in the pile which were to be compared with the calorimetric measurements, surroundings for the chamber were provided which closely reproduced those used with the calorimeter.

The cobalt source employed was devised by Ghormley and Hochanadel and has been described by them[6]. It was made up of a number of cobalt pellets placed around the surface of a cylinder, leaving the space within the cylinder available for irradiation studies. The gamma ray intensity existing in the cylinder had been determined by the same investigators[7] by measuring the heat produced in water placed in the source. Thus, as a result of the chamber measurements in this source, the chamber performance under irradiation by cobalt gamma rays could be compared with that found under pile irradiation.

The reactor measurements were made in one of the vertical instrument holes in the Oak Ridge National Laboratory's graphite pile at a point where the neutron flux was almost completely thermalized. The value determined for the slow neutron flux at the point was about 1.5×10^{10} n's/cm^2/sec. Gamma radiation at the test location consisted of pile gamma rays and various energetic gamma rays which resulted from neutron captures in the calorimeter walls and in the aluminum jackets which lined the test hole. Thus the energies of the gamma rays varied over a wide range - from a low value for those which originated at some distant point in the pile to a value of several Mev for those capture gammas which originated nearby.

The results of the comparison of ionization chamber and calorimetric measurements in the pile showed that the rate of collection of ions in the chamber was 1.93×10^{11} per sec. per gram of CO_2 when the rate of absorption of gamma energy in graphite was 1 micro watt per gram. The estimated probable error of this determination is ± 2%. Another value for the same quantity was found by comparing the CO_2 chamber measurements in the cobalt source with the calorimetric measurements of Ghormley and Hochanadel[7]. In this case, however, it was necessary to apply corrections for the difference between the absorption coefficients of graphite and water and for small differences in the amounts of absorber between source and sample. The corrected value agreed with that given above within the estimated error of the measurements. In order to interpret the significance of these results in terms of the performance of the chamber, the experimental value was combined with Gray's equation to calculate W for CO_2. In making the calculation a value for the relative stopping power per electron in graphite and in CO_2 was assumed and it was also assumed that the chamber performed ideally. W computed in this manner was found to be 31.8 ev.

The results obtained in the comparisons of the relative ionization occurring in different gases are shown in the accompanying table together with the value of W for each gas calculated as before. In these calculations, the previously determined value of 31.8 ev for W in CO_2 was used as a measure of the energy absorption. The values for the relative stopping power per electron in graphite and in the given gas which were employed in these and the previous calculations were estimated from a graph shown by Gray[2] in which the relative stopping power is plotted as a function of atomic number for the recoil electrons produced by Ra(B + C) gamma rays. They are listed in the table under the heading Sc/Sg.

A literature search did not reveal any value for the energy expended by electrons in forming an ion pair in helium. For the other gases, the determinations of W which have been reported indicate that the value for the quantity is dependent upon the energy of the bombarding electrons, and some discussion of the values to be compared with those determined in the present work is desirable. The experimental values of W in air have been considered at some length by Gray[2]. Apparently the most reliable value is that given by the empirical equation, $W\ (ev) = 31.62 + 5.27/E - E_1$, where E is the initial energy in Kev of the bombarding electrons and E_1 is the ionization potential of air in Kev. This expression was derived by Gerbes[8] from the results of his measurements and from those of others and is valid in the range 0.3 to 60 Kev. It implies that the value of W is relatively high at low electron energies but decreases rapidly with increasing energy and levels off at approximately 32 ev per ion pair. For 40 Kev electrons, the value of W found from the equation is about 32.4 ev per ion pair. Gray[2] suggests that this value, with an uncertainty of $\pm$ 1.0 ev as indicated by the equation, may be used for electrons of all energies above about 8 Kev. In the present work the energies of all but a small fraction of the recoil electrons which entered the gas chamber would probably be included in this range.

Values of W in carbon dioxide and in argon for electron energies of 10 Kev to 40 Kev have also been reported by Gerbes[9]. These were determined by measuring the relative ionization resulting from total absorption of electrons in the given gas and in air. Values of W were computed from the results and from the values of W in air determined previously. The ionization in CO_2 relative to that in air was found to remain nearly constant over the energy range investigated. That in argon relative to air decreased by about 5% in going from 10 to 40 Kev electrons. Thus it appears that for CO_2 the use of the derived value of W for 40 Kev electrons for all electrons above about 10 Kev

is probably as valid as the comparable value suggested for air. For argon the uncertainty should probably be increased to ± 2.0 ev.

The values of W given by Gerbes for 40 Kev electrons in carbon dioxide and argon are shown in the final column of the table. These values as well as that for air are in good accord with the values determined in this study. Thus it appears that for gamma rays of energies encountered in this work all-around consistency exists between the theoretical performance of this type of ionization chamber, the available values for relative stopping powers in various materials, and previously determined values for the energies of ion pair formation in various gases.

No significant difference was found between the results obtained in the pile and in the cobalt source when CO_2 or He filled chambers were used. However, the ionization which took place when the air filled chamber was irradiated in the pile was several times greater than that which could be attributed to the absorption of gamma ray energy. The added ionization was due to recoil protons which originated in (n,p) reactions in the nitrogen of air. However, uncertainties in the slow neutron flux and in the fraction of the recoil energy which was absorbed in the gas preclude accurate corrections for this effect.

REFERENCES

(1) L. H. Gray, Proc. Roy. Soc., 156, 578 (1936)

(2) L. H. Gray, Brit J. Rad., 22, 677 (1949)

(3) T. J. Wang, Nucleonics, 7, No. 2 (1950)

(4) AECD-

(5) C. V. Cannon and G. H. Jenks, Rev. Sci. Inst. 21, 236 (1950)

(6) J. A. Ghormley and C. J. Hochanadel, Rev. Sci. Inst. 22, 473 (1951)

(7) J. A. Ghormley and C. J. Hochanadel, to be published

(8) W. Gerbes, Ann. Physik, 23, 648 (1935)

(9) W. Gerbes, Ann. Physik, 30, 169 (1937)

Data for Relative Ionization in Different Gases

Gas	Source of Radiation	Temp. °C.	Pressure mm Hg	Ion Current amps x 10^8	Power Level of Measurement Microwatts/gram of Graphite (Approximate)	Sc/Sg	Energy Per Ion Pair (ev) Calculated from This Work	Energy Per Ion Pair (ev) Previously Determined
CO_2	Pile	25	741	1.54	34	1.02	31.8*	
Air	Pile	25	741	2.39	34	1.02	-	
He	Pile	25	741	0.190	34	0.92	25.7	
CO_2	cobalt	33	745	36.97	671	1.02	31.8*	31.2
Air	cobalt	33	745	23.60	671	1.02	32.6	32.5
He	cobalt	33	745	4.445	671	0.92	26.2	-
A	cobalt	33	745	34.18	671	1.13	25.3	25.2

*Determined in comparisons with calorimeter measurements.