SPECIAL PROBLEMS IN NUCLEAR INSTRUMENTATION

PROGRESS REPORT

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ABSTRACT

The angular dependence of the sensitivity has been studied in the 0.5 cc chamber. A significant variability in neutron sensitivity has been discovered in magnesium chambers. Previous conducting plastic mixtures have been reviewed with regard to composition and equivalence.

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INTRODUCTION

The principal activities under this contract during the past year pertained to the small 0.5 cc thimble type ionization chambers and the experimental and theoretical studies of conducting plastic mixtures. The understanding of the 0.5 cc chambers was advanced in two distinct directions. Firstly, the angular dependence of the chamber response was determined for a nearly pure collimated cobalt-60 photon beam. These measurements were made for the paper presented at the 5th International Congress of Radiation Research held last July in Seattle. Secondly, the neutron response of the magnesium version of the 0.5 cc chambers was studied. A significant variation among individual units was discovered which tentatively is ascribed to surface oxidation. This study represents a collaboration with Frank S. Williamson of the Division of Biological and Medical Research, Argonne National Laboratory. Further work will endeavor to more fully elucidate the underlying phenomenon.

Some batches of the bone-equivalent mixture, B-100, were prepared during the Summer months of July and August. Since the latter part of November, the almost exclusive occupation has been the complete review of the various successful conducting plastic formulations which had been developed over the years in the Physical Sciences Laboratory. A paper was read at the Meeting of the Radiation Research Society held in Miami Beach, May 11-15, 1975. A copy of that paper, Document No. COO-323-33, accompanies this report. A more complete treatment of this matter is the subject of a paper which is intended for publication and which is currently in preparation.

These major activities are discussed in more detail separately below. Additionally a significant amount of total effort is spent in assisting other researchers in diverse ways. The assisting is usually in the form of providing actual materials and services and offering advice and information concerning conducting plastics. The greatest single effort along these lines would be the cooperation extended to Lt. Col. David Verrelli and his group at the Armed Forces Radiobiology Research Institute. Six of the 0.5 cc TE chambers were fabricated for the AFRRRI group. A new thin-walled (.010 inches) 3/4 inch inside diameter air-equivalent chamber was also fabricated for them. Another identical chamber was restored for them by replacing the outer electrode and installing a guard-ring extension. Similar restoration work was successfully performed on a similar thick-walled (0.100 inches) chamber for Frank Williamson.

SMALL IONIZATION CHAMBERS

The chambers which were the center of the studies to be described here are the thimble-type having a nominal sensitive volume of 0.5 cc. These chambers have been mentioned in the last several annual reports. There are actually three distinct chambers, as the identical design has been triplicated using different materials in each. The one version utilizes the Shonka TE plastic, A-150. Another, magnesium. While another is constructed out of the Shonka air-equivalent plastic, C-552. Figure 1 shows a drawing of the TE version including the important dimensions of the sensitive portions of the chamber.

A pair of small tubes serve as gas ports and permit the chamber to be operated with a particular gas by means of continuously circulating the gas through the chamber. The chambers are gas-tight. Therefore, after purging, a flow rate in the neighborhood of 10 microliters

Figure 1 Sectional drawing of the TE version of the 0.5 cc chamber

per minute is adequate to preserve the purity of the gas filling the chamber. A TE gas mixture is used in the TE chamber. Carbon dioxide and argon are the two main choices for the magnesium chambers. In the air version, the gas ports simply allow the chamber to equilibrate with the ambient atmosphere.

The investigation of the angular dependence of a TE chamber and the neutron sensitivity of the magnesium units will be described. Neither study is complete. So what follows represents a preliminary report. The neutron sensitivity question has been pursued in close collaboration with Frank Williamson and Gordon Holmblad.

Although the angular dependence measurements have thus far only been carried out on the TE chamber, the essentially identical geometry would indicate similar behavior for the magnesium and air chambers as well. The measurements were carried out in the Radiation Laboratory which is separate small single-room building having vertical steel casings set in the floor for storing radioactive materials. One such casing is located in the center of the room and holds a single cobalt-60 source of nominal activity of 50 curies. This source in its normal position at the bottom of the well with merely the cover removed, provides a well collimated photon flux for studying the angular dependence. The schematic of the experimental arrangement is given in Figure 2. The ionization currents were measured using a Townsend bridge with an integrating capacitor and an M3 vibrating reed electrometer which had been built many years ago in the Metallurgical Laboratory of the University of Chicago. The feedback voltage was measured with a Brown recording potentiometer. The charge accumulated on the integrating capacitor over an interval of 4 minutes was determined for various orientations of the

Figure 2 Schematic showing the relative positions of chamber, source and collimation for angular dependence studies.

chamber. Readings were generally made at 15 degree intervals except in the regions of $\theta = 0$ and $\theta = 180$ degrees (see Fig. 2 for definition of θ) where 5 degree intervals were used. The tissue dose rate at the position of the chamber is approximately 15 mR/min.

The results obtained for chamber No. 033 are shown in Figure 3. This particular chamber was fitted with a rigid stem in the form of a stainless steel tube .250 inches O.D. by .180 inches I.D. and nearly 12 inches long. The length of the stem prevented reaching orientations with $\theta \leq 45$ degrees in the setup. Only a single reading was taken at each setting of θ except at 95 degrees where two readings were taken. No readings were thrown out. On the whole, the measurements would seem consistent to within one percent. The one clear exception is the reading at 150 degrees. The values at 160 and 170 may be artificially slightly high. The response is constant to within ± 1 percent for angles greater than 90 degrees. There appears to be a hint of a dip at 180 degrees. However, the chief feature of the results is the gradual rise in response as θ decreases below 90 degrees. Of course, at smaller angles than could be reached in the setup, the response is expected to decrease to perhaps 50 percent of that characteristic of the region around 180 degrees. The initial rise in response below 90 degrees is caused by scattering by the base of the chamber, the cable and the stem. The sharp decrease expected around 0 degrees reflects the shadowing of the sensitive volume by the base, cable and stem.

The measurements were repeated using another chamber and a different mounting. The chamber was merely secured to a Lucite shelf $3/32$ inches in thickness, $3/4$ inches wide and 5 inches in length. Two small Lucite V-blocks were attached to the shelf with nylon

Figure 3 Angular dependence for a 0.5 cc TE chamber having a stainless steel stem.

screws and firmly clamped the coaxial cable. The chamber itself projected approximately 2 inches beyond the end of the shelf. This arrangement permitted rotating the chamber through $\theta = 0$. The results obtained on chamber No. 032 are shown in Figure 4. Again only a single reading was taken at each angle except for two readings at 60 and 90 degrees and again no readings were discarded. The results are quite similar to those shown in Figure 3. Again there is a hint of a dip at 180 degrees and there is a rise in the response as θ decreases below 90 degrees. However, the rise below 90 degrees may not begin until nearly 60 degrees and is clearly not as prominent. The results seem to show decidedly reduced scattering effects with the second mounting.

Further measurements are needed to better define the angular dependence and to verify which of the previous readings might have been spurious.

An attempt was made several years ago to experimentally assess that contribution to the neutron sensitivity of the magnesium chambers which is due to recoil protons produced in the chamber insulation. The previous results had to be discarded because of gas leaks in the chambers which cast serious doubt on the composition of gas in the chamber. In order to obtain the answer to this question, eight magnesium chambers were reassembled from old chambers and parts for a fresh experiment. Four of the chambers utilized polyethylene for the collector and shell insulators. The other four, Teflon. Only two of each type were actually used in the experiment, the remaining four serving as spares.

The tests were carried out in the High Level Gamma Facility and Janus Reactor of the Biological and Medical Research Division at Argonne National Laboratory. High purity argon gas was circulated through the four chambers arranged in a simple series gas circuit.

Figure 4 Angular dependence for a 0.5 cc TE chamber clamped directly to a lucite shelf without a stem.

The sensitivity of each chamber was initially determined relative to cobalt-60. The chamber response was then determined for each unit at a fixed position in the High Flux Room of the Janus Reactor. Because of "inconsistencies" in the results, a repeat measurement was made the following day with the gas flowing in the opposite direction through the same series arrangement. Finally, the sensitivity relative to cobalt-60 was redetermined for each chamber.

The results of these measurements are summarized in Tables I, II, and III below. The cobalt-60 response as measured on two different dates is presented in Table I. The data have been corrected for temperature and pressure variations and also for the decrease in source activity between the two sets of measurements. The results are seen to be reasonably consistent between the two days and the four chambers appear to

TABLE I Response of certain 0.5 cc magnesium chambers for fixed cobalt-60 radiation. Chambers are listed in order of position in gas circuit for the first set of values. The gas flow was reversed for the second set. The dates of each set of measurements is indicated.

Chamber	Ionization Current - Arbitrary Units	
	1-16-75	1-24-75
061 (PE)	5.512	5.447
066 (TFE)	4.507	4.476
063 (TFE)	5.445	5.423
060 (PE)	5.433	5.448

TABLE II Response of certain 0.5 cc magnesium chambers at a fixed position in the High Flux Room of the Janus Reactor. The chambers are listed in order of position in the gas circuit for the first set of measurements. The gas flow was reversed for the second set. The dates for each set are indicated.

Chamber	Ionization Current - Arbitrary Units	
	1-23-75	1-24-75
061 (PE)	4.807	4.837
066 (TFE)	2.735	2.757
063 (TFE)	4.266	4.272
060 (PE)	5.345	5.350

TABLE III Ratio of neutron response to cobalt-60 response for certain 0.5 cc magnesium chambers.

Chamber	Neutron / Gamma - Arbitrary Units
061 (PE)	88
066 (TFE)	61
063 (TFE)	78.6
060 (PE)	81.5

be very similar with the notable exception of chamber 066. It is interesting that 066 also stands out in comparing shell-collector capacitances. Of the eight chambers originally made, seven show the value of 0.67 picofarads while 066 has the value 0.74 picofarads. Clearly, there is a significant difference in the geometry. A shorter shell on the one chamber would account for the greater capacitance and the reduced radiation sensitivity.

The comparative neutron responses of the same chambers are given in Table II. Again the results are consistent and reveal independence of the direction of gas flow in the series arrangement. The type insulation used in the chamber is indicated by "PE" for polyethylene and "TFE" for Teflon. To see the effect of the insulator alone, the neutron response is normalized for each chamber to its cobalt-60 response. In this manner, small variations in geometry among the chambers would be eliminated. The result of this procedure is given in Table II.

It is seen that, as expected, the relative neutron response is lower in the TFE units in comparison with the PE units. The average reduction in neutron response is 28.5 percent in the TFE chambers. But in comparing individual chambers the extreme values are 11.3 and 46.5 percent. There are two significant facts which must be reckoned with. One is the magnitude of that portion of the neutron response which is founded in the insulator. However, of greater importance is the variation in the relative neutron response between chambers having the same type of insulator. The clear conclusion seems to be that something is influencing the neutron sensitivity in addition to the insulation material.

Magnesium appears to oxidize to an appreciable extent in time while exposed to the atmosphere. The different components used in these chambers were not all machined at the same time and also may have had different histories. Hence, it is quite likely that the magnesium surfaces in the chambers are not all oxidized to the same degree. Further experiments and analysis are required to fully understand the variable neutron sensitivity of the magnesium chambers.

It should be pointed out that a secondary conclusion of the results reported here is that the High Flux Room of the Janus Reactor must have an unusually small gamma contamination. It is precisely this feature which enabled the variability of the magnesium chamber response to be observed so decisively. At this point it should be stressed that the numbers given in Table II correspond to the total ionization currents generated in the individual chambers. No attempt was made to separate out that portion founded in the gamma contamination. Therefore, the actual magnitude of the insulator effect and the variation between chambers employing the same insulator are greater than the numbers in Table III would indicate. As can be seen, the Janus Reactor provides a rather unique facility, in the virtue of its low gamma contamination, for studying such questions.

MIXING OF CONDUCTING PLASTICS

There were two objectives in the mixing program. The first was to replenish the supply of B-100, a tissue-equivalent (bone) formulation, and of C-552, an air-equivalent formulation. The second objective was to prepare certain test batches related to possible new avenues for producing the tissue-equivalent (muscle) composition. Time only

permitted the first objective to be reached.

The mixing was accomplished without any great difficulty. Of course, handling extremely finely divided carbon black does present certain problems. This is normal and is expected. Setting up the operation outdoors in an improvised tent, however, is an excellent way to minimize the strain on the regular facilities.

The mixture, B-100, involves the very same four components as A-150. Hence, the same procedures found to work for B-100 should work equally well for A-150. The point being that A-150 can be mixed whenever it might be needed.

One area of concern is the compatibility of the ingredients in their initial form. Three of the ingredients, polyethylene, carbon and calcium fluoride, are fine powders while the fourth, nylon, is only available as relatively coarse pellets. Because of the disparity in particle size, it is not possible to obtain and to maintain a homogeneous mixture prior to plasticizing. This problem is handled by following a two-step procedure. The three fine powders are first passed thru an extruder where only a superficial mixing is achieved in terms of microscopically dispersing the carbon particles in the plastic. The extruded material and the nylon pellets are then separately ground to approximately the same size. The appropriate amount of nylon is then added and the composite mixture is then intensively mixed in the patented Shonka plastics mixer.

Tests have verified that the quality of this batch does indeed measure up to the high standards previously established by Francis Shonka. There is no doubt that A-150, because of the similarity to B-100, could be produced when needed with similar success.

A batch of C-552 was prepared according to the particular procedure followed during the Summer of 1971 and described in Progress Report No. COO-323-28. Again the results were entirely satisfactory. However, a distinct reduction was noticed in the mixing rate. This is attributed to wear in the feed screw and barrel which limits the rate at which the raw ingredients can be fed into the mixing chamber and hence limits the overall mixing rate.

REVIEW OF MIXTURES

A considerable effort has been spent on establishing the composition of the various successful conducting mixtures that have been developed here in the Physical Sciences Laboratory. A number of conflicting reports, references and records in our files had to be sorted through. Besides verifying the precise compositions, the different formulations were evaluated with respect to photon equivalence. The total photon attenuation and the photoelectric cross sections were calculated for each mixture over the range of photon energy from 10 KeV to 8 MeV. The cross sections for the elements given in the ENDF/B data file (this data may be found in NBSIR 73-241 "Comparison of Photon Interaction Cross Section Data Sets. VII. Biggs-Lighthill (Rev.) and ENDF/B", G.L. Simmon and J.H. Hubbell, 1973) were the basis for the calculations.

A paper entitled "Composition Variability and Equivalence of Shonka TE Plastic" (Document No. COO-323-33) was presented at the meeting of the Radiation Research Society, Miami Beach, May 11-15, 1975. That paper concentrated on the various successful TE (muscle) mixtures that had been developed. Another paper, which will be submitted for publication in the open literature, is in preparation. This latter paper will be a compre-

hensive review of all the successful conducting plastics.

One of the objectives of the Miami Beach paper was to correct the common misconception that the mixture designated A-150 is that TE (muscle) composition which is defined in the paper presented by Shonka, Rose and Failla at the Second International Conference on the Peaceful Uses of Atomic Energy, Geneva, September 1958 (Progress in Nuclear Energy, Series XII, Volume 1 - Health Physics, 160-166 Peragamon Press, 1959). It was discovered during the course of reviewing the previous work that actually

TABLE IV The composition of several TE (muscle with respect to photons and neutrons) mixtures. The first two columns represent the mixtures defined by Shonka, Rose and Failla in their 1958 Geneva Conference Paper.

Component	Percent by Mass		
	SRF ¹	SRF ²	A-150
Polyethylene	52.1	44.39	45.14
Nylon	28.22	32.79	35.22
Carbon	13.5	15.59	16.06
Silica	2.2	2.60	-----
Calcium Fluoride	4.0	4.63	3.58
	100.02	100.00	100.00

¹ Given explicitly in the Geneva Conference Paper.

² Calculated from $(C)_a(CH_2)_b(C_6H_{11}NO)_d(SiO_2)_e(CaF_2)_g$ using the values 1.12, 2.73, 0.25, 0.03734 and 0.05116 given for a, b, d, e and g respectively in the Geneva Conference Paper.

two TE (muscle) mixtures are defined in the Geneva Conference Paper. The composition of those two mixtures are given in Table IV. The composition of A-150 is also given for comparison. It is clear that there are significant differences between the two compositions defined by Shonka, Rose and Failla as well as between either composition and A-150.

It is interesting to note that no information could be found that would indicate that either mixture was ever actually prepared. It seems that both may have been strictly hypothetical.

The formulation A-150, actually had been reduced to practice just prior to the Geneva Conference.