SPECIAL PROBLEMS IN NUCLEAR INSTRUMENTATION

PROGRESS REPORT

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MASTER

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ABSTRACT

The extraneous charge movements in coaxial and triaxial cables which are used to carry currents generated in ionization chambers have been the subject of further studies. Information pertaining to the preparation and properties of various conducting solid mixtures which have been developed in the Physical Sciences Laboratory is being collected and organized for a special report covering this subject. A new mixture which simulates cortical bone has been prepared and partially evaluated. The standard formulation, A-150, which was introduced as an equivalent for muscle relative to photons and neutrons has been duplicated successfully. Fundamental dosimetry studies of the high energy neutron therapy beam at Fermi National Accelerator Laboratory have been initiated.

INTRODUCTION

This report covers the activities of John J. Spokas, the sole principle investigator under this contract. He has devoted one hundred percent of his time to this project from the beginning and will continue this complete involvement for the balance of the current contract period. No other federal agency has and will contribute any support to the activities reported except as it may be specifically noted below.

Additionally technical support personnel has been available at the level of one full-time person assigned to spend 50 percent of the time on this project.

All of the work reported herein has been performed in the Physical Sciences Laboratory, Illinois Benedictine College using the equipment and instrument resources available therein. Instances where other facilities have been employed are acknowledged explicitly and appropriately in the text of the report.

The major effort covers three distinct areas: cable studies, conducting mixtures, and high energy neutron dosimetry which are described in corresponding separate sections of this report. A paper reporting on the cable investigations was read at the 62nd Scientific Assembly and Annual Meeting of the Radiological Society of North America in Chicago in November 1976. This paper, "An Investigation of Cables for Ionization Chambers", has been assigned the document number COO-323-37 ~~and copies of it accompany the filing of this report.~~

The attention given to conducting mixtures during the current reporting period include:

the design and preparation of a new tissue-equivalent (bone) mixture, the further evaluation of mixtures, the first attempt since the death of Dr. Francis Shonka to reproduce the standard tissue-equivalent (muscle) formulation known as A-150, and the preparation of a technical report reviewing the various successful mixtures achieved to date in the Physical Sciences Laboratory. The development of a new bone mixture represents a collaboration with Dr. David R. White of St. Bartholomew's Hospital, London. An outline of the technical report which is in preparation will be found as an Appendix to this report.

The last area which focusses on neutron dosimetry represents a new study which has been recently initiated. This is a collaborative effort with Drs. Miguel Awschalom and Ivan Rosenberg of the Cancer Therapy Facility at Fermi National Accelerator Laboratory.

Other activities which deserve to be mentioned are the directing of several student conducted research projects and the commenting on the Draft: Dosimeters with ionization chambers as used in radiotherapy prepared by the International Electrotechnical Commission. Directing student research affords an excellent means of extending our technical personnel resources without any expenditure of funds. Unfortunately it is well nigh impossible to define a manageable research topic for even the more capable undergraduate student which relates very directly to the specific research program underway. The necessary program tasks are simply and understandably too dull and dreary to attract and hold the attention of students.

Two student projects centered on atmospheric alpha activity and capitalized on specific

resources available in the Physical Sciences Laboratory. In one case the airborne alpha activity was sampled daily over a two-month span and correlations calculated with other atmospheric data. In the other case the variation of the alpha activity of a fixed air sample was followed for over a period of sixty days. The students involved in this work were Mark Wilson and Maryellen Lissak respectively. A paper, "The Measurement of Atmospheric Alpha Activity", which describes these experiments was read at the Joint Meeting of the North Central and Midwest Chapters of the AAPM in May, 1977. This paper has been assigned the document number COO-323-38, and ~~copies accompany the filing of this report.~~

Another student project, that of Michael Kowalski, endeavored to measure ionic lifetimes in gases at atmospheric pressure at exceedingly low ion concentrations. It was not only successfully demonstrated that the particular methods devised do work but actual lifetimes were measured in dry air and Argon at ion concentrations as low as 500 ions/cm^3 . These concentrations correspond to the saturation concentration due to background radiation alone and are 10^3 times lower than those of any direct lifetime measurements of which we are aware.

The lifetime in dry air was found to be 77 sec at 500 ions/cm^3 and in Argon 72 sec at 830 ions/cm^3 . The variation of lifetime with concentration indicates that the lifetimes are not limited by ion-ion recombination alone.

These experiments employed an 8-inch TE spherical ionization chamber which was developed by Dr. Shonka a number of years ago to measure environmental radiation

dose. The success of the experiment demonstrates unequivocally the efficacy of the redesign of the guarding in these chambers which was described in earlier progress reports (Progress Report, May 1972, Document No. COO-323-28 and Progress Report, May, 1973, Document No. COO-323-30) under this contract.

Comments on the draft standard on exposure-measuring ionization chambers were requested of us by John Tagler, Secretary, American National Standards Committee. That our efforts here were worthwhile and appreciated was indicated by Dr. Robert Loevinger of the National Bureau of Standards, a member of the working group of the IEC charged with the task of writing the standard. Dr. Loevinger informed us that "You have made a unique contribution to this standard, being the only person in the U.S., other than members of the working group, who cared to make detailed and thoughtful comments. Your comments have been both influential and helpful..." Furthermore, recorded in the minutes of the meeting of the working group held in Moscow, June 6-9, 1977 is the item, "A considerable amount of time was spent in studying points raised by Professor Spokas and many of his comments led to the amendments to 62C(Sec) II being agreed upon". 62C(Sec) II is the IEC designation of the draft standard.

CABLE STUDIES

This study was prompted originally by the discovery that in dealing with cable-connected ionization chambers one may encounter significant perturbing currents which are founded specifically in the connecting cable. Thus, the full capability

of a well designed and constructed ionization chamber may not be realized in practice owing to extraneous cable currents. Early measurements showed rather decisively that certain cables which had been used extensively in our laboratory as well as elsewhere were in fact inferior choices for use with ionization chambers in low level critical applications.

A number of distinct phenomena operate here. Our investigations were confined to: noise currents, dielectric leakage (volume resistivity), dielectric polarization, microphonic noise currents, shielding, and radiation induced currents. Seven distinct types of cables were studied thoroughly. In some cases several different specimens of the same type were given the complete battery of tests.

The effort this year was essentially confined to determining radiation induced currents and to standardizing the measurements of the other perturbing currents for a more convenient comparison of different cable types. The radiation measurements were made at Argonne National Laboratory using the Cobalt-60 field in the High Level Gamma Room in the Division of Biological and Medical Research.

Most of the results of this study were presented in a paper at the RSNA/AAPM meeting in November, 1976 which was mentioned above. This material is being readied for publication in Medical Physics. The published article will cover more details than was possible in the oral presentation.

The radiation studies were confined to the direct effect, the constant negative current induced on the central conductor which is substantially independent of bias across the

cable dielectric. However, in the case of the two most promising cables, the Capintec and Exradin types, the conductivity induced in the cable dielectric was also studied.

The exposure rate for these studies ranged from 1.5 to 26 R/min. At an exposure rate of 21 R/min the Capintec cable showed a direct effect of 50 fA/m and induced leakage at 3 V bias of 10 fA/m. For the same exposure rate the Exradin cable showed a direct effect of 40 fA/m and induced leakage at 3 V bias of 50 fA/m. As in practice the cable bias rarely if ever exceeds 1 V, the direct effect will ordinarily be dominant. Interestingly, no deviation from linear dependence on exposure rate was detected for either effect in either cable.

There is another aspect of radiation induced cable effects which was not considered in detail. This involves the complex temporal response of radiation induced conductivity in the cable dielectric and the possibility of essentially permanent changes. In preliminary experiments the purpose of which was to ascertain the magnitude of radiation induced currents, several samples received exposures of several kiloroentgen. One of these cables which has a polyethylene dielectric, Amphenol No. 21-537, showed an increase in leakage without radiation of nearly three orders of magnitude 30 days later.

CONDUCTING PLASTIC MIXTURES

The major mission under this contract is the development and further refinement of practical conducting solids for application to the more accurate determination of radiation exposure and dose. This includes maintaining the capability to produce and advancing

the understanding of such materials and the continual searching for new materials which would better meet the needs of radiation dosimetry. The main requirements of suitable materials are particular radiation absorption characteristics along with certain desirable physical properties such as stability, rigidity, workability, and some minimum electrical conductivity. "Workability" includes the molding, machining, and welding characteristics of a material. Materials having suitable properties are needed most importantly for the construction of various ionization chambers and proportional counters.

A number of acceptable solutions to the material problems of radiation dosimetry have already been achieved under this contract. These have been detailed in the annual progress reports under this contract and in a paper presented at the 1958 Geneva Conference on the peaceful uses of atomic energy ("Conducting Plastic Equivalent to Tissue, Air, and Polystyrene", F.R. Shonka, J.E. Rose, and G. Failla, Progress in Nuclear Energy, Series XII, Health Phys., 1, 160 (1959)). A technical report, the outline of which is given in the Appendix and which is in preparation, will collect and summarize all the available information on the various successful formulations already devised.

The preparation of a series of test mixtures of polypropylene, nylon-11, and carbon was detailed in the previous annual report. Here one is seeking to determine the feasibility of substituting polypropylene and nylon-11 for polyethylene and nylon-6 in A-150. By appropriately adjusting the concentrations of polypropylene, nylon-11 and carbon it is possible to duplicate the theoretical atomic composition of A-150. This would eliminate the uncertainty and variability of the composition of A-150.

(this problem was discussed in the paper "Composition Variability and Equivalence of Shonka TE Plastic" Document No. COO-323-33) besides providing an extended temperature range and other improved physical characteristics.

A number of samples have been molded of each test mixture for the purpose of determining certain physical properties. Samples were molded at four different temperatures 360, 390, 420, and 450 °F. Densities have been determined and are listed in Table I. Samples with which the bulk rigidity, mechanical strength, and electrical conductivity may be measured have been machined. A fixture has been built for determining the

Table I Densities of various mixtures of polypropylene, nylon-11, and carbon.

Mixture No.	Concentration in percent by mass			Density g/cc
	Polypropylene	Nylon-11	Carbon	
E-100	64.8	21.6	13.6	1.079
E-101	43.2	43.2	13.6	1.031
E-102	21.6	64.8	13.6	1.006
E-103	0	86.4	13.6	1.118
E-104	86.4	0	13.6	.978
-----	100	0	0	.905
-----	0	100	0	1.405

bending moment and measurements will commence shortly. All samples have been machined to the same thickness, 3 mm, for these measurements.

The results listed in Table I indicate a slight negative deviation from Vegard's Law for the polypropylene-nylon system. One might interpret this result as indicating a slight interaction between these components.

The density of a multi-component mixture obeying Vegard's Law is related to the density of the individual components according to

$$\frac{1}{\rho} = \sum_i \frac{\beta_i}{\rho_i} \quad (1)$$

where ρ is the density of the mixture, ρ_i the density of the i th component, and β_i the mass fraction of the i th component.

The densities of the mixtures E-103 and E-104 and of pure polypropylene and nylon-11 can be analyzed with the aid of Eqn. 1 in order to obtain the effective density of the carbon black (Vulcan-XC 72, Cabot Corporation) used in the mixtures. Interestingly the carbon black shows a density of 2.006 and 2.010 g/cc in polypropylene and nylon-11 respectively. Considering the accuracy of the measurements this slight difference is not significant and the value of 2.008 g/cc may be used to calculate the final density of other mixtures.

A new conducting plastic mixture to simulate the cortical bone composition given by Woodard (Health Phys., 8, 513 (1962)) was designed in terms of the same four components

employed in B-100, polyethylene, nylon, carbon, and calcium fluoride. The new formulation has been designated B-110 and consists of 2.87 ^w/o polyethylene, 32.07 ^w/o nylon, 13.84 ^w/o carbon, and 51.22 ^w/o calcium fluoride. For comparison B-100 consists of 30.00 ^w/o polyethylene, 21.60 ^w/o nylon, 14.00 ^w/o carbon, and 34.40 ^w/o calcium fluoride.

Despite the low plastic concentration in the new mixture it was successfully blended in the Shonka reciprocating extrusion mixer and can be molded into large blocks. B-110 shows a bulk density of 1.78 g/cc in comparison to 1.85 g/cc, the accepted value for cortical bone. The photon attenuation of B-110 was measured at 17.44 KeV by David White and found to be 10.47 cm^{-1} , just 2 percent higher than calculated from the known composition and the tabulated total cross sections of the elements.

The photon equivalence of B-100 and B-110 with respect to cortical bone was investigated theoretically in terms of total mass attenuation and mass energy absorption over the range of photon energy from .01 to 100 MeV. These results are listed in Table II. It is quite evident that B-110 provides an excellent match for cortical bone over this entire energy range. Further evaluative studies in collaboration with Dr. White are continuing.

The standard tissue-equivalent (muscle) formulation, A-150, has been duplicated for the first time since the death of Dr. Shonka in October, 1970. The last batch had been prepared under the direction of Dr. Shonka during the Summer of 1970. The design of A-150 calls for 45.14 ^w/o polyethylene, 35.12 ^w/o nylon, 16.06 ^w/o carbon, and

Table II. Relative mass attenuation and mass energy absorption coefficients with respect to Woodard's cortical bone for photons of energy between .01 and 100 MeV.

		Photon energy - MeV				
		.01	1.0	1.0	10	100
B-100						
rel. atten.	0.69	0.97	1.02	0.96	0.85	
rel. absorp.	0.68	0.85	1.03	0.96	0.89	
B-110						
rel. atten.	0.99	0.99	0.99	0.98	0.96	
rel. absorp.	1.01	1.01	0.99	0.98	0.97	

3.58 ^w/o calcium fluoride. In view of the low non-plastic concentration, 20 ^w/o, it was expected that the preparation of A-150 would be quite straightforward. Although success was ultimately achieved several unexpected problems were encountered.

Of the four components in A-150 one, nylon-6 (Zytel-69, DuPont), is not readily available as a fine powder. Thus in order to guarantee a high degree of homogeneity in the final product, the mixing is accomplished in two distinct stages. First a pre-mix is prepared consisting of polyethylene, carbon, and calcium fluoride in the precise relative concentrations of A-150. The pre-mix is blended in the special Shonka plastics mixer and granulated to a particle size equivalent to that of Zytel-69 pellets (the only form in which it is available from DuPont). The pre-mix and nylon are then

blended in the correct proportions for A-150 in the Shonka plastics mixer.

The pre-mix was first attempted at the temperature of 280 °F. The results were nearly disastrous. At this temperature the extrusion force generated in this mixer is quite substantial and the small extrusion orifice was insufficient to adequately relieve the extrusion force. As a result, the end-plate was blown off the mixing barrel. Subsequently, it was established that 300 °F is a safe minimum temperature for operating the mixer for the A-150 pre-mix. Actually, even with external cooling of the mixing barrel after commencing mixing, the temperature of the barrel rises to 325 °F or so. This is a vivid manifestation of the significant internal friction generated in the plasticized pre-mix by the action of the mixer.

For calibration purposes prior to combining the pre-mix and nylon, the nylon alone was run thru the mixer at 315 °F. Surprisingly even at a throughput rate half that employed for the pre-mix, the temperature of the mixer did not rise. This indicates significantly less internal friction in nylon as opposed to the pre-mix. Evidently at these temperatures nylon is more elastic than plastic in comparison to the pre-mix.

NEUTRON DOSIMETRY

A high energy neutron beam which utilizes protons extracted from the linear pre-accelerator of the main proton accelerator at Fermi National Laboratory and which is intended for the treatment of cancer in humans has been in operation since 1976. The average neutron energy of 50 MeV or so is higher than any other in use for neutron therapy and gives the experimental facility at Fermi Laboratory a particular capability. Recently

pilot studies in which 82 patients had received prescribed treatments have been completed and clinical trials have begun.

We have entered into a series of collaborative studies directed at the fuller understanding of the absorbed dose produced by particular configurations of this neutron beam and of the means to generally and more precisely measure such absorbed doses. Our participation was sought in this effort based upon the particular resources and expertise we might contribute.

The apparatus needed for the proposed experiments are a phantom constructed of Shonka TE (muscle) plastic, A-150, several ionization chambers, and electrometers and other ancillary instrumentation needed with ionization chambers. Several standard commercially available chambers will be used in these experiments together with a special parallel plate chamber constructed of A-150. Our contribution to the apparatus required consists of the phantom and the parallel plate chamber.

The phantom will be cylindrical with a diameter of 355 mm and length of 270 mm or so. It will be comprised of 12 parallel sections, not all of the same thickness, which may be stacked in arbitrary order. One section of the phantom will contain special holes and plugs in order to accept snugly one or the other of the chambers. Thus far 9 phantom blocks have been molded.

The parallel plate chamber has been designed and the necessary drawings are nearly completed. The chamber will have a front window of 0.5 mm and a gas volume 2 mm in thickness. It will be gas-tight and provide for the circulation of any desired gas

thru it. The collecting volume will be 20 mm in diameter. With this chamber the important features of the depth-dose curve will be fully resolved.

The specific objects of the proposed joint studies include: 1. precision determination of the depth-dose curve, 2. determination of the dose defect, the reduction in dose near the back surface of a phantom, and 3. the effective point of measurement of a given ionization chamber. Actual measurements are expected to commence in October 1977.