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BIOLOGICAL AND CLINICAL DOSIMETRY

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BIOLOGICAL AND CLINICAL DOSIMETRY

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BIOLOGICAL AND CLINICAL DOSIMETRY

ABSTRACT

A second measurement of the event size distribution for 20MeV neutrons was carried out at Ohio University to determine the reproducibility of results. Again a significant difference between measurement and theoretical calculations by Caswell and Coyne was found. The measured fraction of events due to alpha particles was significantly lower than that predicted by the calculation of Caswell and Coyne. Furthermore, the discrepancies with the theoretical calculations made by Caswell and Coyne were confirmed by measurements made with a differently designed T-E proportional counter.

A "non-isolated-sensor" solid polystyrene calorimeter was constructed and tested during the past year. It has the advantages of 1) simple construction 2) simple operation, without vacuum or feedback for temperature control 3) the capability of obtaining simultaneous measurements at different depths and azimuthal angle and 4) the possibility of obtaining measurements with the calorimeter directed in any orientation.

BIOLOGICAL AND CLINICAL DOSIMETRY

INVESTIGATORS TIME & EFFORT ON PROJECT

The principal investigator has devoted approximately 15% of his time and the co-principal investigator approximately 50% of his time to the projects described herein. These percentages are not expected to change during the remainder of the current term.

I. SUMMARY

In the last year we have been able to verify the event size distribution previously measured for a nearly monoenergetic 20 MeV neutron beam. The event size distribution obtained with an A-150 plastic walled counter (EG&G Model LET-1/2) gas filled to give an effective diameter of $1\mu\text{m}$ was similar in shape to that obtained with a Rossi type spherical, wall-less chamber with effective diameter of $0.3\mu\text{m}$. With both counters, the measured fraction of events due to alpha particles was significantly lower than that predicted by the calculations of Caswell and Coyne.

A "non-isolated-sensor" solid polystyrene calorimeter was constructed and evaluated. The advantages of this type of calorimeter are: 1) simplicity of construction, 2) simplicity of operation without vacuum or feedback for temperature control, 3) capability of simultaneous measurements at several depths and azimuthal angles, 4) operation with the calorimeter in any orientation, and 5) very low thermal defect correction with polystyrene.

II. MICRODOSIMETRY

Introduction

Measurements of event-size distribution in lineal energy were repeated in nearly monoenergetic neutron beams whose principal energies were 20 and 25 MeV. The main objective in carrying out this work was to see if the previous results were reproducible. The earlier measurements for 20-MeV neutrons demonstrated significant discrepancies with the theoretical calculations by Caswell and Coyne (1-3), Fig (1). Additional measurements were made by J. Dicello of Los Alamos Scientific Laboratory using a counter of a different design to see if results would be comparable. A tissue equivalent ionization chamber and a G-M counter were also used in the neutron beams to obtain dose rate and gamma component information.

Description of experiment

The 20 and 25-MeV neutrons in this study were produced with the $T(d,n)$ reaction using a pulsed deuteron beam from the Ohio University tandem accelerator with respective deuteron energies of 3.9 and 8.11 MeV. The neutron energy spectra were measured by time-of-flight technique (4).

Our proportional counter was a commercially produced (EG&G Model LET-1/2) A-150 plastic walled instrument. It was filled with propane-based tissue equivalent gas to a pressure of 33 torr thereby simulating an effective counter diameter of 1 μm . A-150 build-up cap of appropriate thickness was used to insure charged particle equilibrium. The other counter used was a Rossi type spherical, wall-less chamber with effective diameter of 0.3 μm . The tissue equivalent ionization chamber was a 1.0 c.c. spherical chamber produced commercially (Far West Technology IC-17). This chamber was employed to measure the total absorbed dose in A-150. The gamma component in the neutron beam was measured by a G-M counter designed and assembled at Sloan-Kettering Institute (5).

The counting system consists of three amplifiers with different gains operated in parallel to observe the entire event-size distribution in one measurement. The data was stored by a mini-computer in three normal linear arrays. Each event was weighted by its pulse height and logarithmically re-binned to obtain the $y^2d(y)$ versus $\log(y)$ spectrum in real time. This unique system enabled on-the-spot viewing of these spectra as the measurement proceeded. The data for 20-MeV run was converted from Ohio University's data disk integer format to a card image format and stored on tape so that the results could be processed by the S.K.I. PDP 11/70 computer using an established program (6).

Results

The event size distribution for 20-MeV neutrons in a $1.0\mu\text{m}$ simulated cavity obtained is shown in Fig. (2). It demonstrated a very similar form to that obtained previously. The main features of the spectrum are recapitulated and thus confirming the deviations from the theoretical calculation. Again, the measured spectrum revealed more details in the region between 100 and $500\text{ keV}\cdot\mu\text{m}^{-1}$. The proton and alpha edges are both resolved in this region. The number of events due to alpha particles in this region is significantly less than that calculated.

The 20-MeV spectrum measured by Dicello's $0.3\mu\text{m}$ wall-less counter displayed a similar shape compared to ours but with slightly more resolution in the proton and alpha edge region. Due to the time limitation, this data was not translated into the format suitable for analysis by our computer system but it was felt that large discrepancies would not be observed.

Techniques were not well established to obtain the event-size distribution in the 25-MeV beam. The major difficulty encountered was the low energy neutron contaminants from the beam which was produced from the interaction of incident charged particles with target backing materials.

Ionization chamber and G-M counter measurements in both 20 and 25-MeV neutron beam are summarized in Table (1).

E_n = Principal neutron energy (MeV)
 TAD = Target to chamber distance (cm)
 $D_{n+\gamma}/m.u.$ = Total dose to A-150 (rad per monitor unit)
 $D_\gamma/m.u.$ = Gamma dose in Air (rad per monitor unit)
 $\frac{D_\gamma}{D_{n+\gamma}} \%$ = Fraction of gamma component
 $\dot{D}_{n+\gamma}$ = Total dose rate/min.

IONIZATION CHAMBER MEASUREMENT IN AIR

TABLE (1)

E_n (MeV)	TAD (Cm)	$D_{n+\gamma}$ m.u. ($\times 10^{-6} \frac{\text{rad}}{\text{m.u.}}$)	D_γ m.u. ($\times 10^{-6} \frac{\text{rad}}{\text{m.u.}}$)	$\frac{D_\gamma}{D_{n+\gamma}} \%$	$\dot{D}_{n+\gamma}$ (rad) min
20	15.0	9.36	0.512	5.47	0.076
20	30.0	1.62	0.122	7.50	0.013
25	15.0	21.87	0.725	3.31	0.509
25	30.0	7.30	0.334	4.58	0.180

The gamma-ray background was in close agreement with that recorded by the time-of-flight system.

Conclusions

Event-size distribution measurements in 20-MeV monoenergetic neutron beam using T-E proportional counters have demonstrated consistent results with measurements made the previous year. Furthermore, the discrepancies with the theoretical calculations made by Caswell and Coyne were confirmed by the measurements made using a T-E proportional counter designed and made differently. To summarize, the most obvious differences in the measured distribution were more details in the 100 to 500-KeV.um⁻¹ region with distinct proton and alpha edges as well as fewer events due to alpha particles.

It is reasonable, however, to state that the approximate agreement between measurements and calculations is good. At this point no source has been found to generate pure monoenergetic neutrons. However, one must keep in mind that the calculations of event size spectra were based on monoenergetic neutrons. In addition, the nuclear data necessary for computation of events due to alpha particles produced by 20-MeV neutrons included that $^{12}\text{C}(n,n')^{13}\text{C}$ cross section are not well known at this energy. A small error in the cross section might produce a sizable effect in the calculated event-size spectrum. It is possible that data now being generated at Ohio University and Lawrence Livermore Laboratory will provide more accurate input data for these calculations.

Fig. 1

20 MeV neutrons $d = 1 \mu\text{m}$

Fig. 2

III. "NON-ISOLATED-SENSOR" SOLID POLYSTYRENE CALORIMETER

A "non-isolated-sensor" solid polystyrene calorimeter was constructed to test the role of thermal diffusion in limiting the length of irradiation time during which temperature measurements with non-isolated sensors could be made sufficiently free of drift for determination of absorbed dose with radiation fields such as gamma, X-rays, and high energy electrons (7).

The essential features of the polystyrene calorimeter are shown in Fig. 3. A picture of the calorimeter with its associated bridges, electrometers and dual-pen recorder is shown in Fig. 4.

Assuming negligible heat loss during the period of irradiation, it can be shown that the dose in red absorbed in the polystyrene (PS), D , is:

$$D = 10^5 \left(\frac{C_p}{\alpha} \right) \left(\frac{\Delta R}{R} \right) \times \text{Thermal Defect of PS, where } C_p \text{ is the specific heat in } \text{J g}^{-1} \text{K}^{-1} \text{ of PS at temperature } T, \alpha \text{ is the thermal coefficient of resistance } \alpha = \frac{1}{R} \frac{\Delta R}{\Delta T} \text{ at } T, \text{ and } (\Delta R/R) \text{ is the fractional change of resistance}$$

due to the increase in temperature caused by the energy absorbed from the radiation field. A value of 1.007 for the thermal defect, based on a report by Sabel et al. (8), was used in calculations of dose. The thermal coefficient of resistance for the thermistors was measured and C_p for random samples taken from the PS material used to build this calorimeter were determined by Dr. R.E. Taylor of the Properties Res. Lab., Purdue Univ. (9).

A typical scan taken with this calorimeter in a Co-60 field is shown in Fig. 5.

Together, Figs 6 and 7 show that for this geometry the thermal diffusion is sufficiently small in PS for measurements to be made with irradiation times of less than 20 minutes.

Comparisons made of absorbed dose determined by cavity ionization measurements with a PS ionization chamber in a PS phantom at the two depths 0.5 and 5 cm and with this polystyrene calorimeter are summarized in Table I. The temperatures of the thermistors at the time of measurement were estimated on the basis of room temperature. It can be shown that the error in determining absorbed dose introduced by this method of estimating thermistor temperature should not be greater than $\pm 2\%$.

The features of this "non-isolated-sensor" solid polystyrene calorimeter that make it worthwhile to investigate further are:

- 1) Simple construction,
- 2) simple operation without vacuum or feedback for temperature control,
- 3) capability of simultaneous measurements at several depths and azimuthal angles,
- 4) operation with calorimeter in any orientation, and
- 5) very small correction for thermal defect with PS.

TABLE I

COMPARISON OF CALORIMETER AND PANCAKE ION CHAMBER - DOSE TO PS IN RAD/MIN.

	Depth	Calorimeter	Pancake Chamber	Calorimeter Pancake Chamber	Ratio	
					5.0 cm 0.5 cm	Pancake Chamber
Co-60 S.S.D.-30cm to top of PS F.S. - 3x8cm	0.5cm	85.7±5.5%*	87.5±2.5%**	0.98		
	5.0cm	64.8±2.0%*	67.5±2.5%**	0.96	0.75±5.2%*	0.77±3.5%**
13 MeV Electrons S.S.D.-103.1cm to top of PS F.S.-10x10cm	0.5cm	161.6±7.4%	165.7±2.5%**	0.98		
	5.0cm	80.71±3.1%*	88.0±2.5%**	0.92	0.50±2.5%*	0.53±3.5%**
11 MeV Electrons S.S.D.-100cm to top of PS F.S. -10x10cm	0.5cm	204.2±1.3%*	212.6±2.5%**	0.96	- -	- -

*The error is the precision in terms of 1σ for N=5**The error in terms of estimated accuracy. The precision is better than $\pm 1\%$.

Features of Calorimeter

Fig. 3

A & B are thermistor leads each to a separate Wheatstone bridge, associated electrometer and pen recorder.

Fig. 4

Measurement in Co-60 Field with Thermistors at 5.0 cm and 0.5 cm

S.A.D. 80 cm to 0.5 cm Depth and 8 x 8 Field
Dose Rate ~ 92 rad/min

Absorbed Dose in Rad:

$D = 10^5 (C_p / \alpha) (\Delta R / R)$, where C_p is specific heat of polystyrene (PS) at temp. T , α is thermal coefficient of resistance at T for the thermistor, and $(\Delta R / R)$ is the fractional change of resistance due to increased temperature caused by energy from absorbed radiation. $\alpha = -B/T^2$ in the vicinity of room temperature.

Fig. 7

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Presentations

J.S. Laughlin

Invited paper, Advance in Absorbed Dose Measurement Calculation and Application with Electrons, at Electron Dosimetry Symposium, Madison, Wisc., Sept 10-11, 1981.