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COMPARISON OF DOSE PATTERNS IN A MINIATURE PIG EXPOSED TO NEUTRON AND TO GAMMA RADIATION

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FOREWORD
(Nontechnical summary)

The objective of this research effort was to characterize the tissue absorbed dose produced by the radiation fields from the AFRRI-TRIGA nuclear reactor and to compare depth-dose patterns for significantly different mixtures of incident radiations.

In an unmodified configuration, the radiation field from the AFRRI-TRIGA reactor is characterized by a neutron to gamma ray tissue kerma ratio, free-in-air, of 0.4. An enhanced neutron radiation field was obtained using a cadmium-gadolinium absorber for thermal neutrons coupled with 6 inches of lead shielding to decrease the gamma ray component of the field. A gamma ray field was obtained using 5 inches of water shielding and the same cadmium-gadolinium absorber. Neutron to gamma ray ratios, free-in-air, of 10 and 0.06 were obtained for the neutron and gamma ray fields, respectively.

Dose distribution patterns in a miniature pig cadaver were measured for neutron and for gamma radiation fields from the AFRRI-TRIGA reactor. Determination of the radiation components across the brain was performed employing the paired ionization chamber technique. The paired chambers used were 0.05 cm^3 cylindrical-spherical Shonka chambers, one of tissue-equivalent plastic filled with tissue-equivalent gas and the other of magnesium filled with carbon dioxide gas. Placement of the dosimeters within the cadaver was verified by radiography and by dissection of the specimen.

For the high neutron field, the ratio of neutron to gamma doses ranged from 3.2 at the entrance to the brain to 1.9 at the brain exit. The ratio incident on the head was measured to be 8.5. For the high gamma radiation field, the incident neutron to gamma ratio was 0.06. For this field, the depth-dose pattern is substantially that produced by a photon field containing no neutrons.

ABSTRACT

Depth-dose patterns were compared for significantly different mixtures of incident radiations from the AFRRI-TRIGA nuclear reactor. Neutron to gamma ray tissue kerma ratios of 10:1 and 0.06:1 were used for exposure of a miniature pig cadaver.

Measurement of the dose distribution patterns across the brain and across the intestinal regions was performed employing the paired ionization chamber technique. Placement of the dosimeters within the cadaver was verified by radiography and by dissection of the specimen.

For the high neutron field, the ratio of neutron to gamma ray doses for a unilateral irradiation ranged from 3.2 at the entrance to the brain to 1.9 at the brain exit. The ratio incident on the head was measured to be 8.5. Across the intestinal region, the neutron to gamma ray dose ratio for a bilateral irradiation ranged from 1.5 to 0.8. For the high gamma ray field, the incident neutron to gamma ray ratio was 0.06. For this field, the dose pattern is substantially that produced by a photon field containing no neutrons.

I. INTRODUCTION

The Armed Forces Radiobiology Research Institute (AFRRI) is conducting a series of biological irradiations to determine the effectiveness of reactor-produced neutron radiations for incapacitation and for intestinal damage in miniature pigs. Characterization of the radiation fields and total dose patterns were reported in AFRRI Technical Note TN71-2.[8] This paper supplements those data previously reported by specifying those components contributing to the dose and by comparing total dose patterns for the neutron and gamma radiation fields.

For neutron irradiations, different organs may receive widely different doses dependent upon density and composition of the organ (soft tissue versus bone). The size of the specimen, the type of source, and the irradiation configuration also affect the depth-dose pattern. Accurate interpretation of the responses of animals to whole-body irradiations requires knowledge of the depth-dose pattern in the animal. This is of particular importance when the biological specimen is not irradiated uniformly. International Commission on Radiological Units and Measurements (ICRU) Report 10e on Radiobiological Dosimetry[3] sets forth the recommendations for classification of whole-body irradiations. The measurements reported here were performed to compare the depth-dose patterns for significantly different mixtures of incident radiations from a nuclear reactor and to classify the irradiations in accordance with the ICRU recommendations.

II. MATERIALS AND METHODS

Detectors. At AFRRI, the paired chamber concept, as described in ICRU Report 10b,[2] is employed for measuring separate neutron and gamma ray components in a mixed neutron-gamma ray field. All measurements reported here were made with the paired miniature 0.05 cm^3 chambers.[6] The estimate of systematic errors associated with these dosimeters is summarized in Table I.

Table I. Maximum Uncertainty in Dose

	Reactor configuration		
	Unmodified field (n-γ ratio = 0.48)	6" lead shield (n-γ ratio = 11)	5" water shield (n-γ ratio = 0.12)
Total dose	± 7%	± 12%	± 7%
Neutron dose	± 8%	± 8%	± 12%
Gamma dose	± 5%	± 30%	± 5%

Irradiation conditions. The AFRRI-TRIGA reactor was the radiation source for these irradiations. As previously reported,[8] the normal radiation field from the reactor was modified to produce a radiation field composed primarily of reactor neutrons and, subsequently, to produce a radiation field composed primarily of gamma rays. Characterization of the exposure conditions is summarized in Table II.

Table II. Radiation Exposure Conditions

Distance to center of reactor core (cm)	Neutron to gamma ray tissue kerma ratio	
	Neutron field	Gamma field
100	10	0.06
150	5	0.06
200	2	0.06

III. DEPTH-DOSE DISTRIBUTION MEASUREMENTS

Specially prepared miniature pig cadavers (embalmed and then submerged in 10 percent unbuffered Formalin) were instrumented with the miniature ionization chambers. The instrumented cadavers were irradiated in the same Lucite cages employed in biological irradiations. Placement of the dosimeters within the specimens was verified by radiography and by dissection of the specimens.

Data by Thorp et al.[7] on the performance of miniature pigs subjected to partial body irradiations suggest that incapacitation is the result of radiation damage to the brain of the animal. Therefore, to observe the dose distributions in the sensitive area, depth-dose patterns across the head of the specimen were obtained for the two different radiation fields. For the neutron field the midbrain probe was located on the center line at 104 cm from the center of the reactor. Figure 1 illustrates the measured components of the depth-dose pattern (neutron and gamma ray) and the total dose across the head. The measured neutron to gamma ratio at the entrance of the head was 8.5. Within the brain, the neutron to gamma ratio was approximately 3.2 at the entrance and 1.9 at the exit. The slight increase in the neutron component of the dose at the exit side of the head (note Figure 1) is attributed to the reflection of neutrons from the back side of the Lucite cage. It is noted that this depth-dose pattern is for the modified TRIGA reactor spectrum and that other sources, such as a 14 MeV

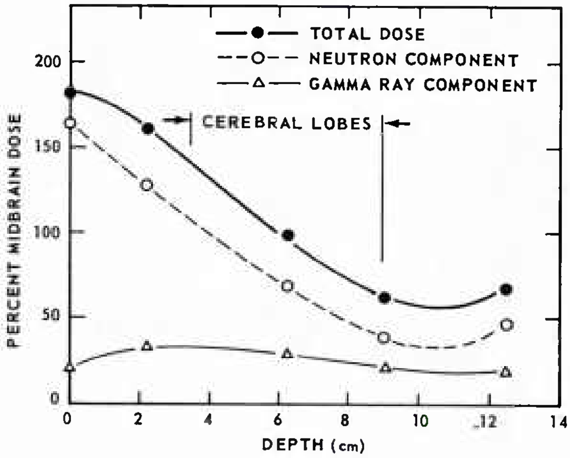

Figure 1. Depth-dose pattern in miniature pig's head irradiated unilaterally by neutron field

neutron generator or another reactor, would produce a different depth-dose pattern with different neutron to gamma ratios within the brain.

For the gamma ray field the midbrain probe location was 72.7 cm from the center of the core. For this field, the dose pattern is substantially that produced by a photon field containing no neutrons. Figure 2 illustrates the measured depth-dose pattern for the two fields.

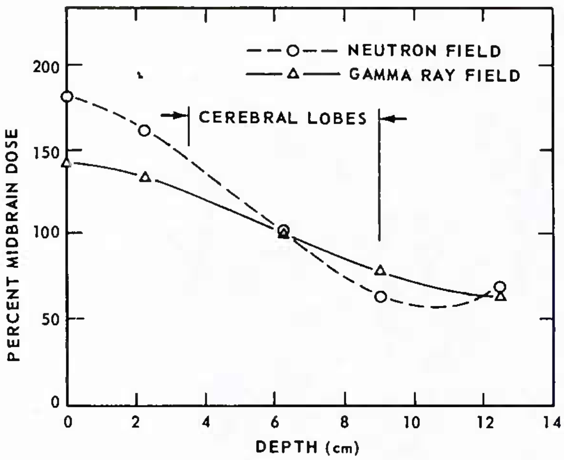

Figure 2. Comparison of total dose patterns in miniature pig's head for neutron and gamma ray fields from a reactor

The entrance to exit dose ratio for the brain was 2.2 and 1.5 for the neutron and gamma ray fields, respectively. Table III summarizes the irradiation conditions for the two different fields. This irradiation configuration is clearly Class B, nonuniform, for both cases.

For the intestinal damage study[5] miniature pigs were positioned with the trunk on the center line of the core. Depth-dose measurements for the neutron field were made with the cadaver positioned at 150 cm from the center of the core. Figure 3 illustrates the measured components of the depth-dose pattern and the total dose across the trunk for a unilateral irradiation. The measured neutron to gamma ray ratio at the entrance of the trunk was 4.3 and at the exit was 0.37.

Table III. Depth-Dose Distribution in Swine Brain

Probe location	N-γ ratio for neutron field	Total dose (percent of midbrain dose)	
		Neutron field	Gamma field
Brain entrance	3.2	140	120
Midbrain	2.3	100	100
Brain exit	1.9	63	78
Midbrain, free-in-air	9	180	122

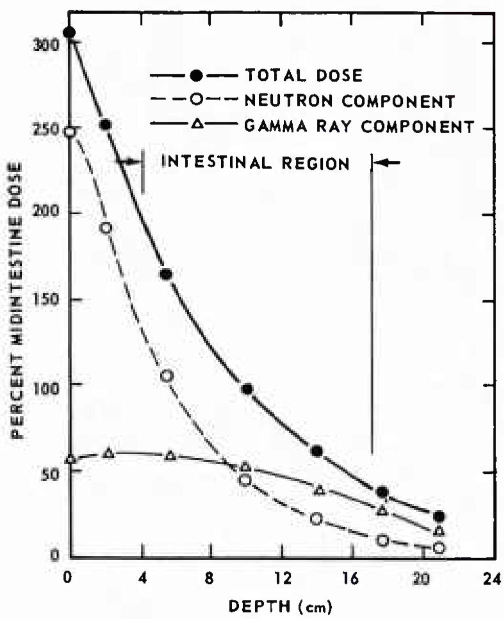

Figure 3. Depth-dose distribution in intestinal region for unilateral exposure by neutron field

For the gamma ray field, the center of the trunk was positioned at 100 cm from the center of the core. Table IV summarizes the depth-dose distributions across the trunk for the two different fields.

In order to obtain a Class A irradiation for each of the two fields, a bilateral irradiation was performed by rotating the animals midway through the exposure. Figure 4 illustrates the depth-dose patterns for a bilateral irradiation. For the neutron field the neutron to gamma ratio was 1.5 at the outer extremity of the intestinal region and 0.8 at the midpoint. A Class A irradiation is approached only if one assumes that the outer 4 cm of the body wall is of no interest to the study.

Table IV. Depth-Dose Distribution in Swine Trunk

Probe location	N-γ ratio for neutron field	Total dose (percent of midintestine dose)	
		Neutron field	Gamma field
Trunk entrance	4.3	306	158
Midintestine	0.80	100	100
Trunk exit	0.37	26	58
Midintestine, free-in-air	5	218	122

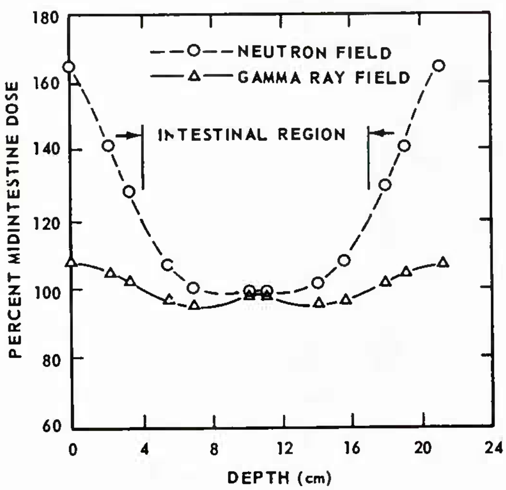

Figure 4. Comparison of total dose distribution in pig intestinal region (bilateral exposure)

IV. DISCUSSION

One of the weaknesses in the interpretation and comparison of biological results is the desire to reduce complicated irradiation conditions to a single dose number. This weakness is particularly common for whole-body irradiations of comparatively large animals when the irradiation is classified as Class B, nonuniform.

The measurements across the brain of the cadaver serve as an excellent example of the differences in the deposition of energy within the brain that can occur although there is an equivalent midbrain dose. The ratio of doses at the entrance to the brain for these two fields was 1.16. At the exit of the brain, this ratio was 0.82. Accordingly, for this irradiation configuration there are parts of the cerebral lobes where the doses for the two fields differ by approximately 20 percent. Different geometrical irradiation conditions could result in even larger differences. Thus classification of an irradiation by a single dose number is, at best, an incomplete picture. This is of significance for those biological experiments where the dose effect relationship is not a linear function, and the biological effect being observed does not originate at a very limited volume in the animal. Data on performance decrement in miniature pigs by George et al.[1] indicate an apparent lack of additivity for the separate components of a mixed neutron-gamma ray field. Thus, even a comparison of the depth-dose patterns for different mixed neutron and gamma ray fields without knowledge of the magnitude of the separate components is not in itself totally sufficient.

The effectiveness of different types of radiations is often examined against some form of average linear energy transfer (LET). ICRU Report 16[4] points out that average values of LET distributions are likely to be useful only in very rough approximations. In the case of whole-body irradiations by neutrons, the LET distributions as a function of depth will change. Consequently, the usefulness of specifying LET distributions for the types of radiations reported here is questionable. Without knowledge of the sensitive site of biological damage, interpretation of biological effect versus LET is not possible.

In the great majority of whole-body irradiations it is not possible to provide a well-defined volume of interest. Consequently, correlation and interpretation of end results based on a single dose number such as midhead dose, midline tissue dose or exposure is not appropriate without detailed considerations of depth-dose patterns. As a minimum, the degree of nonuniformity, such as documentation of entrance and exit doses, should be given. For radiation of limited penetrability, such as neutrons, the components of the high and low LET particles contributing to the dose should be specified.

V. SUMMARY

This paper has presented recent depth-dose measurements in a miniature pig cadaver. The dosimetry methods employed are considered to be among the most reliable for separating radiation field components from a nuclear reactor and for measuring depth-dose patterns in biological specimens. Of particular interest are the depth-dose measurements across the brain of the cadaver.

A neutron to gamma ray tissue kerma ratio of 8.5, incident upon the head of a miniature pig, produced measured neutron to gamma ray tissue dose ratios of 3.2 at the entrance of the brain and 1.9 at the exit. For the same midbrain dose the brain entrance to exit ratios were 2.2 and 1.5 for the neutron and gamma ray fields, respectively.

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Depth-dose patterns were compared for significantly different mixtures of incident radiations from the AFRRI-TRIGA nuclear reactor. Neutron to gamma ray tissue kerma ratios of 10:1 and 0.06:1 were used for exposure of a miniature pig cadaver.

Measurement of the dose distribution patterns across the brain and across the intestinal regions was performed employing the paired ionization chamber technique. Placement of the dosimeters within the cadaver was verified by radiography and by dissection of the specimen.

For the high neutron field, the ratio of neutron to gamma ray doses for a unilateral irradiation ranged from 3.2 at the entrance to the brain to 1.9 at the brain exit. The ratio incident on the head was measured to be 8.5. Across the intestinal region, the neutron to gamma ray dose ratio for a bilateral irradiation ranged from 1.5 to 0.8. For the high gamma ray field, the incident neutron to gamma ray ratio was 0.06. For this field, the dose pattern is substantially that produced by a photon field containing no neutrons.

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