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FAST NEUTRON AND PHOTON DOSES DETERMINED WITH PROPORTIONAL COUNTERS AND IONIZATION CHAMBERS‡

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ABSTRACT

A ^{60}Co teletherapy source has recently been coupled to an existing source of fast neutrons. These sources may be operated to provide precise and controlled mixtures of photons and neutrons. In this work we report the application of paired miniature proportional counters to n/γ dose separation. Graphite- and A150 plastic-walled proportional counters were employed. Results are compared to dose values deduced from a conventional A150 plastic ionization chamber and a neutron insensitive GM counter.

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DISCLAIMER

INTRODUCTION

Considerable research effort has been expended over the past decade in the field of fast neutron dosimetry. This intense effort is supportive of the increasing implementation of cancer treatment by means of fast neutron beams. Among the several areas of research, the characterization of radiation beams in body tissues has been paramount. In particular, various schemes have been proposed and tested to determine the neutron- photon dose fractions in the beam and the beam penumbra (e.g. Attix, Theus, and Rogers, 1974; Kuchnir, Vyborny and Skaggs, 1975).

Reliable results are difficult to obtain as the components of the radiation field are dependent upon the neutron source type and spectrum, the physical size and materials used in collimation of the beam and other uncontrolled and/or undetermined parameters which limit the reproducibility of a specific measurement.

To allow a more precise and controlled investigation of the techniques of dose separation, we have coupled a ^{60}Co-teletherapy source to an existing source of 14.8 MeV neutrons. Arbitrary mixtures of neutrons and photons with excellent reproducibility are then possible. As each source is uncoupled from the other, an investigation of synergistic effects in dose determinations is possible.

In this work we report results of neutron and photon dose determinations for mixed field irradiations with 0%, 15%, 30% and 60% photon dose fractions. Irradiations were performed simultaneously and sequentially. Dose components were deduced from a paired ionization chamber and GM counter dosimeter system as well as with paired miniature proportional counters with walls of A150- plastic and graphite.

MATERIALS AND METHODS

Fast Neutron Source

The University of Wisconsin Gas Target Neutron Source (GTNS) has been developed over the last several years. DeLuca et al. (1978) and Chenevert et al. (1977) described the source development and radiative properties. More recently Attix et al. (USDOE REPORT COO-1105-264,1979) discussed the neutron source irradiation geometry.

In summary, neutrons are produced isotropically along a 55 cm target length. The total output of the resulting line source of neutrons can be as large as 2-3x10^{12} n/sec. Essentially monoenergetic neutrons with a mean energy of 14.8 MeV are emitted in the deuteron beam direction. A 46 cm thickness of iron and paraffin (mixed uniformly by volume), followed by a 31 cm thickness of concrete and steel aggregate (nominal density of ~5 g/cm^3), forms a neutron shield. A tapered rotatable insert constructed of Benelex (compressed wood fibers) forms a 10 x 10 cm^2 field at 108 cm from the end of the target vessel. This shield-collimator assembly rides on tracks aligned with the accelerator axis. Figure 1 schematically depicts the neutron source-shield-collimator geometry.

Photon Source

To provide a stable source of photons with known geometric beam size and dose rate, a ^{60}Co teletherapy source was mounted coaxially with the collimated neutron beam. The ^{60}Co source is contained in a Picker C9000 treatment head remounted on a moveable cart using the same tracks as the neutron collimator (Fig. 1). The treatment head can also be positioned ~80 cm below the neutron beam axis. As the rotational drive of the head was retained, intersecting or coaxial neutron-photon beams can be formed. Neutron-to-photon source distances of 0.6 m to 4 m are possible. The corresponding γ-ray dose rates are 60 to 1.3 rads/min. In this way a considerable range of n/γ-ray dose mixtures can be obtained. Notably the time relationship of the mixed field irradiations is completely arbitrary. Table I summarizes several characteristics of this tandem beam facility.

Dosimeters

We have recently reported the usefulness of a graphite-walled miniature proportional counter to deduce the photon component present in beams of fast neutrons (DeLuca, Higgins, Pearson and Attix, 1980). The success of this technique results from the absence of recoil protons from the counter wall when irradiated by 14.8 MeV neutrons.

Fast protons are recorded as energy loss events of the same magnitude as photon produced recoil electrons, and are indistinguishable from them. Unlike hydrogenous-walled chambers (e.g. A150-plastic), there are essentially no recoil protons from graphite at

14.8 MeV neutron energy. An A150-plastic walled proportional counter, otherwise identical to the graphite-walled counter, is used to assess the neutron dose component. Operated as paired dosimeters, these counters act to unfold the neutron and photon dose components. The filling gases are TE-gas and Ar-CO_2 for the plastic- and graphite-walled counters, respectively. The gas pressure was 8 kPa (60 Torr) for all experiments. In USDOE REPORT EV/1005-284 the composition and performance of these gas mixtures are discussed. The data acquisition apparatus is quite standard and described in detail in USDOE Report EV/01105-272.

To compare with the microdosimetrically deduced dose components, an air-filled A150-plastic walled ionization chamber and a miniature neutron insensitive GM counter were operated as paired dosimeters. Attix et al. (USDOE COO-1105-265, 1979) have concluded that this dosimeter pair is as reliable as any triplet dosimeter group and somewhat more reliable than any pair of dosimeters which excludes the GM counter as a member. All dosimeters, ion chambers, GM-counters and proportional counters were operated in fixed geometry.

Exposure Techniques

In the first sequence of experiments, the neutron and photon exposures were administered separately. For the proportional counters, the three gains used to construct a composite spectrum are such that photon events contribute only to the highest gain data. Thus, various admixtures of photons are produced by recording data at only the highest gain setting - a separate spectrum for each admixture. The photon exposure rate was adjusted to ensure that the counting rates in the proportional counters were less than 5×10^3 sec^{-1}. During the photon only exposures, the A150-plastic ionization chamber was used to deduce the dose.

During the second set of experiments, neutrons and photons were administered simultaneously. The neutron and photon dose rates were comparable, namely 0.06 rad/min and 0.08 rad/min respectively. To provide the various mixtures of neutrons and photons, neutron-only data were first acquired; subsequently additional data with both sources operational were taken. Dynamically, the mixture was that stated above. As already discussed, it was necessary to record proportional counter data only at the highest gain for the simultaneous data.

In essence then, data were taken in such a fashion that composite spectra could be generated from separate neutron and photon exposures as well as from simultaneous exposures. In each case, the neutron and photon dose rates were previously established to allow precise comparison with the deduced result.

DATA ANALYSIS

Proportional counter data were analyzed by the construction of a composite spectrum incorporating spectra taken at each gain setting. Individual spectra were corrected to standard gain values using the calibration α-particle source and the measured linearity of the analogue-to-digital converter. These spectra were then corrected for background and normalized to the system "live-time". Photon doses were deduced from the composite graphite-counter spectra by means of a calibration ^{60}Co-only spectrum. Thus photon doses do not depend absolutely on the internal α-particle calibration, but rather on a dose deduced from the A150-plastic ionization chamber operated concurrently during the ^{60}Co calibration. We thus assume the photon spectrum from the neutron source is well represented by ^{60}Co. Using the graphite-walled counter deduced photon dose and a ^{60}Co calibration spectrum taken with the A150-walled counter, the neutron-only dose in the A150-walled counter was determined. A similar procedure applied to the graphite-walled counter unfolds the neutron dose in that counter. It must be noted that the neutron dose determined in this manner does depend explicitly upon the α-particle calibration source.

The sequential and simultaneous exposures were analyzed somewhat differently. For sequential data, neutron (plus a small (3%) inherent photon component) data were first acquired and stored. Then, photon-only (^{60}Co) data were taken and stored for varying total photon doses. A composite (n+γ) spectrum was then assembled. Unfolding for the photon-only data was trivial and only the neutron data required the procedure outlined above. The A150-plastic ionization chamber and the GM counter were used to deduce neutron and photon dose values during the neutron only exposures. For the ^{60}Co exposures, the GM counter operated erratically due to excessive photon dose rates. Thus, the photon doses were determined from the ionization chamber data.

For the simultaneous (n+γ), exposure, a complete unfolding procedure was applied to all mixtures. As discussed above, the n + γ irradiations resulted in photon dose rates beyond the capabilities of the GM counter. Comparison photon doses were deduced from the known ^{60}Co dose rate and the precisely determined photon source on-time. The neutron dose per monitor chamber charge was constant (±1%) and unaffected by the ^{60}Co beam. Thus the neutron dose could be deduced quite independently from the proportional counter analysis.

RESULTS

Figures 2 and 3 summarize the proportional counter measurements for several n/γ mixtures. The curves representing 100% neutrons are the result of unfolding the inherent 3% photon contamination of the fast neutron beam. Figure 2 (A150-walled counter) demonstrates the extreme difficulty in separating electron recoils resulting from photon interactions from neutron- induced fast recoil protons. In contrast, the graphite walled counter data (Fig. 3) show almost complete resolution of the photon-induced events from the heavier neutron-induced recoils.

Tables II and III summarize the various derived doses. Sequential irradiation results appear in Table II, while the simultaneous irradiation results are given in Table III. Doses are expressed in tissue rads per monitor chamber nC. Neutron doses measured with the graphite-walled counter are determined by normalizing to the muscle-to-carbon kerma ratio at 14.8 MeV (Caswell, 1980). These dose values are in substantial agreement with the A150-walled ionization chamber results, (±5%). Inasmuch as the neutrons are unscattered and in a nominally narrow-beam geometry (Fig. 1) this is not surprising. The neutron doses determined by the A150-walled proportional counter are systematically larger than the ionization chamber results (~11%). This is consistant with the results reported in USDOE Report DOE/EV/01105-284.

Photon doses determined from the graphite-walled proportional counter measurements are in excellent agreement with the predetermined photon doses. The mean ratio of graphite-walled counter to known photon dose is 0.976 ± 0.04. The sequential irradiation results are somewhat better, 0.9914 ± .005, than the simultaneous, 0.96 ± 0.06. It again should be stressed that the proportional counter photon dose values depend only on the ionization chamber calibrated ^{60}Co spectra and not upon the absolute α-particle calibration. In addition, the failure of the GM counter to respond consistently at even modest photon dose rates suggests serious difficulties would be encountered when using such a device in general mixed beam applications.

CONCLUSIONS

The application of a graphite-walled miniature proportional counter to the determination of photon dose values in mixed n + γ fields shows considerable promise. When the initial neutron energy is low enough (less than 20 MeV) to ensure that few recoil protons are generated in carbon, this device offers considerable precision. When the application requires the use of the internal α-particle calibration source, less than satisfactory results have been achieved (e.g. neutron doses deduced from the A150-walled proportional counter). The specifics of this difficulty have yet to be resolved.

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Table I

SOURCE PARAMETERS

Cobalt

Source	1150 Ci ^{60}Co
SSD	0.4 m to 4.5 m
Collimator	variable, rectangular, 0^{o} to 20^{o} half angle
Output	60 rad/min to 1 rad/min

Fast Neutron

Beam	215 kV, 12 mA, $D^{+} + D_2^{+}$
Diameter	5mm
Target	T_2 or D_2 gas 4 to 8 Torr
	5 Stage Differentially Pumped
	100 Ci to 200 Ci per load of T_2
Source	Line 55 cm long 5 to 8 mm diameter
Output	3×10^{12} n/sec 14.8 MeV
	2×10^{10} n/sec 3 MeV
Dose Rate	0-200 rad/min 14.8 MeV
	0-2 rad/min 3 MeV
Collimator	77 cm Benelex, 10 cm x 10 cm at 108 cm from beam stop
	2 rad/min at 108 cm SSD 14.8 MeV

TABLE II

SEQUENTIAL IRRADIATION DOSE COMPONENT DETERMINATIONS*

^{60}Co(%)	$D_n^{IC}(10^{-5})$	$D_\gamma^{IC}(10^{-6})$	$D_n^{C}(10^{-5})$	$D_\gamma^{C}(10^{-6})$	$D_n^{PC}(10^{-5})$
0	8.95	2.12	9.07	2.09	10.0
28	8.95	37.5	9.19	37.0	10.5
56	8.95	114.9	9.41	115.2	9.15

TABLE III

SIMULTANEOUS IRRADIATION DOSE COMPONENT DETERMINATIONS*

^{60}Co(%)	$D_n^{IC}(10^{-5})$	$D_\gamma^{IC}(10^{-6})$	$D_n^{C}(10^{-5})$	$D_\gamma^{C}(10^{-6})$	$D_n^{PC}(10^{-5})$
0	8.95	2.12	8.71	2.17	9.99
16	8.95	19.1	8.74	17.4	10.0
57	8.95	119.5	8.78	113.7	9.89

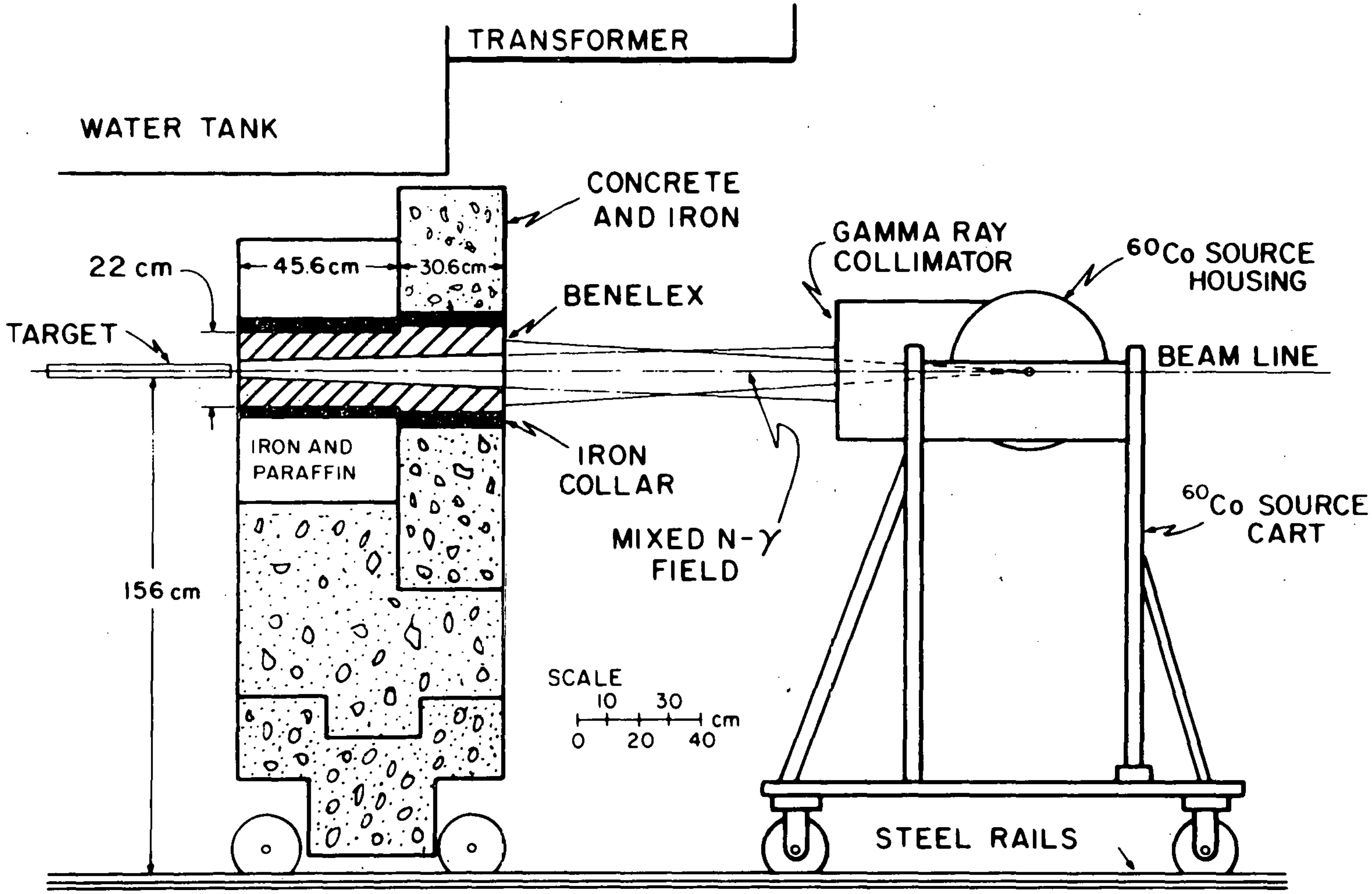
*Doses expressed as rads per monitor nC. IC, C, and PC refer to doses determined with the A150-plastic ionization chamber - GM counter pair, graphite-walled proportional counter and A150-plastic-walled proportional counter, respectively.

FIGURE CAPTIONS

Fig. 1 A schematic representation in plan view of the gas target neutron source, neutron collimator and ^{60}Co teletherapy irradiator.

Fig. 2 Plots of event-size-weighted fractional dose as a function of event-size for the A150-plastic walled proportional counter. Curves are shown for beams of nominally 100% neutrons, 70% neutrons/30% photons and 40% neutrons/60% photons.

Fig. 3 Plots of event-size-weighted fractional dose as a function of event-size for the graphite-walled proportional counter. Curves are shown for beams of nominally 100% neutrons, 70% neutrons/30% photons and 40% neutrons/60% photons.



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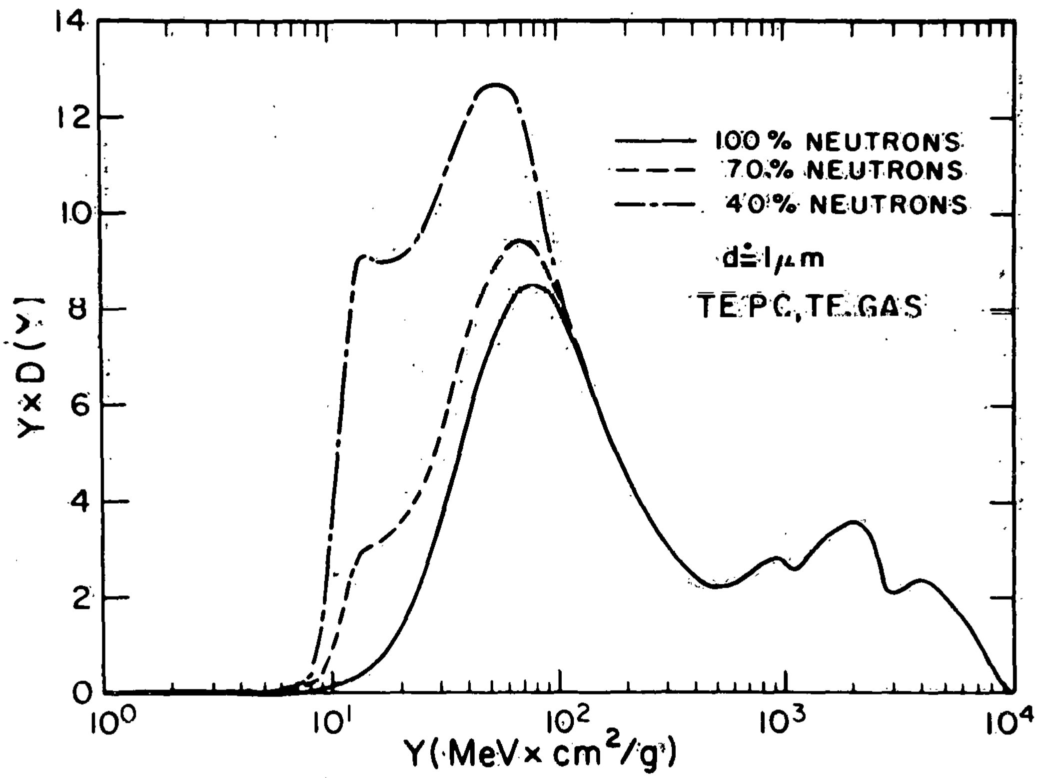
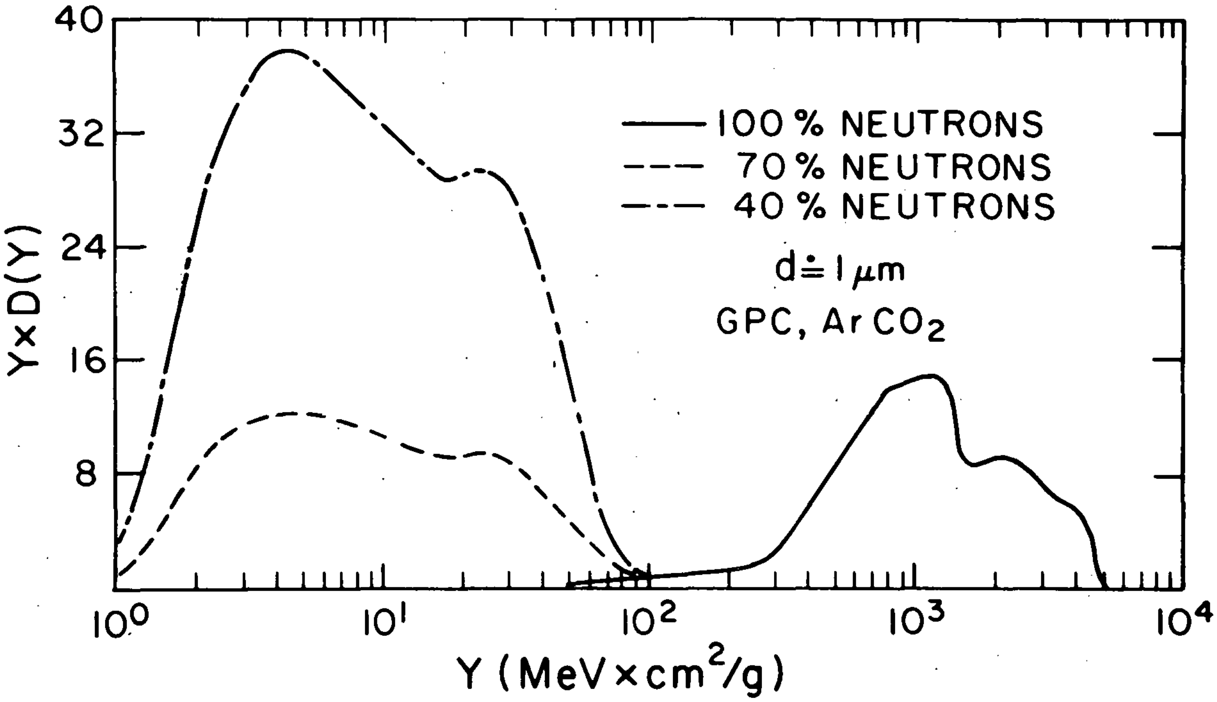


Fig. 2 Plots of event-size-weighted fractional dose as a function of event-size for the A150-plastic-walled proportional counter. Curves are shown for beams of nominally 100% neutrons, 70% neutrons/30% photons and 40% neutrons/60% photons.



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