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INTERCOMPARISON OF NEUTRON DOSIMETRY TECHNIQUES AT THE AFRRI TRIGA REACTOR

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Abstract — In 1983 a programme of neutron dosimetry validation was undertaken at the TRIGA Mark F nuclear reactor at the Armed Forces Radiobiology Research Institute (AFRRI). Since the International Neutron Dosimetry Intercomparison (INDI) of 1973, the development of neutron dosimetry protocols in both the USA and Europe as well as improved knowledge of the physical factors (W, K) involved in neutron dosimetry necessitated a re-evaluation of earlier techniques. The purpose of the present programme was to validate the accuracy of AFRRI ionisation chamber neutron dosimetry by intercomparison with independently calibrated neutron measurement techniques. Two reference configurations of the AFRRI TRIGA nuclear reactor have been used for the intercomparisons, namely unshielded and shielded by a 15 cm lead shield. Calculated neutron and gamma ray energy spectra were available for these reference fields. Neutron dosimetry techniques used in the intercomparisons include (1) paired ionisation chambers, consisting of tissue-equivalent (TE) ionisation chambers with either a magnesium or graphite ionisation chamber or a GM counter, (2) activation foils, (3) fission chambers, (4) a calorimeter, and (5) tissue-equivalent proportional counter (TEPC). The results of this ongoing programme at the AFRRI TRIGA reactor support the general conclusion that fission neutron spectrum kerma values determined by the separate independent techniques agree within the uncertainties of the experimental measurements.

INTRODUCTION

There exists no national standard instrument or radiation field for calibration of absorbed dose of neutron radiations used in radiobiology or radiotherapy. Standardisation is largely achieved by:

(i) Adherence to specific protocols, such as those of the American Association of Physicists in Medicine (AAPM)[1] or European Clinical Neutron Dosimetry Group (ECNEU)[2] for neutron beam dosimetry.

(ii) Intercomparisons between different centres using similar measurement techniques, notably International Neutron Dosimetry Intercomparison (INDI)[3] and European Neutron Dosimetry Intercomparison Project (ENDIP)[4].

(iii) Intercomparisons between fundamentally different dosemeters[5], e.g. ionisation chambers, calorimeters, activation foils, and proportional counters.

The objective of the present work is to measure accurately tissue kerma due to neutrons in the mixed neutron gamma ray radiation fields used for radiobiology research at the Armed Forces Radiobiology Research Institute (AFRRI) TRIGA reactor. Specifically the aim is to validate the accuracy of neutron dosimetry by intercomparing results from fundamentally different detection technologies which have independent calibrations.

Ionisation chamber measurements of absorbed doses of neutron radiation are limited in absolute accuracy to ± 5-10% due to uncertainties in the physical constants used to calculate dose from the measured ionisation. Calorimetry is similarly limited to an overall accuracy of the order of ± 3%. Neutron activation provides information only on the neutron portion of total dose, with accuracy dependent on knowledge of the neutron energy spectrum, kerma factors and cross sections.

An earlier intercomparison of ionisation chamber measurements with activation techniques at AFRRI was reported by Eisenhauer *et al*[6]. This paper describes the present status of the intercomparison programme, including results from a tissue-equivalent (TE) calorimeter and a TE proportional counter.

RADIATION FIELDS

The reactor is a General Atomics TRIGA Mark F water-pool type thermal research reactor, capable of pulsed or steady state operation at various locations within its pool. A semicylindrical portion of the reactor pool projects into the exposure room (Figure 1), which is lined with a gadolinium-cadmium shield to minimise scattered thermal neutron fluence. A lead shield can be rolled into place in front of the reactor core (Figure 1) to increase the neutron to gamma ratio for radiobiology research. The dosimetry measurement point was 70 cm from the centre of the reactor tank wall, and 120 cm above the wood floor (centre height of the reactor core). Measurements are reported for both the unshielded and 15 cm Pb shielded configurations.

STATUS OF THE INTERCOMPARISON PROGRAMME

Ionisation chambers

The paired ionisation chamber method is the primary technique used at AFRRI for neutron dosimetry[7]. We use Exradin 0.5 cm^3 chambers, an A-150 plastic chamber with TE gas and an Mg chamber with Ar (Table 1). AFRRI and NBS staff have completed concurrent absorbed dose measurements with ionisation chambers at the AFRRI TRIGA reactor[8], with excellent overall agreement (1-2%) between the two groups. To ensure the constancy of neutron dosimetry results, a ^{252}Cf irradiator has been built for periodic neutron sensitivity checks of the ionisation chambers, in addition to ^{60}Co calibration of the chambers.

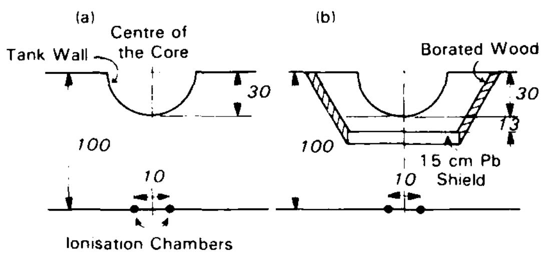

Figure 1. Diagram of the experimental arrangement at the AFRRI TRIGA reactor. All lengths are in cm. (a) With the reactor core brought into place in the pool behind the semicylindrical projection, only a ~2.5 cm thick water layer and the 0.64 cm thick aluminium tank wall separate the edge of the 30 cm radius core from the air in the exposure room. In this bare unshielded array, gamma rays comprise 67% of the total (fission neutron plus gamma ray) tissue kerma in free-air at the measurement point. (b) The 15 cm Pb shield travels laterally on a track for reproducible alignment directly in front of the core, and the borated wood is positioned to reduce scattered radiation. In this 15 cm Pb shielded array, gamma rays comprise 9% of the total kerma in free-air at the measurement point.

Table 1. Physical constants for ionisation chamber measurements.

Reactor Field	Bare	15 cm Pb
Tissue kerma weighted mean neutron energy (MeV)	2.63	1.67
$W_n/W_{Co\text{-}60}$	1.092	1.099
$K_{ICRU\ muscle}$(10^{-11}Gy.cm^2)	2.06	1.73
$K_{A\text{-}150}$(10^{-11}Gy.cm^2)	2.12	1.76
$K_{TE\ gas}$(10^{-11}Gy.cm^2)	2.10	1.75
k_t	0.939	0.922
k_u(Mg-Ar)	0.02	0.01
h_t, h_u, r_{mg}	1.00	1.00

Transport calculations

Neutron and gamma ray energy spectra (Figure 2) and fluences were calculated for AFRRI for selected geometries by two independent investigators [9,10]. Neutron energy spectra calculated by the two independent investigators showed good agreement in spectral shape, especially in the high energy region of the spectra. The calculations are utilised as *a priori* energy spectra to estimate the response of energy dependent detectors, such as activation foils, and to calculate other spectrum dependent quantities, such as lineal energy spectra, for comparison with measurements.

Activation and fission foils

Fission and non-fission foils have been irradiated in the bare and 15 cm Pb shielded reactor fields. Initial neutron kerma rates were derived from the detector measurements using the *a priori* neutron energy spectra (Table 2). Coarse group adjustments to the *a priori* spectra were performed by minimising disagreements between observed and predicted reaction rates. The adjusted spectra were used to form final estimates of the neutron kerma from the foil responses [6,11].

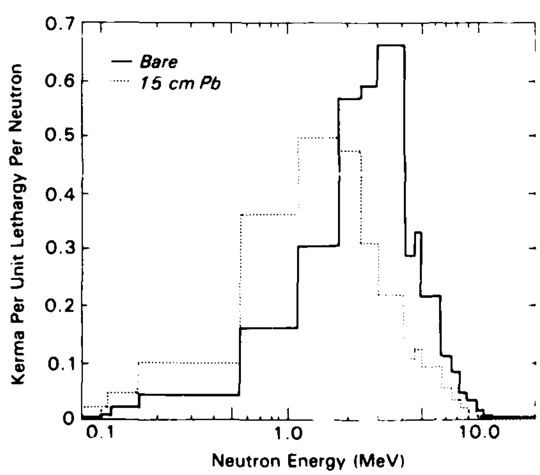

Figure 2. Calculated neutron energy spectra at the dosimetry measurement point[9,10].

Table 2. Dosimetry results in the bare and 15 cm Pb shielded reactor fields.

	Kerma ($mGy.kW^{-1}.s^{-1}$)	
	Neutron	Total
Bare		
Activation/Fission: *a priori*	1.74	
Adjusted	1.88±0.11*	–
Ionisation chamber	2.05±0.10	6.16±0.31
TE calorimeter	–	6.03±0.18
TE proportional counter	–	–
15 cm Pb		
Activation/Fission: *a priori*	0.98	
Adjusted	1.07±0.05	–
Ionisation chamber	1.19±0.06	1.31±0.07
TE calorimeter	–	1.32±0.04
TE proportional counter	1.06±0.16	–

* Measurement uncertainties are the estimated standard deviations.

Calorimetry

Intercomparison of TE calorimeter and paired ionisation chambers has been completed in steady state and in single pulse (10 ms FWHM) reactor fields. Total neutron plus gamma ray dose agreement was within ± 5% for both steady state (Table 2) and for pulse (data not shown) irradiations. Due to technical challenges in making the calorimeter measurements, we do not plan to use this instrument in routine reactor dosimetry.

Tissue-equivalent proportional counters

Data have been obtained from TEPC measurements in the 15 cm Pb shielded reactor. The neutron kerma rate measured by a TEPC agrees with other methods (Table 2). Comparison of the shapes of measured and calculated[13] y-spectra show good agreement above 15 keV.μm^{-1} (Figure 3). Above 15 keV.μm^{-1}, y-spectra measured at midline 15 and 18 cm diameter phantoms were identical in shape to the spectrum in air (Figure 4). Below 15 keV.μm^{-1}, the measured y-spectra show the expected increase in the gamma ray fraction of dose with increasing phantom size (Figure 4).

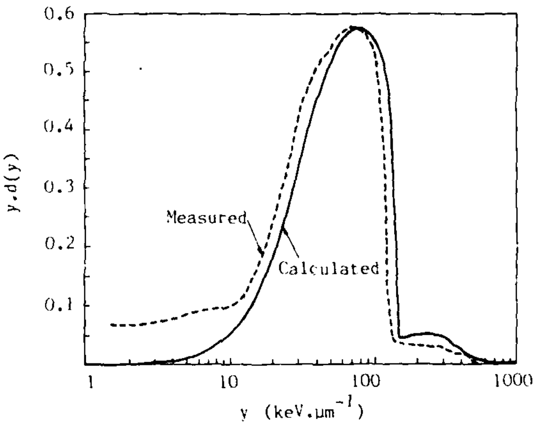

Figure 3. Measured and calculated y-spectra for the 15 cm Pb radiation field in free air. The calculated spectrum was normalised to measurements at the peak.

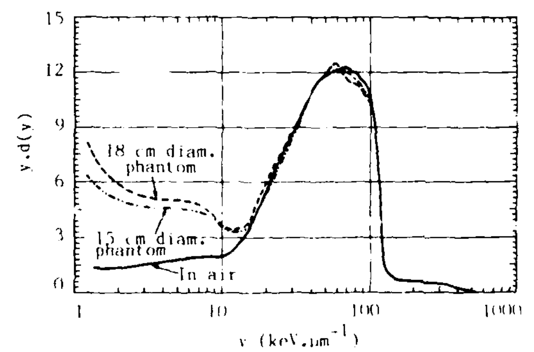

Figure 4. Measured y-spectra for the 15 cm Pb radiation field, normalised to the peak of the in air spectrum.

CONCLUSIONS

Intercomparison of neutron dosimetry results from separate independent measurement techniques can provide confirmation of the accuracy of measured doses. Measurements of total dose by ionisation chambers and by a calorimeter agreed within 5% in the bare and 15 cm Pb fields.

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Measurements of the neutron component of dose by the different techniques agreed within 9% (bare) and 12% (15 cm Pb).

Further efforts in this intercomparison programme will emphasise repeating and extending the present measurements with an improved in-room monitor system to reduce the uncertainty involved in comparing data taken at dose rates (reactor power levels) differing by up to four orders of magnitude.

We interpret the present results as confirming the accuracy of neutron dosimetry measurements at the AFRRI TRIGA reactor within the uncertainties of the experimental measurements.

The opinions and assertions contained herein are those of the authors and should not be construed as reflecting the views of the Department of Defense or the Defense Nuclear Agency.

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