Fermi National Accelerator Laboratory

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RELATIVE KERMA VALUES IN VARIOUS MATERIALS IRRADIATED BY FERMILAB NEUTRON BEAM

David Bewley
Medical Research Council, Hammersmith Hospital
London, England

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To derive the dose in the human body or in biological specimens from dosimetric measurements with T.E. ionization chambers or a calorimeter, one important factor is the kerma (kinetic energy released per unit mass) in the tissue under consideration relative to the kerma in T.E. plastic. I have attempted to calculate relevant kerma ratios for the neutron spectrum measured by Amols et al., (to be published) with 65 MeV protons on a Be target 2.21 cm thick.

This spectrum is shown in Fig. 1. The fluence below 10 MeV was not measured; three alternative extrapolations are shown, marked a), b) and c).

The materials considered and their atomic compositions are listed in Table I. The T.E. (tissue-equivalent) phantom liquid is so close to ICRU tissue that it will not be considered further.

Kerma factors up to 30 MeV for all the relevant elements have been calculated by Caswell, Coyne and Randolph, to be published by the International Commission on Radiological Units (ICRU), in a forthcoming report on Neutron Dosimetry in Biology and Medicine. From 20-70 MeV kerma values for H, C, N and O have been

calculated from a theoretical model by Alsmiller (private communication to M. Awschalom). These calculations can be compared in the region of overlap, 20-30 MeV, and the figures are given in Table II. They are in close accord for H but differ by about 40% for N, up to 30% for O, and between 4 and 8% for C. Alsmiller thinks his theoretical model will be more nearly correct at the higher neutron energies. I have used Caswell's data up to 30 MeV. Above 30 MeV I have used Alsmiller's data, and have converted all elements heavier than O into "Oxygen equivalent" from the ratio of kerma in the element to kerma in oxygen given by Caswell and averaged over 20-30 MeV.

Table III gives the resulting kerma values as a percent of the kerma in ICRU muscle, together with comparable values for neutrons of 14 MeV and for the neutron beam at Hammersmith Hospital (mean energy 7.5 MeV). For Fermilab neutrons, the percentage of the total kerma arising from each element is given in Table IV. The largest contribution is from hydrogen, which varies from 70% in water through 67% in muscle to 55% in bone.

Uncertainties

The uncertainty in these ratios of kerma is difficult to assess. The three alternative extrapolations shown in Fig. 1 have only a small influence. For example, the three extrapolations give

values of A-150/muscle of 109.2, 109.0, 108.8, while the comparable values for bone/muscle are 76.6, 76.4, 76.1. The absolute values of kerma per unit fluence vary more, about ± 3%, but the ratios to kerma in muscle are nearly constant.

Of much greater importance is the uncertainty in the data of Caswell et al., and of Alsmiller, and the uncertainty introduced by the lack of data for all elements except H, C, N and O above 30 MeV. Caswell, Coyne and Randolph estimate the uncertainty in kerma in hydrogen at ± 2%. Neutron interactions with H are well understood and I shall use an uncertainty of ± 2% throughout the whole range of neutron energies considered here. For the other elements Caswell, Coyne and Randolph estimate ± 10% up to 20 MeV and ± 50% from 20-30 MeV. The differences between their values and those of Alsmiller are within this uncertainty (see Table II). Alsmiller considers his results become more accurate at higher energies so the uncertainty is likely to be under 50% over the whole range of neutron energies.

However, the calculations presented in this report are of ratios of kerma in a given material compared to kerma in tissue. Ratios are likely to be less uncertain than the absolute values. The main variation between the materials is a substitution of C (and to a smaller extent F, P and Ca) for O. Thus the uncertainty in the ratio kerma in C/kerma in O is the most important quantity. Caswell and Coyne estimate this to be ± 20% in the range 20-30 MeV (private communication). In Alsmiller's data, ratios of kerma are also likely to be less uncertain than the absolute values.

With these considerations in mind, I have assessed the total uncertainty in the kerma ratios by adding the maximum uncertainty to kerma in C (10% to 20 MeV and 20% above 20 MeV), subtracting the same percentage uncertainty from O, and applying uncertainties to the other elements in a direction such as to alter the kerma ratio as much as possible. The uncertainty in H is taken as ± 2% throughout, in C, N and O ± 10% and ± 20% as above, and in the other elements ± 10% to 20 MeV, ± 20% from 20 to 30 MeV and ± 40% above 30 MeV, the figure of 40% being intended to allow for the fact that Alsmiller gives no data for these elements. The resulting uncertainties in the kerma ratios are the maximum possible within the stated assumptions. The effect of uncertainty in the low energy part of the neutron spectrum is not included, but the uncertainty arising from this is small as explained in the first paragraph of this section.

Conclusion

The kerma ratios to ICRU muscle are similar to those for neutrons at 14-15 MeV and for the Hammersmith spectrum, but the uncertainties are greater. The largest change is for A-150 plastic where the kerma ratio is about 1.11 ± 0.11 instead of 1.04 at 14-15 MeV and 103 at the lowest energy. Lucite also shows a large change over this range of neutron energies.

Note on Fermilab Memorandum TM-701A

Caswell, Coyne and Randolph have revised their calculated values of kerma. New values were attached to their memorandum of February 10, 1977.

I have recalculated kerma ratios using this data, for the neutron beams at Fermilab, Hammersmith, and at 14 - 15 MeV. The accompanying memorandum gives the corrected values and should be substituted for the previous version of Fermilab TM-701. The changes in the kerma ratios are small, mostly about 1%, and the uncertainties in the ratios for the Fermilab neutron beams are almost unchanged.

Table I.

Composition of Materials (Percent)

	H	C	N	O	F	Na	Mg	P	S	K	Cl	(
ICRU Muscle	10.2	12.3	3.5	72.9	-	.08	.02	.2	.5	.3	-	
T.E. Phantom	10.2	12.3	3.5	72.9	-	.07	.02	.2	.32	.39	.08	
A-150 plastic	10.15	77.54	3.52	5.21	1.74	-	-	-	-	-	-	1
Water	11.19	-	-	88.81	-	-	-	-	-	-	-	
Lucite	8.05	59.98	-	31.96	-	-	-	-	-	-	-	
ICRU bone	6.4	27.8	2.7	41.0	-	-	.2	7.0	.2	-	-	14
Sub-cutaneous fatty tissue	11.9	49.6	-	38.5	-	-	-	-	-	-	-	
Brain	10.8	13.1	1.3	73.6	-	-	-	1.2	-	-	-	

Table II. Kerma 10^{-9} rad/unit fluence

Comparison of Kerma Values from Caswell et al., and Alsmiller

Neutron Energy MeV	Data	H	C	N	O
20-22	Caswell et al.	46.7	3.47	3.48	2.71
	Alsmiller	46.5	3.20	2.00	1.92
	$\frac{C-A}{C}$ %	0	+8	+43	+29
28-30	Caswell et al.	44.7	4.05	3.94	2.60
	Alsmiller	44.5	3.90	2.48	2.38
	$\frac{C-A}{C}$ %	0	+4	+37	+8

Table III.

Kerma Ratio[1] as Percent of that in ICRU Tissue using Extrapolation b) in Fig. 1

Material	Spectra		
	Fermilab	14-15 MeV	Hammersmith
ICRU muscle	100.0 ± 0.0	100.0	100.0
A-150 plastic	109. ± 10.6	104.2	102.7
Water	104.4 ± 1.8	105.6	107.2
Lucite	93.1 ± 7.1	88.4	84.1
ICRU bone	76.4 ± 4.5	73.2	71.1
Sub-cutaneous fatty tissue	115.7 ± 6.4	113.9	115.1
Brain	103.6 ± 0.4	103.8	104.6

[1]Kerma ratio = kerma (material)/kerma (muscle tissue).

Table IV.

Percent of Total Kerma Arising from each Element (Fermilab Neutrons)

	H	C	N	O	F	P	Ca
ICRU muscle	67	6	1.5	25.5	-	-	-
A-150 plastic	61	34.5	1.5	2	0.5	-	0.5
Water	70	-	-	30	-	-	-
Lucite	57	31	-	12	-	-	-
ICRU bone	55	18	1.5	18.5	-	1	6
Sub-cutaneous fatty tissue	67.5	21	-	11.5	-	-	-
Brain	68.5	6	0.5	25	-	-	-

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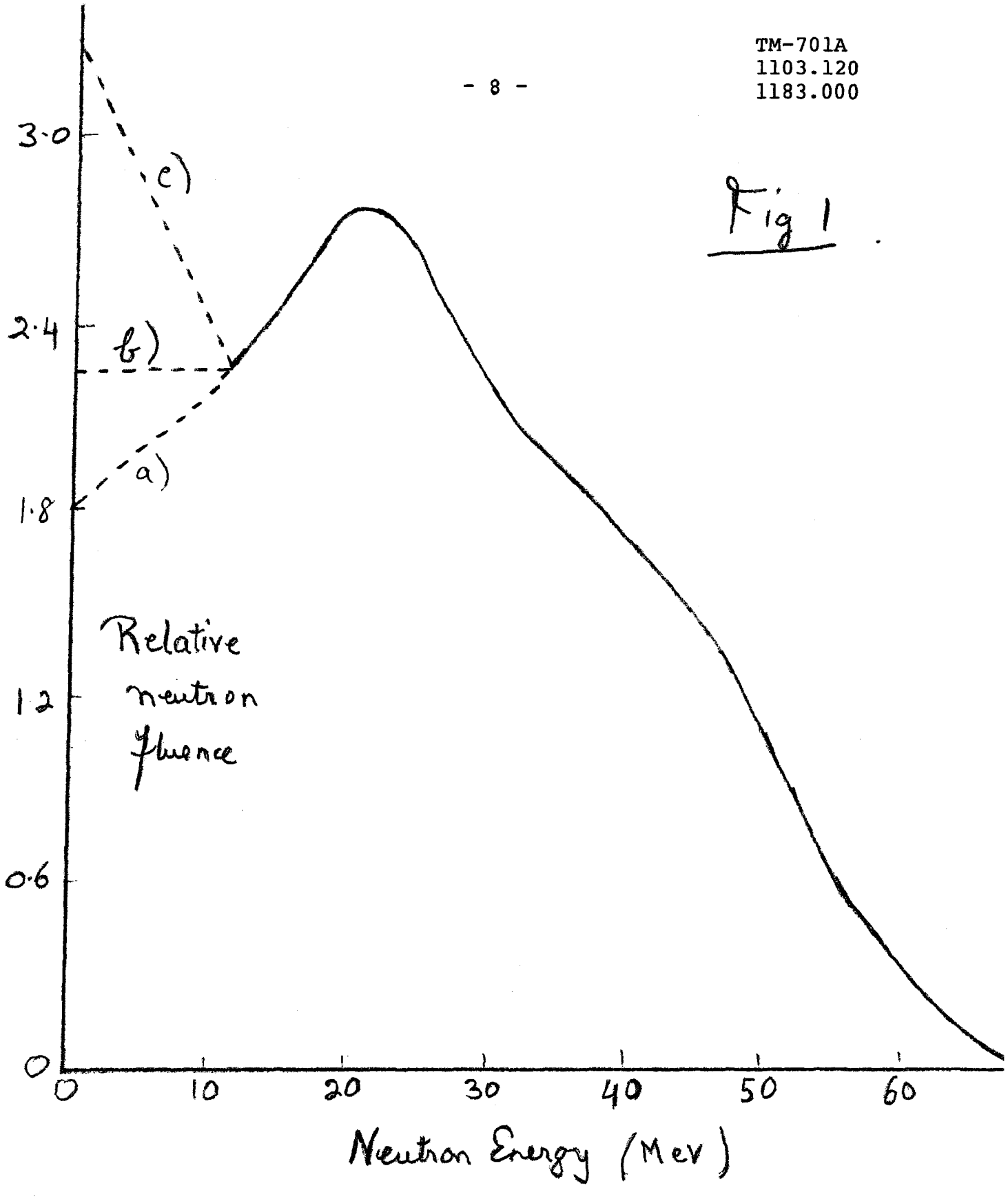

Fig 1