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Neutron Activation Probability for Sodium in Man

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Neutron Activation Probability for Sodium in Man

by

S. A. McGuire

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ABSTRACT

Knowledge of the neutron activation of a man's blood sodium can be used to calculate an accidental neutron dose if the neutron spectrum and the neutron capture probability of the man as a function of energy are both known. This report describes calculations of the neutron capture probability of a 136-lb man, a 200-lb man, and 30-cm-, 24-cm-, and 18-cm-dia by 60-cm-high cylinders.

The capture probability of a man was found to be below that of the 30-cm-dia cylinder at all energies and much closer to the capture probability of the 18-cm-dia cylinder. Below 0.1 MeV, the capture probability of a 136-lb man averages about 20% lower than that of the 30-cm-dia cylinder; but above 0.1 MeV, the gap widens rapidly until the capture probability at 2 MeV is twice as great for the cylinder as for the man.

The man's position with respect to the neutron beam was found to have a considerable effect. The capture probability averages about 20% lower for a man standing side-on to the beam than for one facing into it.

INTRODUCTION

Several authors^{1,2,3} have published values for the capture probability and the sodium activation probability of different energy neutrons incident on a man. The values given are notably discrepant. Most results are given for 30-cm-dia by 60-cm-high tissue-equivalent cylinders on the assumption that this geometry has the same sodium activation probability as a man.

In this paper, multigroup transport theory is used to calculate neutron capture in finite cylinders, and the Monte Carlo method is used to calculate neutron capture in a man.

In these calculations, the composition of a "standard" man⁴ was used: oxygen, 65%; carbon, 18%; hydrogen, 10%; ni-

trogen, 3%; calcium, 1.5%; phosphorus, 1%; sulfur, 0.25%; potassium, 0.2%; and sodium, 0.15%. The multigroup calculations show that there is very little difference (about 1%) between the neutron capture probability of cylinders made of tissue alone and that of the homogenized standard man just described. Actually, homogenizing the entire body is probably more correct because for all but the lowest energy neutrons the thermalized neutron flux peaks well within the cylinder. Neutrons of 3 MeV give a thermal peak at the center of the 30-cm cylinder; 17- to 100-keV neutrons give a thermal peak about 4 cm from the edge of the cylinder.

MULTIGROUP CALCULATIONS ON CYLINDERS

Real-flux shell-source calculations

of sodium capture probability were done for infinite cylinders using the S_4 transport theory with an axial buckling corresponding to a cylinder height of 60 cm. The same calculations were done by the adjoint-flux method as described by Hansen and Sandmeier⁵ which is equivalent to the real-flux shell-source method. The Hansen-Roach 16-group cross sections⁶ were used.

It should be pointed out that a shell source is not exactly equivalent to a monodirectional neutron beam. The boundary condition for a shell source is that the angular flux $\phi(\Omega)$ in the inward direction is a constant. This means that not all shell-source neutrons enter the cylinder perpendicular to the z - axis as they would if they were from a monodirectional beam. (The θ distribution in the $z = \text{constant}$ plane is correct.) The effect of this is that the shell-source neutrons have their first collision closer to the surface than those from a monodirectional beam. Thus, the leakage is larger and the capture probability less than for a monodirectional beam. For thermal and epithermal neutrons the difference would be considerable, but for fast neutrons it should be small--on the order of 10%. This 10% difference was observed between shell-source calculations and distributed- (isotropic-) source calculations in the MeV range and should be about the same as the difference between the shell source and the monodirectional beam.

The adjoint-flux calculations give the sodium activation directly. The capture probabilities were obtained by multiplying by the ratio of the total to sodium macroscopic capture cross sections for thermal neutrons. The real-flux calculations show that this approximation was never more than 3% off. The calculated capture probabilities are given in Table I.

To obtain the sodium capture probability, these numbers are multiplied by $\Sigma_{\text{Na}} / \Sigma_{\text{total}}$ for thermal neutron absorption. $\Sigma_{\text{Na}} / \Sigma_{\text{total}} = 1.756 \times 10^{-5} / .0205$.

TABLE I
NEUTRON CAPTURE PROBABILITIES FOR 60-CM-HIGH
CYLINDERS CALCULATED BY MULTIGROUP THEORY

Incident Neutron Energy Range		Total Capture Probability		
		30-cm dia	24-cm dia	18-cm dia
MeV				
3	- 6	0.328	0.254	0.160
1.4	- 3	0.368	0.305	0.212
0.9	- 1.4	0.352	0.310	0.236
0.4	- 0.9	0.341	0.308	0.246
0.1	- 0.4	0.320	0.295	0.249
keV				
17	- 100	0.295	0.276	0.241
3	- 17	0.292	0.275	0.243
0.55	- 3	0.296	0.280	0.250
eV				
100	- 550	0.303	0.288	0.259
30	- 100	0.311	0.297	0.269
10	- 30	0.315	0.301	0.276
3	- 10	0.316	0.303	0.279
1	- 3	0.313	0.290	0.278

MONTE CARLO CALCULATIONS

Neutrons struck the 136-lb "man", whose dimensions are shown in Fig. 1, from the front in some cases and from the side in other cases. All neutron directions began parallel as if they originated from a point source at an infinite distance from the man. Neutron capture probabilities were calculated at 17 different energies and all points had a statistical error of less than 5%. A 200-lb man was represented by multiplying all dimensions of the 136-lb "man" by 1.139.

The neutron capture probabilities for men of these weights are shown in Figs. 2 and 3. Also plotted are the total capture probabilities for the cylinders discussed earlier and the calculations of others. As can be seen from the figures, a man is not well-represented by a 30-cm-dia by 60-cm-high cylinder.

The captures for irradiation from the side are significantly lower than those for front irradiation. This is believed due to the fact that for side irradiation the arm scatters the incident neutrons but rarely captures them since its volume is so small. This indicates that the position a man is in (sitting, standing, running) has a significant effect on capture probability and also on the ratio of sodium activation to dose. The curves drawn should be within 20% of the actual capture probability for a real man.

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Fig. 1. Representation of 136 pound man for Monte Carlo computations.

Fig. 2. Neutron Capture Probability vs Neutron Energy (Thermal to 10^4 eV).

Fig. 3. Neutron Capture Probability vs Neutron Energy (10^4 to 10^7 eV).