PERSONNEL HAZARDS FROM MEDICAL ELECTRON ACCELERATOR PHOTONEUTRONS*

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INTRODUCTION

For medical accelerators, neutron penetration through the room entry door is the major personnel hazard. Most therapy accelerator rooms are designed with at least a rudimentary maze to avoid the use of massive doors. Often, however, the maze may be similar to those shown in Fig. 1. In Fig. 1, scale outline drawings of some medical electron accelerator rooms are shown where the authors have made neutron measurements outside the doors which were of different thicknesses and compositions. The results are tabulated in Table I. It should be noted that there can be significant dose equivalents (H) at the door when a maze is inadequate, and that all three components - fast neutron, thermal neutron, and neutron capture γ-rays - can be equally important. Also, these capture γ-rays are very penetrating; (TVL ≈ 5-7 cm of lead).

SIMPLE METHODS OF CALCULATING MAZE EFFECTIVENESS

For a good review of neutron penetration of mazes, the authors suggest Chapter 4 by Selph of Ref. 1. Most of the extensive work on mazes is not directly applicable to medical electron accelerators, however, for various reasons. Monte Carlo or albedo computer calculations have been shown to correctly calculate neutron maze penetration.

We have explored several simpler methods of predicting neutron penetration of a maze which do not rely upon computer codes or difficult calculations. Method 1 is an albedo method based upon the work of French and Wells (2), and is described as follows: On a room drawing, the portion of the walls, floor and ceiling that could be directly irradiated by neutrons from the accelerator, and then scatter the neutron directly to the door, are outlined, and their areas determined. An effective center, P, is chosen for each. The incident and reflected angles are measured from these points. Next, the dose albedo α_d (2), is used;

$$\alpha_d = \alpha(E_o) \cos^{2/3}\theta_o \cos\theta \qquad \text{Eq. 1}$$

where θ_o and θ are the incident and reflected angles, respectively, measured from the normal to the wall. For the range of neutron spectra from medical accelerators, a single value for $\alpha(E_o)$ of 0.11 can be used for concrete. Next, H is assumed to propagate according to the inverse square law for the distances, Ra and Rb, from the accelerator source to P and from P to the door, respectively. H at the door then is the sum of the individual contributions from each of the n illuminated areas; that is,

$$H = \sum_{1}^{n} \frac{H_o}{Ra_n^2} \times \frac{A_n \, \alpha_{d_n}}{Rb_n^2} \qquad \text{Eq. 2}$$

where H_o is the dose equivalent at 1 meter from the source, A_n is the area of the nth shaded wall, and α_d is the dose albedo from Eq. 1 above.

Method 2 is one due to Kersey (3) which appears to be an empirical solution based on his measurements of several rooms. The details are given in Ref. 3; essentially he calculates neutron H using inverse squares at a mid-point in the maze which can 'see' the source, and then applies a maze attenuation based on the center line length of the maze and a value of 5 meters of maze length (irrespective of bends) to reduce H by a factor of 10. That is;

$$H = \frac{H_o}{Ra^2} e^{-Rb/2.17} \qquad \text{Eq. 3}$$

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where Ra and Rb are given in meters.

Method 3 is based on the "cookbook" approach of McCall, et al (4) and more exact calculations which show that most of the neutrons at a door have scattered from the wall directly opposite it. In essence, the number of neutrons entering a maze is calculated by the cookbook method. The area of the maze entrance is determined by the shaded wall (A' in Fig. 2), and a current albedo, α_c, from Fig. 7.9 of Ref. 4, is used. These reflected neutrons then are propagated down the maze according to inverse square, and the resulting current illuminates the cross sectional area at the end of the maze (A" in Fig. 2). The resulting fluence is then converted to dose equivalent. That is;

$$H = \frac{\Phi_o A'}{Ra'^2} \times \frac{\alpha_c A'' C}{Rb^2} \qquad \text{Eq. 4}$$

where Φ_o is the fluence at a meter from the source, C is the fluence-to-dose equivalent conversion factor and Ra' is the distance from source to maze entrance. From Ref. 4, the average energy of the scattered neutrons at the door is about 100 keV, which implies a value for C of 2.4×10^8 n/cm^2-rem.

Though there are many assumptions in the above three methods that are difficult to defend from a physics standpoint, they do give reasonable answers as shown in Table II where the results are compared with measurements. For overall accuracy, methods 1 and 3 would seem to be the best choices.

IMPROVING EXISTING MAZES

The simplest solution for improving an existing maze is to add shielding to a door. Neutrons at the door will be attenuated by polyethylene with a dose equivalent TVL of about 4 cm. The outer portion should be borated to capture thermal neutrons. However, this will have little effect on capture γ-rays which contributed about 1/3rd of the total dose outside the doors of the rooms in Fig. 1.

Another solution is to improve a maze. From measurements made at the door of Fig. 2, we have found that all components of H were proportional to the area of the maze entrance, i.e., C-D. Once an accelerator is installed, a maze entrance can be reduced in size by hand-stacked shielding to that necessary for bringing in patients.

A third solution is to add a second hydrogenous door in the maze. An example is shown in Fig. 2 where a 5 cm polyethylene door was added as an internal maze. This arrangement gave reductions in H to 0.12 for thermal plus fast neutrons and 0.36 for capture γ-rays for a total reduction in H to 19%.

Adding a door such that it extends the maze wall, but is illuminated by the source is only about 50% as effective as adding the door across the maze where it is shadowed from the source by the maze wall, such as the doors shown in Fig. 2.

REFERENCES

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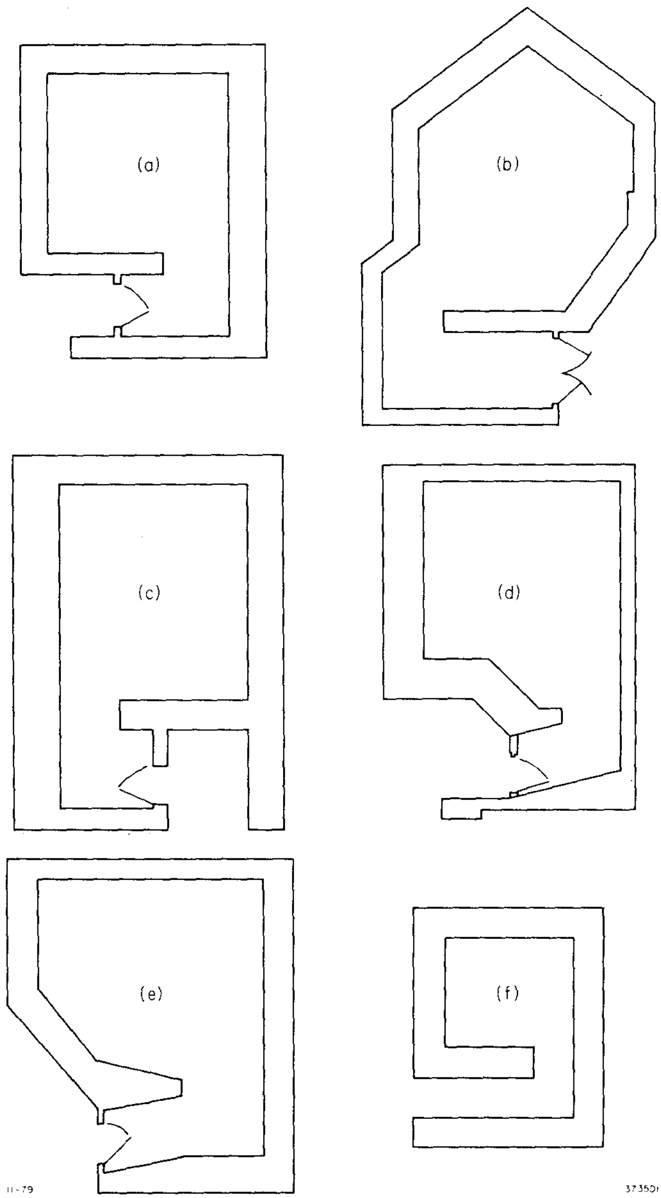

Fig. 1. Various rooms and mazes where measurements have been made.

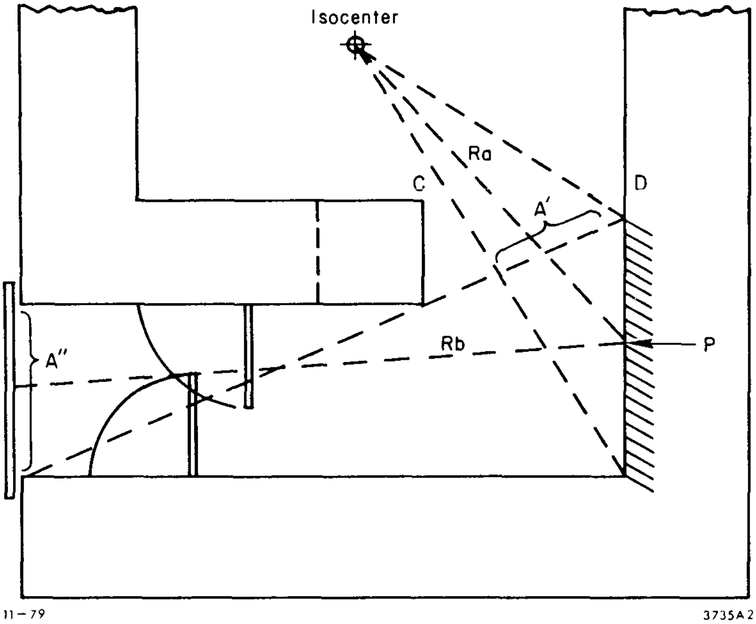

Fig. 2. Maze geometry showing various components described in text.

Table I. Measurements outside doors shown in Fig. 1.

	Dose Equivalent/Year Rem		(Work Load = 10^5 rads/week)	
Room	Thermal Neutrons	Fast Neutrons	Neutron Capture γ-rays	Total
1A	4.7	3.7	5.7	14.1
1B	1.0	2.5	Not Measured	3.5 + γ-ray
1C	1.8	2.3	1.4	5.7
1D	2.3	0.7	4.6	7.6
1E	1.4	1.4	1.5	4.3

Table II. Comparison of calculational methods and measurements.

		Calculated Neutron Dose Equivalent / Measured Neutron Dose Equivalent	
Room	Method 1	Method 2	Method 3
1A	0.68	2.0	0.97
1B	1.4	5.5	1.4
1C	0.94	1.6	0.97
1E	1.7	4.5	1.8
1F (Cf)	1.0	2.0	0.74
1F (Cf/W)	0.71	1.4	0.73