RADIATION SHIELDING FOR MEDICAL LINACS PRODUCING X RAYS OF 6 AND 15 MEV: COMPARISON OF CALCULATIONS WITH MEASUREMENTS

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Calculational models published by the U.S. National Council on Radiation Protection and Measurements (8,9) have been used to determine shielding design requirements. Calculation of x ray dose transmitted through a barrier makes use of measurements of "broad beam" transmission of x rays through various materials while transmitted neutron dose equivalent is based on calculations. For entry mazes, the model depends on empirically derived scattering coefficients.

We evaluated the accuracy of radiation shielding calculations for two medical linear accelerator facilities operating at 6 and 15 MV. We found a need for x ray transmission data for high density concrete, as well as a need to consider the primary and scattered photon energy spectra in dose estimations for scattered radiation.

Shielding design for the two facilities (Figs. 1 and 2) included consideration of unwanted neutrons produced by the 15 MV LINAC. Calculations were made to predict dose equivalent rates of x rays and neutrons at various points in the entry mazes and outside the shielding walls. Transmission of data for normal concrete shielding (8,9) was supplemented by transmission data for high density concrete (1,4,5). Radiation dose equivalent rates from both x rays and neutrons scattered in the entry mazes were estimated using published scattering coefficients (9).

The source terms for x ray dose rates were based on measured primary beam and leakage radiation, while neutron source data were taken from the literature (10). The primary x ray dose rate at 1 m from the target was:

For the 6 MV LINAC:

$$D = 2.25 \text{ Gy/min}$$

For the 15 MV LINAC:

$$D = 3.00 \text{ Gy/min}.$$

The source term for leakage x rays was based on measurements and was in the range of 0.05 to 0.1% of the primary beam dose rate at 1 m from the target. Transmission of leakage radiation was calculated in the same way as for the primary radiation which is likely to be an overestimate as Tochilin points out (11). The x ray transmission through walls as constructed with high density concrete (3.85 g/cm^3) was determined in two ways: 1) the wall thickness was converted to equivalent thickness of normal concrete (2.35 g/cm^3) using a ratio of the densities; 2) based on data presented by Maruyama (5) and Lokan (4).

The neutron fluence rate at 1 m from the 15 MV LINAC target was 4.4×10^5 /cm^{2}s. The average energy of neutrons emerging from medical LINACs of this type is estimated to be 0.3 MeV (7). We assumed that high density concrete was as effective as normal concrete in attenuating neutrons.

X ray dose rate measurements were performed using an ionization chamber survey meter with calibration traceable to the U.S. National Bureau of Standards. Neutron dose equivalent rates were measured using a remmeter of the Andersson-Braun (2) design which had been calibrated against a PuBe source of known intensity. In the areas surveyed, neither instrument was affected by the pulsed nature of the radiation field. Ionization chamber readings were corrected for the neutron response of the instrument.

Tables 1 and 2 present data from both calculations and measurements of the dose equivalent rates of x rays and neutrons at the points designated in Figs. 1 and 2. The transmission results (Table 1) indicate for x rays that better agreement is achieved if transmission data for high density concrete are used. Neutron dose equivalent rates outside the shielding walls were extremely low. Data are not presented, but calculations predicted higher dose equivalent rates than were measured.

TABLE 1
Comparison of Calculated and Measured Dose Equivalent Rates from Primary Photon Radiation Transmitted through Shielding Walls at Medical Linear Accelerator Facilities Operating at 6 and 15 MV.

Meas. Pt. **	Beam Direct	Calculated Dose Equiv. Rate (mSv/h)		Meas. Dose Equiv. Rate (mSv/h)
		Density Scaling	Refs. 4 and 5	
6 MV Photons				
D	North	0.037	0.009	0.008
E	North	0.039	0.011	0.015
F	South	0.026	0.007	0.008
G	South	0.015	0.004	0.006
15 MV Photons				
D	North	0.057	0.025	0.017
E	Up	0.0002	0.00008	<0.001
F	Up	0.0011	0.0007	<0.001

** measurement points refer to Figs. 1 and 2

Calculated dose equivalent rates from scattered radiation in the entry mazes were dominated by single scattered leakage and primary, and double scattered primary radiation. For the 6 MV room dose equivalent rates in the maze were overestimated, but were within a factor of two of the measured values (Table 2). For both x rays and neutrons in the entry maze of the 15 MV room, the dose equivalent rate was sometimes underestimated, but in general was within a factor of two of measured values (Table 2).

Uncertainty in the choice of scattering angle and photon energy when selecting scattering coefficients is one source of error in the calculations. The dose equivalent rate for x rays can be greatly underestimated if an inappropriately high energy is used since the scattering coefficients decrease rapidly with increasing energy. For the calculations presented in Table 2, we assumed an average energy of 2 MeV for the 6 MV beam. We tested this assumption by integrating the scattering over a published 6 MV x ray spectrum (3) and found that the calculated dose rate following the first scatter was within 5% of that calculated assuming an average energy of 2 MeV. When a second scatter was considered, we assumed an average energy of 0.25 MeV for once-scattered photons (6). Similarly, for the 15 MV beam, we assumed an energy of 5 MeV for primary photons and an energy of 0.3 MeV for the scattered photons (6). Also, there is an uncertainty of about a factor of two in the neutron source term for the 15 MV machine.

TABLE 2
Comparison of Calculated and Measured Dose Rates from Transmitted and Scattered Photon and Neutron Radiation in the Entry Maze of 6 and 15 MV Medical Linear Accelerator Facilities

		15 MV		6 MV	
Meas. Pt. **	Beam Direct	Calc. Dose Eq. Rate (mSv/h)	Meas. Dose Eq. Rate (mSv/h)	Calc. Dose Eq. Rate (mSv/h)	Meas. Dose Eq. Rate (mSv/h)
Photons					
A	North	0.42	0.12-0.85	0.48	0.35
A	South	0.08	0.10	4.32	3.50
A	Down	0.09	0.08	0.62	0.60
B	North	0.04	0.05	-	-
B	South	0.04	0.03	0.52	0.25
C	South	0.02	0.02	0.07	0.06
Neutrons					
A	North	0.18	0.40	-	-
A	South	0.30	0.60	-	-
B	North	0.03	0.06	-	-
C	North	0.01	0.01	-	-

** measurement points refer to Figs. 1 and 2

Uncertainties in the x ray dose rate measurements were less than 10%. Uncertainties in the measurements of neutron dose equivalent rates were probably of the order of a factor of two because of the energy dependence of the remmeter.

In summary, calculations used to predict transmitted x ray dose rates at medical LINAC facilities shielded with high density concrete generally agree with measurements within 50% when published transmission data for the appropriate high density concrete are used. Transmitted neutron dose equivalent rates seemed to be overestimated. Data from Adams and Lokan (1) indicate that high density concrete may be more than 10 times as effective as normal concrete for neutron attenuation, and this may account for the observation. The dose equivalent rates from scattered x rays and neutrons were, in general, predicted within a factor of two for both machines. Differences could result because of the assumptions made regarding the radiation energy, the scattering geometry and the source terms, as well as inaccuracies in the measurements.

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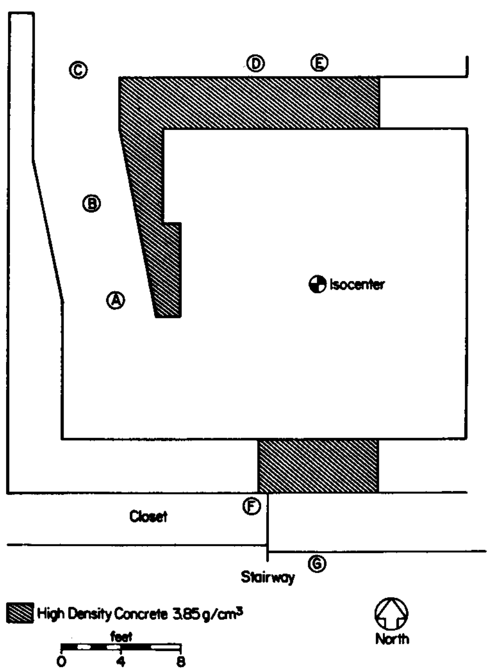

Fig. 1. Floor Plan of 6 MV Accelerator Room

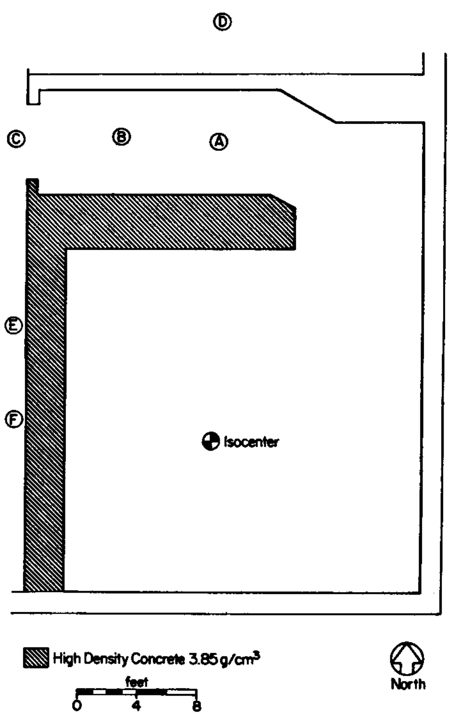

Fig. 2. Floor Plan of 15 MV Accelerator Room