APPLICATION OF THE MONTE CARLO METHOD TO ACCELERATOR SHIELDING ANALYSIS. A NEW ESTIMATION OF THE TENTH-VALUE THICKNESS FOR X-RAYS IN MEDICAL LINEAR ACCELERATORS.

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Abstract

In radiotherapy installations using accelerators it is very important to produce an accurate estimation of the shielding requirements to keep doses lower than limits. Shielding thickness is directly proportional to the tenth-value thickness, which can be obtained from curves recommended by the DIN-6847 standard and also estimated in terms of dose rates calculated for two different values of shielding thickness. In this work, the Monte Carlo method is applied to estimate the tenth-value thickness for X-rays in medical linear accelerators. Results are compared with older simulation data as well as with the values recommended by the DIN-6847 standard.

1 INTRODUCTION

Linear electron accelerators are widely used in radiotherapy installations. The importance of an accurate estimation of the doses that can be received by health workers, patients or public, as well as shielding requirements to reduce doses below established limits is obvious. On the other hand, lower dose limits were recommended in ICRP 60 [1]. According to those recommendations a Directive has been recently issued by the European Community to state a regulatory position to be followed by member states. Therefore, it may be necessary to re-evaluate safety parameters concerning medical installations using accelerators [2].

Two standards, NCRP-51 [3] and DIN-6847 [4], can be used to estimate shielding requirements in those installations. They were comparatively analysed in former works [2, 5]. The interest was focused on the estimation of the tenth-value thickness for X-rays produced in medical electron accelerators. MCNP code [6, 7] based on the Monte Carlo method was and has been again applied to perform this estimation.

2 SHIELDING ANALYSIS

In DIN-6847 standard [4], the shielding thickness is given by the following expression:

$$s_i = z_i \log_{10}\left(\frac{W_A\ U\ T K_i\ q_i}{H_w}\right) \quad (1)$$

where, s_i is the shielding thickness for the ith radiation, referring to electrons, X-rays (primary, secondary, leakage) or neutrons (primary and scattered beam); z_i is the tenth-value thickness; W_A is the weekly workload at the reference distance of a_0 meters (Gy/week); U is the use factor; T is the occupancy factor; K_i is the reduction factor; q_i is the quality factor; and H_w is the weekly equivalent dose.

For primary X-ray beam, $q_i = 1$ and the reduction factor is given by:

$$K = \frac{a_0^2}{a_n^2} \quad (2)$$

where, a_0 is the reference distance (1 m) and a_n is the distance (m) from the source to the point beyond the shielding where the dose is measured.

The tenth-value thickness, $z_i = z_r$, depending on the shielding material can be obtained from curves recommended by DIN-6847 that are reproduced in Figure 1. It can be noted that the same curve is used for aluminium and concrete, and also for iron and copper.

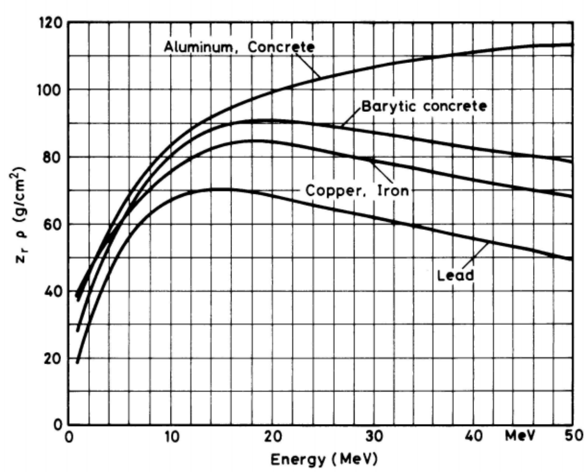

Fig. 1 Mass tenth-value thickness for X-rays.

The following expression for the equivalent dose rate H_w can be obtained from eq. (1) and (2):

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$$H_w = \frac{C}{a_n^2} \left(\frac{1}{10} \right)^{\frac{s}{z}} \tag{3}$$

where C includes all terms depending on the installation and radiation involved. MCNP code was used with a lineal spectrum taken from Chilton [8], to calculate doses for shielding thickness from 0 up to 130 cm. The correlation coefficient between $\log(H_w\ a_n^2)$ and s was calculated to verify that they are linearly related [9, 10].

Therefore, the tenth-value thickness can be estimated in terms of the dose rates calculated for two different values of shielding thickness and related distances, as follows:

$$z = - \frac{s_2 - s_1}{\log_{10} \dfrac{H_{2w}\ a_2^2}{H_{1w}\ a_1^2}} \tag{4}$$

3 RESULTS AND COMPARISON

MCNP code has been run to determine doses at distances considered, for various energy values from 0.5 up to 50 MeV and the materials of interest: aluminium, concrete, barytic concrete, iron, copper and lead.

The photon source was a point, isotropic, and monoenergetic, with all the particles being emitted inside a small solid angle to avoid the leakage radiation. Surface counters were placed in maximal dose zones. Cell importance was the only variance reduction technique applied, due to geometric features of the problem and the type of counters used.

Shielding thickness values have been taken in such a way that for each energy the doses obtained differ by at least an order of magnitude.

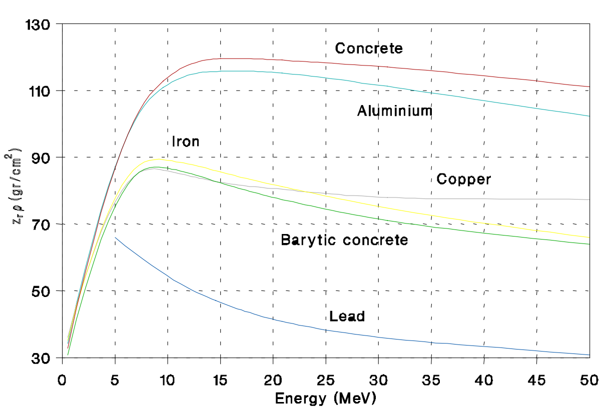

Fig. 2. Results from MCNP 3.2.

The first approach was done using the version 3.2 of MCNP [6]. Results were presented at PAC'93 [9] and MEDICAL PHYSICS 93 [10].

Results for direct radiation are shown in Figure 2. Comparing this figure with Figure 1, one can see that values obtained by MCNP match reasonably with those from DIN-6847 except for lead. At the lowest energy (0.5 MeV) the Monte Carlo values are slightly lower than the DIN ones, whereas for higher values of energy they are higher: always for concrete, up to 40 MeV for aluminium, up to 10 MeV for barytic concrete, and up to 15 MeV for iron and copper. For the rest of energy values, the Monte Carlo obtained values are only slightly lower.

The highest discrepancies were shown for lead. The version 3.2 of MCNP code did not include the transport of photoelectrons, Compton electrons and electron-positron pairs. At higher energies these electrons collide with hard atomic nuclei producing electromagnetic radiation (Bremsstrahlung). These phenomena become more evident in lead. Therefore, results from MCNP 3.2 shall be discarded for lead.

DIN-6847 is less conservative for direct radiation than expected, as it was discussed by authors in an early paper [11] comparing tenth-value thickness from DIN-6847 with those from NCRP-49 [12] for concrete, up to 10 MeV.

On the other hand, the curves obtained for concrete and aluminium are very similar. Furthermore the calculated curves not only for iron and copper but also for barytic concrete are very similar too.

The results would have been in better agreement if we had considered a continuous spectrum rather than a monoenergetic source, but unfortunately these data were not available from the manufacturers.

MCNP determines errors for each calculated dose. With these data a statistical analysis has been performed to prove that results are significant, practically at 100% for relative error of 5%.

Calculations have been repeated with MCNP 4A [7] using the same methodology, materials, and model [13]. MCNP can provide dose conversion factors up to 15 MeV. For higher energies an extrapolation was necessary. However, in latter calculations dose conversion factors from Jaeger [14] have been used, improving results for higher energies, even for MCNP 3.2. Therefore, some calculations were also repeated using version 3.2, in those cases where dose conversion factors have been modified. Anyway it would be convenient to dispose of more appropriate dose conversion factors.

Results obtained from MCNP 4A calculations are represented in Figure 3. As electron transport has been incorporated to the code, all phenomena formerly omitted are now taken into account, so results are quite improved not only for lead but also for the rest of materials, especially at higher energies.

Comparing the three figures some comments can be done. For aluminium it can be noted that estimated values (MCNP 4A) are more conservative than DIN ones. Both curves have a similar shape. The 4A approach is better than that of 3.2. A similar statement can be made for concrete. For barytic concrete the behaviour is slightly differ-

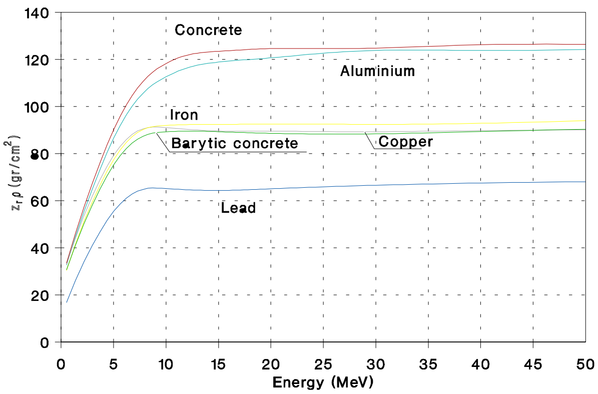

Figure 3: Results from MCNP 4A

ent in the 3 curves. Discrepancies between 4A and DIN are lower in general. For iron and copper the curves obtained from MCNP 3.2 agree better with DIN than those from MCNP 4A. Maybe it is due to the shielding thickness adopted for calculations. For lead, results have been fairly enhanced with respect to MCNP 3.2, which were not considered valid in former calculations. However they are not yet satisfactory, as its behaviour is similar to iron and copper for energies higher than 15 MeV, where the curves have opposite slope values. This difference can be due to dose conversion factors used.

4 CONCLUSIONS

Two versions of MCNP (3.2 and 4A) based on the Monte Carlo method have been used to estimate the tenth-value thickness for X-ray direct beams in medical electron accelerators. Results have been compared between the calculations and with values recommended by the DIN-6847 standard.

It has been verified for primary radiation that without significant errors the same curve may be used for different materials, in particular for concrete and aluminium and for barytic concrete, iron and copper, respectively, though "a priori" it did not appear very logical.

It is not easy to perform experimental dose measurements, in particular in a linear accelerator, so it turns out the importance of simulation methods. Anyway, the comparison between experimental measurements and simulation results is always welcome.

Since the primary beam spectrum in an accelerator is generally unknown, a monoenergetic source has been considered. Next developments will include the estimation of the tenth-value thickness using an actual X-ray spectrum for the accelerator. As well, calculations should be repeated using further versions of MCNP.

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