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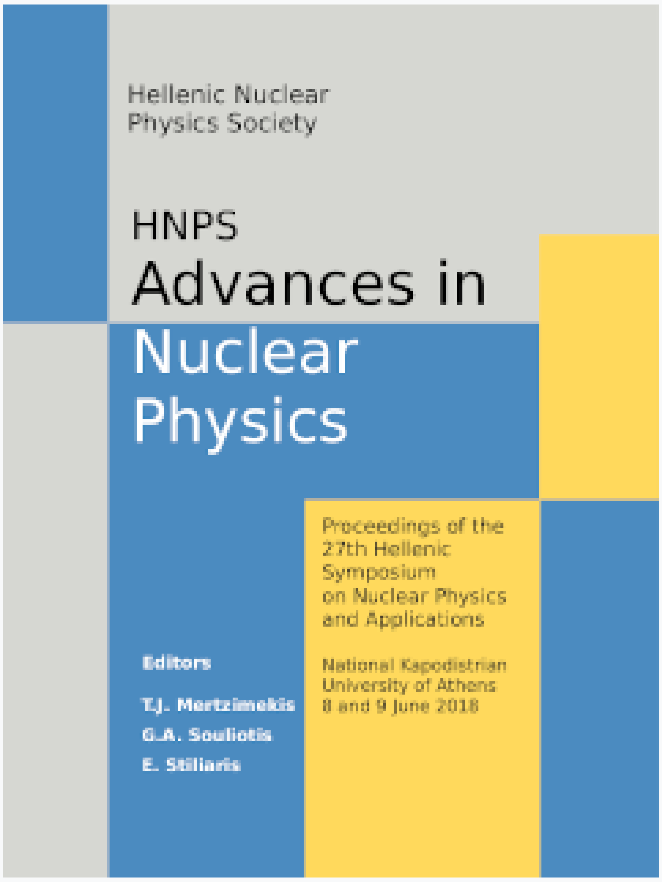

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Evaluation of neutron fluence in the treatment room and along the maze of an 18 MV linear accelerator

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Abstract Neutron fluence and dose equivalent rate in the treatment room and along the maze of an 18 MV medical linear accelerator was evaluated using Monte Carlo code MCNP5. Scope of the study was to test the hypothesis that a simple accelerator head model can adequately estimate the neutron fluence in the treatment room and along the maze without the requirement of a detailed modeling of the complex accelerator head configuration. The accelerator head was modeled either as a spherical cell source of 10 cm in radius or as a point source in the centre of a spherical cell of 10 cm internal and 20 cm external radious, both made of tungsten. The calculations were compared against measurements performed using gold and indium activation foils. A good agreement between calculated and experimental results was observed in the treatment room. However, the calculations at the maze entrance overestimated the neutron fluence by a factor of 3. The results of the study contribute towards the development of a simple and computationally cost effective methodology for the calculation of neutron dose in the treatment room and the maze of high energy medical accelerators providing a representative simulation of the complex accelerator, bunker and maze configurations that cannot be described by presently used analytical expressions.

Keywords neutron dosimetry, radiation therapy, radiation shielding design

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INTRODUCTION

High energy linear accelerators produce neutrons mainly through (γ,n) interactions of photons with high atomic number nuclei of materials that constitute the linear accelerator head and beam collimation system, such as target, flattening filter, primary collimators, jaws and head shielding. In medical linear accelerators, these neutrons increase the out-of-field radiation dose of patients undergoing radiation therapy and have to be taken into consideration in the shielding design of the treatment room and maze configuration as well [1, 2].

Scope of the study was to test the hypothesis that a simple accelerator head model can adequately be used to estimate the neutron fluence in the treatment room and along the maze of a high energy medical accelerator without the requiment of detailed modeling of the very complex accelerator head configuration. For this purpose, neutron fluence in the treatment room and along the maze of an 18 MV medical linear accelerator was evaluated using Monte Carlo code MCNP5. The results of the calculations were compared against measurements performed using indium and gold activation foils.

EXPERIMENTAL

Irradiations were performed using an ELEKTA SYNERGY 18 MV accelerator at Saint Savvas Hospital, Athens. Neutron fluence measurements were performed using sets of indium and gold foils positioned within plexiglass ($C_5H_8O_2$, density of 1,18 gr/cm^3) moderators of cubical shape with edge length of 10 cm. The nuclear reactions used, the product nuclide half-time, the energy of the emitted gamma rays and their abundance are shown in Table 1. The detectors were positioned at several locations within the treatment room and along the maze at a height of 100 cm from the bunker floor. During the irradiation the accelerator jaws were closed (beam area 0 cm x 0 cm). The door of the bunker was closed.

Table 1. Activation foil characteristics

Element	Nuclear reaction	$T_{1/2}$ (h)	Energy (keV)	Iγ (gammas/decay)
Au	^{197}Au (n, γ)^{198}Au	64,56	411,8	0,955
In	^{115}In (n, γ)^{116m}In	0,9	416,9	0,292
			818,7	0,115
			1097,3	0,562
			1293,5	0,844

Gamma measurements were performed using a germanium detector based spectrometry system of 85% relative efficiency and FWHM of 1.82 keV at 1332.5 keV. This system consists of a shielded coaxial germanium detector (EG & G ORTEC), a digital signal and data acquisition system (DSPEC™) and a support bracket for sample positioning during measurement. Spectrum analysis was performed using the Gamma-Vision™ software. The detector was calibrated with respect to energy and full energy peak efficiency using a set of standard sources.

SIMULATIONS

Simulations were performed using Monte Carlo code MCNP5 [3]. The bunker and maze configuration, as well as the moderator and foils were modeled in detail (Fig. 1). However, the linear accelerator head was simulated to be composed of tungsten using two simplified geometries. Firstly, as a uniform spherical source of tungsten of 10 cm in radius [1]. Secondly, as a point source in the centre of a spherical cell composed of tungsten of 10 cm inner and 20 cm external diameter [2]. Their centres were positioned at the centre of the accelerator target at 224 cm floor to taget height. This approach simplified the complex geometry of the accelerator head and therefore decreased significantly the computational time required in order to obtain statistically meaninfull results.

The neutron energy spectrum at the source was assumed to be represented by the relationship proposed by Tosi et al [4]:

$$n(E) = \alpha \frac{E}{T^2} \exp\left(-\frac{E}{T}\right) + \beta \frac{\ln\left|\frac{E_{max}}{E+S_n}\right|}{\int_0^{E_{max}-S_n} \ln\left|\frac{E_{max}}{E+S_n}\right| dE} \qquad (1)$$

where α, represents the fraction of evaporation neutrons (α=0.8929), β represents the fraction of knock-on neutrons (β=0.1071), T is the temperature of the taget nuclei (T=0.5 MeV) , E_{max} is the maximum energy of the accelerated electrons (E=18 MeV) and S_n is the neutron binding energy (S_n=7.34 MeV for tungsten).

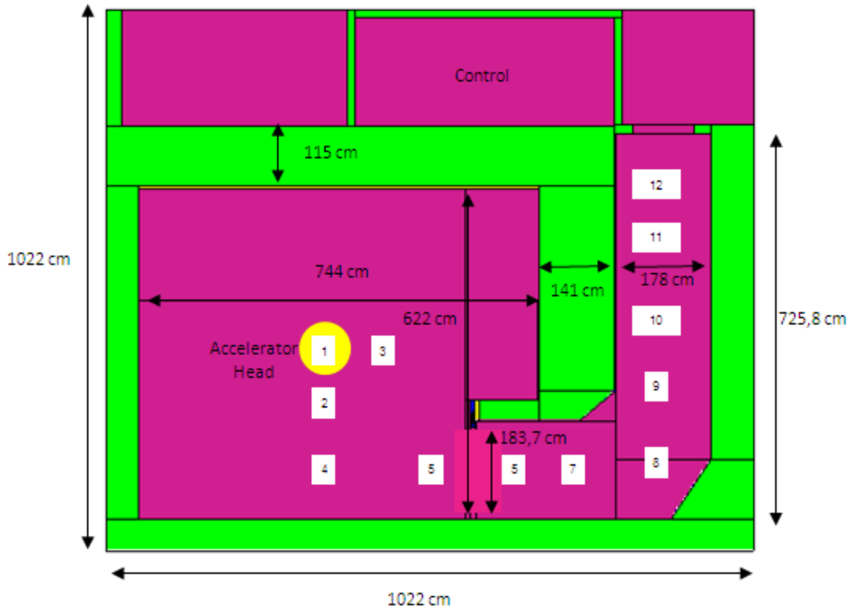

Fig. 1 Accelerator bunker geometry

Calculations were performed to derive neutron fluence at different positions within the treatment room and along the entrance maze shown in Fig. 1. To calculate the response of the activation foils, simulations were performed in two stages. In the first stage, the neutron fluence incident on a sphere of 10 cm in radius surrounding each moderator-foil assembly was calculated. Then, the calculated incident neutron fluence was used as input surface source to derive the response of the foil. Simulations were performed using data from the ENDF/B-VI and IRDFF v.1.05 cross section data library packages.

RESULTS AND DISCUSION

Figures 2 shows a comparison of the calculated and experimentally derived neutron fluence at various positions within the treatment room and along the maze using gold and indium foils. The values are normalized at the isocenter per source neutron. Very good agreement was observed between calculated and experimental results in the treatment room.

However, the calculations along the maze overestimated fluence. The overestimation at the maze entrance level was by a factor of three. Moreover, the two tested source models provided similar results both in the treatment room and at the maze.

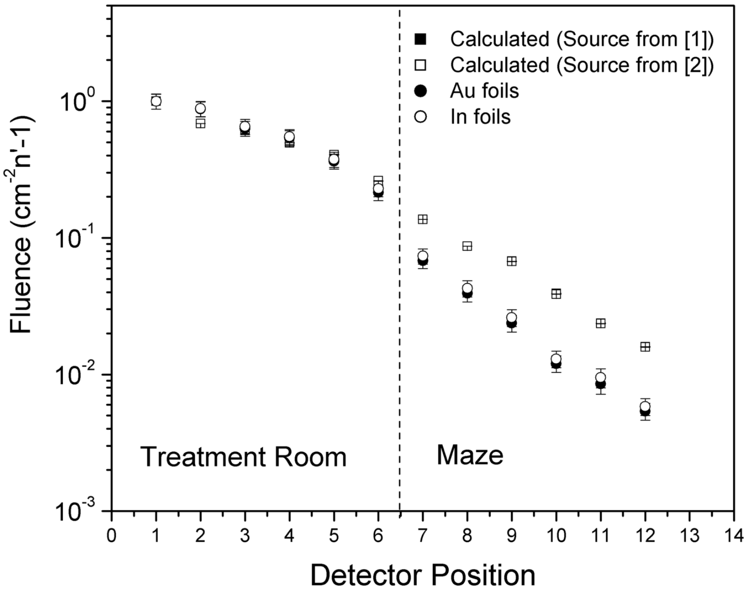

Fig. 2 Comparison of calculated and experimentally determined neutron fluence for different positions in the treatment room and along the maze. Normalization per source neutron.

The results of the study normalized to neutron fluence measurements performed at the accelerator isocenter [5] provide a simple and computationally cost effective methodology for the calculation of neutron dose in the treatment room and the maze of high energy medical accelerators providing a representative simulation of the complex accelerator, bunker and maze configurations that cannot be described by presently used analytical expressions.

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