MONTE CARLO SIMULATION OF THE TOTAL DOSE DISTRIBUTION AROUND THE 12 MEV UPC RACE-TRACK MICROTRON AND RADIATION SHIELDING CALCULATIONS*

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Abstract

The Technical University of Catalonia is building a miniature 12 MeV electron race-track microtron for medical applications. In the paper we study the leakage radiation caused by beam losses inside the accelerator head, as well as the bremsstrahlung radiation produced by the primary beam in the commissioning setting. Results of Monte Carlo simulations using the PENELOPE code are presented and two shielding schemes, global and local, are studied. The obtained shielding parameters are compared with estimates based on DIN 6847 part 2 as international recommendation of the radiation safety standards.

INTRODUCTION

The Technical University of Catalonia (UPC) in collaboration with the Skobeltsyn Institute of Nuclear Physics (SINP) of the Moscow State University and CIEMAT (Madrid) is building a race-track microtron (RTM) whose main envisaged application is Intraoperative Radiation Therapy [1].

A schematic view of the RTM main unit is given in Fig. 1. It consists of an electron gun (1), linac (2) with four accelerating and three coupling cavities, end magnets (3, 4) and a horizontally focusing quadrupole (5). These elements are precisely fixed on a common rigid platform placed inside a steel box which plays the role of the vacuum chamber. The beam can be extracted from any of the four orbits with extraction magnets (6) and exits the microtron along the output trajectory (7). The main RTM parameters are listed in Table 1.

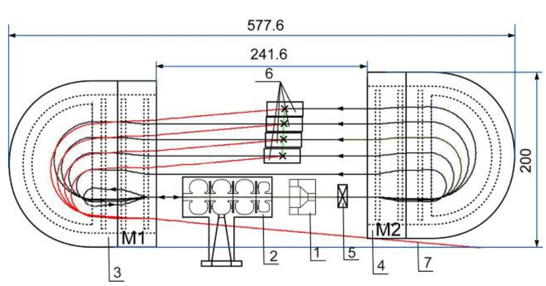

Figure 1: RTM scheme

During RTM operation, the bremsstrahlung radiation is generated by the primary beam hitting a target (detector in case of commissioning and patient during the medical treatment). Also the leakage radiation is produced inside the accelerator head by the recirculating beam impinging internal parts of the accelerator. For a safe operation of the machine the radiation level must be reduced to the allowed one by appropriate shielding. For the design of the shielding one has to know a detailed spatial distribution of the generated radiation.

In the present paper we consider the regime of beam tests and commissioning and study two shielding schemes, namely a global shielding of the accelerator hall and a local one by means of a lead chamber.

Table 1: RTM Parameters

Parameter	Value
Beam energies	6, 8, 10, 12 MeV
Operating frequency	5712 MHz
Synchronous energy gain	2 MeV
Average beam current	1 μA
Beam diameter at the exit	4 mm
Operation time	2000 hours/year
RTM head dimensions	670×250×210 mm

The radiation production and transport calculations and the shielding design have been carried out by means of Monte Carlo simulations using PENELOPE code [2], the results are compared with estimates based on DIN 6847 (part 2) standard [3].

BEAM LOSSES MODEL

An estimate of beam losses inside the accelerator head has been obtained from simulations of beam recirculation inside the accelerator head performed with the RTMTRACE code [4]. To reduce the beam losses at higher orbits it is proposed to place a narrow aluminium collimator at the 4 MeV orbit at the exit of end magnet M2 (see Fig. 1). According to the simulations the main beam losses take place at the entrance of the 2 MeV beam into the linac after the beam reflection in M1 end magnet and at the collimator. In case of normal operation the radiation caused by beam losses at the higher orbits is insignificant.

Therefore, in the PENELOPE simulations two targets modelling beam losses and leakage radiation generation have been considered:

- Target 1: linac front end which absorbs a part of the 2 MeV beam,
- Target 2: an aluminium plate modelling the collimator placed at the face of the end magnet M2 at the exit of the 4 MeV orbit.

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In the dynamics simulations with RTMTRACE also the loss coefficients α_n, defined as a fraction of the injection current lost at a given target, have been calculated. They are given in Table 2 together with the current losses at each target provided the final output current I_{out}= 1 µA.

Table 2: Loss Coefficients and Current Losses (I_{out}= 1 µA)

	α_n	I_{loss} (µA)
Target 1	0.182	1.59
Target 2	0.041	0.35

The bremsstrahlung radiation produced at targets 1 and 2 before exiting the accelerator head interacts with various parts of the RTM. To simulate the dose distribution around the accelerator head we considered a simplified model, shown in Fig. 2, which includes a copper cylinder modelling the linac, two steel blocks of a certain shape modelling the end magnets and vacuum chamber stainless steel walls with a hole covered by a disc modelling the waveguide feeding the linac.

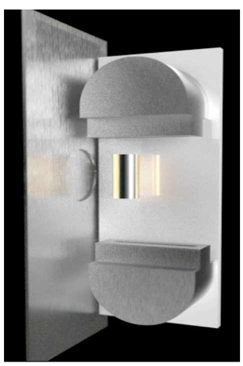

Figure 2: Simplified model of the RTM head.

SIMULATION RESULTS AND SHIELDING DESIGN

It is assumed that the primary electron beam of 12 MeV is directed downwards and hits a Faraday cup which is modeled by an aluminium cylinder in the simulations. The envisaged accelerator hall is a room of dimensions 6.4 x 7.4 x 3.0 m approximately with the RTM being situated in the centre. The parameters used in the simulations are: use factor U=1 for lateral walls and ceiling, occupancy factor T=0.1 for the walls and T=1 for ceiling. The working load is calculated for 2000 hours of RTM operation per year. All the rooms around the accelerator hall were considered as a zone of public access, therefore the dose rate limit of 1 mSv/year established by the Spanish regulations was applied.

By performing Monte Carlo simulations with the PENELOPE code we have found the dose rate distributions due to the secondary radiation generated by the primary beam at the detector and the leakage radiation produced at targets 1 and 2 both without shielding and for the two shielding schemes: (1) shielding of the walls of the accelerator hall with concrete, (2) local shielding by means of a cylindrical lead chamber enclosing the RTM head (see a sketch in Fig. 3). The dose rate is determined at points behind the accelerator hall walls or ceiling for both schemes. However, in the case of the local shielding only the dose attenuation by the lead walls of the chamber are taken into account and the effect of the hall walls is neglected.

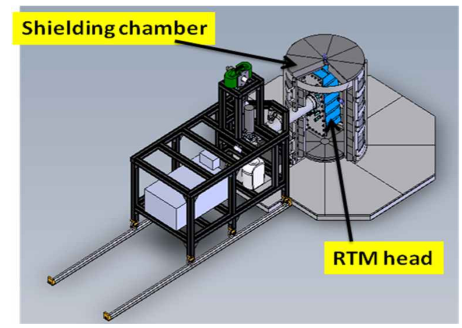

Figure 3: Local shielding scheme.

As an example the dose rate map for the secondary radiation in the horizontal direction at a distance 3.2 m from the source is shown in Fig. 4.

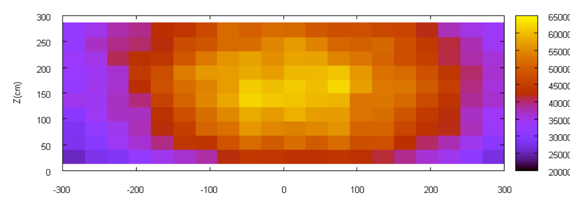

Figure 4: Equivalent dose H*(10) [mSv/year] for the secondary radiation in the horizontal direction at a distance 3.2 m from the source without shielding.

Figure 5 shows the dose rate map for the total leakage radiation going from the internal targets upwards at a distance of 3.0 m from the source. We have obtained that the dose rate produced by the secondary radiation is always higher than that due to the leakage radiation.

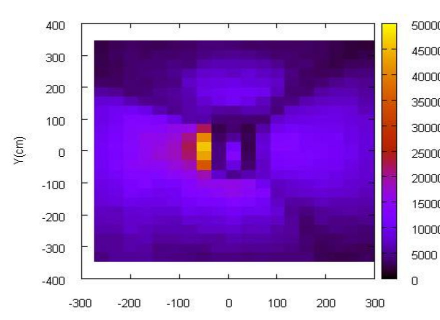

Figure 5: Equivalent dose H*(10) [mSv/year] for the leakage radiation going upwards at a distance 3.0 m from the source without shielding.

Using the results on the specific distribution of the radiation produced by the RTM and the primary beam we have simulated the depth dose rate curves for various shielding elements of the schemes under consideration which allow to obtain the shield thickness. An example of such curve for the local shielding chamber is given in Fig. 6. One can see that the first and second tenth-value layers, TVL_1 and TVL_2, are considerably thinner than the equilibrium TVL.

From the depth dose rate curves, like in Fig. 6 and similar ones for the leakage radiation (see example in Fig. 7) or, if necessary, from their linear extrapolations, we have determined the thickness of the shielding material for the two schemes under consideration which reduce the dose rate down to the allowed limit of 1 mSv/year. The results are given in Table 3. For the output beam current 1 μA the thickness of the walls of the local shielding chamber ascends to 19 cm. In order to avoid structural problems it was decided that during the RTM tests and commissioning the beam current will be 0.1 μA.

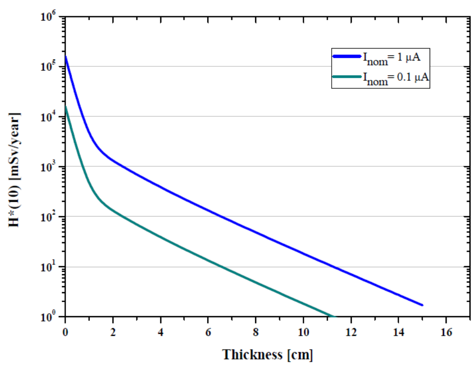

Figure 6: The dose rate of the secondary radiation at the ceiling as a function of the thickness of the local lead shielding for two values of the output beam current.

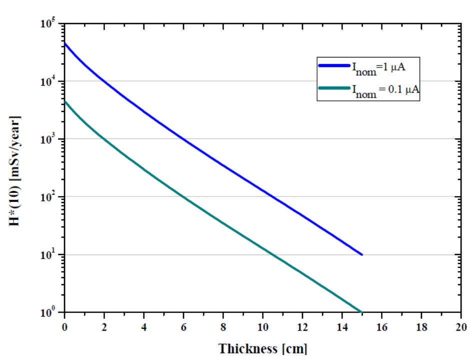

Figure 7: The dose rate of the target 2 leakage radiation at the ceiling as a function of the thickness of the local lead shielding for two values of the output beam current.

We have also made estimates of the shielding material thickness using the DIN-6847 standard (see Table 3). The values are close to those obtained by simulations. The difference is mainly due to a difference between the TVLs for 12 MeV beam obtained in our study and the one recommended by DIN-6847. Similar difference was observed in the comparison of DIN-6847 with results of simulations obtained with MCNP code [5].

We have checked that for the values of the beam current considered here the contribution to the dose from neutrons is quite low and is absorbed by the proposed shielding.

Table 3: Thickness of the Walls for the Global and Local Shielding Schemes

	Concrete shielding of the accelerator hall, I_{nom} = 1 μA		**Lead shielding chamber I_{nom} = 0.1 μA**
	Walls	Ceiling	Walls and cover
PENELOPE	95 cm	123 cm	15 cm
DIN-6847	79 cm	127 cm	18 cm

CONCLUSIONS

We have calculated the distribution of the radiation produced during the tests and commissioning of the 12 MeV UPC RTM, studied two schemes of radiation protection against this radiation and determined the shielding parameters. These results were obtained by Monte Carlo simulations with the PENELOPE code and are roughly in agreement with estimates based on DIN-6847 standard. We checked that the neutron contribution to the dose does not require any additional shielding.

ACKNOWLEDGEMENTS

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