A PROTON THERAPY TEST FACILITY: THE RADIATION PROTECTION DESIGN

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Abstract

A proton therapy test facility with a beam current lower than 10 nA in average, and an energy up to 85 MeV, has to be sited at the Frascati ENEA Research Center, in Italy. The accelerator is composed by a sequence of linear sections. From the radiation protection point of view the source of radiation for this facility is almost completely located at the final target. Physical and geometrical models of the device have been developed and implemented into a radiation transport computer code based on Monte Carlo method. The main scope is the assessment of the dose rates around the radiation source for supporting the safety analysis. For the assessment was used the FLUKA (FLUktuierende KAskade) computer code [1, 2]. A general purpose tool for the calculation of particle transport and interaction with matter, covering an extended range of applications including proton beam analysis. The models implemented into the code are described and the results are presented. The calculated dose rates are reported at different distances from the target. Considerations about personnel safety are issued and the shielding requirements are anticipated.

INTRODUCTION

The TOP-IMPLART project [3, 4] is starting at the Frascati ENEA Research Centre with the aim of realizing an innovative proton therapy facility. It is is based on the use of a linear proton accelerator for producing the beam, throughout a series of modular components. TOP-IMPLART are the acronym of "Terapia Oncologica con Protoni" (Oncological Therapy with Protons) and "Intensity Modulated Proton Linear Accelerator for Therapy". The accelerator constitutes the main peculiar characteristic of this design, it is a linear accelerator, or, better to say, a sequence of linear accelerators.

The project is aimed to develop a proton irradiation facility that could be devoted to different applications taking advantage of the modular nature of the linear accelerators. Using a linear machine instead of a compact circular accelerator (synchrotrons and cyclotrons) permits the possibility to proceed by steps in the construction and operation process and makes it possible the combined use of different irradiation stations at various energies between the minimum (about 7 MeV) and the maximum (about 250 MeV). The first 7 MeV module of the accelerator, is already installed and has been tested. Additional modules will be added to the injector leading proton energy to 30, 70 and 150 MeV in a step by step project.

The present study is finalized to the neutron field analysis for the radiation protection of the workers involved in the testing activities of the linear accelerator, with a final proton energy of 85 MeV. The main irradiation model considers the proton beam hitting a human-like phantom target. The study has been performed using Fluka code, a powerful computer program based on the Monte Carlo method, implemented to simulate the experimental setup in order to evaluate the neutron field parameters.

The linear accelerator has a particular shape if compared to cyclotrons and synchrotrons. It can be easily housed in the long, narrow tunnel, while the RF plants are in a parallel technical room, in such a way that the accelerator occupies practically the same area reserved for the beam transport lines in other types of accelerator.

In the final layout the bunker will be 30 m long and 3 m wide. The TOP-IMPLART hall is part of a building that hosts other four smaller accelerators. The actual site will allow testing the proton beam and the scanning system together up to 115 MeV and the beam alone up to 150 MeV.

The shielding walls are composed by blocks made of ordinary concrete originally used for the walls of the hall that housed the 1 GeV Frascati electron synchrotron, probably the first high energy particle accelerator established in Italy.

SIMULATION MODEL

The 7 MeV injector is already running at ENEA-Frascati, where the project foresees the installation and tests of the whole accelerator up to 150 MeV.

The model presented here has been developed to simulate a 85 MeV proton beam, with an intensity of 6,242E+10 protons/s, hitting a water phantom (50x30x20 cm^3) located in front to the kapton membrane, 50 μm thick, that seals the vacuum chamber of the accelerator. Between the kapton membrane and the phantom there is a 15 cm air-gap. The cross section of the proton beam reaching the kapton membrane has the maximum dimension of 7 mm (in x and y directions) and 10^7 particle stories were used in the Monte Carlo runs.

The main losses during the acceleration process occur below 20 MeV, where the neutron production is very low and the proton range is short and completely included in the accelerator structures. This is the main reason for restricting the simulation model to the final section of the accelerator, where the major radiation diffusion occurs, granting a conservative approach to the radiological risk assessment.

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The calculation model includes the following main sections:

- Final segment of the accelerating section;
- Target (water phantom);
- Shielding walls.

In tables 1 and 2 the main geometrical parameters entered in the code input are shown.

Table 1: Bunker Walls in the Simulation

Shielding	**Material**	**Thickness [cm]**
Ceiling	Concrete	50.00
Beam side walls	Concrete	100.00
Wall in front of beam	Concrete	150.00
Wall opposite to beam	Concrete	100.00
Floor	Iron	4.00

Table 2: Beam and Target Position

Parameter	**Distance [cm]**
Upstream-in-wall to upstream-injector	42.32
Kapton to target-upstream-surface	15.00
Target-center to downstream-inner-wall	325.00
kapton to downstream-inner-wall	350.00

RESULTS

The following main results were obtained:

- Proton fluence inside the bunker, inside the shielding and outside the bunker;
- All particles dose-equivalent inside the bunker, inside the shielding and outside the bunker;
- Neutron dose-equivalent inside the bunker, inside the shielding and outside the bunker;
- Neutron spectrum in air;
- Neutron spectra with respect to the boundary crossing surface target-air;
- Angular distribution of the neutron spectra with respect to the beam axes.

Several secondaries are generated in the inelastic interactions of the beam protons with the water-target.

In table 3 are reported the secondaries produced in the FLUKA model per beam particle. The list provided by the code points out that the higher number of secondary particles generated in prompt radiation is that of the alpha particles, that are not an issue for the radiation protection, due to their low penetration power. In the prompt radiation inventory we have also important amounts of protons, photons and neutrons, the latter being the most concern from the radiation protection point of view: the neutron-intensity of the proton source is about 3.2E-02 neutron per primary.

Table 3: Produced Secondaries per Beam Particles

Secondary	**Prompt radiation**	**Radioactive decays**
Total	2.4206E-01 (100.%)	5.5455E-02 (100.%)
4-Helium	6.6030E-02 (27.3%)	1.9600E-04 (0.4%)
3-Helium	1.7110E-03 (0.7%)	-
Triton	8.3490E-04 (0.3%)	-
Deuteron	3.9485E-03 (1.6%)	-
Proton	9.9327E-02 (41.0%)	-
Electron	-	1.1708E-02 (21.1%)
Positron	-	1.7409E-02 (31.4%)
Neutrie	-	1.7409E-02 (31.4%)
Aneutrie	-	6.7307E-03 (12.1%)
Photon	3.7609E-02 (15.5%)	2.0024E-03 (3.6%)
Neutron	3.2603E-02 (13.5%)	-

Figure 1 shows the all-particles dose-equivalent in Y projection. This result is the most important for the assessment of workers and population safety during the accelerator working phase. In the figures the shielding effect is manifest and the related discussion will be presented in the conclusions of the paper. The computer calculation result has been compared with literature data [5, 6, 7] showing a substantial agreement, at least for the order of magnitude.

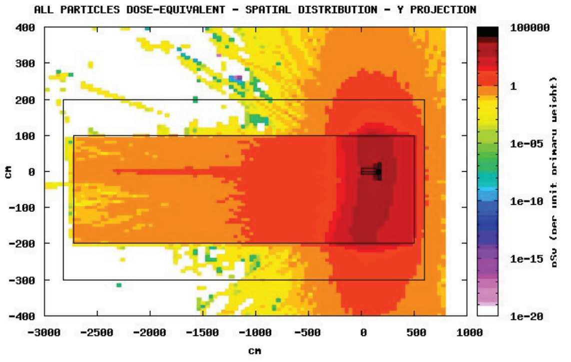

Figure 1: spatial distribution of the all-particles dose-equivalent-rate (pSv) in Y projection.

Figure 2 shows the result of the dose-equivalent spatial distribution for the neutrons, the most hazardous radiation from the radiation protection point of view.

CONCLUSION

FLUKA provides a complete output in term of graphical detail and can be installed on a pc with Linux system.

The TOP-IMPLART section that will be tested at the Frascati ENEA Centre will provide important information on the accelerator characteristics and related safety that will address the design of the whole TOP-IMPLART facility in its final destination.

The current work describes the analysis of the dose rate and of the related radiation protection aspects mainly due to the neutron field produced by the 85 MeV proton beam provided by the accelerating sections housed in the testing facility.

The computer code used in the simulation showed a wide flexibility in defining the physical model and was suitable to produce a large variety of results. As a further example in figure 3 is shown the neutron spectra in air with respect to the beam direction as provided by FLUKA code.

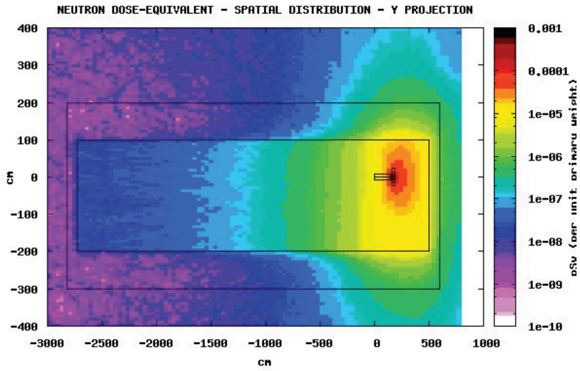

Figure 2: spatial distribution of the neutrons dose-equivalent (pSv) in Y projection.

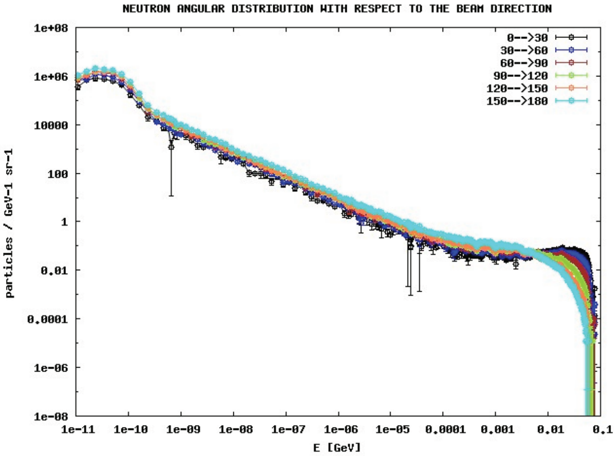

Figure 3: neutron spectra in air with respect to the beam direction.

The result obtained with FLUKA simulation shows that the designed shielding walls and structures are effective in reducing the dose rate at a level consistent with the local law limits, and that the actual size of the shielding will allow for a further reduction in the dose rate levels according to the optimization principle.

Comparison with experimental results published in the reference documents and guides related to similar accelerating facilities showed an acceptable agreement.

With the designed layout and the shielding assessed in the calculation workers protection is guaranteed. No safety issues are foreseen for the people working or living in the vicinity of the facility.

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