A PROTON THERAPY TEST FACILITY: THE RADIATION PROTECTION DESIGN

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Abstract

A proton therapy test facility is planned to be sited in the Frascati ENEA Research Center, in Italy. A 30 m long, 3 m wide bunker has to be designed to host a proton linear accelerator with a low beam current, lower than 10 nA in average, and an energy up to 150 MeV. The accelerator will be part of the TOP-IMPLART project for deep tumors treatment.

The design of the 150 MeV accelerator is under study and the radiation protection solutions are considered in this phase.

The linear accelerator has some safety advantages if compared to cyclotrons and synchrotrons. It can be easily housed in the long, narrow tunnel. The main radiation losses during the acceleration process occur below 20 MeV, with a low neutron production. As a consequence the barriers needed should be substantially lighter than the one used for other types of machines.

In the paper the simulation models and the calculation performed with Monte Carlo codes are described. The related results are presented together with those assessed by applying experimental approaches.

Considerations about workers and population protection are issued in the conclusions.

INTRODUCTION

In Italy a new project is close to be launched with the aim of realizing an innovative proton therapy facility. The TOP-IMPLART project [1, 2] is based on the use of a linear accelerator for producing the beam. TOP-IMPLART are the acronym of Terapia Oncologica con Protoni (Oncological Therapy with Protons) and Intensity Modulated Proton Linear Accelerator for Therapy. The base of the TOP-IMPLART project is substantially the same as the TOP Project. 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 sequential setup of each partial irradiation module and its clinical application also before the whole facility has been completed will match the financial support flux that will be discontinue and spread over many years. This process will provide clinical and social advantages in a shorter time than the one that should be required for the construction and operation of the whole facility. The first 7 MeV module of the accelerator, is already installed and has been tested at the ENEA Research Center in Frascati, Rome. 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 150 MeV. The main irradiation model considers the proton beam hitting a human phantom target. The study has been performed using Fluka code [3], a powerful computer program based on the Monte Carlo method, implemented to simulate the experimental setup in order to evaluate the neutron field parameters.

TESTING STATION LAYOUT

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. In the final layout the bunker will be 30 m long and 3 m wide as it is shown in figure 1. The actual site will allow testing the beam and the scanning system together up to 115 MeV and the beam alone up to 150 MeV.

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.

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 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.

The model has been developed with Fluka Monte Carlo code [3] to simulate a 150 MeV proton beam, with $1x10^{10}$ protons intensity, hitting an anthropomorphous phantom. The phantom is a parallelepiped 30 cm thick (20x30x50 cm^3) made of tissue equivalent material and located at a distance of 30 cm in front to the kapton membrane that seals the vacuum chamber of the accelerator. As much as 10^8 particle stories were used in the Monte Carlo runs.

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 the beam	Concrete	100.00
Wall opposite to the beam	Concrete	100.00
Floor	Iron	4.00

The calculation model includes the following main sections:

- Final segment of the accelerating section;
- Anthropomorphous phantom;
- Shielding walls.

In tables 1 and 2 the main geometrical parameters entered in the code input are shown. The dimensions of the model refers to a preliminary design that is in a development stage. The actual walls dimensions will be thicker at least 30% respect to the design, due to the need of reducing as much as possible the blocks movement in the rearrangement process and to the possible increase of the beam intensity in the future applications.

Table 2: Beam and Target Position

Parameter	Distance [cm]
Upstream-inner-wall to upstream-injector	423.20
Kapton to target-upstream-surface	10.00
Target-center to downstream-inner-wall	300.00
Kapton to downstream-inner-wall	325.00

RESULTS

The following main results were obtained:

- Proton fluence inside the bunker, inside the shielding and outside the bunker;
- Neutron fluence inside the bunker, inside the shielding and outside the bunker;
- All particles dose equivalent rate inside the bunker, inside the shielding and outside the bunker;
- Neutron dose equivalent inside the bunker, inside the shielding and outside the bunker.

In the figures from 3 to 5 the all-particles dose equivalent rate is reported in chromatic graphs showing the projection of the results in the three main surfaces. This result is the most important for the assessment of workers and population safety during the accelerator running 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 [4, 5, 6] showing a substantial agreement, at least for the order of magnitude.

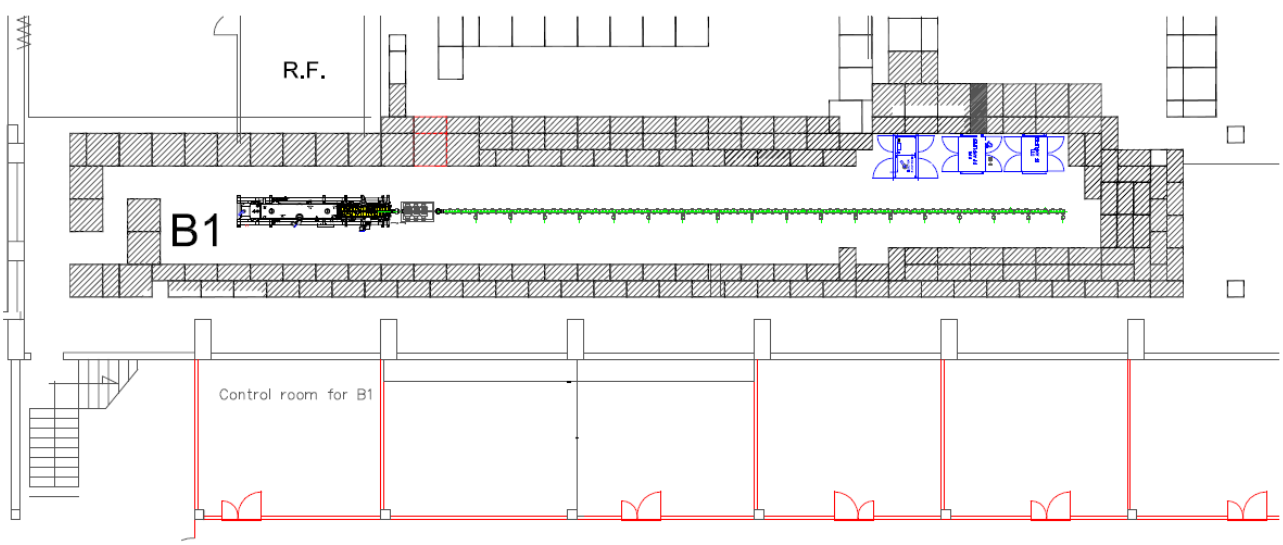

Figure 1: Final layout of the Frascati TOP-Implart bunker.

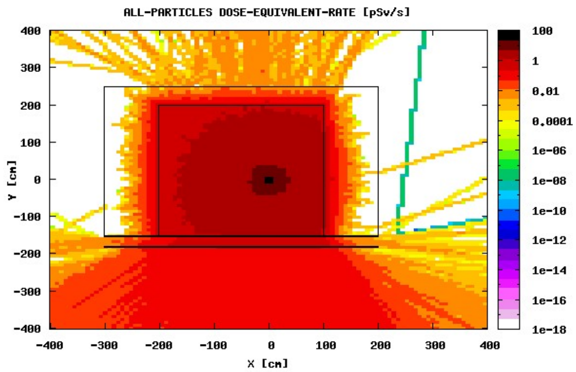

Figure 2: All-particles dose equivalent rate in the surface orthogonal to the z axis.

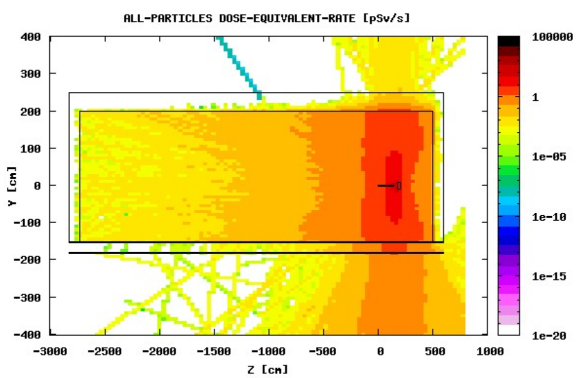

Figure 3: All-particles dose equivalent rate in the surface orthogonal to the x axis.

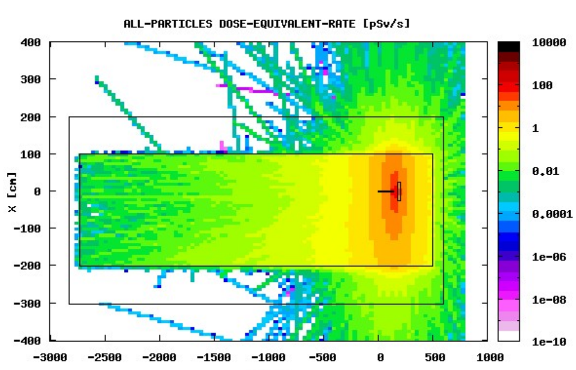

Figure 4: All-particles dose equivalent rate in the surface orthogonal to the y axis.

CONCLUSIONS

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 150 MeV proton beam provided by the accelerating sections housed in the testing facility.

The result obtained with the Fluka code 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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