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CONCEPTUAL PROJECT OF THE PROTON BEAM LINES IN THE NUCLEAR MEDICINE PROJECT OF THE "KURCHATOV INSTITUTE" - PNPI

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Abstract

The paper presents the calculation and layout of the beam transport lines to the target stations, the operation mode of the magnetic elements and beam envelopes. The method of the proton beam formation for ophthalmology and its parameters are described.

INTRODUCTION

The project of a nuclear medicine complex based on the isochronous cyclotron of negative hydrogen ions C-80 is being developed at the National Research Centre "Kurchatov Institute"-PNPI. The project provides for the design of a building, the creation of stations for the development of methods for obtaining new popular radionuclides and radiopharmaceuticals based on them. The commercial component is not excluded. The project also provides for the creation of a complex of proton therapy of the eyesight. For these purposes, the modernization of the beam extraction system of the cyclotron C-80 is planned: a project for the simultaneously two beams extraction systems is being developed. The one for the production of isotopes with an intensity up to 100 mkA and an energy of 40-80 MeV and the second - for ophthalmology with an energy of 70 MeV and intensity up to 10 mkA.

The initial conditions for both beams at the output window from the accelerator were obtained using the Orbita-1 program [1].

A blueprint of the project and beam transfer lines is shown in Fig. 1.

BEAM TRANSPORT LINES

Radio Isotope Complex

The isotope complex (direction A, Fig. 1) includes four target stations. Target stations will be equipped with special devices for removing highly radioactive targets, loading them into protective containers for safe transportation to storage sites or to hot chambers for further processing.

When designing the line for the production of radionuclides for each energy of the proton beam in the range of 40-80 MeV, the optimal parameters of the magnetic elements of the beam were found under conditions of minimal losses of particles in the transportation path, and so that the beam size on the target was at least 20 mm.

The optimization of the beam transfer lines was carried out using the PROTON_MC program created at the NRC KI-PNPI [2]. The calculation algorithm consists in tracing the proton beam trajectories along the transport channel from the source to hitting the experimenter's target or the aperture of the magnetic elements. The initial conditions of the particles are chosen random within normal distribution. The beam from the accelerator is presented in the form of a multidimensional Gaussian distribution in x, x', z, z', Δp/p phase spice. In the case when an absorber is installed in the transport channel the beam parameters after the absorber are calculated using the GEANT4 program [3].

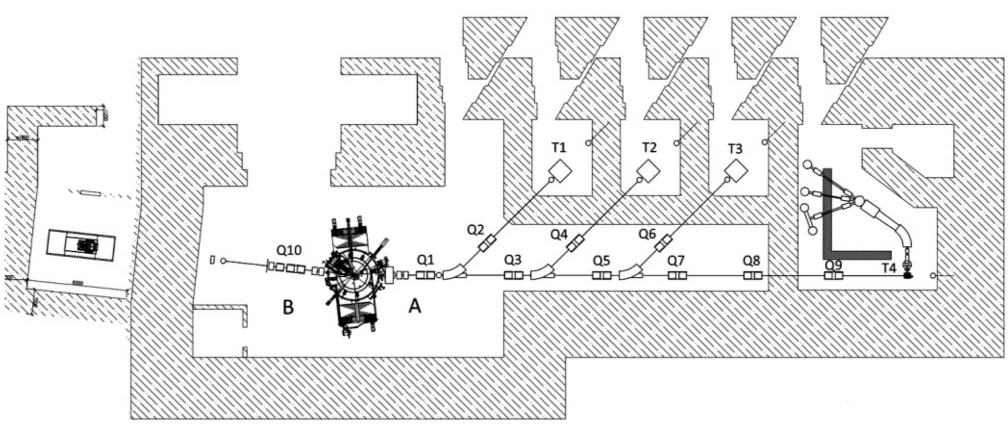

Figure 1: Blueprint of the project and beam transfer lines: (Right) A - beam line for radioisotope part, Q1-Q9 - lens doublets, T1-T4 - target stations. (Left) B - beam line for the ocular oncology complex, Q10 - triplet lenses.

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The output file of this program may be used as the source for the program. The program includes a block for optimizing the any beam parameters presented in a functional form. The random search method is used for obtaining the global maximum of a function of many variables.

Figure 2 shows the results of calculating the beam envelopes in the horizontal (X) and vertical (Z) planes for the target stations T1, T2, T3, T4, respectively. The energy of the protons is E = 70 MeV.

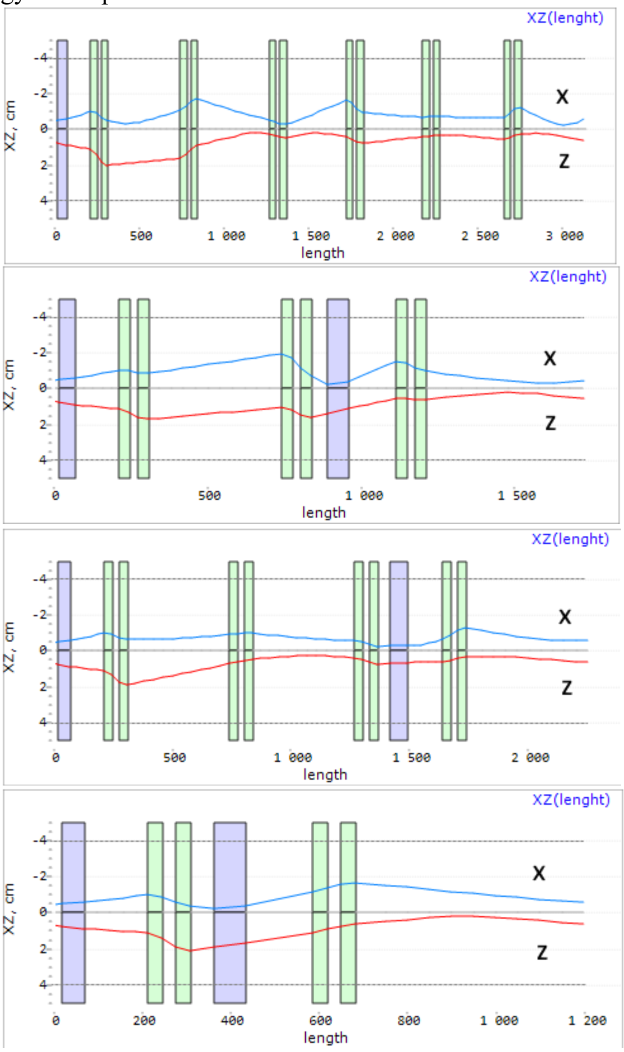

Figure 2: Beam envelopes in horizontal (X) and vertical (Z) planes for stations T1-T4. The upper and lower horizontal lines are the beam aperture.

Figure 3 shows a beam portrait for the most distant T4 direction as an example of the beam quality.

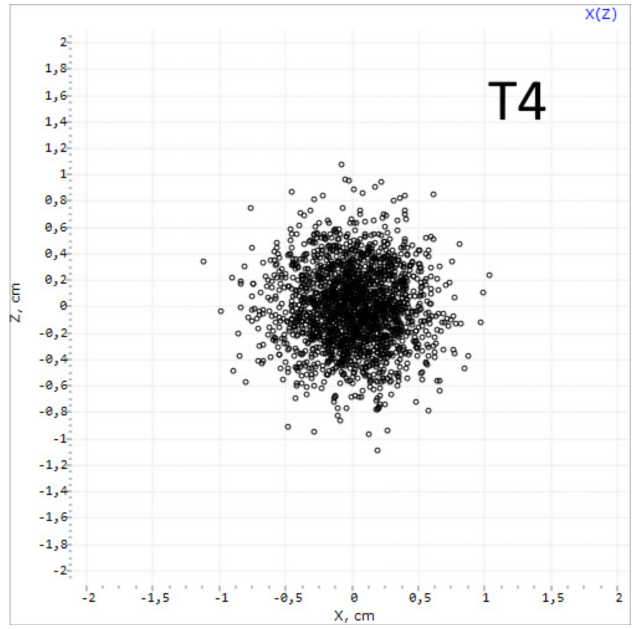

Figure 3: Beam size on the T4 target.

Ophthalmic Oncology Beam Line

Another area of application of the C-80 cyclotron is proton therapy for oncological eye diseases. For this purpose, a beam line was designed for the formation and delivery of a proton beam from the cyclotron to the treatment room, where patients are irradiated (direction B, Fig. 1). Line meets special requirements: beam energy 60-70 MeV; beam diameter at the entrance to the treatment room ≈ 60 mm; beam divergence angle ≈ 1 mrad; the uniformity of the beam in the area of Ø60 mm is not less than 90%.

A challenge in the design of medical tract was the requirement of medical physicists about the simultaneous and independent operation of the two beams of isotopes and medicine. On a cyclotron accelerating H- ions, it turned out the opportunity to provide simultaneous operation of two beams of different intensities and energies - one for the production of isotopes with an intensity of 100 μA and an energy of 40-80 MeV and the second - for ophthalmology with an energy of 60 MeV and intensity 10 mkA.

To implement this idea, it turned out to be necessary to extract the beams in two directions (see Fig. 1) and select a complex configuration of stripping foils.

To obtain a homogeneous beam, a well-known method of beam scattering and sampling of its homogeneous central part were applied.

To implement these conditions, a beam line with a passive scatterer made of tantalum (Ta) foil 300 mkm thick was constructed. The scheme of the beam path is shown in Fig. 4.

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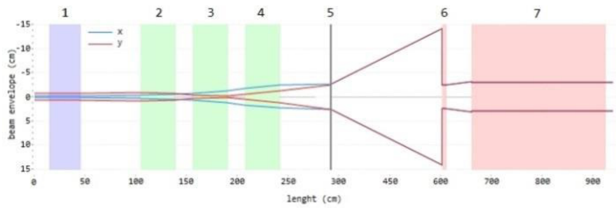

Figure 4: Ophthalmic beam line scheme and beam envelopes: 1 - corrector magnet, 2,3,4 - triplet lenses, 5 - tantalum scatterer 300 mkm thick, 6 - collimator, 7 - protective wall in front of the irradiation room.

The proton beam E = 70 MeV, extracted from the accelerator, is transported to the Ta foil, on which a beam size of ~ Ø30 mm is formed by a triplet lens. The optimization of the proton beam transport line in this section was also carried out using the PROTON_MC program. The results of the passage of protons through a Ta foil with a thickness of 300 mkm, obtained using the GEANT4 program, were the initial conditions of the PROTON_MC program during further transport of the diverging proton beam in free space of ~ 3.7 m. The phase ellipses of the beam at the entrance and exit from the foil are shown in Fig. 5.

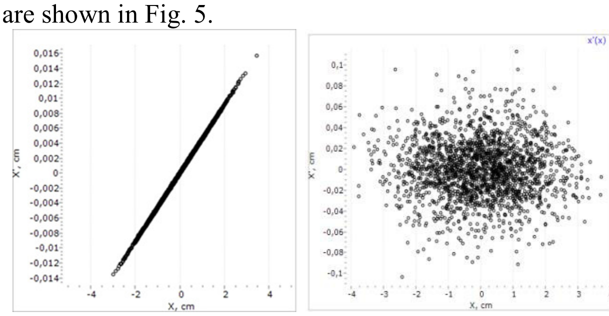

Figure 5: Phase ellipses of the beam (x-x ') at the entrance and exit from the foil, respectively.

A collimator with an optimal beam length of 100 mm and a diameter of 50 mm, installed in front of the protective wall, finally forms a beam with specified conditions as shown by Fig. 6.

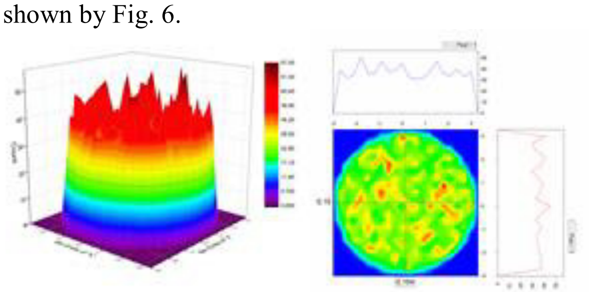

Figure 6: Distribution of the intensity of the proton flux in the beam at the entrance to the irradiation room of patients.

CONCLUSION

Within the framework of this project, the radioisotope and onco-ophthalmological beam line for the transport of the proton beam were designed. We managed to place the necessary equipment within the allocated area.

Calculations show that this configuration of the channels will provide a proton beam with the required parameters.

ACKNOWLEDGMENT

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[3] GEANT4, https://geant4.web.cern.ch