Development of Proton Irradiation Facility at the INR Linac

S Bragin[1], A Feschenko[1], S Gavrilov[1], O Grekhov[1], Y Kalinin[1], Y Kiselev[1], L Latysheva[1], S G Lebedev[1], A Melnikov[1], V Serov[1], N Sobolevskiy[1], A Titov[1], O Volodkevich[1], D Arbuznikov[2], O Podgornaya[2], E Prokhorov[2], S Razinkov[2], P Tsedrik[2] and S Tsibryaev[2]

[1] Institute for Nuclear Research, Russian Academy of Sciences, Moscow, Russia
[2] Russian Federal Nuclear Center, All-Russian Research Institute of Experimental Physics, Sarov, Russia

s.gavrilov@gmail.com, lebedev@inr.ru

Abstract. The results of development, installation and tests of an experimental facility for irradiation of different products and materials at the INR RAS linear accelerator are presented. The beam energy range is 20÷210 MeV. The energy is adjusted by switching on/off the fields in accelerating cavities and with energy degraders. The intensity range is from 10^7 protons per separate pulses up to 1 μA of average beam current. Also the activation of the beam dump and the test unit as well as the radiation conditions in the vicinity of the facility are estimated.

1. Introduction

The accelerating complex based on the linear proton accelerator of Institute for Nuclear Research RAS [1] is a multipurpose facility with a wide range of objectives in neutron research [2-3], radioactive isotope production [4] and medical physics [5]. This paper describes the development and construction of the Proton Irradiation Facility (PIF) for studies of irradiation induced effects in electronics and other materials. PIF essentially expands the range of tasks performed at the INR linac. The structure of the linac is shown in Figure 1. After the analysis of possible locations of PIF the decision was made to locate it downstream of the existing 7.5° bending magnet in the 600 MeV areas at the exit of the accelerator.

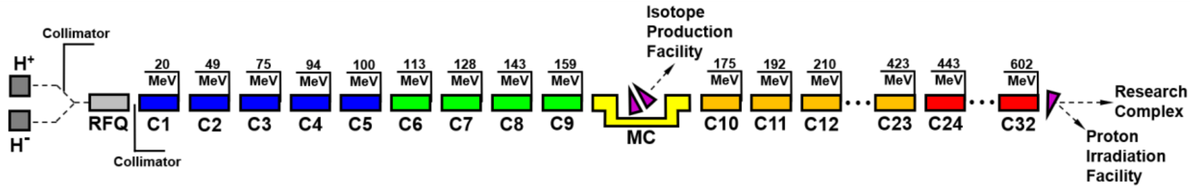

Figure 1. Diagram of the INR linac. C1…C5 – drift tubes accelerating tanks; C6…C32 – disk and washer accelerating cavities; MC – matching cavity.

As the energy range for PIF is 20÷210 MeV beam dynamics simulations with the aim to verify lower energy beam transportation to the exit of the accelerator as well as to find the focusing elements settings have been done. The simulations have been carried out with TRACE-3D code [6] and have shown that in the whole specified energy range the beam can be transported to the exit of the accelerator with minimum beam losses, no focusing elements are needed downstream of the bending

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magnet and the size of the beam at the PIF target can be controlled with the last three accelerator quadrupole doublets.

2. PIF configuration and main parameters

The general PIF configuration is shown in Figure 2. The main elements are: bending magnet with vacuum chamber, beam pipe, beam dump, target positioning system, energy degrader and beam diagnostics.

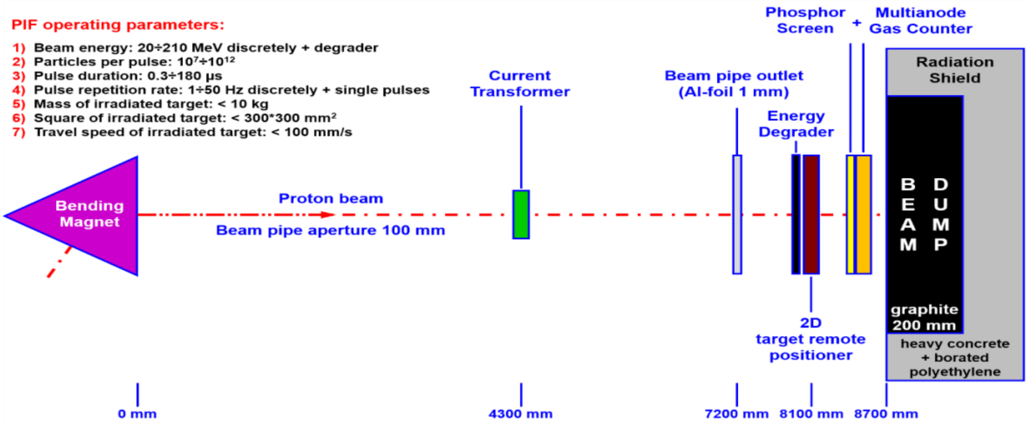


Figure 2.PIF configuration.

Beam energy at the PIF is adjusted mainly by a switching on/off the accelerating cavities, which provide discrete energy values with a full energy spread < 1%. For intermediate beam energy values the energy degrader is used. The presence of the degrader along with the outlet of 1 mm aluminium foil window and 900 mm air gap results in a significant increase of the energy spread, especially for lower beam energies. As an example figure 3 demonstrated the energy spectrum calculated with TRIM [7] for 49 MeV beam at the exit of the 4.6 mm aluminium degrader.

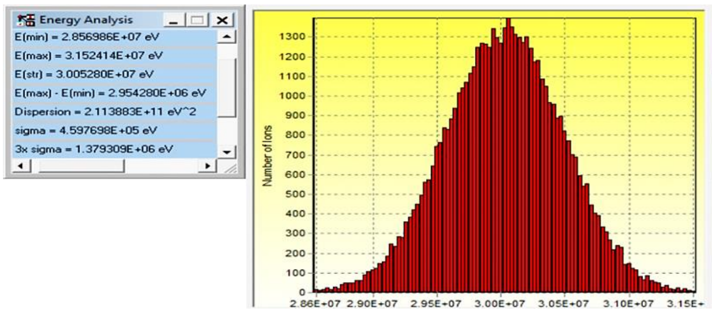


Figure 3. Energy spectrum of the 49 MeV proton beam after 1 mm aluminium window, 900 mm air gap and 4.6 mm aluminium energy degrader.

Beam intensity is defined by a combination of three parameters: pulse current, which can be adjusted in the range of $10^7 \div 10^{12}$ protons per pulse with two collimators in the linac injection line, pulse duration, variable in the range of 0.3÷180 μs, and pulse repetition rate. The available repetition rates are 1, 5, 10, 20, 25, 40 and 50 Hz. The preset number of beam pulses can be produced at any of the above repetition rates.

The two-dimensional target positioner 3 (Figure 4) is intended for the irradiated target positioning in the prescribed transverse point and for moving it with the speed up to 100 mm/s in the range of ±150 mm with respect to the beam axis. The mass of the irradiated element is limited to 10 kg.

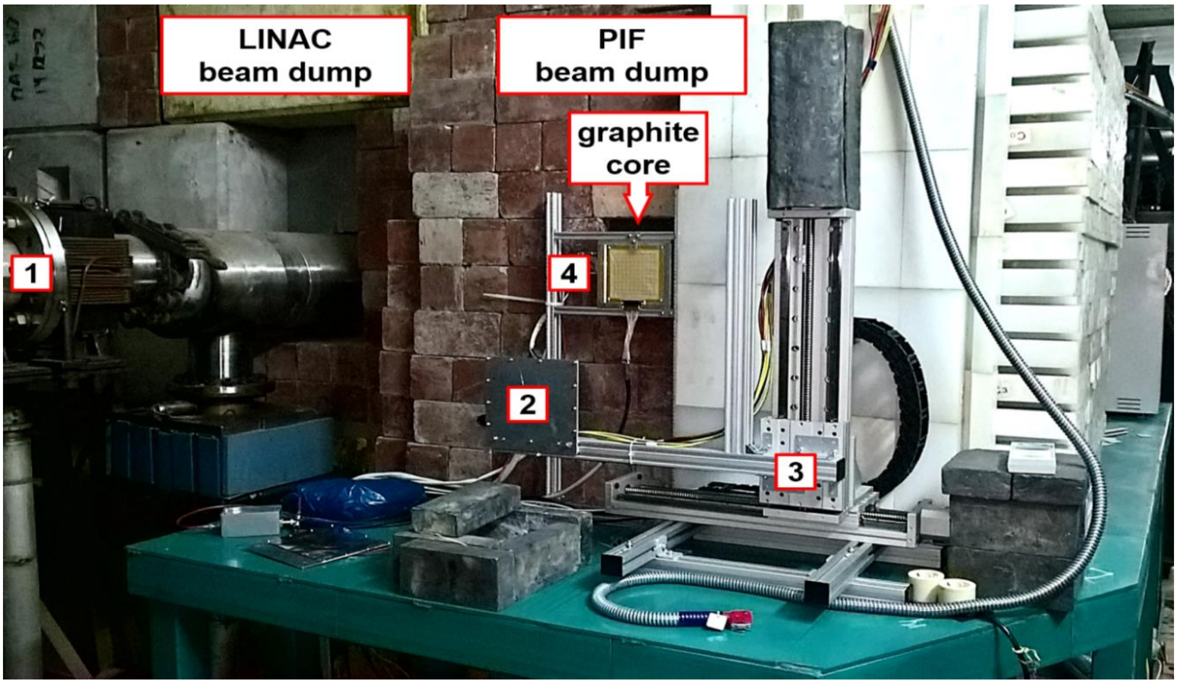


Figure 4. PIF installation. 1. Beam pipe outlet. 2. Beam energy degrader. 3. 2D target positioner. 4. Multianode gas counter with phosphor screen.

2.1. Beam dump

The beam dump consists of the graphite core surrounded by the shield of heavy concrete and borated polyethylene blocks. The calculations of shielding were carried out using the transport code SHIELD [8]. For the maximum specified beam current of 1 μA with the energy of 210 MeV the most intensive neutron fluxes are generated upwards ($2 \cdot 10^7$ n/cm^2/sec) and sideways ($5 \cdot 10^5$ n/cm^2 /sec). These fluxes are lowered to the acceptable levels by the existing 1.7 m concrete shield and 7 m soil layer. The calculations of the backward neutron flux from the dump to the irradiated unit show, that the integral flux does not exceed 10% of the neutron flux generated inside the irradiated unit and the energy of these neutrons is below 1 MeV. Hence the influence of the backward neutrons on the results of irradiation tests is negligible.

Calculations of the target activation were done with the code DCHAIN-SP [9]. The composition of the target was taken to be the following: silicon 90%, epoxy resin 5%, copper 5%. The total activity of all the radionuclides produced in the target after 8 hour irradiation with the 209 MeV, 1 μA beam is 10^9 Bq. It decreases by two orders of magnitude within one day (Fig. 5). The dose rate on the surface of the irradiated target in a day is 27.5 μSv/h

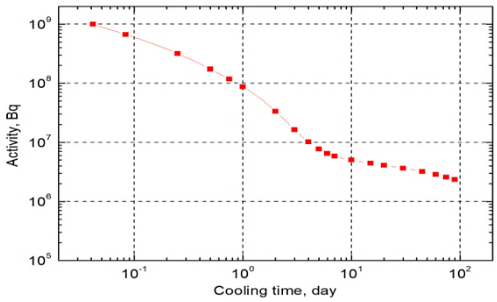


Figure 5. Integral activity of all radionuclides in the PIF target after 8 h irradiation by 210 MeV protons with 1 μA average current.

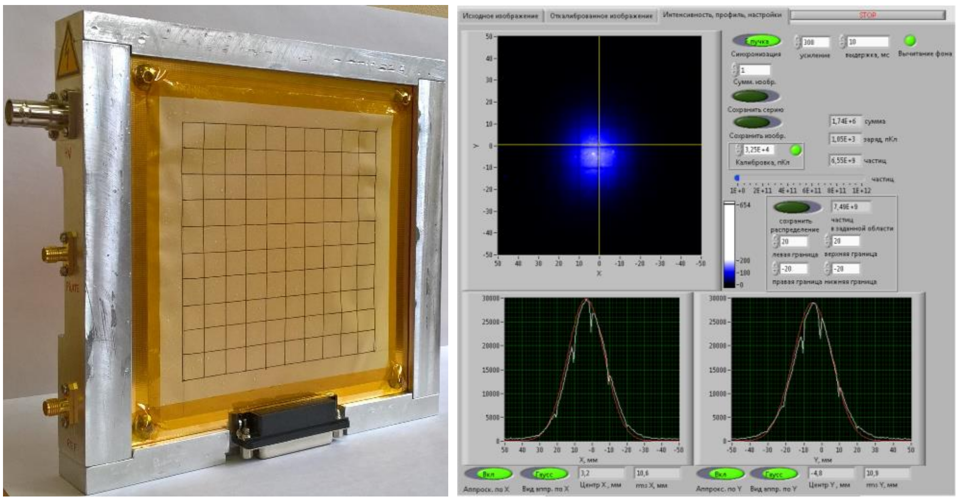
2.2. Beam diagnostics

PIF beam diagnostics includes three devices: beam current transformer (BCT), multianode gas counter (MGC) and phosphor screen (PS). The BCT is installed in the beam pipe about 3 m upstream of the outlet window and provides absolute nondestructive measurements of beam pulse current with the amplitude > 50 μA, which corresponds to about $>10^{10}$ protons per pulse with typical pulse durations.
For smaller beam intensities a special gas counter has been developed and fabricated (Figure 6a). The counter includes several parts: single-anode ionization chamber for beam current measurements in the range of $10^7 \div 10^{11}$ protons per pulse and two proportional chambers, each containing 25 anode 100 μm gold-plated strips with 4 mm spacing (Figure 6b) for beam transverse profiles and position measurements in 100×100 mm^2 area. In the existing design an ambient air filling is used, so MGC must be calibrated regularly with BCT for absolute beam current measurements.

a) b)

Figure 6. a) Multianode gas counter. b) Strips for profile measurements in proportional chambers.

The phosphor screen is covered with P43 phosphor (Figure 7a). The image on the screen is visualized with CCD-camera. PS provides beam profile and beam position measurements (Figure 7b) with the resolution of about 1 mm in the 100×100 mm^2 area. Also it was experimentally tested, that PS can be used to measure number of particles per beam pulse independently on its duration. The threshold sensitivity was found to be near 5×10^7 proton/cm^2. The linearity of the measurement was tested within the range of $10^8 \div 10^{10}$ proton/cm^2.



a) b)

Figure 7. a) Phosphor screen fixed at the surface of the gas counter. b) PS diagnostics software.

3. PIF beam tests

Beam tests were done within a full range of the PIF operating parameters to check all the systems. Figure 8 shows some results of irradiation with initial beam energies about tens of MeV, when protons are strongly scattered or completely stopped inside the specimen, when a “shadow” image is formed at PS.

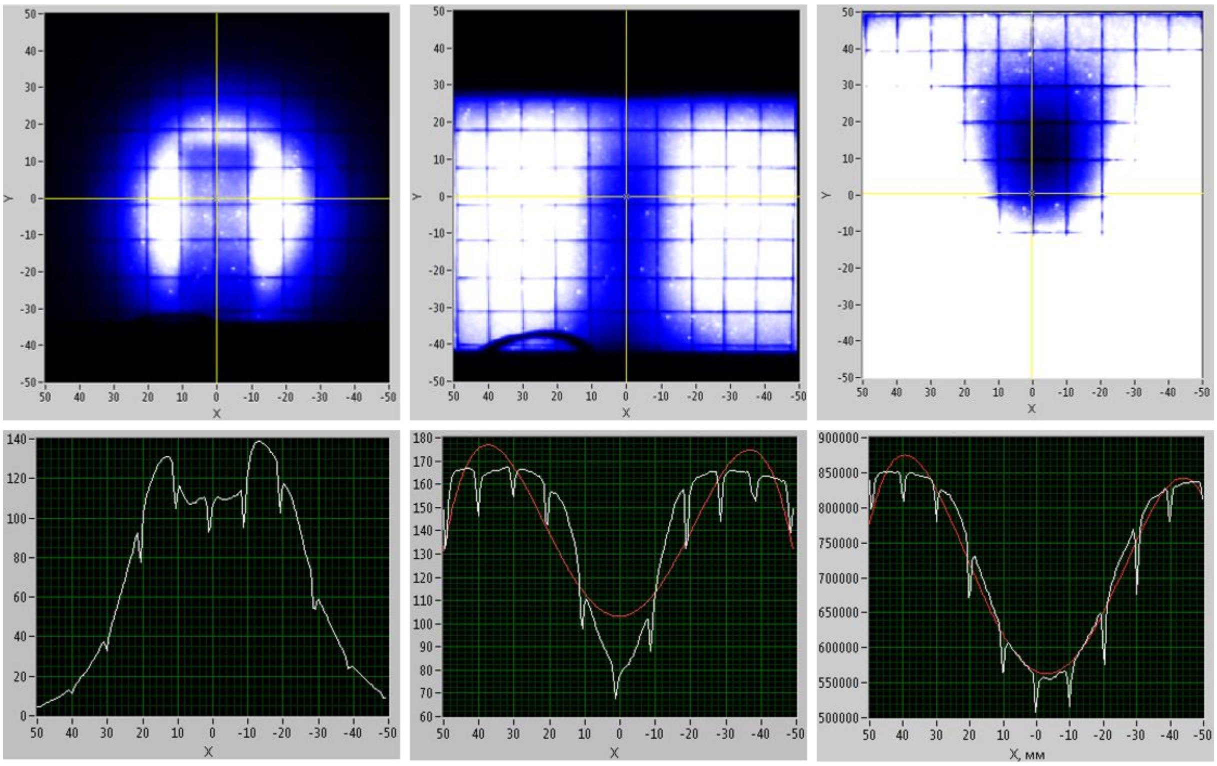


Figure 8. The “shadows” of irradiated specimens and transverse profiles found from the images on PS.

The results of the tests confirmed the correctness of the decisions taken at the stage of development of the irradiation facility and the feasibility of all the declared parameters. The experience gained in the course of the tests will subsequently speed up and optimize the irradiation procedure.

This work was done with the use of the equipment of the Shared Research Facility “Accelerator Center for Neutron Studies and Nuclear Medicine of INR RAS” of the of the Institute for Nuclear Research of the Russian Academy of Sciences.

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