The Potential of the Radiation Effects Investigations on the Accelerator Facilities at Gatchina

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Abstract

The accelerator facilities at Gatchina which are used both for the basic physics purposes and for investigation of the radiation effects are described. The beam parameters and diagnostic methods for 1 GeV synchrocyclotron, 14 MeV neutron generator and 1,8 MeV electrostatic accelerator are presented.

I. 1 GeV Synchrocyclotron [1].

1 GeV synchrocyclotron is a basic accelerator facility of PNPI at Gatchina. The scheme of the accelerator, experimental area and beam lines is presented in Figure 1.

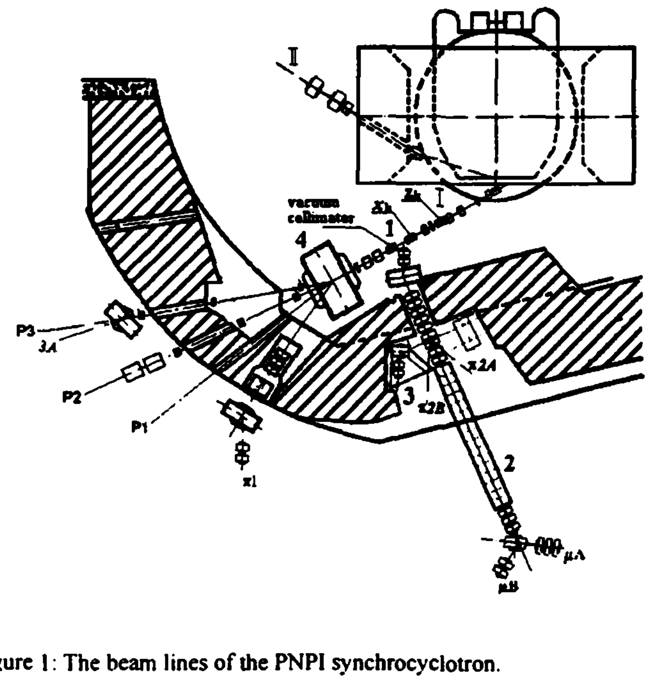

Figure 1: The beam lines of the PNPI synchrocyclotron.
1-the meson-production target; 2- the μ-meson channel; 3- the low energy π2-channel; 4-the bending magnet; π1-high energy pion beam. P1, P2, P3 - proton beam lines.

A. The proton beam.

The proton energy is fixed and equals 1 GeV. The extracted beam intensity can be varied from 10^6 up to $6\cdot10^{12}$ 1/s. The beam spot can be varied from 5 mm up to 500 mm. The long burst operation system provides variation of the beam macro pulse duration from 300 μs up to 10 ms. The proton beam parameters are presented in Table 1.

Table 1.
The proton beam parameters.

The energy of extracted beam	1 GeV (fixed)
The energy spread ΔE/E	1%
The beam intensity inside the chamber	≤3 μA (var)
The intensity of the extracted beam	≤1 μA (var)
The extraction efficiency	30%
Repetition rate	40÷60 Hz
Duration of the macropulse	300 μs÷10ms
Duration of the micropulse	6 ÷ 10 ns
Beam spot diameter	5 mm ÷500 mm

B. The secondary beams.

One meson-production target installed in the accelerator hall is used by the three meson channels, so that channels (π1, or π2 and μ) can operate simultaneously. The basic parameters of the secondary beams are presented in a Table 2.

Table 2.
Secondary beam parameters

Particles	Momentum, [MeV/c]	Δp/p [%]	Intensity $[s^{-1}\cdot\mu A^{-1}]$	Beam line
π^+	450	6	$3\cdot10^5$	π1-channel
π^-	450	6	$3\cdot10^6$	
π^-	250	2,5÷12	$10^5\div5\cdot10^6$	π2-channel
π^+	250	2,5÷12	$3\cdot10^5\div10^7$	
μ^-	160	10	$9\cdot10^4$	μ-channel
μ^+	170	10	$3\cdot10^5$	

1). The π1-channel have been designed for the focusing and separation of the pion beam, generated at zero angle and for that reason the pion beams with the maximum for PNPI energy (up to 700 MeV/c) and high intensity are produced on that channel. Momentum resolution of the π1-channel is $\Delta p/p = 1.5\% \div 6\%$. The measurements of beam contamination on an exit of the channel have shown, that apart from base components ($\pi^{+/-}$, p^+ и $e^{+/-}$), in a beam there are deuterons (3 %), μ-mesons (4 %), tritium (0.5 %) and ^{3}He (0.5 %). In Figure 2 and in Figure 3 beams contamination for the π1-channel is presented versus momentum.

2). The π2-channel have been designed for the low-energy pion beam of high intensity. The momentum resolution of π2-channel can be varied from 2,5 up to 12 % by using the momentum collimator. The intensities versus momentum on an channel exit is shown in Figure 4 (for π^-) and in fig 5 (for π^+). The dose distribution on the exit of the channel is shown in Figure 6.

3). The μ-channel have been designed to produce the separated muon beams. The parameters of the muon beams are presented in Table 2. In Figure 7 and in Figure 8 the μ-channel beams are presented versus momentum. In Figure 7 μ-channel beams are presented for the operation mode when the first (pion) analyzer is tuned on the fixed momentum P=200 MeV/c and the second (muon) analyzer momentum is varied from 80 up to 280 MeV/c. The momentum P=200 MeV/c corresponds to unseparated beams with more high intensity. Momentum P=100 MeV/c corresponds to separated μ^--beam which is generate by the back decay of π^--meson.

4). Secondary proton beam. The proton beams on π1- and π2-channels with energy smaller 1 GeV and with the same parameters as meson beams can be obtained either by the energy degradation of the primary proton beam in the medium or as a result of the nuclear interaction of the primary beam with a target.

5) Neutron beam and TOF spectrometer GNEIS. The neutron time-of-flight spectrometer GNEIS gives unique opportunity for the neutron spectroscopy due to its very high energy resolution. The short start time for the TOF spectrometer is provided by one-turn inclination of the internal beam on the neutron-production target. The parameters of the evaporated neutron beams are presented in table 3.

Table 3.

Neutron beam

Energy	Intensity $[s^{-1}]$	Pulse duration	Repetition rate [Hz]
10^{-2} eV÷ 10 MeV	$3\cdot10^{14}$	10 ns	50

II. Small Energy Accelerators.

A. The neutron generator (NG) [2].

The yield of neutrons with 14 MeV energy is up to $2\cdot10^{12}$ s^{-1}. The NG construction permits to place the irradiated sample on the small distance of ~6 cm from the neutron target. This disposition permits to obtain the neutron flux up to 10^{11} $n\cdot cm^{-2}\cdot s^{-1}$ on the irradiated sample. The time of double decrease of neutron yield is ~2 h. The neutron flux is measured by the proportional ^{3}He-counter which is calibrated by activation of a copper foils.

B. The electrostatic accelerator (ESA) [3].

ESA accelerates protons, deuterons and electrons in the range of 0.3 - 1.8 MeV. The intensity of the ion beam is from 1 nA up to 30 μA. Energy stability of ion beams $\Delta E/E \sim 10^{-4}$. The electron beam can be brought out through the aluminum window of 50 μm thick with sizes 20x230 mm^2 from the vacuum chamber into atmosphere. The beam current is up to 150 μA. It can be swept in the angle range of 30° with the frequency of 50 Hz. The ion and electron beams of necessary sizes and intensity can be formed on the target.

III. The Beam Diagnostics, Monitoring and Dosimetry.

There is well developed system of the beam diagnostic and monitoring. The stationary installed profilometers are used to control the proton beam position and distribution. The time variation of the intensity is controlled by the calibrated ionization chamber. The method of the induced radioactivity and luminescent probes are used to control the proton flux. Absolute calibration is produced by using the nuclear reactions ^{12}C (p, pn) ^{11}C and ^{27}Al (p, 3pn) ^{24}Na with well known value of the cross-section. MWPC method is used for diagnostic of the secondary beams. The time-of-flight method is used for measurement of the meson beam contamination.

IV. SEE Investigations at PNPI.

For some years SEE effects were investigated at PNPI as theoretically as experimentally [4]. Two parameter model for predicting SEU rate was introduced, energy deposition in thin silicon slab was investigated, SEU cross sections for different parts were measured.

V. Conclusion.

After 25 years of operation PNPI synchrocyclotron continue to be one of actively operating and most cheap proton and meson beams facilities in Russia. Results of previous experiments dealt with SEU phenomena and carried out at PNPI accelerator show that it is a unique tool for such investigations. Now PNPI accelerator facilities ready to expand the investigations on radiation effects and are open for wide international co-operation.

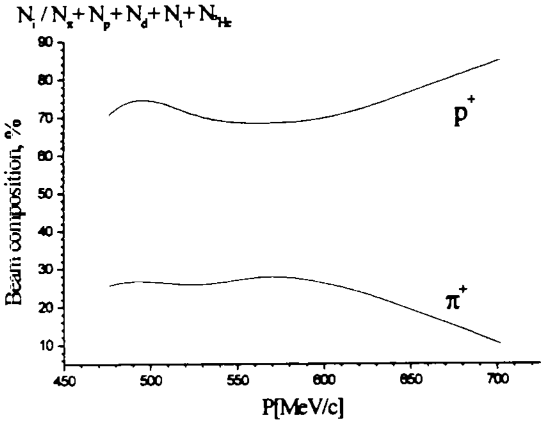

Figure 2: The base beam contamination on π1-channel

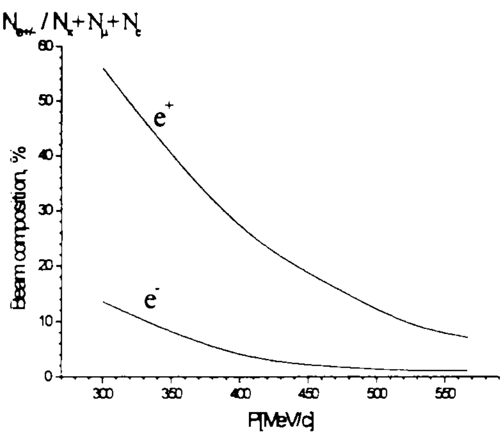

Figure 3: The electron components on π1-channel

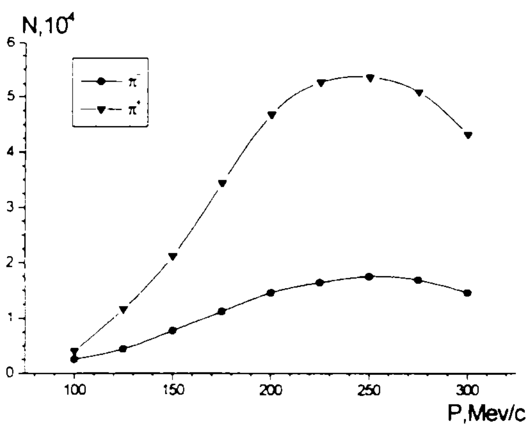

Figure 4: The pion intensity versus momentum on π2-channel

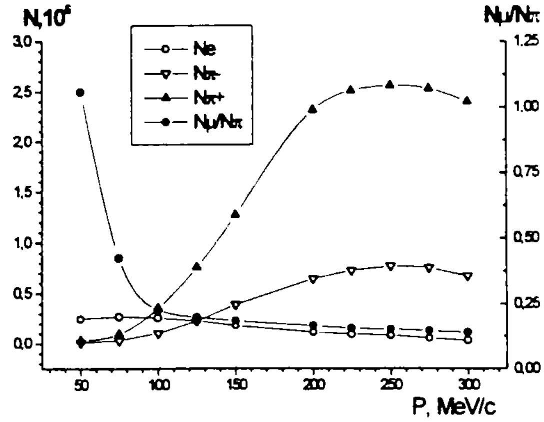

Figure 5: The beam contamination versus momentum on π2-channel

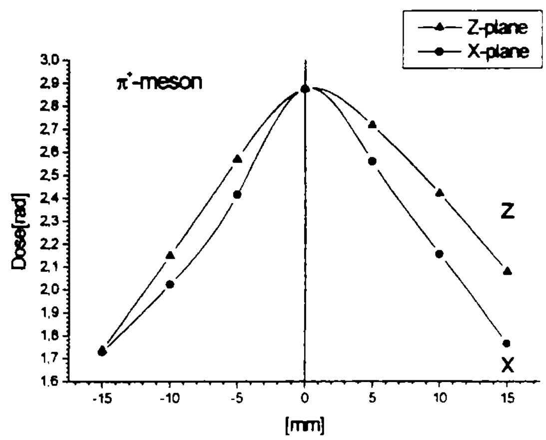

Figure 6: Dose distribution on the exit π2-channel.

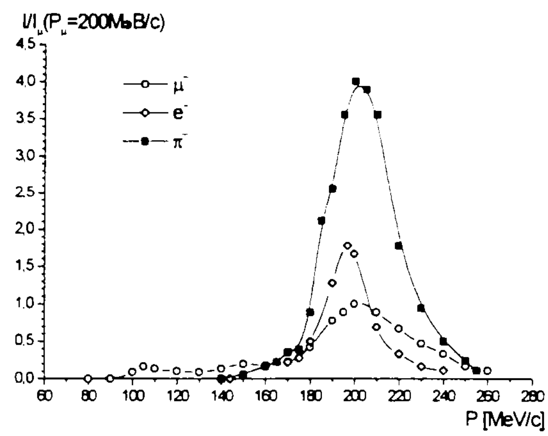

Figure 7: The μ-channel beams versus momentum for channel operation mode when the pion analyzer is tuned on P=200 MeV/c and the second (muon) analyzer momentum is varied.

IV. Features of the beam and of the installation

A. Beam extracted from the machine

The SC200 beam is a pulsed 200 MeV proton beam with a range of intensity from 5 nA to 300 nA for clinical applications. Higher intensities can be produced for other users (up to 1 µA). The intensity is tunned manually by the machine operator.

The macro-structure is : pulse width 20µs, period 2200 µs and the micro-structure is given by the 19,2 MHz HF frequency.

B. End-line beam conformation systems

The passive scattering elements (modulator, degraders, scatterers) shown in figure 3 permit to obtain a wide range of fields:

- Energy: from 10 MeV to 180 Mev (step 1 MeV)
- Fluence (nominal on a Ø10cm): 10^8 p.cm^{-2}.s^{-1}
- Size: homogeneous beam on a Ø15cm (max) (figure 4)

Each setup of the line (field) have to be configured manually on the banc. By the end of 1999, we'll have the remote control of the degrader (energy).

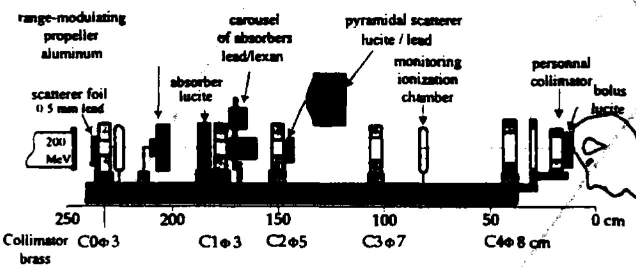

Figure. 3 : the intracranial treatment beamline

C. End-line dosimetry instrumention

Off-line: a pencil ionization chamber put in a water phantom achieved an acurate 3D dosimetry (standard system from the radiotherapy industry).

On-line: the monitoring of the dose is realized with plates ionization chambers (control of the deposited dose <1cGy).

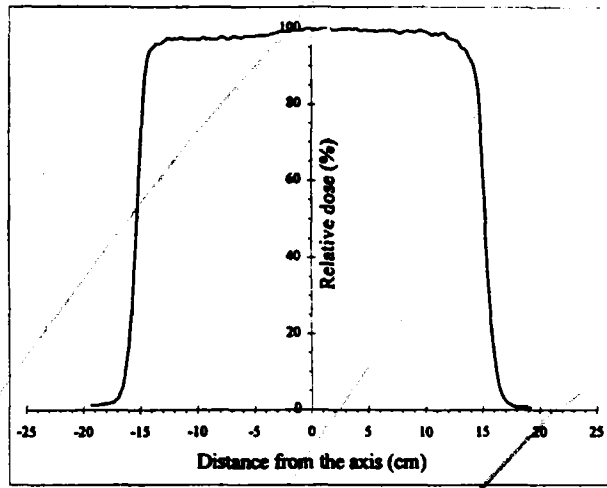

Figure 4 : samples of beam profiles obtained

D. Positionning systems

The specific robot developped for this acurate therapy achieved a 1/10 mm acuracy positionning.

The positionning and centering operations are helped with optical and radiographic centering systems.

Specific supports have been already realized for electronic cards.

D. Control room- Safety

- The control room is closed to the irradiation room
- Shielded rooms and safety systems are done in respect of the EC regulations (dose rate level and routine procedures)

E. Constraints

The basic constraints for potential « outside users » are :

- quasi-transparency for the medical utilization
- beam configurations close to the existing standard conditions
- radioprotection limits
- technical support of the CPO personnal.

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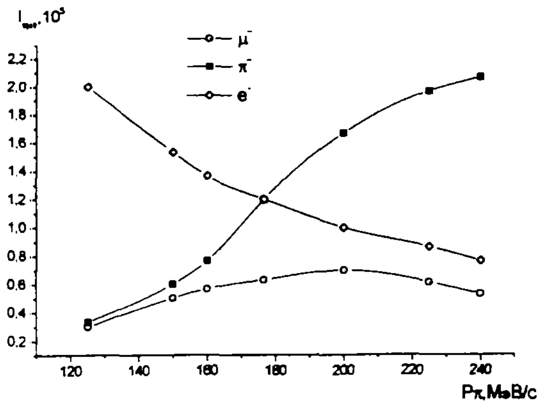

Figure 8: The μ-channel beams versus momentum for channel operation mode when the pion analyzer is varied coincidentally with muon one.

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