USE OF USSR PROTON ACCELERATORS FOR MEDICAL PURPOSES

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Abstract

Proton beams of the Joint Institute for Nuclear Research (LNP, JINR) Dubna synchrocyclotron and of the proton synchrotron of the Institute for Theoretical and Experimental Physics (ITEP) Moscow have been used for medical and biological purposes since 1967. 58 patients in JINR and 163 in ITEP with various types of malignant tumors have been treated.

Results of clinical research showed that use of high energy protons for treatment of malignant tumors is quite expedient and may serve as a good approach developing better means for irradiation in oncological therapy.

Proposals for proton and meson beams at the JINR high intensity phasotron and for proton beams at the ITEP medical and biological center are discussed. The ITEP center will consist of 4 cabins for therapy and 2 cabins for radiobiological research, which will permit to treat ~ 100 patients per day.

Research on proton beam use in oncology had been started in Dubna in 1966 and in ITEP in 1967.

There are enough facts now to show that proton beams have very important advantages not only in proton hipophysectomy but in therapy as well.

Our experience has shown that the results of proton beam therapy are the same as of traditional radiation therapy, but no observable general reactions or changes in blood count have ever been seen. Tissues, situated behind the beam range are not damaged practically. For the first time in the USSR the proton beam for therapy with variable energy from 90 and up to 200 MeV was accomplished at 680 MeV synchrocyclotron of JINR (Dubna) in April 1967.[1] Lay-out of transport and formation systems of the proton beam at the operating synchrocyclotron are presented at Fig. 1. The proton beam ejected from the accelerator vacuum chamber with 680 MeV energy is focused by a pair of quadrupole lenses on a degrader. Slowed down protons are cleaned by means of a deflecting magnet from other particles and are transported by a magnet channel into a procedure room, situated behind a concrete shield. Beam intensity is 10^9 proton sec^{-1} in the procedure room. Dose rate in Bragg peak is 200 rads/min for 90 MeV beam.

Dosimetry, adjustment and auxiliary equipment to control radiation treatment of patients and other biological targets by proton beam is installed in the procedure room and in the control room (Fig. 2).[2] Dose distributions in tissue equivalent phantoms are measured by small movable semiconductors. Sometimes dose in tumors are measured by semiconductors introduced directly into the cavities of human body (for example into esophagus). These detectors make it possible to put the Bragg peak exactly at the target. The accelerator is turned out automatically from the control room after the necessary dose is achieved. The beam cross section is chosen in accordance with the form of the irradiation target by a special collimator, which consist of movable plates. The maximum diameter of the beam cross section is 11 sm. During irradiation treatment the patient is fixed in an armchair, which can be moved in horizontal and vertical planes and automatically rotated around the vertical axis in the chosen angle interval. Alignment of patients with beam axis is carried out by optical equipment, x-ray tube and image amplifier. A television set and periscope system are used to watch patients during irradiation procedure. Large research work has been carried out with tissue-equivalent phantom to choose, calculate and measure dose fields in homogeneous and heterogeneous media.

58 patients with various type malignant tumors (skin melanoma, larynx tumor, cancer of esophagus and of lungs, malignant tumors of bones) had been treated at comparative small room of the JINR medical proton beam till July 1972.

Heavy particles therapy in JINR seems to have good future in connection with reconstruction of the synchrocyclotron into a high-intensity phasotron.[3] The beam intensity will be 50 mka instead of 2, 3 mka and the extracted proton intensity will increase by a factor of about 100.

Various particle beams (including those for therapy), which will be established after reconstruction are shown in Fig. 3. Space for medical and biological research will increase considerably. Number of procedure rooms will be doubled. Possibility of beam switching from one cabin to another will be foreseen. In this way the effect of accelerator use for patient treatment will be raised.

The clinical beam of π-mesons is supposed to be constructed at the high-intensity phasotron. The scheme of π-meson beam is shown in Fig. 3. The ejected proton beam is deflected down to first floor level by deflecting magnets and is transported to a solenoidal wide-angle meson lens with non-uniform axially symmetric magnetic field along a strong focusing magnetic channel, installed in a concrete tunnel.[4] This lens with carefully picked out distribution of magnetic fields ensures an acceptance space angle of ~ 0.5 s radn with small spherical and chromatic abberations. If the intensity at the meson target will be about 20 mka, it is possible to have the intensity of π-mesons in the focus of such lens about 10^9 sec^{-1}. This intensity will ensure the rate dose up to several hundreds rads/min with 10 sm target diameter, what is quite enough for radiobiological experiments and patients treatment.

In 1968 the second clinical proton beams with energy varied from 70 up to 200 MeV has been extracted from the 7.2 GeV ITEP strong-focusing proton synchrotron. A small accelerator cycle up to 200 MeV follows each of the main cycles of acceleration without time loss for high energy physics. The intensity of the clinical beam reaches

10^{11} protons per pulse with 4 sec intervals between the pulses that corresponds to several thousands rads/min.

Broad beams (up to 8 sm in diameter) are used for therapy irradiations and narrow beams (5÷8 mm) for neurosurgery. Beam energy is chosen individually in therapy irradiation and is equal to 200 MeV during neurosurgery. Beam energy is varied by choice of time when it is extracted from the synchrotron. Desired dose depth distribution is achieved by a single ridge filter of variable thickness. The patient sits (or lies) on an arm-chair (Fig. 4) which is used for various irradiations including hynecological. The arm-chair can be lifted, pushed aside and rotated by wish.

During hypophysectomy the patient lays on his back on a table, which can be rotated within $\pm110^{\circ}$ around the vertical axis (Fig. 5). Simultaneously the head of the patient is being rotated within $\pm35^{\circ}$ around his neck. Both axes of rotation and the beam intersect in the pituitary gland. Dose field measurements have been accomplished by ionization chambers, photodensitometers and TLD-detectors.[6] A set of standard dose distributions consists of 35 fields for therapy and of 5 convergent beam fields for neurosurgery. Field cross section may be circular, oval, rectangular or more sophisticated. A special calculation program for arbitrary fields has been developed.

Over 150 oncological patients have been treated since 1967 according to the table:

Deseases	Number
Cancer cervix uterus	56
Vulvar causer	30
Osteogeneous sarcoma	17
Cancer and melanoma of skin	41
Metastatic breast cancer (hypophyse suppression)	19
Total	163

Our experience shows that maximum necessary energy for medical purposes in 200 MeV. The advantages of proton beam irradiations are used completely, if a monochromatic beam with variable energy is extracted.

In 1972 a project of a medical and biological center has been started. The center will include four procedure rooms for clinics, and special rooms for radiobiology and physics. The beam will be transferred to the procedure room in question when the patient is ready for irradiation. Over 100 irradiations per day can be accomplished by that means.

Medical and biological centers, which are being designed at the JINR high-intensity phasotron and at the ITEP proton synchrotron will permit to extend considerably the possibilities of high energy proton and meson treatment and to get necessary practical experience for the wider utilization of new kinds of radiations for radiotherapy of oncological patients.

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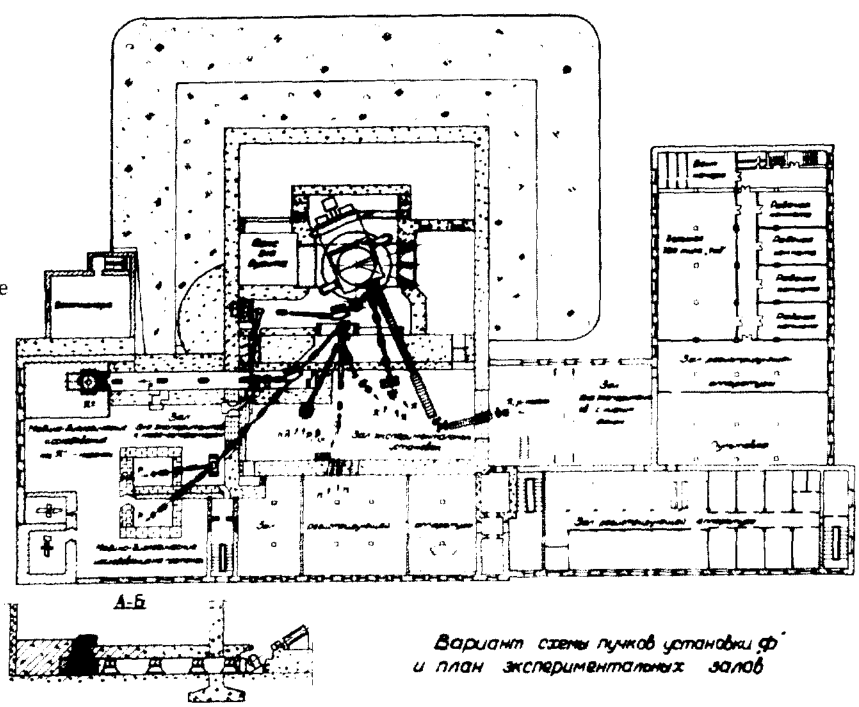

FIG. 1--
Lay-out formation equipment of therapeutic proton beam and of arrangement of the clinical room in the building of the JINR synchrocyclotron.
ВКУ - vacuum chamber of accelerator deflectors; Р - ejected proton beam with 680 MeV energy; - magnetic quadrupole lens for focusing of primary beam; ТФ - degrader; ОМ - deflecting magnet; К - collimators; ВТ - vacuum guide; МФЛПК - magnetic focusing lenses of proton channel; ЗВ - shielding door; ДА - dosimetric devices; ВК - rotating arm-chair; I - procedure room; 2 - control room; 3 - room for medical check of patients.

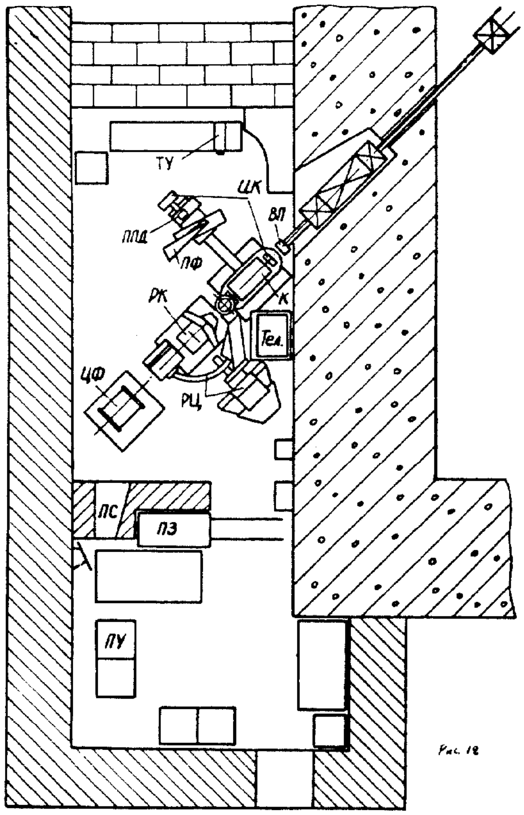

FIG. 2--Dosimetry, adjustment and auxiliary equipment lay-out in the procedure room at LNR JINR. *ВП* - vacuum guide; *К* - collimator; *ЦК* - ionization chambers; *ПФ* - movable plexiglass phantom; *ППД* - semiconductor dosimeters; *РК* - rotating arm-chair; *ЦФ* - Faraday cup; *ПС* - periscope system for patient watching; *ПЗ* - movable concrete shielding; *РЦ* - X-ray centrator with TV set; *ТУ* - TV set to watch the patient; *ПУ* - control set.

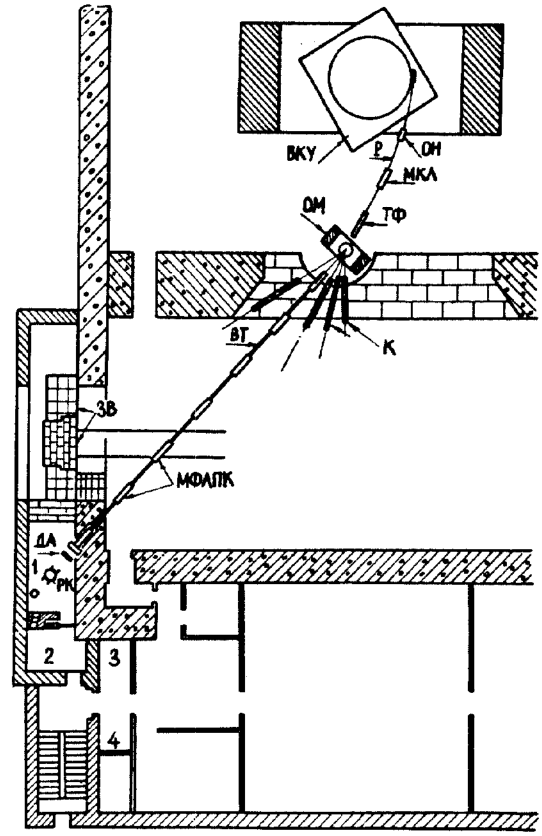

FIG. 3--Proposed variant of beam distribution and the plan of experimental halls after reconstruction the JINR synchrocyclotron. At the bottom of the drawing a vertical section of the system for transportation of the primary proton beam and a scheme of focusing of the therapeutic π-meson beam by wide angle magnetic lens.

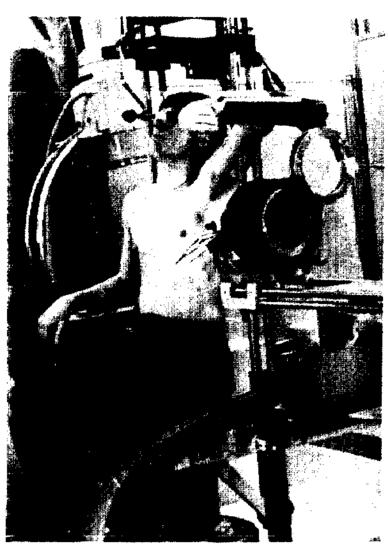

FIG. 4--Photograph showing radiation therapy of desired dose depth distribution using single ridge filter of variable thickness.

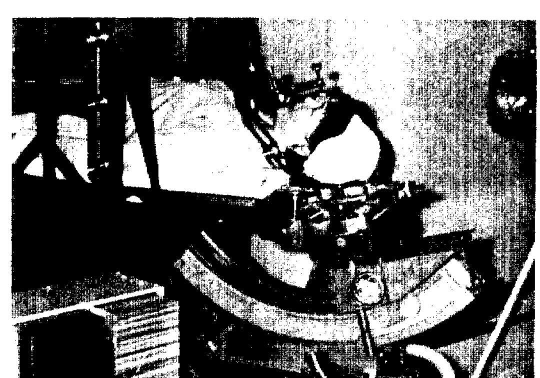

FIG. 5--Photograph showing use during hypophysectomy. Patient reclines on a table, which can then be rotated within $\pm 110^{\circ}$ around the vertical axis.