PROTON THERAPY COMPLEX WITH THREE PROCEDURE ROOMS

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Summary. Since 1969 a number of Moscow medical centers has carried out proton radiation therapy of patients with different types of deseases by ITEP synchrotron proton beam with the energy up to 200 MeV. These irradiations employing a specially extracted proton beam are used in routine practice and are made in parallel with physical research program. Two additional channels as well as two new procedure rooms have been operated since 1982. A special set-up of equipment, including clinical dosimetry devices, patient irradiation equipment (four special units) and computer-controlled systems are now installed at the facility. By present, more then 1500 patients have been irradiated. This report presents a description of physical and dosimetry equipment and techniques of irradiations. A summary table containing date about patients and clinical results is also presented.

Radiation therapy by proton beam or other Heavy Charged Particles (HCP) is carried out or is planned to be started in next future at about 10 centres in the world. Three of them are located in the Soviet Union, namely in Dubna[1], Moscow and Leningrad[2].

More than 6000 patients with different diseases have been treated by HCP beams in the world. At the end of the sixties, when this work was started in the USSR, foreign scientiest had accumulated certain experience in irradiation of small intracranial structures. Irradiation of new growths localized in other parts of human body had been carried out in small number of cases.

From the very beginning soviet clinicists considered proton beams as a means of irradiation of new growths and structures havihg different dimensions and localized in different parts of human body[3,4]. This conseption defines the development of clinical work at the 70-200 MeV proton beam of ITEP synchrotron for about twenty years. Proton irradiations are carried out here by a number of Moscow leading clinical centres*[5]. From 1969 to 1986 1270 patients received about 1500 proton treatment courses (see Table 1). At the same time techniques employed for irradiation of targets having different shapes, volume and localization, as well as the equipment for dose field forming and dose field measuring, the stands for patient positioning and shifting during irradiation and for checking and control have been developed and improved. At first the work was carried out in one procedure room equipped with devices for intracranial targets and eye tumours irradiation (first device), and for uroginecological tumours irradiation (second device).

Table 1

Radiotreatment at the ITEP synchrotron proton beam

No. / Year	1	2	3	4	5	6	7	8	9
1969	-	6			5				11
1970	7	22			20				49
1971	4	29			3				36
1972	6	30	19		8				63
1975		10	1						11
1976		10	30		1		1		42
1977		15	25			4			44
1978		14	22	2	3	8	3		52
1979		24	15	12	4	11	26		92
1980		8	3	26		17	20		76
1981		9	3	49		21	32		114
1982		7	20	41		19	26	1	114
1983		3	7	52	2	30	26	10	130
1984		13	11	113		26	40	17	222
1985		21	6	45	1	27	28	26	154
1986			2	20		15	17	6	60
Total number	17	221	164	360	47	182	217	60	1270

1-skeleton tumours irradiation; 2- sexual sphere tumours irradiation; 3- irradiation of gland with disharmonal malignant tumours; 4- combinative (p+gamma) irradiation of pituitary gland and metastases of mammary gland cancer; 5- skin melanoma and metastases; 6- malignant tumours of eye; 7- pituitary gland adenoma; 8- intracranial blood vessel malformation; 9- total number of patients.

In order to start new radiotreatment techniques and to increase the productivity of the facility (number of radiation sessions per day) additional procedure rooms were required to install new specialized equipment. Erection of the building with three procedure romms (Fig. 1) was completed at 1980.

Irradiations in the procedure rooms are carried out by turns. The beam with the ener-

* All-Union Oncological Scientific Centre of the Academy of Medical Science (AMS) of the USSR; Helmholtz Scientific Research Institute for Eye Diseases (Ministry of Public Health (MPH) of the RSFSR); Bourdenko Scientific Research Institute for Neurosurgery (AMS of the USSR); Scientific Research Institute for Endocrinology and Hormone Chemistry (AMS of USSR); Scientific Research Institute for Urology (MPH of the RSFSR).

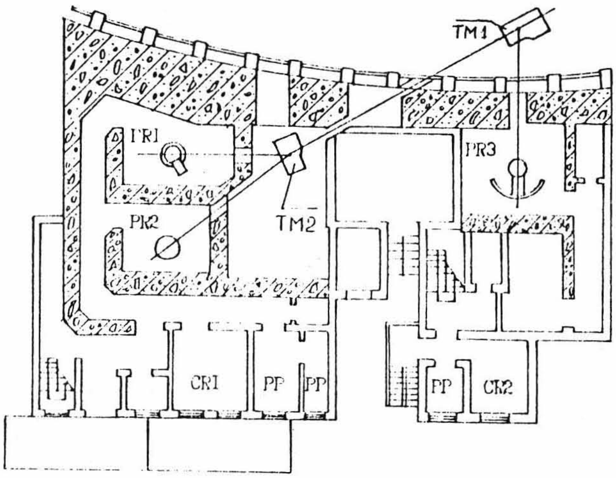

Fig.1 Plan of the complex with three procedure rooms. TM-bending magnets; PR-procedure rooms; CR-control rooms; PP-patient preparing rooms.

gy proper for irradiation session considered is kicked out from the accelerator orbit and transported through the vacuum ion quide to one of the procedure rooms (Fig.2).

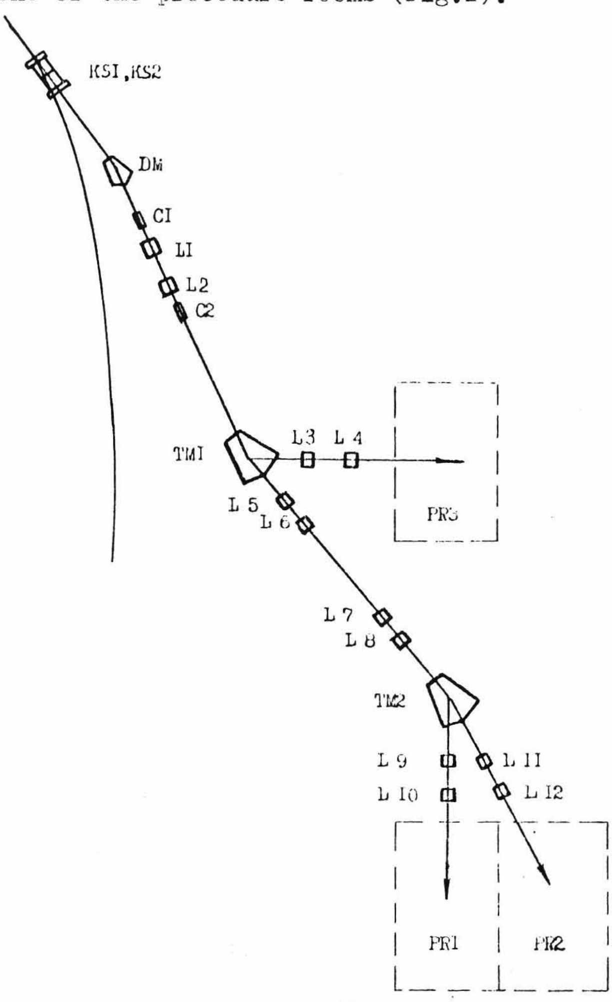

Fig.2 Diagram of proton beam transporting channels. KS-kicker sections; DM-deflecting magnets; TM-bending magnets; C-magnetic correctors; L-quadrupole lenses; PR-procedure rooms.

The beam in all the procedure rooms are horizontal, their axes are fixed at about 1.5 m above the floor. The proton beam is extracted from the accelerator in short pulses of 100 ns with 0.3 Hz repetition frequency. The beam intensity is 10^{10}-10^{11} particles per pulse. Therapeutic dose is given in a fraction of a minute in the case of one-field irradiation. If the patient is moved during the irradiations, dose accumulation time is determined by the velocity of the patient displacement with respect to the beam and increases up to 30 min. Patient positioning lasts from 2-3 to 30 min. In complicated clinical cases a special positioning session is carried out one or two days before the irradiation.

It is necessary to mention an important feature of the work organization at the ITEP accelerator proton beam. Not more then 8% of particles is taken from synchrotron orbit for medical purposes and kicked out at the energy needed for medical irradiation. The remaining beam is accelerated further for use in physical experiments. Thus optimal conditions for clinical work and attendant dosimetric and radiobiological experiments are created. Such work can be carried out every day during the whole accelerator working time not interfering with research in high energy physics. The accelerator works during five one-and-a-half monthes cycles a year with four fortnight intervals and one two-month stop.

Three specialized irradiation devices (stands) are functioning now in two procedure rooms. The patient is placed in a lying position (Fig.3).

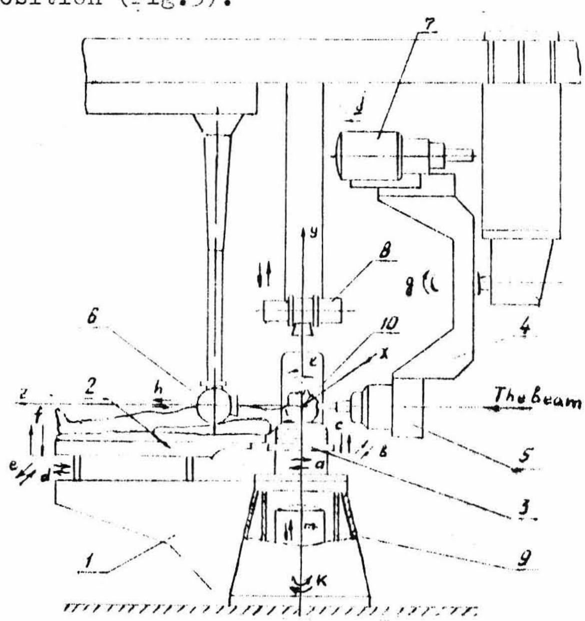

Fig.3 First procedure room equipment (stand for intracranial target irradiation). Degrees of freedom for equipment elements are shown by arrows. 1-rotating table; 2-desk for patient positioning; 3-head supporting platform with headholder; 4-turning device; 5-collimator; 6,7-side view introscopic centrator (a couple of an X-ray tube and electrooptical transducer); 8,9-frontal view introscopical centrator; 10-stereotaxic pole.

The possibility of directing the beam practically from any side of patient's head is an important feature of the device. The single shadowing part of rotation mechanism at the will of the operator can be put in a position, which leaves both sincipital and temporal parts of the scull open for beam entrance. Such stand transformation takes one or two minutes and does not alter other conditions of the equipment functioning. In contrast to the stand of the first generation two parts of introscoping centrators (X-ray tube and electrooptical transduser) are managed on the irradiation stand. It increases the patient positioning accuracy and reliability and shortens the total irradiation session time. The stand is equipped with light centrators simulating the proton beam and the introscoping centrator axes.

Possible stand movements are shown by arrows (see Fig.3). The stand provides rotation of the lying patient around the vertical axis and its head turning around the horizontal axis (the body vertebral axis). The point of intersection of the axis (the so called rotation pole) is fixed in the space being brought in line with the beam axis. The intracranial target to be irradiated is brought to the same point.

The patient's head is fixed by an individual thermoplastic mask stiffly fastend to the head supporting platform. The target is placed in the rotation pole by means of introscoping and light centrators. For the purpose, the head supporting platform is able to move in three mutually perpendicular directions. Displacement range and discretion are presented in Table 2.

Table 2

Intracranial irradiation stand displacements

Movement direction	Range	Discretion
a, d, +- Z	+- 70 mm	0.1 mm
b, e, +- X	+- 70 mm	0.1 mm
s, f, +- Y	+- 85 mm	0.1 mm
k around Y	+- 126 degrees	1 degree
l around X	+- 36 degrees	1 degree

The second procedure room is equipped with a therapeutic armchair intended for irradiation of targets located in thorax, in head and neck, and in eye targets. The layout of the stand is presented in Fig.4.

Patient fixation in a sitting position, rotation around the fixed vertical axis intersecting the beam axis, and linear displacements in three mutually perpendicular directions are provided.

When eye and orbit targets are irradiated, the head of the sitting patient is fixed by an individually adjusted mask in a special device. In more simple cases the patient is fixed without mask. The device provides the same angular and linear displacement as the armchair. The possibility of forced turning of the head around the horizontal axis intersecting with the beam axis, and the vertical rotation axis is provided additionally. The target to be irradiated is put to the point of intersection of the three axis. The second procedure room is also equiped with the introscoping centrator and a multibeam laser light centrators developed by the Central Design Office of the Academy of Medical Sciences of the USSR.

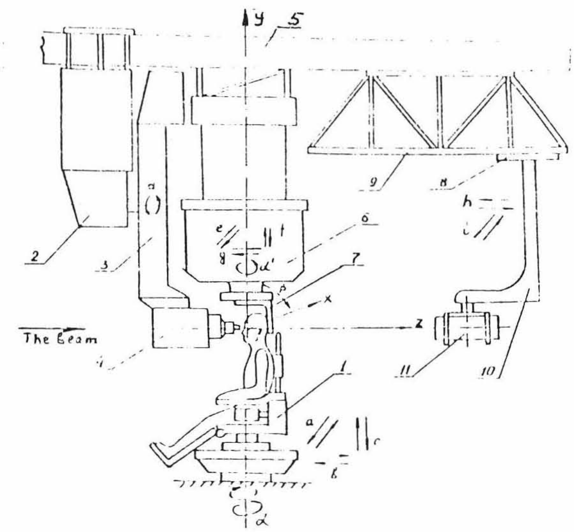

Fig.4 Second procedure room equipment (stand for thorax, neck, head, eye and orbit target irradiation). Degrees of freedom of equipment elements are shown by arrows. 1-rotating armchair; 2,3-collimator turning device; 4-collimator; 5-ceiling beam; 6-eye and orbit irradiation device; 7-head support; 8,9,10-introscopic centrator adjustment and movement device; 11-introscopic centrator (a couple of X-ray tube and electrooptical transduser).

Possible displacement range and discretion of the second procedure room equipment is presented in Table 3.

Table 3

Displacements of the stand for thorax, neck, eye and orbit targets irradiation.

Movement direction	Range	Discretion
e + x	+ 80 mm	0.1 mm
g + z	+ 50 mm	0.1 mm
f + y	+ 75 mm	0.1 mm
& around y	+ 180 grad	30 min
b around x	+ 30 grad	30 min
a + x	+ 250 mm	0.5 mm
b + z	+ 250 mm	0.5 mm
c + y	+ 800 mm	1.0 mm
& around y	+ 180 grad	1 grad

A radiotreatment stand for irradiation of target located in urogynecological sphere of lying and standing patients is now in assembly in the third procedure room.

Speaking about the dose field formation it is necessary to note that protons are extracted from the accelerator with several fixed energy values. The energy and the corresponding range of the proton beam are to be chosen more precisely by changing the thickness (not more than 4 g/cm^2) of the degrade located before the irradiated object. Depth dose distribution is formed by a ridge filter and a bolus compensating surface curvatures at the beam entrance. Dose distribution formation in transverse cross-section is accomplished by a thin scatterer which improves dose distribution uniformity, and by collimators. The general tendency in formation system development is not the selection of a good enough field from an available dose field set, as it has been up to the present, but the creation of individual dose fields for each separate clinic case.

Dose distribution and dose measuring are complicated due to high synchrotron beam pulse power. 10^{10}-10^{11} particles pass through the target in 100 ns. That corresponds to 10^{6} - 10^{8} Gy/s pulse dose rate. Monitoring of such beam by means of ionization chambers is difficult. Inductive probes (current transformers) measuring proton flux are used as monitors in irradiations[6]. Specially developed ionization chambers with small volume and gap serve for depth dose distribution measuring and for research[7]. Transverse dose distributions are investigated by the photographic film technique[8]. In dose distribution investigations photoluminescent detectors are used as well[9]. Adoptation of a commercial automatic system with semiconductor detectors to high pulse energy proton beam is nearly completed[10].

Absolute dose calibration is carried out by the induced activity method in $^{12}C(p,pn)^{11}C$ reaction. Information is translated from analogue into digital form, processed and indicated by systems working on line with the computer, when all the mentioned dosimetry methods are used.

The accuracy of our dosimetric measurements can be estimated as follows: absolute dose calibration and dose delivery $\pm 8\%$, dose distribution measuring accuracy 0.5- 1.0 mm.

The three procedure rooms complex is controlled in a large measure by computers. One can mark out some local sub-systems controlled by computers. Three microcomputers MERA/60 are controlling the equipment located in the procedure rooms as well as the beam extracting and transport devices. A sub-system for patient registration and follow up and a sub-system for processing dosimetric film information use minicomputers SM-3. Radiotreatment planning and optimization system uses minicomputer SM-4. Consolidation of local control sub-system in a general automatic system of the complex will be accomplished within next two or three years. That will enlarge the possibilities of physical and dosimetrical investigations, as well as preclinical and clinical procedure automation. Considerable improvement of reservation possibilities of each control channel shall be an especially important result of the general automation system.

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References

1. V.P.Dzhelepov, O.V.Savchenko, B.V.Astrakhan et al. "Multichamber complex of the Nuclear Problem Laboratory of the Joint Institute for Nuclear Research for using heavy charged particles", Proceedings of the first International Seminar, Moscow, 6-11 December, 1977, No.1, p.43-49.
2. B.A.Konnov, D.L.Karlin, V.D.Nizkovolos et al. "Physical-Technical complex of 1000 MeV proton therapy on the LINP synchrocyclotron", Proceedings of the first International Seminar, Moscow, 6-11 December, 1977, No.1, p.50-55.
3. Abazov V.I., Astrakhan B.V., Blokhin S.I. et al. "Use of Proton Beam in the USSR for Medical and Biological Purposes", JINR, E-5854, Dubna, 1971.
4. Goldin L.L., Lomanov M.F., Khoroshkov V.S. "Use of proton beams for medical purposes (ITEP practice)", A.I.Alikhanov Memorial Proceedings "Problems of Nuclear and Elementary Particle Physics", Nauka, M., 1975, p. 280-301.
5. Chuvilo I.V., Goldin L.L., Khoroshkov V.S. et al. "ITEP Synchrotron Proton Beam in Radiotherapy", Proceedings of the International Conference on Applications of Physics to Medicine and Biology", Trieste Italy, 30 March- 3 April, 1982, World Scientific, p. 45-67.
6. Kleinbock Ya.L. Marinsky V.M. "The Operative Measuring System of the Medical-Biological Proton Beam Intensity", Atomnaya Energiya, 37, No.7, 1974, p. 69-70.
7. Lisovets S.P., Lukyashin V.E., Shimchuk G.G. "Ionization Chamber in Proton Pulse Beams with High Dose Rate", Theses of Reports to the VII-th All-Union Workshop on dosimetry of intenseve beams of ionizing radiations, Obninsk, 1983, p.142-143.
8. Kostyuchenko V.I., Lisovets S.P., Gruz I.A., Kaplun L.Ya. "Accelerated Proton Photodosimeter", Pribory i Tekhnika Experimenta, 1984, No.2, p.23.
9. Kostyuchenko V.I., Khoroshkov V.S., "Photoluminoscent detectors ID-II in Proton Radiation Fields", Theses of Reports to the VII-th All-Union Workshop on dosimetry of intensive beams of ionizing radiations, Obninsk, 1983, p. 147.
10. Rikner G., Grussel E., Lukyashin V.E., Lomanov M.F., Kostyuchenko V.I., "Radiation damage and dose rate linearity response of a P-Si detector in 70 MeV protons", Nuclear Instruments and Methods, v. 217, No. 3, 1983, p. 501.