

## THE PROTON THERAPY SYSTEM FOR MGH'S NPTC: EQUIPMENT DESCRIPTION AND PROGRESS REPORT

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At the beginning of 1994, the Massachusetts General Hospital (MGH) of the Harvard Medical School in Boston, MA, USA, a pioneer in proton therapy since 1959, selected a team led by IBA to supply the proton therapy equipment of its new Northeast Proton Therapy Centre (NPTC). The IBA integrated system includes a compact 235 MeV isochronous cyclotron, a short energy selection system transforming the fixed energy beam extracted from the cyclotron into a variable energy beam, one or more isocentric gantries fitted with a nozzle, a system consisting of one or more horizontal beam lines, a global control system including an accelerator control unit and several independent but networked therapy control stations, a global safety management system, and a robotic patient positioning system. The present paper presents the equipment being build for the NPTC, with a particular emphasis on the status of the cyclotron construction.

### 1. A cyclotron based proton therapy system

IBA has integrated the technologies developed for its low and medium energy cyclotrons into a high energy system dedicated to proton therapy. The objective was to meet all the clinical specifications of a state-of-the-art proton therapy facility in the most simple, reliable and cost effective manner. The main elements composing the proton therapy system for the NPTC are the following:

-a 235 MeV isochronous cyclotron, able to deliver beams of up to 1.5  $\mu$ A, but hardware-limited at 300 nA in order to limit the maximum possible dose rate to the patient.

-an energy selection system transforming the fixed energy beam extracted from the cyclotron into a variable energy beam (235 to 70 MeV range) provided with energy spread and emittance limitations and verification.

-a beam transport and switching system connecting the exit of the energy selection system to the entrance points of a number of gantries and fixed beam lines.

-one complete isocentric gantry (the installation of a second one is foreseen as a possible upgrade) fitted with a nozzle, and a system consisting of two horizontal beam lines, the large field one being equipped with a nozzle. For beam

spread-out on the gantries and on the large field line, both beam scattering and beam wobbling are available.

-a robotic patient positioning system. Combined with the gantry, the equipment provides complete 4p coverage of the patient.

-a global control system including, in addition to an "accelerator control unit", several independent, but networked "therapy control stations". Through the network, each of these irradiation control systems can also take control of the accelerator control unit controlling the cyclotron, the beam line and the gantry optics.

-a global safety management system independent of the control system. This safety management system uses a combination of hardwired interlocks and independent PLC's to achieve a safety level meeting applicable standards.

Additional details concerning this system are given elsewhere<sup>1,2,3,4</sup>. The advantages of this system, and in particular of the choice of a cyclotron for proton acceleration, are related to its simplicity, reliability, operability, safety and maintainability<sup>2,4</sup>. Moreover, the system is scanning ready. Indeed, the high intensity, continuous extracted beam can be intensity controlled from the ion source within 15  $\mu$ sec turn on/turn off time, and only 30  $\mu$ sec separate the time of the beam living the source and

reaching the patient. The beam is, for these reasons, perfectly suited for beam scanning and wobbling. The high available intensity easily allows respiration gating without extending treatment times, even for very large fields.

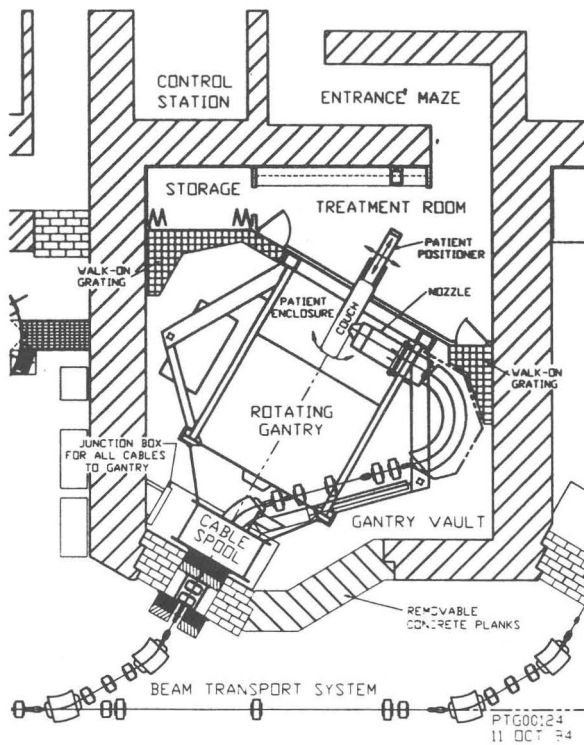


Figure 1: Plan view of a treatment room

## 2. The IBA team and the status of the NPTC project

The cyclotron steel was cast in August 1994 and the machining started in October 1994. The cyclotron main coils and harmonic coils were delivered to IBA at the end of January after factory inspection and testing. The mapping of the magnetic field started in June 1995. The presently available results show that the measured magnetic field is in complete agreement with the calculations, thus confirming the 235 MeV energy expected for the extracted beam. Preliminary tests were performed on the ion source, demonstrating that the beam turn on and turn off time (20 to 80 %) by the ion source will be about 1  $\mu$ s. This performance is even better than what was initially foreseen (10 to 15  $\mu$ s). The first beam is expected to be produced, in the IBA factory, in March 1996. The final design of the other parts of the system is foreseen to be completed by the end of this year. The building should be ready in November 1996 and the equipment delivery and installation will start at that date. The system acceptance tests on site are expected to be performed in October 1997, and the first patient should be treated in April 1998.

Four other papers presented to this conference will cover in more detail the recent developments in RF design and construction (poster N° P1-35), on beam dynamics (poster N° P2-22), magnetic field mapping and shimming (poster N° P1-29), and magnetic system design and construction (poster N° P1-28).

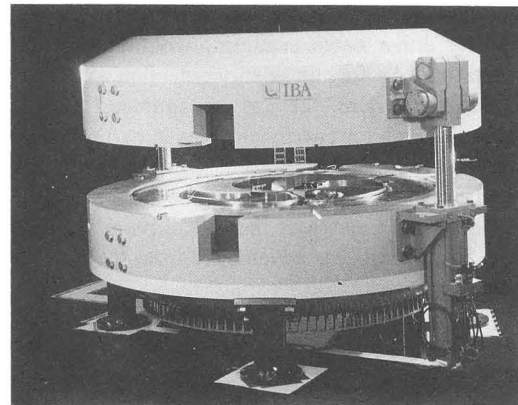
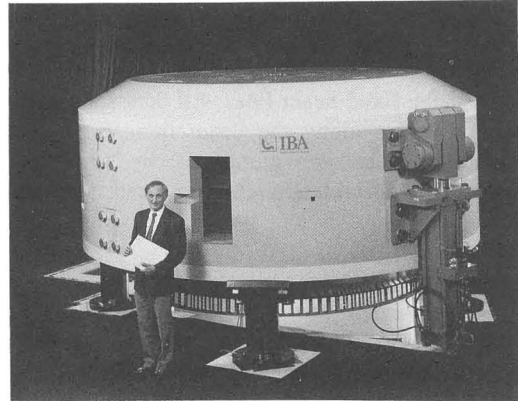


Figure 2: IBA's 235 MeV cyclotron for proton therapy. This cyclotron splits at the median plane allowing easy maintenance

IBA is the prime contractor and is in charge of the system integration, the accelerator and the control system. General Atomics is responsible for the beam transport, the gantries and the patient positioner, while Sumitomo Heavy Industries is in charge of part of the accelerator design, design review, and RF cavities construction. A number of specialists well-known for their competence in special fields were asked to act as consultants to the team.

## 3. The energy selection system

The energy variability of the system is achieved by means of a carbon wedge used as an energy degrader. As a result of the energy degradation, there is an increase in emittance and energy spread. Emittance slits are therefore used to define

the emittance of the transmitted beam, while an analysing magnet system limits the energy spread. Energy changes are completed in two seconds, using laminated magnets and quadrupoles.

**4. The beam transport system**

The beam transport and switching system connects the exit of the energy selection system to the entrance points of the gantries and the fixed beam lines. All bends are achromats. At strategic points along the beam transport system, the beam characteristics are monitored by grid ionisation chambers. This information can be used for automatic tuning.

**5. The gantry**

The NPTC equipment includes one complete isocentric gantry (the installation of a second one is foreseen as a likely upgrade). The gantry is an achromatic system. Its optics can be tuned for either beam scattering/wobbling or for pencil beam scanning. As for the energy selection system and the beam transport system, the use of laminated magnets and quadrupoles allows for energy changes in two seconds.

Instead of a huge “squirrel cage” - like configuration, the proposed concept for the rotating structure breaks it down in a series of individual parts. This concept, illustrated in figure 3, has advantages from the point of view of building costs reduction.

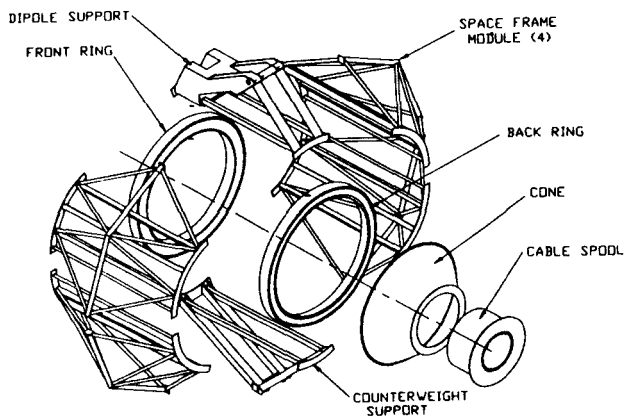


Figure 3: Proposed configuration of the gantry structure.

**6. The nozzles**

The isocentric gantry and one of the horizontal beam lines, the large field one, will be fitted with nozzles. The functions of the nozzles include the 3-D beam shaping to irradiate the target volume at a constant dose, the beam monitoring and

dosimetry, the help for patient positioning and field alignment verification, and the support of patient specific devices. The spreading techniques provided by the IBA nozzle are the double scattering for small to moderate fields, and the wobbling technique for the largest and deepest fields.

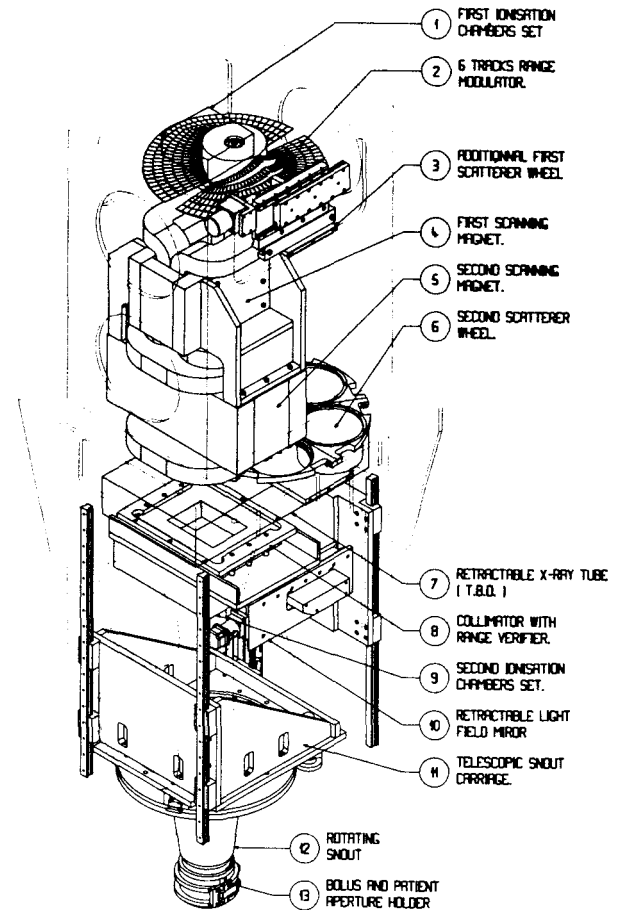


Figure 4: Nozzle components

The nozzle is compatible with a future upgrade to pencil beam scanning. The proposed design provides a static lateral beam spreading system, based on a double scattering method. The provision of 6-position barrels for the two scatterers and multitrack, scattering compensated range modulating wheels combined with the gating of the beam in synchronism with the wheel rotation allow versatile and reliable operation at a large span of field areas, ranges and modulation depths with optimum dose uniformity. A 1m long space, just after the scatterer/range modulator, is used for the installation of the X-Y beam sweeping magnets appropriate for beam wobbling. The nozzle is equipped with several dose monitoring devices (transmission ionisation chambers) at different locations in the beam. The snout of



the nozzle is telescopic to allow the final collimator and the bolus to be placed as close as possible to the patient, minimising deterioration of the penumbra.

## 7. The patient positioning system

The patient positioner which will equip the gantry room is a robotic system allowing rotations around a virtual axis. It offers high precision, stability and reproductibility. Combined with the gantry, the equipment provides complete  $4\pi$  coverage of the patient.

The primary function of this system is to precisely position a patient lying in the supine position, such that beam can be directed at any treatment point and at any treatment angle. Coupled with the gantry which provides  $360^\circ$  rotation of the beam about one vertical axis, the patient positioner must provide a minimum of four axis of motion (three translations and one rotation) to accomplish this objective. Isocentric rotation of a target on the couch about isocenter must be accomplished using compound motions of the couch translation axes to carry the couch turntable in an arc such that the couch rotation axis traces a circle of constant radius about the point of rotation. The dashed lines in figure 5 show the range over which the couch rotation axis must move to cover motions for both couch rotation and patient anatomy positioning.

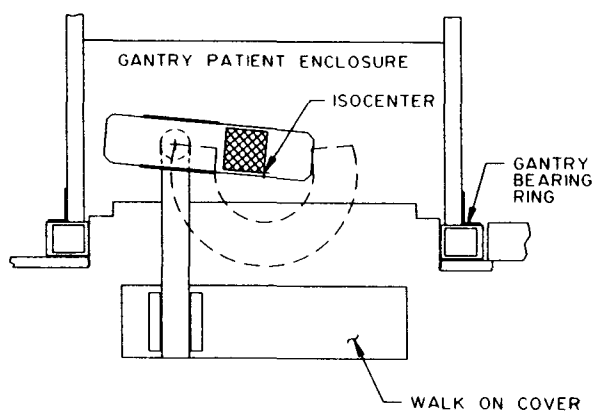


Figure 5: Translation motion envelope of the couch rotary axis

The system is also required to make small corrections in treatment angle and position by small corrections of any axis. This requirement adds two additional rotation axes due to singularities in a four axis system (pitch and roll capability). The need to locate the support structure outside the gantry, coupled with providing clearance for the nozzle that rotates  $360^\circ$  about a vertical plane, forces large cantilever distances from the patient positioner support to the patient/equipment centre of gravity. This cantilever distance, combined with the large number of axes, provides challenges

to the designer. Present estimations foresee a reproducible error of 4 mm and a non-reproducible error of 0.2 mm. The customer's requirement being a precision of 0.5 mm, software compensation will be used.

## 8. The control system

The control system plays an important role in the operation of a system like a proton therapy system. This implies that the architecture has to guarantee flexibility and modularity to simplify testing and debugging tasks during the development and to allow future expansions of the system. A control system designed as a network of modules, each one dedicated to a pre-defined point of the system, represents an ideal answer to these demands and may be easily implemented using commercial standard products. By using commercial tools, the attention may be moved from the home made development basic components to the definition of general rules for the integration of commercial products in a suitable environment.

The NPTC Control System is developed on three levels: the equipment control level where we have the process controllers close to the equipment, the management level, which is responsible for the operation of a set of high level functions, and the user interface level with the operator interface. Networks provide the connection between the different levels and between units at the same level. The process controllers, using VME card cages or industrial PLCs, are connected through a highly reliable serial bus (CANBus). An Ethernet network allows the connectivity from the equipment control level to the user interface level and the database system running on UNIX-based work stations. The software engineering methods and rules applied to the development of the control system follows good manufacturing practices and will be compliant with FDA requirements.

## References

1. Y. Jongen *et al*, "Progress report on the IBA-SHI small cyclotron for cancer therapy", *Nuclear Instruments and Methods in Physics Research B79* (1993) 885-889
2. "The IBA Proton Therapy System", Brochure describing the Proton Therapy System proposed by Ion Beam Applications s.a., available upon request
3. Y. Jongen *et al*, "New features in the design of the IBA-SHI proton therapy facility", Proceedings of the EPAC 94, London, May 1994
4. Y. Jongen and P. Cohilis, "The proton therapy system for the NPTC", 4th European Conference on Accelerators in Applied Research and Technology, Zürich, August 29 - September 2, 1995