The Northeast Proton Therapy Center at Massachusetts General Hospital

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Massachusetts General Hospital, Northeast Proton Therapy Center

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The Northeast Proton Therapy Center (NPTC) is currently being designed and constructed for completion in 1998. The goal of the project is to provide the Northeast region of the United States with a state of the are proton therapy facility which has the capabilities needed for the conduct of innovative research, and proven treatments using proton therapy. The NPTC is being built on the Massachusetts General Hospital (MGH) main campus. MGH has contracted Bechtel Corporation to coordinate the design and construction of the civil component. Ion Beam Applications (IBA) who is teamed with General Atomics (GA), is responsible for the equipment. Detailed discussion of aspects of the IBA cyclotron and equipment can be found in accompanying papers in this conference. Aspects of the facility goals, design, and status will be presented.

1. INTRODUCTION

Massachusetts General Hospital, in collaboration with the Massachusetts Eye and Ear Infirmary, has been treating patients with high energy proton beams for cancer and other diseases. This work, based at the Harvard Cyclotron Laboratory (HCL), has been ongoing for more than 30 years. The success of the current program has created a pressure for capabilities which cannot be satisfied by the HCL. The promising results of the existing treatments have prompted a desire to initiate protocols at new sites. This calls for a facility which is modern, integrated with the hospital services, capable of satisfying regional needs and has the technical capacity to support more advanced treatment techniques. Such a new facility, the Northeast Proton Therapy Center, is under construction on the Massachusetts General Hospital (MGH) campus. This facility is funded by the Massachusetts General Hospital and the National Cancer Institute. The work described herein is the result of many contributors from within the project team including MGH, IBA, Bechtel, HCL and consultants.

II. Clinical Performance Specifications

At the HCL the cyclotron is limited to a maximum energy of 160 MeV. Protons of this energy can penetrate only 16cm in soft tissue and are limited to the treatment of head and neck tumors and some few, relatively superficial, tumors at other sites. In order to reach deeper-seated tumors in all body sites an energy of at least 235 MeV is needed. Also the HCL treatment beams are oriented horizontally which makes it difficult to position many patients for their treatments and essentially impossible to treat some patients other than in a sitting or near-sitting position. For more effective treatment it is necessary to treat patients with multiple beams which enter the supine patient from optimum directions.

In the more than 30 years of clinical work at HCL, over 6,000 patients have been treated. Approximately 56% of the large field patients and 48% of the uveal melanoma patients treated at the HCL reside in Massachusetts and neighboring states in the northeastern US. The number of referrals drops off at a radius beyond 250 miles and becomes essentially flat which includes patients from foreign countries. Within this 250 mile radius is a population of over 38 million. The NPTC is being designed to accommodate the projected regional needs.

Protons have very different physical characteristics from the high energy x-rays used in conventional radiation therapy. Protons of a given energy penetrate a well-defined distance into the patient and then come to rest and deposit more energy (dose) near the end of their range than upstream of it. As a result, when protons are directed at a tumor, they deliver virtually no dose beyond the tumor, and less dose than do x-rays upstream of it. This can lead to very favorable dose distributions which can allow more dose to be delivered to a tumor. In order to take advantage of these properties, it is necessary that the system delivering the beam preserve the precise nature of the proton dose distribution. Thus there must be stringent constraints upon the flatness of the dose distribution and the sharpness of the fall-off at the extremes of the dose volume (i.e. in the transverse direction the fall-off extent is called the penumbra and in the longitudinal direction it is called the distal fall-off).

Clinical Specifications

Parameter	Specification
Range in Patient	32 g/cm^2 Max 3.5 g/cm^2 Min
Range Modulation	Steps of < 0.5g/cm^2
Range Adjustment	Steps of <0.1g/cm^2
Avg. Dose Rate	25cmx25cm modulated to 32g/cm^2: 2Gy in < 1min
Spill Structure	Scanning Ready
Field Size	Fixed >40cmx40cm Gantry >40cmx30cm
Dose Uniformity	2.5%
Effective SAD	~2.5m
Distal Dose Fall-off	<0.1g/cm^2
Lateral Penumbra	<2mm

Facility Specifications

Parameter	Specification
Time for startup from standby	<30min
Cold Startup Time	<2hours
Time for Shutdown to Standby	<10min
Time for 'Manual' Setup in one room	<1min
Time for Auto Setup in one room	<0.5min
System Availability	>95%
Dosimeter Reproducibility	1.5% (Daily) 3.0% (Weekly)
Time to Switch Rooms	<1 min
Switch energy in one room	<2 sec
Radiation Levels	ALARA

The above requirements lead to a list of 'clinical performance specifications' for the facility which are summarized in the above table.

III. MAGNETIC GANTRY REQUIREMENTS

The required proton therapy equipment can be divided into eight subsystems. The equipment is being built by Ion Beam Applications (IBA) of Belgium. These subsystems include:

3.1 A Fixed Energy 235 MeV, CW Cyclotron Accelerator:

The IBA Cyclotron will be capable of up to 300 nA delivered continuously. The stable continuous nature of the beam extracted from the cyclotron should prove to be a advantage for use with scanning proton beams. The dynamic range of the delivered current will be over a factor of 1000 with the speed capability of controlling this current variability measured in tens of microseconds. The Cyclotron magnet and coil construction is complete and has achieved a maximum field of 3.2 Tesla, which exceeds the NPTC requirements. Below shown in figure 1 is a photo of the cyclotron at IBA which is presently being field mapped.

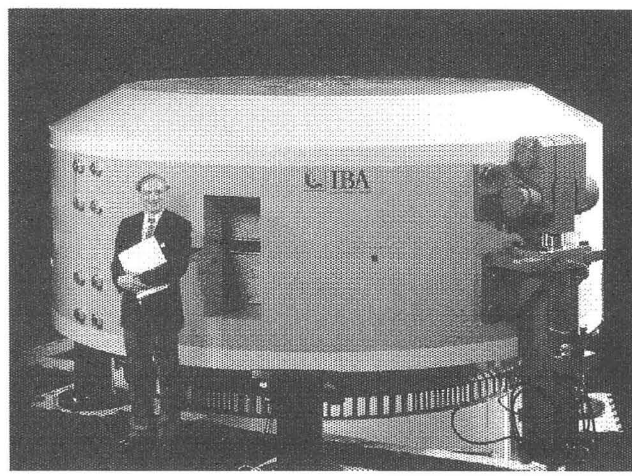


Figure 1. IBA C235 Cyclotron at the Factory

3.2 An Energy Selection system (ESS) including a degrader and energy analyzer:

The ESS includes a degrader which is a material of variable thickness intercepting the proton beam used to degrade the energy of the beam. An adjustable collimator downstream of this degrader is used to limit the emittance transmitted to the remainder of the beam line. This beam is then energy analyzed in an achromat which also includes slits to limit the proton beam momentum spread transported by the rest of the system. Once the energy analysis is complete, the beam is directed to treatment rooms.

3.3 Beam Lines (BTS) directing the Energy Selected beam to the treatment rooms:

The beam lines provide the required focussing and achromatic bends to deliver the beams to each of three treatment rooms. A portion of the beam line is shown below in figure 2. At least one of the rooms will contain an isocentric Gantry. A beam with twiss parameters equal in both planes is presented to the gantry optics so that the beam exiting the Gantry will be independent of the Gantry orientation.

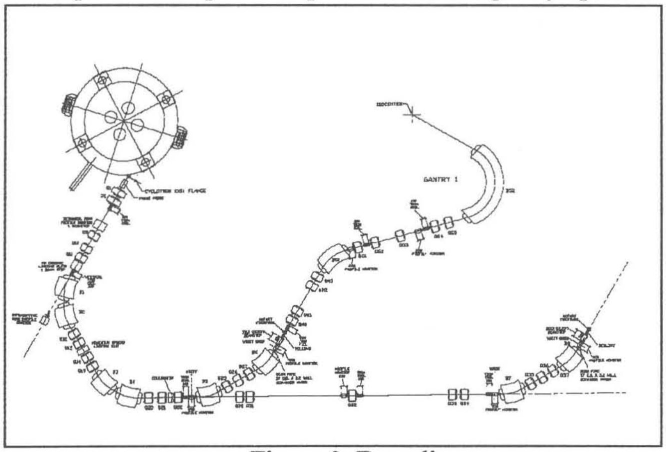


Figure 2. Beamline

Within the third treatment room, the beam is split futher into three beamlines allowing a total of five treatment stations in the facility.

3.4 Gantries:

The Gantries will be conventional gantries in the sense that all the bends are in the same plane. It will be capable of over 360 degrees of rotation about an isocenter with the virtual source about 2.3 meters from the isocenter.

The Gantry support structure is assembled in the Gantry room and employs a space frame design for weight reduction while maintaining a high rigidity. The Gantry and Nozzle assembly will be designed to point the beam to within a 1 mm sphere for all Gantry orientations.

The beam lines and Gantry are being designed by General Atomics (GA) of San Diego Californian, a subcontractor to IBA. The subsystems are in the Final Design phase.

3.5 Beam Delivery Systems (Nozzles):

The beam delivery system includes a passive scattering system [1] and a wobbling system [2,3]. The wobbling will be accomplished using a slow raster scanning technique with beam spread by a single scatterer. The Wobbling system is used to meet the field size specification without increasing the beam energy to that which would be required if double scattering were use to achieve the maximum depth specification simultaneously with the maximum field size specification. A schematic of the Nozzle is shown in figure 3.

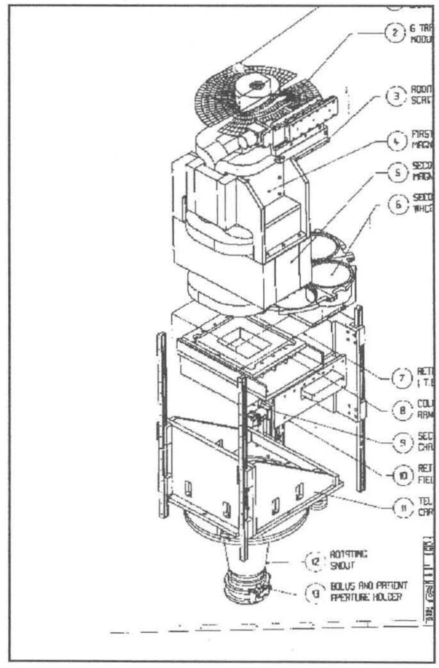


Figure 3. Schematic of Nozzle Components

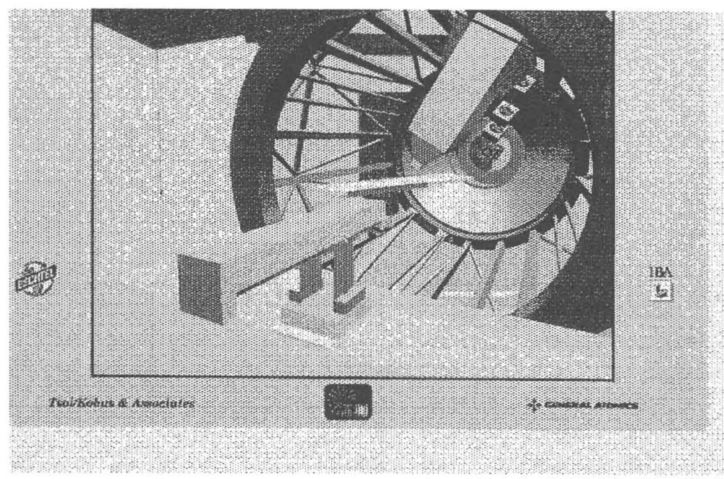


Figure 4. Treatment Room view of Gantry, Nozzle and Patient Positioning System

3.6 Patient Positioning System:

The Patient Positioning System (PPS), shown in figure 4,will hold the patient securely in the supine or prone position, and permit proton beam entry from almost any oblique direction, without danger of collision with the gantry or nozzle. The PPS allows 3 axis positioning as well as rotation and pitch and roll. This arrangement is necessary considering the cantelevered requirements. The accuracy of directing the beam to the desired location is critical. The PPS and Gantry system will be capable of allowing accurate and reproducible alignment of beam to patient within +/- 0.5mm.

3.7 An Computer Control System:

A control system will be able to perform the rapid beam switching, automatic setup and shutdown of the entire system. It will provide the required monitoring of the equipment and the safety system. The design calls for operation without an accelerator operator. However provision is made for comissioning and diagnostics as necessary.

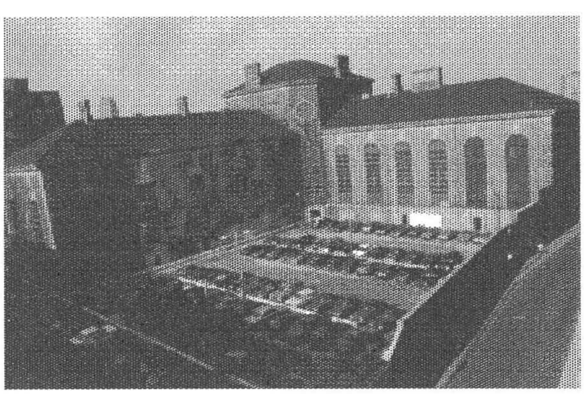
The safety of the equipment is supervised by the computer control system.

3.8 A Safety System:

The Safety system is dedicated to the safety of personnel via the prevention of accidents. It is a hardwired system which is monitored by the computer control system, but does not rely upon software for its operation.

IV. NPTC BUILDING

The NPTC building houses the proton therapy equipment and related program space such as clinical space and administrative space. It will provide approximately 23,000 net square feet of program space including three clinical treatment rooms, accelerator equipment, and offices. The treatment floor of the building will be underground and pits to accommodategantry rotation extend below that floor. The facility will be designed so as to be capable of subsequent expansion to four treatment rooms, three of which can contain gantries, the remaining room being a fixed horizontal field room which can be used for the



treatment of head and neck sites and steriotactic radiosurgery. The building will be constructed on the

Figure 5. Site of NPTC Building

Hospital site in the parking lot shown in the accompanying photo shown in figure 5.

Once completed the NPTC building will become part of the main campus of the Massachusetts General Hospital as

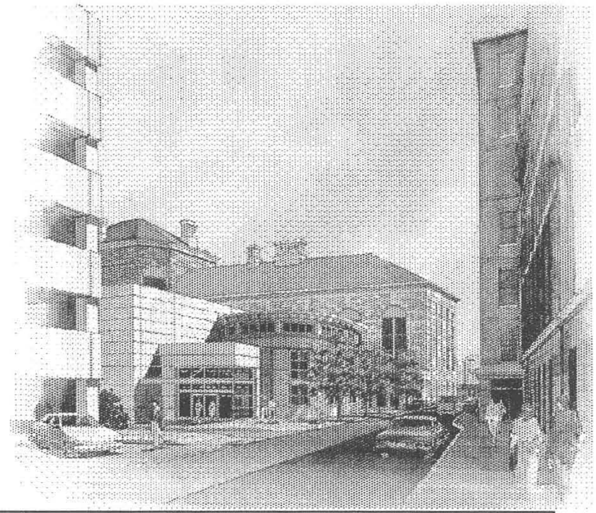


Figure 6. View of Completed NPTC

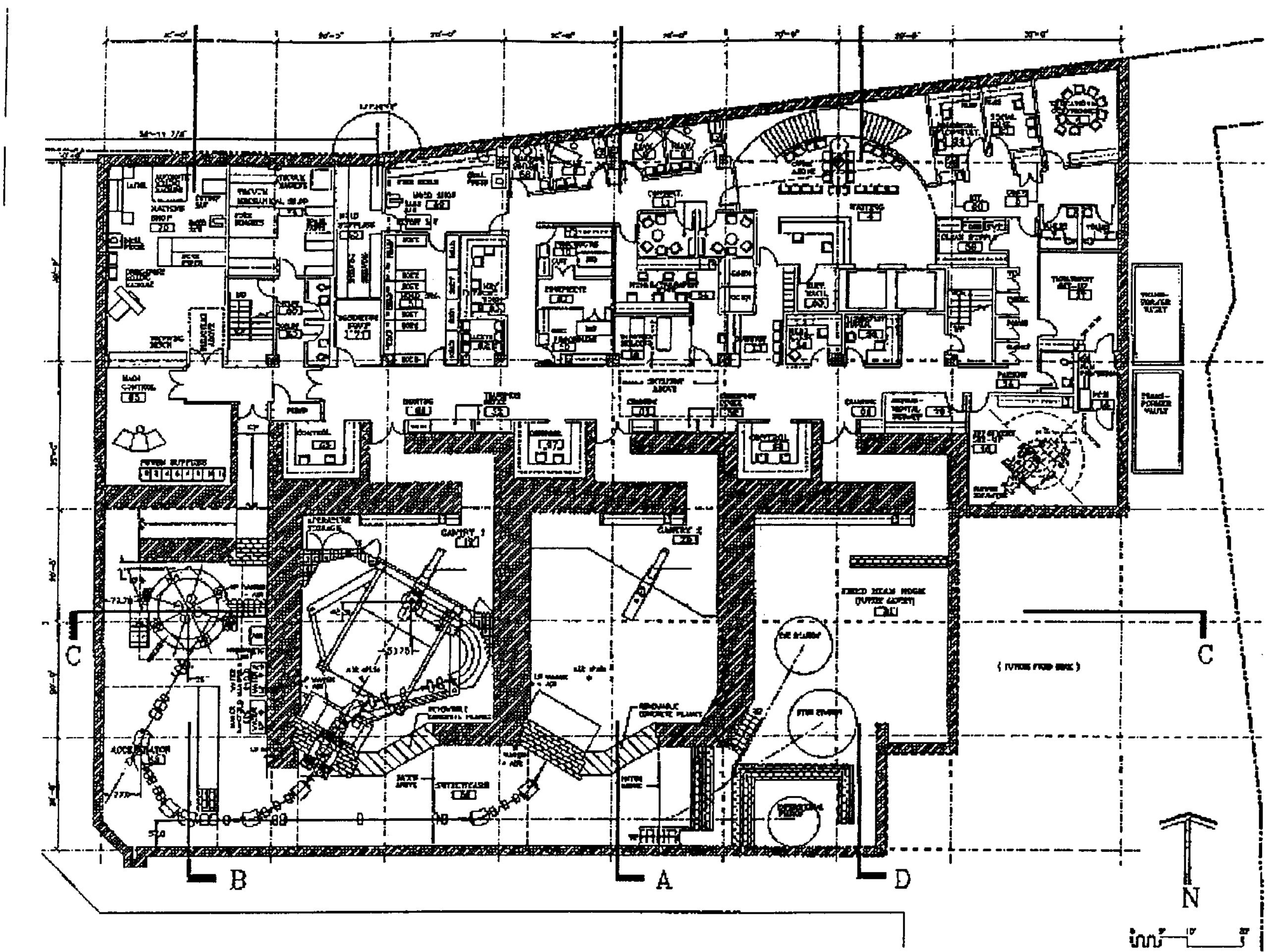
in the rendition shown in figure 6.

The lower level Layout of the building is shown in figure 7 below. The lower level contains the accelerator, treatment rooms and some equipment support space. It also includes clinical space for patient examination and care. The ground level contains administrative, staff and miscellaneous support space as well as aspects of equipment support and clinical space.

The NPTC space programming underwent a rigorous optimization procedure and the space remaining is probably as lean as possible. This is evident in comparisons with other facilities. However, the spread in the data is not large and it is interesting to note the similarity in relative program area among the projects.

V. FACILITY PROCUREMENT STRATEGY

To ensure the project's success, an organizational structure was developed that provides broad-based participation both within and from outside of MGH. A small, but broadly-experienced and focused NPTC management staff provides both day-to-day and long term direction and oversight of the project. Expert consultants are retained to provide services as needed.



The NPTC contractors were chosen from a group of competitive bids using a peer review process. This review process continues during the facility design and construction. The equipment is being procured through a fixed price contract. The building contract has developed a maximum guaranteed price.

The building design was continually reviewed by Hospital groups and groups from the National Cancer Institute throughout the design process.

The project is structured to be a true team effort. All participants are working toward the goal of producing a first class proton therapy system.

References

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[2] B. Larsson, L. Leksell, B. Rexed and P. Sourander, Acta Radiol. 51, (1959) 52.

[3] W.T. Chu, S.B. Curtis, J. Llacer, T.R. Renner and R.W. Sorensen, IEEE Trans. Nucl. Sci. NS-32, (1985) 3321.