A PROTON THERAPY FACILITY PLAN

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ABSTRACT

A dedicated proton beam therapy facility has being designed. Its first plan was made in 1988 with a synchrotron as its main accelerator. A new plan based on the small SHI-IBA cyclotron is being made. It has two treatment rooms, one is equipped with a rotating gantry, the other with horizontal and vertical fixed beams. Specifications for proton beams were reexamined based on the energy and field size statistics of PMRC clinical trials. Former design goals of 230 MeV and 20 nA are supported. A double scatterer system, in which the second scatterer consists of a central disk and a peripheral ring, will give flat proton distributions in a region of 20 cm in diameter. Efforts are being made to keep the cyclotron building wall 2 m thick.

1. INTRODUCTION

To improve conventional radiation therapy with photons and electrons, several modalities have been investigated. They are divided into two categories, low LET radiation and high LET one. Neutrons, heavy ions and π^- are high LET radiations which have larger biological effects than low LET ones. Proton beams are much different from photons and electrons in point view of physics research, however, they are classified to low LET's as well as photons and electrons in radiation biology. However, they have a big advantage over photons or electrons in clinical purposes. Dose of photons or electrons decreases almost monotonically when they penetrate in human body. Dose distribution of high energy proton beams in water and also in tissue is characterized with plateau and Bragg peak. Almost constant low ionization occurs in plateau for high energy protons whereas sudden high dose appears at the end of proton range as shown in Fig. 1. This is a favorable property for deep-seated cancer therapy [1] because of sufficient dose for cancer with lower dose in normal tissue between body surface to the cancer and with no dose in normal tissue behind the cancer. The low LET characteristic was thought to be a disadvantage of proton beams at the beginning of new modality search because of high OER (oxygen enhancement ratio), but it ensured their quick recognition as a new radiation therapy modality because their acute and late effects are easily estimated with huge amount of experiences on conventional radiotherapy. Recent development of diagnostics and modern treatment planning with computer prepared practical use of

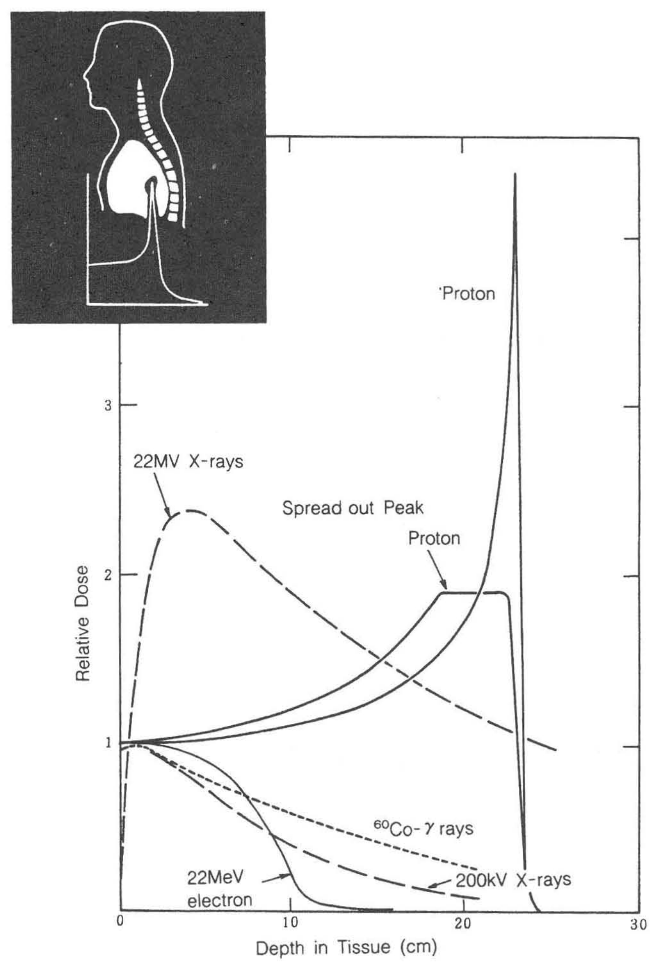

Fig. 1 Comparison of depth-dose distribution.

proton beams.

To confirm the potentiality of proton beams, a clinical therapy facility, PARMS (Particle Radiation Medical Science Center) was built and clinical trials were started at Tsukuba in 1983. The fast-extracted 500 MeV Booster beam of KEK Proton Synchrotron Complex is degraded to 250 MeV with a graphite degrader and guided to treatment areas[2]. Because the clinical results are so promising, a dedicated proton beam therapy facility plan has been made since 1988. Its design goal of proton energy and intensity were 230 MeV and 20 nA and these will be reviewed later. The facility will be built next to the conventional radiation therapy building of the University Hospital. A linear accelerator, a cyclotron or a synchrotron can be used for the beam specifications.

A synchrotron was chosen as the main accelerator in the first plan [3,4]. Many high energy synchrotrons have been built so that little R&D is required for the dedicated machine. The proton energy can be variable and protons can be extracted either in fast-extraction or slow-extraction modes.The protons are potentially extracted without loss in the fast-extraction mode and with around 90% efficiency in the slow-extraction mode. The former provides a possible way of detecting Bragg peak in the body during irradiation[5] and the latter is needed for advanced raster scan of the beam in the future. Total weight of the magnets is much less than 100 tons. In fall of 1991, SHI Japan and IBA Bergium jointly disclosed a commercially available small cyclotron for proton beam therapy in a hospital. A new plan based on this cyclotron is being made.

2. PROTON BEAM THERAPY FACILITY PLAN

No dose-rate effect for therapy is expected to appear between CW beams and fast-extracted beams of a synchrotron. Thus the time structure of the beam is selected by an accelerator, a beam delivery system or other factors such as Bragg peak detection mentioned above. The SHI-IBA cyclotron is 4.3 m in outer diameter and 2.1 m high[6]. Its accelerator room is smaller than that of the synchrotron, and this make the cyclotron attractive with a simple magnet power supply for hospital use. A cyclotron delivers usually CW beams. They will be suitable for advanced 3D beam scan in the future if they are switched on and off quickly or their intensity is regulated properly with a modern external ion source. At the present, the beam is spread by a scatterer of 6 mm thick Pb plate and shaped by a multi-leaf slit made of 5 mm thick brass plates in transverse plane at PMRC which succeeds PARMS. Its Bragg peak is spread out by a ridge filter and distal peak is shaped by a bolus. Although this passive method needs to make a bolus for each direction of irradiation of each patient, it has no preference for beam time structure.

In the new facility, a rotating gantry will be installed in one treatment room, while the other room will be equipped with two isocentric fixed beams, one is horizontal and the other is vertical. Passive beam delivery system is assumed because of its dependability. To reduce the rotating gantry size, "ex-centric" system is being studied, where a patient and a beam delivery system with some magnets rotate simultaneously around an axis.[7,8] If necessary space was assumed for patient setting by MDs and/or therapeutists, the rotating gantry did not reduce as expected before. Tentative facility layout is shown in Fig. 2. An alternative is an isocentric gantry with a smaller field size, which is not necessary to be same as that of the fixed beams. Field sizes and other properties used for therapy at PMRC in 1991 are surveyed to design the proper field size.

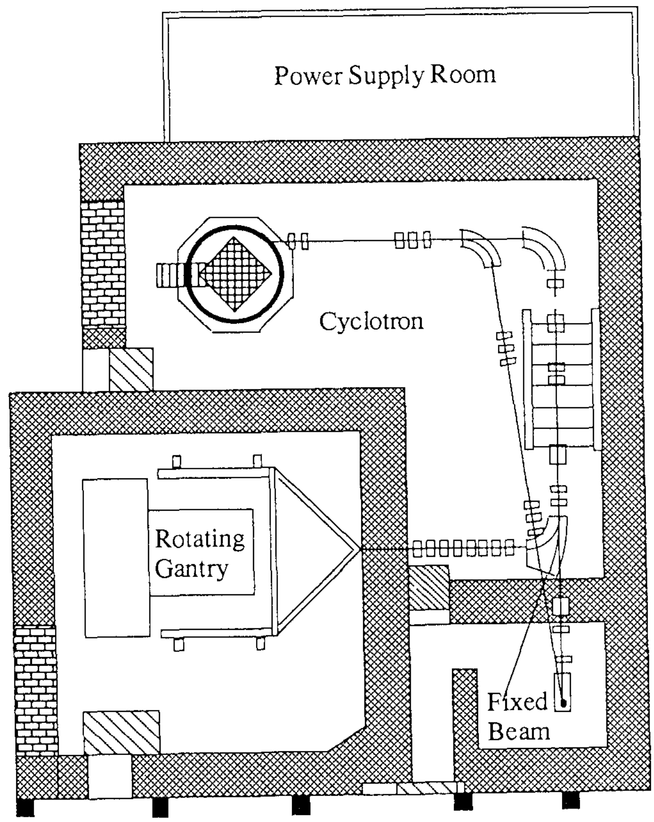

Fig. 2. Preliminary layout of proton beam therapy facility with a 230 MeV cyclotron as the main accelerator.

3. FIELD SIZES, ENERGIES AND SOBP USED IN 1991

50 patients of liver, lung and other cancers were treated with proton beams in 1991 at PMRC. There are horizontal and vertical irradiation ports. The totals of port selection are 121, in which 56 are horizontal and 65 are vertical. Patients are irradiated 10-30 times with every selected port (fractionation). The maximum field size and the integrated port selection

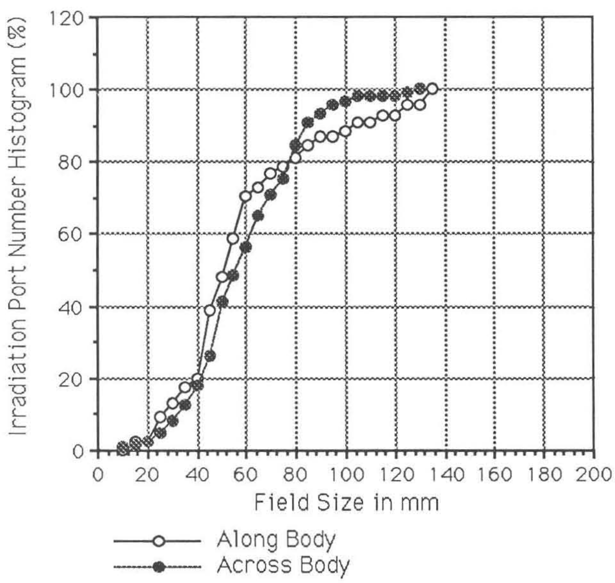

Fig. 3 Irradiation port selection histogram to differ ent field sizes for 50 patients treated in 1991. The totals are 121.

number are shown in Fig. 3. Breath-synchronized irradiation was applied when it was effective.The port selection numbers are summed up separately for along body and across body, but no big difference between them. It is found that all patients were treated with field sizes of less than 14 cm and 90% were treated with field sizes of less than 10 cm. If the beam is spread axial-symmetrically, a 20-cm diameter field covers all these sizes.

The maximum proton energies on patients and retated SOBP (Spread-out Bragg Peak) are plotted in Fig. 4. The

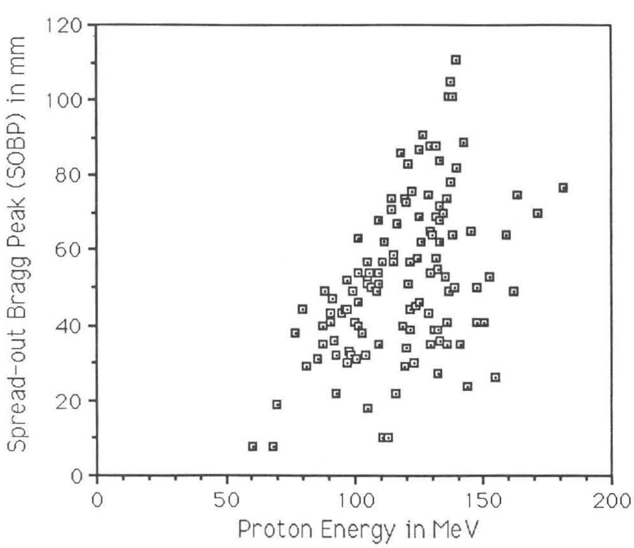

Fig. 4. Maximum proton energies on patients and Spread-out Bragg Peak depths.

energies are distributed in a region from 60 MeV to 182 MeV which correspond to ranges of 3 cm and 22 cm in water. The design energy of 230 MeV will be sufficient even if scatterers are used for beam spreading where 10-20 MeV energy is lost in scatterers. The SOBP spread in a wide range from 0.8 cm to 11 cm. Several ridge filters were prepared for covering the range. Some are made of copper, others are of brass or aluminum.

4. DOUBLE SCATTERER BEAM SPREADING

Field shaping with a double scatterer system is investigated to get good flatness as well as high efficiency. The first scatterer is made of a high-Z material such as Pb. The second one consists of a high-Z material disk surrounded by an annular low-Z material plate. Both the disk and the plate have equal energy loss for penetrating protons. Calculation is made for the 2 mm thick first scatterer with the second one of a 4 mm thick, 23.8 mm in radius Pb disk with 10.9 mm Al annular

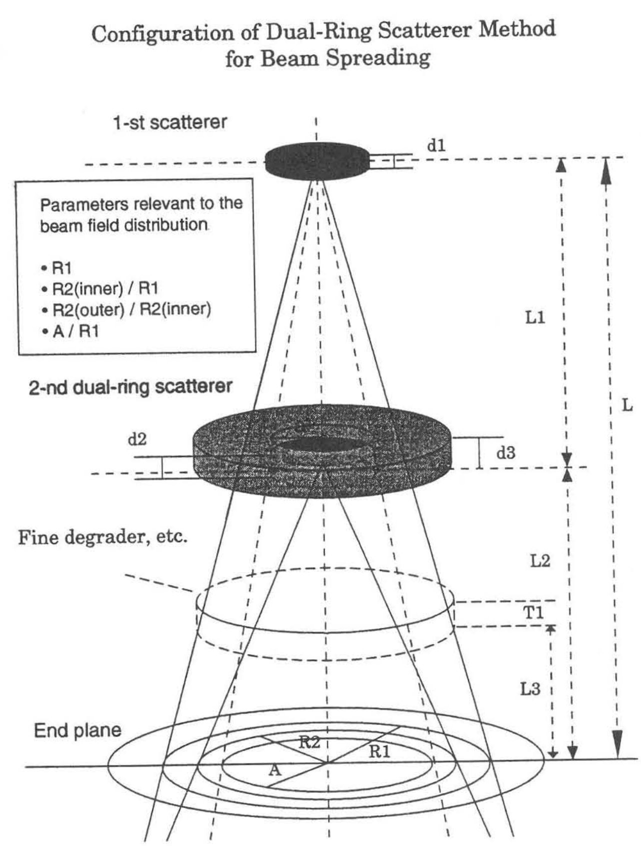

Fig. 5. Double scatterer system with a dual-ring scatterer.

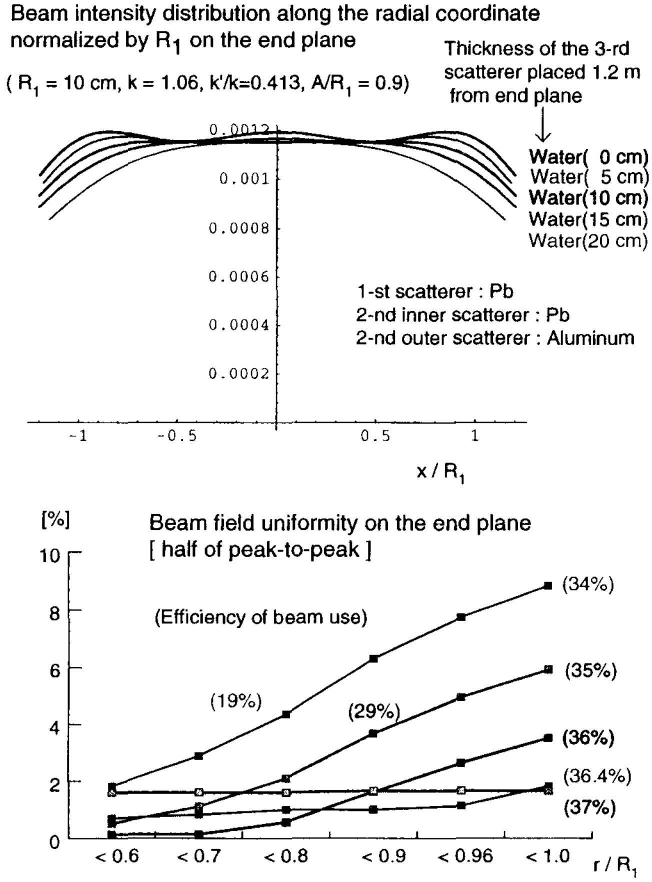

Fig. 6. Beam intensity distribution along the radial coordinate and percentages of proton beam inside specific radii for different thickness of water fine degrader

plate. The distance between the first one and the second is 87.4 cm (Fig. 5). If the incident beam angle deviation is less than 1 mrad, the beam uniformities within 20 cm diameter region are excellent as shown in Fig. 6 for different fine degrader thickness with a distance of 3.3 m from the first scatterer to the target. 37 % of incident protons to the first scatter will enter into the 20 cm diameter region for the highest energy and 34% for a degraded energy with 20 cm thick water fine degrader. Combining these with the field sizes above mentioned, the rotating gantry will be redesigned.

5. RADIATION SHIELDING

Since 50% extraction efficiency of the cyclotron is guaranteed by SHI, a design goal of 2 m thick wall is set for accelerator and treatment rooms. If thicker wall were needed, the cyclotron would lose its advantage to a great extent for hospital use. Following simple estimation is made for setting the intensity design goal. At the present time, 250 MeV proton beams are supplied to the fixed beam delivery systems at PMRC. They are scattered by a scatterer, pass through a fine energy degrader and a ridge filter, then they are shaped with a slit and a bolus as mentioned above. This method is assumed at the beginning operation of the new facility for 230 MeV incident beams. The beam intensity to the scatterer is 10 nA now and patients are ordinarily irradiated in two to three minutes. When breath-synchronized irradiation is applied, it takes two times longer or more. Therefore the design goal of 20 nA at the first scatterer is chosen for the new facility, and the design goal of the wall thickness is hoped to be attained. Apparently higher beam utilization efficiency is expected with future 3D beam delivery system.

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