PROPOSAL OF THE PION FACILITY FOR THE CANCER THERAPY

K. Hayakawa, K. Tsukada, K. Sato, T. Tanaka and O. Takeda
Atomic Energy Research Institute, Nihon University
Kanda-Surugadai, Chiyoda-ku, Tokyo 101, Japan

INTRODUCTION

Nihon University has proposed to build pion facility for cancer therapy. In this facility, pions are generated by an electron beam. Because of relatively low conversion efficiency from electrons to pions, high-power electron beam and large acceptance pion focusing and irradiation devices are required.

The accelerator for the pion facility will be 1 GeV, 300 μA, CW Double-Sided-Microtron (DSM)[1] which has enough beam power to generate pions for therapy if combining with the large acceptance focusing and irradiation devises. The forcusing and irradiation device consists of two coaxial super-conducting coils, Which acceptance is about 1 str.

The proposal also includes large building for the accelerator and irradiation device.

GENERAL DESIGN CONSIDERATIONS

Layout of the proposed facility are shown in Fig. 1. The bottom floor of the building is situated about 15 m below ground level.

The DSM consists of two linacs, four quadrant magnets, focusing elements and injection and extraction systems. In the DSM the beam is returned to linacs by means of uniform field quadrant magnets. On successive passes, the beam must pass through the linac at the same synchronous phase of the rf field. This resonance condition can be expressed by the relation[2]

$$\frac{(\pi-2)\Delta W}{eBc} = \nu\lambda \qquad (1)$$

Where ΔW is the energy gain per turn, e is the unit charge, c is thelight velocity, B is the field of quadrant magnet, ν is the integer number and λ is the rf wave length. The integer number, ν, should be as small as possible to maximize the phase stability and minimize the accelerator size. So that we have chosen one as ν. Rf frequency is determined by the commercial availability of high-power CW klystrons. The only available high-power CW klystrons are 2.45 GHz (λ = 12.2 cm).

An important cost consideration for a large microtron is the size of the quadrant magnets. The radius of the final orbit in the quadrant magnet is proportionl to the final energy divided by the magnetic field. Therefore large B is desired to minimize the size of the quadrant magnet. On the other hand, from Eq. (1), the field B is proportional to the energy gain per turn. Large ΔW requires long linacs and/or large rf power, which also increase a cost of the accelerator.

The injector is a 5 MeV CW electron linac with chopper and buncher systems. The beam is injected through the chicane system and accelerated to 21 MeV by first linac of the DSM. The phase slip in the low energy region is compensated by the phase matching system installed in the short straight section at the first turn orbit. Beam extraction is performed by two septum magnets. One is in the short straight section and the other is in the drift space between the quadrant magnet and the linac. The values of design parameters of the DSM are shown in Table 1.

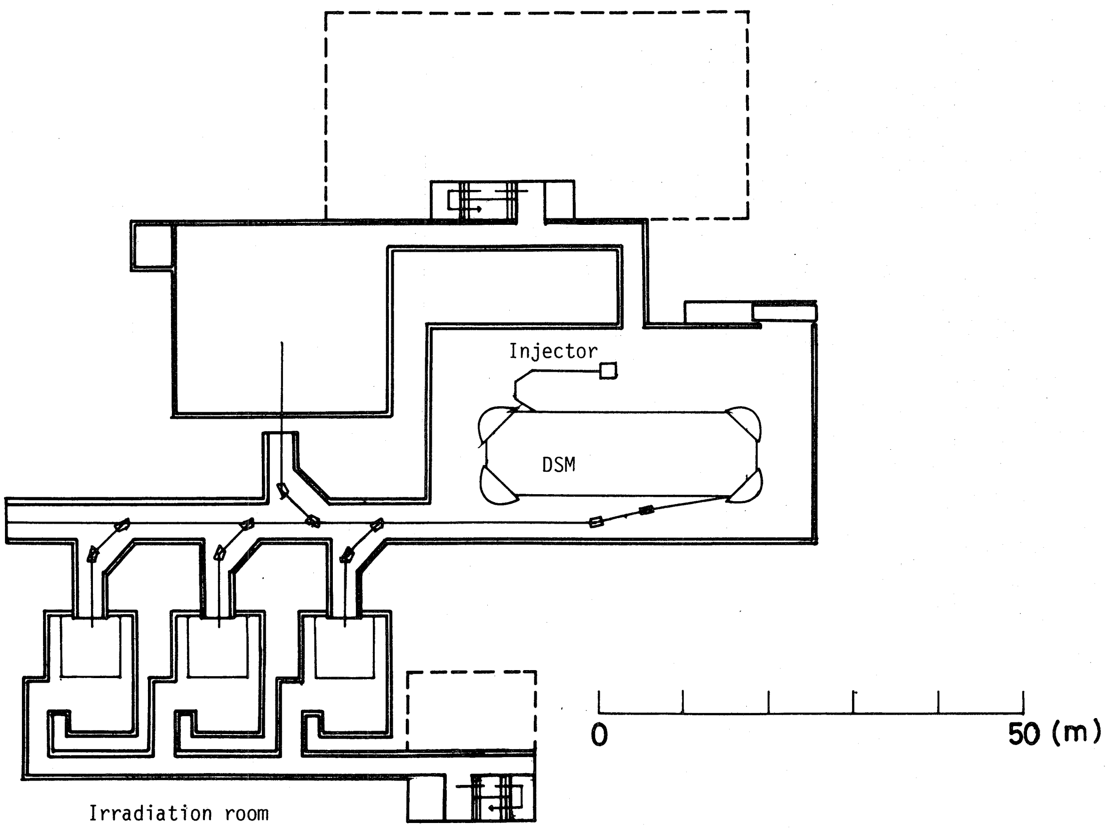

Fig. 1. Layout of the proposed facility.

Table 1. Design parameters of the DSM.

Maximaum energy	1045 MeV
Beam current	300 μA
Duty cycle	100 %
Injection energy	5 MeV
Energy gain per turn	32 MeV
Accelerating field	1 MeV/m
Effective shunt impedance	75 MΩ/m
Rf wave length	12.2 cm
Number of recirculations	32.5
Magnetic field	0.998 Tesla
Maximum orbit radius	3.49 m
Minimum orbit radius	0.07 m

INJECTOR

The required performance parameters of injection linac are shown in Table 2. The injection linac consists of an electron gun, a chopper and buncher system and a preaccelerator. A 100 kV, 2 mA DC electron gun of which transverse emittance is 1π mm-mrad can be made without serious problems.

The chopper is similar in design to the system that has been developed at NBS[3]. The beam from the gun is chopped and reduced to ±30° of rf phase angle. The buncher consists of a prebuncher cavity and a tapered β accelerating tube, followed by preaccelerator. After passing through the chopper the beam is bunched and accelerated to 5 MeV.

Beam current	≧ 300 μA
Duty cycle	100 %
Energy spread	± 50 keV
Bunch width	± 1 deg.
Transverse emittance	1π mm-mrad.
Electron gun	
voltage	100 kV
beam current	≧ 2 mA
emittance	1π mm-mrad.

MAGNET DESIGN AND BEAM DYNAMICS

Beam focusing in the DSM is performed by Q-magnets installed in short straight section of every orbit. Typical beam envelopes of the normal orbit in which phase slip is not a serious problem are shown in Fig. 2.

A low energy injection to the DSM has serious problems as follow.

1. The 45°entrance and exit pole-face angle of the quadrant magnet are both defocusing in the vertical direction.
2. Uniform magnetic field along the orbit is difficult to make because the distance from the pole-face to the middle point of the orbit in the quadrant magnet is comparable to the gap height.
3. The phase of the center of the bunch slips during the acceleration in the linacs and passing through the drift space, because the electron velocity is slightly smaller than the light velocity.

To solve these problems, we adopt rather complex magnet system shown in Fig. 3. In this design, pole-faces which face the linacs have angle to accomplish vertical focusing (horizontal defocusing)[4]. And the pole-piece has an extention as shown in Fig. 3. In the extended

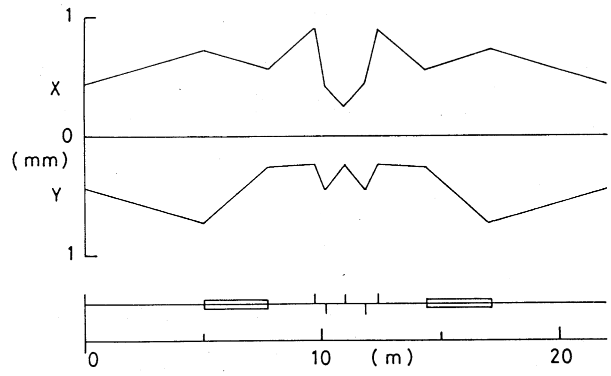

Fig. 2. Beam envelopes at 501 MeV in the DSM.

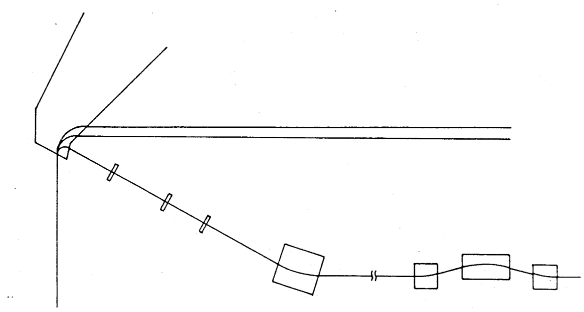

Fig. 3. Achromatic bending system and phase matching system.

pole-fiece, the magnetic field can be uniform in the wide range along the first turn orbit and the beam of the first turn is bend 120°. After passing through the drift space and Q-magnets, the beam is bend by 30°in inverse direction by a successive sector magnet. Then the beam is parallel to the other orbit of short straight section. This transfer system performs an achromatic translation. Therefore, the beam of the first turn orbit is dispersion free. Three dipole magnets which constitute a roundabout way for the beam are installed in the center of the short straight section. These magnets can change the orbit length to compensate the phase slip. Beam envelopes are given in Fig. 4.

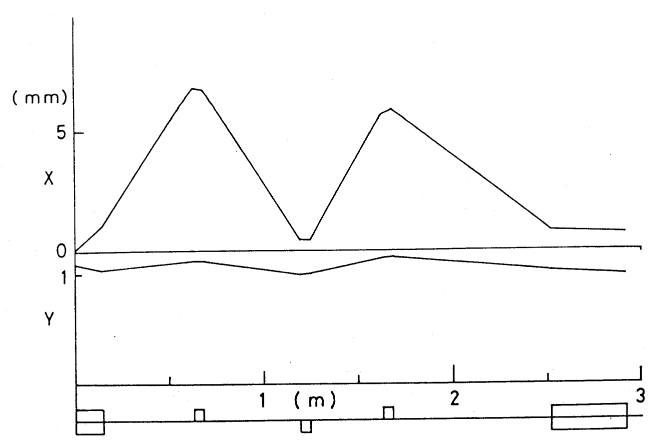

Fig. 4. Beam envelopes at the first orbit.

RF STRUCTURES

For the linacs of the DSM and the injector, the Disk-And-Washer (DAW)[5]structure developed at Nihon University will be used. In this structure each washer is supported by two radial stems oriented by 90° each other. Serious problems with TM_{11}-like deflecting mode are avoided in our design.

IRRADIATION DEVICES

A coaxial type focusing and irradiation device[6] is schematicaly shown in Fig. 5. Negative pions are generated bremsstrahlung gamma ray at the target which is installed in center of the coil. The negative pions are converged to tumor by the pair of super-conducting coils. Typical particle orbits are shown in Fig. 6.

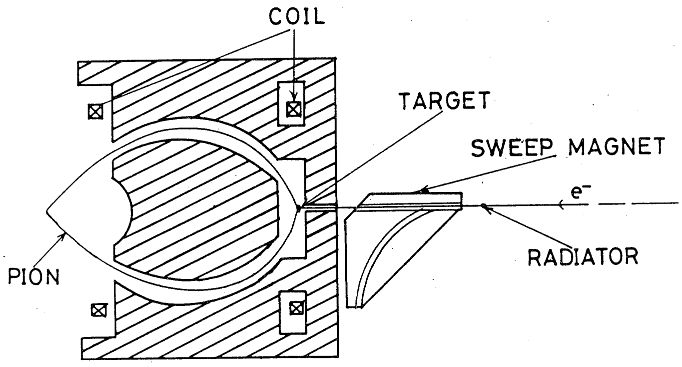

Fig. 5. Schematic layout of the irradiation device.

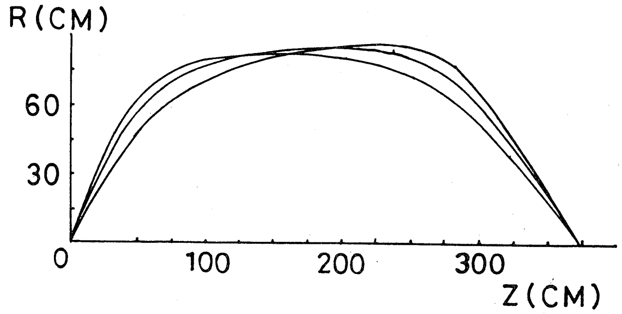

Fig. 6. Typical orbits in the irradiation device.

REFERENCES

1. K. Hayakawa et al., IEEE Trans. Nucl. Sci., NS-30, 3224, 1983.
2. K.H. Kaiser, Proc. conf. on possibilities for electron accelerator, V-1, 1979.
3. M.A. Wilson et al., IEEE Trans. Nucl. Sci., NS-30, 3021, 1983.
4. Tat K. Khoe et al., IEEE Trans. Nucl. Sci., NS-28
5. T. Tanaka et al., Proc. of 1984 Liner Accelerator Conf., (Darmstadt), (to be published).
6. D.E. Lobb, Nucl. Inst. Meth, 148, 163, 1978.