RADIATION CALCULATIONS FOR ADVANCED PROTON THERAPY FACILITY

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Abstract

The shielding calculations of bulk shielding for Advanced Proton Therapy Facility (APTRON) which is under design in Shanghai were carried out. The thickness of radiation shielding walls for the accelerator and treatment rooms of APTRON were determined by Monte Carlo simulation and empirical methods [1~3]. Assumptions of beam loss scenarios and workloads of different energy at LINAC, synchrotron, transport and treatment line are given for the calculations. The calculations were carried out for the proton energy of 150MeV, 220MeV and 250MeV, and the targets of iron and equivalent tissue material. Source terms and attenuation length were calculated with different angles by the simulation using FLUKA code. Based on the source terms and the attenuation length, the thickness of the bulk walls were determined by the empirical formula to ensure the dose rate outside the shielding walls' surface less than 1μSv/h. Local shielding and maze design were also concerned.

INTRODUCTION

The Advanced Proton Therapy Facility (APTron), which will be built at Jiading district of Shanghai, is a hospital-based facility designed by Shanghai Institute of Applied Physics. The layout of APTron is shown in Fig.1. It consist of a 7 MeV LINAC injector, a 24.6m circumference synchrotron capable of accelerating protons up to 250MeV, two horizontal fixed beam line and an isocentric gantry beam line in phase I, and can upgrade total 3 gantry beam lines in phase II. Some main parameters of the accelerator are list below:

- Injection energy: 7MeV;
- Extraction energy: 70~250MeV;
- Extraction current: 12.8nC (8.0×1010p/spill);
- Repetition frequency: 0.1~0.67Hz;
- Dipole Magnet field change: 0.2~1.74T.

Dose equivalent limit is 2mSv per year, corresponding to 1μSv/h for personal working full-time for 2000h/a. Occupancy factors are assumed as shown in Fig.1.

BEAM LOSS SCENARIOS

Calculations of shielding of structure are based on some assumption of beam loss scenarios and workloads. Workloads of 150MeV, 220MeV and 250MeV proton energy are considered and their beam loss scenarios are list as Table1.

For a conservative consideration, beam loss position is assumed at the end of LINAC where there is a faraday cup. During in the course of injection process, no more

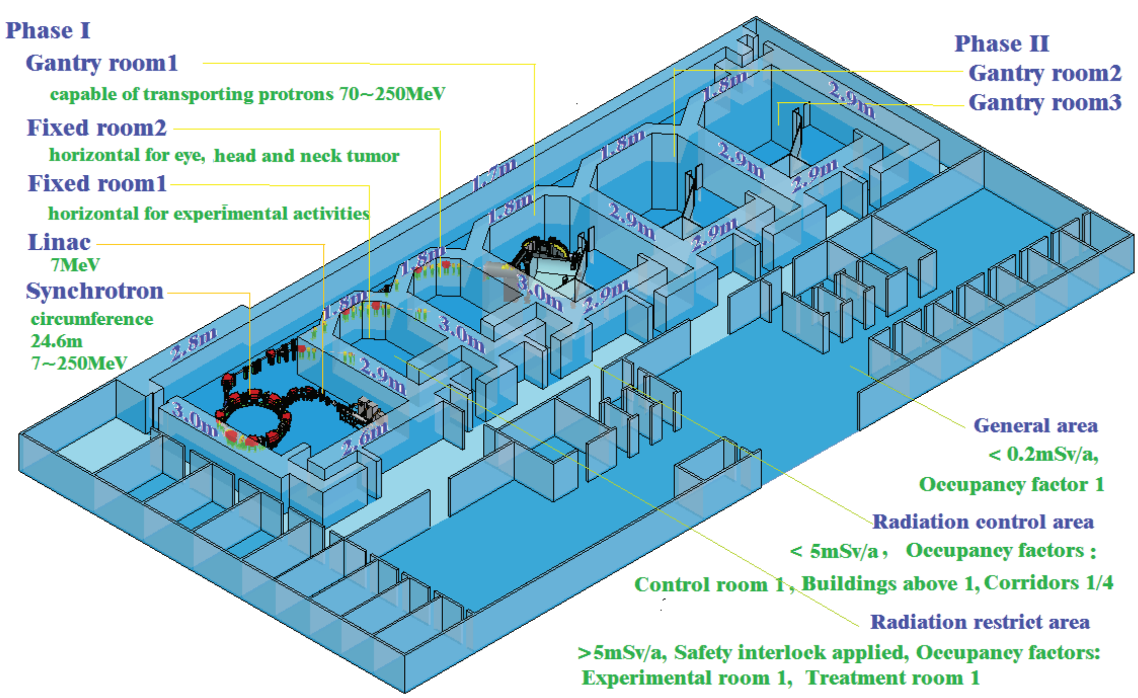

Figure 1: Schematic layout of APTron Facility.

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than 70% of 7MeV protons are lost at injection septum. The total beam losses at synchrotron will less than 35%. In practice beam will mostly likely be lost at the dipoles in the course of the acceleration process. Since there are 8 dipoles, 4.4% beam losses at each dipole can be assumed and taken in a tangential direction with respect to the ring at that point. The total beam losses along transfer line should not more than 10% and each dipole assumed no more than 1.5%. For any treatment room, the 100% beam loss must be assumed.

Table 1: Beam Loss Scenarios and Workloads

	Maximum beam current (proton/1.5s)	Loss factor (%)	Workloads
	5.7×10^{11}		
Linac		20%	100%@7MeV
	4.56×10^{11}		
Injection		70%	100%@7MeV
	1.37×10^{11}		
Synchrotron		35%	80%@150MeV 20%@250MeV
	8.9×10^{10}		
Extraction		10%	20%@150MeV 75%@220MeV 5%@250MeV
	8×10^{10}		
Transfer line		0-10%	20%@150MeV 75%@220MeV 5%@250MeV
	8×10^{10}		
Treatment room		100%	20%@150MeV 75%@220MeV 5%@250MeV

SOURCE TERM AND ATTENUATION LENGTHEN FOR NEURTON

A spherical shell model of multi-layers normal concrete is built in FLUKA code [4,5]. The inter diameter of this spherical shell is 10m in respect that the distance from shielding wall to the accelerator is at a range from 2 or 8 meters. The source terms and attenuation lengthens are gotten by FLUKA simulations for 150MeV, 220MeV and 250MeV proton at different solid angle from bombarded direction. The data for iron cuboid target (density of 7.874g/cm^3, thickness 7cm, width of 10×10cm^2) are list in table 2. The data for equivalent tissue (density of 1.0g/cm^3, thickness 30cm, width of 30×30cm^2) are list in table 3.

Table 2. Attenuation of the Total Dose Equivalent in Ordinary Concrete for Protons Impinging on a Thick Iron Target.

Proton energy	Angle bin	Source term (Svm^2/p)	Attenuation length (gcm^{-2})
150MeV	0-10°	3.28×10^{-15}	84
	40-50°	4.13×10^{-16}	79
	80-90°	1.16×10^{-16}	69
	130-140°	3.13×10^{-16}	38
220MeV	0-10°	7.49×10^{-15}	94
	40-50°	7.42×10^{-16}	90
	80-90°	1.11×10^{-16}	76
	130-140°	8.84×10^{-17}	54
250MeV	0-10°	1.03×10^{-14}	107
	20-30°	5.58×10^{-15}	99
	40-50°	1.92×10^{-15}	93
	60-70°	7.86×10^{-16}	87
	80-90°	4.35×10^{-16}	76
	130-140°	2.44×10^{-16}	57

Table 3. Attenuation of the Total Dose Equivalent in Ordinary Concrete for Protons Impinging on an Equivalent Tissue Target.

Proton energy	Angle bin	Source term (Svm^2/p)	Attenuation length (gcm^{-2})
150MeV	0-10°	1.92×10^{-15}	85
	40-50°	5.69×10^{-16}	71
	80-90°	3.05×10^{-16}	57
	130-140°	6.97×10^{-17}	44
220MeV	0-10°	4.21×10^{-15}	96
	40-50°	1.24×10^{-15}	87
	80-90°	1.53×10^{-16}	70
	130-140°	3.19×10^{-16}	54
250MeV	0-10°	1.60×10^{-14}	108
	20-30°	5.37×10^{-15}	103
	40-50°	1.92×10^{-15}	92
	60-70°	8.48×10^{-16}	80
	80-90°	3.11×10^{-16}	72
	130-140°	3.72×10^{-16}	58

SHIELDING CACULATION

An expression for evaluation the surface dose equivalent rate out of the shielding, as shown below (Eq.1), can be derived from the Moyer model as a function of the thickness of barriers, the beam current, the beam loss scenario and other factors etc. For a view point, the dose equivalent is contributed by multi beam loss positions (use i mean the number of loss positions) for different energy protons (j means the number of particle energies).

$$H_{Max} = \sum_{j}^{m} \sum_{i=1}^{n} \cdot k \frac{H_{0ij}(\theta_i)\cdot I_{ij}\cdot f_{ij}\cdot t_{ij}}{(a_i+d)^2\cdot \csc^2\phi_i}\cdot \exp\left(-\frac{d\cdot\csc\phi_i}{\lambda_{ij}(\theta_i)}\right) \quad (1)$$

H_{max} (μSv/h) is the maximum dose equivalent rate after shielding barriers, changing by barrier thickness d. When H_{max} reduced to the limit level, appropriate barrier thickness can be selected. θis the angle between the incident direction and the line from beam loss position to view point; $H_{0ij}(\theta)$ (Sv m^2 per ion) is the source term along the direction θ for the No. j energy proton at the No. i beam loss position. The values of $H_{0ij}(\theta)$ which are list at table 2 and table 3 according to different target, are gotten by FLUKA simulations; I (p/s) means the proton current; f means beam loss fraction; t means workloads or duty factor; a means the distance from loss position the barrier; φis the angle between a_i and line from loss position to view point; λ(θ) is the mean attenuation length of neutron shield material in the direction θ. The λ(θ) values are list at table 2 and table 3; k is a constant taking into account the different time units used in the formula.

Appropriate thickness of each bulk wall of APTron facility is gotten by Eq.1 based on the facility layout and parameters list in table 1, table 2 and table 3. The recommend results of shielding wall thickness are shown in Fig.1.

LOCAL SHIELDING AND MAZE

Maze of facility are designed according to the methods and experience in some literature [6,7,8]. Evaluation simulations are carried out by FLUKA code. Here a dose equivalent rate distribution of fixed treatment room is present at Fig.2. The simulation takes 20% 150MeV, 70% 220MeV and 5% 250MeV protons as radiation source.

The total dose rate at the entrance, considering both from wall penetrating and maze scattering, is less than the dose rate limit.

As shown in Fig.2, the high equivalent dose area from penetrate radiation is concentrate in the area outside the 45 degree wall from the incident direction. Less than 50cm thick iron layer is needed in this wall for local shielding to decrease the dose equivalent under the limit. Less than 20cm iron layer is also needed inside the first wall of maze as well.

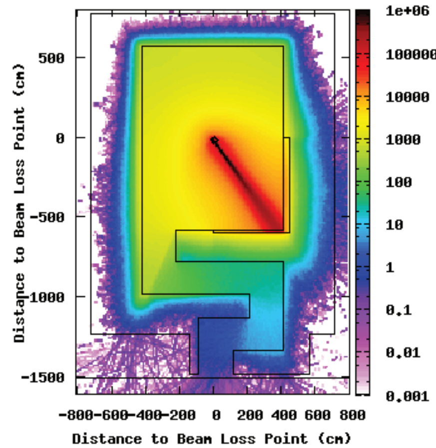

Figure 2: Dose equivalent rate distribution of fixed treatment room.

SUMMARY

For calculation the shielding wall of the under design APTron, source terms and attenuation length are gotten by a 10m diameter spherical shell model. An expression like Eq.1 is derived in order to simultaneously considering various energy protons and various beam loss positions. The needed thicknesses of each bulk wall of APTron facility are shown in Figure1. Local shielding and maze design evaluation are gotten by dose equivalent rate distribution as shown in Figure 2. It found that the dose equivalent rate outside the shielding wall or entrance is below the dose rate limit 1μSv/h.

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