Primary Radiation Calculation for Sun Yat-Sen Proton Hospital

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Abstract： Sun Yat-Sen Hospital is under construction, which is a cyclotron based proton therapy facility. In order to evaluate the dose level and impacts to environment, a primary understanding of the various radiation sources is needed for shielding design. These radiation sources correspond to the locations where the proton beam interacts with matter, i.e. the cyclotron room, along the beam line and inside the treatment. The goal of this work is to get the dose distribution of the whole facility and verify whether the wall can shield the radiation to the limit value.

Key words： Radiation Shielding, FLUKA simulation, Proton therapy

1. Introduction

Sun Yat-Sen Hospital consists of a cyclotron provided by IBA, 3 gantry treatment rooms and 2 fixed beam treatment rooms. The cyclotron generates proton beams with a fixed energy of 230 MeV. The max current extracted from the cyclotron is usually limited to 300 nA. The material of the wall is standard concrete. The annual workload in a treatment room is 211.76 nA.h. But we adopt 500nA.h for a conservative calculation.

This work is a primary calculation based on IBA's original design, for a full optimized simulation please refer to Qingbiao Wu [1].

2. General Method

A simple analytical model is often useful for a first estimate before going into complex Monte Carlo simulations[2][3]. Eq. (1) gives the equivalent dose behind the shielding wall for a single shielded neutron:

$$H(E_p,\theta,\alpha,d,\lambda) = \frac{H_0(E_p,\theta)}{OA^2}\exp\left[-\frac{AD}{\lambda(\theta)}\right] = \frac{H_0(E_p,\theta)}{R^2}\exp\left[-\frac{d\rho}{\lambda(\theta)\cos\alpha}\right]. \quad (1)$$

The wall thickness at 0 °direction of 230MeV for controlled area is 3.94m.

A novel and reliable dose calculation in proton therapy is using Monte Carlo codes, i.e. FLUKA, MCNPX and GEANT4. In this work we choose FLUKA because of its friendly interface FLAIR and can also cooperate with SimpleGEO.

2.1 Geometry

The building of this hospital is quite complicated, thus structures do not relate to radiation are ignored or simplified. Fig 1 shows the 3D FLUKA geometry of treatment level in proton therapy facility.

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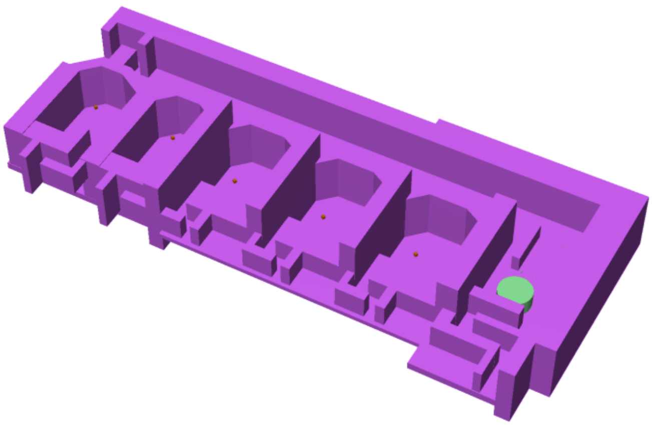

Fig 1 3D geometry of proton therapy facility

2.2 FLUKA settings

Conversion coefficients from fluence into effective dose and ambient dose equivalent are based on fits to values for discrete energies as suggested by ICRP74 [4]. Thus card USRBIN and AUXSCORE are used to score the dose equivalent.

Beam parameters vary in different sources, i.e. energy varies from 130 MeV ~ 230 MeV. Beam position and direction will be discussed in each section. For each source 5 energy points (130 MeV, 160 MeV, 180 MeV, 210 MeV, and 230 MeV) will take an independent simulation, and the gantry treatment room will have 4 direction's (0°, 90°, 180°, and 270°) simulation with 5 energy points.

Beam loss data is come from some clinic assumptions and energy weight [5].

3. Cyclotron room

There are 4 sources in cyclotron room, including cyclotron, degrader & collimator, divergence slits and momentum slit, as showed in Fig 2(a). Degrader & collimator, divergence slits and momentum slit are the main components of Energy Selection System (ESS).

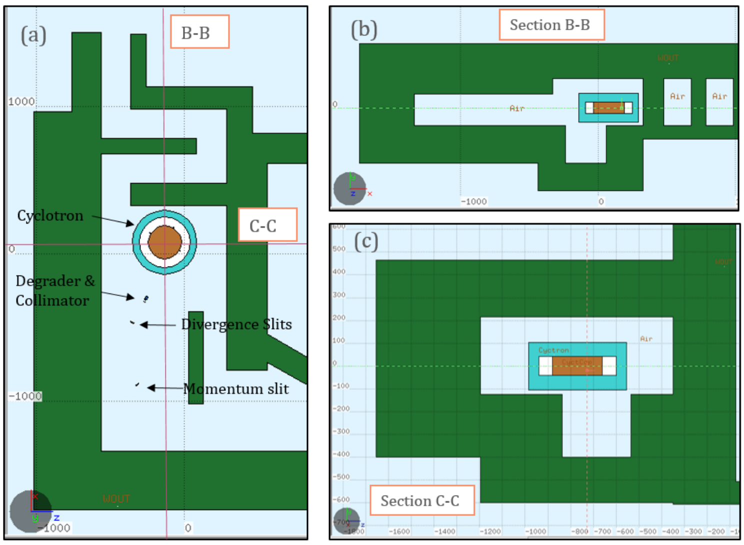

Fig 2 Sources in cyclotron room

3.1 Cyclotron

There are three sub-sources on cyclotron, the losses on the two counter-D's represent 20% of the accelerated beam current and are distributed equally on the two counter-D's, the protons are lost with their maximal energy of 230 MeV, and 40% of the accelerated beam is lost on the extraction septum with maximal energy of 230 MeV.

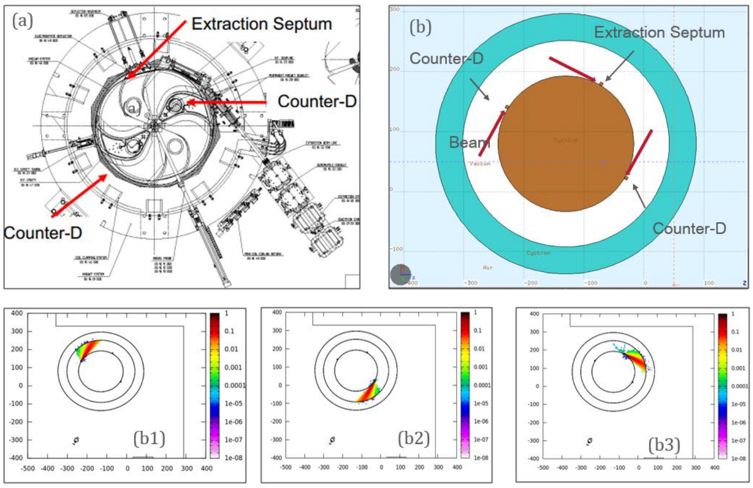

Fig 3 Cut view of the locations of the counter-D's the extraction septum, and the beam directions.

Fig 3(b) is the simplified cyclotron model in FLUKA, proton beam bombard onto 3 tiny copper cubes on the circumference with a tangent direction. Material of counter-D is copper, the yoke is stainless steel and between them is vacuum. Fig 3(b1~3) is simulated fluence.

3.2 Energy Selection System

Degrader & collimator, divergence slits and momentum slit are the main components of Energy Selection System (ESS). For convenient, degrader and collimator are simulated as one source. Beam size will increase in graphite degrader and decrease after tantalum collimator. Before radiation simulation, transmission and thickness of degrader for different energy should be calculated.

230 MeV proton beam transmission through a thick block of graphite is simulated by FLUKA, showed in right of Fig 4, it consists with IBA's data simulated by MCNPX.

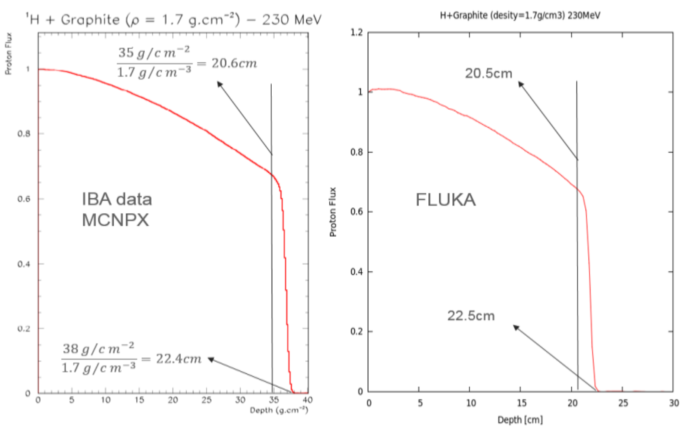

Fig 4 230 MeV proton beam transmission through a thick block of graphite

Fig 5 shows the Degrader & Collimator Model in FLUKA. The beam direction is 30 °angle to x-axis.

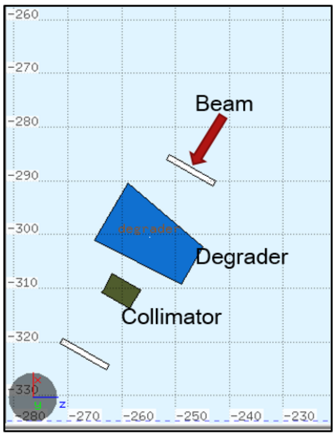

Fig 5 Degrader & Collimator Model in FLUKA

3.3 Dose in Cyclotron Room

Total Dose in Cyclotron Room is in Fig 6. Dose at the exit of maze (P1), outside of the left wall (P2) and bottom wall (P3) will exceed public limit 1mSv/a. Thus the maze and the wall of cyclotron room should be strengthened.

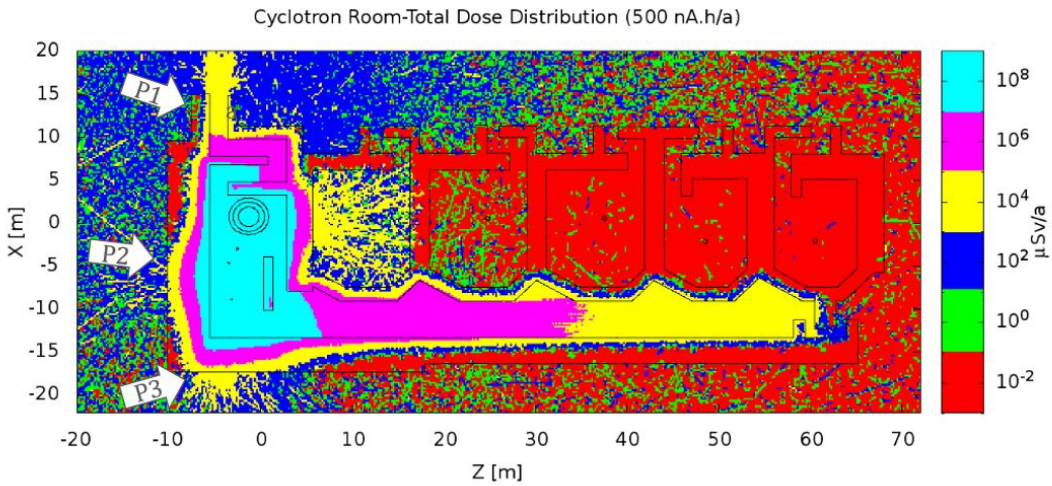

Fig 6 Total Dose in Cyclotron Room

4. Gantry Treatment Room

Gantry's rotation range is 0°~360°, to simplify the work the gantry treatment room (GTR) will have 4 direction's (0°, 90 °, 180 °, and 270 °) simulation with 5 energy points. Every direction has the same weight of 1/4. As shown in Fig 7, the target is a 40cm×40cm×40cm water tank. The 90 °and 270 °beam direction is 30 degree angle to Z-axis while the 0 °and 180 °is perpendicular to Z-axis.

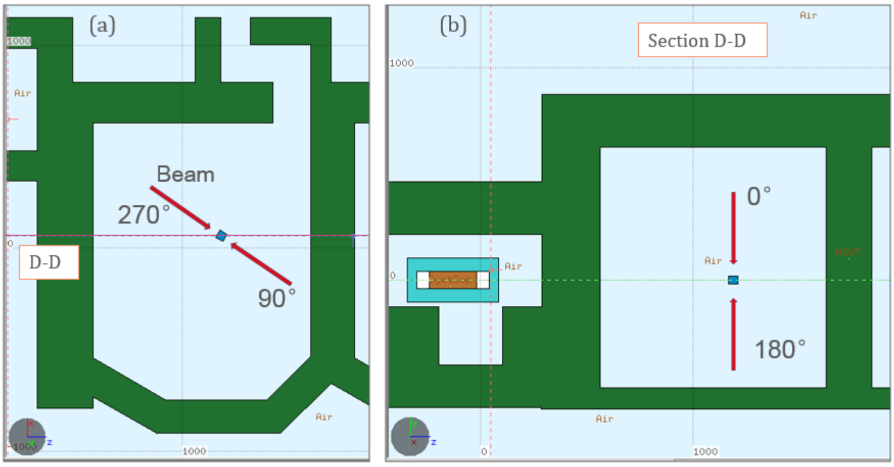

Fig 7 Gantry Treatment Room

Sum the 4 directions, dose in gantry treatment room is distributed by Fig 8. The boundary of 1mSv/a is inside the building.

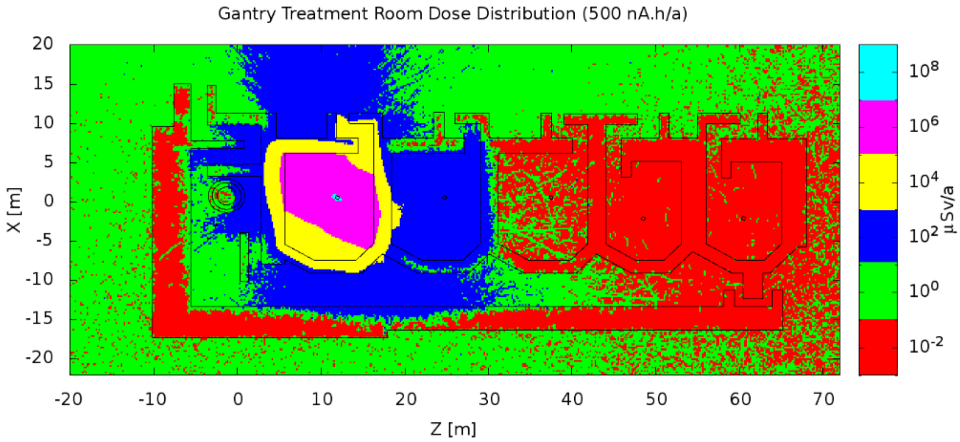

Fig 8 Gantry Treatment Room Dose Distribution

For 211.76 nA.h case, the distribution Fig 9 (a) consists Frederic's work Fig 9 (b) [6].

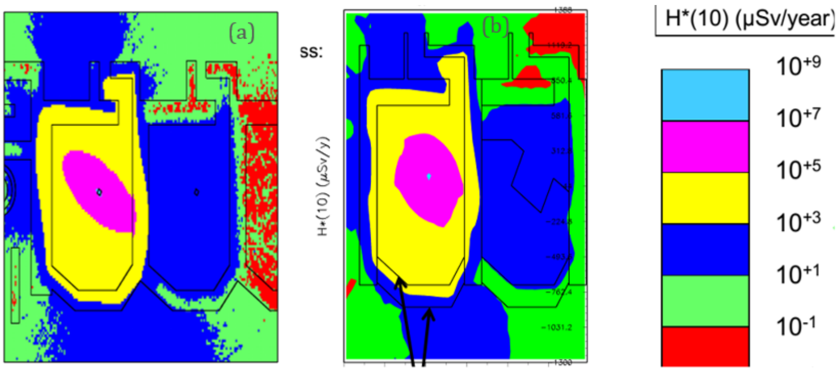

Fig 9 (a) Dose for 211.76nA.h, (b) Dose of Frederic's work

5. Fixed Beam Treatment Room

As in Fig 10, the target in fixed beam treatment room is a 40cm×40cm×40cm water tank and the beam direction is 60 °to Z-axis.

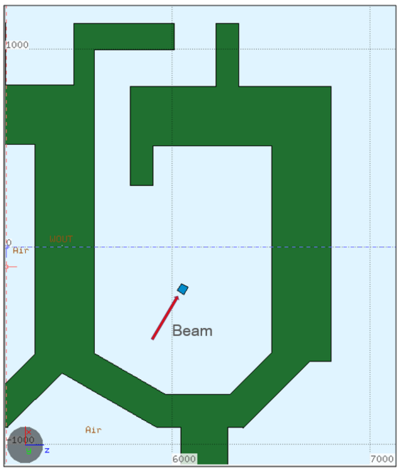

Fig 10 Fixed Beam Room

The dose distribution is in Fig 11. The 1mSv/a boundary is inside the wall.

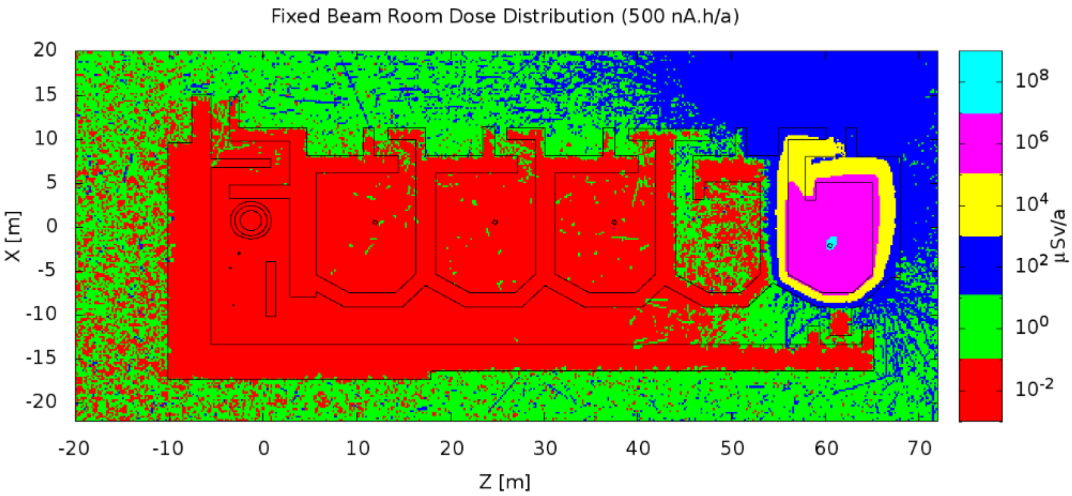

Fig 11 Fixed Beam Room Dose Distribution

6. Total Dose and Summary

Fig 12 shows the summed annual dose of all sources with their weight. The 1 mSv/a boundary is quite clear, almost inside the wall, but the 0.1 mSv/a is obscure and mostly outside the wall.

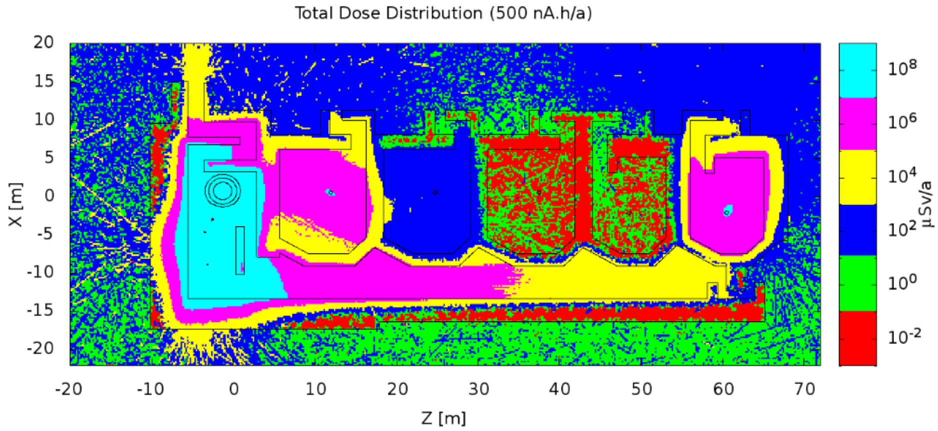

Fig 12 Total Dose Distribution of the Proton Therapy Facility

The original thickness of the wall is not enough to shield radiation to the objective value 0.1 mSv/a, especially the cyclotron room, however, the hospital can rezone the controlled & supervised area. What's more the treatment level will be underground, the soil can also shield some radiation.

The dose outside the building is higher than the objective limit value with IBA orignial thickness and 500 nA.h workload. The most dangerous point is at the outside of cyclotron room and exit of its maze. Radiation safety includes a lot of areas, this report just finish the simulation part, reference [1] is a full radiation shielding design for Sun Yat-Sen Proton Hospital.

Reference

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