SHIELDING CALCULATIONS FOR PROSCAN

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INTRODUCTION

As part of the project PROSCAN, a dedicated cyclotron for proton therapy will be installed in the NA-hall at PSI feeding two treatment rooms and one experimental area (see [1] for last year's progress report and other contributions in this volume). It will produce 250 MeV protons at a maximum current of 500 nA. A degrader in the first beam line section after the cyclotron can be used to produce lower-energy protons. The computational method for the shielding design of this new facility and the corresponding results that were used as a basis for the shielding layout are described.

COMPUTATIONAL METHOD

The shielding calculations for PROSCAN use the concept of exponential dose attenuation:

$$H(E_p, \theta, d(\theta)) = \frac{H_0(E_p, \theta)}{r^2} e^{-\frac{d(\theta)}{\lambda(\theta)}}$$

where E_p is the proton beam energy, r is the distance from the target to the measuring point and $d(\theta)$ is the effective shielding thickness (i.e., the length of shielding material that is being traversed), θ is the angle with respect to the beam direction. Parameters for the angle dependent source terms $H_0(E_p, \theta)$ and for the attenuation lengths $\lambda(\theta)$ in normal concrete were taken from S. Agosteo et al. [2]. The source terms include dose rate contributions from neutrons at all energies and from photons. Contributions from other secondary particles produced in the shielding materials are also included, but are negligible. Based on Monte Carlo calculations at PSI using MCNPX[1] and published results (e.g., [3]), the following dose attenuation lengths are being used in the case of iron shielding: λ=140 g/cm^2 at θ=0° and λ=120 g/cm^2 at θ=90°; linearly interpolated values are used for the angles inbetween. Table 1 shows the parameters used for E_p=250MeV on an iron target. Parameters for a tissue target can be found in [2].

A shielding experiment has been carried out to support the computational method [4,5]. As a conclusion, the lateral shielding for PROSCAN was designed in such a way, that the calculated dose rate at 65° (the predicted "hotspot"[2]) is below the limiting value as defined by the radiation protection specifications. Beam losses were assumed to occur in iron-like materials and, in case of the new Gantry room, in tissue.

Angular bin [degrees]	H_0 [Sv m^2 p^{-1}]	λ concrete [g cm^{-2}]	λ iron [g cm^{-2}]
0-10	9.0E-15	109.0	140.0
10-20	7.5E-15	106.0	137.7
20-30	6.8E-15	110.0	135.3
30-40	3.9E-15	98.7	133.0
40-50	3.3E-15	92.9	130.6
50-60	2.5E-15	89.0	128.3
60-70	2.0E-15	83.7	125.9
70-80	8.1E-16	78.2	123.6
80-90	6.2E-16	62.8	121.2
90-100	3.8E-16	60.1	118.9

Table 1: Parameters for the shielding calculations (E_p=250 MeV, iron target).

BOUNDARY CONDITIONS

The relevant radiation protection specifications are:

- < 1 μSv/h outside all side shielding walls.
- < 10 μSv/h on top of the roof shielding.
- < 1-10 μSv/h in the irradiation areas with beam off (due to adjacent beam lines and irradiation areas).

Table 2 shows the p-beam related conditions used in the shielding calculations for the various areas. It was assumed that beam losses in the cyclotron and along the beam lines can occur at any point along the path. In the experimental and treatment areas the major part of the p-beam was assumed to be stopped at a localized point: in a sample or beam dump either in the center or in the back wall of the experimental area, in the OPTIS modulator or in a patient in Gantry 2.

	Energy [MeV]	Beam loss [nA]	Beam usage [min/h]
Cyclotron	250	50	60
Degrader, BL sect. 1 [3]	250	500	60
BL sect. 2	250 70	1 20	60 60
Experimental area	250	10 (wall) 1 (center)	60 60
OPTIS area	70 250	10 1	60 6
Gantry 2 area	250	1	8 (for each directional quadrant)

Table 2: Proton beam related conditions used in the shielding calculations (beam line = BL).

[1] The MCNPX code has been developed at the Los Alamos National Laboratory and merges their well known codes MCNP (for Monte Carlo neutron and photon transport) and LAHET (high-energy Monte Carlo transport code for nucleons, pions and muons).

[2] While the source term increases for more forward angles, the effective shielding thickness for lateral shielding also increases with 1/sin(θ); this leads to a maximum dose rate at 65° ("hotspot").

[3] For the production of 70 MeV protons, about 95% of the beam intensity are lost in the degrader and the 2 subsequent apertures.

CALCULATED SHIELDING THICKNESSES

The calculated shielding thicknesses for the various areas are listed in Table 3. Because of various openings at beam height and towards the top, the iron of the cyclotron magnet has not been taken into account as additional shielding material for the cyclotron bunker.

	Side walls [m]	Roof [m]	BL wall [m]
Cyclotron	Fe: 0.9 NB: 3	NB: 2.5	
Degrader, BL sect. 1	NB: 4	NB: 3.5	
BL sect. 2	NB: 2.5	NB: 2	
Experimental area	NB: 2.5 back wall: 3-4m NB [4] with 1.8m Fe behind beam dump	NB: 2	NB: 2.5 or: Fe: 0.6 NB: 0.8
OPTIS area	NB: 2.5	NB: 1	NB: 2.5 or: Fe: 0.5 NB: 1.0
Gantry 2 area	NB: 2.5	NB: 1.5	NB: 2.5 or: Fe: 0.7 NB: 1.0

Table 3: Calculated shielding thicknesses for the various areas. Iron = Fe, normal concrete = NB; the beam line wall is the wall through which the beam line (BL) enters the irradiation area.

To ensure that beam line components are not located within the beam line walls, the walls had to be minimized leading to the options with an iron/concrete combination.

When iron is to be used in combination with normal concrete, a sandwich structure with iron as a middle layer should be built. An inner layer of concrete, which can be thin, is used because it is activated less than iron. The outer layer of concrete should be at least about 0.5 m thick and is necessary to compensate for the “window” in iron for neutrons in the 100 keV – 1 MeV region.

SOME SPECIAL CONSIDERATIONS

Since the new facility adds to the already existing dose rate in the Experimental Hall, care was taken that the shielding walls towards the Experimental Hall result in a dose rate well below 1 μSv/h.

Due to already existing infrastructure limiting the available space for shielding, the south wall of the cyclotron bunker had to be specially designed. It has to be built around the existing structures and contains more iron.

Another complication arose for the walkways which run along the wall in the Experimental Hall which separates it from the NA-Hall. The lowest walkway runs at a height of about 5.6 m and will be shielded from the cyclotron area by only about 2 m of material.

[4] Where space restrictions limit the thickness of the back wall to 3m, the shielding next to the Fe-layers should include 1-1.5m of heavy concrete.

To ensure that the walkways can be kept open, the east shielding wall of the cyclotron bunker will include iron layers of 0.6 m thickness at the relevant height and position.

ACCESS FOR PERSONNEL AND SUPPLY MEDIA

Mazes and openings for personnel access, ventilation ducts, cooling pipes and cables need to be designed in such a way that the overall efficiency of the shielding is not undermined. On the one hand, they weaken the existing shielding, on the other hand, radiation can scatter through them to the outside. The formalism developed in [6] is used to take account of the latter effect.

Access ways for personnel have been finalized for the cyclotron and the experimental area but may still change for the OPTIS and Gantry 2 areas. The cyclotron access includes a heavy-concrete door; for the experimental and treatment areas, a polyethylene door may prove to be necessary.

The planned supply-media access into the cyclotron bunker and the planned ventilation duct have been checked from the shielding point of view. Most of the electric media will be led through a maze which runs parallel to and above the access maze to the cyclotron. Additional openings will run through the shielding walls of the cyclotron bunker. The high-frequency power connection will be led through an underground channel which may have to be partly filled with polyethylene shielding.

For the rest of the facility, further clarification of supply-media access may become necessary.

REFERENCES

[1] E. Pedroni et al., *The Proscan Project: a Progress Report*, PSI Scientific and Technical Report 2001, Volume VI, 109.

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[3] H. Hirayama, *Intercomparison of Medium Energy Neutron Attenuation in Iron and Concrete*, Workshop Proceedings: Shielding Aspects of Accelerators, Targets and Irradiation Facilities-SATIF 5, July 18-21, 2000, 189.

[4] S. Teichmann et al., *Dose Rate Measurements Behind Different Shielding for 250 MeV Protons on a Thick Copper Target*, PSI TM-86-02-01, May 2002.

[5] S. Teichmann et al., *A Shielding Experiment for Proscan*, PSI Scientific and Technical Report 2002, Volume VI.

[6] A.H. Sullivan, A Guide to Radiation and Radioactivity Levels Near High Energy Particle Accelerators, Nuclear Technology Publishing, 1992, chapter 2.4.