Bulk shielding design for the MAX IV facility

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Abstract

This paper reports on the design of the bulk shields of the linac tunnel, the ring and the short pulse facility of the new MAX IV facility. MAX IV is funded and construction is planned to start in 2010.

1. Overview

MAX IV will be situated in the outskirts of Lund, Sweden and replaces the current MAX-lab facility which houses three rings with energies of 500, 700 and 1500 MeV. The MAX IV facility has a 3 GeV full energy linac injector for its 530 m circumference ring. The linac will also be used for the Short Pulse Facility (SPF) at which the electrons pass through one or several undulator devices to generate very short light pulses in the keV range. Figure 1 shows an overview of the site.

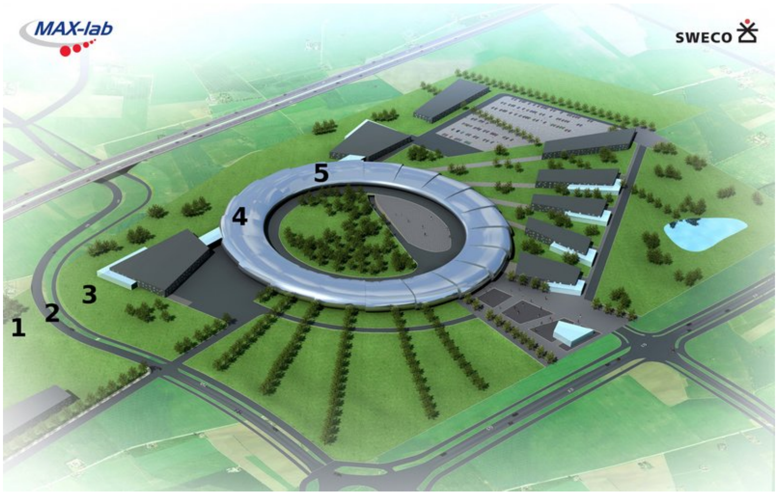

Fig. 1 – Overview of the MAX IV site.

The source model used in the shielding calculations for the dose equivalent rate due to bremsstrahlung, low, medium and high energy neutrons was adopted from [1] but normalized to the 90° data in [2]. The shielding material attenuation lengths were mainly obtained from [3].

2. The linac

The linac will be operated in two different modes. One is where it is used to fill or top-up the ring and this mode will always be active, i.e. its “duty” is 1. The linac can also be operated for the SPF and will then run at full power. This mode will only be active 1/3 of the time. The different operating modes of the linac are summarized in table 1.

The projected electron losses in the linac tunnel and transport beam lines during normal operation will determine its required shielding. At this stage, no data concerning these losses exist for the MAX IV facility. Values from similar facilities found in literature range between 0.1% and 12%. The values adopted for MAX IV are provided in table 2

Mode	Rate (Hz)	Energy (GeV)	Charge (nC)	Power (W)	Duty
Fill/top-up	0.1	3.0	1	0.3	1.0
SPF	100	3.0	1	300	0.33

Table 1 – Operating modes of the linac.

Location	Energy (GeV)	Loss (%)	Beam power @100Hz(W)	Loss power @100Hz(W)
linac	0-0.2	20	0-20	0-4
linac	0.2-3	1	20-300	0.2-3
transport/SPF	3	1	300	3

Table 2 – Projected maximum losses at a single point during normal operation of the linac. The beam power and loss power is for the linac SPF mode

Referring to figure 1, the linac runs in an underground tunnel which starts at location 1 and continues to location 4 where the electrons can be directed upwards to the ring. The electrons can also continue in the linac tunnel to the SPF located at 5. The area above the tunnel at locations 1, 2 and 3 does not belong to the MAX IV facility and is freely accessable to the public. The length of the linac between locations 1 and 4 is approximately 300 m.

The bulk shielding calculation was carried out for the linac tunnel at locations 1-4. The electron energy and the projected losses at a single point at these locations are provided in table 3 (refer also to table 2).

Location	Energy (GeV)	Loss (%)	Loss @ 100 Hz (W)
1	0.2	20	4
2	1.0	1	1
3	1.5	1	1.5
4	3.0	1	3

Table 3 – The electron energy and the projected losses at a single point for locations 1-4. The last column is the loss in Watts when the linac operates in SPF mode.

Table 4 shows the linac tunnels at location 1. The klystron tunnel is to the left and the linac tunnel to the right. The electrons travel into the figure. The linac is located 100 cm off the floor and the height of the linac tunnel is 250 cm. The vertical shield thickness above the linac is 50 cm of concrete, 20 cm of insulation and 380 cm of earth. The dose rates for bremsstrahlung, low, medium and high energy neutrons were calculated on the grids g0-g4 which are offset 10 cm from the ground. The result of this calculation is also shown in table 4.

At a maximum dose rate of 0.1 μSv/h, the public can spend 1000 h at location 1 until the dose limit adopted for MAX IV of 100 μSv is reached. Taking the duty of 0.33 into account, this increases to 3000 h. The procedure above was carried out for locations 2, 3 and 4 and table 5 summarizes these results.

From table 5 it follows that the public can spend 2000 h per year above the linac tunnel. At location 4 iron had to be added in order to obtain an occupancy of 2000 h per year. The weight of the iron shield at location 4 is approximately 1260 kg/m .

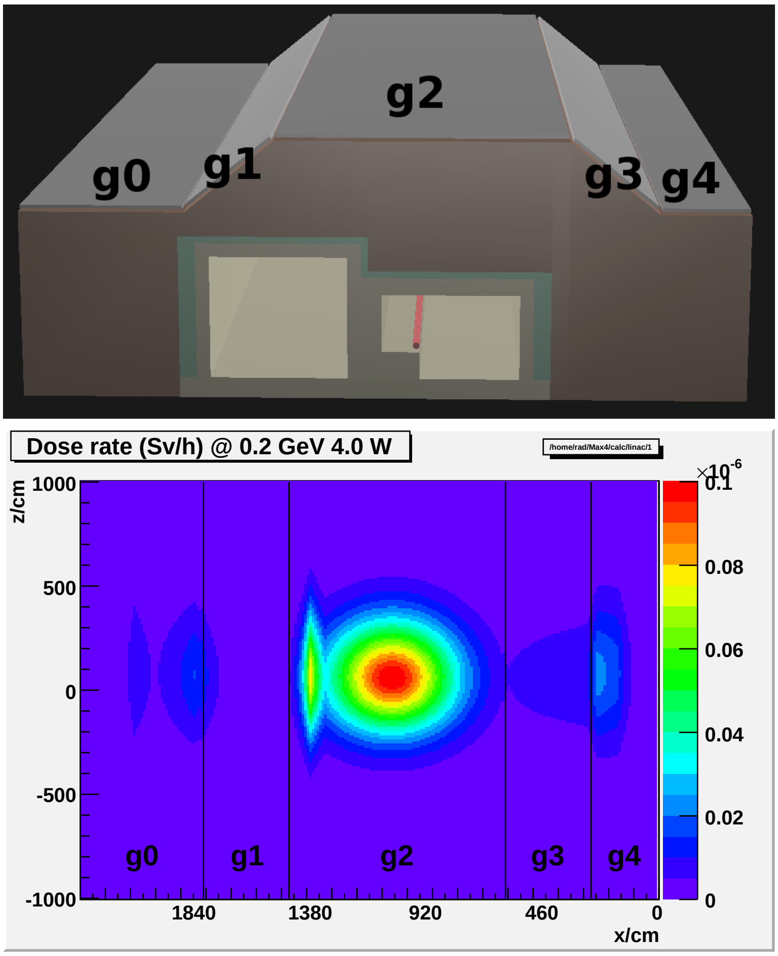

Table 4 – Top: the linac and klystron tunnels at location 1 and the grids g0-g4 on which the dose rate was calculated. Bottom: the corresponding dose rate on grids g0-g4 for a loss at z=0.

Location	Vertical shield	Dose rate (μSv/h)	Dose limit (mSv)	Hours
1	50 cm concrete, 380 cm earth	0.10	0.1	3000
2	230 cm concrete	0.15	0.1	2000
3	150 cm concrete, 200 cm earth	0.05	0.1	6000
4	30 cm iron, 150 cm concrete	1.50	1.0	2000

Table 5 – The results for locations 1-4. The number of hours was calculated taking the duty factor into account.

3. The Short Pulse Facility

If the electrons are not directed upwards to the MAX IV ring, they can continue in the extension of the linac tunnel to the SPF. The electrons will pass through an undulator device, generating photons with energies in the region of 10 keV. These photons travel parallel to the electron beam up to the point at which the electron beam is deflected by a dipole magnet towards another undulator, the test beam facility or the beam dump.

It is assumed that 1% of the electrons can be lost at a single point but since losses at different points can add up in the forward direction, a loss of 2% was assumed at the dipole bend.

Table 6 shows the result of this calculation. The upper panel of table 6 shows the experimental area (upstream view). The electrons are deflected 20° by the dipole (not shown) and the undulator photons continue at 0° through the wall to the experimental area. The grids g0 and g1 on which the dose rates were determined are located on the walls of the experimental area. x is the distance to the photon beamline along grid g0, y is the height above the photon beamline and w is the distance to the photon beamline along grid g1. The loss points were at the dipole bend (2%) for grid g0 and outside the side wall (1%) for grid g1.

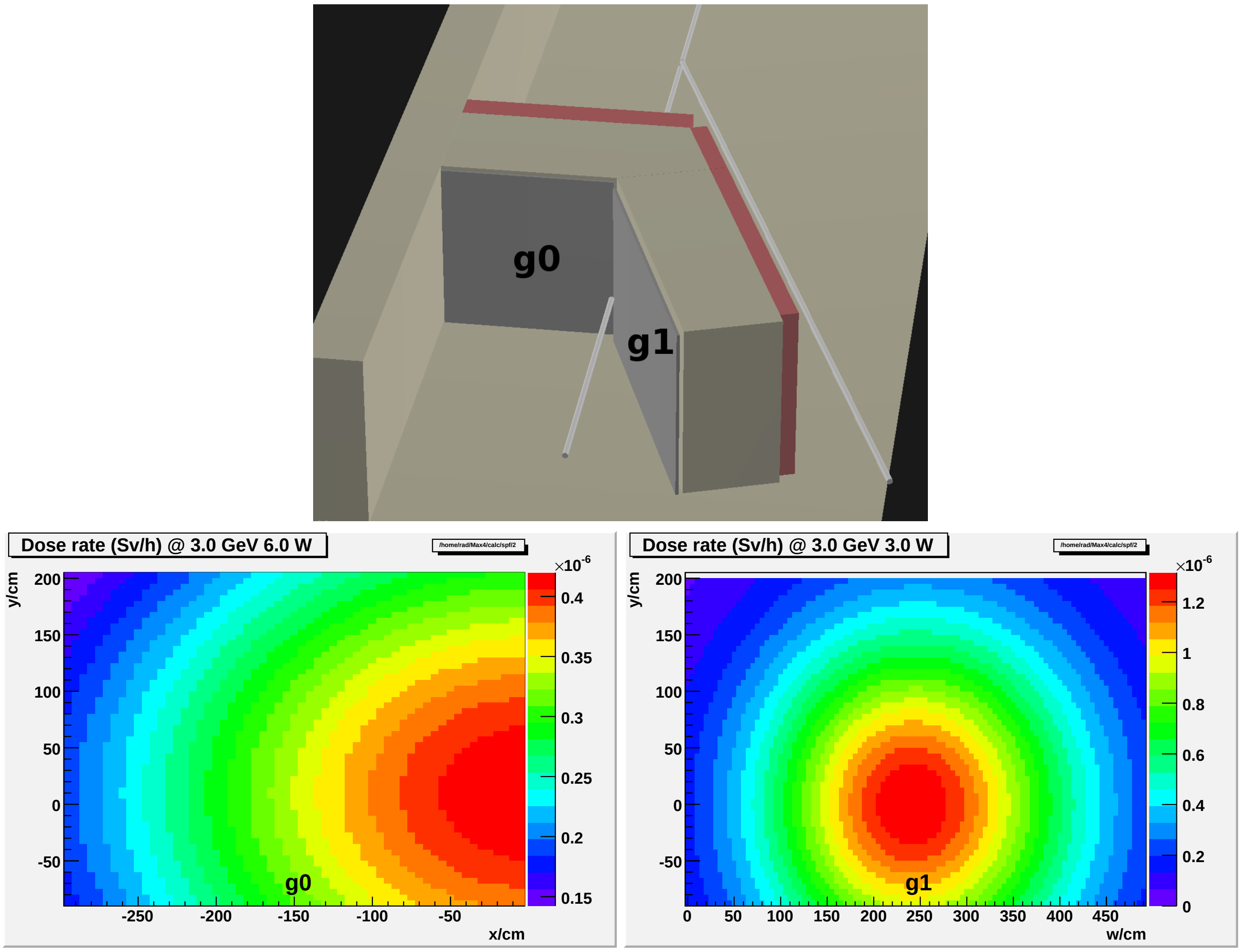

Table 6 – The calculated dose rates for the SPF. Top: the SPF layout showing the two grids on which the dose rates were calculated. Bottom: the dose rate on the the forward (g0) and side (g1) grid.

The results for the SPF are given in table 7. The corresponding number of hours have been determined for the two grids taking the duty factor into account.

Grid	Shield	Dose rate (μSv/h)	Dose limit (mSv)	Hours
g0	50 cm iron, 200 cm concrete	0.4	1.0	7500
g1	30 cm iron, 160 cm concrete	1.3	1.0	2300

Table 7 – The results for grids 0 and 1. The number of hours was calculated taking the duty factor into account.

4. The ring

The circumference of the MAX IV 3 GeV ring is 530 m and it contains 20 straight sections, one for injection and 19 for insertion devices (the length of one straight section is 5 m). The stored current will be 500 mA. For 4 injections per 24 h, the assumed electron loss scheme is given in figure 2

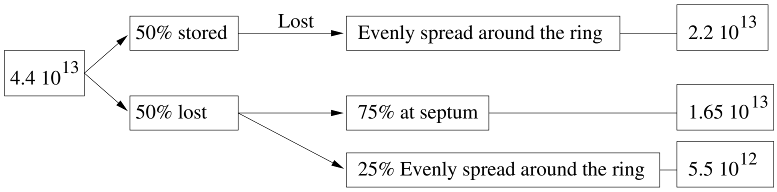

Fig. 2 – 24 h electron loss scheme. 50% of the electrons are lost during injection, mostly at the septum.

The losses that are spread evenly around the ring are assumed to occur with equal probability at a single point in each of the 20 cells. In table 8 one sector of the ring is shown between the positions of the centers of two adjacent long straight sections. The distance between the centers is 26.5 m. The assumed point of loss is in the center of the straight section as indicated by the solid circle. The shielding wall is 1 m concrete and the distance from the loss point to the ratchet wall is about 20 m. The ratchet wall is reinforced with 10 cm of lead covering 2^o or 70 cm on both sides of 0^o.

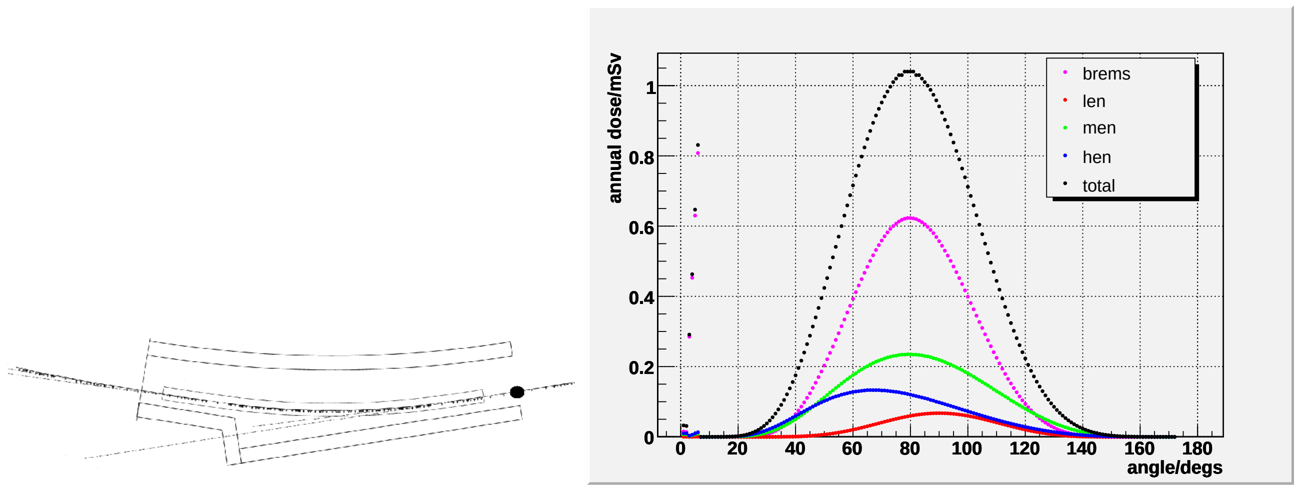

Table 8 – A section of the ring and the calculated dose.

The annual dose (2000 h) 50 cm off the concrete wall is also shown in table 8 as a function of the angle with respect to the direction of the electron beam. The total dose is shown as well as the individual contributions due to bremsstrahlung, low, medium and high energy neutrons. In table 9 an alternative to the normal shielding wall is shown. In order to decrease the distance from the center of the long straight section to the exit of the ratchet wall to about 16 m, two parameters are changed. First, the shielding wall is moved closer to the ring magnetic structure, second the 1 m concrete wall is replaced by 30 cm iron and 10 cm borated polyethylene over a distance of 6 m.

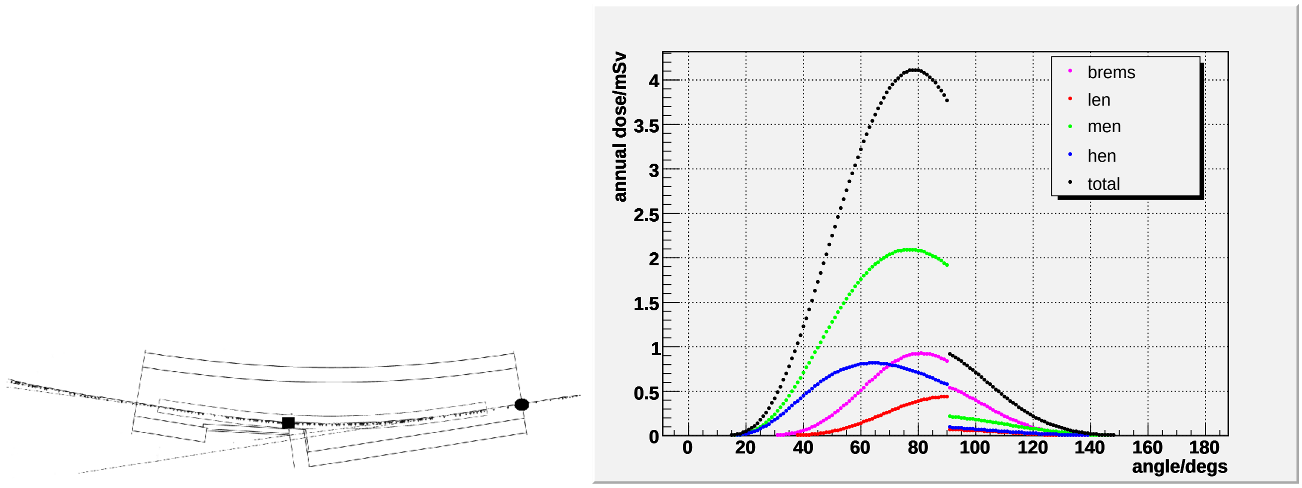

Table 9 – A section of the ring for the alternative configuration and the calculated dose.

The point of loss is assumed to be located at the solid rectangle. The annual dose (2000 h) 50 cm off the wall is also shown in table 9 as a function of the angle with respect to the direction of the electron beam. The location at which the maximum dose of 4 mSv occurs is in the first optical hutch of the beamline. The occupancy time of 2000 h is probably a factor of 10 too much. The hutch will be interlocked when the beamline shutters located just before the ratchet wall are open and access will not be permitted.

5. Conclusions

In this paper the bulk shielding calculations for the upcoming MAX IV facility were presented. The shielding for the linac tunnels is dictated by the requirements imposed by the SPF mode and the fact that parts of the tunnels are below an area accessible to the public. The MAX IV ring, with a circumference of 530 m, will be operated in top-up mode, and the required shielding is similar to other 3 GeV storage rings with a circulating current of 500 mA. Finally, the shielding of the SPF was described in some detail.

References

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National Council on Radiation Protection and Measurements, 2003

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[3] NSLS-II Preliminary Design Report (2007)
Brookhaven National Laboratory