A SHIELDING EXPERIMENT FOR PROSCAN

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INTRODUCTION

To support the computational method described in [1,2] which has been used for the shielding design of the new PROSCAN facility, a shielding experiment has been carried out. It was conducted in the provisional PIF area (Proton Irradiation Facility) of the NA-Hall. Dose rates behind different shielding were measured for 250 MeV protons incident on a thick copper target. The experiment, measurement results and a comparison with calculations are described. Further details can be found in [1].

LAYOUT

590 MeV protons from the Ring Cyclotron were degraded down to 250 MeV and stopped either

(a) in the regular 30-cm-thick copper beam dump (BD1) set into the wall at the end of the experimental area or

(b) in a cylindrical copper block (BD2), of 10 cm diameter and 7 cm length, located at the PIF irradiation position, about 1.5 m in front of the above mentioned wall.

The proton beam current of the experiment, measured in an ionization chamber directly in front of BD2, was 3.1 nA.

The residual shielding wall behind BD1 consisted of 0.5m iron shielding and of 2 m normal concrete. Dose rate measurements were made directly behind the shielding wall at beam height and at an angle of about 20±2° with respect to the beam entrance point in BD1 (point mp1). The roof shielding of BD2 starts at 1.5 m above the beam height and is of normal concrete. This was varied from 0.5 m to 3 m thickness in steps of 0.5 m. Dose rate measurements were made on top of the roof shielding directly above BD2, i.e., at 90±2°, and at 78±2° with respect to the beam direction. Due to the layout of the experimental area it was not possible to take measurements at more forward angles. Fig. 1 shows the experimental layout.

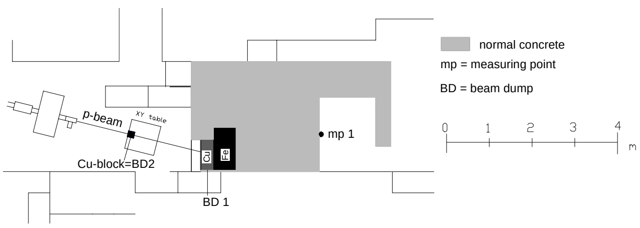

Fig. 1: Experimental layout at beam height. BD2 was put in place for the second set of dose rate measurements. mp1 indicates the measurement point when the beam was stopped in BD1.

The first set of dose rate measurements were made without BD2 in place and with a roof thickness of 0.5 m. For the second set of dose rate measurements, BD2 was put in place and the roof thickness was varied. Fig. 2 shows part of the setup with BD2 in position. Fig. 3 shows BD1 with its iron shielding during the dismantlement of the shielding wall.

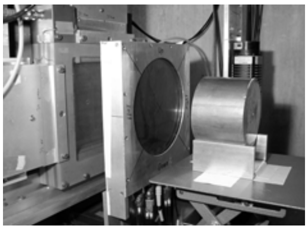

Fig. 2 and 3: Cu-block (BD2) behind the ionization chamber and the copper beam dump BD1 with its iron shielding during dismantlement of the shielding wall.

MEASURING SYSTEMS

All dose rate measurements were made by radiation protection personnel. γ-dose rates were measured either with a Teletektor Graetz or with a Bicron/Low Energy instrument. Dose rates due to neutrons below 20 MeV were measured with a Berthold LB 123 / LB 6411 rem counter. Dose rates due to high-energy neutrons ($E_n > 20$ MeV) were determined using a C-11 monitor, which is based on the measurement of the induced C-11 acitivity in a plastic scintillator. The latter was employed only for measurement points at 90° and could be used only for 0.5 - 1.5 m concrete shielding due to the low intensity of high-energy neutrons behind thicker shielding.

RESULTS

The γ- and low-energy neutron dose rates were read directly from the measuring devices. Dose rates due to neutrons above 20 MeV were derived from the measured high-energy neutron flux assuming an average energy of about 60 MeV [5] and using the corresponding flux-to-dose conversion factor of 370 pSv cm^2 [3]. At 1 m and 1.5 m roof thickness the contribution due to high-energy neutrons corresponded to about 45 - 50% of the dose rate due to low-energy neutrons ($E_n <$ 20 MeV) indicating that equilibrium is reached at about 1.5 m shielding thickness. For thicker shielding, the shape of the neutron spectrum is not expected to change. Furthermore, it was assumed that the shape of the neutron spectrum at 78° does not differ significantly from the one at 90°.

[5] Derived from Monte Carlo simulations using MCNPX.

For the subsequent analysis, the following assumptions were therefore made:

- for a shielding thickness of more than 1.5 m, the dose rate contribution due to high-energy neutrons corresponds to 50 % of the dose rate due to low-energy neutrons (E_n < 20 MeV),
- for 78° and a shielding thickness up to 1.5 m, the dose rate contribution due to high-energy neutrons is the same as for 90°.

Tab. 1 shows the total dose rates H_{tot} (γ + n) at measurement points on the roof used for the subsequent comparison with calculations. The result for mp1 is: H_{tot} = 8.8 μSv/h. Photons contribute 10-20 % to the total dose rates, depending on the shielding thickness. The total measurement uncertainty is approximately 20 %.

	H_{tot} [μSv/h] beam stop in BD2					
	0.5m	**1.0m**	**1.5m**	**2.0m**	**2.5m**	**3.0m**
90°	3700	290	36	5.5	1.3	0.4
78°	4500	340	40	7.1	2.0	0.5

Tab. 1: Total dose rates H_{tot} for different shielding thicknesses on the roof, using the above assumptions for the high-energy neutron contributions.

COMPARISON WITH CALCULATION

Forward shielding

The calculated total dose rate H_{tot} at mp1 is 8.1 μSv/h. This value agrees with the measured total dose rate within the measurement uncertainty. For the calculation, the shielding effect of copper was assumed to be the same as for iron. After subtracting the range of protons in copper, the total effective thickness of iron used for the shielding calculation was 0.75 m.

Lateral shielding

Fig. 4 shows a comparison of the measured total dose rates H_{tot} on the roof with results from calculations, as a function of angle with respect to the beam direction and for different normal-concrete shielding thicknesses. The calculations predict a dose rate maximum at around 65°. The occurrence of such a maximum can be explained by the fact that while the source term H_0 becomes larger at more forward angles, the effective shielding thickness also becomes larger with 1/sin(θ). In general, the calculations underestimate the dose rates. The difference between calculation and measurement is the worst for 3 m roof shielding. However, for this shielding thickness, the measured dose rates are close to the detection limit of about 0.1 μSv/h and may therefore have a larger uncertainty than shown. For 0.5 – 2.5 m shielding, the measured dose rates at 78° agree within a factor of about 2 with the calculated results; the measured dose rates at 90° are higher by factors of about 3 - 10 (the worst case being observed at 2.5 m shielding).

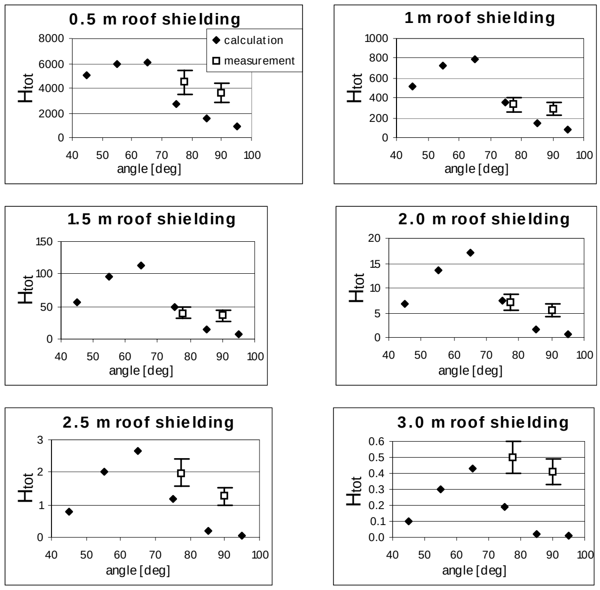

Fig. 4: Comparison of measured and calculated total dose rates [μSv/h] on top of the roof shielding. The calculated points represent angular bins of ±5° [1,2]. The angular uncertainty of the measured points is about ±2°.

CONCLUSIONS

The agreement between calculated and measured dose rates behind the forward shielding wall, consisting of iron/copper and concrete, is very good. For the case of the lateral roof shielding, the calculations tend to underestimate the dose rates. At 78°, the agreement seems to be better than at 90°, possibly indicating a smaller angular dependency than predicted by the calculations. Additional measurements at more forward angles would be necessary to confirm this. However, disregarding the measurements at 3 m roof shielding, which were near the detection limits, the trend seems to be that the angle-dependent maximum measured dose rate would not significantly exceed the calculated dose rate at 65° (the predicted "hotspot"). In practice, therefore, the lateral shielding for PROSCAN was designed in such a way that the calculated dose rate at the "65°-hotspot" is below the limiting value as defined by the radiation protection specifications. For the design of the forward shielding for PROSCAN, the computational method was considered to be accurate enough.

REFERENCES

[1] S. Teichmann et al., *Dose Rate Measurements Behind Different Shielding for 250 MeV Protons on a Thick Copper Target*, PSI TM-86-02-01, 10 May 2002.

[2] S. Teichmann, *Shielding Calculations for Proscan*, PSI Scientific Report 2002, Volume VI.

[3] Swiss federal publication SR 814.501.43, *Verordnung über die Personendosimetrie*, Oct. 1999.