SHIELDING OF AN INTERNAL DUMPING FACILITY FOR THE PS:
RESULTS OF EXPERIMENTS IN THE SE 62 TEST BEAM AND
COMPARISON WITH MONTE CARLO CALCULATIONS

R. Gouiran, Ch. Steinbach, MPS
J.M. Hanon, M. Höfert, Health Physics
K. Lambert, ISR
1. INTRODUCTION

The internal dumping of $10^{13}$ protons per pulse raises the problem of the dose received by the next PS magnet unit and its pole face winding. The estimations are that it would take something like 2000 hours' continuous dumping on a conventional internal dump target before the pole face windings fail and the sheets of the magnet come apart\(^1,2\). This has to be compared with the average 6000 hours of PS acceleration per year, of which approximately 5% will be devoted to internal dumping.

A movable shielding arrangement (shower catcher) has been proposed\(^3\) to attenuate the radiation damage due to internal dump targets and its study has been approved\(^4\).

Other sophisticated dumping systems have been suggested as well\(^5-7\), all aiming to dispose of the beam by fast vertical deflection directly onto a block under or above the closed orbit in a straight section.

Monte Carlo programs for hadron cascades\(^8\) allow for the calculation of the energy deposition (dose) in cylindrical geometries approximating to a magnet downstream of a target. The results of such calculations are given below and are compared with experimental results.

An appropriate location for an experimental set-up was the slow extraction test beam in the East Hall junction, as shown in Fig. 1.

As a last preliminary remark we have to mention that some of the results have already been quoted or used in other reports\(^6,7,9,10\).

2. EXPERIMENTAL STUDIES

2.1 Layout

The experimental layout common to all three experiments consists of an assembly of iron blocks each measuring $27 \times 10 \times 10$ cm (Fig. 2). The gap
of this 3.80 m long collimator simulates a magnet with a gap of 7 cm. Slots are provided for insertion of expanded polystyrene plates holding the dosimeters and activation detectors (Fig. 3).

The shower catcher in front of this assembly (used in experiments 2 and 3) is built of lead blocks 20 × 10 × 5 cm with, here again, slots for insertion of detector supports (Fig. 2). The gap has been chosen equal to 4 cm, a reasonable value simulating the movable shield according to beam size expectations for high intensity beams within a factor of 2.

The dump target finally used in experiments 1 and 2 is simulated by an external target of tungsten in air, 75 mm long and 6.3 mm diameter placed 130 cm in front of the magnet, therefore simulating a short PS straight section. About 70% of the incident protons, measured on the secondary emission chamber SEC 1, interact in the target as the interaction length in tungsten is about 6 cm.

2.2 Experimental programme

Three experiments were carried out:

1. simulation of an internal dump target in a PS short straight section in order to measure the dose* in the next magnet;

2. simulation of an internal dump target followed by a shower catcher in the straight section to estimate the reduction of dose to the next magnet;

3. a direct hit of the shower catcher by a proton beam to evaluate doses in the next magnet in a simulation of a vertical deflection dumping system. The beam in this case hits the upper part of the local shield at about 3 cm from the axis, i.e. 1 cm from the edge. It is about 15 mm wide and 8 mm high.

* Dose in this context means dose to iron. As the magnet is built of laminated iron sheets separated by organic insulation material, the dose to the latter is determined by the dose to the iron resulting from the nuclear cascade.
2.3 Approximation to the actual situation

The simulation of the magnet following the target has two disadvantages: flat "pole faces" instead of hyperbolic ones, and the absence of a magnetic field in the gap of the magnet.

The lead bricks employed in experiments 2 and 3 do not exactly simulate the real absorber proposed in ref. 5, since the latter is made up of two collimators, the first one having an aperture of 2.8 cm and the second 5.2 cm. The experiment should however give a good approximation to the radiation situation in the case of the shower catcher. The efficiency of the external tungsten target used in experiments 1 and 2 lies in the same region as the multi-traversal efficiency of an internal dump target. All values given in this report have, however, been normalized to one incoming proton for the purpose of comparison with results from Monte Carlo programs.

The R.M.S. Coulomb scattering angle in the target vertically for 24 GeV/c protons is $\sigma = 2.9$ milliradians, so less than 2% of the scattered primary protons should hit the magnet according to Rossi's model.

3. DOSIMETRY

3.1 Glass dosimeters

3.1.1 Radiophoto luminescent (RPL) dosimeters

Exposure to ionizing radiation of the glass (LiPO$_3$ and Al(P0$_3$)$_3$ in equal parts + 7% Ag(P0$_3$)) induces stable luminescent centres which possess discrete allowed energy levels. The absorption of a photon of the appropriate frequency in the UV region produces excitation and radiative transitions between these energy levels, and the intensity of the luminescent emission resulting from optical stimulation is a function of the absorbed radiation dose. The dosimeter dimensions are 6 mm × 1 mm ø and the dose range is from 1 rad to $5.10^8$ rad.
3.1.2 Optical absorption dosimeters - "CERN Glass"

Ionizing radiation induces optical absorption bands in the glass (by weight % $P_2O_5$ (70.5), $K_2O$ (12), $Al_2O_3$ (9), MgO (4), $B_2O_3$ (3) and other components (1.5)), of which the principal one is measured spectrophotometrically at 510 nm. The glasses have surface dimensions of 36 mm $\times$ 12 mm and are used in two thicknesses, i.e. 5 mm and 1.5 mm to cover the dose range of $1.6 \times 10^4$ rad to $2 \times 10^7$ rad.

3.2 Activation detectors

Different activation detectors fixed to the polystyrene plates were inserted into the slots of the shower catcher or simulated magnet. During the experiments aluminium foils and sulfur disks were used and the following reactions allowed for the study of fast neutrons (FN) and high energy particle (HEP) flux densities. In the energy ranges quoted the cross-sections given below are assumed:

- $^{27}Al(n,\alpha)^{24}Na$ Neutrons 6 - 25 MeV $\sigma = 120$ mb
- $^{32}S(n,p)^{32}P$ Neutrons 3 - 25 MeV $\sigma = 300$ mb
- $^{27}Al(spal)^{22}Na$ Hadrons above 25 MeV $\sigma = 20$ mb

It has been shown in the past that estimations for radiation doses in organic material could be made by combining a detector for fast neutrons and a detector for high energy particles into linear relations $^{15}$. Thus the following equations were used for the determination of absorbed doses $^{16}$:

$$D = 5 \times 10^{-8} \phi_{\text{NA22}} + 6 \times 10^{-8} \phi_{\text{P32}}$$

where $D$ is the dose in rad and $\phi$ are the fluences measured with the different detectors in cm$^{-2}$.
4. EXPERIMENTAL RESULTS

The experimental results are presented in Figs. 4 to 7. The dose in rad per incoming proton is plotted over the position of the slots in both shower catcher and simulated magnet. The normalization to absorbed dose per incoming proton allows for the direct comparison of the results of Monte Carlo calculations. Although more positions were covered with detectors during the experiment, the following discussion will be limited to the upper (Figs. 4 and 6) and lower (Figs. 5 and 7) central positions, i.e. to detectors positioned in the central axis but in the slots just below and above the air gap. The doses recorded on these detectors turned out to be the highest ones and thus most important for the problem of protecting the following magnet by a shower catcher.

As can be seen from Fig. 3 the location of the detectors considered was not exactly the same in all positions. Aluminium foils cover a much greater area than the other detectors. For this reason the results of the glass dosimeters and activation detectors cannot be directly compared. It is however possible to correlate the same detector results for the three experiments.

5. MONTE CARLO CALCULATIONS

The Monte Carlo program MAGKA makes use of a cylindrical geometry. To simulate both shower catcher and magnet as well as the experimental layout the following dimensions were used:

<table>
<thead>
<tr>
<th></th>
<th>Length cm</th>
<th>Diameter cm</th>
<th>Hole cm</th>
<th>Material cm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Magnet</td>
<td>210</td>
<td>35</td>
<td>7</td>
<td>iron</td>
</tr>
<tr>
<td>Shower catcher</td>
<td>80</td>
<td>20</td>
<td>4</td>
<td>lead</td>
</tr>
</tbody>
</table>

The target is placed at 134 cm in front of the magnet or 12.5 cm in front of the shielding cylinder.
6. EFFECT OF A SHOWER CATCHER FOLLOWING A DUMP TARGET IN A SHORT STRAIGHT SECTION

A comparison is made for the maximum doses at the position of the pole-face windings, when the beam is incident on a thick dump target located on the beam axis, with the dose at the magnet front face, when the latter is protected by an 80 cm lead shower catcher to be placed in a short straight section.

6.1 Results of glass dosimeters

At point No 6 in the lower position on the front face of the magnet (Fig. 5) the dose in experiment 1 without shield or shower catcher is $1.6 \times 10^{-10}$ rad per incoming proton. By comparing this value with the situation in experiment 2 where the shielding had been placed between target and magnet - the dose determined is $6 \times 10^{-11}$ rad per proton - an attenuation factor of 2.6 is calculated.

For the upper position (Fig. 4) the comparison is not possible as the glass dosimeter in point No 6 could not be evaluated.

It should however be noted that the protection factor of 2.6 for the front face upper position decreases with penetration into the magnet and reaches a zero value after approximately 60 cm.

6.2 Results of activation detectors

The results of experiment 1 without shower catcher clearly show a small build-up of the dose with depth in the magnet. Thus the maximum values without shield should be compared with the maximum values in case a shower catcher protects the front face. In the upper position the doses under consideration are thus $1.4 \times 10^{-10}$ rad per incoming proton, to be compared with $5 \times 10^{-11}$ rad/proton. This results in an attenuation factor of 2.8. In the lower position the corresponding figures are $1.2 \times 10^{-10}$ and $5 \times 10^{-11}$ rad/proton, which leads to protection in dose for the pole-face winding in the magnet by a factor of 2.4.
6.3 Results of program MAGKA

The result of the Monte Carlo calculation shows a pronounced build-up in dose for the unshielded magnet with a dump target in front. On the front face a dose of $7 \cdot 10^{-10}$ rad per incoming proton is calculated, increasing to a value of $1.4 \cdot 10^{-9}$ rad/proton at a depth of 40 cm. This maximum value is to be compared with the dose of $7 \cdot 10^{-10}$ rad/proton behind the shower catcher of 80 cm length in a short straight section. This leads to an attenuation of a factor of two.

7. EFFECT OF A BEAM DUMP DIRECTLY HIT BY THE PROTON BEAM AND LOCATED IN A LONG STRAIGHT SECTION

The aim is to evaluate the protection given by a dump arrangement proposed in ref. 5. By a vertical deflection the proton beam hits a block of metal installed in a long straight section. To simulate such a dump system the shower catcher was thus hit directly by the proton beam. For an estimation of the protective effect of such a device the dose maximum at the place of the pole-face winding in the unshielded case has to be compared with the position at a distance of 230 cm from the beginning of the shield (position 9 in the experiment).

7.1 Results of glass dosimeters

The dose of $1.6 \cdot 10^{-10}$ rad per incoming proton in the unshielded case at the front end of the magnet has thus to be compared with a value of $2.4 \cdot 10^{-11}$ rad in point No 9 upper position. The attenuation in dose amounts to a factor of 6.7.

For the lower position two types of glass dosimeters were used. For the Toshiba radiophoto luminescent dosimeters the corresponding values are $1.6 \cdot 10^{-10}$ and $2.7 \cdot 10^{-11}$ rad per incoming proton, thus the attenuation is 5.9.
The CERN optical absorption dosimeters were only used in experiment 3. The value in position 9 is $2.2 \times 10^{-11}$ rad per incoming proton. Previous experience with these glass dosimeters on the front end of a magnet steel block at the end of a long straight section with a thick dump target has lead to values of $1.4 \times 10^{-10}$ rad per incoming proton. The protection factor is thus 6.4.

7.2 Results of activation detectors

Also for these detectors the maximum dose at the place of the pole-face winding of a magnet following a thick dump target in a short straight section will be compared with point No 9.

The comparison is only possible for the lower position. The value without shield of $1.2 \times 10^{-10}$ and the value of $2.3 \times 10^{-11}$ rad per incoming proton behind a long dump system leads to an attenuation in dose of a factor of 5.2.

8. CONCLUSIONS

8.1 Merit of a shower catcher following a dump target

If one wants to lower the radiation damage caused by an internal dump target on the next PS magnet, the average protection factor, as calculated in section 6, is 2.5. Taking into account the complexity, the price and maintenance foreseen, it seems questionable whether such a device is warranted.

8.2 Merit of kicking the beam vertically onto a block

It has been shown in section 7 that a protection factor of about 6 could be expected at the end of a long straight section for a direct hit on a beam dump. One should consider the fact that, in the present situation as described in ref. 5, the beam will not be deflected upwards instantaneously. A finite rise time ranging between 0.7 and 1 µs already cuts this factor by
nearly a half and consequently only a protection factor of 2 to 4 could be expected from such a configuration.

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TV CAMERA

TUNGSTEN TARGET 0.63 x 7.5 cm

PS SLOW EXTRACTED BEAM

LEAD BRICKS COLLIMATOR

IRON BLOCK SIMULATED MAGNET

Fig. 2: EXPERIMENTAL SET UP
POLYSTYRENE PLATE

upper position

ALUMINIUM
SULFUR

lower position

CERN GLASS
SULFUR
TOSHIBA
ALUMINIUM

GAP

FIG. 3
upper position

FIG. 4
lower position

- NA22 + P32, EX. 1
- NA22 + P32, EX. 2
- NA22 + P32, EX. 3

FIG. 7