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Additional Booster shielding calculations

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I. INTRODUCTION

An earlier note by Gollon[1] estimated shielding requirements for the Booster. Since the publication of that note, a number of changes have occurred which require additional analysis. The purpose of this report is to document those analyses.

II. SOURCE TERMS

Beam losses associated with Booster have been previously estimated by Lee[2]. However, for purposes of shielding design, a more conservative set of loss assumptions have now been used to assure that the shielding analysis has an adequate margin of safety[3]. The new assumptions are listed in Table I.

Table I

ASSUMPTIONS FOR SHIELDING DESIGN

- Operating Beam - 6E13 p/s @ 1.5 GeV
- 20% Beam losses at injection - 1E13 p/s @ 200 MeV
- 1% Beam loss during acceleration - 6E11 p/s @ 0.7 GeV
- 1% Beam loss at extraction - 6E11 @ 1.5 GeV
- Maximum Credible Accident - 100% of beam at a point

A significant source has been added since the previous note. A combination beamstop/scraper has been added to the planned operation. The purpose of this device is to catch as much of the beam losses at one point rather than have it lost around the ring in general, and to provide a dump for accelerated beam that cannot be ejected to the AGS. Design considerations for the dump have been discussed by Stevens[4]. For purposes of the shielding calculation, we assume that the dump receives beam primarily during studies, which are performed 70 days/yr, 8 hours/study. Studies are assumed to average 1.5×10^{13} p/s at 1.5 GeV.

III. SHIELDING CRITERIA

The design criteria for shielding is to limit the dose rate in uncontrolled or normally occupied areas to less than 0.5 mRem/hr under normal operating conditions. Higher levels are permitted if the access control and warning systems as specified in OH&S Guide #2.4.0 are met.

IV. SHIELDING CALCULATIONS

Calculations are made using the formulation proposed by Tesch[5] for estimating dose equivalent per proton outside a lateral concrete shield when protons strike a long copper target:

$$H = \frac{H_G}{r^2} \exp(-d/\lambda)$$

Here H is in rem/p, r is in meters, and d is in gcm^{-2}. From references 1 and 5, the other parameters required for these calculations are:

Table II

Beam Energy	λ	H_G
200 MeV	72 g/cm^2	3x10^{-14} rem-m^2/p
700 MeV	95 g/cm^2	6x10^{-13} rem-m^2/p
1.5 GeV	110 g/cm^2	1.3x15^{-12} rem-m^2/p

Attached are Tables III, IV, and V showing the results of these calculations at each energy at a given beam loss. These results can be used to show the resulting dose rates for each of the situations reviewed below.

A. NORMAL BEAM LOSSES AT INJECTION OR ACCELERATION

We assume that one-half of the losses listed in Table I occur at a single point where the vertical thickness of shield is 15 feet and the minimum horizontal thickness is 20 feet.

5x10^{12} p/s @ 200 MeV -	0.18 mRem/hr (vertical),
	<0.01 mRem/hr (horizontal)
3x10^{11} p/s @ 700 MeV -	3.3 mRem/hr (vertical),
	0.12 mRem/hr (horizontal)

B. NORMAL BEAM LOSSES AT EXTRACTION

We assume that one-half of the extraction loss occurs on the extraction magnet located under the 10 foot earth shield over Bldg. 914.

3x10^{11} p/s @ 1.5 GeV - 525 mRem/hr (vertical)

In addition, a shield wall will be provided between the occupiable area of Bldg. 914 and the portion containing the Booster line. This wall must be sufficient to reduce the levels in the occupiable part to <0.5 mRem/hr. The wall is at a distance of 37 feet from the principal loss point (the extraction magnet). Table VI shows the result of this calculation. An equivalent of 19 feet of earth will be necessary for this shield wall.

C. BEAM DUMP

The beam dump consists of a 18.3cm radius steel (ρ=8.1 g/cm^3) object which will be enclosed in a 20cm thick marble (2.7 g/cm^3) shield. The additional shielding provided by the marble and steel is equivalent to 3.7 feet of earth, which gives the equivalent of 18.7 feet of shielding vertically. At the location of the dump there is approximately 60 feet horizontal shielding.

$1.5\text{x}10^{13}$ p/s @ 1.5 GeV - 130 mRem/hr (vertical)
<0.05m/Rem/hr (horizontal)

The dose equivalent rate at the fence will be increased by scattered radiation from the high dose rate penetrating vertically. The area of the radiation levels vertically is about 600 feet^2. The scattered levels at the fence from the emerging vertical fields are approximated by the formula

$$D_s = \frac{A}{24\pi d^2} D_v$$

Where D_v is the dose equivalent rate vertically, A is the area of the berm through which D_v emerges, and d is the distance from the center of A to the fence line.

$$A = 600 \text{ ft}^2$$
$$D_v = 210 \text{ mRem/hr}$$
$$d = 42 \text{ ft}$$

$$D_s = \frac{600 \text{ ft}^2}{24\pi \, (42\text{ft})^2} \text{ x } 130 \text{ mRem/hr} = 0.6 \text{ mRem/hr}$$

E. SKYSHINE

The high energy portion of the emerging neutron field can create radiation fields at ground level from scattering in air. This type of radiation is commonly called skyshine radiation and can be estimated from the formula $H(r) = 3\text{x}10^{-13} \exp(-r/\lambda)/r^2$ rem/n developed by Stevenson and Thomas[6]. The number of neutrons escaping can be estimated from the of the escaping field. Therefore, from the beam dump

$$H(r) = 3\text{x}10^{-13} \frac{\exp(-r/\lambda)}{r^2} \quad \frac{130 \text{ mRem/hr}}{18.4 \frac{\text{nRem}}{\text{ncm}^{-2}}} \quad \text{Rem/n}$$

$$= 3.4\text{x}10^{-6} \frac{\exp(-r/\lambda)}{r^2} \quad \frac{\text{n}}{\text{cn}^2\text{hr}} \quad \frac{\text{rem}}{\text{n}} \text{ x } 600\text{ft}^2\text{x}\left(\frac{30.48\text{cm}}{\text{ft}}\right)^2$$

$$H(r) = 1.2 \frac{e^{-r/\lambda}}{r^2} \quad \text{rem/hr} \qquad \lambda = 700\text{m}$$

The nearest routinely occupied area is approximately 450 feet (140m) away.

$$H(r) = \frac{1.2 \, e^{-r/\lambda}}{r^2} = \frac{1.2 \, e^{-140/700}}{(140)^2} = 4.6\text{x}10^{-5} = 46 \ \mu\text{Rem/hr}$$

The site boundary is approximately 1.1 km

$$H\ (1.1\ \text{km}) = \frac{1.2\ e^{-1100/700}}{(1100)^2} = 2.1\text{x}10^{-7}\ \text{Rem/hr} = 0.2\ \mu\text{Rem/hr}$$

Another skyshine source that should be considered is the emerging field through the top of 914 from the routine extraction losses. The area of this source is approximately 400 ft^2.

$$H(r) = 3\text{x}10^{-13}\ \frac{\exp\ (-r/\lambda)}{r^2}\ \ \frac{525\ \text{mRem/hr}}{18.4\ \text{nRem/ncm}^{-2}}\ \text{x}\ 400\ \text{ft}^2\ \text{x}\ (\ \frac{30.48}{\text{ft}}\ )^2$$

$$= 3.2\ \frac{e^{-(r/\lambda)}}{r^2}\ \text{rem/hr}$$

at 140 m

$$H(140) = 3.2\ \frac{e^{-\ (140/700)}}{(140)^2} = 134\ \mu\text{Rem/hr}$$

at site boundary

$$H\ (1.1\ \text{km}\ ) = 3.2\ \frac{e^{-1100/700}}{(1100)^2} = .55\ \mu\text{Rem/hr}$$

Therefore, the total outside dose in a 2000 hr. work year at 140m is

$$46\ \text{x}\ 10^{-6}\ \text{rem/hr x 70 day x 8 hr/day} + 134\text{x}10^{-6}\ \text{x 140 day/yr x 8 hr/day}$$

$$= 26 + 150 = 176\ \text{mRem/yr.}$$

and at 1.1 km

$$H\ (1.1\text{km}) = .2\ \mu\text{Rem/hrx70x8} + .55\ \mu\text{Rem/hr}\ (130\text{x}24 + 70\text{x}16) = .1 + 2.3 = 2.4\text{mRem/yr.}$$

F. MAXIMUM CREDIBLE ACCIDENT

If the full circulating beam at 1.5 GeV is lost at a point in the ring, the resulting dose rate can be calculated using the Tesch formula above

$6\text{x}10^{13}$ p/s @ 1.5 GeV - 105 Rem/hr (vertical - 914 roof)
4.7 Rem/hr (vertical - ring)

Beam loss monitors which alarm and interlock the beam will be necessary to assure that substantial beam losses are promptly detected and inhibited. It should be recognized that the assumption of full beam being lost at a single point is very conservative. Even in the absence of radiation monitors, such a beam loss would be quickly observed by the operators and corrected.

REFERENCES

1. P. Gollon, "Booster Tunnel Shielding Calculation", Booster Tech. Note #66 (1986).

2. Y. Y. Lee, Memorandum Y.Y. Lee to P. Gollon, dated 6/16/86.

3. R. Casey, Memorandum R. Casey to B. Weng, dated 6/8/87.

4. A. Stevens, Memorandum A. Stevens to B. Weng, dated 7/30/87.

5. K. Tesch, Radiation Protection Dosimetry 11,165 (1985).

6. G. R. Stevenson and R. H. Thomas, Health Physics, 46, p.115 (1984).

TABLE III

100 MeV SHIELDING VALUES I RING

```
LIST RUN
Enter the energy of the incident proton: 200
ENTER THE APPROPRIATE HCASC 3e-14
ENTER THE APPROPRIATE LAMBDA 72
Enter the beam losses that you want to calculate (p/s) 1e13
This calculation is for a proton energy of 200
It uses a lambda =  72  g/cm^2

Shielding       Dose Rate
Thickness       mRem/Hr.
Ft. (soil)
10                29.09
11                11.83
12                 4.85
13                 2.01
14                 0.84
15                 0.35
16                 0.15
17                 0.06
18                 0.03
19                 0.01
20                 0.00
21                 0.00
22                 0.00
This calculation assumes a point loss of  1E+13  p/s
Ok
```

TABLE IV

700 MeV SHIELDING VALUES IN RING

```
RUN
Enter the energy of the incident proton: 700
ENTER THE APPROPRIATE HCASC 6e-13
ENTER THE APPROPRIATE LAMBDA 95
Enter the beam losses that you want to calculate (p/s) 3e11
This calculation is for a proton energy of 700
It uses a lambda =  95  g/cm^2

Shielding       Dose Rate
Thickness       mRem/Hr.
Ft.(soil)
10               110.45
11                54.00
12                26.64
13                13.25
14                 6.63
15                 3.34
16                 1.69
17                 0.86
18                 0.44
19                 0.23
20                 0.12
21                 0.06
22                 0.03
This calculation assumes a point loss of  3E+11  p/s
Ok
```

TABLE V

1500 MeV SHIELDING VALUES IN RING

```
LOAD"RUN
Enter the energy of the incident proton: 1500
ENTER THE APPROPRIATE HCASC 1.3e-12
ENTER THE APPROPRIATE LAMBDA 110
Enter the beam losses that you want to calculate (p/s) 3e11
This calculation is for a proton energy of 1500
It uses a lambda =  110  g/cm^2

Shielding      Dose Rate
Thickness      mRem/Hr.
Ft.(soil)
10              525.99
11              278.25
12              148.52
13               79.89
14               43.28
15               23.59
16               12.93
17                7.12
18                3.94
19                2.19
20                1.22
21                0.68
22                0.38
This calculation assumes a point loss of  3E+11  p/s
Ok
```

TABLE VI

SHIELDING VALUES FOR 914 SHIELD WALL

```
RUN
Enter the energy of the incident proton: 1500
ENTER THE APPROPRIATE HCASC 1.3e-12
ENTER THE APPROPRIATE LAMBDA 110
Enter the beam losses that you want to calculate (p/s) 3e11
This calculation is for a proton energy of 1500
It uses a lambda =  110  g/cm^2

Shielding       Dose Rate
Thickness       mRem/Hr.
Ft.(soil)
10                46.67
11                27.17
12                15.84
13                 9.24
14                 5.39
15                 3.15
16                 1.84
17                 1.08
18                 0.63
19                 0.37
20                 0.22
21                 0.13
22                 0.07
This calculation assumes a point loss of  3E+11  p/s
Ok
```