# 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 - $6 \mathrm{E} 11 \mathrm{p} / \mathrm{s}$ @ 0.7 GeV
- $1 \%$ Beam loss at extraction - 6E11 @ $1: 5 \mathrm{GeV}$
- 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 $1.5 \times 10^{13} \mathrm{p} / \mathrm{s}$ 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 $0.5 \mathrm{mRem} / \mathrm{hr}$ 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:

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

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

## Table II



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.

$$
\begin{aligned}
& 5 \times 10^{12} \mathrm{p} / \mathrm{s} \text { @ } 200 \mathrm{MeV} \text { - } 0.18 \mathrm{mRem} / \mathrm{hr} \text { (vertical), } \\
& \text { <0.01 mRem/hr (horizontal) } \\
& 3 \times 10^{11} \mathrm{p} / \mathrm{s} \text { @ } 700 \mathrm{MeV} \text { - } 3.3 \mathrm{mRem} / \mathrm{hr} \text { (vertical), } \\
& 0.12 \mathrm{mRem} / \mathrm{hr} \text { (horizontal) }
\end{aligned}
$$

## 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.

$$
3 \times 10^{11} \mathrm{p} / \mathrm{s} \text { @ } 1.5 \mathrm{GeV} \text { - } 525 \mathrm{mRem} / \mathrm{hr} \text { (vertical) }
$$

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 $<0.5$ $\mathrm{mRem} / \mathrm{hr}$. 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 18.3 cm radius steel ( $\mathrm{p}=8.1 \mathrm{~g} / \mathrm{cm}^{3}$ ) object which will be enclosed in a 20 cm thick marble ( $2.7 \mathrm{~g} / \mathrm{cm}^{3}$ ) 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.

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

$$
D_{S}=\frac{A}{24 \pi d^{2}} \quad D_{v}
$$

Where $D_{V}$ is the dose equivalent rate vertically, $A$ is the area of the berm through which $\mathrm{D}_{\mathrm{V}}$ emerges, and $d$ is the distance from the center of A to the fence line.

$$
\begin{aligned}
\mathrm{A}=600 \mathrm{ft}^{2} \\
\mathrm{D}_{\mathrm{v}}=210 \mathrm{mRem} / \mathrm{hr} \\
\mathrm{~d}=42 \mathrm{ft} \\
\mathrm{D}_{\mathrm{S}}=\frac{600 \mathrm{ft}^{2}}{24 \pi(42 \mathrm{ft})^{2} \quad} \quad \times 130 \mathrm{mRem} / \mathrm{hr}=0.6 \mathrm{mRem} / \mathrm{hr}
\end{aligned}
$$

## 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 $H(r)=3 \times 10^{-13} \exp (-r / \lambda) / r^{2} r e m / n$ 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

$$
\begin{aligned}
H(r) & =3 \times 10^{-13} \frac{\exp (-r / \lambda)}{r^{2}} \quad \frac{130 \mathrm{mRem} / \mathrm{hr}}{18.4 \frac{n R e m}{n c m^{-2}}} \mathrm{Rem} / \mathrm{n} \\
& =3.4 \times 10^{-6} \frac{\exp (-r / \lambda)}{r^{2}} \frac{n}{\mathrm{cn}^{2} \mathrm{hr}} \frac{\mathrm{rem}}{\mathrm{n}} \times 600 \mathrm{ft}^{2} \times\left(\frac{30.48 \mathrm{~cm}}{\mathrm{ft}}\right)^{2} \\
H(r) & =1.2 \frac{e^{-r / \lambda}}{r^{2}} \quad \mathrm{rem} / \mathrm{hr} \quad \lambda=700 \mathrm{~m}
\end{aligned}
$$

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

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

The site boundary is approximately 1.1 km
$\mathrm{H}(1.1 \mathrm{~km})=\frac{1.2 \mathrm{e}^{-1} 100 / 700}{(1100)^{2}}=2.1 \times 10^{-7} \mathrm{Rem} / \mathrm{hr}=0.2 \mu \mathrm{Rem} / \mathrm{hr}$
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 $400 \mathrm{ft}^{2}$.

$$
\begin{aligned}
H(r) & =3 \times 10^{-13} \frac{\exp (-r / \lambda)}{r^{2}} \frac{525 \mathrm{mRem} / \mathrm{hr}}{18.4 \mathrm{nRem} / \mathrm{ncm}}-2 \times 400 \mathrm{ft}^{2} \times\left(\frac{30.48}{\mathrm{ft}}\right)^{2} \\
& =3.2 \frac{\mathrm{e}^{-}(\mathrm{r} / \lambda)}{\mathrm{r}^{2}} \mathrm{rem} / \mathrm{hr}
\end{aligned}
$$

at 140 m
$H(140)=3.2 \frac{e^{-}(140 / 700)}{(140)^{2}}=134 \mu \mathrm{Rem} / \mathrm{hr}$ at site boundary
$\mathrm{H}(1.1 \mathrm{~km})=3.2 \frac{\mathrm{e}^{-1100 / 700}}{(1100)^{2}}=.55 \mu \mathrm{Rem} / \mathrm{hr}$
Therefore, the total outside dose in a 2000 hr . work year at 140 m is

$$
\begin{aligned}
& 46 \times 10^{-6} \mathrm{rem} / \mathrm{hr} \times 70 \text { day } \times 8 \mathrm{hr} / \text { day }+134 \times 10^{-6} \times 140 \mathrm{day} / \mathrm{yr} \times 8 \mathrm{hr} / \mathrm{day} \\
& =26+150=176 \mathrm{mRem} / \mathrm{yr} .
\end{aligned}
$$

and at 1.1 km
$H(1.1 \mathrm{~km})=.2 \mu \mathrm{Rem} / \mathrm{hr} \times 70 \times 8+.55 \mu \mathrm{Rem} / \mathrm{hr}(130 \times 24+70 \times 16)=.1+2.3=2.4 \mathrm{mRem} / \mathrm{yr}$.

## 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

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

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.

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).
```
LIST RUN
Eriter the erergy af the irociderit protom: EQQ
ENTER THE APGROFRIATE HCASC 3e-14
ENTER THE AFFROFRIATE LAMEDA 7E
Erter the beam losses that you want to calculate (p/s) 1e13
This calculatiors is for a proton erergy of eQQ
It uses a lambda = 7E g/cm`
Stieldirg Dase Rate
Thickriess mFem/Hr.
Ft.(scil)
1Q E5.09
11 11.83
1こ 4.85
13 E.D1
14 Q.84
15 0.35
16 Q. 15
17 Q. QE
18 Q.QZ
19 Q.Q1
ご Q.QQ
E1 B.QQQ
Eこ Q. QQ
This calculatiom assumes a poirit loss of 1E+13 p/s
OH
```

```
RUN
Eriter the emergy of the irmcident pratorn: 70Q 
ENTER THE APFROFRIATE HCASC EE-13
ENTER THE APFROFRIATE LAMEDA }9
Eriter the beam losses that you warit to calculate (p/s) 3e11
This calculatiori is for a protom energy of 70,0
It uses a lambcta = 95 g/cme
Stieldirg Dase Rate
Thickress mRem/Hr.
Ft.(scil)
10 110.45
11 54.040
1巳 EE.E4
13 13.E5
14 E.63
15 3.34
1G 1.EG
17 Q.8E
18 Q.44
19 Q.こご
EQ
Q.1E
E1
                                D. DE
Eこ Q.Q\Xi
This calculatiom assumes a poirit loss of 3E+11 p/s
OK
```

```
LOAD"RUN
Eriter the eriergy of the incident protaris 15Qo
ENTER THE AFFROPRIATE HCASC 1. 3e-1E
ENTER THE AFFROFRIATE LAMEDA 11Q
Eriter the beam lasses that you warit ta calculate (p/s) 3e11
This calculation is for a protorn erergy of 150Q
It uses a lambda = 110 g/cma`
Shieldirg Dase Rate
Thickriess mfem/tir.
Ft.(scil)
10 5こ5.95
11 E78. E5
1E 149.5E
13 79.89
14 43.\Xi日
15 2З.59
1G 1こ.Эコ
17 7.1E
18 3.74
19 E.19
きロ 1.ここ
E1 Q.E8
ここ Q.3B
This calculatiom assumes a paimt lGSs GT 3E+11 p/s
Ok.
```


## TABLE VI

## SHIELDING VALUES FOR 914 SHIELD WALL

```
RUN
Eriter the eremgy af the imciderit protom: 15QQu
ENTER THE AFPROFRIATE HCASC 1. 3e-1E
ENTER THE AFFRROPIATE LAMEDA 11Q
Eriter the beam losses that you warit to calculate (p/s) Jel1
This calculatiorn is for a protorn erergy of 15QQ
It uses a lambda = 110 g/cm*e
Shieldirg Dose Rate
Thickress mRem/Hr
Ft. (scil)
1& 4E.E7
11
E7.17
1こ 15.84
13 Э.\Xi4
14 5.39
15 3.15
1G 1.84
1 7 ~ 1 . 0 2 8 ~
18 Q.E3
19 Q.37
きQ Q.ここ
21 Q.13
ジ Q.07
This calculaticm assumes a poirit loss af 3E+11 p/s
OK
```


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