BNL-105724-2014-TECH
EP&S No. 8;BNL-105724-2014-IR

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September 1967

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U.S. Department of Energy
USDOE Office of Science (SC)

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EP & S DIVISION TECHNICAL NOTE

No. 8

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September 6, 1967

CALCULATIONS FOR THE BACKSTOP AND SHIELDING FOR THE SLOW EXTERNAL PROTON BEAM (SEB) AT THE AGS

The shielding of the slow external beam from the AGS is a matter of some concern because of the energy and intensity of the beam and the fact that personnel, especially in Phase I, must work continually directly downstream from the beam backstops. What is thought to be a fairly conservative design has been adopted for the backstops to minimize the radiation hazards involved. The designs for the cores of the analytic (T) channel and experimental (S) channel backstop are given in Fig. 1 and 2 respectively. The choice of tungsten (Hevimet) for the upstream face of the cores was dictated by the short nuclear interaction length (4") in tungsten. This short interaction length minimizes the number of π- and K- mesons decaying into muons before being absorbed and so suppresses μ productions at the source. Uranium has almost as short an interaction length (4.4") and is cheap (free) so the bulk of the core is of uranium. The total length of the core was determined from cascade and μ-meson range considerations. The relative length of tungsten and uranium were determined by distributing the available tungsten equally in terms of length between the two cores. Core cross sections attempt to take into account the respective beam spot sizes and operating modes and the spread of the nuclear cascade in moving through matter.[1] These cores are to be embedded in steel as shown on the 1/4" scale drawing for Phase I of the SEB with revisions dated August 30, 1967. Both cores were placed in re-entrant cavities to cut down the radiation hazard arising from the activation of the tungsten by the beam.

Evaluation of the Shielding Effectiveness

1. The Nuclear Cascade - The S-channel core has 55.5 nuclear interaction lengths, while the T-channel has 52.8 interaction lengths. It is assumed that the cascade in tungsten and uranium behaves as it does in iron, i.e., there is a transition length of 1 nuclear interaction length (nmfp) and thereafter, the cascade is exponentially attenuated with an attenuation length approximately equal to 1 nmfp.[2] Under this assumption the attenuation factor for either core is $>10^{-20}$, which should be adequate for 10^{12} incident particles. The T-channel backstop will be instrumented to obtain experimental data on the cascade in the tungsten and uranium.

In the event of accidental loss of the beam, the worst condition (condition of minimum shielding) is had if both switching magnets fail simultaneously (cf. Phase I drawing). In that eventuality, the shielding along the beam line consists of 47' of heavy concrete (1 nmfp = 14.95") and 2' of lead (1 nmfp = 7.24") for a total of 41 nuclear interaction lengths. Under the same assumption on the behavior of the cascade in concrete[3] as was made above for tungsten and uranium, the attenuation factor for the cascade is

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1 A. Citron, et al., Nuclear Instruments and Methods 32, 1965, 48-52.

2 A. Citron, et al., loc. cit.

3 A. Citron, L. Hoffman, C. Passow, Nuclear Instruments and Methods 14, 1961 97-100

$\sim 10^{-17}$, reasonably good for 10^{12} incident protons. Even in the worst case of equipment failure then, there appears to be adequate shielding for the nuclear cascade.

2. Muon Shielding

At AGS energies and intensities, the shielding in the forward direction will be dominated by the muon problem. Considering the cores of the two backstops again, there is a total of 13960 gm/cm^2 of tungsten and uranium in the S-channel and 13420 gm/cm^2 in the T-channel. Using the range tables of UCRL 2426, Vol. II, 1966 Edition, and assuming that tungsten and uranium go like lead, this much material will range out $\sim$22 GeV/c muons. The muon flux coming through the cores will be from muons with an initial momentum >22 GeV/c. (We will neglect production beyond the first interaction length in this approximation.) From Sanford and Wang's[4] production curves (in Be) pion production by 30.9 BeV/c protons $\approx 0.3\pi$'s/interacting proton/sr/GeV/c for a pion momentum of 25 GeV/c. By looking at the 30.9 BeV/c production, there is some compensation for using curves for production in Be. Assuming 10^{12} protons interact, the production of pions with momenta in the range $22 < P_\pi < 28$ GeV/c is given by:

$$N_\pi \cong (0.3\ \pi\text{'s/interacting proton/Sr/GeV/c}) \times (10^{12}\ \text{protons/pulse}) \times (6\ \text{GeV/c})$$

$$N_\pi \approx 1.8 \times 10^{12}\ \pi\text{'s/Sr/pulse}$$

Following Cocconi[5], it is a reasonable approximation to say that essentially all pions in the momentum band around 25 BeV/c are produced in a core whose half angle is given by:

$$\theta \approx \frac{500}{P\pi} = \frac{500}{25} = 20\ \text{mr}$$

4 AGS Internal Report JRS/CLW-1, March 1, 1967

5 Cocconi, Koester, and Perkins, UCRL 10022, p. 167 (unpublished)

The production solid angle is then

$$\Omega_{25} \approx 1.6 \times 10^{-5} \text{ sr} \quad \text{and}$$

$$N_{\pi}^{1} = (1.8 \times 10^{12} \ \pi\text{'s/sr/pulse}) \times 1.6 \times 10^{-5} \text{ sr}$$

$$\approx 2.9 \times 10^{7} \ \pi\text{'s/pulse}$$

The number of these decaying in one nmfp of tungsten is approximately

$$N_{decay} \approx \frac{\lambda_{nmfp}}{\lambda^{\pi}_{decay}} = \frac{\lambda n}{55 p\pi} = \frac{.1}{1370} = 6 \times 10^{-5}$$

So $\quad N\mu \approx (3 \times 10^{7} \ \pi/\text{pulse}) \times (6 \times 10^{-5} \ \mu/\pi) \approx 1800 \ \mu/\text{pulse}.$

The area of the base of the production cone for point production at the upstream face of the tungsten is:

$$A \approx 300 \text{ cm}^2.$$

So, assuming uniform particle density, the muon flux at the downstream end of the core is:

$$\phi_{\mu} \approx 6 \ \mu/\text{cm}^2/\text{pulse}$$
$$\approx 2 \ \mu/\text{cm}^2/\text{sec}$$
$$\text{Dose} \approx 1/9 \text{ mrem/hr}$$

This neglects coulombs scattering and beam spot size at the face of the tungsten.

A similar analysis can be made for the case of both switching magnets failing simultaneously (minimum shielding condition). For purposes of the muon calculation, the total path length of material in the beam path is 5170 gm/cm^2 of heavy concrete and 670 gm/cm^2 of lead. Treating all of this as heavy concrete and assuming that the range momentum relation for concrete is not much different from carbon, 5840 gm/cm^2 will range out muons up to 12.5 BeV/c. For what follows, we assume that all muons are from pions produced in the first nuclear interaction length of the concrete. The available pion momenta are divided into three 5 BeV/c bins; 15 $\pm 2\frac{1}{2}$ BeV/c. 20 $\pm 2\frac{1}{2}$ BeV/c, 25 $\pm 2\frac{1}{2}$ BeV/c. The fractions of pions of the central momentum decaying on the average in one interaction length of concrete are:

$$f_{15} \approx 4.6 \times 10^{-4}$$

$$f_{20} \approx 3.45 \times 10^{-4}$$

$$f_{25} \approx 2.8 \times 10^{-4}$$

The pion production at these momenta with 30.9 GeV/c incident protons is given by the Sanford-Wang curves.

$$P_{15} \approx 1\pi/\text{interacting proton/sr/BeV/c}$$

$$P_{20} \approx 0.5\ \pi/\text{interacting proton/sr/BeV/c}$$

$$P_{25} \approx 0.1\ \pi/\text{interacting proton/sr/BeV/c}$$

Folding all of these factors into the appropriate Cocconi angle for the central momentum of the 5 BeV/c bin, and assuming $N_p = 10^{12}$ protons/pulse interacting in the first nmfp of concrete. The muons per pulse produced in each bin is given by

$$N_\mu = N_p \times P_\pi \times \Omega_{ckp} \times \Delta p \times f_\mu$$

$$N_\mu\ (15\ \text{BeV}/c\pi) \approx 170 \times 10^3\ \mu/\text{pulse}$$

$$N_\mu\ (20\ \text{BeV}/c\pi) \approx 19.5 \times 10^3\ \mu/\text{pulse}$$

$$N_\mu\ (25\ \text{BeV}/c\pi) \approx 1.12 \times 10^3\ \mu/\text{pulse}$$

The flux at the downstream shield face is calculated by assuming a uniform density of pions in the Cocconi cone and 0° decay of the muons relative to the parent pion direction. We make the further simplifying assumption that all of the muons have sufficient momentum not to be ranged out by the concrete. Assuming that all of the muons see the full 85 feet from the first upstream face of concrete to the downstream end of the shield wall, the particle flux is given by the sum over the various momentum bins of the total number of muons over the area of the base of the appropriate Cocconi cone.

$$D = \Sigma N_{\mu i}/A_i$$

$$\approx 170 \times 10^3\mu/23.1 \times 10^{-3}\ cm^2 + 19.5 \times 10^3\mu/13.22 \times 10^3\ cm^2$$

$$+ 1.12 \times 10^3\mu/8.45 \times 10^3\ cm^2$$

$$D = 9\mu/cm^2/pulse$$

$$\approx 3\mu/cm^2/sec$$

$$DR \approx 1/3\ mrem/hr$$

This again neglects coulomb scattering and beam spot size.

The simplifying assumptions made are in both directions, to increase and decrease the dose rate, and should cancel one another to some extent at least. The conclusion is that the shield and backstop as designed should be a reasonably conservative protection for operating personnel in the downstream region.

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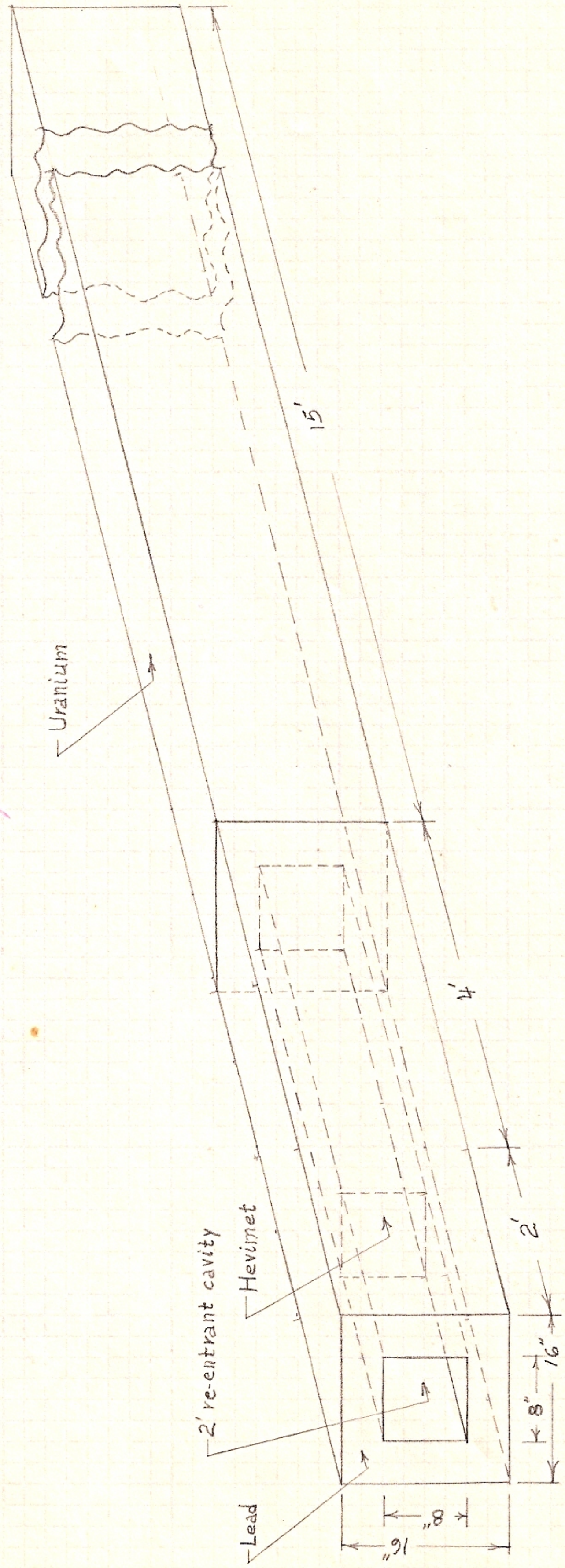

Figure 1

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BY TET DATE 9/1/67 SUBJECT SEB Backstop, Core for Experimental (S) Channel SHEET No. 8 OF 8

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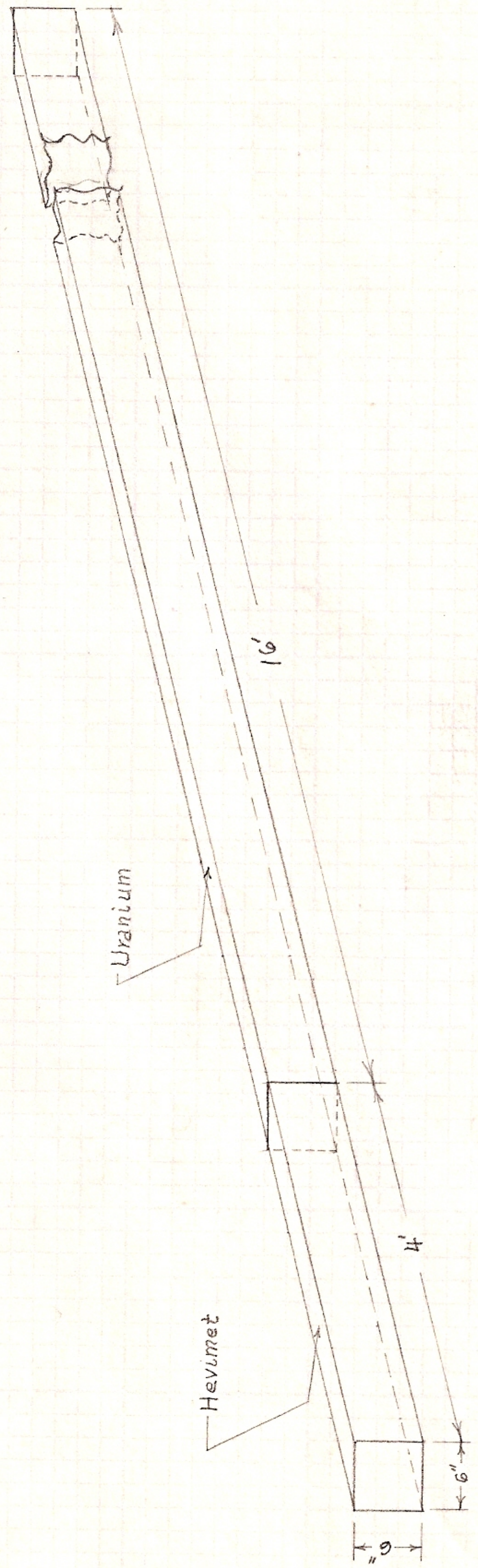

Figure 2