REDUCTION OF THE THERMAL NEUTRON FLUX IN CONCRETE USING PARAFFIN MODERATORS

SUMMARY

The estimated residual radiation level in the neighborhood of a scraper due to the sodium activity in the concrete walls would be reduced if a hydrogenous shield plus a benign thermal neutron absorber were placed around the scraper.¹

We have performed several experiments to determine the efficiency of such shields. We present the results in a form which should prove useful in estimating the concrete activity for various geometries and beam powers. The results shown in Fig. 3 show that 10 inches of paraffin surrounded by cadmium reduce the thermal neutron flux by a factor of 10.

The absolute yield of neutrons from 40 MeV and 990 MeV electrons is about 0.2 neutrons/BeV (1.25 x 10⁹ n/sec-watt) in reasonable agreement with calculation²,²¹ and other experiments.³,⁴
A. INTRODUCTION

When an electron beam strikes a target, the photons of the shower produce neutrons with a wide spread in energy from photo-nuclear reactions. The giant resonance neutrons are most abundant; their energies are around an MeV, and they are isotropic in the lab. Very roughly the same amount of photon energy goes into high energy interactions as into giant resonance reactions, so high energy neutrons are appreciably less abundant. This kind of argument suggests that measurements with a 70 MeV electron beam are meaningful for calculations of thin shields for much higher energy electrons. If the electrons do not hit the concrete, the major activity in the concrete arises because the neutrons are moderated in the concrete, and are eventually captured by the roughly 1% of sodium ($\sigma = 0.5$ barns) present in the aggregate. For ordinary concrete with very low sodium content there may be a significant manganese activity.5

This residual activity may be reduced by adding boron to the concrete mix, so that the thermal neutrons preferentially capture on the B$^{10}$ ($\sigma = 3840$ barns) rather than the sodium.1

Another way to reduce the activity is to thermalize the neutrons and capture them before they get to the concrete, which is the method investigated here. Paraffin, lucite, or water act as good moderators. The thermal neutrons can be effectively captured by a 1/32 inch cover of cadmium ($\sigma = 2300$ barns).

The neutron fluxes were measured by the activation of indium foils, either bare or placed inside paraffin moderators. The observed activities were converted to neutron fluxes by calibrating the system against neutron sources of known strength,6 and by making corrections for irradiation and decay times. For the Mark IV experiments the fluxes were normalized to one watt of beam power.

The effective source size was small compared with the distance involved, and the results were analyzed in terms of a point source for which one can write approximately

$$\varphi = \frac{q}{4\pi r^2} B(x) e^{-x/\lambda}$$

- neutron flux ($n/cm^2$-sec)
- neutron source strength - approximately proportional to absorbed beam power ($n/sec$)
- distance from source to foil
A solid copper target, 1-1/2" diameter x 8" length, water-cooled, and surrounded by various thicknesses of paraffin and a cadmium cover, was placed in the 70 MeV beam of the Mark IV accelerator. Concrete slabs were horizontally positioned directly below the target assembly, and bare indium foils were centered between the slabs, which were separated by 1/4 inch. Figure 1 shows the general experimental geometry. The foils were irradiated for a specified time, removed to a remote spot, and counted. The general theory and methods of thermal neutron detection by indium foils is described in the literature.7-11 The calibration6 of our system using a source of known strength yielded a saturation counting rate of 1 count/sec for a neutron flux of 13.9 n/cm²-sec, and for a foil-weight of 1.4210 gms. The background counting rate was 19c/min.

The results are plotted in Fig. 2 where we notice the expected build-up and attenuation with concrete depth, and we also see the effect of the shield. Figure 3 shows the reduction in activity as a function of moderator thickness.

C. Pu-Be EXPERIMENT

To check the point source model we use a Pu-Be neutron source, surrounded by 1-1/2 inches of lucite and a cadmium cover. A typical Pu-Be spectrum12 peaks at about 4 MeV and falls off at zero and 12 MeV. The energy spectra of photoneutrons from such elements as Ca, S, Bi, Au, O, and C13-17 look very similar to the Pu-Be spectrum, and we assume that copper is not too different.

The same concrete slabs were used; however, the experiment was performed outdoors in order to reduce scattering from walls, etc. Indium foils were again irradiated and counted for various source-to-concrete distances.

Figure 4 shows the experimental set-up, and Fig. 5 shows the results. The geometrical correction (the inverse r square) accounts for most of
the differences in the fluxes. The average intercept at \( x = 0 \) is
0.88 \times 10^7 \text{ n/sec}, which is comparable with the known source strength of
1.94 \times 10^7 \text{ n/sec}, but somewhat lower. One would expect this because the
foils only determine the thermal flux, whereas the source emits mostly
fast neutrons.

D. MARK IV EXPERIMENT #2

As another check on the point source approximation, moderated indium
foils were placed inside the trench of the Mark IV as shown in Fig. 6. These
foils have a response that is independent of incoming neutron energy within
the range of about 40 keV to 14 MeV. These units were calibrated with a
Pu-Be source with the result 1 count/sec at saturation per 8.26 \text{n/cm}^2\text{-sec}.
The electron beam energy was 40 MeV, and the target was the lead Faraday
cup. Foils were placed directly under the Faraday cup and at varying dis-
tances along the accelerator structure. Figure 7 gives the results. The
source strength is roughly 10^9 \text{n/sec-watt}, or \( \sim 0.2 \text{n/BeV} \).

E. MARK III EXPERIMENT*

At the Mark III a 990 MeV electron beam from the 9-foot port struck an
iron block 5 inches in diameter and 17 inches long (24 radiation lengths).
Neutron fluxes were measured at five angles with the same devices used in
the second Mark IV experiment (cadmium covered, moderated indium foils; see
Fig. 6a). The electron beam current was measured with an SEM (efficiency of
about 7\%). The measured neutron yields as a function of angle were

<table>
<thead>
<tr>
<th>Angle with respect to Beam Direction</th>
<th>Neutron/BeV (iron)</th>
</tr>
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<tbody>
<tr>
<td>0°</td>
<td>0.10</td>
</tr>
<tr>
<td>30°</td>
<td>0.16</td>
</tr>
<tr>
<td>50°</td>
<td>0.22</td>
</tr>
<tr>
<td>90°</td>
<td>0.22</td>
</tr>
<tr>
<td>135°</td>
<td>0.26</td>
</tr>
</tbody>
</table>

*Dirk Neet and Roger Coombes performed this experiment.
There is a trend toward higher yields at back angles. No correction was made for attenuation or scattering of the neutrons in the iron block, which may account for the low value at $0^\circ$. The other four values are within about 20% of the average which is not a very significant difference. The principal uncertainties in the relative values are probably in the distance from the target, and in the contribution from the neutrons scattered by nearby dense objects. For example, the $135^\circ$ point was taken near the lead Faraday cup, and the $90^\circ$ point was taken atop a big shielding block which also supported the iron block. In connection with general room-scattering effects it is worth noting that the Mark III target area is about 60 or 70 feet square with thick walls about 12 feet high (on the average), thin walls above that, and a thin roof. The iron block was about 20 feet downstream of the bunker wall at beam height (7 feet).

The observed yields are about the same as the calculated giant resonance yields. It is somewhat surprising that there is no noticeable contribution from the high energy neutrons. These would not have been detected directly because the detector sensitivity falls above a neutron energy of about $10 - 15$ MeV, but the lower energy secondaries might have been detected.

F. CONCLUSIONS

The result of the first Mark IV experiment is that a moderator and thermal neutron absorber can reduce the concrete activity by a factor of 10 (see Fig. 3). In the practical case of the scrapers along the machine the effective reduction might not be so great for two reasons. First, because of the complex geometry it is impossible to surround the scraper with the shield. Secondly, for high energy electron beams some high energy neutrons are produced which easily penetrate the shield and are hardly attenuated at all; however, the moderator may still reduce the nearby radiation level significantly, because the radiation level depends on the distribution of activity along the tunnel as well as on the total activity. Without a shield the concrete activity from the high energy particles is probably at most comparable with that from the giant resonance neutrons, and it is much more spread out so that the activity from the giant resonance neutrons probably dominates the radiation level near the scraper. Thus for high
energies we expect that a moderator and absorber would significantly lower the radiation level from the concrete in the neighborhood of the scraper.

In the two Mark IV experiments the neutron source strengths are comparable with the predictions of a calculation\(^2\) based on measured integrated giant resonance cross sections and the track length formula from Approximation A of shower theory,\(^20\) in which ionization loss is neglected. Our results are in reasonable agreement with the measurements of Barber and George,\(^3\) who found good agreement with shower theory after taking ionization loss into account.

The build-up curves given in Fig. 2 allow one to estimate the thermal neutron flux for various geometries and beam conditions, as a function of depth into the concrete. This should enable one to calculate radiation levels due to the sodium activity in the concrete walls around beam scrapers and the like, and to take account of the attenuation in the concrete of the decay photons.

ACKNOWLEDGMENTS

It is a pleasure to thank Dr. R. C. McCall and G. Warren for discussions and assistance with the experiments, and T. Shipman for counting the foils. In addition, we wish to thank the Lawrence Radiation Laboratory Health Physics staff at Berkeley for letting us use their thermal neutron cavity.
REFERENCES


FIGURE 1. MARK IV EXPERIMENT #1.
(not drawn to scale)
MARK III EXPERIMENT #1. NEUTRON INTENSITY AS A FUNCTION OF DEPTH IN CONCRETE FOR VARIOUS PARAFFIN THICKNESSES.

**Figure 2.**

70 Mev electrons on copper

$\rho_{\text{concrete}} = 2.25 \text{ g/cm}^3$

Statistical errors are smaller than symbols.
MARK IV EXPERIMENT #1. — NEUTRON INTENSITY AS A FUNCTION OF 10° PARAFFIN THICKNESS AT SEVERAL DEPTHS IN CONCRETE.

FIGURE 3.
Cadmium Can
Lucite, T = 1/2"
Pu-Be Source
(1.94 x 10^7 m/sec.)

Concrete Slabs
Beryllium Foiis

30"

\[ d \]

\[ n \]

Ground

FIGURE 4. Pu-Be Experiment (not to scale)
PU-Be EXPERIMENT — THERMAL NEUTRON FLUX AS A FUNCTION OF DISTANCE AND CONCRETE THICKNESS.

**Figure 5**

- **Source to concrete distance, d**
  - 12.8" (square symbol)
  - 20.8" (triangle symbol)
  - 45.8" (circle symbol)

- Porosity = 2.25 g/cm²
FIG. 6a. MARK IV EXPERIMENT No. 2. ( NOT TO SCALE )
FIG. 6b. MARK IV EXPERIMENT No.2 (NOT TO SCALE)
MARK IV EXPERIMENT #2 — NEUTRON INTENSITY VERSUS DISTANCE FROM FARADAY CUP.

FIGURE 7.

$E_0 = 40 \text{ Mev}$
$I = 8\mu\text{a}$
$A = 4\text{ feet}$