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Historical Document
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Released 1994

**Prepared for the U.S. Department of Energy
under Contract DE-AC06-76RLO 1830**

**Pacific Northwest Laboratory
Operated for the U.S. Department of Energy
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November 29, 1965

NEUTRON BEAM FACILITY

Technical Report

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DUN-504

Page 2

NEUTRON BEAM FACILITY

Technical Report

Introduction

Using the high neutron fluxes of the Hanford reactors as a source, one can design a collimated neutron beam facility where fluxes of 10^6 to 10^7 (nv) are produced. The facility discussed in this report is designed to meet the following specifications:

1. Sample exposures of 10^{10} (nvt) must be feasible.
2. The beam must be at least 90% thermalized, and as gamma free as possible.
3. Maximum horizontal divergence should be no greater than 2° .
4. Cross-section dimensions of the beam should be two by three inches.

General Description

Since the allowable energy range of the beam includes the whole thermal range, a simple arrangement of thermalizing and filtering materials is used to create the thermalized low gamma source. Graphite is used to thermalize the beam and lead is used to attenuate the gamma source. It will be seen in the detailed description that these materials are removable and interchangeable with other materials. Beams of different compositions can thus be produced.

Collimation is achieved through a simple aperture type device, with horizontal divergence dependent on aperture width and separation.

Location

The facility is designed to fit into the Y test channel, on the X-2 level of the C Hanford reactor. The Y channel is a $4 \frac{3}{16}$ inch square, side to side channel. The facility is 61 inches long, reaching from the reactor face to just through the thermal shield.

Collimator

The discussion of components begins with the collimator because its minimum length is fixed by the maximum allowable horizontal divergence of the beam and by the beam cross section dimensions. Figure 1 shows the geometric relations used to analyze the horizontal divergence.

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DUN-504
Page 3

Figure 1

where: θ = horizontal divergence
 l = separation of apertures
or, collimator length
 w = beam widths

To meet the beam specifications, the collimator is made of a 4 1/16 inch square, 45 inches long, steel barrel, with a 2 by 3 inch hole through the center. The hole is splined horizontally and vertically with steel strips, making, in effect, four 45 inch long collimators with 1 by 1 1/2 inch bores, grouped together to produce one beam. Then,

$$\theta = \tan^{-1} \frac{1.5 \text{ inches}}{45 \text{ inches}} = 1.9^\circ$$

There will be some neutrons scattered near the output of the collimator with a large horizontal divergence. This should be negligible compared to the main beam strength.

Figure 2 shows the collimator.

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The inner end of the collimator is sealed with a thin steel plate. The output end makes a gas tight fit with the reactor face. The beam thus propagates through an air atmosphere.

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Thermalization

Graphite is used to thermalize the beam because of its thermalizing properties, high melting point, ready availability, and ease of handling and fabrication. The criteria that must be met is a 90% thermalized beam.

The thermal to fast neutron ratio of the source is 5 to 1 (a conservative number), and to be conservative, a graphite length that increases this ratio by a factor of 5 will be used.

The relaxation length for thermal neutrons in graphite is approximately 52 cm. Therefore, the attenuation of thermal neutrons in X cm. of graphite is,

$$N_{th} \left(\frac{1}{2.72} \right)^{\frac{X}{52 \text{ cm}}}$$

Where N_{th} is the thermal neutron source.

The relaxation length for fast neutrons in graphite is approximately 9 cm. Therefore, the attenuation of fast neutrons in X cm. of graphite is,

$$N_f \left(\frac{1}{2.72} \right)^{\frac{X}{9 \text{ cm}}}$$

Where N_f is the fast neutron source.

If $X = 18 \text{ cm}$. the final ratio is,

$$\frac{N_{th} \left(\frac{1}{2.72} \right)^{\frac{18 \text{ cm}}{52 \text{ cm}}}}{N_f \left(\frac{1}{2.72} \right)^{\frac{18 \text{ cm}}{9 \text{ cm}}}} = \frac{5}{1} \times 5.23 = 26.2$$

Thus, a seven inch block of graphite is used to thermalize the beam to approximately 96%. To facilitate removal of the block from the reactor channel, a one inch eye bolt is connected to the front of the graphite block. Thus, a total of 8 inches is required for thermalization.

Figure 3 shows the graphite block.

Figure 3 - Graphite Block and Lead Block

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Gamma Attenuation

The overall facility length is 61 inches with 53 inches used for collimation and thermalization. Eight inches are available for gamma attenuation. A 7 inch block of lead is used as a gamma filter, with a one inch eye bolt connected to the front to facilitate removal from the reactor.

There is a possible melting problem with the lead, so it is encased in 1/16 inch steel. A void must be left in the steel casing to allow expansion of the lead.

The gamma dosage at the collimator output ($G(o)$), is,

$$G(o) = G(s) e^{-\mu t} B(\mu, t) \times \frac{1}{4\pi D^2}$$

Where: $G(s)$ = gamma source = 3.7×10^5 ($\frac{R}{hr}$)

μ = attenuation coefficient for lead = 0.794 ($\frac{1}{cm}$)

$B(\mu, t)$ = the dose build-up factor for one M ev. neutrons in 7 inches of lead = 4.81.

D = the distance from the source to the output = 61 inches.

$$G(o) = 4.8 \times 10^{-6} \left(\frac{R}{hr} \right)$$

Figure 3 also shows the lead block.

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Thermal Neutron Flux

The following calculations will show the neutron flux to be approximately 4×10^6 (nv). An exposure of 10^{10} (nvt) would require approximately one hour. The flux calculations are approximate, neglecting such things as thin steel plates around the graphite block and across the end of the collimator, the passage of the neutrons through the air atmosphere, the streaming of neutrons through voids between component pieces, etc. Some of these effects are not dealt with because they are negligible, and others because of their complexity. The flux could be an order of magnitude larger or smaller, and exposure of 10^{10} (nvt) would still be feasible.

Flux at the interface of the lead and graphite blocks ($\phi(Pi)$), is,

$$\phi(Pi) = \phi(s) e^{-\Sigma_T t} + \phi(s) (1 - e^{-\Sigma_s t}) P(\theta)$$

Where: $\phi(s)$ = SOURCE STRENGTH = 1.5×10^{14} (nv)

Σ_T = TOTAL MACROSCOPIC REMOVAL CROSS-SECTION = 0.371 ($\frac{1}{cm}$)

Σ_s = MACROSCOPIC SCATTERING CROSS-SECTION = 0.365 ($\frac{1}{cm}$)

t = LENGTH OF LEAD BLOCK = 7 in.

$P(\theta)$ = THE PROBABILITY THAT A SCATTERED NEUTRON WILL BE SCATTERED INTO THE INTERFACE = 7.5×10^{-4}

$$\phi(Pi) = 3.2 \times 10^9 \text{ (nv)}$$

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Flux at the collimator output $\phi(o)$, is,

$$\phi(o) = \phi(Pb) e^{-\Sigma_T t} + \phi(Pb) (1 - e^{-\Sigma_S t}) P(\theta)$$

Where: 1. $\Sigma_T = 0.38 (1/cm)$

2. $\Sigma_S = 0.38 (1/cm)$

3. $t = 7 in.$

4. $P(\theta) = 1.1 \times 10^{-4}$

$$\phi(o) = 4.2 \times 10^6 (nv)$$

Shielding

Any work with the facility requires shielding designed and placed around the collimator output. The shielding must both afford personnel protection and facilitate access to the work being done.

Figure 4 shows an overall, cut-away, view of the facility.

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FIG. 4. OVERALL CUT-AWAY VIEW

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