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Westinghouse Astronuclear Laboratory

WESTINGHOUSE ASTRONUCLEAR EXPERIMENTAL FACILITY

EVALUATION OF PROPOSED TEST CELL LINER MATERIALS
AND A COLLIMATOR DESIGN

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1. INTRODUCTION

Recent measurements¹⁻² of the radiation flux pattern above the PAX NERVA critical reactor with shield mockups having surface density $>140 \text{ gm/cm}^2$ in place have indicated that the background radiation environment is considerably higher than the direct measured component. The background signal at the detector is primarily due to scattering and/or secondary radiation produced by the room walls, the reactor supporting structures, and the air in the room, and is constant within an order of magnitude regardless of location. Methods suggested for the reduction of this unwanted background at the detector include the use of collimators or shields around the source and/or the detector, lining of the test cell walls, installation of the reactor further away from the walls, or the performance of the measurements in an unenclosed geometry. The primary purpose of these experiments was to partially evaluate the first and second methods described above to reduce the scattered and secondary radiations from the test cell walls by covering them with suitable materials and by surrounding the detector by a collimator. The secondary purpose was the experimental evaluation of the LASL collimator design in a reactor environment. The experimental results are reported below.

These experiments provide basic information in support of shielding trade studies required to evaluate various proposed facilities for nuclear shield testing. This experimental data will also support methods development to permit improvements of future shield measurements and analysis techniques.

2. SUMMARY AND CONCLUSIONS

Gamma ray dose rate, thermal neutron flux density, and fast neutron flux density wall albedo measurements were made for the proposed test cell wall liner materials listed in Table III. These measurements were made using the FCX reactor and a collimator on loan from the Los Alamos Scientific Laboratory for the geometry shown in Figure 1. The results indicate that of the material combinations tested, the most effective wall lining materials for reduction of wall produced radiation are as follows:

1. "Synthesis of Calculational Methods for the Design and Analysis of Radiation Shields for Nuclear Rocket Systems", WANL-PR(LL)-022, September 1968. Volume 1, "Radiation Measurements in a Nuclear Rocket Propellant Tank Mockup Using Simulated Liquid Hydrogen".
2. "R-1 Parametric Shield Measurements Conducted on the NERVA Permanent Assembly Experiment (PAX) Reactor", WANL-TME-1852, in publication.

- 1) For gamma dose rate: 1/4" lead + 2" B-polyethylene
- 2) For thermal neutrons: 1/4" Boral + 2" polyethylene + 1/4" Boral
- 3) For fast neutrons: 2" B-polyethylene

The respective wall albedos are $0.27 \pm .03$, $0.12 \pm .01$, and $0.45 \pm .06$. For a best compromise, a material composition sandwich, composed of 1/8" lead, 1/8" Boral and 2" lithiated paraffin, was tested and its respective albedos are $0.38 \pm .04$, $0.22 \pm .02$, and $0.65 \pm .09$ for the gamma rays and thermal and fast neutrons. A feasible supplement and/or alternative to lining the cell walls is the use of a detector collimator. Hence, the use of the LASL collimator for these experiments provides valuable experience and basic data which will aid in the future design of a collimator system to be used at WANEF.

3. EXPERIMENTAL PROCEDURE

The Flexible Critical Experiment (FCX) reactor was used to perform the wall albedo measurements discussed below since: 1) the PAX reactor was unavailable, 2) the FCX reactor had a cleaner wall geometry, and 3) the PAX and the FCX reactors have approximately the same radiation spectrum. The geometry of these measurements is shown in Figure 1. Each detector, in turn, was enclosed in a collimator³ which was loaned to WANEF by the Los Alamos Scientific Laboratory. These collimator measurements were made with the 15.3 degree aperture (subtended conical angle) unit as shown in Figure 2. The rather limited solid angle of the collimator made it possible to observe the radiation flux from an approximate 31" diameter area on the test cell wall (Figure 1). This area was illuminated by the FCX reactor leakage radiation at a 34.8° incident angle and reflected to the collimator at 20.8° from the normal to the wall. When the first background measurements were made, it was found that the attenuation of direct gammas through the sides of the LASL collimator was inadequate. It must be pointed out, however, that this collimator was originally designed to view direct radiation and reduce background. The design capability is exceeded by doing the reverse in this experiment. So an additional 8" thick layer of lead bricks, a 1-1/2" thick aluminum plate, and a 1/4" thick Boral

3. LA-3139, "Fabrication of a Lead-Boron Carbide Component of a KIWI Collimator".

sheet as shown in Figure 3 was added on the reactor side of the collimator to reduce the direct flux from the reactor. This shield wall remained in position during all subsequent measurements reported here.

All detectors were placed near the center of the collimator, about 25 inches from its opening with their axes along the collimator axis. Each detector was wrapped with paper to fill the void between the detector and the collimator wall. These detectors are of the standard type, having a predominate sensitivity for one type of radiation. They are described in detail in Section 3.7 of Reference 1 and are listed in Table I.

The wall liner materials employed in these evaluation measurements are described in Table II. Each wall albedo* measurement consisted of three operations: 1) a background measurement of the bare wall with the collimator aperture closed by the collimator plug, 2) a measurement of the flux from the bare concrete wall, and 3) a measurement of the flux with a candidate liner material in front of the concrete wall. All operations were carried out at an indicated reactor power level of 200 watts as obtained from linear neutronic detector channel number one. The results, which are given in the form of ratios (after background subtraction) of the test material to bare wall measurement of flux or dose, were obtained from the following formula:

$$\text{Ratio}^{**} = \frac{\text{Test Material Signal} - \text{Plugged Collimator Signal}}{\text{Bare Wall Signal} - \text{Plugged Collimator Signal}}$$

No attempt was made to derive absolute dose or flux from these measurements. The resultant ratios are given in Table III, and typical experimental geometries are shown in Figures 3, 4, and 5. It may be noted in Table II that the candidate wall liner materials are generally limited to the order of 2" in thickness since greater thicknesses are felt to be impractical from a structural and economic standpoint for lining the test cell.

* The albedo is defined as the ratio of the radiation current reflected from a surface to the current incident on that surface.

** This ratio is, therefore, a relative albedo with respect to the bare wall.

4. GAMMA RAY SPECTRUM MEASUREMENTS

Information on the spectra of the gamma rays from the various wall liner materials was also obtained for certain selected materials. Those measurements were performed to provide a possible indication of the nature of the indirect gamma source. A standard 3" x 3" NaI scintillation spectrometer (Harshaw 12512/3H) was placed in the LASL collimator and a pulse height spectrum was obtained for the same three conditions mentioned previously for the other detector measurements, i. e., bare wall, with wall liner materials, and background with the collimator plugged.

The pulse height spectrum above 2 MeV for the proposed wall liner material 4 (3-1/2" of 2 w/o boron in polyethylene), material 6 (2" of 12.6 w/o boron in paraffin) and the necessary plugged collimator and bare wall exposures are shown in Figure 6. All spectra were obtained at an indicated reactor power level of 0.47 watts and the total counting time was five minutes. The pulse height spectrum from the bare concrete wall shows the expected 2.2 MeV gamma ray from the (n,γ) reaction in hydrogen. There are two probable broad peaks at 3.59 and 4.96 MeV, possibly from thermal neutron capture in carbon. These peaks do not appear distinctly, but they are larger than their respective uncertainty shown following each peak. Two more noticeable peaks at 7.62 and 7.70 MeV may arise from capture in iron and aluminum, respectively. A peak at 8.03 MeV may arise from chromium capture in the steel structures. The pulse height spectrum from the test materials 4 and 6 are similar from an energy of 2 MeV to about 6.5 MeV. Above 6.5 MeV, the relative pulse height spectrum from the 3-1/2" of borated polyethylene falls off more rapidly than that from the 12.6 w/o boron mixed paraffin. Divergence of the spectral shape of test material 6 from the others at around 7.5 MeV is not understood at the present. Several peaks may occur in this region, but they* may not be resolved by this spectrometer. No attempts have been made to determine the effects on the gamma pulse height spectrum from the neutron background. This is a complicated problem in itself.

It should also be noted that the gamma dose rate for each liner material (from the CO_2 ion chamber) is roughly proportional to the area under each corresponding spectral

* See Appendix 1.

curve (number of counts per channel versus gamma energy). This result adds confidence to the internal consistency of the data.

5. DOSE AND FLUX ALBEDO MEASUREMENTS

The data given in Table III indicates the effective reduction factor of radiation reflected by the proposed liner materials over that from the bare test cell concrete wall. Results in Column 1 indicate that the indirect or reflected gamma ray dose is not seriously changed by the addition of material causing the absorption or scattering of fast neutrons. The most effective method for the reduction of wall produced gamma rays is simple absorption by a high Z material such as lead. The difference in gamma ray "reflection" caused by the other absorbers is due to a combination of density change and changes in thermal neutron absorption cross section which results in changes in the direct thermal neutron produced secondary gamma emission. Of all the material combinations considered in these experiments, the most effective wall liner for reducing gammas was 1/4" Pb + 2" B-polyethylene with a reduction factor of about 3.7.

In the case of thermal neutrons, the results indicate that borated paraffin (12.6 w/o boron) is more effective than either the 2 w/o borated polyethylene or the lithiated paraffin (11.1 w/o lithium), all of approximately the same thickness. However, the concrete wall albedo for thermal neutrons is most effectively reduced by a Boral-polyethylene-Boral sandwich combination with a reduction factor of about 8.3.

The measurements of the fast neutron indirect component indicates that the reflection of fast neutrons of energy greater than 1.5 MeV cannot be reduced much more than a factor of 2 by any material or combination of materials in the quantities employed in these measurements. This is expected since the albedo for fast neutrons is most dependent on hydrogen content, and increasing the hydrogen content from that of concrete to that of polyethylene should decrease the albedo by about a factor of 3. Also, the attenuation length for 1 MeV neutrons in most materials is about 2". Thus, the

factor of 3 reduction cannot be realized with the finite 2" thickness employed here. As expected, the most effective material for reduction of fast neutron scattering is polyethylene. A 2" thickness (2 w/o boron) of this material resulted in a reduction of the scattered fast flux component by about a factor of 2.

The measurement of radiation flux background in the WANEF test cell, discussed in References 1 and 2, has indicated that the signal to background ratio at any given location is much lower for detectors measuring thermal neutrons than for gamma ray or fast neutron dose rate. From the results in Table III, it appears that the best neutron moderation and absorption type materials in practical thicknesses can reduce the thermal flux by almost an order of magnitude (0.12) but can reduce the gamma rays and fast neutrons by little more than a factor of two. Also, it appears that no material composition tested was best for reducing all quantities simultaneously.

On the basis of these results, a compromise combination test sandwich was developed as material 9, having 1/8" lead + 1/8" Boral + 2" lithiated paraffin. This sandwich has an albedo of 0.39 for gamma ray dose, 0.22 for thermal neutron flux density and 0.65 for fast neutron flux density. This combination of materials was thus found to be the best compromise for reducing all three quantities (the gamma dose rate, thermal and fast neutron flux) but was not quite as good as any one best material configuration for reducing each single quantity.

6. EVALUATION OF LASL COLLIMATOR

The two ton collimator, which was loaned to WANEF for these measurements, was designed by the Los Alamos Scientific Laboratory as part of the KIWI program. A determination of the collimator direct attenuation for radiation incident on the side walls was made by measuring the detector output with the same detectors in the same location relative to the reactor and test cell wall with and without the collimator present. The results in

Table IV indicate that the gross attenuation factor of the collimator for radiation incident to the sides is about 250 for gammas, 90 for fast neutrons, and 20,000 for thermal neutrons (the lead wall remained in place). These factors were obtained by taking the ratio of the bare detector output without the collimator to that with the collimator plugged.

In the case of the fast neutron attenuation measurement, the lead and Boral wall would not be expected to significantly affect the direct neutron flux ($E > 1.5$ MeV) incident on the side of the collimator from the FCX reactor. Hence, the measured neutron attenuation should be characteristic of the direct attenuation of the FCX leakage spectra through the side of the collimator.

In the case of the gamma ray attenuation measurement, two types of measurements were made. The first set of measurements was made in the absence of the lead wall. Thus, this case should again be characteristic of the direct gamma attenuation of the FCX leakage spectra through the sides of the collimator. The second set of measurements was made with the lead wall in place. In this case, the attenuation ratio of dose rate with no collimator to dose rate in a plugged collimator should be characteristic of the attenuation of the scattered and secondary radiation from the wall. The measured attenuation factors of 220 and 264 for the direct and indirect radiation, respectively, seems consistent with the softer spectrum anticipated for the indirect scattered radiation, i.e., the softer spectrum would be expected to give a higher attenuation. However, the shielding thickness and composition of the collimator end plug is not identical to that of the collimator walls. Therefore, it is difficult to say if this is solely a spectral effect without further analysis of the results.

The attenuation factor for thermal neutrons was obtained only with the lead-Boral wall present. However, previous measurements on the PAX reactor during the PAX/R-1 shielding experiments have shown that the thermal flux background is relatively constant throughout the test cell regardless of what shield configuration is interposed between reactor and

detector. This is due to the fact that a large fraction of the measured thermal response is contributed by test cell scattering. Hence, the attenuation of 20,000 measured with the wall present is believed to be characteristic of that which would be obtained during shielding type measurements. However, from the present measurements, it is not clear whether this attenuation is predominantly due to neutrons penetrating through the sides or the ends of the collimator. From relatively crude calculations, it appears that the attenuation may be primarily due to leakage through the back plug of the collimator (see Figure 2) where the polyethylene is thinnest.

The LASL collimator is provided with four aperture cones to permit changing the solid acceptance angle, or in the case of a disk source, to permit performing the measurements at various distances. This is a very necessary part of a collimator employed for a reactor and/or shield studies. In the use of the LASL collimator, it was found that the mechanical problem of changing apertures was excessively time consuming and difficult. It would be desirable if the collimator unit could be set on a flat surface with the opening down such that the aperture (or background plug) could be detached by as simple a process as removal of a pin or pins. The collimator could then be moved to another spot where the next size aperture could be picked up with the same simple manipulation.

At WANEF, a simple steel frame was built to attach the LASL collimator to the WANEF test cell crane by means of the trunnion pins supplied on the collimator. Although WANEF safety rules did not permit the collimator to be lifted off the floor without an additional safety rope which was not available, the trunnion mounted frame was used enough to show that a motor-driven tilting mechanism and angle readout device could be very readily added to the support structure. Thus, with X,Y,Z positional control from the crane and tilt angle control at the collimator trunnion, a complete remote control data positioning system would be available. With remote control of position and angle and a number of aperture inserts to match the solid angle of the source, acceptable flux pattern measurements could be made in a heavy walled room without the attendant difficulty and inaccuracy of obtaining the test cell-induced background and subtracting this background from the total measurement to obtain the "direct" component.

The problem of distortion of source flux and/or spectrum by the collimator openings, which has been discussed elsewhere, ^(4,5) was not investigated in the limited time during which the collimator was available.

(4) "Neutron Physics Division Annual Progress Report for Period Ending May 31, 1967", ORNL-4134.

(5) "Fast Neutron Collimator Studies", E. A. Straker and M. B. Emmett, ORNL, Circa, 1966.

TABLE 1 - LIST OF DETECTORS

<u>Measurement Quantity</u>	<u>Type of Detectors</u>	<u>Designation</u>
Gamma Dose Rate	CO ₂ Ion Chamber	Reuter Stokes RSG-8A (929)
Thermal Neutron Flux	B-Lined Ion Chamber	Westinghouse WX-5362
Fast Neutron Flux	U ²³⁸ Fast Fission Chamber	Westinghouse WX-30748
Gamma Pulse Height Spectrum	3" diameter x 3" NaI Crystal Scintillator Detector	Harshaw 12512/3H

TABLE II - DESCRIPTION OF WALL LINER MATERIALS

1. Polyethylene, 2 w/o boron, 2 pieces, each 1" thick.
2. Boral plates, 18.1 w/o boron, 2 pieces, each 1/4" thick.
3. Sandwich of 1/4" Boral plate, two 1" polyethylene, and one 1/4" Boral plate (same Boral plates as in 2).
4. Polyethylene, 2 w/o boron, 3 pieces, each 1" thick, the fourth 1/2" thick.
5. Physical mixture of 26.17 Kg of Li_2CO_3 in 18.08 Kg paraffin or 11.1 w/o of lithium in a 2" thick slab.
6. Physical mixture of boric acid and paraffin with 12.6 w/o boron in a 2" thick slab.
7. Polyethylene, 2 w/o boron, 2 pieces, each 1" thick; 1/8" thick lead.
8. Polyethylene, 2 w/o boron, 2 pieces, each 1" thick; 1/4" thick lead.
9. Compromise composite developed from above results, 1/8" lead, 1/8" Boral, and 2" lithiated paraffin.

TABLE III - RATIO OF MEASURED RESPONSE WITH WALL LINER TO RESPONSE WITH BARE WALL

<u>Material**</u>	<u>Gamma Ray Dose Rate</u>	<u>Thermal Neutron Flux</u>	<u>Fast Neutron Flux</u>
1. 2" Borated Polyethylene	$0.60 \pm .06^*$	$0.46 \pm .03^*$	$0.45 \pm .06^*$
2. 1/2" Boral Plates	$0.80 \pm .07$		$0.85 \pm .09$
3. 1/4" Boral - 2" Polyethylene - 1/4" Boral	$0.76 \pm .07$	$0.12 \pm .01$	$0.64 \pm .09$
4. 3-1/2" Borated Polyethylene	$0.56 \pm .05$		
5. 2" thick slab of Li_2CO_3 plus Paraffin	$0.45 \pm .04$	$0.50 \pm .04$	
6. 2" thick slab of Boric Acid plus Paraffin	$0.61 \pm .06$	$0.35 \pm .02$	
7. 1/8" Pb + 2" Borated Polyethylene	$0.36 \pm .04$		
8. 1/4" Pb + 2" Borated Polyethylene	$0.27 \pm .03$		
9. Test Sandwich, 1/8" Pb + 1/8" Boral, + 2" Lithiated Paraffin	$0.38 \pm .04$	$0.22 \pm .02$	$0.65 \pm .09$

* In case of gamma dose rate and thermal neutron flux, errors are estimated to be $\pm 3\%$ from power stability and $\pm 3\%$ from reading the picoammeter for a total of $\pm 4.5\%$. In case of fast flux, statistical errors from counting rates vary between 3% and 5%.

** The first item is closest to the FCX reactor with each succeeding item placed closer to the concrete wall.

TABLE IV - RATIO OF MEASURED RESPONSE WITH NO
COLLIMATOR TO RESPONSE WITH COLLIMATOR PLUGGED

<u>Gamma Ray Dose</u>	<u>Thermal Neutron Flux</u>	<u>Fast Neutron Flux</u>
264 ± 19	$19,600 \pm 1400$	90.6 ± 4.5
$220^* \pm 17$		

* This value is obtained from the results of two reactor runs with no lead wall.

FIGURE 1 - ORIENTATION OF THE LASL COLLIMATOR IN THE TEST CELL

FIGURE 2 - LASL COLLIMATOR WITH BOTH PLUGS IN PLACE

FIGURE 3

Photo of the Lead Bricks, Aluminum and Boral Plates
Shielding the LASL Collimator From the FCX Reactor

LEAD WALL

ALUMINUM
& BORAL
PLATES

TEST CELL
DOOR

BARE WALL

FCX REACTOR

FIGURE 4

Photo of Top View of the LASL Collimator With Opening Pointing
Towards the Concrete Wall on the Right Hand Side

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Laboratory

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FCX REACTOR

TEST WALL

FIGURE 5

Front View of the LASL Collimator With Its Opening Plugged

FIGURE 6
Gamma Ray Pulse Height Spectra of Bare, Wall Background,
Borated Polyethylene, and Borated Paraffin

APPENDIX I - CALIBRATION OF THE PULSE HEIGHT SPECTRUM

The obtained pulse height spectra are calibrated against three different gamma energies. They are:

(1) 1.173 MeV from Co^{60}

(2) 1.333 MeV from Co^{60}

(3) 4.45 MeV from the following reaction in a 5 Ci PuBe neutron source moderated by 13" of borated polyethylene.

A kev/channel versus channel number curve was plotted, and the "true zeroth" channel was extrapolated. The kev/channel values of the above three gamma energies were recalibrated, and an average value for the pulse height spectrum calibration was thus obtained with $\pm 0.7\%$ uncertainty, assuming linearity over the complete energy range of interest.