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MEASUREMENT OF THE FAST-NEUTRON DOSE RATE TRANSMITTED
THROUGH A LiH SHIELD WHEN USED AS A WINDOW
IN IRON-OIL SHIELD MOCKUPS

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Abstract

Measurements were made of the fast-neutron dose rates transmitted through a LiH SNAP shield surrounded by various collar shield mockups of iron and oil. The source used was a collimated beam of neutrons from the TSR-II reactor. Data were obtained at a constant distance behind the LiH shield for combinations of several angles of neutron incidence, iron-oil configurations, and different locations of neutron incidence with respect to the shield axis. Comparisons of these results with predictions from Monte Carlo techniques used in the design of the collar shield are presented in ORNL-TM-2423.

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I. INTRODUCTION

An experiment was performed at the Tower Shielding Facility (TSF) to

- 1) examine a SNAP-2 LiH shield for neutron streaming paths that might exist in the shield or between the shield and the walls of its container, and
- 2) measure the neutron dose transmission through this shield when surrounded by various collar shield mockups of oil and iron. The source used in both series of measurements was a collimated beam of neutrons from the TSR-II.

In the first group of measurements, the SNAP-2 shield, obtained from Atomics International, was placed in an iron tank which was then filled with oil. For measurement of the neutron dose transmission through the shield it was mounted in a rectangular iron tank filled with transformer oil. Iron slabs, cut to fit the curvature of the LiH shield, were inserted around the sides of the shield; hence, the term "collar shield." Fast-neutron dose-rate measurements were made at a constant distance behind the LiH shield for combinations of three angles of neutron incidence, four horizontal positions of the neutron beam center line with respect to the LiH shield axis, and four iron-oil configurations.

II. EXAMINATION OF LiH SHIELD

Since the LiH shield is in a stainless steel casing, it was felt that neutron transmission measurements should be made to check for cracks in the shield and for voids between the LiH and the wall of the casing.^{1,2} For these measurements, the shield was placed in a cylindrical iron tank with the largest end of the LiH shield protruding through one end of the tank (see Fig. 1). The iron tank was then filled with transformer oil. The tank was mounted on a motor driven set of rollers so that the shield and tank

Mockup of LiH Shield in Cylindrical Oil Collar Shield

could be rotated about the shield axis on the horizontal plane. The rollers were attached to the top of a mine car placed on tracks so that the shield could be moved laterally (see Fig. 2). The tracks were movable so that the angle of neutron incidence upon the shield could be varied; the movement of the LiH shield, both rotational and lateral, was observed through the use of a television camera. The rotational position of the tank was read to better than 0.2° , and the lateral displacement was determined within $1/16$ of an inch.

A schematic of the LiH shield casing and its dimensions are given in Fig. 3. The casing was made of Type-321 stainless steel and was in the form of a truncated cone having a half angle of $7^\circ 27'$ at the apex. The container was completely sealed and gas-tight and had several small copper tubes penetrating the bottom of the casing.

For this experiment, the TSR-II, a water-moderated spherical reactor, was placed inside a spherical lead-water shield from which a collimated beam of neutrons emerged in the horizontal plane (see Fig. 4). The beam was collimated by a 30-in.-long x $1\frac{1}{4}$ -in.-diam duct.

The neutron intensity transmitted through the LiH shield was measured with a modified long counter (MLC). The counter was placed inside a detector shield at a fixed distance from the back of the iron tank containing the LiH shield. Neutrons penetrating the LiH shield reached the detector through a cylindrical collimator in the hemispherical end of the detector shield. The detector collimator opening was 3 in. in diameter for all but two measurements for which the detector collimator was changed to 1 in. in diameter in an attempt to determine the width of a void observed using the 3-in.-diam collimator.

Experimental Arrangement of the LiH Shield With Respect
to the TSR-II Reactor and the Detector Shield

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Schematic of LiH Casing

SIDE VIEW

Configuration for Mapping of the Neutron Leakage Through the LiH Shield

Experimental Results

In the first series of measurements, the collimated beam of neutrons was incident at an angle of 0° with respect to the shield axis. For each inch of lateral movement of the shield, the shield was rotated through 360° and the count rate from the detector was recorded on a variplotter. This procedure was used for a total lateral movement of the shield axis of 12 in., thus examining the shield out to a point about 1 in. beyond the smaller radius of the shield. Throughout this series of measurements, the axis of the detector collimator and the axis of the beam center line were coincident and stationary. Typical results are shown in Fig. 5.

No abrupt changes in neutron intensity which would indicate cracks in the LiH were observed at the detector for neutrons incident on the face of the shield. However, the measurements at the 12-in. radius did show some irregularities in the flux distribution pattern. Therefore, a second series of measurements were taken with the LiH shield, mine car, and tracks rotated through an angle of 7.5° on the horizontal plane so that the center line of the beam of neutrons from the reactor coincided with the conical side of the shield. For this series of measurements, the incident neutron beam was moved in small increments near the outer periphery of the shield and the LiH shield rotated through 360° for each increment the shield was moved laterally. The detector count rate and shield position were again supplied to the variplotter to obtain a continuous record of the variations in neutron intensity. Results from some of these mappings are shown in Figs. 6 and 7.

One notes some very large peaks in the neutron flux resulting from voids when the incident beam was very close to coincidence with the

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Fast-Neutron Dose Rate Mapping of Neutron Transmission
Through LiH Shield - Incident Neutron Angle 0°

Fast-Neutron Dose Rate Mapping of Neutron Transmission
Through LiH Shield - Neutrons Incident at an Angle
of 7.5° 11 in. from Center Line

Fast-Neutron Dose Rate Mapping of Neutron Transmission
Through LiH Shield - Neutrons Incident at an Angle
of 7.5° 10.5 in. from Shield Center Line

shield wall. Such streaming would tend to dominate the neutron transmission through the shield when it is used in conjunction with the collar shield and a SNAP reactor. Thus it became necessary to fill these voids with a substance whose shielding qualities closely approached that of LiH and could withstand deterioration from elevated temperatures.

Dry mineral oil was used to fill the voids in the shield. A vacuum was maintained inside the shield to make sure that the oil would be forced into any cracks that existed in the shield itself or between the shield and container wall. Approximately 11,000 g of mineral oil were put into the shield.

The shield was again placed in the reactor beam at the same angle of 7.5° , and radial and lateral traverses of the shield were repeated. As can be seen in Fig. 8, the peaks no longer existed.

III. COLLAR SHIELD EXPERIMENT

Upon completion of the first phase of this experiment, attention was focused on the primary purpose of this work - obtaining experimental data leading to a successful design of a collar shield for use in future work involving the LiH shield. For this study, the LiH shield was removed from the cylindrical tank and placed inside a rectangular iron tank 10-ft 4-in. long x 4-ft high x 1-ft 8.312-in. wide (see Fig. 9). Holes were cut in the faces of the tanks to fit the two ends of the truncated cone of the LiH shield. These openings were joined by a perforated iron cone that just fit the LiH shield to 1) act as a support for the LiH, 2) keep the tank wall from bulging when filled with oil, and 3) protect the LiH from absorbing

Fast-Neutron Dose Rate Mapping of Neutron Transmission
Through LiH Shield - Incident Neutron Angle 7.5°

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Schematic for Measurement of the Neutron Leakage Through the LiH Collar Shield Configuration

impacts during the insertion of the iron slabs which formed the collar shield. The LiH shield was fastened in position by bolting the flanges on its shell to the tank wall. The shell was sealed to the iron tank at both ends of the shield with a silicone rubber compound so that neutrons incident on the smaller end of the shield could leave the larger end of the shield without passing through the tank wall or any of the transformer oil.

As shown in Fig. 10, the collar shield was mounted on a motor driven mine car set on a pair of tracks. This system could be pivoted about a vertical axis such that the angle of incidence of the neutron beam upon the shield could be varied from 0 to 45° . At specified angles in this range, the collar shield could then be moved laterally through a distance of 18 in. either side of the reactor beam center line.

In this series of measurements, the detector shield and collar shield were always rotated through the same angle using the same point of reference. This point coincided with a vertical line passing through the reactor beam center line at a distance of 30 in. from the end of the reactor shield collimator insert. Its location was previously determined by mapping the beam profile in both vertical and horizontal directions. Thus, the tracks for both shields were kept parallel and the detector-shield separation was kept the same for each angle of rotation. Positions of the collar shield with respect to the neutron beam center line, and the detector shield with respect to the collar shield, were observed through the use of a television camera mounted on the detector shield carriage.

The detector shield was also mounted on a motor driven mine car positioned on a pair of tracks (see Fig. 11). Thus, the detector could be moved to coincide with movement of the collar shield. Neutrons leaving the

Mockup of LiH Shield in Collar Shield

Experimental Arrangement of TSR-II Reactor With Respect
to the LiH Shield in the Collar Shield

collar shield reached the detector through a truncated cone collimator whose sides, when projected to the neutron emergent side of the collar shield, enclosed only the LiH shield. The detectors were located 4 ft from the smaller end of the collimator.

To obtain adequate neutron intensity incident on the shield, a 6-in.-diam reactor beam collimator insert was used. The space between the collar shield and the reactor shield outside the beam profile generated by the 6-in.-diam collimator was filled with lithiated paraffin bricks to reduce the background at the detector from neutrons scattering around the collar shield. Throughout the measurements, the distance from the end of the reactor shield collimator insert to where its beam center line intercepted the face of the collar shield assembly nearest the reactor was always 30 in.

Both the Hurst-type fast-neutron dosimeter (FND) and a MLC, designed by H. G. Blosser, were used as detectors in this experiment. The greater sensitivity of the MLC made it the prime instrument for these measurements. Sufficient data were obtained with the FND at several of the MLC locations so that the multiple collision dose reading with the MLC could be converted to single collision dose units in ergs/g/hr/W.

The MLC consists of a 1-in.-diam BF_3 neutron detector contained within a polyethylene cylinder whose dimensions have been tailored to obtain a count rate from the detector that is proportional to the Snyder-Neufeld multi-collision dose. The MLC is designed so that the detector gives true dose readings only for those neutrons that enter one end of the detector. Since the neutron sensitive region of the whole detector is quite large (a 12-in.-long by 7-in.-diam cylinder), it was necessary to measure a

background for each foreground point. The background was obtained by placing a cylindrical piece of polyethylene 24-in. long and 7-in. in diameter in front of the detector.

The MLC was calibrated using a PoBe source of known neutron intensity, making both foreground and background measurements as described in the last paragraph. The count-rate difference was then converted to dose rate per unit count rate.

The FND consists of a polyethylene-lined proportional counter containing ethylene gas. It operates on the basis of the Bragg-Gray principle and requires an integration technique for obtaining the total energy deposited within the gas. Two methods were used. Pulses from the detector were divided into both an electronic integrator and a Nuclear Data analyzer. In the electronic integrator, all pulses above 6 V were weighted according to size with a corresponding count-rate output. Use of the analyzer to measure dose rate required a little more effort. Pulses from the detector were fed into a pulse-height selector (PHS) system that produced an output pulse only when triggered by an input pulse of 6 V or greater. The PHS output pulses were used to trigger the analyzer, permitting storage of only those pulses equal to or greater than 6 V. The differential spectrum was then converted to an integral spectrum and the area under the curve was determined using Simpson's rule. The area was then converted to dose rate using the calibration factor.

The FND was calibrated using a PoBe source of known intensity. The gas amplification in the detector was adjusted using the gamma rays from a known intensity ^{60}Co source. The detector output, when exposed to the

PoBe source, was treated in the manner described in the last paragraph. The count rates were then divided into the neutron dose rate at the detector to determine the calibration factor.

Experimental Results

The profile and intensity of the fast-neutron dose rate incident upon the collar shield were obtained with a FND in air. Detector traverses were made in both the horizontal and vertical planes perpendicular to the reactor shield collimator axis at a distance of 30 in. from the nearest end of the collimator. Results from one of the traverses are listed in Table 1 and plotted in Fig. 12 to give the dose rate profile. From these measurements, the total dose rate incident on the shield can be calculated. For all of the neutron transmission measurements, the detector was always located at a distance of 15 ft from the back of the LiH shield. Traverses perpendicular to the reactor beam center line were made with the FND at this location when the collar shield was removed. Measurements were made with the detector in its shield and with the detector in air. These results are given in Table 2 and plotted in Fig. 13. The FND was replaced in the shield by the MLC, and data, both foreground and background, were obtained at four points ($X = 0, 6, 12,$ and 18 in.). These are listed in Table 3.

The collar shield, containing only oil around the LiH, was then placed in the beam and dose-rate equivalent measurements were obtained with the MLC for $\theta = 0^\circ$, where θ was the angle the incident neutron beam made with respect to the LiH axis. Measurements were made with the detector and collar shield located at four values of X , where X (in

Table 1. Results for Oil as Collar Shield

θ (deg)	X (in.)	Long Counter (cts/min/W)	
		Foreground	Background
A: No Shield Behind LiH			
0	0	9.95×10^{-3}	2.55×10^{-3}
	6	1.36×10^{-2}	3.38×10^{-3}
0	12	2.68×10^{-2}	5.90×10^{-3}
	18	5.92×10^{-2}	1.10×10^{-2}
B: 12 in. Polyethylene Behind LiH			
0	0	3.12×10^{-3}	1.46×10^{-3}
			1.29×10^{-3}
	6	4.97×10^{-3}	1.82×10^{-3}
	12	1.39×10^{-2}	3.51×10^{-3}
	18	3.84×10^{-2}	8.59×10^{-3}
C: 19 in. H ₂ O Tank Behind LiH			
0	0	8.48×10^{-4}	4.66×10^{-4}
	6	9.10×10^{-4}	5.24×10^{-4}
	12	9.62×10^{-4}	5.81×10^{-4}
	18	9.17×10^{-4}	5.35×10^{-4}

Fast-Neutron Dose Rate Mapping of the Neutron Beam 30 in.
from the Reactor Shield

Table 2. Results for Collar Shield Mockup of 10 in. Fe
Followed by 10 in. Oil - Detector Shield Removed

θ (deg)	X (in.)	Long Counter (cts/min/W)		FND (ergs/gm/hr/W)	
		Foreground	Background	Foreground	Background
A: No Shield Behind LiH					
0	0	3.98×10^{-2} 4.03×10^{-2}	2.80×10^{-2}	1.81×10^{-7}	3.84×10^{-8}
	6	4.53×10^{-2}	3.11×10^{-2}	2.17×10^{-7}	4.13×10^{-8}
	12	5.82×10^{-2}	4.01×10^{-2}	2.66×10^{-7}	5.03×10^{-8}
	18	5.73×10^{-2}	4.13×10^{-2}	2.10×10^{-7}	4.39×10^{-8}
B: 12 in. Polyethylene Behind LiH					
0	0	3.38×10^{-2}	2.61×10^{-2}	1.00×10^{-7}	3.81×10^{-8}
	6	3.70×10^{-2}	2.87×10^{-2}	1.02×10^{-7}	3.61×10^{-8}
	12	4.71×10^{-2}	3.61×10^{-2}	1.45×10^{-7}	4.71×10^{-8}
	18	5.35×10^{-2}	4.00×10^{-2}	1.79×10^{-7}	4.30×10^{-8}
C: 19 in. H ₂ O Tank Behind LiH					
0	0	2.79×10^{-2}	2.33×10^{-2}	---	3.88×10^{-8}
	6	2.87×10^{-2}	2.48×10^{-2}	---	3.79×10^{-8}
	12	3.53×10^{-2}	3.11×10^{-2}	---	4.02×10^{-8}
	18	3.77×10^{-2}	3.33×10^{-2}	7.65×10^{-8}	4.03×10^{-8}

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Fast-Neutron Dose Rate Mapping of Neutron Beam 242 in. from the Reactor Shield

Table 3. Results for Collar Shield Mockup of Alternate
1 in. Fe and 1 in. Oil Slabs

θ (deg)	X (in.)	Long Counter (cts/min/W)		FND (ergs/gm/hr/W)	
		Foreground	Background	Foreground	Background
A: No Shield Behind LiH					
0	0	9.40×10^{-3}	2.46×10^{-3}	---	---
	6	1.24×10^{-2}	3.20×10^{-3}	---	---
	12	1.69×10^{-2}	4.12×10^{-3}	---	---
	18	1.16×10^{-2}	3.37×10^{-3}	---	---
25	0	5.55×10^{-3}	2.02×10^{-3}	4.90×10^{-8}	---
	6	9.65×10^{-3}	2.78×10^{-3}	9.16×10^{-8}	---
	12	1.10×10^{-2}	3.42×10^{-3}	9.62×10^{-8}	---
	18	7.00×10^{-3}	2.95×10^{-3}	---	---
B: 12 in. Polyethylene Behind LiH					
0	0	2.65×10^{-3}	1.25×10^{-3}	---	---
	6	4.16×10^{-3}	1.60×10^{-3}	---	---
	12	6.80×10^{-3}	2.29×10^{-3}	---	---
	18	8.78×10^{-3}	2.97×10^{-3}	---	---
25	0	2.42×10^{-3}	1.25×10^{-3}	---	---
	6	5.91×10^{-3}	2.05×10^{-3}	---	---
	12	7.79×10^{-3}	2.88×10^{-3}	---	---
	18	5.85×10^{-3}	2.83×10^{-3}	---	---

Table 3 Continued

θ (deg)	X (in.)	Long Counter (cts/min/W)		FND (ergs/gm/hr/W)	
		Foreground	Background	Foreground	Background
C: 19 in. H ₂ O Tank Behind LiH					
0	0	8.30×10^{-4}	4.72×10^{-4}	---	---
	6	8.36×10^{-4}	5.33×10^{-4}	---	---
	12	8.27×10^{-4}	5.10×10^{-4}	---	---
	18	4.88×10^{-4}	3.56×10^{-4}	---	---
25	0	4.93×10^{-4} 4.75×10^{-4}	4.39×10^{-4}	---	---
	6	5.22×10^{-4}	4.27×10^{-4}	---	---
	12	5.76×10^{-4}	5.00×10^{-4}	---	---
	18	6.11×10^{-4}	5.51×10^{-4}	---	---

inches) was the distance between the point on the front surface of the LiH shield (incident neutron surface) through which the horizontal axis of the LiH shield passed and the point at which the reactor beam center line is incident upon the collar shield (see Fig. 9). A minimum number of X values were selected (0, 6, 12, and 18 in.) since preliminary studies indicated that data at these points should be sufficient to determine the attenuation characteristics of the collar shield mockups. Foreground and background measurements were made at each shield location for three shield configurations directly behind the LiH: 1) no shielding, 2) 12-in. thickness of polyethylene, and 3) 19-in. thickness of water. The diameters of the polyethylene slabs varied to form a truncated cone whose shape resided within the cone formed at that location by the diameter of the rear of the LiH and the collimator in the detector shield. The 19-in. thickness of water was 5 ft x 5 ft to provide a background-type measurement of the dose rate at the detector from neutrons other than those emerging from the collar shield and reaching the detector uncollided through the detector shield collimator. From these measurements the neutron dose rate emerging from the LiH and reaching the detector and the dose rate from the collar shield that reached the detector can be determined from a series of subtractions. The results from the measurements are listed in Table 4.

Dose-rate measurements were made behind three collar shield mockups containing a series of 1-in. Fe slabs spaced throughout the oil. The same procedure was used for obtaining the data as described previously, along with a series of FND measurements to obtain count-rate to dose-rate conversion factors for the MLC. The angle of incidence (θ) was varied, keeping the reactor collimator to collar shield and collar shield to detector shield

Table 4. Results for Collar Shield Mockup of 4 in. Fe,
 1 in. Oil, 3 in. Fe, 2 in. Oil, 2 in. Fe,
 3 in. Oil, 1 in. Fe, 4 in. Oil

θ (deg)	X (in.)	Long Counter (cts/min/W)	
		Foreground	Background
A: No Shield Behind LiH			
0	0	9.54×10^{-3}	2.48×10^{-3}
	6	1.29×10^{-2}	3.28×10^{-3}
	12	1.67×10^{-2}	4.00×10^{-3}
	18	9.90×10^{-3}	3.10×10^{-3}
25	0	5.11×10^{-3}	1.76×10^{-3}
	6	9.01×10^{-3}	2.64×10^{-3}
	12	1.00×10^{-2}	3.19×10^{-3}
	18	5.83×10^{-3}	2.62×10^{-3}
B: 12 in. Polyethylene Behind LiH			
0	0	2.80×10^{-3}	1.35×10^{-3}
	6	3.98×10^{-3}	1.50×10^{-3}
			1.68×10^{-3}
	12	6.01×10^{-3}	2.08×10^{-3}
25	18	6.96×10^{-3}	2.44×10^{-3}
	0	2.25×10^{-3}	1.22×10^{-3}
	6	5.37×10^{-3}	1.89×10^{-3}
			1.88×10^{-3}
25	12	7.13×10^{-3}	2.60×10^{-3}
	18	4.97×10^{-3}	2.50×10^{-3}

Table 4 Continued

θ (deg)	X (in.)	Long Counter (cts/min/W)	
		Foreground	Background
C: 19 in. H ₂ O Tank Behind LiH			
0	0	9.11×10^{-4}	6.04×10^{-4}
	6	9.79×10^{-4}	5.88×10^{-4}
	12	1.01×10^{-3}	6.77×10^{-4}
	18	6.02×10^{-4}	5.29×10^{-4}
25	0	5.02×10^{-4}	4.34×10^{-4}
	6	5.50×10^{-4}	4.96×10^{-4}
	12	6.74×10^{-4}	5.55×10^{-4}
	18	6.70×10^{-4}	5.95×10^{-4}

distances constant. Results from the measurements for a mockup (see Fig. 14) of alternate 1-in. thicknesses of Fe and oil are given in Table 5 and for varying thicknesses of Fe and oil in Table 6.

Data were obtained behind a collar shield mockup of 10 in. of Fe, followed by 10 in. of oil (see Fig. 15), rotated to angles of 0, 25, and 45°. At each of these angles the detector shield was also rotated so that for each lateral movement of collar shield the detector shield could be moved the same distance to always keep the axes of the detector shield and collar shield coincident. Results from these measurements are given in Table 7. For $\theta = 0^\circ$, measurements were made with the detector shield removed for comparison with the previous data. These measurements are given in Table 8.

Schematic of the LiH Shield Contained in Collar Shield

Table 5. Results for Collar Shield Mockup of 10 in. Fe
Followed by 10 in. Oil

θ (deg)	X (in.)	Long Counter (cts/min/W)		FND (ergs/gm/hr/W)	
		Foreground	Background	Foreground	Background
A: No Shield Behind LiH					
0	0	9.88×10^{-3} 9.67×10^{-3}	2.59×10^{-3} 2.57×10^{-3}	9.40×10^{-8}	3.63×10^{-9}
	6	1.31×10^{-2} 1.28×10^{-2}	3.26×10^{-3} 3.19×10^{-3}	1.31×10^{-7}	3.41×10^{-9}
	12	1.47×10^{-2} 1.57×10^{-2}	4.12×10^{-3} 4.04×10^{-3}	1.74×10^{-7}	4.53×10^{-9}
	18	1.01×10^{-2} 9.48×10^{-3}	3.33×10^{-3} 3.01×10^{-3}	9.14×10^{-8}	2.58×10^{-9}
25	0	5.35×10^{-3}	1.87×10^{-3}	4.88×10^{-8}	2.82×10^{-9}
	6	9.16×10^{-3}	2.85×10^{-3}	9.42×10^{-8}	3.32×10^{-9}
	12	1.04×10^{-2}	3.46×10^{-3}	9.90×10^{-8}	2.73×10^{-9}
	18	6.08×10^{-3}	2.79×10^{-3}	4.41×10^{-8}	3.55×10^{-9}
45	0	3.40×10^{-3}	1.43×10^{-3}	2.70×10^{-8}	2.68×10^{-9}
	6	4.75×10^{-3}	1.80×10^{-3}	4.00×10^{-8}	---
	12	4.94×10^{-3}	2.08×10^{-3}	3.67×10^{-8}	---
	18	3.56×10^{-3}	1.98×10^{-3}	2.12×10^{-8}	---
B: 12 in. Polyethylene Behind LiH					
0	0	2.83×10^{-3} 2.87×10^{-3}	1.31×10^{-3} 1.34×10^{-3}	1.28×10^{-8} 1.49×10^{-8}	
	6	4.15×10^{-3} 3.93×10^{-3}	1.70×10^{-3} 1.64×10^{-3}	2.54×10^{-8}	
	12	6.25×10^{-3} 6.00×10^{-3}	2.28×10^{-3} 2.22×10^{-3}	4.52×10^{-8}	
	18	7.44×10^{-3} 6.53×10^{-3}	2.73×10^{-3} 2.53×10^{-3}	5.85×10^{-8}	

Table 5 Continued

θ (deg)	X (in.)	Long Counter (cts/min/W)		FND (ergs/gm/hr/W)	
		Foreground	Background	Foreground	Background
B: 12 in. Polyethylene Behind LiH					
25	0	2.50×10^{-3}	1.23×10^{-3}	1.65×10^{-8}	2.14×10^{-9}
	6	5.60×10^{-3}	1.92×10^{-3}	4.80×10^{-8}	2.45×10^{-9}
	12	7.38×10^{-3}	2.71×10^{-3}	6.77×10^{-8}	2.43×10^{-9}
	18	5.41×10^{-3}	2.73×10^{-3}	4.17×10^{-8}	2.11×10^{-9}
45	0	2.22×10^{-3}	1.16×10^{-3}	1.29×10^{-8}	1.84×10^{-9}
	6	3.52×10^{-3}	1.59×10^{-3}	2.66×10^{-8} 2.73×10^{-8}	---
	12	4.09×10^{-3}	1.88×10^{-3}	2.85×10^{-8}	---
	18	3.20×10^{-3}	1.94×10^{-3}	1.97×10^{-8}	---
C: 19 in. H ₂ O Tank Behind LiH					
0	0	9.32×10^{-4}	5.64×10^{-4}	---	---
		8.75×10^{-4}	4.97×10^{-4}	---	---
	6	9.87×10^{-4}	6.39×10^{-4}	---	---
		9.26×10^{-4}	5.76×10^{-4}	---	---
	12	1.02×10^{-3}	7.04×10^{-4}	---	---
		1.05×10^{-3}	6.45×10^{-4}	---	---
	18	9.36×10^{-4}	6.45×10^{-4}	---	---
		6.39×10^{-4}	5.31×10^{-4}	---	---
25	0	6.14×10^{-4}	5.54×10^{-4}	---	---
		5.54×10^{-4}	4.59×10^{-4}	---	---
	6	5.34×10^{-4}	4.77×10^{-4}	---	---
		5.90×10^{-4}	5.03×10^{-4}	---	---
	12	6.81×10^{-4}	5.89×10^{-4}	---	---
		7.39×10^{-4}	6.28×10^{-4}	---	---
	18			---	---
				---	---

Table 5 Continued

θ (deg)	X (in.)	Long Counter (cts/min/W)		FND (ergs/gm/hr/W)	
		Foreground	Background	Foreground	Background
C: 19 in. H ₂ O Tank Behind LiH					
45	0	6.10×10^{-4}	5.06×10^{-4}	---	---
	6	5.55×10^{-4}	4.93×10^{-4}	---	---
		5.56×10^{-4}			
	12	5.80×10^{-4}	5.31×10^{-4}	---	---
	18	5.79×10^{-4}	5.33×10^{-4}	---	---

Table 6. Results Without Collar Shield in the Neutron Beam

θ (deg)	X (in.)	Long Counter (cts/min/W)		FND (ergs/gm/hr/W)	
		Foreground	Background	Foreground	Background
0	0	1.92×10^3	2.67×10^2	1.65×10^{-2}	---
	6	1.84×10^3	2.74×10^2	1.60×10^{-2}	---
	12	1.60×10^3	2.71×10^2	1.33×10^{-2}	---
	18	1.31×10^3	2.35×10^2	1.05×10^{-2}	---

Collar Shield Mockup of 10 in. Fe Followed by 10 in. Oil

Table 7. Mapping of the Fast-Neutron Dose Rate (LiH and Collar Shield Removed) Along a Line Perpendicular to the Reactor Beam Center Line Using an FND at the Same Location as When the Collar Shield was in the Beam

Detector Location	Dose Rate (ergs/gm/hr/W)			
	Detector in Shield Integrator Value	Detector in Air Integrator Value	Detector in Shield Analyzer Value	Detector in Air Analyzer Value
Center Line	1.79×10^{-2}	1.66×10^{-2}	1.72×10^{-2} 1.78×10^{-2}	1.69×10^{-2}
2 in. N	1.77×10^{-2}	1.66×10^{-2}	---	---
4	1.72×10^{-2}	1.58×10^{-2}	---	---
6	1.64×10^{-2}	1.54×10^{-2}	---	---
8	1.56×10^{-2}	1.44×10^{-2}	---	---
10	1.47×10^{-2}	1.36×10^{-2}	---	---
12	1.38×10^{-2}	1.29×10^{-2}	---	---
14	1.31×10^{-2}	1.18×10^{-2}	---	---
16	1.21×10^{-2}	1.08×10^{-2}	---	---
18	1.08×10^{-2}	9.70×10^{-3}	---	---
21	9.04×10^{-3}	7.98×10^{-3}	---	---
25	6.40×10^{-3}	5.64×10^{-3}	---	---
27	---	4.53×10^{-3}	---	---
29	3.12×10^{-3}	---	---	---
31	8.22×10^{-4}	2.48×10^{-3}	7.81×10^{-4} 8.04×10^{-4}	2.63×10^{-3}
33	5.89×10^{-5}	1.66×10^{-3}		
35	1.09×10^{-5}	1.06×10^{-3}	---	---
37	6.86×10^{-6}	6.96×10^{-4}	---	---
39.5	4.81×10^{-6}	4.62×10^{-4}	---	---
2 in. S	1.78×10^{-2}	1.64×10^{-2}	---	---
4	1.76×10^{-2}	1.62×10^{-2}	---	---
7	1.67×10^{-2}	1.52×10^{-2}	---	---
10	1.53×10^{-2}	1.42×10^{-2}	---	---

Table 7 Continued

Detector Location	Dose Rate (ergs/gm/hr/W)			
	Detector in Shield Integrator Value	Detector in Air Integrator Value	Detector in Shield Analyzer Value	Detector in Air Analyzer Value
13 in. S	1.39×10^{-2}	1.28×10^{-2}	---	---
16	1.24×10^{-2}	1.13×10^{-2}	---	---
19	1.07×10^{-2}	9.90×10^{-3}	---	---
22	8.87×10^{-3}	8.22×10^{-3}	---	---
25	6.55×10^{-3}	6.66×10^{-3}	---	---
28	1.90×10^{-3}	5.01×10^{-3}	---	---
29	7.05×10^{-4}	4.49×10^{-3}	6.99×10^{-4} 7.02×10^{-4}	4.33×10^{-3}
31	5.62×10^{-4}	3.50×10^{-3}	---	---
34	1.13×10^{-5}	2.25×10^{-3}	---	---
37	5.54×10^{-6}	1.21×10^{-3}	---	---
40	4.96×10^{-6}	6.64×10^{-4}	---	---
Center Line	1.77×10^{-2}	1.63×10^{-2}	---	---

Table 8. Mapping of Fast-Neutron Dose Rate Incident
on the Face of the LiH Shield at 30 in. from
the End of the 6 in. Diam Reactor
Collimator Using an FND

Detector Location	Dose Rate (ergs/gm/hr/W)	
	Integrator Value	Analyzer Value
Center Line	3.78×10^{-1}	3.86×10^{-1}
1 in. N	3.75×10^{-1}	---
2	3.55×10^{-1}	---
3	3.33×10^{-1}	3.44×10^{-1}
4	2.86×10^{-1}	---
5	2.03×10^{-1}	---
6	1.19×10^{-1}	---
7	5.03×10^{-2}	5.97×10^{-2}
8	2.15×10^{-2}	---
9	9.08×10^{-3}	---
10	6.50×10^{-3}	---
11	4.90×10^{-3}	---
12	4.15×10^{-3}	---
14	3.03×10^{-3}	---
16	2.53×10^{-3}	---
18	2.03×10^{-3}	---
20	1.93×10^{-3}	---
1 in. S	3.58×10^{-1}	---
2	3.55×10^{-1}	---
3	3.43×10^{-1}	---
4	2.68×10^{-1}	---
5	1.78×10^{-1}	---
6	1.06×10^{-1}	---
7	4.58×10^{-2}	---
8	1.87×10^{-2}	---
9	8.53×10^{-3}	---

Table 8 Continued

Detector Location	Dose Rate (ergs/gm/hr/W)	
	Integrator Value	Analyzer Value
10 in. S	5.95×10^{-3}	---
11	4.53×10^{-3}	---
12	4.10×10^{-3}	---
14	2.98×10^{-3}	---
16	2.53×10^{-3}	---
18	2.12×10^{-3}	---
20	1.72×10^{-3}	---

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