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OPERATION HENRE

DISTRIBUTION OF RADIATION
FROM A 14 MEV NEUTRON SOURCE
IN AND NEAR STRUCTURES

J. S. Cheka

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CIVIL EFFECTS TEST OPERATIONS
U.S. ATOMIC ENERGY COMMISSION

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DISTRIBUTION OF RADIATION FROM A 14 MEV NEUTRON SOURCE IN AND NEAR STRUCTURES

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Chapter 1

INTRODUCTION

1.1 OBJECTIVES

Operation HENRE¹ (High Energy Neutron Reactions Experiment) was a further extension of studies begun in 1956 for evaluating the radiation doses sustained by persons exposed to nuclear weapons, especially the residents of Hiroshima and Nagasaki, in Japan. Program I of HENRE comprised the determination of spectra, angular distributions,² and effect of air-ground interface on radiation patterns from a monoenergetic neutron source over an extended air-ground interface.³ Furthermore, measurements of the penetration of neutron and secondary gamma radiation were made in cylindrical phantoms with respect to wall thickness and wall material.⁴ Also, measurements were made in a Japanese domicile-type structure to be compared with reactor produced radiation measurements made in Operation BREN, and alteration of angular dose distribution due to the structure was measured. Some measurements were made also of attenuation of the radiation by concrete walls. Project 1.3 reported herein, was concerned with those phases of the operation dealing with structures.

1.2 BACKGROUND

Extensive measurements were made on distribution of neutron and gamma radiation in facsimiles and radiation analogs of Japanese houses during weapons tests in 1957^{5,6} and 1958.⁷ Because of discrepancies in gamma dose distributions due to difficulties encountered in the use of chemical dosimeters during weapons tests, such measurements were again made during Operation BREN in 1962,⁸ using GM type dosimetry.

However, in neither type of test were there measurements made of angular distribution of radiation in the houses nor were there measurements made on heavier structures; Program No. 1 of Operation HENRE was designed to supply information in both of these categories.

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Chapter 2

MATERIALS, INSTRUMENTATION, AND EXPERIMENTAL TECHNIQUES

2.1 RADIATION SOURCE

The radiation source was a 14 MeV neutron generator¹ (Fig. 2.1) utilizing the $^3\text{H}(\text{d},\text{n})^4\text{He}$ reaction, with the design capability of 500 ma of beam current, and a neutron output of $\sim 10^{13}$ n/sec over a 4-hr period. It was mounted in a hoist car on the 1500-ft tower formerly used for Operation BREN² (Fig. 2.2) and could be positioned at elevations from 25 ft to 1500 ft.³

2.2 STRUCTURES

A "radiation equivalent" Japanese residence was used. This was identical with house Type A (Fig. 2.3) used in Hardtack II,⁴ and BREN.⁵ Japanese-type wood framing was used, but the Japanese clay mixture on the bamboo lattice for walls and wood-clay-tile structure for roofs was replaced by cement asbestos board of proper thickness. This material had been tested at ORNL and found to be close ($\pm 10\%$) in relative gamma and neutron attenuation to both classes of Japanese structural materials.⁶

Since there was not room inside the house to mount a turret carrying collimators to measure angular distribution of radiation, a simple method, capable of "looking at" a 2π solid angle in several directions was devised. This consisted of a pair of right, regular, hexagonal prisms of borated concrete, one of which was placed inside the house (Fig. 2.4) and the other at the same distance and orientation outside and at some distance from the house. The orientation was such that one face was perpendicular to a line from the foot of the tower. The prisms were 3 ft high and each face was 2 ft wide. The material produced virtually complete attenuation of neutrons and gamma rays incident on the blocks. Grooves were made in each face and top of each prism, during fabrication, to accommodate 1 in. diam counter tubes with the center line of the tube in the plane of the face.

Walls were build of 9 x 19 x 38 cm concrete blocks of 2.07 gm/cm³ density. Several hundred of these were available, and walls of several geometries were dry stacked during the course of the experiment. In one geometry, a "roof" was constructed by placing concrete slabs of 3 in. x 30 in. x 36 in. on a platform which was placed atop the wall structure.

Fig. 2.1--View of 14 MeV Neutron Generator Mounted on Tower

Fig. 2.2--General View of Experimental Area

Fig. 2.3--Radiation analog of Japanese Residence

Fig. 2.4--Hexagonal Concrete Prism Placed Inside Japanese House

2.3 INSTRUMENTATION

It was originally planned that a "phantom probe" fast neutron detector⁷ and the small "Phil" GM tube⁸ be utilized for the radiation measurements on the prisms. However, because of the low neutron and gamma-ray intensities existing at the location of the structures, and the low sensitivity of these instruments, the Radsan⁹ was used for neutron dosimetry and the larger RCL GM tube was used for gamma measurements.

The Radsan dosimeter consists of the Hurst proportional counter, a polyethylene lined, cyclopropane filled counter; preamplifier; amplifier; integrator; timer; and readout scaler. The amplitude of pulses produced in the counter are proportional to the energy deposited, so that a summation of the pulse heights is proportional to dose. The integrator weights pulses according to amplitude, and sums the products.

The RCL 10-60 GM tube was enveloped in a Sn-Pb shield to minimize energy dependence,¹⁰ and a ^6LiF shield to eliminate low energy neutron response.¹¹ The response of the RCL was 44.5 ± 3.1 times that of the "Phil" for gamma rays above 100 keV. The fast neutron response was similar to that of the "Phil", which had previously been determined to be less than 2% of that to gamma-ray dose.

Two normalizing channels, each consisting of a BF_3 tube in a paraffin cylinder (Fig. 2.5), were mounted in fixed positions in the open and away

Fig. 2.5--Paraffin Jacketed Neutron Normalizing Channels

from possible scattering structures on the 750 yd arc, in order to normalize Radsan readings. One of these was used while the other, which had been cross-calibrated, was on standby. A pair of RCL 10-60 GM tubes encased in LiF was similarly placed (Fig. 2.6) to normalize RCL 10-60 GM readings.

Fig. 2.6--LiF Shielded Gamma-Ray Normalizing Channels

2.4 TECHNIQUES

Measurements in the house were made with the instruments mounted in pairs consisting of one Radsan and one GM tube on racks at points 3 and 5 ft above selected points corresponding to some of those used in Hardtack II and BREN, and also at points before and behind the house.

Since the counters used were larger than those originally intended, the grooves on the concrete prisms were too shallow. Concrete blocks, 9 x 19 x 36 cm, were placed flat against the faces of the prisms. Aluminum racks were used to hold the counters so that the axes were in the plane of the new "faces." In this case, direct comparisons were made between inside and outside measurements.

When measurements were made behind the concrete block dry walls, a pair of detectors was mounted on the rack used in house measurements (Fig. 2.7), at 3 ft above ground level.

All of these measurements were made at a distance of 750 yd from the base of the tower.

Fig. 2.7--Pair of Detectors Mounted on Stanchion Inside Concrete Block Structure

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Chapter 3

PROCEDURES

3.1 STANDARDIZATION AND CALIBRATION PROCEDURES

Angular response of the RCL 10-60 has been measured.¹ It is not uniform, but varies by about 25% with polar angle with respect to the axis (Fig. 3.1). Consequently, it is difficult to calibrate for dose response with a point source. However, since the chief interest in these experiments was comparison, absolute values were not critical. The different counters used were cross-calibrated in a fixed geometry, and also compared in the diffuse radiation existing in the field to establish counter factors. The two methods gave results less than 1.5% apart, which is well within the experimental error range.

The Radsan was standardized by adjusting the four discriminators (5V, 10V, 20V, and 40V) with the aid of a pulser and oscilloscope. After alignment of the discriminators, the gain of the amplifier was set by setting the discriminator at 5V and adjusting the fine gain to yield 1/2 maximum count rate of the built-in alpha source.

The counters were then calibrated with a 1-ci PuBe source. Calibration was made before and after each run.

The normalizing channel was standardized by means of the PuBe source.

3.2 MEASUREMENTS

Measurements of both neutron and gamma-ray intensity were made at selected points in the A house, and also at points 4 ft in front of and 4 and 14 ft behind the house with the source elevation at 1125 ft and 500 ft. The points selected were some of those corresponding to the grid used in Hardtack II and BREN. The data were corrected for counter factors, and the neutron values were normalized to readings on the BF₃ normalizing channel. Because of the independent normalizing channels, air density corrections did not have to be made.

The adjusted values for both gamma-ray and neutron doses, relative to "air dose", were plotted in their respective positions on the floor plan of the house as decimal fractions of air dose, for each source elevation, according to the key appearing in Fig. 3.2. These values are presented in Figs. 3.3 and 3.4.

Fig. 3.1--Angular Response of RCL 10-60 Detector

NOTE:
BLANK SPACE IN ANY POSITION INDICATES
NO MEASUREMENT AT THAT LOCATION

Fig. 3.2--Key to Presentation of Ratios of Measured Doses to Air Doses at
Corresponding Distances at Indicated Locations

Fig. 3.3-- D_m/D_a ($Dose_{measured}/Dose_{air}$) In House--Source Elevation 1125 ft

Fig. 3.4-- D_m/D_a in House--Source Elevation 500 ft

Table 3.1 shows the data for a source elevation of 1125 ft, together with values at the corresponding points obtained from BREN. The measurements with a source elevation of 500 ft are given in Table 3.2.

The two hexagonal prisms were placed as shown in Fig. 3.5, with the outside prism far enough from the house to make perturbation due to scatter negligible. Starting with the front face of the prism as position No. 1, Nos. 2, 3, and 4 followed counterclockwise, as shown in Fig. 3.6. The top of the prism was No. 5. Measurements were not made on the other two faces, as they were symmetrical to 3 or 4.

Measurements were made at source elevations of 300 ft and 1125 ft in January, 1967. At the resumption of the operation in July, the 1125 ft source position was repeated, and measurements were also made with the source at 500 ft elevation. The data, corrected for counter factors, and normalized to the gamma monitor in the case of GM readings and to 10^5 counts of the BF_3 neutron reference channel in the case of Radsan readings appear in Table 3.3 to 3.6. The tables contain columns showing percent of total. The reference total is obtained by summing values on opposite faces, assuming 2π acceptance angles at each location.

Angular distributions of radiations due to the neutron source were measured. However, because of low source intensity and instrument sensitivity, measurements were made only from polar angles of 0 to 90° with collimators of 30° acceptance angles. On the basis of these values and the angular distributions measured on weapons tests and BREN, approximations were made of the angular distributions with extrapolations from a polar angle of 90° to 180° , as shown in Fig. 3.7. From these approximations distribution functions were calculated, giving radiation arriving through each 10° zone centered on the line from the source to the detector. The spherical coordinate projector² was used to evaluate fractions of zones intercepted by the shields. The spherical coordinate projector consists of a transparent plastic sphere, on the surface of which are inscribed 10° latitude and longitude lines, and in the center of which is a small light bulb approximating a point source. It is used with a scale model of the shield being evaluated. The light is placed at the point corresponding to the location of the detector, and the axis placed along the direction of the line from the detector to the source. The model of the shield then has projected upon it the zones, and sections of zones, which correspond to the part of the incoming radiation which had been intercepted by the shield.

A series of measurements was made on geometric designs comprising one or several walls of concrete blocks, stacked dry. One set consisted of the detectors placed behind a single wall of 2 m width, and 1.55 m height, the thickness being 0, 9, 19, and 38 cm. Another set comprised up to three 19 cm walls and a partial roof. The results of these measurements appear in Tables 3.7 to 3.10.

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Table 3.1 HENRE HOUSE MEASUREMENTS (1125 ft Elevation)

DECIMAL FRACTION OF AIR DOSE								
Station	Neutron 5 ft Elevation	Corresponding BREN Values	Neutron 3 ft Elevation	Corresponding BREN Values	Gamma 5 ft Elevation	Corresponding BREN Values	Gamma 3 ft Elevation	Corresponding BREN Values
4'Fr.	.96 ± .13	.96	1.13 ± .20	1.01	1.08 ± .04	1.20	1.03 ± .05	1.25
A	.53 ± .24	.68	.97 ± .17	.86	1.01 ± .06	1.40	1.12 ± .04	1.43
B	.69 ± .08	.61	.82 ± .19	.75	1.01 ± .02	1.43	1.04 ± .07	1.33
D	.44 ± .05	.46	.57 ± .32	.44	.83 ± .03	1.40	.90 ± .04	1.32
E	.68 ± .22	.46	.60 ± .24	.45	.88 ± .06	1.44	.91 ± .07	1.35
H	.49 ± .08	.43	.46 ± .09	.41	.88 ± .03	1.39	.76 ± .04	1.32
K	.44 ± .08	.35	.61 ± .15	.31	.80 ± .01	1.31	.82 ± .04	1.17
4'R ₁	.46 ± .10	.42	.55 ± .13	.49	.73 ± .03	1.10	.71 ± .03	1.01
14'R	.84 ± .17	.59*	.67 ± .14	.69*	.87 ± .03	.97*	.74 ± .05	.96*

*Back of "B" house - not directly comparable

Table 3.2 HENRE House Measurements (500 ft Elevation)
Decimal Fraction of Air Dose

Station	Neutrons 5 ft Elevation	Neutrons 3 ft Elevation	Gamma 5 ft Elevation	Gamma 3 ft Elevation
4'Fr	.98 $\pm$.12	.99 $\pm$.14	1.07 $\pm$.04	1.08 $\pm$.06
A	.78 $\pm$.18	1.00 $\pm$.14	1.10 $\pm$.04	1.12 $\pm$.05
B	.76 $\pm$.16	1.05 $\pm$.20	1.06 $\pm$.04	1.11 $\pm$.05
D	.53 $\pm$.06	.77 $\pm$.14	.89 $\pm$.02	1.01 $\pm$.04
E	.60 $\pm$.08	.91 $\pm$.13	.95 $\pm$.04	1.03 $\pm$.04
H	.46 $\pm$.07	.59 $\pm$.11	.85 $\pm$.03	.93 $\pm$.04
K	.46 $\pm$.06	.53 $\pm$.11	.78 $\pm$.01	.83 $\pm$.03
4'R ₁	.46 $\pm$.05	.55 $\pm$.15	.78 $\pm$.03	.70 $\pm$.03
14'R	.65 $\pm$.07	.78 $\pm$.10	.71 $\pm$.02	.70 $\pm$.03

Fig. 3.5--Plot Showing Location of Hexagonal Concrete Prisms

Fig. 3.6--Detail of Concrete Prism

Fig. 3.7--Angular Distribution of Neutron and Gamma-Ray Radiation at Location of Experiments

Table 3.3 Hexagonal Prisms - Source Elevation 300 ft

Face	Outside	Percent of Total *	Calculated Percent of Total	Inside House	Percent of Total	Ratio $\frac{\text{Inside}}{\text{Outside}}$
Gamma-Rays						
1	1.52 ± .09	81	83	1.31 ± .03	73	.86 ± .05
2	1.37 ± .01	73	76	1.34 ± .05	75	.98 ± .04
3	.50 ± .06	27	24	.54 ± .01	30	1.08 ± .12
4	.35 ± .02	18	17	.40 ± .01	22	1.14 ± .05
5	1.30 ± .06	70	56	1.25 ± .02	70	.95 ± .04
Neutrons						
1	.69 ± .06	69	74	.37 ± .03	77	.53 ± .06
2	.60 ± .08	60	67	.35 ± .05	74	.59 ± .11
3	.34 ± .09	34	33	.09 ± .03	19	.26 ± .11
4	.44 ± .28	44	26	.14 ± .05	30	.33 ± .23
5	.53 ± .05	54	53	.29 ± .04	60	.53 ± .08

*Total is the sum of values on opposite faces

Table 3.4 Hexagonal Prisms - Source Elevation 1125 ft (January)

Face	Outside	Percent of Total	Calculated Percent of Total	Inside House	Percent of Total	Inside Ratio Outside
Gamma-Rays						
1	1.21 ± .02	74	81	1.19 ± .02	75	.99 ± .03
2	1.14 ± .03	70	71	1.10 ± .05	69	.97 ± .05
3	.52 ± .01	32	29	.50 ± .01	31	.96 ± .02
4	.39 ± .02	24	19	.40 ± .01	25	1.03 ± .04
5	1.18 ± .02	72	72	.91 ± .02	57	.78 ± .02
Neutrons						
1	.51 ± .10	81	72	.43 ± .06	83	.85 ± .21
2	.39 ± .05	62	61	.37 ± .01	70	.94 ± .12
3	.21 ± .02	34	39	.14 ± .02	28	.68 ± .12
4	.17 ± .02	27	28	.12 ± .01	22	.67 ± .10
5	.54 ± .06	85	62	.31 ± .03	59	.58 ± .08

Table 3.5 Hexagonal Prisms - Source Elevation 1125 ft (August)

Face	Outside	Percent of Total	Calculated Percent of Total	Inside House	Percent of Total	Ratio $\frac{\text{Inside}}{\text{Outside}}$
Gamma-Rays						
1	1.06 ± .06	77	81	1.10 ± .10	74	.95 ± .10
2	.96 ± .04	70	71	.92 ± .03	67	.95 ± .05
3	.43 ± .02	32	29	.47 ± .04	34	1.08 ± .09
4	.29 ± .02	21	19	.34 ± .02	25	1.16 ± .09
5	1.01 ± .02	74	72	.84 ± .03	62	.83 ± .04
Neutrons						
1	.55 ± .04	75	72	.46 ± .10	81	.85 ± .19
2	.46 ± .05	62	61	.33 ± .09	57	.72 ± .22
3	.27 ± .04	37	39	.12 ± .08	21	.43 ± .30
4	.19 ± .02	26	28	.17 ± .04	30	.91 ± .26
5	.50 ± .05	68	62	.38 ± .06	66	.75 ± .13

Table 3.6 Hexagonal Prisms - Source Elevation 500 ft

Face	Outside	Percent of Total		Calculated Percent of Total	Inside House	Percent of Total		Ratio $\frac{\text{Inside}}{\text{Outside}}$
Gamma-Rays								
1	1.28 ± .06	82	82	82	1.20 ± .06	78	.94 ± .06	
2	1.10 ± .04	71	76	76	1.06 ± .03	69	.96 ± .04	
3	.43 ± .05	28	24	24	.48 ± .02	31	1.13 ± .12	
4	.30 ± .02	19	18	18	.35 ± .02	22	1.15 ± .09	
5	.98 ± .01	63	66	66	.89 ± .01	58	.91 ± .02	
Neutrons								
1	.52 ± .02	74	73	73	.49 ± .15	83	.94 ± .28	
2	.51 ± .07	72	65	65	.40 ± .07	67	.78 ± .18	
3	.23 ± .01	32	35	35	.19 ± .06	32	.84 ± .24	
4	.17 ± .04	24	27	27	.11 ± .02	18	.63 ± .19	
5	.56 ± .11	78	58	58	.43 ± .12	73	.78 ± .26	

Table 3.7

Neutron Penetration - Single Wall					
Wall Thickness	$R_s/10^5$ L.C.*	Wall/Air	% of Radiation Blocked	% of Radiation Open	Penetration**
0	$.603 \pm .089$	$1.00 \pm .15$	0	100.0	1.00
9 cm	$.574 \pm .129$	$.95 \pm .18$	56.5	43.5	$.92 \pm .32$
19 cm	$.298 \pm .106$	$.49 \pm .19$	56.5	43.5	$.10 \pm .34$
	$.338 \pm .093$	$.56 \pm .18$	56.5	43.5	$.23 \pm .30$
38 cm	$.250 \pm .039$	$.41 \pm .09$	56.5	43.5	$-.02 \pm .15$

*All readings were normalized to 10^5 counts on the neutron normalizing channel.

**The unblocked fraction (penetration = 100%) was subtracted from the Wall/Air value before calculation.

Table 3.8

Gamma-Ray Penetration - Single Wall					
Wall Thickness	γ_s/W^*	Wall/Air	% of Radiation Blocked	% of Radiation Open	Penetration**
0	$1.03 \pm .02$	$1.00 \pm .02$	0	100.0	1.00
9 cm	$.87 \pm .04$	$.84 \pm .04$	58.2	41.8	$.73 \pm .08$
19 cm	$.65 \pm .05$	$.63 \pm .05$	58.2	41.8	$.37 \pm .09$
	$.63 \pm .10$	$.61 \pm .10$	58.2	41.8	$.33 \pm .17$
38 cm	$.56 \pm .05$	$.54 \pm .05$	58.2	41.8	$.22 \pm .09$

*Readings were compared directly to the gamma normalizing channel, W.

**See note, Table 3.7.

Table 3.9

Neutron Penetration - Block "House"					
Wall Geometry	$R_s/10^5$ L.C.**	Wall/Air	% of Radiation Blocked	% of Radiation Open	Penetration***
0	.451 ± .016	1.00 ± .04	0	100.0	1.00
Front	.337 ± .022	.75 ± .06	33.4	66.6	.24 ± .17
Front and West	.262 ± .090	.58 ± .20	51.1	48.9	.18 ± .39
3 Walls	.264 ± .068	.58 ± .15	63.0	37.0	.34 ± .24
3 Walls and 3 in. Roof	.210 ± .056	.47 ± .11	90.2	9.8	.41 ± .12*
3 Walls and 9 in. Roof	.182 ± .061	.40 ± .14	90.2	9.8	.34 ± .15

*Thin "Roof" used here.

**See note, Table 3.7.

***See note, Table 3.7.

Table 3.10

Gamma-Ray Penetration - Block "House"					
Wall Geometry	γ_s/W	Wall/Air	% of Radiation Blocked	% of Radiation Open	Penetration
0	1.05 ± .02	1.00 ± .02	0	100.0	1.00
Front	.82 ± .03	.78 ± .02	36.8	63.2	.40 ± .06
Front and West	.73 ± .08	.69 ± .05	46.7	53.3	.34 ± .12
3 Walls	.72 ± .04	.68 ± .03	69.4	35.1	.47 ± .04
3 Walls and 3 in. Roof	.61 ± .05	.58 ± .03	90.8	9.2	.56 ± .02*
3 Walls and 9 in. Roof	.54 ± .04	.51 ± .02	90.8	9.2	.46 ± .02

*Thin "Roof" used here.

Chapter 4

DISCUSSION

4.1 HOUSE GRID MEASUREMENTS

Although the complete grid used during BREN was not utilized during HENRE, the stations where measurements were made were elements of this grid. A comparison of the average values of the HENRE measurements with the average of the corresponding measurements on BREN shows that for neutrons there is an increase of ~13% at the 5 ft detector elevation and ~30% at the 3 ft elevation, while for gamma radiation there is a decrease of ~33%. This implies that the neutron spectrum was more penetrating, and that the gamma build-up on BREN was caused primarily by neutron capture in the walls rather than degradation of the high energy gamma-rays; the verification of these phenomena was the major reason for making this series of measurements.

Calculations have been made on the neutron spectrum expected from the HENRE¹ accelerator at a distance of 770 m, which is approximately the slant range at 750 yd from tower with the source at 1125 ft elevation. Spectrum measurements were made in the field at and above 2 MeV.² In this range the agreement was good, so it is assumed that the lower energy values are also valid. While spectrum measurements were not made on BREN, similar neutron spectra were measured on weapons tests with threshold detectors.³ This method gives a measure of thermal neutrons and an energy-fluence histogram for energies above ~1 keV. Table 4.1 shows the comparison between the measured weapons spectrum and the calculated HENRE spectrum at the appropriate distance. In addition, in the weapons radiation, there are 25% as many neutrons at thermal energy as there are above ~1 keV, while the calculated HENRE spectrum shows much less than 1%, although measurements show several percent present.⁴

4.2 ANGULAR DOSE DISTRIBUTION USING HEXAGONAL PRISMS

This set of measurements was an approximation because of the large acceptance angles (2π steradians). It also was noted that the sum of readings on opposite faces of the prisms was larger than an air measurement at the same distance. Several factors contribute to this phenomenon. The albedo of the concrete is probably the largest single factor, amounting to 32% for neutrons.⁵ There is probably some leakage through the corner of the blocks flanking the counter, so that the geometry is not limited

2 π . There is also an increase in dose due to the effect of a nonisotropic radiation field making the effective center of a chamber not coincide with the geometric axis.

Using the estimated angular distribution of each kind of radiation, the expected readings in air were calculated. In most cases, the agreement in gamma-dose distribution was good. There were larger differences in the neutron measurements, but the large differences occurred in those cases where the average of the series of measurements had the largest standard deviation.

Table 4.1 Comparison of neutron spectra of weapons
(Measured) and HENRE (Calculated).

Detectors	Energy Range	Weapons	HENRE
Pu - Np	~1.00 keV - .75 MeV	59.2	28.0
Np - V	.75 keV - 1.2 MeV	24.7	38.7
U - S	1.2 keV - 2.5 MeV	10.7	12.8
S	>2.5 MeV	5.4	20.5

There appeared a relative build-up of gamma dose inside the house on the rear faces of the prism, while there was attenuation on the forward and top faces. In any case, these were not large.

With neutrons there was attenuation on all faces of the prism, with the least attenuation on the forward faces. The neutron results were not as consistent because of the low radiation intensity and the relatively higher instrument background count, causing larger standard deviations.

4.3 CONCRETE WALL ATTENUATION

In the case of the concrete wall configurations, the spherical co-ordinate projector together with the previously mentioned approximation of the angular distribution function was utilized to determine the fraction of radiation intercepted by the shield. Transmission was determined by subtracting the unintercepted fraction from the net reading, and dividing this difference by the value of the intercepted fraction. Using the 9 and 38 cm measurements from the single wall, and averaging the 19 cm values with those derived from the multi-wall structure, the half-thickness of this concrete is indicated to be 16.5 cm or 34 g/cm² for this spectrum of gamma radiation and 5.5 cm or 11 g/cm² for the neutrons.

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CIVIL EFFECTS TEST OPERATIONS REPORT SERIES (CEX)

Through its Division of Biology and Medicine and Civil Effects Test Operations, the Atomic Energy Commission conducts certain technical tests, exercises, surveys, and research directed primarily toward practical applications of nuclear effects information and toward encouraging better technical, professional, and public understanding and utilization of the vast body of facts useful in the design of countermeasures against weapons effects. The activities carried out in these studies do not require nuclear detonations.

The following is a partial list of reports available from studies that have been completed. All reports listed are available, at \$3.00 each, from the Clearinghouse for Federal Scientific and Technical Information, U. S. Department of Commerce, Springfield, Va. 22151.

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