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NEUTRON FLUX MEASUREMENTS IN THE
BULK SHIELDING FACILITY REACTOR

By
John W. Hill, Jr.

May 15, 1951

Oak Ridge National Laboratory
Oak Ridge, Tennessee

Technical Information Service, Oak Ridge, Tennessee

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THE BULK SHIELDING FACILITY REACTOR

By
John W. Hill, Jr.

May 15, 1951

Work performed under Contract No. W-7405-Eng-26

OAK RIDGE NATIONAL LABORATORY
Operated By
Carbide and Carbon Chemicals Company
Post Office Box P
Oak Ridge, Tennessee

OAK RIDGE NATIONAL LABORATORY

Memorandum

To: J. L. Meem
From: John W. Hill, Jr. *
Subject: Neutron Flux Measurements in the Bulk Shielding Facility
Reactor

Introduction

Neutron flux distributions have been measured in the BSF) Reactor with gold foils to provide data for a calculation of the reactor power level. A description of the reactor is given in ORNL-991, so only the location of fuel and reflector pieces are shown here.

Three different lattice arrangements were investigated as shown in Figures 1, 2, and 3.

Horizontal and vertical traverses were made through the lattice in representative positions. Enough points are presented to make possible an estimate of the neutron flux every six inches through each fuel element. This estimate will be done by J.L.Meem and reported separately. Only the points actually measured are

* The work reported was done by : J. W. Hill, Jr., E. B. Johnson, Grace McCammon, and M. P. Haydon.

FIG. 1

FUEL ASSEMBLY ARRANGEMENT — TEST No. 1

CRITICAL EXPERIMENTS — BULK SHIELDING FACILITY REACTOR

NOTE: BeO REFLECTOR ONE SIDE
WATER REFLECTOR THREE SIDES

FIG. 2

FUEL ASSEMBLY ARRANGEMENT — TEST No. 2

CRITICAL EXPERIMENTS—BULK SHIELDING FACILITY REACTOR

FIGURE 3

FUEL ASSEMBLY ARRANGEMENT — TEST No. 3

CRITICAL EXPERIMENTS — BULK SHIELDING FACILITY

reported here.

Results of the measurements are presented in three sections based on the three different lattice arrangements. All the data taken are shown in tables while representative traverses are plotted as saturated activity versus distance.

Lattice Number One

Table 1 is a summary of all the measurements taken in this lattice. Horizontal traverses through the lattice at its mid-plane are shown in Figures 4 and 5. The vertical traverse in Figure 6 shows the symmetry of the flux from top to bottom. Figure 7 is a plot of two east-west traverses taken in water at the mid-plane of the lattice, 3 and 6 inches from the north face of the reactor.

Lattice Number Two

Table 2 summarizes the data taken in the second lattice. Figure 8 is a horizontal traverse taken along the north-south centerline of the reactor, while Figure 9 shows the variation along a north-south line six inches east of the centerline. Figures 10, 11, and 12 are vertical traverses at the center and two corners of the lattice.

TABLE 1

SUMMARY OF FLUX MEASUREMENTS IN BSF LATTICE #1

Lattice Position	Assembly Face	Vertical Position on Assembly	A _s bare	A _s Cd covered	A _s Thermal	n _v Thermal	Cd Ratio
(5)	North	CL	1.069x10 ⁶	1.282x10 ⁵	9.408x10 ⁵	8.467x10 ⁶	8.34
	South	CL	1.162x10 ⁶	3.143x10 ⁵	8.477x10 ⁵	7.629x10 ⁶	3.70
		6"above CL	9.712x10 ⁵				
		12"above "	5.532x10 ⁵				
		6"below "	9.861x10 ⁵				
		12" " "	4.928x10 ⁵				
(25)	North	CL	1.352x10 ⁶	3.884x10 ⁵	9.636x10 ⁵	8.672x10 ⁶	3.48
	South	CL	1.745x10 ⁶				
(45)	North	CL	1.587x10 ⁶				
	South	CL	1.280x10 ⁶				
(43)	North	CL	1.151x10 ⁶				
		12"above CL	5.251x10 ⁵				
		12"below "	4.751x10 ⁵				
	South	CL	1.093x10 ⁶				
(47)	North	CL	1.081x10 ⁶				
		12"above CL	5.826x10 ⁵				
		12"below CL	5.724x10 ⁵				
	South	CL	1.014x10 ⁶				
(12)	West	CL	7.490x10 ⁵				
	East	CL	8.729x10 ⁵				
(14)	West	CL	9.877x10 ⁵				
	East	CL	1.166x10 ⁶				
(16)	West	CL	1.186x10 ⁶				
	East	CL	1.014x10 ⁶				

Continued

TABLE 1 (Continued)

Lattice Position	Assembly Face	Vertical Position on Assembly	A_s bare	A_s Cd covered	A_s Thermal	n_v Thermal	Cd Ratio
(18)	West	CL	9.511×10^5	2.314×10^5	7.197×10^5	6.477×10^6	4.11
		6" above CL	7.843×10^5				
		12" " CL	4.002×10^5				
		6" below CL	7.996×10^5				
		12" " CL	3.795×10^5				
	East	CL	8.113×10^5				
Horizontal Traverse in water, 3" from North Face of Reflector							
		CL	3.213×10^5				
		6" west of CL	2.346×10^5				
		12" west of CL	6.530×10^4				
		6" east of CL	2.386×10^5				
		12" east of CL	6.280×10^4				
Horizontal Traverse in water, 6" from North Face of Reactor							
		9" east of CL	2.695×10^4				
		3" east of CL	5.298×10^4				
		3" west of CL	5.387×10^4				
		9" west of CL	2.671×10^4				
		14" west of CL	93.41

TABLE 2

SUMMARY OF FLUX MEASUREMENTS IN BSF LATTICE #2

<u>Lattice Position</u>	<u>Assembly Face</u>	<u>Vertical Position on Assembly</u>	<u>A_S bare</u>	<u>A_S Cd covered</u>	<u>A_S Thermal</u>	<u>n_v Thermal</u>	<u>Cd Ratio</u>
(5)	North	CL	1.007x10 ⁶	1.958x10 ⁵	8.112x10 ⁵	7.301x10 ⁶	5.14
		6"above CL	8.203x10 ⁵				
		12" " "	4.371x10 ⁵	5.480x10 ⁴	3.823x10 ⁵	3.441x10 ⁶	7.98
		6"below "	8.435x10 ⁵				
	12" " "	4.551x10 ⁵	5.058x10 ⁴	4.045x10 ⁵	3.641x10 ⁶	9.00	
	South	CL	1.058x10 ⁶	3.485x10 ⁵	7.095x10 ⁵	6.386x10 ⁶	3.04
(25)	North	CL	1.328x10 ⁶	4.128x10 ⁵	9.152x10 ⁵	8.237x10 ⁶	3.22
		6"above CL	1.039x10 ⁶				
		12" " "	6.821x10 ⁵				
		6"below "	1.090x10 ⁶				
	12" " "	6.866x10 ⁵					
	South	CL	1.645x10 ⁶	4.228x10 ⁵	1.222x10 ⁶	1.010x10 ⁷	3.89
(45)	North	CL	1.480x10 ⁶	3.715x10 ⁵	1.108x10 ⁶	9.972x10 ⁶	3.98
		6"above CL	1.140x10 ⁶				
		12" " "	9.155x10 ⁵	3.160x10 ⁵	8.240x10 ⁵	7.416x10 ⁶	3.61
		6"below "	5.083x10 ⁵				
	12" " "	9.821x10 ⁵					
	South	CL	5.726x10 ⁵				
(7)	North	CL	6.594x10 ⁵	1.271x10 ⁵	5.323x10 ⁵	4.791x10 ⁶	5.19
		6"above CL	5.346x10 ⁵				
		12" " "	2.925x10 ⁵	3.505x10 ⁴	2.574x10 ⁵	2.317x10 ⁶	8.34
		6"below "	5.420x10 ⁵				
	12" " "	2.944x10 ⁵	3.452x10 ⁴	2.599x10 ⁵	2.339x10 ⁶	8.53	
	South	CL	7.334x10 ⁵				
(27)	North	CL	9.516x10 ⁵				
		6"above CL	9.964x10 ⁵	2.797x10 ⁵	7.167x10 ⁵	6.452x10 ⁶	3.56
		12" " "	7.878x10 ⁵				
		6"below "	5.235x10 ⁵	7.496x10 ⁴	4.485x10 ⁵	4.037x10 ⁶	6.98
	12" " "	7.943x10 ⁵					
	South	CL	5.084x10 ⁵	8.706x10 ⁴	4.213x10 ⁵	3.792x10 ⁶	5.84

Continued

TABLE 2 (Continued)

Lattice Position	Assembly Face	Vertical Position on Assembly	A _s bare	A _s Cd Covered	A _s Thermal	nv Thermal	Cd Ratio
(47)	North	CL	8.500×10^5				
	South	CL	8.311×10^5	2.052×10^5	6.259×10^5	5.633×10^6	4.05
		6"above CL	6.493×10^5				
		12" " "	3.997×10^5	6.104×10^4	3.613×10^5	3.252×10^6	6.92
		6"below "	7.696×10^5				
		12" " "	4.223×10^5				
16	North	CL	1.037×10^6				
	South	CL	1.412×10^6				
		6"above CL	1.187×10^6				
		12" " "	6.706×10^5				
		6"below "	1.226×10^6				
		12" " "	6.688×10^5				
46	North	CL	1.079×10^6				
		6"above CL	9.164×10^5				
		12" " "	5.908×10^5				
		6"below "	9.446×10^5				
		12" " "	6.092×10^5				
	South	CL	1.072×10^6	2.876×10^5	7.844×10^5	7.060×10^6	3.73

FIG. 9
 BULK SHIELDING FACILITY
 FOIL DATA LATTICE NO. 2
 MIDPLANE HORIZONTAL TRAVERSE
 FROM NORTH TO SOUTH THROUGH
 C OF EAST ROW OF FUEL
 6" EAST OF N-S C OF REACTOR

FIG. 10
 BULK SHIELDING FACILITY
 FOIL DATA LATTICE NO. 2
 VERTICAL TRAVERSE ON NORTH
 FACE OF FUEL IN POS 25

FIG. II
 BULK SHIELDING FACILITY
 FOIL DATA LATTICE NO. 2
 VERTICAL TRAVERSE ON NORTH
 FACE OF FUEL IN POS. 7

FIG. 12
 BULK SHIELDING FACILITY
 FOIL DATA LATTICE NO. 2
 VERTICAL TRAVERSE ON SOUTH
 FACE OF FUEL IN POS. 45

Lattice Number Three

Table 3 shows the points measured. Figures 13, 14, and 15 are horizontal traverses while Figures 16, 17 and 18 show vertical measurements.

Experimental Procedure

Gold foils (1 cm. sq. 0.005 in. thick) were scotch taped to the sides of the fuel elements for exposure. Cadmium covers 0.020 in. thick, were used to shield the foils when the activity due to epithermal neutrons was measured.

The foils were counted on mica window GM tubes with two counts being taken on each side of the foil to give an average value for the saturated activity.

Both foils and counters were calibrated using the graphite standard pile described in CP-2804. It is assumed that the error introduced by comparing foils exposed in graphite to those exposed in a water-uranium mixture is negligible. The measured ratio between foil saturated activity and thermal neutron flux is

$$(NV)_{\text{thermal}} = 9.0 \times (A_S)_{\text{thermal}}$$

where $(A_S)_{\text{thermal}}$ is the saturated activity of a bare foil minus the saturated activity of a cadmium covered foil exposed in the same position.

Data taken in different runs were normalized by repeating

TABLE 3

SUMMARY OF FLUX MEASUREMENTS IN BSF LATTICE #3

Lattice Position	Assembly Face	Vertical Position on Assembly	A _s bare	A _s Cd covered	A _s Thermal	n _v Thermal	Cd Ratio
(14)	North	CL	7.825x10 ⁵	1.779x10 ⁵	6.046x10 ⁵	5.441x10 ⁶	4.40
	South	CL	1.069x10 ⁶	2.463x10 ⁵	8.227x10 ⁵	7.404x10 ⁶	4.34
(15)	North	CL	1.006x10 ⁶	Lost			
	South	CL	1.117x10 ⁶	Lost			
(16)	North	CL	1.169x10 ⁶	Lost			
		6"above CL	9.319x10 ⁵	2.229x10 ⁵	7.090x10 ⁵	6.381x10 ⁶	4.18
		12" " "	5.523x10 ⁵	8.937x10 ⁴	4.629x10 ⁵	4.166x10 ⁶	6.18
		6"below CL	9.656x10 ⁵	2.455x10 ⁵	7.201x10 ⁵	6.481x10 ⁶	3.93
		12" " "	4.903x10 ⁵	7.483x10 ⁴	4.155x10 ⁵	3.740x10 ⁶	6.55
	South	CL	1.597x10 ⁶	Lost			
(25)	South	CL	1.425x10 ⁶	Lost			
(36)	North	CL	1.721x10 ⁶	4.139x10 ⁵	1.307x10 ⁶	1.176x10 ⁷	4.16
	South	CL	1.301x10 ⁶	4.020x10 ⁵	8.990x10 ⁵	8.091x10 ⁶	3.24
(45)	North	CL	1.326x10 ⁶	3.365x10 ⁵	9.895x10 ⁵	8.906x10 ⁶	3.94
	South	CL	1.095x10 ⁶	2.689x10 ⁵	8.261x10 ⁵	7.435x10 ⁶	4.07
(46)	South	CL	1.241x10 ⁶	Lost			
(34)	East	CL	1.088x10 ⁶	3.027x10 ⁵	7.853x10 ⁵	7.068x10 ⁶	3.59
		6"above CL	7.927x10 ⁵				
		12" " "	5.554x10 ⁵	8.892x10 ⁴	4.665x10 ⁵	4.199x10 ⁶	6.25
		6"below "	9.313x10 ⁵				
		12" " "	5.814x10 ⁵	8.888x10 ⁴	4.925x10 ⁵	4.433x10 ⁶	6.54
	West	CL	8.534x10 ⁵	2.198x10 ⁵	6.336x10 ⁵	5.702x10 ⁶	3.88
(36)	East	CL	1.414x10 ⁶	4.493x10 ⁵	9.647x10 ⁵	8.682x10 ⁶	3.16
	West	CL	1.392x10 ⁶	4.079x10 ⁵	9.841x10 ⁵	8.857x10 ⁶	3.41

Continued

TABLE 3 (Continued)

<u>Lattice Position</u>	<u>Assembly Face</u>	<u>Vertical Position on Assembly</u>	<u>A_s bare</u>	<u>A_s Cd covered</u>	<u>A_s Thermal</u>	<u>nv Thermal</u>	<u>Cd Ratio</u>
(38)	East	CL	1.044x10 ⁶	2.794x10 ⁵	7.646x10 ⁵	6.881x10 ⁶	3.74
	West	CL	1.279x10 ⁶	3.866x10 ⁵	8.924x10 ⁵	8.032x10 ⁶	3.31
		6"above CL	9.837x10 ⁵				
		12" " "	6.851x10 ⁵	1.101x10 ⁵	5.750x10 ⁵	5.175x10 ⁶	6.22
		6"below CL	1.034x10 ⁶				
		12" " "	6.666x10 ⁵	1.140x10 ⁵	5.526x10 ⁵	4.973x10 ⁶	5.85
(48)	South	CL	1.033x10 ⁶	2.251x10 ⁵	8.079x10 ⁵	7.271x10 ⁶	4.59
		6"above CL	8.870x10 ⁵				
		12" " "	4.824x10 ⁵				
		6"below CL	9.457x10 ⁵				
		12" " "	4.723x10 ⁵

FIG. 14
BULK SHIELDING FACILITY
FOIL DATA LATTICE NO. 3
MIDPLANE HOR. TRAVERSE FROM
EAST TO WEST $4\frac{1}{2}$ " FROM SOUTH
FACE OF REACTOR

FIG. 17
 BULK SHIELDING FACILITY
 FOIL DATA LATTICE NO.3
 VERTICAL TRAVERSE ON SOUTH
 FACE OF FUEL IN POS. NO.48

FIG. 18.

BULK SHIELDING FACILITY
 FOIL DATA LATTICE NO. 3
 VERTICAL TRAVERSE ON EAST FACE
 OF FUEL IN POS. NO. 34

exposures in several positions each time. Since the foils were exposed to the varying neutron flux which occurs during the reactor's rise to level power, a startup correction is applied to each run. This correction and its derivation by Dr. E. C. Campbell are shown in the Appendix.

- - - - -

APPENDIX

Startup Correction

Foils in the reactor lattice are exposed to the varying neutron flux which occurs while the reactor is being brought up to level power. The observed saturated activity calculated using the level exposure time must then be corrected for the activity induced during startup. The time required to shut down the reactor is essentially zero and will be ignored.

If the reactor is brought up to level power on a known period and held level for the remainder of the exposure, the startup contribution is shown by the following formula where A_0 represents the foil activity due to startup and A_1 is the activity due to the level exposure.

$$\frac{A_0}{A_1 + A_0} = \frac{\frac{1}{\lambda + \Lambda} (e^{\Lambda t_0} - e^{-\Lambda t_0}) e^{-\Lambda(t_1 - t_0)}}{\frac{e^{\Lambda t_0}}{e^{\Lambda t_0}} [1 - e^{-\Lambda(t_1 - t_0)}] + \frac{1}{\lambda + \Lambda} (e^{\Lambda t_0} - e^{-\Lambda t_0}) e^{-\Lambda(t_1 - t_0)}}$$

where

t_0 = startup time

$t_1 - t_0$ = level exposure time

$\Lambda = \frac{1}{\text{pile period}}$

λ = decay constant of isotope counted

A derivation of this formula due to Dr. E. C. Campbell of the Physics Division follows.

An approximate picture of the situation is given by the following sketch.

The neutron flux $\phi = \phi_0 e^{\lambda t}$ where

ϕ_0 = the background flux

$\lambda = \frac{1}{\text{pile period}}$

t = time

Let

n = number of active atoms

N = total number of atoms in the foil

σ = cross section for neutrons

$$\frac{dn}{dt} = \phi_0 e^{\lambda t} N \sigma - \lambda n$$

$$\frac{dn}{dt} + \lambda n = \phi_0 e^{\lambda t} N \sigma$$

$$\frac{dn}{dt} + \lambda n = 0 \quad \text{taking homogeneous part of the equation}$$

$$\frac{1}{n} \frac{dn}{dt} = -\lambda$$

$$\int_{n_0}^n \frac{dn}{n} = - \int_0^t \lambda dt$$

$$\ln n - \ln n_0 = -\lambda t$$

$$\ln\left(\frac{n}{n_0}\right) = -\lambda t$$

$n_H = n_0 e^{-\lambda t}$ is solution of homogeneous equation

Solution of inhomogeneous equation equals solution of homogeneous equation plus particular solution.

Try:

$$n = C e^{\lambda t}$$

$$C \lambda e^{\lambda t} + \lambda C e^{\lambda t} = \phi_0 e^{\lambda t} N \sigma$$

$$C(\lambda + \lambda) = \phi_0 N \sigma$$

$$C = \frac{\phi_0 N \sigma}{\lambda + \lambda}$$

$$n = \frac{\phi_0 N \sigma}{\lambda + \lambda} e^{\lambda t}$$

The general solution is then

$$n = n_0 e^{\lambda t} + \frac{\phi_0 N \sigma}{\lambda + \lambda} e^{\lambda t}$$

The initial conditions are $n = 0$ when $t = 0$, so

$$0 = n_0 \cdot 1 + \frac{\phi_0 N \sigma}{\lambda + \lambda} \cdot 1$$

The final solution is

$$n(t) = \frac{\phi_0 N \sigma}{\lambda + \lambda} (e^{\lambda t} - e^{-\lambda t})$$

At time t_1

$$A_0 = \frac{\phi_0 N \sigma}{\lambda + \lambda} (e^{\lambda t_1} - e^{-\lambda t_1}) e^{-\lambda(t_1 - t_0)}$$

$$A_1 = \frac{\phi_0 N_0 e^{-\lambda t_0}}{\lambda} [1 - e^{-\lambda(t_1 - t_0)}]$$

Since $\phi_0 N_0$ cancels and for practical cases $(e^{-\lambda t_0} - e^{-\lambda t_0})$ is essentially equal to $e^{-\lambda t_0}$, the relation becomes

$$\frac{A_0}{A_1 + A_0} = \frac{\frac{1}{\lambda + \lambda} e^{-\lambda(t_1 - t_0)}}{\frac{1}{\lambda} [1 - e^{-\lambda(t_1 - t_0)}] + \frac{1}{\lambda + \lambda} e^{-\lambda(t_1 - t_0)}}$$