MARTIN MARIETTA ENERGY SYSTEMS LIBRARIES
3 4456 0361274 9

CENTRAL RESEARCH LIBRARY
DOCUMENT COLLECTION

cy 4

ORNL-2545
Reactors-General

CALCULATION OF THE PHOTONEUTRON FLUX IN THE WATER NEAR THE BULK SHIELDING REACTOR

G. deSaussure

OAK RIDGE NATIONAL LABORATORY
operated by
UNION CARBIDE CORPORATION
for the
U.S. ATOMIC ENERGY COMMISSION

CENTRAL RESEARCH LIBRARY
DOCUMENT COLLECTION
LIBRARY LOAN COPY
DO NOT TRANSFER TO ANOTHER PERSON
If you wish someone else to see this document, send in name with document and the library will arrange a loan.

Printed in USA. Price 50 cents. Available from the

Office of Technical Services
U. S. Department of Commerce
Washington 25, D. C.

LEGAL NOTICE

This report was prepared as an account of Government sponsored work. Neither the United States, nor the Commission, nor any person acting on behalf of the Commission:

A. Makes any warranty or representation, express or implied, with respect to the accuracy, completeness, or usefulness of the information contained in this report, or that the use of any information, apparatus, method, or process disclosed in this report may not infringe privately owned rights; or

B. Assumes any liabilities with respect to the use of, or for damages resulting from the use of any information, apparatus, method, or process disclosed in this report.

As used in the above, "person acting on behalf of the Commission" includes any employee or contractor of the Commission to the extent that such employee or contractor prepares, handles or distributes, or provides access to, any information pursuant to his employment or contract with the Commission.

ORNL-2545

Contract No. W-7405-eng-26

Applied Nuclear Physics Division

CALCULATION OF THE PHOTONEUTRON FLUX IN THE WATER NEAR THE BULK SHIELDING REACTOR*

G. deSaussure

DATE ISSUED

JUL 9 1958

*Previously published in ORNL-2389, p. 22 (Sept. 1, 1957).

OAK RIDGE NATIONAL LABORATORY
Oak Ridge, Tennessee
operated by
UNION CARBIDE CORPORATION
for the
U.S. ATOMIC ENERGY COMMISSION

MARTIN MARIETTA ENERGY SYSTEMS LIBRARIES
3 4456 0361274 9

ABSTRACT

The measurement of the gamma-ray dose rate at a distance 267 cm from the Bulk Shielding Reactor has been used to estimate the photoneutron flux at that point. The resulting calculated flux was 1.65×10^{-5} neutron$\cdot$w$^{-1}\cdot$sec$^{-1}\cdot$cm^{-2}. This is to be compared with a measured value of the thermal-neutron flux of 1.58×10^{-5} neutron$\cdot$w^{-1}.sec^{-1}.cm^{-2}, all of which is assumed to consist almost entirely of photoneutrons.

TABLE OF CONTENTS

Introduction. 1

I. Method of Calculation 1

II. Result of the Calculation 2

III. Conclusions. 5

INTRODUCTION*

It has been pointed out[1] that at distances larger than 200 cm from the Bulk Shielding Reactor (BSR) essentially all the neutrons in the water are photoneutrons. This assertion is borne out by the fact that beyond 200 cm the relaxation length of the thermal-neutron flux is essentially the same as that of the gamma-ray dose rate.[2]

The measurement of the gamma-ray dose rate at a distance of 267 cm from the reactor has been used to estimate the photoneutron flux at that point. This calculation and a comparison of the results with the measured thermal-neutron flux at this point are given below.

I. METHOD OF CALCULATION

The following relation was assumed between the gamma-ray flux and the photoneutron flux at a distance r from the reactor:

$$\phi(r) = d\Omega(r)\,\frac{\int_{E_o}^{\infty} \Gamma(E_\gamma, r)\,\Sigma_{\gamma,n}(E_\gamma)\,dE_\gamma}{\Sigma_a^{th}}, \tag{1}$$

where

$\phi(r)$ = thermal-neutron flux at a distance r in centimeters from the reactor surface (neutrons$\cdot$cm$^{-2}\cdot$w$^{-1}\cdot$sec^{-1}),

$d\Omega(r)$ = solid angle under which the reactor is seen from a point at a distance r from the face of the reactor, steradians,

$\Gamma(E_\gamma, r)$ = gamma-ray flux of energy E_γ at a distance r from the reactor face (photons$\cdot$cm$^{-2}\cdot$w$^{-1}\cdot$sec$^{-1}\cdot$Mev$^{-1}\cdot$steradian^{-1}),

$\Sigma_{\gamma,n}(E_\gamma)$ = macroscopic cross section of water (cm^{-1}) for the reaction γ(D,p)n,

E_o = threshold energy (Mev) for the reaction γ(D,p)n,

Σ_a^{th} = macroscopic absorption cross section of water for thermal neutrons, cm^{-1}.

---

* This paper was previously published in ORNL-2389, "Applied Nuclear Physics Division Annual Progress Report for Period Ending September 1, 1957," p. 22.

1. J. M. LaRue et al., "An Estimate of the Photoneutron Flux in the Water Surrounding the Bulk Shielding Facility Reactor," ORNL CF-51-8-290 (Aug. 24, 1951).

2. F. C. Maienschein et al., "Attenuation by Water of Radiations from a Swimming Pool Type Reactor," ORNL-1891 (Sept. 7, 1955).

There are two approximations implicit in Eq. 1:

1. It is assumed that the thermal-neutron flux is given by the product of the gamma-ray flux and the ratio of the cross section for photoneutron production to the cross section for absorption of neutrons. This does not account for the fact that some photoneutrons do not become thermalized at the point where they are created. However, this approximation is good, since the neutron slowing-down length in water (about 5 cm) is short compared with the gamma-ray relaxation length (about 40 cm).

2. It is assumed that the total gamma-ray flux at the distance r is equal to $d\Omega(r)$ times the flux in the forward direction, where $d\Omega(r)$ is the solid angle under which the reactor face is seen from a point at a distance r from the reactor. Actually, no data are available on the angular distribution of the gamma-ray flux far away from the reactor. But the gamma rays of interest for this calculation are those with energies larger than the threshold for photoneutron production (2.225 Mev). Such high-energy photons cannot have suffered a large-angle scattering, or their energy would have been appreciably reduced. Thus it is a good approximation to assume that the photons which will be important in photoneutron production are those which are deflected very little or not at all. Thus the actual photon angular distribution, which is not known, is approximated by a distribution that is nearly uniform over those directions which intersect the reactor and is otherwise zero.

II. RESULT OF THE CALCULATION

The macroscopic cross section for the production of photoneutrons in water was calculated to be

$$\Sigma_{\gamma,n}(\mathrm{cm}^{-1}) = 2\mu\left(\frac{\rho}{A}\right)N\sigma = 10^{-8}\,\sigma, \tag{2}$$

where

μ = fraction of deuterium in hydrogen by natural occurrence
= 1.5×10^{-4} atom of deuterium per atom of hydrogen,[3]

ρ = density of water = 1 g/cm^3,

A = molecular weight of water
= 18 g/mole,

N = Avogadro's number = 0.602×10^{24} molecules/mole,

σ = microscopic cross section of deuterium (mb) for the (γ,n) reaction (σ is a function of the gamma-ray energy).

The solid angle $d\Omega(r)$ under which a point on the center line at a distance r from the reactor face sees the reactor face is

$$d\Omega(r) = \frac{\text{surface of the reactor face}}{r^2} \tag{3}$$

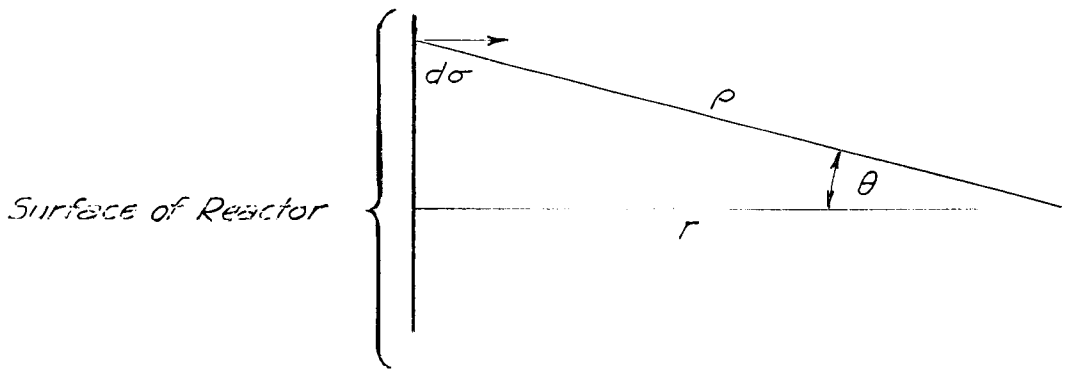
This relation is valid only for large distances from the reactor face (large values of r). A more exact relation is

$$d\Omega(r) = \int_{\text{reactor face}} \frac{d\sigma}{\rho^2} \cos^2 \theta \ , \tag{3a}$$

where

ρ = distance between the point where the flux is measured and a surface element $d\sigma$ on the reactor face,

θ = angle between the center line of the reactor and the line ρ joining the surface element $d\sigma$ and the point where the flux is measured (see sketch).



3. D. J. Hughes and J. A. Harvey, "Neutron Cross Sections," BNL-325 (July 1, 1955).

One of the factors cos Θ comes from the projection of the surface element $d\sigma$ on a plane perpendicular to ρ; the other comes from the fact that close to the forward direction the angular distribution of the gamma-ray flux at the surface of the reactor is expected to be proportional to cos Θ.

For large values of r, $\rho \cong r$, cos $\Theta \cong 1$, and Eq. 3a reduces to Eq. 3. Equation 3a can then be rewritten as

$$(3b) \qquad d\Omega(r) = r^2 \Big/ \frac{d\sigma}{\rho^4} \cong \frac{ab}{r^2}\left[1 - \frac{2(a^2 + b^2)}{3r^2}\right],$$

where

a = height of reactor face
= 62.5 cm,
b = width of reactor face
= 38 cm.

Therefore

$$d\Omega(r) = 3.17 \times 10^{-2}.$$

On substituting Eq. 2 into Eq. 1, the photoneutron flux becomes

$$(4) \qquad \phi(r) = 2\mu \frac{\rho}{A} N \frac{d\Omega(r)}{\Sigma_a^{th}} \int_{E_o}^{\infty} \sigma(E_\gamma)\, \Gamma(E_\gamma, r)\, dE_\gamma,$$

where the symbols have the same significance as above. Replacing them by their values gives

$$(4a) \quad \phi(r = 267 \text{ cm}) = 10^{-8} \times \frac{3.167 \times 10^{-2}}{0.022} \int_{2.225 \text{ Mev}}^{\infty} \sigma(E_\gamma)\, \Gamma(E_\gamma, 267 \text{ cm})\, dE_\gamma$$

$$= 1.44 \times 10^{-8} \int_{2.225 \text{ Mev}}^{\infty} \sigma(E_\gamma)\, \Gamma(E_\gamma, 267\text{cm})\, dE_\gamma.$$

The integration in Eq. 4a can be performed graphically. With the use of values of $\Gamma(E_\gamma, 267\text{ cm})$ from ORNL-1719[4] and values of $\sigma(E_\gamma)$ from Evans,[5] the integral is

$$\int_{2.225\text{ Mev}}^{\infty} \sigma(E_\gamma)\Gamma(E_\gamma, 267\text{ cm})dE_\gamma = 1.15 \times 10^3 \quad ,$$

in appropriate units for Eq. 4a. This leads to a calculated value of the photoneutron flux of

$$\phi_{calc}(r = 267\text{ cm}) = 1.65 \times 10^{-5}\text{ neutron}\cdot w^{-1}\cdot sec^{-1}\cdot cm^{-2},$$

which is to be compared with a measured value of the thermal-neutron flux of

$$\phi_{exp}(r = 267\text{ cm}) = 1.58 \times 10^{-5}\text{ neutron}\cdot w^{-1}\cdot sec^{-1}\cdot cm^{-2}$$

obtained by interpolation of values reported by Maienschein et al.[2]

III. CONCLUSIONS

The calculated value is about 4% higher than the measured value, but this discrepancy is not considered to be significant. The gamma-ray flux may be overestimated by assumption 2 discussed above, since probably not all the surface of the reactor is emitting high-energy radiation with the same intensity. On the other hand, the experimentally determined neutron flux may be in error by as much as 10%, as discussed in ORNL-1891.[2] The experimentally determined gamma-ray flux may be in error by an even larger factor, and the cross section for photoneutron production is quoted to within 14% error.

---

4. F. C. Maienschein, F. T. Bly, and T. A. Love, ORNL-1714, p 32 (Aug. 20, 1954) (Classified).

5. R. D. Evans, The Atomic Nucleus, p 335, McGraw-Hill, New York, 1955.

INTERNAL DISTRIBUTION

1. C. E. Center
2. Biology Library
3. Health Physics Library
4-5. Central Research Library
6. Reactor Experimental Engineering Library
7-26. Laboratory Records Department
27. Laboratory Records, ORNL R.C.
28. A. M. Weinberg
29. L. B. Emlet (K-25)
30. J. P. Murray (Y-12)
31. J. A. Swartout
32. E. H. Taylor
33. E. D. Shipley
34. A. H. Snell
35. E. P. Blizard
36. M. L. Nelson
37. W. H. Jordan
38. G. E. Boyd
39. R. A. Charpie
40. S. C. Lind
41. F. L. Culler
42. A. Hollaender
43. J. H. Frye, Jr.
44. M. T. Kelley
45. J. L. Fowler
46. R. S. Livingston
47. K. Z. Morgan
48. T. A. Lincoln
49. A. S. Householder
50. C. P. Keim
51. C. A. Preskitt
52. C. E. Winters
53. D. S. Billington
54. H. E. Seagren
55. D. Phillips
56. A. J. Miller
57. M. J. Skinner
58. R. R. Dickison
59. J. A. Harvey
60. A. Simon
61. F. C. Maienschein
62. C. E. Clifford
63. A. D. Callihan
64. R. R. Coveyou
65. W. Zobel
66. F. L. Keller
67. C. D. Zerby
68. D. K. Trubey
69. S. K. Penny
70. R. W. Peelle
71. E. G. Silver
72. G. deSaussure
73. V. R. Cain
74. L. B. Holland
75. E. B. Johnson
76. G. T. Chapman
77. M. J. Muckenthaler
78. A. B. Reynolds
79. Francis Alsmiller
80. F. L. Friedman (consultant)
81. H. Goldstein (consultant)
82. H. Hurwitz, Jr. (consultant)
83. L. W. Nordheim (consultant)
84. R. R. Wilson (consultant)
85. ORNL - Y-12 Technical Library, Document Reference Section

EXTERNAL DISTRIBUTION

86. G. K. Dicker, Aircraft Reactors Branch, Washington, D.C.
87-88. Convair, San Diego (1 copy each to C. E. Chapman and Dr. Donaldson)
89-94. General Electric Company (ANPD) (1 copy each to W. E. Edwards, J. Carver, R. H. Clark, F. A. Aschenbrenner, L. S. Byrnes, J. MacDonald)
95. Headquarters, Air Research and Development Command, Baltimore (C. L. Scoville)

96-98. The Martin Company (1 copy each to C. R. Fink, F. N. Greene, and G. J. Rausa)
99. R. Zirkind, Bureau of Aeronautics
100. K. L. Rooney, Curtiss-Wright Corporation, Quehanna, Pennsylvania
101. J. Van Hoomissen, General Electric Company, Idaho
102-103. Lockheed Aircraft Company (1 copy each to J. C. Flack and F. N. Watson)
104-105. Pratt and Whitney Aircraft Division (1 copy each to J. B. Dee and W. E. Price)
106. A. G. Peiper, U. S. Naval Research Laboratory
107. Convair, Fort Worth (N. M. Schaeffer)
108. J. W. McKee, Douglas Aircraft Company, Santa Monica
109. I. M. Karp, National Advisory Committee for Aeronautics, Cleveland
110. R. Aronson, Technical Research Group
111-112. WADC, Wright-Patterson Air Force Base (1 copy each to L. L. Antes, WCRRX and E. J. Zawalick, WCLIX)
113. R. K. Osborn, University of Michigan
114-699. Given distribution as shown in TID-4500 (13th ed., Rev.) under Reactors-General category (75 copies - OTS)
700. Division of Research and Development, AEC, ORO