AECD-4220

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**Notes on Predicted Fast Neutron Dose
from Thermal Neutron Data in Water**

by

Henry E. Stone

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Abstract

An approximate method has been applied to predict fast neutron dosimeter data from thermal neutron measurements. Results are compared with actual dosimeter data and it is concluded that the method presented gives a good approximation for fast neutron dose. This is important since in many previous experiments fast neutron dosimeter data had not been taken, but thermal neutron data had been obtained.

Introduction

It is often necessary to know the fast neutron flux in a given location, since generally fast neutrons are responsible for the largest part of the biological dose. For a given dose, usually expressed in rep/hr, one can stand about 50 times as many thermal neutrons as fast neutrons; hence, if the fast neutron flux is known, the neutron dose can fairly well be estimated. There are, however, few very reliable fast neutron instruments that are rugged and dependable, especially in a high gamma background. One such instrument is the fast neutron dosimeter, developed at Oak Ridge, which can be calibrated to rep/hr with a standard Po-Be source. This instrument is usually biased around 0.5 mev, which means it will not count neutrons of lower energies than the bias setting. This is done to cut out gamma ray pulses. It is, however, the ideal counter for fast neutrons (neutrons above this bias setting). In many experiments it has been found easier and less time-consuming to measure neutron fluxes with a Bf₃ or a fission counter.

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These instruments measure essentially a flux proportional to thermal neutron flux and can be calibrated with foils to produce thermal neutron data. It is the purpose of this memo to show a simple method by which one can approximate the fast neutron flux from thermal neutron measurements taken in water. The method is suggested by E. P. Blizard in CF-51-10-70, part II (revised). In this memo (HES-9) "calculated" fast neutron results are compared with experimental values obtained in experiments performed at the Brookhaven National Laboratory and the Oak Ridge National Laboratory.

Method of Calculations

The simplified equation (eq. 106 in CF-51-10-70, part II (revised)) is as follows:

$$(1) \quad I(s') = \lambda \sum_a \phi_{th} \left(s' + \frac{\tau}{\lambda} \right)$$

where $I(s') =$ fast neutrons/cm²sec at "s'" cm in H₂O

$\lambda =$ relaxation length (cm) of thermal neutron curve
in H₂O evaluated between s' and $\frac{\tau}{\lambda}$

$\sum_a =$ thermal neutron absorption cross section in H₂O —
0.0215 cm⁻¹

$\phi_{th} =$ thermal flux in H₂O at $(s' + \frac{\tau}{\lambda})$ cm in neutrons/cm²sec

$\tau =$ Fermi age for slowing down in water in cm²

A major difficulty arises in the determination of the Fermi age τ . For calculations in this memo this was found as follows:

The second moment of the thermal neutron flux equals twice the age (equation 2).

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- (2) $\bar{s}^2 = 2\bar{J}$ equation 152 "Introduction to the Theory of Diffusion and Slowing Down of Neutrons" - IV by R. E. Marshak, H. Brooks, H. Hurvits, Jr.

(3) where
$$\bar{s}^2 = \frac{\int_0^\infty s^2 \phi(s) ds}{\int_0^\infty \phi(s) ds}$$

ϕ = thermal neutron flux, neutrons/cm²sec

s = distance in water from end of mockup

The above equation shows that $\bar{J}$ may be evaluated if the thermal neutron flux in water is known. This has been done for all cases.
(see results)

The next item to be evaluated is the relaxation length λ equal to the slope of the thermal neutron curve between points s' and $s' + \frac{\bar{J}}{\lambda}$. This is a trial and error process by assuming a value for λ , evaluating $\frac{\bar{J}}{\lambda}$, and then computing λ at a point half way between s' and $s' + \frac{\bar{J}}{\lambda}$. This must be done until the assumed λ equals the actual λ . Where there is very little change in slope between s' and $s' + \frac{\bar{J}}{\lambda}$ this is very simple.

Equation (1) may be applied now to compute fast neutrons/cm²sec at various distances s' , knowing λ , Σ_a , $\bar{J}$ and the thermal flux at $s' + \frac{\bar{J}}{\lambda}$, which may be read from the thermal neutron curve.

The data used in these calculations were taken from those experiments where both thermal and fast neutron data were available behind identical configurations from Brookhaven and Oak Ridge tests. Fast

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neutron data expressed in mrep/hr were expressed in fast neutrons/cm²sec by using the following conversion:

$$1 \text{ mrep/hr} \approx 70 \text{ fast neutrons/cm}^2\text{sec}$$

Results

The results are presented in graphical form in Figures 12 - 22. Figures 1 - 11 show thermal neutron data with explanations of their origins. Where thermal neutrons from ORNL experiments were expressed in mrep/hr equivalent the following conversion was used:

$$\text{mrep/hr equivalent} \times 400 = \text{thermal neutrons/cm}^2\text{sec (nv)}$$

The solid lines in Figures 12 - 22 indicate "calculated" fast neutron data. The dotted lines on the same figures are measured "dosimeter" fast neutron data.

Conclusions

As seen in Figures 12 - 22, there is a fairly good correlation between calculated fast neutron data and actual measurements. In cases where dose due to fast neutrons is desired but only thermal measurements in water are available, it is recommended to use the above method to obtain a fairly good approximation. This should be particularly important in neutron duct and streaming experiments where no dosimeter data have been taken due to low counting rates and other difficulties.

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In a good shield design the dose due to neutrons should only be a fraction of the total design (about 10%). An underestimate by a factor of two will, therefore, result in only a small error in the total dose.

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$W/KW - \text{neutrons/cm}^2 \cdot \text{sec} - KW$

$W/KW - \text{neutrons/cm}^2 \cdot \text{sec} - KW$

BNL-KARL EXPERIMENT III
END OF MOCKUP AT 15.2 INCHES
THERMAL FLUX
FIGURE 1

INCHES

255-008

255-008

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Page 9

BNL - KAPL EXP IV
END OF MOCKUP AT 53.3 INCHES
THERMAL FLUX
- FIGURE 2

$\frac{nv}{KW} - \text{neutrons/cm}^2 - \text{sec} - KW$

INCHES

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BNL-KAPL EXP V

END OF MOCKUP AT 53.3 INCHES

THERMAL FLUX

FIGURE 3

$\frac{nv}{KW} - \text{neutrons/cm}^2\text{-sec} - KW$

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255 010

Page 11
 BNL-KAPL EXPERIMENT VI
 END OF MOCKUP AT 124 INCHES
 THERMAL FLUX
 FIGURE 4

NO. 3408-1-510 DESIGN GRAPH, PART 1
 FROM DOCUMENTATION
 10 DIVISIONS PER INCH
 10 DIVISIONS PER INCH

INCHES

255 011

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Page 12

BN - KAPL EXPERIMENT I'

END OF MOCKUP AT 54.3 INCHES

THERMAL FLUX

FIGURE 5

$\text{nv} / \text{KW} - \text{neutrons} / \text{cm}^2 - \text{sec} - \text{KW}$

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CM^x

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50

100

150

200

250

300

10⁸

10¹

Page 13

CF-51-5-62 Exp. I

THERMAL FLUX

FIGURE 6

nv/watt - neutrons/cm² - sec - watt

nv/watt - neutrons/cm² - sec - watt

10000

1000

100

10

1

0.1

0.01

10⁰

10⁻¹

10⁻²

10⁻³

10⁻⁴

10⁻⁵

10⁻⁶

ⓧ Note: Top cm. scale is different from bottom scale

CM^x

RL for H. Stone

CE-9-5-1A EXP. 2
THERMAL FLUX
FIGURE 7

CM FROM END OF MOCKUP

255-014

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Page 15

CF-53-5-1 PART 2
CONFIGURATION 6
END OF NOCKUP AT 6.77 CM
THERMAL FLUX
FIGURE 2

ny - neutrons/cm²-sec

CM

RL for H.E. Stone

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CF 52-51 PART V
END OF MONITOR AT 3000S
THERMAL FLUX
FIGURE 10

CM 255 017

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CF-52-5-1 PART 9
 CONFIGURATION 1
 END OF MOCKUP AT 66.6CM
 THERMAL FLUX
 FIGURE 31

$\text{mv} - \text{neutrons/cm}^2 - \text{sec}$

CM

RL for NE Stone

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BNL - KAPL EXPERIMENT II
 END OF MOCKUP AT 18.2 INCHES
 FAST NEUTRON FLUX
 FIGURE 12

$$I \text{ neutrons/cm}^2 \cdot \text{sec} \cdot \text{KW}$$

— CALCULATED
 --- EXPERIMENTAL

INCHES

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BNL - KARL EXPERIMENT IV
END OF MOCKUP AT 59.3 INCHES
FAST NEUTRON FLUX
FIGURE 13

Γ neutrons/cm² - sec - KW

— CALCULATED

- - - EXPERIMENTAL

INCHES

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255 020

MODEL

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BNL-KAPL EXPERIMENT V
END OF MOCKUP AT 53.3 INCHES
FAST NEUTRON FLUX
FIGURE 14

I neutrons/cm²-sec-KW

— CALCULATED
- - EXPERIMENTAL

INCHES

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BNL-KAPL EXPERIMENT VI
END OF PICKUP AT 92.4 INCHES
FAST NEUTRON PAUX
FIGURE 15

NEUTRONS / $\sqrt{N^2}$ - SEC - KW

SEMILOGARITHMIC
15 CYCLES X 10 DIVISIONS PER INCH

— CALCULATED
- - - EXPERIMENTAL

INCHES

RL. for H. Stone

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DATE

Page 23

BNL - KAPL EXPERIMENT I
END OF MOCKUP AT 56.3 INCHES
FAST NEUTRON FLUX
FIGURE 16

Γ neutrons/cm² - sec - KW

CALCULATED

EXPERIMENTAL

INCHES

255 023

KL For H. Stone

800 10

CF-51-5-62 EXP I
FAST NEUTRON FLUX
FIGURE 17

Page 24

CELS-1.1 PART 2
 CONTINUATION 15
 END OF MORNUP AT 67000
 EAST NEUTRON FLUX
 FIGURE 19

I
 - neutrons/cm²-sec.

61

255

026

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CP 52-S-1 PART 7
END OF MOCKUP AT 200CM
FAST NEUTRON FLUX

FIGURE 31

255 (28)

AL for HE 50cm

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CF-52-5-1 PART 9
CONFIGURATION 2
END OF MOCKUP AT 66.6 CM
FAST NEUTRON FLUX

FIGURE 3.2

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