1 of 1

HW-56644

**Cover Sheet for a Hanford
Historical Document
Released for Public Availability**

Released 1994

**Prepared for the U.S. Department of Energy
under Contract DE-AC06-76RLO 1830**

RECEIVED

MAY 04 1994

OSTI

**Pacific Northwest Laboratory
Operated for the U.S. Department of Energy
by Battelle Memorial Institute**

DISCLAIMER

This is a **historical document** that is being released for public availability. This was made from the best available copy. Neither the United States Government nor any agency thereof, nor Battelle Memorial Institute, nor any of their employees, makes any **warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights.** The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

(CLASSIFICATION).

GENERAL ELECTRIC

HANFORD ATOMIC PRODUCTS OPERATION - RICHLAND, WASHINGTON

DOCUMENT NO.

HW-56644

SERIES AND COPY NO.

28

DATE

June 4, 1958

X

THIS DOCUMENT CONTAINS NEITHER RECOMMENDATIONS NOR
DATA DEFINED IN THE ECONOMIC ACT. IT IS THE PROPERTY OF THE
ITS TRANSFER OR THE DISCLOSURE OF ITS CONTENTS IN ANY MANNER IS AN UNAUTHORIZED
PERMISSION IS PROHIBITED.

TITLE

BEAM HOLE FLUX MONITORS

11

OTHER OFFICIAL CLASSIFIED INFORMATION

THIS MATERIAL CONTAINS INFORMATION AFFECTING THE NATIONAL DEFENSE OF THE UNITED STATES WITHIN THE MEANING OF THE ESPIONAGE LAWS, TITLE 18, U.S.C., SECS. 793 AND 794, THE TRANSMISSION OR REVELATION OF WHICH IN ANY MANNER TO AN UNAUTHORIZED PERSON IS PROHIBITED BY LAW.

AUTHOR

D. B. LOVETT

CIRCULATING COPY

RECEIVED 700 AREA

JUL 14 1958

RETURN 10

TECHNICAL INFORMATION FILES

THIS DOCUMENT MUST NOT BE LEFT UNATTENDED OR WHERE AN UNAUTHORIZED PERSON MAY HAVE ACCESS TO IT. WHEN NOT IN USE, IT MUST BE STORED IN AN APPROVED LOCKED REPOSITORY WITHIN AN APPROVED GUARDED AREA. WHILE IT IS YOUR POSSESSION AND UNTIL YOU HAVE OBTAINED A SIGNED RECEIPT FROM CLASSIFIED FILES, IT IS YOUR RESPONSIBILITY TO KEEP IT AND ITS CONTENTS WITHIN THE LIMITS OF THIS PROJECT AND FROM ANY UNAUTHORIZED PERSON. ITS TRANSMITTAL TO, AND STORAGE AT YOUR PLACE OF RESIDENCE IS PROHIBITED. IT IS NOT TO BE DUPLICATED. IF ADDITIONAL COPIES ARE REQUIRED, OBTAIN THEM FROM THE RELATED ISSUING FILE. ALL PERSONS READING THIS DOCUMENT ARE REQUESTED TO SIGN IN THE SPACE PROVIDED BELOW.

ROUTE TO:

PAYROLL NO.

LOCATION

FILES	ROUTE	DATE
100-443888-100	100-443888-100	100-443888-100

SIGNATURE AND DATE

[illegible]

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

(CLASSIFICATION)

DECLASSIFIED

HW-56644

This document contains Restricted Data as defined in the Atomic Energy Act of 1954. Its transmission or the disclosure of its contents in any manner to an unauthorized person is prohibited.

This document consists of
20 pages, No. 28 of
30 copies.

BEAM HOLE FLUX MONITORS

Classification Cancelled and Changed To

DECLASSIFIED

By Authority of SE Gydesen,
RLO-CG-4, 11-22-93

By DK Hanson, 12-17-93

Verified By Jenni Mally 1-4-94.

June 4, 1958

Classification Cancelled (Change to

~~CONFIDENTIAL~~

By Authority of Printout

~~By~~

~~11-4-74~~
~~3/13/75~~

D. B. Lovett
Reactor Design Analysis Operation
IRRADIATION PROCESSING DEPARTMENT

DISTRIBUTION

1. E. R. Astley
2. R. O. Brugge
3. J. R. Carrell
4. A. B. Carson
5. D. L. Condotta
6. R. L. Dickeman
7. W. J. Dowis
8. A. G. Dunbar
9. J. F. Fletcher
10. G. C. Fullmer
11. C. H. Gydesen
12. W. M. Harty
13. R. C. Hoffman
14. J. E. Kaveckis
15. D. S. Lewis

16. G. L. Locke
17. D. B. Lovett
18. J. D. McCullough
19. D. W. McLenegan
20. J. S. McMahon
21. G. F. Owsley
22. R. S. Paul
23. R. A. Rohrbacher
24. W. A. Richards
25. M. H. Russ
26. G. H. Strong
27. R. E. Trumble
28. M. R. Wood
29. 300 Area File
30. Record Center

MASTER

DECLASSIFIED

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

BEAM HOLE FLUX MONITORS

INTRODUCTION

The octant monitors are an improvement over the early sub-pile flux monitors, but they still do not monitor the flux in the active zone of the reactor. Chambers located within the pile active zone would give the desired information but the inpile environment is too severe to allow a reasonable life for these chambers. A beam hole monitor is suggested to provide the desired flux monitoring.

SUMMARY AND CONCLUSIONS

The problem of reactor flux monitoring is discussed. The beam hole monitors have the advantage of providing adequate active zone coverage. Calculations were made to show the neutron current and current density at the chamber location as a function of the collimation of the detector assembly. These curves show the present sub-pile and octant monitors are sensitive primarily to the flux in the pile reflector rather than in the active zone. The beam hole monitors can be made sensitive to the active zone flux only. Sufficient chamber current can be obtained to operate available trip circuitry.

It is recommended that experimental work be started to prove out these beam hole monitors so any new reactor program may take advantage of them and that the monitoring of present piles can be improved.

DISCUSSION

The flux monitors of a reactor are used to indicate the heat generation rate in the reactor. The ion chamber currents are proportional to the flux levels which in turn are related to the heat rate.¹ Changes in the fission rate are immediately indicated by the flux level and rapidly shown by the ion currents.

The ion current is directly related only to the flux within the chamber itself. This chamber flux is related to the surrounding flux but the dependence decreases as the distance from the chamber increases - probably either exponentially or as an inverse power. The neutron diffusion length is defined as the square root of one sixth the mean square distance a thermal neutron travels from formation to capture. This is equal to $1/2.45$ the root mean square distance that a neutron travels before being absorbed.

$$L = \frac{\bar{r}^2}{6} = \frac{1}{2.45} r_{rms}$$

$$\text{or } r_{rms} = 2.45 L$$

DECLASSIFIED

1. HW-50086, "Calculation of Average Thermal Flux in the Fuel Element of a Reactor", E. R. Astley, 5/6/57.

Thus, it is reasonable to assume that most of the neutrons that reach the chamber originate within 2.5 or 3 diffusion lengths from the chamber. Certainly very few neutrons originating beyond 5 or 6 diffusion lengths away ever reach the chamber. The diffusion length of neutrons in graphite is about 50 cm. The sensitive volume about a chamber then can qualitatively be represented by two concentric spheres. The inner sphere of radius ~ 50 inches represents the rms volume of sensitivity while the outer sphere of ~ 100 inches radius represents the probably limit of sensitivity of the chamber. The figures in this document attempt to illustrate this decreasing sensitivity by a decrease in shading with an increase in radius. If the chamber were located on the edge of the pile, its sensitive volume would be a hemisphere of similar radii. These sensitive volumes are shown in Figure 1-a.

If the physical dimensions of a reactor are large in comparison to this effective chamber volume, a single flux sample cannot give information about the total or average reactor flux. Several chambers must be used and these chambers must be placed in a manner such that their sensitive volumes adequately cover the active zone of the reactor.

The active zones of the Hanford piles are roughly cylinders whose diameters^{2,3} and length range between 380 to 430 inches and 340 to 400 inches, respectively. These dimensions are large in comparison to the effective volumes of the chambers, indicating that several well placed chambers are required to adequately monitor the flux.

Large reactors of this type also are subject to flux distortions that oscillate about the pile volume. This cycling of the flux peak makes it necessary to have several flux detectors throughout the pile active zone so that the magnitude and location of the peak flux may be determined for control and safety purposes.

The early Hanford reactors had flux monitor chambers located in horizontal pipes placed in the pile foundation. Openings extended from the chamber location up through the shielding to the bottom of the graphite reflector. This system monitored the neutron flux in the bottom reflector adequately, but is questionable how representative it was of the active zone flux. Operating experience has shown that severe flux distortions can occur that are not detected by sub-pile chambers.^{4,5,6}

The deficiencies of the sub-pile chamber location were realized and the octant monitor system was incorporated in subsequent piles. The octant system is made up of eight chambers, one located near the center of each quadrant of both the near and far sides of the graphite stack. Holes extend about four feet into the

2. H-1-21522, H-1-21487, Blueprints of "K" Graphite Layers.
3. P-2343, P-2342, Blueprints of "H" Graphite Layers.
4. HW-53481, "H-Reactor Start-up Causing Fuel Element Ruptures", P. C. Walkup, 10/28/57.
5. HW-41495, "Reactor Incidents at Hanford", S. L. Nelson, 4/1/56.
6. HW-50126-RD, "Instrumentation Needs Based on Operating Experience", R. O. Brugge, 5/7/57.

DECLASSIFIED

graphite in front of each chamber, but in most cases, graphite plugs have been inserted in these holes. The octant system improves the quality of the flux monitoring, but still does not provide the coverage of the active zone flux that is desired.

The relative location of the effective volumes of the chambers in the pile are shown in Figures 2-a and 2-b for the sub-pile and octant installations. These figures are approximately to scale and illustrate clearly the large fraction of the pile that is not properly monitored.

The active zone flux is best monitored by allowing a portion of that flux to reach the ion chamber directly. This can be done in two ways. The most direct way is to put a chamber in the pile at the location where the flux measurement is required. This system has the disadvantage of imposing rather stringent requirements on the chamber materials due to the environment of intense nuclear radiation and temperatures approaching 600°C.. It is difficult to obtain materials that will maintain the leak tightness, structural stability and high insulation resistance required of ion chambers for long periods of time under these conditions. Water cooled chambers would minimize the temperature problem, but not alter the radiation damage problem and would introduce reactivity losses. The high flux exposures received by the materials in these locations induce so high a level of radioactivity that maintenance and replacement of the chambers becomes difficult and expensive.

An alternate system for obtaining a measure of the active zone flux is to allow a beam of neutrons to escape from the active zone down a hole in the graphite and fall upon the ion chamber. The chamber may be collimated so that only neutrons originating in the desired area can reach the chamber. This technique of obtaining a sample of neutrons from the interior of the reactor is similar to that used for the neutron spectrometers at DR and KE piles.

The effective volume of this chamber arrangement can be considered as the previous concentric spheres, but now centered about the inside end of the beam hole channel. This arrangement is illustrated in Figure 1-b. A disadvantage of the beam hole monitor is the large attenuation suffered by the beam in its collimation ($\sim 10^4$ for typical geometries). The lower flux at the chamber requires more sensitive chambers or higher amplification of the signal. The low flux, however, minimizes total exposure of the chamber materials and hence, radiation damage and activities are less.

The use of less collimation allows the detector to see both the end and some of the walls of the channel. The source of the neutrons detected then becomes "smeared out" along the channel length and at the same time, the total neutron current at the detector is increased for a given active zone flux. The detector effective volume for the semi-collimated chamber is then a region between 2.5 to 5 diffusion lengths in all directions from the walls of the beam hole that the chamber sees. Figure 1-c shows the approximate sensitive volume of a partially collimated beam hole monitor.

This partially collimated beam hole monitor could monitor the pile active zone much more effectively than the other systems considered. The total monitored volume of the pile could be increased to a relative large portion of the active zone by use of a few of these partially collimated detectors. Thus, it is

DECLASSIFIED

shown qualitatively that the collimated beam hole monitors can provide flux monitoring with better total volumetric coverage of the reactor and also the flux can be related to particular regions of the active zone. Variation of the degree of collimation can provide some control of the volume of the reactor from which the flux sample is taken.

In Appendix I, equations expressing the ratio of neutron current density at a collimated external detector to the maximum pile flux as a function of the degree of collimation are developed. The degree of collimation is expressed by the distance from the edge of the graphite to the point where the detector first "sees" the walls of the beam hole. The half angle at the apex of the cone from the detector to the point of "first sight" would also specify the degree of collimation, but this expression does not provide as clear a picture as the distance and is not used in the examples.

To illustrate the theoretical performance of these beam hole detectors, examples were calculated for varying degrees of collimation. The three examples differed only in the distance the chamber was located from the edge of the graphite (8, 24 and 48 inches). A circular hole of 1.875 inch radius was used which is a reasonable approximation to possible NFR beam holes. The linear approximation to the reactor flux discussed in Appendix II was used.

Figure 3 shows the ratio of the neutron current density at the detector to the flux in the flattened zone of the pile for the three detector locations. Figure 4 shows the total neutron current at the detector as a function of the collimation. It was assumed that the current density was uniform over the open area of the collimator.

These figures show that an uncollimated detector - even though located at the end of a hole into the pile (such as the octant monitors) - will respond primarily to the neutrons escaping from the reflector region. It is necessary to collimate the detector in order to shut out the reflector flux and get a signal of the active zone flux.

Since it appears that the beam hole monitors will give a better indication of the reactor flux, the question of whether or not they are practical will arise. Actually, this question cannot be answered definitely until some experience with the devices is obtained. Their main disadvantage is the flux attenuation and consequent reduction in signal strength. An estimate of the electrical current output from a chamber at the end of a collimated beam hole was made in Appendix IV. It appears that currents of about 10^{-7} amperes can be obtained with no problem. Magnetic amplifiers are commercially available that will operate on currents as low as 3×10^{-6} amperes. There should be no particular problem in using a beam hole - chamber - magnetic amplifier trip circuit arrangement to monitor the pile flux.

The beam hole monitors offer the potential of more adequately monitoring the reactor neutron flux. It is recommended that tests be made with these type of monitors to determine their practicability for operational use and that these tests be initiated soon enough that any new reactor design can take advantage of them.

DECLASSIFIED

APPENDIX I

DERIVATION OF EXPRESSION FOR NEUTRON CURRENT DENSITY AT BEAM HOLE CHAMBER

The beam hole monitor consists of a collimated detector located exterior to the pile graphite and in front of a hole extending into the interior of the pile active zone.

The following sketch shows the arrangement and nomenclature of the symbols used:

The detector is located at O, the edge of the graphite is at G, the reflector graphite is between G and R and the hole continues into the active zone with its bottom at B. The diameter of the hole is 2a. The linear approximation to the flux rises from 0 at e to its maximum value at F and continues at this maximum on into the center of the pile. (See Appendix II.)

The detector at O is collimated so that only those neutrons whose path angle is equal or less than α can enter the chamber, or stated in another manner, the detector sees only neutrons that leave the beam hole walls at distances beyond the point of first sighting, S. The distance from the detector down the center line of the beam hole is designated the positive x direction.

The neutron current density entering the beam hole from the walls is directly proportional to the local flux and is the same function of distance as the flux, see derivation in Appendix II.

$$\begin{aligned} \text{For } x &\leq e & J &= 0 \\ e &\leq x \leq F & J &= J_m \frac{(x - e)}{(F - e)} \\ F &\leq x & J &= J_m \end{aligned}$$

DECLASSIFIED

The neutron current at the detector from a differential area of the beam hole wall is inversely proportional to the square of the distance from the detector (r) and directly proportional to the projected area of this wall section.

$$dJ = J(x) \frac{1}{r^2} dA \sin \alpha$$

The total neutron current falling upon the detector is the integral of dJ from the point of first sighting to the end of the beam hole plus the contribution of the end. The integration must be done in parts so that the function $J_{(x)}$ is continuous over the limits of integration.

If the point of first sighting is in the linear approximation region, the following integrals apply,

$$J_T = \int_S^F dJ_e + \int_F^B dJ_f + \int_{\text{end}} dJ_f$$

The dJ_e is in the linear flux portion, while dJ_f is in the flat flux zone.

If the point of first sighting is at or before the zero flux point e , the current is the maximum and equal to

$$J_T = \int_e^F dJ_e + \int_F^B dJ_f + \int_{\text{end}} dJ$$

since the position between 0 and e contributes no neutron current.

If the point of first sighting is in the flat flux region (beyond F), the expression is,

$$J_T = \int_S^B dJ_f + \int_{\text{end}} dJ$$

The contribution from the end may be integrated separately or evaluated by observing that it is equal to the contribution of the integral from the end on out to infinity with a constant flux.

$$\int_{\text{end}} dJ = \lim_{\beta \rightarrow \infty} \int_B^\beta dJ_f = \int_B^\infty dJ_f$$

Addition of this end integral merely changes the limits of the last part of the wall integral.

The integrals will now be evaluated. In the flat flux region,

$$dJ_f = J_m \frac{1}{r^2} \sin \alpha \, dA$$

From the geometry: $\sin \alpha = \frac{a}{r}$

Where a is the radius of the channel and r is the crow flight distance from the surface element to the detector.

DECLASSIFIED

$$dJ_f = J_m \frac{1}{r^2} \frac{a}{r} 2\pi r dx$$

$$r = \sqrt{a^2 + x^2}$$

$$dJ_f = \frac{J_m 2\pi a^2 dx}{(a^2 + x^2)^{3/2}}$$

$$\int_{\alpha}^{\beta} dJ_f = 2\pi J_m \left[\frac{x}{(a^2 + x^2)^{1/2}} \right]_{\alpha}^{\beta}$$

If β approaches infinity, as is necessary to take into account the contribution of the end of the channel, the integral takes the following value:

$$\int_{\alpha}^{\infty} dJ_f = \lim_{\beta \rightarrow \infty} 2\pi J_m \left[\frac{\beta}{\sqrt{a^2 + \beta^2}} - \frac{\alpha}{\sqrt{a^2 + \alpha^2}} \right]$$

$$\int_{\alpha}^{\infty} dJ_f = 2\pi J_m \left[1 - \frac{\alpha}{\sqrt{a^2 + \alpha^2}} \right]$$

In the linear flux region, $J(x) = J_m \frac{(x - e)}{(F - e)}$

$$dJ_e = J_m \frac{(x - e)}{(F - e)} \frac{1}{r^2} \frac{a}{r} 2\pi r dx$$

$$dJ_e = \frac{2\pi a^2 J_m}{F - e} \left[\frac{xdx}{(a^2 + x^2)^{3/2}} - \frac{edx}{(a^2 + x^2)^{3/2}} \right]$$

$$\int_{\alpha}^{\beta} dJ_e = \frac{2\pi a^2 J_m}{F - e} \left[\int_{\alpha}^{\beta} \frac{xdx}{(a^2 + x^2)^{3/2}} - e \int_{\alpha}^{\beta} \frac{dx}{(a^2 + x^2)^{3/2}} \right]$$

$$\int_{\alpha}^{\beta} dJ_e = \frac{2\pi J_m}{F - e} \left\{ a^2 \left[\frac{-1}{\sqrt{a^2 + x^2}} \right]_{\alpha}^{\beta} - e \left[\frac{x}{\sqrt{a^2 + x^2}} \right]_{\alpha}^{\beta} \right\}$$

DECLASSIFIED

The total neutron current at the detector J may be evaluated. The ratio of $\frac{J}{2J_m}$ is used instead of J since it will be shown in Appendix III that the ratio of neutron current density to maximum flux is this value.

For $e \leq S \leq F$

$$\frac{J}{2J_m} = \frac{\pi}{F-e} \left\{ a^2 \left[\frac{1}{\sqrt{a^2 + S^2}} - \frac{1}{\sqrt{a^2 + F^2}} \right] - e \left[\frac{F}{\sqrt{a^2 + F^2}} - \frac{S}{\sqrt{a^2 + S^2}} \right] + \left[1 - \frac{F}{\sqrt{a^2 + F^2}} \right] \right\}$$

$$\frac{J}{2J_m} = \frac{\pi}{F-e} \left\{ (F-e) - \sqrt{a^2 + F^2} + \left[\frac{a^2}{S} + e \right] \sqrt{\frac{S^2}{a^2 + S^2}} \right\}$$

For $F \leq S \leq$ other side of flattened zone

$$\frac{J}{2J_m} = \pi \left[1 - \sqrt{\frac{S^2}{a^2 + S^2}} \right]$$

The term $\sqrt{\frac{S^2}{a^2 + S^2}}$ is used frequently. A compilation of its values for various

values of S has been prepared and is presented in Table I. The ratio $\frac{J}{2J_m}$ is a small number and is obtained as a difference of large numbers so it is necessary to calculate these numbers to several significant figures in order to obtain any precision in the results.

DECLASSIFIED

TABLE I
VALUES OF THE FUNCTION $\sqrt{\frac{s^2}{a^2 + s^2}}$ AND ITS COMPLEMENT FOR $a^2 = 3.52 \text{ in}^2$

<u>S</u> <u>(Inches)</u>	<u>$\sqrt{\frac{s^2}{a^2 + s^2}}$</u>	<u>$\left[1 - \sqrt{\frac{s^2}{a^2 + s^2}}\right] \times 10^5$</u>
8	0.973 584 77	2642
20	0.995 628 83	437.1
24	0.996 958 38	304.2
35	0.998 566 36	143.4
40	0.998 901 81	109.8
50	0.999 296 75	70.33
60	0.999 511 47	48.85
70	0.999 641 01	35.90
75	0.999 687 26	31.27
80	0.999 725 11	27.49
90	0.999 782 79	21.72
120	0.999 877 80	12.22
128	0.999 892 60	10.74
136	0.999 904 86	9.51
140	0.999 910 22	8.98
147	0.999 918 56	8.14
160	0.999 931 26	6.88
200	0.999 956 00	4.40
220	0.999 963 64	3.64
240	0.999 969 44	3.05
280	0.999 977 55	2.25
286	0.999 978 48	2.15
300	0.999 980 44	1.96
365	0.999 986 79	1.32
400	0.999 989 00	1.01
420	0.999 990 02	0.998

DECLASSIFIED

APPENDIX II

LINEAR APPROXIMATION TO REACTOR FLUX

The exact neutron flux profile across a pile is a rather complicated expression. Proceeding radially outward from the center, the flux remains constant throughout the flattened zone, thereafter it decreases following a Bessel function until the edge of the reflector is reached. Superimposed upon these functions are local variations due to the heterogeneous arrangement of alternating moderator and fuel. At the reflector, the thermal flux increases then falls off exponentially with distance from the active zone.

For the purposes of this report, a crude approximation to this flux profile was considered adequate. The flux (starting from the outside of the pile) was considered to be zero until the point e was reached. At this point, the flux increased linearly with distance until it reached the maximum value at point F. From F into the center of the pile, the flux was constant. The points e and F were chosen in a manner that attempted to hold the area under the approximate and actual flux curves equal and to match as closely as possible the slope in the unflattened and reflector zones. The following sketch illustrates a flux distribution and its linear approximation:

In the linear approximation region, $\Phi(x) = a + bx$

The values of the constants are determined by the boundary conditions.

$$\begin{aligned} \text{At } x &= e & \Phi(x) &= 0 \\ x &= F & \Phi(x) &= \Phi_m \end{aligned}$$

which gives the following expression for flux:

$$\Phi(x) = \Phi_m \frac{(x - e)}{(F - e)} \quad e \leq x \leq F$$

DECLASSIFIED

Farther into the pile than F, the flux is independent of distance and equal to Φ_m . Farther out of the pile than e, the flux is zero.

Summarizing:

$$\begin{aligned}\Phi(x) &= 0 & x &\leq e \\ \Phi(x) &= \Phi_m \frac{(x - e)}{(F - e)} & e &\leq x \leq F \\ \Phi(x) &= \Phi_m & F &\leq x \leq \text{other side of flattened zone.}\end{aligned}$$

Note that although x, e and F are all measured from the detector location, only their differences are used in the calculations and the detector location cancels out.

$$\frac{(x - G) - (e - G)}{(F - G) - (e - G)} = \frac{x - e}{F - e}$$

referred to edge of
graphite

referred to detector
location

Tentative values for the NPR flux distribution were obtained⁽⁷⁾⁽⁸⁾, plotted and the values of the constants for the best appearing straight line through them were obtained.

Parameter	Distance of Chamber from Graphite		
	8"	24"	48"
G	8 inches	24 inches	48 inches
(R - G)	54 inches	54 inches	54 inches
(F - e)	85 inches	85 inches	85 inches
F	120 inches	136 inches	160 inches
e	35 inches	51 inches	75 inches
Φ	205 inches	221 inches	245 inches

DECLASSIFIED

(7) Wood, D. E., personal communication, 4/58.

(8) Mansius, C. A. , personal communication, 4/58.

APPENDIX III

RELATIONSHIP OF J AND Φ^*

Consider a small area in the xy plane of a reactor. If we denote J_+ as the neutron current density in the + direction and J_- in the negative direction, elementary diffusion theory⁽⁹⁾ gives,

$$J_+ = \frac{\Phi_0}{4} - \frac{\lambda}{6} \left(\frac{\partial \Phi}{\partial z} \right)_0$$

$$J_- = \frac{\Phi_0}{4} + \frac{\lambda}{6} \left(\frac{\partial \Phi}{\partial z} \right)_0$$

$$J = J_+ - J_- = -\frac{\lambda}{3} \left(\frac{\partial \Phi}{\partial z} \right)_0 \quad (A)$$

Since $J = -\frac{\lambda}{3} \left(\frac{\partial \Phi}{\partial z} \right)_0$, then J_+ may be written as $J_+ = \frac{\Phi_0}{4} + \frac{J}{2}$ (B)

The albedo or reflection coefficient is defined⁽¹⁰⁾ as

$$\beta \triangleq \frac{J_{out}}{J_{in}}$$

Converting the J_{out} and J_{in} of the medium on the positive side of the xy plane to our nomenclature yields,

$$\begin{aligned} J_{out} &= J_- \\ J_{in} &= J_+ \\ \beta &= \frac{J_-}{J_+} \end{aligned} \quad (C)$$

Equations (A), (B), and (C) are manipulated to obtain an expression for J_+ in terms of β and Φ .

$$\beta = \frac{J_-}{J_+} = \frac{J_+ - J}{J_+} \quad (\text{From C and A})$$

*Developed in the method suggested by E. R. Astley; personal communication. 4/58.

(9) Glasstone & Edlund, "The Elements of Nuclear Reactor Theory", 1952. D. Van Nostrand Company, Chapter 5, Section 5.9.

(10) Glasstone & Edlund, Chapter 5, Section 5.97.

DECLASSIFIED

$$J_+ (\beta - 1) = -J$$

$$J = J_+ (1 - \beta) \quad (D)$$

$$J_+ = \frac{\bar{\Phi}}{4} + \frac{J}{2} = \frac{\bar{\Phi}}{4} + \frac{(1 - \beta)}{2} J_+ \quad (\text{From B and D})$$

$$(J_+) \left[1 - \frac{(1 - \beta)}{2} \right] = \frac{\bar{\Phi}}{4}$$

$$J_+ \left[\frac{2 - (1 - \beta)}{2} \right] = J_+ \left(\frac{1 + \beta}{2} \right) = \frac{\bar{\Phi}}{4}$$

$$J_+ = \frac{\bar{\Phi}}{2(1 + \beta)} \quad (E)$$

Thus, the neutron current density out of the interface is equal to the flux divided by $2(1 + \beta)$.

If the second media is a vacuum, $\beta = 0$ and

$$J_+ = \frac{\bar{\Phi}}{2}$$

The beam hole has no reflection back from the direction of the detector. The flux in the vicinity of the beam hole is probably not seriously perturbed by the beam hole's presence. Therefore, the neutron current density leaving the beam hole walls in the direction of the chamber is approximated by one-half the local flux.

If the local flux is given as a function of distance $\bar{\Phi}(x) = \bar{\Phi}_{\max} F(x)$, then the local neutron current density may also be expressed in this manner:

$$J(x) = \frac{\bar{\Phi}(x)}{2} = \frac{\bar{\Phi}_{\max}}{2} F(x)$$

The ratio $\frac{J}{2 J_{\max}}$ was used in the previous derivations since

$$2 J_{\max} = \bar{\Phi}_{\max}$$

and the ratio then is simply

$$\frac{J}{2 J_{\max}} = \frac{J}{\bar{\Phi}_{\max}}$$

which relates the neutron current in the detector to the flux in flattened zone.

DECLASSIFIED

APPENDIX IV

CALCULATION OF CHAMBER CURRENT OUTPUT FROM BEAM HOLE MONITORS

The electrical current output of a chamber may be expressed approximately by,

$$I = J A S \frac{E_r}{E_a} \sum e f$$

where I - chamber current - amperes

J - neutron current density at chamber - n/cm^2 -sec.

A - area of chamber target - cm^2

S - thickness of target - cm

$\sum$ - macroscopic reaction cross section - cm^{-1}

E_r - reaction energy delivered to air

E_a - energy to form one ion pair

e - electronic charge - 1.6×10^{-19} coulombs

f - chamber efficiency

The range of fission fragments is about 4 mg/cm^2 corresponding to a distance of $2.1 \times 10^{-4} \text{ cm}$ in uranium. There would be no point in making the active material any thicker than this since the fission fragments produced below this depth will not escape. It is assumed that the target is of this thickness and the efficiency factor will be used to account for the energy loss of the deep fragments before reaching the air.

The range of the α particles from the (n, α) reaction in boron is about one-fourth that of the range of fission products or 1 mg/cm^2 which corresponds to a length of about $4 \times 10^{-4} \text{ cm}$ in boron.

The chamber current that might be expected from the beam hole monitors can be calculated. It is assumed that the beam hole monitors are collimated to give a $J A$ of about 10^{-3} (chamber at - 24 inches looking in at 100 inches - See Figure 4.)

The reactor maximum flux is assumed to be 10^{13} n/cm^2 -second. It is assumed that chamber targets are made of the pure isotope (U^{235} for the fission chambers and B^{10} for the boron lined chambers) and their thickness is equal to the range of the reaction products. A chamber efficiency of 1 percent was arbitrarily chosen for both chambers.

The data used and current calculated are tabulated below:

DECLASSIFIED

	Fission Chamber <u>U²³⁵</u>	Boron Chamber <u>B¹⁰</u>
Σ	26 cm ⁻¹	567 cm ⁻¹
s	2.1 x 10 ⁻⁴ cm	4 x 10 ⁻⁴ cm
E _r	1/2 x 168 Mev	1/2 x 2.35 Mev
E _a	32.5 ev	32.5 ev
e	1.6 x 10 ⁻¹⁹	1.6 x 10 ⁻¹⁹
f	0.01	0.01
$\frac{JA}{Q_m}$	10 ⁻³	10 ⁻³
$\bar{Q}_m$	10 ¹³	10 ¹³
I	2.3 x 10 ⁻⁷ amperes	1.8 x 10 ⁻⁷ amperes

A beam hole detector collimated so that its first point of sight is 100 inches inside the NPR will give currents in the neighborhood of 10⁻⁷ amperes with either U-235 or B¹⁰ targets. These currents are adequate to operate some magnetic amplifier trip devices.

DECLASSIFIED

FIGURE 1. COMPARISON OF SENSITIVE VOLUMES OF VARIOUS CHAMBERS

1-a. Sensitive Volumes of Exterior and Interior Inpile Ion Chambers

1-b. Sensitive Volume of Fully Collimated Beam Hole Chamber

1-c. Sensitive Volume of Partially Collimated Beam Hole Chamber

DECLASSIFIED

FIGURE 2. RELATIVE CHAMBER AND PILE VOLUMES
FOR THREE DIFFERENT MONITOR SYSTEMS

2-a. Original Sub-Pile Chamber System

2-b. Octant Monitor System

2-c. Inpile or Beam Hole Monitor System

DECLASSIFIED

[REDACTED]

Figure 3

DECLASSIFIED

DATE

FILMED

6/10/94

END