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STATUS REPORT

IRON-MASONITE SHIELD ATTENUATION EFFECTIVENESS

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IRON-MASCNITE SHIELD ATTENUATION EFFECTIVENESS

By:

P. D. Gross

April 15, 1965

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STATUS REPORT
IRON-MASONITE SHIELD ATTENUATION EFFECTIVENESS

I. INTRODUCTION

This is the fifth in a series of reports presenting the status and deterioration rates of the B, D, DR, F, and H biological shields^{1,2,3,4}. The last previous report,⁴ covering the period from 1959 through March 31, 1961, indicated no significant decreasing trends in the attenuating effectiveness of the biological (iron-masonite) shields. At that time the combination of increasing average helium percentages and adding fringe poison in the smaller reactors resulted in corresponding reductions in shield temperatures below previous levels. Since then, there has been both an increase in reactor power levels and a greater emphasis on reduction of helium usage.⁵ Consequently, to limit biological shield temperatures and reduce the shield leakage, additional fringe poison has been employed for shield protection.

This report covers the period from late 1960 through January 1, 1964. It is intended that a final report covering DR, F, and H Reactors up to the time of their respective shutdowns be issued at a later date.

II. CONCLUSIONS

During the next five years, assuming no more than a five per cent increase in reactor power levels, radiation leakage escaping the bulk reactor shields is not expected to present any significant problems (see figures 1-5). Maximum leakage rates in the farside and top biological shields (aside from perforate locations) are not expected to exceed 30 mr in the B and D Reactors in the next five years provided combinations of shield poison and helium concentration maintain an average maximum masonite temperature of 90C or less. It is possible, however, to operate within reactor process standards and still attain leakage rates of 1.0 r or more through the top and side bulk shields within the next five years if the maximum biological shield temperature is allowed to reach and maintain a continuous 160C. The C Reactor iron masonite side biological shields and the K reactor concrete biological shields are provided with cooling tubes which reduce biological shield temperatures appreciably.

¹HW-54358, "Interim Report Number I, Development Test IP-102-C, Biological Shield Data, Use of Neutron Detector Facility", WL Bunch, 7-25-57

²HW-57373, "Biological Shield Data - Use of Neutron Detector Facility, Interim Report Number II, Development Test IP-102-C", WL Bunch, 8-29-58

³HW-64951, "Attenuation Effectiveness of the Hanford Reactor Iron-Masonite Shields", WL Smalley, 4-27-60

⁴HW-69640, "Status Report - Iron-Masonite Shields", WL Smalley, 5-21-61

⁵HW-79281, "PITA IP-26-I, Transition to High CO₂ Concentration and Revision of Gas Purity Limits and Controls", RE Baars, 10-17-63

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In the top biological shields of the K reactors, however, there is a distinct possibility that maximum temperatures will have to be limited by fringe poison additions should the cooling tubes pull out of the cast iron blocks of the top thermal shield due to contraction of the supporting graphite stack.^{6,7}

III. DISCUSSION

A. Background

The masonite within the biological shields is deteriorating progressively with time as a result of both high shield temperatures and radiation damage effects (with the latter effect having minor significance).⁸ As a result of the loss of the masonite moderator from the shields, increases in radiation leakage through the shields occur in excess of increases due to higher power levels.

In order to determine deterioration rates and their dependence upon shield temperatures, shield monitoring facilities were installed in 1956 and 1957 at the B, D, DR, F, and H Reactors. Both thermocouples and foil activation equipment were installed at that time. An empirical equation to correlate normalized neutron flux leakage through the iron-masonite shields (as measured by activation of gold foils) with days of operation and masonite temperature has been formulated.² The equation appears below and was used to evaluate the data and make predictions as to future leakage rates. The increase in normalized neutron flux leakage through an iron-masonite shield during an operating period of t days at a fixed temperature distribution may be determined by the relation:

$$L = L_0 e^{bt} \quad (1)$$

where L_0 = original normalized leakage rate

L = final normalized leakage rate

$$b = \frac{\mu_b X_b}{m} A \sum_{i=1}^m e^{-B/T_i}$$

and μ_b = attenuation coefficient of masonite

X_b = total thickness of masonite in the shield

A and B = constants

T_i = operating temperature of the i th masonite layer ($^{\circ}\text{K}$)

m = total number of masonite layers in the shield.

⁶HW-74736, "Top Shield Temperature at Existing Hanford Reactors," JD Agar, 8-28-62

⁷HW-73064, "The Effect of Fringe Poison on Heat Generation in the Shield Complex," EG Peterson, WL Bunch, 3-19-62

⁸HW-35202, "Hanford Shield Masonite Deterioration Studies," LA Wilson, 8-8-55

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The above expression considers only temperature as the deterioration parameter since the effects of radiation damage in the Hanford Reactor shields are relatively small.

A form of the above expression was used as the basis for a computer program, ICARUS, to allow the evaluation of the constant A from actual data. The program solves for the leakage, L, in

$$L = L_o e^{\frac{\mu_b X_b A}{m} \sum_{i=1}^n t_i \sum_{j=1}^m e^{-B/(T_{i,j}+273.)}} \quad (2)$$

where $\frac{\mu_b X_b}{m} = 1.15$ for the Hanford reactor shields

$\sum_{i=1}^n t_i$ = time between L and L_o in power days*

$T_{i,j}$ = masonite temperature during time i for masonite layer j

n = total number of sets of temperature data between L_o and L

L. A. Wilson⁹ reported values of 5870. ± 123. and 3730. ^{+2400.}_{-1470.} for B and A respectively in 1955 using equation (2) on out-of-pile experiments. The constant B is defined as E/R where E is the molar energy of activation of the masonite and R is the molar gas constant. Thus B is a property of the masonite itself, regardless of its environment. The constant A, however, varies with the environment and the property of the masonite under study; therefore the value of B measured by Wilson is used whereas A is determined from the operating data.

In 1958 W. L. Bunch² reported a value of A = 200 ± 160 based upon data from the D, DR, F, and H Reactors for about 270 power days of operation (see previous footnote). During this period, however, fringe poison was being introduced, power levels were being increased, gas compositions were changing, and the data were quite erratic. In some instances the data actually suggested that the shield attenuation effectiveness was increasing with time.

The latest reported value of A = 1930 was determined in 1960 by Smalley³ based upon 550 power days of operation at F Reactor.

Letting B = 5870., ICARUS was used in the current study to iterate to the value of A which fits the leakages calculated from temperature data by equation (2) above to the actual normalized leakage data obtained from the gold foil activation. The results are tabulated as follows.

⁹HW-35202, "Hanford Shield Masonite Deterioration Studies," LA Wilson, 8-8-55

*One power day is defined as a day during which the production equals or exceeds 1000 MWD.

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<u>Reactor*</u>	<u>A</u>	<u>Approximate Power Days</u>
B	3555.7	460
D	901.8	650
F	1211.4	720
H	2335.5	675
AVG	2001.1	625

B. Source of Neutron Leakage Data

The neutron detector facilities used were installed in the far side shields of the B, D, DR, F, and H Reactors during the CG-558 outages in 1956 and 1957. They provide a means of measuring neutron leakage through the shields by gold foil activation. During the same outages, thermocouples were also placed in these shields to allow measurement of operating temperatures of each steel layer in the shield. (The temperature of a particular masonite layer is taken to be the average of that of the two adjacent steel layers.) Sketches of the neutron and temperature detection facilities are shown in figures 6 and 7. Using this equipment, routine neutron leakage and shield temperature data have been taken since 1958. No neutron leakage data has been available from the DR Reactor, however, due to the presence of the DR gas loop preventing access to the foil holder facility. Early in 1964 the measurement of neutron leakage was resumed at the DR Reactor.

C. Discussion of Observations to Date

Figures 8 through 11 show normalized count rates of the gold foils irradiated in the neutron detector facilities of the B, D, F, and H Reactors plotted against power days. The data are fitted with a linear least squares fit (solid line), and the figures include 90 per cent confidence limits to the fit (dotted lines). The figures also show the leakage trends predicted for the same period by the ICARUS program using actual shield temperatures to calculate A in equation (2) above.

Dates of insertion of shield poison for the six smaller reactors are shown in figures 12-17.

Plots of relative power levels, helium percentages, and maximum top biological shield temperatures for the B, D, DR, F, and H Reactors appear in figures 18-22. A typical temperature profile through the biological shields for each of B, D, DR, F and H Reactors appears in figures 23-27.

The values of A iterated to by ICARUS for equation (2) above indicate the approximate rate of increase of neutron leakage escaping the biological shields per unit temperature during the observed interval. However, large values of A for a shield running at low temperatures

*Foil activation data was not available from DR Reactor due to the presence of the gas loop in the reactor.

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can result in less of an increase in the leakage rate than shields having low values of A and yet running at higher temperatures. The actual increase in leakage rate is proportional to the exponential of the product of A and the temperature. Due to the exponential form of equation (2) above, the maximum temperature has much more emphasis than the average temperature upon leakage rates except when several temperatures are close to the maximum (i.e., a flat temperature profile). Using the values of A calculated alone, it is possible to calculate the changes in neutron leakage rates as a function of temperature. Figures 1-4 show the effect of different maximum shield temperatures at the smaller reactors. These plots are based upon a 75 per cent TOE and no increases in power levels. The dotted line on each graph represents the observed neutron leakage increase based upon average shield operation during the period from 1961 through December, 1964.

It is noteworthy that even though B Reactor had the largest value of A, the leakage rates increased at a similar rate at H Reactor for the same maximum temperature due to the flatter temperature profile through the H Reactor side shield. Gamma leakage should roughly increase with neutron leakage since reduction of the neutron attenuation properties of a shield results in the gammas being "born" closer to the outer edge of the shield and therefore escaping more easily.

1. B Reactor

Fringe poison was being used at B Reactor prior to 1959 (see figure 12). Data used for calculation of the constant, A, was from December 1961 through December 1963. Just prior to December 1961 there was a marked change in the efficiency of the scintillation counter used to count the gold foil which made the data appear quite erratic. High CO₂ operation and concurrent addition of fringe poison in June 1963 appeared to have little immediate effect upon shield leakage rates, but significant increases in shield temperatures were apparent. B Reactor seems to have the greatest potential rate of increase of shield leakage of the four reactors described in this study with a value of A of approximately 3500 compared to an average value of A for the four reactors of approximately 2000. Together with this, the high maximum shield temperature at B Reactor (the latter being somewhat compensated by a steep temperature gradient through the shield) resulted in an increase in shield leakage at B Reactor more than twice as great as that occurring at any of the other reactors studied. The flatter temperature gradient at H Reactor, however, results in about the same increase in shield leakage at H Reactor for equivalent maximum temperatures. Figure 1 shows expected increases in neutron leakage at B Reactor as a function of maximum biological shield temperature assuming an operating efficiency of 75 per cent. Figure 5 as well as the dotted line in figure 1 represents the observed average conditions during the period under study in which the average maximum temperature of the masonite in the side biological shield was 85.6C.

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2. D Reactor

No fringe poison was placed in D Reactor until August 1963 (see figure 14); data up to that time was used to evaluate the constant A. Even without the presence of fringe poisoning D Reactor shows one of the lowest rates of increase in neutron leakage with A approximately equal to 900 compared to an average A of about 2000 for the four reactors. The low value of A at D Reactor resulted in a lower-than-average increase in leakage during the period under study even though the average temperatures of the D Reactor shields were the highest temperatures encountered. Since D Reactor has the lowest value of A of all of the reactors studied as well as an average temperature gradient through the shields it also has the lowest leakage rate of all of the reactors for the same maximum shield temperature. Figure 2 shows expected increases in neutron leakage at D Reactor as a function of maximum biological shield temperature assuming an operating efficiency of 75 per cent. Figure 5 as well as the dotted line in figure 2 represents the observed average conditions during the period under study for which the average maximum shield temperature of the masonite in the side biological shield was 90.1C.

3. F Reactor

Fringe poison was placed in F Reactor as early as 1959. (See figure 16) Data used for calculation of the constant, A, was from August 1960 through September 1963. Late in 1963 the high CO₂ program was started at F Reactor but no data from this period was used in evaluating A. With the exception of D Reactor, F Reactor's leakage rate appears to be one of the lowest (A is approximately 1200 at F Reactor compared to an average of about 2000.) of those evaluated. The low value of A together with low shield temperatures resulted in F Reactor having the least increase in neutron leakage rates of the four reactors studied during the period under study. F Reactor has the second lowest rate of increase in neutron leakage at equivalent maximum shield temperatures (D Reactor having the lowest rate of increase). Figure 3 shows expected increases in neutron leakage at F Reactor as a function of maximum biological shield temperatures assuming an operating efficiency of 75 per cent. Figure 5 as well as the dotted line in figure 3 represents the observed average conditions during the period under study for which the average maximum temperature of the masonite in the side biological shield was 65.7C.

4. H Reactor

Prior to the charging of the lithium blanket in 1961, H Reactor had one of the highest absolute readings from gold foil activation analysis. Since the lithium blanket has been present, a value of A approximately equal to 2300 has been evaluated compared to an

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average of about 2000, showing H Reactor to be second highest, just below B Reactor, in neutron leakage rate increases through the biological shields. Thus, although the addition of the lithium blanket has reduced the foil count rate by a factor of four, the rate of increase of leakage is still above average. During the period under study, H Reactor had the lowest temperatures so that the observed rate of increase in shield leakage during the period was the second from the lowest (F Reactor being lower). However, the flat temperature gradient indicates that at corresponding temperatures, H Reactor has one of the highest rates of increase of neutron leakage through the bulk biological shields (just below that of B Reactor). Figure 4 shows the expected increases in neutron leakage at H Reactor as a function of maximum biological shield temperatures assuming an operating efficiency of 75 per cent. Figure 5 as well as the dotted line in figure 3 represents the observed average conditions during the period under study for which the average maximum temperature of the masonite in the side biological shield was 58.0C.

Although the above predictions were based upon neutron leakage measurements taken in the side biological shields of the various reactors, they are also applicable to other portions of the reactor biological shields. In some instances, the leakage through various shield penetrations are orders of magnitude greater than that resulting from leakage through the bulk shields (e.g., VSR channels on the top, HCR channels on the near, and test holes on the sides). The leakage through these penetrations may be expected to increase somewhat as the shields burn out but not as rapidly as the leakage increases through the bulk shields.

In most instances where there is severe leakage through shield penetrations there is limited access and/or additional shielding (as the sandwich wall between the inner and outer rod rooms).

Leakage through the near side has increased with the introduction of a near side enriched ring. It still causes no operating problem, however, due to the additional protection provided by the rod room sandwich wall.

There is little increase in inlet shield leakage from burnout of masonite since the front shields are cooled by the process channels. The greatest changes in inlet shield leakage rates will occur from relocation of the charge with respect to the front nozzle.

P. D. Gross

P. D. Gross, Engineer
Operational Physics Subsection
Research and Engineering Section

PDG:gs

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Extrapolated Leakage Rate as a Function of Time
and Maximum Masonite Temperature

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Figure 2

Extrapolated Leakage Rate as a Function of Time
and Maximum Masonite Temperature
D Reactor

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Figure 3

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Extrapolated Leakage Rate as a Function of Time
and Maximum Masonite Temperature

F Reactor

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Figure 4

Extrapolated Leakage Rate as a Function of Time
and Maximum Masonite Temperature

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Figure 5

Extrapolated Leakage Rate as a Function of Time
for Constant Shield Temperatures (From 1-1-64)

Far Side View of Reactor Showing Approximate Location of the Neutron Detector Facility

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NEUTRON DETECTOR FACILITY - LOCATION AND DETAILS *

* Taken from reference No. 1

Figure 7

Thermocouple Locations in the Biological Shields

Note: One group of seven thermocouples as shown here is located at the approximate geometrical center of each of the top and far side shields at the B, D, DR, F and H reactors.

THERMOCOUPLE ARRANGEMENT B, D, DR, F AND H REACTOR
TOP AND FAR SIDE SHIELDS

(Installed as part of CG - 558 Project)

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Figure 8
B Reactor

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Figure 9
D Reactor

Figure 10
F Reactor

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Figure 11
H Reactor

Figure 12

Dates for Initial Insertion of Fringe Poison

B Reactor

REF ASSIEN

Figure 13

Dates for Initial Insertion of Fringe Poison
C Reactor

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Figure 14
Dates for Initial Insertion of Fringe Poison
D Reactor

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DR Reactor

Dates for Initial Insertion of Fringe Poison F Reactor

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Figure 17

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Dates for Initial Insertion of Fringe Poison

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H Reactor*

*Fringe poison was actually introduced on the far side of H Reactor prior to 1957 under a production test to determine its effectiveness. Since the pattern varied and was not used at that time for actual shield protection, it is not shown here.

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Relative Pile Power, Gas Composition, and Maximum top Biological Shield Temperatures

B Reactor

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Figure 19
Relative Pile Power, Gas Composition, and Maximum
Top Biological Shield Temperatures
D Reactor

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Figure 20
Relative Pile Power, Gas Composition, and Maximum
Top Biological Shield Temperatures

DR Reactor

Figure 21

Relative Pile Power, Gas Composition, and Maximum
Top Biological Shield Temperatures

F Reactor

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Relative Pile Power, Gas Composition, and Maximum Top Biological Shield Temperatures

II Reactor

Figure 22

Figure 23

Average Biological Shield Temperature
Profile at B Reactor

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Figure 24

Average Biological Shield Temperature
Profiles at D Reactor

Figure 25

Average Biological Shield Temperature
Profile at DR Reactor

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Figure 26
Average Biological Shield Temperature
Profiles at F Reactor

Figure 27

Average Biological Shield Temperature
Profiles at H Reactor

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Masconite Layer

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