2 of 3

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NEUTRON DOSIMETRY SAMPLING OF THE OMRE PRESSURE VESSEL AND GRID PLATES

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TABLE OF CONTENTS

ABSTRACT

Upon the shutdown of the Organic Moderated Reactor Experiment (OMRE) at the National Reactor Testing Station in Idaho, a program was initiated to determine the total neutron dosage and radiation induced transition temperature increase to the pressure vessel and upper grid plates. Drillings were made across the grid plate and the chips were collected from each position to determine the cross-plate neutron exposure gradient. Drillings were taken and collected from the pressure vessel at the fuel centerline, upper and lower grid plate regions, and mid-way between, to determine the vertical neutron flux gradient.

The results of the neutron dose analysis of these components are presented. Based upon the results, recommendations are made for testing of the material to determine the transition temperature increase.

PROBLEM STATUS

This is a final report on the dosimetry phase of the analysis of the OMRE. Work on other phases is continuing.

AUTHORIZATION

NRL Problem M01-14
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Task 0858; AT(49-5)-2110; ERG-5-64

INTRODUCTION

A problem of considerable concern to experimenters in the field of radiation embrittlement to reactor pressure vessels is the correlation of radiation induced transition temperature or nil ductility temperature (NDT) increase data obtained in accelerated irradiations in test reactors to actual conditions in power reactors for which the research is conducted. This problem is manifested in the fact that most of the experimentation is done within or near the fuel core of the test or research reactor where the neutron flux and spectrum are different from the environment at a reactor pressure vessel wall. The majority of test data accumulated thus far have been in light water moderated reactors. Because of the probable difference in moderating properties of an organic medium, analysis of the integrated neutron exposure and the testing of specimens from sections of an organic moderated reactor becomes quite significant in that the neutron spectrum in such a reactor would be quite different.

The acceptance of experimental data from water moderated test reactors as being representative of the damage sustained by in-service power reactors would be greatly increased by a satisfactory correlation between such test data and the results of tests on materials from an organic moderated reactor

The only correlation to date between test data and in-service power reactors has been performed on the SL-1 vessel (1). A second opportunity for correlation tests has recently been made available with the permanent shutdown of the Organic Moderated Reactor Experiment (OMRE) at the National Reactor Testing Station in Idaho. The OMRE operated at a power level of 6 to 8 megawatts for prolonged periods beginning in 1957. The pressure vessel and grid plates of the reactor were made of ASTM Type A387 Grade B steel; the operating temperature was approximately 600°F. This reactor presents the unusual opportunity of having the same type material irradiated under like conditions of neutron exposure and temperature in both stressed and unstressed conditions. Although the operating pressure of 200 psi was low, it was not insignificant.

At the request of the U. S. Atomic Energy Commission, a program was initiated by the U. S. Naval Research Laboratory to determine the neutron exposure and, if practical, the radiation induced transition temperature increase to the pressure vessel and critical components of the OMRE in order to further the correlation of data from test reactor experiments to on-line power reactors. The first phase of the program outlined was to remove samples of material from the grid plate and pressure vessel to determine the actual neutron dose. If dosimetry measurements, based upon the reaction Fe^{54} (n,p)Mn^{54}, indicated a large enough integrated dose to predict a significant transition temperature increase, a second phase would be initiated which would involve the removal of sections of material from the vessel and components, the machining of test specimens, and the evaluation of properties in the NRL High Level Radiation Laboratory. If unusual or unpredicted results were obtained in phase two, then a more comprehensive third phase of advanced testing might be initiated. The continuation of this effort to phases two and three would depend, of course, upon a complete evaluation of dosimetry data and upon the potential value of data which might be generated in the later phases. This report describes the operations involved in the removal of samples of materials from the OMRE and presents the results of the neutron exposure analysis.

PLANNING AND PREPARATION

The primary areas from which dosimetry samples were to be taken were the pressure vessel in the core region and the upper grid plate. Initially however, it was not known if these areas would be accessible to sampling at all. Discussion of the features of the reactor, possible problem areas, and the establishment of an acceptable approach to the sampling operation were conducted on site (at the National Reactor Testing Station, Idaho - NRTS) between NRL personnel and on-site representatives of the reactor operators (Atomics International), the U. S. Atomic Energy Commission, and the Phillips Petroleum

Company (operators of the NRTS). All facets of the physical plant and site operational limitations were reviewed including the physical plant layout, time schedules with respect to weather, radiation levels in various proposed working locations, and safety aspects.

The discussions revealed that the grid plate and thermal shield could not be easily removed in order to gain access to the pressure vessel wall from the inside. Shielding water would not be permitted to escape from the pressure vessel but could be pumped out later into a leaching pit. Timing of the operation with respect to weather was critical as operations could not be confidently planned after mid-autumn because of the onset of cold weather which might result in freezing the shielding water or at least limiting the possibilities for pumping water into or out of the pressure vessel.

The general layout of the OMRE site is shown in Fig. 1. Following on-site discussions, a scheme was devised by NRL to bore through the earth between the coolant pipe gallery and reactor gallery to reach the pressure vessel for sampling. Grid plate samples were to be taken by drilling operations from the top of the reactor.

The major problem to be solved in the execution of the sampling operation was the shielding of personnel from the intense radiation field of the reactor structural components. The radiation level above the reactor was found to be 3R per hour; radiation fields in the coolant pipe gallery were as

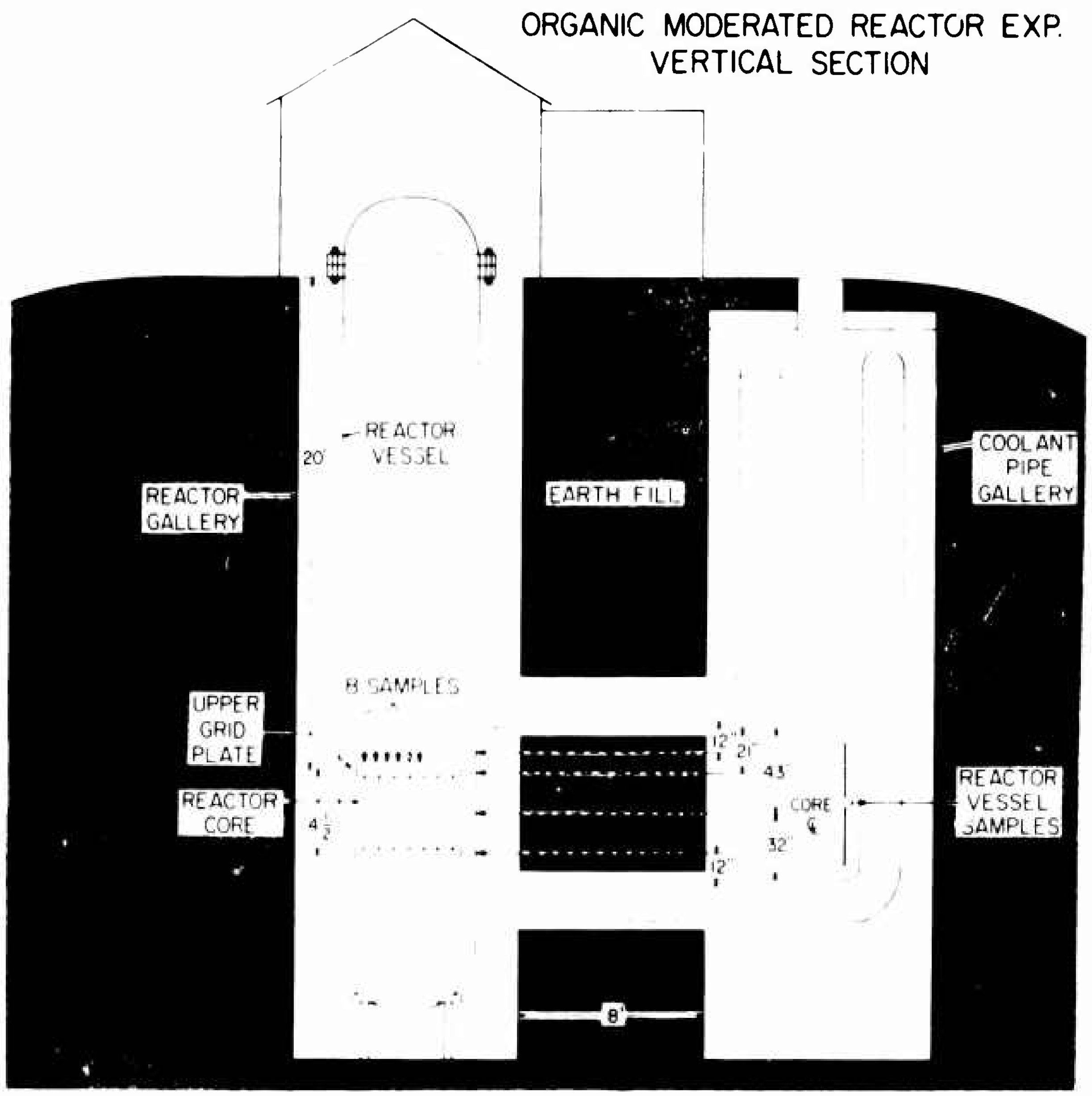

Fig. 1 - Schematic sectional view of OMRE site showing dosimetry sampling locations

much as 400 mr per hour, occurring primarily as streaming along the coolant pipe conduit running from the reactor gallery to the pipe gallery. Water pumped into the reactor vessel was to serve as radiation shielding during grid plate sampling. Operations in the pipe gallery for borings to the pressure vessel would be hampered by radiation streaming along the coolant pipe conduits between the galleries and radiation emanating from the pipes themselves. For this operation, plans included the wrapping of 1/8-inch lead sheet around the pipe and the covering of conduit gaps with "doughnut" shaped lead sheets.

In order to accomplish the sampling by the scheme devised, special tools were designed, built, and proof tested in dry runs on realistic mock-ups. Modifications were made to the tools as necessary and sampling procedures were practiced until all personnel to be involved were adept at every step of the operations. Special scaffolding to provide a suitable working platform in the pipe gallery was prefabricated to fit through the access hole to the pipe gallery for rapid set-up in the high radiation field. Lead shielding was made to proper length, size, and shape to be put in place rapidly without on-site fabrication. All tools, equipment, shielding, sample bottles, transfer casks, and miscellaneous tools were shipped to the site prior to the arrival of personnel. All security clearances, transportation and scheduling were also arranged prior to arrival of personnel.

Arrangements were made with the Radiation Counting Laboratory of the Materials Testing Reactor at the NRTS to perform the neutron exposure analysis on drill chips removed from reactor components. Further arrangements were made to have the Mn^{54} isotope separated from the sample chips if interfering gamma emission peaks prevented routine analysis procedures.

NEUTRON DOSIMETRY SAMPLING OPERATIONS

Grid plate drillings were accomplished from a platform placed over the top of the reactor vessel as shown in Fig. 2. To permit safe prolonged operations, the reactor tank was filled with water to a point above the grid plate.

For grid plate sampling, a 20-ft long, 1-1/2-in. diam. drill guide tube was made, in sections, and fitted with a set of removable magnets on the bottom. The magnets were designed to permit a drill bit extending the entire length of the tube to pass between them and, the magnets in turn, served to collect the chips as they were formed. The magnet mount was made to slip over the cross supports of the core grid network thus holding itself and the guide in place during drilling. After drilling a pre-set depth, the entire rig was raised, the magnets removed and a new set of clean magnets replaced for another sample. Chips were taken from the withdrawn magnets (Fig. 3), placed in sample bottles and stored for transfer to the Radiation Counting Laboratory for analysis. In all, eight samples were taken from the

Fig. 2 - Grid Plate Drilling Operations

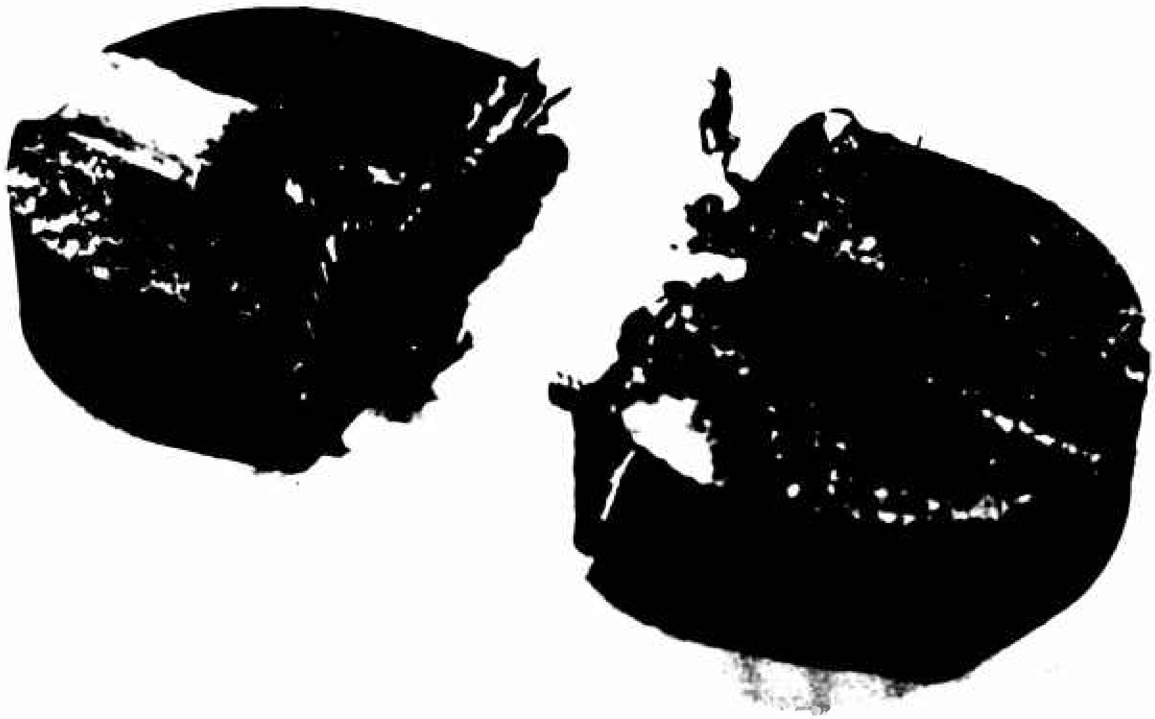

Fig. 3 - Magnets and Chips from Grid Plate Sampling

center to the periphery of the fuel element positions of the grid plate. The grid plate sampling operations were completed in one-half day.

The entire pipe gallery operation for sampling the pressure vessel was completed in less than two days. Prefabricated scaffolding was set up in the gallery to provide a working stage (Fig. 4). Radiation levels in the pipe gallery were reduced from 400 mr per hour to a maximum of 25 mr per hour through the placement of sheet lead shielding. The water pumped into the pressure vessel for shielding of the grid sampling operations partially filled the coolant pipes and served as additional shielding during the pressure vessel drillings.

After a hole had been cut in the pipe gallery wall, a 1-in. diam. tube, closed and pointed on one end, was driven through the earth to the reactor gallery wall by an electric hammer. A long, sectional drill was then used to cut through the pointed tube end and the reactor gallery wall. This drill was withdrawn and another tube inserted in the original drive tube through the gallery wall and directly up to the pressure vessel. A magnetized drill bit was then inserted inside the second tube, pushed up against the pressure vessel and sampling drilling begun. Care was exercised to assure that drill penetration did not exceed half the thickness of the 13/16-in. reactor vessel wall. Both the drill and second tube were

Fig. 4 - Coolant Pipe Gallery During Pressure Vessel Drilling Operations

carefully withdrawn together after drilling. The sample chips were retained inside the tube by the magnetic drill bit from which the chips were easily removed and collected for analysis (Fig. 5). A new drill was used for each sampling to prevent any cross contamination of samples. The operations were repeated three times so that a total of four samples were taken at positions representing the fuel centerline, upper and lower grid plates, and an intermediate position.

After the pressure vessel samples were taken, the water was pumped from the reactor vessel into a leaching pit. The drilling samples were then taken to the Radiation Counting Laboratory for counting and analysis. It was found that chemical separation of the Mn^{54} isotope was not necessary since the gamma emission peak for this isotope was very pronounced, and other possible interfering radiation peaks were not present.

DOSIMETRY ANALYSIS

For purposes of the dosimetry analysis the OMRE operating history was divided into six operating periods and five shutdown periods. All other shutdown periods were less than about 20 days and distributed rather uniformly throughout each period of operation. The exposure time for each operating period, as shown in Table I, was assumed to be the total elapsed time from startup to scram and the average power level calculated accordingly. This mode of reporting exposure time was used to account

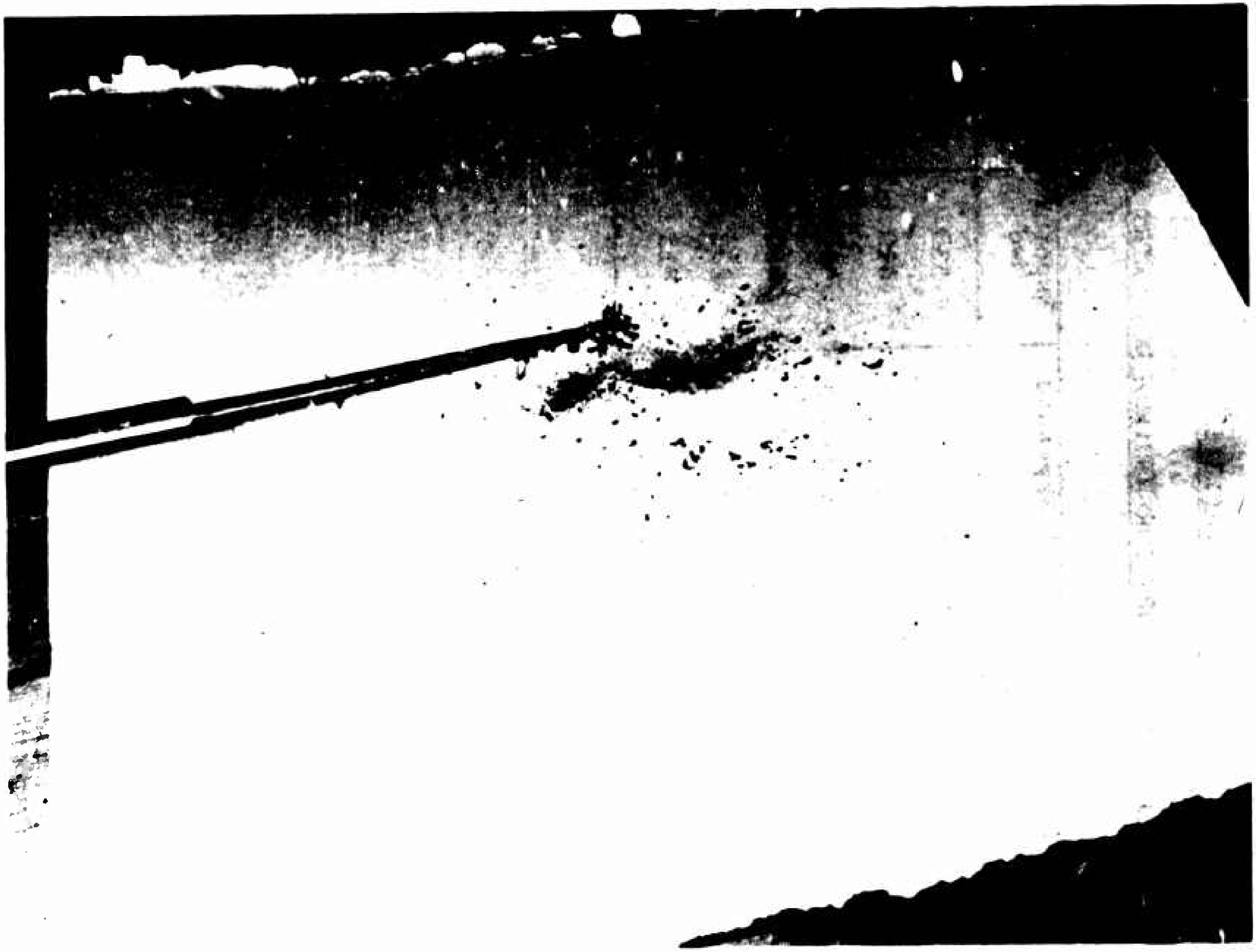

Fig. 5 - Magnetic Drill Bit and Chips from Pressure Vessel Drillings

TABLE I

OMRE OPERATING HISTORY FOR NEUTRON DOSIMETRY ANALYSIS

Period	Dates	Exposure Time (Days)	Exposure Mwd	Power Level Mw	Decay Time (Days)
1	1/ 1/58 - 6/23/58	175	535	3.06	1925
2	7/23/58 - 11/25/58	125	410	3.28	1772
3	6/ 1/59 - 8/25/59	86	440	5.12	1498
4	10/23/59 - 4/18/60	147	465	3.16	1292
5	6/14/61 - 10/11/60	119	282	2.37	720
6	6/12/62 - 4/ 2/63	295	815	2.76	181

TABLE II

OMRE PRESSURE VESSEL AND GRID PLATE

INTEGRATED NEUTRON EXPOSURE

Samples	Integrated Neutron Exposure (n/cm^2 1 Mev)
Grid Plate	
Core Periphery	2.06×10^{19}
	2.30
	2.56
	2.84
	2.89
	3.10
Core Center	3.30
	3.10
Pressure Vessel	
Upper Nozzle	0.248
Upper Grid	0.521
Core Centerline	2.74
Lower Nozzle	0.98

for the decay of the Mn^{54} during each period. The working equation for the analysis is:

$$D = \frac{N\phi\sigma}{0.692}\left[k_1 \left(1-e^{-\lambda t_{e_1}}\right) e^{-\lambda t_{w_1}} + k_2 \left(1-e^{-\lambda t_{e_2}}\right) e^{-\lambda t_{w_2}} \ldots\right]$$

where,

D = Mn^{54} disintegration rate per mg of Mn^{54} at count time,

ϕ = the average fast neutron flux greater than 1 Mev in neutron energy for period No. 6 (arbitrarily chosen),

σ = the neutron cross section averaged over a fission neutron spectrum for the reaction $Fe^{54}(n,p)Mn^{54}$ (68 mb),

k = the flux weighting factor (proportional to power level with period No. 6 taken at 1.00),

λ = the decay constant for Mn^{54} (2.21×10^{-3} per day^{-1} day, half-life = 314 days),

t_e = the exposure time,

t_w = the decay time, and

the subscripts, numbers 1 through 6, refer to the exposure periods. The impurities in the Fe amounted to 2.8%. Table II lists the integrated fast neutron exposures (1 Mev) for the samples. Grid plate samples are listed from the outer edge to the center of the fuel element positions and are shown schematically in Fig. 6. Pressure vessel samples, Numbers 1 and 4, were taken near the upper and lower coolant nozzles respectively; Number 3 from the core centerline, and Number 2 from a point opposite the upper grid area.

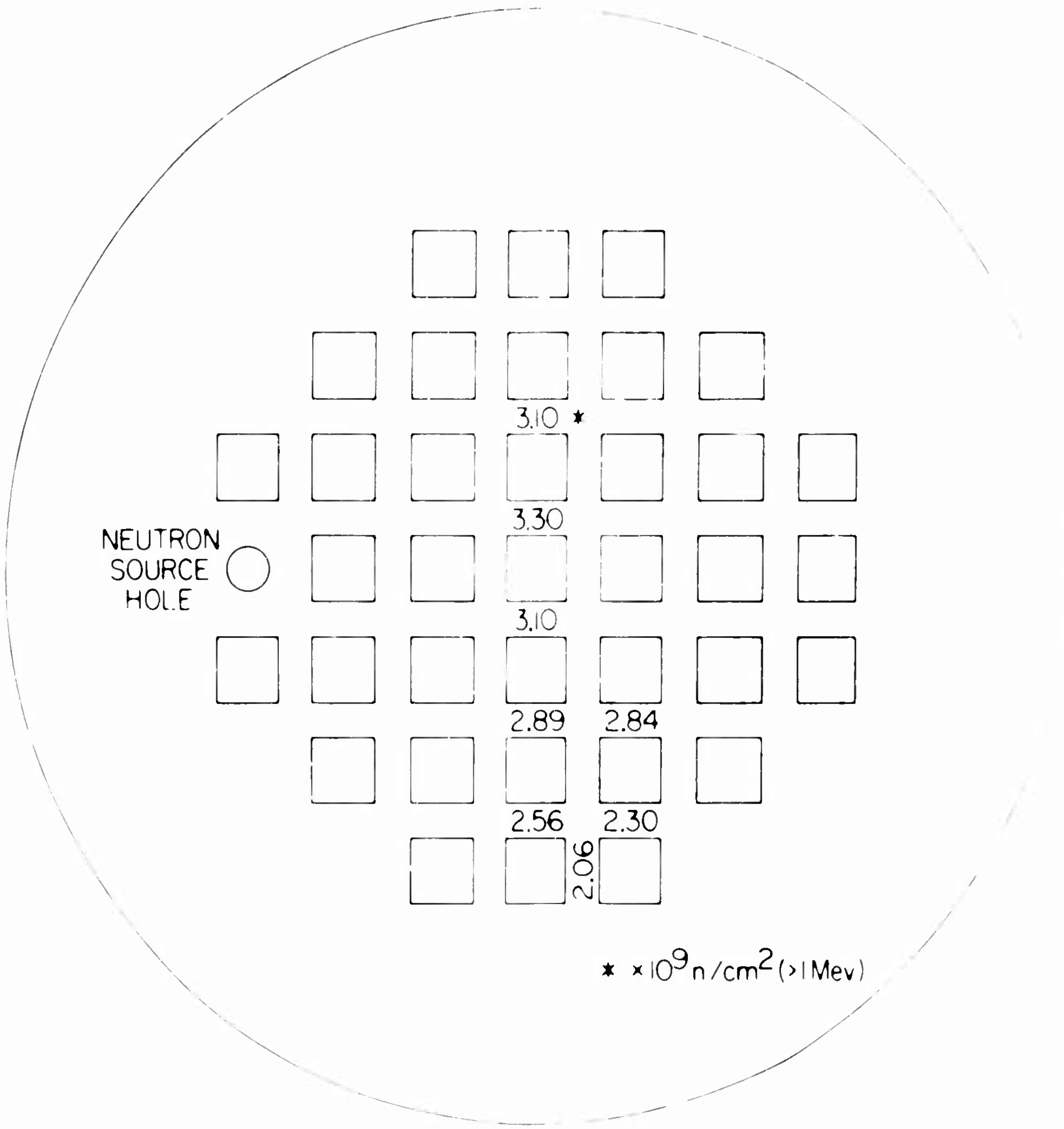

Fig. 6 - Fast Neutron Dosage to Upper Grid Plate, OMRE

It is interesting to note that the exposure to the center of the grid plate was very similar to the pressure vessel belt line dose, and that the dose varied across the grid plate by a factor of one half. It should be noted that a thermal shield was in place between the fuel and the pressure vessel with organic moderator on either side of the shield.

SUMMARY AND CONCLUSIONS

The magnitudes of the exposures observed in the OMRE pressure vessel and grid plate are such as to suggest significant changes in mechanical properties, thus indicating the desirability of examining these components for assessment of radiation damage. The exposures from the grid plate, in particular, indicate a gradient but not as much as might be expected. It appears, therefore, that the neutron energy spectrum of the OMRE is rather unlike that of light water reactors and further increases the desirability of evaluating specimens made from the reactor pressure vessel for correlation to experimental data from test reactors.

The usefulness of the $Fe^{54}(n,p)Mn^{54}$ reaction for dosimetry analysis has been demonstrated for long-term exposures. Such application aids in the confidence placed in exposure results from short-term accelerated test reactor data which in many cases are based upon this reaction. The use of the reaction for radiation damage surveillance to operating power reactors has already been proposed (2).

The entire operation for sampling and analysis of the OMRE components proceeded smoothly and rapidly with a minimum of personnel exposure. This is attributed largely to careful advance planning and coordination of all possible aspects of the operation, to the effectiveness of the tools devised, and to the extensive dry-runs and proof testing of this special equipment.

ACKNOWLEDGMENTS

It is a pleasure to acknowledge the fine efforts of Mr. Frank F. Newman who devised the special tools used for the sampling operations and Mr. William E. Kinkade who helped in their fabrication and proof testing. The assistance rendered by these personnel in the sampling operation is also gratefully acknowledged. We wish to thank the personnel of the Phillips Petroleum Company at the NRTS and of the Idaho Operations Office, U. S. Atomic Energy Commission, for their very fine assistance and interest in this operation.

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