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EFFECT OF SIMULATED THERMAL SHIELD MOTION ON NUCLEAR INSTRUMENT RESPONSE—MEASUREMENTS AND CALCULATIONS

(LWBR Development Program)

cp

AUGUST 1979

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BETTIS ATOMIC POWER LABORATORY
WEST MIFFLIN, PENNSYLVANIA
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FOREWORD

The Shippingport Atomic Power Station located in Shippingport, Pennsylvania was the first large-scale, central-station nuclear power plant in the United States and the first plant of such size in the world operated solely to produce electric power. This program was started in 1953 to confirm the practical application of nuclear power for large-scale electric power generation. It has provided much of the technology being used for design and operation of the commercial, central-station nuclear power plants now in use.

Subsequent to development and successful operation of the Pressurized Water Reactor in the DOE-owned reactor plant at the Shippingport Atomic Power Station, the Atomic Energy Commission in 1965 undertook a research and development program to design and build a Light Water Breeder Reactor core for operation in the Shippingport Station.

The objective of the Light Water Breeder Reactor (LWBR) program has been to develop a technology that would significantly improve the utilization of the nation's nuclear fuel resources employing the well-established water reactor technology. To achieve this objective, work has been directed toward analysis, design, component tests, and fabrication of a water-cooled, thorium oxide fuel cycle breeder reactor for installation and operation at the Shippingport Station. The LWBR core started operation in the Shippingport Station in the Fall of 1977 and is expected to be operated for about 3 to 4 years. At the end of this period, the core will be removed and the spent fuel shipped to the Naval Reactors Expended Core Facility for a detailed examination to verify core performance including an evaluation of breeding characteristics.

In 1976, with fabrication of the Shippingport LWBR core nearing completion, the Energy Research and Development Administration established the Advanced Water Breeder Applications (AWBA) program to develop and disseminate technical information which would assist U. S. industry in evaluating the LWBR concept for commercial-scale applications. The program will explore some of the problems that would be faced by industry in adapting technology confirmed in the LWBR program. Information to be developed includes concepts for commercial-scale prebreeder cores which would produce uranium-233 for light water breeder cores while producing electric power, improvements for breeder cores based on the technology developed to fabricate and operate the Shippingport LWBR core, and other information and technology to aid in evaluating commercial-scale application of the LWBR concept.

FOREWORD (Cont)

All three development programs (Pressurized Water Reactor, Light Water Breeder Reactor, and Advanced Water Breeder Applications) have been administered by the Division of Naval Reactors with the goal of developing practical improvements in the utilization of nuclear fuel resources for generation of electrical energy using water-cooled nuclear reactors.

Technical information developed under the Shippingport, LWBR, and AWBA programs has been and will continue to be published in technical memoranda, one of which is this present report.

An experiment has been performed to determine the effect of motion of a thermal shield on the neutron signal expected from ex-core detectors. Using a mockup of the LWBR reactor vessel, thermal shield, and core barrel in conjunction with a ^{252}Cf neutron source, the change in detector signal with displacement of the various components was investigated. It was found that moving the thermal shield would produce a significant change in detector signal, although the effect was smaller than would be produced by moving the source and core barrel together. The results were substantiated by two-dimensional discrete-ordinate calculations.

EFFECT OF SIMULATED THERMAL SHIELD MOTION ON NUCLEAR INSTURMENT RESPONSE - MEASUREMENTS AND CALCULATIONS

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I. INTRODUCTION

The Light Water Breeder Reactor (LWBR) Program is developing the technology to breed fissile material in a light water reactor in order to make the use of nuclear fuel significantly more efficient in light water thermal reactors. To achieve this objective, technology is being developed through the design and fabrication of a breeder reactor core that is operating in the existing Department of Energy (DOE) owned pressurized water reactor plant at Shippingport, Pennsylvania. The design and operating environment of the LWBR reactor are described in Reference 1. This report presents the results of work performed in support of this program.

The experiment described herein was undertaken to determine the effect expected to be observed in the LWBR nuclear instrumentation detectors if there were transverse motions of the thermal shield. The thermal shield is cylindrical in shape, supported at its upper end by a flange in the reactor vessel. The analysis of fluctuations in the signal from ex-core nuclear instrumentation detectors is a widely used method for detecting and monitoring motion of reactor internals. This method has heretofore been applied primarily to the investigation of motion of the core barrel. At the Palisades nuclear power station, for example, a loss of holddown clamping of the core barrel which led to excessive motion was discovered and subsequently monitored using the technique of analyzing fluctuations in the neutron detector signals (Reference 2). The same technique has been used at a number of other reactors to monitor core barrel motion (References 3 through 5) and various theoretical investigations have been carried out to permit quantitative interpretation of the data (References 6 and 7).

There appear to have been no previous attempts to apply this method to the investigation of motion of a thermal shield. Indeed, it is not initially evident what effect, if any, would be produced on the signal from an external detector by a small amount of movement of a thermal shield. If the core barrel moves, the effect on the detector signal is relatively straightforward - the neutrons passing from the core to the detector must traverse a certain thickness of water between the barrel and the reactor vessel. If the barrel is displaced toward the vessel, the total water thickness between the core and the detector decreases, since the core will normally move along with the core barrel. This causes an increase in the number of neutrons arriving at the detector because fewer neutrons are absorbed in the water. In addition, the reduced water thickness means less moderation of neutrons to the lower energies at which they are strongly absorbed in the iron of the vessel. Similarly, a displacement of the core barrel away from the vessel causes an increase in water thickness and a corresponding decrease in the detector signal. However, if a thermal shield moves while the core barrel and vessel remain fixed, the total water channel thickness does not change. In this case an increase in the size of the water layer on one side of the shield is accompanied by a corresponding decrease in the water layer on the other side of the shield, and the neutrons must penetrate the same total thickness of water to reach the detector. Nevertheless, there may still be a change in the detector signal caused by the fact that the water on one side of the shield does not have exactly the same effect on the neutrons as the water on the other side of the shield. This phenomenon is explained in Section IV.

The experimental arrangement and procedures are described in Section II and the results are presented in Section III. A computer simulation of these results and some insights into the source of the effect, as provided by the computer simulation, are given in Section IV. The conclusions are discussed in Section V.

II. EQUIPMENT AND PROCEDURES

A diagram of the LWBR core barrel, thermal shield and vessel, showing the location of a typical ex-core detector, is given in Figure 1. Figure 2 illustrates the experimental arrangement used to mock up the LWBR internals. Steel plates of the appropriate thickness were used to represent the core barrel, thermal shield and reactor vessel. (The reactor vessel plate was in fact a group of plates 2.5 or 3.2 cm thick, bolted together.) All plates were 61 cm square. The neutrons were produced by a 1.6 mg ^{252}Cf source with linear dimensions less than 1 cm, doubly encapsulated in stainless steel and mounted in a polyethylene container, centered 13 cm in front of the barrel plate. The detector was a BF_3 proportional counter, 2.5 cm long and 0.6 cm in diameter, located at the end of a long tube. This counter was inserted into a lead holder and centered 3.3 cm from the back of the vessel plate. The whole apparatus was immersed at room temperature in a tank of water 180 cm in diameter and 200 cm deep.

Calculations carried out using a two-dimensional discrete-ordinate computer program similar to the DOT program (Reference 8) indicate that the size of the plates was adequate to prevent any significant neutron leakage around the plates to the detector.

The experiment was carried out in a static fashion. That is, the detector count rate was determined for a series of different fixed positions of the various structural components and from this information was inferred the change in signal that would result from small oscillations in component position toward and away from the source. This procedure is valid where the frequencies of the oscillations are sufficiently low that the corresponding wavelengths in water are large compared to the thickness of the water layers between the components in question. For a properly clamped core barrel, the resonance vibrational frequency is expected to lie typically between about 4 and 13 Hz (Reference 6); a similar frequency may be expected for a thermal shield of the LWBR type. The corresponding wavelength range in water at operating temperature (530°F) and pressure (2000 psi) is several hundred feet. An abnormal occurrence such as a loss in clamping would be expected to reduce the vibrational frequency and hence increase the wavelength. At Palisades, the motion of the unclamped core barrel was confined largely to frequencies below 1 Hz (Reference 2). Thus, we may conclude that the static experimental approach is a valid method of evaluating the effect of fluctuations that would occur even in the event of an abnormal occurrence such as a loss of clamping.

The component displacements which were employed in the experiment - as much as 1.3 cm from the nominal position - were much larger than the amplitude of any vibration that might be expected to occur in LWBR. The use of such large displacements was prompted by two considerations: First, to magnify the changes in detector count rate and thereby to minimize the effect of fluctuations due to counting statistics; and second, to minimize the effect of any small inaccuracies in component positioning.

It was necessary to lift the apparatus out of the water tank each time a component was moved. The source and detector, however, remained in the water at all times and had to be removed from the apparatus when the position of a component was changed. A great deal of care was taken to ensure that the repeated repositioning of the source and detector did not lead to significant systematic error in the measurements. The source and detector mountings were designed for accurate reproducibility of positioning. The source was rotated in its holder frequently to correct for any possible movement of the source material within its encapsulation. The source was also removed completely from its holder and replaced at frequent intervals in order to verify that any repositioning errors were small. In addition, each time the apparatus was removed from the water tank to change the position of the core barrel or thermal shield plate, the source and detector were placed in a precisely defined geometry in the tank and a set of reference counts was taken. These reference runs served as a further check on repositioning accuracy and also as a test of the stability of the electronics. No evidence of long-term electronic drift was found, so no drift correction was applied to the data. Finally, the geometry used for the data taken at the beginning of the day was repeated at the end of the day as an ultimate check on reproducibility.

The reproducibility of the data serves as an indication of the systematic error. The rms spread in the reference counts over a day's running was about

0.4 percent, with a statistical error slightly greater than 0.1 percent. For each configuration of the components, enough counts were obtained for a statistical accuracy of 0.2 percent in most cases. The overall uncertainty (systematic plus statistical, added in quadrature) is therefore approximately ±0.5 percent. The agreement between the data taken at the beginning and at the end of the day indicates that the 0.5 percent figure is a reasonable estimate of the uncertainty in the measurements.

A representative set of data taken in one day is given in Table 1. Each "Reference Count" entry in the table is actually the sum of eight 30-second counts, with the source rotated 90 degrees in its holder after every second count. Each individual entry for a thermal shield position is the sum of twenty 30-second counts, with the source rotated 90 degrees in its holder after every fifth count. The source was removed from its holder after each set of 20 counts for a given thermal shield position and then replaced for the next set of counts. The entries in the table are given in the order in which the data were actually obtained.

Three sets of measurements were performed - one in which only the thermal shield plate was moved, one in which only the core barrel plate was moved, and one in which the core barrel and source were displaced together as a unit. The last case represents core barrel vibration as discussed in the literature, since the reactor core is coupled rigidly to the barrel. In addition, a few measurements were made to determine the effect of moving the source closer to the core barrel plate and the effect of moving the detector farther from the reactor vessel plate.

III. EXPERIMENTAL RESULTS

Figure 3 shows variation in count rate versus displacement of the thermal shield plate from its nominal position, with all other components fixed. Positive displacement corresponds to increased distance between the source and the thermal shield plate. The experimental data points are averages of the data tabulated in Table 1. The calculated points are discussed below in Section IV.

The solid curve is a least-squares fit of a quadratic function to the experimental data. This function was chosen empirically because it provides a good fit to the data. The slope of the curve gives the change in count rate for a small change in displacement. At the nominal thermal shield position, the slope corresponds to a 4.3 percent change in count rate per centimeter. This means that if the thermal shield plate were to vibrate about its nominal position with an amplitude of, for example, 0.01 cm, the detector signal would fluctuate about its average value with an amplitude of 0.043 percent.

It may be noted from Figure 3 that the fit curve is significantly nonlinear. This means that the slope, and hence the percent change in count rate, depends on the thermal shield position.

As was noted above, measurements were also made in which the core barrel plate was moved and in which the core barrel and source were moved together as a unit. The latter type of motion was investigated only at a displacement from the nominal position of -1.0 cm. The change in count rate was -15.3 percent. Movement of the core barrel plate alone (which actually represents a type of motion unlikely to be encountered in a reactor) was investigated at displacements of +1.3 and -1.3 cm from the nominal position. The count rate change was found to be 2.5 percent per centimeter.

A few measurements were also made to determine whether the change in count rate with thermal shield position was dependent on the location of the source and/or detector. With the distance between the source and core barrel reduced from 13.0 to 1.3 cm, the percent change in count rate with thermal shield displacement was found to be essentially unchanged. However, an increase in the distance between the detector and the reactor vessel plate from 3.4 cm to 14.9 cm reduced the percent change in count rate to approximately 3/4 of the value obtained with the detector in its normal position.

IV. COMPUTER SIMULATION OF RESULTS

The experimental results were compared with calculations performed using a 2-dimensional discrete-ordinate computer program, similar to the DOT program (Reference 8). The program used P_0 and P_1 scattering components and 11 energy groups. The group structure is given in Table 2. The extended transport approximation described in Reference 9 was employed in this discrete-ordinate program. Each plate or water channel in the experimental setup was explicitly represented in the program.

The calculated values for the change in count rate due to displacement of the thermal shield plate are shown as open circles in Figure 3. (The calculated values are normalized to the experimental point at the nominal position.) The agreement is reasonable, although the calculated values are slightly outside the experimental error bars. Calculations were also performed using a better representation of the actual reactor geometry than is afforded by the experimental setup - specifically, using an extended rather than a point source, elevated rather than room temperature, and cylindrical rather than slab geometry. These calculations were done by an equivalent of the P3MG1 program (Reference 10), using P_0 through P_3 scattering components and a 54-group structure for non-thermal neutrons. The calculations indicated that the sensitivity to thermal shield motion would be approximately half as great for the actual reactor geometry and operating conditions as it was for the experimental setup.

The computer calculations also supply some insight into the reasons why motion of a thermal shield should affect the detector signals. This insight comes from an examination of the effect of a change in position of the thermal shield on the flux in different energy groups. Figure 4 shows the percent change in flux due to a positive displacement of the thermal shield plate by 1.1 cm (i.e., decreasing the thickness of the water channel between the shield and vessel plates), displayed by energy group as a function of distance from the source. The curves extend from the inner surface of the reactor vessel plate to a point in the water tank well beyond the usual detector position. In order to simplify the figure, the 11 energy groups have been represented by only six curves. It was found that the behavior of some of the energy groups is very similar, so that more than one group may be represented adequately by a single curve.

The change in flux in each of groups 1 through 4, the high energy groups, follows closely the solid line in Figure 4. It is apparent that the flux in these groups is not greatly affected by the displacement of the thermal shield. Group 5 follows a slightly different curve but, as with the higher-energy groups, the displacement of the thermal shield causes less than 2 percent change in the flux. Neutrons may scatter both into and out of these groups by inelastic scattering in the iron of the shield, as well as by elastic scattering in the water.

Group 6, which extends below the iron inelastic threshold, shows a significant increase due to the shield displacement. This is even more evident in groups 7 and 8, both of which follow the dashed curve in Figure 4. Neutrons in the iron of the shield or the vessel may inelastically scatter into, but not out of, these groups. On the other hand, neutrons may downscatter out of these groups in the water layer between the shield and the vessel. Thus, the flux is higher in this energy region when the thickness of the water layer is smaller, because there is less downscattering out of groups 6 through 8.

The flux in groups 9 and 10 shows a small positive change at the left edge of the reactor vessel plate, which becomes larger as one moves through the plate and into the water beyond the plate. It is probably true that neutrons have downscattered into these groups predominately in the water rather than in the iron. Since these neutrons have downscattered out of groups 7 and 8, which show a positive change to the right of the vessel plate, groups 9 and 10 similarly show a positive change. To the left of the vessel plate, however, the decrease in water thickness provides less moderation and less tendency to downscatter into groups 9 and 10.

The thermal group shows a strong decrease at the left edge of the vessel plate when the thermal shield is displaced. This is clearly a consequence of the reduced moderation in the narrower water channel. Since thermal neutrons do not penetrate far into iron, the change rapidly becomes less pronounced towards the center of the vessel plate. Near the right side of the plate, the thermal group shows an increase due to the increase in the higher-energy groups, which are thermalized mainly in the water to the right of the plate.

Finally, one may observe that the change in flux becomes gradually smaller as one moves to the right, away from the vessel plate. The probable explanation is that the farther a neutron penetrates into the water to the right, the more likely it is to have been in one of the high energy groups when it previously passed through the thermal shield and the water layers. As a high-energy neutron, it was relatively unaffected by the displacement of the shield.

Thus, it is possible to provide a qualitative explanation for the general features of the calculated flux changes and for the experimental observation that the flux at the detector position increases as the thermal shield plate is moved towards the vessel plate. The increase is less pronounced if the detector is placed farther away from the vessel plate.

V. CONCLUSION

This experiment demonstrated that displacement of a thermal shield can produce a significant change in the signal from an ex-core neutron detector. In the experimental configuration, which mocked up the geometry of the LWBR internals, the percent change in count rate for a small displacement of the thermal shield plate was found to be 4.3 percent per centimeter. This is to be compared to the larger value of 15.3 percent change in count rate measured for a 1.0 cm displacement of the core barrel mockup and source together, which simulates motion of the reactor core barrel to which the core is rigidly coupled. (Displacement of the core barrel plate alone, corresponding to the unlikely situation where the reactor core barrel would move while the core remained fixed, was found to produce a 2.5 percent change in count rate per centimeter of displacement.) It is concluded that the technique of analyzing fluctuations in the signal from ex-core neutron detectors to test for the presence of core barrel motion can be applied to the detection of motion of a thermal shield of the LWBR type as well, but with reduced sensitivity - the difference in sensitivity being 4.3 percent per centimeter versus 15.3 percent per centimeter in the experimental configuration. Nuclear instrument signals are known to be highly sensitive to core barrel motions and the additional capability of detecting thermal shield motion adds to the usefulness of the technique.

Neutron noise measurements have subsequently been performed on the LWBR core and the results indicate that there is no detectable motion of either the thermal shield or the core barrel.

VI. ACKNOWLEDGMENT

The assistance of R. R. Gurley and R. F. Metzger in fabricating the equipment is gratefully acknowledged.

VII. REFERENCES

1. D. R. Connors, et al, "Design of the Shippingport Light Water Breeder Reactor," WAPD-TM-1208, January 1979.
2. D. N. Fry, R. C. Kryter, and J. C. Robinson, "Analysis of Neutron-Density Oscillation Resulting from Core Barrel Motion in a PWR Nuclear Power Plant," Ann. Nucl. Energy 2, 341-351 (1975).
3. F. Cioli, G. D'Anna, and F. Velona, "Special Techniques for Inspection, Repairs, and Surveillance of ENEL Nuclear Plants," in "Proceedings of the Fourth United Nations International Conference on the Peaceful Uses of Atomic Energy, Geneva, 1971." A/CONF. 49/P/171, pp 1 - 12, United Nations, Geneva, 1971.
4. J. C. Robinson, J. E. Mott, R. L. Currie, and J. R. Penland, "Noise Analysis Investigation at the Oconee Nuclear Power Plant," Trans. Am. Nucl. Soc. 19, 383 (1974).

5. "Vibration and Noise Analysis in Nuclear Power Plants," Commission of the European Communities, Luxembourg, EUR 5294e, December 1974.
6. J. A. Thie, "Theoretical Considerations and Their Application to Experimental Data in the Determination of Reactor Internals' Motion from Stochastic Signals," *Ann. Nucl. Energy* *2*, 253-259 (1975).
7. J. C. Robinson and Farshid Shahrokhi, "Determination of Core Barrel Motion from the Neutron Noise Spectral Density Data-Scale Factor," *Trans. Am. Nucl. Soc.* *23*, 458-459 (1976).
8. F. R. Mynatt, et al., "DOT III: A Two-Dimensional Discrete Ordinates Transport Code," ORNL-TM-4280, September 1973.
9. K. Shure, "Additional Few-Group and Multigroup Calculations of Neutron Penetration," *Nucl. Sci. Eng.* *56*, 219-224 (1975).
10. H. Bohl, Jr., et al, "P3MG1 - A One-Dimensional Multigroup P-3 Program for the Philco-2000 Computer," WAPD-TM-272, 1963.

TABLE 1. EXPERIMENTAL DATA FOR DISPLACEMENT OF THERMAL SHIELD

Thermal Shield Position	Total Counts
(Reference Count)	541761
Nominal	72622 71998 71993
(Reference Count)	538024
Nominal - 0.64 cm	70485 71329 70443
(Reference Count)	536259
Nominal + 0.64 cm	74800 74703 74360
(Reference Count)	541635
Nominal + 1.11 cm	77151 76452 76565 76762
(Reference Count)	538481
Nominal - 1.27 cm	69263 69725 69909
(Reference Count)	539440
Nominal	72283 72050 72478
(Reference Count)	535080

TABLE 2. ENERGY GROUP STRUCTURE USED IN COMPUTER ANALYSIS

Group Number	Lower Energy Limit of Group
1	7.990 MeV
2	6.070 MeV
3	4.720 MeV
4	2.860 MeV
5	1.740 MeV
6	0.820 MeV
7	67.400 keV
8	5.530 keV
9	22.600 eV
10	0.625 eV
11	0.000

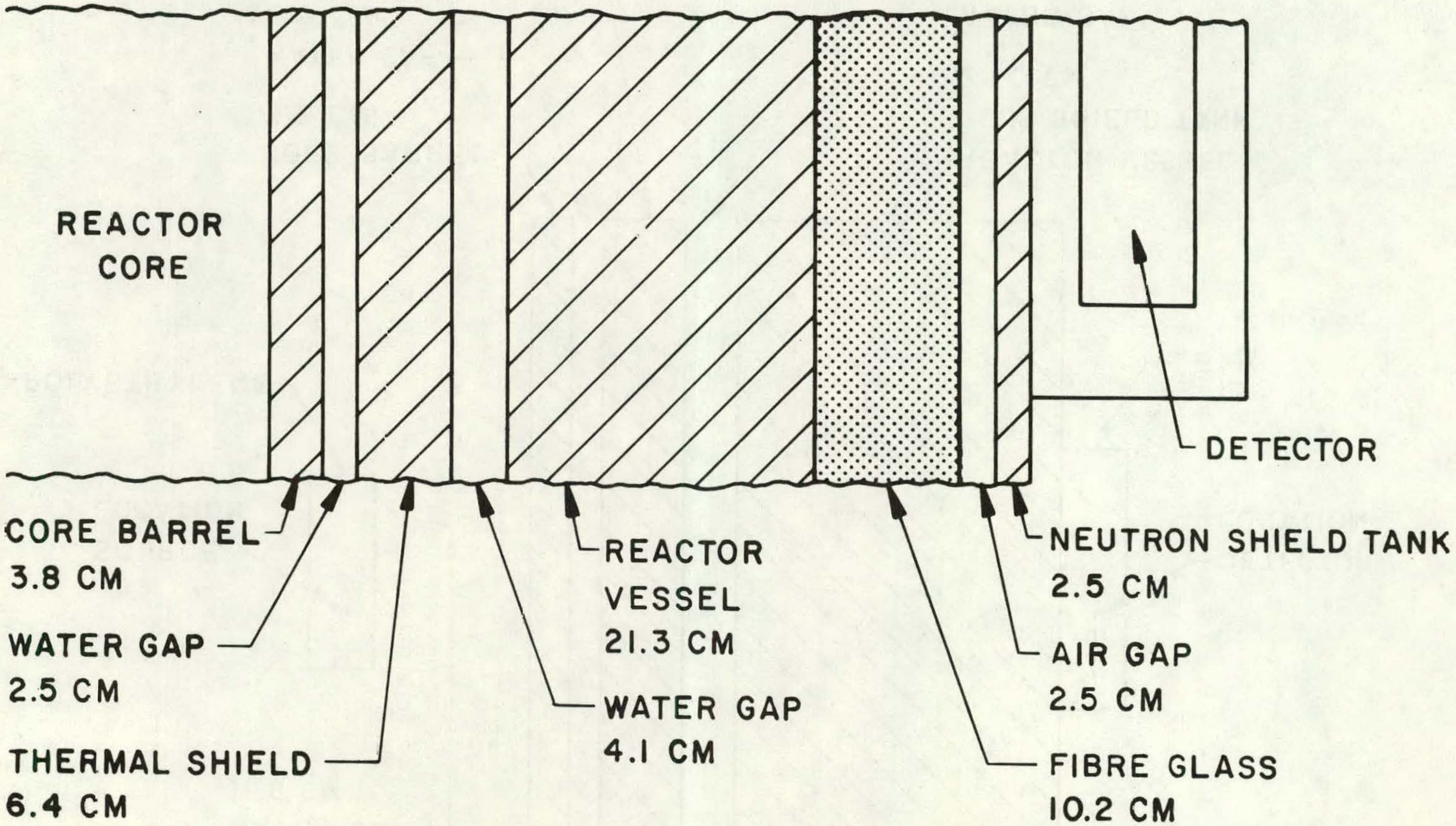

Figure 1. Diagram of LWBR Internals

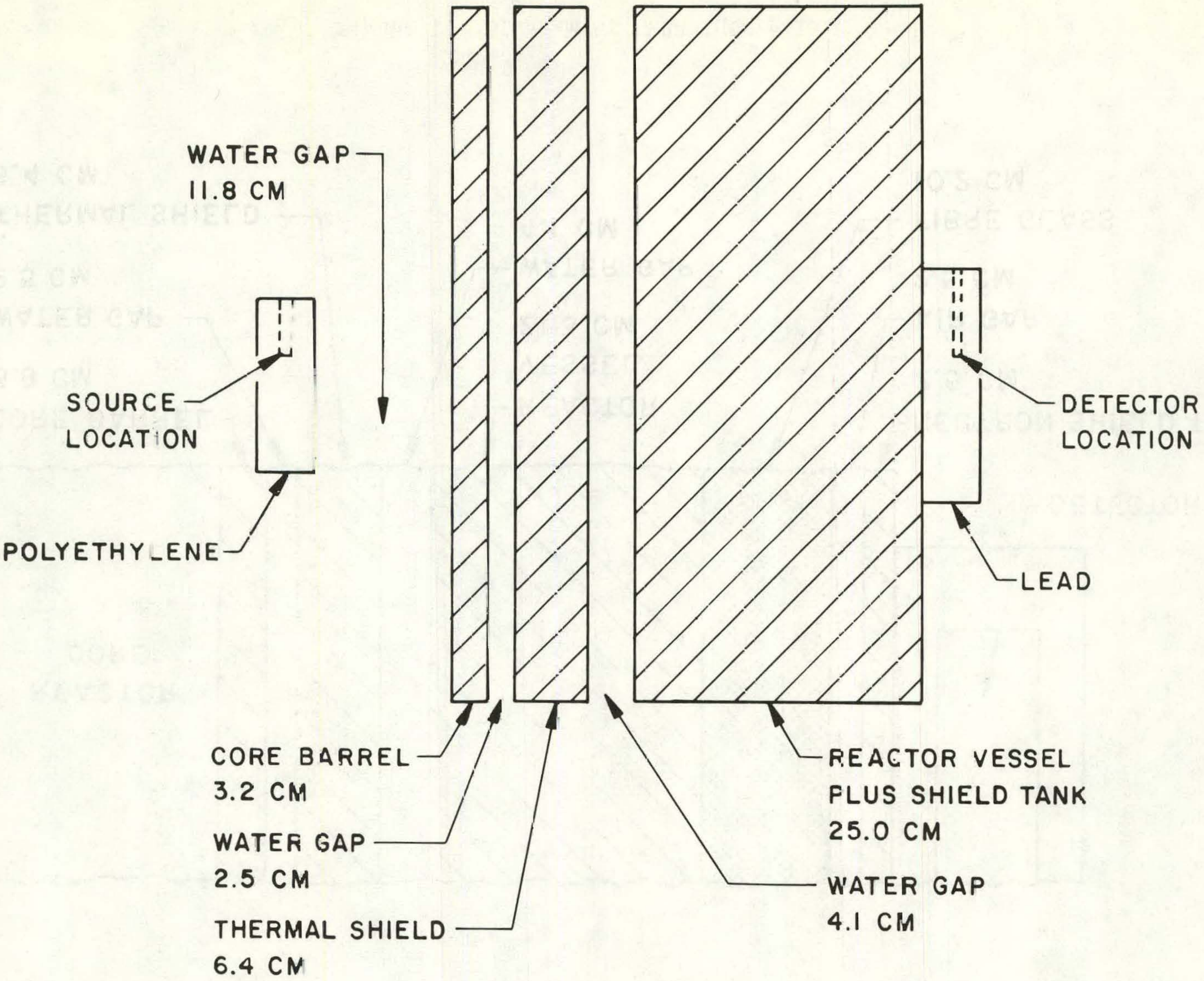

Figure 2. Diagram of Experimental Apparatus, Showing Nominal Position of Components in Water Tank

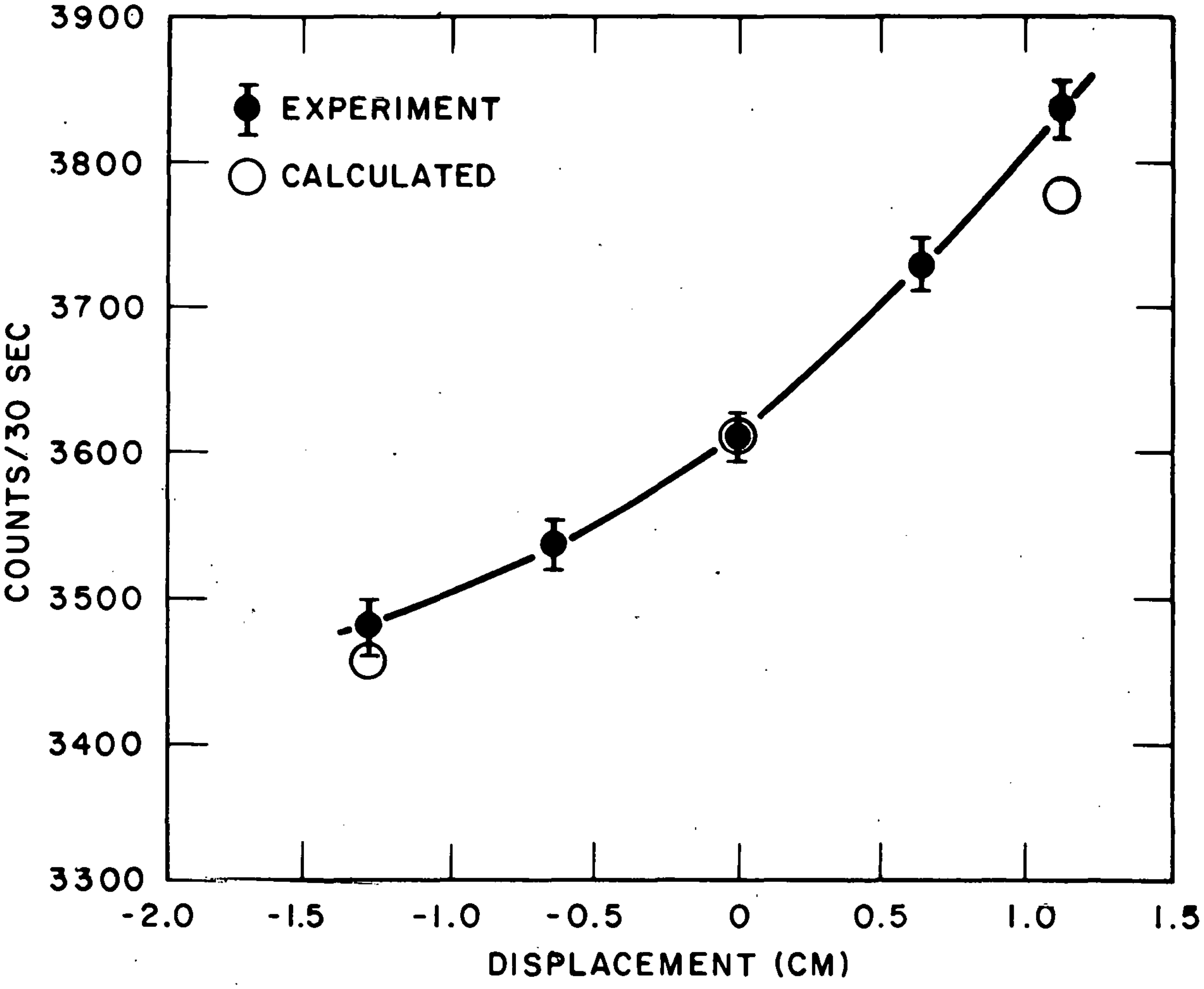

Figure 3. Neutron Detector Count Rate Versus Displacement of Thermal Shield from Nominal Position

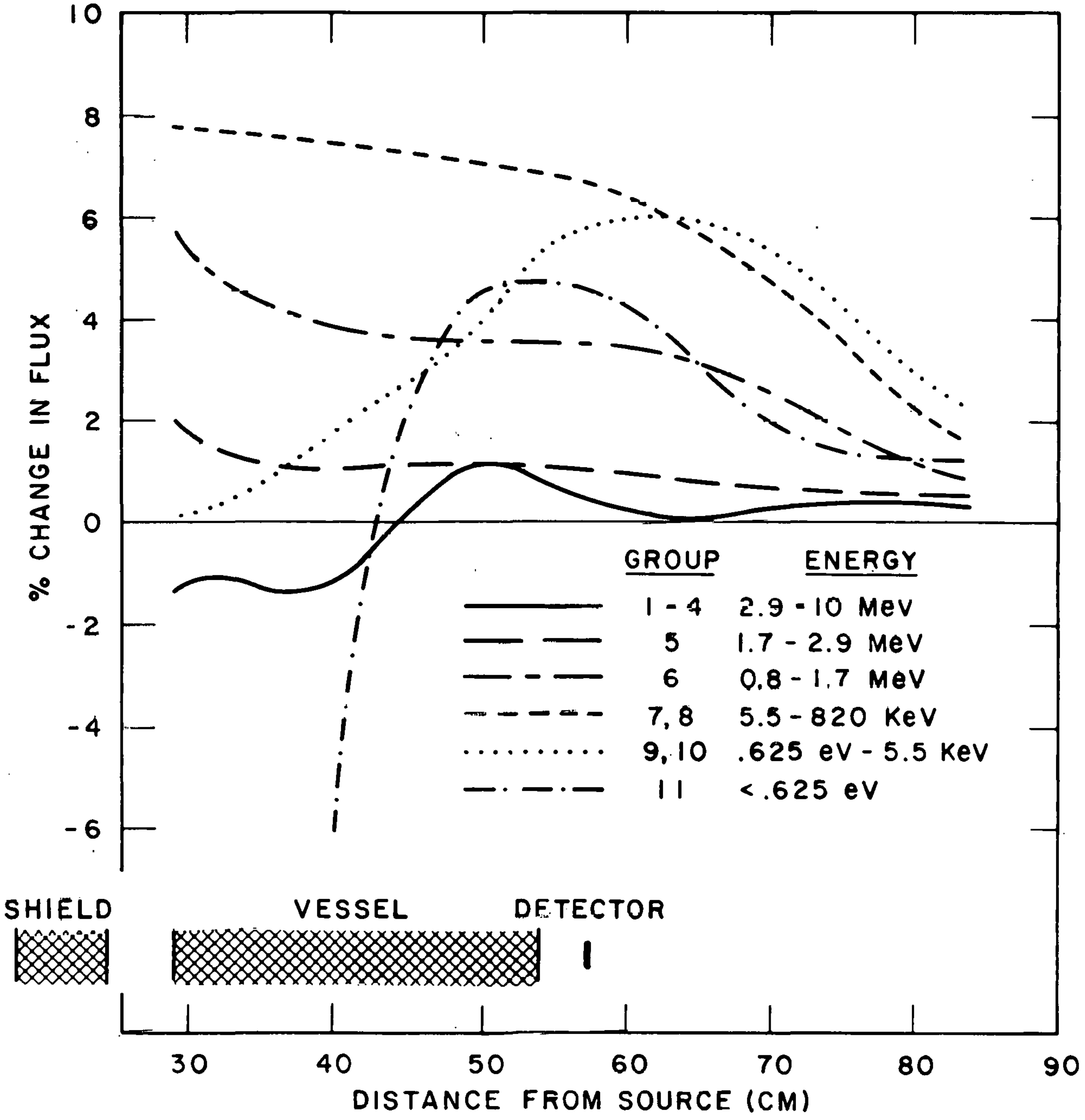

Figure 4. Percent Change in Calculated Flux Versus Distance from Source, Caused by a Displacement of the Thermal Shield of +1.1 cm, Plotted for Different Neutron Energy Groups

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES