NAA-SR-3467
REACTORS-POWER
31 PAGES

FIRST SODIUM REACTOR EXPERIMENT (SRE) TEST OF HALLAM NUCLEAR POWER FACILITY (HNPF) CONTROL MATERIALS

(Interim report, development project on control materials for Hallam Nuclear Power Facility)

By

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A DIVISION OF NORTH AMERICAN AVIATION, INC.
P.O. BOX 309 CANOGA PARK, CALIFORNIA

CONTRACT: AT(11-1)-GEN-8
ISSUED: JUN 1 1959

DISCLAIMER

ACKNOWLEDGMENT

The work of the following people is gratefully acknowledged:

L. B. Copeland	R. P. Justice
H. C. Field	R. S. Keppel
W. L. Fisher	N. C. Miller
T. Gifford	R. C. Noyes
D. Hovley	W. S. Peck
O. G. Jenkins	H. Strahl

DISTRIBUTION

This report has been distributed according to the category "Reactors - Power" as given in "Standard Distribution Lists for Unclassified Scientific and Technical Reports" TID-4500 (14th Ed.), October 1, 1958. A total of 625 copies was printed.

CONTENTS

FIGURES

ABSTRACT

An experiment was conducted in the Sodium Reactor Experiment to measure temperatures and neutron flux levels in and near a boron-containing simulated control rod. The data are being used to check analytical methods developed for prediction of control rod heat generation rates and maximum temperatures in this type of control rod in the Hallam Nuclear Power Facility.

The maximum observed temperatures with a reactor power level of 20 Mw were 1363°F for a boron-nickel alloy ring having a 0.105-in. radial clearance with the thimble and 1100°F for a boron-nickel alloy ring having a 0.020-in. radial clearance. The maximum temperature difference between the coolant and the control rod was 473°F. It is concluded that the expected greater heat generation rates in the Hallam reactor would prohibit the use of boron-containing absorber materials in a combined shim-safety rod.

I. INTRODUCTION

The control rods of the sodium graphite reactors designed or built thus far operate within thimbles which isolate the control rod and the actuating mechanism from the sodium coolant. As a result heat generated in the control rod must be transferred across a small helium annulus and through the thimble to the sodium coolant. Since the coolant temperature is of the order of 900°F, the operating temperature of the control rod may reach 1300 to 1500°F. At the latter temperatures there is considerable reduction in material strength for most conventional alloys such as types 316 or 347 stainless steel.

This temperature problem has been solved in the Sodium Reactor Experiment by the use of two types of control rods: shim, or regulating rods with a small radial clearance (on the order of 0.020 in.) between the absorber column and thimble; and a separate safety rod with a large radial clearance (approximately 1/8 in.) to permit reliable, rapid insertion on reactor scram. Reduced neutron absorption results in little heat generated in the safety rod, so that the larger radial clearance does not result in high operating temperatures.

However, there are significant economic advantages in combining the functions of all types of control rods into a single type. The reduction in the required number of control rods improves neutron economy in the reactor and reduces the reactor capital cost. This means, however, that a relatively large radial clearance must be maintained between the control rod and the thimble for reliable reactor scramming, without inducing excessive operating temperatures in the control rod during normal reactor operation. Such a combination of control rod functions is considered highly desirable for the Hallam Nuclear Power Facility (HNPF), under construction at Hallam, Nebraska by Atomics International for the Atomic Energy Commission.

In order to determine the feasibility of such a combined rod, accurate prediction of control rod operating temperatures is required. Accurate prediction depends upon knowledge of heat generation rates in the control rod material as well as the heat transfer characteristics of the immediate environment in which the control rod operates.

In the early days of the SRE (Figure 1) development work, a series of experiments was conducted with mockups of SRE control rod components using electrical heaters to simulate heat generation.[1] Temperatures were measured in the simulated control rod material at various radial clearances, in order to choose the maximum radial clearance allowable based on calculated heat generation rates. It was on this basis that the 0.020-in. radial clearance used in the SRE shim-regulating rods was selected. However, the heat generation rates necessary for accurate prediction of operating temperatures were not known, and no experimental determination of these rates had been made.

It was felt that extrapolation from the mockup data to the reactor core geometry and flux levels in the Hallam reactor would not be sufficiently reliable. It was decided, therefore, to conduct an inpile experiment to measure temperatures of SRE-type control rods (which would allow calculation of heat generation rates) and to use these data for extrapolation to HNPF, as well as to check calculational techniques previously developed. This document describes that inpile experiment and reports the results.

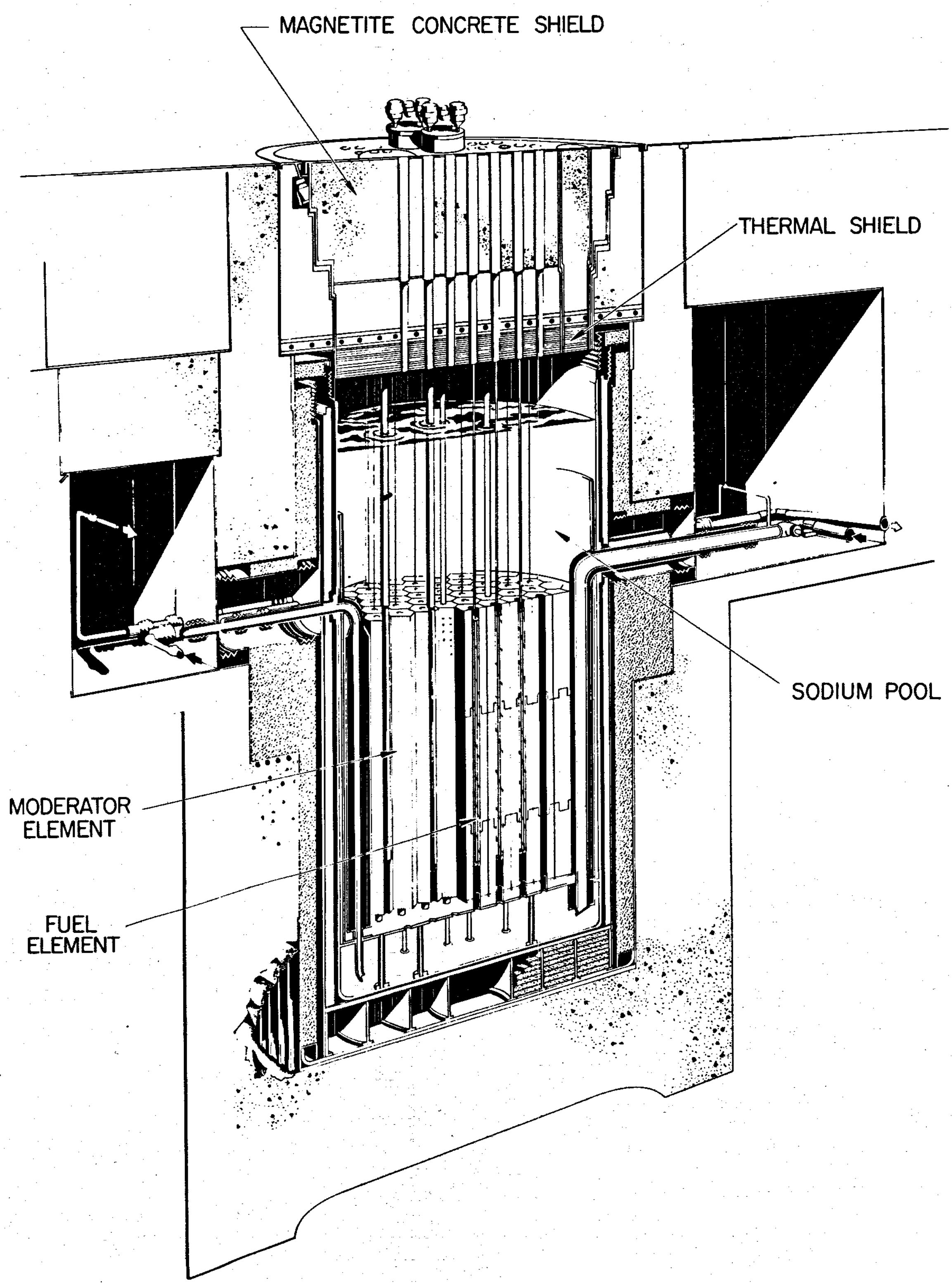

Figure 1. SRE Reactor Section

II. DESCRIPTION OF EXPERIMENTAL EQUIPMENT

The experiment to measure temperatures and flux levels of a simulated control rod containing boron was conducted in the SRE. The SRE is a graphite-moderated, sodium-cooled, experimental reactor with a thermal power rating of 20 Mw. The active core is approximately 6-ft high and 6-ft in diameter. The moderator is made up of hexagonal graphite blocks clad with a thin zirconium sheet. The sodium coolant enters at the bottom of the core at approximately 500°F, passes upward through the fuel channels, and out at the top at a temperature of 960°F. Fuel elements are located in holes through the center of the moderator elements; control rods and instrument channels are located in corner channels formed by the intersection of three adjacent moderator cans. This experiment was conducted in one of the control rod channels in the reactor. A sectional view of the SRE is shown in Figure 1.

A. EXPERIMENTAL RINGS

The experimental rod, Figure 2, consisted of five instrumented boron-nickel alloy* annular rings: one instrumented stainless steel annular can packed with granular boron carbide and five noninstrumented boron-nickel alloy rings supported on a flanged-end tube passing through the center of the stack of rings. The upper end of the tube was attached to a radiation shield plug which filled the upper portion of the control rod channel. The rod was positioned to place the lowest ring of the experimental assembly at the horizontal midplane of the reactor core, thus simulating a normal control rod half inserted into the active core zone.

Ring no. 1, the bottom test ring, was a boron-nickel alloy ring containing 1.63 wt % boron with an outside diameter of 2.312 in. and an 0.375-in. wall thickness. The ring was 4 in. high, as were all of the instrumented rings in the test assembly, and had a 0.105-in. radial clearance with the enclosing thimble. Five of the Chromel-Alumel thermocouples were installed in this ring; three were located approximately 1/4 in. above the bottom end of the ring at 120-degree spacing, and two were located approximately 1/4 in. from the top at 180-degree spacing. This ring provided temperature data comparable to those from a rod with the same radial clearance as an SRE safety rod. This ring was expected to

* Stoody Co., Whittier, Calif; nominal composition: 81% Ni, 11% Cr, 4% Fe, 2% B, 1.0% Si.

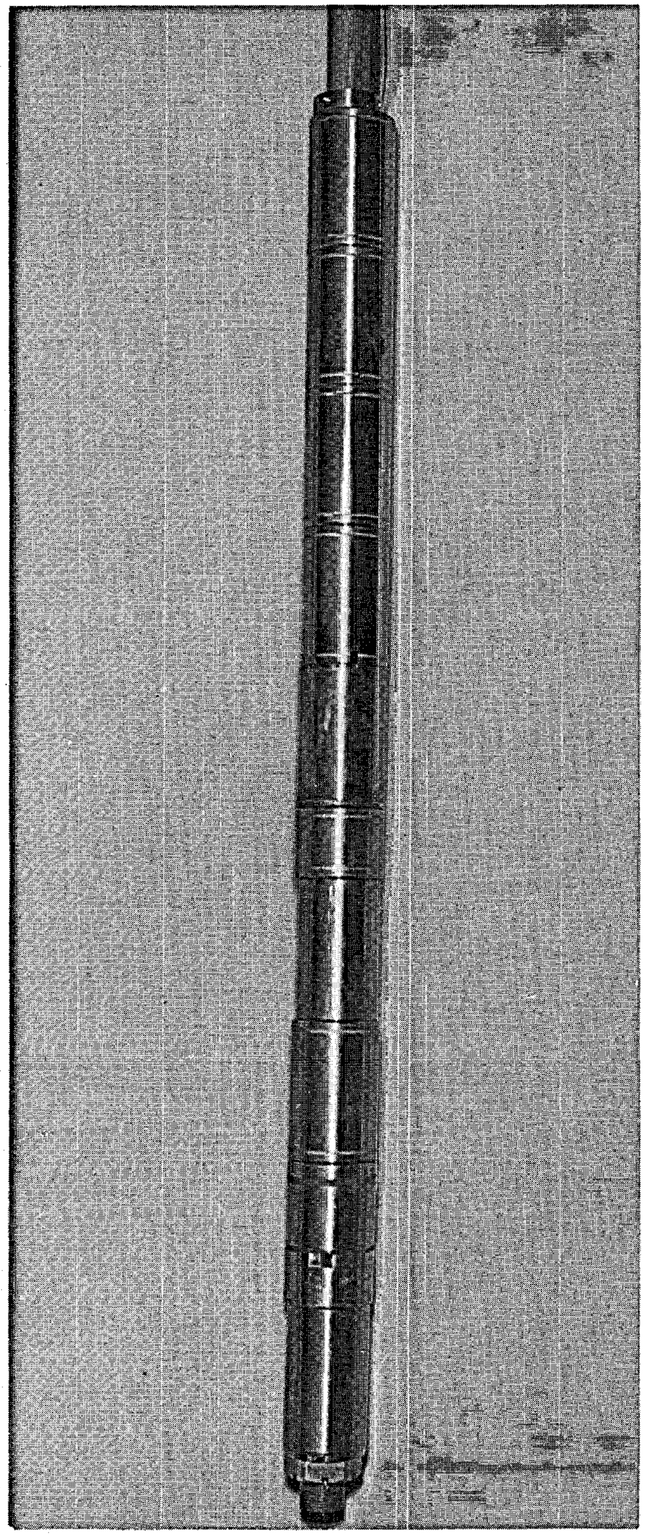

Figure 2. The Experimental Control Rod

have the highest heat generation rate since, due to the exposed lower end, it would receive the largest neutron current. The highest temperatures in the test assembly were therefore expected to occur in this ring.

Ring no. 2 was a boron-nickel alloy ring containing 1.9 wt % boron. However, it had a 2.484-in. outside diameter and a 1.750-in. inside diameter. This ring was used to measure the neutron flux attenuation rate in the boron-nickel alloy. The manganese alloy* material used to measure fluxes in the assembly was placed at various depths through the wall of the ring in the form of 0.005-in.-thick by 0.200-in.-wide foils covered by a split shell of the same boron-nickel alloy with a stepped-thickness section. The two half-shells were held on the ring with a 0.030-in.-diameter wire of the same manganese alloy. No thermocouples were installed in this ring. The partially assembled ring with the manganese flux foils in place is shown in Figure 3.

Ring no. 3 was also of the boron-nickel alloy material with the same outside diameter as ring no. 2, but containing 1.63 wt % boron. The purpose of this ring was to measure control-rod heating due to gammas. The temperature of an inner ring of the same material, except for the absence of boron, was monitored. A 0.030-in. clearance was maintained between the two shells of the ring. Four thermocouples were placed in each of the two shells and were located approximately on the horizontal centerline of the shells. The inner shell of this ring is shown in Figure 4. The slots, located at 45 degrees to the placement of the four thermocouples, provide clearance for the thermocouples installed in the outer shell. The thermocouples installed in this ring had insulated "hot" junctions to permit electrical connection of the thermocouples in a differential arrangement. This provided an accurate means of measuring the expected temperature differential between the two shells due to the gamma heating in the inner ring.

Ring no. 4 was of the same material and size as ring no. 1. It was intended that this ring would be positioned eccentrically to the column so line contact would be maintained between the ring and the thimble on the side of the test assembly nearest the reactor centerline. The purpose of this ring was to investigate the worst possible heat transfer case. On the side of the ring away from the reactor centerline, the clearance between the ring and the thimble

* Chase, P Alloy, Metals & Controls Corp., Attleboro, Mass.; nominal composition: 72% Mn, 18% Cu, 10% Ni.

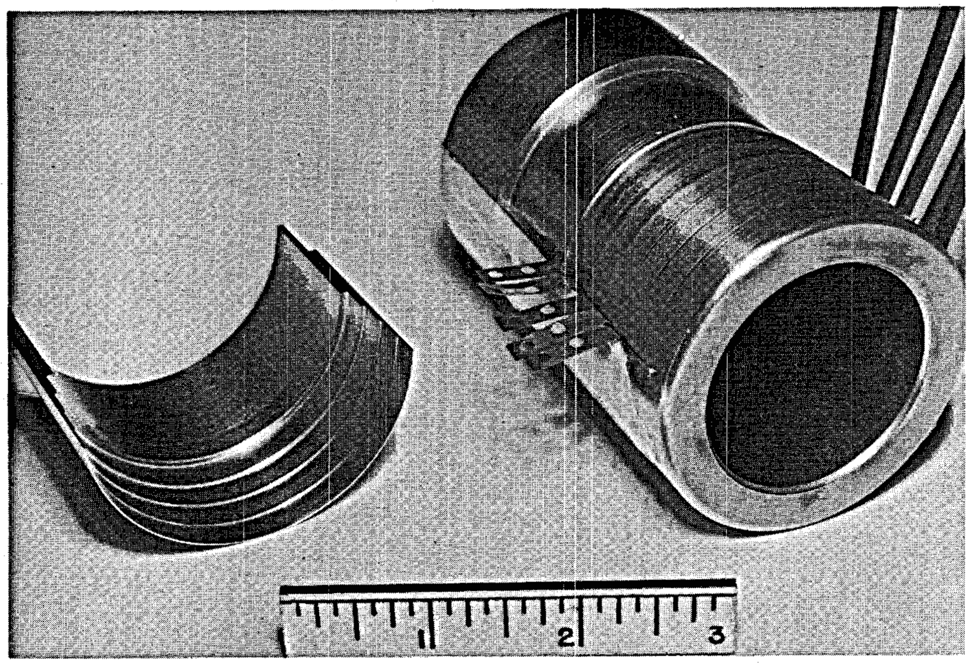

Figure 3. Ring No. 2

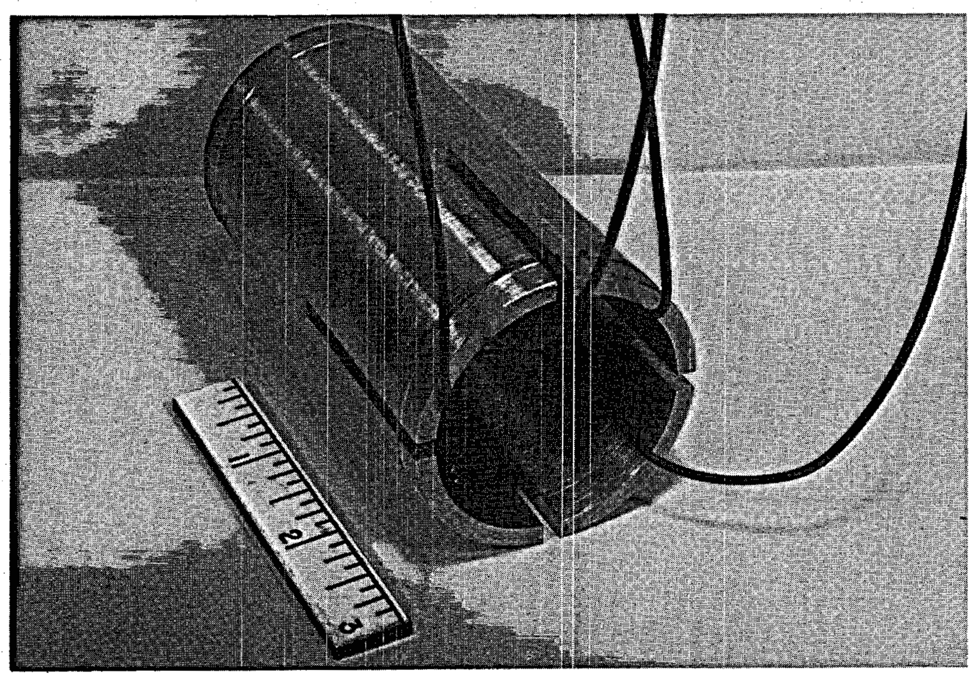

Figure 4. Inner Shell of Ring No. 3

would be nearly 1/4 in. This presents a longer heat transfer path, resulting in a circumferential temperature gradient. It was expected that the temperature difference might be as high as 800°F.

A mechanical means was provided for positioning the ring against the thimble wall after the rod was installed within the thimble. A cam was placed inside the tube supporting the entire column (known as the "pull tube") to push the ring toward the thimble wall when the cam was rotated 90 degrees. Two wires were attached to this cam; they ran to the top of the assembly so that the cam could be operated remotely. Several horizontal slots were cut into the sides of the pull tube above and below this ring to provide a heat-flow barrier which would minimize end effects in this portion of the test assembly.

The ring was provided with four thermocouples: one pair was located on the side of the ring that was expected to be nearest the thimble; the other pair was located diametrically opposite. These thermocouples were located at approximately the vertical centerline of the ring. Figure 5 shows the method of attaching thermocouples, which was typical for mounting in the boron-nickel rings. Holes for each thermocouple were provided which placed the thermocouple hot junction at approximately the center of the ring wall.

Figure 5. Ring No. 4

Ring no. 5 was a noninstrumented boron-nickel alloy ring only 2-in. high. Its purpose was to shield against possible end effects on the eccentric ring from ring no. 6, which was of a different material.

Ring no. 6 was a type 304 stainless steel annular can filled with granular boron carbide containing 79.15 wt % B. The boron carbide was packed to a bulk density of 1.60 gm/cm^3 by a vibratory method. This ring had the same outside diameter (2.484 in.) as the boron-nickel rings used to simulate an SRE shim-regulating rod configuration. The thickness of the boron carbide layer was 0.250 in. The can had a 0.027-in.-thick stainless steel wall on both the inside and outside of the boron carbide. Two thermocouples were placed in this can at approximately the vertical centerline: one was attached to the inside of the outer tube; the other was attached to the outer diameter of the inner wall. Thus the temperature drop due to internal heat generation could be used to correlate the heat generation characteristics of this material with the boron-nickel alloy. Four 0.030-in. manganese alloy wires were placed in small stainless steel tubes on the ring wall diagonal to provide data on the radial flux attenuation rate through the boron carbide. Figure 6 shows this ring before the top of the can was welded in place and the flux wire tubes cut flush with the top plate.

The four rings above ring no. 6 were of the boron-nickel alloy and were noninstrumented. Their purpose was to complete the similarity to an SRE rod and to maintain the same neutron flux perturbations that would be observed with a normal control rod half-inserted into the core. The top of the uppermost ring in this group was positioned at the interface between the fuel zone and the reflector.

B. THIMBLE

The thimble used with this test was of type 304 stainless steel. In the region of the experiment, the thimble was of 2.522-in. inside diameter with a 0.049-in. wall. Six thermocouples of varying lengths were tack welded at their hot junction to the outside of the thimble by means of small horseshoe clips. The thermocouple leads ran within the thimble in the upper section, passed through the thimble wall just above the core zone, and were attached to the outside thimble wall for the remainder of their lengths. The temperatures obtained by these thermocouples, together with the temperatures of the bulk inlet and

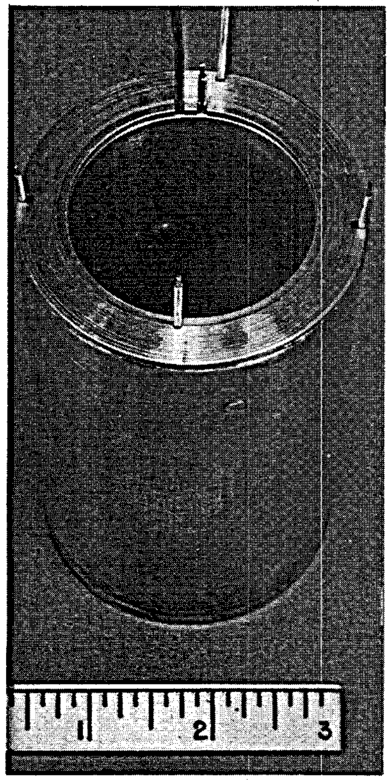

Figure 6. Ring No. 6

outlet sodium temperatures as recorded by the reactor temperature monitoring system, enabled a fairly complete profile of the sodium temperature through the control rod channel. The axial thermal flux distribution along the control rod was determined by the activation of a 0.030-in.-diameter wire of the manganese alloy placed in a 3/32-in.-outside-diameter tube which was positioned in the same manner as the thimble-temperature-sensing thermocouples.

The thimble was welded leak tight after stringing the thermocouples, to prevent the entry of sodium. Figure 7 shows the section where the thimble thermocouples pass through the wall. It can be seen that small tubes of a slightly larger interior diameter than the outside diameter of the thermocouples were used as a means of effecting the leak-tight seal weld. A previous attempt at welding the thermocouples directly to the heavy thimble section resulted in burning through the thermocouple sheath.

The pull tube used was of type 304 stainless steel with a 1.250-in. outside diameter and a 1/8-in. wall. Six thermocouples were located within the tube.

Small holes were drilled through the tube wall and the hot junctions of the thermocouples were wedged into the holes. Two of these thermocouples were spaced 180 degrees apart and 1 in. above the bottom end of the tube (corresponding to the bottom of ring no. 1). Two pairs were placed opposite ring no. 4 (the eccentric ring).

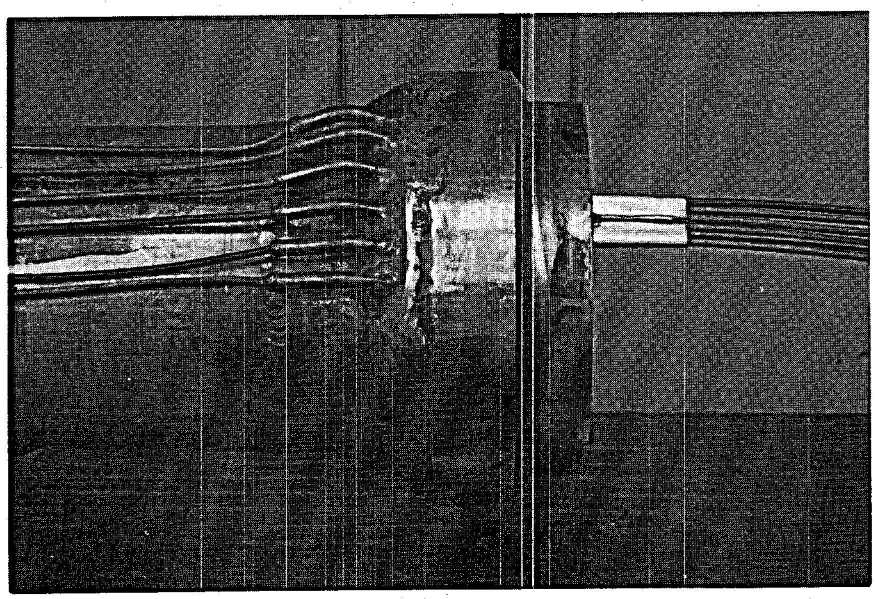

Figure 7. Thermocouple Installation in Thimble

C. SHIELDING

A radiation shield plug was necessary at the upper end of the test assembly to prevent radiation streaming out of the reactor core. This plug matched the main SRE radiation shield plug with respect to overall density and height. It was composed of steel shot, lead shot, and granular boron carbide loaded to an overall bulk density of 3.5 gm/cm^3. The thermocouples included in the pull tube and test rings were spiraled through this shield to prevent radiation streaming. Two thermocouples were included in the shield to provide information on the temperature distribution within the shield. They were located at 49 in. and 60 in. below the reactor floor. The radiation shield plug was completely effective, as no detectable radiation streaming occurred during the test run.

Attached just below the radiation shield plug was a series of washers spaced 1/2-in. apart. Their purpose was to prevent convective flow of the helium atmosphere within the thimble, which might otherwise raise the temperature of the main SRE shield to such an extent that melting of the lead, surrounding the cooling coils placed in the bottom of the main shield, could occur. This section of the test assembly is shown in Figure 8.

D. THERMOCOUPLES

Temperatures in the experimental assembly were monitored by means of 30 chromel-alumel thermocouples. These thermocouples, supplied by the Aero Research Corporation, were 1/16-in.-diameter stainless-steel-sheathed and insulated with magnesium oxide. The conductors were 0.010 in. diameter. A total of 33 thermocouples was originally installed, but three failed prior to the start of the test: two by short circuit where the thermocouples were spliced to extension wires, and one at the junction of the thermocouple. None failed during the actual experiment, which lasted approximately 3 weeks. Duplicate instrumentation had been installed for the more critical temperature measurements, and all failures occurred at these positions. Therefore, the failure of the three thermocouples was not serious.

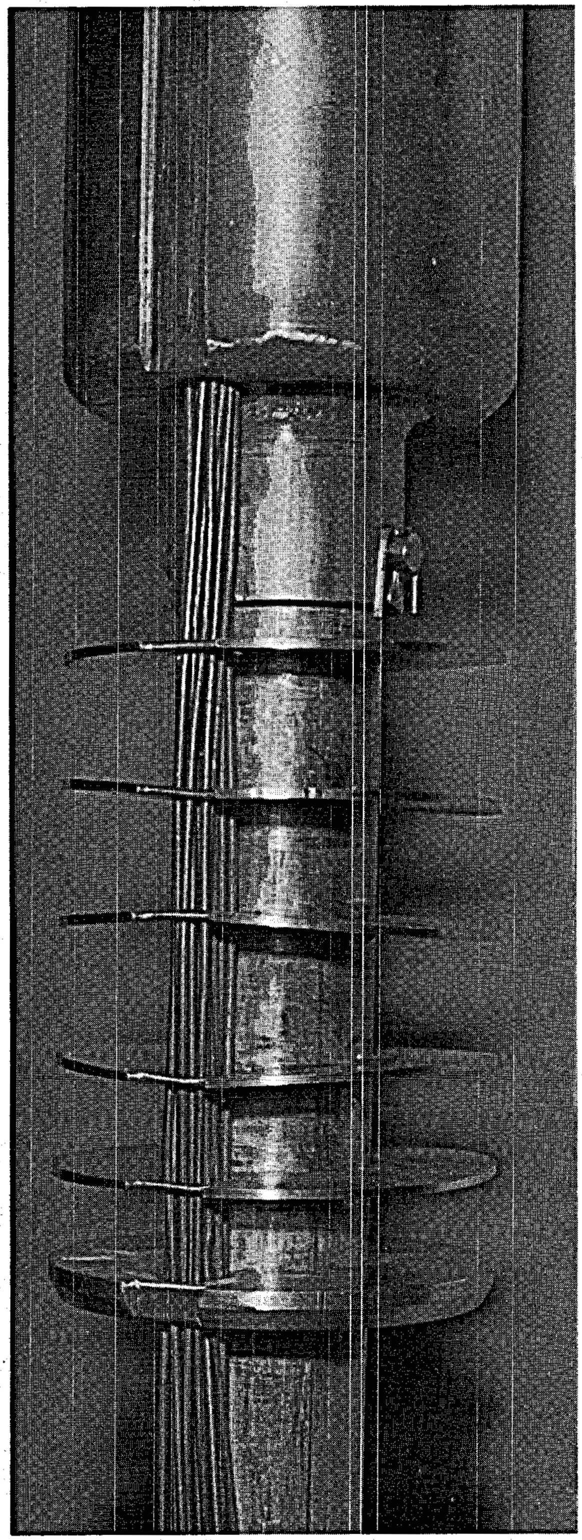

Figure 8. Experimental Rod Thermal Shield

III. DESCRIPTION OF EXPERIMENTAL PROCEDURE

After the experimental rod was assembled and installed in the thimble, the wires were pulled to position the eccentric ring, and the assembly was filled with helium by a repeated evacuation-and-fill technique. The entire assembly was then placed in a control-rod test furnace, gradually heated to 1000°F, and then allowed to cool. This process served the dual purpose of drying the test components to remove any effects of moisture on the thermal conductivity of the helium atmosphere and to provide a means of checkout and calibration of the thermocouples in the assembly.

The rod was gammagraphed to check the positioning of the eccentric ring. The resulting films showed that, instead of having contact between this ring and the thimble, a clearance of about 0.070-in. existed. From the gammagraphs it was apparent that the cam mechanism did not operate as intended. The horizontal slots in the pull-tube weakened the tube, and motion of the cam deformed the pull-tube rather than move the ring against the thimble wall. Thus, the clearance between the ring and the thimble remained nearly uniform.

The test assembly was installed in reactor hole 38, a channel located at the corners of three adjacent moderator cans and ordinarily used by the no. 1 shim rod (Figure 9.). Thermocouple extension cables led from connector plugs located at the top of the test rod assembly to an instrument rack where temperatures were observed and recorded on a 12-channel Brown recorder, a 12-channel Weston recorder, and a portable potentiometer.

Periodic test assembly temperatures, sodium temperatures, and reactor power were recorded every half-hour during reactor operations. Since the test was conducted during an experimental power run of the SRE at a time when new reactor equipment requiring reactor scramming for functional testing was being evaluated, reactor operating conditions were not stable. In addition, approximately 2 hr of steady-state reactor operation were required before temperatures in the test assembly came to steady-state conditions. Thus, even though the experimental rod was in the reactor for about 3 weeks, only four valid steady-state tests were obtained at different power levels.

When the reactor operating period was concluded, the rod assembly and thimble were removed from the reactor using the fuel-handling cask. The assembly was placed in a storage cell where the rod was removed from the thimble to the reactor hot cell facility. The wires in the boron-carbide-filled can and the foils in the boron-nickel-alloy ring were removed by use of remote-operating equipment. The axial-flux-measuring wire was removed from the empty thimble by pulling it onto a reel in a lead-shielded cask.

The neutron-sensing materials were counted for the Mn^{56} isotope 2.58-hr β activity with a gas flow proportional counter. The wire and foils were cut into suitable lengths for counting. A weight check was run after counting in order to correct the count-rate data for the mass of the pieces.

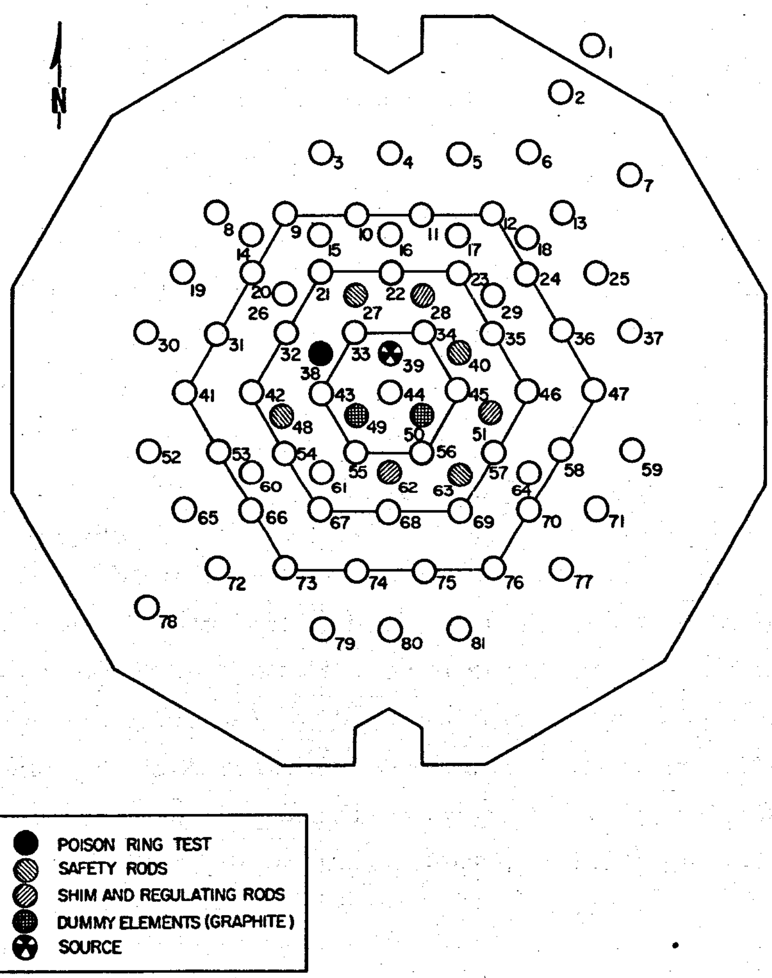

Figure 9. SRE Core Configuration

IV. RESULTS OF EXPERIMENT

A. TEMPERATURE

A tabulation of the temperature data for each reactor power level at which steady-state operation of sufficient duration occurred is shown in Table I. As pointed out in Section II, steady-state condition is defined to require unchanged reactor operating conditions over the prior 2-hr period.

For ease in correlation of the tabulated temperatures to thermocouples in the test assembly, the following convention was adopted. The first number in the left column is the number of the ring in which the thermocouple is located. The letter refers to vertical position in the ring, and the second number refers to angular position based on a clockwise angle from the line on the assembly nearest the core centerline when the rod is viewed from above, e. g., 1-T-180 is a thermocouple at the top of ring no. 1 on the side away from the core centerline.

B. FLUX MEASUREMENTS

The corrected results of the flux measurements using the manganese alloy detector material are shown in Figures 10 and 11. The data obtained from the activation of the wires and foils in the assembly were corrected to yield thermal flux by subtraction of the epithermal contribution by an indirect technique. This indirect procedure was necessary since operating temperatures in the SRE do not permit use of cadmium (as would be required to obtain the usual cadmium ratio). The procedure employed makes use of the same method as an exponential experiment performed in connection with other work, in which the thermal and epithermal fluxes inside and outside a boron-nickel alloy ring were measured using dysprosium as the detector material. Here, the boron-nickel alloy ring took the place of the usual cadmium required for thermal flux measurements, and the results of the inpile-test flux measurements could be used to obtain the equivalent of a cadmium ratio by comparing foil activation inside and outside a test ring. The resulting ratio was applied uniformly to all flux measurements in the test assembly.

The flux distribution along the control rod as measured by the manganese alloy wire was not of the general shape expected: a general increase in flux

TABLE 1

STEADY STATE TEST ASSEMBLY TEMPERATURES

Time and Date		Temperature (°F)			
		0930/5-5	1100/5-12	0500/5-22	1930/5-24
Reactor Power (Mw)		3.0	6.8	20.1	18.0
Bulk Na Inlet (°F)		464	475	570	560
Bulk Na Outlet (°F)		530	672	940	890
1-B-0		645	847	1363	1265
1-B-120		640	840	1363	1265
1-B-240		640	835	1349	1255
1-T-0		607	785	1298	1215
1-T-180		600	778	1295	1214
3-C-0		-	-	1099	1040
3-C-90		-	-	1082	1020
3-C-180		-	690	1072	995
3-C-270		550	690	1075	1010
3-C-45		-	690	1098	1035
3-C-225		-	-	1099	1040
3-C-315		-	-	1080	1010
4-C-0		600	780	1243	1160
4-C-0		600	780	1249	1165
4-C-180		600	775	1240	1155
4-C-180		600	780	1245	1160
B4C Can	Outer	565	708	1096	1030
	Inner	570	725	1170	1095
Pull Tube:	0°	600	778	1246	1163
(at ring no. 4)	0°	600	780	1252	1169
	180°	600	780	1255	1169
	180°	603	785	1263	1176
Lower end of pull tube (at no. 1 ring)	180°	635	835	1354	1265
Thimble:					
Below no. 1	300°	505	595	838	880
at no. 1	240°	515	618	890	850
at no. 3	60°	523	640	884	840
at no. 4	0°	525	644	940	900
above no. 6	270°	528	653	942	890
Shield Plug:	Upper	75	75	80	83
	Lower	109	110	148	149

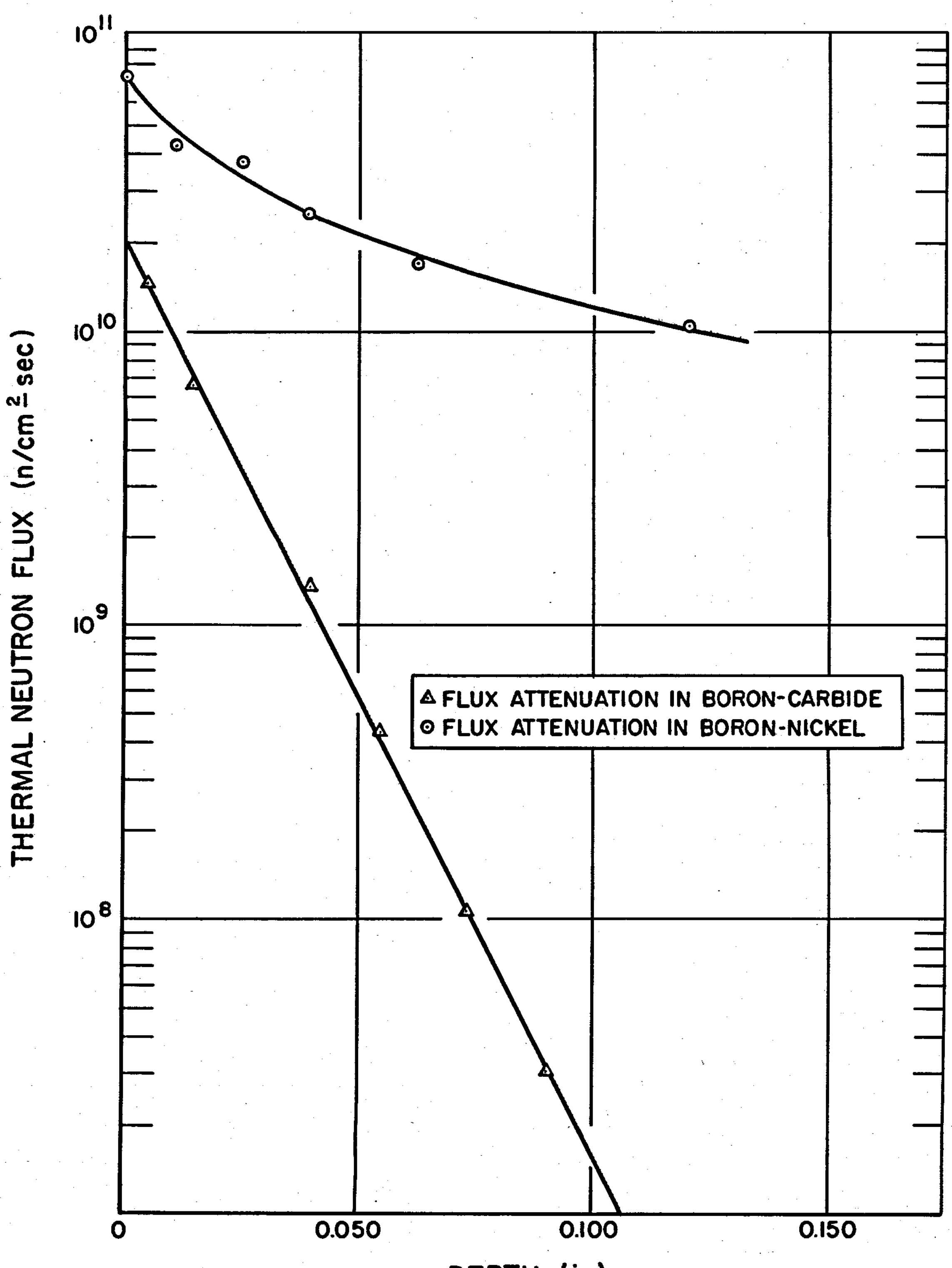

Figure 10. Flux Attenuation in Poison Rings

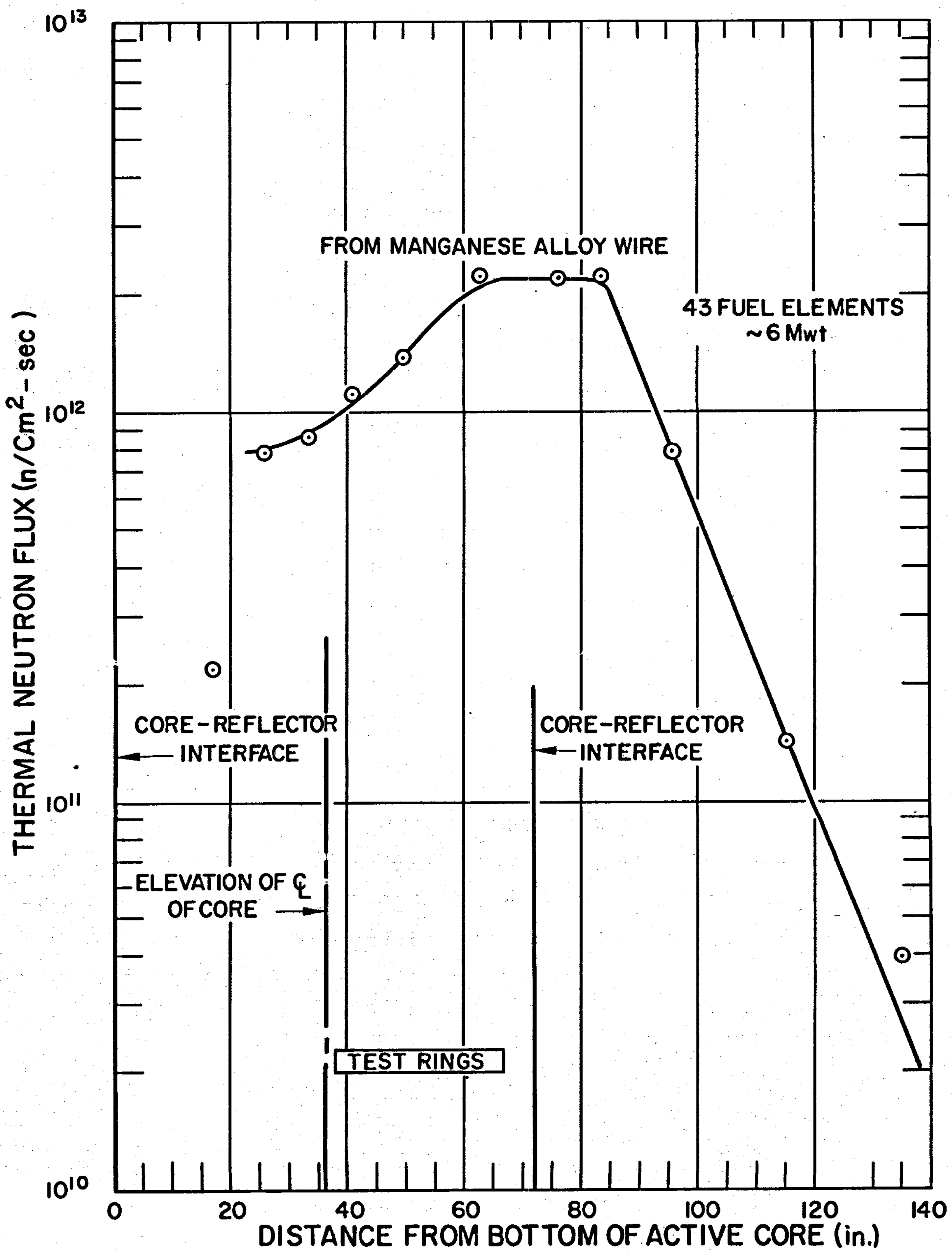

Figure 11. Axial Flux Distribution Near Experimental Assembly

level from the top of the experimental rod to the bottom, and a peak somewhere in the lower half of the active core where there was no strong absorber material present. The experimental data showed the opposite to be the case in the upper portion of the core. The shape of the curve is unchanged by correction for eipthermal activation because a uniform correction was applied. No data were obtained below reactor core centerline because the detector wire broke during removal from its enclosing tube. The break occurred a few inches below the lower end of the experimental assembly.

As a qualitative check on the wire data, a survey was made of the gamma activity of the thimble used for the test. It was reasoned that the activity of the thimble should follow fairly well the flux distribution during the test. (This proportionality would be affected only by differences in contribution to activity by epithermal and thermal neutrons as a function of distance from the core center. This was expected to be a small effect.)

The equipment used to conduct the gamma survey is sketched in Figure 12. A Geiger counter was placed about 10 ft from the thimble in a lead shield with only a 5/8- by 3-in. window exposing the counter to the thimble activity. The thimble was drawn by the counter arrangement at a constant speed using the SRE fuel handling cask. The output signal from the Geiger tube was fed into a strip-chart recorder which was later calibrated to yield the activity vs position data shown in Figure 13. Several runs were made using different count rate ranges of the Geiger counter in order to yield the greatest detail in activity consistent with a noise level low enough to yield a smooth curve. The plot of thimble activity vs position is qualitatively much more reasonable than the axial flux measurement made using the manganese wire. No explanation has been advanced for their discrepancy, and in view of their difference and the peculiar shape of the wire activity plot, it can only be concluded that no reliable measure of the thermal flux near the experimental rod was obtained. Even though the plots of flux vs depth into the boron-carbide and boron-nickel alloy are reasonable with regard to slope and absolute value, these are suspect since they, too, were obtained with manganese alloy detector material.

The whole problem of flux measurement in a reactor at operating temperatures in excess of 1000°F is one of lack of suitable detector materials. Metallic

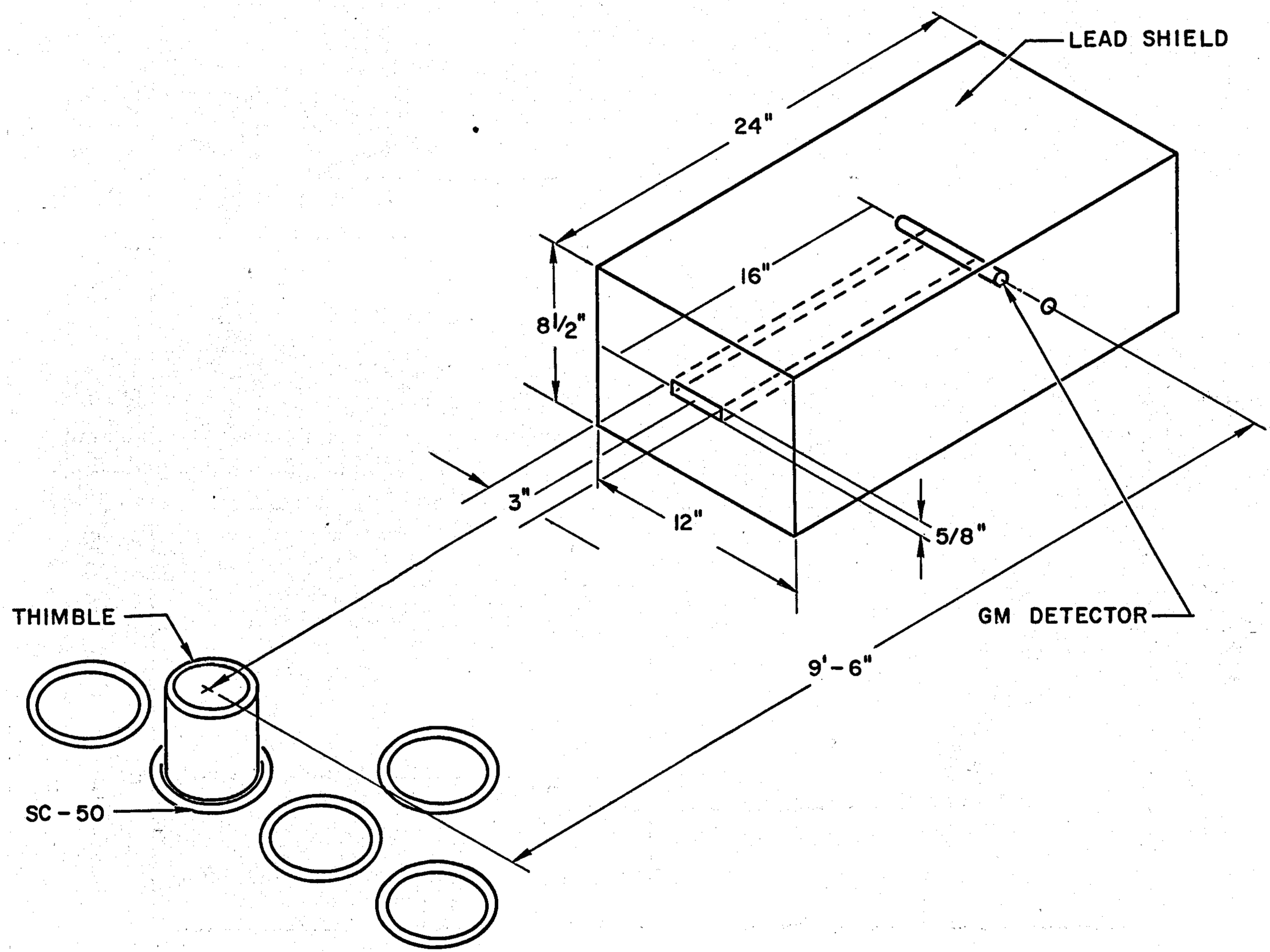

Figure 12. Gamma Survey Equipment

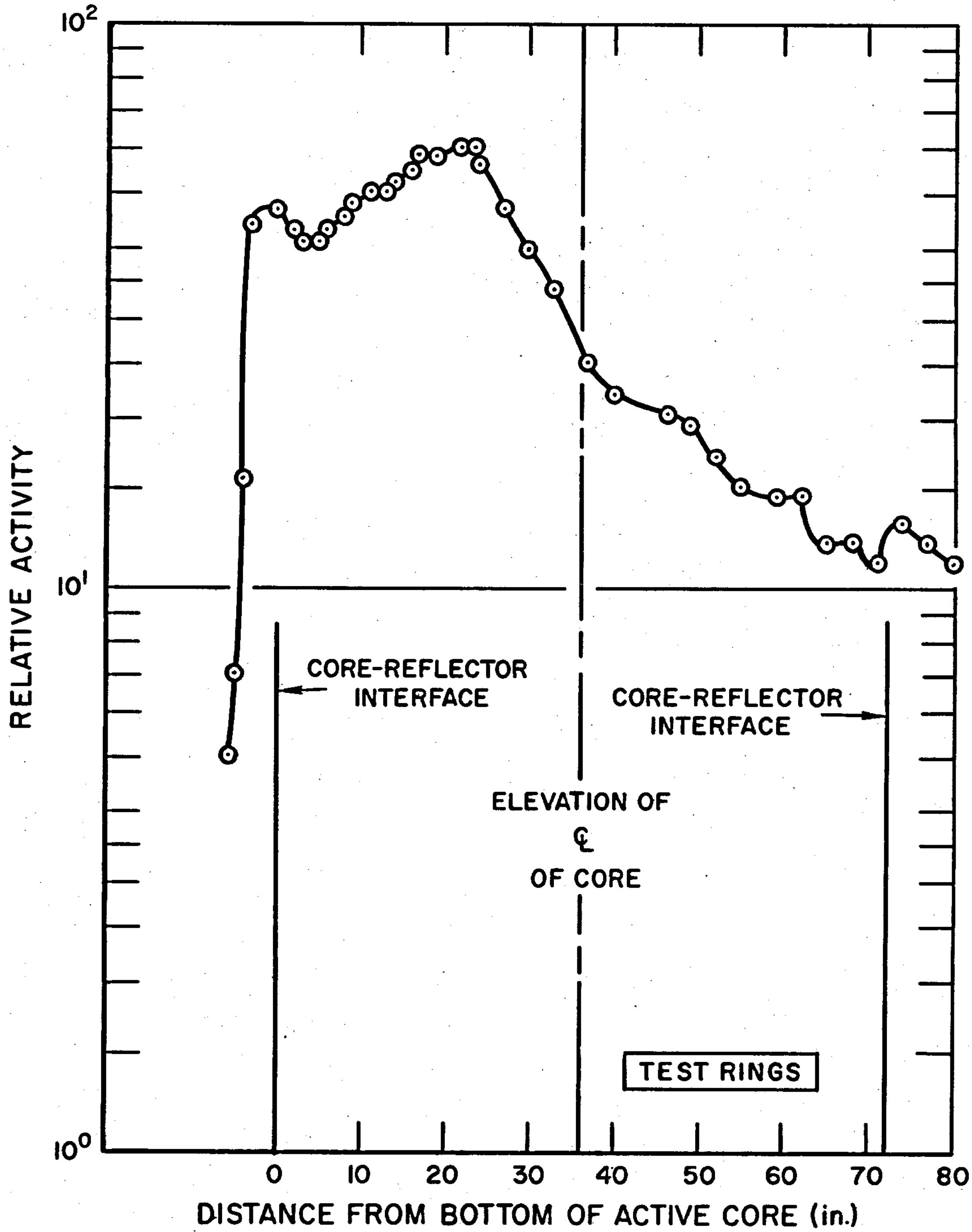

Figure 13. Gamma Activity of Thimble

cadmium is unusable because of its melting point, as is the cobalt-aluminum alloy used successfully at other reactor installations. Pure cobalt has a severe radiation level problem associated with irradiation for the length of time required by other experimental considerations at the SRE. In the second of the control rod heat generation and temperature experiments being conducted in support of the HNPF effort, it is planned to use a high-cadmium-bearing ceramic material, in the form of beads, over a metallic detector material (probably a cobalt alloy) in an effort to obtain a legitimate cadmium ratio. This technique may provide an explanation for the unexpected shape of the axial flux distribution obtained in this test, since one of the theories advanced in explanation of this anomaly uses a nonuniform distribution of thermal and epithermal flux in the reactor core as a basic assumption.

V. DISCUSSION

The only significant mechanical failure in the test was the shortcoming of the eccentric-ring-positioning mechanism. Had this mechanism proved satisfactory, it would have been possible to make direct comparison of the test data to the results of the mockup test data,[1] almost all of which dealt with the eccentric case. However, it has become apparent that this failure was not as serious as believed earlier since direct comparison can be made with the temperatures of ring no. 1, which was of the same material and had the same dimensions. The comparison is quite useful since ring no. 1 was subjected to flux at its lower end (the so-called "lightning-rod" effect), resulting in a larger heat generation rate.

With regard to the split ring, the clearance between the two shells was chosen to give a temperature difference between the parts of about 100°F at 20 Mw of reactor power. The basis for the selection was an estimate of heating due to SRE gammas and not upon empirical information. In order to measure the expected temperature difference as accurately as possible, opposing pairs of thermocouples were connected to read differentially. Early in the test period it became apparent that the heating due to gammas was much smaller than estimated; temperature differences were insignificantly small (10°F maximum). These differences were of the same magnitude as the errors of the thermocouple indications. The thermocouples were then connected to read absolute temperature only. This then, is why temperatures are not given in Table I for the split ring during low-power reactor operation.

Considerable emphasis was placed on accuracy in calibration of the thermocouples. They were purchased for the test under ISA specifications for Chromel-Alumel thermocouples which call for an accuracy of plus or minus 3/4%. Each thermocouple was individually calibrated against a platinum-rhodium secondary standard prior to installation into the test assembly. Since the thermocouples were all about 20-ft long, it was impossible to immerse them completely in the calibration furnace; only the first 2 ft were at the temperature of calibration. The resultant calibration curves showed variations in output as large as 2%.

However, the results from the calibration run made during the off-gassing and drying operation showed about 1/4% variation from the mean readings of all nearby thermocouples (those in the same ring). Even though this was not strictly a calibration, the results indicated that the thermocouples were much more accurate than the calibration performed prior to installation into the assembly would indicate. A research project performed on Chromel-Alumel thermocouples under Oak Ridge sponsorship[2] indicates that the depth of immersion of Chromel-Alumel thermocouples affects thermocouple output. This effect may result in outputs varying by as much as 50°C for a change in immersion depth of as little as 4 in.

It is believed, therefore, that the furnace calibration check was the better technique, since the entire assembly was at temperatures near the experimental ones, and that the calibration errors were smaller than any other source of error in the experiment. Consequently, no corrections have been made on the recorded temperatures, and none are believed necessary in light of the overall accuracy of the experiment.

With regard to the overall accuracy of the experiment, it must be noted that there were several sources of errors. Many of these are inherent with inpile testing where it is impossible to control or detect all the variables as well as may be desired. In addition, many quantities necessary for heat generation and heat transfer calculation, e. g., the neutron flux, the radiant emmissivity, and the thermal conductivity of the various components, are not easily determined or are not well known. In the present experiment, a variation or error in clearance between the poison rings and the thimble wall of even two or three thousandths of an inch could mean an error of 15% or more in heat transfer calculations. Dimensional uncertainties of this magnitude are certainly likely even though all parts were carefully measured before the test was begun and every possible precaution was taken to ensure well-defined dimensions. The measured temperatures, however, should be correct within 1 or 2%. With these thoughts in mind, it should be noted that prediction of heat generation rates and temperatures to be expected of this general type of control rod and these absorber materials should still be within 20 or 30% of the actual values.

VI. CONCLUSIONS

Though the test was quite complex and not all variables were under complete control, e. g., reactor power operating conditions and coolant temperatures, the results of the experiment were generally valuable data for analysis and design of SGR control rods. The analysis of the test results is not yet complete. However, preliminary results indicate that use of combined shim-safety rods employing boron absorber materials will not be feasible in the Hallam reactor since the maximum temperature of the pull tube might reach 2000°F. (The specific power density will be somewhat greater in HNPF than in SRE.) Development work is in progress utilizing rare earth oxide materials which absorb neutrons by an (n-γ) reaction. These materials, because of their nuclear characteristics, would have a much lower specific heat generation rate and should therefore permit operation at safe temperatures with a sufficiently large radial clearance to permit a combined shim-safety type control rod. A second test to be conducted in the SRE, quite similar to the one reported here, is in the planning stage and will employ these rare earth oxide materials as neutron absorbers. The results of the second test are expected to decide feasibility for the use of a combined shim-safety rod in the Hallam reactor.

REFERENCES

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2. D. L. McElroy, "Progress Report I, Thermocouple Research Report for the Period 1 November 1956 to October 31, 1957," ORNL 2467, 5 March 1956