OPERATION OF A WATER BOILER NEUTRON SOURCE

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ABSTRACT

A low power homogeneous reactor of the water boiler type has been in operation in the Atomic Energy Research Department of North American Aviation, Inc., Downey, California since April, 1952. The reactor, which was designed primarily as a research reactor, is described in some detail. Some of the operational characteristics and experimental uses at power levels up to one watt are given. The operational history, which has been quite varied up to the present, has pointed out the usefulness and versatility of the reactor as a tool for a great many varied research programs.

This report is based on studies conducted for the Atomic Energy Commission under Contract AT-11-1-GEN-8.

I. INTRODUCTION

A low power homogeneous reactor of the water boiler type[1] has been in operation at the Atomic Energy Research Department of North American Aviation, Inc. since April, 1952. This reactor, called the water boiler neutron source (WBNS), was designed primarily as a source of neutrons for experimental purposes. The reactor is operated at power levels up to one watt, and at this level, it supplies a maximum thermal flux of approximately 4×10^7 neutrons/cm^2-sec at the center of a test hole through the spherical core, along with somewhat lesser values of flux in exposure facilities in the graphite reflector.

The WBNS is well suited for neutron absorption cross section measurements by the danger coefficient technique because of its low nuclear cross section which results in a high sensitivity. It is an economical type of reactor on which personnel training, instrument and material testing along with other reactor engineering studies, can be conducted. It will also furnish sufficient neutron flux for a great many types of neutron irradiations for studies in nuclear physics, radiochemistry, and biophysics. The water boiler type reactor also combines strong inherent safety features with the above characteristics. These result from the very large negative temperature coefficient and negative power coefficient of reactivity. These negative coefficients are sufficient to shut down the reactor in the event of accidental releases of large amounts of reactivity. This shutdown will occur with a relatively small release of energy.

II. DESCRIPTION OF THE WBNS

The WBNS is a light water moderated graphite reflected solution type reactor. The core consists of a solution of highly enriched uranyl nitrate in a 1-foot diameter stainless steel sphere. This sphere is encased in a cylinder of pile grade graphite, 5 feet in diameter by 6 feet high, which serves as a reflector and vertical thermal column. The entire cylinder is surrounded by a 2-foot thick concrete block radiation shield. The reactor installation is shown in Fig. 1, which is a view of the graphite cylinder with an experimental tank in place on top of the vertical thermal column. One wall of the concrete shielding blocks has been removed to show the installation in some detail.

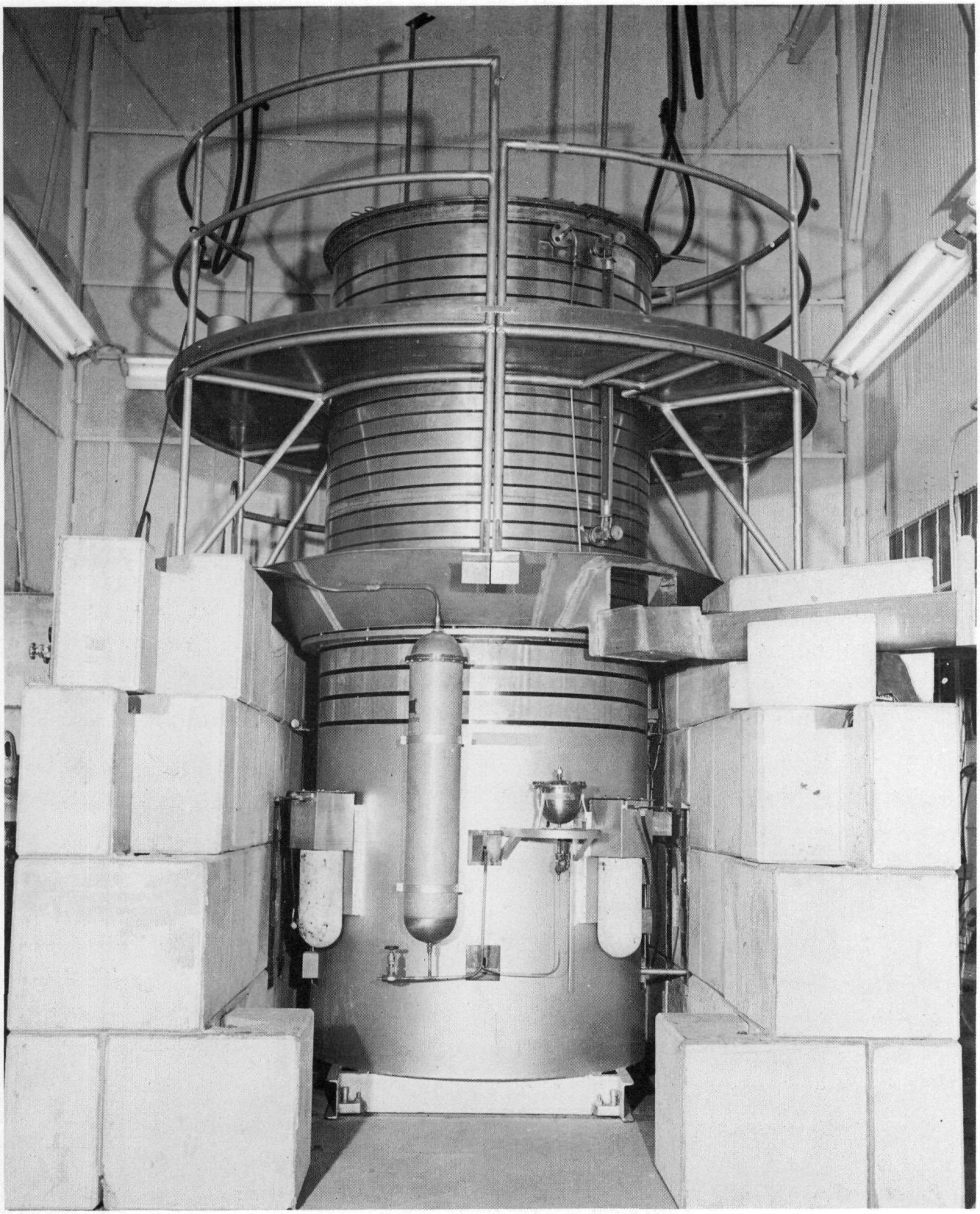

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Fig. 1. WBNS Installation

Figure 2 is a sectional view of the reactor showing locations of the stainless steel sphere forming the reactor core, the control and safety rods, the central exposure facility through the graphite reflector and through the sphere, and the removable graphite stringers which provide additional neutron irradiation facilities.

A. Graphite Reflector

The graphite reflector was formed by stacking graphite bars, 4-1/8 inch by 4-1/8 inch in cross section, horizontally inside a steel tank with the bars in alternate layers placed orthogonal to each other. Eight of these graphite bars (stringers) near the sphere, as shown in Fig. 2, can be removed to form radiation exposure facilities. Parallel to the removable stringers is the central exposure facility which passes through the graphite and through the stainless steel sphere and permits access with small samples to the region of highest flux. The steel tank containing the graphite has walls 1/4-inch thick and is supported by 6-inch channel beams welded to the bottom. The reflector installation is shown in Fig. 3, which shows the removable stringers out of the reflector. The central exposure facility is shown passing through the sphere. A second view of the installation showing the concrete shielding partially in place along with the removable shielding plugs is given in Fig. 4.

B. Core and Fuel Handling System

The fluid fuel handling system consists of the stainless steel sphere, a fluid mixing tank, a gas accumulator tank, and the necessary piping and valves. With the exception of the teflon seats in the valves and a neoprene rubber bag, the entire fuel handling system is constructed of Type 347 stainless steel. Prior to the loading with uranyl nitrate solution, the system was vacuum tested with a mass spectrograph type leak detector and pressure tested to 150 psi. A schematic diagram is given in Fig. 5, and a view of the external parts of the system before completion of the assembly of the shield is shown in Fig. 6.

The sphere forming the reactor core is constructed from two hemispherical spinnings of stainless steel sheet, 1/16-inch thick, and has a volume of 14.38 liters. The central exposure facility in the core has been formed by inserting a tube, 1-1/8 inches inside diameter, through the sphere with its center line 3 inches below the horizontal diameter of the sphere. A tube, 3/16-inch

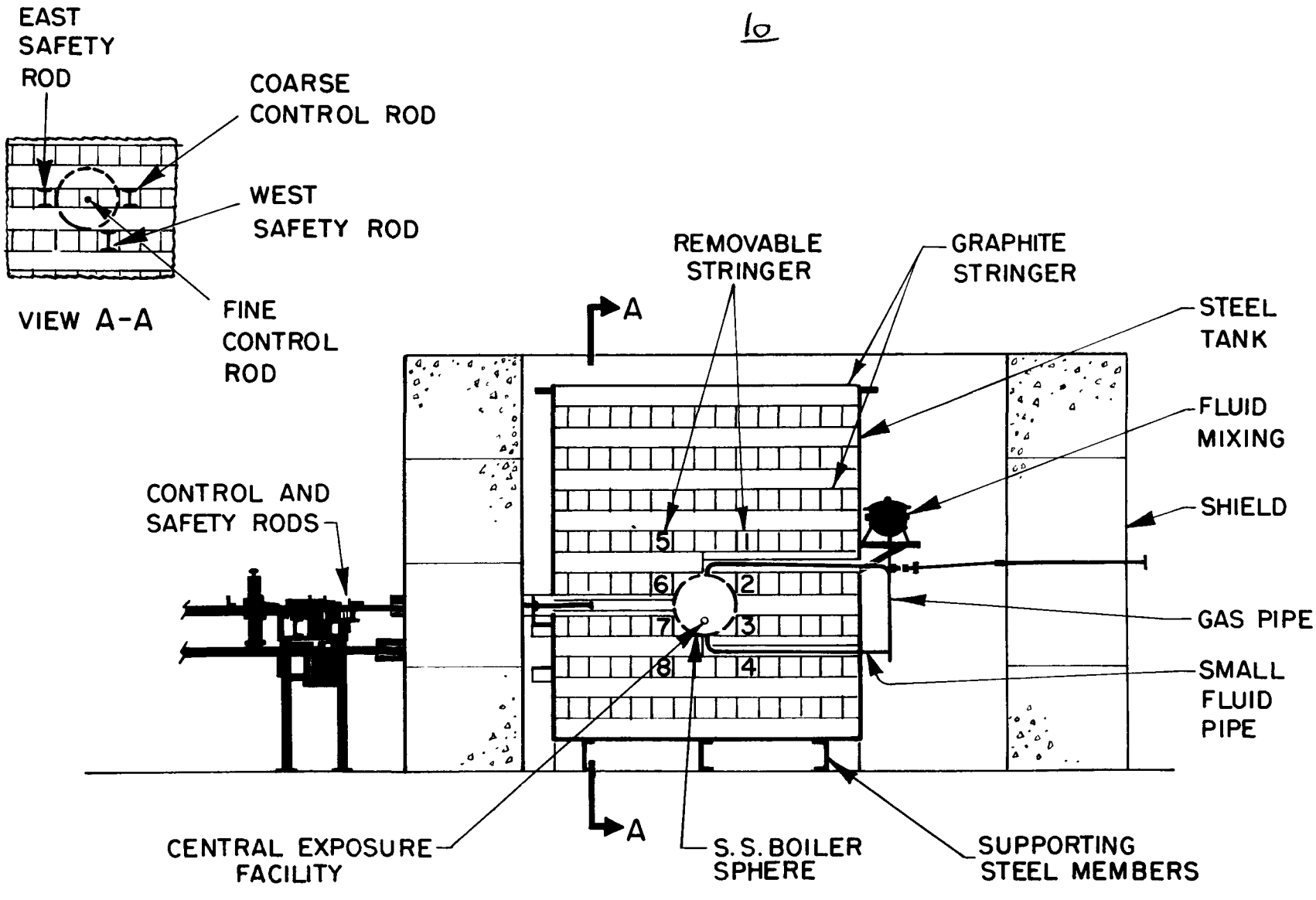

Fig. 2. Sectional Assembly of the WBNS

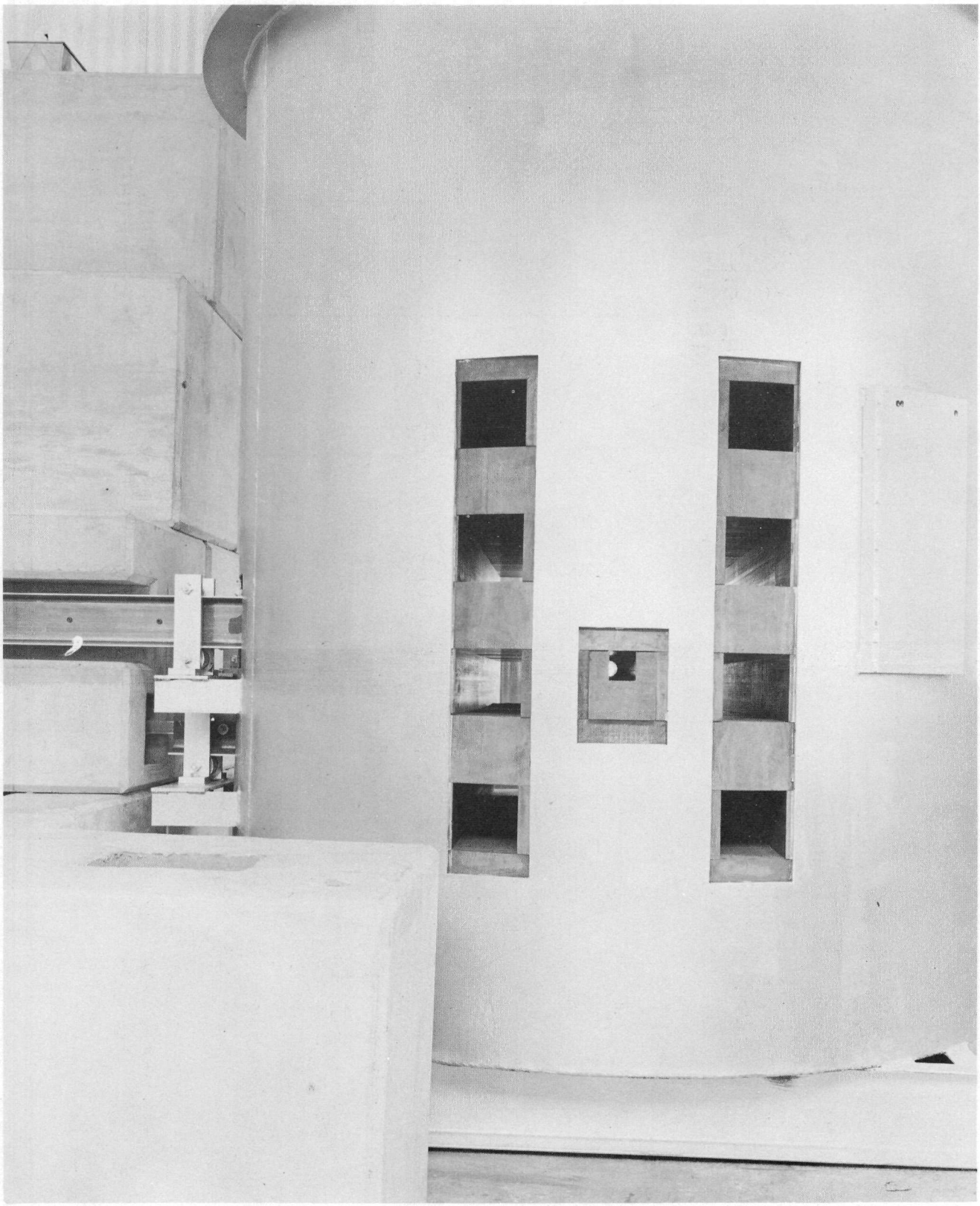

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Fig. 3. Graphite Reflector Installation, Removable Stringers

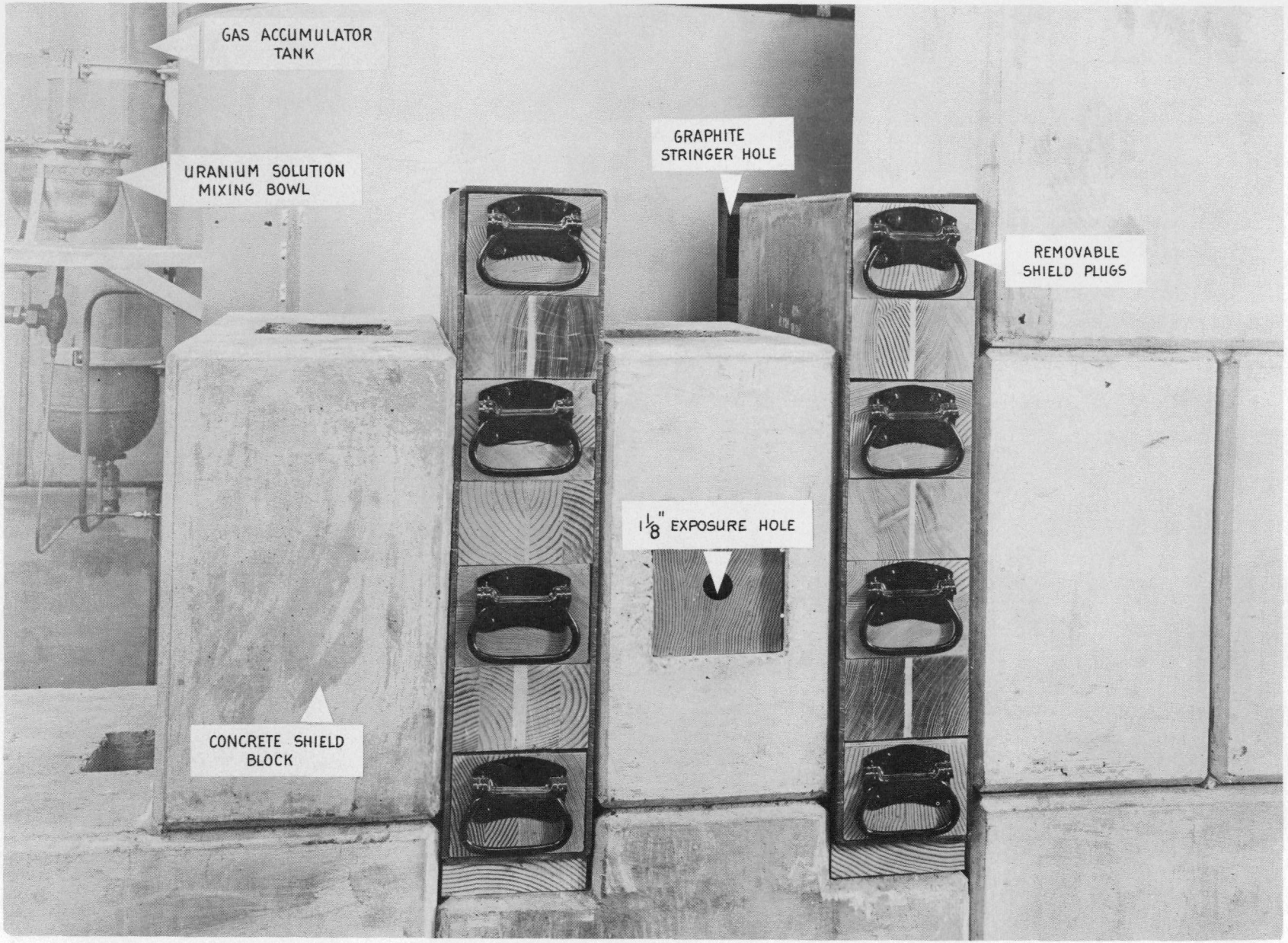

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Fig. 4. Graphite Reflector Installation, Concrete Shielding and Removable Shielding Plugs

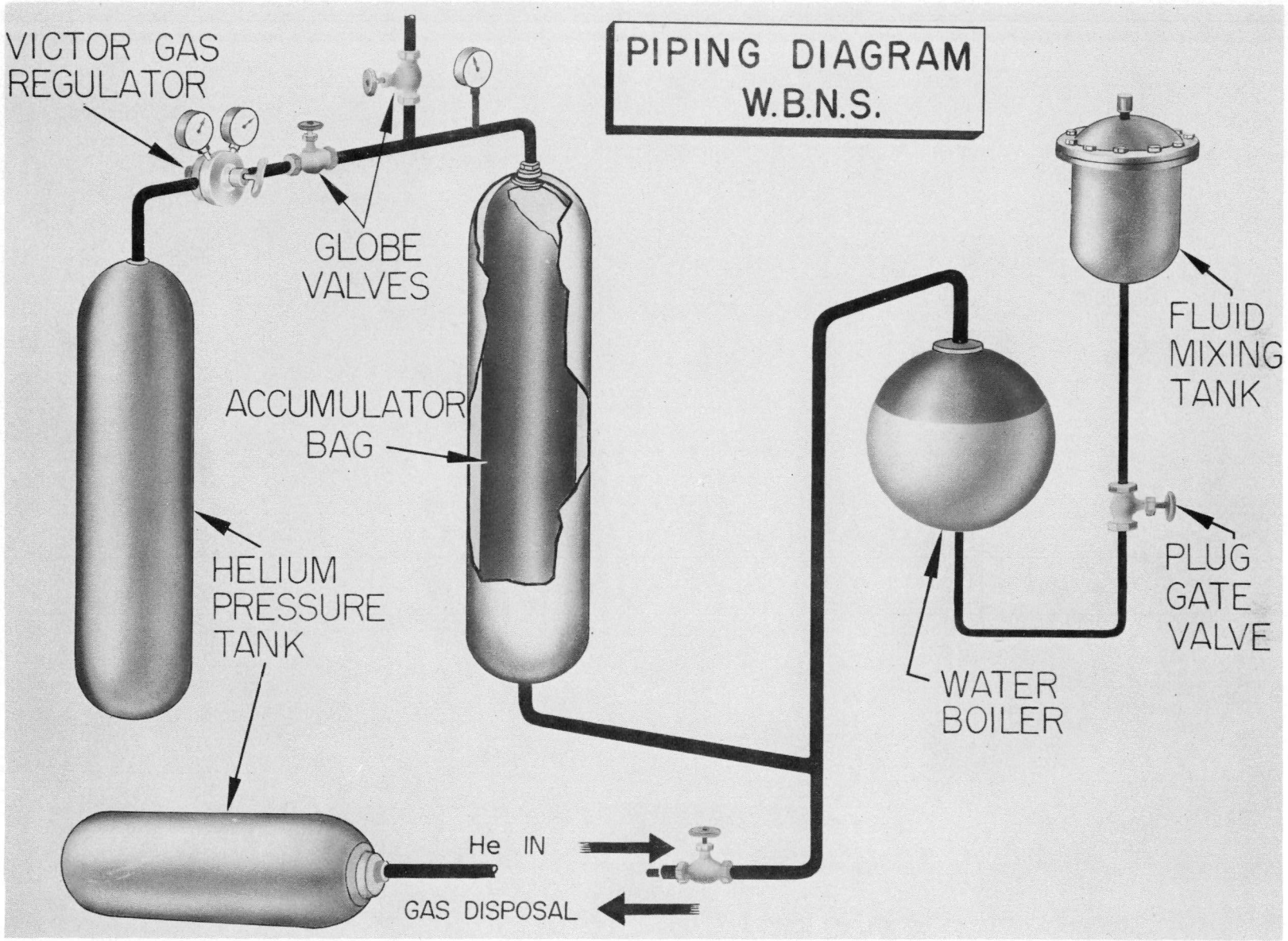

Fig. 5. Schematic Diagram of the Fuel Handling System

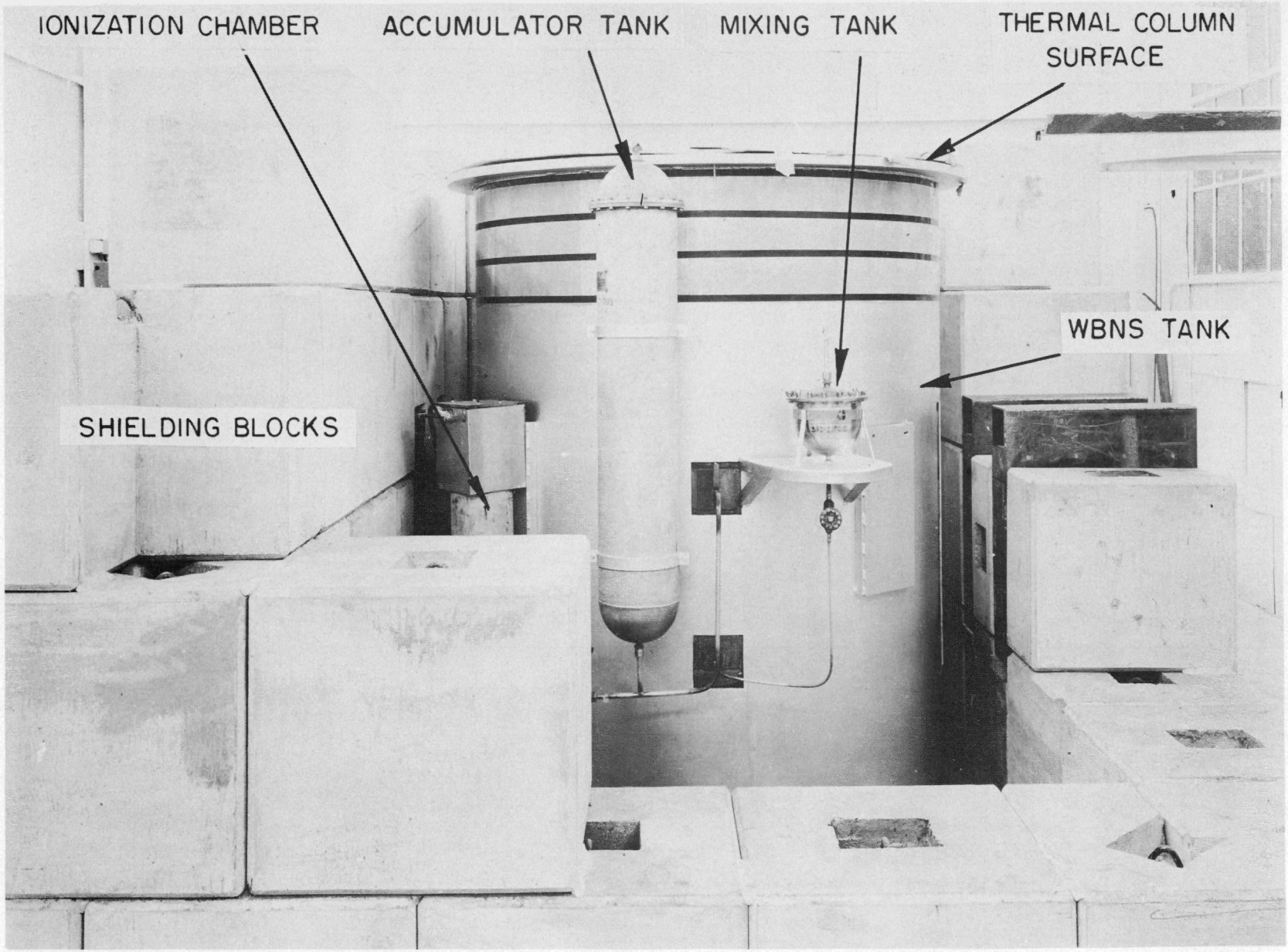

Fig. 6. Installation of Fuel Handling System External to the Steel Tank Containing the Graphite

inside diameter at the bottom of the sphere connects to the fluid mixing tank through a stainless steel gate valve, and a tube, 1/2-inch inside diameter, at the top of the sphere allows passage of gas to the accumulator tank.

The fluid mixing tank, which has a volume of approximately three liters, has a removable cover with a stainless steel flared tube fitting. Solution may be added to the system by piping it into the mixing tank and then allowing it to flow by gravity into the spherical core.

The gases which are evolved from the fission process and from the decomposition of the solution are collected in the gas accumulator tank of stainless steel of approximately 40 liters volume. The inside of this tank is divided by a neoprene rubber bag, and the gas is collected between the outside of the bag and the inside of the tank. When necessary the gas can be removed by transferring it from the accumulator to a storage vessel.

C. Control and Safety Rod System

The reactivity control is maintained with two safety rods, east safety and west safety, a coarse control rod and a fine control rod located as shown in Fig. 2. These rods move horizontally through the concrete shield and into the graphite reflector adjacent to the stainless steel sphere. Each safety rod is constructed of two 1/4-inch thick strips of Boral attached to aluminum channel beams. This forms an I beam about 3 feet long by 4 inches high. The rods are removed from the graphite reflector manually and are held in the "out" position by magnetically actuated latches. If the holding magnets are de-energized, the safety rods are pulled into the reflector in approximately 0.5 seconds by weights suspended from cables placed over pulleys.

The coarse control rod is constructed similarly to the safety rods, but with cadmium sheet instead of Boral as the neutron absorber. The motion of this rod is obtained with a reversible electric motor drive system. The traverse of the rod is 80 centimeters, and approximately 155 seconds are required for the movement from the "in" position to the "out" position.

The fine control rod, which is used as an automatic power regulating rod, consists of a 1-inch diameter steel pipe with provision at the end for insertion of varying amounts of cadmium. At present, this rod controls approximately 0.1 per cent in reactivity. The automatic control feature utilizes a Brown servoamplifier, whose input is the difference between the signal from one of the

electrometers monitoring the neutron level of the reactor and a variable standard signal. The output of the amplifier drives a two-phase motor (a chart-drive motor from a Brown chart recorder), which in turn drives the fine control rod through a suitable gear train. Each of the control rods is provided with a selsyn remote indicator. The installed control and safety rod mechanisms are shown in Fig. 7.

D. Instrumentation and Control Console

Figure 8 shows a view of the instrument control panel which is located in a laboratory area immediately adjacent to the reactor. A block diagram of the instrumentation for control of the reactor is shown in Fig. 9. Four neutron flux measuring instruments placed at different positions around the graphite reflector are used for monitoring the power level of the reactor. Two of these are BF_3 ionization chambers connected to vibrating reed electrometers. The others are a boron-lined counter connected to a counting rate meter and a BF_3 proportional counter connected to a scale of 128 scaling unit. A Brown recorder located in the instrument panel continuously records the signal from one of the ionization chambers to provide a permanent record of the reactor power level. Sensitrol relays are connected to the output of each electrometer and to the counting rate meter. Operation of any one of these three relays will release the safety rod latches and shut down the reactor.

E. Shield

The biological shield consists of a concrete block wall 7 feet in height completely surrounding the reactor. The blocks were fabricated of ordinary concrete and are 24 inches by 24 inches by 21 inches high. Each of the blocks weighs approximately 1000 pounds and can be easily handled with a hoist by means of a steel hook cast into the block and countersunk below its top surface.

III. CRITICAL ASSEMBLY

The critical assembly was performed by making successive additions of highly concentrated uranyl nitrate solution to the reactor core. Prior to the addition of any fissionable material, 11,980 cm^3 of distilled water was added to the stainless steel sphere, and the fuel system was flushed with helium. After

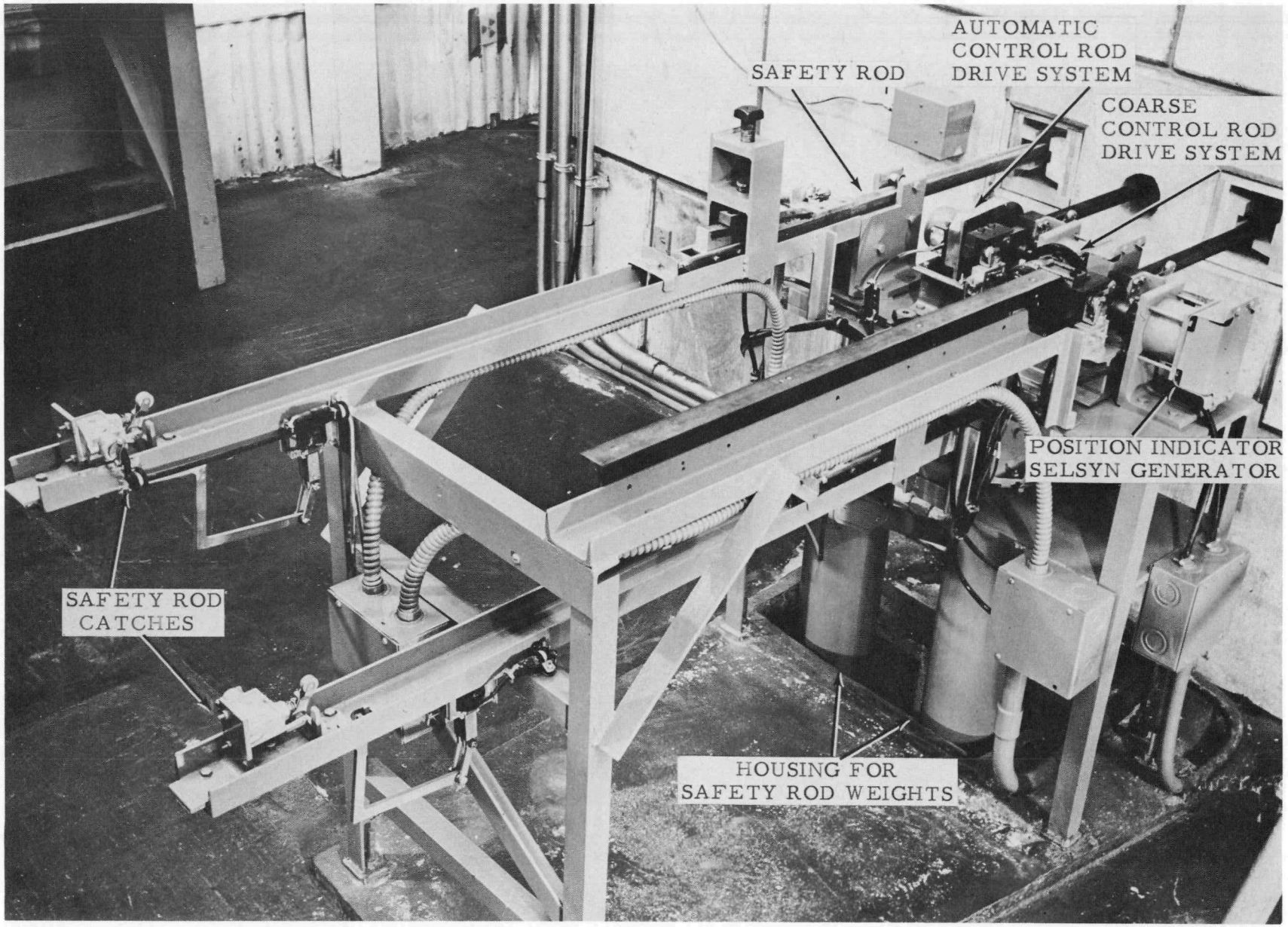

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Fig. 7. Control and Safety Rod Assembly Located Outside the Concrete Shielding Blocks

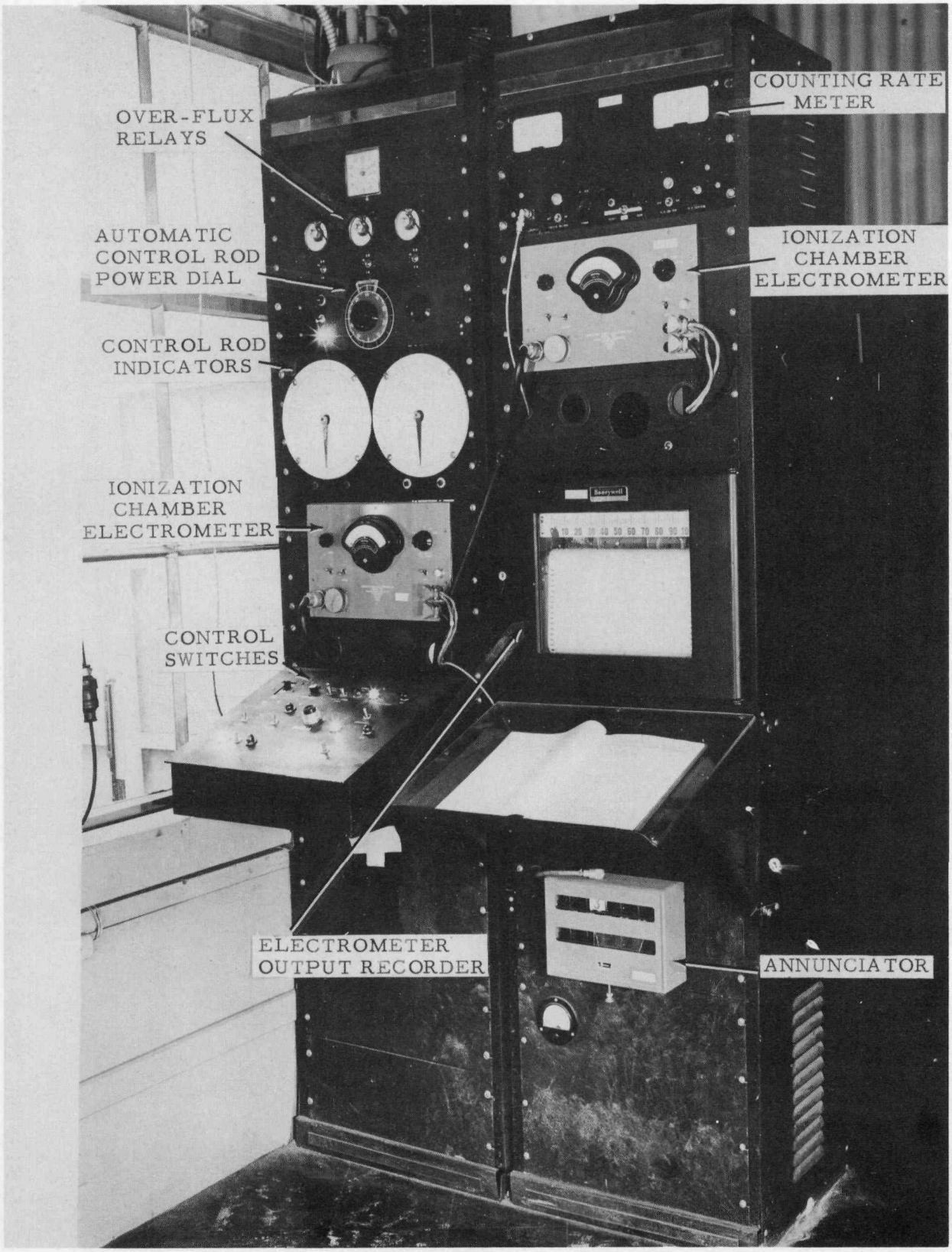

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Fig. 8. Control Console for WBNS

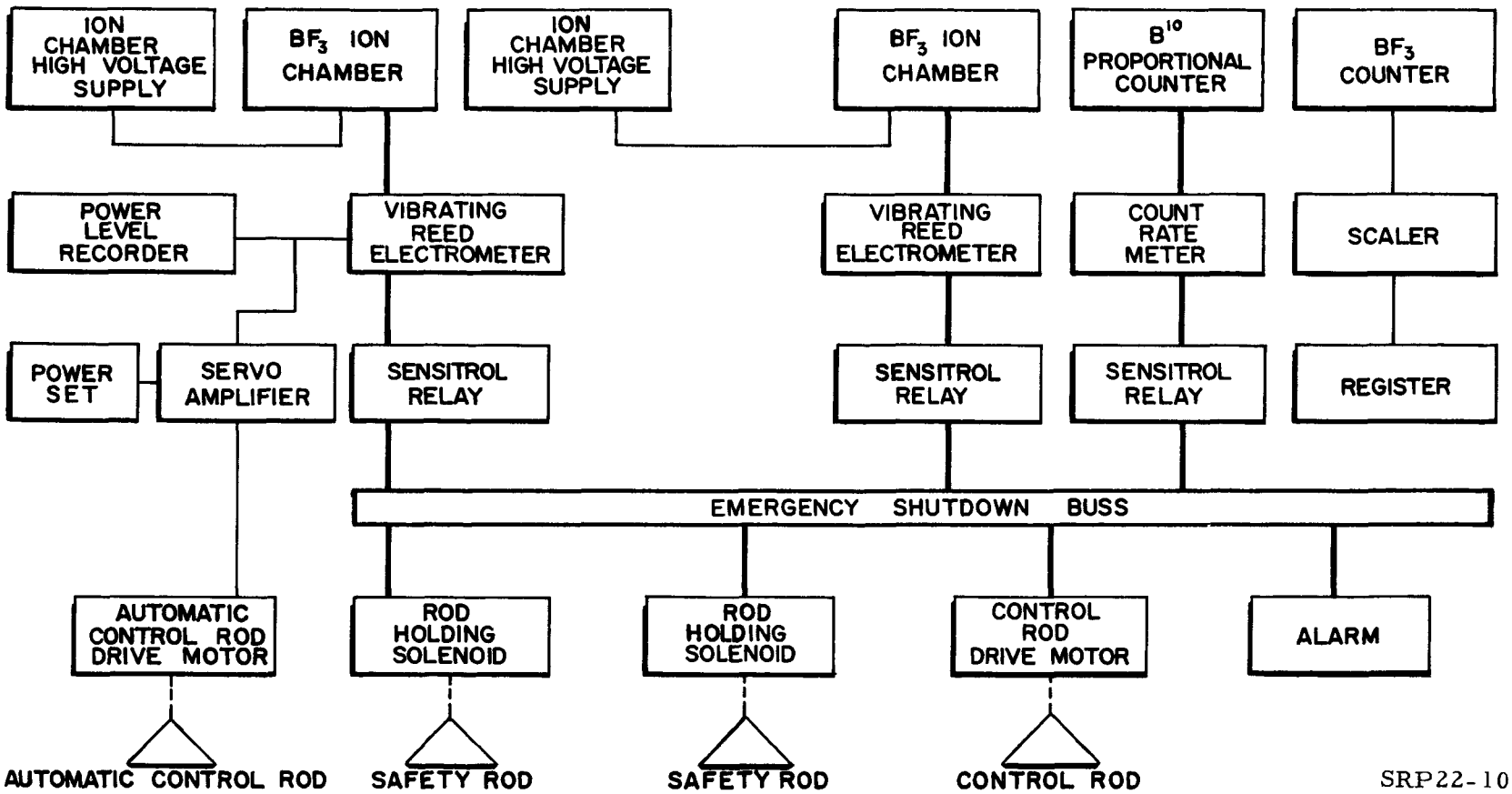

Fig. 9. Block Diagram of the Instrumentation for Operation and Control of the WBNS

each addition of fissionable material measurements were made on the change in reactivity produced by the addition of the U^{235}. The changes in reactivity were observed by the multiplication of a 5.7 curie Po-Be neutron source inserted in the central exposure facility up to the center of the tube through the sphere. The measurements were made with suitably located BF_3 ionization chambers, boron-lined neutron counters, and with indium foils (approximately 90 mg/cm^2) located in the graphite reflector along a radial line from the edge of the sphere out to the edge of the graphite. Plots of the reciprocal counting rates as functions of the amount of fuel in the sphere permitted an extrapolation to the critical mass some time prior to the attainment of the critical state. Typical results are shown in Fig. 10, in which are given the data obtained with three types of neutron detectors used during the critical assembly. The differences in these curves result from the different locations of the detectors during the assembly. The lower curves resulted from detectors placed at greater distances from the reactor core. The reciprocal counting rates given here have all been normalized to unity with the sphere essentially full of water and with no fissionable material present. The extrapolated critical mass from these curves is 635.7 grams of U^{235}. This amount less the 1.8 grams of equivalent absorption of the Po-Be source gives a critical mass of 633.9 grams of U^{235} for the WBNS with all the control and safety rods retracted.

A total of 638.2 grams of U^{235} was added to the reactor core. This amount of fissionable material was sufficient to give a divergent chain reaction with a period of 26 seconds, corresponding to an excess reactivity of 0.21 per cent. A mass coefficient of reactivity for the WBNS was determined to be 0.050 per cent per gram of U^{235}. The mass coefficient of reactivity for LOPO[1] was determined by means of a "boron bubble" experiment to be 0.0548 per cent per gram of U^{235}. It is interesting to note here that these mass coefficients appear to be inversely proportional to the critical masses of the two reactors, i. e.,

$$\left(\frac{\Delta k}{\Delta M}\right)_{WBNS} (M_c)_{WBNS} = 0.050 \times 633.9 = 31.7$$

$$\left(\frac{\Delta k}{\Delta M}\right)_{LOPO} (M_c)_{LOPO} = 0.0548 \times 565.5 = 31.0$$

During the critical assembly, measurements of the multiplication of the neutron source were also made with the coarse control rod completely inside the reflector. Extrapolation of the reciprocal counting rate versus amount of U^{235} for these data indicate the absorption of the coarse control rod to be

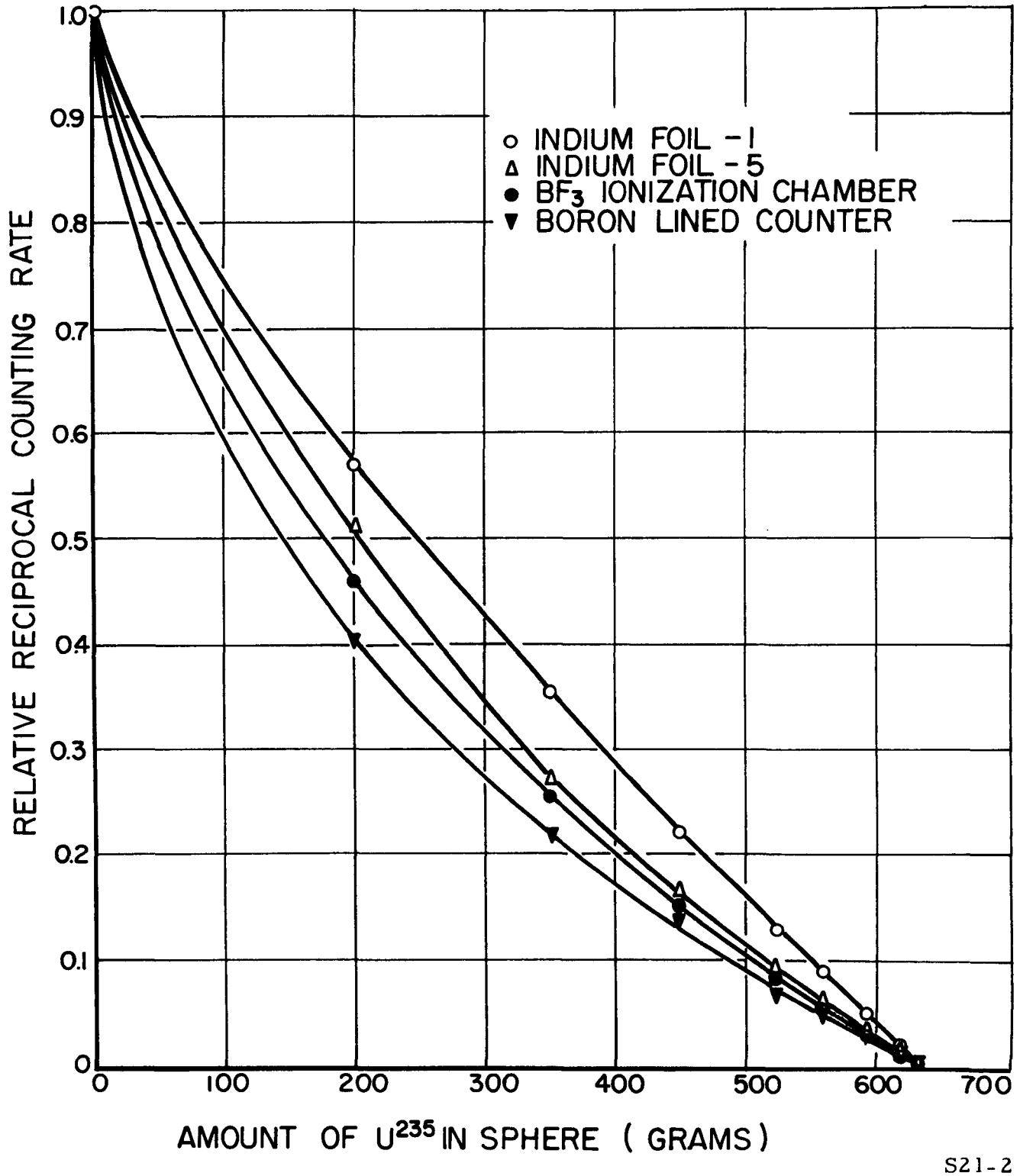

Fig. 10. Data Obtained with Three Types of Neutron Detectors During the Critical Assembly of the WBNS

equivalent to 21 grams of U^{235}. Using the above determined mass coefficient of reactivity, the coarse rod is then found to control 1.05 per cent in reactivity.

IV. OPERATIONAL CHARACTERISTICS

The WBNS is started into operation with a 250 millicurie Ra-Be neutron source inserted in the center of graphite stringer number 4 (see Fig. 1). This source emits about 3×10^6 neutrons/sec, which results in a "shutdown" power level of the reactor of about 0.5 milliwatt. A very large part of the operation is carried out with the source in place in the reflector. This results in quite a stabilizing influence on the operation, particularly at the low power levels at which the reactor is operated.

A. Effectiveness of Control and Safety Rods

The reactivity control of the safety rods individually, the two rods together, and the safety rods plus the coarse control rod has been determined. Since the reactor loading and the amount of control by the coarse control rod are known, k_{eff}, the reproduction factor for the reactor, is known for the subcritical state produced with the safety rods withdrawn and the coarse control rod completely in the reactor. The relative multiplications of a Po-Be neutron source inserted into the sphere of the reactor were determined with this configuration of control and safety rods and with other appropriate subcritical configurations necessary to determine the amounts of control desired. The multiplication in these subcritical states will be given by:

$$M = \text{multiplication} = \left(\frac{1}{1 - k_{eff}} \right) \quad . \qquad \ldots (1)$$

Then from two measurements of relative multiplications for different rod configurations, one obtains:

$$(k_{eff})_1 = 1 - \frac{M_o}{M_1} \left[1 - (k_{eff})_o \right] \quad , \qquad \ldots (2)$$

where M_o and $(k_{eff})_o$ are the multiplication and reproduction factor for the known subcritical configuration, and M_1 is the measured multiplication for a configuration in which $(k_{eff})_1$ is unknown. After values of k_{eff} for these unknown configurations have been determined, the amount of control in the rods is readily obtainable.

The results of these measurements are shown in Table I. It is to be noted that there is some shadowing between the rods, since in no case is the amount of control by two rods together equal to the sum of the amounts of control by each rod separately. Since the two safety rods are identical in construction but are located in different regions of the reflector (see Fig. 2), the difference in reactivity control by these rods should be expected.

TABLE I

REACTIVITY CONTROL OF CONTROL AND SAFETY RODS IN WBNS

Rods	Reactivity Control (in per cent)
Coarse Control Rod	1.05
East Safety Rod	1.45
West Safety Rod	1.17
Coarse Rod and East Safety	2.44
Coarse Rod and West Safety	1.93
East Safety and West Safety	2.44
Coarse Rod and Both Safety Rods	3.27

B. Calibration of Power Level

The power level of the water boiler has been determined by measuring the thermal neutron flux in the central exposure facility. The power, P, of the reactor is given by

$$P = \frac{N_{25}\ \sigma_{25}\overline{nv}}{3 \times 10^{10}} \quad ,$$

where P is the power in watts, N_{25} is the number of atoms of U^{235} in the sphere, σ_{25} is the fission cross section of U^{235}, and $\overline{nv}$ is the average flux in the reactor core. From flux measurements in the Los Alamos water boiler,[2] the average flux, $\overline{nv}$, is determined to be 0.74 of the flux at the center of the spherical core. Since the WBNS is very similar to the Los Alamos reactor, the flux distribution and ratio of $\overline{nv}/(nv)_{max}$ should be comparable. Hence, this value has been used in our determination. The neutron flux was measured with standardized indium foils which had been exposed to a known thermal flux. These measurements were then used to calibrate one of the BF_3 ionization chambers and the

Brown recorder used to monitor the power level of the WBNS. This absolute calibration is accurate to only about ±30 per cent, because of a lack of accuracy in the standardization of the indium foils.

C. Rate of Gas Evolution

Gas evolution resulting from the dissociation of water on the absorption of fission product energy in the solution has been observed at operating levels as low as 0.1 watt. The rate of gas evolution has been determined by the following procedures. After a period of operation in which the total fission energy release is determined from integration of the recorded power level, the gas in the accumulator system is removed into a known volume in which the pressure and temperature are measured. Samples of the gas are then analyzed for hydrogen content by mass spectrographic means. The rate of hydrogen evolution is then determined from the amount of hydrogen in the accumulator and the total operation for the period.

Several measurements of this rate have been made after periods of operation totaling 30 to 50 watt-hours. Data from operation of the Los Alamos HYPO version of the water boiler[1] indicated that the rate of gas evolution would be about 7 to 8 cm^3 of hydrogen per watt-hour of operation. Therefore, the above mentioned periods were chosen to prevent the possibility of formation of an explosive mixture of hydrogen and oxygen in the closed accumulator system. The measurements show the rate of hydrogen evolution to be approximately 10 cm^3/watt-hr. The determinations are consistent, but this value for the rate of evolution is subject to the uncertainty in the power level calibration previously mentioned. However, the rate determined here is consistent with that obtained at Los Alamos. Further, there are indications that the rate is somewhat less (approximately 10 to 20 per cent) at power levels of 0.1 watt as compared to operation at levels up to 1 watt.

D. Neutron Flux Distributions

Thermal neutron flux distributions in various available regions in the graphite reflector and in the central exposure facility have been measured by the activation of indium foils. Both bare and cadmium covered indium foils were used at each point to give the cadmium ratio (defined by the ratio of bare foil activity to cadmium covered foil activity) as well as the thermal neutron flux in each region. Most of the data were taken with indium foils 1 square

centimeter in area and approximately 90 mg/cm^2 in thickness. The cadmium covers were small boxes made of 20 mil cadmium sheet. For the flux distributions in the reflector, the foils were placed in a milled slot in the top of one of the graphite bars. This slot was just large enough for the foils to fit easily into it. The flux distribution in the central exposure facility was determined with foils mounted on a 2-SO aluminum foil holder. This results in some "neutron streaming" along this hole through the reflector. During each exposure a monitor foil was placed in a standard geometry in the reflector. The activities of these monitor foils permitted a suitable normalization of the activities of all the different foils.

The results of these measurements are shown in Figs. 11-13, where the flux is normalized to unity at the center of the sphere in the central exposure facility in the sphere. The cadmium ratio with these indium foils varies from 3.7 in the central exposure facility to 36.0 at the edge of the reflector in stringer number 1. The results show essentially symmetrical distributions about a vertical plane through the center of the core and graphite reflector with a peaking of the flux inside the spherical core. The perturbations introduced by the coarse control rod and the east safety rod channel are shown in the flux distribution along the top of stringer number 7 in Fig. 13. One should expect the distribution here to be very similar to that in stringer 2 (see Fig. 12), and this is observed except for the depressions in the vicinity of the rod channels. The flattening by the coarse control rod is more pronounced than that by the east safety rod channel, since the safety rod was completely withdrawn from the reflector, and the coarse control rod was withdrawn only about 35 centimeters, which placed the end of the rod at approximately the outer edge of the stringer.

Independent measurements of the flux distribution through the central exposure facility have been made with "lindium" foils (75 per cent indium and 25 per cent lead) 0.2 by 1.0 centimeters with thicknesses of approximately 70 mg/cm^3 of indium. The foils were placed in a cylindrical graphite holder which essentially filled the void in the tube through the sphere. These results are presented in Fig. 14, along with data taken in the LOPO sphere[2] with a U^{235} ionization chamber. The two sets of data were normalized at the common point, 7.6 centimeters from the geometrical centers of the spheres. This normalization is believed to be better than any other because of the difference in the reflectors of the two reactors, BeO for LOPO and graphite for the WBNS.

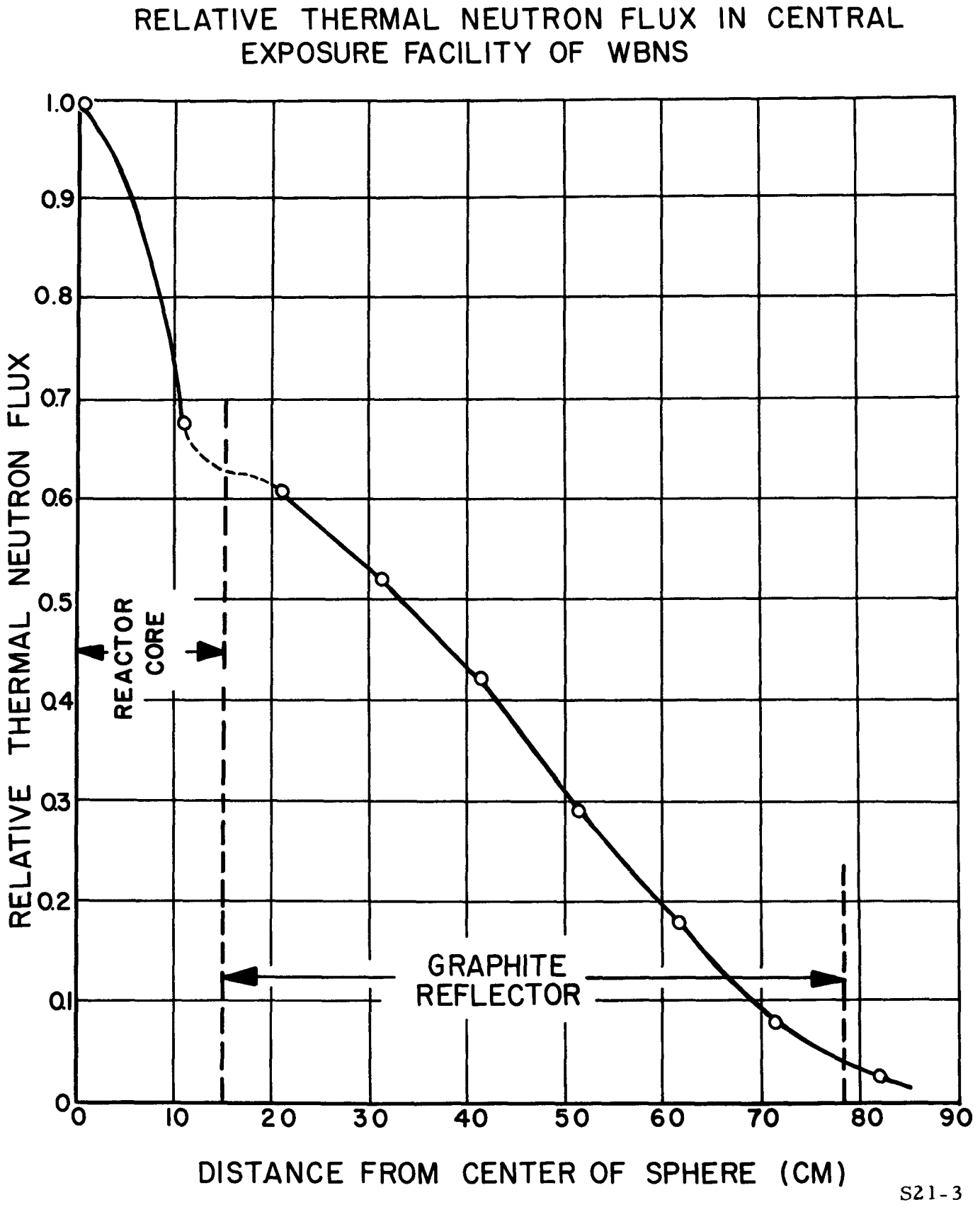

Fig. 11. Thermal Neutron Flux Distribution in the Central Exposure Facility

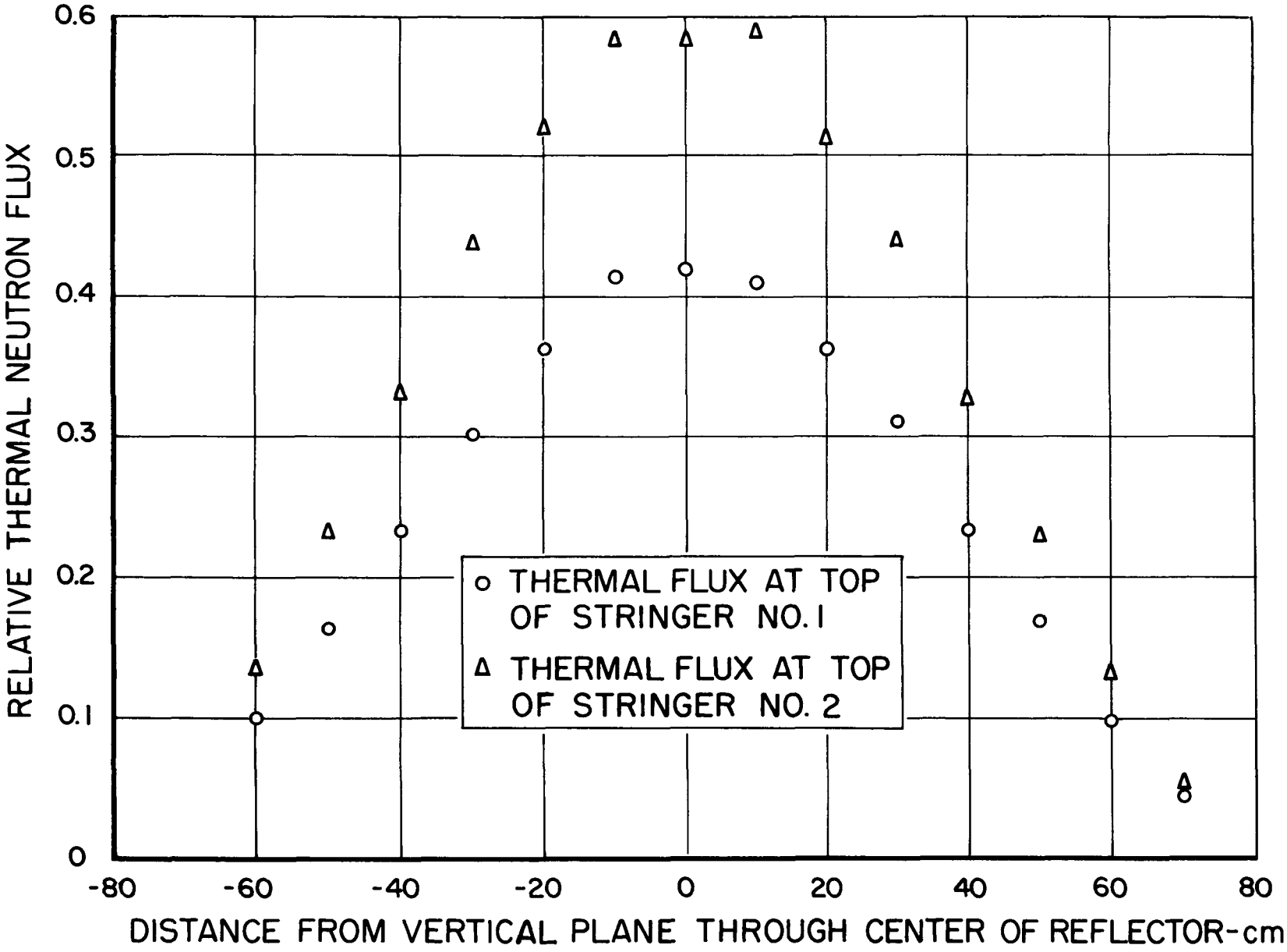

Fig. 12. Thermal Neutron Flux Distributions at the Top of Two of the Removable Graphite Stringers (The ordinate scale is the same as that of Fig. 11.)

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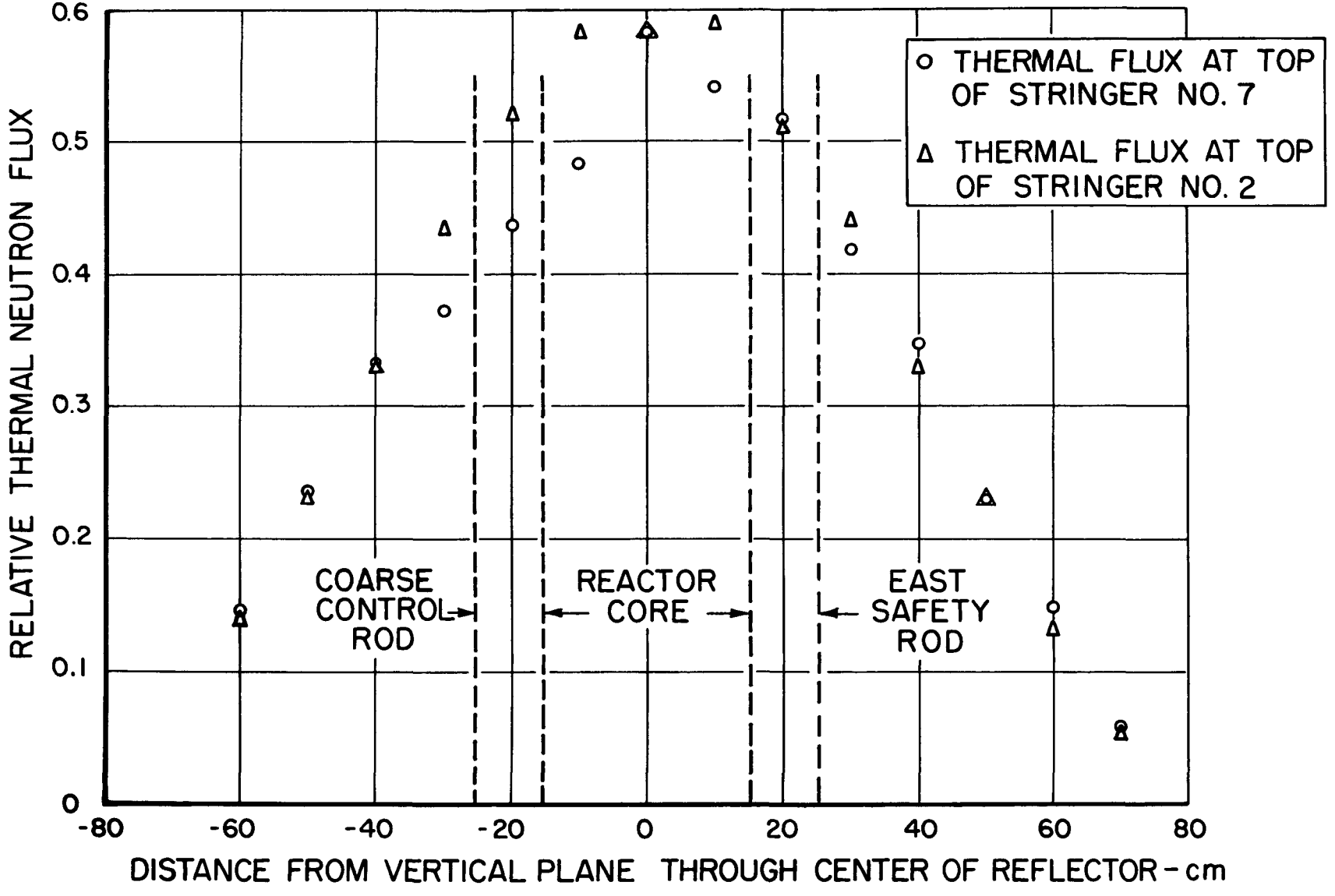

Fig. 13. Thermal Neutron Flux Distribution in Removable Stringer No. 7
(The ordinate scale is the same as that of Figs. 11 and 12.)

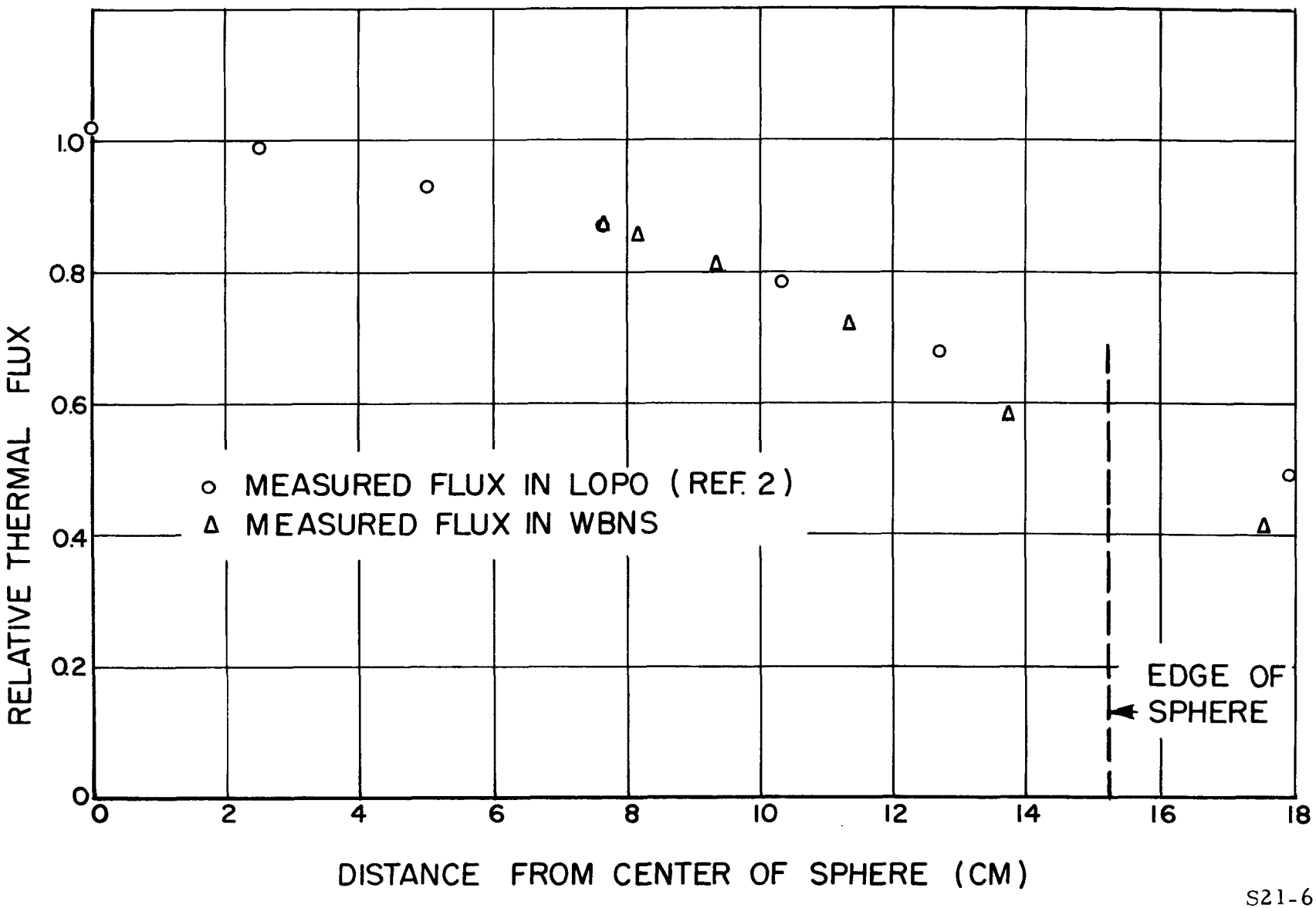

Fig. 14. Thermal Neutron Flux Distribution in the Central Exposure Facility Plotted as a Function of the Radius of the Sphere Along with Similar Data for LOPO at Los Alamos

The flux in the WBNS appears to fall below that in LOPO at the edge of the sphere. This is to be expected because of the greater production of thermal neutrons by the BeO reflector of LOPO compared to those produced in the graphite reflector of the WBNS.

Cadmium ratio measurements which have been made in the central exposure facility with foils of indium, gold, and manganese show that there is considerable fast neutron flux in the core of the WBNS. This property of a water boiler reactor could very possibly make it a useful source for the study of fast neutron radiation damage.

V. EXPERIMENTAL USES

The WBNS has been found extremely useful as a neutron irradiation facility where a thermal flux of the order of 10^6 to 10^7 is required. Subjects for irradiation can be placed in the central exposure facility or in one of the removable graphite stringers. There is also a flux of about 10^6 neutrons/cm^2-sec per watt available at the top of the vertical thermal column. The calculated k_∞ for the reactor is 1.56, and hence the leakage probability is 0.360, so that a large leakage flux per unit power is available for experimental purposes.

The various experiments in which the WBNS has already proved to be a valuable tool include the following:

1. Testing and calibration of ionization chambers, boron trifluoride proportional counters, and boron-lined counters for reactor instrumentation and neutron physics studies.
2. Irradiation of foils to be used in the development of absolute counting techniques.
3. Irradiation of foils in the study of resonance absorption of neutrons in various elements.
4. Study of radiation effects in structure-sensitive materials.
5. Testing and calibration of health physics instruments.
6. Testing of various materials for neutron absorbing impurities by the danger coefficient method to be described below.
7. Irradiation of iridium for research by staff members of the Chemistry Department of the University of California at Los Angeles on

electron-transfer isotopic exchange reactions of iridium complex ions in aqueous solutions.

Of very great importance has been the use of the WBNS as a neutron source for exponential experiments.[3] The vertical thermal column provides a rather large extended source of thermal neutrons on which various subcritical assemblies can be constructed. Neutron flux distributions are determined in these assemblies, which are mock-ups of the lattices in various types of reactors under study. Information derived from the measurements in the subcritical assemblies has contributed to the general knowledge of reactor theory as well as having aided materially in the design of specific reactor lattices.

The WBNS is also well suited for thermal neutron absorption cross section measurements by the danger coefficient technique.[4] This technique involves the insertion of a neutron absorber in the reactor which changes the reactivity of the reactor. By properly calibrating a reactor control rod with the insertion of known amounts of neutron absorbing material into the reactor core, the displacement of the control rod can be used as a precision measure of the absorption cross sections. Since the total neutron absorption cross section of the WBNS core is quite small (it has been calculated to be about 1440 square centimeters), the WBNS is very sensitive to the effects of neutron absorbers inserted in the central exposure facility.

Apparatus for this type of measurement with the WBNS includes a BF_3 ionization chamber located between the shield and the reflector. The signal from the ion chamber is fed to a sensitive galvanometer (10^{-10} amp/mm) which is used as a null device. The current from the ionization chamber is balanced by current from a standard source consisting of a potentiometer and a set of precision resistors. This is used to monitor the power level of the WBNS. Absorbing samples are placed in a specially fabricated graphite sample holder which is inserted in a reproducible geometry in the central exposure facility. The control rod position is indicated on a 36-inch steel scale which is mounted alongside of the channel in which the outer extremity of the control rod assembly moves external to the shield. A vernier fixed to this movable end of the control rod slides along the steel scale. This arrangement permits one to determine the position of the rod to $\pm$ 0.001 inch.

The control rod has been calibrated with standard samples containing 3.72 milligrams of boron in the form of bakelite impregnated with boric acid.

As would be expected from the location and configuration of the control rod, the reactivity control is a nonlinear function of the control rod position. At a rod setting of approximately 26 centimeters (the control rod withdrawn 26 centimeters from the reflector), the reactivity control has been determined to be equivalent to 5.91×10^{-4} square centimeters of absorption cross section per mil of control rod. This is based on a neutron absorption cross section for boron of 750 barns.[5] In this region it is found that the critical position of the control rod can be determined to within $\pm$ 0.002 inches, so that the uncertainty in cross section for a given critical determination is $\pm 1.2 \times 10^{-4}$ square centimeters. Since two determinations of the critical position are required for a cross section measurement, the uncertaingy resulting from the control rod settings alone is then only $\pm 1.7 \times 10^{-3}$ square centimeters.

From period measurements the reactivity control of the rod in the above mentioned region is determined to be 0.0141 inh/mil of rod. Using the inhour equation for a water boiler type reactor,[1] this is found to correspond to 4.33×10^{-5} per cent reactivity per mil of rod.

At a control rod setting of about 60 centimeters, the effect of the control rod is equivalent to 8.3×10^{-5} square centimeters of absorption per mil of rod. In this region the critical position of the rod can be determined to within $\pm$ 0.008 inches, so that the uncertainty in a cross section measurement resulting from the control rod settings is $\pm 10^{-3}$ square centimeters.

The great advantage in sensitivity of the WBNS for measurements using this technique is shown when one determines the effect on reactivity for a given cross section from the above data. This constant for samples placed in the central exposure facility of the WBNS is found to be 4.19×10^{-2} cm^2/inh. This can be compared to the constant obtained for the Argonne Graphite reactor[4] of 2.05 cm^2/inh.

One of the problems associated with this technique is that of maintaining minimum extraneous reactivity changes in the reactor during the period required for the measurement. A method of surmounting this difficulty is to operate the WBNS at a very low power level, approximately 0.2 watts, so that changes resulting from temperature effects, power coefficients, and other variations in reactivity associated with high power operation are minimized. The effects of any reactivity drifts are also very greatly decreased by performing the measurements in a cyclic time sequence, i.e., the critical position of the control rod is

obtained for sample A, for sample B, and then for sample A again. The slow variation in reactivity is then averaged out.

To check the effects of possible variations in reactivity a series of critical position determinations has been made at a power level of 0.2 watt during which nothing was changed in the WBNS except the small changes in the control rod required to determine the exact critical position. During the period required for the data taking, the reactor reactivity was observed to decrease, i.e., the control rod had to be withdrawn slightly to keep the reactor critical. Plotting the critical position as a function of time during the experimental run, it was determined that the reactivity changed at an approximate rate of 1.05×10^{-3} inh/min. It should be noted that this rate of change of the reactivity varies from time to time and is not always negative. The value given here appears to be typical. A similar set of data was then taken at an operating power level about three times greater than the one used above. Again the reactivity was observed to decrease but at a rate of only 1.77×10^{-3} inh/min. Phenomena which are strongly suspected of contributing to this slow variation of reactivity with time include the slight heating of the solution by the absorption of the fission energy, the possible buildup of the gases of dissociation in the solution or a combination of these along with others.

In connection with the above problem, it is of interest to examine the uncertainty that a drift in reactivity of the magnitude observed would introduce in a cross section measurement. The time difference between the two critical position determinations necessary for a cross section measurement is about one hour. During this time a reactivity drift of approximately 6.3×10^{-2} inhour might be expected on the basis of the above data. Thus, if no correction for the drift is made, an uncertainty in the cross section determination of about 2.6×10^{-3} square centimeters might be introduced. However, this uncertainty can be reduced considerably by making the cyclic measurements mentioned above.

In conclusion, it may be stated that the WBNS has proved to be an extremely versatile and useful tool for a great many varied research programs. Because of the small physical size of the core and the low critical mass, this type reactor gives a very high neutron flux per unit power over a small region. The use of this particular design of a water boiler type reactor is somewhat limited because of its low power rating. However, with suitable design changes the power rating can be readily increased many-fold, so that a neutron flux of 10^{12} n/cm^2-sec is easily obtainable.

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