These are connected to form an emergency shutdown buss and a normal shutdown buss. A separate alarm buss monitors the core tank pressure, graphite temperature, D_2O temperatures, and D_2O flow. Erratic behavior of these will not shut down the reactor but will sound an alarm. Remote rod-position indicators, rod-holding magnet current, and various other minor instrumentation are not tied into any one of the three main buss systems.

Present Status

This reactor has been designed up to the point of making detail drawings of the various components. The technique of mixing graphite and uranium for the core has been worked out in full scale and was tested by a small scale experiment in another reactor. Other components are combinations of commercial parts in straightforward design. It is estimated that the cost of this reactor would be approximately $500,000, the exact amount depending on the extent of experimental facilities to be associated with it. The reactor described has the benefit of a very conservative design, and every effort has been made toward simplicity. It is a unit that will meet the requirements of safety while operated by unskilled personnel such as students in universities or technicians in a research institute.

Operation of the North American Aviation Water Boiler Neutron Source[1,2]

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A LOWPOWER HOMOGENEOUS REACTOR of the water-boiler type (*1*) has been in operation at the Atomic Energy Research Department of North American Aviation since April, 1952. This reactor, called the Water Boiler Neutron Source, or WBNS, was designed primarily as a source of neutrons for experimental purposes. The reactor is operated at power levels up to 1 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 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 shut down will occur with a relatively small release of energy.

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-ft diameter stainless steel sphere. The sphere has been constructed from two hemispherical spinnings of Type 347 stainless steel sheet, 1/16 in. thick, and has a volume of 14.38 liters. A central exposure facility in the core has been formed by inserting a tube, 1⅛ in. ID, through the sphere with its center line 3 in. below the horizontal diameter of the sphere. This sphere is encased in a cylinder of pile grade graphite, 5 ft in diameter by 6 ft high, which serves as a reflector and vertical thermal column. The entire cylinder is surrounded by a concrete block radiation shield 2 ft thick. A sectional assembly of the reactor is shown in Fig. 1. Figure 2 is a photograph of the installation with an experimental tank on top of the vertical thermal column.

The graphite reflector was formed by stacking graphite bars, $4\frac{1}{8} \times 4\frac{1}{8}$ in. in cross section, horizontally inside a steel tank with the bars in alternate layers placed orthogonal to each other. Eight of these graphite bars, or "stringers," near the sphere, as shown in Fig. 1, 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 reactivity control is maintained with two safety

[1] Based on a paper presented at the 1953 Conference on Nuclear Engineering at the University of California, Berkeley, Sept. 9–11, 1953.

[2] Based upon studies conducted for the Atomic Energy Commission under Contract AT-11-1-GEN-8.

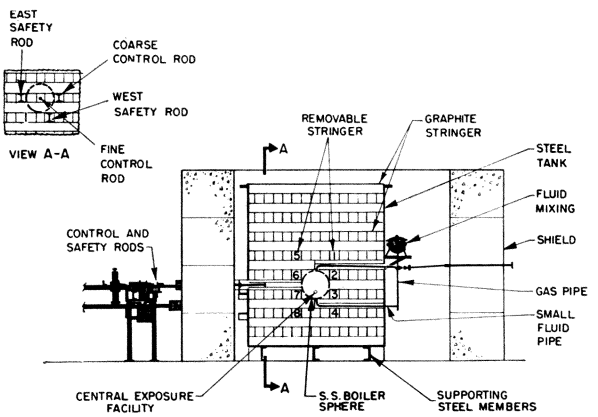

FIG. 1. Sectional view of WBNS showing locations of the stainless steel sphere forming the reactor core, the control and safety rods, the central exposure facility through the graphite reflector and through the sphere, and the removable graphite stringers which give additional neutron irradiation facilities.

rods, east safety and west safety, a coarse control rod and a fine control rod, located as shown in Fig. 1. 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 ¼-in. thick strips of Boral attached to aluminum channel beams. This forms an I-beam about 3 ft long and 4 in. 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 second by weights suspended from cables placed over pulleys.

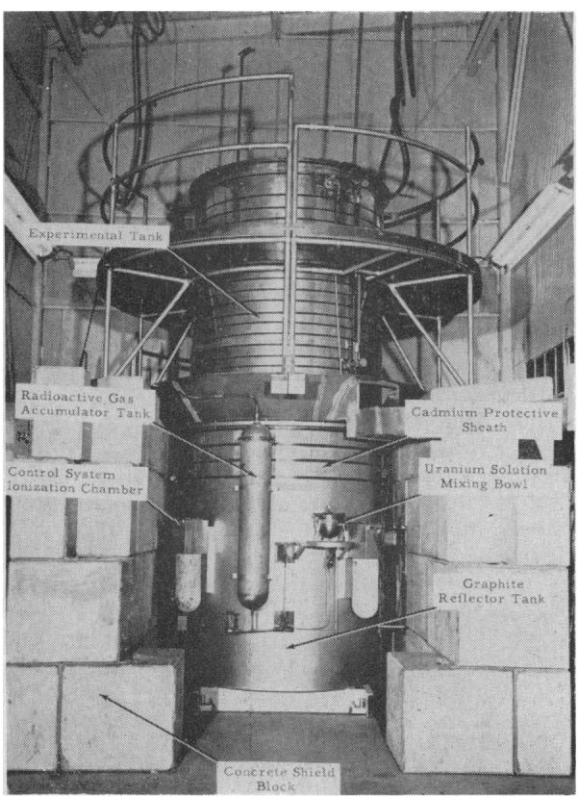

FIG. 2. Completed WBNS assembly with one shield wall removed. Lower tank contains graphite reflector and spherical core. Upper tank is experimental equipment.

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 cm, 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-in. diameter steel pipe with provision at the end for insertion of varying amounts of cadmium. At present, this rod controls approximately 0.1 percent in reactivity. The automatic control feature utilizes a Brown servo-amplifier 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. 3.

Figure 4 shows a view of the instrument control panel which is located in a laboratory area immediately adjacent to the reactor. 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.

The gases that are evolved from the fission process and from the decomposition of the solution are collected in a 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.

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

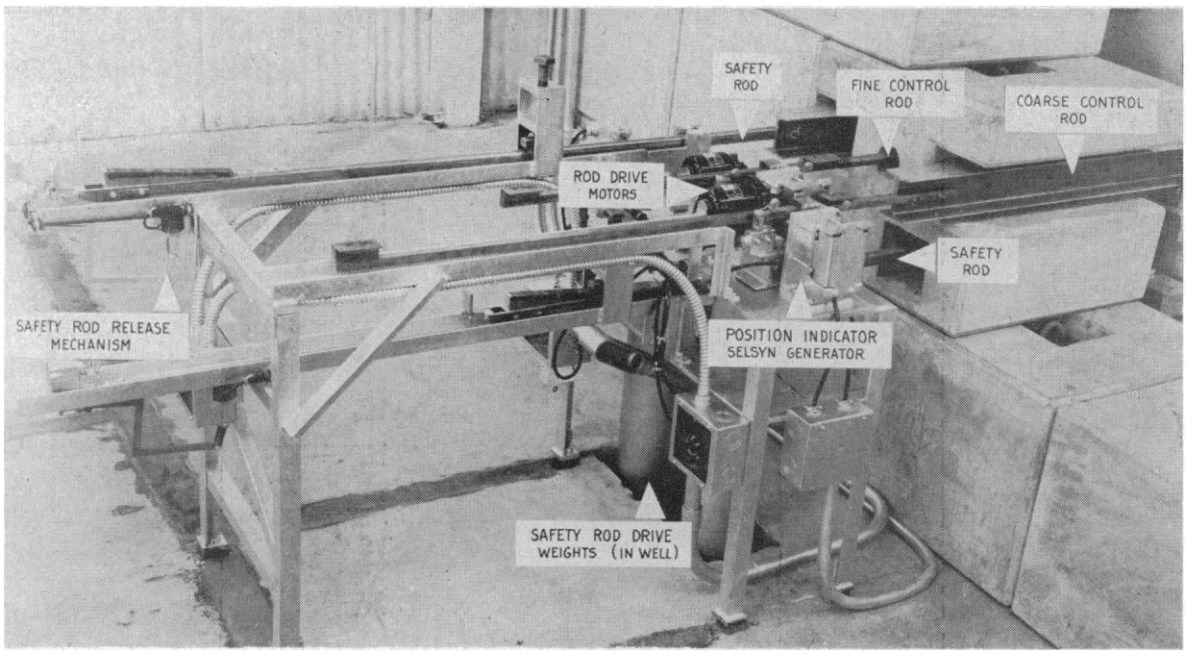

FIG. 3. Control and safety rod mechanism.

water was added to the stainless steel sphere, and the fuel system was flushed with helium. After 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 (approx. 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. 5, and from these the critical mass with all the control rods retracted is found to be 633.9 g of U^{235}.

A total of 638.2 g 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 sec, corresponding to an excess reactivity of 0.21 percent. A mass coefficient of reactivity for the WBNS was determined to be 0.050 percent 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 percent 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, that is,

$$(\Delta k/\Delta M)_{\text{WBNS}}(M_c)_{\text{WBNS}} = 0.050 \times 633.9 = 31.7,$$
$$(\Delta k/\Delta M)_{\text{LOPO}}(M_c)_{\text{LOPO}} = 0.0548 \times 565.5 = 31.0.$$

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 indicates the absorption of the coarse control rod to be equivalent to 21 g of U^{235}. Using the afore-determined mass co-

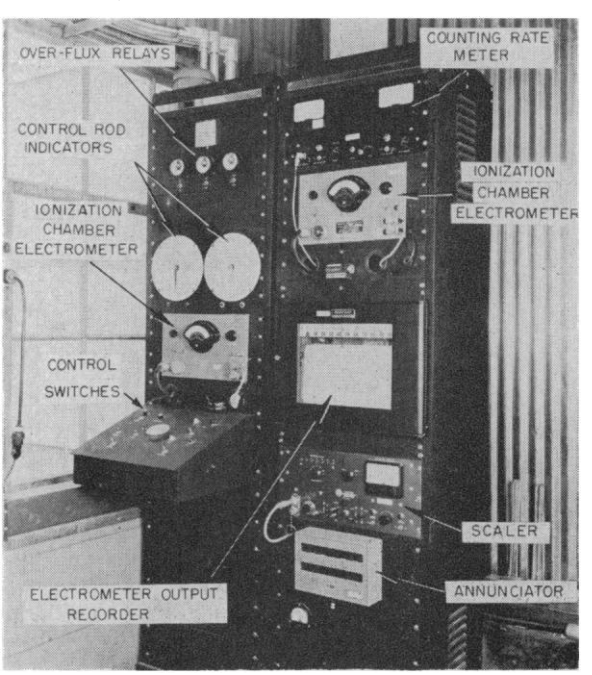

FIG. 4. Control console for WBNS located immediately adjacent to the reactor room.

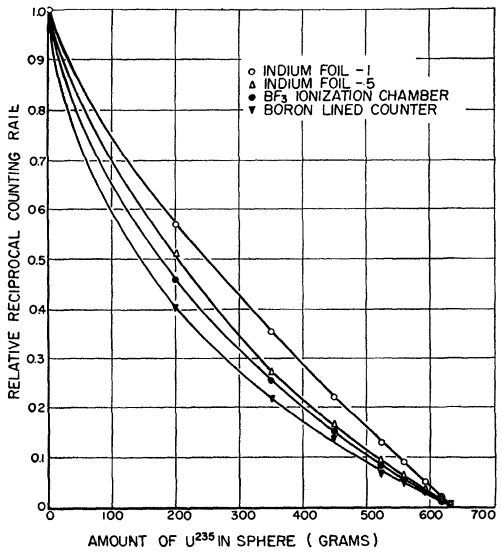

FIG. 5. Data obtained with three types of neutron detectors during the critical assembly of the WBNS. The reciprocal counting rates have all been normalized to unity with the sphere essentially full of water, with no fissionable material present. The extrapolated critical mass from these curves is 635.7 g of U^{235}. This amount, less the 1.8 g equivalent absorption of the Po-Be source, gives a critical mass of 633.9 g of U^{235}.

efficient of reactivity, one finds that the coarse rod controls 1.05 per cent in reactivity.

OPERATIONAL CHARACTERISTICS

The WBNS is started into operation with a 250-millicurie Ra-Be neutron source inserted in the center of graphite stringer No. 4 (see Fig. 1). This source emits about 3×10^6 neutrons/sec, which results in a "shut-down" 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.

Control and Safety Rod Effectiveness. 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 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 M in these subcritical states will be given by

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

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

$$(k_{eff})_1=1-\frac{M_0}{M_1}\left[1-(k_{eff})_0\right], \qquad (2)$$

where M_0 and $(k_{eff})_0$ 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 1. It is to be noted that there is some shadowing between the rods, since in none of the cases is the amount of control by the two rods together equal to the sum of the amount of control by each rod separately. The two safety rods are identical in construction, but are located in different regions of the reflector (see Fig. 1), so the difference in reactivity control by these rods should be expected.

TABLE 1. Reactivity control of control and safety rods in WBNS.

Rods	Reactivity Control (%)
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

Power Calibration. 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

$$P=\frac{N_{25}\sigma_{25}\overline{nv}}{3\times10^{10}}\text{ watts},$$

where 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 for our determination. The neutron flux was measured with standardized indium foils that 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 was used to monitor the power level of the WBNS. This absolute calibration is accurate to only about ± 30 percent because of a lack of accuracy in the standardization of the indium foils.

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 30–50 watt hr. Data from operation of the Los Alamos HYPO version of the water boiler (*1*) indicated that the rate of gas evolution would be about 7–8 cm³ of hydrogen per watt hour of operation. Therefore, the afore-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 cm³/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 (approx. 10–20%) at power levels of 0.1 watt as compared to operation at levels up to 1 watt.

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 cm² in area and approximately 90 mg/cm² 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 resulted 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.

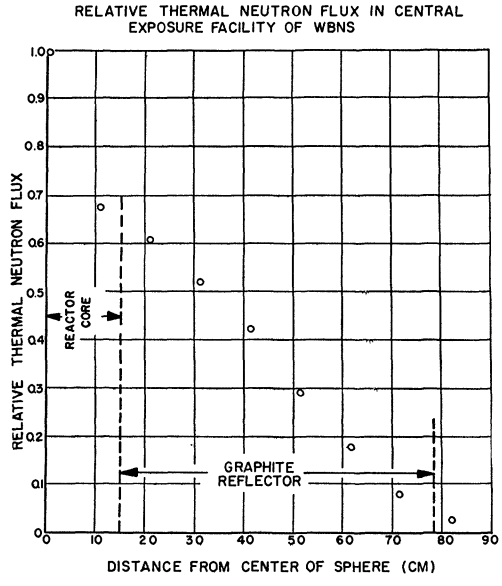

FIG. 6. Thermal neutron flux distribution in the central exposure facility of the WBNS. The flux has been normalized to unity at the center of this exposure facility, which is 3 in. below the geometric center of the sphere.

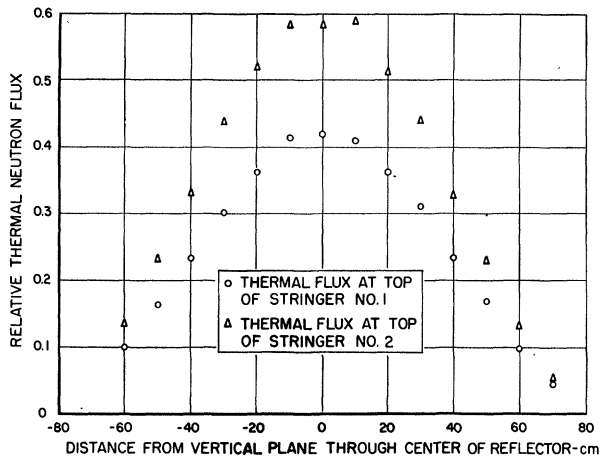

FIG. 7. Thermal neutron flux distributions at the top of two of the removable graphite stringers. The ordinate scale here is the same as that used in Fig. 3.

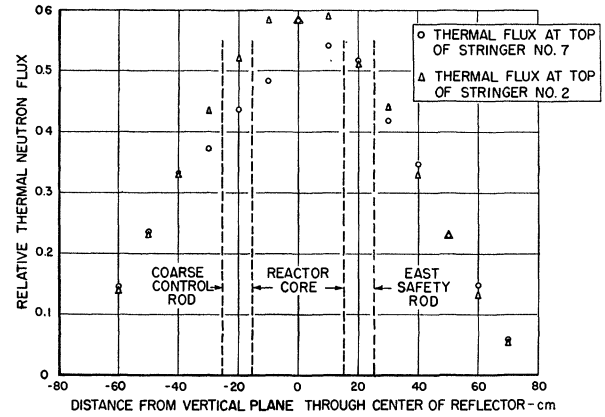

FIG. 8. Thermal neutron flux distribution in removable stringer No. 7. The distribution in stringer No. 2 has been plotted for comparison purposes. This latter distribution should be very similar to that in stringer No. 7 except for the effects of the control rod and east safety rod. The ordinate scale here is the same as that in Figs. 3 and 4.

The results of these measurements are shown in Figs. 6–8, 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 No. 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 are shown in the flux distribuiton along the top of stringer No. 7 in Fig. 8. One should expect the distribution here to be very similar to that in stringer No. 2 (Fig. 7), and this is observed except for the depressions caused by the two rods. The flattening by the coarse control rod is somewhat greater than that by the east safety rod, since the safety rod was completely withdrawn from the reflector, and the contribution to the flux depression is that of the void from which the rod has been withdrawn. The coarse control rod was withdrawn about 35 cm 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% indium and 25% lead) 0.2×1.0 cm and of thickness approximately 70 mg/cm^2 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. 9, along with data taken in the LOPO

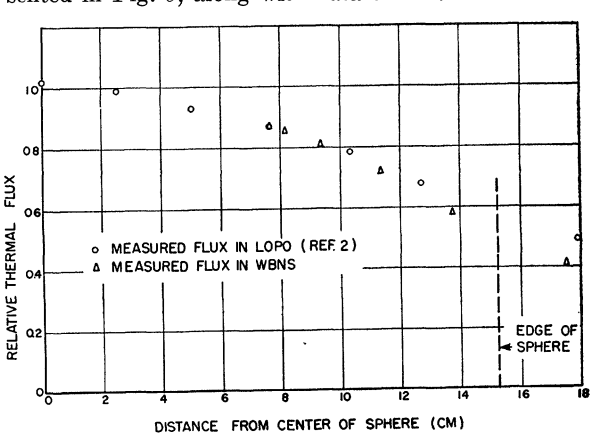

FIG. 9. Thermal neutron flux distribution in the central exposure facility of WBNS plotted as a function of the radius of the sphere along with similar data for LOPO at Los Alamos.

sphere (2) with a U^{235} ionization chamber. The two sets of data were normalized at the common point, 7.6 cm from the geometric 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. 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 that 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.

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:

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 technics.
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 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 and has 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 technic (*4*). This technic involves the insertion of a neutron absorber in a reactor which produces a change in the reactivity. 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 cm^2), 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 consists of 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-in. steel scale which is mounted along side 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 ± 0.001 in.

The control rod has been calibrated with standard samples containing 3.72 mg 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 position. At a rod setting of approximately 26 cm (the control rod withdrawn 26 cm from the reflector), the reactivity control has been determined to be equivalent to 5.91×10^{-4} cm^2 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 ± 0.002 in., so that the uncertainty in cross section for a given critical determination is $\pm 1.2 \times 10^{-3}$ cm^2. Since two determinations of the critical position are required for a cross-section measurement, the uncertainty resulting from the control rod settings alone is then only $\pm 1.7 \times 10^{-3}$ cm^2.

From period measurements, the reactivity control of the rod in the aforementioned 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} percent relativity per mil of rod.

At a control rod setting of about 60 cm, the effect of the control rod is equivalent to 8.3×10^{-5} cm^2 of absorption per mil of rod. In this region the critical position of the rod can be determined to within ± 0.008 in., so that the uncertainty in a cross-section measurement resulting from the control rod settings is $\pm 10^{-3}$ cm^2.

The great advantage in sensitivity of the WBNS for measurements using this technic 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 the danger coefficient technic is that of maintaining minimum extraneous reactivity changes in the reactor during the period required for the measurements. A method of surmounting this difficulty is to operate the WBNS at a very low power level, approximately 0.2 watt, 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 greatly decreased by performing the measurements in a cyclic time sequence, that is, 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, that is, 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 activity 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 that 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 build-up 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 1 hr. During this time a reactivity drift of approximately 6.3×10^{-2} inh 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 only about 2.6×10^{-3} cm^2 might be introduced. However, this uncertainty can be reduced considerably by making the cyclic measurements mentioned above.

It may be stated that the WBNS has proved to be an extremely versatile and useful tool for a great many

varied research programs. This type of 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 increased many-fold so that a neutron flux of 10^{12} neutrons/cm^2 sec is easily obtainable.

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News and Notes

Heavy-Water Reactor Conference in Oslo, Norway

AN international Conference on Heavy Water Moderated Nuclear Reactors was held in Oslo and at Kjeller, Norway, Aug. 11–13. The Conference was sponsored by the Dutch-Norwegian Joint Establishment for Nuclear Energy Research (JENER). There were about 100 participants, with representatives from most countries in the Western World. The program consisted of papers on reactor design and construction, kinetics and control, and neutron physics. Ample time was provided for discussions.

In his opening address G. Randers (JENER) discussed the possible use of heavy-water reactors in industry. Since most European countries are unable to procure enriched fuels at the moment and since even natural uranium is scarce and relatively expensive, a good moderator becomes essential. Furthermore, the geometry of the reactor must allow an initial reproduction factor which is adequate for a 1% burn-up of the fuel. Thus the call for a heterogeneous heavy-water moderated natural-uranium reactor. Design studies for such a reactor to produce 5000 kw of electricity are being made at Kjeller.

J. V. Dunworth (A.E.R.E., Harwell, England) underlined the advantages of using heavy-water as moderator in general. He maintained, however, that with the present high price of heavy-water it is difficult to make an electricity-producing reactor-plant which competes favorably with conventional plants. Where there is a need for a small, compact system the situation is more favorable.

As a pleasant break in the discussions on future reactors, J. M. West (Argonne, U.S.A.) described the latest Argonne research reactor CP-5. This reactor is a result of the experiences gained at Argonne with their earlier heavy-water moderated research reactors CP-3 and CP-3′. The latter reactors were described in a later session by West from a paper prepared by S. McLain. CP-3, which operated from early 1944 to early 1950, contained natural uranium as fuel. CP-3′ and CP-5, on the other hand, contained enriched fuels. The maximum slow neutron fluxes were for CP-3 about 10^{12} cm^{-2} sec^{-1}, for CP-3′ at 275 kw $3{,}4 \times 10^{12}$ and for CP-5 a calculated average thermal flux at 1000 kw of 2×10^{13}. The reason for using enriched fuel in the latter reactors is to obtain a greater fission rate per unit mass of fissile material. Heavy-water is preferred to light-water as moderator due to the larger reactor core for experimentation and the longer lifetime of slow neutrons. This makes the problem of control easier.

In a paper on the past, present, and future of heavy-water reactors L. Kowarski (Saclay, France) stressed that a greater excess reproduction factor can be obtained with a heavy-water moderator than with a graphite moderator. As a result the reactor is easier to construct and to run. In a situation where the abundance of pure fissile materials is low, the natural-uranium heavy-water system offers the best solution as a power reactor. This situation may, according to the speaker, last for more than 20 years.

A. M. Weinberg (Oak Ridge, U.S.A.) presented a description of the A.E.C. materials testing reactor (MTR) from a paper written by S. McLain. This reactor was designed so as to maximize the fast neutron flux. In order to achieve this it is necessary to make the power per unit cross-section for scattering of fast neutrons as high as possible. The volume of the reactor core for a given power is therefore made as small as possible. Highly enriched uranium-235 is used in the core and beryllium is used as reflector. At 30,000 kw the flux of uncollided fission neutrons is of the order of 10^{14} and the average slow neutron flux is 2×10^{14}. Weinberg also described briefly the Swimming Pool Reactor and the Homogeneous Reactor Experiment at Oak Ridge. The strong coupling which exists between the temperature and power in the latter reactor was discussed.

Some of the reactor projects in Europe were also treated briefly. L. Kowarski described the Saclay reactor, which is a natural-uranium–heavy-water reactor which is cooled by blowing compressed nitrogen gas along the rods. J. Bernot gave an account of the cooling system. O. Dahl (Norway) and P. Scherrer and W. Zünti (Switzerland) presented the plans for heavy-water moderated and cooled natural-uranium reactors with a heat generation of the order of 10,000 kw. S. Eklund (Sweden) gave some details of the