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SHIELDING-RESEARCH AREA AT BATTELLE

by

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The design and construction of the shielding facility at Battelle is described in this report. This facility consists of an open pool with a fission plate, an instrument bridge and tower, a control room, and radiation-detection instruments. The shielding pool is located at the end of the thermal column of the Battelle Research Reactor (BRR).

The fission plate is 28 in. in diameter and contains approximately 3.5 kg of uranium-235. The plate was fabricated from three pieces of highly enriched uranium and clad with about 25 mils of 2S aluminum. It generates about 24 w during steady-state reactor operation.

The fission spectra of neutrons and gamma rays produced by the fission plate are free from appreciable background radiations. The ratio of thermal to epithermal neutrons impinging upon the fission plate is approximately 67, indicating a low fast-neutron background. Assuming an average energy of 2 Mev for background gamma rays results in a ratio of thermal-neutron flux to gamma flux of 16.

INTRODUCTION

The development of nuclear reactors requires information on the performance of materials and configurations as shields against nuclear radiations, primarily neutrons and gamma rays. This report treats the construction and preliminary calibration of a facility developed for the General Electric Company, Aircraft Nuclear Propulsion Department, to obtain data on material shielding.[1]

The needs for shielding data may be divided into three principal categories.

(1) Requirements for general basic information.
Shielding research has not developed to the point where complete handbook data are available on such things as removal cross sections and parameters for determining the production of secondary gamma rays.

(2) Data to support calculational methods.
Data are required to improve and develop shielding theory. Experiments can provide checks on present theory and indicate the direction for new and improved theories.[2]

(3) Information on specific shielding designs.
Shields of complex geometry with irregularly shaped ducts must be checked experimentally to obtain accurate shielding data. Even when the deficiencies in Areas (1) and (2) above have been resolved, the need for experimental data may still exist.

(1) References at end.

Most shielding data compiled to date have come from either "lid-tank" facilities or research reactors which can be used for shielding studies.[3] A lid-tank facility is a pool of water (or other liquid) in which shields are exposed to a fission source of neutrons and gamma rays. The source radiation is produced in a uranium-bearing converter (fission) plate by thermal neutrons from a reactor. The principal merits of the lid-tank facility are better defined neutron and gamma sources than obtainable with direct core radiations; also, research can be conducted independently of the other experimental programs using the reactor. On the other hand, direct use of a reactor provides a more intense radiation source (advantageous to spectroscopy work) and permits full-size shielding mock-ups to be placed around the core. The facility described in this report is a lid-tank facility which differs from the ORNL Lid-Tank Facility principally in size and source strength.

The thermal column of the BRR is approximately 12 ft in length and 4 ft square and is stacked with high-purity graphite blocks. To produce the desired power in the fission plate, the column is partially voided to provide a higher flux at the horizontal access. The long thermal column provides a thermal-neutron flux with a low fast-neutron background. The end of the thermal column has been modified by a paraffin collimator to produce a current of thermal neutrons with a fairly flat distribution across the diameter of the fission plate.

The shielding specimen is placed in a tank adjacent to the fission plate and is subjected to fission neutrons and gammas. The radiations are detected by instruments suspended from the instrument tower which is supported by a motorized bridge spanning the shielding tank. Figure 1 shows the tank and bridge in the foreground and the control room in the lower right background.

In addition to gross radiation attenuation, information can be obtained on fast-neutron removal cross section, secondary-gamma-ray production within the shield, and energy degradation of the radiations. With special instrumentation temperatures within the shield may be measured. Experiments can be performed with various thicknesses of material to optimize shield thickness with respect to the quantities of radiation absorption and secondary-gamma production. Combinations of slabs can give insight into intershield gamma-ray production and attenuation. Shield optimization can also be examined with respect to combinations of different materials. As mentioned previously experiments can also be performed on shields of special geometry.

Special experiments can be performed on the effects of the medium in which the shield is placed, i.e., the tank may be filled with water, borated water, or oil. With a few modifications the facility may be converted to a gamma source for gamma-shielding measurements undisturbed by the presence of neutrons. The lid-tank facility is also adaptable to studies of basic physics properties of fission neutrons (neutron age, relaxation length, etc.). The well-defined fission source can be used in developing instrumentation for shielding measurements. This listing of possible uses is by no means complete but demonstrates the flexibility of such a facility.

DESCRIPTION OF SHIELDING-RESEARCH AREA

The design and construction of the shielding-research area have constituted the major effort during the first year of the research program. Since two similar

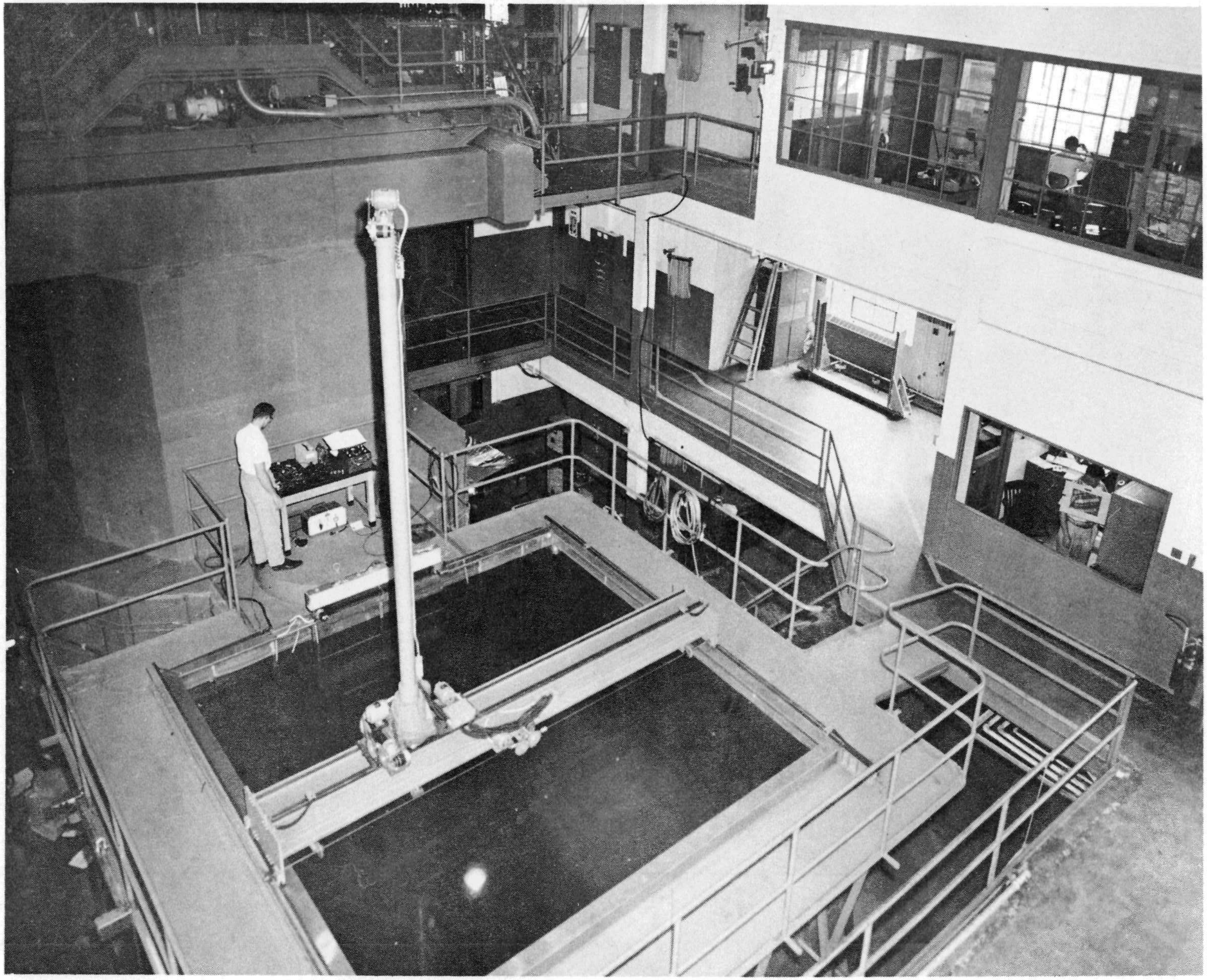

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FIGURE 1. SHIELDING-RESEARCH AREA

installations have been constructed and operated for several years[3], the experience obtained with these facilities could be drawn upon in the design of this facility.

The fission plate is 28 in. in diameter and 0.020 in. in thickness. It is made of highly enriched uranium foil and jacketed in aluminum. The diameter chosen was small enough to assure a relatively flat flux across the plate and to avoid radiation leakage around the shielding specimens. Experimentally, it has been shown that the increase in power production is small for an increase in uranium thickness above about 0.020 in. The precise thickness was determined by the availability of the material and limitations of fabrication techniques.

The uranium for the plate was fabricated by Metals and Controls Nuclear, Incorporated, in the form of a disk 28 in. in diameter made of three pieces 9-1/3 in. wide. Measurements at Battelle indicated the initial thickness to be 0.0228 in. with a root-mean-square deviation of 0.0001 in. and the diameter to vary between a maximum of 28.036 in. and a minimum of 27.985 in.

The uranium was nickel plated and then enclosed in an aluminum picture frame which had been cleaned and pickled. Then cover plates of aluminum were welded onto the picture frame to form an assembly 30 in. square. This assembly was evacuated and pressure bonded, and trimmed to about a 28-in. circle.

Final Specifications of the Fission Plate

The principal dimensional change in the uranium core during fabrication was a reduction in the core thickness due to loss of uranium in the pickling process preparatory to nickel plating the core. The final thickness of the core is estimated to be 19.9 mils.

The thickness of the completed plate was measured at several locations and the results are shown in the sketch of Figure 2. As seen from this sketch, the measurements of the actual plate thickness varied from 70.0 to 73.0 mils. On the basis of these measurements it can be estimated that the cladding thickness varies from about 24.5 to 25.8 mils.

The specifications of the fission plate are listed below.

Plate diameter		
	Over-all	28-3/8 ± 1/16 in.
	Core	28.0 in.
Plate thickness		
	Over-all	0.070 in. (nominal)
	Core	0.0199 in. uranium 0.0014 in. nickel
	Cladding	0.025 in. (nominal)

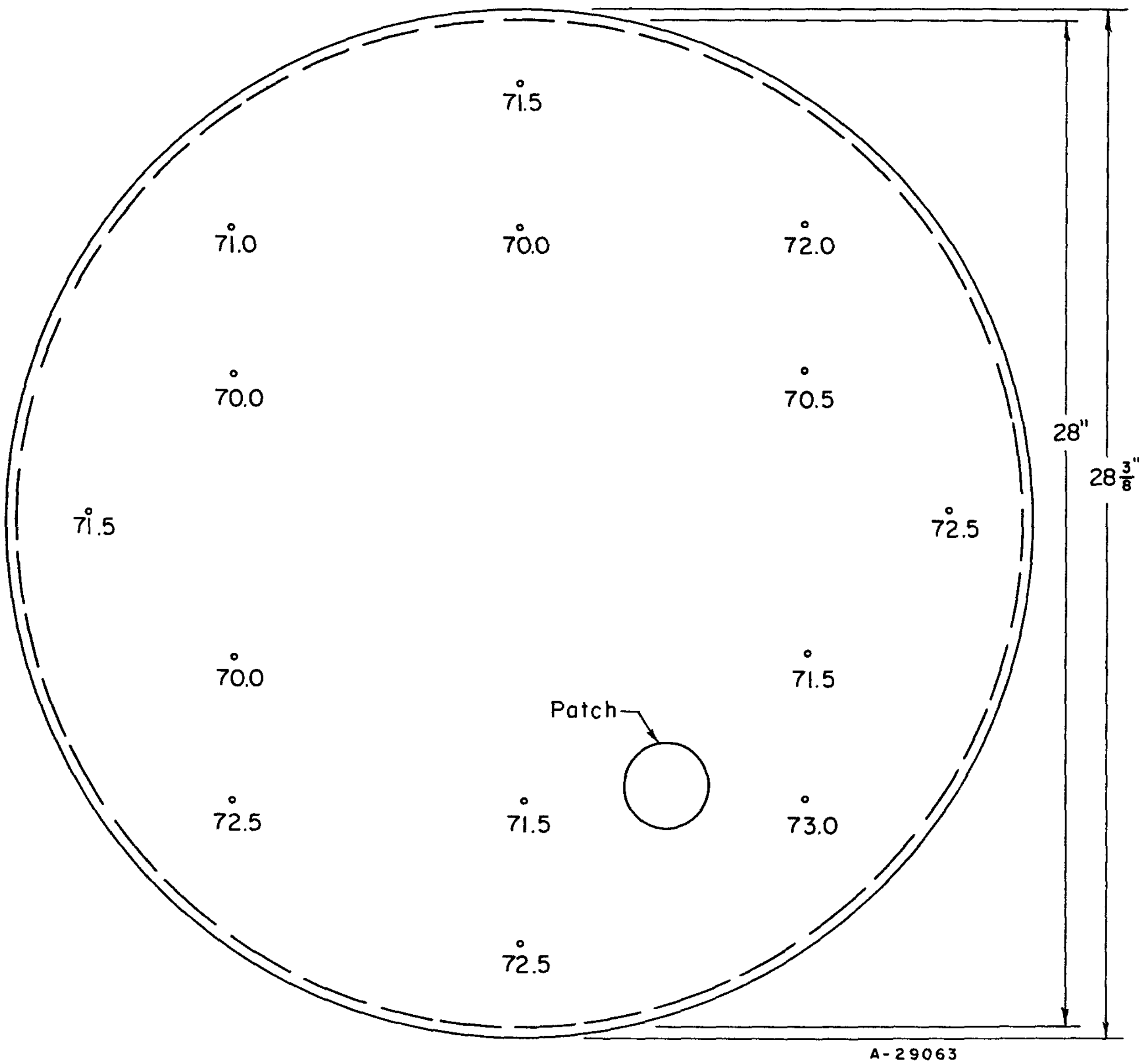

FIGURE 2. THICKNESS MEASUREMENTS ON CLAD FISSION PLATE

All measurements in mils.

Plate materials

Cladding	2S aluminum
Core	Nickel-plated uranium, 3741 g total uranium (3484 g uranium-235, 93.14 per cent enrichment)

It is suggested that these specifications (subject to the qualifications discussed) be used in all future calculations concerning the fission plate.

Fission-Plate Assembly

The complete fission-plate assembly consists of an aluminum frame containing the source plate, resistance thermometers, and electrical-heater plate, and Lavite spacers. The source plate and heater plate are in intimate contact and insulated both thermally and electrically from the aluminum frame by the ceramic spacers. An exploded view of the assembly is shown in Figure 3.

The heater plate consists of a 1/4-in.-thick flat aluminum disk 28 in. in diameter with a heater coil embedded in a spiral groove cut into the plate. The heater coil is 24-gage copper wire covered with a double layer of glass-fiber insulation and has 20-gage feeder leads. The cover for the source and heater-plate assembly is a 31-in.-diameter aluminum disk recessed to receive the fission plate.

Six resistance thermometers of glass-insulated nickel wire (Model SN-1 Stikons) were attached to the front side (shielding-pool side) of the fission plate to permit temperature readings for power calibration. See Figure 4. The finished fission-plate assembly is shown in the photograph of Figure 5. This photograph is a view looking at the rear (thermal-column side) of the assembly. The lead wires for the heater coil enter from a 1/2-in. aluminum tube (seen attached to the side of the assembly) through the back of the heater plate at the center. The resistance-thermometer lead wires cross the front of the source plate and also feed from the 1/2-in. aluminum tube.

Shielding Tank

The dimensions of the tank are based on the space required for large radiation-detection instruments with collimators and for the largest shields which were anticipated. The inner dimensions of the tank (15 by 15 by 12-1/2 ft) give ample room for angular studies of radiation from the shielding specimens and provide a sufficient volume of water for biological shielding in front of the fission plate.

The tank consists of a buttressed 8-in.-thick concrete shell lined with 3/16-in.-thick aluminum sheets. A sketch of the tank showing the principal materials and dimensions is shown in Figure 6.

The section of the wall parallel to the face of the thermal column and the first 3-1/3 ft of the lateral walls are composed of barytes high-density concrete. The

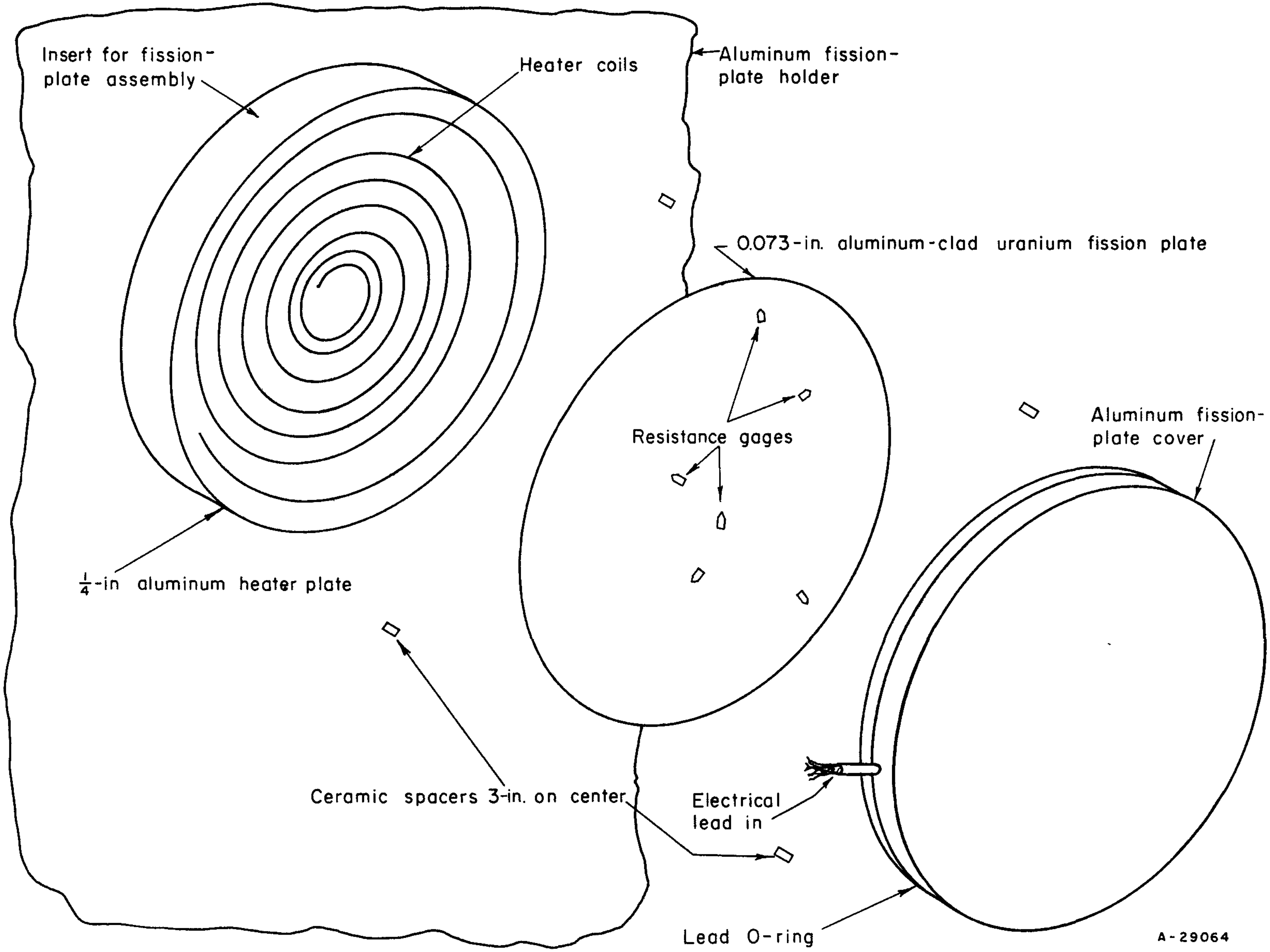

FIGURE 3. EXPLODED SKETCH OF FISSION-PLATE ASSEMBLY

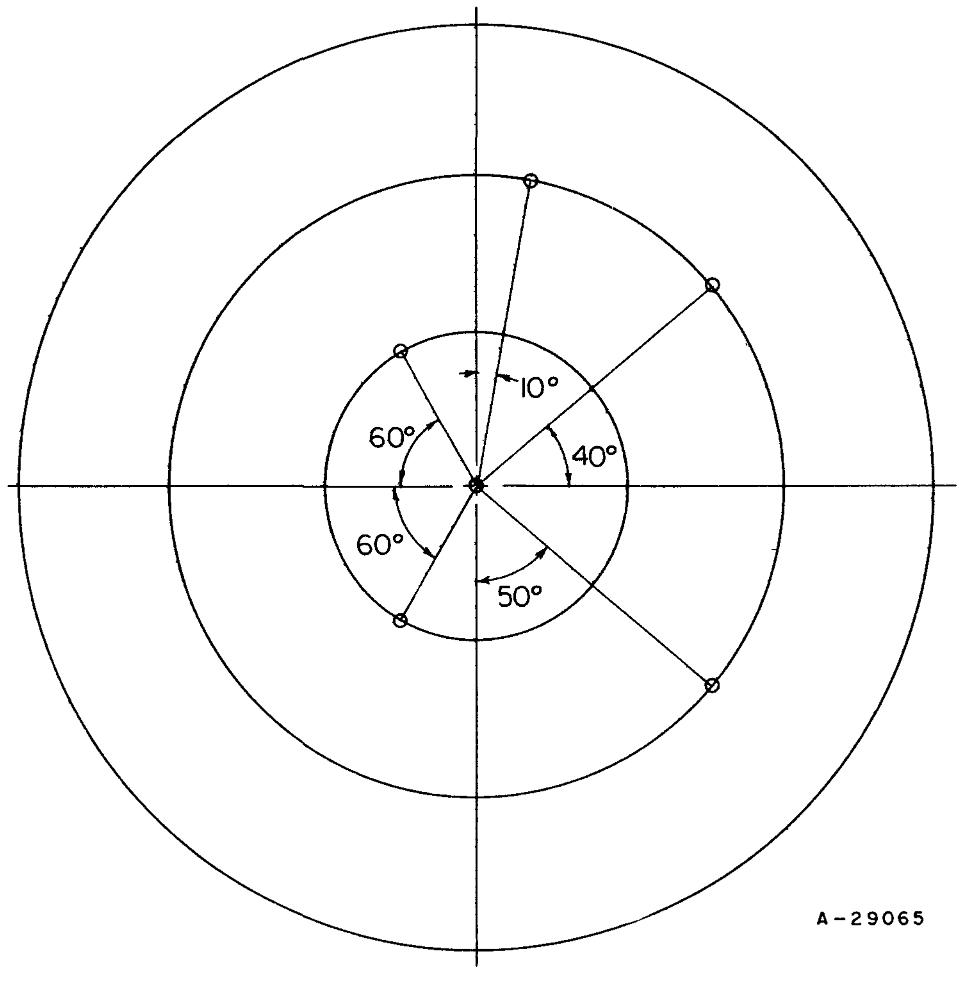

FIGURE 4. LOCATION OF THE SIX RESISTANCE THERMOMETERS ATTACHED TO THE FRONT OF THE FISSION PLATE

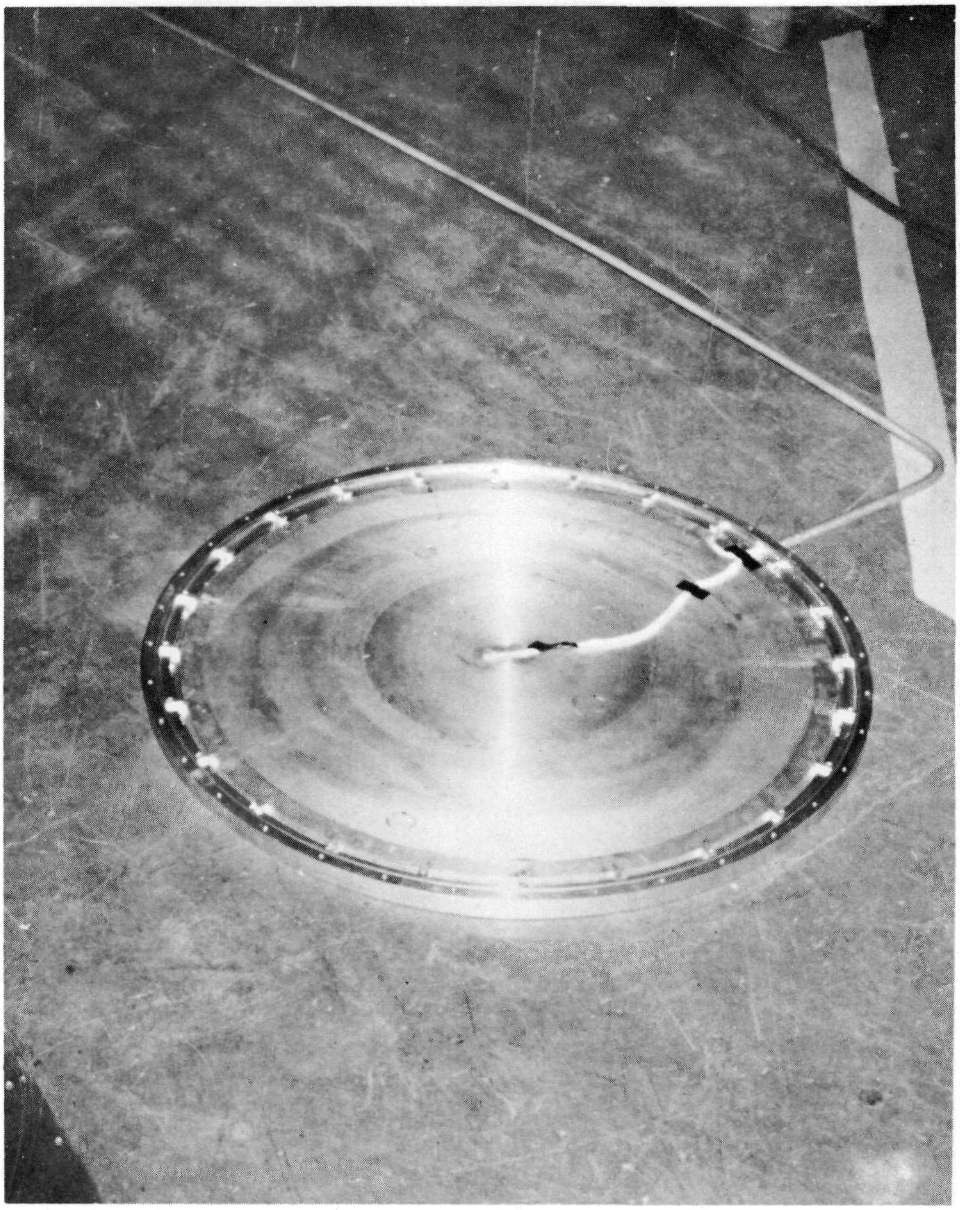

FIGURE 5. THE FISSION-PLATE ASSEMBLY

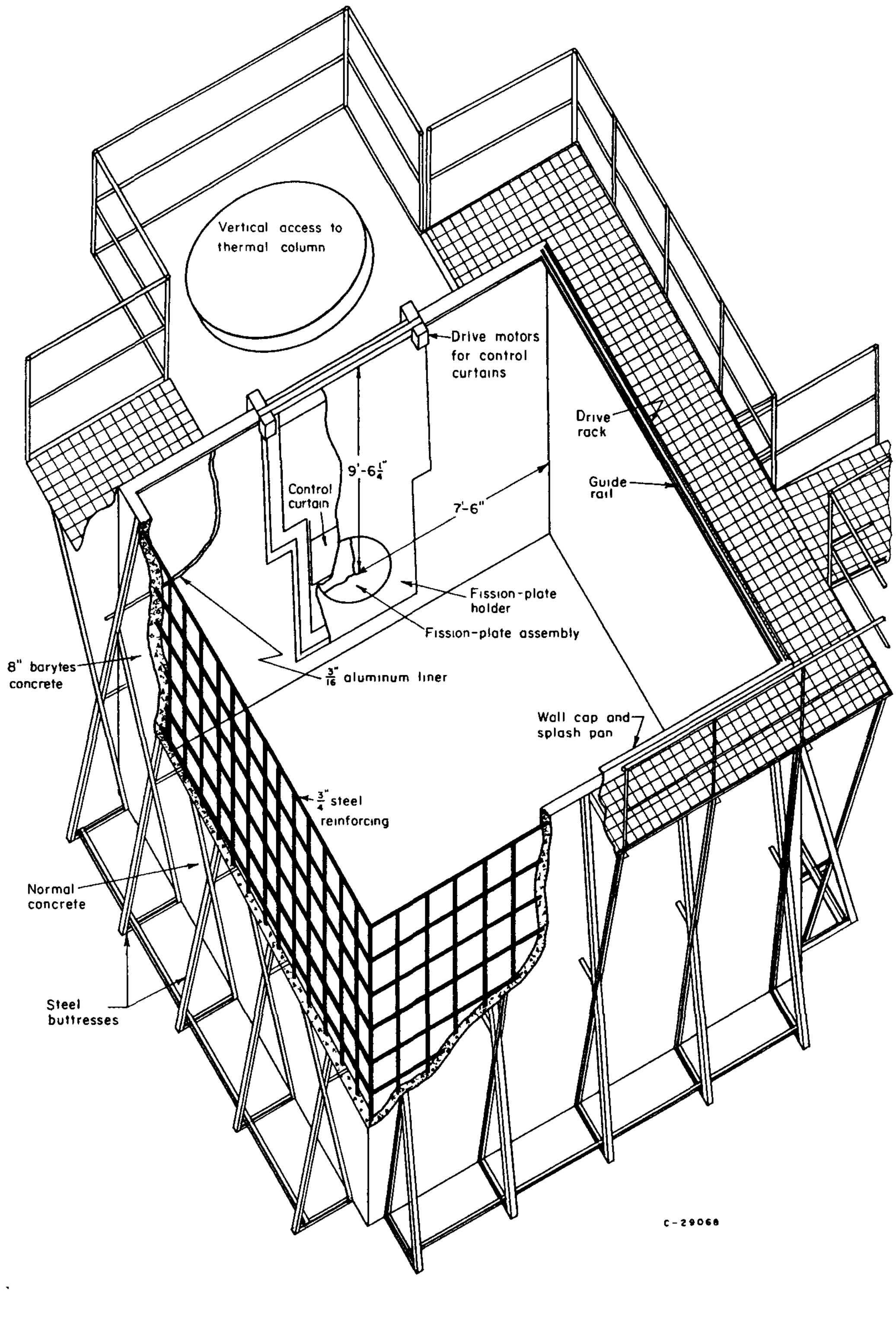

FIGURE 6. SKETCH OF TANK FOR SHIELDING FACILITY

remainder of the tank is a monolithic pour of regular concrete. Twelve tie bars were left protruding from each section of the wall parallel to the thermal-column face to support stacks of barytes blocks arranged for biological shielding during operation of the facility. A 3-in. drain was installed in a rear corner of the pool, and a 500-gpm electric pump was attached to the drain to change liquids in the pool.

The 3/16-in. aluminum lining for the pool was formed from sheets of 6061 alloy 4 by 12 ft.

The fission-plate arrangement consists of the aluminum wall section, control curtains, fission-plate holder, fission-plate assembly, and Boral curtain. These components are shown in the exploded sketch of Figure 7. By reducing neutron reflection, the Boral curtain on the pool side of the fission plate minimizes power changes in the fission plate due to neutron reflection from shielding specimens.

To shut down the fission plate without shutting down the reactor (both to preserve uranium and to permit measurement of the background radiations from the reactor) a removable curtain was constructed and installed in the area between the tank wall and the fission-plate holder (see Figure 7). The shutdown curtain is a sheet of Boral 30 by 30 by 1/4 in. backed up by a 0.060-in.-thick sheet of cadmium, both mounted in a sliding frame. The entire curtain mechanism may be removed from the tank during operation. The curtain is held in place and guided in its travel by a graphite slide arrangement. The curtain is raised by activating from the instrument console a pair of 1/8-hp a-c motors which drive a set of sprocket chains. It may be moved a total of 31-1/4 in. to remove it completely from the path of the neutrons. Limit switches indicate, by position lights on the control console, the extremes of the curtain travel.

To reduce the power for gamma-ray measurements a duplicate of the shutdown-curtain mechanism was constructed and can be equipped with lithium-magnesium-alloy plates of several thicknesses. This second curtain is easily interchangeable with a curtain of 0.020-in. aluminum foil. The aluminum curtain is used to support foils for neutron-flux measurements and does not disturb the neutron beam incident on the fission plate to any appreciable extent.

A stepped shielding plug has been constructed to fit the gap above the curtains to prevent streaming of neutron and gamma radiations from this gap.

A pair of 7-in. I-beams are attached to the top of the buttresses along the lateral walls. Square hardened steel rails were bolted to the top of the I-beams. The tops of these rails were milled flat, and the rails were leveled to within ±0.005 in. over the 15-ft span. These rails support the bridge, which rides on two pairs of hardened steel rollers. Rollers contacting each side of one rail guide the bridge. To drive the bridge, a Boston L2016 3/4 by 5/8-in. rack was installed along the length of each rail.

Instrument Bridge

The instrument bridge spans the pool parallel to the plane of the fission plate and moves normal to the plate. An instrument tower is attached to the bridge and is capable of lateral, vertical, and rotational movement to position the radiation-detecting

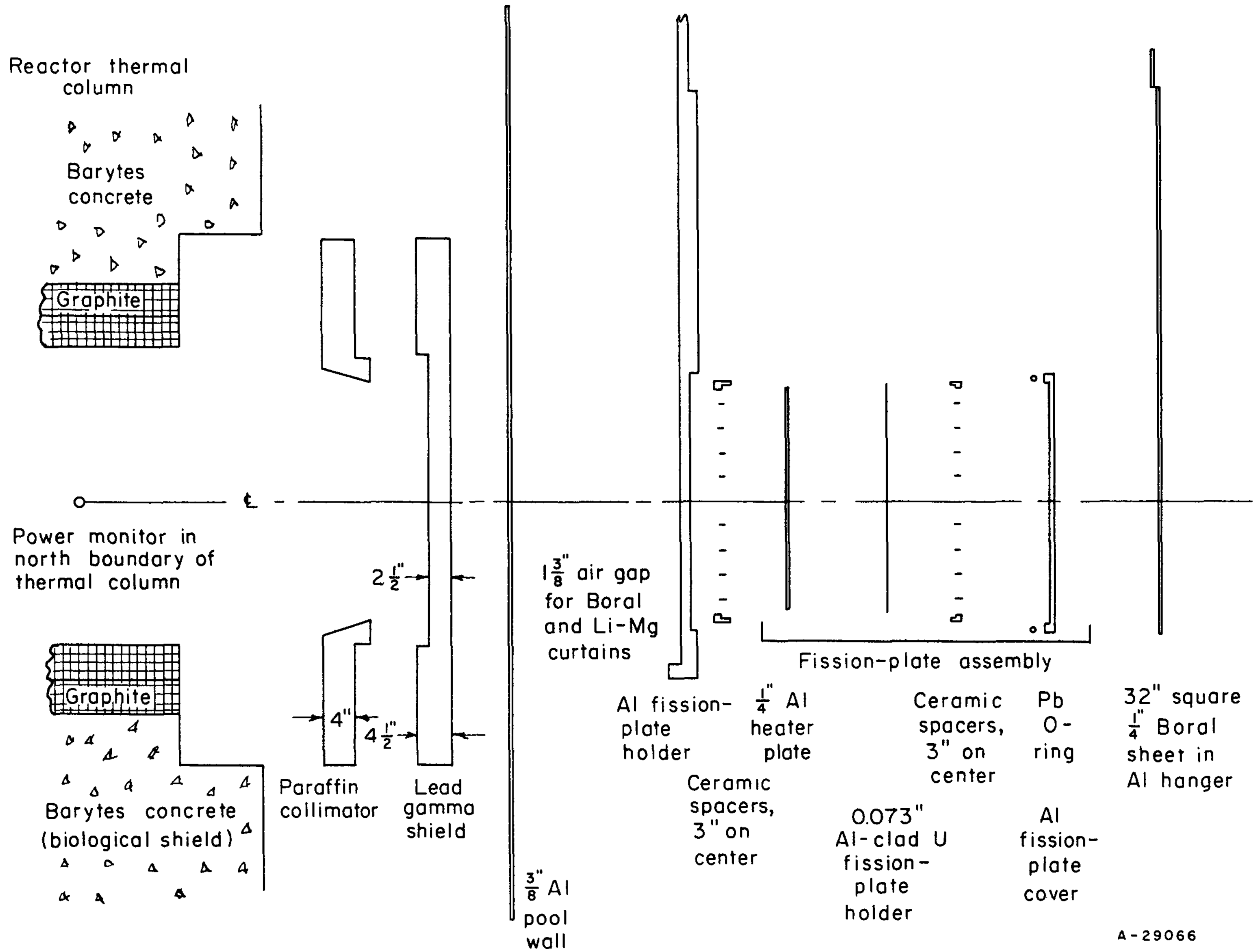

FIGURE 7. VERTICAL CROSS SECTION OF FISSION-PLATE ENVIRONMENT

instruments in the pool. The tower can be rotated through 180 deg about a vertical axis. The bridge can be seen in Figure 1. Two concentric tubes attached to a carriage or trolley make up the instrument tower. The outer tube is a 4-in. cast iron pipe which is geared to rotate in a casting attached to the trolley. The inner tube is a 3-in. aluminum pipe. It is free to move vertically but is keyed to prevent rotation within the larger pipe. Vertical drive is accomplished by a long screw which turns in a threaded brass bushing secured to the top of the aluminum tube. This assembly is capable of lifting 1500 lb. The carriage is moved laterally by driving along a 1-in.-square gear rack bolted in place parallel to the machined rails guiding the carriage.

All the drives use a d-c motor geared directly to a transmitting synchro. The drive speed is controlled by a Variac and can be continuously reduced to zero. The transmitting synchros are geared so that one revolution is equal to about 1/8 in. of travel. The receiving synchros trigger a five-decade mechanical counter which subtracts a count for a revolution in one direction and adds a count for a revolution in the opposite direction. The motion between revolutions is indicated by a dial on the receiving synchro. By this arrangement positions can be read to 1/180 revolution which corresponds to about 0.0007 in.

Thermal-Column Modifications

With the initial solid graphite thermal column, the neutrons emerging from the column were well thermalized but the magnitude of the flux at the horizontal access was found to be too low to produce the desired power in the fission plate. A study of the diffusion length for the thermal neutrons in the column led to the decision to partially void the interior. In the final arrangement, 29 per cent of the graphite was removed by use of a single large void in the center of the thermal column. A layer of solid graphite approximately 8 in. thick was left around the boundary of the thermal column as a reflector.

Although removing graphite from the thermal column decreased the cadmium ratio, the ratio of thermal to epithermal flux is approximately 67. This value is still sufficiently large to provide a low epithermal-neutron background at the fission plate.

Neutron Collimator and Gamma Shield

To eliminate neutrons which would add to the background by entering the pool around the periphery of the fission plate, a paraffin neutron collimator was constructed as shown in Figure 7. A 4-in. thickness of paraffin is sufficient to eliminate most of the neutrons not directed through the 28-in.-diameter window. Since it has a large scattering cross section, the paraffin is not completely black to the neutrons at the periphery of the 28-in.-diameter window and, hence, does not decrease the neutron flux at the edges of the window as abruptly as Boral or cadmium sheet.

In addition to the neutron collimator, it was desirable to further modify the thermal-column entrance by adding a final gamma-ray shield to suppress the gamma radiation mixed with the neutron beam. For this purpose a lead slab was placed in front of the neutron collimator as shown in Figure 7.

After the collimator and shield were added, the neutron-flux distribution was again measured with the geometrical and material environment of the fission plate mocked up with aluminum, polyethylene, and Boral. A 1/4-in. -thick Boral plate 28 in. in diameter was used to mock up the fission plate. The thermal-neutron-flux distribution was obtained by activating manganese-iron wires attached to the plate. The resulting flux distribution at the face of the plate is shown in Figure 8. As seen from this diagram, the flux is fairly uniform over the plate. The root-mean-square deviation from flatness is approximately 10.5 per cent. The drop in flux at the edge of the plate could be reduced by enlarging the iris of the neutron collimator. However, this would lead to higher neutron leakage around the fission plate into the pool.

Gamma Radiation

To obtain a source of gamma rays only, a sheet of material with a large (n, γ) cross section for a given energy gamma can be inserted in the place of the first of the two control curtains. The thermal neutrons transmitted by the first curtain will be captured by the Boral curtain directly behind. Since the cadmium ratio at the end of the thermal column is near 100, the number of fast neutrons contaminating the gamma beam will be negligible. There will, however, be some stray gamma background from the reactor, thermal column, and structural materials.

The gamma dose rate at the face of the fission plate was measured with ferrous sulfate chemical dosimeters prior to activation of the fission plate (with the Boral curtain in the shutdown position). The background gamma source was 205 ± 10 rep per hr. Assuming a calculated attenuation of 28 per cent by the fission-plate mounting and assembly, the gamma dose rate at the curtain is 285 rep per hr. The thermal-neutron flux at the curtain measured at the time of the gamma determination was 1.26×10^9 $n/(cm^2)(sec)$. Thus the neutron flux-to-gamma dose rate ratio at the location of the curtains is approximately 4.4×10^6 neutron flux per rep per hr. Assuming a gamma photon energy of 2 Mev, the ratio of thermal-neutron flux to gamma flux is approximately 16. Hence, with an efficient gamma conversion plate, a gamma source many times the background gamma level can be obtained.

NUCLEAR INSTRUMENTS

The shielding-research area is equipped with instruments to measure fast-neutron dose rate, gamma dose rate, thermal-neutron flux, fast-neutron energy spectrum, and gamma energy spectrum. Each detecting head is canned in aluminum and fitted with an adapter which attaches it to the instrument column of the bridge. In addition to the specialized radiation-detecting instruments, the facility is instrumented for measurement of pool and fission-plate temperatures, pool radiation level, pool water level, and control-curtain limit positions. The thermal-column neutron flux is continuously monitored. A block diagram of the instrumentation for the shielding-research area is shown in Figure 9. The instruments shown within the dotted line are contained in a console located in a control room near to the pool. The RIDL 200-channel analyzer is located adjacent to the instrument console. Figure 10 is a photograph of the instrument control room showing the console and analyzer.

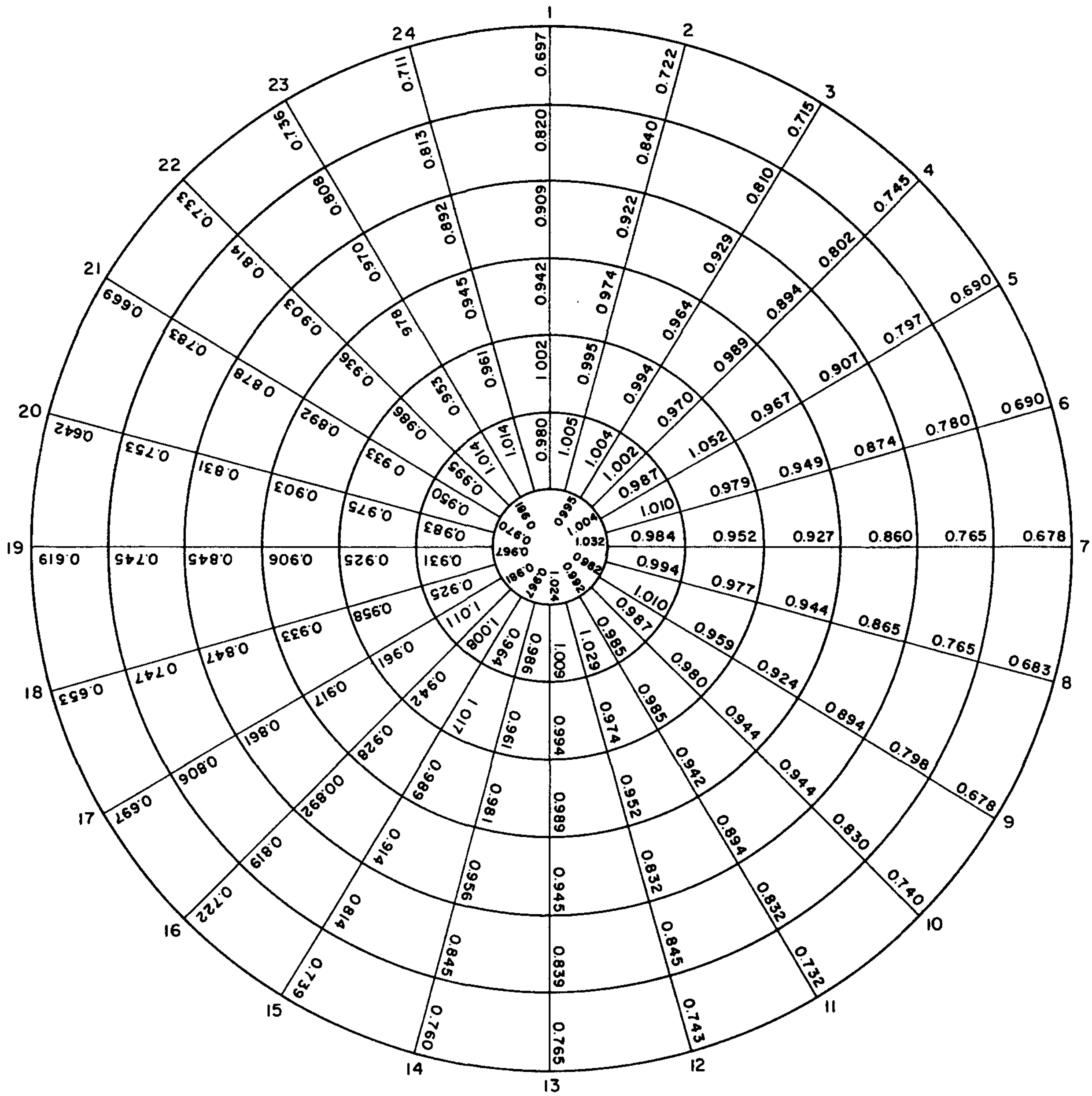

FIGURE 8. RADIAL MAP OF NEUTRON-FLUX DISTRIBUTION AT FISSION PLATE

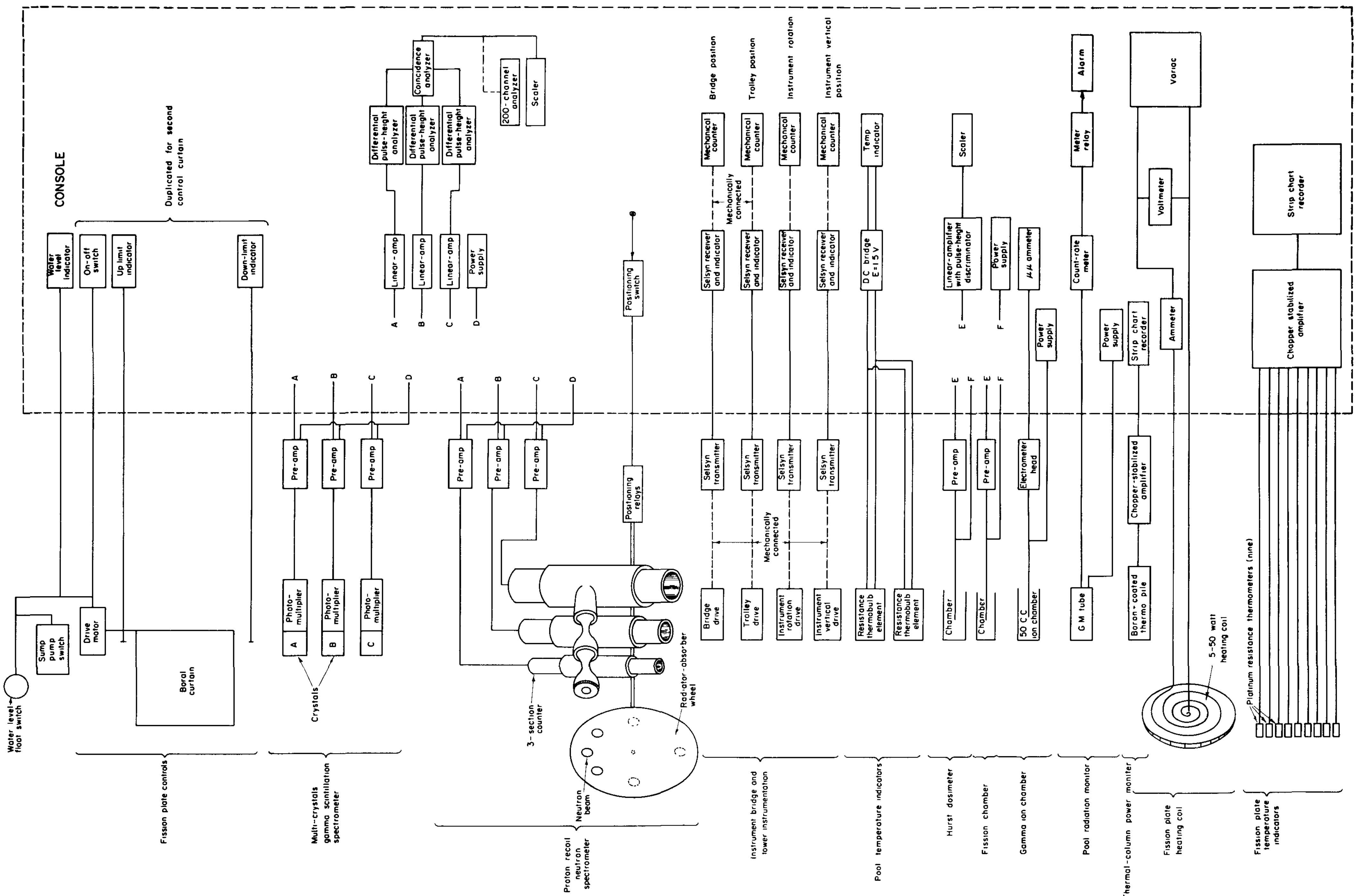

FIGURE 9. BLOCK DIAGRAM OF INSTRUMENTATION FOR SHIELDING-RESEARCH AREA

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FIGURE 10. CONTROL ROOM AND CONSOLE FOR SHIELDING-RESEARCH AREA

Fast-Neutron Dosimeter

A Hurst-type[4, 5] fast-neutron dosimeter will be used. The detector will be calibrated by comparison with a dosimeter which has a built-in calibrated alpha source. A polonium-beryllium source will be standardized and used to check the calibration of the detector periodically. Supporting instruments for the dosimeter include a preamplifier which is canned with the detector.

Gamma Dosimeter

For gamma dose-rate measurements a Westinghouse WX-3343 aluminum-walled 50-cm^3 ionization chamber is used. The chamber is filled with high-purity argon at 250 psi and saturates at 600 v. The output of the chamber is 10^{-13} amp/(mr)(hr) and it has a range from 10 mr per hr to 100 r per hr. Since the output is a low-current signal and the leads are more than 50 ft long, the instrument is sensitive to stray electrical pickup due to motion of the chamber and from a-c fields present in the building. To increase the signal-to-noise ratio, a balanced electrometer head feeds the chamber signal through the cabling to a Kintel electronic galvanometer. The galvanometer has a 1-v full-scale output which can be fed into a recorder.

Thermal-Neutron-Flux Detector

A 3/4 by 1-1/2-in. fission chamber is used to measure the thermal-neutron-flux distribution. This chamber is equipped with a preamplifier which feeds the signal into a linear amplifier with a pulse-height discriminator. For absolute flux determinations the output of the fission chamber is normalized to fluxes determined by foil activation. If the need arises, larger chambers can be used to obtain thermal-neutron fluxes below the sensitivity of the present chamber.

Fast-Neutron Spectrometer

A proton-recoil-type fast-neutron spectrometer similar to the type developed at Oak Ridge National Laboratory[6, 7] is being constructed. The proton-recoil spectrometer utilizes the principle that protons produced by interaction of an incident fast-neutron beam with a hydrogenous material (radiator) have an isotropic distribution in the center of a mass system[7]. Consequently, the range of the recoil proton is directly related to the energy of the incident neutron for a specified recoil angle. The detecting instrument consists of a radiator wheel and three-section counter that is connected to three nonoverloading linear amplifiers, a coincidence circuit, and a scaler. The spectrometer is jacketed by a waterproof aluminum can designed to partially support the weight of the spectrometer. Since this is a low-efficiency device, neutron-spectrum data can be taken only in high-flux neutron fields (i. e., very near the shield).

Multicrystal Gamma Spectrometer

A three-crystal gamma spectrometer has been constructed, patterned after a similar instrument developed by Oak Ridge National Laboratory[8, 9].

With this instrument measurements in the range of 0.2 to 10 Mev are possible. Two methods are employed to determine the energy of an incident gamma ray. For energies less than about 2 Mev, the Compton effect is used. The Compton-recoil electron and scattered gamma rays are detected in coincidence and the energy of the incident gamma ray calculated from the measured energy of the recoil electron and known scattering angle. For energies above 2 Mev, pair production is used by measuring the energy of the electron-positron pair detected in coincidence with the two annihilation quanta. The principal modifications of this instrument from the ORNL design are that the entire crystal suspension may be rotated within the large outer shielding shell and the distance from the center crystal to either outer crystals may be varied. The first modification permits variation of the detection angle for Compton scattering. This will also permit selection of the best angle for interception of the gamma rays produced by pair production. The second modification permits improvement of resolution (at the expense of detection efficiency).

Other Instrumentation

The radioactivity in the area of the pool is monitored by a GM remote area count-rate system (with console indication) which trips an alarm at 4 mr per hr.

The bulk temperature of the pool liquid is measured by two Alnor thermobulbs. The fission-plate temperature, of course, is measured by the six nickel resistance thermometers.

The thermal-neutron-flux level in the thermal column is monitored continuously with a boron thermopile[10]. The thermopile consists of several closely spaced temperature-sensitive elements with the alternate elements boron coated. The output of the thermal-column monitor is approximately 33 μv at a reactor power of 1 megawatt. This output is recorded at the control console and is calibrated in terms of fission-plate power.

FISSION-PLATE CALIBRATION

In the Battelle facility, two methods of calibrating the fission plate are used: (1) direct electrical substitution, and (2) measurement of the thermal-flux depletion in passing through the plate. The first method yields the most accurate results and will be discussed below.

As previously described, the fission-plate chamber consists of a heater plate in intimate thermal contact with the fission plate, and isolated from the walls of the chamber by an air gap as seen in Figure 7. The diameter of the fission plate is 28 in. A 1/4-in. annulus of air insulates the circumference of the heater-fission-plate assembly from the chamber walls. Electric power is supplied to the heater through 1250 in. of 24-gage copper wire embedded in a uniform spiral groove on the side of the heater plate which is in contact with the fission plate. Small ceramic spacers are used to insure uniform air-gap dimensions. Temperature drops across the 0.092-in. air gap between the fission plate and pool are measured with thin, nickel resistance thermometers.

Analysis of Electric-Substitution Method

In principal, the electric-substitution method of calibration consists of matching the temperatures produced by the fission source to those produced by an equivalent electric source. In practice, an electric source with the same power distribution as the fission source is difficult to achieve. However, the 1/4-in. -aluminum heater plate decreases the temperature gradients caused by the nonuniform fission heating, so that only a very slight numerical correction is necessary. An analytical comparison of the temperatures produced by fission heating with those produced by an equal electric power indicates that if all of the resistance thermometers are used in series, the fission-plate power is overestimated by 1 per cent. This difficulty would not arise if enough resistance gages were used to give complete area weighing. Experimental measurements show the actual overestimate to be 1.4 ± 0.5 per cent.

Another assumption inherent in the electric-substitution method is that ambient wall temperatures of the fission-plate chamber are the same for the fission as for the electric heating. In the Battelle system, this condition is met by maintaining all of the chamber walls at the temperature of the pool water. The front wall, being in contact with the water, presents no difficulty. However, conditions at the surface of the back wall are dependent on air temperatures and curtain positions behind the chamber. With the 1-1/8-in.-thick plate on the back wall, variation of 10 F in the ambient air temperature between the time of the electric and fission heatings results in only a 1 per cent error. Actually, the two runs are made at nearly the same time, so that the variation is less than 1 F.

In the design of the chamber, three principal factors were considered: (1) the time constant should be kept as small as possible in order that the system may reach equilibrium quickly, (2) temperatures must be high enough for accurate measurements, and (3) the heater plate should have a high heat capacity so that major corrections for nonuniform power distribution are avoided. The following formulas show that these factors are not mutually independent, and that improvement of one can only be done at the expense of another.

$$\tau = \frac{\Sigma_\alpha C_{p\alpha} \rho_\alpha t_\alpha}{h},$$

$$\Delta T = \delta / h,$$

where

C_{p_α} = specific heat of material α

ρ_α = density of material α

t_α = thickness of material α

h = heat-transfer coefficient from fission plate to water

τ = time constant

δ = heat generation per unit plate area.

A low h value produces a high ΔT, but a long time constant. On the other hand, a thin heater plate results in a small time constant, but poor integration of power variations. In the system finally chosen, the time constant is 20 min, and the temperature drop is 9 F for 33 w. The temperature drop and uniformity could be improved in the present system by partially evacuating the fission chamber. This would, however, increase the time constant, which is not desirable.

Experimental Procedure

The current supply for the heater consisted of two 6-v storage batteries feeding a voltage divider. The voltage divider was tapped off to supply the current necessary for a given power. The current was measured by an electronic galvanometer which indicated the voltage drop across a standard resistance. The resistance of the standard was determined with a double Kelvin bridge to an accuracy of ±0.05 per cent. The electronic galvanometer was standardized against a standard cell and checked after each reading. The galvanometer could be read to four places.

The resistance of the fission-plate-heater wire was measured separately with a Wheatstone bridge and a Kelvin bridge and found to be 2.722 ± 0.005 ohm.

The resistance change of the Stikon thermometers is determined with an unbalanced-bridge method. One leg of the bridge contains the thermometers on the fission plate and another leg contains a set of similar thermometers suspended in the pool water at the same level as the fission plate.

The bridge was supplied with a direct current of 20 ma, applied at least 1 hr prior to the actual calibration and initial balancing of the bridge. The unbalance was sensed by a Kintel electronic galvanometer equipped with a Sola constant-voltage transformer and noted to have less than 1/2 per cent zero drift on a scale 100 times more sensitive than the scale used. The output of the Kintel was recorded by a Brown recorder.

Calibration Experiment

Direct-current heating and cooling curves were run at 5-w intervals from 0 to 35 w. These curves are shown in Figure 11. One hour and 15 minutes was allowed for heating to about 97.6 per cent of equilibrium, and the same time for cooling. The purpose of these curves is to allow an immediate rough evaluation of the fission power. For more precise comparisons further electric-heating curves were run immediately after the fission-heating run. These were matched to the fission curve, as shown in Figure 12. The purpose of calibrating near equilibrium conditions is that minor variations in heating time and initial temperature conditions become relatively unimportant.

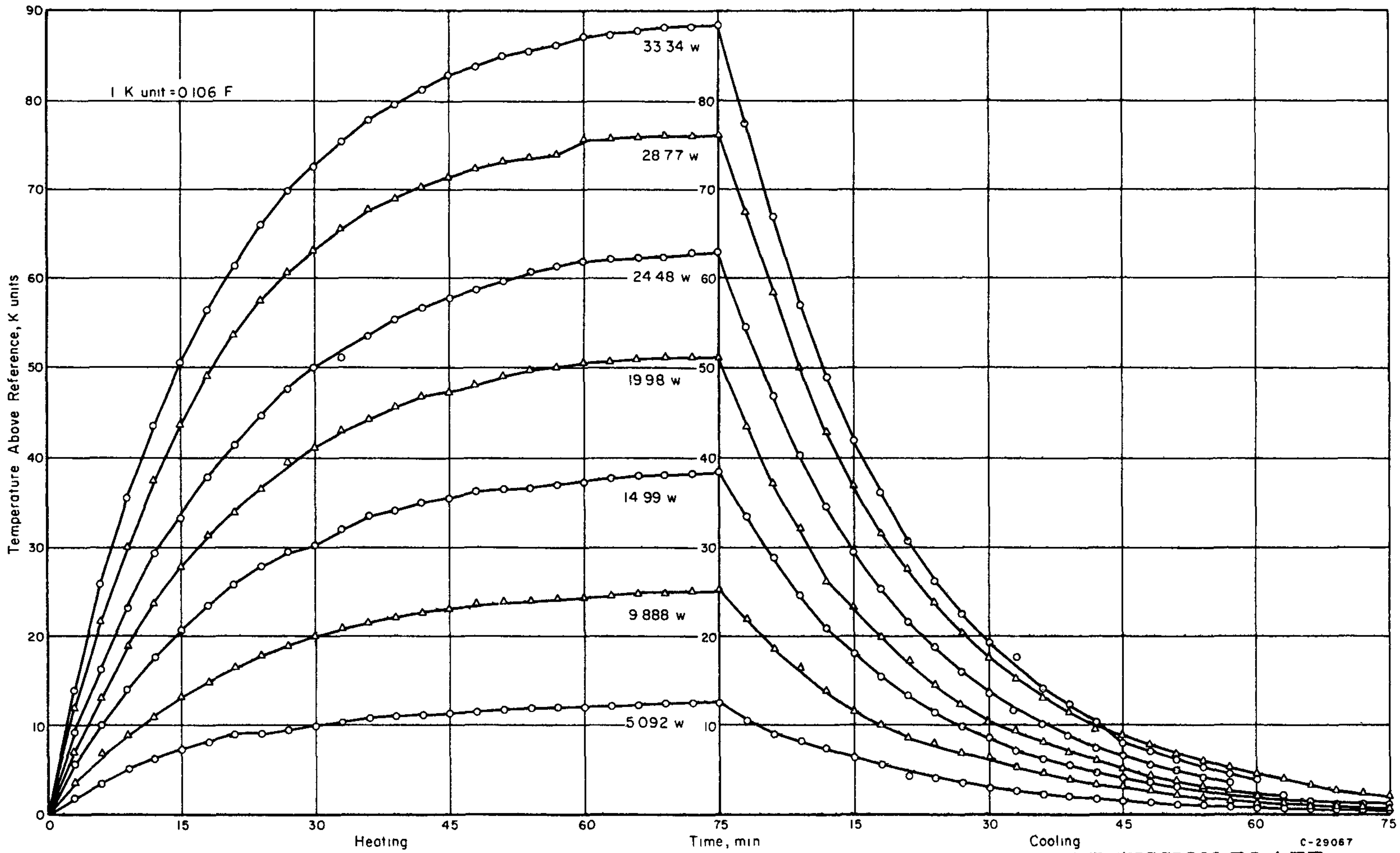

FIGURE 11. HEATING AND COOLING CURVES FOR ELECTRICAL HEATING OF FISSION PLATE

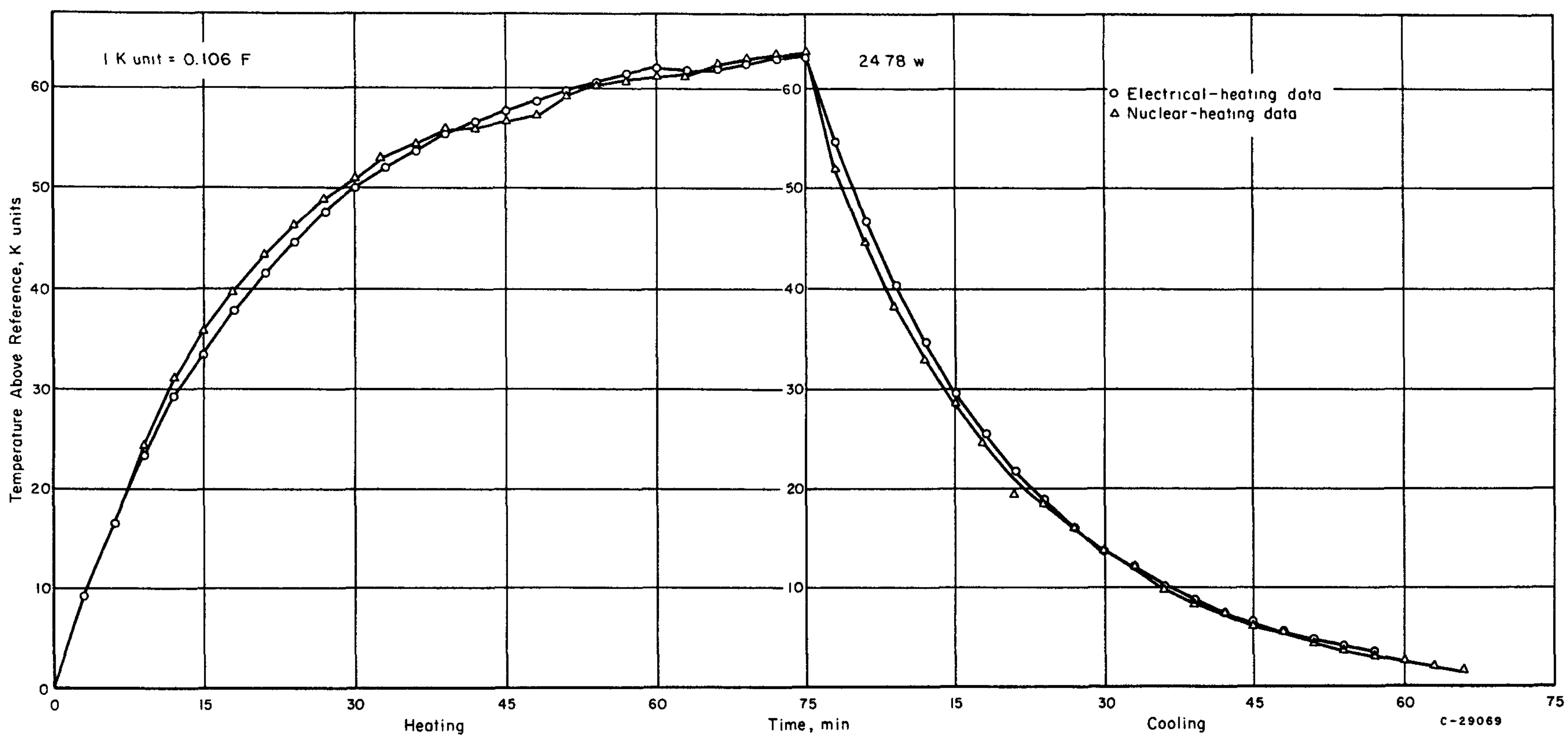

FIGURE 12. COMPARISON OF HEATING AND COOLING CURVES FOR ELECTRICAL AND NUCLEAR HEATING OF FISSION PLATE

The six resistance thermometers were attached in series for maximum sensitivity in these calibrations.

The temperatures across the plate were measured at each resistance-thermometer position. A temperature decrease of 4 per cent from the center to the outside of the plate was found in the fission-heating case. To correct for this temperature distribution, it is necessary to decrease the fission powers determined in the calibration by 1.4 per cent.

The fission-plate power, with the above correction, was found to vary from 28.19 w at the beginning to 24.43 w at the end of the cycle. This variation is due to changes in control-rod positions in the reactor. Most of this variation occurs during the first 2 days of the 12 days of continuous reactor operation.

Error Analysis

The sources of error in the power calibration fall into three groups: (1) errors due to difference in extraneous heat loss between the fission and electrical runs, (2) errors due to nonuniform temperature distribution in the plate, and (3) instrument errors. The first group consists of errors from changes of ambient air and water temperatures between the electric and fission runs. A 6 F change in water temperature causes enough variation in the heat-transfer coefficient in the air gaps to produce a 1 per cent error. However, the electric and fission runs were always done close enough together that the temperature variation of the water was much less than 1 F. The total error due to Group (1) was estimated to be less than 0.2 per cent. The errors in Group (2) were discussed previously. After the 1.4 per cent correction was made, this error was estimated at 0.5 per cent. Instrumentation errors, Group (3), include the errors in measuring I^2R for the heater and the error in matching temperature curves. Table 1 shows the individual errors over the over-all root-mean-square error.

TABLE 1. ERRORS IN FISSION-PLATE-POWER CALIBRATION

Source of Error	Per Cent Error
Group (1)	0.2
Group (2)	0.5
Current squared	0.2
Resistance	0.5
Matching temperature curves	0.25
Root-mean-square error	0.8

In converting from watts to fissions per second, it is necessary to know the average power per fission for the system. Since gammas and fast neutrons can easily escape the fission plate, this value will be lower than the 200 Mev per fission figure usually used for reactors. The best value available for the energy per fission, neglecting the energy of the neutrons and gammas, is 177 Mev ±3 per cent[11]. Using this value, 1 w equals 3.53×10^{10} fissions per sec.

Fission-Plate Power With the Boral Plate Removed

For normal use of the facility, a 1/4-in. Boral plate is attached to the front of the fission plate (between the fission plate and shielding specimen) to prevent changes in power due to neutron reflection from the shielding specimen. However, experiments can also be performed without the Boral plate, which is easily removed. Removal of the plate has been observed to increase the power of the fission plate by a factor of 1.36. Hence, at the initiation of a reactor operating cycle a power of approximately 38 w can be obtained which would then decrease to about 33 w within 2 days and remain at this power during the remainder of the 12-day cycle.

CONCLUSIONS

From the work performed on the shielding-research area during the first year of the research program it is concluded that

(1) The fission plate for the facility produces a power of approximately 24 w during steady-state reactor operations, and under special conditions can produce a power as high as 38 w.

(2) A low epithermal-neutron background is present at the fission plate; the ratio of thermal to epithermal flux in the impinging neutron beam is approximately 67.

(3) The neutron flux is fairly uniform over the fission plate. In a mock-up experiment it was found that the root-mean-square deviation from flatness is approximately 10.5 per cent.

(4) With a few modifications the facility may be used as a pure-gamma source. Assuming a gamma photon energy of 2 Mev, the ratio of thermal neutron flux to gamma flux at the control curtains is approximately 16.

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