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A LOW POWER WATER BOILER REACTOR NEUTRON SOURCE

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ABSTRACT

A discussion of a low power Water Boiler Neutron Source in operation at the Atomic Energy Research Department of North American Aviation, Inc. is presented. The core of the reactor consists of a small stainless steel sphere containing a U^{235} enriched uranyl nitrate solution. The sphere is surrounded by a cylindrical graphite reflector, which in turn is surrounded by a concrete block shield. The reactor is designed to operate at power level of 100 milliwatts giving a maximum flux of 4×10^6 thermal neutrons/cm²-sec.

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I. INTRODUCTION

In July, 1951, the Atomic Energy Commission granted the Atomic Energy Research Department of North American Aviation, Inc. permission to build a small reactor of the water boiler type to be used as a source of neutrons for experimentation. This reactor, called the Water Boiler Neutron Source, or WBNS, was completed in April, 1952. It is a modification of a water boiler reactor in operation at Los Alamos.*

II. DESCRIPTION OF THE WBNS

The core of the WBNS consists of a homogeneous water solution of enriched uranyl nitrate in a 1-foot diameter stainless steel sphere. This sphere is encased in a cylinder of graphite, 5 feet in diameter, which serves as a reflector and thermal column. The axis of the graphite cylinder is vertical, and its top surface provides a broad source of thermal neutrons. The entire cylinder is surrounded by a concrete block radiation shield 2 feet thick. The design of the reactor is indicated in Fig. 1.

The critical mass of the WBNS is approximately 630 grams of U^{235} . The reactor is designed to operate at a power level of 100 milliwatts, which provides a flux of about 4×10^6 thermal neutrons/cm²-sec at a test hole near the center of the core and about 10^5 neutrons/cm²-sec at the top of the thermal column. The reactor is equivalent to a source of approximately 2.4×10^9 neutrons per second at the 100 milliwatt power. In addition to the thermal column experiments, this reactor may be used for cross section measurements, instrument and material testing, shielding measurements and biological experiments.

A. Graphite Reflector

The graphite reflector is a right circular cylinder of pile grade graphite 5 feet in diameter and 6 feet high. It was formed by stacking graphite bars horizontally inside a steel tank with the bars in alternate layers placed orthogonal to each other. The stainless steel sphere is supported at the center of the reflector by the graphite, which was machined to form a spherical

*R.S.I. 22, 489 (July, 1951).

cavity for the sphere. The steel tank holding the graphite has walls $1/4$ inch thick and is supported by 6-inch channel beams welded to the bottom.

Eight graphite bars close to the sphere may be removed to accommodate ionization chambers and other instruments or materials (see Fig. 1). Parallel to the eight removable bars is a small "glory" hole ($1-1/8$ inches ID) which passes through the graphite and through the stainless steel sphere. This hole permits access to the region of highest flux.

B. The Reactor Core and Fuel Handling System

The fluid system consists of the water boiler sphere, a fluid mixing tank and a gas accumulator tank. It is located within the concrete shield. Except for the teflon seats in the valves and a neoprene rubber pressure bag, the entire fluid system is constructed of type 304 stainless steel. Prior to loading with the uranyl nitrate solution, the system was tested by pressurizing to 300 psi. A schematic diagram is given in Fig. 2, and a photograph of the external parts of the system before completion of the assembly of the shield is shown in Fig. 3.

The water boiler sphere is constructed from two hemispherical spinings of $1/16$ -inch stainless steel sheet and has a volume of 14,385 cubic centimeters. The hole through the sphere is about 1 inch below center and is formed of $1-1/8$ -inch ID, $1/16$ -inch wall thickness stainless steel tubing. A $1/8$ -inch ID tube at the bottom of the sphere connects to the filling tank and a $1/2$ -inch ID tube at the top of the sphere allows the passage of gas to the accumulator tank.

The fluid mixing tank, which has a volume of approximately 3 liters, has a removable cover with a stainless steel flange 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 stainless steel sphere.

Any decomposition and fission product gases that are evolved during reactor operation are contained by the gas accumulator tank. The inside of the tank is divided into two parts by a neoprene rubber bag. The gas is collected between the outside of the bag and the inside of the tank. During operation the inside of the bag contains principally helium at approximately atmospheric pressure. The decomposition and fission product gas is regularly sampled. When necessary, it can be removed by transferring the gas from the accumulator tank to a storage vessel. In order to sample or remove the fluid

from the system, the neoprene bag may be pressurized with helium to force the fluid in the sphere back into the fluid mixing tank.

A Borden type gauge connected to the system measures the gas pressure. The level of the fluid in the sphere is measured by an electrical probe which may be inserted through the fluid mixing tank into the small filling pipe. Water may be removed from the system by vacuum distilling from the mixing tank. The mixing of the fluid after an addition of solution may be accomplished by bubbling helium into the sphere through the mixing tank or by pressurizing the neoprene bag and forcing the fluid back and forth between the water boiler sphere and the mixing tank.

C. Control and Safety Rod Mechanisms

Two safety rods, a coarse control rod and a fine control rod are used to control the reactor. 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 a 1/16-inch thick strip of cadmium between two aluminum channel beams. This forms an I-beam about 3 feet long by 4 inches high. The rods slide in and out of holes in the graphite reflector on roller bearings and are held in the "out" position by magnetically actuated catches. If the holding magnets are de-energized, the safety rods are pulled into the reflector in approximately one-half second by weights suspended from cables passing over pulleys. The safety rods are automatically released if the power of the reactor exceeds some predetermined value. Electric power failure or manual operation of a "scram" switch will also release the safety rods. Fig. 4 is a photograph of the installed control and safety rod mechanisms.

The coarse control rod is constructed similarly to the safety rods. It controls approximately 1 per cent in reactivity. The fine control 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. Reversible electric motor drive systems are used to move the control rods. Each control rod is provided with a selsyn remote indicator.

D. Shield

A concrete block wall surrounds the reactor to protect personnel from

fast and slow neutron flux and gamma radiation. The blocks are composed of ordinary concrete and are 24 inches by 24 inches by 21 inches high and weigh approximately 1000 pounds each. A hoist can be used to lift each block by means of a steel hook cast into the block and countersunk below its top surface.

E. Instrument Control Panel

Fig. 5 shows a view of the instrument control panel which is located in the laboratory area immediately adjacent to the WBNS building. 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 other two are boron lined counters, one of which is connected to a counting rate meter and the other to a scaling unit. To reduce the counting rate, the counters are covered with cadmium sleeves. 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. Indium foils are inserted into the graphite when it is necessary to measure the flux distribution or its absolute value.

III. FUEL LOADING PROCEDURE

The approach to criticality was quite straightforward. The procedure paralleled that used with the Los Alamos water boiler. The operation of all the control circuits, the mechanical operation of the control and safety rods and the "tightness" of the fluid system were carefully checked. The BF_3 counters and the ionization chambers which are placed at different positions around the outside of the graphite reflector were used to monitor the reactor power. In addition, seven bare indium foils were placed in the glory hole, between the outside of the sphere and the outside of the reflector. A Po-Be source of approximately 10^7 neutrons/second was placed at the center of the glory hole and the control and safety rods were retracted. Twelve liters of distilled water were added to the steel sphere, and the flux measurements were made. Decreasing amounts of uranyl nitrate solution containing 0.5 gram of

U^{235} per milliliter were added until criticality was reached. After each addition, the solution was mixed by blowing helium gas through the filling tank into the sphere. The degree of mixing was followed by observing the rise in the flux at the monitoring instruments. When the flux no longer increased, the mixing was considered complete. Foil measurements were then taken, and all the readings were recorded. The approach to the critical mass was followed by plotting the reciprocal of the neutron flux determinations against the mass of U^{235} in the system. Some of these data are presented in Fig. 6. When the critical mass had been determined, an excess of about 4 grams of U^{235} was added. This is sufficient for convenient yet safe operation of the WBNS. With a correction of 1 gram for the fluid in the filling pipe, the critical mass was determined to be 633 grams. The volume of the solution in the sphere was determined to be 13.3 liters. This leaves a 5-centimeter space between the liquid level and the top of the sphere.

The shortest period of the pile, with all rods retracted, was found to be 26 seconds. A preliminary measurement of the gas evolution was determined to be less than 6 cubic centimeters of $H_2 + O_2$ per watt hour of operation. The two safety rods were found to control the equivalent of about 30 grams of U^{235} . This has been increased to approximately 60 grams by the addition of two 1/4-inch by 3-3/8 inch by 24-inch boral plates to each safety rod. During normal operations, the Po-Be source is located in the position of one of the lowest removable graphite bars.

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Fig. 3

Fig. 4

Fig. 5

FIG. 6