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THE ORNL ANALYTICAL CHEMISTRY DIVISION'S 150-KV COCKCROFT-WALTON GENERATOR

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Abstract

A general description of the facilities used by the Nuclear Analyses Group of the Analytical Chemistry Division at Oak Ridge National Laboratory to house a small Cockcroft-Walton generator is presented. Preliminary information and data are given as to the operational performance of the generator, the radiation safety controls involved, and the expected use of the device. In addition, an automatic-manual device for control of tritium target usage is described.

The Nuclear Analyses Group of the Analytical Chemistry Division at Oak Ridge National Laboratory has obtained and installed a 150-KV neutron generator of the Cockcroft-Walton type for use in its research and development programs. The following report is made to describe the installation and preliminary operation of this device. Radiation safety controls, mode of operation, proposed improvements to the physical system and expected analytical programming are generally described in this report.

Generator Description - General

The generator is of the Cockcroft-Walton type manufactured by the Texas Nuclear Corporation, Austin, Texas. Designated as Texas Nuclear's Model 9501, it has a 150-KV high voltage supply and can be used to produce 14-Mev neutrons by striking a tritium target with accelerated deuterons from an ion source. Figure 1 shows the physical shape of the generator. It is 5 ft. in length, 4 ft. in height, and approximately 3 ft. in width. Besides the 150-KV power supply, an operating console is provided. The controls of the console (Figure 2) are electromechanically coupled to the accelerator by means of synchronous motors. The control console is connected to the accelerator by two 33-ft. cables.

The generator is also equipped with a beam-pulsing system which allows the operator to gate the beam with a rise and fall time of approximately 0.25 microsecond. This operation is accomplished prior to ion acceleration by a rapid change of potential on deflection plates located in the Einzel lens. A pumping system of the Vac Ion type is used to maintain oil-free vacuums (in the range of 2×10^{-7} mm of Hg) upon the system.

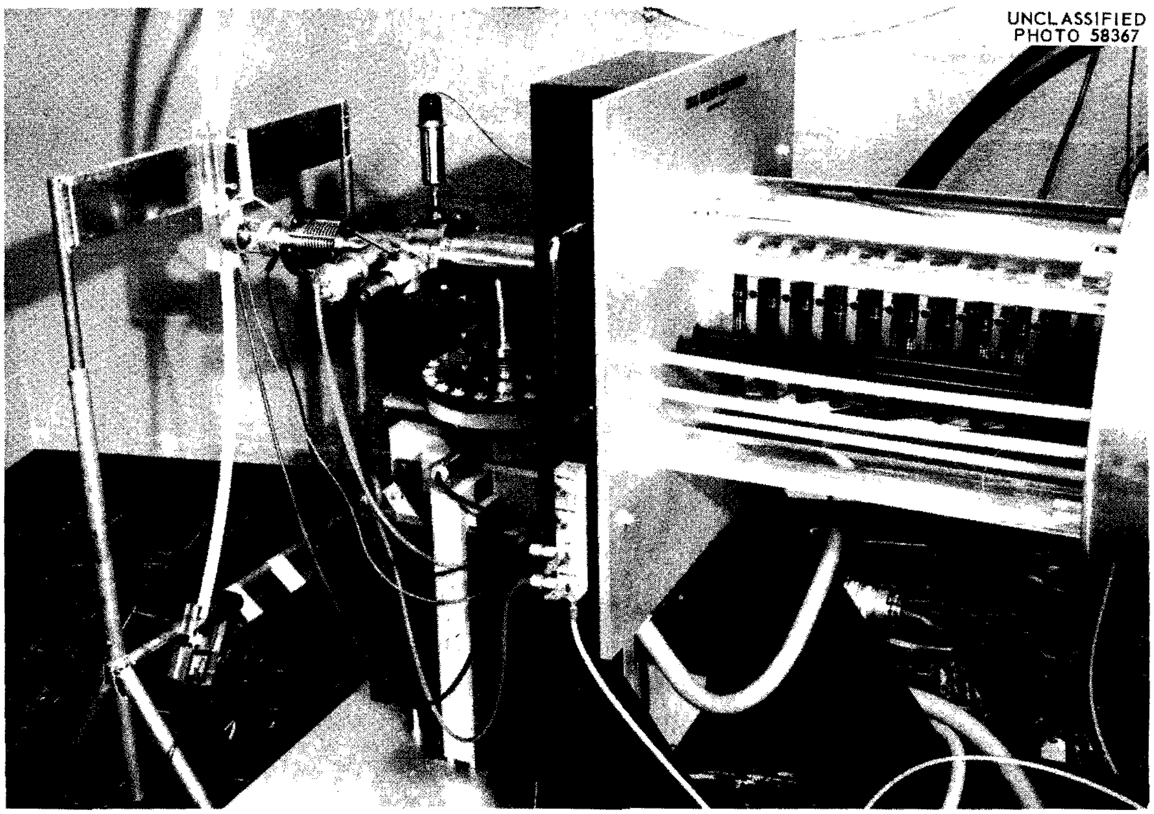

Fig. 1. Neutron Generator with Rabbit Stepping Device in Position.

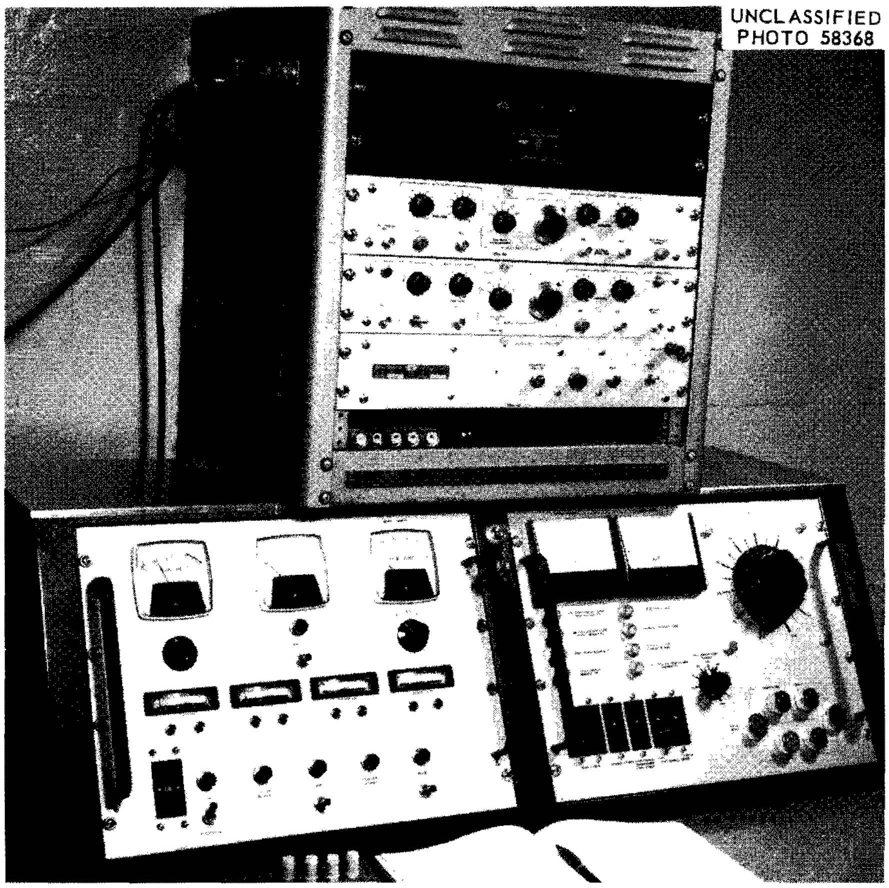

Fig. 2. Operating Console and Beam Switching Controls.

The protection devices of the generator include an automatic output voltage shorting mechanism, gaseous discharge devices for meters and relay protection, a series resistance in the output circuit, spark gaps to ground from meters and transformer primaries, zero start interlock, overcurrent relay, and an overvoltage relay. In addition, provisions for an external interlock on the overall physical system are available.

Physical Installation of the Generator

In contemplation of this installation within the laboratory areas of the Analytical Chemistry Division, a preliminary "Hazard Evaluation Report" was made to the Department of Radiation and Safety Control.(1) Many of the ideas incorporated in this installation and appearing in this report resulted from discussions with personnel of both the Department of Radiation and Safety Control and the Health Physics Division. More specifically, the following items are concerned with the establishment of a safe operational area.

Neutron Shielding: Arnold(2) has provided calculations on the neutron dose rate attenuation factor vs. thickness of normal concrete for a 15-Mev neutron source. These data are shown in Figure 3. In effect, a 100-cm thick concrete block shield will reduce the dose rate by a factor of 10^4. Our installation (Figure 4) which locates the target of the generator 4 feet from the nearest wall will result in a maximum dose rate of 0.5 mrem/hr. at the outside of the shield (a distance of 7.5 feet from the target).

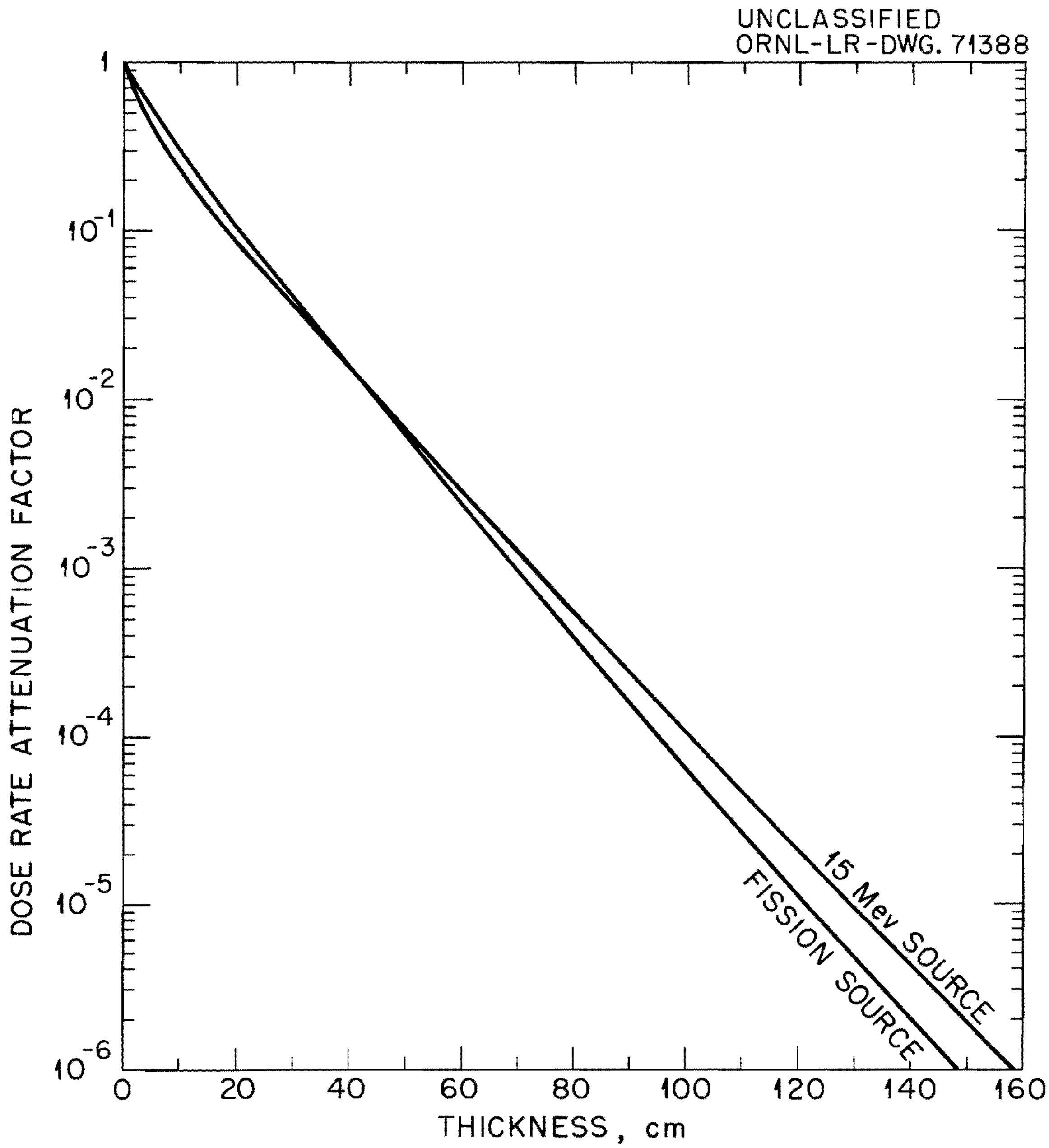

Fig. 3. Neutron Attenuation as a Function of Concrete Thickness.

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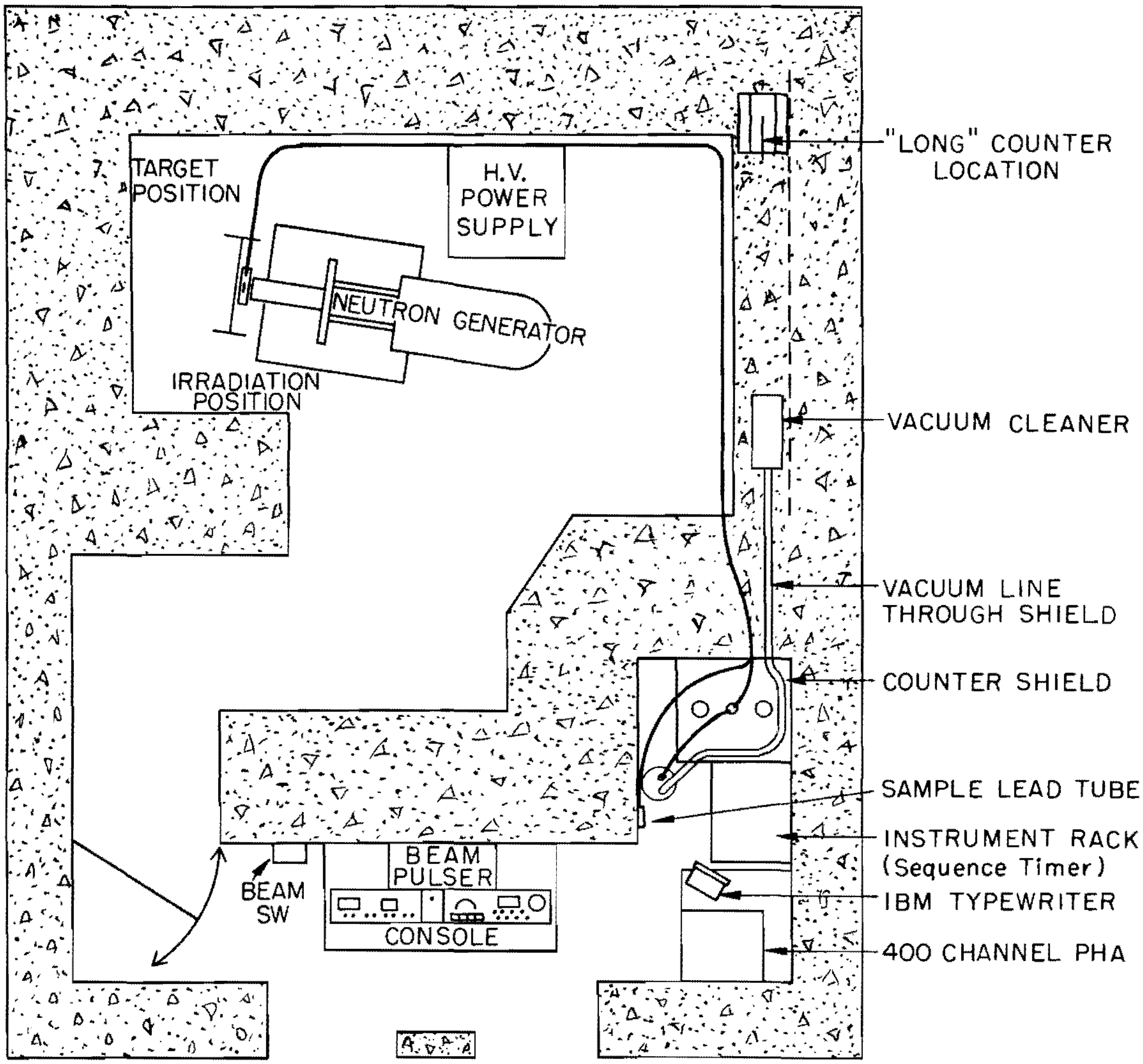

Fig. 4. Schematic of Generator Installation and Shielding.

In actual operation, using a 1-curie tritium target and a 600 μa beam current, it was found that the total neutron output of the target was approximately 3.5×10^{10} n/s. The neutron background in the console area was not detectable, and the gamma background in the same area while the generator was operating was approximately 0.2 mr/hr.

"Sample" Transport System: In order to irradiate sample materials and rapidly transfer the irradiated materials to a radiation detection device, a simple transport system has been designed. Figure 4 shows this schematically. Made from 5/8-inch ID; 3/4-inch O.D. polyethylene tubing, the system is mounted on wall brackets and extends from the counter area of the installation (passing through the concrete wall) to immediately in front of the tritium target. The sample container, or "rabbit," is sucked into the target area by the action of a vacuum cleaner motor (1/8 hp) and remains in the target area for a preset time and is returned to the radioactivity detection device by the same vacuum system. The details of the "rabbit" stopping and discharge mechanism are shown in Figure 5. The "rabbit" is returned to a fixed location in the radiation detection device. Figure 6 shows the details of this device. The preset-timing device for control of irradiation periods is part of the "sequence circuit" described below. The "rabbit" is inserted in the open-end tube located near the console, sucked into the target area. At the end of the irradiation period, it is discharged by opening a solenoid valve to provice an air-leakage path to lift the "rabbit" into the vacuum system for transport back to the radiation detection device. The discharge of the "rabbit" from the detection area to a storage area is accomplished in a similar manner.

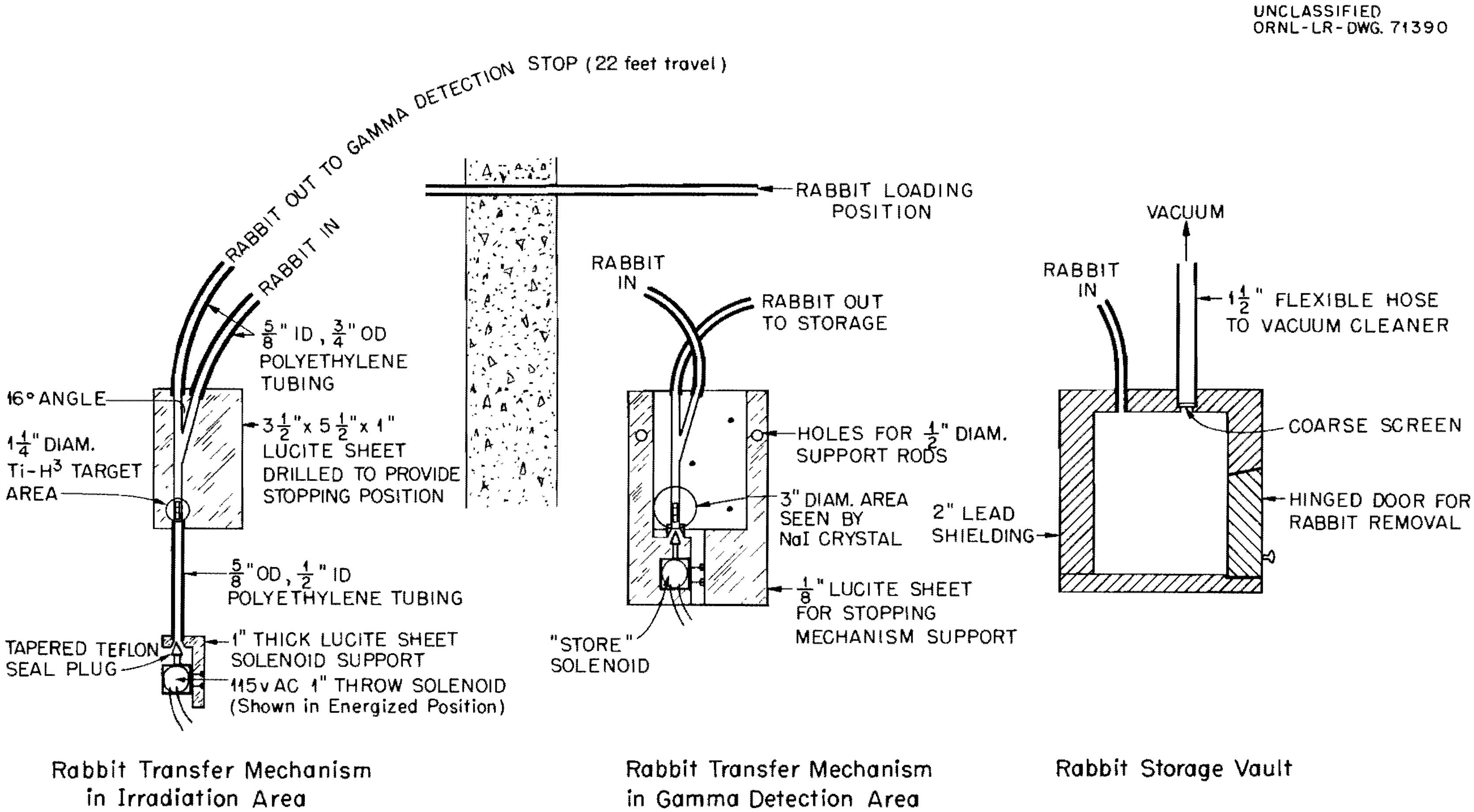

Fig. 5. Schematic of the Rabbit Transport System.

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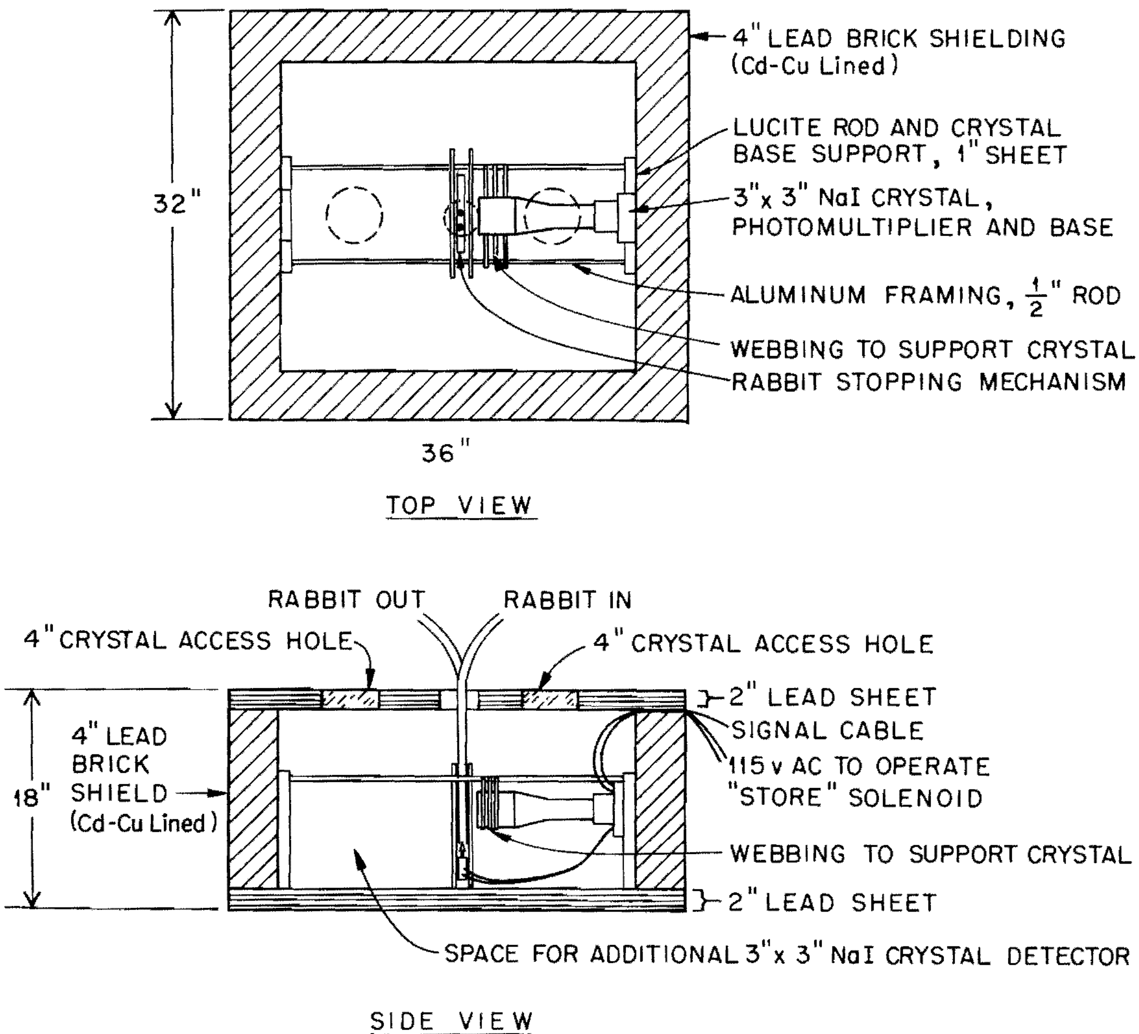

Fig. 6. Rabbit Stopping Device in Counting Shield.

The "rabbit" used in this system is made of high-density polyethylene. Its dimensions are 2.78 cm long x 1.48 cm in. diameter (see Figure 7); inner dimensions are 1.95 cm long x 0.90 cm in diameter. Rabbits made from high-density propylene can be used also.

Deuteron-Beam Control: In the experiences of other users of similar neutron-producing devices, it has been found that the tritium targets lose maximum neutron-output as a function of time and beam current. In our experiences, we have found it practical to minimize these losses by limiting the duration of target bombardment by the ion beam to the actual time required for sample irradiation and beam adjustment. In order to accomplish this, the beam-pulsing system supplied with the generator is driven by an external signal, either automatically or manually, so that the beam is allowed to impinge upon the target only during sample irradiation. Figure 8 shows the circuitry employed to supply the pulses to actuate the Einzel lens. In the automatic mode, the operation of this circuit is triggered by a "sequence-timer" circuit (shown in Figure 9) through a microflex timer to provide variable irradiation times from 1 - 120 seconds. The use of a different model microflex timer could extend these irradiation periods.

The "sequence timer" operates in the following manner: When the master switch, S-1, is turned on, it supplies power to the "rabbit" vacuum system motor and the contacts of the start-switch, Pb-1. When Pb-1 is momentarily depressed, the microflex timer is energized and through its contacts the relay coil, S-2, is energized to turn on a neutron counter which monitors the neutron output. S-2 also supplies power to activate the relay coil of the "beam-switching circuit"

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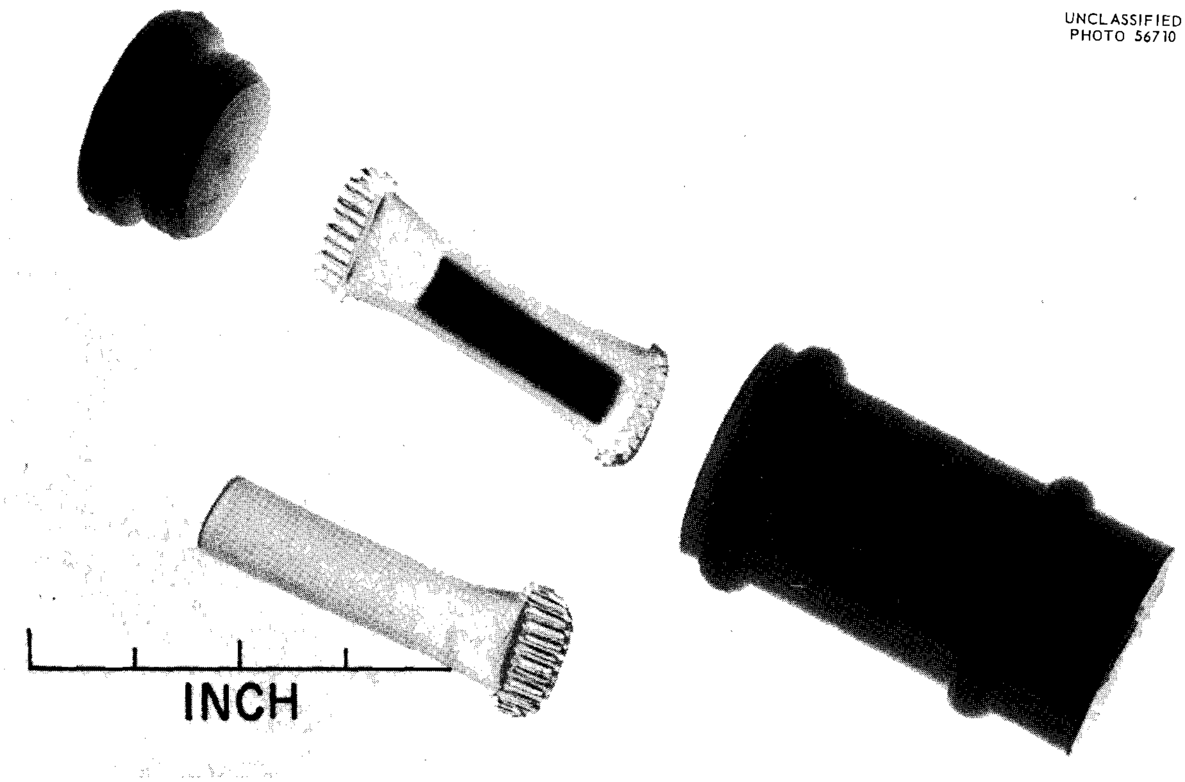

Fig. 7. Irradiation Container.

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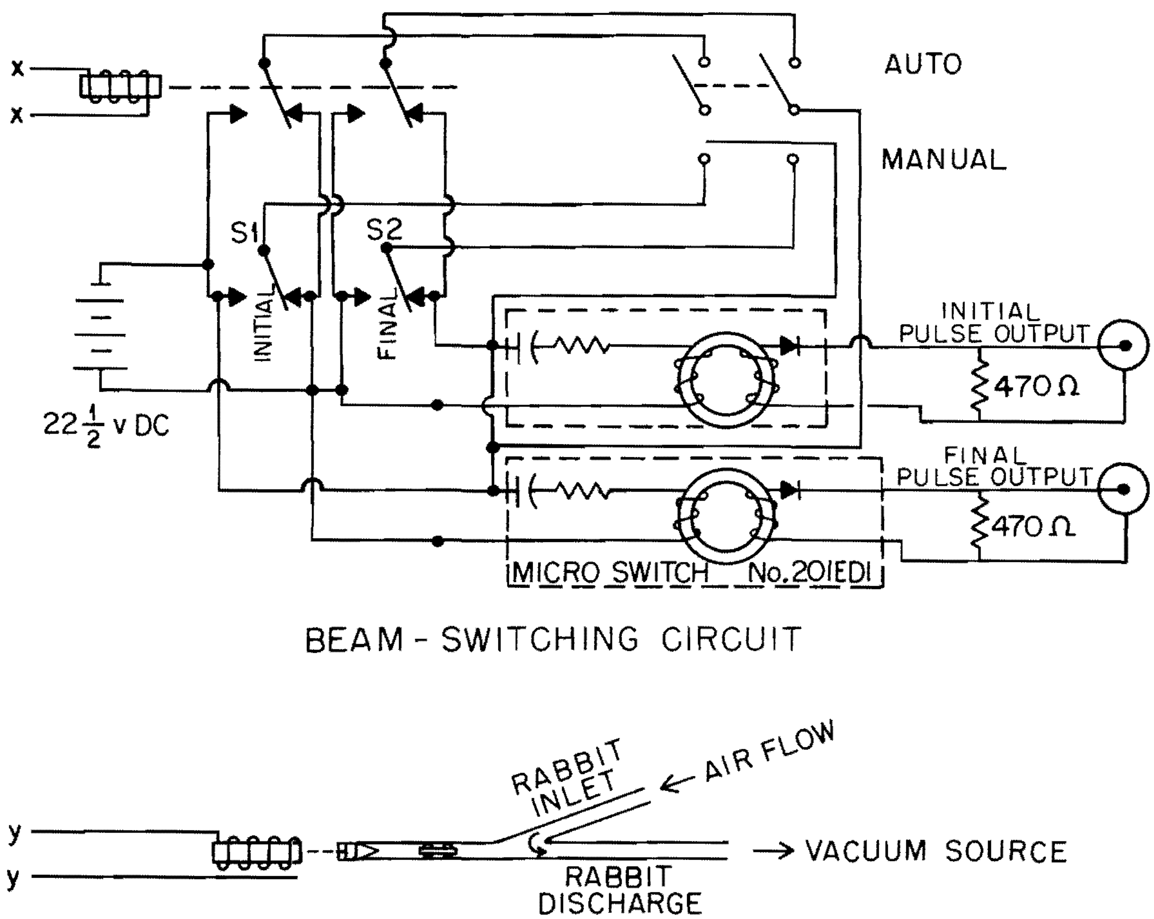

Fig. 8. Rabbit Transfer Solenoid.

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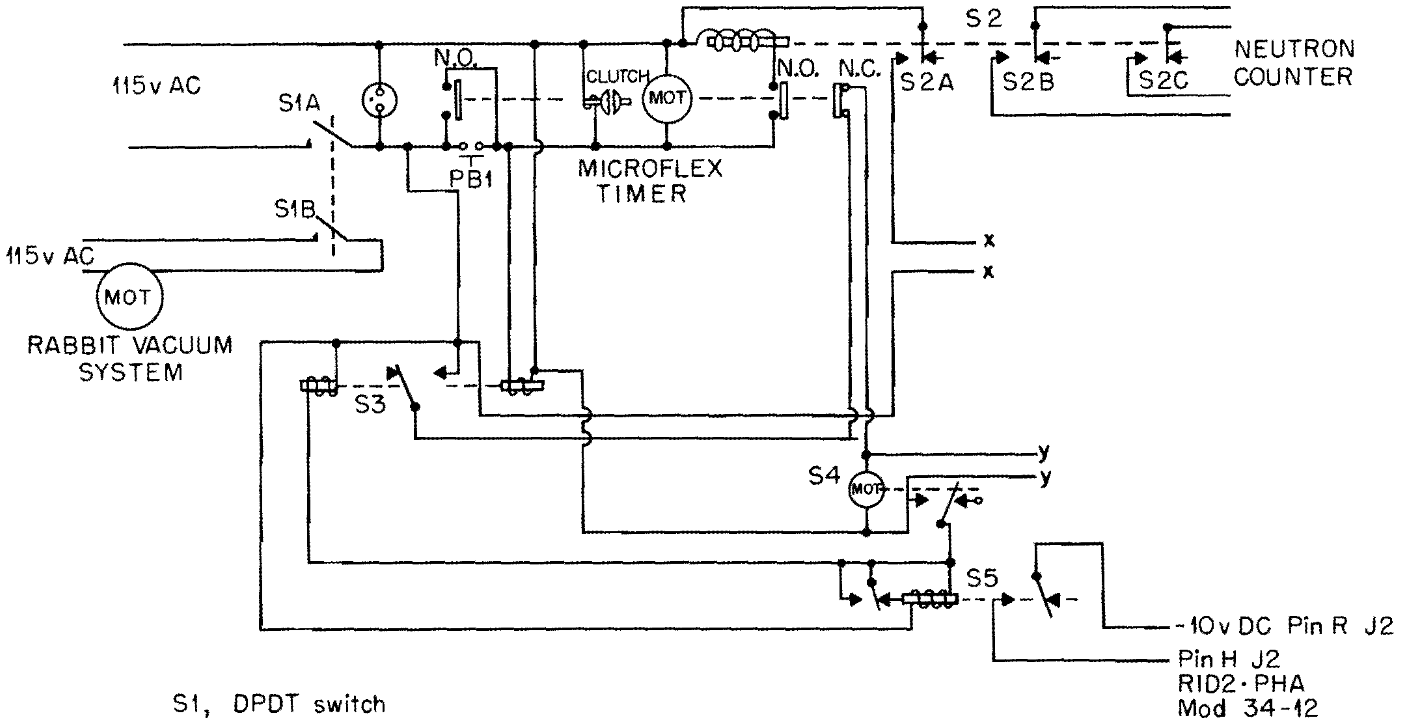

S1, DPDT switch

PB1, Push button momentary contact (start)

Microflex timer, 0-120 sec

S2, TPDT switch

S2A turns on neutron generator beam

S2B and S2C turn on neutron flux monitor

S3, SPDT bistable switch

S4, Motor driven 0-10 sec time delay relay

S5, SPDT starts pulse height analyzer at S4 rundown

Fig. 9. Sequence Timer Circuit.

generating an initial pulse which turns the ion beam on. At the end of the preset time interval (established by the operator), the microflex timer resets, turning off the neutron counter through S-2 and the relay in beam-switching circuit to generate a final pulse to cut off the ion beam. The timer also supplies power to S-4 to begin a 1.6-second delay and to energize the "rabbit" transfer solenoid in order to remove the "rabbit" from the target area. At the completion of the 1.6-second delay (to allow for an 0.8-second travel time of the rabbit), the contacts of S-4 close, energizing S-5. S-5, in closing, supplies a -10 V DC potential to initiate the multichannel analyzer counting system. The contacts, S-5, also complete the circuit to energize S-3 to reestablish the original state of the system.

In a typical operation, the "beam-switching circuit" (Figure 8) is placed in the manual position and the Einzel lens pulsed on by depressing the initial switch, S-1. The beam current is raised to the desired microampere level by adjustment of the extraction and Einzel lens' controls on the console. When the desired beam current has been achieved, the beam is turned off manually by depressing switch, S-2. The manual-automatic control is then switched to the automatic position, and the irradiations automatically controlled through the sequence timer.

Through this automatic beam control system, minimal burnout of target has been observed, and it is possible to have gated neutron generation with rise and fall time intervals of 0.25 microsecond. Experimental data obtained by use of this control system is given below.

The Multichannel Analyzer Counting System: The radiation detection system initially provided in this installation consists of a gamma spectrometer. The spectrometer is equipped with a 3" x 3" solid NaI (Tl activated) scintillation crystal. The crystal output is amplified through a 3-inch photomultiplier tube, a transistorized preamplifier, and a transistorized linear amplifier and pulse height analyzer. The analyzer has 400 channels of data storage which either can be read out as a display upon a cathode ray tube, or recorded by means of either an IBM typewriter, or X-Y plotter, or punched tape.

Neutron Detection

The manufacturer of the generator does not provide neutron detection apparatus. In order to perform useful activation analyses, it is necessary for the analyst to know the flux of neutrons available during the irradiation of a sample. There are several ways presently in use for monitoring flux, i.e., simultaneous irradiation of an internal standard with the test sample, monitoring of the induced 7.4-s N^{16} by the $O^{16}(n,p)N^{16}$ reaction) radioactivity in the target cooling water, and low-efficiency neutron counting. For the present, our system involves only the measurement of neutrons by a high pressure BF_3 proportional counter.

This detector has an active volume of 1/4" x 1" and is filled to a pressure of two atmospheres with 95% $B^{10}F_3$. The detector is housed in a "long" counter, whose paraffin moderator and reflector are located approximately 15 feet from the target of the generator. Its efficiency for neutron detection was measured by the use of a standard Am^{241}-Be neutron source and was found to be 5.48×10^{-8} neutrons per count. For example, for a generator neutron output of 4×10^{10} n/sec, the neutron counter will have a count rate of 2192 counts per second.

These counts are recorded during the irradiation interval by means of a 1024 scaler which is automatically turned on and off by the "sequence-timer." It can also be operated manually during beam adjustment to determine total neutron output.

Neutron Flux: In order to correlate total neutron output with neutron flux, a series of tests has been made in which the radioactivity induced into the test materials has been compared with the neutron count measured by the BF_3 detector. Using $Si^{28}(n,p)Al^{28}$ as a fast flux monitor,[3] it has been established that the counts recorded by the BF_3 detector are linearly proportional to the neutron output for ion beam currents ranging from 50 μa to 700 μa. Figure 10 shows this relationship. The calculated flux at a beam current of 600 μa was 3.5×10^8 n/cm^2/sec. after a 1-week intermittent operation with a 1-curie tritium target.

Target Decay: Only a very limited amount of work has been done on studies concerned with target decay. However, during the initial operation periods to determine shielding efficiency, it was found that a beam current of 40 μ amperes striking a target for at least 15 minutes reduced the neutron output by about 3%. At a 100-μa beam current and a steady operation for a period of 24 minutes, the neutron flux was reduced from 2.05×10^8 to 1.44×10^8 n/cm^2/sec.

With the pulsed-beam control, the target bombardment time is reduced by more than a factor of 20 over that used for continuous operation. This intermittent operational system has resulted in a conservation of target and has reduced the gamma background. For instance, it has been observed

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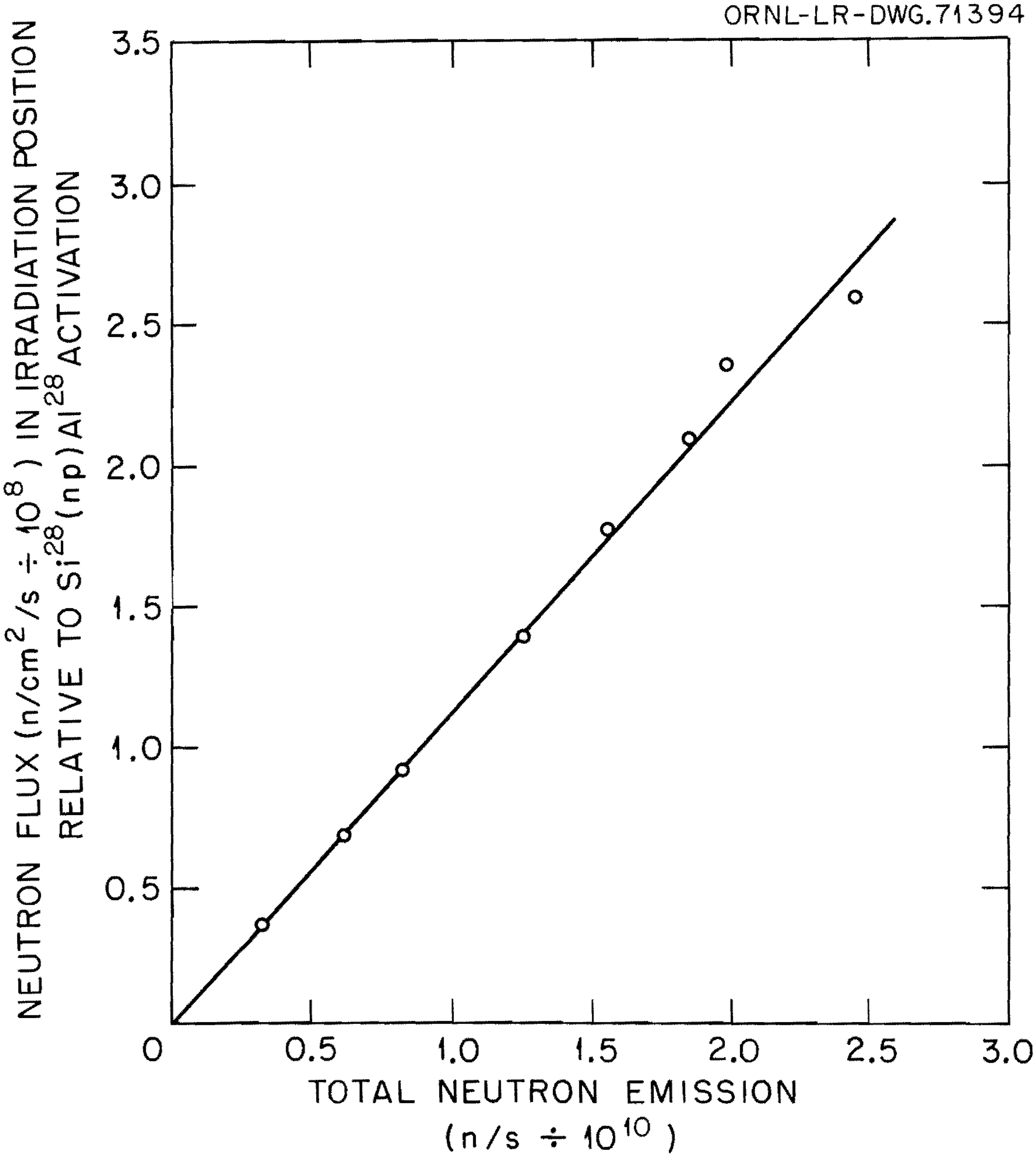

Fig. 10. Relationship Between Neutron Flux in the Sample to Total Neutron Emission as Measured by the $B^{10}F_3$ Counter.

that after 35 ten-second sample irradiations at 600 μa, the neutron flux was reduced only a few percent.

Gamma Background

The environmental gamma background (natural radioactivity from shielding materials) is much less than 0.05 mr/hr. During the operation of the generator, a gamma background of 0.2 mr/hr is observed in the console area. The reduction of generator operation through use of the automatic beam-control circuit, minimizes operator exposure. It is postulated that this gamma background arises from photons produced by fast neutron scatter, principally from hydrogen.

Immediately following the irradiation of 10 samples for 20 seconds each, the generator room background was less than 0.1 mr/hr while the tritium target assembly on the generator gave a reading as high as 20 mr/hr. Much of this radioactivity is due to radionuclides induced into the materials of the target assembly; for example, 15-h Na^{24}.

Summary

The studies carried out so far by use of this generator in its present physical installation (Figure 1) show that minimal radiation hazards exist when a neutron output of 3.5×10^{10} n/sec. is available. An increased tritium content of the target will result in higher neutron output which should not greatly increase the radiation hazards for personnel operating in this laboratory area.

Since these initial studies have generally shown the practicability of this installation, work efforts are now being directed to the requirements of the research and development efforts of the Nuclear Analyses

Group. At present, applications of fast neutron activation analyses, especially for oxygen by the $O^{16}(n,p)N^{16}$ reaction, will be studied. In addition, the following areas of study will be considered:

1. Investigation of shielding requirements for both gamma and 14.3-Mev neutron radiation.

2. H^3 target evaluation and half-life studies.

3. Use of the 14.3-Mev neutrons to induce (n,p), (n,α), and (n,2n) reactions in a variety of low atomic numbered elements for analysis purposes and pure research.

4. Determination of the cross-section and half-lives of some of the less well known fast neutron products.

5. Develop the irradiation sequence techniques which would allow reproducible studies of short-lived products.

6. Report the over-all results in a single report which could be used as a guide to neutron generator applications in analytical problems.

References

1. Memorandum to F. Kertesz (per G. W. Leddicotte) dated February 5, 1962.

2. Arnold, E. H., private communication

3. Hughes, D. J., and Schwartz, R. B., BNL-325, Neutron Cross-Section, July 1, 1958.

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