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A STUDY OF THE SHIELD OF THE VIRGINIA POLYTECHNIC INSTITUTE UTR-10 REACTOR

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ABSTRACT

A study of the radiation leakage from the shield of the Virginia Polytechnic Institute UTR-10 nuclear reactor was completed in February of 1962. Fast-neutron, thermal-neutron, and gamma-ray dosimeters of high sensitivity were employed to obtain a detailed network of data over all surfaces of the shield. Supplementary experiments evaluated gamma-ray dose rates in a corridor and in a classroom adjoining the reactor room and also determined a rough value for argon dispersal through the reactor room ventilating system.

The results of the detailed survey showed generally satisfactory performance of the shield for fast- and thermal-neutron radiations, but a number of regions were identified in which the gamma-ray dose rate was higher than that predicted by the shield design.

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INTRODUCTION

During the latter part of 1961 and in early 1962 a series of studies of the as-built performance of the biological shields of various reactor types has been carried out.[1,2] These studies have been made under the sponsorship of the Division of Compliance, U. S. Atomic Energy Commission. The work was accomplished by the Neutron Physics Division of Oak Ridge National Laboratory and utilized a mobile van-contained radiation detection laboratory designed for accurate measurement of extremely low levels of radiation.

The program thus far has been largely devoted to study of university-owned reactors. A number of factors have dictated this course. The typical university reactor is of relatively low power and physically small in comparison to, say, electric power production reactors. These features contributed to more rapid development of our experimental techniques. Again, many university-owned reactors are commercially designed and built "stock" models. A single study effectively describes many similar installations. Finally, and perhaps most importantly, it is most desirable to be assured of the integrity of the shields of university reactors because of the close-up use given them by youthful students.

The present report describes the study of the shield of the nuclear reactor of the Virginia Polytechnic Institute at Blacksburg, Virginia. The V. P. I. reactor is located in a multipurpose building housing other laboratories, classrooms, shops, and offices, in roughly the northwest corner of

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1. T. V. Blosser, R. M. Freestone, Jr., and J. M. Miller, <u>A Study of the Shield of the University of Illinois TRIGA Mark II Research Reactor</u>, ORNL-TM-178 (April 23, 1962).
2. Reports covering studies of the shields of the Oak Ridge Graphite Reactor, the Westinghouse Testing Reactor, and the University of Virginia Reactor are in press or in preparation.

the Institute campus. The reactor is a 10-kw UTR-10, heterogeneous, light-water moderated and cooled, and graphite reflected.[3] Its basic design follows that of the Argonne National Laboratories' Argonaut. The general appearance of the facility is shown in Fig. 1, and more details are shown in the plan and cross section of Fig. 2. The reactor core consists of a 3-ft 8 in. by 4 ft 8 in. stack of graphite 4 ft 0 in. high, in which two rows of fuel elements, contained in aluminum core tanks, are embedded. The core tanks are spaced two ft apart, center to center, thus providing a sort of flux trap region, 18-5/16-in. wide, in which a flux of 1.3×10^{11} neutrons$\cdot$cm$^{-2}\cdot$sec^{-1} is maintained at full power. Each tank is subdivided into six fuel chambers each containing a 12-plate fuel assembly. Fuel is enriched uranium (90% U^{235}) contained as UAl_4 solid solution in aluminum. The total mass of U^{235} is 3 kg.

The shield of the reactor consists of 80 in. of ordinary concrete on all sides except the east, where the bulk shield tank is located. It is penetrated by two opposing, 6-in.-dia, stepped beam ports, perpendicular to the plane of the section in Fig. 2, four control rod drive housings, a slim, curved conduit for the manual source positioner, and a 4-ft by 5-ft graphite thermal column. Access to the core is from the top, and top closure and thermal column closure are of high density concrete. Shortly before the present study the shield was fortified by the addition of 8 in. of concrete block to the face through which the thermal column penetrates.

3. The UTR-10 reactor (from "University Training Reactor") is designed and built by the Advanced Technology Laboratories Division of American-Standard, Mountain View, California.

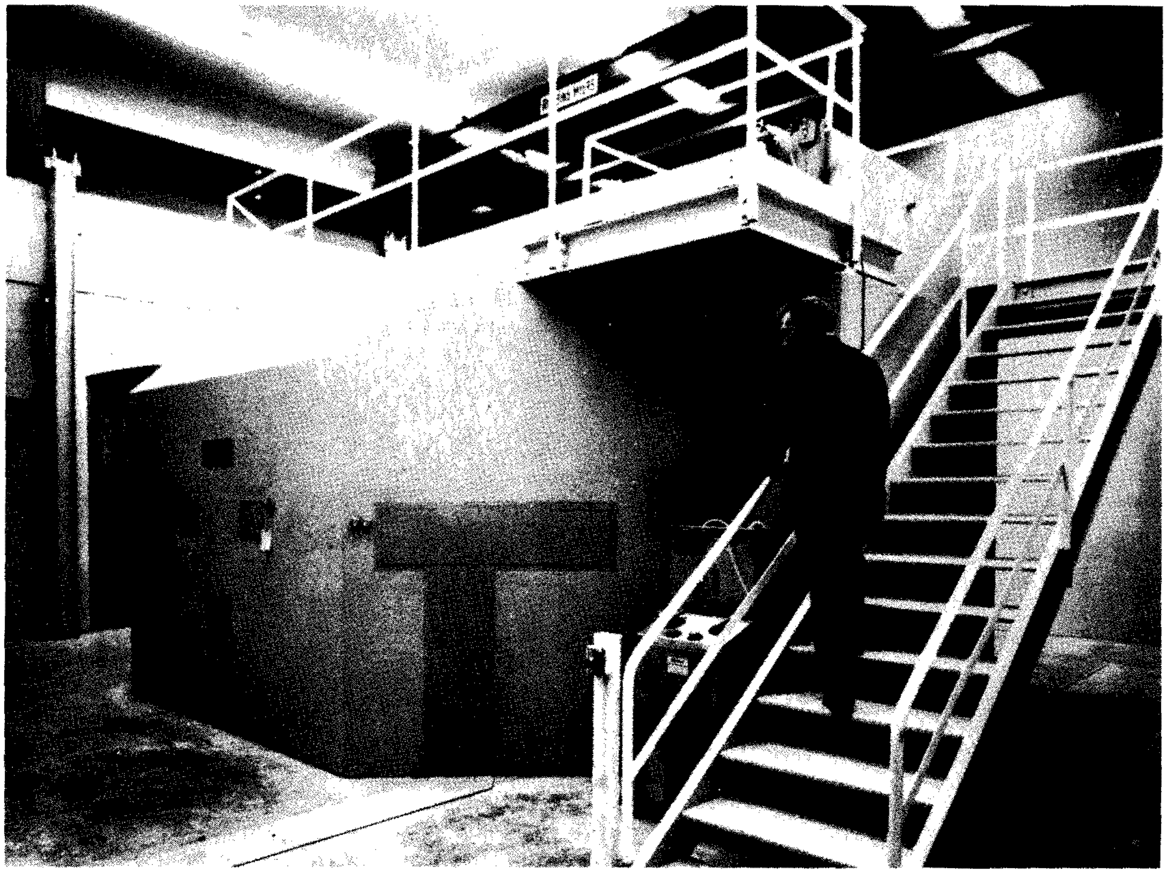

Fig. 1. The Virginia Polytechnic Institute UTR-10 Reactor.
(Advanced Technology Laboratories photograph)

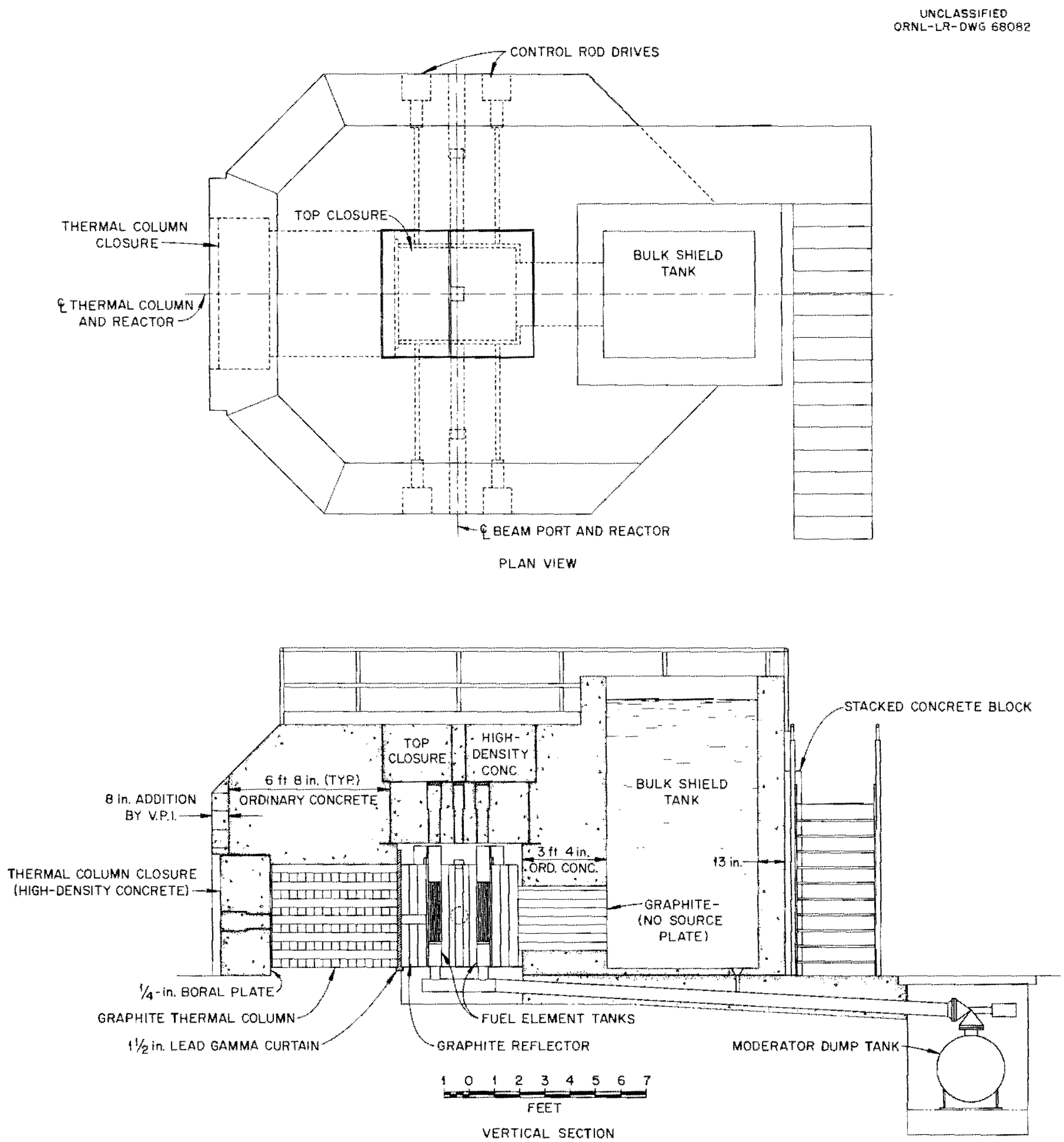

Fig. 2. Plan and Section of the VPI UTR-10 Reactor Shield.

EXPERIMENTAL APPARATUS

The mobile radiation detection laboratory with which this study was made is shown in Figs. 3 and 4. Contained within the vanette are seven shock-mounted racks of instrumentation, shielded calibration sources, and the necessary supporting test and calibration equipment required to make the laboratory completely self-sufficient. Instrumentation and the high sensitivity detector heads are interchangeable, although for convenience certain detectors are usually used with particular sets of electronics. Since the detectors have been described previously,[1,4] it will only be noted here that in the present study thermal-neutron fluxes were measured with the high-pressure BF_3 proportional counter, fast-neutron dose rates with the modified long counter, and all gamma-ray dose rates with the anthracene crystal scintillation detector.

EXPERIMENTAL PROCEDURE

In order to permanently reference the data, a grid was established on the vertical faces of the V. P. I. reactor. The grid points were at 3-ft intervals, and the origin of coordinates was taken as the beam port centerline on the north and south faces. On the east and west faces the origin of ordinates was chosen at the same elevation as the north and south zeros; the origin of abscissas was the vertical centerline of the shield face. North and south grid systems were simply extended to locate data on the northwest, northeast, southwest, and southeast faces. A polar grid, with zero over the reactor centerline, was used on the top surface of the shield.

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4. T. V. Blosser and R. M. Freestone, Jr., Nucleonics 21(2), 56 (1963).

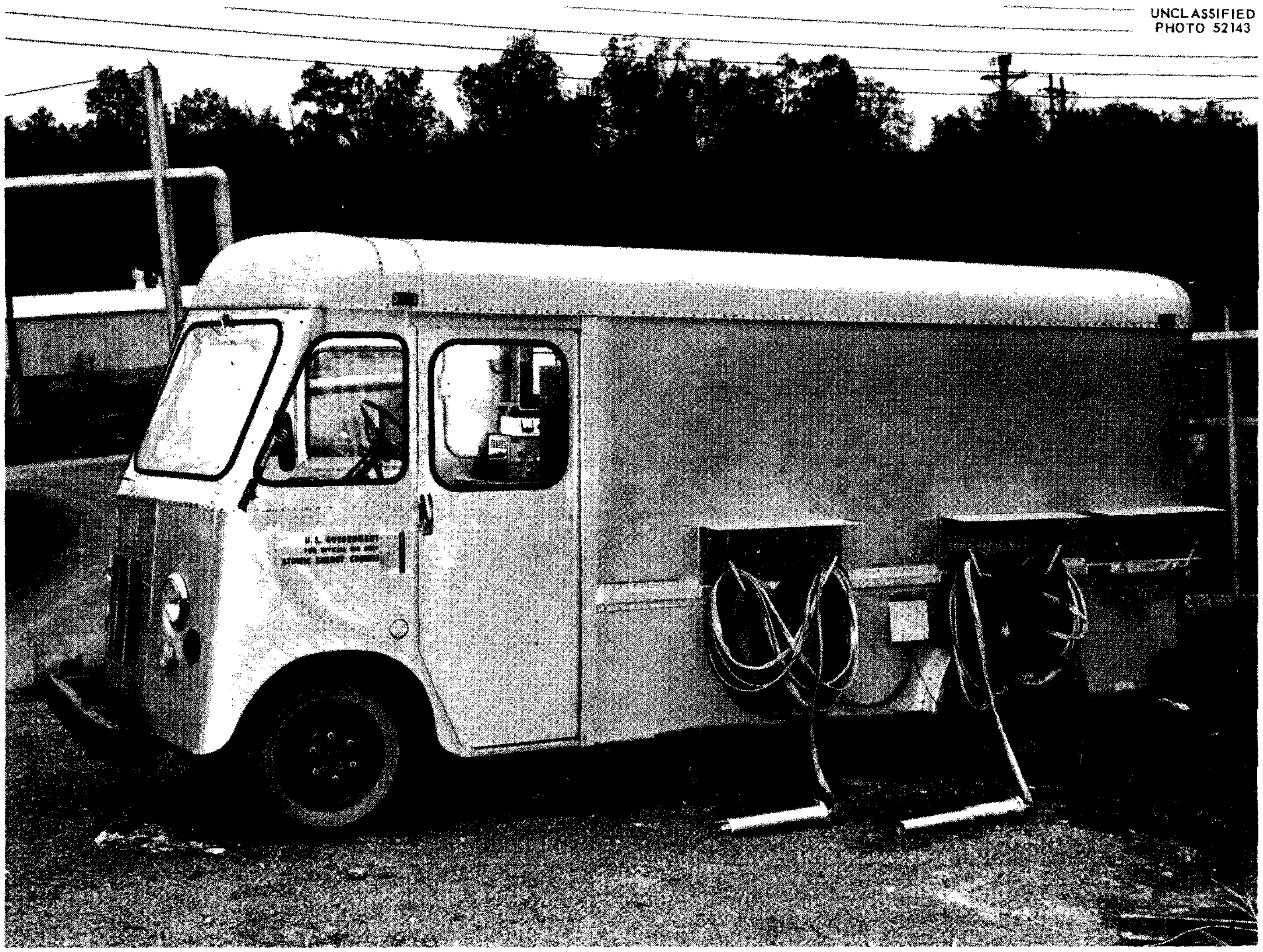

Fig. 3. The ORNL Mobile Shielding Laboratory No. 1.

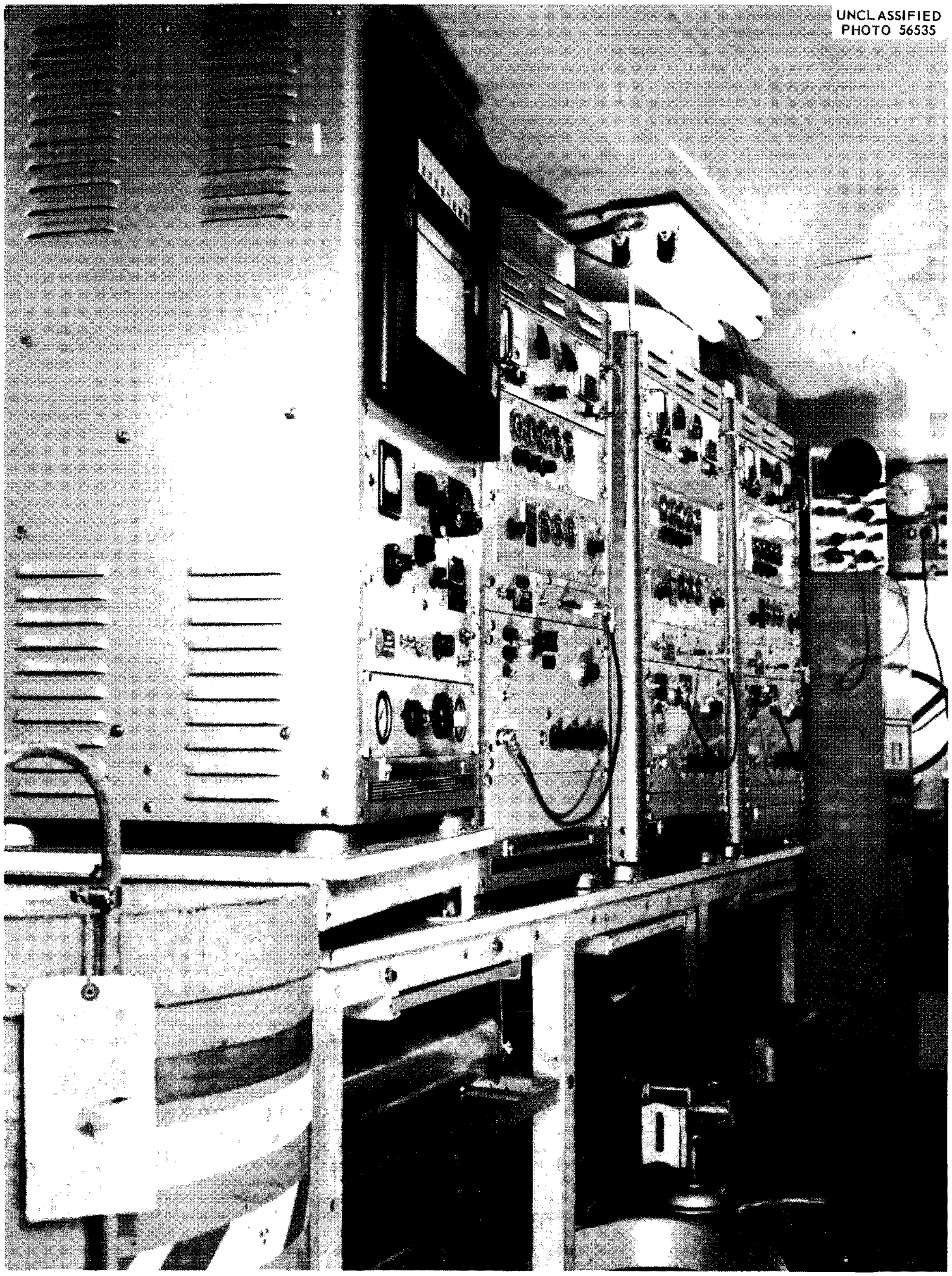

Fig. 4. Interior of the Mobile Shielding Laboratory.

A particularly useful feature of the mobile laboratory is the use of sound-powered telephones to maintain constant contact between the operator handling the detector and his counterpart at the scaling equipment within the vanette. The count rate being detected is continuously heard as clicks in the headsets of both men, and thus each has an instant knowledge of the intensity of the field being examined. Provision is made for scaling the click rate by factors of 10, 10^2, and 10^3 to cover a wide range of count rates. In this study, a single timed count (1/2 min for gamma rays, 1 min for fast and slow neutrons) was taken at all grid points, and the detector was then slowly swept over the entire surface between points. Since the count rate was continuously audible, any region of unusual activity was readily discovered, related to the coordinate system, and a supplementary count taken. At points of higher than reasonable intensity, counts were repeated after checking instrument calibrations.

RESULTS

Shield Faces

The major portion of the present study was devoted to a detailed examination of fluxes and dose rates at the surface of the UTR-10 shield. For presentation of these data the shield surfaces have been developed, or "unwrapped" to lie flat upon the page. Thermal-neutron fluxes are shown in Fig. 5, fast-neutron dose rates in Fig. 6, and gamma-ray dose rates in Fig. 7.

Thermal-neutron fluxes were in general very low. There was, however, some evidence of streaming at the lower edge of the thermal column closure, with a maximum flux of 679 neutrons$\cdot$cm$^{-2}\cdot$sec^{-1} being observed at floor level at the center of the door. Streaming to a lesser degree was evidenced

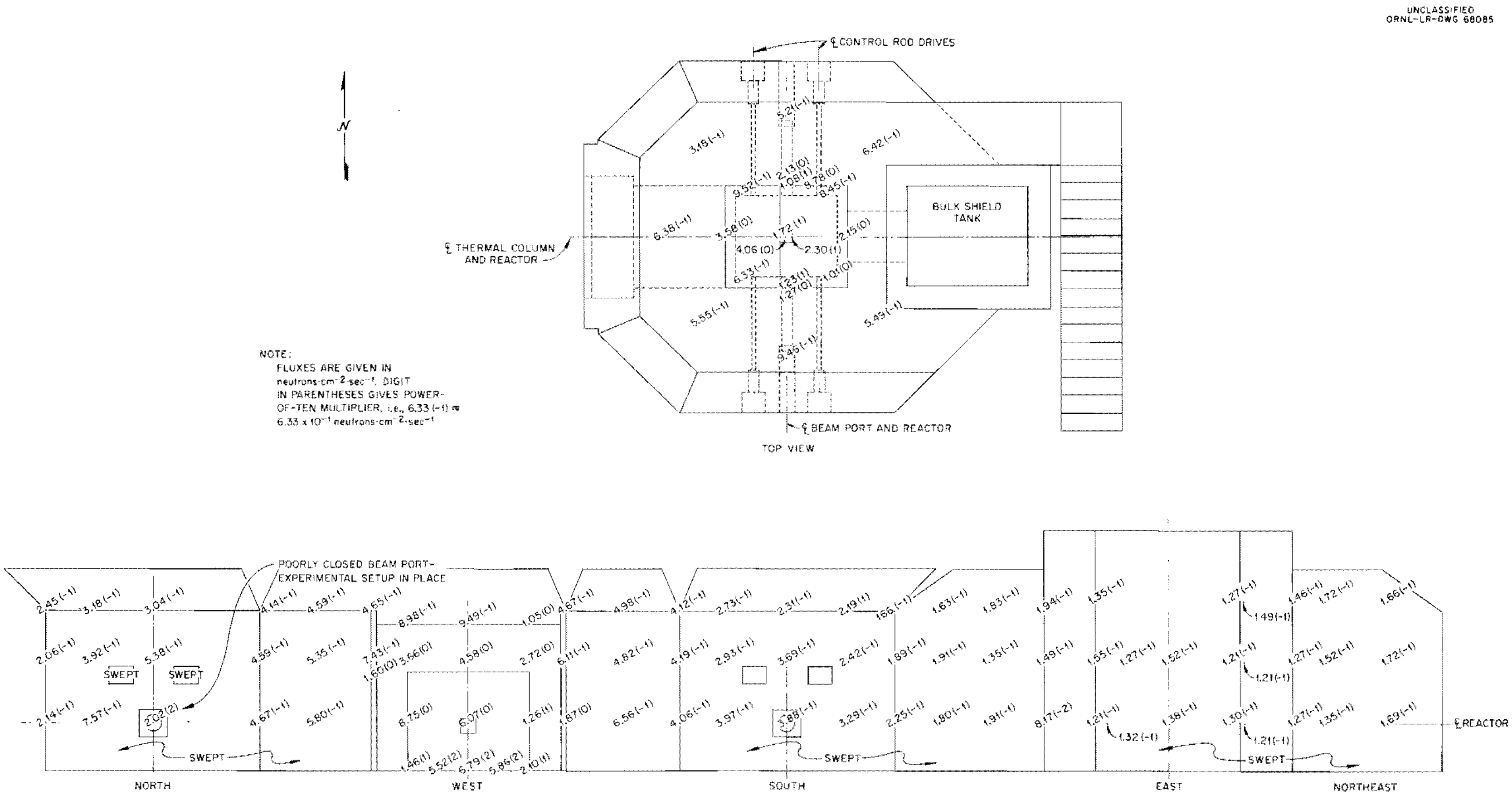

Fig. 5. Thermal-Neutron Fluxes at Surface of VPI UTR-10 Reactor Shield. Reactor power level: 10 watts nominal.

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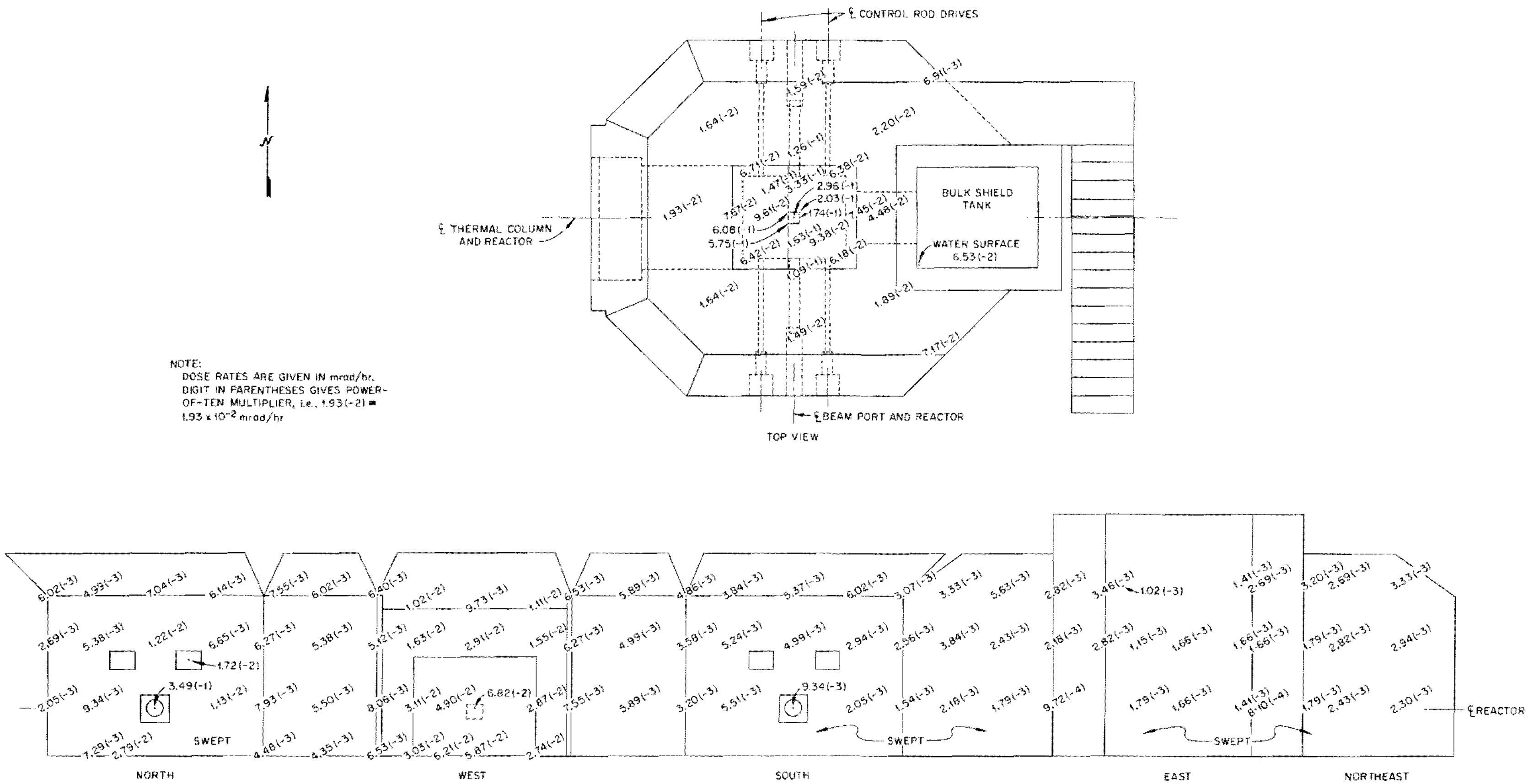

Fig. 6. Fast-Neutron Dose Rates at Surface of VPI UTR-10 Reactor Shield. Reactor power level: 10 watts nominal.

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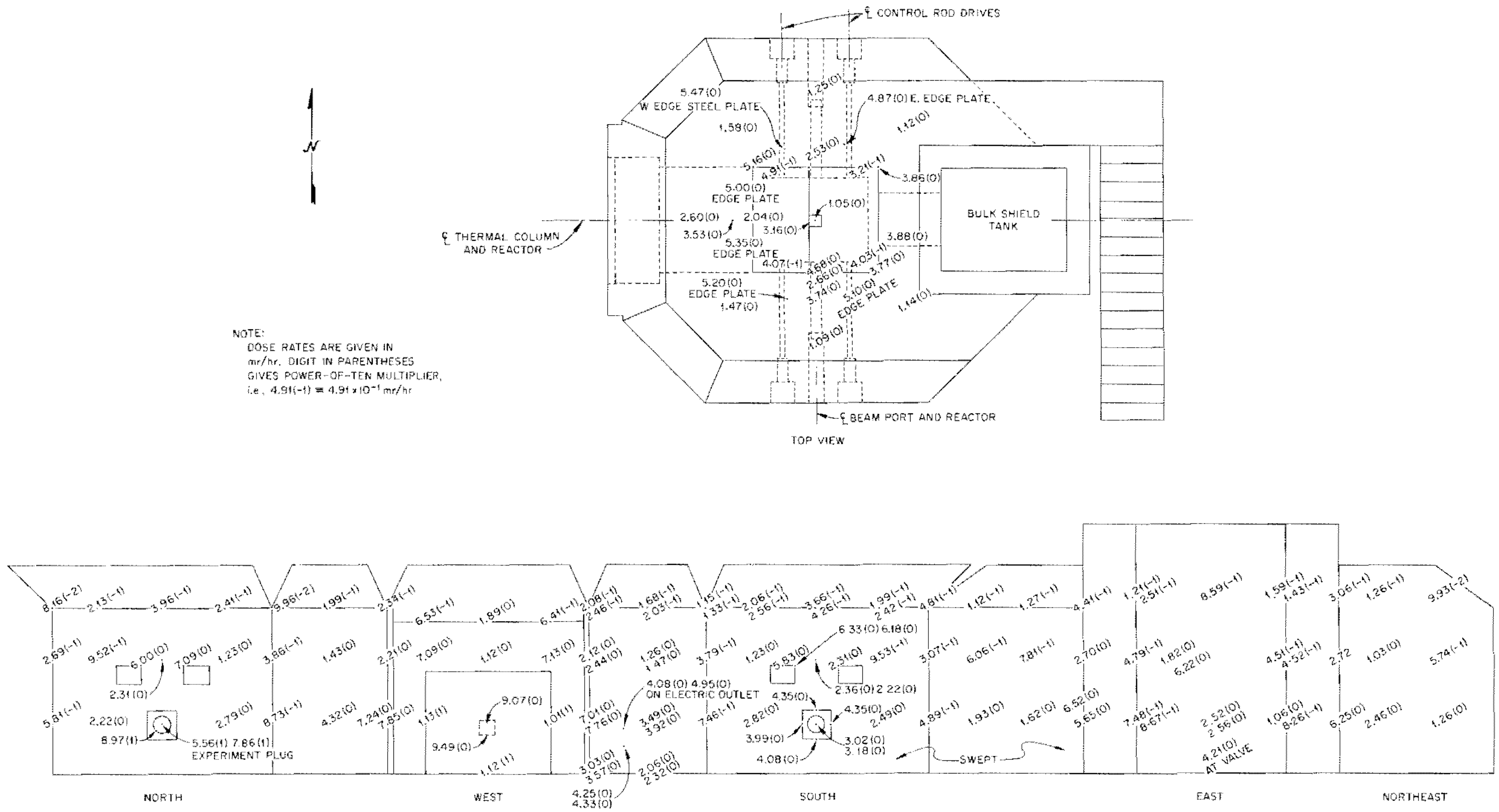

Fig. 7. Gamma-Ray Dose Rates at Surface of VPI UTR-10 Reactor Shield.
Reactor power level: 10 watts nominal.

by flux readings of from 3.58 to 23 neutrons$\cdot$cm$^{-2}\cdot$sec^{-1} obtained at various cracks around the top shield closure. During the progress of this work, an experimental arrangement was in place at the north beam port, and the port was closed with temporary devices. This accounts for the relatively high (202 neutrons$\cdot$cm$^{-2}\cdot$sec^{-1}) flux at this point.

Fast-neutron dose rates were very low over most of the shield. The maximum rate observed was only 0.06 mrad/hr, at the foot of the thermal column door. The rate of 0.349 mrad/hr at the north beam port, of course, was due to the experimental setup as noted above.

With reference to the fast-neutron dose rates measured in the present work, a comment is necessary. The modified long counter used for fast-neutron dosimetry is inherently directional. It responds in terms of correct multicollision dose in air only when the neutrons are incident on its front face. Its response to neutrons impinging on its sides is considerably greater. Used against the face of a shield, where the radiation sensed is that coming through the shield or through cracks or voids in the shield, the reported dose rate is probably very nearly the true dose rate. When the source extends to either side of the counter face, however, as might be the case in examining a crack beneath a large door, the dose recorded is probably an overestimate, due to the contribution from neutrons scattered or beamed to the sides of the counter. Thus any dose rate reported above must be considered as an upper limit to the true dose rate at a given point, the probable error varying with the particular situation.

In the case of the gamma-ray dose rates the situation disclosed by the data is somewhat surprising. Dose rates as high as ~ 7 mr/hr were observed in some regions of the apparently unpenetrated shield, with rates up to 11 mr/hr in spots where streaming was probable. At the experimental setup at the north beam port a high of nearly 90 mr/hr was observed. In nearly every case of a high count rate the rate was verified by a repeat of the count following detector calibration, and the check count has been shown on the plots.

Corridor and Classrooms

Since the V. P. I. reactor is located in a multipurpose building whose corridors, classrooms, and offices were used by an unmonitored population, it was of interest to examine the most adjacent of the classrooms and corridors to determine the levels of radiation existing in them with the reactor at its full licensed power of 10 kw. The reactor room is separated from a principal building corridor by a 16-in.-thick concrete wall, with a heavy wooden door giving access to the reactor room for handling of materials and supplies. (This door is normally locked; always locked when reactor operates.) A line of gamma-ray observations was run along the corridor wall nearest the reactor room beginning at a point 3 ft south of the door and continuing north at a level of 3 ft 7 in. above the floor to the edge of a main stairway at the northwest corner of the building. The dose rate along this line varied somewhat irregularly from a low of 2.18×10^{-2} to highs of 1.96×10^{-1} mr/hr at the center of the wooden door and 9.41×10^{-2} at the approximate point that the line passed the reactor. An average line excluding the peaks falls around 3.6×10^{-2} mr/hr.

A 250-man classroom occupies the space directly above the reactor room. A few gamma-ray dose rate measurements were made in this classroom, generally over a 5-ft-dia circle approximately centered on the reactor. Dose rates 4 ft above floor level ranged from 1.13×10^{-2} mr/hr to 6.46×10^{-2} mr/hr.

Ventilation System

The ventilation system of the V. P. I. reactor facility is somewhat unusual in that it dispenses with the customary tall off-gas stack. Instead ventilation is accomplished by drawing a large volume of outside air by a high velocity fan through an intake located in the southwest corner of the reactor room. The air circulates through the reactor room by convection and the force of its entry, and diffuses to the outside air through an exit vent high in the northwest corner of the room. Intake and outlet vents are roughly 20 ft above ground level.

An attempt was made to evaluate the efficacy of this system by a crude experiment. A gamma-ray dosimeter was attached to the ledge at the lower edge of the 3-ft by 3-ft outlet vent, on the centerline of the vent. This placement gave the crystal a line of sight about 10 ft above the reactor. In this position the gamma-ray dose rate recorded by the dosimeter was due to the argon activity in the ventilating air plus a background of the leakage radiation from the reactor. A rough figure for the background was obtained by opening the large double doors at the west side of the reactor room. The ventilating air thus took this shorter, easier path to the atmosphere. (A guard was posted outside the building while the doors were open.) Twenty one-min counts were taken, with the average number of counts being 339 per min, a gamma-ray dose rate of 2.49×10^{-2} mr/hr.

When the doors were closed, the flow of air was channelled through the exit vent, and the count rate rose to a higher level. Thirty one-min counts under this condition resulted in an average count rate of 386 per min, or 2.84×10^{-2} mr/hr. The increase over background of 47 counts/min, equivalent to a dose rate of 3.5×10^{-3} mr/hr, was assumed to be due entirely to argon activity in the ventilating air.

The admittedly rough nature of this experiment precludes further manipulation of its results. It may be calculated, however, that the dose rate quoted is equivalent to that which would be sensed by a detector observing a point source of ~ 4.5×10^{-7} curies of argon at a distance of 1 ft.

ERRORS

The adoption of a fixed counting time for the measurements of this study makes impossible an assignment of an over-all statistical error to the data. It is obvious, however, that as the importance of any measurement increased, in the sense of significant dose rate, so did the number of counts and thus the statistical accuracy.

The thermal- and fast-neutron detectors are believed to have an inherent error of ±6% at 1 mrem/hr (1 mrad/hr in the case of the fast-neutron detector), based upon previous calibrations. The calibrations of the gamma-ray detector indicate that an error of ±10% is probable. It is therefore concluded that for the significant fast- and thermal-neutron data a reasonable over-all error is ±8%. For the gamma-ray data a conservative error of ±12% is assumed.

CONCLUSIONS

The examination of the Virginia Polytechnic Institute UTR-10 reactor shield demonstrated that in general the shield is thoroughly effective against neutrons. Against gamma rays, however, the predictions of the design (a maximum radiation level of 0.75 mrem/hr at a power level of 10 kw) are not realized. At the dose rate of ~ 7 mr/hr observed in a few regions, the current A.E.C. permissible dose of 1-1/4 rem per calendar quarter (whole body; head and trunk; active blood-forming organs; lens of eyes; or gonads) would be accumulated in about 180 hr, or 4-1/2 normal work weeks. The permissible dose is reduced to 10% of the above value for minors - those under 18 years of age. A.E.C. regulations, in fact, require the posting of radiation warning signs in areas where the dose rate exceeds 5 rem/hr.

Although a detectable radiation field exists in the corridor outside the reactor room and in the classroom directly above the reactor room, it is so low as to be insignificant in terms of potential cumulative dose.

The cursory examination made of the reactor room ventilation system obviously does not justify any conclusions as to its effectiveness. A detailed study of this system under various conditions of reactor argon production and various outside atmosphere conditions may well be desirable.

ACKNOWLEDGMENTS

It is a pleasure to acknowledge the whole-hearted cooperation of Dr. Andrew Robeson, of the V. P. I. Physics Department and in charge of the reactor, during this study. We are also indebted to M. L. Winton, B. W. Colston, and T. D. Anderson, all of the Maritime Reactor Group of the ORNL Reactor Division, for their help in data taking.

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