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A RADIATION STUDY OF THE WESTINGHOUSE TESTING REACTOR

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ORNL-TM-332

Contract No. W-7405-eng-26

Neutron Physics Division

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Date Issued

DEC 11 1963

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ABSTRACT

Gamma-ray, fast-neutron, and thermal-neutron dose rate measurements utilizing instruments of high sensitivity have been made over a major portion of the biological shield of the Westinghouse Testing Reactor (W.T.R.) at Waltz Mill, Pennsylvania. Observed rates were well below the rate of 1 mr/hr predicted for the shield for a reactor power of 60 Mw. Selected regions of the area within the W. T. R. security fence were examined to determine radiation levels due to gamma-ray "shine" from the elevated primary coolant tank. Dose rates ranging from 0.08 mr/hr to 10 mr/hr were observed. The existence of a considerable fast-neutron flux in the reactor coolant exit stream at distances as great as $\sim$ 245 ft from the core was established, but the source for these neutrons was not definitely determined.

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INTRODUCTION

The Neutron Physics Division of Oak Ridge National Laboratory has made a study of the biological shields of a number of typical nuclear reactors for the Division of Compliance, U. S. Atomic Energy Commission. The measurements utilize a van-contained radiation detection laboratory, originally assembled for measurement of extremely low-level radiation leakage expected from the shield of the N. S. SAVANNAH.

The Westinghouse Testing Reactor (WTR) at Waltz Mill, Pennsylvania, was chosen as a typical example of a high-power testing reactor* and measurements were made at that site late in December of 1961. The WTR is a heterogeneous, water-moderated, water-cooled, low-pressure, low-temperature, general testing reactor, similar in design to the Atomic Energy Commission's Materials Testing Reactor (MTR) in Idaho, but operating at a normal power level of 60 Mw, 50% higher than the MTR's 40 Mw. It is used to perform experiments for Westinghouse and Westinghouse's commercial customers, and in particular is equipped for high-pressure dynamic loop testing of the effects of radiation on solid fuels and associated engineering equipment. It may also serve as a source of neutrons, may be used for isotope production, etc.

The core of the WTR is a hexagonal prism of equidistant fuel assemblies, each consisting of three concentric fuel-bearing cylinders held

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* The U. S. Atomic Energy Commission defines test reactors as "...only those reactors having (1) a thermal output of 10,000 kw or more; (2) test loops or experimental facilities within, or in proximity to the core; and (3) the use of nuclear radiation for testing the life or performance of reactor components as its major function."

together by cylindrical spiders at each end. The cylinders are made of a uranium-aluminum alloy containing 13 wt% uranium enriched to 93 wt% in U^{235}. Outside diameter of the assembly is 2.5 in., and the length of the fuel-bearing portion of the element is 36 in. Center-to-center spacing of elements is 3-1/8 in., and the operating core consists of about 87 elements. The core is contained in a pressure vessel made of 1-in.-thick type 304 stainless steel, with an outside diameter of 8 ft and an over-all height, including top and bottom covers, of 32.5 ft. Thermal shielding, consisting of 3 concentric stainless steel cylinders spaced 1 in. apart and successively 1, 2, and 3 in. thick, is fastened to the pressure vessel by heavy radial brackets. It is cooled by the upward flow of the reactor coolant water after it has passed downward through the core.

The biological shield of the WTR consists of an 8.5-ft-thick annulus of limonite concrete contained within a 25-ft-OD, 3/8-in.-thick steel cylinder extending from about 6 ft below the reactor centerline to 11-1/2 ft above it. Above this elevation the diameter of the shell abruptly decreases to 19 ft, continuing upward for about 8 ft. The only significant radial penetration of this shield is an 8-in. ID beam hole at the level of the core ℄ at the south side. The shielding above the core consists of 18 ft of water and 15.5 in. of steel during reactor operation. A cutaway view of the shield, taken from an artist's conception drawn before construction, is shown in Fig. 1.

EXPERIMENTAL APPARATUS

The equipment used during this study has been described elsewhere.[1]

1. T. V. Blosser and R. M. Freestone, Jr., Nucleonics 21(2), 56 (1963); see also, T. V. Blosser, R. M. Freestone, Jr., and J. M. Miller, A Study of the University of Illinois TRIGA Mark II Research Reactor, ORNL-TM-178 (April 23, 1962).

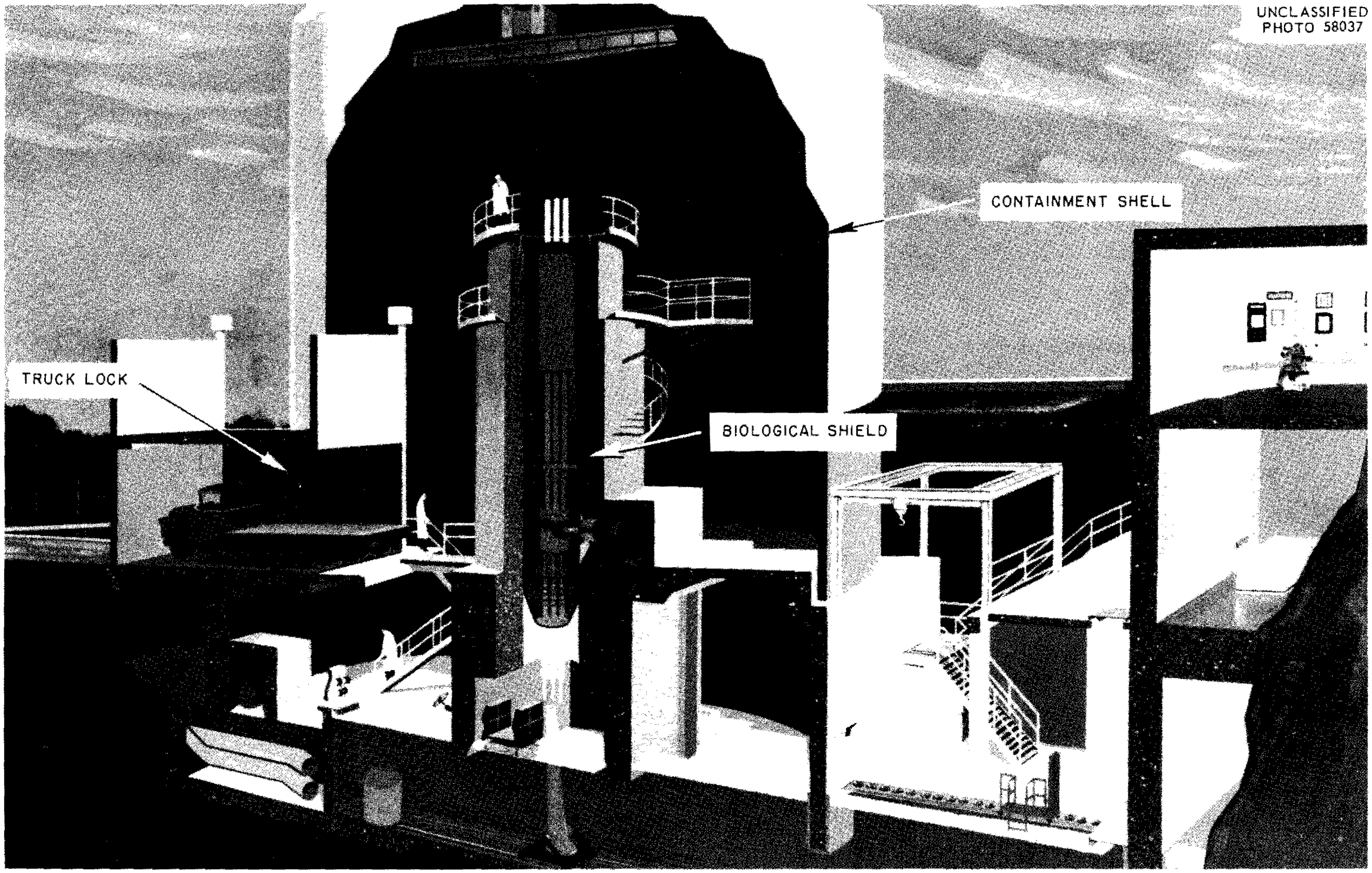

Fig. 1. Cutaway View of Westinghouse Testing Reactor Shield and Containment Shell.

Briefly, it consisted of gamma-ray dosimeters of two types, one an anthracene crystal scintillation detector, used to measure dose rates in the range 0.02 - 20 mrad/hr, and the other a conventional 50-cc carbon-walled CO_2-filled ionization chamber, used in regions of high gamma-ray flux. Thermal-neutron fluxes were measured with a BF_3 proportional counter, and epithermal and fast-neutron dose rates with a modified long counter, the response of which had been empirically adjusted to parallel the multi-collision dose curve for tissue to within $\pm$ 5% over the energy range .025 to 10 Mev. Supporting electronics, including power supplies, scalers, timers, etc., are permanently housed within a Ford vanette, thus constituting a completely mobile detection laboratory.

During a portion of the work described below the vehicle was parked in the open air between the Reactor Facility and the Process Building; during the remainder of the effort it was stationed within the large truck lock of the Reactor Facility. These locations are identified in Fig. 2, also an artist's conception before construction.

EXPERIMENTAL PROCEDURE

Because of the limited time available for the study of this physically large reactor shield, it was decided in advance to restrict the study to a few experiments from which it was felt that the greatest amount of significant data could be obtained. These included gamma-ray, fast-neutron, and thermal-neutron dose rate measurements over representative areas of the annular shield; a similar study of the top of the shield, with particular attention given to the experiment access holes; a radiation survey of selected regions within the security fence surrounding the entire facility to determine gamma-ray dose rates resulting from activities in the large

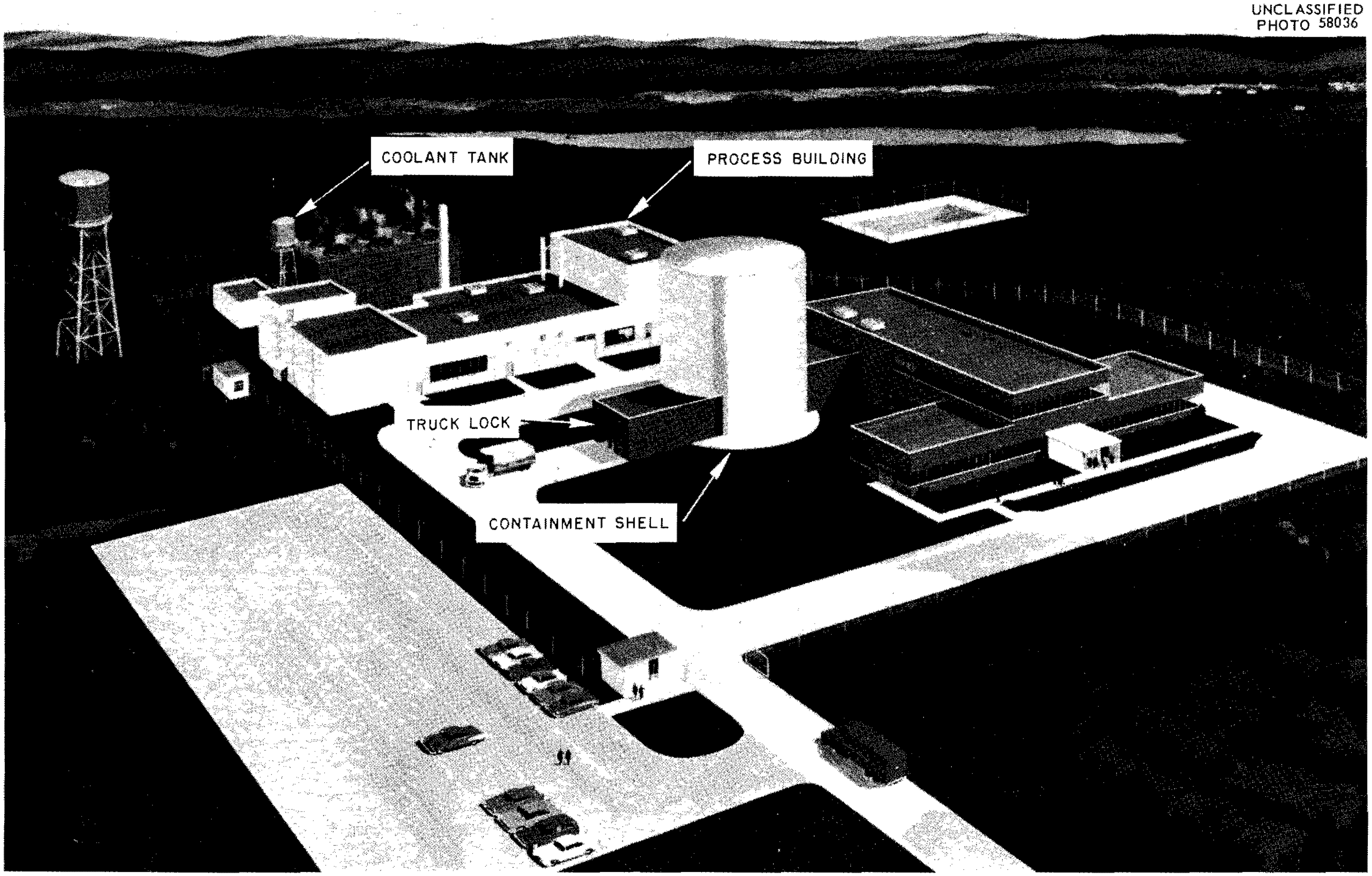

Fig. 2. The Westinghouse Testing Reactor Site.

elevated water tank which serves as a primary coolant tank for the reactor; and finally, a study of the activity contained within the coolant circulation system.

RESULTS

Annular Shield Leakage Rates

The scheme adopted for the examination of the annular shield is diagrammed in Fig. 3. It consisted of the assignment of a set of coordinates to each of the four quadrants of the lower shield between elevations 32.25 ft and 51 ft. The zero of abscissas was in each case the intersection of the north-south or east-west centerline of the reactor with the shield surface; the zero of ordinates was the horizontal midplane of the reactor core. Above elevation 51 ft a single set of coordinates was "wrapped" around the shield. For this set zeros of both abscissas and ordinates were those of the grid of the north quadrant of the lower shield. One-minute counts were taken with gamma-ray, fast-neutron, and thermal-neutron detectors at 3-ft coordinate intervals over nearly all of the north, east, and west quadrants, and the shield surfaces between counting locations were thoroughly examined by slowly sweeping or "scanning" with each detector. Unfortunately, during the period covered by this study the beam hole and much of the shield surface in the south quadrant were inaccessible, because of the presence of a large temporary shield, delicately positioned equipment, etc., being used in an experiment in this region. Our data in the south quadrant are therefore sparse.

For presentation of the data, the quadrant surfaces have been "developed" or flattened out. Thermal-neutron fluxes are shown in Fig. 4, fast-neutron dose rates in Fig. 5, and gamma-ray dose rates in Fig. 6. It must

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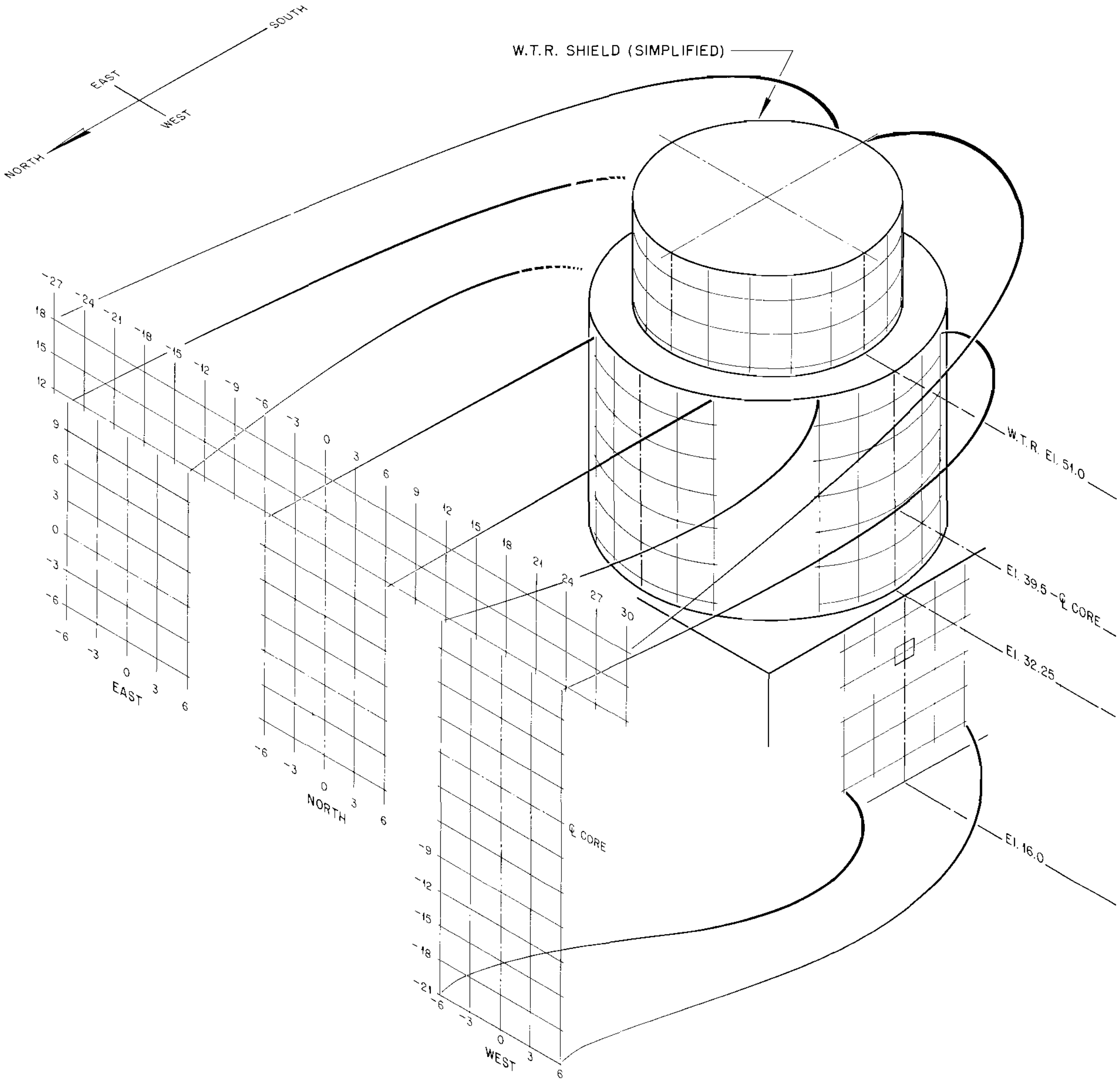


Fig. 3. Grid Scheme Used for Locating and Displaying Data from Westinghouse Testing Reactor Shield Study.

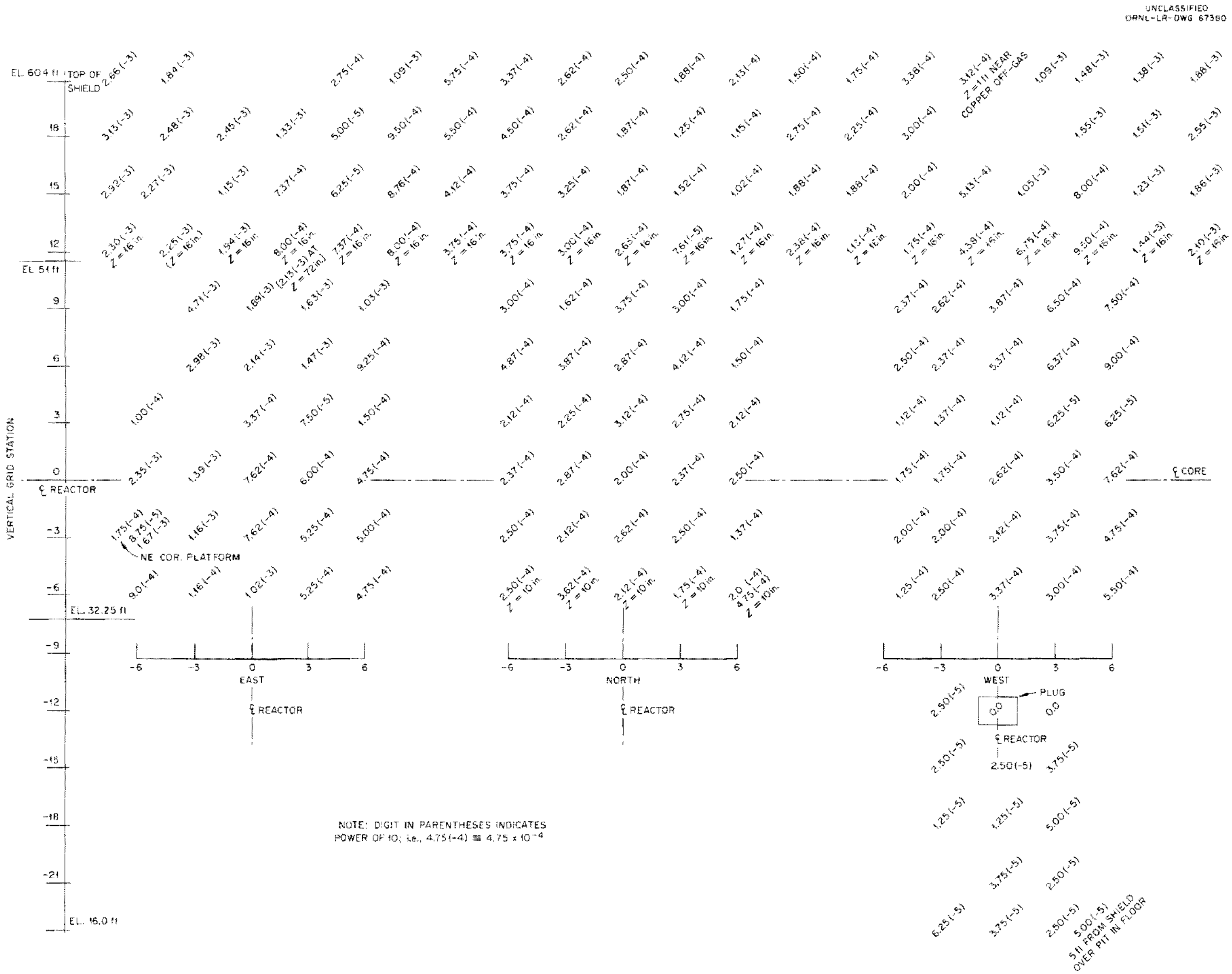


Fig. 4. Thermal-Neutron Dose Rates (mrem/hr) at the Shield Surface of the WTR.

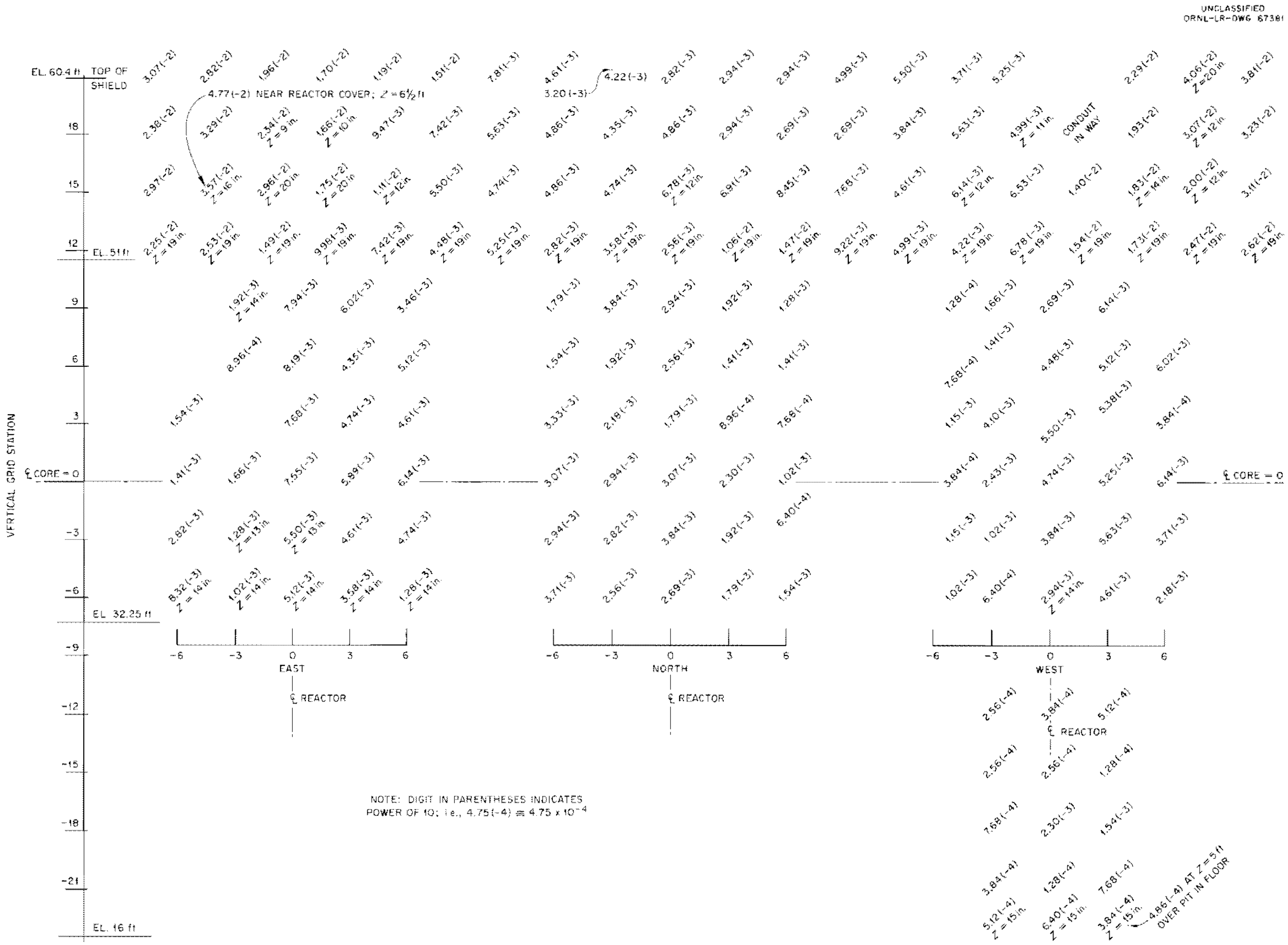


Fig. 5. Fast-Neutron Dose Rates (mrad/hr) at the Shield Surface of the WTR.

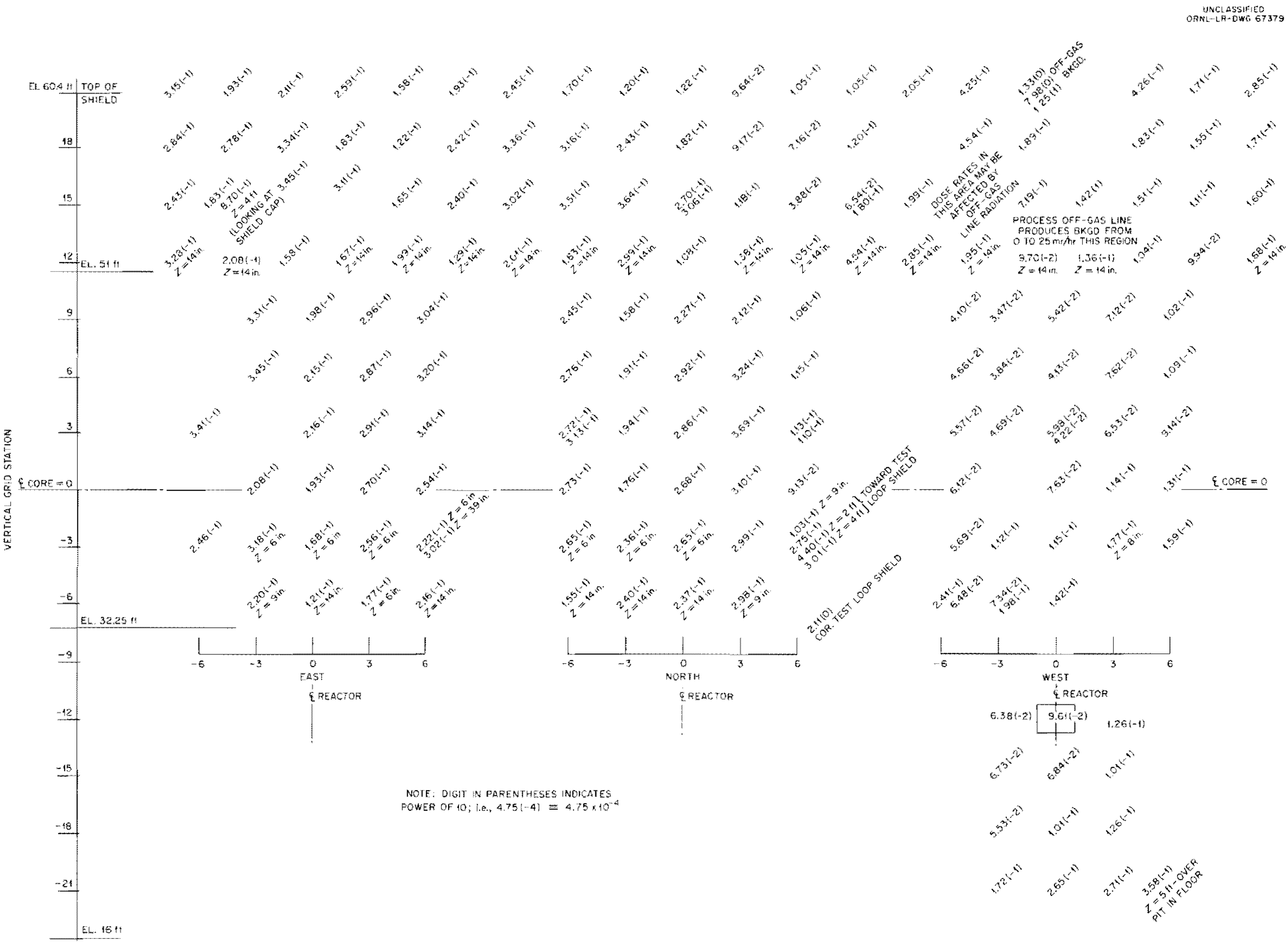


Fig. 6. Gamma-Ray Dose Rates (mr/hr) at the Shield Surface of the WTR.

be emphasized that although the data correctly represents the fluxes and doses observed at the shield surfaces, it was impossible to separate the contributions due on the one hand to leakage through the shield and on the other hand to scattering from nearby experimental facilities and loops.

Top Shield Leakage

As may be seen in Fig. 7, the top shield of the WTR carries a complex of instrument access tubes, experiment access ports, and control rod drives. Data obtained in this region was complicated by the existence of rather high background radiation from experiment connections, one of which can be seen in the background of Fig. 7. Results are plotted in Fig. 8.

Security Fence and Related Regions

A prominent feature of the WTR landscape is the 60,000 gal. elevated storage tank immediately east of the Process Building. This tank serves as the head tank for both fuel element coolant water and coolant water for nonpressurized experiments.

It was of interest to determine the amount of gamma-ray activity emanating from this tank, and data were accordingly obtained under several conditions. The first accumulation was obtained under reactor shutdown conditions, after the reactor had been down for a period of approximately ten days. Further collections of data were made while the reactor was operating at its nominal peak power of 60 Mw, the last data being taken after the reactor had been operated nearly continuously at 60 Mw for 11 days. The data are compared in Fig. 9, a plot plan of the WTR area.

The gamma-ray dose rates in the area enclosed by the security fence ranged from 0.08 mr/hr, near the visitors parking lot, to nearly 10 mr/hr at the fence surrounding the water tank. Access to the latter region is limited by a chain across the roadway, placed at a point where the dose rate is $\sim$1 mr/hr.

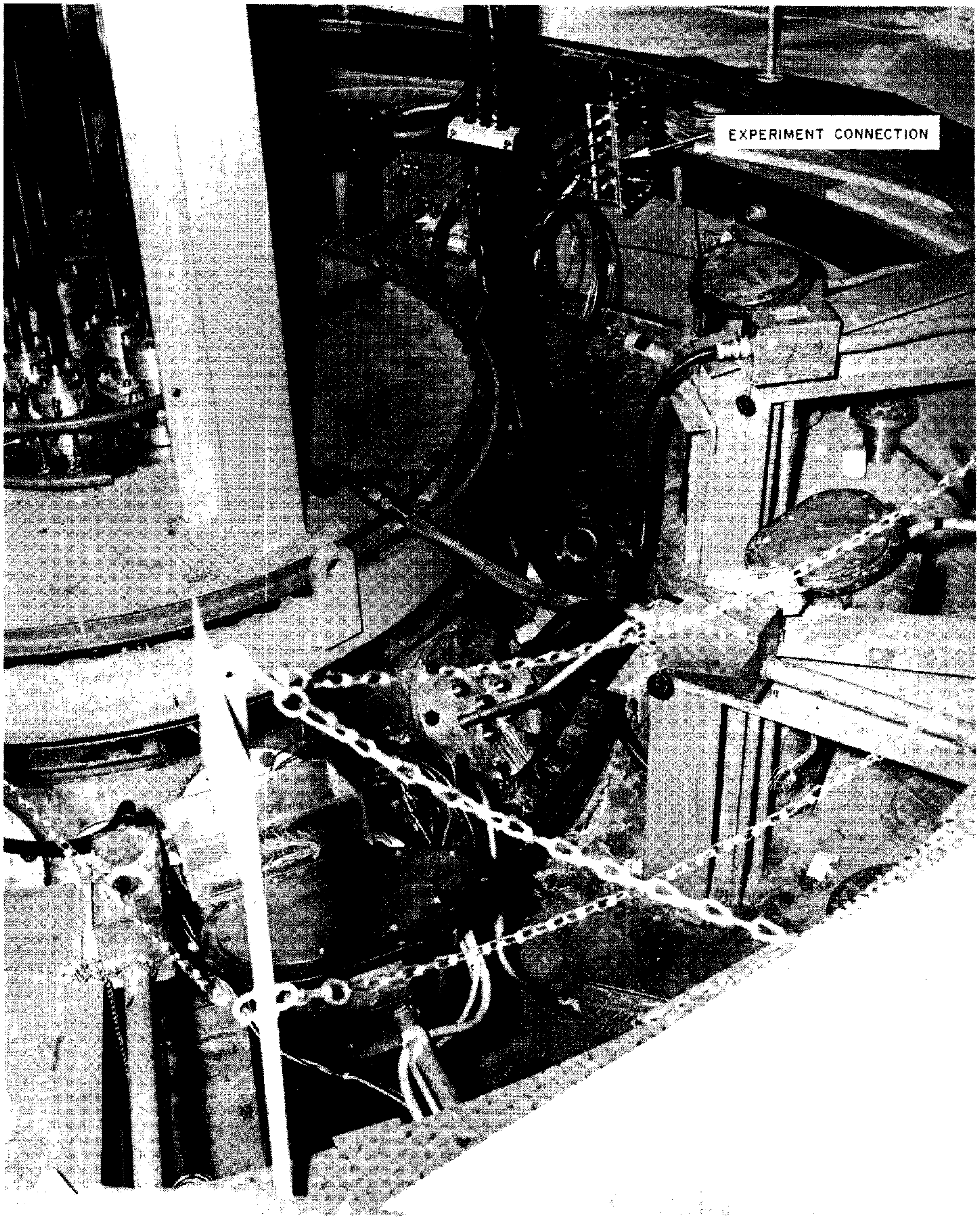


Fig. 7. Portion of the Top of the WTR Shield.
(Photograph by WTR staff photographer)

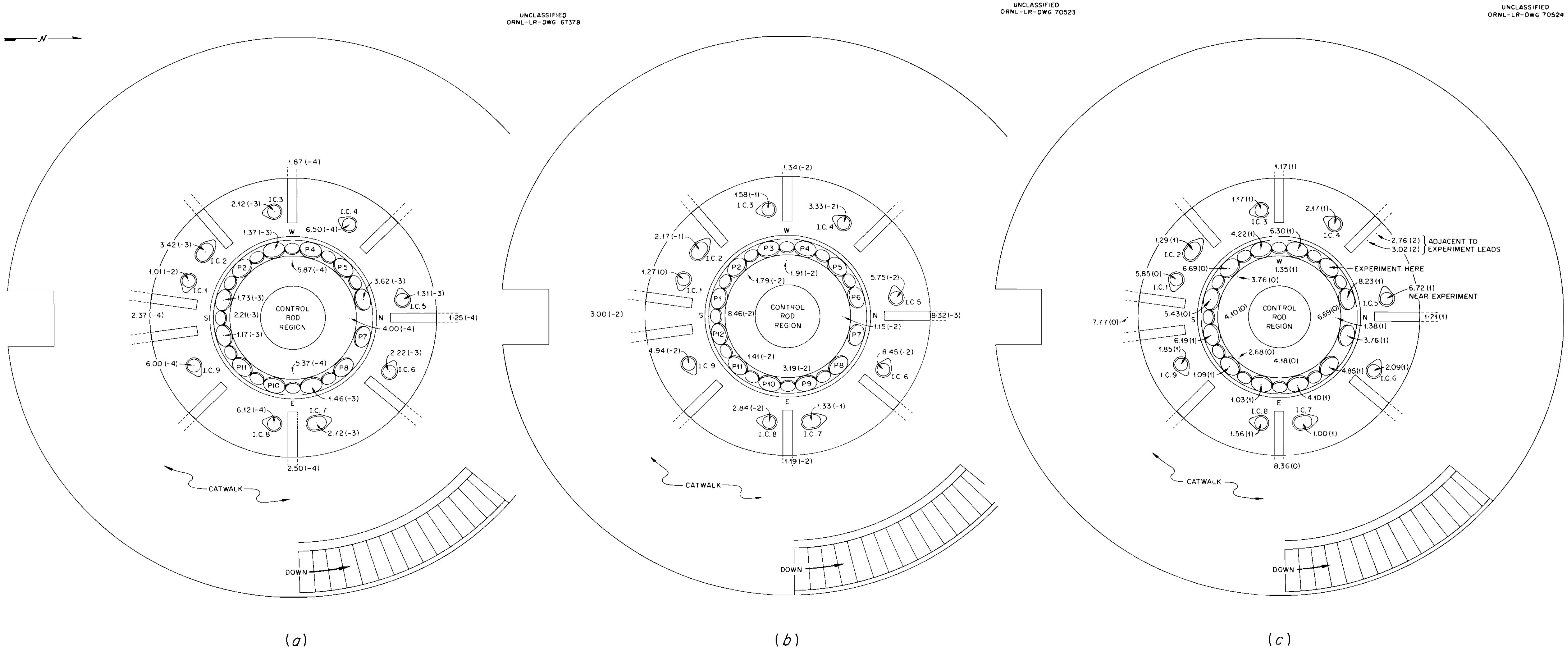
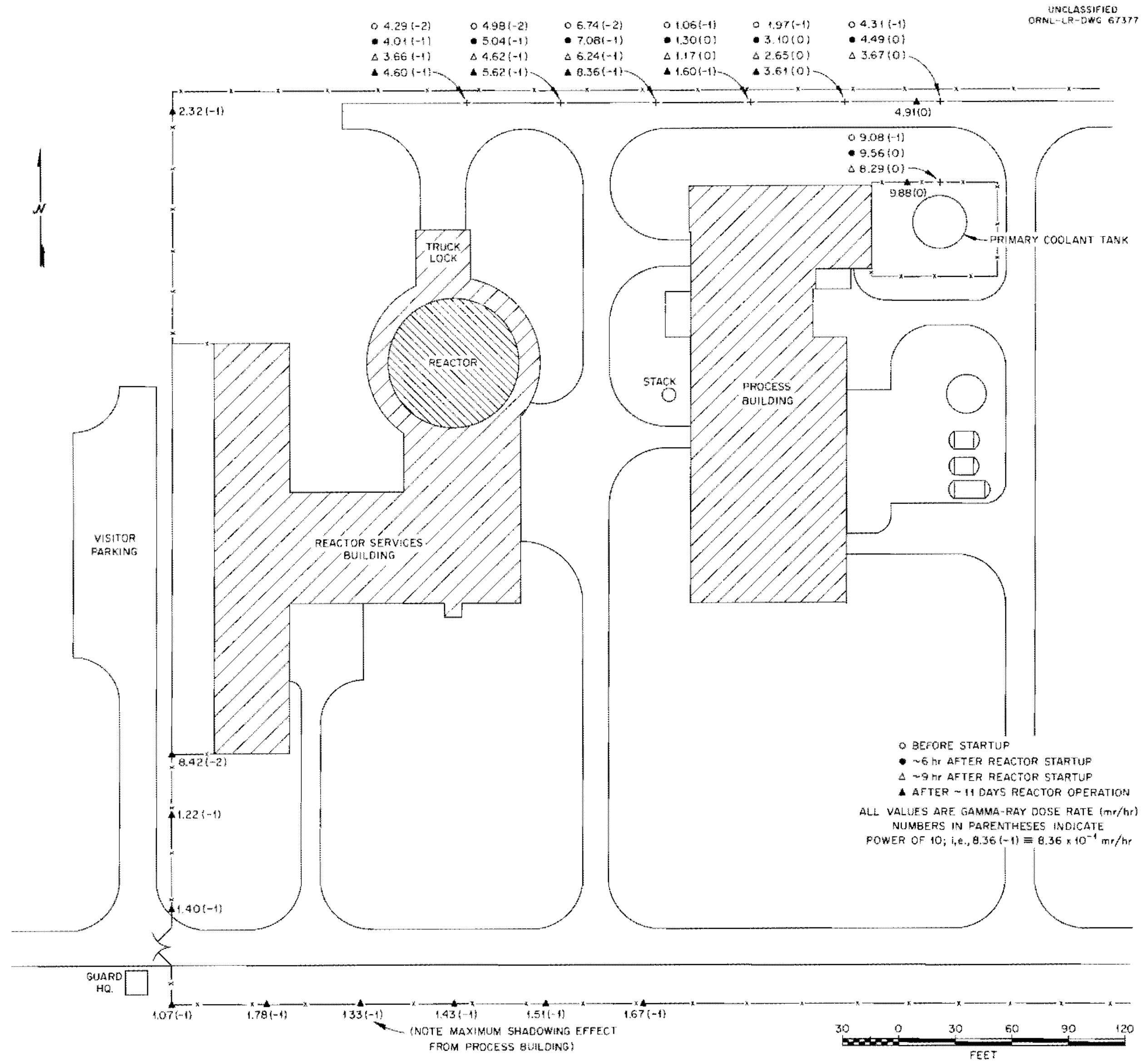


Fig. 8. (a) Thermal-Neutron Dose Rates (mrem/hr); (b) Fast-Neutron Dose Rates (mrad/hr); and (c) Gamma-Ray Dose Rates (mr/hr) on Top Surface of WTR Shield.



Partial Plot Plan, Westinghouse Testing Reactor Waltz Mill, Pa.

Fig. 9. Gamma-Ray Dose Rates at Various Locations in WTR Area.

Coolant Water Activity

Informal conversations with WTR health physicists during a previous visit to the site had implied an interest in the possibility of the existence of neutrons in the coolant water flow at points considerably downstream from the reactor. In order to test this possibility, fast-neutron dosimeters were placed in two locations along the 36-in.-dia coolant exit pipe prior to reactor startup. The fast-neutron dosimeters had previously been shown to be insensitive to 100 r/hr of gamma-ray radiation in tests with a Co^{60} source. One dosimeter was located directly beneath and nearly touching the pipe at a point near the bottom of an access manhole just outside the truck lock door at the north side of the reactor building. A 50-cc carbon-walled CO_2 ionization chamber was also located here to monitor the gamma-ray dose rate. As nearly as could be determined from a study of reactor piping drawings, this location was approximately 135 ft from the reactor vessel. A second fast-neutron dosimeter was positioned beneath the 36-in.-exit pipe at a location approximately 110 ft further downstream. This location was reached through a manhole inside the Process Building. All three instruments were continuously operated during the reactor startup of Dec. 8, 1961, from about 3 a.m. until after 9 a.m. The results are plotted in Fig. 10. The lowest curve of the set of four represents the reactor power level as given at the reactor control console. The next higher curve shows the monitoring of the gamma-ray dose at the location nearest the reactor, while the pair of curves at the top represent the fast-neutron dose rates at the two locations described above. The highest curve is, of course, from the detector nearest the reactor. The detailed correspondence of

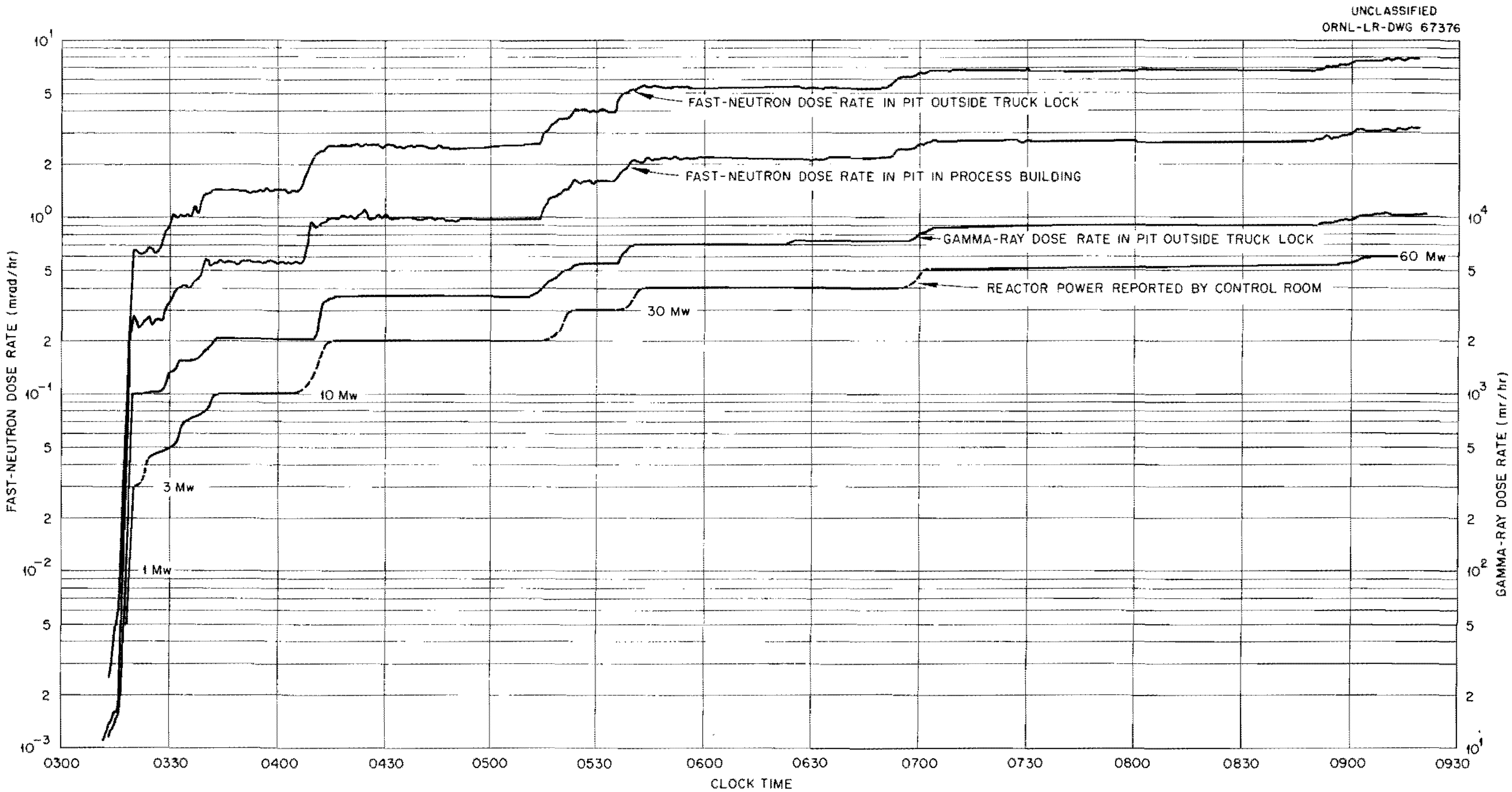


Fig. 10. Dose Rates and Power Levels During Startup of WTR, Dec. 8, 1961.

all three detector curves to the stated reactor power is noticeable. The ratio between the fast-neutron dose rates at the two locations, 110 ft apart, is seen to be fairly constant and on the average is very nearly 2.5:1.

The observed ratio appeared to be somewhat too small if the observed neutron activity is to be attributed solely to neutrons from the decay of the N^{17} nucleus formed by the fast-neutron irradiation of water. Samples of the exit coolant water were therefore obtained, and an attempt to identify possible sources of delayed neutrons has been made both by chemical analysis and by gamma-ray spectral analyses. The results of the chemical analysis are presented in Table 1. The values shown are the average of four separate analyses of the same sample. Of interest is the identification of uranium in the sample. The total amount represented by the concentration shown would be about 9.07 g in the completely full 60,000 gal. head tank, perhaps as much as 15 g in the entire primary coolant system.

Table 1. Chemical Analysis of Coolant Water Samples from the Westinghouse Testing Reactor

Element or Ion	Concentration (ppm)	Element or Ion	Concentration (ppm)
U	0.035	Cu	<0.5
NO_3^-	<1	PO_4^-	2
Si	1.25	Cl^-	0.4
Fe	<0.5	F^-	<10
Cr	<0.5	Ca	<0.2
Ni	<0.5	Mg	<1
Al	<2	Na	<0.2
$SO_4^=$	6		

Lack of the most suitable equipment and lack of time prohibited an exhaustive analysis of the water samples by gamma-ray spectral methods. A number of spectra were measured however, and some of the more prominent peaks in the spectrum were tentatively identified. The spectrum shown as Fig. 11 was made shortly after removal of the sample from the coolant stream. The prominent peaks due to the 1.37- and 2.75-Mev gamma rays from Na^{24} can be seen, and were exactly identified by the use of a comparison source of Na^{24} gammas. The existence of a typical fission product, Ba^{140}, in the coolant sample was also strongly suggested by comparison of the coolant spectrum with the spectrum of a Ba^{140}-La^{140} source.

A spectrum obtained after the coolant sample activity had decayed for approximately 15 days is shown in Fig. 12. A considerable amount of fine structure is evident. About 6 complete spectra were run during the period spanned by Figs. 11 and 12, and a study of peak heights as a function of time indicated that few, if any, of the prominent peaks had settled down to a simple exponential decay after 15 days. This, of course, implies that most peaks represent combinations of activity from two or more isotopes.

Although the existence of a fast-neutron flux in the coolant exit stream at a surprisingly great distance from the reactor core is perhaps the most interesting result of this study, it was not deemed economical of time and effort to press the investigation further, and although a part of a spectrum was run on Jan. 2, 1962, the study was essentially terminated with the run of Dec. 26, 1961.

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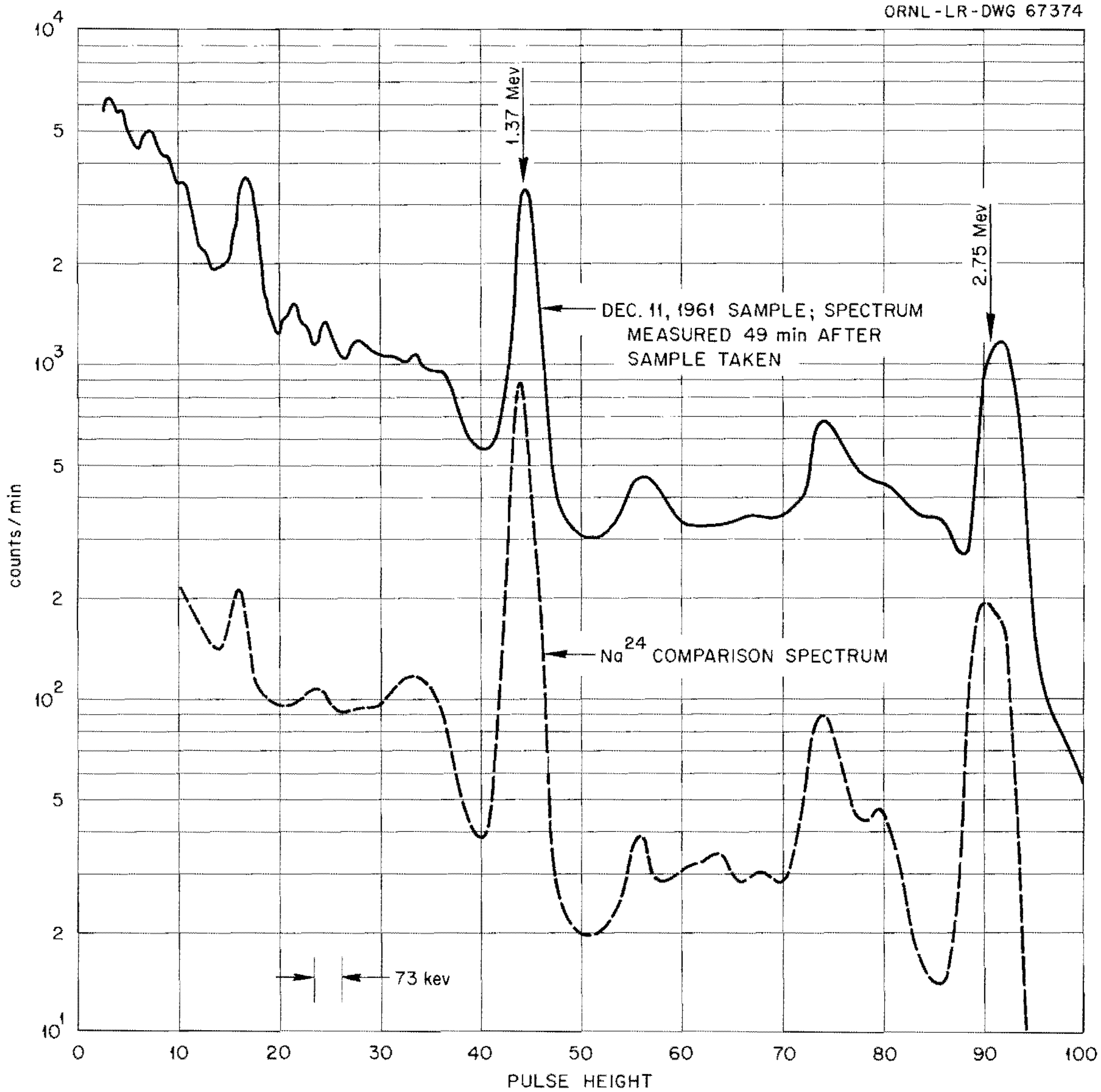

Fig. 11. Gamma-Ray Spectrum of WTR Coolant Water.

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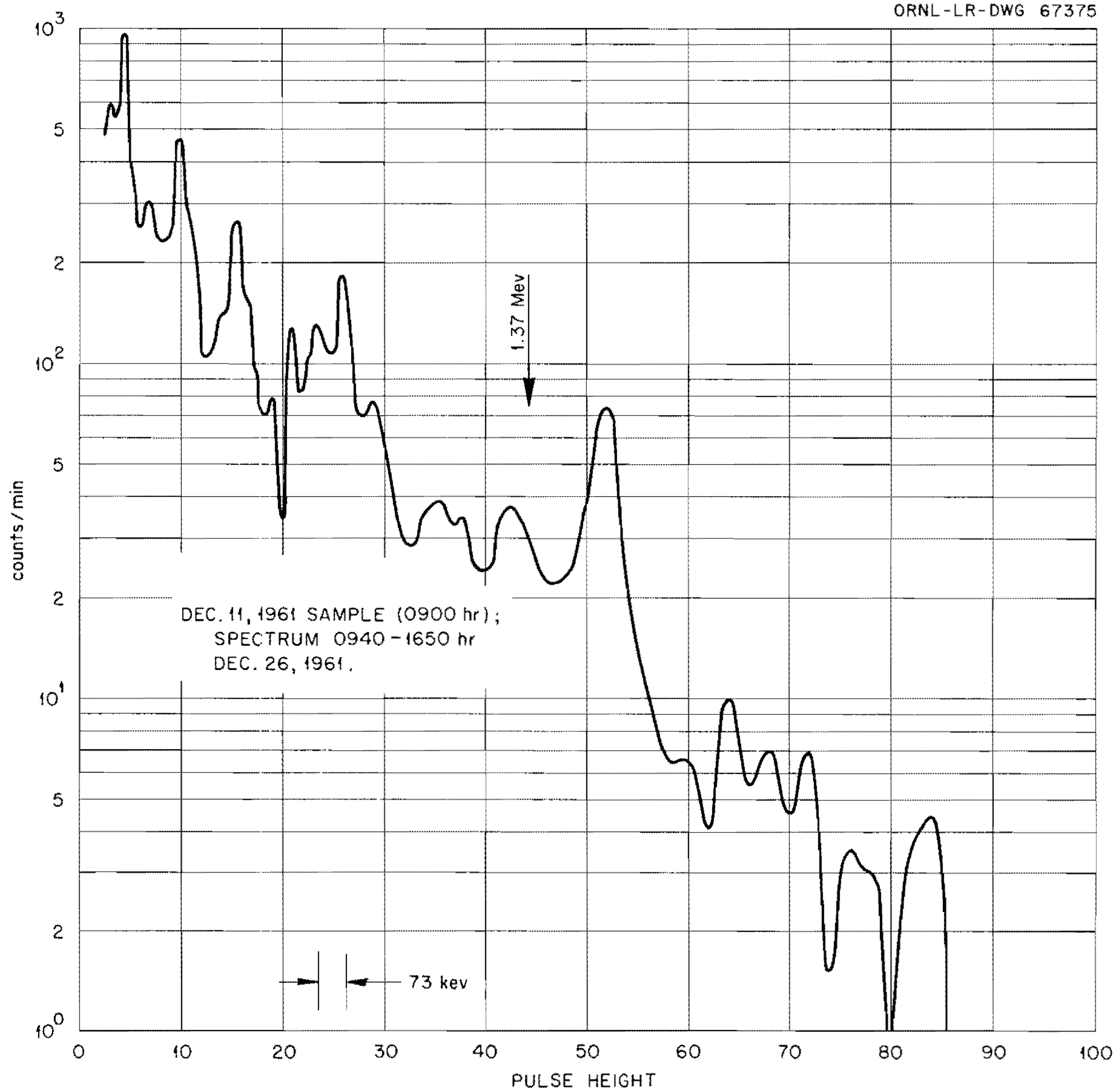

Fig. 12. Gamma-Ray Spectrum of WTR Coolant Water after ~15-day Decay of Activity.

ERRORS

In order to expedite the progress of this and similar studies, a fixed counting time of one minute was adopted for the shield survey points, regardless of the number of counts accumulated. It is apparent, then, that the statistical error will fluctuate from point to point. However, the statistical error will clearly diminish as the importance of any measurement, in the sense of significant dose rate, increases.

The inherent error attached to the thermal and fast-neutron detectors has been established from calibrations against standard sources to be $< \pm 6\%$. A similar figure for the gamma-ray detectors is conservatively $\pm 10\%$. After taking into account an average value for statistical error, we assign an over-all error of $\pm 8\%$ to the fast- and thermal-neutron data, an error of $\pm 12\%$ to the gamma-ray data.

An additional error, however, must be attached to a portion of the fast-neutron data. The modified long counter used to measure fast-neutron dose rate is strongly directional, responding correctly in terms of multicollision dose only when the neutrons are incident upon its end. For neutrons striking the side of the counter its response is higher and may not be parallel to the front end response. Therefore, in general, recorded fast-neutron dose rates must be regarded as upper limits to the true dose rate.

CONCLUSIONS

The shield of the WTR was designed to limit the dose rate at its surface to 1 mr/hr during 60-Mw operation. According to our data, this requirement is thoroughly satisfied by the biological shield of the reactor. Where dose rates greater than 1 mr/hr were observed, in every case they were due to more or less temporary experimental arrangements connected to the reactor and were at least approximately known by the site health physicists.

The questions posed by the apparent existence of copious quantities of fast neutrons at an apparently unreasonable location in the coolant stream have not been fully answered by this study. We have demonstrated the existence of these neutrons, however, and suggest that a more complete investigation of their origin might appropriately be launched by WTR personnel.

ACKNOWLEDGEMENTS

The progress of this study was speeded and smoothed in many ways by many people at the Westinghouse Testing Reactor. We particularly acknowledge the cooperation of R. J. Catlin, Manager, Health Physics, and D. C. Collins, Supervisory Engineer, Health Physics. Dr. C. C. Webster was invaluable as a source of reports and background information, while R. A. Leasure patiently shepherded us during our work in limited-access areas. The secretarial services provided by Patricia Walt were appreciated, and Health Physics Shift Engineers D. D. Payne, F. M. Cox, S. C. Bushong, and J. B. Zuzik were always cooperative in matters of work permits, sampling, and other affairs within their province. Two members of the Compliance Division, New York Operations Office. A.E.C., A. J. Fleming and W. J. Lorenz, joined us early in the study and labored in yeoman fashion during all phases of the work. We are particularly grateful to J. M. Miller, E. Beckham, and J. R. Taylor of ORNL for their experienced and skillful help during data acquisition and analysis.

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