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SUMMARY OF RECENT EXTERNAL NEUTRON-YIELD MEASUREMENTS BY THE $MnSO_4$ TANK METHOD

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Publication Date

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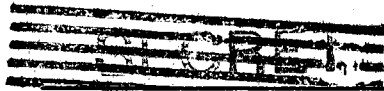
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SUMMARY OF RECENT EXTERNAL NEUTRON-YIELD MEASUREMENTS
BY THE $MnSO_4$ TANK METHOD

Walter E. Crandall and George P. Millburn

September 17, 1954

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SUMMARY OF RECENT EXTERNAL NEUTRON-YIELD MEASUREMENTS

BY THE $MnSO_4$ TANK METHOD

Walter E. Crandall and George P. Millburn

Radiation Laboratory, Department of Physics
University of California, Berkeley, California

September 17, 1954

The purpose of this report is to summarize all external yield data not yet published. Previous yield measurements have been reported in MTA Quarterly Progress Reports UCRL-1009, -1137, -1436, -1573, -1903, -2194, and UCRL-2318. A complete description of the $MnSO_4$ tank method and a summary of earlier yield measurements is given in UCRL-2063, which should be consulted for details of the measurements and for a discussion of possible systematic errors. All yield values quoted herein are uncorrected for any systematic errors except background as noted.

The work reported was done under the supervision of Dr. C. M. Van Atta and with the assistance of F. Adelman, W. Birnbaum, D. Hicks, J. Ise, Jr., R. Main, R. Pyle, L. Schecter, and M. Whitehead.

320-Mev Deuterons

The yields for deuterons of approximately 320 Mev were measured using the deuterons produced by stripping He^3 ions. The energy of the deuterons was checked by determining the Bragg curve for two runs spaced 9 months apart; on these runs 4 and 6 measurements were made giving respective averages of

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9.12 ± 0.29 and 9.77 ± 0.27 neutrons per incident deuteron for a $10\text{-}1/8 \times 12 \times 12$ -inch uranium target. The mean energy was 315 ± 10 Mev for both runs. (See Ise, Pyle, Hicks and Main, Rev. Sci. Instr. 25, 437 (1954) for a description of the beam so obtained.) The "background" measured with no target in the tunnel and with the MnSO_4 plug removed from the beam was about 10 percent of the above numbers but was not subtracted (see UCRL-2194, p. 12), since it is not believed to represent the background present when the target is in position. In addition, the "background" was measured once with the cyclotron operating and with the target in position but with the steering magnet current off so accelerated charged particles could not directly reach the cave; this background was entirely negligible.

The uncertainty in the beam monitor is greater than normal since the ion chambers could not be directly calibrated (low beam intensity). Instead the ratio of dE/dx at 190 and 320 Mev was calculated from the Range-Energy Curves of Aron, Hoffman, and Williams (AECU-663) and the multiplication of the chamber at 320 Mev calculated from the calibrated multiplication at 190 Mev. One calibration was performed and gave satisfactory agreement with the calculated ratio.

The following table lists the best values of the yields measured by the MnSO_4 tank for this beam. (The measurements made in the 12-inch tank may be systematically higher than those made in the 18-inch tank because of the increased neutron leakage.) For targets less than one range thick, the background was subtracted as in UCRL-2194, p. 12.

Table I
Yields for 320-Mev Deuterons

| Target (inches) | Yield (neutrons per Incident deuteron) | Tank Used |
|--------------------------|--|-----------|
| Uranium 10-1/8 x 12 x 12 | 9.1 ± 0.3 | 18-inch |
| Uranium 10-1/8 x 12 x 12 | 9.8 ± 0.3* | 18-inch |
| Uranium 1/2 x 12 x 12 | 2.16 ± 0.10 | 18-inch |
| Uranium 1 x 12 x 12 | 4.50 ± 0.15 | 18-inch |
| Carbon 8 x 24 x 24 | 1.2 ± 0.2 | 12-inch |
| Carbon + 8 x 24 x 24 | | |
| Uranium 10-1/8 x 24 x 24 | 4.3 ± 0.2 | 12-inch |
| Beryllium 9 x 24 x 24 | 1.9 ± 0.2 | 12-inch |

* This value is based on a direct calibration of the ionization chamber with the 320-Mev deuteron beam.

Neutrons

Yields for various targets in the 90- and 160-Mev neutron beams have been measured and are described in somewhat more detail in UCRL-2706. The results are listed in the following table (with measured backgrounds subtracted). The 18-inch MnSO_4 tank was used in all measurements. Only one run was made for each target.

Table II

Yields for 90- and 160-Mev Neutrons

| Target (inches) | Yield (neutrons per incident neutron) |
|----------------------------|---------------------------------------|
| <u>A. 90-Mev Neutrons</u> | |
| Uranium 1/2 x 6 x 6 | 1.23 ± 0.12 |
| Uranium 1 x 6 x 6 | 2.33 ± 0.24 |
| Uranium 1 x 12 x 12 | 2.37 ± 0.25 |
| Uranium 1-1/8 x 12 x 12 | 2.77 ± 0.28 |
| Uranium 3-3/8 x 12 x 12 | 7.32 ± 0.74 |
| Uranium 6-3/4 x 12 x 12 | 10.7 ± 1.1 |
| Uranium 10-1/8 x 12 x 12 | 12.2 ± 1.2 |
| Uranium 14-5/8 x 12 x 12 | 12.7 ± 1.3 |
| Cadmium 1-3/8 x 4 x 4 | 0.46 ± 0.05 |
| Copper 2-5/8 x 4 x 4 | 0.85 ± 0.09 |
| Copper 1-5/16 x 4 x 4 | 0.41 ± 0.04 |
| Aluminum 4-1/4 x 4 x 4 | 0.24 ± 0.02 |
| Carbon 6-13/16 x 4 x 4 | 0.29 ± 0.03 |
| <u>B. 160-Mev Neutrons</u> | |
| Uranium 2-1/4 x 12 x 12 | 6.2 ± 0.6 |
| Uranium 5 x 12 x 12 | 10.8 ± 1.1 |
| Uranium 9 x 12 x 12 | 16.0 ± 1.6 |
| Uranium 15-3/4 x 12 x 12 | 17.5 ± 1.8 |

490-Mev He³ Particles

One run was made with the deflected 490-Mev He³ beam. One run was made on each of the following targets with the exception of uranium, for which two runs were made. The first two targets are differential and the background has been subtracted as above; the last two are greater than a range. The ionization-chamber multiplication was calibrated against a Faraday cup. The 18-inch tank was used.

Table III

Yields for 490-Mev He³ Particles

| Target | Yield (neutrons per incident He ³) |
|--|---|
| Cadmium 6.101 gm/cm ² , 4 x 4 in | 0.35 ± 0.04 |
| Cadmium 12.24 gm/cm ² , 4 x 4 in | 0.71 ± 0.07 |
| Tantalum 28.75 gm/cm ² , 3 x 4 in | 1.80 ± 0.2 |
| Uranium 54.15 gm/cm ² , 3 x 3 in | 3.26 ± 0.21 |

340-Mev Protons

Several differential targets were used with the 340-Mev proton beam. The measured yields with the background subtracted as above are given in the following table. The target dimensions were 4 x 4 in. except: thorium, 4-1/4 in. dia. cylinder; uranium, 3 x 3 in. The 18-inch tank was used.

Table IV
Yields for 340-Mev Protons

| Target | Yield (neutrons per incident proton) | No. of Runs |
|-----------------------------------|---|-------------|
| Aluminum 28.77 gm/cm ² | 0.328 ± 0.040 | 1 |
| Aluminum 57.53 " | 0.666 ± 0.042 | 3 |
| Copper 29.93 " | 0.631 ± 0.040 | 1 |
| Copper 59.82 " | 1.17 ± 0.04 | 3 |
| Cadmium 30.71 " | 1.11 ± 0.04 | 1 |
| Cadmium 61.43 " | 1.91 ± 0.10 | 2 |
| Thorium 32.45 " | 1.90 ± 0.10 | 1 |
| Thorium 62.14 " | 3.83 ± 0.24 | 3 |
| Uranium 62.35 " | 4.38 ± 0.19 | 2 |
| Uranium 1/2 x 3 x 3 in | 1.79 ± 0.07 | 2 |
| Uranium 1 x 3 x 3 in. | 3.71 ± 0.12 | 2 |
| Uranium 2 x 3 x 3 in | 6.40 ± 0.19 | 2 |
| Uranium 3 x 3 x 3 in | 8.29 ± 0.28 | 2 |
| Uranium 6 x 3 x 3 in | 8.90 ± 0.27 | 2 |
| Uranium 12 x 3-3/8 x 3-3/8 in | 9.10 ± 0.27 | 2 |

190-Mev Deuterons

The yield data for 190-Mev deuterons are conveniently broken into two parts: differential (less than one range), and laterally "infinite" (24 x 24 in. or greater) targets. Yields for differential targets were measured in the 18-inch tank; those for laterally infinite targets, in the 12-inch tank.

Table V

Differential Target Yields for 190-Mev Deuterons
(background subtracted)

| Target | Yield (neutrons per incident deuteron) | No. of Runs |
|---|--|-------------|
| Uranium 1/16 x 2 x 2 in | 0.266 ± 0.013 | 2 |
| Uranium 1/8 x 2 x 2 in. | 0.503 ± 0.025 | 2 |
| Uranium 1/4 x 2 x 2 in. | 1.04 ± 0.05 | 1 |
| Uranium 1/2 x 2 x 2 in. | 1.92 ± 0.10 | 1 |
| Uranium 5/8 x 2 x 2 in. | 2.30 ± 0.12 | 1 |
| Uranium 1 x 2 x 2 in.* | 2.42 ± 0.12 | 1 |
| Uranium 2 x 2 x 2 in.* | 2.73 ± 0.13 | 1 |
| Uranium 3 x 2 x 2 in.* | 2.88 ± 0.14 | 1 |
| Carbon + Uranium 10-1/8 x 12 x 12 in.* | 1.83 ± 0.07 | 2 |
| Uranium 12.07 gm/cm ² x 3 x 3 | 1.02 ± 0.05 | 5 |
| Thorium 14.82 gm/cm ² x 4-1/4 dia. | 1.10 ± 0.08 | 4 |
| Lead 12.39 gm/cm ² x 4 x 4 | 0.724 ± 0.030 | 1 |
| Cadmium 12.24 gm/cm ² x 4 x 4 | 0.599 ± 0.015 | 5 |
| Copper 11.74 gm/cm ² x 4 x 4 | 0.411 ± 0.020 | 2 |
| Copper 11.48 gm/cm ² x 4 x 4 | 0.402 ± 0.018 | 2 |
| Aluminum 11.92 gm/cm ² x 4 x 4 | 0.292 ± 0.015 | 4 |
| Carbon 7.67 gm/cm ² x 4 x 4 | 0.164 ± 0.014 | 2 |
| Beryllium 10.20 gm/cm ² x 4 x 6 | 0.438 ± 0.015 | 4 |
| Lithium 4-1/2 x 4 dia. | 0.208 ± 0.012 | 1 |

* nondifferential targets

Table VI

Laterally-Infinite Target Yields for 190-Mev Deuterons

| Target | Yield (neutrons per incident deuteron) | No. of Runs |
|---------------------------------|--|-------------|
| (3-3/4 C + 10-1/8 U) x 24 x 24 | 2.3 ± 1.4 | 2 |
| 4 x 12 x 15 Be | 0.99 ± 0.05 | 1 |
| 10 x 12 x 15 Be | 1.23 ± 0.06 | 2 |
| 22 x 12 x 15 Be | 1.25 ± 0.06 | 1 |
| 4 x 24 x 24 Be | 0.98 ± 0.05 | 2 |
| 4 x 24 x 24 Be* | 0.94 ± 0.05 | 1 |
| (4 Be + 5-5/8 U) x 24 x 24 | 2.72 ± 0.13 | 4 |
| (4 Be + 10-1/8 U) x 24 x 24 | 2.40 ± 0.12 | 5 |
| (4 Be* + 5-5/8 U†) x 24 x 24 | 2.08 ± 0.10 | 4 |
| (4 Be* + 10-1/8 U†) x 24 x 24 | 1.90 ± 0.10 | 3 |
| (4 Be* + 10-1/8 U) x 24 x 24 | 1.93 ± 0.10 | 2 |
| (3 Be* + 5-5/8 U†) x 24 x 24 | 2.10 ± 0.10 | 2 |
| 5-5/8 x 24 x 24 U | 3.46 ± 0.17 | 2 |
| 10-1/8 x 24 x 24 U | 3.19 ± 0.18 | 1 |
| (5/8 U** + 10-1/8 U†) x 24 x 24 | 2.98 ± 0.13 | 5 |
| 5 x 36 x 36†† | 2.36 ± 0.12 | 4 |

* Moderated Primary: 1/4 Al between each 1 Be

** Moderated Primary: 0.022 Al between each 1/16 U

† Moderated Secondary: 3/16 Al between each 1-1/8

†† Moderated Target: First 1 of U: 3/32 CH₂ between each 1/16 U;
Second 4 of U: 3/32 CH₂ surrounding 1/2 x 1/2 x 36 bars of U.

Note: Because of increased neutron leakage, the measurements in the 12-inch MnSO₄ tank may tend to be 5 percent higher than those in the 18-inch tank (UCRL-1903, p. 84).

This work was performed under the auspices of the U. S. Atomic Energy Commission.

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