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Source-Strength and Long-Counter-Response Calibrations at the BSF 300-kev Accelerator

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Abstract

By means of an Am-Be neutron source calibrated by the National Bureau of Standards the absolute neutron production of the 300-kev Cockcroft-Walton accelerator and of another Am-Be source was measured. The response of a "modified Hanson-McKibben" long counter as a function of distance from the source and angular orientation was also measured.

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Introduction

With the prospect of increasingly diversified use of the BSF 300-kev particle accelerator following its relocation in Building 3114, it became desirable to measure the absolute neutron yields available from the machine and to calibrate a monitoring instrument which could thereafter be used for routine measurements of the neutron-source intensity.

Experimental Arrangement

The accelerator target holder had attached to it a small source holder which would position the Am-Be sources as close as possible to the target foil of the accelerator. The holder was made of lead, 3/32 in. thick, so arranged that both the Am-Be neutrons and the accelerator neutrons would pass through it to reach the long counters. The purpose was to attenuate the copious low-energy gamma radiation from the Am-Be sources.

Two similar long counters were used, one directly beneath the target position with its front surface 76.2 cm from the center of the target foil, the other on a mobile stand, also at right angles to the accelerator beam direction at a standard distance of 265 cm from the center of the target. The former counter was kept fixed at all times during the experiment and used as a monitor for those runs in which the location or orientation of the other counter was varied as parameter. The two counters are called, respectively, Channel I and Channel II.

Two types of detectors were used in the experiments with the long counters. The first is the original type of BF_3 counter 1.43 cm in diameter, surrounded by a 1-cm-thick cylinder of Ceresin wax according to the Hanson-McKibben design,[1] and the second is a replacement type supplied by

1. A. O. Hanson and J. L. McKibben, Phys. Rev. 72, 673 (1947).

Instrumentation and Controls Division and intended for standard use at ORNL in the future. The latter is a BF_3-filled tube, 2.54 cm in diameter, surrounded by a Teflon cylinder 0.52-cm thick. The total boron content of the new type detector is the same as that in the original type. In Channel I a new type detector was used throughout the measurements, whereas in Channel II measurements were made with both types of detectors to determine the relative response rate. Assuming that the energy response function of the two detector types is the same, the new, larger diameter BF_3 tube was found to count 1.33 $\pm$ 0.03 times as fast as the old-style detector exposed to the same flux in the same long counter body.

Dead-Time Measurements and Calculations

The dead times of both long-counter systems were measured using two Am-Be sources, Nos. 9955 and 21. The dead time was assumed to be non-extending, which leads to the equation:

$$\tau = \frac{1}{N_{12}}\left[1 - \left(1 - \frac{N_{12}}{N_1} - \frac{N_{12}}{N_2} + \frac{N_{12}^2}{N_1 N_2}\right)^{\frac{1}{2}}\right],$$

where τ is the dead time and N_1, N_2, and N_{12} are, respectively, the counting rates with one source, the other source, and both sources present.

An average value of τ for both detectors was found to be $(4.18 \pm 0.83) \times 10^{-5}$ sec. Assuming the dead-time equation to be

$$R_t = \frac{R_o}{(1-R_o\tau)},$$

where R_t is the true counting rate and R_o the observed rate, it follows that

$$\delta R_t = \left[\frac{(\delta R_o)^2}{(1-R_o\tau)^4} + \frac{R_o^4(\delta\tau)^2}{(1-R_o\tau)^4}\right] = \left[F(R_o)\,(\delta R_o)^2 + G(R_o)\right]^{\frac{1}{2}}.$$

The functions $R_t(R_o)$, $F(R_o)$, and $G(R_o)$ were computed and plotted, and applied to each measurement of R_o to obtain the values of R_t and the error in R_t.

Source Calibrations

The source strength of Am-Be source No. 21 was measured by comparison with Am-Be source No. 9955. Both sources were repeatedly measured in the target location by both counters in various orientations with respect to the counters. The relative count rate, R_{9955}/R_{21}, was found to be (0.567 ± 0.0027).

The National Bureau of Standards calibrated the Am-Be source No. 9955 and reported the value $(4.16 \pm 0.11) \times 10^6$ neutrons/sec as the intensity of this source. This yields the result that the source strength of source No. 21 is:

$$S_{21} = (7.33 \pm 0.196) \times 10^6 \text{ neutrons/sec.}$$

Accelerator Source Strength

The accelerator was then operated with a target containing 526 $\mu g/cm^2$ of tritium. The neutron detection rate in the long counters was used to determine the absolute source strength of the accelerator target assuming (1) that the flux at right angles to the beam direction is equal to the mean flux averaged over all solid angles, and (2) that the relative neutron detection efficiency for the 14-Mev neutrons from the D-T source compared to those from the Am-Be source was 0.85 ± 0.075.[2]

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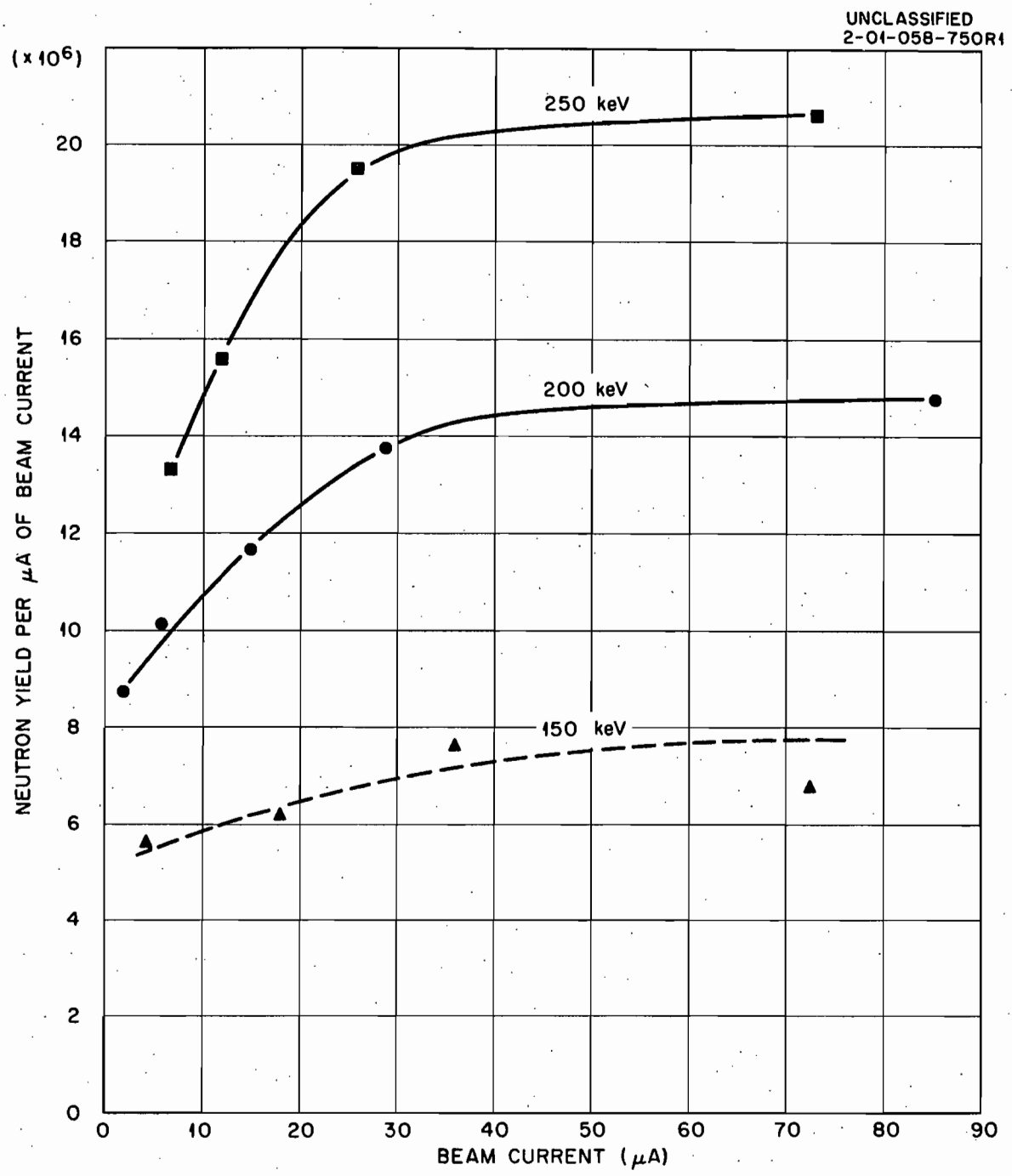
2. Private communication from R. Macklin, ORNL.

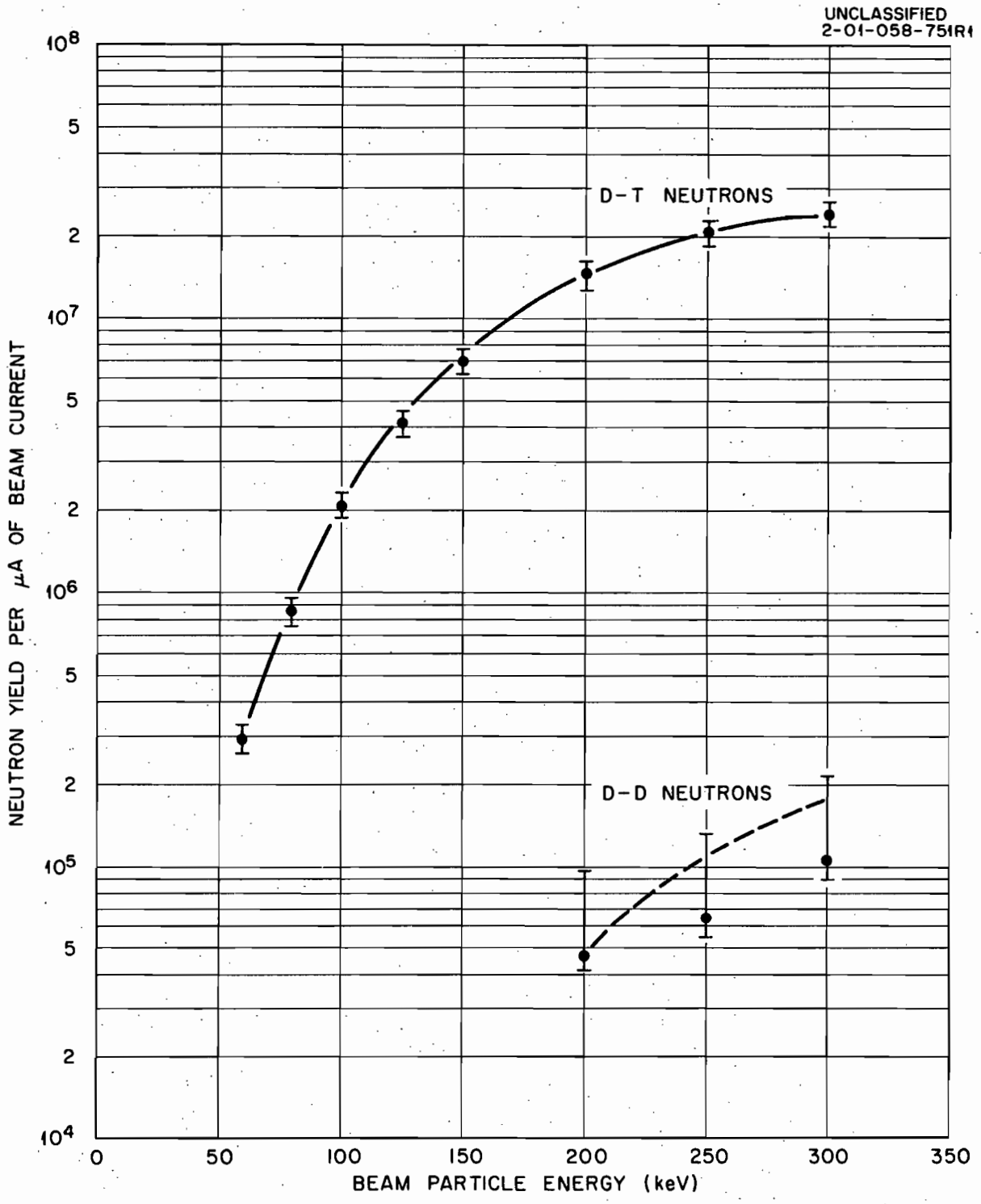
For the purpose of determining the beam-source strengths only the detector Channel II (the more distant) was used since the close channel was subjected to extremely high count rates for which the correction for dead-time was of the same order as the count rate observed.

The contributions to the quoted errors include: (1) the counting statistics including dead-time correction errors, (2) the beam strength uncertainty (taken to be 5%, which is the reading error and does not include any systematic errors of the microammeter circuit), (3) the long counter energy response uncertainty of 8.8%, and (4) the source calibration error of 2.7%. It appeared from the data that there is an increase in the beam effectiveness, i.e., in the number of neutrons produced per second per microampere of beam current at a given beam energy as the beam current increases. Figure 1 shows this variation. The cause of this phenomenon is not certain but most likely is due to errors in the microammeter calibration in the lowest range, since the curves seem to level out above about 30 microamperes of beam current. Accordingly, the values observed at high-beam currents are used as the correct values in plotting the neutron yield per microamp of beam current as a function of deuteron energy. This is shown in Fig. 2, which also includes data taken with a deuterium target. The latter data are very inaccurate since the deuteron concentration on the target was not at equilibrium when the measurements were made. The energy response of the long counters was assumed to be the same for D-D (2.4 Mev) and D-T (14 Mev) neutrons. Since the highest beam-energy data with the D-D target were taken first and the neutron production continued to rise, amounting to an increase of about a factor of two over the time of the data collection, the high-energy points are relatively too low by about this



Measured Variation of Neutron Yield per Microampere of Beam Current for Three Beam Energies.

Fig. 1.



Measured Total Neutron Production per Microampere of Beam Current as Function of Beam Energy.

Fig. 2.

factor. The dotted line in the figure is a rough estimate of the true variation of D-D neutron production with voltage.

Distance Effect of Long-Counter Response

With the new-style detector in the long counter at the standard distance of 265 cm from the target center, at right angles to the beam, the response to 14-Mev neutrons was measured to be:

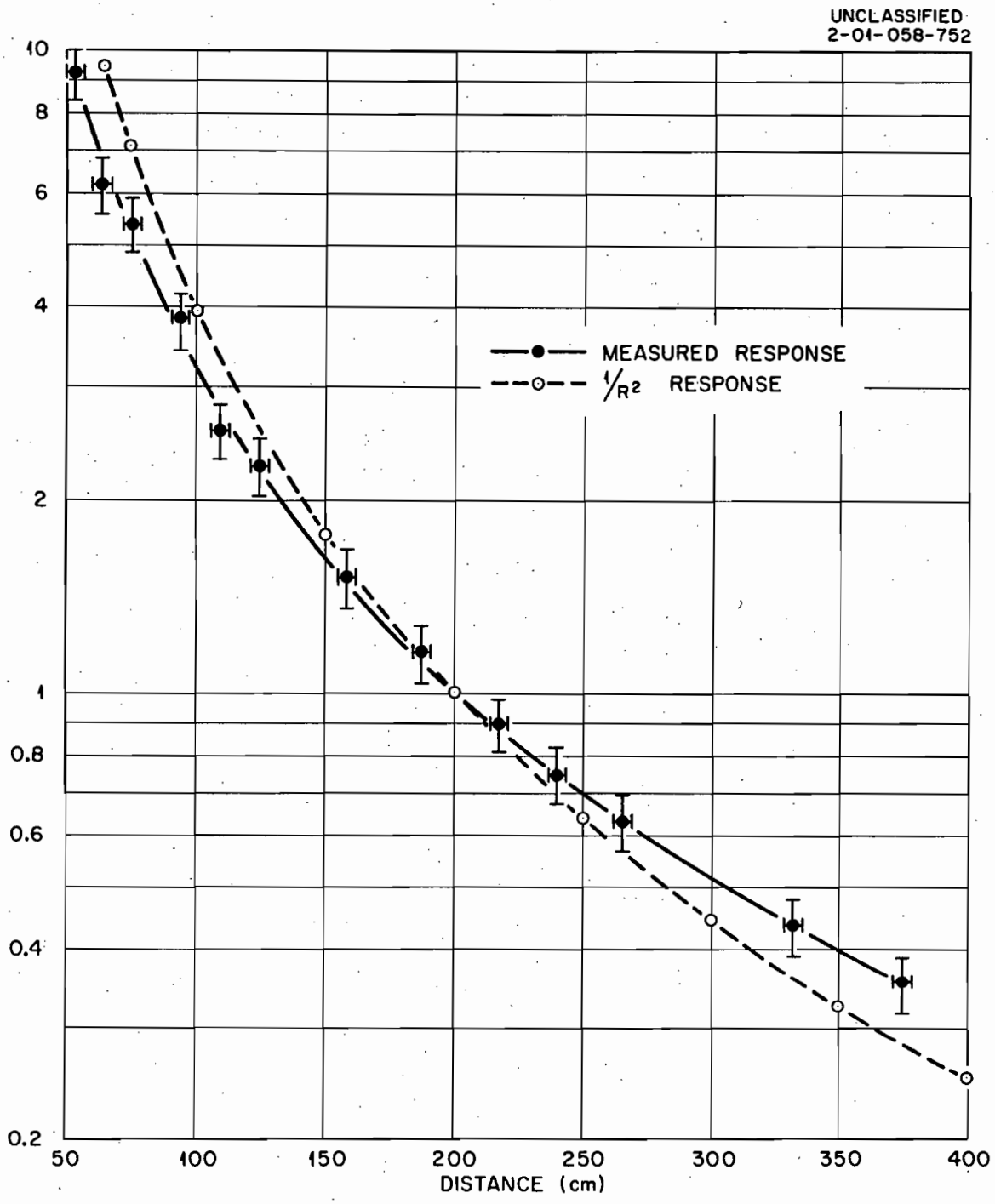
$(2.77 \pm 0.14) \times 10^{-6}$ long-counter counts per Am-Be neutron produced, and

$(2.35 \pm 0.21) \times 10^{-6}$ long-counter counts per 14-Mev neutron produced.

In order to facilitate the use of the long counter as an absolute monitor at other locations, data were taken at various distances, always at right angles to the beam direction, and normalized by the use of data from the fixed-position monitor. Figure 3 gives the relative count rate as a function of distance from the source of 14-Mev neutrons. The distances are measured to the front surface of the long counter. The $1/R^2$ curve is shown for comparison. The less steep falloff of the actual curve is ascribable to the fact that the center of detection lies several inches behind the front face of the counter, and also to the effect of the divergent geometry of the neutrons when the counter is close to the source.

Angular Dependence of Long-Counter Efficiency

In order to estimate the effect of misalignment of the long counter on its counting efficiency and to determine the long-counter shield's efficiency in discriminating against scattered neutrons from rearward directions, the angular response was measured. The counter was placed at the "standard" distance of 265 cm from the target (target center to front face) and then rotated about a vertical axis through the approximate center of

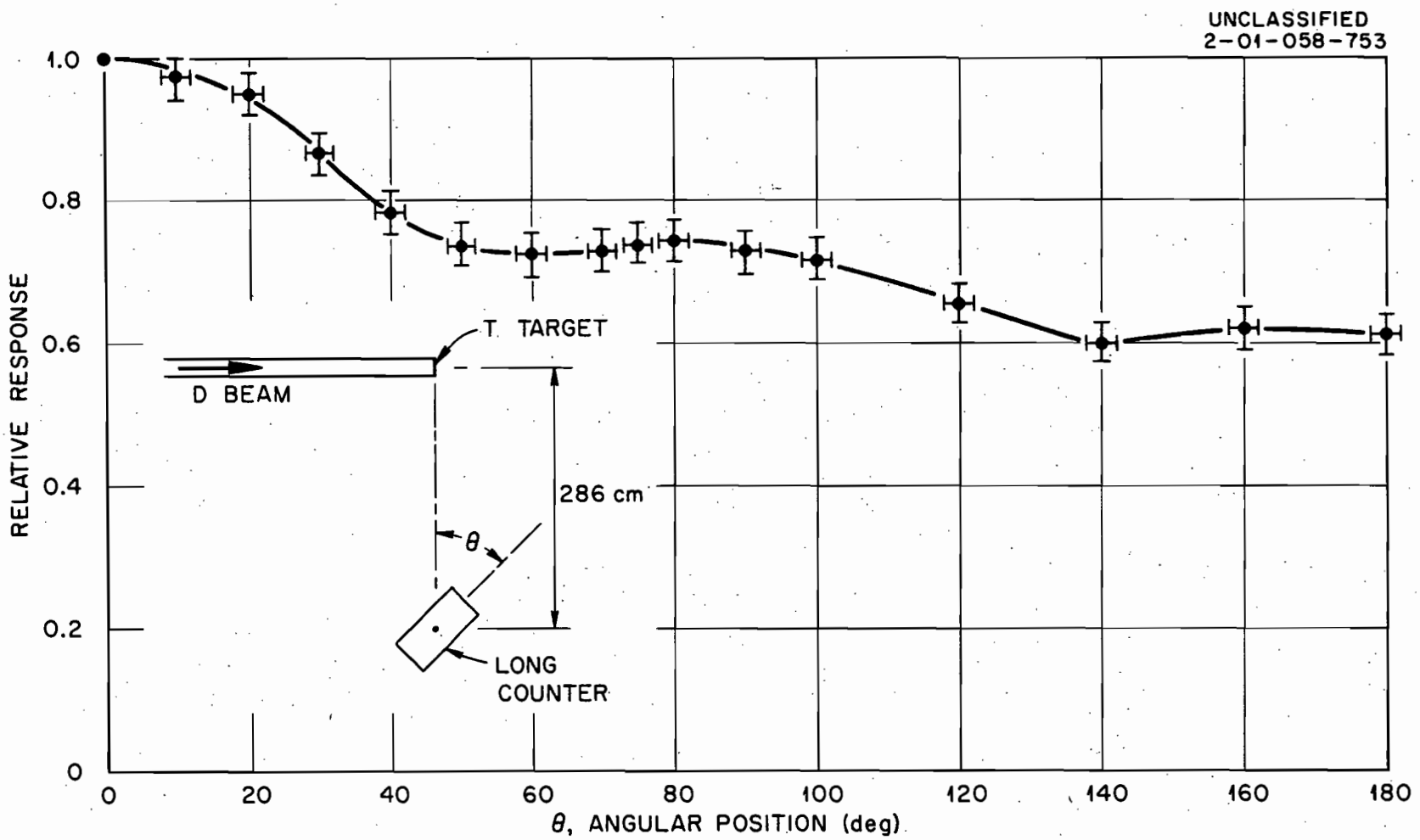


Relative Long Counter Response as a Function of the Distance Between Front Face of Counter and D-T Neutron Source, at a Right Angle to D-Beam. The $1/R^2$ Curve is Shown for Comparison. Both Curves are Normalized to Unity at 200 cm Separation.

Fig. 3.

gravity of the counter located 286 cm from the target center. The fixed monitor counter again served to normalize the count rates.

The results are shown in Figure 4. The "hump" around 90° is probably due to the larger surface and the effectively thinner hydrogenous shield which is interposed in this orientation.



Relative Response of Long Counter as a Function of Its Angular Position. At $\theta = 0°$, the Front of the Long Counter was 265 cm from the Target Center.

Fig. 4.

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