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JOINT REPORT

Physics Division
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Test of Radiation Attenuation Through Concrete Shield Containing A Helical Duct.

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TEST OF RADIATION ATTENUATION THROUGH CONCRETE SHIELD CONTAINING A HELICAL DUCT

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TEST OF RADIATION ATTENUATION THROUGH CONCRETE SHIELD CONTAINING A HELICAL DUCT

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TEST OF RADIATION ATTENUATION THROUGH CONCRETE SHIELD CONTAINING A HELICAL DUCT

ABSTRACT

This report presents the test results of the effect of a helical duct on the shielding properties of concrete. These tests were conducted at the X-10 pile at the Oak Ridge National Laboratory.

Tests included transverse neutron intensity measurements across the specially constructed test blocks containing the helix as well as longitudinal neutron surveys along the helix. Survey of the helix was made with uncovered and cadmium covered BF_3 counters. Gamma ray intensity measurements were made along the helix as well as external to the helix.

Results indicate a continuously varying neutron attenuation along the helix, so that no single relaxation length can be assigned to the shield. The cadmium ratios also varied considerably along the helix as shown in Fig. 17. A specially constructed 100 R chamber indicated a gamma ray relaxation length of 14.8 cm.

Data is also presented on the characteristics of an experimental methane counter for measurement of fast neutrons.

The results of these tests indicate that the helical duct of the dimensions tested has possibilities for use in conducting coolants from the pile without unduly reducing the effectiveness of the shield.

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TEST OF RADIATION ATTENUATION THROUGH CONCRETE SHIELD CONTAINING A HELICAL DUCT

I. Introduction

One of the problems encountered in the design of high power gas cooled and water cooled piles is that concerned with removing the coolant from the pile without seriously reducing the effectiveness of the shielding. This could be accomplished by using a duct with a large number of bends, but use of a duct of this nature would introduce large pressure drops in the coolant flow. Another method that has been considered is the use of a section of duct containing pebbles so that radiation could be attenuated without unduly restricting the flow of coolant; this method however, requires the use of a duct of large dimensions in order to permit flow of coolant around the pebbles without undue pressure drop.

The most promising proposal has been that involving the use of a helical duct. Pressure drop calculations indicate that for a 5" diameter duct in the shape of a cork screw with two complete turns on a 12" mean diameter the frictional loss is one-third of that for four standard right angle bends.

Since no means is available for computing the effectiveness of a shield containing such a helix, a joint Physics, Power Pile and Technical Divisions program was undertaken to measure the reduction in effectiveness of the shield caused by insertion of such a helix. This was done by casting a helical duct in concrete test blocks similar to those which previously had been tested as solid blocks in the facility hole in the rear face of the X-10 pile shield.

It was recognized that test of a single helix would not yield sufficient data for extensive generalization. It was felt, however, that such a test would give the effect in at least one useful configuration and would indicate the advisability of further tests.

II. Construction of Helix

For the purpose of this test a 5" helical duct was constructed from 24 pieces of straight pipe made of 16 gauge mild steel plate. The duct was welded into a continuous right hand helix which had two complete turns wrapped on a 12" mean diameter, 84" long, to fit into the 84" thickness of the X-10 shield. The duct was cut into four sections which were then mounted in four steel forms so that concrete could be poured around them. These forms are normally used for tests in the X-10 shield test hole. The concrete was poured around the duct sections in such a way that when the blocks were inserted in the hole they formed a continuous helix. A diagram of the blocks as aligned in the test hole is shown in Fig. 3.

The concrete used for these blocks consisted of a standard mix containing one part by volume of Lone Star Portland cement, two parts of sand (made up chiefly of $Si\ O_2$) and three parts of coarse aggregate of almost pure (98% calcium carbonate) limestone. This concrete contains about 20% water by weight.

The blocks are numbered consecutively from 1 to 4 beginning at the pile side of the shield. Block number 1 was provided with a 1 1/2" inside diameter vertical steel tube, lined with a 1/4" thickness of paraffin into which was inserted a 1" wooden dowel notched to hold five gold foils for measurement of the transverse neutron intensity. Block number 2 was provided with two such holes, one vertical and one horizontal, to receive wooden dowels containing seven gold foils. The location of these holes are indicated in Fig. 3.

Each block was further provided on each end with a 4" x 4" plug, 2" thick, on the longitudinal centerline of the blocks behind which were placed gold foils for obtaining neutron intensity measurements along the longitudinal axes of the blocks. These plugs are not shown in Fig. 3.

III. Radiation Detection Instruments

Neutrons were detected by three methods. The first was by means of BF_3 proportional counters. These consisted of thin-walled brass tubes filled with enriched boron trifluoride (80% B_{10}) at 13 cm Hg pressure. One tube was 1" in diameter with a 10" effective length. The other was 1/4" in diameter and had a 1/2" effective length. These tubes were used in conjunction with a one stage preamplifier of the cathode follower type, the output of which was fed into a standard Al type linear amplifier with controllable pulse height selector, band width and gain. The pulse height selector output of the preamplifier was fed directly into a 1024 scaler. This circuit has scaled as high as 3×10^6 counts/minute with a large BF_3 counter, when a scale of 64 was in series with the scale of 1024. However, in this test the counting rate did not exceed 500,000 c/m.

Attempts were also made to use a new type methane-filled proportional counter constructed in the same manner as the large BF_3 tube. This tube is operated in the proportional region and records the pulses obtained from proton recoil, and hence should be an energy dependent neutron detector. It was hoped that this tube could be used to obtain the attenuation through the duct of fast neutrons. However, since the tube also responds to gamma and beta radiations, which were very intense in the innermost portions of the shield and which could not be duplicated in intensity with the absence of neutrons, the data is subject to question. Also, since this tube is very insensitive to neutrons, it was not possible to calibrate it in the low fast flux available from known radium beryllium sources. However, it is felt that this data might be valuable in the light of further investigation.

Neutrons were also detected by means of gold foils which were 1 1/2" x 2 5/8" x 5 mils. These foils were exposed for a period of one week and were then counted on a standard GM tube counter and corrected for decay. A series

of readings were taken on each foil to verify the half life. All foils showed the accepted 2.70 days with the exception of one set which exhibited a long half life contamination, the cause of which is being investigated further.

Gamma attenuation was measured in two geometries, and with both GM tubes and an ion chamber. The GM tube or the ion chamber was inserted in the 5" duct of the helix by means of a special probe. The GM tube was also mounted in a lead shield 82" from the outer face of the X shield. The lead shield consisted of at least 8" of lead completely surrounding the tube, through which was bored a 1" hole aligned with the centerline of the facility hole. This hole was chosen to admit only radiation from an area somewhat smaller than the actual size of the facility hole. It should be noted that this geometry was such as to measure only gamma rays parallel with the axis of the facility hole. Gamma ray attenuation was also measured with an ion chamber which consisted of a thin (10 mil) walled aluminum tube 2 1/2" in diameter and 4 1/2" effective length. This chamber was filled with air at 1 atmosphere and designed to give full scale readings in a flux of 100 R/hr.

Figure 1 is a photograph of the probe tube. Figure 2 is a photograph of the end of the probe tube showing the counter and preamplifier. Figure 3 shows a diagram of the duct in the blocks.

IV. Test Procedure

The measurements taken in this test were as follows:

(1) Neutron Attenuation along the Centerline of the Five Inch Duct. This was measured in three ways.

(a) BF_3 counters, mounted on a corkscrew probe. Both the large and small tubes were used with and without a 40 mil cadmium cover. Data are presented in Fig. 12 and Fig. 17.

(b) Methane tube with variable pulse height selector. This was used to determine if this type tube would give any indication of the variation of neutron spectrum through the sample. Data are given in Fig. 14.

(c) Gold foils in paraffin filled duct. This was done to simulate duct being filled with a hydrogenous liquid. Data in Figs. 12 and 13.

(2) Neutron Attenuation along the Longitudinal Centerline of the Blocks by means of Gold Foils. Foils were inserted 2" in from the front and rear face of the blocks by means of the plugs mentioned above (Section II); the three center foils on the pipe inserts, positioned as indicated in Fig. 3, provided additional data along this centerline.

From previous measurements it has been determined that the foils in the pipes, which are surrounded by paraffin, will read approximately 5 to 8% higher than those in the plugs. These data are presented in Figs. 12 and 13.

(3) Neutron Measurements along Horizontal and Vertical Traverses at various thickness of blocks.

(a) BF_3 counter horizontal traverses both across the horizontal centerline of blocks and across the horizontal centerline of the duct exit, behind 84" (Figs. 5 and 6) and behind 64" (Figs. 7 and 8) of shield.

(b) Gold foils in pipe inserts behind 16" of shield (vertical traverse) Fig. 9, behind 25" (horizontal) Fig. 10, and behind 34" (vertical) Fig. 11.

(4) Gamma Attenuation Through Blocks.

(a) Measurements along 5" helix with ion chamber (Fig. 15) and with the GM tube with pile power on and off (Fig. 16).

(b) Overall attenuation of parallel rays with GM tube in the geometry described in Radiation Instrument Section. (Fig. 15)

The gold foils were counted on a standard glass walled GM tube set up and were corrected for decay only. Since all the foils were exposed for an interval of one week during which time the pile power varied somewhat, the saturated activity was not calculated; however, enough data has been taken in previous tests to indicate that for a one week exposure with the pile operated in its normal routine, deviations of less than 10% can be expected from week to week.

The BF_3 counter was covered with a U shaped (40 mils cadmium) shield for all horizontal traverses the open side of which was against the face of the block; see Fig. 4. The BF_3 counter tubes had previously been exposed to a neutron free gamma flux of 500 R/hr. from a 10 gram antimony source in which they gave no counts.

V. Discussion of Results

(1) Neutron Measurements along Centerline of Five Inch Duct.

Since the intensity from the front face to the back face of the blocks varied by a factor of 10^8 it was necessary to use two BF_3 counters of the geometries described in Section III. Readings were taken with the

large tube by reducing the pile power as the tube was inserted further into the helix. By this means it was possible to measure over 73" along the duct with the single tube. The data from the large tube was normalized to the small tube in Fig. 12 to give a continuous distribution.

The small BF_3 tube used in these measurements was a recent development of the Instrument Department and has not been sufficiently in use to determine all its operating characteristics. The tube exhibited a very short plateau (50 volts) and non-uniform pulse height. These facts may be an explanation for the low readings of the Cadmium covered small tube (see Fig. 12) since it has been noted that excessive gamma flux decreases the pulse height of the tube and the Cadmium cover would greatly increase the gamma flux in which the tube was operating due to capture gamma production. The large tube, however, had a plateau of 250 volts and a very uniform pulse height.

Fig. 12 is presented to compare attenuations for different situations and detecting techniques. The gold foil data obtained in the different situations have been normalized by different factors so that they would all coincide with the small BF_3 data. All the data from the large BF_3 tube, however, were multiplied by the same constant (.00375) so that it would coincide with that of the small tube.

Although it is not too apparent among the multitude of points shown in Fig. 12, the data for each run indicated a periodic fluctuation or wave which corresponds roughly to half the pitch of the helix. This might be due to several factors, one of which is the fact that the probe was not rigid and, hence, could quite possibly change its length as it was inserted into the helix. Since the distance was always measured from the outside end of the probe and the probe length assumed to be constant, this change of length would appear as a variation in the data. However, even the gold foils which are cast into the paraffin indicated some waviness with a frequency of only half of the BF_3 data. There is also a possibility that the tube did not remain in the center of the helix, which could cause further perturbations.

Compared to the overall attenuation, deviations in neutron distribution and intensity seem very slight, both with instruments (gold foils vs. counters) and situations (solid blocks vs. helix).

The data taken with the methane filled proportional counter (Fig. 14) were obtained with various pulse height settings on the Al amplifier with a constant voltage on the tube. The unusual behaviour for pulse height settings above 10 must be assigned to tube characteristics rather than neutron distribution. This tube also was checked with the 500 R per hour gamma flux, and the voltage was regulated so that it did not count in this flux. However, it appears from the data that the counter discharge pulse height was somewhat reduced due to the excessive beta and gamma radiation inside the tube, both from the pile and from the increasing radioactivity in the chamber walls. These phenomena are indicated by the row of points coming straight down from the curve (Fig. 14) labeled "pulse height 12". Successive readings were taken with all settings remaining constant and show the characteristic decay with time. It is assumed that the tube was becoming radioactive and decreasing

the average neutron pulse height, resulting in a decreasing number of counts. The attenuation measured by this tube on the lowest pulse height setting was quite a bit less than that observed in the region of 40" to 55" for either the bare or cadmium covered BF_3 counters.

(2) Neutron Attenuation along the Longitudinal Centerline of the Blocks by means of Gold Foils.

The neutron distribution obtained by the gold foils inserted in the centerline of the blocks containing the helix has been plotted in Fig. 13. Included in Fig. 13 is a plot of data obtained from tests at an earlier date of solid concrete blocks. A comparison of data from these blocks with the blocks containing the helix is questionable because the two sets of blocks may have had different moisture content.

(3) Neutron Measurement along Horizontal and Vertical Traverses At Various Thicknesses of Blocks.

The horizontal and vertical neutron traverses presented in Figs. 5 through 11 were obtained by positioning the counter flush against the portion of the shield being tested and were shielded with 40 mil cadmium on all sides except the side against the shield, where there was an aluminum window. A cross section of the tube so wrapped is shown in Fig. 4. A single run was made with the counter held perpendicular to the shield as shown in Fig. 3 in which the counter was in a cadmium tube with the open end toward the shield. This method tends to measure only radiation parallel to the axis of the tube and since it yielded low counting rates, it was not used for the bulk of the tests.

In Figs. 5 and 6, where readings are shown up to and beyond the edge of the blocks, a dip in the neutron intensity is indicated at the edge of the block below the level for the main X-10 shield. This dip is due to the fact that the edges of the blocks consist of a 3/8" steel framework which holds the concrete in place. The steel frame has a higher thermal neutron capture cross section than the concrete and therefore reduces the thermal neutron intensity.

The neutron traverses along the face of the block (Fig. 5-11) indicate more clearly the effect of the open helix on the shield. To indicate the extremes of the variations from solid block to open helix the ratio of the highest intensity noted in the open helix measurements to that of the solid or paraffin filled blocks is presented in the following table.

TABLE I

Ratios of Extreme Increase in Neutron Intensity of Open Helix to Solid Block

Fig. No.	5	6	7	8	9	10	11
Shield thick	84"	84"	64"	64"	16"	25"	35"
Horiz. or Vert.	H	H	H	H	V	H	V
Block or Helix Centerline	Block	Helix exit	Block	Helix exit	Block	Block	Block
Peak	.012	.0145	.37	3.1	1.47×10^8	1.22×10^7	8.8×10^5
Paraffin	.00585	.00565	.293*	.283	3.75×10^7	1.71×10^6	1.12×10^5
Concrete					3.95×10^7	2.3×10^6	1.72×10^5
Ratio Peak to Paraffin	2.051	2.566	1.263	10.954	3.920	7.135	7.857
Ratio Peak to Solid Concrete					3.722	5.304	5.116

* This value obtained by extrapolation from value in Fig. 5.

Qualitatively, the localized effect of the helix diminishes with increase in shield thickness; hence, the peak intensity appears over the portion of the helix closest to the outer surface. It should be noted that the counting rate was very low behind the full 84" of shielding and, therefore, statistical error is high in these readings.

(4) Gamma Attenuation Through the Blocks.

Since the helix in this test arrangement afforded a more adaptable facility than any previously available for measuring gamma ray intensities in the bulk of the shield, extensive data, at close intervals were taken to compare results obtained with various types of instruments and geometries. Fig. 15 presents the data taken on the ion chamber inserted into the helix and on the GM tube in the lead shield located 82" from the shield face. The data shown in Fig. 15 for the GM tube in the lead shield located 82" from the shield face was obtained with two different apertures in the lead shield and have been normalized for plotting.

Fig. 16 presents the data obtained using the GM tube inserted into the five inch duct. The curvature exhibited by this data at high counting rates is assumed to be due to a very excessive counting rate and is not indicative of a real distribution of gamma intensity. Unfortunately the range of the tube was too limited for the readings at 3750 KW to be very conclusive. During the

readings at zero pile power the pile was, of course, decaying; however, two runs were taken, one following another and the discrepancy due to decay not excessive and all data have been plotted without correction.

The following gamma relaxation lengths were obtained by the various techniques described above.

(1) 100 R ion chamber along helix, pile power on - 14.8 cm

(2) GM tube along helix, pile power on - 16.2 cm

(3) GM tube in lead shield, pile power off -
Through 2nd Block - 15.7 cm
Through 3rd Block - 20 cm

No quantitative explanations of these numbers is presented at this time.

VI. Conclusions and Recommendations.

The data presented in this report is inadequate for extensive generalization about the effectiveness of shields containing helical ducts. Even for the specific helix tested a more complete mapping of the neutron intensities should be made to permit the comparison of volume of the helix with the volume of extra shielding required.

The results of these tests indicate that the helical duct of the dimensions tested has possibilities for use in conducting coolants from the pile without unduly reducing the effectiveness of the shield. In order to provide data for engineering design additional tests should be made on ducts of different dimensions and a dimensional correlation of their effects on the shield should be made.

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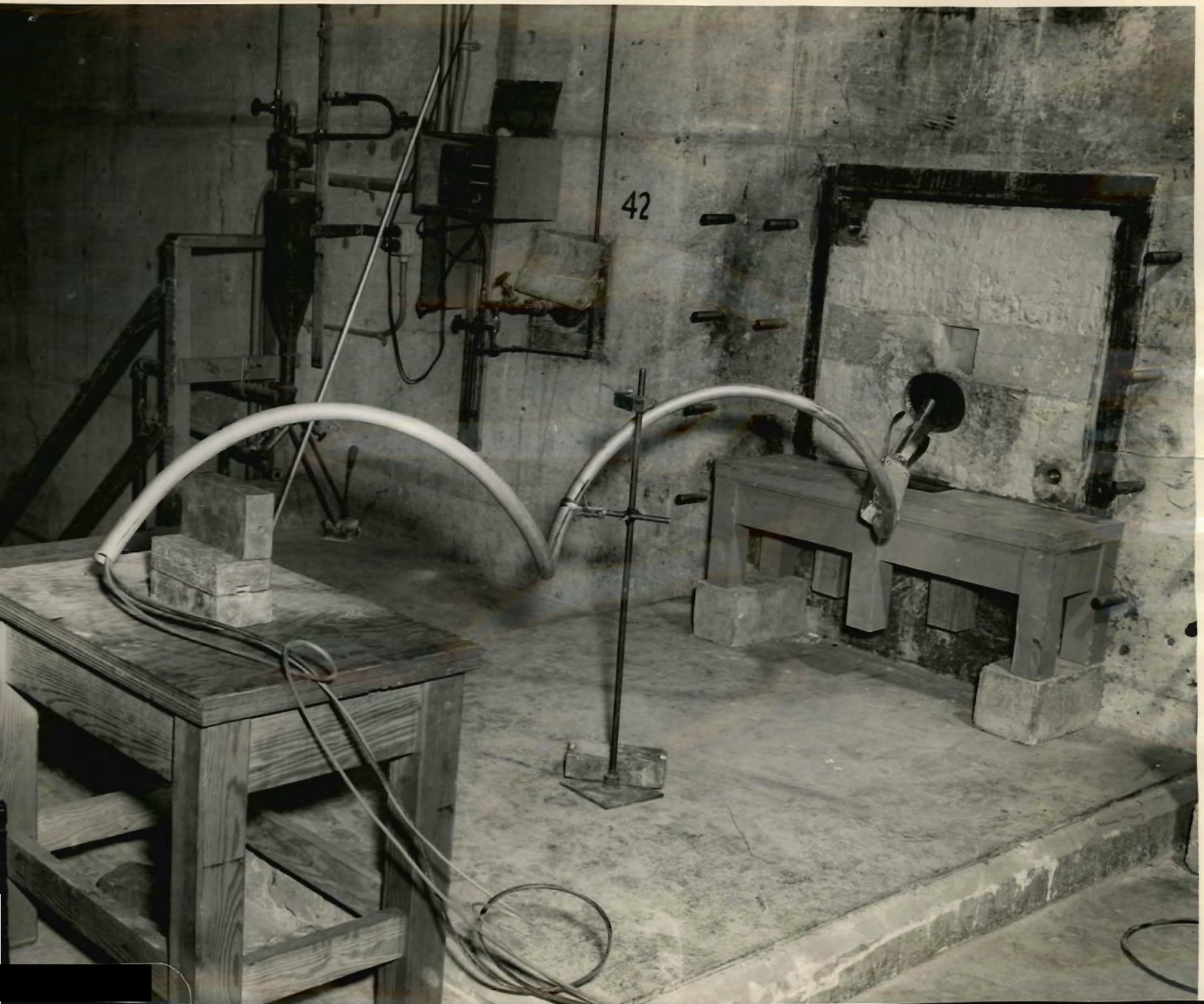
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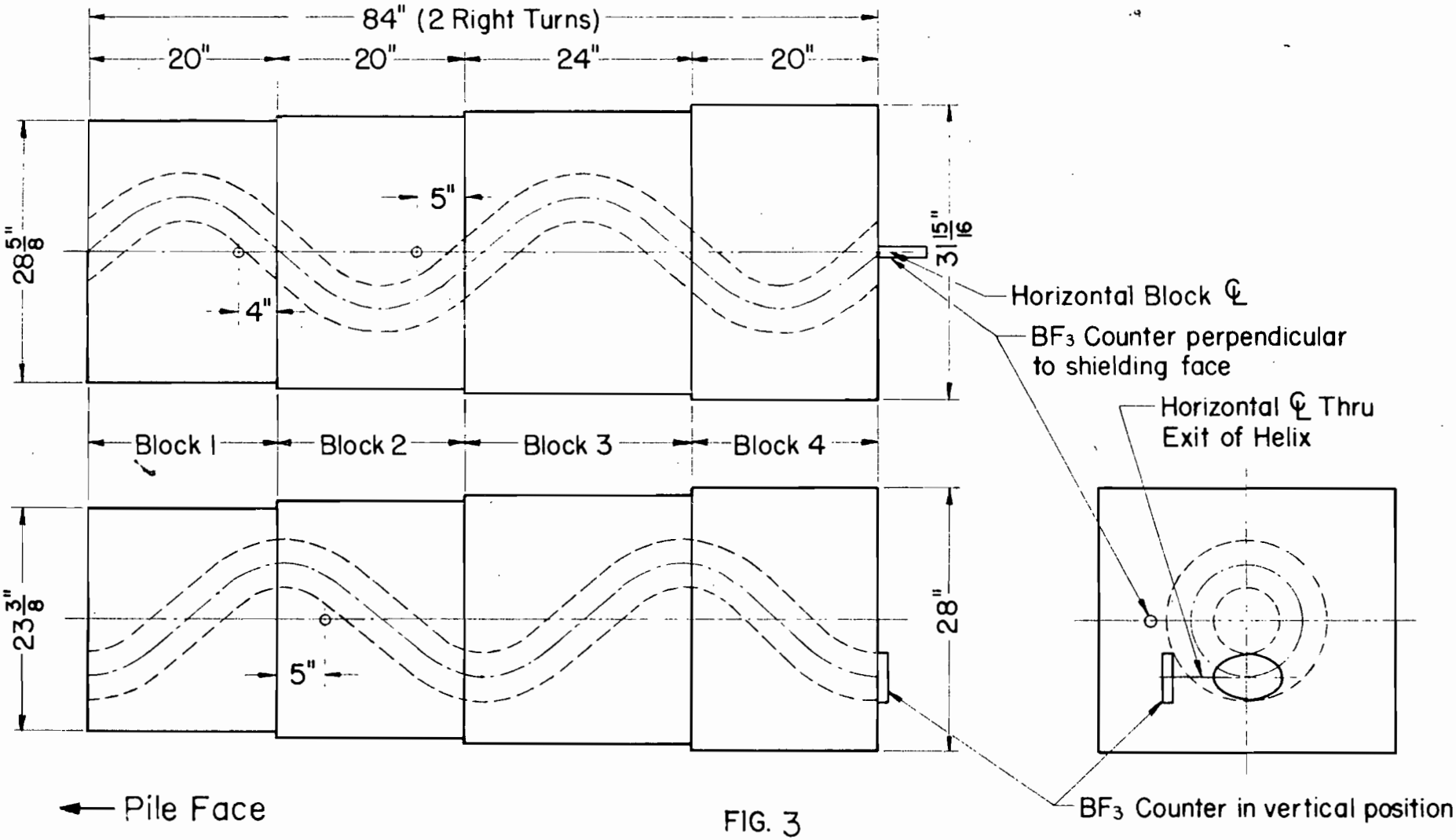

FIG. 3

Test of Radiation Attenuation Through Concrete Shield Containing A Helical Duct.

Diagram of Test Blocks Showing Helical Duct

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FIG. 4

CROSS-SECTION OF CADMIUM COVERED BF_3 COUNTER USED FOR EXTERNAL NEUTRON TRAVERSES

TEST OF RADIATION ATTENUATION THROUGH CONCRETE SHIELD CONTAINING A HELICAL DUCT.

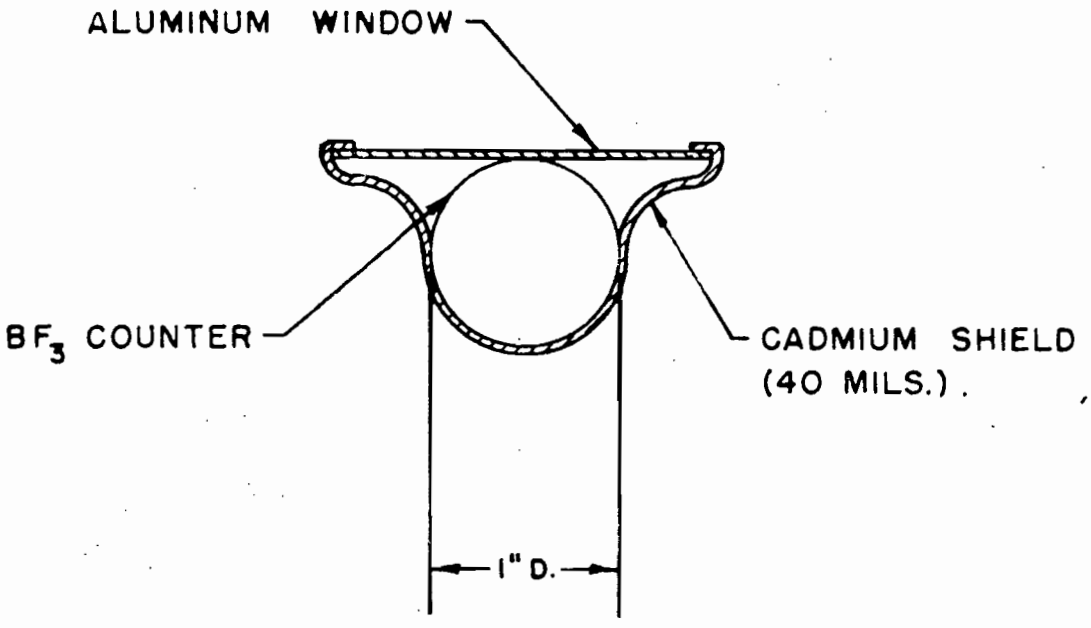

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Fig. 5

TRANSVERSE NEUTRON INTENSITY MEASUREMENTS ALONG HORIZONTAL CENTERLINE OF TEST BLOCK FACE OF 84" SHIELD.

Test of Radiation Attenuation Thru Concrete Shield Containing a Helical Duct.

Thickness of Shield 84" (4 Blocks in Place)
BF_3 Counter No. P-236; Voltage on Counter 1450
Counter Shielded with Cadmium on all Sides Except the Side Against Block.

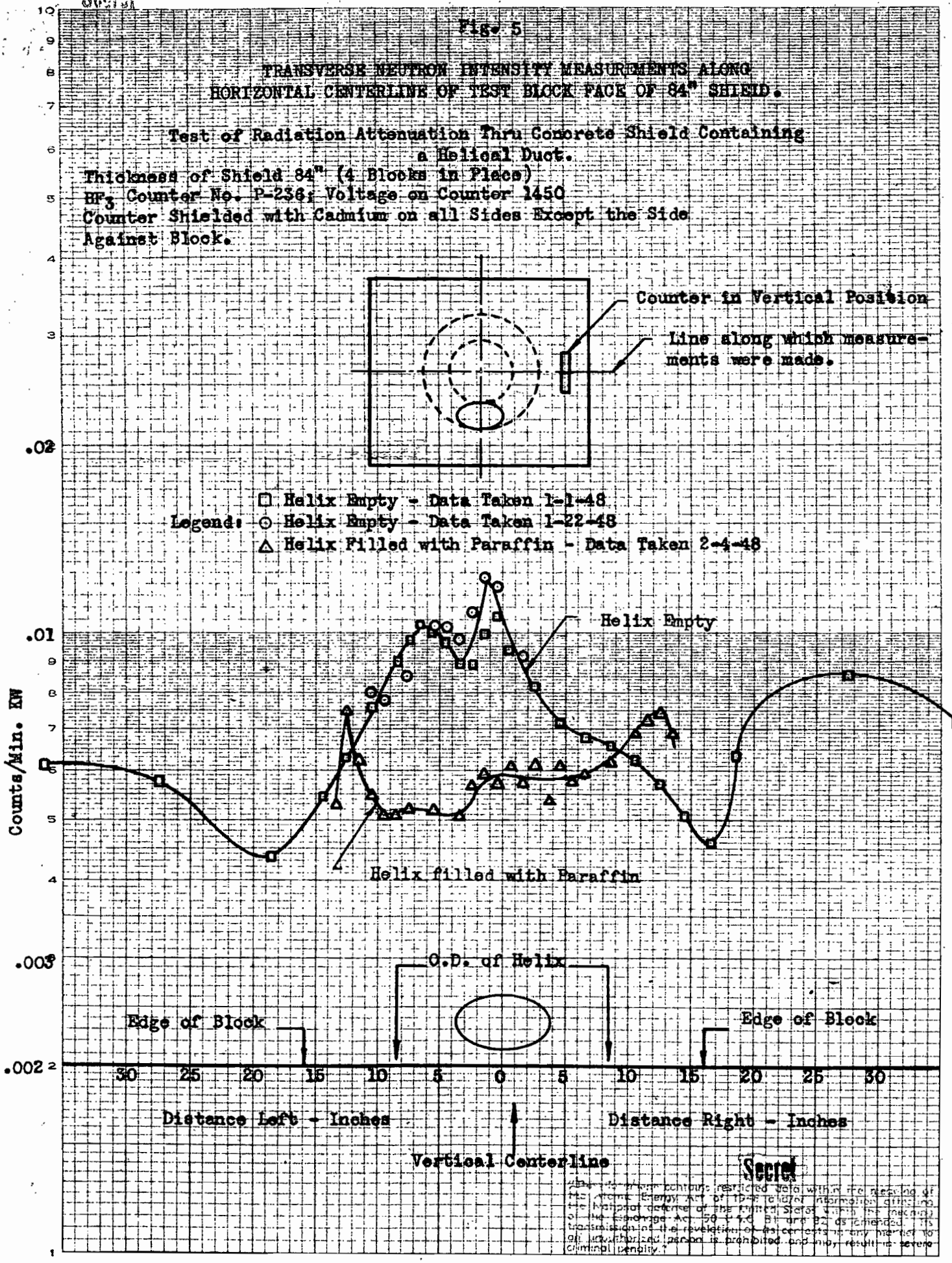

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FIG. 6

TRANSVERSE NEUTRON INTENSITY MEASUREMENTS ALONG HORIZONTAL CENTERLINE THROUGH HELIX EXIT OF 84" SHIELD

Test Of Radiation Attenuation Through Concrete Shield Containing A Helical Duct

Thickness of shield: 84" (4 blocks in place)
BF_3 Counter No. P-236; Voltage on counter: 1450
Counter shielded with Cadmium on all sides except the side against the block

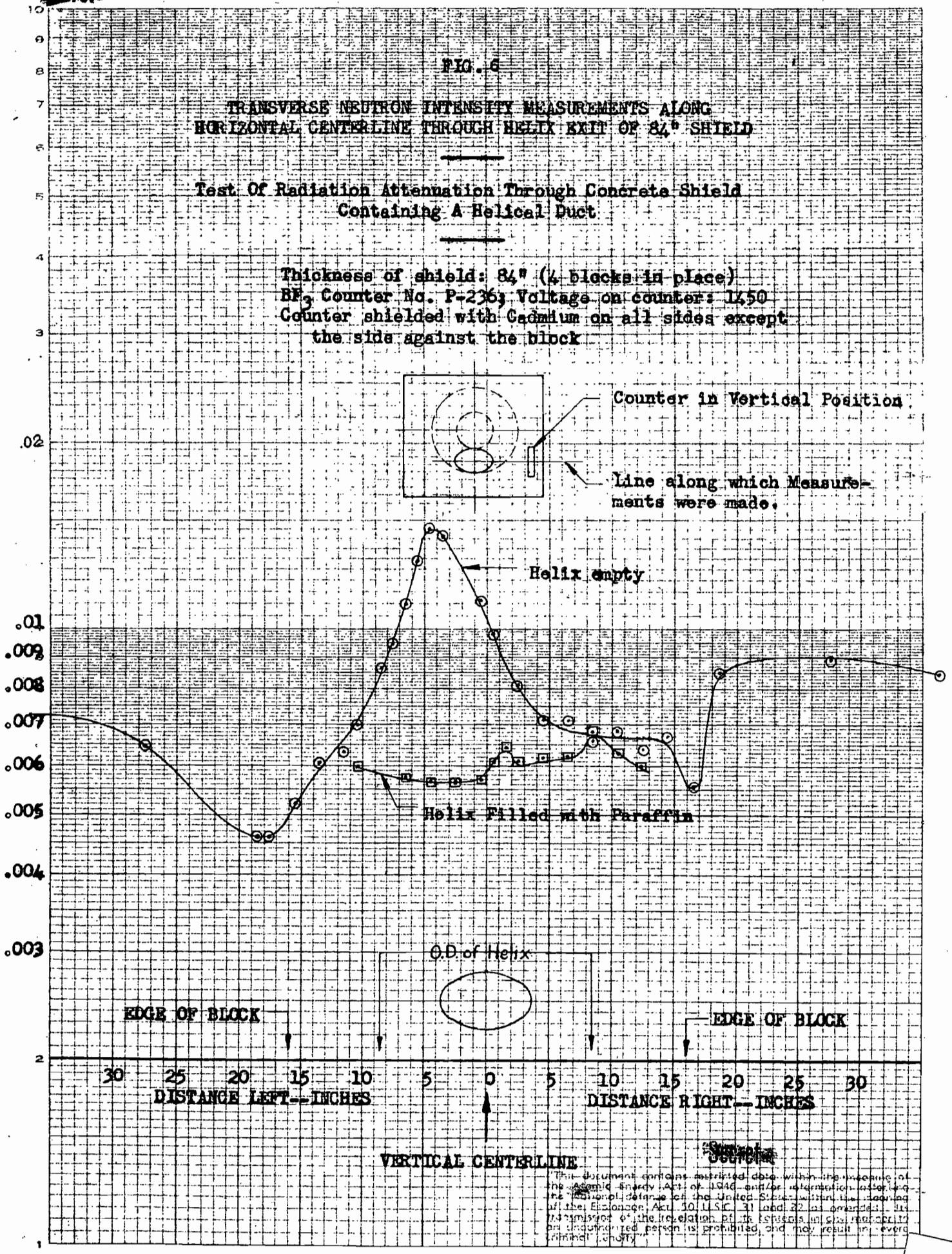

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Fig. 7

TRANSVERSE NEUTRON INTENSITY MEASUREMENTS ALONG HORIZONTAL CENTERLINE OF TEST BLOCK FACE OF 64" SHIELD.

Test of Radiation Through Concrete Shield Containing a Helical Duct.

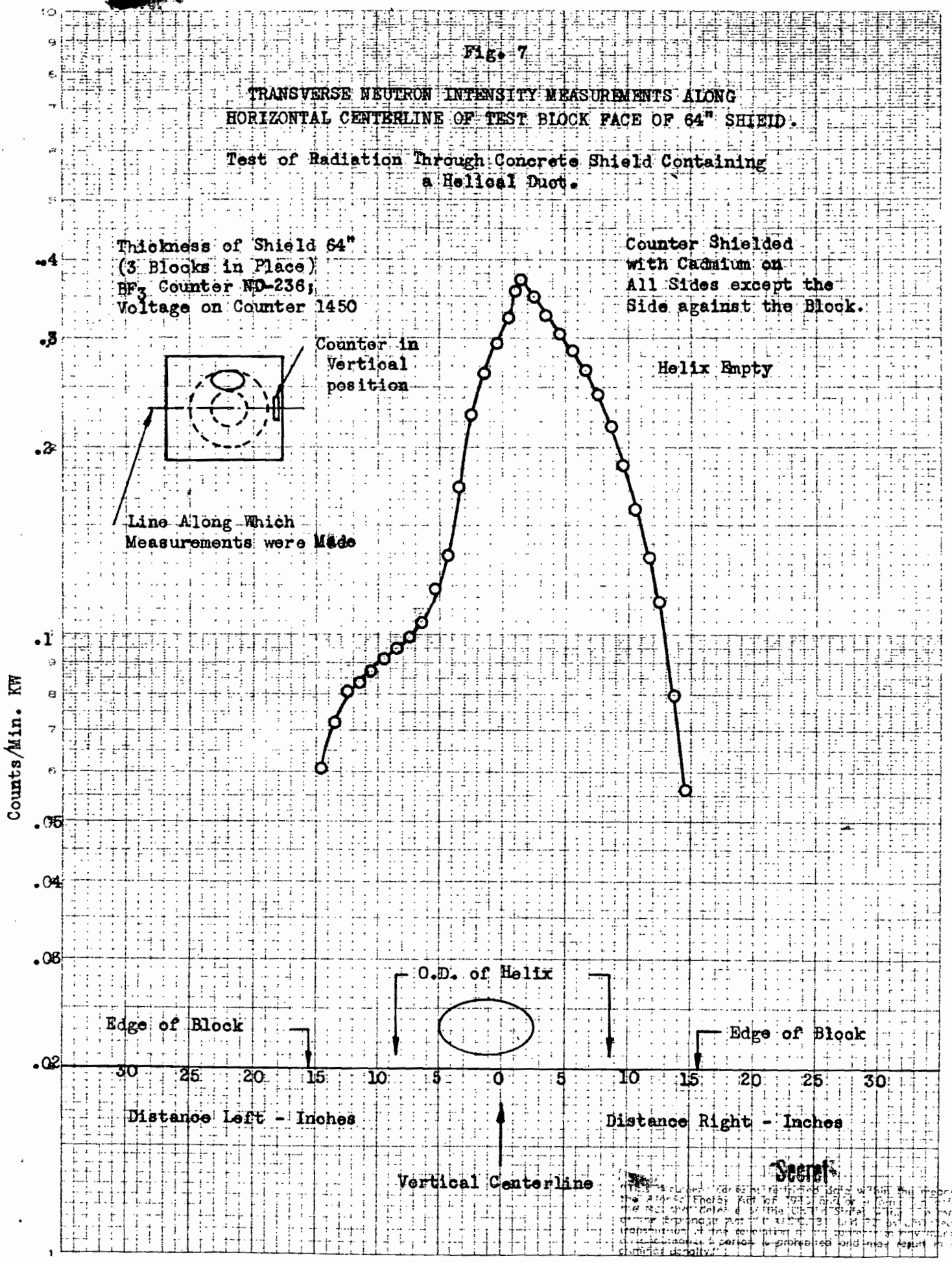

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Fig. 8

TRANSVERSE NEUTRON INTENSITY MEASUREMENTS ALONG HORIZONTAL CENTERLINE THROUGH HELIX EXIT OF 64" SHIELD

Test of Radiation Through Concrete Shield Containing a Helical Duct

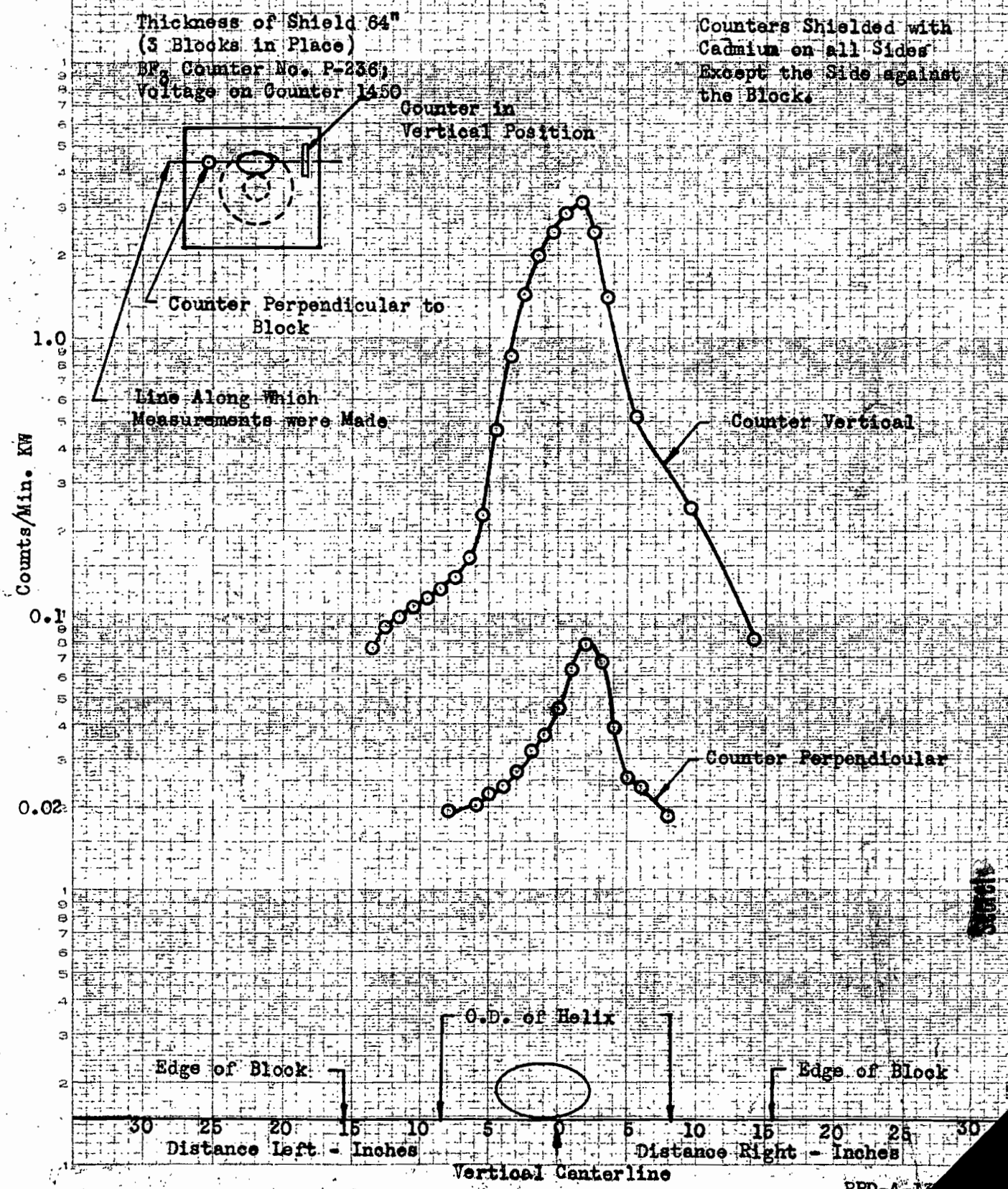

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Fig. 9

TRANSVERSE NEUTRON INTENSITY MEASUREMENTS
OBTAINED BY USE OF GOLD FOILS ON VERTICAL ROD INSERT, BLOCK NO. 1

Test of Radiation Attenuation Through Concrete Shield
Containing a Helical Duct

Thickness of Shield 16". Vertical Rod Insert in No. 1 Block

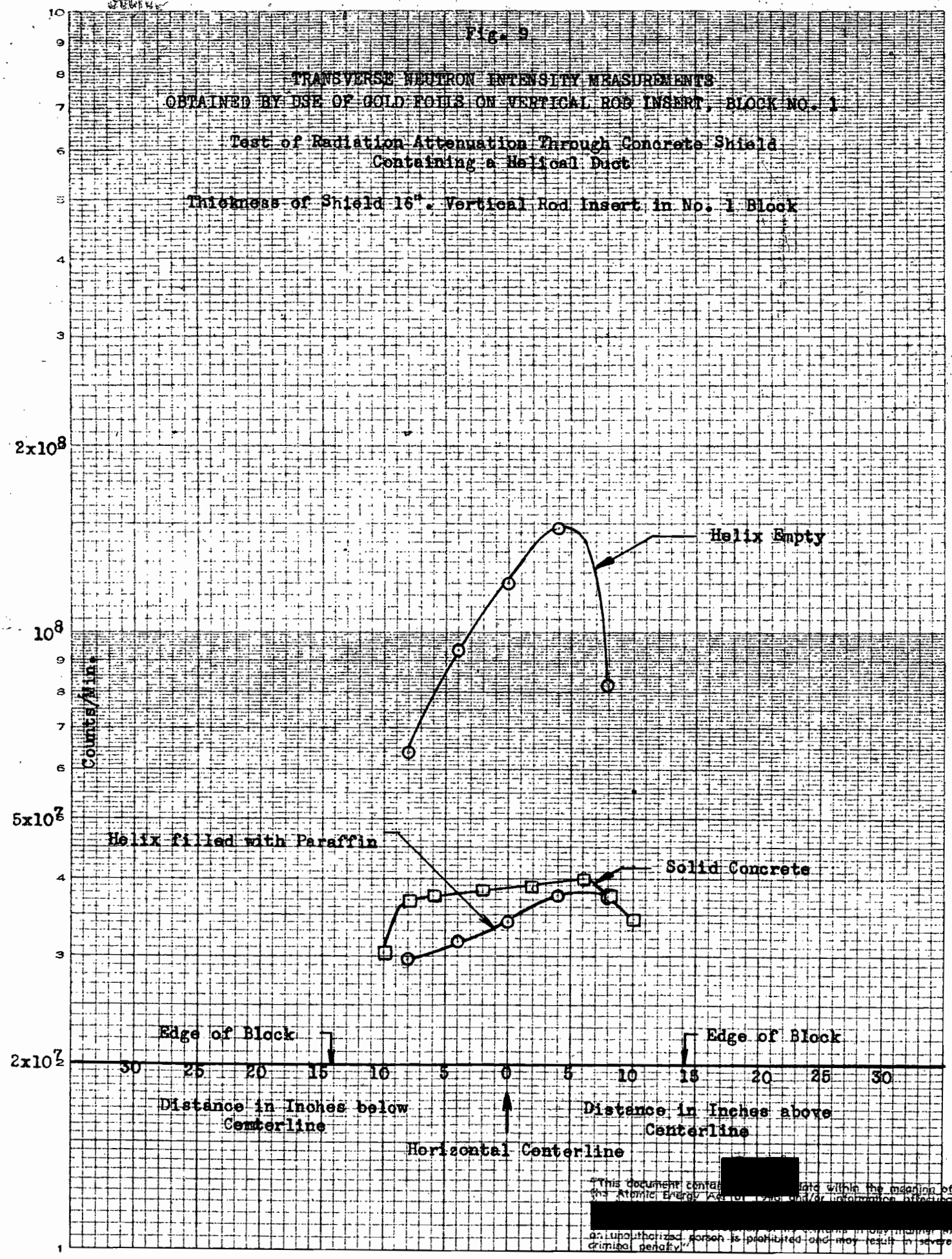

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Fig. 10

TRANSVERSE NEUTRON INTENSITY MEASUREMENTS
OBTAINED BY USE OF GOLD FOILS ON HORIZONTAL ROD INSERT, BLOCK NO. 2

Test of Radiation Attenuation Through Concrete
Shield Containing A Helical Duct

Thickness of Shield 25". Rod in No. 2 Block
Helix Empty.

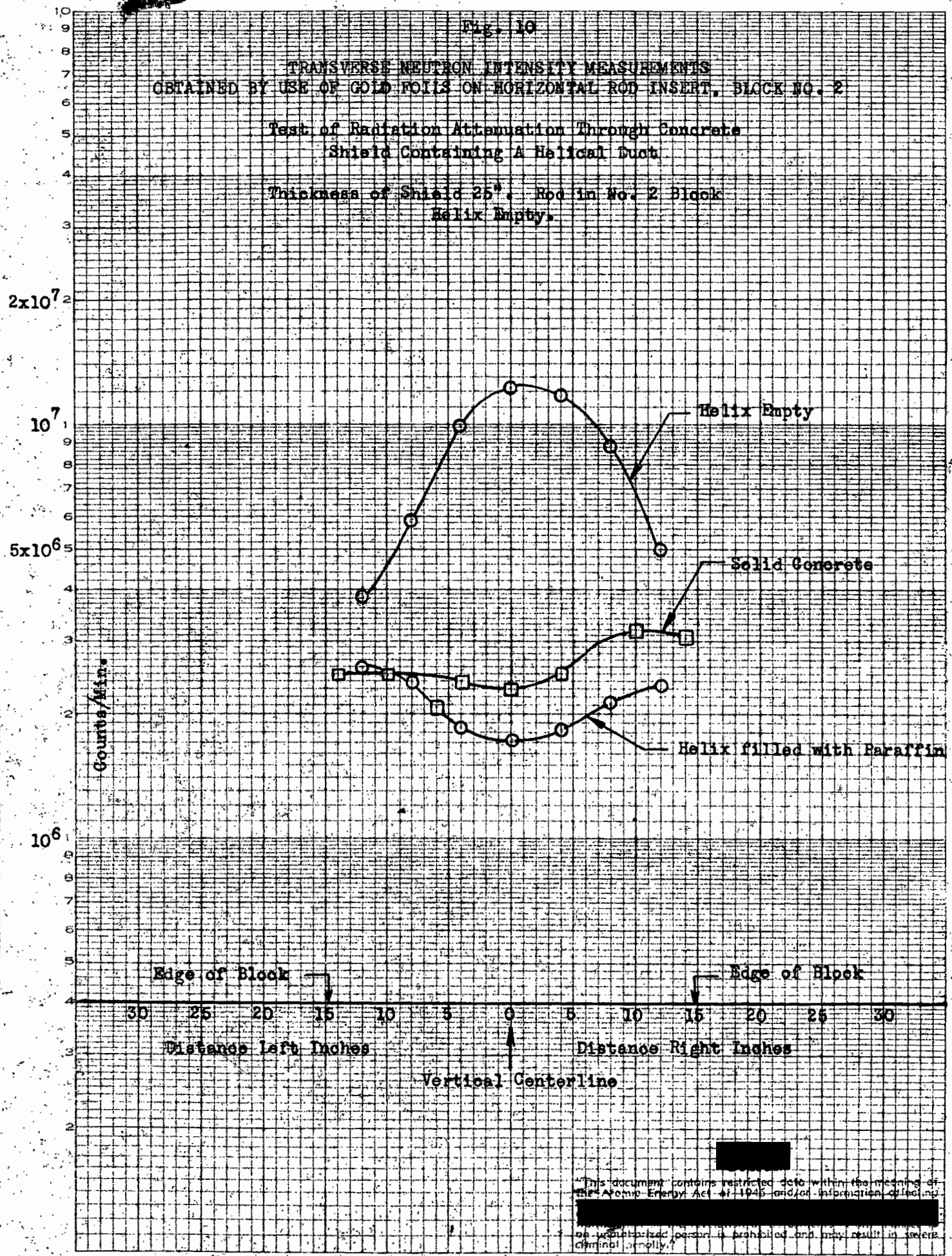

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Fig. 11

TRANSVERSE NEUTRON INTENSITY MEASUREMENTS
OBTAINED BY USE OF GOLD FOILS ON VERTICAL ROD INSERT
BLOCK NO. 2

Test of Radiation Attenuation Through Concrete*
Shield Containing a Helical Duct

Thickness of Shield 35" Rod in No. 2 Block

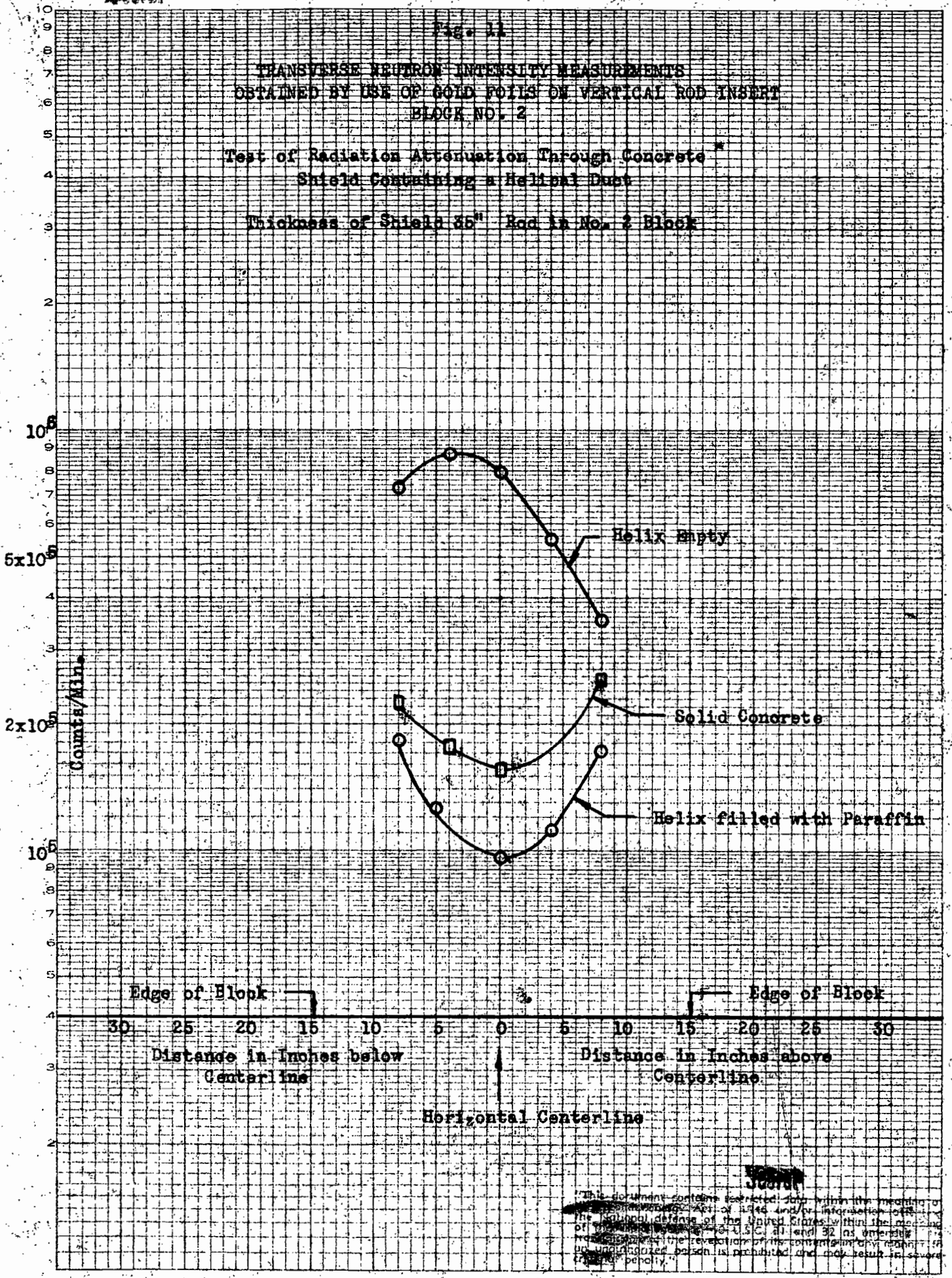

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Fig. 12

NEUTRON INTENSITY MEASUREMENTS ALONG HELIX

Test of Radiation Attenuation Through Concrete Shield Containing a Helical Duct

Thickness of Shield 84"
Length of Helix - 2 Turns in 24 Inches
Diameter of Duct - 5 Inches
Mean Diameter of Helix - 12 Inches

Legend:
● Small BF_3 Neutron Counter (Helix Empty)
○ Large BF_3 Neutron Counter, Normalized (Helix Empty) By Factor 3.75×10^{-3}
□ Gold Foil Data, Normalized (Helix Empty) By Factor 3.8×10^{-5}
△ Gold Foil Data, Normalized (Helix Filled with Paraffin) By Factor 3.18×10^{-4}

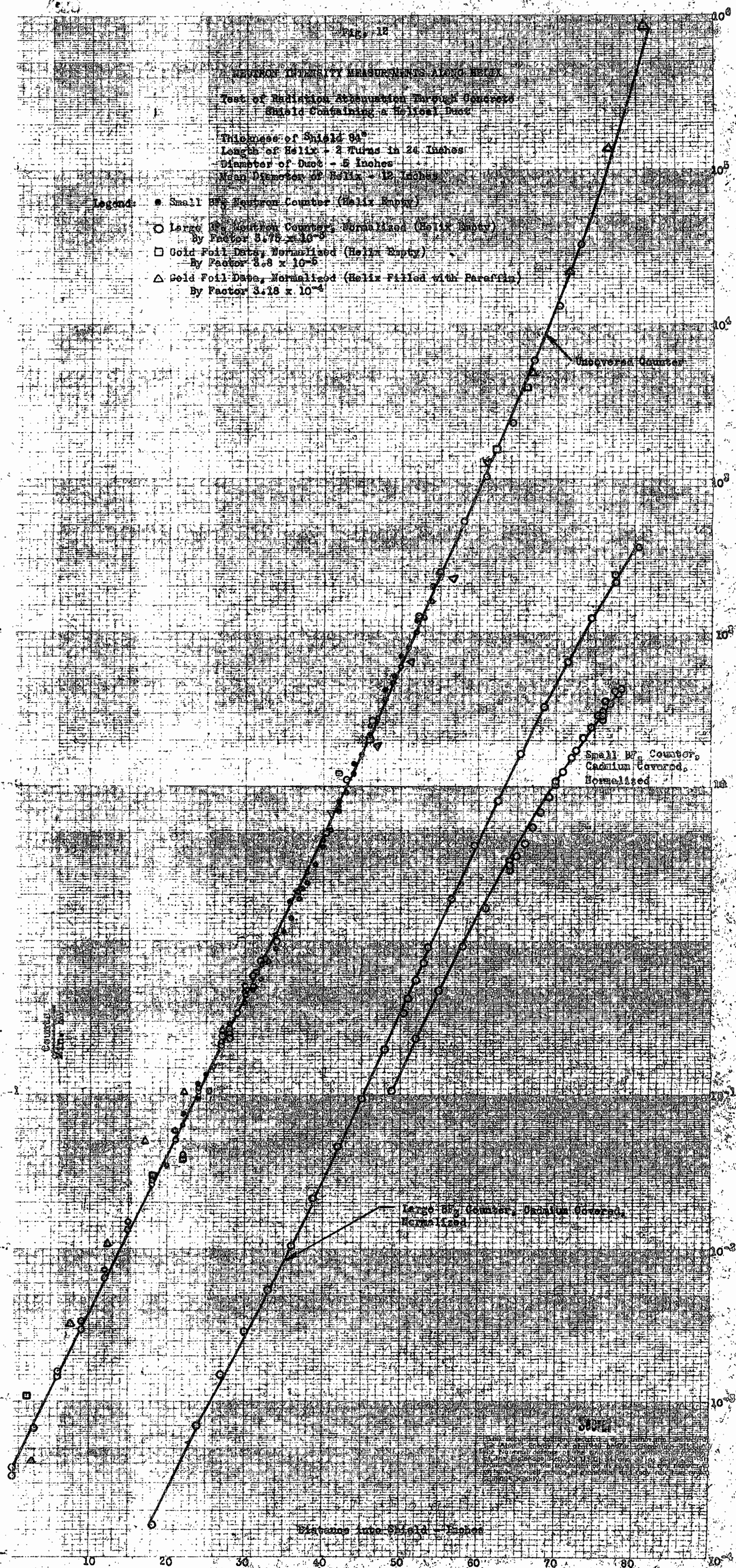

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Fig. 13

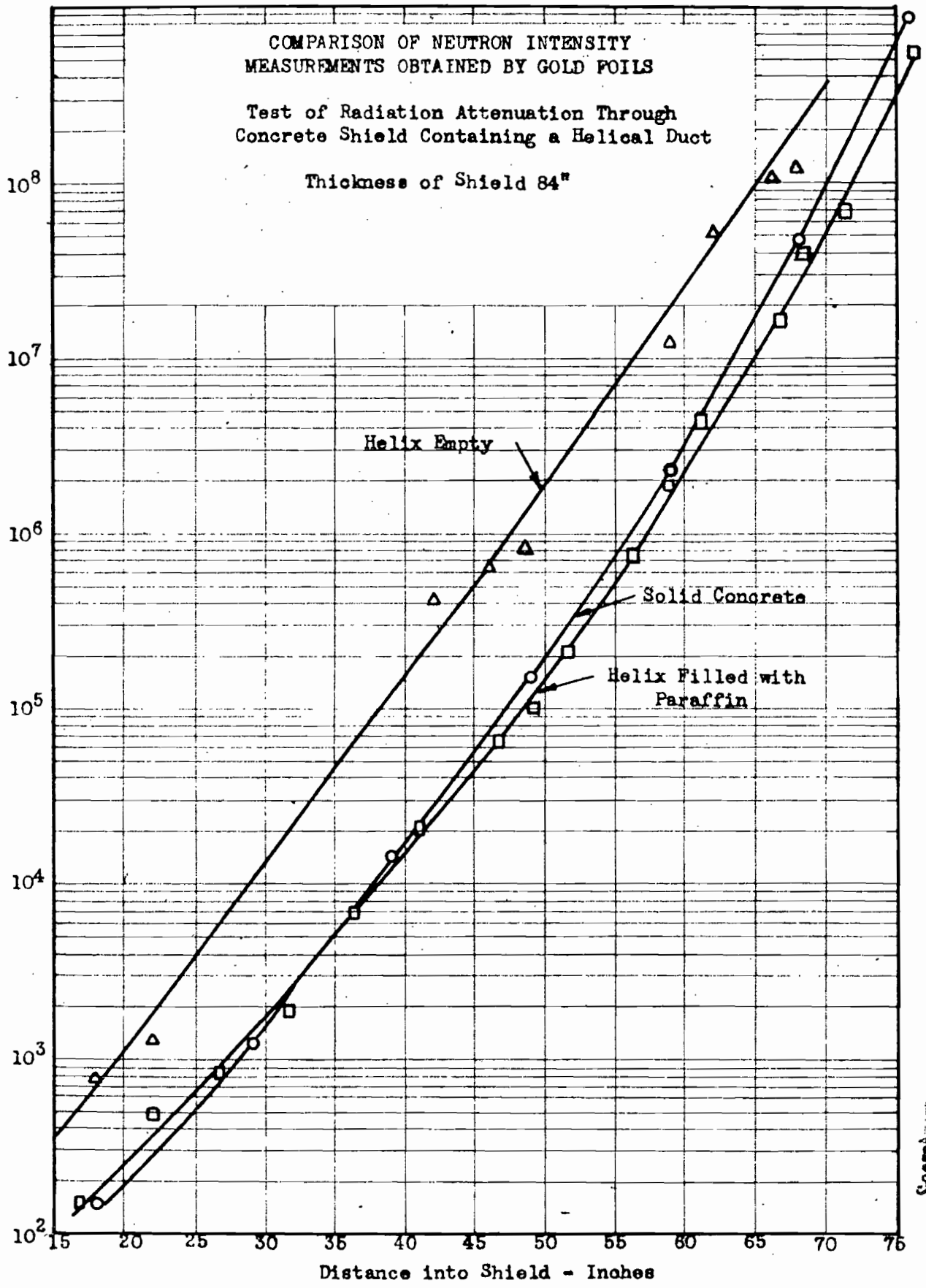

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Fig. 14

NEUTRON INTENSITY MEASUREMENTS ALONG HELIX MADE WITH EXPERIMENTAL METHANE COUNTER USING VARIOUS "PULSE HEIGHT" SELECTIONS

Test of Radiation Attenuation Through Concrete Shield Containing a Helical Duct

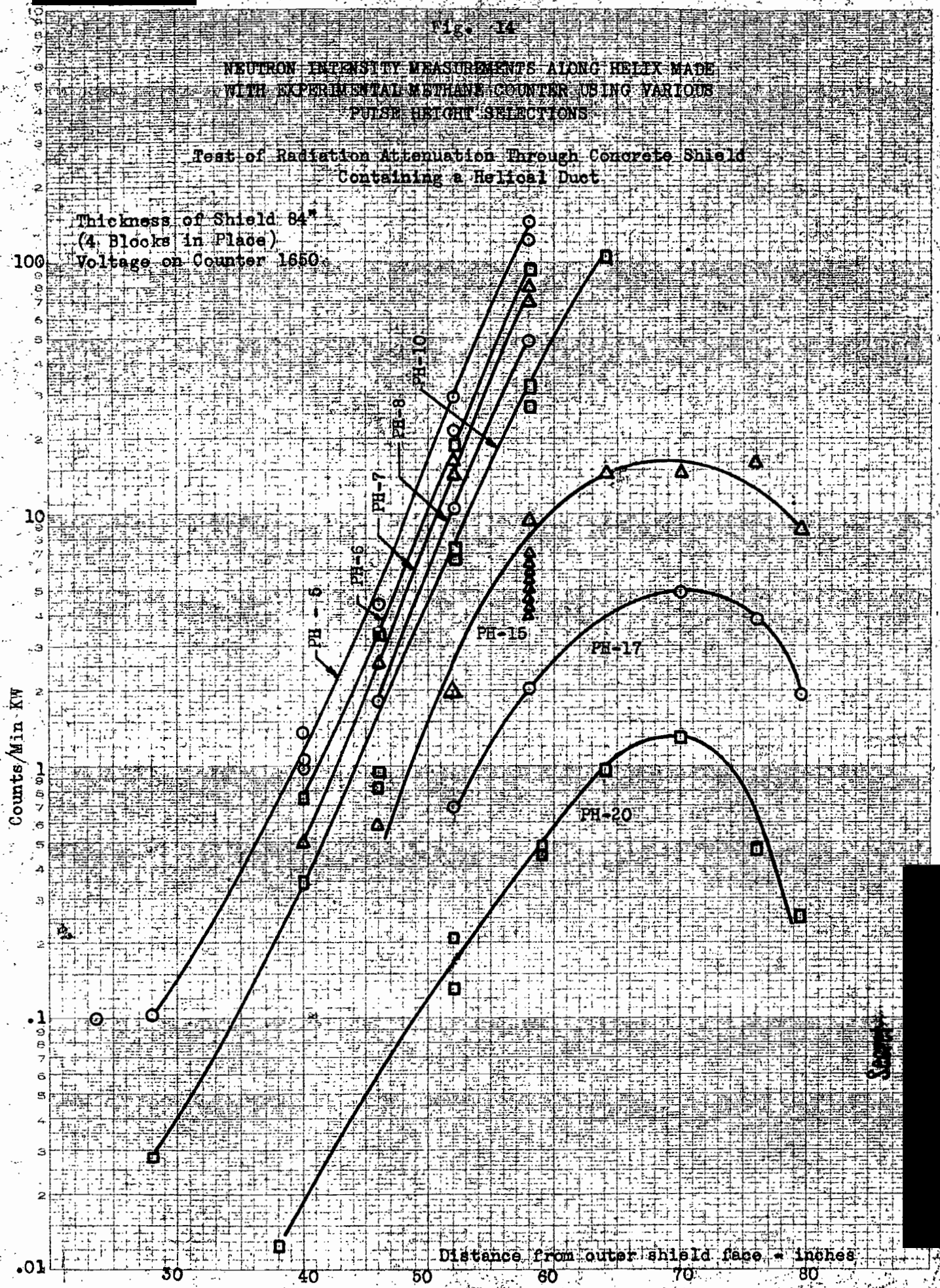

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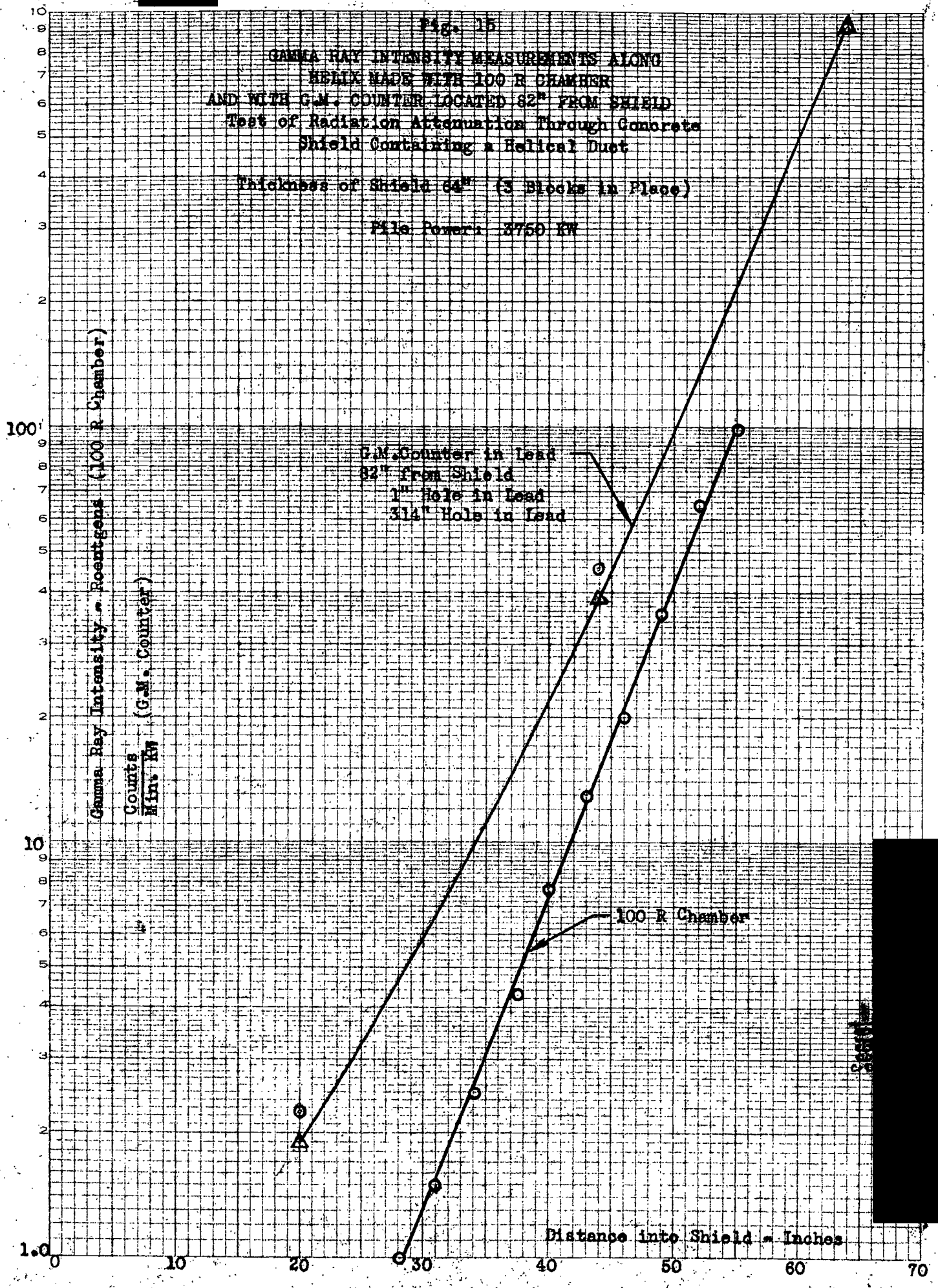
Fig. 15

GAMMA RAY INTENSITY MEASUREMENTS ALONG
HELIX MADE WITH 100 R CHAMBER
AND WITH G.M. COUNTER LOCATED 82" FROM SHIELD
Test of Radiation Attenuation Through Concrete
Shield Containing a Helical Duct

Thickness of Shield 64" (3 Blocks in Place)

Pile Power: 2750 KW



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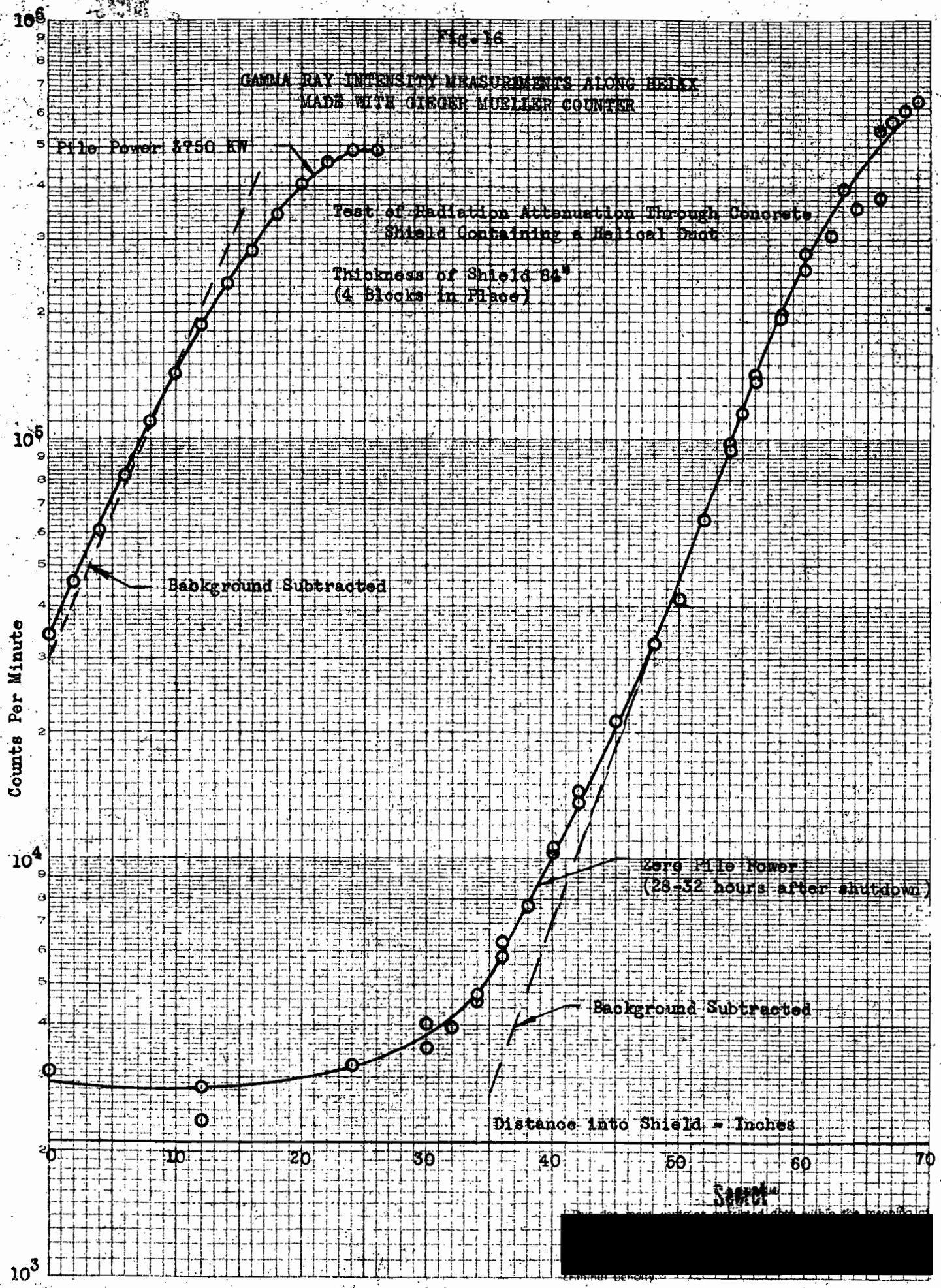

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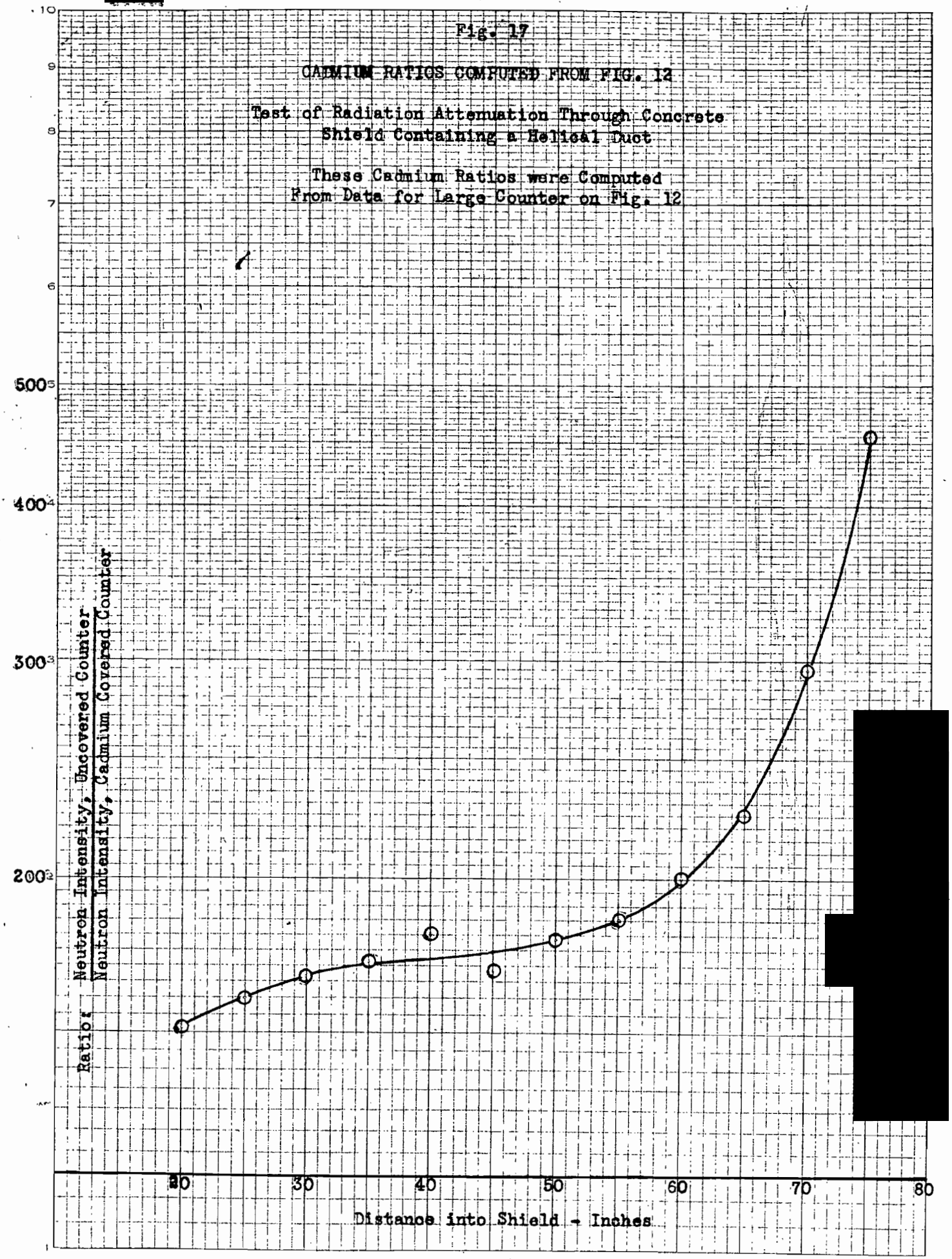
Fig. 17

CADMIUM RATIOS COMPUTED FROM FIG. 12

Test of Radiation Attenuation Through Concrete Shield Containing a Helical Duct

These Cadmium Ratios were Computed From Data for Large Counter on Fig. 12



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