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AEC RESEARCH AND DEVELOPMENT REPORT

ANALYSIS OF LID TANK NEUTRON DATA FOR LEAD AND IRON

S. PODGOR

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PHYSICS DIVISION

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S. Podgor*

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Analysis of Lid Tank Neutron Data for Lead and Iron

S. Podgor *

Abstract

An analysis of the lid tank neutron data for Pb-H_2O and Fe-H_2O is made. "Effective" fast neutron cross sections for the metals are obtained. This is based on the "one collision theory" of shielding. Values are 3.4 barns for Pb and 2.0 barns for Fe. These compare very well with those obtained by Albert and Welton based on other lid tank data and another method of calculation.

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*NEPA personnel

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I. Introduction

It was considered that an analysis of the lid tank data for Pb-H_2O and Fe-H_2O to obtain "effective" fast neutron cross sections for the metals would be very useful for shielding calculations. Such an analysis is carried out here according to a method suggested by Welton. It is based on the "one collision theory," i.e. if a collision of a fast neutron with a nucleus results in either a degradation of energy or a large angle scattering from the beam, then the neutron is considered lost from the shielding point of view. The cross section for this process is here designated as the "effective" cross section. Previous discussions have indicated that this value should lie somewhere between the inelastic scattering cross section and the total cross section.

The procedure consists of obtaining a good empirical fit to the 100% H_2O data and finding the proper metal cross section which will reproduce the metal-water attenuation data. This includes taking into consideration the geometry of the source. In this manner values were obtained for both Pb and Fe which compared quite well with those obtained by Welton and Albert[1] who made similar calculations. However their method was somewhat different, and it was based on older data, which is considered not quite as good as the present data.

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[1] WAPD - 15 - Albert and Welton

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II. Analytical Procedure

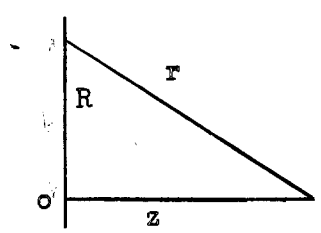
The lid tank geometry has been described fully in other reports.[2] Briefly, it consists of a circular disc fission source of 28 inches in diameter followed by a tank of water into which slabs of material can be inserted at various intervals. In order to reproduce analytically the attenuation data based on this geometry, the following procedure was adopted.

It is assumed that a point source of neutrons is attenuated in water in the following manner:

$$P(r) = \frac{A e^{-\alpha r} + B e^{-\beta r}}{4\pi r^2} \qquad (1)$$

where r is the distance in cm. from the source, and A, B, α, β are constants for the medium. This particular form is used because it is then simpler to introduce the metal attenuation into the equation later on.

When the point kernel is integrated over a disc source of radius b, we obtain at a distance of z cm. from the center of the source, the flux, $\varphi(z)$



$$\varphi(z) = \int_0^b P(r)\, 2\pi R\, dR$$

$$r^2 = R^2 + z^2, \quad 2\pi\, r\, dr = 2\pi R\, dR$$

$$\varphi(z) = \int_z^{\sqrt{z^2+b^2}} P(r)\, 2\pi r\, dr \qquad (2)$$

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[2] See for example ORNL-427, Ergen, Blizard, Clifford and Young, 10/11/49

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Inserting (1) into (2) we have

$$\varphi(z) = \frac{1}{2}\int_{z}^{\sqrt{z^2+b^2}} \left(A e^{-\alpha r} + B e^{-\beta r}\right)\frac{dr}{r}$$

$$\varphi(z) = \frac{1}{2}\left[\int_{z}^{\infty}\left(A e^{-\alpha r} + B e^{-\beta r}\right)\frac{dr}{r} - \int_{\sqrt{z^2+b^2}}^{\infty}\left(A e^{-\alpha r} + B e^{-\beta r}\right)\frac{dr}{r}\right]$$

Let $S = \alpha r$, $dr = \frac{dS}{\alpha}$, etc.

$$\varphi(z) = \frac{1}{2}\left[A\,E(\alpha z) + B\,E(\beta z)\right] - \frac{1}{2}\left[A\,E(\alpha\sqrt{z^2+b^2}) + B\,E(\beta\sqrt{z^2+b^2})\right]$$

Where $E(x) = -Ei(-x) = \int_{x}^{\infty}\frac{e^{-u}}{u}\,du$

or

$$\varphi(z) = \frac{A}{2}\left[E(\alpha z) - E(\alpha\sqrt{z^2+b^2})\right] + \frac{B}{2}\left[E(\beta z) - E(\beta\sqrt{z^2+b^2})\right] \qquad (3)$$

The right side of equation (3) is then fitted to the water data and the constants A, B, α, β are determined.

The metal attenuation is then inserted into the point kernel and the integration is very similar to the case of the 100% H_2O. Let us take y cm. of metal with a constant cross section of σ cm^{-1}. The assumption of a constant cross section appears to be reasonable in the 3-10 Mev region. The metal is put up against the source and followed by water.

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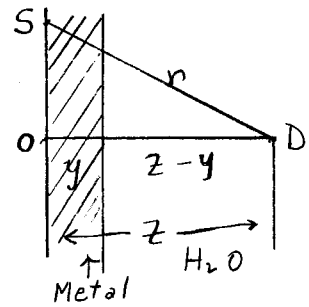
A point source of neutrons at S at a distance r from the detector D will be attenuated as follows:



$$P(r) = \left[A\, e^{-\frac{\alpha (z - y) r}{z}} + B\, e^{-\frac{\beta (z - y) r}{z}} \right] \frac{e^{\frac{-\sigma y r}{z}}}{4 \pi r^2}$$

Integrating over the disc source of radius b we have as before:

$$\varphi(z) = \int_z^{\sqrt{z^2 + b^2}} \frac{2 \pi r dr}{4 \pi r^2} \left[A\, e^{\frac{-\alpha (z - y) r}{z}} + B\, e^{-\frac{\beta (z - y) r}{z}} \right] e^{\frac{-\sigma y r}{z}}$$

$$\varphi(z) = \frac{1}{2} \int_z^{\sqrt{z^2 + b^2}} \frac{dr}{r} \left\{ A\, e^{-\frac{r}{z} [\alpha z + (\sigma - \alpha) y]} + B\, e^{-\frac{r}{z} [\beta z + (\sigma - \beta) y]} \right\}$$

Let $T = \frac{r}{z} [\alpha z + (\sigma - \alpha) y]$, etc.

Then

$$\varphi(z) = \frac{A}{2} \left\{ E\left(\alpha z + [\sigma - \alpha] y\right) - E\left(\left\{ \alpha z + [\sigma - \alpha] y \right\} \frac{\sqrt{z^2 + b^2}}{z} \right) \right.$$

$$\left. + \frac{B}{2} \left\{ E\left(\beta z + [\sigma - \beta] y\right) - E\left(\left\{ \beta z + [\sigma - \beta] y \right\} \frac{z^2 + b^2}{z} \right) \right\} \qquad (4)$$

As can be seen from the above equation, the spacing of the metal slabs in the water is not considered in this analysis. In other words, the results are the same as if all the slabs were placed together next

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to the source and then followed by the water. This is reasonable because a ray going from the source to the detector will see the same thickness of metal and H_2O, no matter how the slabs are placed between them. Of course, the analytical results have no meaning for a z smaller than the position of the last metal slab. Actually the calculated values are valid only for z's some distance beyond the last slab. This is due to the buildup of lower energy neutrons in the region of the metal, which is not taken into account in this analysis. Here the assumption is made that the fast flux of neutrons is proportional to the thermal flux.

III. Applications to Experiments

(A) Pb and H_2O -- Experiment 8

The arrangement in this particular experiment[3] was 1 in. of Pb followed by 2 in. of H_2O, with successive alternating layers of Pb and H_2O. Equation (3) was fitted to the H_2O data from $z = 80$ to 140 and the following constants were obtained:

$$\frac{A}{2} = 2.3568 \times 10^{10} \qquad \frac{B}{2} = 2.4932 \times 10^{6}$$

$$\alpha = .103 \text{ cm}^{-1} \qquad \beta = .05 \text{ cm}^{-1}$$

The following table shows a comparison between the experimental data and the analytical fit used. This is shown graphically in Figure I.

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[3] ANP Quarterly Report for May - August, 1950, ORNL-858, Nov. 29, 1950, p. 18, ff.

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z	Experimental-Counts/min.	Analytical-Counts/min.
80	4.01124×10^5	3.9545×10^5
90	1.19365×10^5	1.1814×10^5
100	3.5625×10^4	3.5877×10^4
110	1.1067×10^4	1.1172×10^4
120	3.610×10^3	3.5413×10^3
130	1.143×10^3	1.1483×10^3
140	3.92×10^2	3.8676×10^2

These fit to better than 2%, which is considered to be within the experimental error. Calculations were made using Pb cross sections, first of 3.5 barns and then of 3.4 barns. The latter value appears to fit the experimental results better for the highest values of z measured. This can be seen from Figures II, III and IV, where the analytical fit for the two values of σ are compared with the experimental values at z = 140, 130 and 120 respectively. The agreement is within 5%.

(B) Fe and Borated H_2O -- Experiment 10

In this arrangement,[4] the Fe slabs were put right up against the source and followed by the borated water. A new fit of equation (3) was made to this water data from z = 60 to 130 and the following constants were obtained:

$$\frac{A}{2} = 5.7000 \times 10^9 \qquad \frac{B}{2} = 4.4588 \times 10^6$$

$$\alpha = .11 \text{ cm}^{-1} \qquad \beta = .06 \text{ cm}^{-1}$$

[4]ANP Quarterly Report for Sept. - Nov., 1950, ORNL-919

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The table shows the comparison between experimental and analytical values. It is shown graphically in Figure V.

z	Experimental	Analytical
60	7.40247×10^5	7.3951×10^5
70	1.99753×10^5	2.0008×10^5
80	5.4668×10^8	5.5619×10^4
90	1.6038×10^4	1.5885×10^4
100	4.692×10^3	4.6791×10^3
110	1.455×10^3	1.4330×10^3
120	4.693×10^2	4.5987×10^2
130	1.480×10^2	1.5581×10^2

This fits to about 2% except for the last point at z = 130 to 5%. But that is not important because not more than about 120 cm of H_2O is used with the Fe slabs.

A reasonable value of σ for Fe appeared to be 2.0 barns, and that was used in equation (4). It seemed to give good overall agreement with the experimental results, as shown in Figure V. For the highest z's the agreement is roughly within 5%; however two or three points are off by at most 10%.

V. Discussion of Results

The agreement of the present results with those of Albert and Welton[1] is very good in view of the different methods of calculation and the different experimental results used. For the Pb they obtain 3.6 barns, we 3.4 barns, or a difference of 5 to 6%. This is not

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considered excessive. For Fe, we both obtain 2.0 barns.

However the results are not in as good agreement with those obtained by an analysis[5] of data from the core hole shield testing facility. Actually the latter were considered quite tentative at the time they were issued.

A discussion giving a qualitative theoretical justification for these "effective" cross sections is given by Welton in the TAB report.[6]

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[5]Sleeper, H. P. - ORNL-436, p. 18, Dec. 21, 1949

[6]ANP-52 - Report of the TAB to the Technical Committee of the ANP Program, August 4, 1950, p. 171

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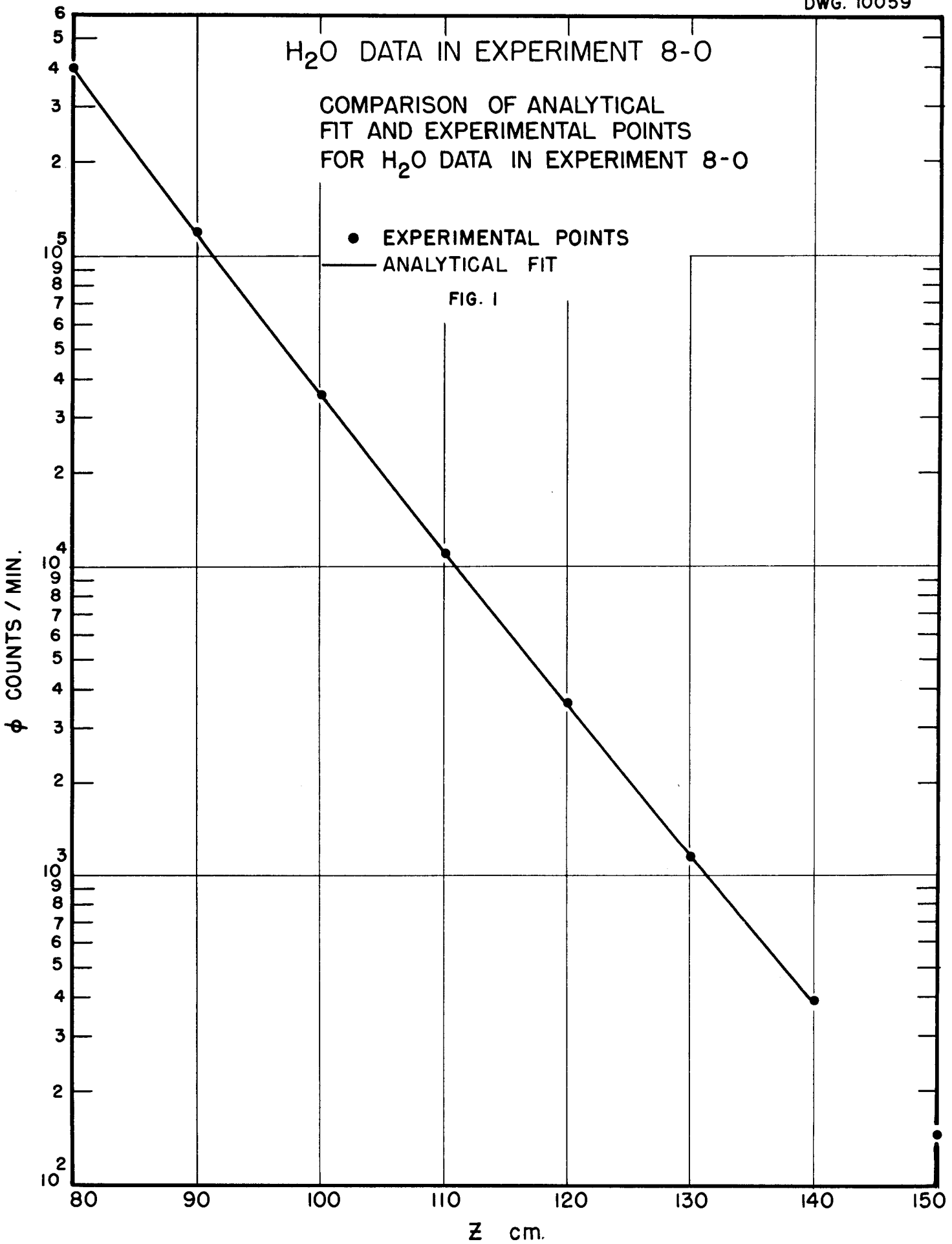

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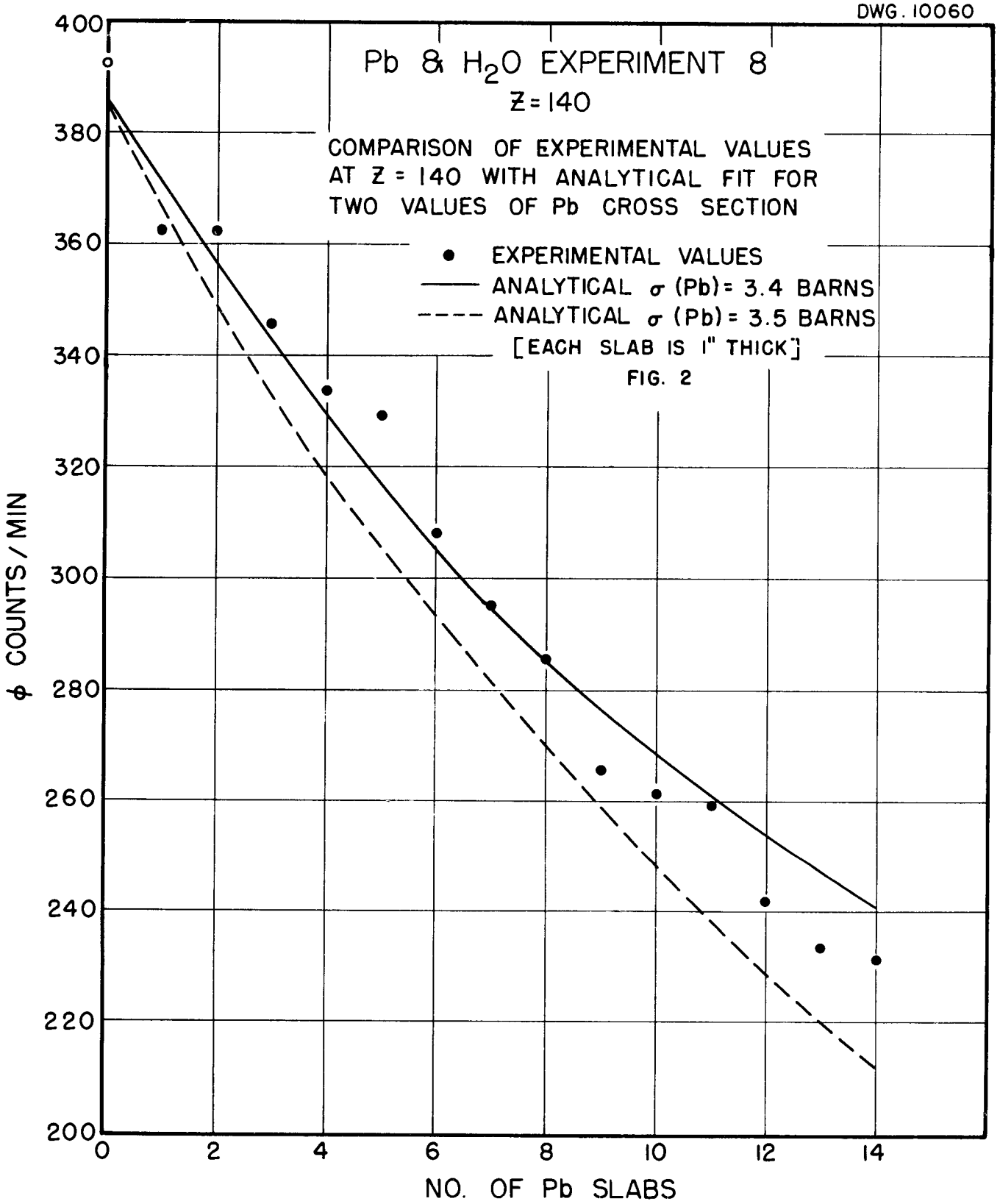

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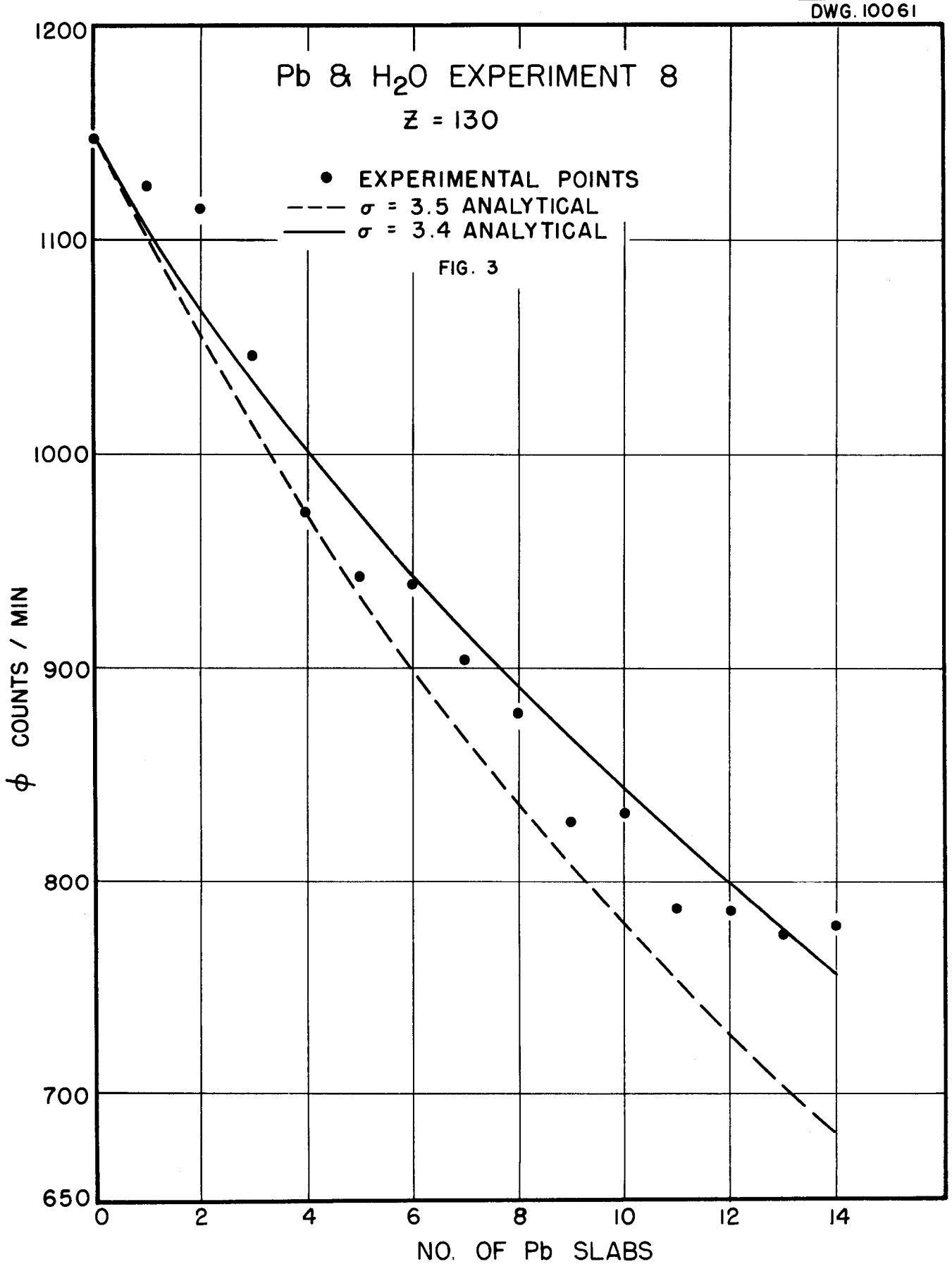

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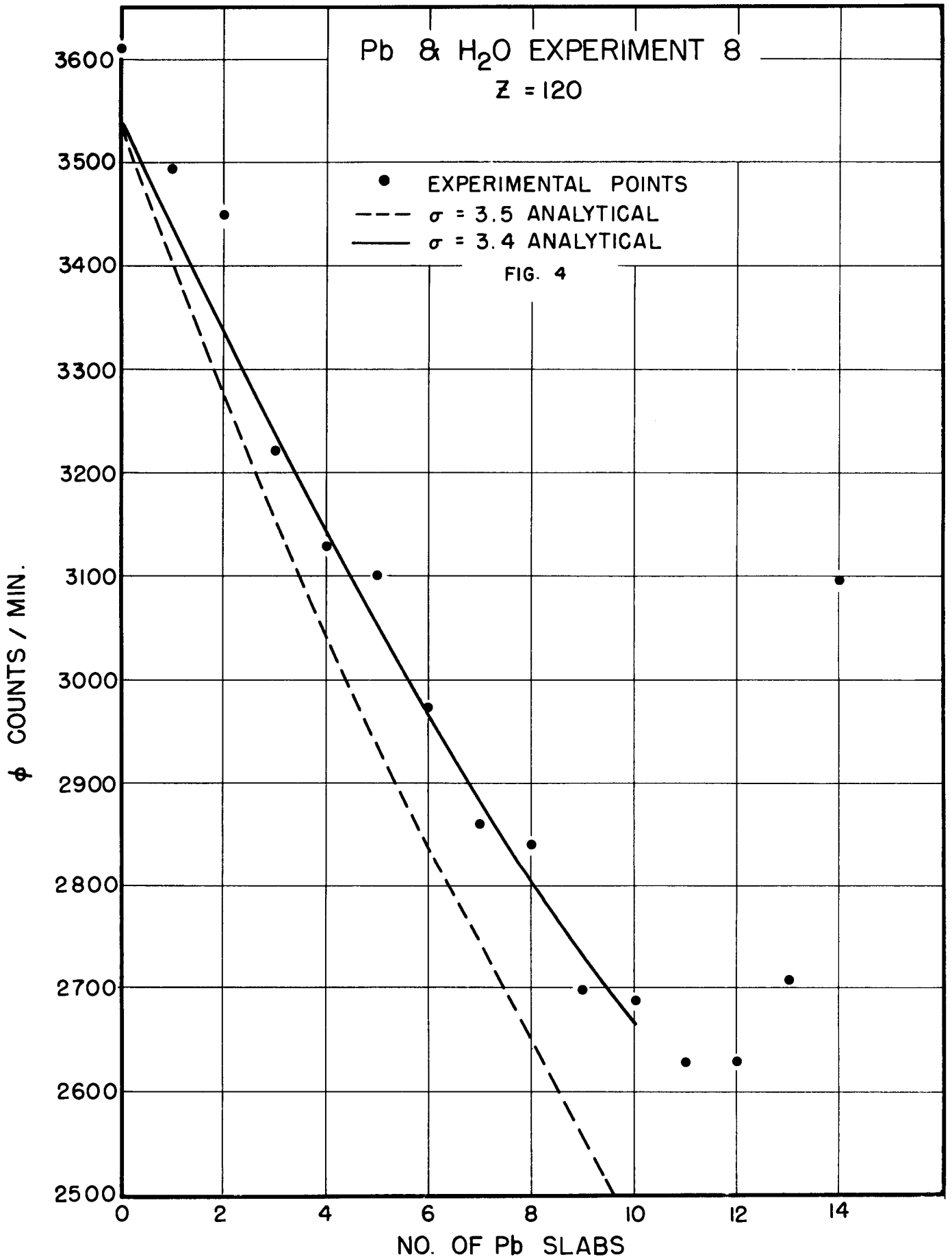

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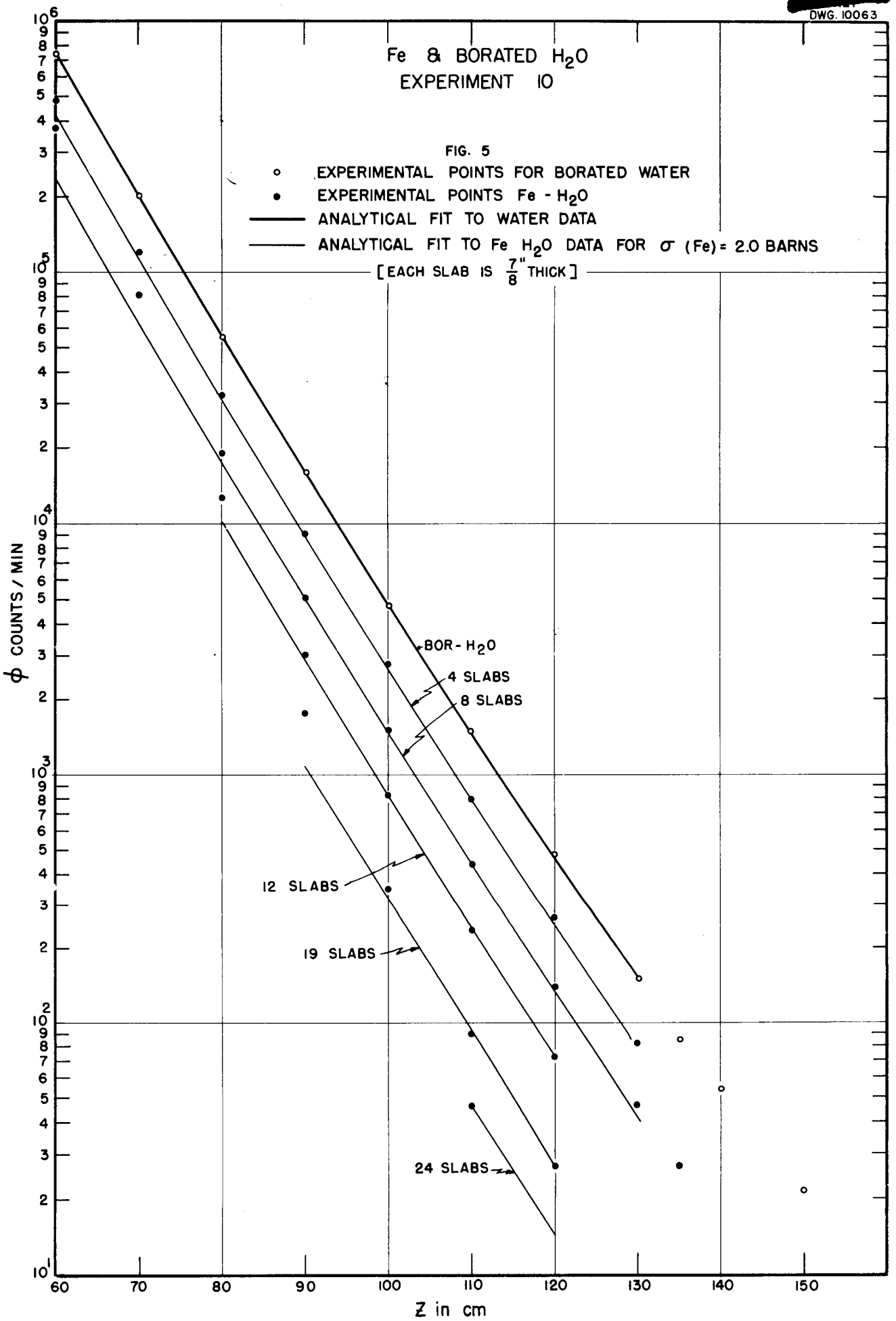
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