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DETERMINATION OF SHIELD REQUIREMENTS FOR A 4-INCH SQUARE STRAIGHT HOLE THROUGH THE ORNL SHIELDS

R. L. CLARK
J. D. FLYNN
C. E. CLIFFORD

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Technical Division

Section IV, Engineering Materials

R. N. Lyon, Section Chief

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Operated By
Carbide and Carbon Chemicals Corporation
For The
Atomic Energy Commission
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Oak Ridge, Tennessee

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ABSTRACT

Measurements were made of fast and thermal neutrons, and of gamma radiation, streaming through a four-inch square straight hole (#61-S) through the ORNL reactor and shield. The hole was covered with slabs of lead, paraffin, and "boroffin" (paraffin - B_2O_3 mixture), in various arrangements. The following conclusions are drawn:

1) The minimum shield thickness to reduce all radiation to 8-hour operating tolerance is twenty-two inches.

2) The presence of boron has a small, but worthwhile, effect on the gamma attenuation.

3) The arrangement resulting in minimum weight and cost consists of four four-inch layers of boroffin, separated by three two-inch layers of lead. Moving the lead further into the shield increases appreciably the production of secondary gamma radiation in the shield.

4) Nearly equal neutron shielding is required in all directions, i.e. scattering in the paraffin causes the hole to appear almost as an isotropic point source, requiring a hemispherical shield.

[redacted]

Measurements were made at hole 61-south in the ORNL pile to determine the minimum thickness of a blister-type shield to be used in connection with the installation of a new type radioisotope stringer. This would require an empty hole extending through the shield and pile. This experiment was intended to determine only a first approximation of the best thin shield design for such an empty hole.

It was assumed that the thinnest shield feasible from an economic point of view would consist of lead, paraffin and boron. These materials in the form of lead bricks and slabs of paraffin some of which contained B_2O_3 were used in the various geometries shown in Figures I, II, and III.

The radiation measurements were taken with the following instruments and methods:

A. Thermal neutrons
   (1) BF_3 proportional counter, behind various shield thicknesses.
   (2) Differential readings from a calibrated boron-coated Lauritsen electroscope, behind the full thickness of shield.
   (3) Indium foils, placed within the paraffin portion of the shield.

B. Fast Neutrons
   (1) A portable methane proportional counter, quantitatively calibrated with a secondary-standard polonium-beryllium source.
   (2) A differential methane-filled ion chamber (Chang & Eng).

C. Gamma intensity
   (1) Lauritsen electroscope.
   (2) Portable ion chamber (cutie pie).

The authors wish to acknowledge the assistance of Messrs. G. S. Hurst and P. W. Reinhardt in supplying and operating the calibrated fast neutron counters.

Materials and Fabrication

The lack of space around hole 61-S limited the size of the test slabs to 24 inches square. A set of slabs containing 7% (wt.) boron in the form of

B_2O_3* was made to determine the effectiveness of boron in reducing secondary gamma production.

In preparing the pure paraffin slabs, the paraffin was melted and poured into wooden forms coated with form oil, and allowed to cool, with further additions to take care of shrinkage.

For the boroffin slabs, a 1/4 inch layer of liquid paraffin was poured into the forms and allowed to cool slightly. More paraffin was then poured into the forms and while it was still molten, 20% by weight of finely ground B_2O_3 was added and the mixture stirred until the paraffin cooled enough to hold the B_2O_3 in suspension. After this mixture had cooled, it was covered again with molten paraffin.

Twenty-two 2" slabs were prepared, half of which contained the B_2O_3 mixture. The lead layers were built up of 2" x 4" x 8" lead brick, after the paraffin was in place over the hole.

Procedure

Three tests were made to determine the intensity of the radiation transmitted through various arrangements of the lead and paraffin slabs.

Indium foils were placed on three slabs in the first test to give a map of the thermal flux in the paraffin, and in all tests measurements were taken with the other instruments directly behind the full shield on a line with the axis of the hole.

The first test, a measurement through paraffin only, was made to determine the minimum thickness of hydrogenous material required to attenuate the fast neutron flux to safe operating levels (i.e., 100 n/cm.^{2}/sec.). Figure I gives the arrangement of the slabs with respect to the hole.

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*Christened "boroffin" by Clark Goodman of MIT.

The data are presented in Figures 4 through 8. Figure 4, giving the distribution of thermal neutron flux in the first test, is presented to indicate the scattering of the initial beam. It is evident from this figure that the size of the paraffin slabs was too small. A suitable shield would have to give approximately the same attenuation in all directions; i.e., a hemisphere of approximately 22 inch radius. Figures 5 and 6 give the indium foil measurements down the centerline of the paraffin (along the axis of the hole) and also the horizontal and vertical traverses from which the data for Figure 4 were obtained.

Figure 7 presents fast neutron data behind the various arrangements of shielding. The first test indicated that 16 inches of paraffin and more than 4 inches of lead were required to attenuate the fast neutron flux and the gamma intensity to a safe level. The second test (Figure 2) was made to determine the effect on the gamma attenuation of borating the paraffin and moving the lead close to the inner portion of the shield. The boron was introduced to reduce the production of secondary gamma from the capture of neutrons within the shield itself. The data presented in Figure 8 indicates that some reduction was obtained in the gamma transmission of the shield by the introduction of the boron. It was found that an additional 2 inches of lead were required over the amount present in test 2 to reduce the gammas to below safe operating level (i.e., 5MR/hr.); hence a third test (Figure 3) was done with 6 inches of lead.

Optimizing Weight and Cost

If the shield were arranged with all of the boroffin on the inside and the lead outside, the six-inch-thick hemispherical shell of lead would weigh 5600 lbs. and cost more than $1500 (>90% of the total shield cost). These figures could be drastically reduced if the lead were moved inward and the boroffin it replaces

moved to the outside. But previous experiments with lead and borated hydrogenous material showed that if the lead is moved in to a point where the neutron flux is commensurate with the gamma flux, then the production of secondary gammas in the lead becomes appreciable. One arbitrary but reasonable way of preventing this, is to precede every tenth-thickness of lead with a tenth-thickness of boroffin. In this case, such a shield would consist of four four-inch shells of boroffin, separated by three two-inch shells of lead. This reduces weight and cost to one-half, without increasing the desired minimum thickness. Further decrease in weight and cost could probably be effected if one were willing to increase the total shield thickness.

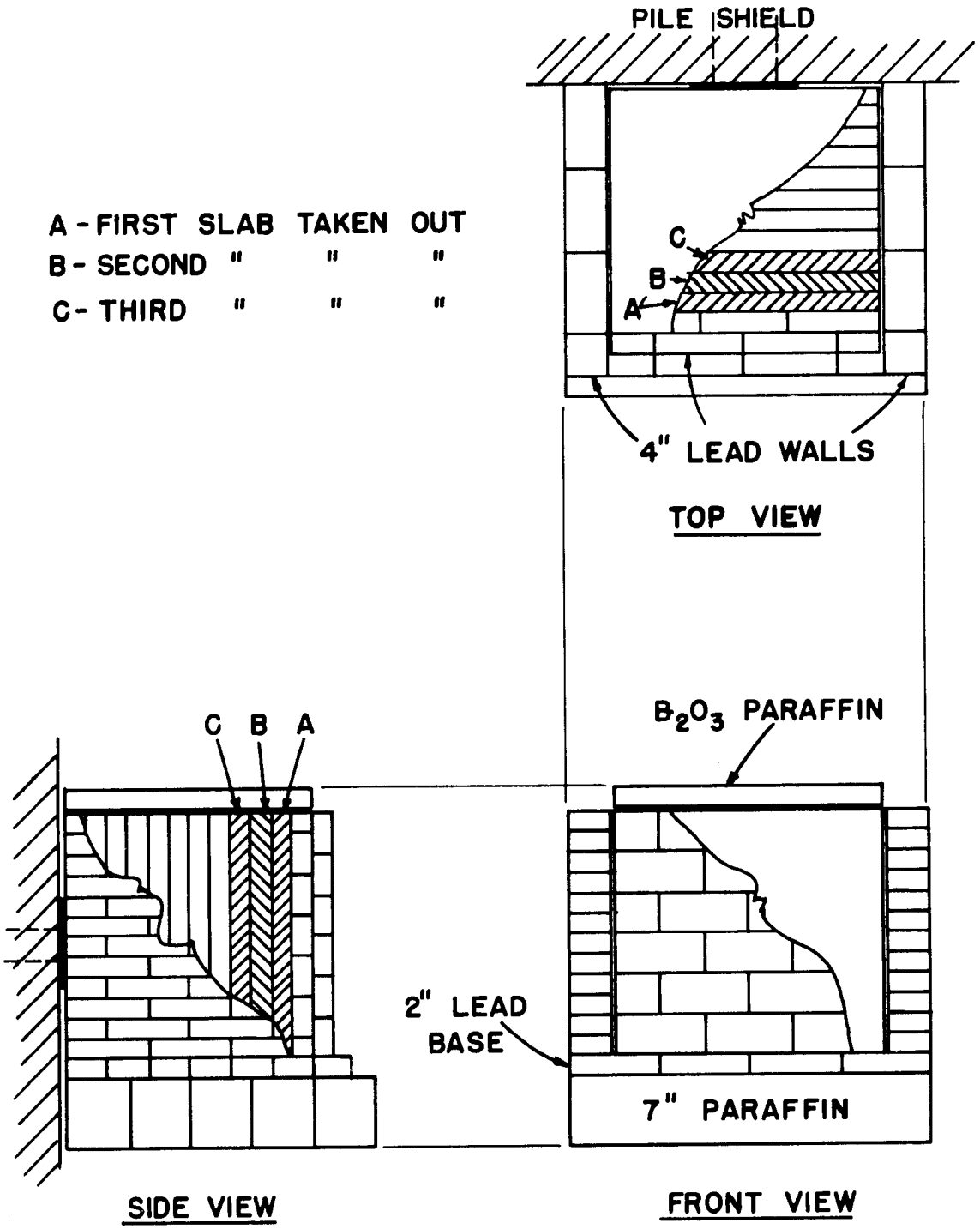
PILE SHIELD
A - FIRST SLAB TAKEN OUT
B - SECOND " " "
C - THIRD " " "
C
B
A
4" LEAD WALLS
TOP VIEW
C B A
B_2O_3 PARAFFIN
2" LEAD BASE
7" PARAFFIN
SIDE VIEW
FRONT VIEW

FIGURE # 1

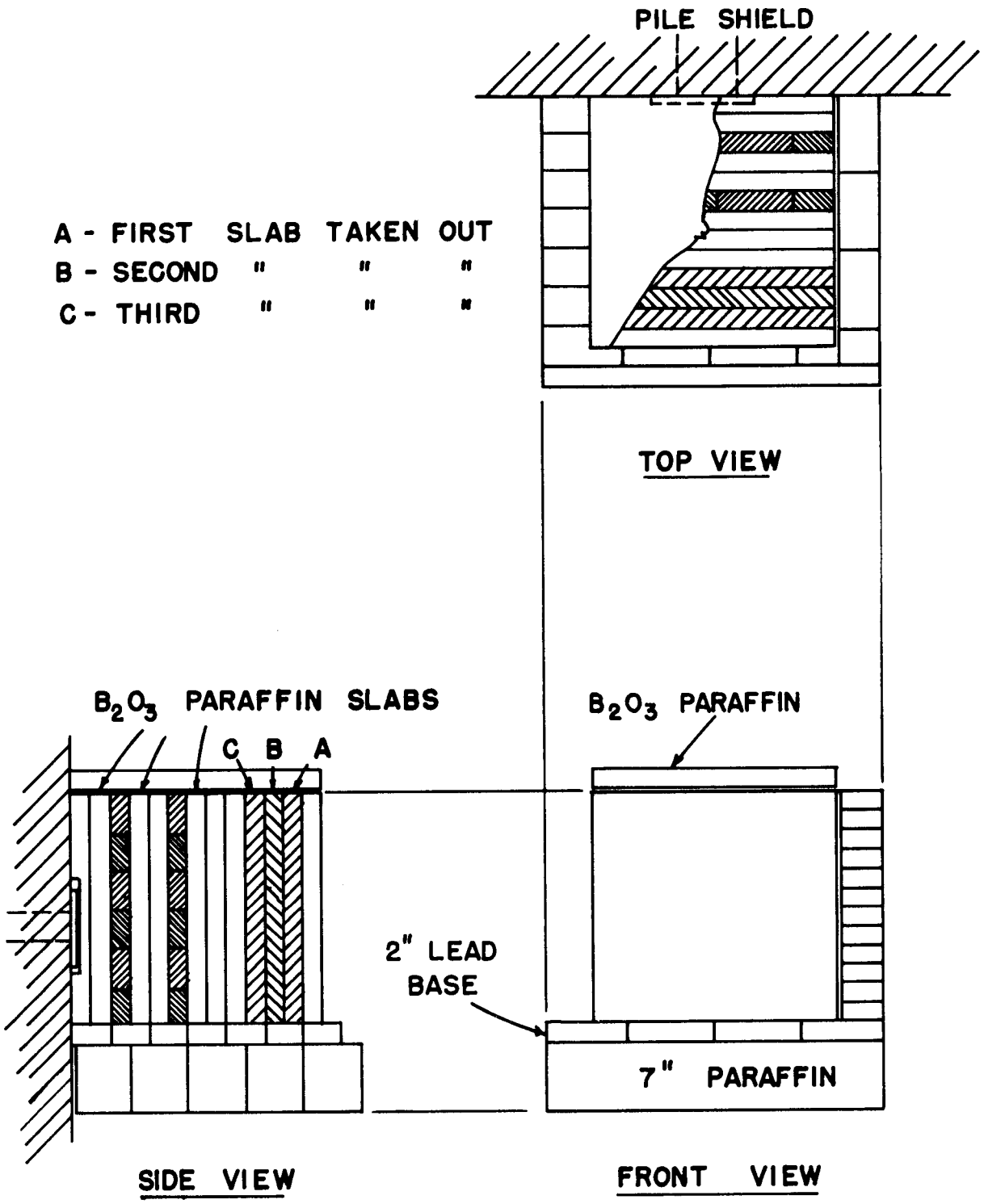
PILE SHIELD
A - FIRST SLAB TAKEN OUT
B - SECOND " " "
C - THIRD " " "
TOP VIEW
B_2O_3 PARAFFIN SLABS
C B A
B_2O_3 PARAFFIN
2" LEAD BASE
7" PARAFFIN
SIDE VIEW
FRONT VIEW

FIGURE #2

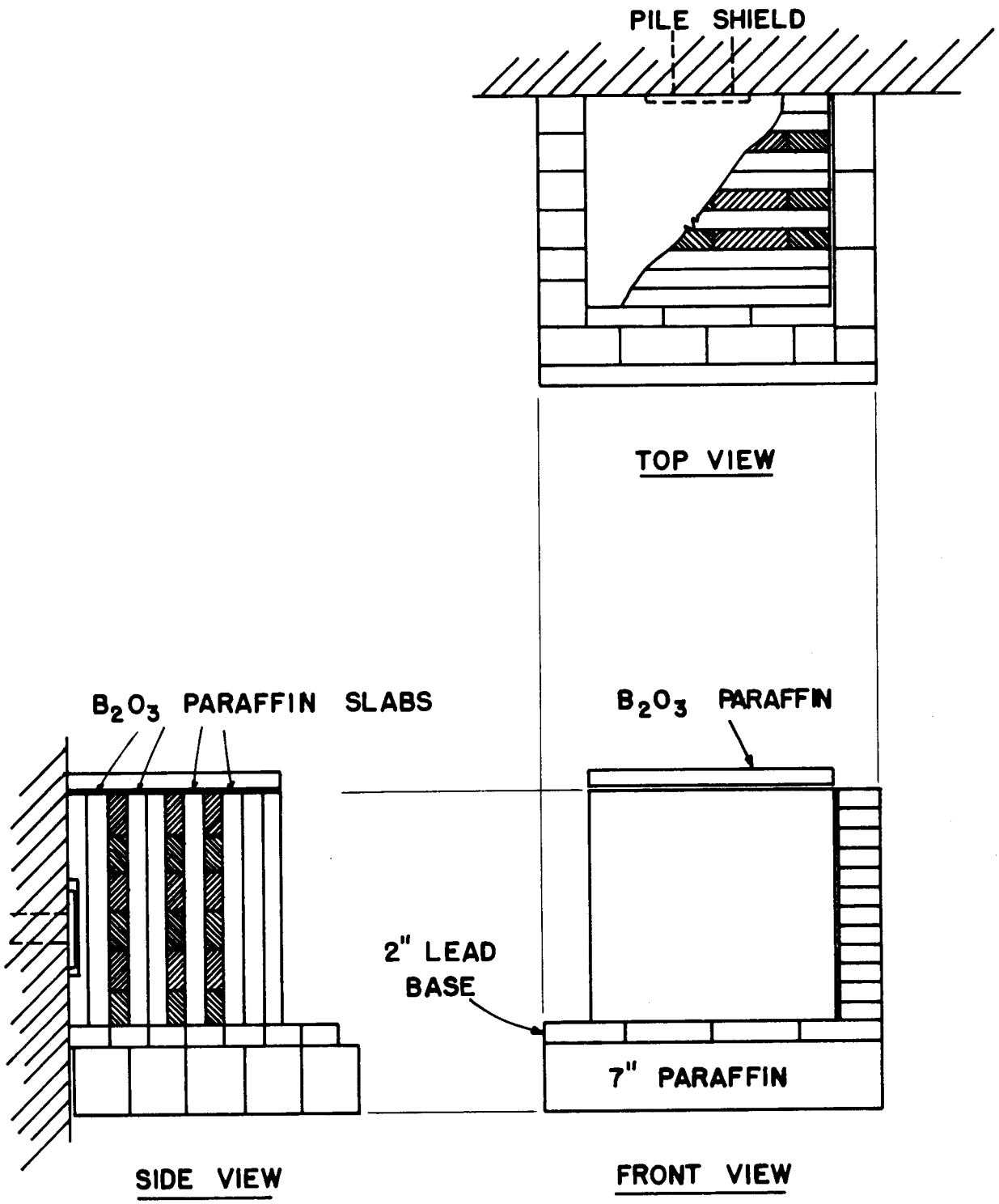
PILE SHIELD
TOP VIEW
B_2O_3 PARAFFIN SLABS
B_2O_3 PARAFFIN
2" LEAD BASE
7" PARAFFIN
SIDE VIEW
FRONT VIEW

FIGURE # 3

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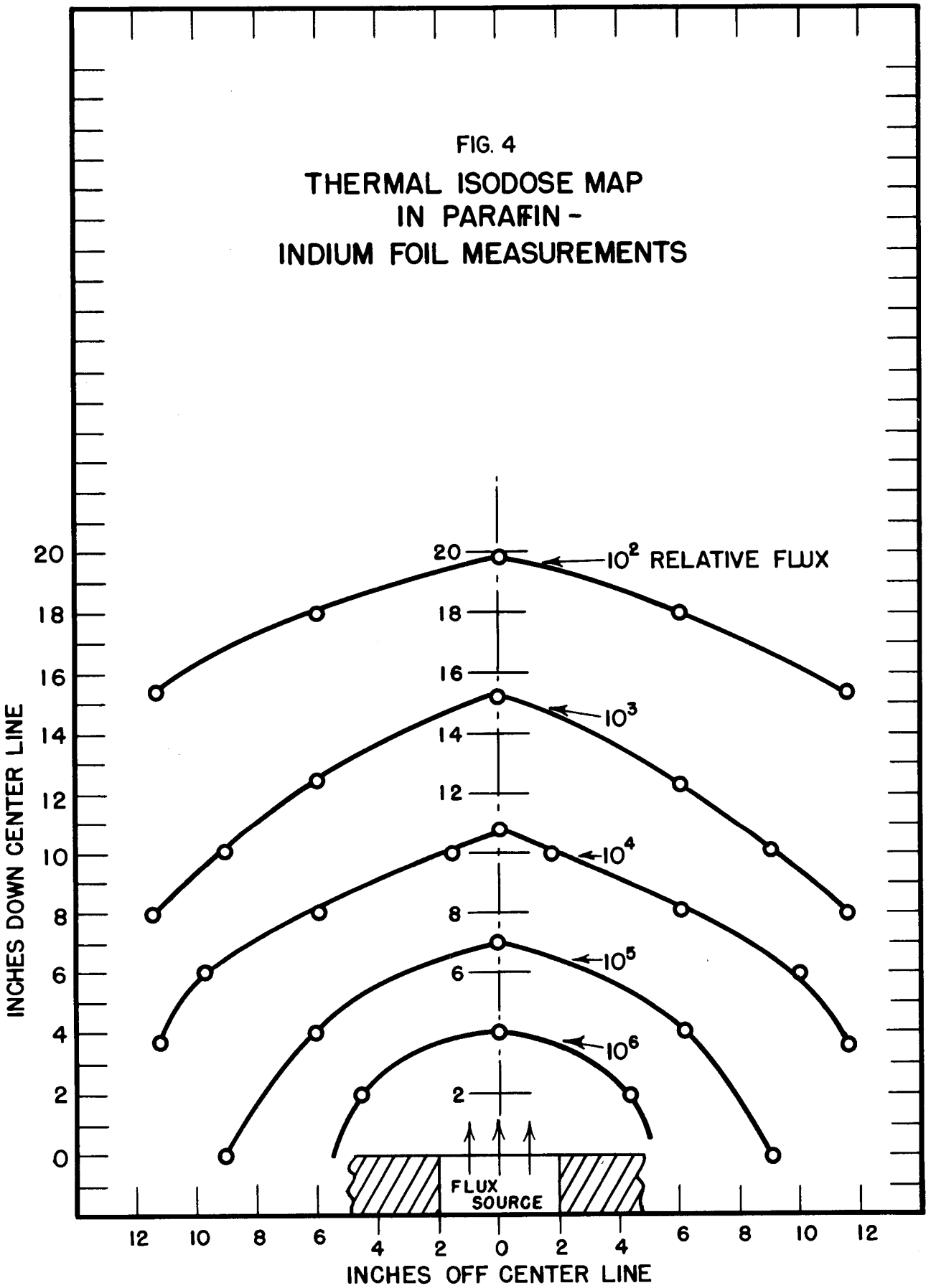


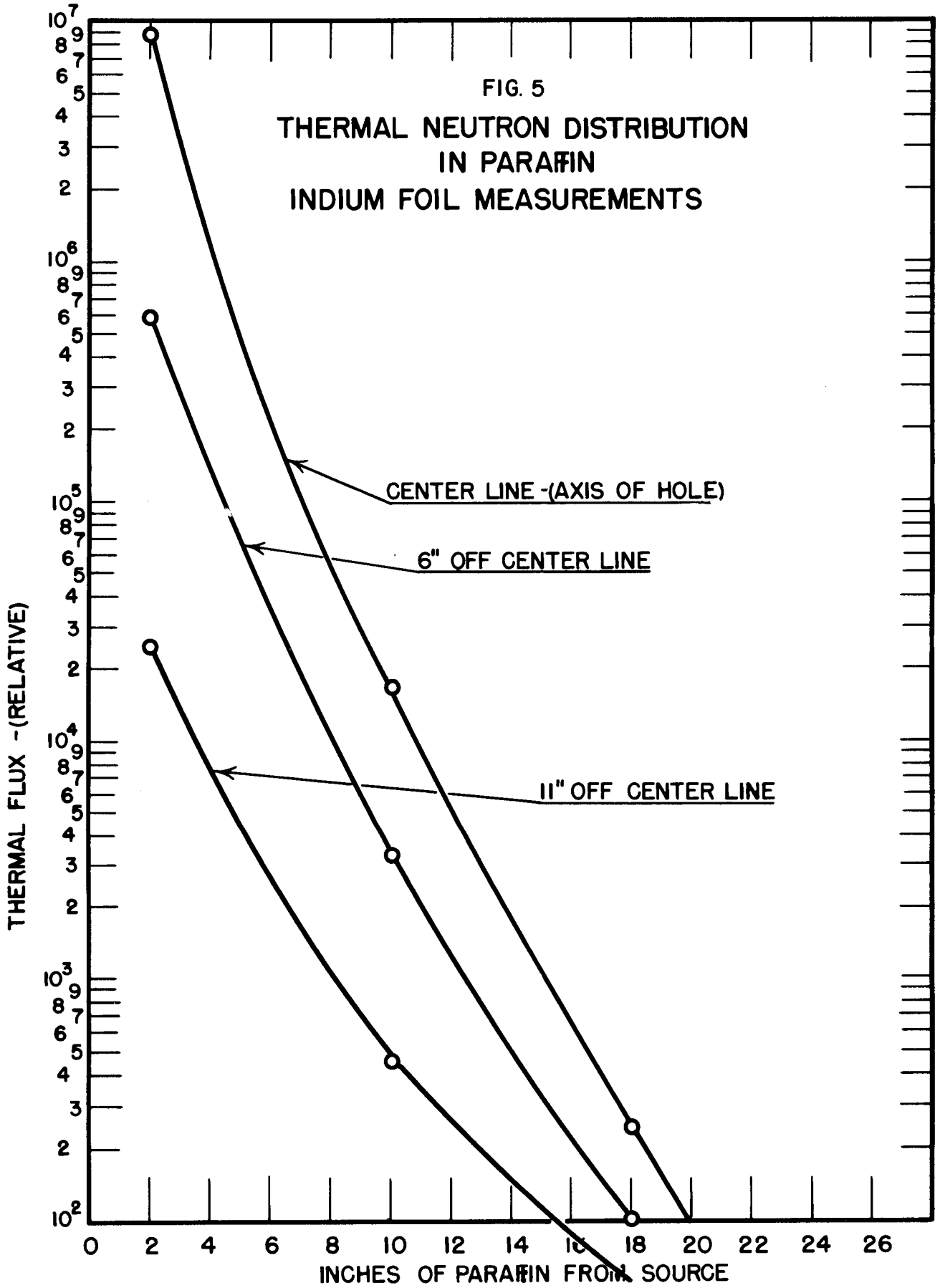
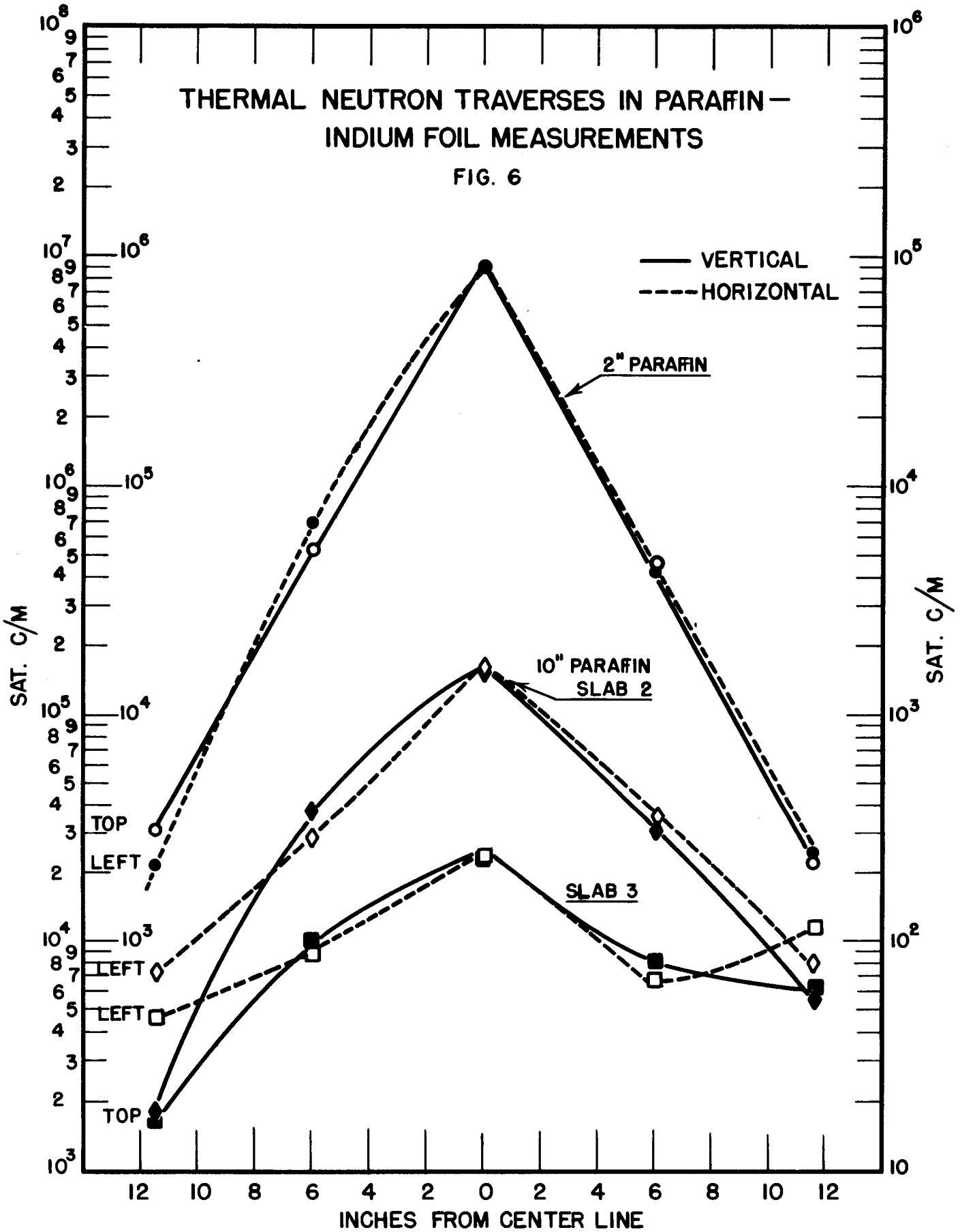


FIG. 5
THERMAL NEUTRON DISTRIBUTION
IN PARAFFIN
INDIUM FOIL MEASUREMENTS
CENTER LINE -(AXIS OF HOLE)
6" OFF CENTER LINE
11" OFF CENTER LINE
THERMAL FLUX -(RELATIVE)
INCHES OF PARAFFIN FROM SOURCE
0
2
4
6
8
10
12
14
16
18
20
22
24
26
10^2
10^3
10^4
10^5
10^6
10^7

[redacted]


THERMAL NEUTRON TRAVERSES IN PARAFFIN—
INDIUM FOIL MEASUREMENTS
FIG. 6
VERTICAL
HORIZONTAL
2" PARAFFIN
10" PARAFFIN
SLAB 2
SLAB 3
TOP
LEFT
LEFT
LEFT
TOP
SAT. C/M
SAT. C/M
INCHES FROM CENTER LINE
12 10 8 6 4 2 0 2 4 6 8 10 12

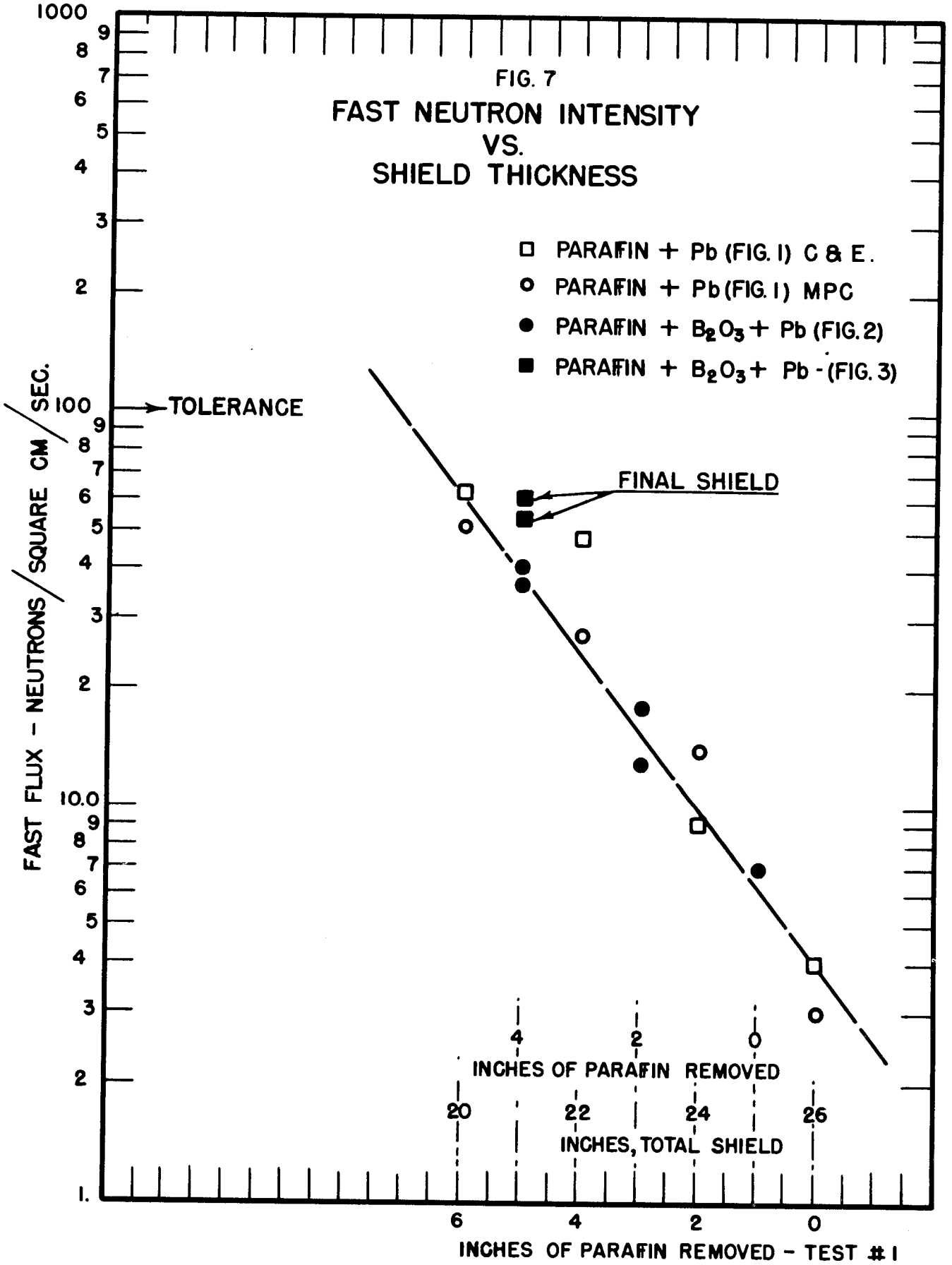


FIG. 7
FAST NEUTRON INTENSITY
VS.
SHIELD THICKNESS
PARAFFIN + Pb (FIG. 1) C & E.
PARAFFIN + Pb (FIG. 1) MPC
PARAFFIN + B_2O_3 + Pb (FIG. 2)
PARAFFIN + B_2O_3 + Pb - (FIG. 3)
TOLERANCE
FINAL SHIELD
FAST FLUX - NEUTRONS / SQUARE CM / SEC.
1000
100
10.0
1.
INCHES OF PARAFFIN REMOVED
INCHES, TOTAL SHIELD
INCHES OF PARAFFIN REMOVED - TEST #1

[redacted]

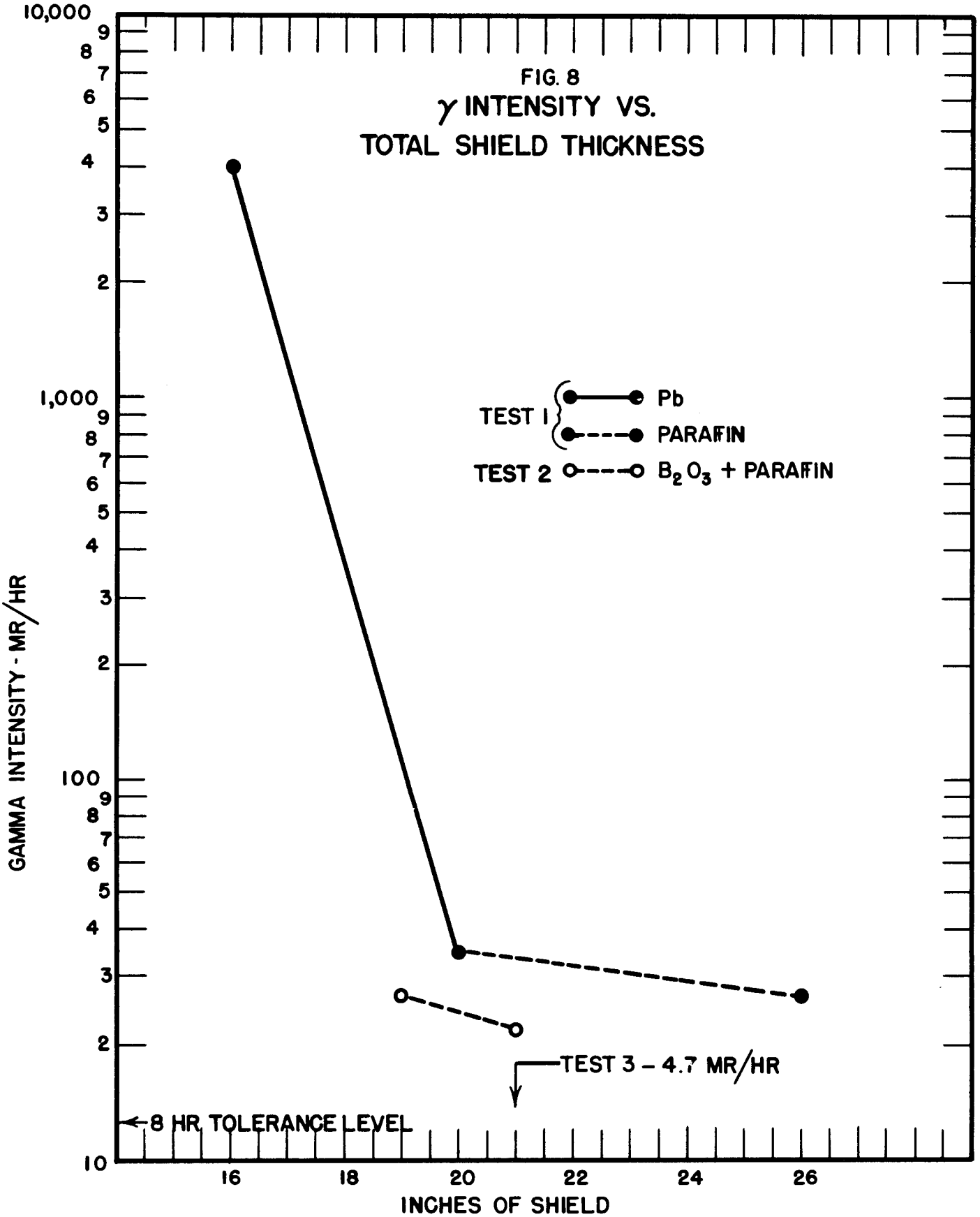


FIG. 8
γ INTENSITY VS.
TOTAL SHIELD THICKNESS
TEST 1
Pb
PARAFFIN
TEST 2
B_2O_3 + PARAFFIN
TEST 3 – 4.7 MR/HR
8 HR TOLERANCE LEVEL
GAMMA INTENSITY - MR/HR
INCHES OF SHIELD
10,000
1,000
100
10
16
18
20
22
24
26