[redacted]

CP 2602
G Copy 1A -

Contract No. W 7405 - eng. 39

* * * * * * * *

Section I

A. H. Snell, Section Chief

DECLASSIFIED Per Letter Instructions Of T.I.D.-1065
M.S. for M.T. Bracy
5/27/54 SUPERVISOR LABORATORY RECORDS
ORNL

FINAL REPORT

NEUTRON DISTRIBUTION IN THE CLINTON PILE

PROBLEM ASSIGNMENT NO. 106-X38P

* * * * * * * *

Haydn Jones
L. B. Watson
T. Arnette
I. Coveyou

This document has been approved for release to the public by:

David R. Hamrin 2/6/95
Technical Information Officer Date
ORNL Site

February 27, 1945.

Series A Received 4/14/45 Series A Issued 4/14/45
Series B Received _____ Series B Issued _____

[redacted]

[redacted]

[redacted]

ABSTRACT

Several of the experimental holes of the Clinton pile have been scanned using Ag wires. From these the relative neutron densities throughout the pile have been determined roughly to be

$$\rho = 0.88 \cos \frac{\pi (r + .338)}{23.83} \cos \frac{\pi (x + .172)}{19.8}$$

where r is the radial displacement and x is the displacement along the axis in feet.

A direct calibration against the "Standard Graphite Pile" gives at the center of the Clinton pile

$$\underset{\text{(thermal)}}{nv \ \text{watt}^{-1}} = 3.234 \times 10^{5} \text{ neutrons cm}^{-2} \text{ sec}^{-1} \text{ watt}^{-1}.$$

A comparison has been made against the control rod calibrations.

[redacted]

[redacted]

[redacted]

Experimental Procedure

Ag wires (.020" diameter) were run completely through Holes 13, 14, 15, 18, 20, 50, 52 and 62 and to about the center of Holes 59, 60 and 61 of the Clinton pile. With the exception of Holes 14, 15 and 18, these wires were irradiated at the same time with approximately 135,503 KWH. Wires from 14, 15, and 18 have been corrected to this same irradiation. Table I and Drawing 1253 give the location of these holes.

About fourteen days elapsed between the time the wires were removed from the pile and the time they were cut and counted. One inch samples were cut every eight inches beginning eight feet from the south outside edge of the concrete. These samples were weighed, cleaned with acetone, mounted on Al discs and covered with Scotch tape. The samples were counted under one inch Pb on upright mica window Geiger counters. Counting rates were calculated for each sample. Comparable results were obtained by making corrections for weight differences, high counting rates and counter positions.

Coordinate Systems and Scales

Throughout this report the coordinate system in the Clinton pile has been set up with its origin at the geometrical center of the pile loading. Positive directions for the axes are north, west and up.

On the drawings showing the transverses, three abscissae scales are given: (1) The practical scale placed at the bottom of the page shows distances in feet from the outside edge of the concrete along the hole. (2) At the top of the page is a scale showing the displacements in feet from the center of the hole. (3) Where different from (2), the radial

[redacted] [redacted]

[redacted]

distances in feet from the pile axis are shown. The minimum value for the radial scale is obviously the distance from the pile axis to the hole.

Discussion of Results

A least squares fit to a cosine function was made to the data from Hole 62 (see Dr. 1252). This gave $\cos \frac{\pi(x + .1722)}{19.795}$, where x is the distance in feet from center of pile loading.

The relative neutron densities for the other holes were adjusted to correspond to this fit. The data in the graphite reflector outside of the metal for Hole 62 show a relaxation length of 51.07 cm. This value is larger than that for the graphite of which the reflector is made because of the open channels (1.75" x 1.75") which lead to the loading face of the pile. It should be pointed out that the streaming of the neutrons through these channels may account for the absence of the bump in the neighborhood of the metal edge which is present on all the transverses made normal to the pile axis. These bumps are due to slowing down of the neutrons in the reflector. No detailed study has been made of the Cd ratio. Most of the data reported here have not had Cd differences applied. Within the lattice between U-rods, 75% of the activation of the Ag is due to slow neutrons.

The density of slow neutrons along the axis (Hole 62) was enhanced by the particular loading of the pile (see Dr. 1253). That is, Channels 1867 and 1868 were essentially empty. This also explains the central peaks found in Holes 13, 14 and 18 (see Drs. 1254, 1255 and 1259). The U doughnuts in Channel 1867, the thorium in Channels 1866 and 1871 have depressed the central part of Hole 62 and eliminated the central peaks from Holes 15 and 20

[redacted]

[redacted]

(see Drs. 1256 and 1261). As is evident, an additive correction $\left[-0.03 \cos \frac{3\pi(x + .1722)}{19.795}\right]$ can be applied to the least square fit for Hole 62 to flatten the central region to give a better fit.

In order to determine a simple analytical expression for the variation of the neutron density in the radial direction, the data for the north-south holes were adjusted to the middle plane using the axial data (Hole 62). Their average was fit by a cosine function to give $0.88 \cos \frac{\pi(r + .338)}{23.83}$ where r is the radial distance from the pile axis in feet. This is nearly equivalent to $0.88\, Jo(0.189\, r + 0.064)$, where Jo is the zeroth order Bessel's function.

Integrating the relative density function

$$\rho = 0.88 \cos \frac{\pi(r + .338)}{23.83} \cos \frac{\pi(x + .172)}{19.8} \qquad (1)$$

over the active part of the lattice, we get the average density to be

$$\overline{\rho} = \frac{1855}{4723} = 0.3928 \qquad (2)$$

which implies that the central density is 2.55 times the average density. However, due to the fact that cosine fit of Hole 62 is known to be high for most of the lattice, a better value is possibly

$$\frac{\text{Central density}}{\text{Average density}} = 2.55 \times 0.88 = 2.24. \qquad (3)$$

[redacted]

[redacted]

One can calculate that if the lattice contained 7119 cells, each containing the same number of neutrons as the central cell, (where by a central cell is meant a similar cylinder whose volume is $(8")^3$ located at the pile center) they would contain all of the neutrons in the active part of the lattice.

Statistical Weights

The statistical weight w(R) of a region, R, in the pile is a measure of the contribution of its Laplacian to the Laplacian of the entire pile of volume V

$$w(R) = \frac{\int_R \rho^2 \, dv}{\int_V \rho^2 \, dv} \qquad (4)$$

An evaluation of the integral in the denominator over the active part of the pile using (1) gave 1486. For the present loading a channel of U metal on the edge of the lattice is equivalent to 1.8 inhours of reactivity.

There is about a 5% ripple in the north-south transverses between the U rods. For this reason the Ag wire samples were taken every eight inches between U rods.

Control Rods and Poisons

If one assumes that equation (1) is sufficiently general to apply to the entire pile, it can be used to determine roughly the sensitivity of the control and shim rods, namely,

$$\text{Inhours/inch} = 2.03 \cos^2 \frac{\pi (R + 4.06)}{286} \cos^2 \frac{\pi (X + 2.06)}{237.6} \qquad (5)$$

[redacted]

[redacted]

where X is the displacement in inches of the control rod hole in the direction of the pile axis, and $R(R^2 = Y^2 + Z^2)$ is the radial coordinate in inches. (For earlier pile loading see CP 1300, p. 27.) With proper precautions, this expression might be applied to the determination of the poisoning effect of a neutron absorber placed within the pile.

Absolute Calibration of Neutron Density and Flux

In order to establish the neutron density, n, within the Clinton pile, we require a conversion factor, ϕ, between the operating power of the pile and the neutron density at the pile center, say. At present this factor is quite uncertain. In fact, the various determinations for ϕ range from 1.47 to 2.33. A special committee has been formed at Clinton Laboratories to try to establish a reliable ϕ-value.

In connection with our work with Ag wire detectors, we have used the calibration of the "Standard Graphite Pile" as a standard source. Using two methods of comparison against the Clinton pile, we have determined

$$\phi = 1.47 \text{ neutrons cm}^{-3} \text{ watt}^{-1} \qquad (6)$$

at the center of the Clinton pile for the loading of 2-24-45 through 2-27-45. This value depends directly on the calibration of the source strength of the Rn-Be source used in the "Standard Graphite Pile" and on the calibration of the No. 1 galvanometer against pile power. We claim no special merit for the value and add the word of caution that until a more reliable

[redacted]

[redacted]

ϕ-value is established, it must be considered possibly to be in error by as much as the range noted above.

For monoenergetic thermal neutrons of velocity 2.2×10^5 cm sec^{-1}, we get at the center of the Clinton pile,

$$nv \text{ watt}^{-1} = 1.47 \times 2.2 \times 10^5 = 3.234 \times 10^5 \text{ neutrons cm}^{-2} \text{ sec}^{-1} \text{ watt}^{-1} . \quad (7)$$
(thermal)

The usual question asked is "What is the nv at a particular spot in the pile?" No great care is used to specify for which velocity or velocity distribution nv is desired. For this reason a brief discussion may be in order.

It is known that the actual velocity spectrum within an inhomogeneous chain-reacting pile is quite complicated and varies markedly within the lattice cells, however, (1) a concept of pile neutrons of velocity, v_p, has developed which means (for a particular pile) neutrons as found at the center of the moderator of a lattice cell. (2) Spectrometer measurements on neutron beams escaping from the pile and studies with Cd difference neutrons using $(\frac{1}{v})$ absorbers (boron) within the pile indicate that such neutrons have roughly a gaussian distribution corresponding to a temperature of 550° K. Often (3) direct comparisons are made against a "Standard Graphite Pile" whose distribution of velocities, v_c, of neutrons is taken to be gaussian at room temperature.

The following rough conversion factors relate the cross sections corresponding to these velocities to those for monoenergetic thermal neutrons

[redacted]

(as produced by a velocity selector or modulated source) of velocity, $v_{th} = 2.2 \times 10^5$ cm. sec^{-1}, assuming ($\frac{1}{v}$) absorption for the detector.

$$\sigma_{th} = \frac{2}{\sqrt{\pi}} \sigma_c = 1.128 \sigma_c = 1.54 \sigma_p$$

for

$$\sigma_c = \sqrt{\frac{550}{293}} \sigma_p = 1.37 \sigma_p \quad . \qquad (8)$$

Summary on Use of Graphs

The graphs have been appended to help answer the ever present question "What is the approximate thermal nv in a particular region in the Clinton pile operating at a known power?" In using these graphs at some later date, all changes of loading, poisoning and control rod positions must be considered. For points not given on the graphs formula (1)

$$\rho = 0.88 \cos \frac{\pi (r + .338)}{23.83} \cos \frac{\pi (x + .172)}{19.8} \qquad (1)$$

should be useful where r and x are distances in feet from the pile center. It has been presented in this form because of the relative scarcity of tables of Bessel's function on the plant and likely the fit is better to a cosine than a Bessel's function anyway due to pile flattening.

Equation (7) gives for the pile center

$$\underset{\text{(thermal)}}{nv\ \text{watt}^{-1}} = 3.234 \text{ neutrons cm}^{-2} \text{ sec}^{-1} \text{ watt}^{-1} .$$

We give two examples:

Example I. What is the thermal nv, in Hole 50, fifteen feet from the outside south edge of the concrete shielding when the pile is operating at 4000 KW?

From equation (7) at pile center

$$\underset{\text{(at center)}}{nv_{\text{thermal}}} = 3.234 \times 10^5 \times 4.0 \times 10^6 = 12.9 \times 10^{11} \text{ neutrons cm}^{-2} \text{ sec}^{-1} . \quad \text{(a)}$$

From Drawing 1264, the relative density fifteen feet from the south edge of the concrete is 0.337, therefore, we have, using (a),

$$\underset{\text{(Hole 50, 15 feet)}}{nv_{\text{thermal}}} = 12.9 \times 10^{11} \times .337 = 4.36 \times 10^{11} \text{ neutrons cm}^{-2} \text{ sec}^{-1} .$$

Example II. What is the thermal nv in Channel 1063, twenty-five feet from the outside east edge of the concrete with the pile operating at 2000 KW?

From equation (7)

$$\underset{\text{(at center)}}{nv_{\text{thermal}}} = 3.234 \times 10^5 \times 2 \times 10^6 = 6.468 \times 10^{11} \text{ neutrons cm}^{-2} \text{ sec}^{-1} . \quad \text{(b)}$$

Drawings 1252 and 1253 show that the coordinates of the point in question are (- (5' + 4") south; 3' west, (3' + 4") up). In order to use equation (1), we find $r = -\sqrt{(5'+4")^2 + (3'+4")^2} = -(6.009 \text{ feet})$. Hence, from equation (1)

$$\rho = 0.88 \cos \frac{\pi(-6.009 + .338)}{23.83} \cos \frac{\pi(3 + .172)}{19.8}$$

$$\rho = 0.88 \times .7333 \times .8760 = 0.5653.$$

therefore, using (b), we have

$nv_{thermal} = 6.468 \times 10^{11} \times .5653 = 3.656 \times 10^{11}$ neutrons cm^{-2} sec^{-1}.
(Channel 1063, 25 feet)

Using the dotted lines for the functions given on Drawings 1250 and 1252,

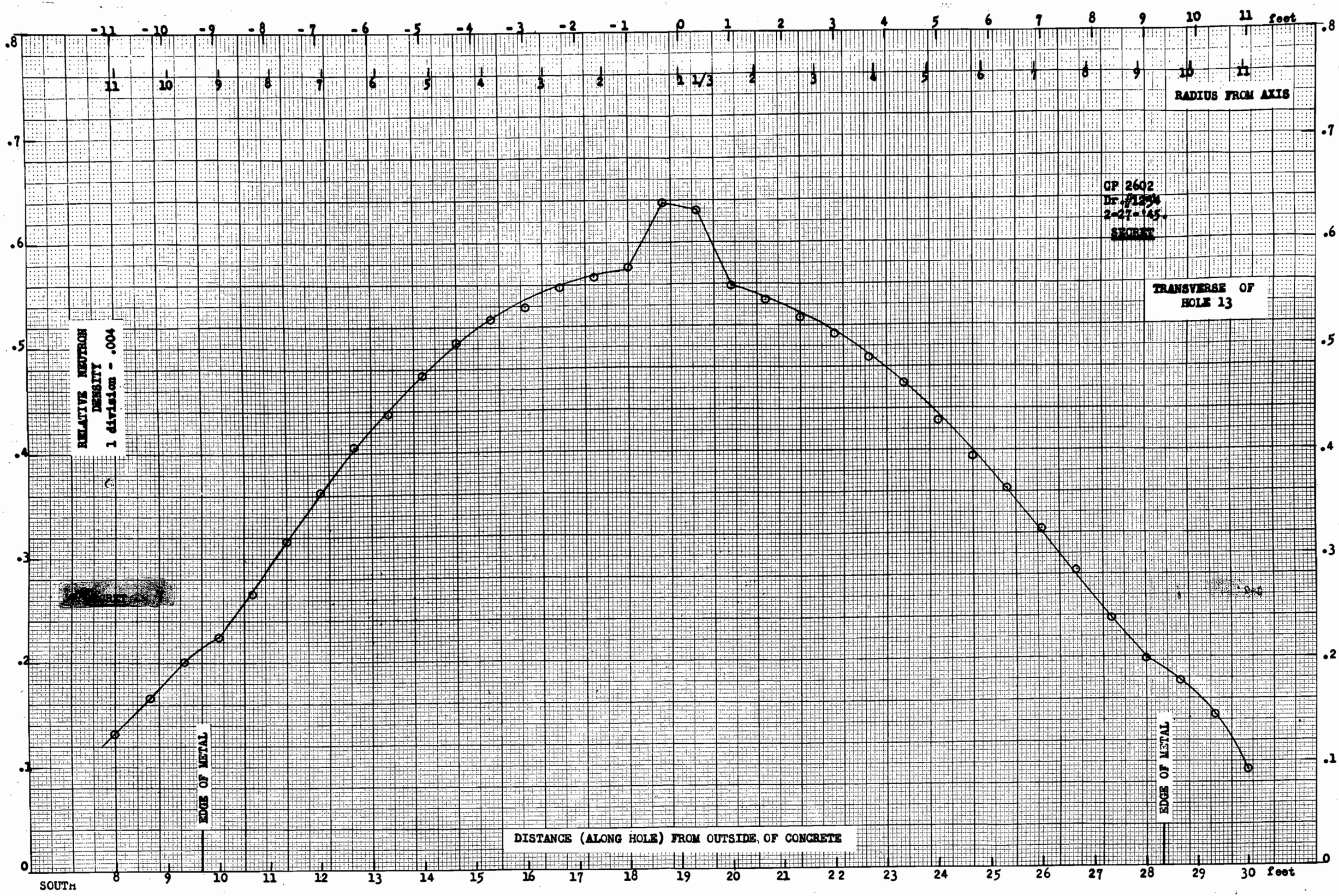
$$\rho = 0.645 \times 0.8777 = 0.5657.$$

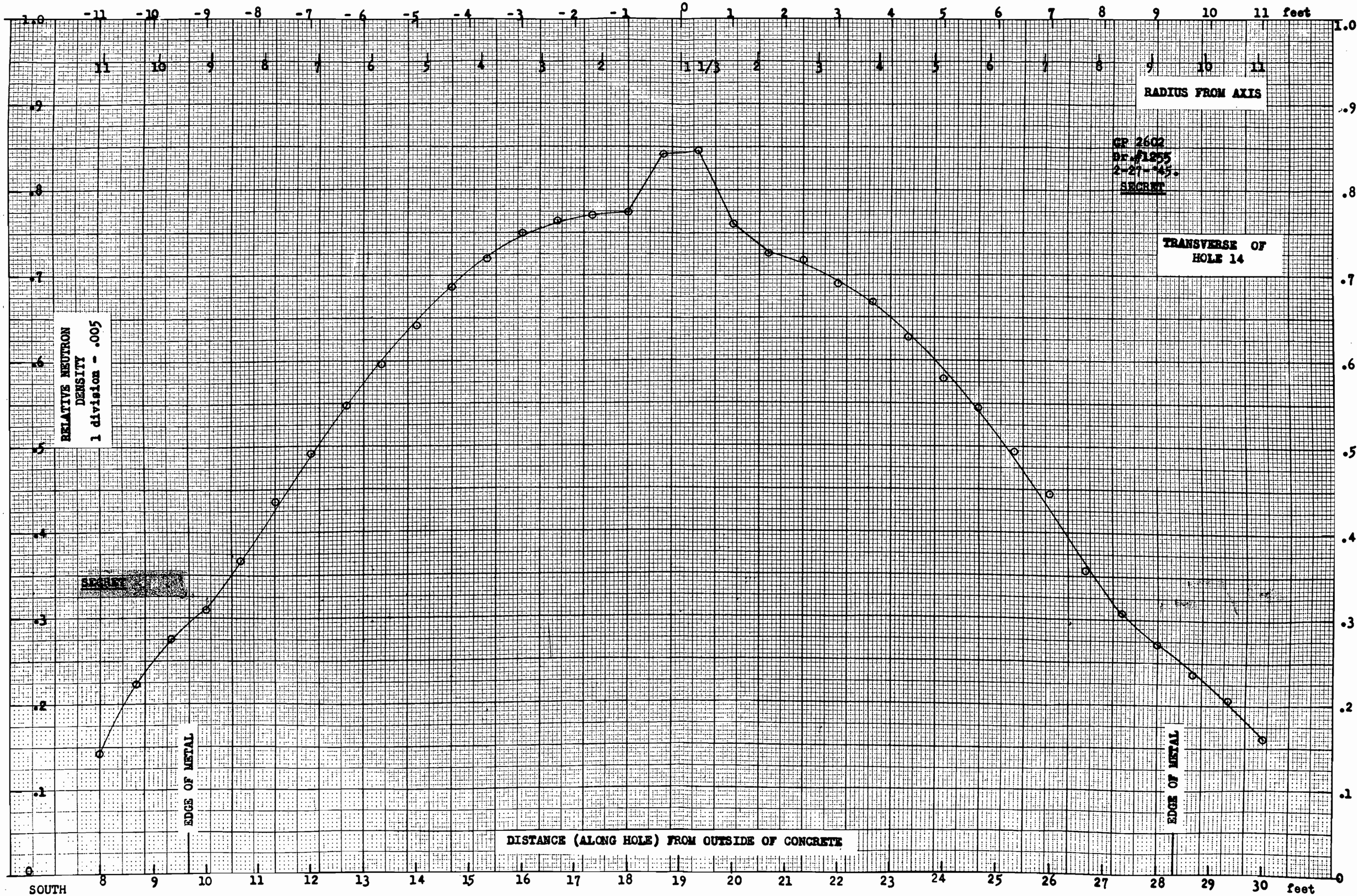
[redacted]

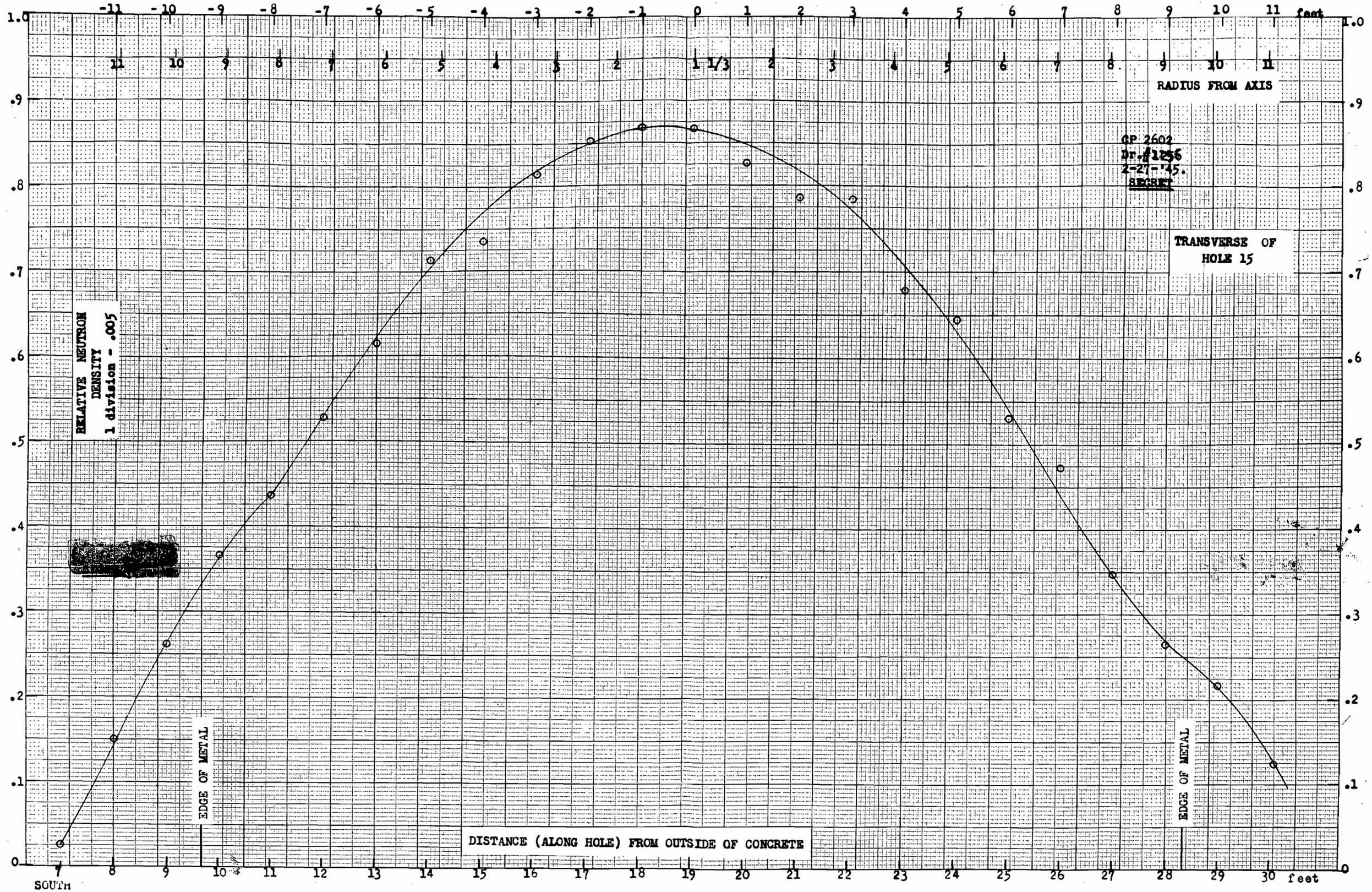
TABLE I

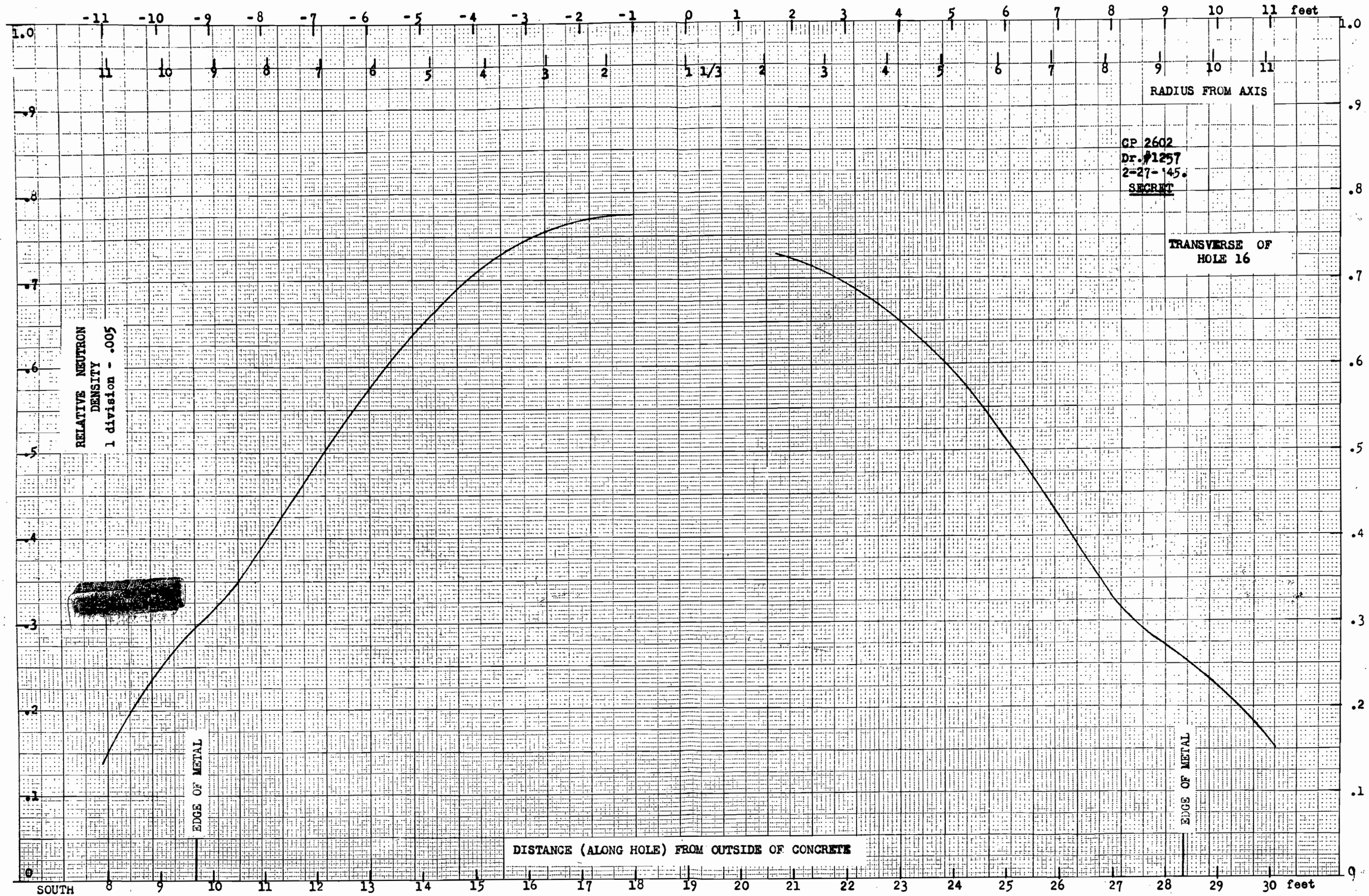
Slot	Distance from Center of Pile		Remarks
13	5.3' west	1.3' up	To be charged with about 7 Bi bricks
14	2.667' west	1.3' up	To be charged with about 18 Bi bricks
15	0.000'	1.3' up	Filled with 10 Bi bricks (4" x 4" x 12")
16	2.667' east	1.3' up	
17	5.3' east	1.3' up	
18	5.3' west	1.3' down	
19	2.667' west	1.3' down	
20	0.000'	1.3' down	Graphite removed
21	2.667' east	1.3' down	Sample hole
22	5.3' east	1.3' down	Pneumatic Rabbit tube
50	6' east	6' up	
51	0.000	6' up	
52	6' west	6' up	
56	6' east	6' down	Contains BF_3 chamber near south edge
57	0.000	6' down	Filled with H^3 factory - 200 gm Li over central 12 feet
58	6' west	6' down	
59	6' east	0.000	Enters south side, ends at core - 1.5 ft. from center
60	0.000	0.000	Enters south side, ends at core
61	6' west	0.000	Enters south side, ends at core
62	0.000	0.000	Runs along pile axis
53	6' east	0.000	Enters north side, ends at core
54	0.000	0.000	Enters north side, ends at core
55	6' west	0.000	Enters north side, ends at core

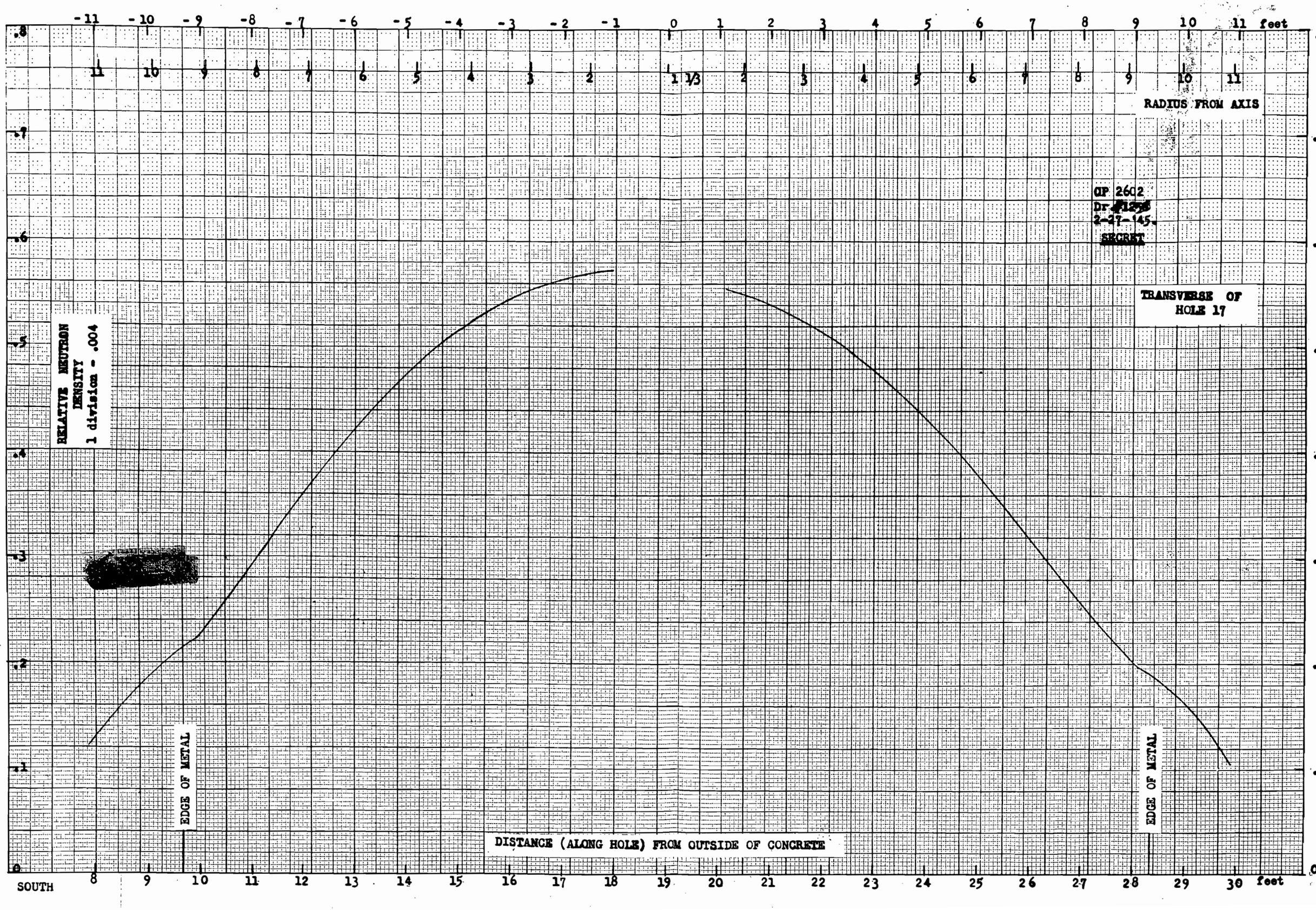
[redacted]


RADIUS FROM AXIS
CP 2602
Dr. #1254
2-27-'45.
SECRET
TRANSVERSE OF HOLE 13
RELATIVE NEUTRON DENSITY
1 division - .004
EDGE OF METAL
EDGE OF METAL
DISTANCE (ALONG HOLE) FROM OUTSIDE OF CONCRETE
SOUTH
feet
feet

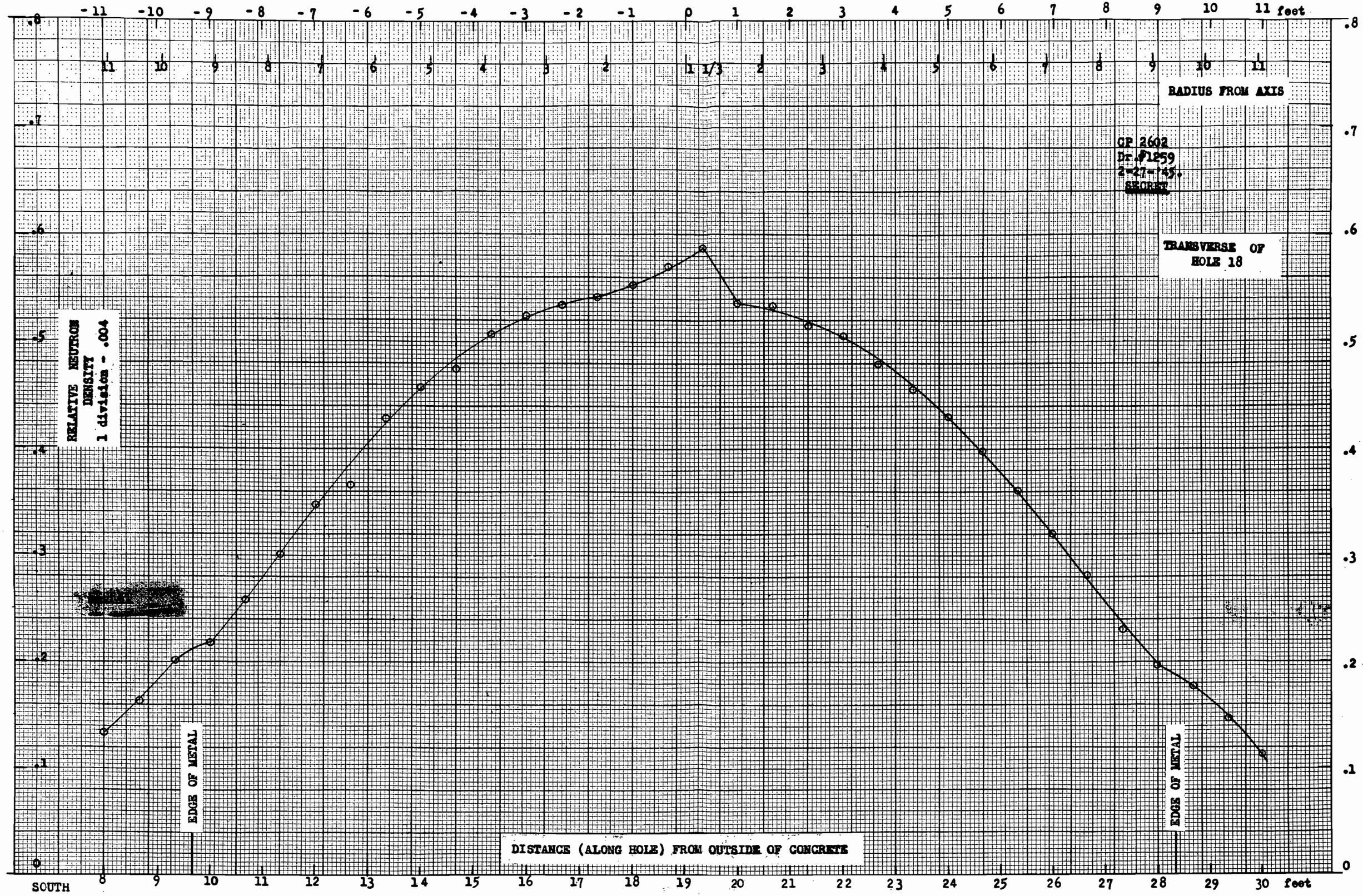

-11 -10 -9 -8 -7 -6 -5 -4 -3 -2 -1 0 1 2 3 4 5 6 7 8 9 10 11 feet
11 10 9 8 7 6 5 4 3 2 1 1/3 2 3 4 5 6 7 8 9 10 11
RADIUS FROM AXIS
GP 2602
Dr. 1255
2-27-45.
SECRET
TRANSVERSE OF HOLE 14
RELATIVE NEUTRON DENSITY
1 division - .005
SECRET
EDGE OF METAL
EDGE OF METAL
DISTANCE (ALONG HOLE) FROM OUTSIDE OF CONCRETE
SOUTH
8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 feet
1.0 .9 .8 .7 .6 .5 .4 .3 .2 .1 0

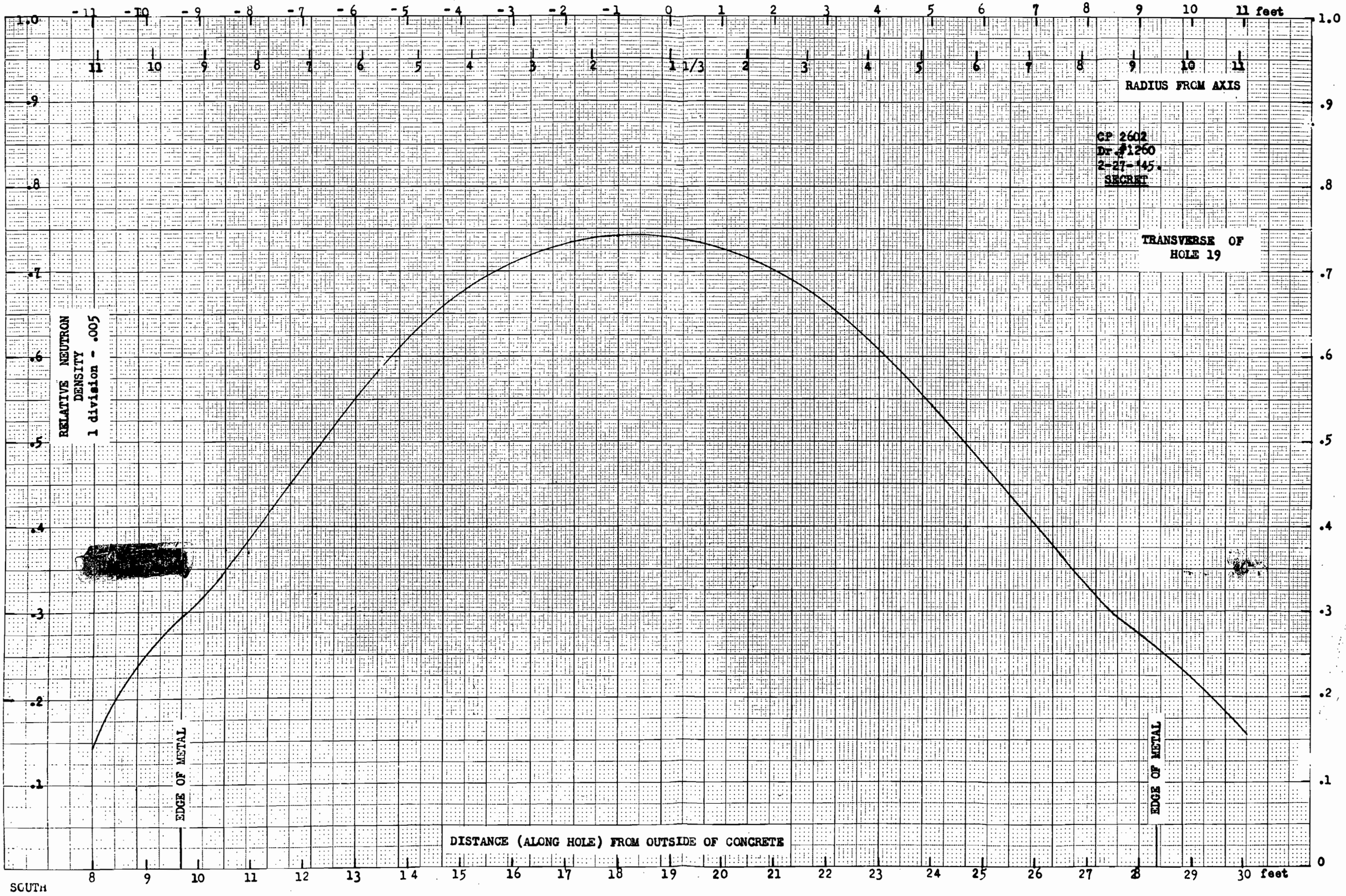

RADIUS FROM AXIS
feet
GP 2602
Dr.#1256
2-27-'45.
SECRET
TRANSVERSE OF HOLE 15
RELATIVE NEUTRON DENSITY
1 division - .005
EDGE OF METAL
EDGE OF METAL
DISTANCE (ALONG HOLE) FROM OUTSIDE OF CONCRETE
SOUTH
feet

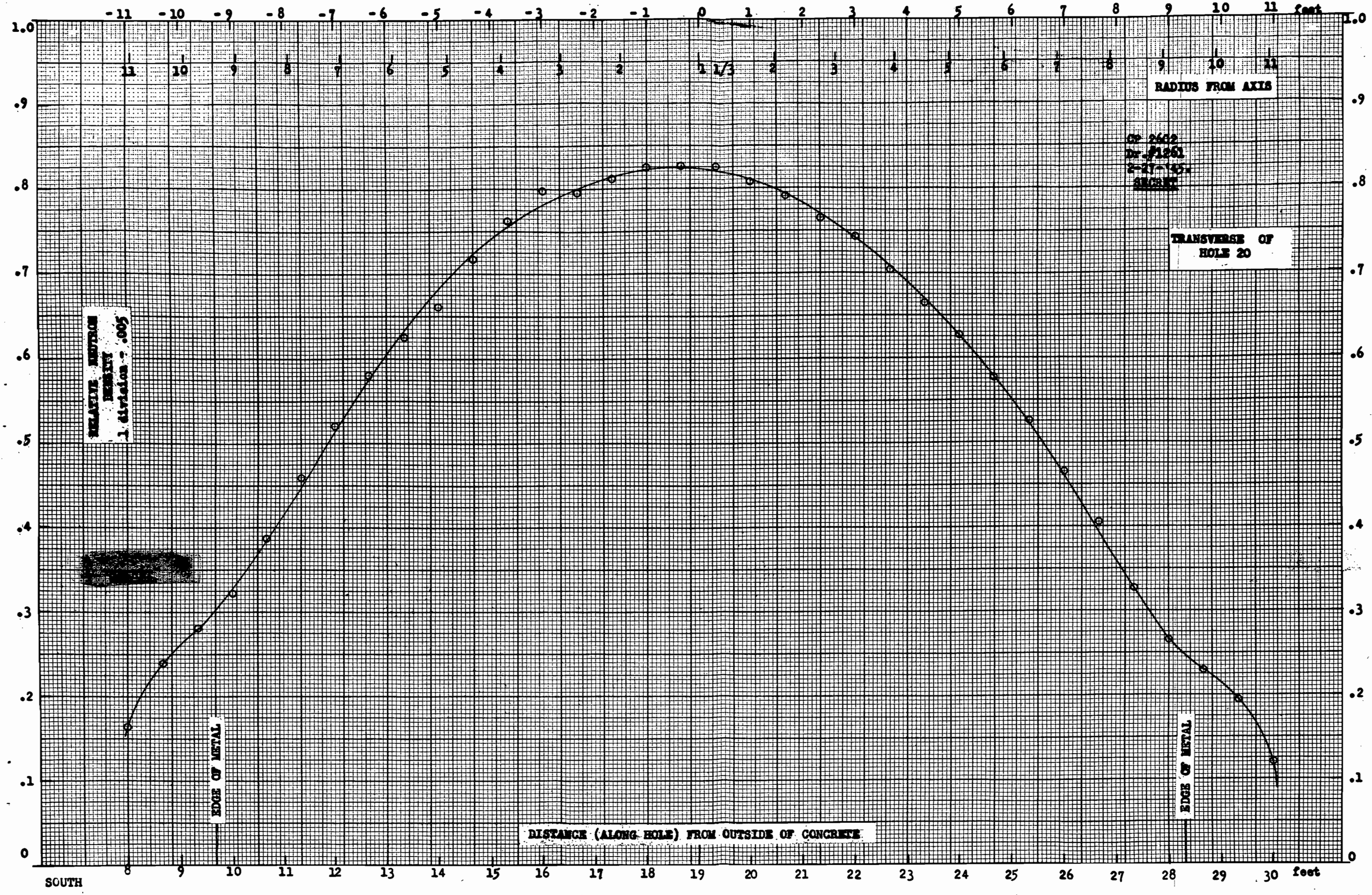

-11 -10 -9 -8 -7 -6 -5 -4 -3 -2 -1 0 1 2 3 4 5 6 7 8 9 10 11 feet
11 10 9 8 7 6 5 4 3 2 1 1/3 2 3 4 5 6 7 8 9 10 11
RADIUS FROM AXIS
CP 2602
Dr. #1257
2-27-45.
SECRET
TRANSVERSE OF
HOLE 16
RELATIVE NEUTRON
DENSITY
1 division - .005
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
0
EDGE OF METAL
EDGE OF METAL
DISTANCE (ALONG HOLE) FROM OUTSIDE OF CONCRETE
SOUTH
8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 feet

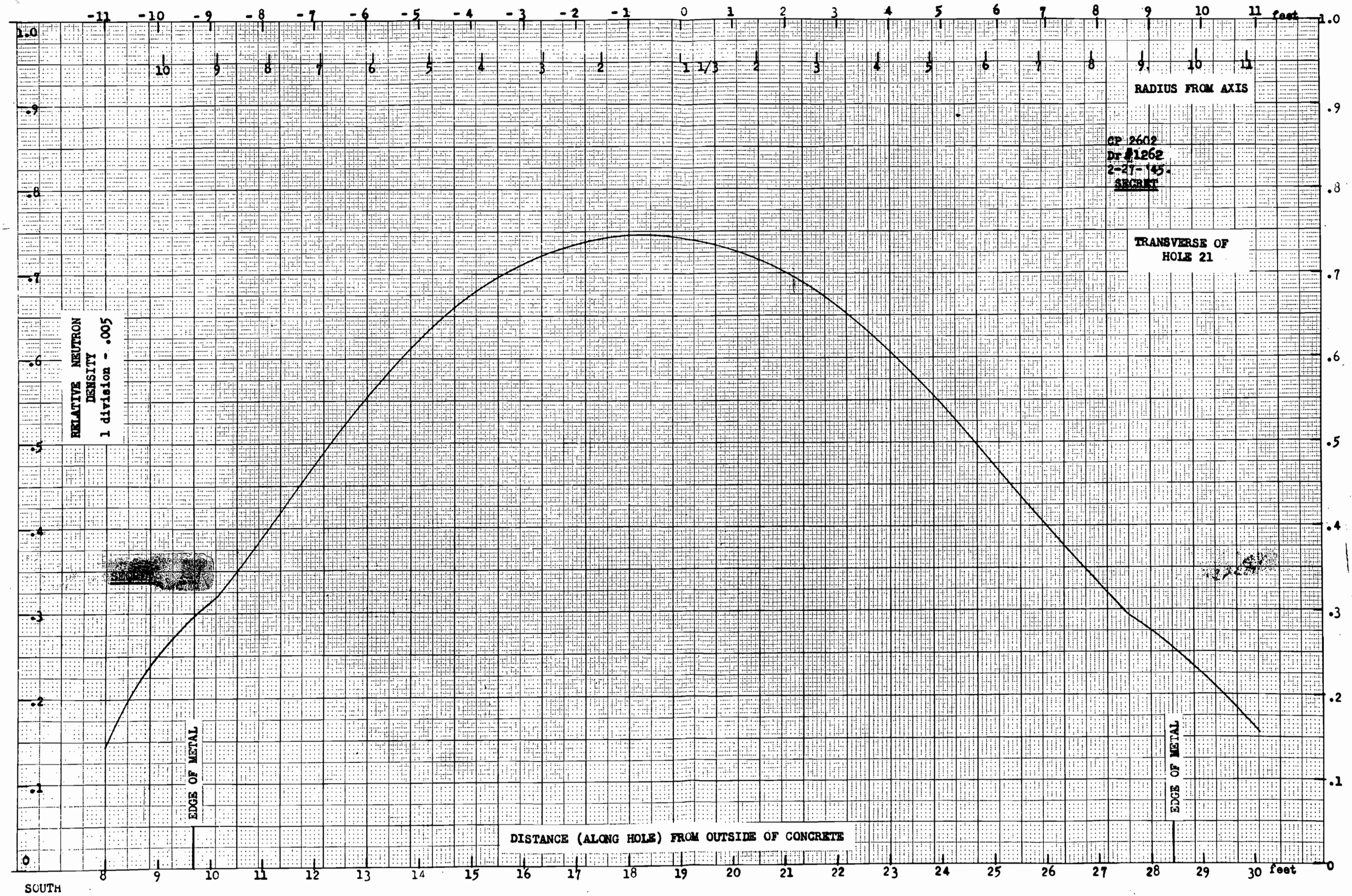


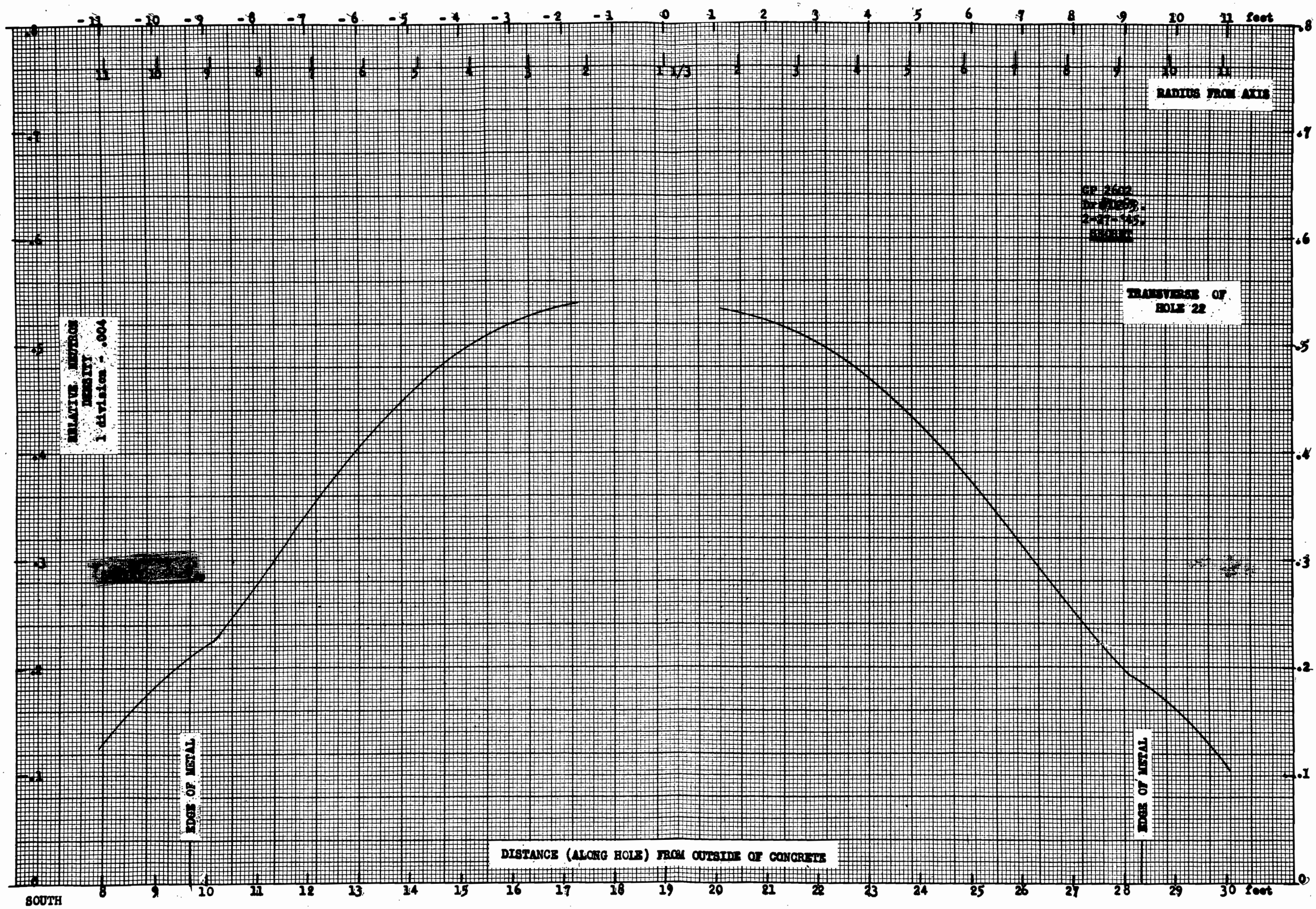
RADIUS FROM AXIS
CP 2602
Dr. #1258
2-27-'45.
SECRET
TRANSVERSE OF HOLE 17
RELATIVE NEUTRON DENSITY
1 division = .004
EDGE OF METAL
EDGE OF METAL
DISTANCE (ALONG HOLE) FROM OUTSIDE OF CONCRETE
SOUTH
feet

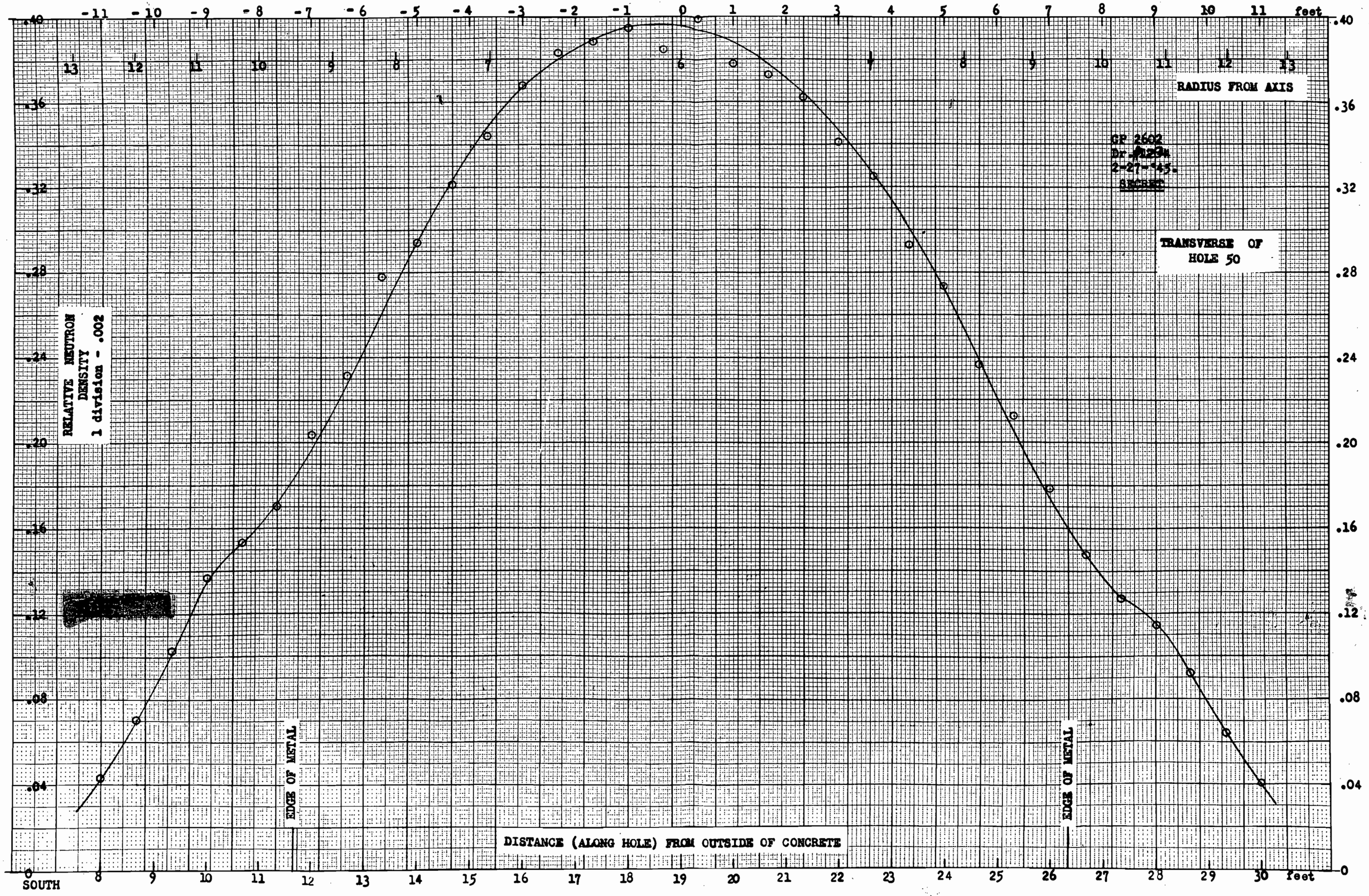

RADIUS FROM AXIS
CP 2602
Dr. #1259
2-27-45.
SECRET
TRANSVERSE OF HOLE 18
RELATIVE NEUTRON DENSITY
1 division - .004
EDGE OF METAL
EDGE OF METAL
DISTANCE (ALONG HOLE) FROM OUTSIDE OF CONCRETE
SOUTH
feet
feet

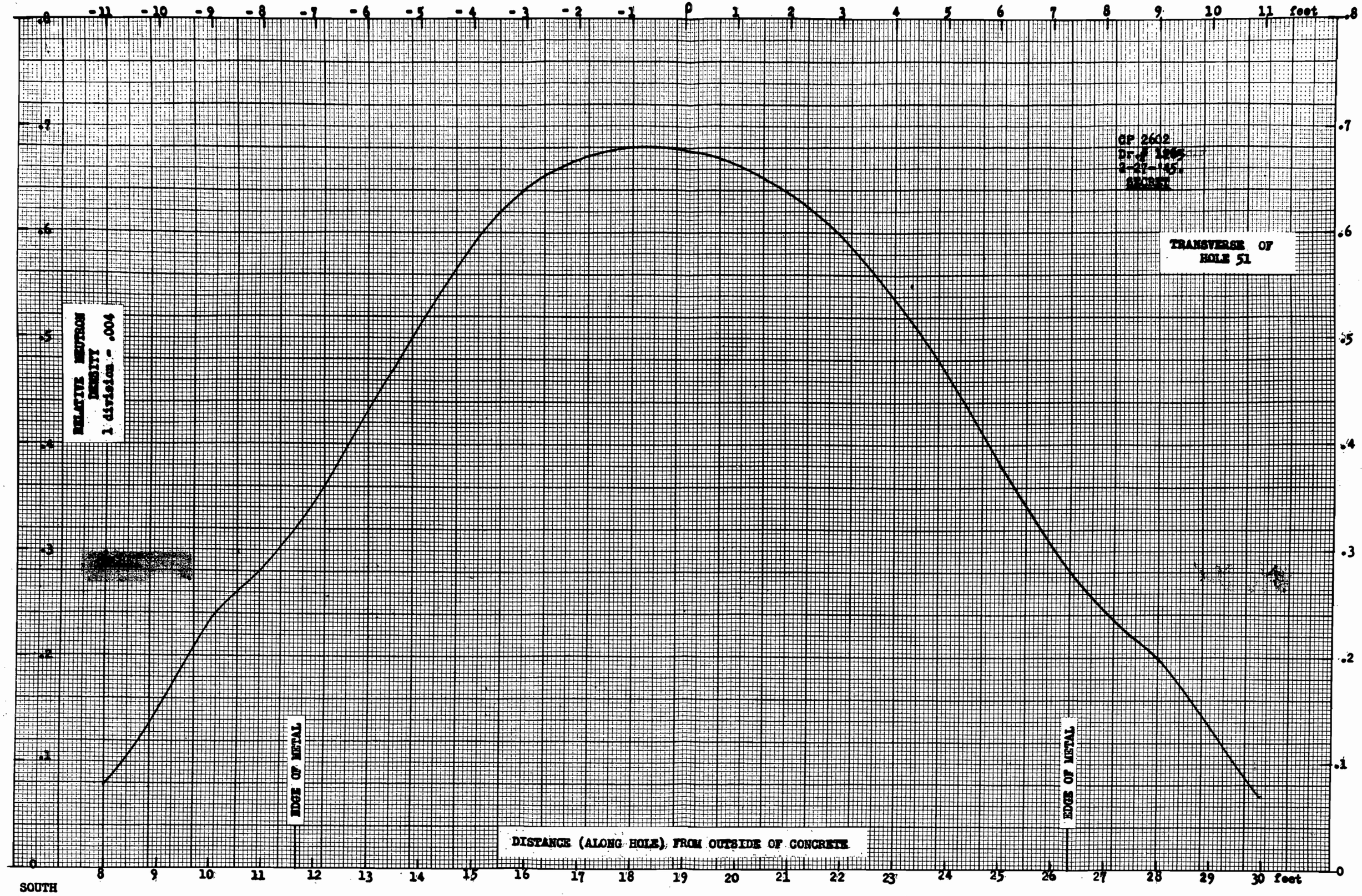

-11 -10 -9 -8 -7 -6 -5 -4 -3 -2 -1 0 1 2 3 4 5 6 7 8 9 10 11 feet
11 10 9 8 7 6 5 4 3 2 1 1/3 2 3 4 5 6 7 8 9 10 11
RADIUS FROM AXIS
CP 2602
Dr #1260
2-27-'45.
SECRET
TRANSVERSE OF HOLE 19
RELATIVE NEUTRON DENSITY
1 division - .005
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
0
EDGE OF METAL
EDGE OF METAL
DISTANCE (ALONG HOLE) FROM OUTSIDE OF CONCRETE
8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 feet
SOUTH


RADIUS FROM AXIS
TRANSVERSE OF HOLE 20
RELATIVE NEUTRON DENSITY
1 division = .005
EDGE OF METAL
EDGE OF METAL
DISTANCE (ALONG HOLE) FROM OUTSIDE OF CONCRETE
SOUTH
feet
feet

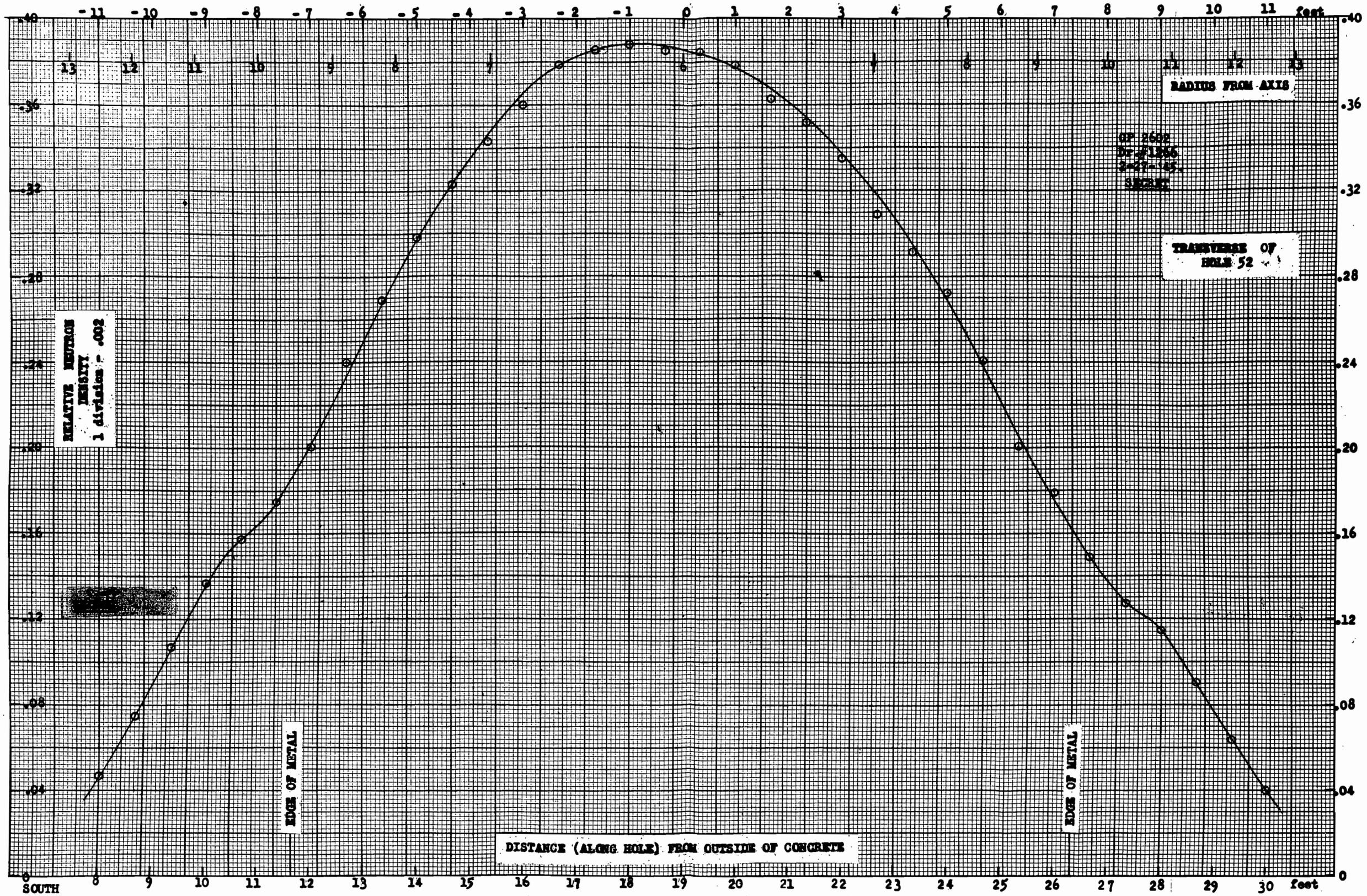

RADIUS FROM AXIS
CP 2602
Dr #1262
2-27-'45.
SECRET
TRANSVERSE OF HOLE 21
RELATIVE NEUTRON DENSITY
1 division - .005
EDGE OF METAL
EDGE OF METAL
DISTANCE (ALONG HOLE) FROM OUTSIDE OF CONCRETE
SOUTH
feet
feet

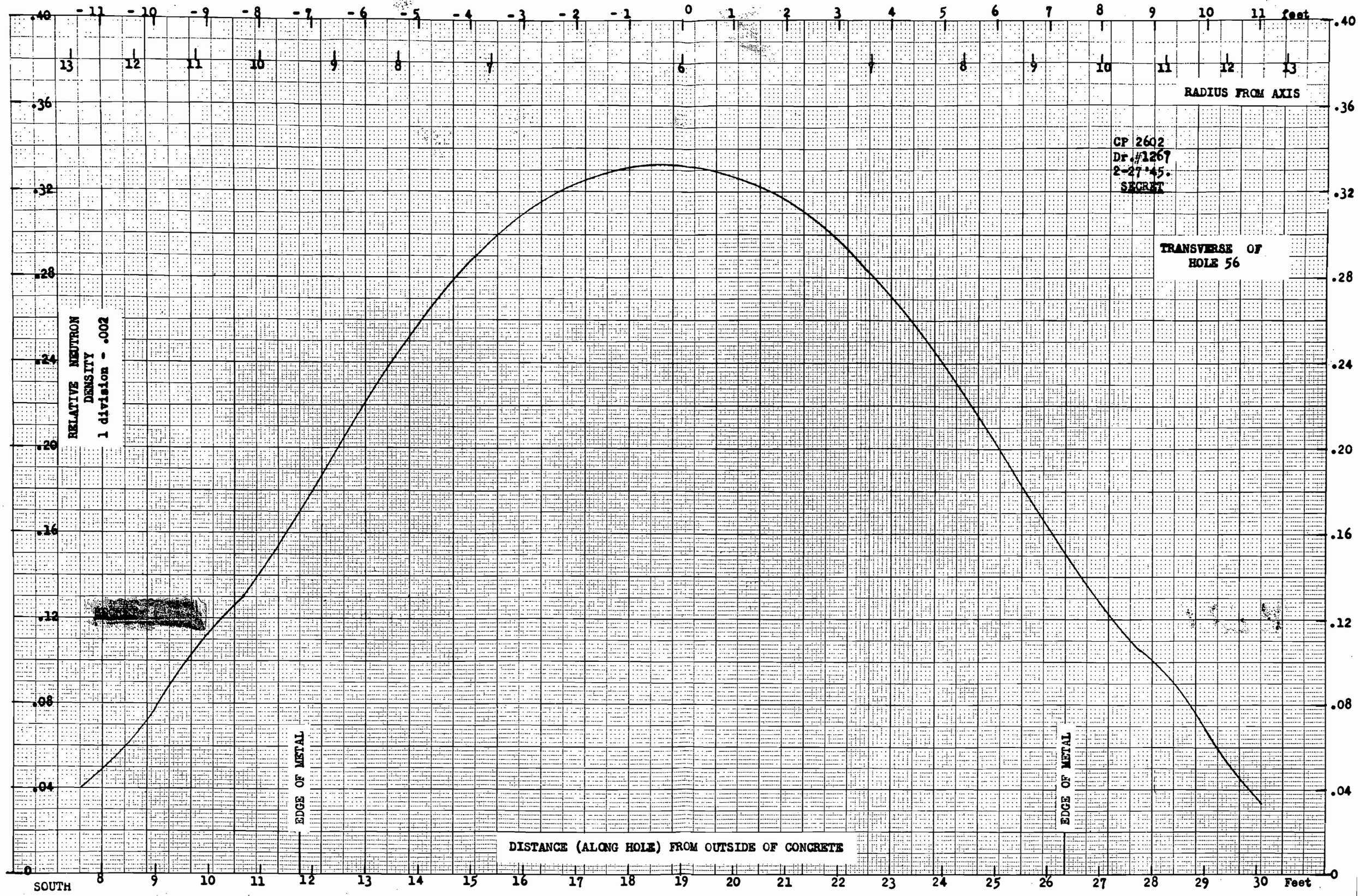

-11 -10 -9 -8 -7 -6 -5 -4 -3 -2 -1 0 1 2 3 4 5 6 7 8 9 10 11 feet
RADIUS FROM AXIS
TRANSVERSE OF HOLE 22
RELATIVE NEUTRON DENSITY
1 division = .004
[redacted]
EDGE OF METAL
EDGE OF METAL
DISTANCE (ALONG HOLE) FROM OUTSIDE OF CONCRETE
SOUTH
8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 feet
.8
.7
.6
.5
.4
.3
.2
.1
0

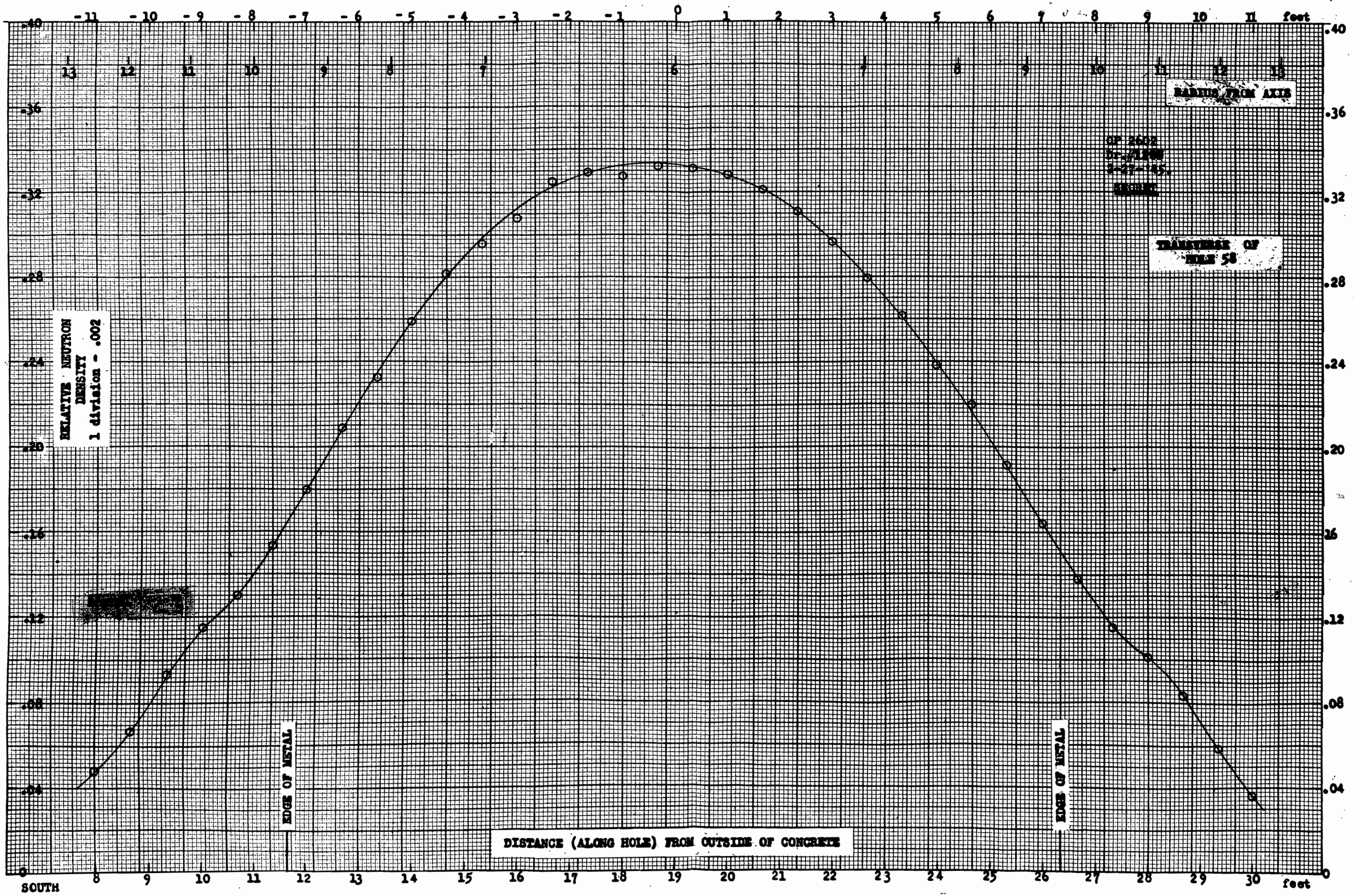

RADIUS FROM AXIS
GP 2602
Dr. #1234
2-27-45
SECRET
TRANSVERSE OF HOLE 50
RELATIVE NEUTRON DENSITY
1 division - .002
EDGE OF METAL
EDGE OF METAL
DISTANCE (ALONG HOLE) FROM OUTSIDE OF CONCRETE
SOUTH
feet
feet



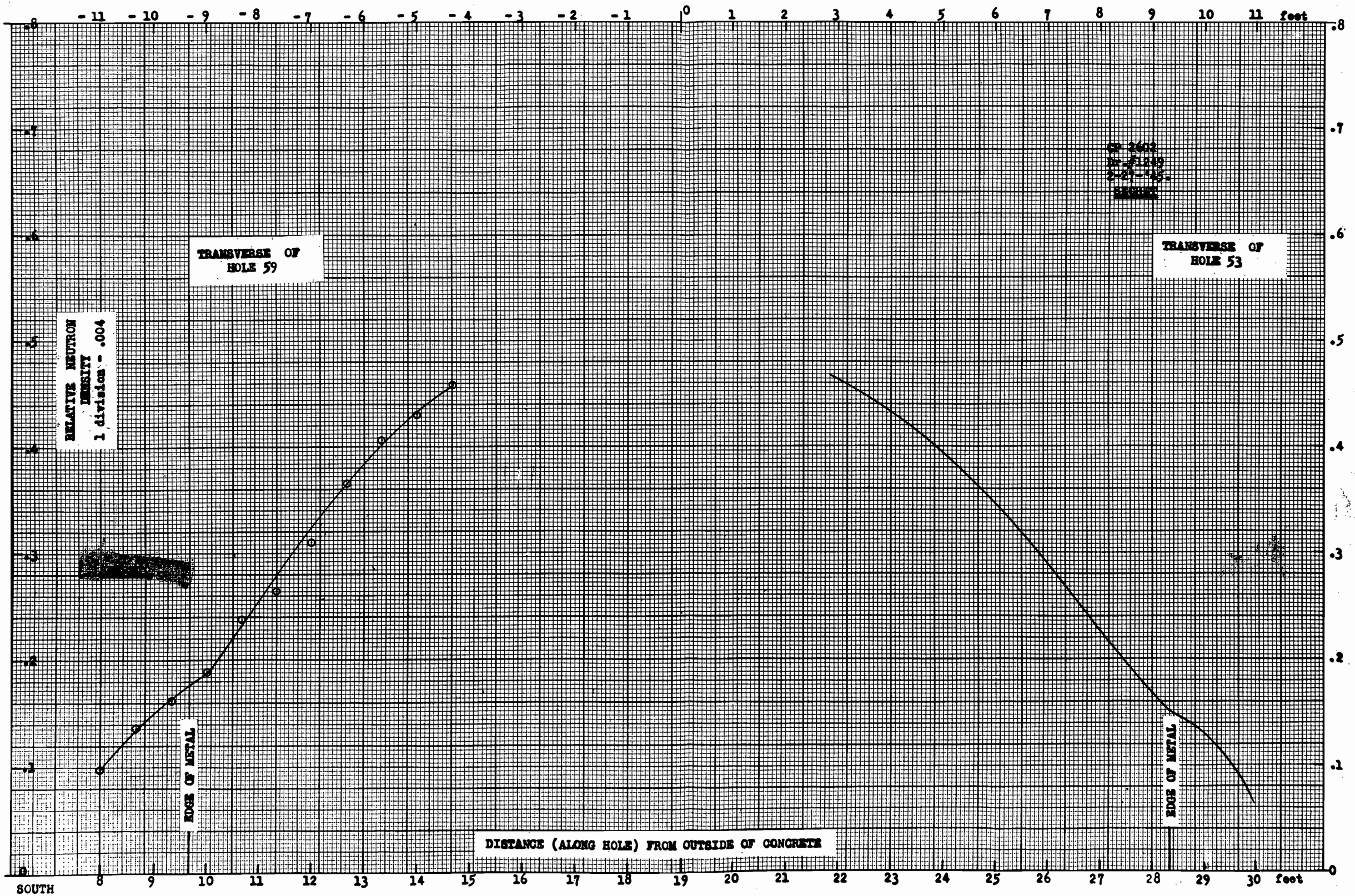
10 × 10 to the ½ inch, 5th lines accented.
MADE IN U.S.A.

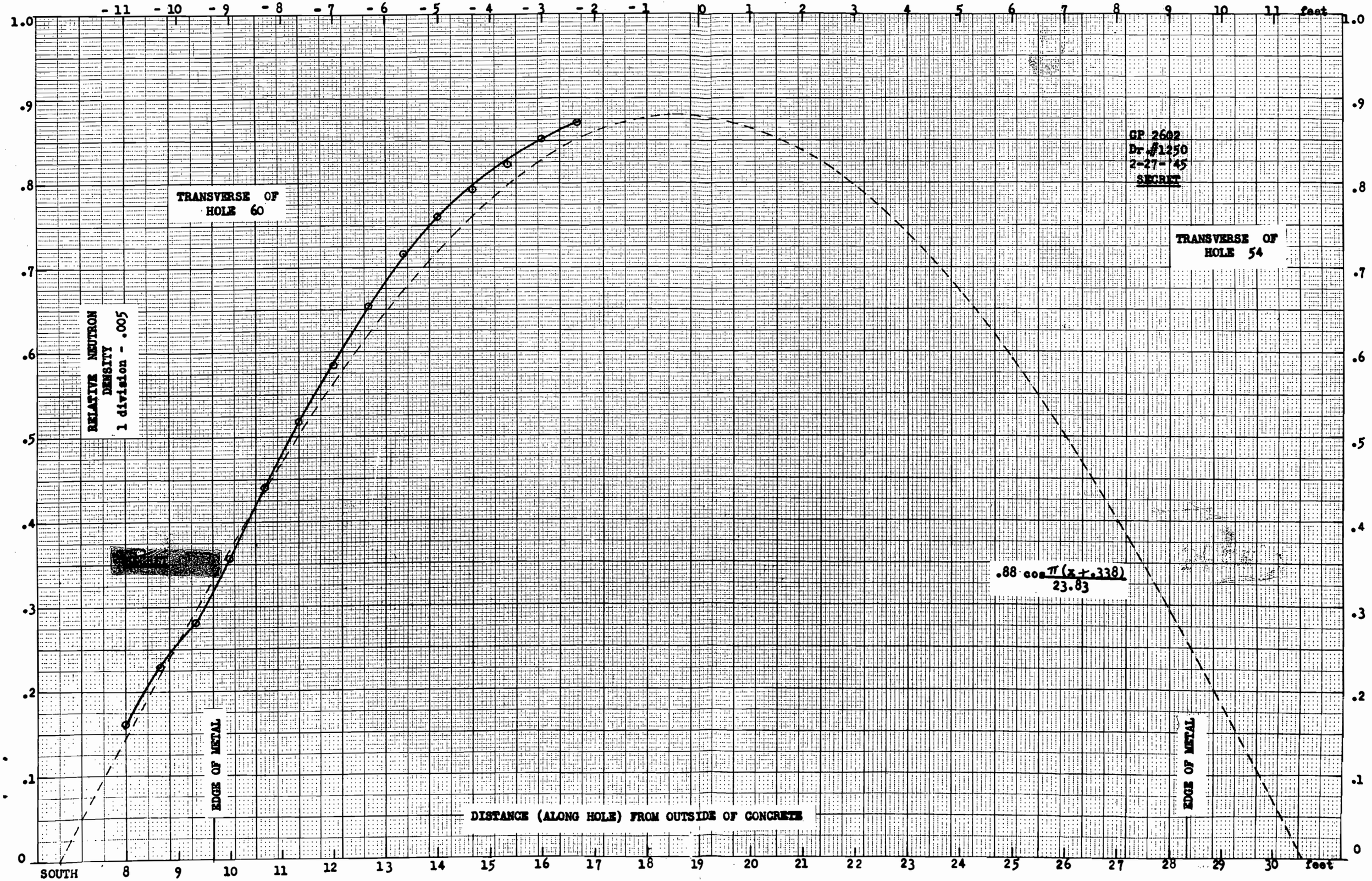

RADIUS FROM AXIS
feet
OP 2602
Dr #1266
2-27-45
SECRET
TRANSVERSE OF HOLE 52
RELATIVE NEUTRON DENSITY
1 division = .002
EDGE OF METAL
EDGE OF METAL
DISTANCE (ALONG HOLE) FROM OUTSIDE OF CONCRETE
SOUTH
feet

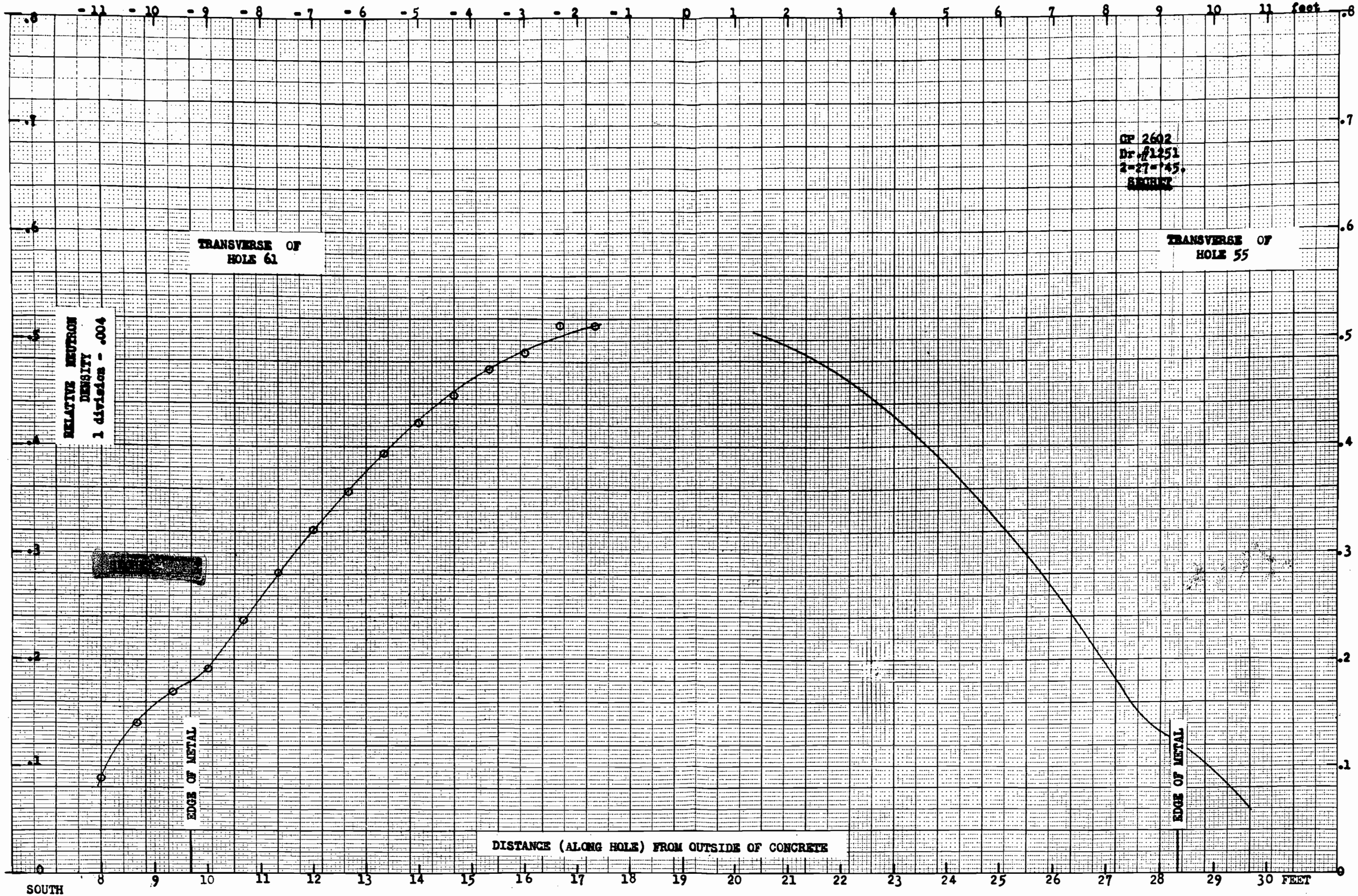

RADIUS FROM AXIS
CP 2602
Dr. #1267
2-27-45.
SECRET
TRANSVERSE OF
HOLE 56
RELATIVE NEUTRON
DENSITY
1 division - .002
EDGE OF METAL
EDGE OF METAL
DISTANCE (ALONG HOLE) FROM OUTSIDE OF CONCRETE
SOUTH
Feet
feet

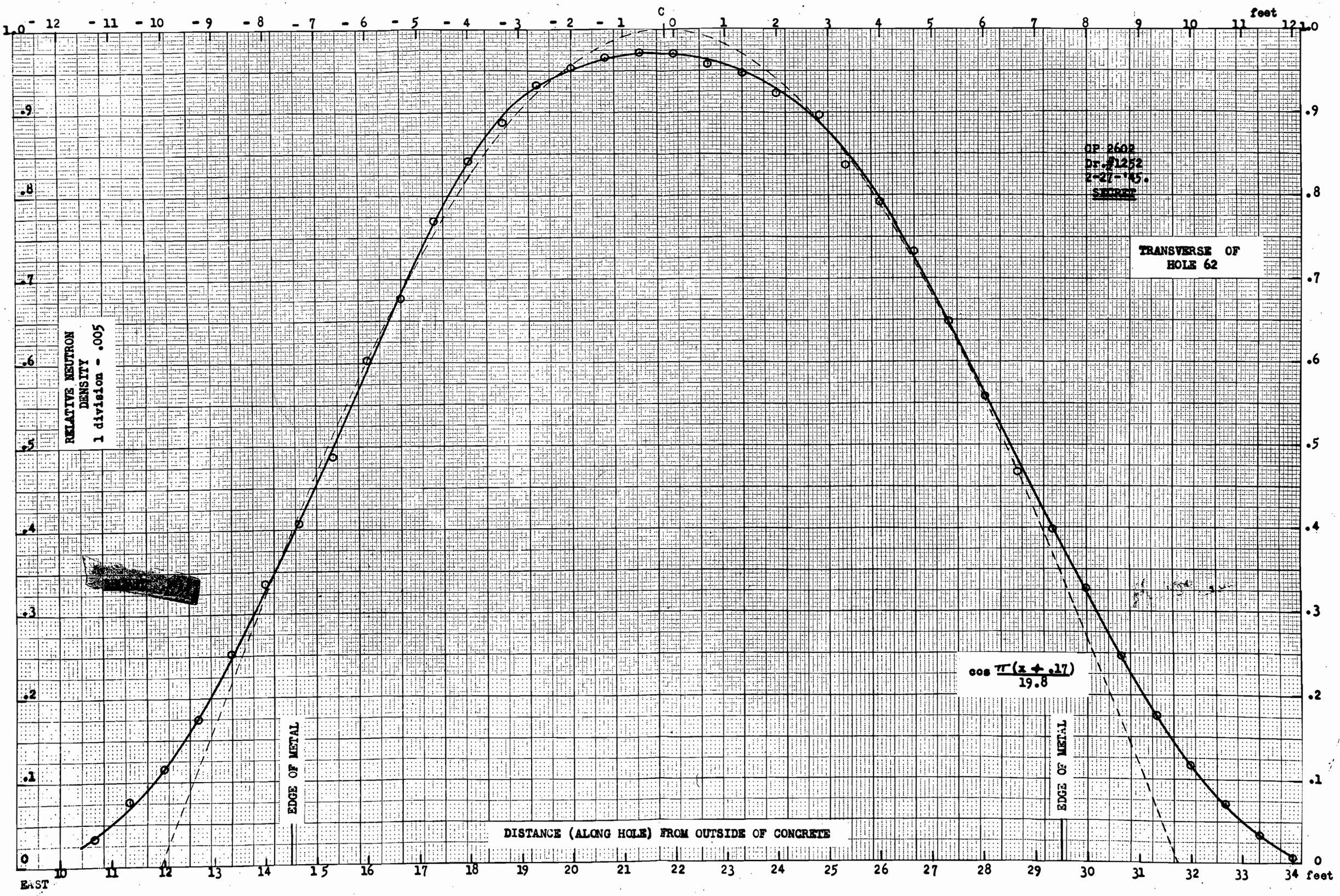


RADIUS FROM AXIS
CP 2602
TRANSVERSE OF HOLE 58
RELATIVE NEUTRON DENSITY
1 division - .002
EDGE OF METAL
EDGE OF METAL
DISTANCE (ALONG HOLE) FROM OUTSIDE OF CONCRETE
SOUTH
feet
feet


-11 -10 -9 -8 -7 -6 -5 -4 -3 -2 -1 0 1 2 3 4 5 6 7 8 9 10 11 feet
.8
.7
.6
.5
.4
.3
.2
.1
0
RELATIVE NEUTRON DENSITY
1 division = .004
TRANSVERSE OF HOLE 59
TRANSVERSE OF HOLE 53
EDGE OF METAL
EDGE OF METAL
DISTANCE (ALONG HOLE) FROM OUTSIDE OF CONCRETE
SOUTH
8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 feet

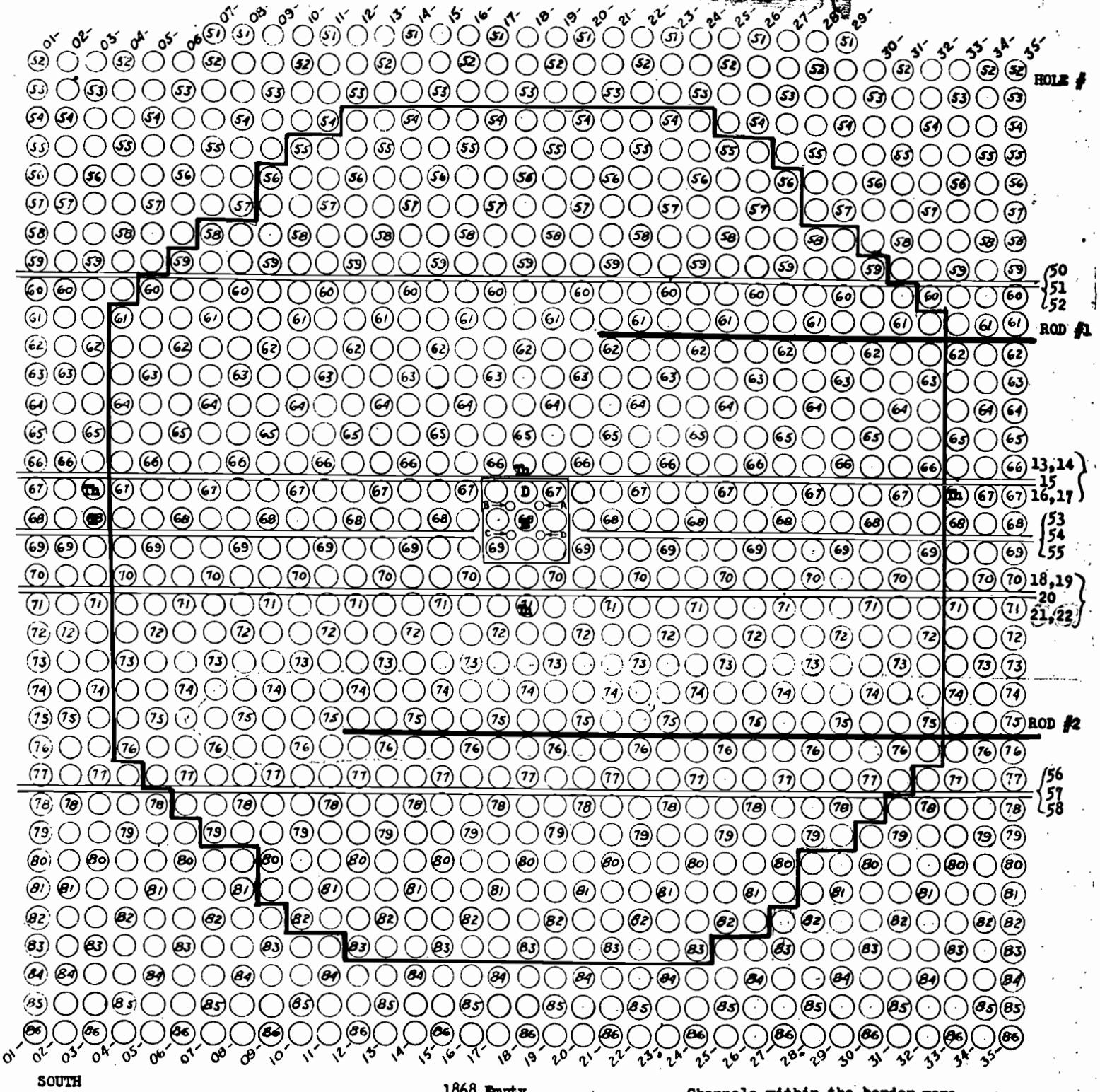

GP 2602
Dr #1250
2-27-'45
SECRET
TRANSVERSE OF HOLE 60
TRANSVERSE OF HOLE 54
RELATIVE NEUTRON DENSITY
1 division - .005
[redacted]
$.88 \cos \frac{\pi(x+.338)}{23.83}$
EDGE OF METAL
EDGE OF METAL
DISTANCE (ALONG HOLE) FROM OUTSIDE OF CONCRETE
SOUTH
feet
feet


-11 -10 -9 -8 -7 -6 -5 -4 -3 -2 -1 0 1 2 3 4 5 6 7 8 9 10 11 feet
.8
.7
.6
.5
.4
.3
.2
.1
0
CP 2602
Dr. #1251
2-27-'45.
[redacted]
TRANSVERSE OF HOLE 61
TRANSVERSE OF HOLE 55
RELATIVE NEUTRON DENSITY
1 division - .004
[redacted]
EDGE OF METAL
EDGE OF METAL
DISTANCE (ALONG HOLE) FROM OUTSIDE OF CONCRETE
SOUTH
8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 FEET


CP 2602
Dr.#1252
2-27-'45.
SECRET
TRANSVERSE OF HOLE 62
RELATIVE NEUTRON DENSITY
1 division - .005
EDGE OF METAL
EDGE OF METAL
DISTANCE (ALONG HOLE) FROM OUTSIDE OF CONCRETE
$\cos \frac{\pi(x + .17)}{19.8}$
C
feet
EAST
feet

[redacted]

CP 2602
Dr.#1253
2-27-'45.



1868 Empty
0367 7 cans $ThCO_3$
1866 15 cans $ThCO_3$
1871 15 cans $ThCO_3$
3367 7 cans $ThCO_3$
0368 24 U slugs
1867 dough-nuts of U.
Hole 15 Bi bricks.
Hole 21 usual set of samples
Hole 57 filled with H^3 factory (Li).
200 gm. over central 12 feet

Channels within the border were loaded with 44 centrally located canned U-slugs 1.1" diam. x 4".

[redacted]