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S E C R E T

Date: April 4, 1949

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Subject: Submittal of Experimental Safety-Shim Control Rod Design for the ORNL Pile

OAK RIDGE NATIONAL LABORATORY
CENTRAL FILES NUMBER
49-4-135

To: L. B. Emlet

From: C. L. Segaser

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S E C R E T

TRANSMITTAL

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TABLES

FIGURES

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April 4, 1949

To: L. B. Emlet

Subject: Submittal of Experimental Safety-Shim Control Rod Design for the ORNL Pile.

The attached drawings for an experimental combined type of safety-shim control rod, designed to ultimately replace the existing safety rods and shim rods of the ORNL Pile, are herein submitted for your comments. This rod and auxiliary shielding plug has been designed in compliance with your memorandum request of December 31, 1946 to Mr. J. A. Lane as a possible solution to the problem as outlined, i.e., to modify the existing ORNL pile shim rod and control mechanism in such a manner that a new north balcony can be installed to provide more accessible research facilities to the pile. It is anticipated that if the two existing shim rods in holes 5 and 6 can be removed to another pile location, the proposed new balcony can then be designed and installed by modifying the supporting structure for the remaining regulating rods to conform with the desired specifications of the new balcony.

Because of the unreliability with which the dimensions of the new shim-safety rod could be theoretically calculated, the decision was made to approach the problem experimentally. Therefore, the dimensions of the proposed rod are specified as large as practically possible to insert in the vertical bored holes in the graphite directly under holes 7, 8, 9, and 10. Safety-shim rods of the new design are to ultimately replace the existing safety rods in holes 7, 8, 9, and 10 pending their successful function as revealed by tests. Contingent upon the successful outcome of the tests, a suitable mechanism and new control circuit will be designed to replace the existing mechanism for the safety rod hoists.

The experimental and production capacities of the pile will be expanded by this approach since the existing holes 5 and 6, in which the existing shim rods are presently inserted, will be freed for other purposes.

Your comments pertaining to the attached preliminary prints should be returned to me for modification if required. A conference pertaining to this design may be arranged if deemed necessary. Following is a discussion of the pertinent features of the design specifications.

Chas. L. Segaser

C. L. Segaser

CLS:wj

[redacted]

[redacted]

SPECIFICATIONS FOR AN EXPERIMENTAL SAFETY-SHIM CONTROL ROD FOR THE ORNL PILE

I. General Statement of Problem

On December 31, 1948 the directors of the Technical Division Design Section (Section III) received a memorandum[1] from Mr. L. B. Emlet, directing that a study be made of the feasibility of altering the existing shim rod and shim rod drive mechanism of the ORNL Pile. The existing shim rods and mechanism, as presently installed, interferes with the erection of a proposed north balcony required to expand the research facilities of the pile. Also, the elimination of the shim rods from holes 5 and 6 in the pile should result in the freeing of these holes with consequent increased research and isotope production capacity. Contingent upon the successful solution of this problem, the Austin Company is to proceed with the design and erection of the proposed balcony.

On January 28, 1949, a preliminary meeting was held with Messrs. Ramsey, Cagle, and Tench of the Pile Operating Division, to discuss possible approaches to the problem. Several suggestions were offered, as discussed in the memorandum[2] from Segaser to Gall, dated February 1, 1949. The suggestion made by Cagle appeared to offer the best possibilities, hence, subsequent analysis has proceeded on this basis. Mr. Cagle suggested that the existing safety rods, presently located in holes 7, 8, 9 and 10 on the top of the pile, could be redesigned to function as combined safety and shim rods. If this approach should prove feasible, obviously the existing shim rods could be eliminated, and the Austin Company could proceed with the balcony design as requested. A secondary benefit will result from eliminating the accompanying shim rod hydraulic control system, since the hydraulic accumulators located in the northwest corner of the first floor of the pile building can also be eliminated, thereby making available greater floor area. During the discussion the proposed general construction of the combined experimental safety-shim rod was decided upon as well as the scope of the auxiliary work to be performed on the pile for its installation.

In order to confirm the conclusions arrived at during and subsequent to the discussion of January 28, as to the proposed design procedure and calculations, a request was made to the Physics Division for a general discussion of control rod physical problems. Dr. Jordan and Dr. Snell volunteered to discuss these problems; consequently, on March 1, 1948, Dr. Snell and Messrs. Cagle, Ramsey, and Segaser (Dr. Jordan did not attend) met in the Conference Room of Building 703-C. The problem was

[redacted]

[redacted]

stated and the following conclusions were substantiated:

1. That, whereas the size and composition of the new combined safety-shim rods might be theoretically calculated, the results of such calculations would probably be unreliable, depending on the accuracy of the data available and assumptions made; hence, the best procedure to arrive at the size of the replacement rods would be the direct experimental approach.

2. The existing 1.5% Boron-steel shim, regulating, and safety rods are essentially "black" to all thermal neutrons impinging on the surfaces.

3. A comparatively thin cadmium sheet (in the order of 10 mean free paths thick) will be black to all thermal neutrons with energies less than about 0.3 electron volt.

4. Square control rods are preferable to round since across the diagonals, the projected area is maximum for a given hole size.

II. Scope of Work

In order to properly resolve the problem as stated, the following design, construction, and experimental work must be accomplished.

1. With information obtained from construction drawings of the pile, combined with information pertaining to the effect of the existing control rods on the reactivity of the pile, and information gleaned from conferences and literature, the general overall dimensions and specifications of the new experimental combined safety-shim rods were determined. From these, the attached detail shop drawings of the rod have been prepared. (See Figure 1 - Drawing TD-1144). A work order will be executed in order that one experimental rod may be fabricated pending approval by the operating division of these drawings.

2. A new top plug for hole 7 will be required as specified by Figure 2 (Drawing TD-1139) in order to accomodate the new rod dimensions and furnish adequate radiation shielding.

3. With proper health-physics precautions not to expose workmen to excess radiation hazards, the existing top plug, safety rod, and graphite guide blocks shall be removed from hole 7 in the pile.

4. The new safety-shim rod and top plug shall be installed using the existing 1/4 inch cable and hoist for the experiment. See Figure 3 (Drawing TD-1141) for the installation.

[redacted]

[redacted]

5. The new combined rod shall be calibrated for inhours per inch of travel against the previously calibrated regulating rod. This work shall be done under the strict supervision of Mr. Ramsey.

6. The new rod shall be test dropped a distance of 16'-0" on a 1" x 4" x 4" 2-S aluminum impact plate resting on a stack of 4 inch square graphite blocks to simulate the effect on the rod and graphite in the event of a mechanical failure and the rod should fall unchecked in the pile for this distance.

7. A new hoisting device and revised control circuit shall be designed for the new rods assuming the tests are satisfactorily performed.

8. With the approval of the installation of the new rods and controls, the old shim rods and mechanism may be removed and work initiated on the new balcony.

III. Existing Control System of the ORNL Pile

The ORNL graphite pile is controlled by the introduction of absorber to lower k. Three different functional names have been given to these; (1) Safety rods, which ordinarily can be fully withdrawn without the pile becoming critical, represent an extra factor of safety and also are of value in rapid shutdown. (2) The shim rods, which are large absorbers, control most of the excess reactivity built into the pile to override fuel depletion, experiments, xenon and other fission product poisoning, large temperature effects, etc. (3) Regulating rods, which generally are low inertia rods, useful in control of small effects such as those due to cooling air barometric changes, temperature changes, and humidity[3]. Also, in an extreme emergency, Boron-steel pellets can be scattered in the pile for shutdown.

Figure 4 shows diagrammatically, the location of the existing shim and regulating rods in relation to the fully inserted and fully withdrawn positions. Figure 5 is a similar diagrammatic sketch of the existing safety rods. Table I lists the specifications and characteristics of these rods. Recently, the reactivities of the X-10 control rods were calibrated by a group from Massachusetts Institute of Technology, the results of which are presented in the memorandum report, BNL-LOG-2562[4]. Figure 6 and Figure 7 are reproduced from this report in order to aid in the calibration of the new experimental safety-shim rod. Figure 6 shows the reactivity of regulating rod No. 1, as a function of rod position, and Figure 7 is a similar calibration curve for Regulating Rod No. 2. The reactivity in inhours of each rod was calculated from the inhour equation of Hughes, et al (Physical Review, January 15, 1948) as follows[5]:

$$\text{Inh.} = \frac{54}{T} + \frac{20.3}{T + 0.62} + \frac{204}{T + 2.19} + \frac{535}{T + 6.5} + \frac{2036}{T + 31.7} + \frac{787}{T + 80.3}$$

[redacted]

[redacted]

The significance of the inhour and the meaning of the terms in the above equation is discussed in Appendix I.

Since the affectiveness of a control rod is also a function of the value of the square of the average neutron flux in which it is inserted[3], it is of interest to show the variation of thermal neutron flux along the axis of the existing shim and safety rods in the ORNL pile. It may be noted from Figure 6 and Figure 7 that the inhours of each rod does not vary linearly with distance, but is apparently an exponential curve, as intimated by the above expression. It is claimed that the approximate formulae[6],

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

can be used to determine roughly the sensitivity of the existing control and shim rods. In this formula,

X = Displacement in inches of the control rod in the direction of the pile axis.

R = Radial coordinate in inches $= \sqrt{y^2 + z^2}$

No attempt has been made to correlate this equation with the experimental results given in BNL-LOG-2562. The statement is also made that with proper precautions, this expression could be applied to the determination of the poisoning effect of any neutron absorber placed within the pile. These precautions were not elaborated upon, hence, the above equation should be applied with caution.

The relative neutron densities throughout the ORNL pile may be determined from the equation[6],

$$\rho = 0.88 \cos \frac{\pi(r + 0.338)}{23.83} \cos \frac{\pi(x + 0.172)}{19.8}$$

Where r = Radial displacement, ft.
x = Displacement along the axis, ft.

The coordinate system from which the above values are measured has been established with its origin at the geometrical center of the pile loading. Positive directions for the axes are north, west and up.

The value of the absolute thermal neutron flux at the geometrical center of the ORNL pile has been established to be[6],

$$nv_0 \text{ watt}^{-1} = 3.234 \times 10^5 \text{ thermal neutrons cm}^{-2} \text{ Sec}^{-1} \text{ watt}^{-1}$$

From these relations, the value of nv (flux at any particular spot in the pile may be obtained. Hence, the value of nv along the position

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[redacted]

TABLE I

CHARACTERISTICS OF CONTROL RODS

ORNL PILE

	Existing				Proposed - to eliminate Shim Rods in Holes 5 & 6
	Regulating Rods	Shim Rods	Safety Rods	Safety Tubes	Experimental Shim-Safety Rod
Number	2	2	4	1	4
Location	Holes No. 1 and No. 2.	Holes No. 5 and No. 6.	Holes 7, 8, 9, and 10.	Hole 12	Holes 7, 8, 9, and 10.
Inhours	#1 - 185 #2 - 145 330 Total.	235 each, 470 Total.	105 each, 420 Total.		222 each, 888 Total.
Direction of Travel	Horizontal	Horizontal	Vertical	Vertical	Vertical
Material	1.5% Boron Steel	1.5% Boron Steel	1.5% Boron Steel	1.5% Boron Steel	1/16 in. thick Cadmium sheet.
Size and Shape	1.75 in. sq. bar x 19'-0" Lg.	1.75 in. sq. bar x 19'-0" Lg.	1.5 in. dia. x 8'-0" Lg. rod	5/16 in. dia. pellets	3-3/4 in. x 3-3/4 in. sq. rod x 9'-0" Lg.
Method of Operation	Direct electric motor driven.	Hydraulic cylinder; normal operation - pump; emergency accumulator.	Gravity when latch solonoid de-energized. Out by electric motor.	Gravity, when plunger raised from bin outlet by cable manually operated.	Normal operation - electric motor. Emergency - gravity when electric clutch de-energized.
Travel into Pile	Out: To 1'-0" outside North face, in shield. In: To within 5'-0" of South face.	Out: To 1'-0" outside North face, in shield. In: To within 5'-0" of South face.	In: 4'-0" below and 4'-0" above pile center Out: Just withdrawn from graphite.	In: 5'-0" below &12'-2" above pile center. Out: Bin located in top shield.	In: 4'-6" below & 4'6" above pile center. Out: Dragging top of graphite - 12 in.
Speed of Travel	#1 Max. in 6.9 in./sec. Max. out 6.9 in./sec. #2 Max. in 4.76 in./sec. Max. out 4.76 in./sec. Min. in 0.044 in./sec. Min. out 0.044 in./sec.	In: Normal - 6 in./sec. Emergency - full travel in 4 seconds. Out: 1-in./sec.	About 3 or 4 seconds for full travel.	About 19 seconds to fill tube.	Normal: 1 - in./sec. in or out. Emergency: About 1 sec. for full travel.
Guide Tube	2-1/4" x 2-1/4" sq. openings out into graphite blocks.	2-1/4" x 2-1/4" sq. openings out into graphite blocks.	2 in. diameter circular opening cut into graphite blocks.	1.75 in. O.D. x 0.083 in. wall aluminum tube 17'-2" Lg.	4" x 4" sq. opening out into graphite blocks.

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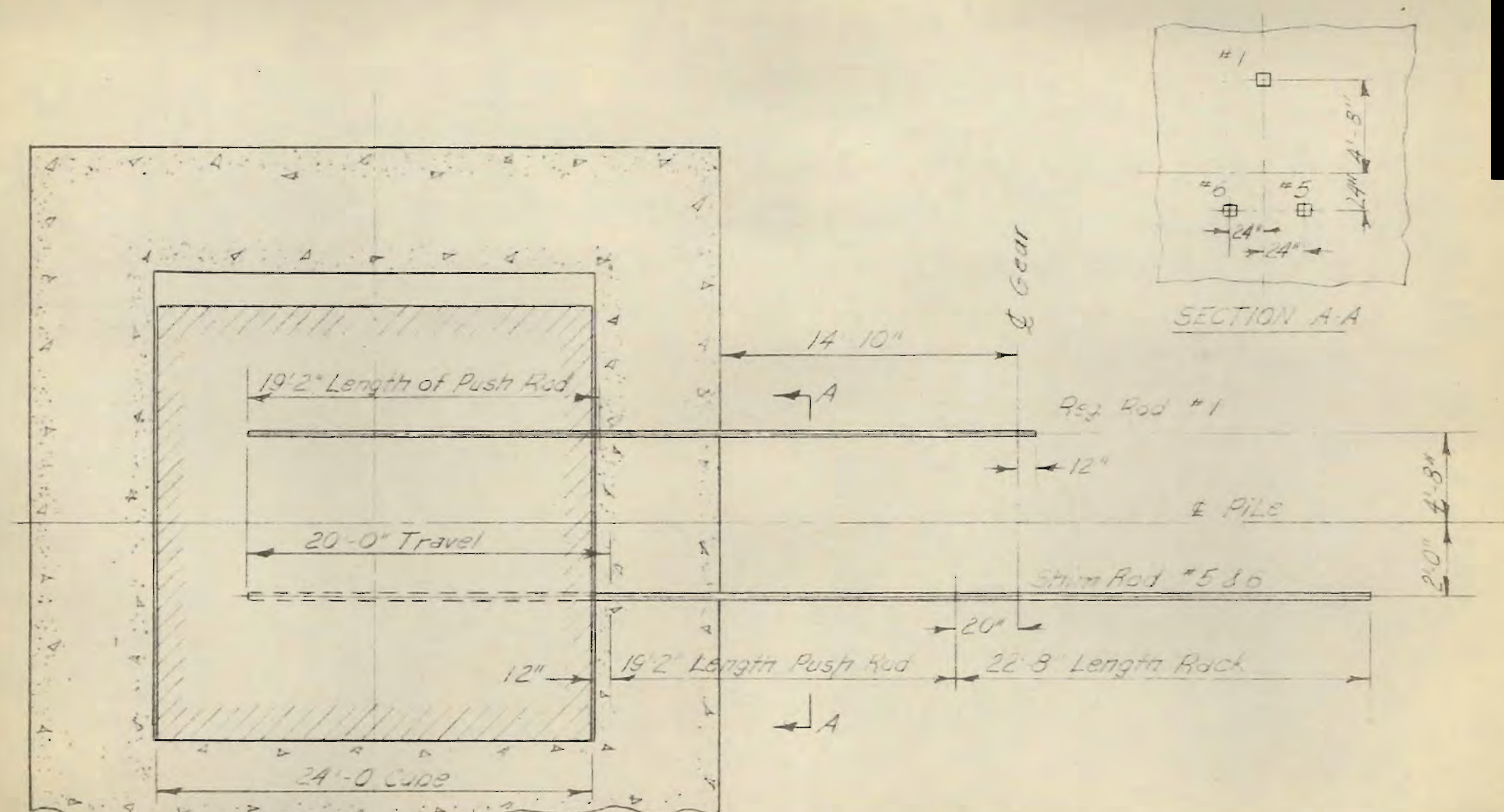

DIAGRAM SHOWING FORWARD & BACK POSITIONS OF EXISTING SHIM & REGULATING RODS WITH FEED RACKS

FIG. 4

Drawing # 7013

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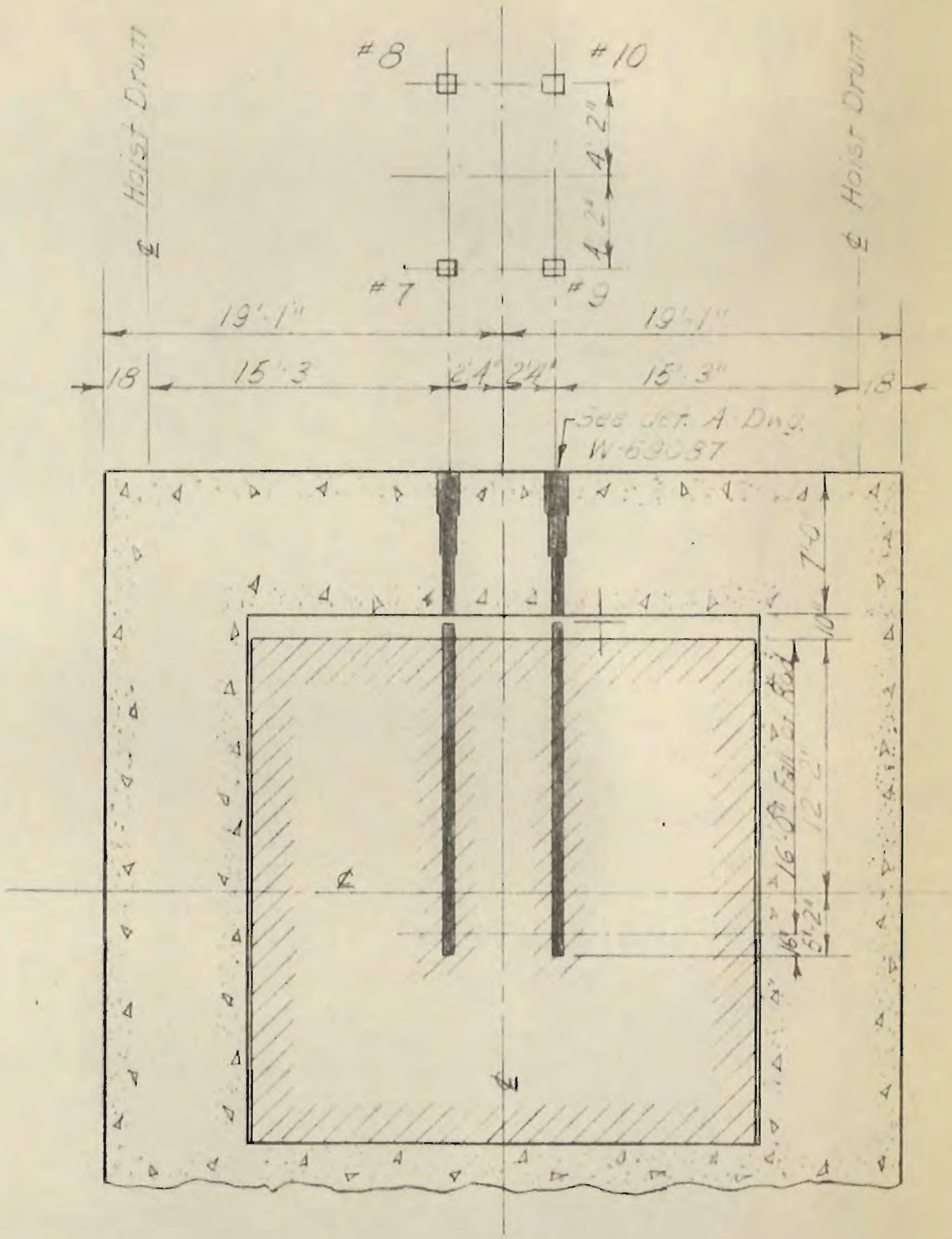

N-S SECT. THRU PILE SHOWING

SAFETY ROD HOLES

FIG. 5

[redacted]

[redacted]

occupied by shim rod No. 5 at a pile power of 3600 kw may be determined by substitution of values.

At 3600 kw, the thermal flux in the geometrical center of the pile is,

$$nv_o = (3.234 \times 10^5)\ (3.6 \times 10^6)$$

and, $nv_o = 1.16 \times 10^{12}$ neuts/cm²/sec.

No. 5 shim rod enters from the north face along a constant coordinate of 2'-0" from the pile center, and r varies as follows:

$$r = \sqrt{y^2 + 4}$$

Substituting in the relative neutron density equation

$$\rho = 0.828 \cos \frac{\pi(\sqrt{y^2 + 4} + 0.338)}{23.83}$$

$$\underline{nv}_{th} = \rho \cdot \underline{nv}_o = 1.16 \times 10^{12} \rho$$

Upon substitution of values, solving and plotting results, the curve of Figure 8 is obtained showing the thermal flux distribution along the axis of No. 5 shim rod at a pile operating level of 3600 kw. Integrating the area of the curve over the distance traveled by the rod gives an average neutron flux seen by the rod of 0.634×10^{12} neuts/cm²/sec.

A similar analysis gives as the value of the thermal flux along the axis of a safety rod,

$$\underline{nv}_{th} = 0.789 \times 10^{12} \cos \frac{\pi(\sqrt{z^2 + 5.43} + 0.338)}{23.83}$$

from which the average value of the thermal flux seen by a safety rod at 3600 kw output may be computed as,

$$nv_{th} = 0.512 \times 10^{12} \text{ neuts/cm}^2\text{/sec.}$$

The variation of neutron flux along the axis of any safety rod in the ORNL pile is shown by Figure 9.

From the average values of neutron flux seen by the shim rods and safety rods, one would expect the shim rods to be effective only in the ratio of the square of the average fluxes seen by the rods provided the shim rods were bodily transported from their existing positions in holes 5 and 6 to say holes 7 and 8. Hence, a shim rod, if placed in a safety rod hole, should be expect to be only,

$$\frac{(0.512 \times 10^{12})^2}{(0.634 \times 10^{12})^2}$$

or 65.5 less effective in pile control.

[redacted]

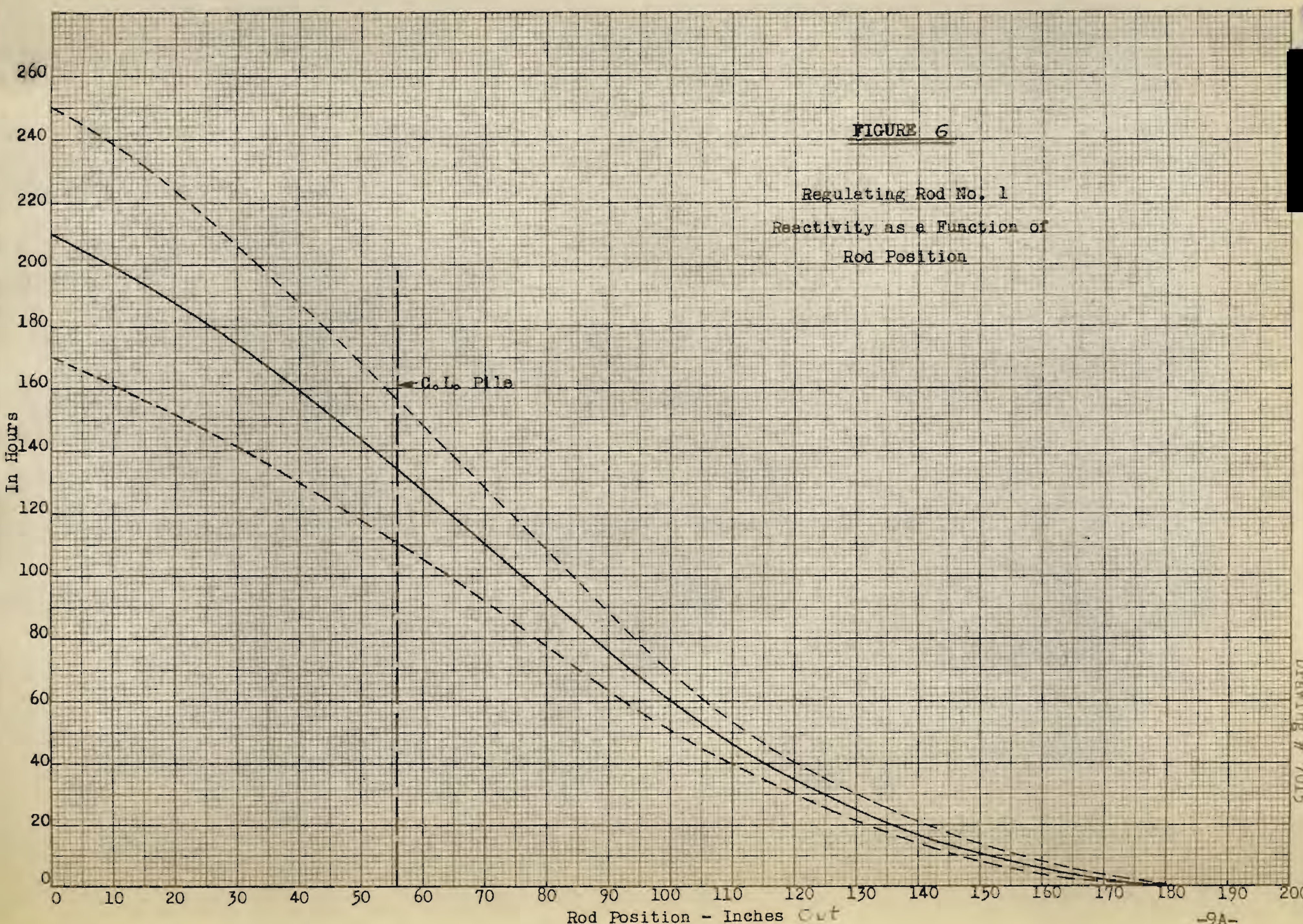
FIGURE 6
Regulating Rod No. 1
Reactivity as a Function of
Rod Position
C. L. Pile
In Hours
Rod Position - Inches Out
0
20
40
60
80
100
120
140
160
180
200
220
240
260
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
180
190
200
Drawing # 7015

[redacted]

[redacted]

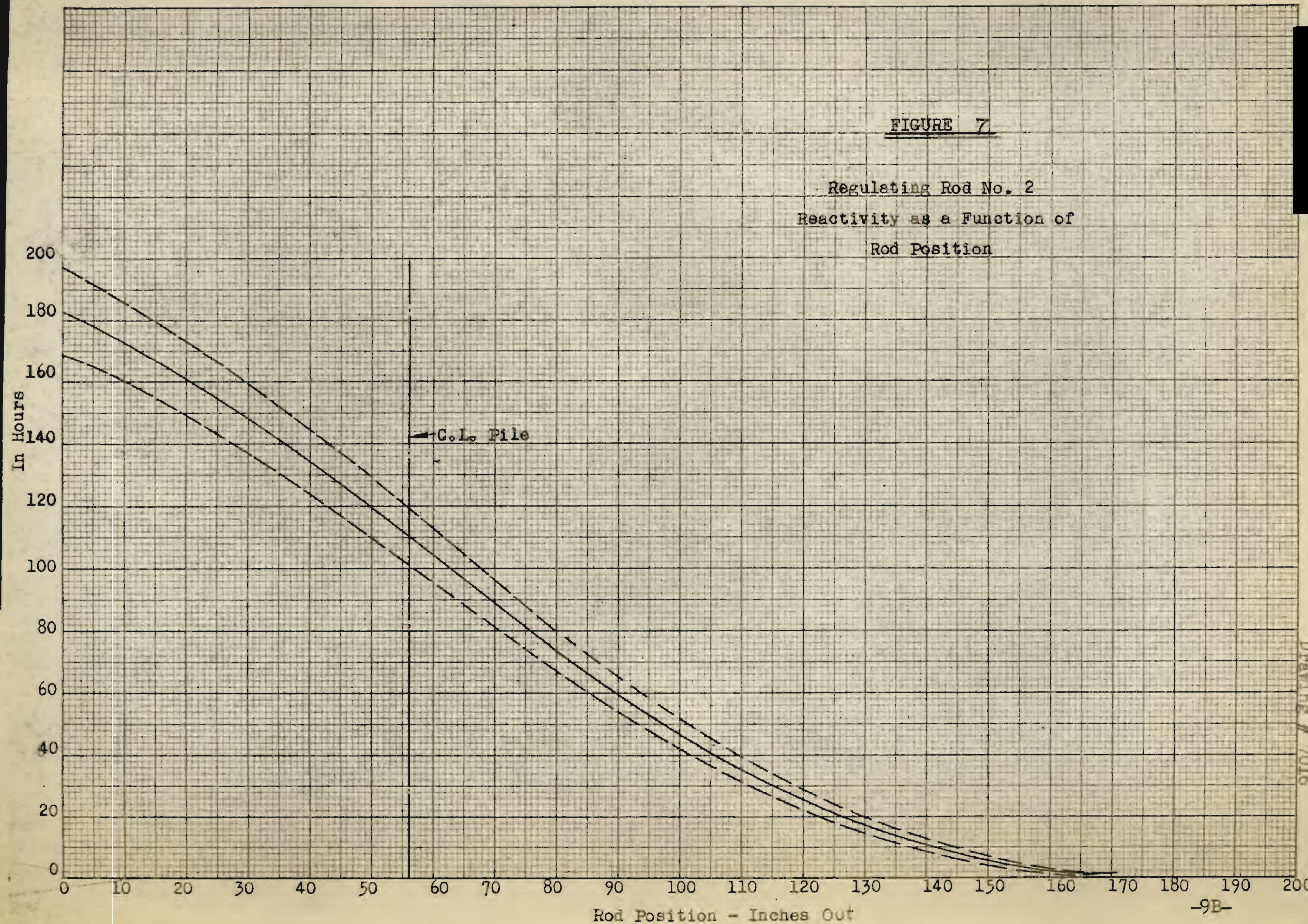
FIGURE 7
Regulating Rod No. 2
Reactivity as a Function of
Rod Position
In Hours
200
180
160
140
120
100
80
60
40
20
0
C.L. Pile
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
180
190
200
Rod Position - Inches Out
Drawing # 7016

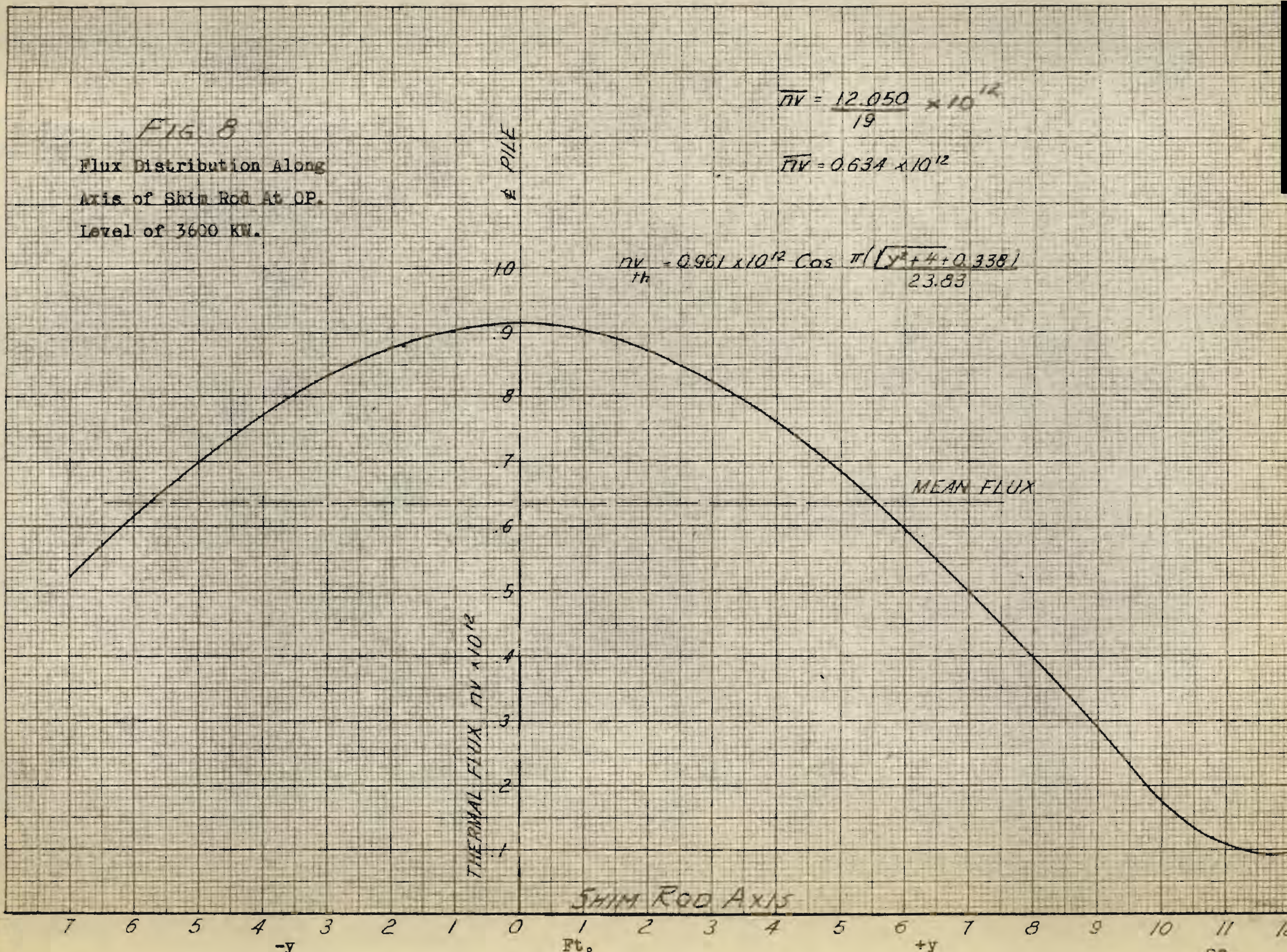

FIG. 8
Flux Distribution Along Axis of Shim Rod At OP. Level of 3600 KW.

Drawing # 7017

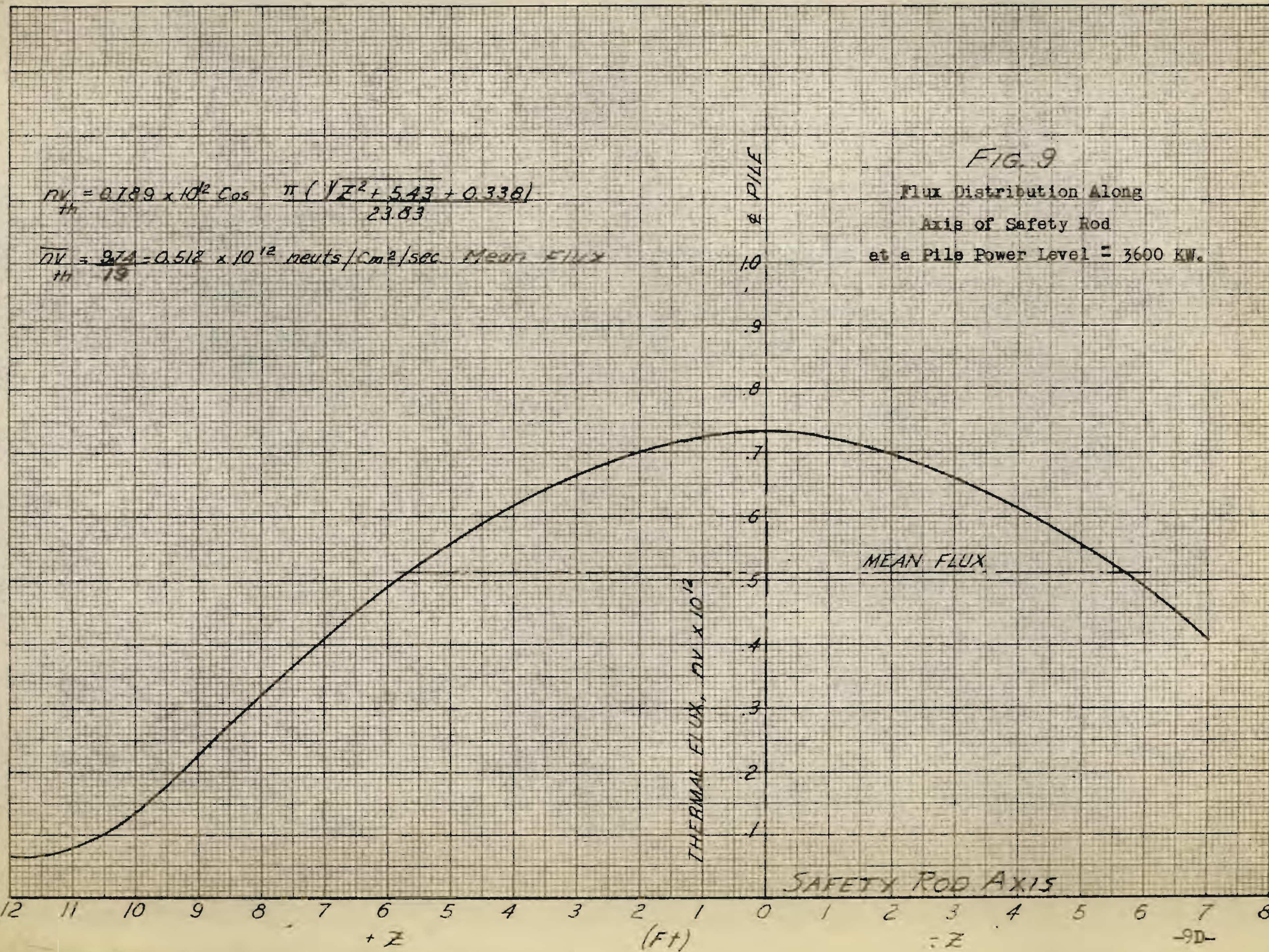

FIG. 9
Flux Distribution Along
Axis of Safety Rod
at a Pile Power Level = 3600 KW.

[redacted]

Drawing # 7018

[redacted]

IV. Determination of Cadmium Requirements for New Safety-Shim Rod

Thick cadmium has the property that practically all neutrons with energies less than about 0.3 electron volt which impinge against its surface are absorbed, hence, cadmium is very suitable as a control material for thermal piles which are operated at comparatively low temperatures. Kay Way lists the cross-section of cadmium for thermal neutrons as 2900 barns[7], but physically, cadmium does not compare favorably to Boron-steel for applications where strength and temperature are critical. A few of the physical characteristics[8] of cadmium are listed in Table 2.

TABLE 2

PHYSICAL PROPERTIES OF CADMIUM

Atomic Weight	112.41
Density of 20°C	8.65 Gm/cm^3 or 540 lb/ft^3
Melting Point	320.9°C or 609.6°F
Coefficient of Thermal Expansion	0.00001755 per °F
Thermal Conductivity	624 Btu/hr/ft^2/°F/in.
Specific Heat	0.0570 Btu/lb/°F
Tensile Strength	12,000 lb/sq in.
Elongation in 2 in.	52%
Reduction of Area	80%
Modulus of Elasticity	10,000,000
Brinell Hardness No.	21-24

For isotropically distributed thermal neutrons, the total neutron cross-section of a cadmium rod may be obtained from its geometrical dimensions. The equation for this relation is[9],

$$A = 1/4 \pi D l$$

Where A = Total cross-section, Cm^2
D = Diameter of rod, Cm
l = length of rod, Cm

In estimating the dimensions of the experimental safety-shim rod, the assumption is somewhat arbitrarily taken that this equation holds also for a Boron-steel rod in that the Boron-steel rods are also considered black to thermal neutrons.

From Table I, the following total reactivity of the rods is obtained,

4 safety rods @ 105 inh.	420 Inh.
2 shim rods @ 235 Inh.	470 Inh.
Total	890 Inh.

[redacted]

Hence, the new combined experimental safety-shim rod should have a reactivity of

$$\frac{890}{4} \approx 220 \text{ inh.}$$

The new rod is to be inserted in the same position in the pile as presently occupied by the existing safety rod No. 7. Assuming the existing rod is "black" to thermal neutrons, and that the equation $A = \frac{\pi}{4} Dl$ is also valid for the 1.5% Boron rod, substitution of values gives,

$$A = \frac{\pi}{4} (3.82)(244)$$

$$A = 731 \text{ Cm}^2 \text{ cross-section per rod.}$$

Hence, the effect of the existing safety rod is

$$\frac{731}{105} = 6.95 \text{ Cm}^2/\text{Inh.}$$

If the new safety-shim rod is assumed to have the same effect, the total cross-section required is

$$A = (6.95)(220) = 1530 \text{ Cm}^2 \text{ per rod}$$

But, $A = \frac{\pi}{4} D\,l$

Hence, $D = \frac{(4)(1530)}{(\pi)(244)}$

or $D = 8$ Cm $= 3.14$ In. Dia. for the same length rod.

Therefore, it would appear that a square section of cadmium, 3-5/8 inches on the side, would be more than adequate to replace the existing safety rods and shim rods from a purely absorptional point of view, neglecting the effect on neutron leakage due to the new rod effective diameter.

Cadmium sheets approximately 1/16 inch thick, and of a size large enough to obtain the necessary strips for the safety-shim rod, are obtainable on the area. These sheets are of the order of 18.4 mean free paths for capture of thermal neutrons thick. The fraction of neutrons which will penetrate unabsorbed to thickness t is,

$$\text{Fraction unabsorbed} = e^{-\Sigma_a t}$$

substituting values,

$$\text{F.U.} = e^{(-115)(.16)}$$
$$\text{F.U.} = e^{-18.4}$$
$$\text{F.U.} = 0.00000001$$

[redacted]

[redacted]

This fraction is of such negligible value that for practical purposes it may be ignored and, therefore, a cadmium sheet 1/16 inch thick may be considered to capture every thermal neutron impinging upon its surface.

V. General Description of Experimental Safety-Shim Rod

The new experimental safety-shim rod is to replace the existing safety rod in hole 7, and is designed for the largest practical dimensions which can be inserted in the 4 inch vertical hole in the graphite directly below hole 7. The new rod is to have a maximum overall length of 9'-0" and will have a square section of 3-3/4 inches on the side to provide a 1/8 inch clearance all around with the graphite. The general construction and detail specifications of this rod are shown on Figure I (Drawing TD-1144). The rod will be of sandwich-type construction with the cadmium absorber inserted between an outer sheath of 16 gauge sheet steel and an inner backing of 1/8 aluminum plate. This construction was chosen to provide adequate support for the cadmium which of itself would not be self supporting. The rod is designed with the thinnest gauge sheet steel which is judged to be consistent with the necessary rigidity in order to obtain a minimum rod weight. Even so, the estimated weight of the rod is calculated to be 95 pounds, as compared to the weight of the existing safety rod of 48 pounds. A spring shock absorber has been designed into the rod in order to protect the graphite in case of overtravel of the rod on rapid insertion. Also, the shock absorber is capable of absorbing an appreciable fraction of the energy of free fall if the 1/4 inch cable should accidently fail and the rod should fall into the pile under the acceleration of gravity.

VI. Top Plug Radiation Shield

In order to accomodate the new rod dimensions and provide adequate radiation shielding, it has been necessary to specify a new top plug. The detailed specifications of this plug are shown on Figure 2 (Drawing TD-1139). The plug will be fabricated from structural steel sections and will be of the same general size and shape as the existing plug. Radiation shielding is obtained by pouring structural concrete of the same mix as the concrete shielding presently surrounding the pile into the space between the outer sheath and the inner 4 inch square entrance tube.

VII. Control Rod Hoisting Mechanism

The new safety-shim rods will require a mechanism capable of positioning and accurately maintaining the rods at any predetermined position relative to the pile axis and, which will also instantly release the rods such that they will fall into the pile under the force of gravity in case of emergency for rapid shutdown. The construction of the existing mechanism does not readily permit adaptation to these requirements.

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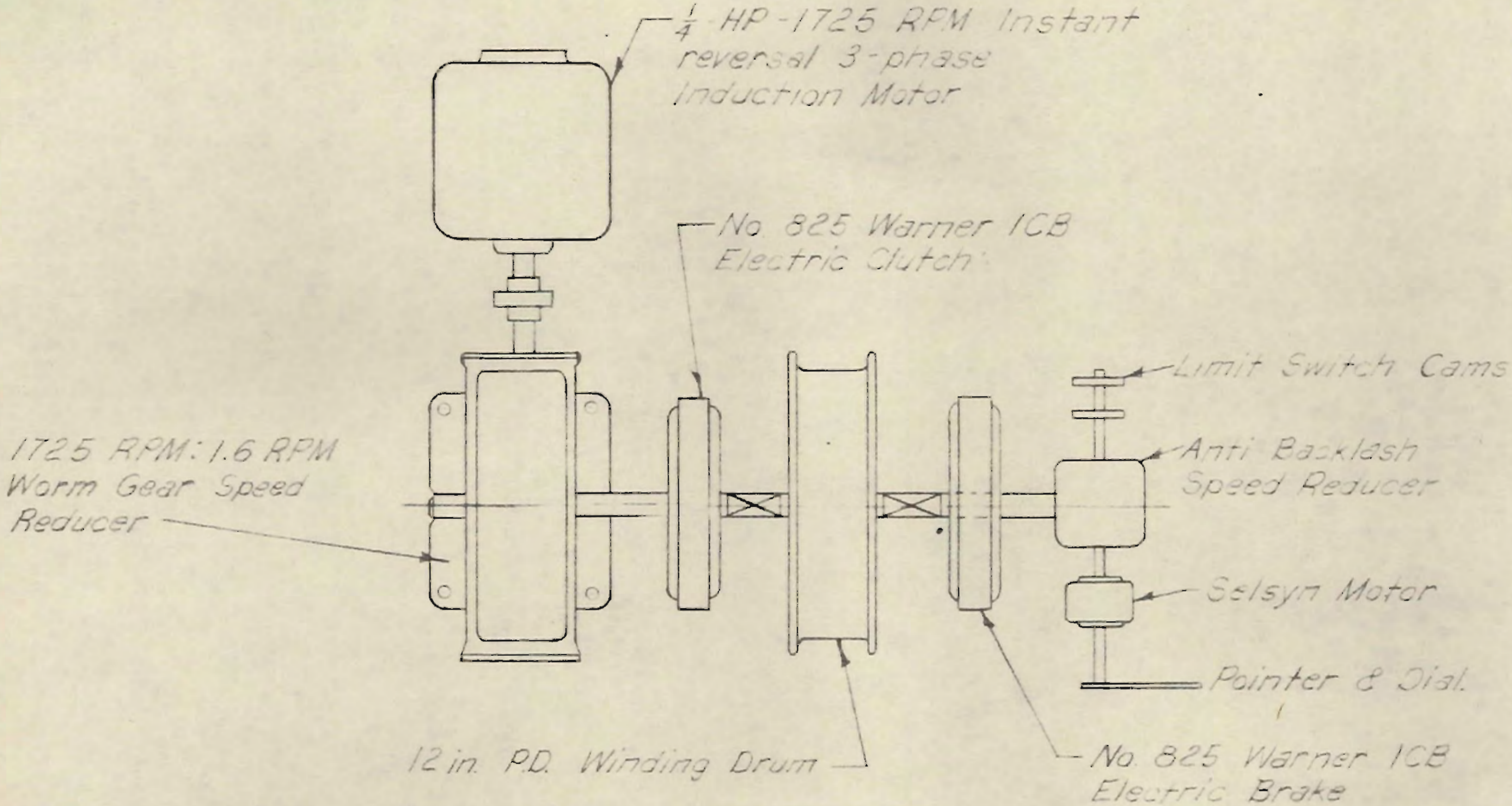

SCHEMATIC DIAGRAM OF SUGGESTED HOISTING MECHANISM FOR NEW SAFETY SHIM RODS

UNCLASSIFIED

Drawing # 7014

FIG. 10

[redacted]

A system comprised of the elements represented schematically by Figure 10 is suggested as a suitable hosting mechanism for the new safety-shim rods. This system will be assembled almost entirely from standard items of power transmission equipment as follows:

1. Motor A three-phase 1800 RPM synchronous speed induction motor wired for instant reversal is recommended. The normal speed of travel out for the shim rod is 1 inch per second. Therefore, the required horsepower is,

$$Hp = \frac{(95)(1/12)}{550} = 0.0145$$

at an assumed overall efficiency of 65%, the motor horsepower is,

$$Hp = \frac{0.0145}{.65} = 0.0223$$

2. Speed Reducer Assuming a 12 inch pitch diameter cable-drum, winding at a rate of 1 inch per second, the RPM of the drum and output shaft of the speed reducer is,

$$N = \frac{S \times 60}{2\pi R}$$

Where N = RPM of drum
S = surface speed, inches per sec.
R = radius of drum, inches

Substituting, $N = \frac{(1)(60)}{(6)(2\pi)}$

and, $N = 1.6$ RPM

The torque rating of the speed reducer is,

$$T = (6)(95) = 570 \text{ inch pounds.}$$

3. Electric Clutch and Brake A size 825 ICB Warner Composite Clutch Brake System is suggested for control of the hoisting drum. The clutch shall be inserted between the output shaft of the speed reducer and the drum, with the magnet coupled to the speed reducer output shaft and the clutch armature coupled to the drum. The brake shall have the armature coupled to the drum and the magnet to the drum support or housing. Under normal conditions, the brake shall be de-energized and the drive shall be through the clutch. Upon receiving an emergency signal from the pile, the clutch shall be immediately de-energized and the rod shall fall by gravity to a point near its full travel, whereupon a limit switch shall be made to actuate the brake in order to stop the rod before impact with the graphite. The manufacturers of the Warner electric brake and clutch claim instant operation, constant self adjustment, infinite control, high heat dissipation, compact installation, few

[redacted]

[redacted]

parts and low power requirements; attributes which apparently are suitable for a control rod drive installation.

4. Hoist Drum The hoist drum shall have a 12 inch pitch diameter and shall be grooved for a 1/4 inch diameter flexible stranded-steel cable. The width between flanges shall be adequate to take 16 feet of cable. Assuming a 1/2 inch pitch between grooves, the number of turns required and the width between flanges shall be

$$N = \frac{16 \times 12}{12 \times \pi} = 5.1 \quad \text{say 6 turns.}$$

Allowing 1/2 inch at either end between the last groove and the flange, the minimum distance between flanges is 3-1/2 inches.

5. Position Indicator and Limit Switch Acturator A 5.1 to 0.750 anti-backlash reducing gear unit shall be coupled to the drum shaft for a positioning indicator device and a limit switch cam stop. The positioning indicator shall consist of an electrical indicating device (Selsyn Motor and Drive) for remote indication at the instrument control panel, and a dial mounted directly on the hoist support housing for direct reading. An extension of the indicator shaft opposite the reducing gears shall be used for mounting the limit travel switch cams.

6. All units comprising the rotating or moving parts of the hoisting unit shall be mounted on anti-friction bearings and shall be of as low a moment of inertia as is consistent with strength requirements.

7. Suitable control circuits and power source shall be provided for the clutch brake drum hoist unit, as well as for the speed reducer drive motor.

VIII. Control Rod Calibration

The effect of inserting an absorber in the pile may be obtained by observing the displacement of a regulating rod required to return the pile to the critical condition[9]. The pile is considered to be in the critical condition when the neutron intensity remains constant. This condition is achieved when the average number of neutrons produced from one original neutron in a chain reaction is unity, and this number is called the reproduction factor, k. The value of k depends on the balance of neutron production, absorption, and leakage.

[redacted]

[redacted]

In the ORNL pile, the critical condition is obtained by the adjustment of one or more rods of high neutron absorption cross-section. When the value of k is slightly larger than unity the neutron intensity will drift upwards, while with k slightly less than unity, the neutron intensity will drift downward. The reactivity is a measure of the excess of k over unity. For $k-1 = 2.5 \times 10^{-5}$, the neutron intensity will increase with a period of about one hour. For pile periods very long, compared to the longest delayed neutron period, (k-1) is inversely proportional to the period. For a given change in reactivity, the displacement of a control rod required is not always the same, but depends on the position of the control rod in the pile. For this reason the inhour unit of reactivity has been introduced. With this unit, displacements of the rod measured in inhours are always proportional to (k-1). In order to provide a precise definition of such a unit, use is made of the property of a pile that its period is proportional to $\frac{1}{(k-1)}$ in the limit of long periods. Accordingly, the unit of rod position was given the name inhour (from "inverse hour", symbol: ih.) with the significance that when the control rod is displaced from the critical position by one inhour, the pile will have a period of one hour. (The neutron density will increase by a factor of e in one hour).

[redacted]

[redacted]

APPENDIX I

The Inhour[9] - The inhour is proportional to (k-1), thus,

$$ih = C(k-1)$$

where the value of C is given by

$$C = \lim_{k \to 1} \frac{1}{T(k-1)}$$

and T is the period of the pile in hours.

The relation between the displacement from criticality in inhours and the period of the pile, may be obtained from the intensities and periods of the delayed neutron emission. For the ORNL uranium-graphite pile, the following equation is used:

$$ih = \frac{54}{T} + \frac{20.3}{T + 0.62} + \frac{204}{T + 2.19} + \frac{535}{T + 6.5} + \frac{2036}{T + 31.7} + \frac{787}{T + 80.3}$$

where T is the period of the pile in seconds. The numbers in the denominators are the periods of the various delayed neutron emissions in seconds. Because of the way in which the inhour is defined, the accuracy with which this equation gives the period becomes greater for larger and larger values of the period. This formula is adjusted to equal unity for T = 3600 secs.

Calibrations of a control rod may always be effected with the use of this formula by observing the period of the pile for a given displacement of the control rod from the critical position. The value of the inhour is measured from its zero value corresponding to the control rod out of the pile.

The inhour is useful as a measure of rod displacement because it is a measure of pile reactivity which is independent of the position of the control rod, so that linear interpolations are accurate in comparing the effects of different absorbers. Moreover, its value has an almost unambiguous significance for all graphite-uranium piles.

The value of the constant C is known for uranium-graphite piles to be

$$C = 2.5 \times 10^{-5} \text{ hours}^{-1}$$

with an accuracy of about 20 percent.

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Appendix 2

Stress Analysis

1. Cable Support. - A $\frac{1}{4}$-in. dia. extra flexible (Composed of 8 strands - a hemp center - 19 wires to the strand) plow steel hoisting rope is recommended. The breaking strength of this rope is 2.15 Tons and the maximum safe working load is 0.40 Tons.

The static load on the cable due to the weight of the safety-shim rod is 95-Lbs. The safe working load of the cable is 800-Lbs.

The maximum rate at which the rod can be decelerated to not exceed the safe working load of 800-Lbs is,

$$F = \frac{W}{g} a$$

where F = Force on cable, Lbs.
W = Weight of rod, Lbs.
a = Deceleration, Ft/sec^2
g = 32.2

Since the cable must support the static load of 95-Lbs,

$$F = 800 - 95$$
$$F = 705 \text{ Lbs}$$

Substituting,

$$a = \frac{(705)(32.2)}{95}$$

$$a = -239 \ Ft/sec^2$$

SUBJECT Stress Analysis - Experimental Shim-Safety Rod, ORNL Pile
J.O. No. ______
SK- ______

The current rise of the Warner ICB brake-clutch unit follows a curve which has a time base of approximately one-tenth second. If it is assumed that the rod is brought to rest in this time, the rod shall have traveled a distance of,

$$S = \frac{1}{2} a t^2$$

$$S = \left(\frac{1}{2}\right)(239)(0.1)^2$$

$$S = 1.19 \text{ Ft.}$$

if decelerated at a rate of 239 ft/sec².

The $\frac{1}{4}$-in. cable is connected to Item 13 of the rod by means of an American Cable Co. "Tru-Lock Fitting" swaged and soldered to the cable. The fitting attaches to Item 13 with a $\frac{7}{16}$-14NC-2 thread.

Minor Diameter = 0.345-in.

$$\text{Root Area} = \frac{\pi}{4}(.345)^2 = 0.0933\text{-in}^2$$

$$\text{Tensile Stress @ Root} = \frac{800}{0.0933} = 8{,}570 \text{ Psi}$$

Factor of Safety based on ultimate strength of 60,000 Psi.

$$F.S. = \frac{60{,}000}{8{,}570} = 7$$

The thread will not fail by shear since the depth of the tapped hole is,

$$\frac{1.125}{.438} = 2.57$$

times its major diameter. A tapped hole of depth equal to diameter develops the full strength of the thread.

SUBJECT: Stress Analysis - Experimental Shim-Safety Rod, ORNL

J.O. No. ______
SK- ______

2. Stress Induced in Housing (Item 9).-

The weight of the rod will be supported in tension by the Housing (Item 9). Assuming the deceleration load of 800 Lbs,

$$S_t = \frac{800}{(4)(3.750)(.062)}$$

$$S_t = 860 \text{ Psi.}$$

and, $F.S. = \frac{60,000}{860} = 70$

The permissable unit stress through the throat of a butt weld is 16,000 Psi. The factor of safety of the welded joint between Item 9 & Item 13, therefore, is:-

$$F.S. = \frac{16,000}{860} = 18.6$$

3. Shear Stress in Screws - Item 6.- Twenty No. 5-40NC Flat Head steel machine screws are specified to support all of the weight of the rod with the exception of Item 9 & Item 13. The static load on these screws is, then;-

$$95 - \text{Wt. (Item 9 + Item 13)}$$

$$= 95 - (3.5 + 27.3) = 64.2 \text{ Lb.}$$

The inertia load of decelerating 64.2 Lb. at -239 Ft/sec² is,

$$F = \frac{64.2}{32.2} \times 239$$

$$F = 477 \text{ Lb.}$$

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Root diameter of No. 5-40 NC screw:-

Minor diameter = 0.0925

" Area = $\frac{\pi}{4}(0.0925)^2$

" " = 0.00672 in^2

Root area of 20 screws = (20)(.00672)

= 0.134 in^2

Stress = $\frac{477}{0.134}$ = 3560 Psi.

Factor of Safety = $\frac{60,000}{3560}$ = 17

4. Shock Absorber Springs:-

(a) Outer Spring:- Outside Diam. = $1\frac{7}{8}$ in.
Inside Diam. = $1\frac{1}{8}$ in.
Diam. wire = 0.375
Pitch Diam. = 1.500 in.

For an assumed design stress of 90,000 Psi.,

$$P = \frac{S\pi d^3}{8D}$$

where, P = Allowable load on spring, Lbs.
S = Maximum stress, Psi.
d = Dia. of wire, in.
D = Mean dia. of spring, in.

Substituting:-

$$P = \frac{(90,000)(0.375)^3}{(2.55)(1.500)}$$

P = 1240 Lb.

SUBJECT Stress Analysis - Experimental Shim Safety Rod - ORNL Pile.

J.O.No. ______
SK- ______

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OR 1240-Lb. is the maximum load which spring can support without overstressing. For a deflection of 6-in, the number of turns required is,

$$N = \frac{GFd^4}{8PD^3}$$

Where, N: Number of active coils.
G: Torsional modulus of rigidity, 11,500,000
F: Total deflection, inches
P: Load on spring, pounds.
d: Dia. of wire, inches
D: Mean dia. of spring, inches

Substituting;-

$$N = \frac{(6)(11,500,000)(.375)^4}{(8)(1240)(1.500)^3}$$

And, N: 41 Active coils.

The spring rate is;-

$$R = \frac{1240}{6} = 207 \text{ Lb./in.}$$

(b) Inner Spring:- To maintain approximately the same stress per inner coil as the outer coil, the ratios of their mean diameter to wire diameter must be equal;-

$$\frac{D_o}{d_o} = \frac{D_I}{d_i}$$

$$\therefore \quad d_i = \frac{D_I}{D_o} d_o$$

Subst., $d_i = \frac{0.750}{1.500} \cdot 0.375$

$d_i = 0.187$ or $\frac{3}{16}$ in.

SUBJECT Stress Analysis - Safety-Shim Rod OPNL Pile. J.O.No. ______ SK- ______

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Since the free-height of the inner spring must equal that of the outer spring plus $\frac{1}{8}$ in. on either end for retainers;-

$$H = 22 + \frac{1}{4} = 22\frac{1}{4} \text{ in.}$$

But, $H = N(d+f) + 1.25d$

$\therefore$ $N = 85.5$ Turns. (Say 85)

The load required for a 6-in. deflection for this spring is:-

$$P = \frac{(6)(11,500,000)(.187)^4}{(8)(0.750)^3(86)}$$

or, $P = 290$ Lb.

At 290 Lb load, the shearing stress is;

$$S = \frac{(2.55)(290)(.750)}{(.187)^3}$$

$S = 85,000$ Psi.

5. Shock-Absorber Spring Housing:-

Maximum tension load on housing at full compression of springs.

$$P = 1240 + 290 = 1530 \text{ Lbs}$$

The springs are housed in a standard $2\frac{1}{4}$-in O.D. $\times$ 11 Ga. (.120) W.T. TUBE.

$$S = \frac{1530}{0.818} = 1870 \text{ Psi.}$$

$$F.S. = \frac{60,000}{1870} = 32.$$

SUBJECT Stress Analysis, Safety Shim Rods ORNL Pile

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Appendix 3

Safety-Shim Rod Motion Study

(1) Unretarded Free Fall of Rod Into Pile.-

Assuming the somewhat unlikely probability of cable failure, the rod will fall with the acceleration of gravity into the pile. The distance traveled in time, t, and acceleration, a, is;-

$$S = \frac{1}{2} g t^2$$

From which,

$$t = \sqrt{\frac{2S}{g}}$$

Where,

t = Time in seconds
S = Distance traveled, Ft.
g = 32.2 Ft/sec^2

Substituting,

$$t = \sqrt{\frac{2 \times 16}{32.2}}$$

$$t = 0.998 \text{ Sec.}$$

Terminal Velocity of Rod Before Impact.-

$$V_T = g \cdot t$$

$$V_T = (32.2)(0.998)$$

$$V_T = 32.1 \text{ Ft/sec}$$

Kinetic Energy of Rod At Impact.-

$$K.E. = \frac{1}{2} \frac{W}{g} V^2 = \left(\frac{1}{2}\right)\left(\frac{95}{32.2}\right)(32.1)^2$$

$$K.E. = 1520 \text{ Ft-Lb.}$$

SUBJECT Safety-Shim Rod Motion Study
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SK- ____

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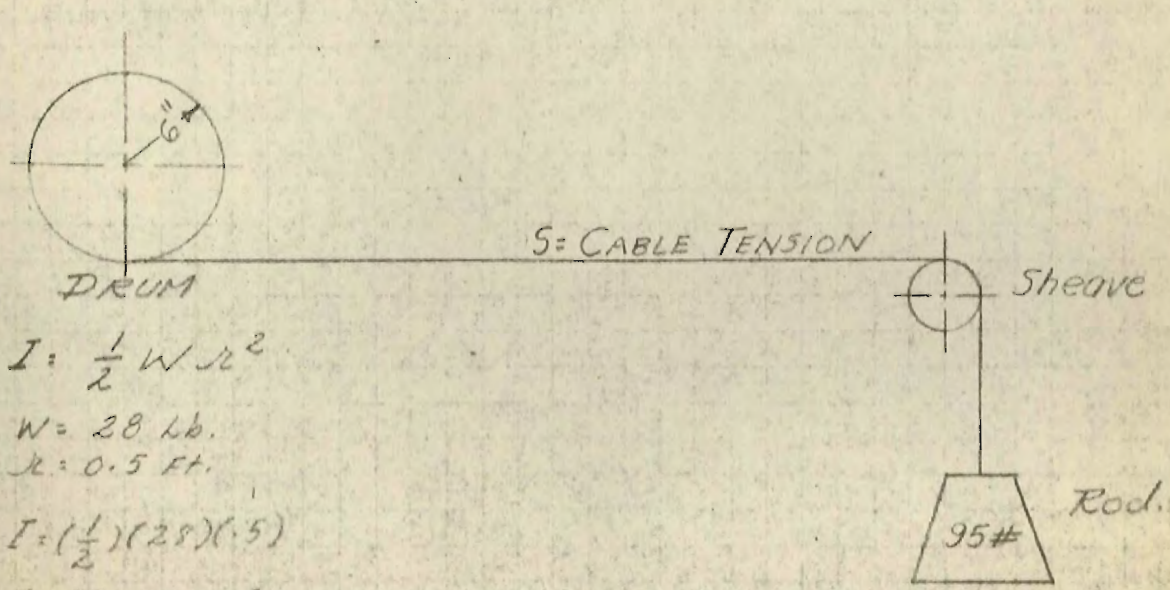
(2) Calculated Actual Time of Descent:-

Because of inertia of the cable-drum and the sheave and friction in the bearings and cable, the actual acceleration of the rod into the pile will be less than that of unretarded free fall. The pitch-diameter of the cable winding-drum is assumed at 12-in. The number of turns required for a capacity of 16'-0" of $\frac{1}{4}$-in. cable is,

$$n = \frac{(16)(12)}{12\pi} = 5.1 \text{ (Say 6 Turns)}$$

Assume a spacing between turns of $\frac{1}{2}$-in., the approximate width of drum required is $3\frac{1}{2}$-in.

Neglecting the inertia of the sheave (from assuming the drum as a solid steel disc, 12-in diam. by $3\frac{1}{2}$-in. thick) and also assuming the solid disc as being equivalent to the sum of the inertias of the clutch and brake discs and the small inertias of the rotating parts of the position indicator, the rod and hoist system may be represented as follows:-



$I = \frac{1}{2} W r^2$

$W = 28$ Lb.

$r = 0.5$ Ft.

$I = (\frac{1}{2})(28)(.5)$

$I = 7$ LB-FT^2

SUBJECT Safety- Shim Rod Motion Study
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Assume that 5# of the 95# rod weight is required to overcome friction in the bearing and cable. Then, the force available to overcome inertia is 90#. Let S equal the cable tension, then (90 − S) is the force remaining to accelerate the rod, therefore;

$$90 - S = \frac{95}{32.2} a$$

where, a = Acceleration of rod in Ft/sec².

The cable tension, S, exerts torque on the cable drum. This torque, applied steadily, causes the drum to rotate with angular acceleration, ϕ rad./sec².

$$T = \left(\frac{6}{12}\right)(S) = 0.5S$$

where, T = Torque, Ft-Lbs.

But, $T = \dfrac{I\phi}{g}$

where, I = Moment of Inertia, Lb-Ft²
ϕ = Angular acceleration, Rad/sec²
g = 32.2 Ft/sec²

However, the following relation must exist between the displacement acceleration of the rod and the angular acceleration of the drum:-

$$a = \phi \cdot r$$

Since,

$$S = \frac{I\phi}{.5g}$$

$$S = \frac{I a}{.5 g r}$$

Substituting,

$$90 - \frac{I a}{.5 g r} = \frac{95}{32.2} a$$

SUBJECT Safety - Shim Rod Motion Study.
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Substituting values & solving:-

$$90 - \frac{(7)(a)}{(.5)(32.2)(.5)} = \frac{95}{32.2}\,a$$

$$90 - 0.871a = 2.94a$$

$$3.811a = 90$$

And $$a = 23.7 \ \text{Ft/sec}^2$$

Under this acceleration, the time for the rod to fall 16'-0" into the pile is,

$$t = \sqrt{\frac{(2)(16)}{23.7}} = \sqrt{1.35}$$

$$t = 1.16 \ \text{Sec.}$$

The terminal velocity at the end of 1.16 sec. is,

$$V = (1.16)(23.7)$$

$$V = 27.5 \ \text{Ft/sec.}$$

The kinetic energy of the rod is,

$$K.E. = \left(\frac{1}{2}\right)\left(\frac{95}{32.2}\right)(27.5)^2$$

$$K.E. = 1110 \ \text{Ft-LB.}$$

SUBJECT: Safety - Shim Rod Motion Study.

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(3) Percent Energy Absorbed by Shock Absorber

The kinetic energy of the rod under unretarded fall is 1520 Ft-Lb. The total force required to compress the shock absorber springs a distance of 6-in. is:-

$$P = 1240 + 290$$
$$P = 1530 \text{ Lb.}$$

Therefore, the springs can absorb,

$$W = \left(\frac{1530}{2}\right)\left(\frac{6}{12}\right)$$

$W = 383$ Ft-Lb. of energy.

Hence,

$$\frac{383}{1520} \times 100 = 25.2\%$$ for unretarded fall.

For the free fall with connected cable,

$$\frac{383}{1110} \times 100 = 34.5\%$$

of the kinetic energy of the rod will be absorbed.

The remainder of the energy must be dissipated in the rod & graphite, if the rod is allowed to impact on the bottom of the hole.

SUBJECT: Safety-Shim Rod Motion Study. J.O. No. ______ SK- ______

[redacted]

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OAK RIDGE NATIONAL LABORATORY

TECHNICAL DIV. — P.O. BOX P. — OAK RIDGE, TENN.

TOP PLUG EXPERIMENTAL
SAFETY SHIM ROD
X 10 PILE

DRAWN BY	DATE	SCALE
A Ludlow	3-14-49	As Shown
CHECKED BY	**DATE**	**DRAWING NO.** TD-1139
C.L.S. 3/29/49		**REV.**

erted in position in the pile, the chinery and guards replaced and the ety-shim rod $\frac{1}{4}$-in. cable connected to hoist mechanism.

new safety-shim rod shall be brated against the existing regulating s by the operating division and if nd suitable, the remaining three shall mately be replaced as explained, with essary alterations to the hoisting pment and triggering circuits.

Alumnium impact plate will not be uired for the purpose of the test.

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SHARP EDGES UNLESS OTHERWISE SPECIFIED.
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ATE	OAK RIDGE NATIONAL LABORATORY TECHNICAL DIV. — P.O. BOX P. — OAK RIDGE, TENN.		
	INSTALLATION OF NEW SAFETY SHIM ROD X 10 PILE		
	DRAWN BY A. Ludlow	DATE 3-14-49	SCALE 1" = 1'
	CHECKED BY C.E.S. 3-14-49	DATE	DRAWING NO. TD-1140 / REV.

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		EXPERIMENTAL SAFETY SHIM ROD FOR X10 PILE ASSEMBLY

DRAWN BY	DATE	SCALE 1" = 1"
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