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W. Brown
For: N. T. Bray, Supervisor
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Metallurgical Project
A. H. Compton, Project Director

* * *

Metallurgical Laboratory
S. K. Allison, Director

* * *

PHYSICS RESEARCH - ENGINEERING DESIGN

E. Fermi, Division Director; E. P. Wigner, Section Chief

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GENERAL ENGINEERING DESIGN FEATURES OF THE PILE FOR A LIGHT WATER COOLED P-9 POWER PLANT

L. A. Ohlinger
July 16, 1943

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Abstract

This report presents and discusses some of the general engineering problems and details involved in the design of a light water cooled pile for a P-9 power plant producing 50,000 Kw. or better from about 10 tons of P-9 moderator and 6 tons of metal.

Drawings are included to show some designs and variations in both horizontal and vertical piles, with miscellaneous details developed.

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I. INTRODUCTION

The P-9 design committee of the Metallurgical Laboratory is responsible for designing a P-9 uranium chain reacting pile that will produce element 49. Specifically the following objectives are to be borne in mind:

1. That the pile shall be a prototype production pile that can be reproduced with a minimum of alteration when need be. This involves consideration of

    a) Ease of construction
    b) Ease of loading and unloading
    c) Control
    d) Reliability
    e) Maintenance and rehabilitation

2. That the pile shall be capable of being built rapidly.
3. That the pile shall be useful for experimental purposes.

These objectives are listed in decreasing order of importance. They are to some extent incompatible so that the advantages of a particular design feature for one objective must be weighed against its disadvantages for another objective.

The present report confines itself to one general type of P-9 pile, namely, the light water cooled, P-9 moderated, heterogeneous pile. It discusses some of the general problems presented by such a pile and suggests several possible solutions. It attempts to relate these solutions to the particular objectives outlined above.

II. GENERAL DESCRIPTION OF THE PILE

A certain minimum amount of P-9 is necessary to make a pile go at all. This is estimated at about 5 tons for a heterogeneous pile. Granted that amount of P-9 and an optimum lattice arrangement, the power of the pile, i.e., the 49 production, is controlled largely by the cooling system. In a preliminary memorandum (MUC-AMW #5) Young and Weinberg have made calculations indicating a possible output of approximately 50,000 Kw (50 gms. of 49 per day) with ten tons of P-9, 6 tons of metal and 80 tons of graphite reflector. These calculations are based on the principle of

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getting the greatest 49 production from the limited amount of P-9 available under the present program. The lattice geometry imposed by this principle of P-9 economy is assumed in the present report and appears to be feasible. It is, however, somewhat difficult from the point of view of design and construction. Should further study show it to be impracticable, a more widely spaced lattice could be used without very serious loss of productivity. If U should become available in the form of tubes or certain other more complicated structures, the spacing could be increased without loss in production rate.

In the present design, the uranium in the pile would be in the form of rods 2 cm. in diameter with an aluminum sheath $\frac{1}{2}$ mm. thick, surrounded by a water annulus which is 2.2 mm. thick contained within and flowing through a ribbed aluminum tube not over 3 mm. in thickness, as indicated in the typical rod detail, Figure 1. About six tons of these rods would be required in the form of 460 individual rods, each about 7 feet long, arranged in a square geometry at about 4" centers both ways. About ten tons of the P-9 moderator would be required and would be contained within an aluminum tank about 8' in diameter by about 9' long. Since it would be very difficult from a standpoint of construction and very undesirable from a standpoint of replacement to weld the 460 tubes which pass through the moderator tank directly to the ends of the tank (referred to hereafter as the tube sheets), extension tubes would be attached to the tube sheets at the top and bottom of the tank (except in Type IV or the horizontal pile described later). These aluminum extensions would not be replaceable, but the pile tubes which pass through them could be replaced. To reduce the radiation leakage space, the clearance between the tubes and the extension tubes would be very small, say a few thousandths of an inch.

Immediately surrounding the moderator tank on all sides, but not the ends, would be a dry reflector made of graphite. This graphite annulus would be about 18" thick and extend the full height (or length, in a horizontal pile) of the moderator tank. The reflector, in turn, would be enclosed in a flanged steel shell. Surrounding the tank and reflector on all sides would be adequate shielding of a type dictated by the other design features of any type pile. The above is all indicated diagrammatically in Figure 2.

The moderator tank would not be completely full of P-9 but would have a vapor space above the liquid through which He would be circulated. Other empty spaces within the enclosing shield would also be filled with He for reasons of heat transfer and radiation. Provisions must be made to protect the moderator against contamination and against leakage, but in such a way that, in an emergency, the moderator can be completely discharged from its tank in much less than a minute.

The cooling water through the tubes, which amounts to about 13,000 gpm, would be pumped in at one end under pressure and discharged at the other end with a small back pressure. This water would pass once through the pile and would not be recirculated. At the discharge end where the water outside the end shield might be radioactive due to coating failures, provision should be made to shield the operators. Rod removal and replacement will be described later where the various type piles are shown.

III. DISCUSSION OF ENGINEERING DESIGN ALTERNATES AND PROBLEMS

A. General

Most of the problems encountered in the design of the graphite pile must still be faced and solved in the design of a heterogeneous, light water cooled P-9 pile, with the added difficulties of handling, containing and protecting a mobile moderator of great value. These new problems are discussed below along with a recapitulation and discussion of the "graphite pile" problems pertinent to a P-9 plant. Wherever it was possible to make a decision between design alternates, such has been noted herein; otherwise, the discussion will merely present the various possibilities with the hope of a decision in the near future.

B. General Pile Types

In Figures 3, 4, 5 and 6 are shown four arrangements for a vertical pile (i.e., where the tubes through the pile are vertical). Type I shows the tubes all connected into headers to form a closed pressure system at both the water inlet and discharge. In this arrangement, the cooling water may flow either upwards or downwards. Since the rods would probably be removed from above the pile, an extra γ-ray shield (such as proposed at the rod withdrawal end of the graphite pile) must be placed above the piping manifold, in addition to the regular end shield. By having upward flow, this γ-ray shield also serves to protect the personnel against accidental radioactivity in the water discharge lines. With downward flow, a shield would also be needed below the bottom piping manifold.

Type II indicates the same header system at the top for introducing the cooling water, but has an extension on the bottom as a collecting tank for the cooling water discharge. Flow is downward through the pile. The advantage of the collecting tank at the bottom is to simplify the outlet piping, which is quite complex in a manifolded header system.

Type III is the reverse of Type II, having the inlet pressure manifold at the bottom of the pile with upward flow through the pile, discharging into a reservoir above the top shield. This arrangement seems to be an improvement over Type II in that, in addition to simplifying the piping, it provides a storage reservoir above the pile. In the event of water failure, this storage reservoir would at least provide some reserve capacity which could flow through the pile by gravity for partial cooling.

Type IV combines both the inlet and outlet headers at the top end of the pile with the tubes through the pile arranged in the form of "U's", with rods hanging in each leg of the U's. Although this arrangement eliminates the complexity in the lower end of the pile, the upper end is rendered more complex by this arrangement, the power output is slightly reduced, and the replacement of the aluminum tubes is made much more difficult, since tubes cannot be replaced individually but must be replaced in entire groups.

In addition to the four types of vertical piles shown, there is a fifth type, - a horizontal pile in which the tubes through the pile are horizontal. This type might also be subdivided to have either piping manifolds or tanks for the distribution and collection of the cooling water, but since these are but variations of the same arrangements shown for the vertical piles, it is assumed the reader will apply the various arrangements shown for the vertical piles to the horizontal piles described later in this report.

C. Horizontal versus Vertical Pile

In contrast to a horizontal pile in which the graphite moderator provides a structural support (however dubious it may be) for the tubes through the pile, the liquid moderator in the P-9 pile offers no support for the tubes and, therefore, supports must be provided in the tank between the end tube sheets. These intermediate supports may be in the form of hangers, perforated diaphragms, or other means. The objection to these intermediate supports is the introduction of an absorber which reduces the effective multiplication factor k.

The horizontal pile offers one particular advantage over the vertical pile - it allows the use of a special device to handle the leakage of the moderator from its tank. In all the vertical pile designs, collecting the moderator which leaks out of any joint or corroded area is so difficult that it is preferable to use heavy sections to resist corrosion, and adequate seals at any construction joint. The device proposed for the horizontal pile deliberately allows the moderator to leak out, but under proper control at all times and without loss of the liquid or its vapor. The liquid under pressure leaks slowly through a clearance annulus, is collected, and is pumped back into the main body of the liquid.

A vertical pile of Type III offers an advantage over any of the other vertical or horizontal piles in handling the rods removed from the pile. By extending the discharge tank above the pile, it can serve as a shielding medium through which a rod may be moved into its container for transportation to the chemical plant without providing additional cooling facilities. In all other types, where the rod is removed from tubes connected to a header system, a dry coffin is required with separate cooling water provision (except in Figure 23).

As a preliminary choice, it would appear that a vertical pile of Type III and a horizontal pile should be investigated and compared for final choice.

D. Tank Type vs. Manifolded Header System for Distribution and Collection of Cooling Water

Although a pressure tank for distributing the cooling water to the pile tubes in a P-9 plant would be much smaller than in a graphite plant, and therefore more feasible, its construction would still be complicated by the necessity in general of withdrawing tubes and rods through a tank which must maintain pressure, and so it appears no more desirable for a P-9 plant than for the graphite pile.

A tank on the outlet end of the pile tubes for collecting the cooling water has the advantage of eliminating at least one of the crowded header systems, but has the disadvantage of rendering the outlet ends of the tubes somewhat inaccessible. In order to approach these outlet ends for the purpose of replacing tubes, the water in the outlet tank must be withdrawn. However, as pointed out above, in a pile of Type III, a tank for the collection of the cooling water can very usefully serve other purposes in handling the rods and providing a safety reservoir.

In view of the above, it appears preferable to use a closed system of manifolded headers at the water inlet end of the pile and a tank at the water outlet end.

E. Location of Pile Above or Below Ground

It is obviously economical to take advantage of the shielding value of the earth in replacing a portion of the artificial shield required around a pile above ground. Despite the small size of the pile proper for a P-9 plant, its high radiation intensity requires shielding many times the size of the pile. By placing a pile underground, all shielding except the very compact end shields is eliminated.

However, where a very deep liquid layer is maintained above the pile, as in Figure 16, the total excavation may extend as much as 60 to 80 feet underground, necessitating a caisson job with excavation and back-filling of an amount that renders this almost a major construction job. Conditions may be slightly improved by locating such an excavation near the side of a hill so that the upper end of the construction is at the top of the hill and the lower end at a level which connects horizontally with the ground adjacent to the foot of the hill. Of course, locating such an ideal site at the few locations available might prove difficult.

Constructing the pile above ground with water as a shield (since it is inexpensive and has no priorities on it) requires a large tank 70 to 90 feet in diameter by 40 to 60 feet high, as indicated in Figure 20. However, by careful design of the shielding, this size might be reduced as indicated in Figure 20A or Figure 24. This shielding problem will be described later under the title "Shielding".

In view of the above, it appears preferable to investigate the shielding potentialities more carefully and place the pile partially or wholly above ground.

F. Shielding

The shields around the pile are made up of two functional parts, - a relatively thin "heat" shield for the dissipation of the major portion of the heat induced in the shield by radioactivity, and the "biological" shield for the protection of the operating personnel. The thickness of the biological shield will depend considerably upon how long and how close it is intended that people shall remain near the pile. Cooling systems must be provided for the shields, (1) for carrying away the heat generated in the heat shield and (2) for controlling the differential expansion of the shield and its parts.

There are three distinct types of shielding required for the pile:

(1) End Shields

These are perforated to permit the passage of the pile tubes while permitting a minimum of radiation leakage. They should be thin for convenience in handling the rods yet they should be thick enough to eliminate the necessity of shielding plugs in the section of the tubes passing through the end shields. They should be adequate to protect any gasketing or mechanisms which might be impaired by radiation and to permit the proximity of workmen during pile operation for at least a short period and preferably for an indefinite length of time. They must be constructed so as to absorb fast and slow neutrons, neutrons in the resonance regions, and primary and secondary γ-radiation.

A dry shield such as used at W has the advantage of being a little simpler to fabricate and erect where the total shield is so large it must be made in small sections. However, a P-9 pile is small enough that the end shields may be made in one piece. In that case, a combination of iron and water with possibly the addition of some lead appears to offer the best solution for a shield answering all the requirements above. Instead of the shot and water tank arrangement suggested for the graphite pile, it appears preferable from the standpoint of ease of construction, supporting and cooling to make the end shields for the P-9 pile of a laminated construction similar to that shown in Figures 7, 8 and 9. Immediately adjacent to the pile would be a thick steel slab acting as a heat shield and as a structural support for the balance of the shield and any superimposed loads. Welded into this slab would be the steel sheath tubes through which the aluminum extension tubes would pass. Over these sheath tubes would be dropped a series of steel plate diaphragms, perforated to just fit over the tubes and with small spacer

plates welded on between holes to act as columns for transmitting the weight of the plates above, as spacers to keep the diaphragms at a specified distance apart, and as guide channels for the cooling water flowing across the end shields between these plates. Figure 9 indicates a small section of these plates and Figure 8 a possible arrangement in the shield. These diaphragms would not be welded to anything, but would merely be slid into place. They would be an inch to two inches in thickness with an equal space between for water flow across the plates. Water would enter at one side of the shield, pass back and forth across the plates several times, and emerge from the same or opposite side of the shield. The cooling water streams would be divided into two or three sections, one entering next to the heavy heat shield slab and emerging after passing one-third of the way through the shield and the others located at will. This separation of streams prevents any accidental activity picked up adjacent to the pile from being carried too close to the outer surface of the shield. The final closing plate at the outside surface would be welded to each of the sheath tubes. Enclosing the diaphragms would be a cylindrical steel shell plate welded so as to enclose the entire shield as a liquid tight tank. To avoid radiation leakage in the small annular gaps where the sheath tubes pass through the diaphragms, it might be necessary to make the sheath tubes stepped with two or three offsets in thickness and holes in the diaphragm plates to match. Although a shield as described above is somewhat heavy, it does answer all the requirements of an end shield, it is compact and not too difficult to handle as a single unit, and it appears quite feasible and not too difficult to construct.

(2) Side Shields

Since the side shielding is perforated only in a very few places, its construction can be varied according to the designer's needs. The least expensive medium and easiest to obtain is obviously water, but this requires a relatively large thickness of shield, possibly amounting to as much as 30 or 40 feet. Such a shield is indicated in Figure 20. At the other extreme, the shield could be made of laminated steel and water construction similar to the end shields, but made of concentric steel shells with water flowing between them. This type shield (indicated in Figure 24) is the most compact type that appears feasible of construction and has the advantages of being small in size while still answering all the requirements of a shield. However, it has the disadvantage of using a large amount of critical material. Intermediate between the two extremes would be some compromise, e.g. that shown in Figure 20A. Here the pile is surrounded by only a few steel shells with water flowing between, surrounded by an annular space filled with steel and cast iron scrap through which water also flows. This serves as the heat shield

and a portion of the biological shield and requires a much smaller thickness of plain water shielding surrounding the pile. Instead of the heavy concrete tank shown in Figure 20, since the overall tank size is naturally reduced by this compromise arrangement, a lead lined steel tank might well be used as the final shield for primary and secondary γ-radiation.

(3) Shielding during Removal of Rods

When the rods are withdrawn from the pile, the only protection required is against γ-radiation after the rod passes the outer face of the end shield. If "dry" coffins are used such as for Types I, II and IV vertical piles, this γ-shield may best be made of about 8" of lead supported in a steel framework similar to the arrangement shown in Report CE-407. If, however, a water tank is used above the vertical pile such as in the Type III piles shown in Figures 16, 16A, 20 and 20A, the γ-shield would consist of a layer of water or water and light hydrocarbon about 20 to 40 feet thick. The great thickness would be used where the rods are pulled out of the pile directly into the water tank above the pile and transferred, still under water, to the coffin pot which also would be under water while being loaded. To reduce this water shield thickness it is possible to use a transfer coffin open at the bottom but submerged in the water tank above the shield. The rods would be pulled up into this coffin as they were removed from the pile, and transferred in this coffin, still under water, to the coffin pot into which the rod would be dropped. Under these conditions the water layer over the pile would be about 20 feet thick and that over the coffin pot would still be about 40 feet thick. Such an arrangement is indicated in Figure 16A.

Of all of the above arrangements the most desirable appear to be:

(1) the laminated steel plate and water construction for the end shields,

(2) the compromise steel, scrap iron, water, and lead combination for the side shield, and

(3) plain water for the γ-shield required during rod removal.

G. Geometry and Handling of Rods in the Pile

Since there is no preference in lattice geometry from the physicists' standpoint, the square lattice spacing will be adopted in preference to the hexagonal spacing in order to give the maximum space between tube rows for the headers.

Because it is desirable to eliminate the shielding plugs in the portion of the tubes passing through the end shields, the coated metal

rods would probably be suspended in the pile tubes where they pass through the moderator tank. Therefore, small cables would be attached to the coated metal rod for handling it in the tube. Since it is generally easier to pull an object through a tube than to push it through, it might be necessary to have cables attached to both ends of the rod so that it may be pulled through in either direction or so that new rods may be pulled into the tube when a rod is removed.

Since the total length of rod for a P-9 plant is small (about 7 feet), there seems to be no particular advantage in making the rod in short segments instead of in one single piece, particularly in a vertical pile where the suspension of a series of small segments would introduce additional complications. Even in a horizontal pile, the cable arrangement for handling the rods through the pile makes the one piece rod appear preferable.

In all the arrangements shown, it is perfectly possible to remove any single rod desired. Therefore, there seems to be no immediate need or reason for arranging for group removal of the rods.

H. Handling of Rods into and out of the Pile

All of the arrangements shown and described presuppose the handling of the rods in solid form between the pile and the chemical extraction plant because of the problems introduced by dissolving the metal in situ. In order to dissolve the rod, it is necessary first to dissolve the aluminum sheath. This aluminum solvent would also dissolve the aluminum tank and extension tubes unless they were of stainless steel, which does not appear desirable at the present time. Therefore, the pile would undoubtedly have to be abandoned each time the rods were removed. This makes the life of the pile a matter of only a couple of weeks, and even the cheapest, simplest construction makes this method undesirable.

The simplest container for transporting the rods to the extraction plant appears to be a covered lead pot as indicated in Figures 16, 20 and 23. The rods would stand or lie loosely in this pot surrounded by water which would cool the rods in transit by being boiled off.

By having an individual cable attached to each rod, any single rod could be lifted by hand out of the pile tube, carried under water to the coffin pot and lowered into the pot where it would be cooled by the shielding water until the pot were removed. A potential cable transfer system combining the manual lifting of rods with a trolley arrangement for moving them over to the pot is indicated in Figures 15, 16, 17 and 18. Here auxiliary cables are hooked to the rods supporting cable with controlled releases for dropping the rod into the pot. Other possibilities may suggest themselves to the reader. Figure 23 indicates a potential unloading arrangement for a horizontal pile.

The pot itself with its cover is swung from a bail and handled by overhead hoisting equipment. As indicated above, an additional piece of equipment, called a transfer coffin, may be used to convey the rods under water from the pile to the pot, as indicated in Figure 16A.

I. Tubes through the Pile

As pointed out earlier in this report, it would be difficult to construct the pile with permanent tubes and therefore the more desirable arrangement of having replaceable tubes has been adopted. Since the moderator provides no lateral support for the tubes in the event of warping, it becomes even more desirable in a P-9 pile than in a graphite pile to prevent warping as much as possible. Since rod warping is self-aggravating, the use of ribs to partially limit the offense will be adopted here even though the rods are vertical and may be self-centering.

J. Chemical and Electrochemical Corrosion of Pile Materials under Radiation

Although investigations are being made on the possibilities of using uncoated uranium in the P-9 pile, the lack of information on this subject necessitates the preliminary assumption that the uranium must be protected from the water by a sheath or coating. This sheath must be of a material which is corrosion resistant and is not attacked appreciably by hot water, etc. and which should have a low danger coefficient. This eliminates most materials and leaves only aluminum and beryllium. Because of the high danger coefficient, stainless steel cannot be used for the pile tubes but might be used for the tank and extension tubes. However, until it has been proven that aluminum and stainless steel can be safely placed in contact or near each other in water under the pile conditions, it cannot safely be assumed that electrochemical corrosion will be negligible. This almost necessitates the use of the same material for the tank and extension tubes as for the pile tubes. Although at this time a centrifugal casting process for beryllium tubes is under development, and the outcome looks encouraging, it is still too early to plan on the use of beryllium instead of the one and only material that appears practical at this time, - aluminum.

The present testing program on corrosion and erosion of aluminum and aluminum-steel junctions will undoubtedly help clarify the materials problem for the P-9 plant as well as the graphite plant.

K. Thermal Stresses and Differential Expansion

Due to the small size of this pile compared to the graphite pile, the expansion problems in a P-9 pile are materially reduced. Likewise, the use of water throughout the shielding provides cooling and expansion control. The expansion of the extension tubes will be

taken care of by the flexibility of the aluminum tube sheets. Other expansion problems will be met and taken care of in the individual designs.

L. Controls and Control Rods

Following the memorandum by Young and Weinberg, referred to earlier in this report, the present author favors control by varying the P-9 level. If other type control is desired, such as movable rods, they would have to be entered at right angles to the pile tubes or else used in one or more of the pile tubes in place of the metal.

One suggestion for a control rod consists of a shaft in the vapor space above the P-9, paralleling the water surface (i.e., at right angles to the pile tubes) and extending out through the pile wall at at least one end. At this end, a stuffing box arrangement would provide a bearing and a seal against loss of D_2O vapors and against infiltration of H_2O. The other end of the shaft could be supported on an internal bearing. Attached to this shaft would be several large flat plate blades at right angles to the shaft in such a position that these blades would pass down between the rows of tubes as the shaft was rotated. In one extreme position, the blades would be completely out of the D_2O and in the vapor space above. By rotating the shaft any desired amount, the blades could be immersed as desired for control. With this type control a rotation of only 90° would provide the full scale range of control. This same arrangement might also be used for the emergency controls. These controls must be quick acting safety devices arranged to enter the pile in fractions of a second when necessary for stopping the pile action immediately. Since very little travel is required for full entry of the blades, it is obvious that this type of device would be admirably suited to use as emergency controls, as well as normal operating controls. Cooling of the shaft and blades would be either by helium flowing past in the vapor space or by liquid coolant flowing through the shaft and blades.

A gage glass connected to the moderator tank could be used to indicate the level of the moderator and to control alarms, indicator lights, etc. by electrical contacts.

M. Helium System

Helium will be used to fill the vapor spaces above the moderator and to fill spaces outside the moderator tank but within the shielded area which might otherwise be filled with air. The function of the latter is to improve the heat transfer. The function of the former is to have a gas which is practical from a radiation standpoint where it can be used to help control the P-9 level, help blow out the P-9 in an emergency and carry off the decomposed P-9 gases for recombination. Since the helium over the P-9 will have heavy water vapor in it, it should be kept separate from the balance of the helium which might have light water vapors.

N. Instrumentation

Except for the special controls for the P-9 level and other k-controlling devices, the instrumentation for the pile proper will be only nominal. The cooling water temperatures and pressures will be measured at the inlets and outlets by usual methods. A flow meter will measure the flow of cooling water and if feasible thermocouples will record the moderator temperatures. Provisions should be made for fast neutron and γ-ray counters or intensity indicators and openings should be provided for inserting ionization chambers. They may be located in the graphite reflector either in the pile or elsewhere but must be carefully arranged to avoid radiation hazards for the operating personnel.

If the aluminum sheath on a rod fails, the corrosion of the uranium will contaminate the water with radioactive metal and with fission products. Detectors should be provided to check the pile regularly for indication of such sheath failures. These detectors should signal the operator in the control room either by audible or visual alarms or both.

If a pile tube should corrode through or fail, the heavy water will be contaminated by light water. This will be indicated by a sudden drop in k and by a rise in liquid level of the moderator in the tank. Alarms should be provided to warn of such an occurence.

O. Commercial Production of Pile Parts

The production of uranium rods of the length required for the P-9 pile has already been developed. Sheathing these rods has been largely developed. The construction of the aluminum tank with its extension tubes and other construction problems is being investigated along with the development of an aluminum welding program. The gasketed and packed joints are being investigated and will be tested at an early date. The ribbed tubes are no longer a problem since the facilities for producing these have been developed for the graphite pile.

The facilities for producing a P-9 moderator are such that it is a valuable substance which must be carefully protected against contamination and against leakage. Provision must therefore be made for getting the P-9 out of the pile as rapidly as possible at the least sign of danger. This will be covered in the next section.

P. Protection, Handling and Control of the Moderator

In order to get the moderator out of the tank rapidly, it is proposed to have several openings of sufficient size and number to pass all the moderator in much less than a minute. These openings would be controlled by special valves having a spring and piston arrangement control. The spring would be arranged in a control cylinder underneath the piston so as to hold the valve open until pressure were released into the cylinder against the opposite face of the piston to

force the valve closed. With this arrangement, a single pressure control valve could be connected to all the safety devices which normally actuate pile controls (too high neutron density, too high coolant outlet temperature, failure of plant power supply, too great radioactivity in the emergent coolant, too low a back pressure on the pile, increase in level of the P-9 in the tank). As soon as the pressure on these valves was released, either by one of these controls or because of failure of the actual pressure system, all valves would be snapped open by the springs and would release the P-9 into the blowdown drum. The blowdown drum could be arranged either to pump or blow the P-9 back into the moderator tank or off into a special storage reservoir. Slight leakage of the valves would not be serious in such an arrangement, since a small pump could be utilized to carry leakage into this blowdown drum back into the system. Since it is possible to handle the P-9 with pneumatic pressure and the proper use of check and other valves, it appears desirable to use this method for the design with auxiliary pumps for small transfers or for emergency.

Where heavy and light water are adjacent with only a thin metal or a gasket or packed joint separating the two, it is preferable if possible to arrange the construction and pressures so that the light water will leak into the heavy water rather than the reverse.

IV. DESCRIPTION OF SOME POSSIBLE PILE DESIGNS

A. Vertical Pile Underground

Figure 16 shows a potential arrangement for a Type III vertical pile underground. Here the pile arrangement indicated in Figure 11 is utilized with a deep discharge tank above the top shield. Adjacent to this discharge tank is another smaller tank joined to it by a neck extending practically the full depth of the tank as indicated in Figure 17. This second and smaller tank is for the coffin pot which is lowered into it by overhead hoisting equipment and left there until the desired number of rods have been placed therein. The cover for this pot is stored above ground until the pot is filled, after which it may be lowered into the tank before removing the pot. The water emerging from the upper end of the pile would fill a portion of the space in the top tanks. Above that would float a light hydrocarbon of low volatility. Below the interface between the pile discharge water and the hydrocarbon would be a series of holes in the large tank wall connecting to an external annular trough for carrying away the discharge water. Above ground the rod transfer system referred to before and indicated in Figures 17 and 18 would be located. Below the bottom shield the inlet ends of all the pile tubes would be connected to a manifolded header system for distributing the cooling water throughout the pile tubes. This is indicated in Figures 13 and 14. Figure 10 indicates one quadrant of the bottom tubes and headers and shows one possible arrangement of the headers so that the tubes in the center $\frac{1}{2}$ of the pile would carry a little more water than the tubes in the outer $\frac{1}{2}$ without complication or interference of the headers and piping connections. Figure 13 shows how the top extension tubes and

the pile tubes are sealed outside the end shield against leakage of heavy water vapor out of the pile or leakage of light water from the discharge tank into the moderator tank. It also shows how the extension tube at the lower end of the pile is sealed with a double gasketed arrangement to prevent the loss of heavy water from the moderator tank and how the pile tube is connected into the distributing head for receiving the water from the distributing headers. Figure 14 shows a couple of the distributing heads attached to the cross headers.

Figures 13 and 15 show the arrangement of the rods supported in the pile tube. Since the differential pressure in the water stream at the lower and upper end of the rods is greater than the weight of the rod, there will be a tendency for the rod to be lifted out of the tube. One arrangement for overcoming this difficulty is indicated in Figure 13. It consists of a tapered plug, called a pressure hold-down plug, attached to the lower end of a cable which is in turn attached to the lower end of the rod. This hold-down plug seats in the end plug of the distributing head, resting in the hole in a metal backed neoprene gasket. The inlet pressure of the water on this hold-down plug is great enough to counteract the uplift on the rod above and holds the rod down until the pressure is released or a sufficiently great pull made on the rod lifting cable. The hold-down plug is self-sealing, also, since the water pressure against the neoprene gasket forces it into its seat and retains the liquid. However, even if the neoprene were to leak a little, the large hole in the end plug would permit this to be carried off and still maintain a differential pressure on the hold-down plug that would keep it in place. The lifting and supporting cable attached to the upper end of the metal rod is supported from a perforated spider at the top of the tube. The supporting cable is adjusted and formed into a loop to which is attached the auxiliary lifting cables. The end shields, top discharge tank and steel shell around the reflector are all joined by gasketed and bolted joints in the approved pressure vessel manner, as shown in Figure 12. The aluminum moderator tank and its cover are sealed against leakage of heavy water vapor, their edges being used as a gasket in connecting the top shield and outer steel shell. This figure also indicates one of the D_2O emergency release lines.

Below the bottom shield would be an enclosed protected space for repairs and maintenance on the distributing piping, blowdown lines, etc. The foundations are arranged to permit access to all bolting for tightening during a shut down period after a period of operation.

Since the major function of the water and hydrocarbon shield above the pile is to protect the personnel from γ-radiation during the transfer of rods from the pile to the coffin and while in the pot until covered, the total height of this water might be reduced, as explained previously, by the use of a transfer coffin over the pile and by lowering the coffin pot accordingly, as indicated in Figure 16A. This would reduce the total depth of excavation. Whether the transfer coffin arrangement or the deep-water tank arrangement is used, the depth of excavation might still further be reduced by bringing at least a portion of the top water tank above ground and surrounding it by a heavy concrete tank with or without a lead lining and of such a thickness as to adequately

shield during the unloading.

One possible location for the D_2O blowdown and rundown drum is indicated in Figure 16. Other arrangements are quite possible and will be governed by the site. Access tunnels, so located and constructed as to be adequately shielded, must be provided for entry below the pile, and to the blowdown drum and other points requiring accessibility.

B. Vertical Pile above Ground

Figure 20 indicates in somewhat less detail one possibility for a vertical pile of Type III located entirely above ground. The details and portions not shown are sufficiently like the pile just described as to require no further comment at this point. Obviously, the hoisting equipment, whatever may be its nature, must be supported on the tank high in the air. Other than this, no special problems are involved.

Figure 20A indicates the same pile with the compromise shield arrangement and lead lined steel tank. In this scheme, the overhead hoisting equipment may require separate supports.

Figure 24 shows a vertical pile of Type I above ground, utilizing individual rod coffins. The details and general design of the pile and end shields are as described previously in Section IV-A. The enclosing side shields have been described in Section III-F. The only other feature of note here is the auxiliary γ-shielding for rod withdrawal. This consists of a shell extension above the top shield for containing a lead solution into which the coffin is immersed while removing a rod.

C. Horizontal Piles

Figure 21 shows a minimum size horizontal pile above ground, but without a reflector. No additional problem of any importance is introduced by this omission except one of size. A pile with reflector and with steel and water side shielding would look like the pile in Figure 23 with the addition of the side shields shown in Figure 21.

The moderator tank would be a flanged steel shell, aluminum lined, with heavy steel end plates, aluminum faced, to serve as tube sheets. Intermediate aluminum diaphragms would support the tubes through the tank. The holes through the tube sheets would also be aluminum lined, fitting closely around the pile tubes. At either end of the moderator tank would be a P-9 leakage space constructed of an aluminum lined shell and another heavy aluminum faced tube sheet. The D_2O leaking past each of the pile tubes through the small annular clearance would spray into this leakage space and be collected at the bottom and drained off into the blowdown and rundown drum. Emergency release lines for blowing out the moderator in an emergency would be provided as in the vertical pile. Also, as in the vertical pile the moderator could be

blown or pumped back from the blowdown drum to the moderator tank. Helium would be introduced into the space just beyond the P-9 leakage space and would leak through the small annular clearance around the tubes. This helium bleeding constantly into the D_2O leakage space would prevent the escape of heavy water vapors. The end shields and side shields are as previously described for the vertical pile and under the heading "Shielding".

An auxiliary lead and steel γ-shield would have to be provided at the rod withdrawal end as previously described. Rod handling would be by individual coffins using the pile water while adjacent to the pile during the actual rod withdrawal, and an auxiliary source of cooling water thereafter.

Figure 23 indicates a horizontal pile not using the laminated steel construction. The arrangement shown would hold for a pile with or without the side reflector. The major portion of the scheme is a repetition of that shown in Figure 21 with the addition of a light water leakage space having tube sheets as previously described with helium bleeding into the light water leakage space to prevent light water vapors from passing on through into the heavy water compartments. One laminated shield would be required under the pile to permit access to the piping below. All other shielding would consist of water with or without steel and scrap iron, and contained within a lead lined steel or concrete tank.

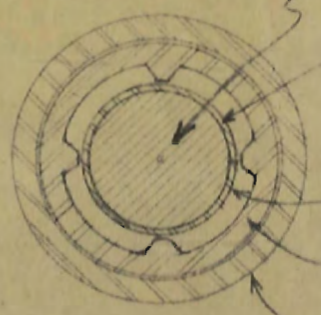
Rod removal could be from the manifolded header as for the pile in Figure 21 but might better be as sketched in Figure 23, at the outlet end of the pile tubes. In this case, the coffin is large enough to hold several rods and is suspended from cables and hoisting equipment above in a horizontal position under water in the tank. The coffin cover rests in the bottom of the tank and can be handled from above to cover the coffin before it is removed from the shield tank. A long arm would extend down into the shield tank from above for handling the rods out of the pile. This arm would be capable of lateral or vertical motion but would be rigid in any position. To remove a rod, the coffin would be brought up underneath the rod, the arm hooked to the pulling cable and the rod pulled out until it was close to the arm. In this position, without pulling the cable further, the arm would move laterally to withdraw the rod and to allow it to fall into the coffin. Cables could then be disengaged and passed back through the pile for reloading.

V. CONCLUSIONS AND RECOMMENDATIONS

Of the arrangements shown, the most promising would seem to be the vertical pile of Type III largely or wholly above ground with the composite shielding arrangement but without the transfer coffin.

A second choice would be a horizontal pile with composite shielding, submerged rod removal and located above ground.

It is recommended that an immediate review of the designs presented herein be instigated with the intention of developing the most promising, or two most promising, designs immediately and freezing them for detailing and construction.



TUBALLOY ROD – 2 CM. ϕ, 460 REQ'D. } ARRANGED IN SQUARE GEOMETRY, 4" O.C. B.W.

½ MM. THICK AL SHEATH

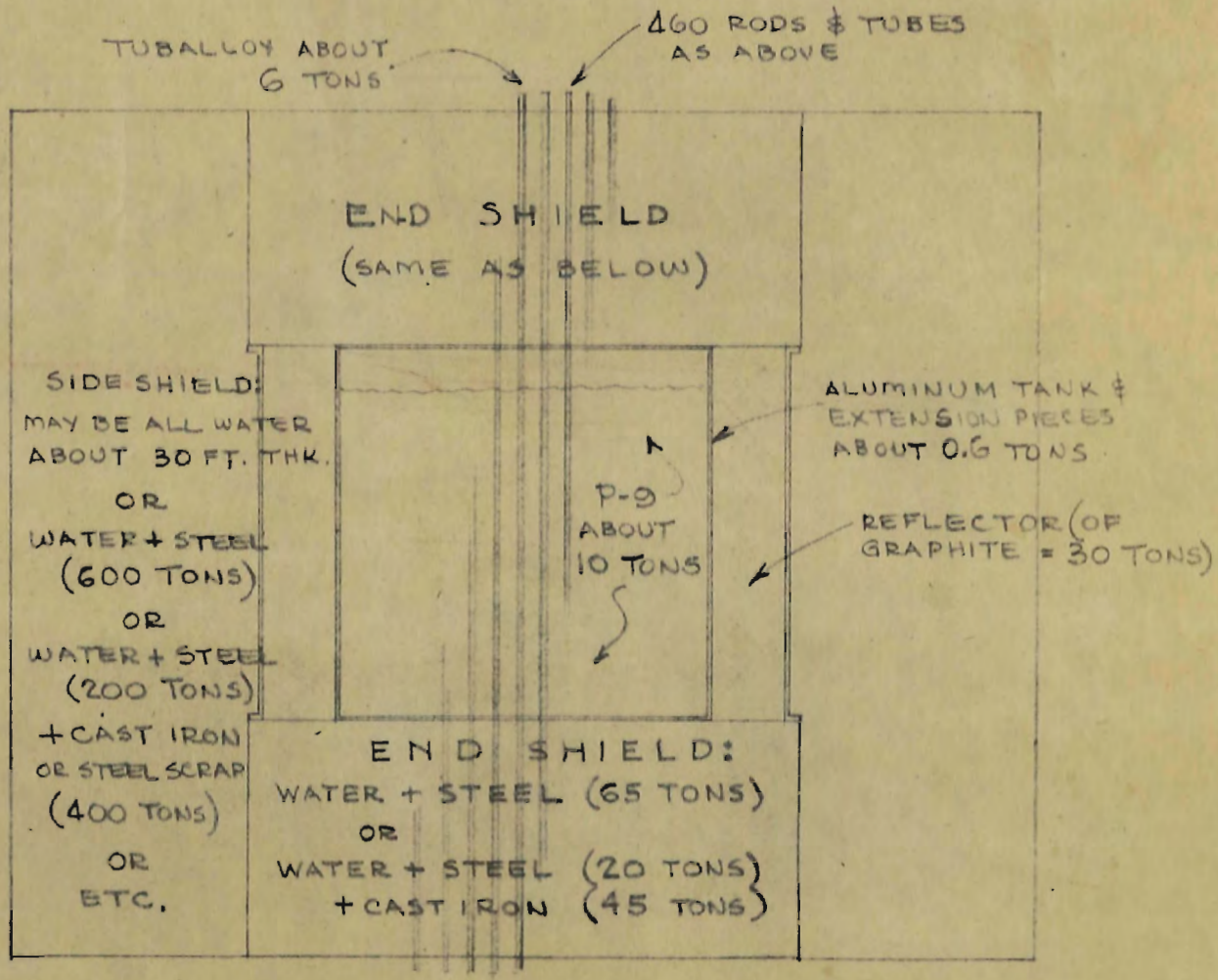
2.2 MM. WATER ANNULUS (COOLING WATER)

ALUM. (250) TUBE 1" ϕ I.D. × 3 MM. WALL

ALUM. (250) EXTENSIONS OF P-9 TANK TUBE SHEETS – 3 MM THK.

TYPICAL ROD DETAIL

FIGURE 1



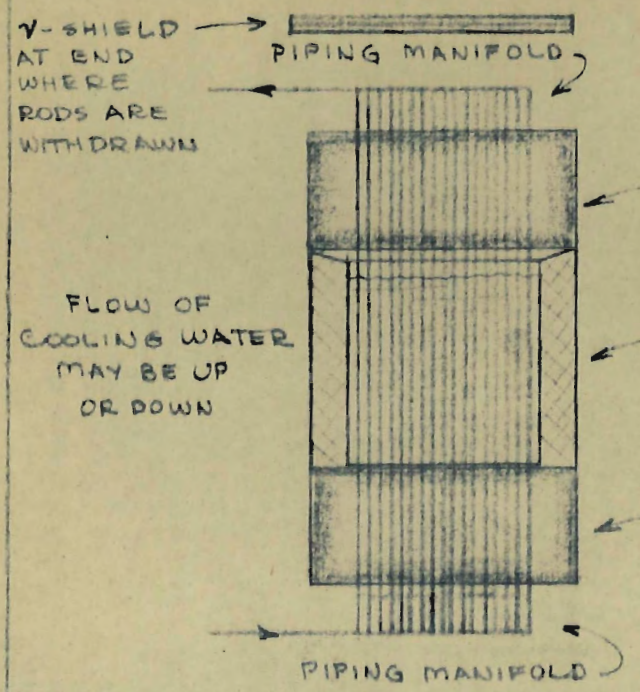
DIAGRAMMATIC SKETCH OF PILE

FIGURE 2

7-1-43 OMLINGER

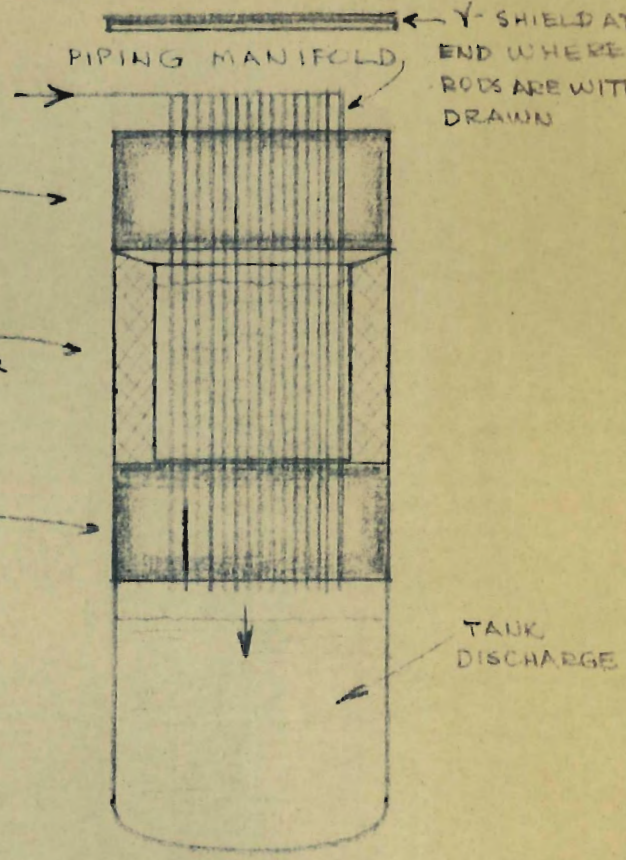
DIAGRAMMATIC ARRANGEMENTS FOR TYPICAL PILES

(SIDE SHIELDS, HELIUM CONN., ETC. OMITTED FOR SIMPLICITY)



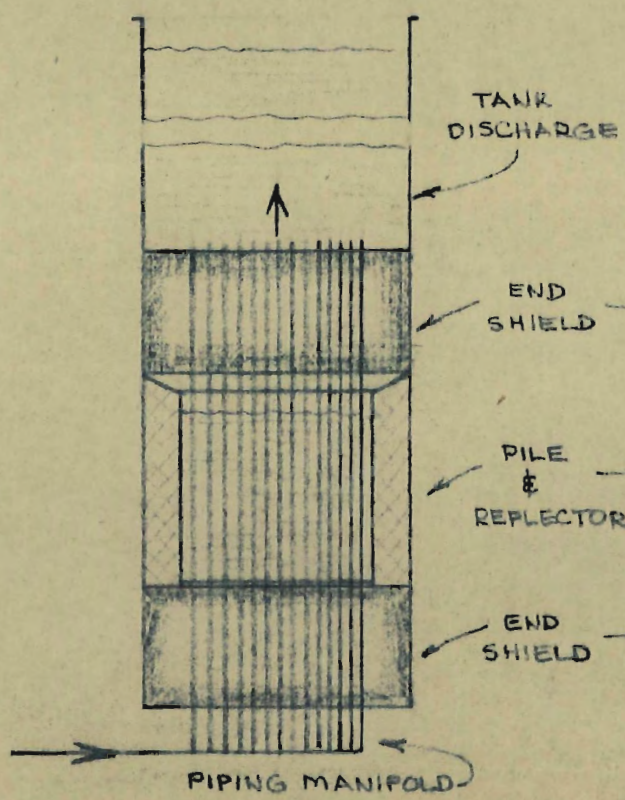
TYPE I

FIGURE 3

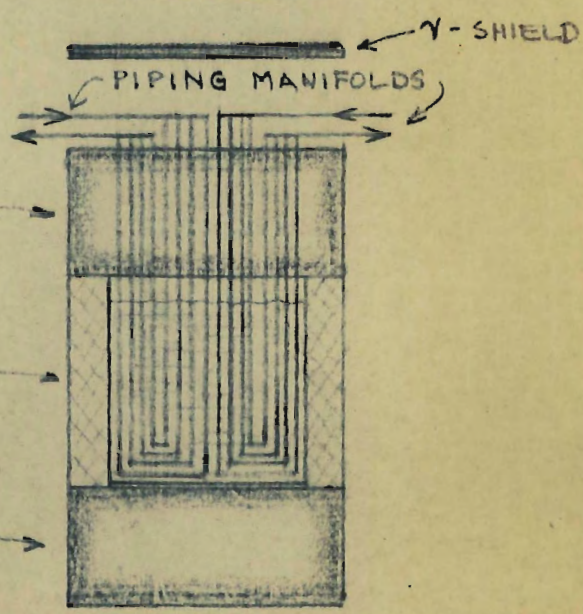


TYPE II

FIGURE 4

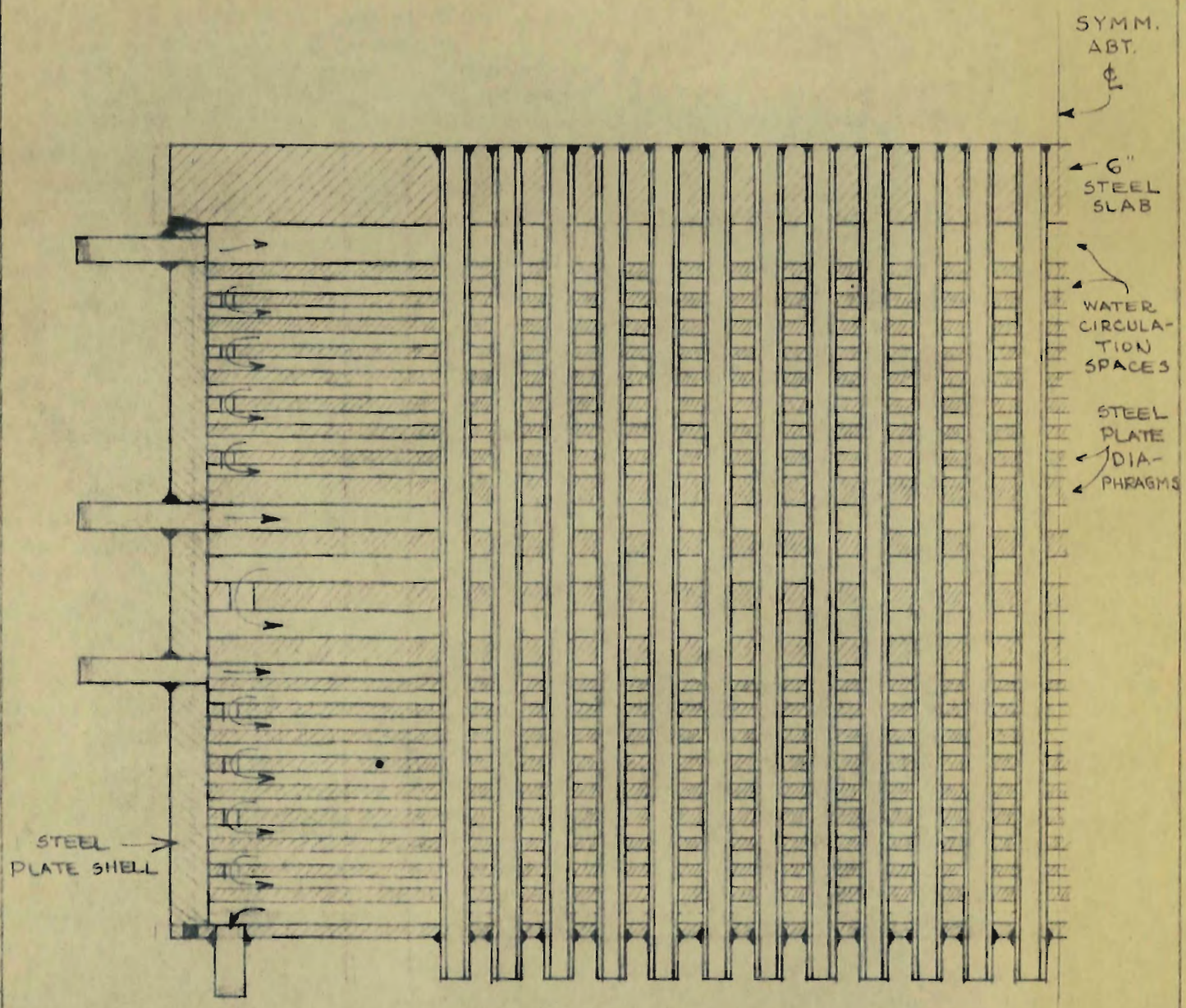


TYPE III - FIGURE 5



[redacted]

TYPE IV - FIGURE 6



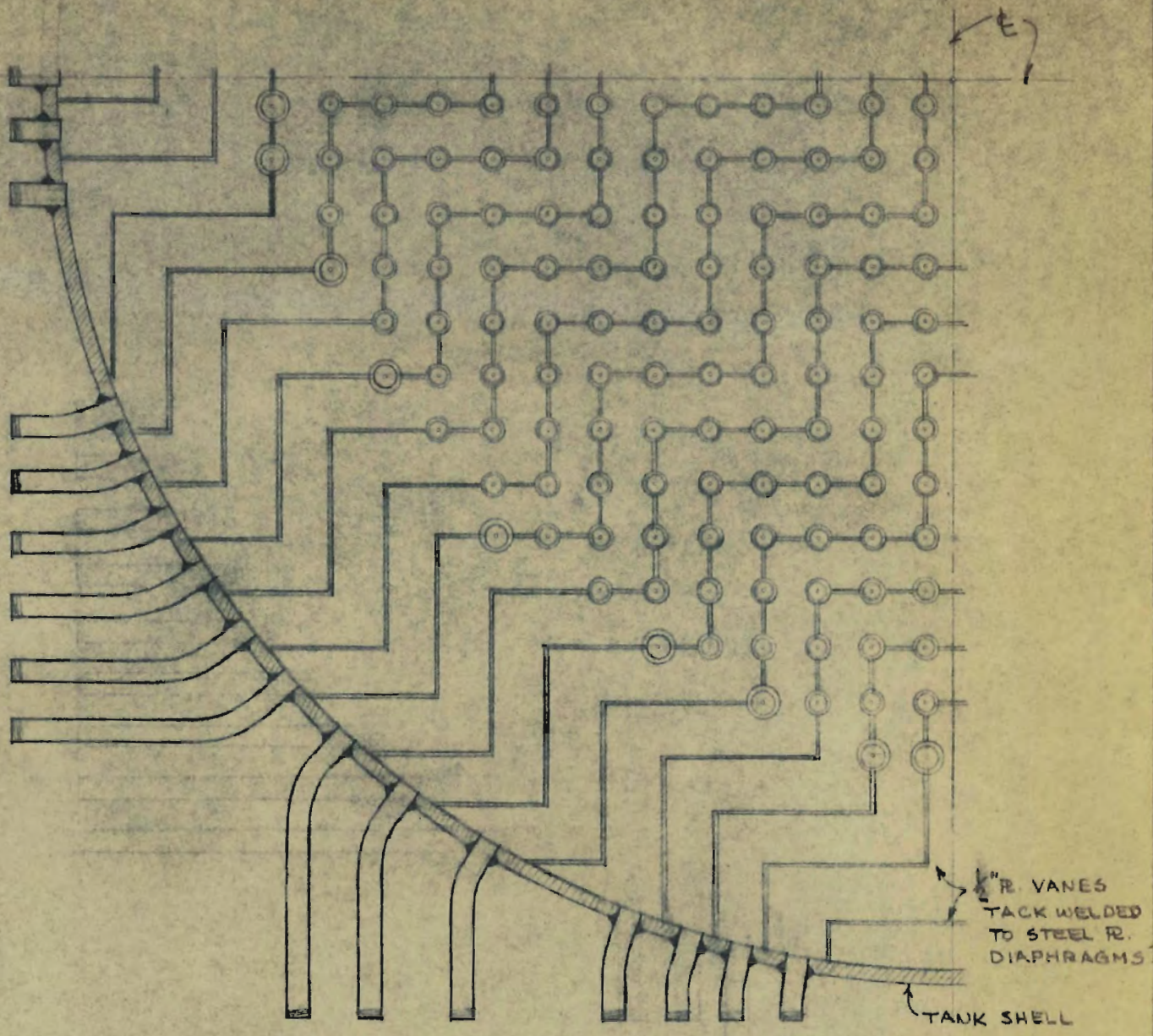
TYPICAL SHIELD SECTION

FIGURE 7

(NOTE: D_2O EMERGENCY RELEASE NOT SHOWN. SEE FIG. 12)

[redacted]

7-1-43 OHLINGER



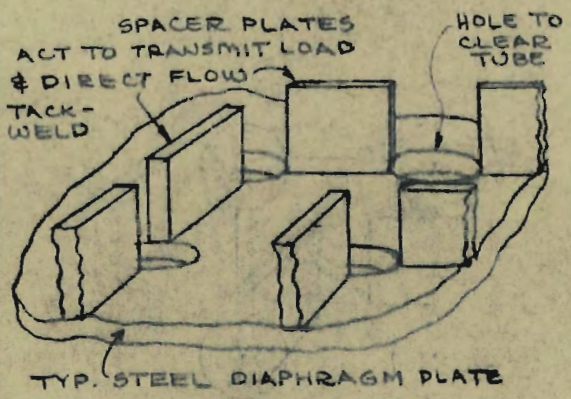


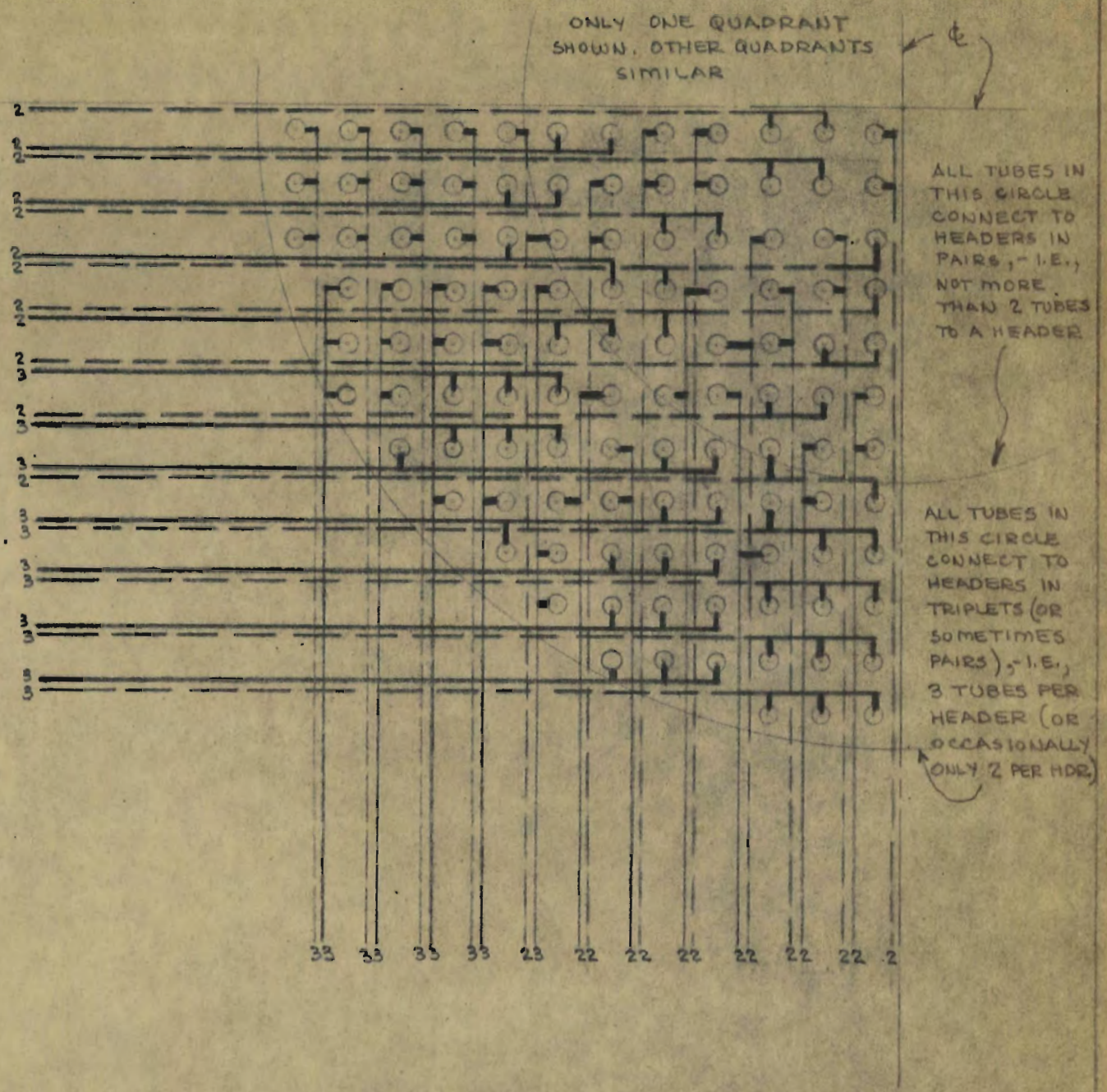
FIG. 9

TYPICAL SECTION THRU
TANK SHIELD
SHOWING
COOLING CHANNELS, ETC.

FIGURE 8

[redacted]

7-1-45 OHLINGER



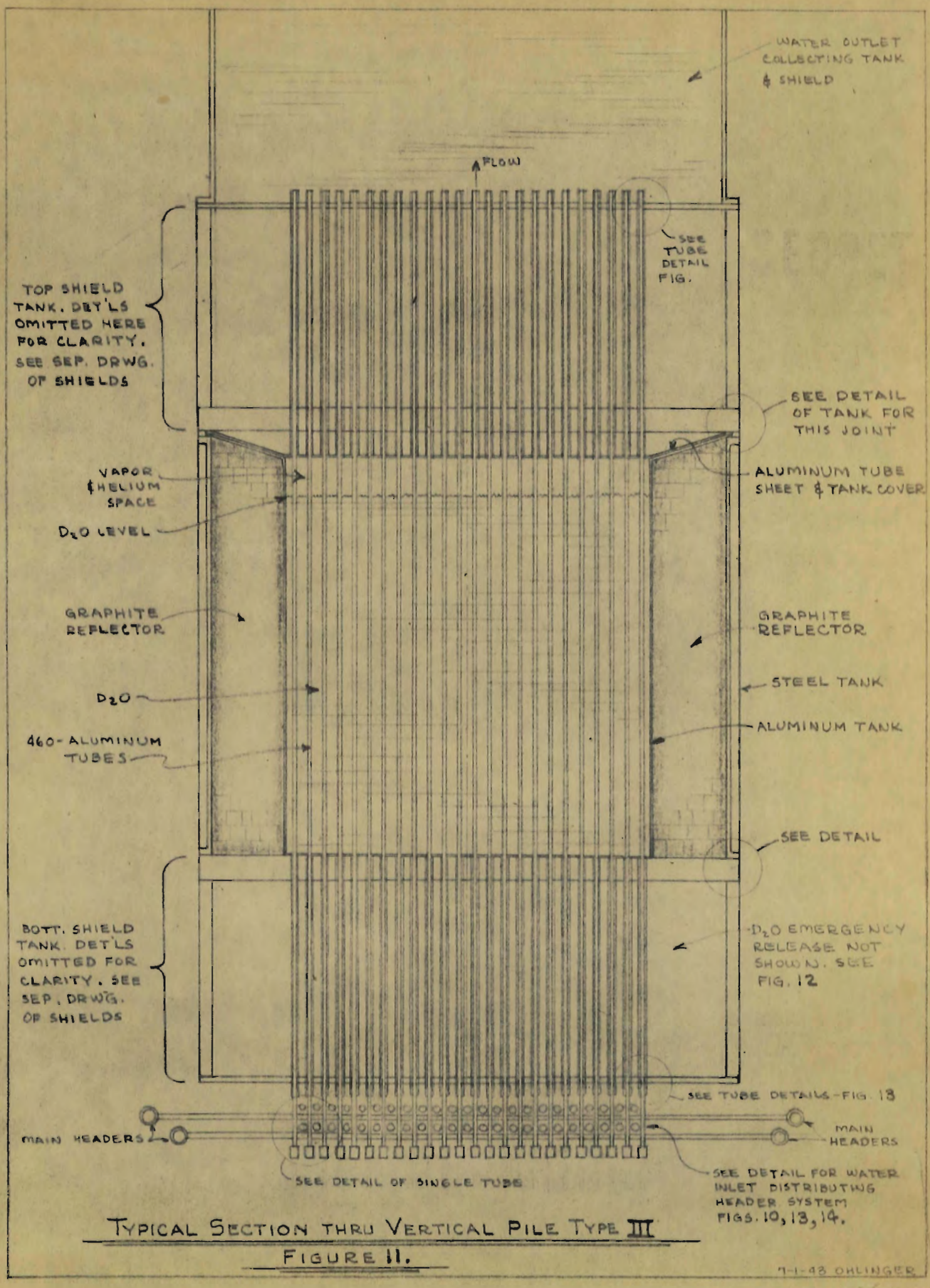
DIAGRAMMATIC ARRANGEMENT OF HEADERS

(448 TUBES)

FIGURE 10

[redacted]

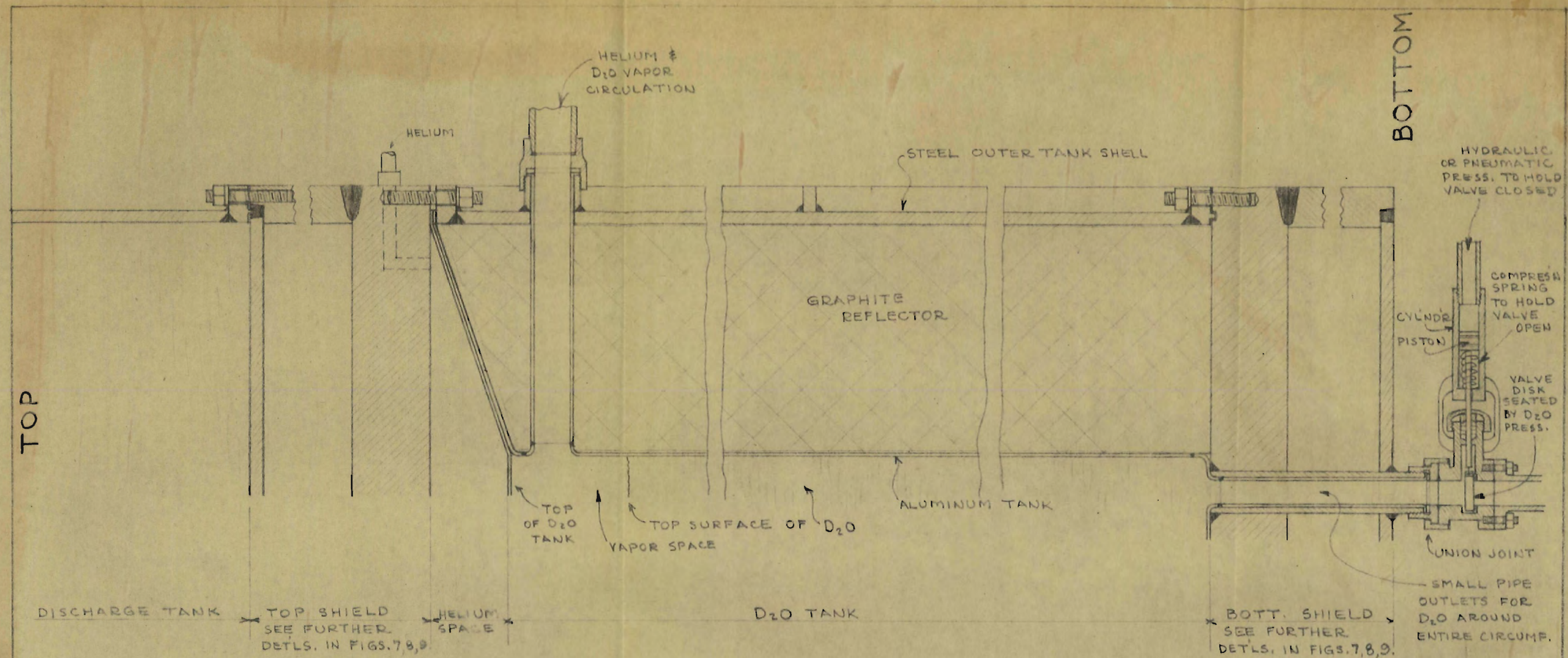
7-1-43 OHLINGER



TYPICAL SECTION THRU VERTICAL PILE TYPE III

FIGURE 11.

7-1-43 OHLINGER

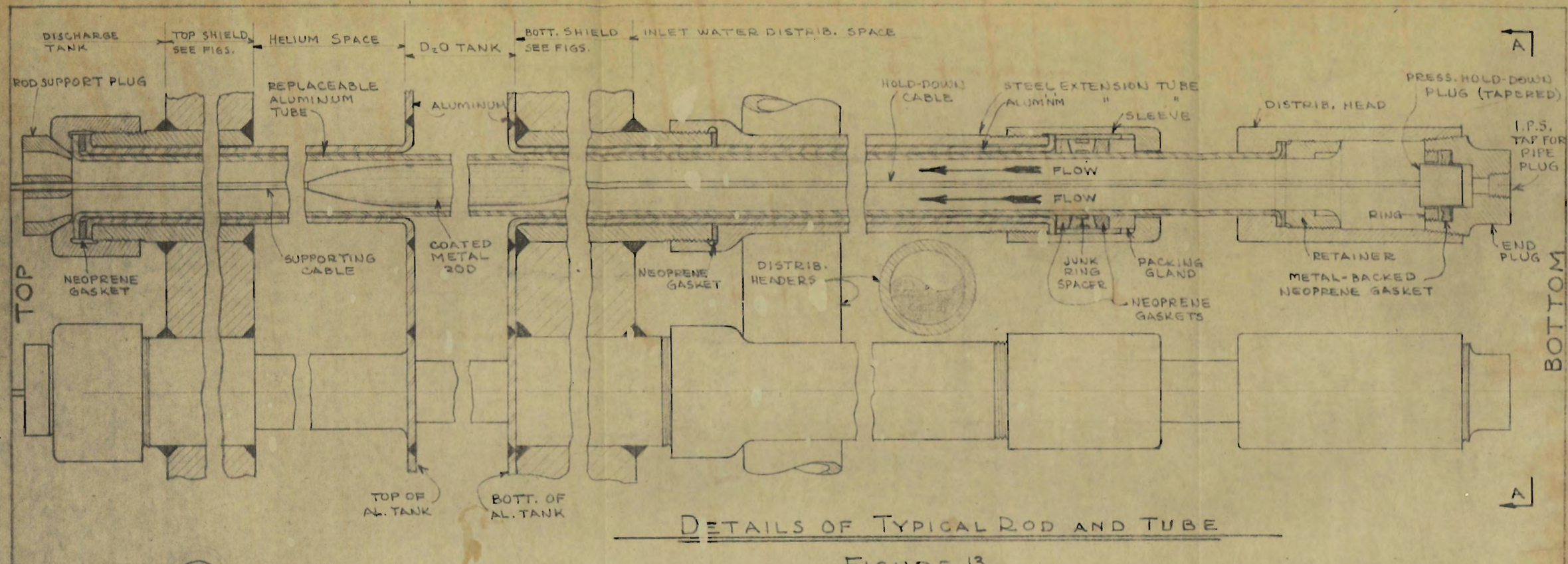


TANK DETAILS & D_2O EMERGENCY RELEASE

FIGURE 12

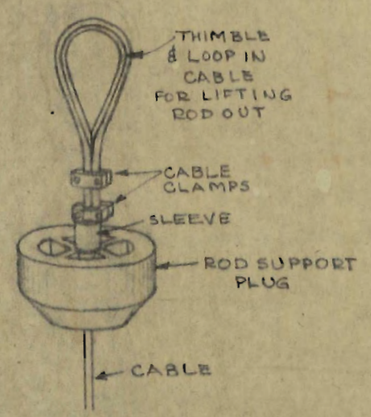
[redacted]

7-1-43 OHLINGER



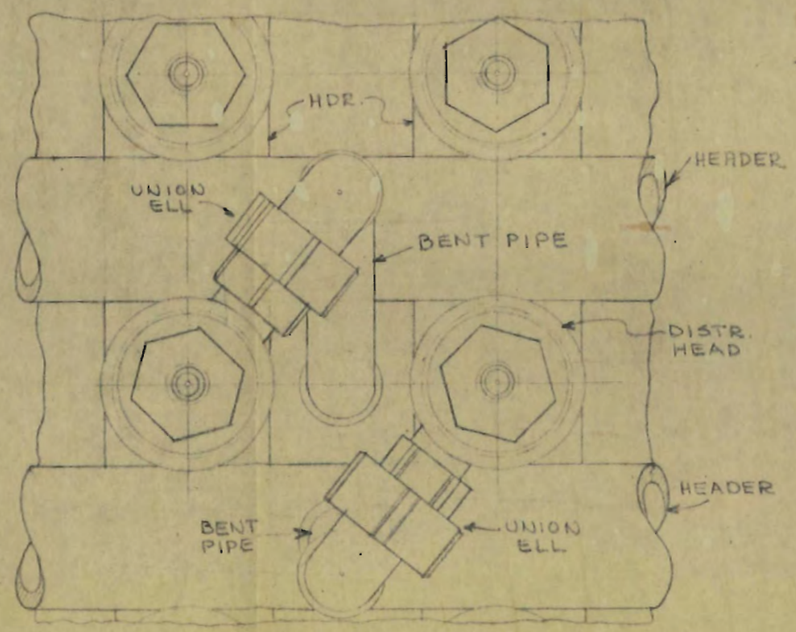
DETAILS OF TYPICAL ROD AND TUBE

FIGURE 13



DETAIL OF ROD SUPPORT

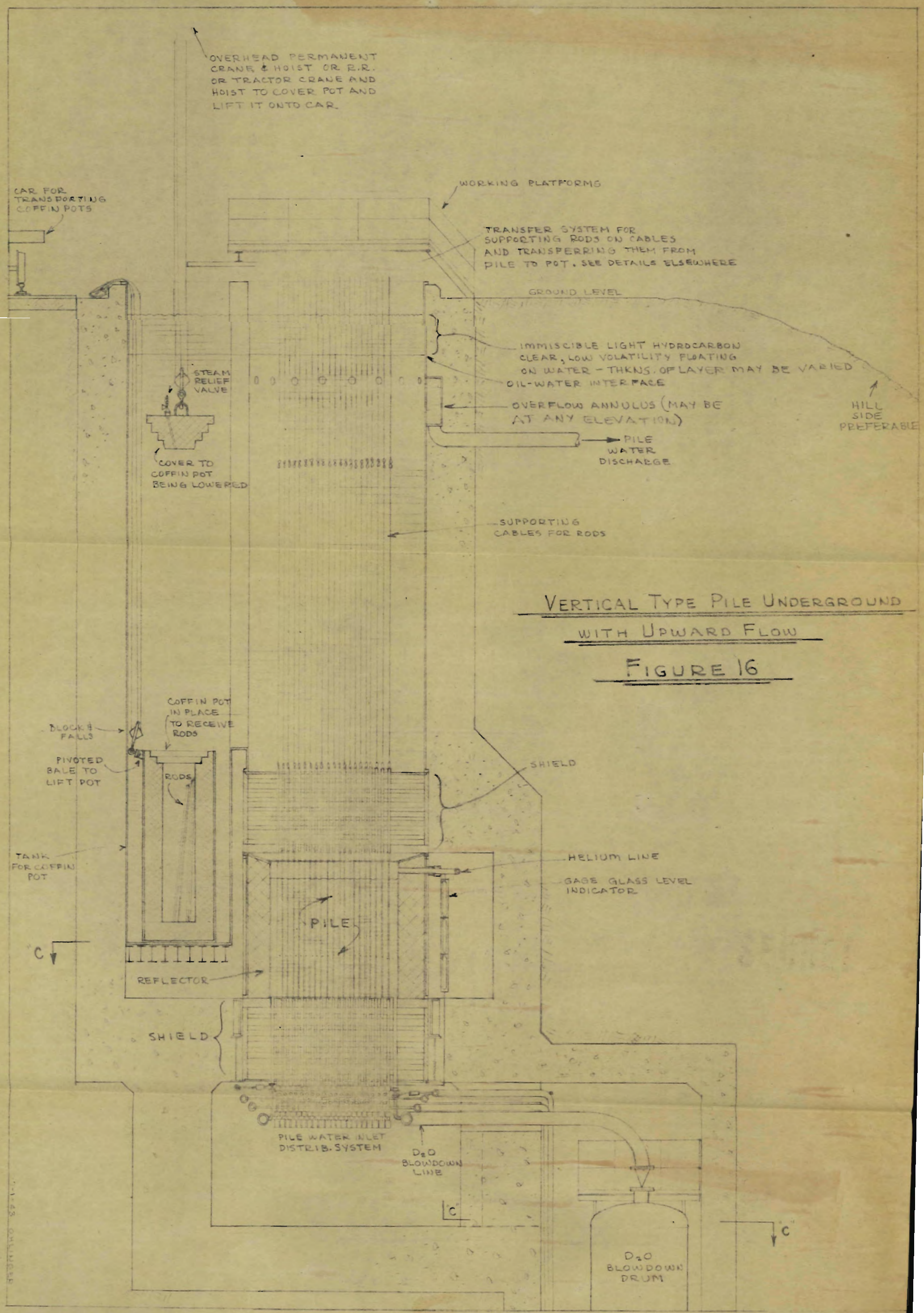
FIG. 15



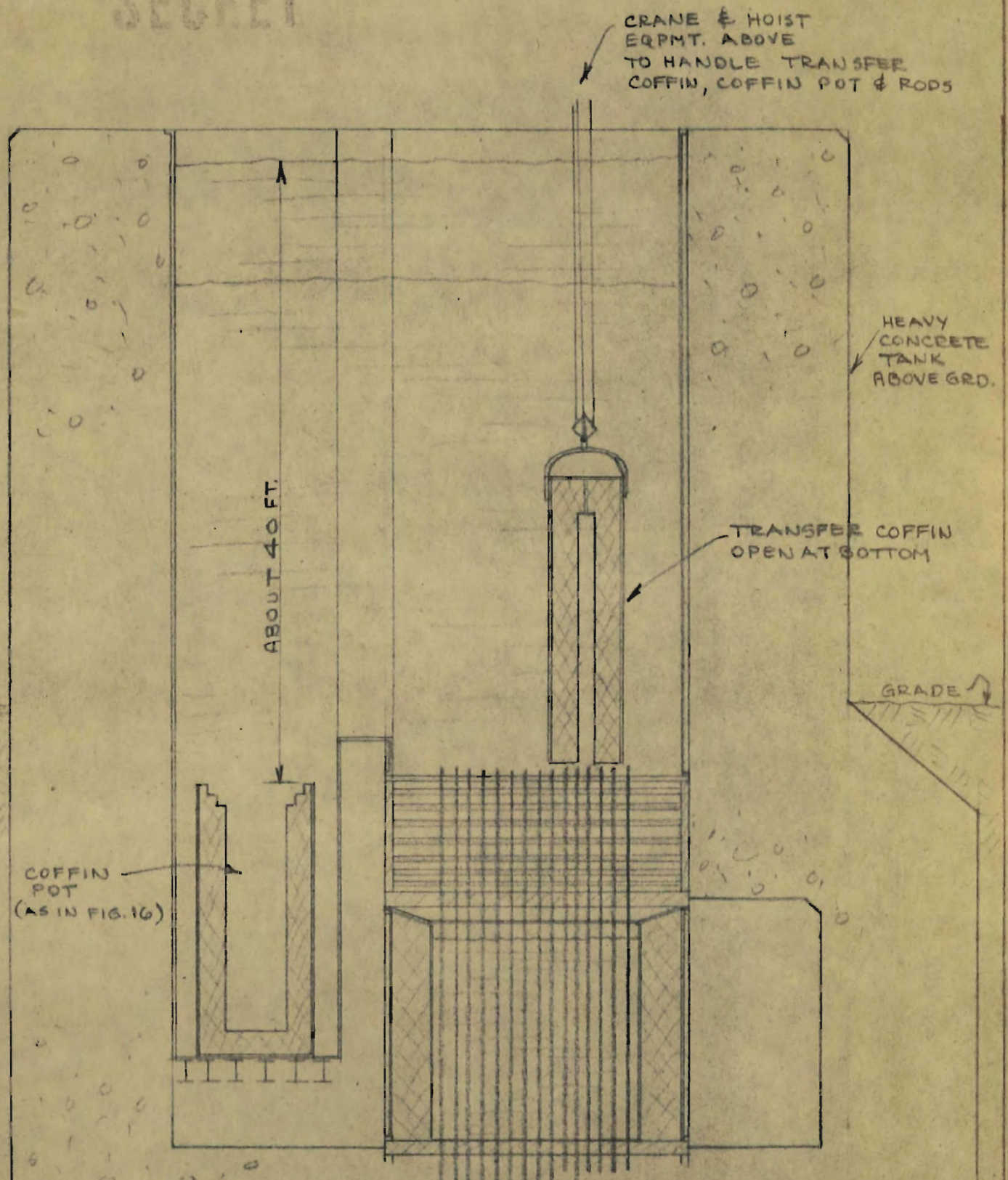
VIEW AT BOTTOM LOOKING UP SECT. A-A SHOWING TYPICAL CONN. TO HEADERS

FIG. 14

[redacted]


OVERHEAD PERMANENT CRANE & HOIST OR R.R. OR TRACTOR CRANE AND HOIST TO COVER POT AND LIFT IT ONTO CAR.
CAR FOR TRANSPORTING COFFIN POTS
WORKING PLATFORMS
TRANSFER SYSTEM FOR SUPPORTING RODS ON CABLES AND TRANSFERRING THEM FROM PILE TO POT. SEE DETAILS ELSEWHERE
GROUND LEVEL
IMMISCIBLE LIGHT HYDROCARBON CLEAR, LOW VOLATILITY FLOATING ON WATER - THKNS. OF LAYER MAY BE VARIED
OIL-WATER INTERFACE
STEAM RELIEF VALVE
OVERFLOW ANNULUS (MAY BE AT ANY ELEVATION)
HILL SIDE PREFERABLE
PILE WATER DISCHARGE
COVER TO COFFIN POT BEING LOWERED
SUPPORTING CABLES FOR RODS
VERTICAL TYPE PILE UNDERGROUND WITH UPWARD FLOW
FIGURE 16
COFFIN POT IN PLACE TO RECEIVE RODS
BLOCK & FALLS
PIVOTED BALE TO LIFT POT
RODS
SHIELD
TANK FOR COFFIN POT
HELIUM LINE
GAGE GLASS LEVEL INDICATOR
PILE
C
REFLECTOR
SHIELD
PILE WATER INLET DISTRIB. SYSTEM
D2O BLOWDOWN LINE
C
C
D2O BLOWDOWN DRUM

SECRET



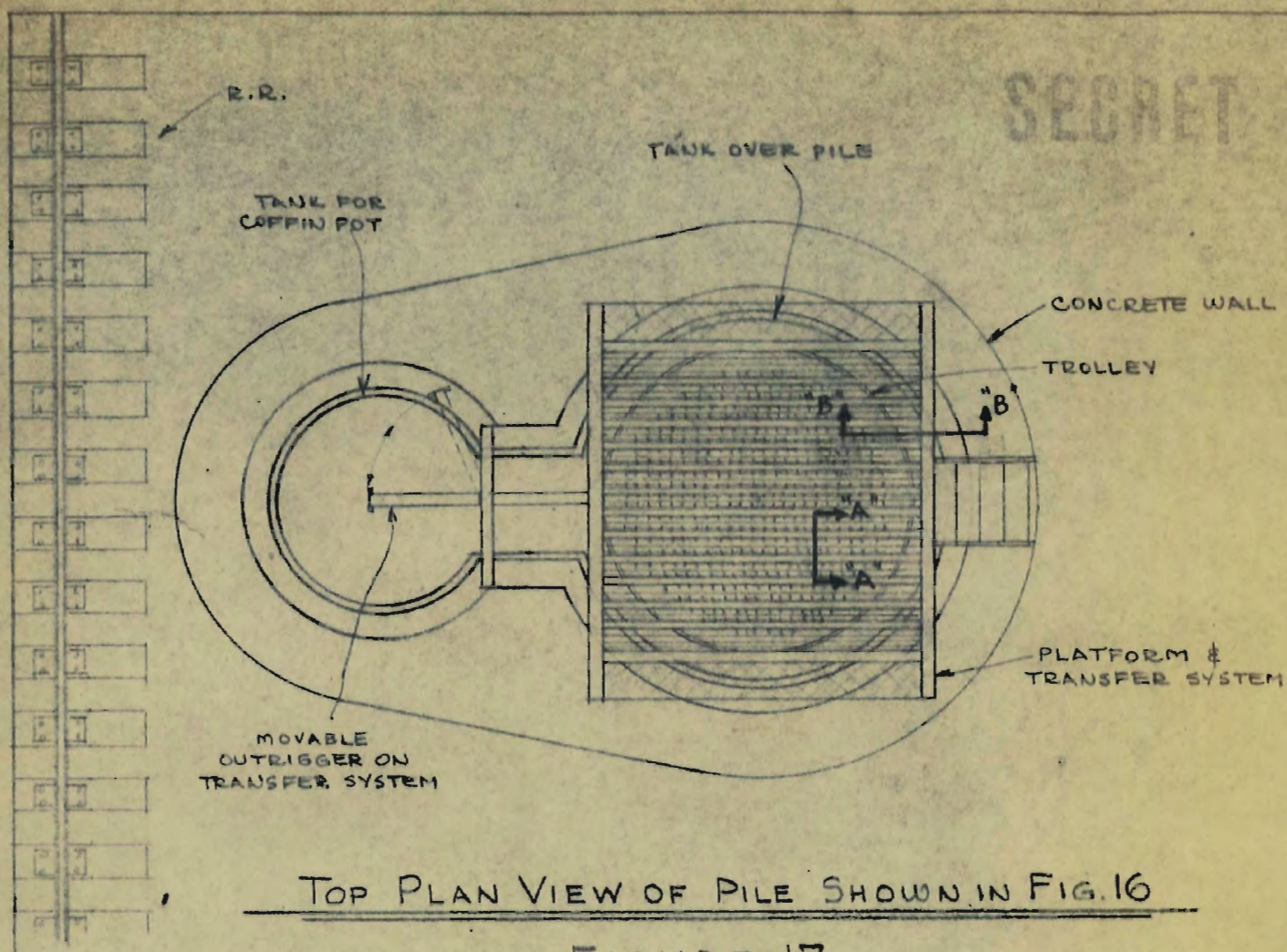
LOWER PORTION OF THIS PICTURE & DETAILS NOT SHOWN
SAME AS IN FIGURE 16.

ALTERNATE TOP ARRANGEMENT FOR PILE IN FIGURE 16

FIGURE 16A.

7-1-43 OHLINGER

SECRET

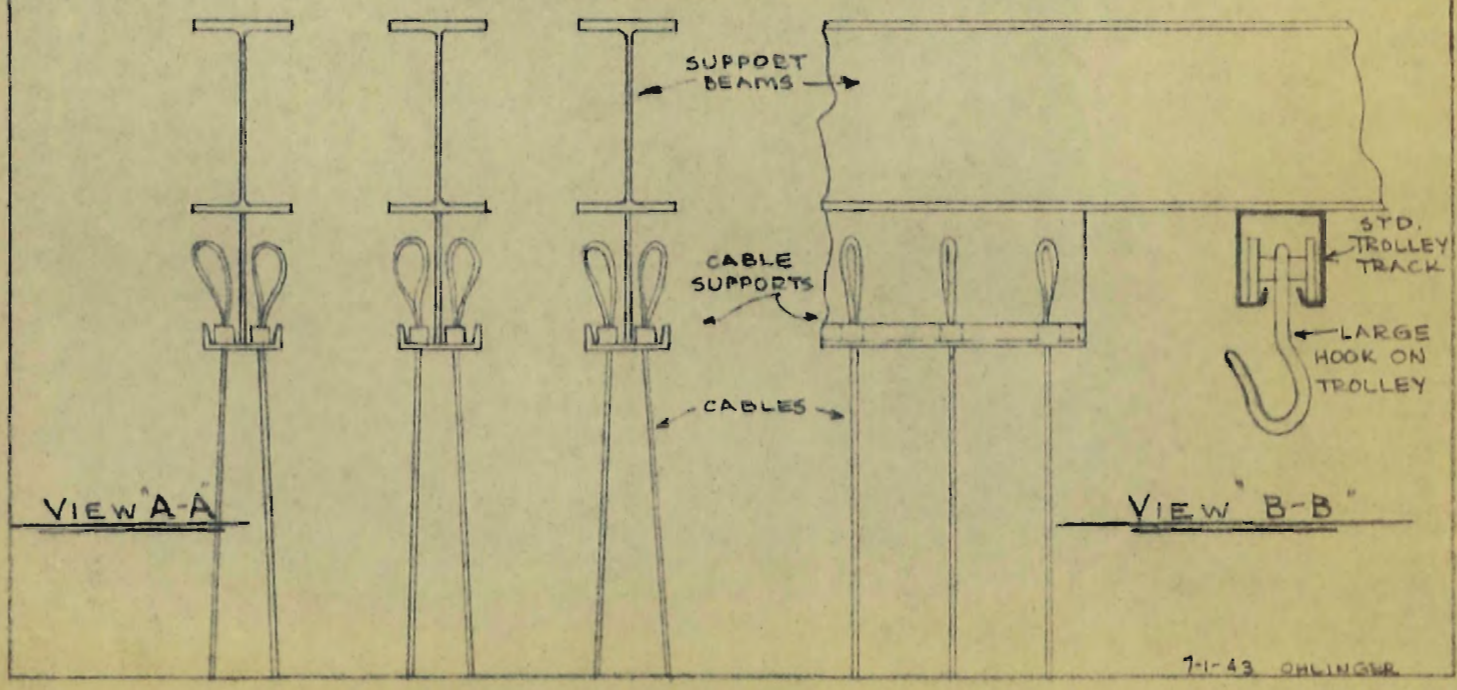


TOP PLAN VIEW OF PILE SHOWN IN FIG. 16

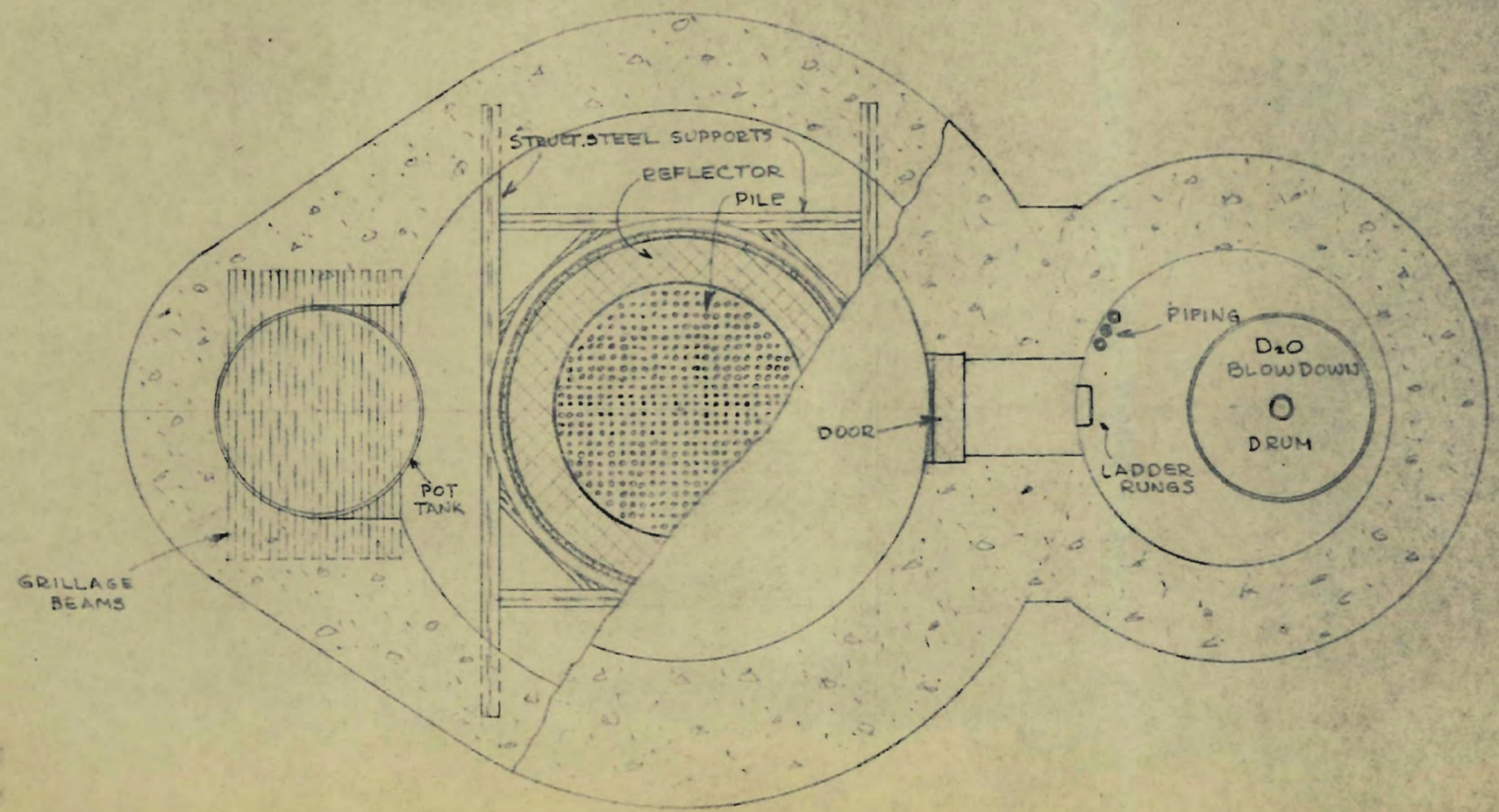
FIGURE 17

PARTIAL DETAIL BELOW OF TRANSFER SYSTEM. DESCRIPTION IN TEXT

FIGURE 18



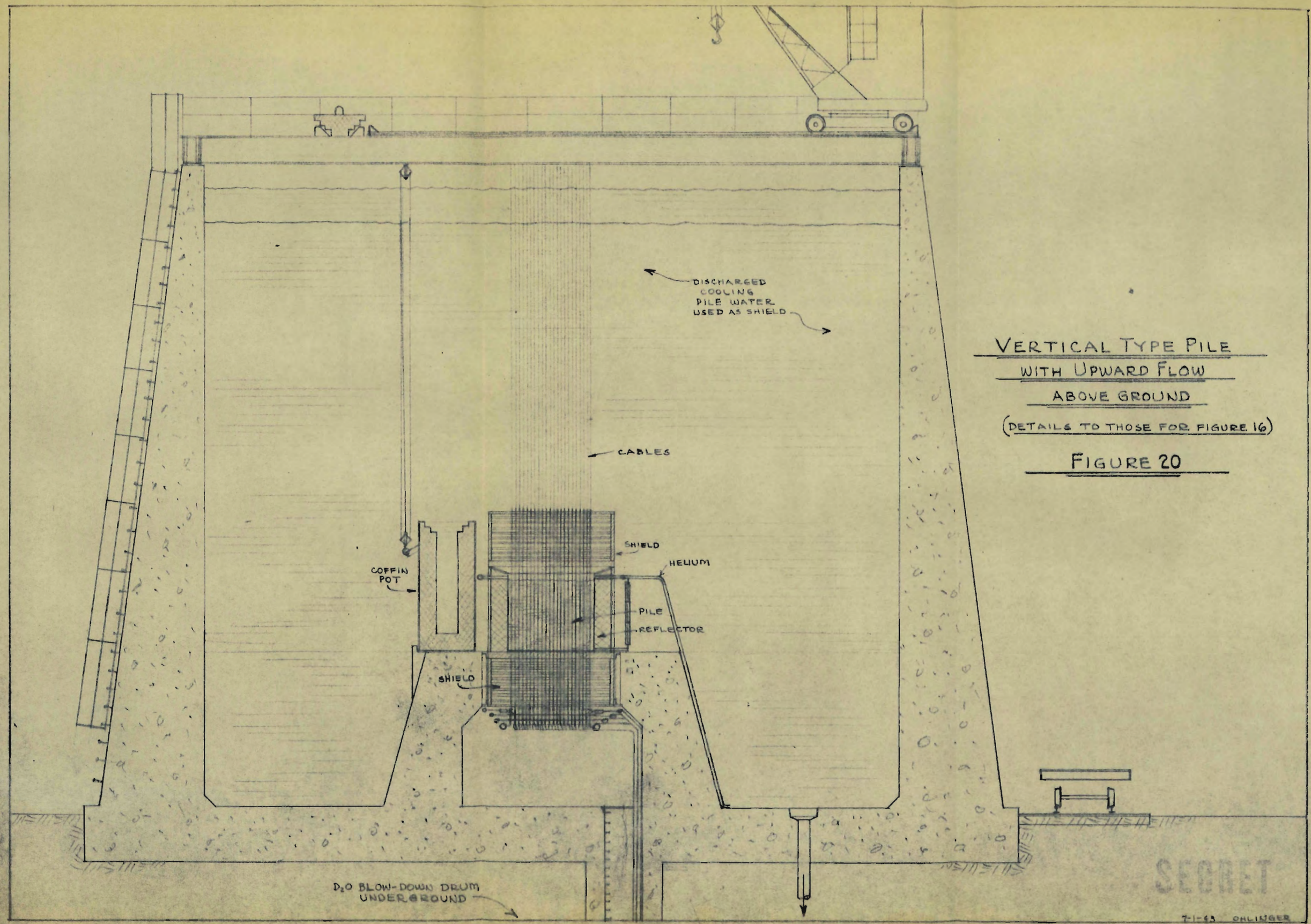
7-1-43 OHLINGER



PLAN SECTION (BROKEN) "C-C" IN FIG. 16

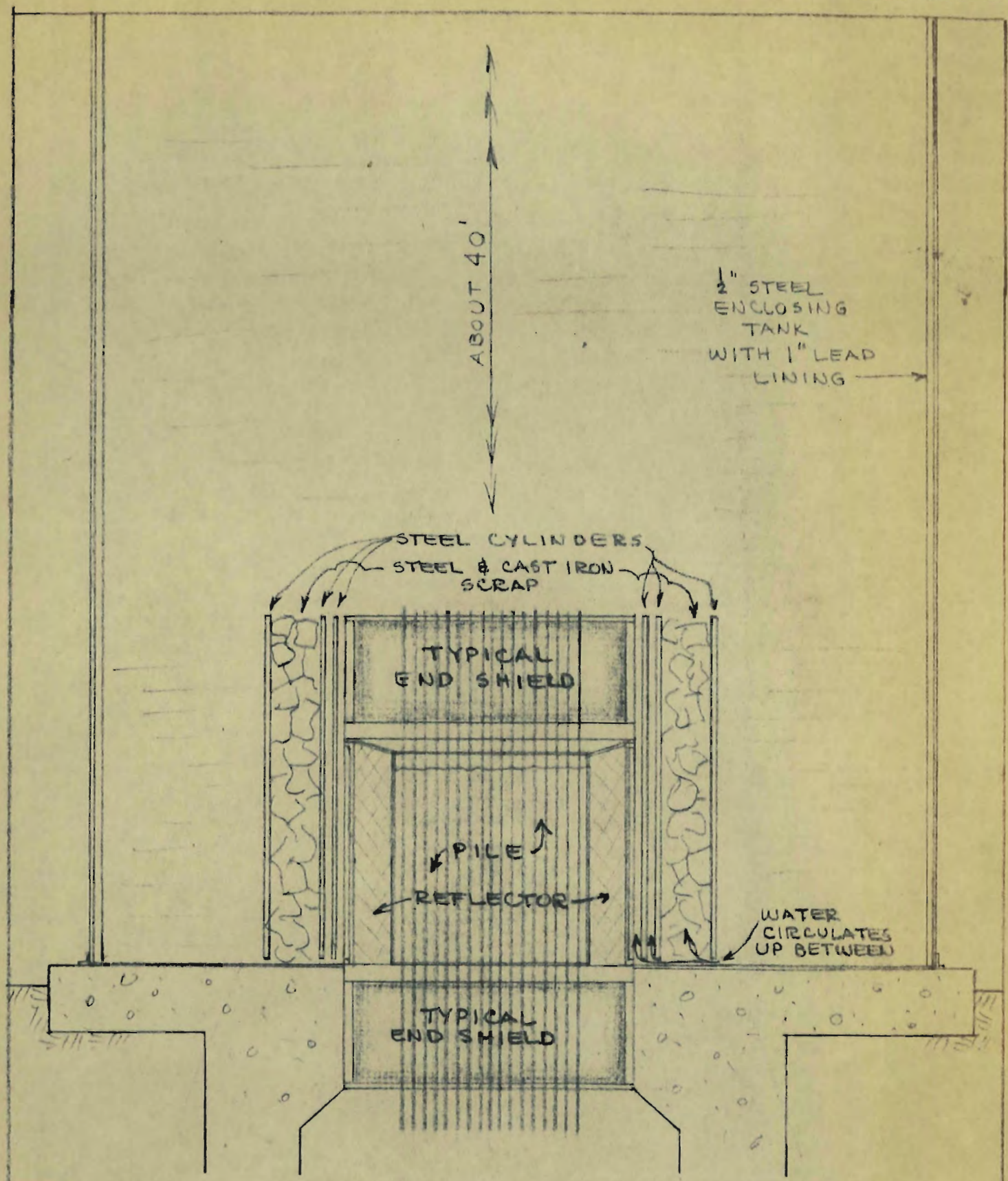
FIGURE 19

7-1-48 OHLINGER



VERTICAL TYPE PILE
WITH UPWARD FLOW
ABOVE GROUND
(DETAILS TO THOSE FOR FIGURE 16)

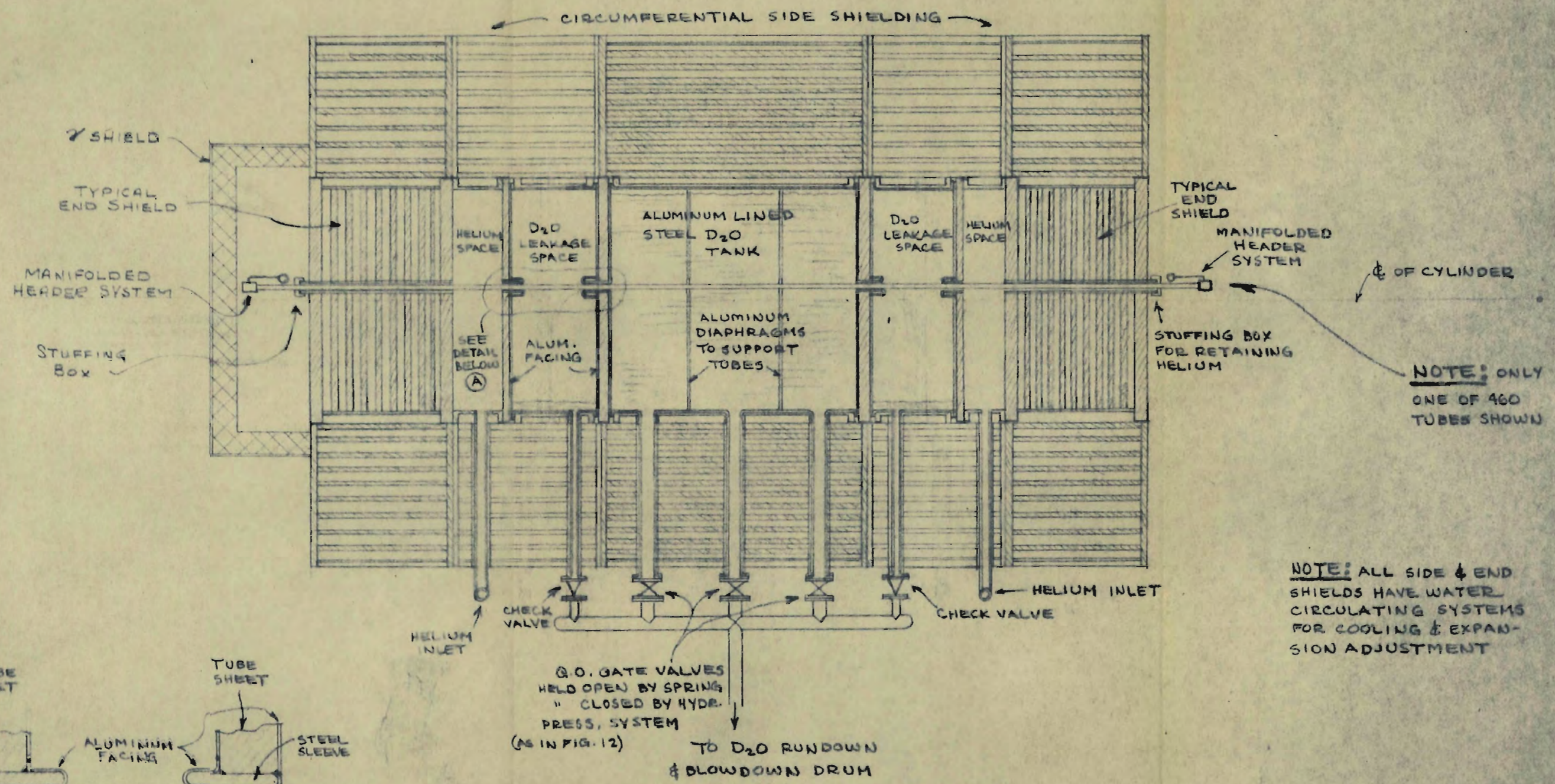
FIGURE 20



VARIATION IN FIGURE 20 USING STEEL TANK AND STEEL SIDE SHIELDS

FIGURE 20A

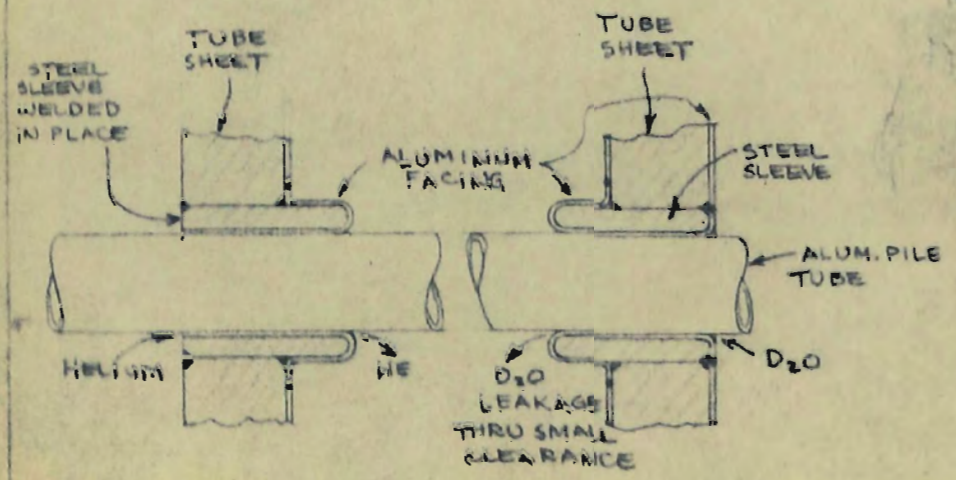
7-1-43 OHLINGER



TYPE V - HORIZONTAL PILE

(NO REFLECTOR - STEEL & WATER SHIELDING)

FIGURE 21



DETAIL (A)

FIGURE 22

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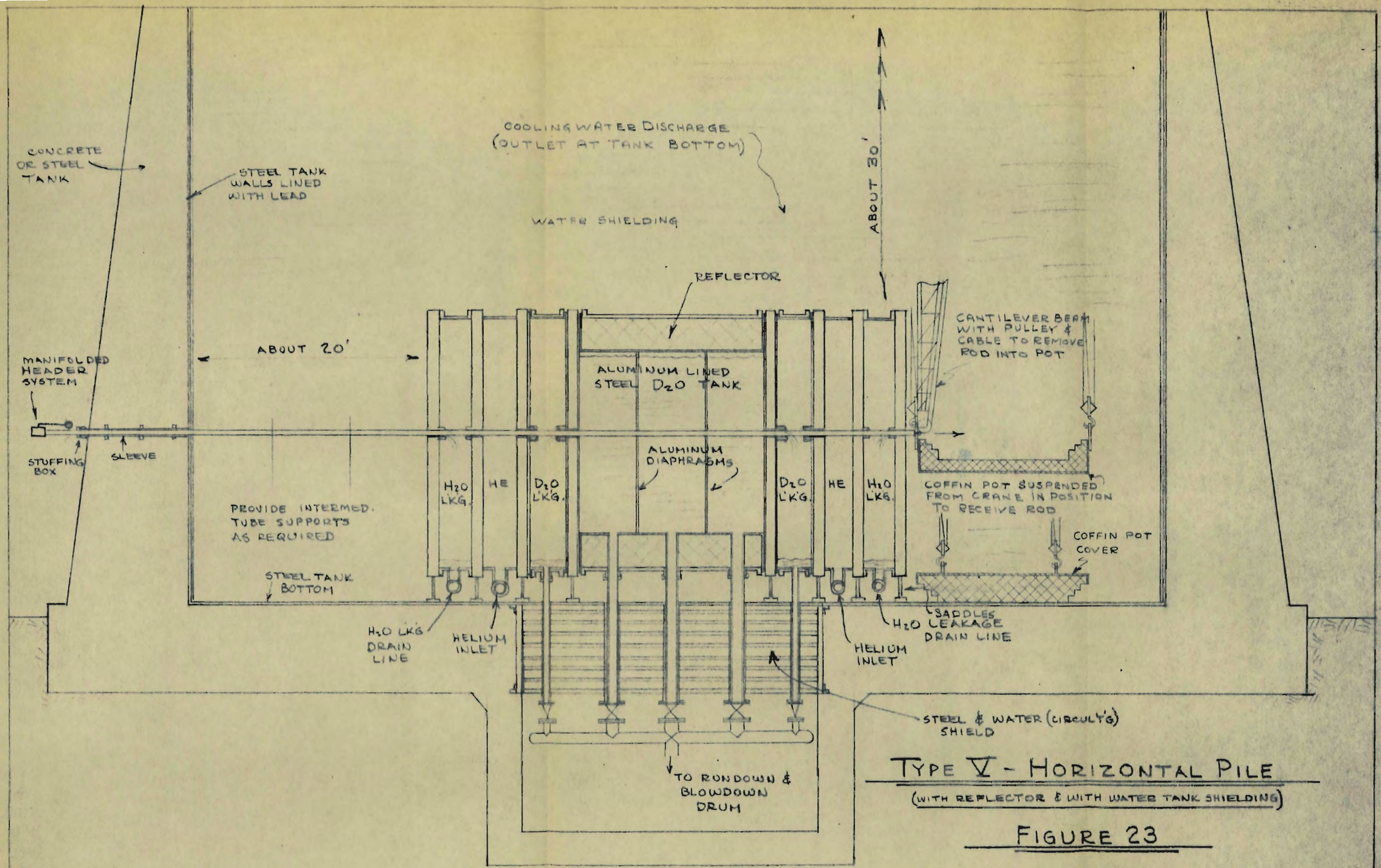
7-1-43 OHLINGER



TYPE V - HORIZONTAL PILE

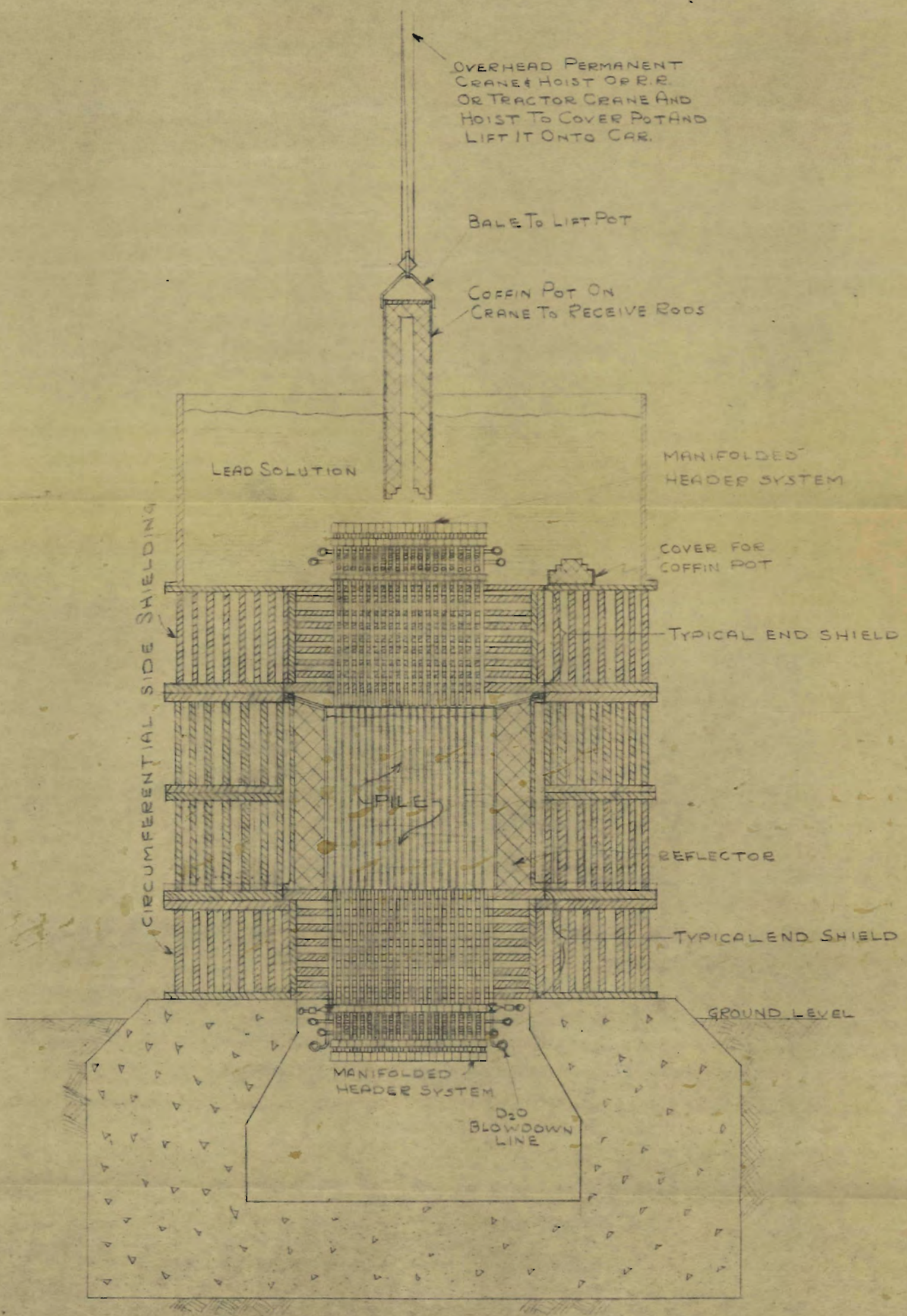
(WITH REFLECTOR & WITH WATER TANK SHIELDING)

FIGURE 23

(SIMILAR TO FIGURE 21. SEE SAME FOR FURTHER DETAIL)

SECRET

7-1-43 OHLINGER



VERTICAL TYPE PILE - TYPE I

ABOVE GROUND WITH UPWARD FLOW

FIGURE - 24

SECRET

7-20-43 HARRIS

RECEIVED
AUG 17 1943
M. D. WHITAKER