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Metallurgical Project

A. H. Compton, Project Director

* * *

Metallurgical Laboratory

S. K. Allison, Director

* * *

TECHNOLOGICAL RESEARCH - P-9 STUDIES SECTION

C. M. Cooper, Division Director; H. C. Vernon, Section Chief

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SHIELDING OF HETEROGENEOUS P-9 PILE

G. F. Quinn and [redacted]

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SUMMARY

This work was undertaken at the request of H. D. Smyth to investigate the problems encountered in the design of an end shield for a heterogeneous P-9 pile. The group consisted of engineers and physicists and this report covers the work of the engineering aspects only. It of course reflects the work of all the participants but does not undertake to cover the theoretical work except from an engineering point of view. A separate report is anticipated to cover the balance of the work. This will be issued through the Physics Section. The work was terminated because of increased interest in a homogeneous pile, not because this study is considered complete.

The most important problems encountered are:

A: Problems involved in construction.

1. Provision to shield the inhomogeneities introduced into the shield by passage of coolant tubes.

2. Support for the shield.

B: Problems concerned with radiation.

1. Selection of materials

2. Removal of heat and of any gas of decomposition.

Important Results:

Iron and lead appear to be the most practical dense materials. Water and Masonite pressed wood are the most attractive wet and dry hydrogenous materials. The inclusion of boron in the shield may be advantageous. The use of concrete in end shields is not attractive because of the large thickness required.

End shields may be composed of either a single large structure or a number of smaller units; each of these types has specific advantages. Prefabrication is desirable.

A wet layer-type shield offers a convenient method of temperature control, while a dry one has constructional advantages in the multi-unit type. A shot and water (uniform type) shield appears to be the simplest to construct.

Possible schemes for shielding the inhomogeneities have been considered, but their effectiveness has not been evaluated.

Stress calculations for the design of the supporting members, envisioned as either a large plate or a number of small beams, have been made. The shield framework, in some cases, can advantageously be made the supporting member.

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Heat removal may possibly be accomplished by conduction into the pile cooling water. Auxiliary cooling may, however, be necessary.

Recommendations: The termination of this investigation while in an incomplete stage has prevented drawing the conclusions necessary to recommend definitely any one type of shield for a heterogeneous P-9 pile

Prepared by

George F. Quinn

LaRoy B. Thompson

Submitted by

J. H. Chapin
Group Leader

H. G. Vernon
Section Chief

Approved by John Chipman
Associate Division Director

II: General Discussion

Origin of Investigation: A shielding group was formed to summarize the problems involved in the design of the end shields of a 40,000 KW, heterogeneous, P-9 pile and to investigate possible solutions. The shielding required was to be sufficient to allow complete accessibility to the pile faces (a) at all times, or (b) only after the pile had been shut down for one hour. Wet and dry shields were to be considered. The group was subdivided into a theoretical section and an engineering section. The duties of the former were to stipulate the critical dimensions of the selected materials, while the engineering section was to be concerned with the materials of construction, design from the strudural viewpoint, methods of construction, and removal of heat.

Discussion: Because of decreased interest in the heterogeneous pile in view of the promise shown by the homogeneous type, the work on this shielding problem is being discontinued. This report, therefore, summarizes the problems and possible solutions to them which have been considered to date. In many cases, because of the termination of the work, it has been necessary to leave certain problems without satisfactory solutions. On the other hand, in no case has an attempt been made to enumerate all the possible solutions to a given problem, but rather only those which appeared most attractive because of their simplicity and feasibility, the availability of the required materials, etc.

Since accessibility to the pile faces has been made one of the criteria of design, it must be mentioned that the radio activity present in the effluent cooling water from the running pile presents a separate problem in itself. The pipe carrying this water requires a separate shielding system in the case where access to the pile face is to be permitted during operation. Access to the water piping itself is possible only in the sense that valves and other mechanical devices may be operated through this separate shield.

The function of the pile shield is to diminish the intensity of the pile radiation (neutrons and γ rays) to a value fixed by some design criterion. In this work it was postulated that a man working at the face of the pile should receive no more radiation than the tolerance dose in an 8 hour day (0.1r). When access is required only after a period of shutdown, it is necessary to install two shields, - one between the piping headers and the pile proper to protect against residual radiation and the second between the headers and the outside of the pile site to prevent radiation from leaving the system during operation. The design of the inner shield is essentially the same (except for thickness) as for the case of complete accessibility.

In order to slow down and adsorb neutrons, and to absorb gamma radiation, a shield, to function efficiently, should contain a hydrogenous material, a substance with a large cross-section for neutron absorption, and a dense material. If none of these happens to be a substance with structural strength, a structural material must be added for support. Since the absorption of neutrons, once they are decelerated to the thermal region, is readily accomplished, shield materials are selected chiefly for their effectiveness in performing the functions of γ ray absorption and deceleration of neutrons.

The primary consideration in the design of a shield from the "protection against radiation" point of view is the selection of materials, both dense and hydrogenous, the thicknesses of each type required, and the physical arrangement of the two. The fact that the shield materials, especially those nearest the pile, will possibly become radioactive and require shielding must be noted. The inhomogeneities in the shield, introduced by the passage of the aluminum tubes, provide gaps and weakly absorbing regions within the shield. These add to the physical complexity of the final shield assembly. Piping connections may also become radioactive if subject to neutrons and require additional shielding precautions.

The chief problems in shield design from constructional considerations are those of meeting the shielding requirements as regards the allowable sizes of the clearances and gaps in the inhomogeneities. Methods and procedures of fabrication are of prime importance here. The most serious structural problem is the support of the weight of the shield plus the weight of additional equipment supported by it. Other engineering problems of importance are those of removing the heat generated within the shield, in order to control temperature and thermal expansion. Provision for the escape of any gas that may be evolved from the shield materials as a result of the action of incident radiation is an additional problem.

III: Present Conditions

Shields at present in use or in the state of construction include those at Argonne, at Site X and at Site W. Since the Argonne and X piles are designed for considerably lower power outputs, the Site W shield is the most analagous to our present case. For these low-power piles, concrete of either standard or special mix is used. For the Site W pile, where the radiation intensity is much greater (though not as great as that expected from the P-9 pile) the shield consists of separate thermal and biological sections. The thermal section is a ten-inch thickness of cast iron in which over 99% of all the radiant energy is removed as heat. The biological shield consists of laminations of iron plates and Masonite, a pressed wood product, the total thickness being about 4 feet, to reduce the residual 1% to biological tolerance levels.

Shields that have been suggested for the W pile (CE-407) and for the P-9 pile (CE-805) include the use of iron or lead shot and water, alternate layers of iron plate and water, in which the water is also used for the coolant, and a combination of one of these with a large thickness of water. Water is attractive because of its availability and easy mobility, as well as its shielding power for neutrons. Each of these types has been considered here, with the exception of the large thickness of water, the use of which would not satisfy the criterion of accessibility which was a condition to be fulfilled by any design evolved in this study.

The overall reduction in intensity required is of the order of 10^{10}.

IV: Investigation

A: Materials

(1) Hydrogenous Materials: The hydrogenous material may be either a solid or a liquid depending on the type of shield (see Section IIIB for advantages of wet and dry shields). Composition and properties (both chemical and physical), price, availability, suceptibility to structural incorporation, decomposition and gas evolution under radiation, and corrosive action appear to be the chief criteria by which hydrogenous materials may be compared. Water or any of a variety of organic compounds are possible liquid-phase hydrogenous materials. The effects of radiation on the properties of several organic liquids have been measured by Burton's group (CC monthly reports). As a rule, the molecular weight appeared to increase with the quantity of radiation absorbed, i. e. the viscosity increased. It is doubtful that a material will be found that fulfills the requirements of a liquid hydrogenous material as well as water. The typical effects of radiation on water are decomposition and peroxide formation.

Most of the experimental work done thus far on dry hydrogenous materials (CC 967) consists of measuring the amount of gas evolved when various materials are irradiated by β rays and deuterons. Masonite pressed wood which contains about 6% hydrogen and has a specific gravity of 1.3 appears to be a suitable shielding material. A special Masonite product (HD128) has been chosen for the "W" shield; experiments indicate that about 26 cubic feet of gas will be evolved per day from this material when used in the "W" shield. Since, however, the choice of a hydrogenous material is not an important factor in the engineering design of a shield, this phase of the problem was not investigated further than a review of the work that has been done to date on the subject.

(2) Dense Materials: Because dense materials are severely limited by their availability and cost, the use of only two of them, iron and lead, appears probably, (concrete is discussed separately). Although its gamma rays absorptive powers make iron only about 75-80% as effective as lead, an inelastic scattering effect in iron contributes considerably to the reduction in neutron intensity. In addition, the structural strength of steel, as well as its availability and cost make its use almost imperative for the support of the heavy shield.

(3) Concrete: The use of a standard or a special concrete mix (as in the Site X shield) is possible; however, a relatively thick shield is then necessary. For equal shielding against gamma rays, for example, a concrete shield must be 3-4 times as thick as an iron one. By using a porous material such as Haydite for the fine aggregate, the water content of a standard concrete can be considerably increased, thus improving the effectiveness of the mix for decelerating the neutrons. The resultant decrease in density, however, must be compensated for by the addition of a dense material, (eg. barytes as in the Site X shield), to increase the gamma ray absorption. For end shields, however, the large thickness required makes the use of concrete unattractive.

(4) Special Materials: To reduce the induced activity in the shield materials and to decrease the number of secondary gamma rays, the inclusion in the shield of a substance with a large neutron-absorption cross-section, eg. boron, has been suggested. The presence of boron is most advantageous when placed toward the outside of the shield where prevention of secondary gamma rays and induced activity is more important because there is only a part of the shield thickness remaining for protection. Boron could be introduced into the shield as boron steel or, in a wet shield, as a solution of borax or boric acid. The disadvantages of its use are: possible leak of solution containing borax; change in the physical properties of steel by the addition of boron.

B: Overall Design Consideration

(1) General Dimensions: For the purposes of this investigation, a heterogeneous P-9 pile was assumed to consist of a vertical cylindrical tank, through which, parallel to its axis on a 3.8 in. (9.65 cm.) square lattice, were 456 aluminum tubes in which were the aluminum-coated active rods, forming an annular cooling water passage. The diameter of the coated rods was taken as 0.866 in. (2.2 cm.) and the inner and outer diameters of the aluminum tubes as 1.06 in. (2.7 cm.) and 1.26 in. (3.2 cm.) respectively. The diameter of the aluminum tank was about 8 feet (2.5 m.). Because provision must be made for the charging and removal of rods, as well as tube replacement, these tubes must pass through the shield to a point of accessibility. Therefore, a leakproof connection between these tubes and the aluminum ends of the tank (called the tube sheets) is required outside the shield. This may be achieved by the provision of secondary aluminum tubes welded to the tube sheet: these extend through the shield and through each passes one of the replaceable cooling water tubes. A tube closure outside the shield provides the leakproof connection between the concentric tubes, and may also serve as a connection to the piping of the cooling water system. The shield design, therefore, must accommodate the passage of these 456 outer aluminum tubes of 3.8 inch spacing. Shielding the 456 outer aluminum tubes on 3.8 inch spacing. Shielding the inhomogeneities introduced into the shield by their passage is one of the major problems involved in the design.

(2) Constructional Types of Shield: From the construction point of view, the shielding of the 8-foot diameter faces of the pile may be accomplished either by a single structural unit which accommodates the 456 aluminum tubes, or by a number of smaller units would be easier to handle and fabricate, but a shield consisting of many small units must provide for the shielding of the clearance between two adjacent units, say by overlapping sections or by staggering layers of small units. Smaller clearances between the aluminum tubes and the shield and less alignment difficulty can be expected with smaller units. In the alignment difficulty can be expected with smaller units. In the construction of the top shield, for example, the lowering of a large single-unit type shield over a "forest" of 456 tubes so the clearances are small, is a problem which could be simplified by the use of smaller units. Also, less difficulty with thermal expansion may be expected with the smaller units. In a wet shield, however, the use of these units would require a large number of water tight boxes and would introduce piping difficulties if the liquid were to be circulated.

To provide added strength to the shield (see Sec. III D), to protect the aluminum tubes from damage in assembling or corrosion by the shield materials (e.g. water), to make the shield unit leakproof in the case of a wet shield, and to provide a concentric cylindrical surface around the aluminum tubes in which a close fit can be made, steel pipes or tubes on the same

spacing as the aluminum tubes are made an integral part of the shield. These pipes are welded to the end plates of the shield. See Figure I, p. . In the construction of a large unit of this type, the lowering of the final plate of the shield over the large number of pipes and the obtaining of small clearances such that the pipes may be welded to the plate presents a considerable alignment problem. Figure II, p. shows a possible means of lessening the difficulty. A tapered collar is welded to each pipe; then the plate, drilled and tapered to fit the collars can be lowered over the "forest" much more easily since precise alignment before lowering is not necessary. As the plate is lowered, it will tend to align itself properly on the tapered collars.

The procedure used to insert the outer aluminum tubes into the steel pipes of the shield has several alternatives. The tubes may be inserted through the shield individually and subsequently welded to the tube sheet; the tube sheet with the tubes already attached may be introduced as a unit. The former method will probably allow the clearance between the tube and pipe to be smaller, which is desirable for several reasons. Unless prefabrication of the tube sheet, tubes, the bottom plate of the shield and the shield pipes is possible, however, the procedure of inserting the tubes individually is not a desirable one in the case of the top shield, because it would require overhead welding of aluminum, which is not recommended. However, if the multiple unit type is used for the top shield, a close clearance may be obtained by lowering a shield unit over a single tube, the reverse of the other procedure. The lowering of a single-unit top shield over the 456 aluminum tubes is undesirable because of the difficulties of alignment, obtaining small clearances, and of handling of a heavy shield without damaging the tubes. In the bottom shield, however, the tube sheet, punched with the appropriate holes, may be laid on the shield and the tubes then pushed through and welded to it.

Smaller clearances may be obtained between the plates and pipes, alignment difficulties may be simplified, and the complications of shrinking rings on the forest of pipes can be appreciably reduced, by prefabricating the entire shield with the aluminum tubes and tube sheet before setting it in place. The chief disadvantage of complete prefabrication is the large weight (50-80 tons) of the complete unit.

(3) Shield Types: From a shielding-materials viewpoint, the types of shield may be classified into two groups; layer type, in which the shield is composed of alternate layers of dense and hydrogenous materials, and the uniform type, a more or less homogeneous mixture of the two substances.

(a) Layer type shields: Layer shields may be either wet or dry, and are constructed by (a) welding vertical steel tubes or pipes to the bottom plate and then (b) slipping over these pipes the alternate layers of the two-shielding materials, unless, of course, as in the case of wet shield, the hydrogenous material may be introduced later. In the wet shield, spacers may be provided to keep the metal plates at the desired spacing. These spacers may be long rectangular steel strips welded to the plates and running between two rows of tube holes; they may also be made to guide the flow of the hydrogenous liquid in the event it is to be circulated as coolant. An alternative

to the use of these spacers is to build up the shield by alternately laying plates and channels around the periphery, the channels serving to keep the plates spaced, and the plates supporting their own weight. One difficulty encountered in this type of shield, however, is the escape of radiation through the clearances between the plates and the steel pipes. If standard constructional procedures cannot provide a sufficiently small clearance, the condition may be remedied by the use of shrink rings or collars. These are metal annular rings which are shrunk on to the pipes after each plate is lowered into position; they may also serve as the spacers to support the weight of the plate above (See Fig. III, p.). An outgrowth of this idea is to enlarge these rings sufficiently to provide the shielding, thus eliminating layers of large plates. Such a scheme is sketched in Figure IV, p. . The shield pipes have welded to them, on appropriate spacing, square plates or collars drilled to accommodate the pipe; the length of the side of the square plate is equal to the tube spacing. These pipes with the collars welded on can be easily prefabricated; they are then inserted in the lower end plate of the shield and welded to it as in the usual construction. The clearance between the collars on two adjacent pipes may be shielded by sliding long metal strips between the rows of tubes such that they extend across the shield. The strips on the next layer would be inserted perpendicular in direction to the former layer, such that in two layers no gap is unblocked. This type of construction eliminates the difficulties of sliding heavy plates over a number of pipes and keeping the clearances small; it also leaves no clearance between plate and pipe.

The advantages of a wet layer-type shield are: (i) the hydrogenous material may be the coolant, permitting good temperature control throughout the shield, (ii) the hydrogenous liquid will fill all corners, clearances, etc., (iii) in cases where the hydrogenous liquid is the coolant, any decomposition products may be removed from the shield as the coolant is circulated. However, this type of shield requires a leak-proof construction, and care must be taken that no sizable gas pockets are present within the shield. Also, the coolant may cause corrosion of the other material and may become active itself. In a dry layer-type shield, although the leak-proof construction is avoided (except where cooling water must be circulated), provision for adequate removal of evolved gas must be made. Grooves or corrugations in the plates may be a satisfactory solution to this problem. High temperatures in the poorly-conducting hydrogenous material must be avoided by careful design.

(b) Uniform shields: Two possibilities have been considered in this category, viz. concrete and the shot type. The concrete may be a standard mix or one of special composition, similar to that used at Site X. The shot type consists of small pieces of metal, (lead or iron) with water or other hydrogenous liquid as the surrounding medium. The shape of the shot pieces may be varied to provide sufficient free volume so that the required water-metal ratio is attained. If this is impossible, screens may be used to increase the free volume. Either of these two materials may be poured into a water tight box consisting of a bottom plate with the steel pipes welded into it and enclosing walls on the sides. The construction of this type of shield is probably the simplest of those discussed.

The concrete mass may be cooled by embedding cooling water pipes at appropriate points, or water may be circulated through holes in the concrete itself. In order that the water content of the concrete be kept high, it may be desirable to keep a concrete shield flooded with water at all times. A problem which requires some care in its solution is that of the strains introduced into the shield pipes by any change in volume of the concrete upon setting. Relatively thick concrete shields would be required. (See Sec. III-A).

In an iron shot shield boron may be introduced easily as boron steel shot. In the form of shot where the strength of the material is unimportant, the boron content need not be limited as it would be, for example, in the case of self-supporting plates in a wet layer type shield.

(c) Separate thermal shield: The shield may, as at Site W, be divided into two sections; thermal and biological. The two sections may be physically and structurally separated. The biological section may be anyone of the types discussed above; the thermal shield may be made of a thick plate or of thick cast iron blocks in either of which over 99% of the incident energy can be removed. Blocks appear more attractive. These blocks fall into the multi-unit classification, (see Sec. IV-B-2) and must overlap one another to prevent radiation leakage between two adjacent blocks. (See Fig. IX, p.). The advantage of such a construction is that any local thermal expansion or stress is not directly transmitted to the remainder of the shield. Each block may be made to fit over any number of tubes; however, it may be desirable to provide a block for each tube for two reasons; (a) less difficulty with thermal expansion and (b) easier assembly of the top shield where the blocks must be slid down over the aluminum tubes. A possible system is sketched in Figure V, p. .

C: Inhomogeneities:

The previous sections have considered the main body of the shield and the inhomogeneities introduced by the steel pipes which pass through the shield and enclose the aluminum tubes. Within these pipes, however, there are three gaps through which radiation could escape: (1) between the outer aluminum tube and the steel pipe, (2) between the inner and outer aluminum tubes, and (3) inside the inner aluminum tube. (See Sec. IV-B-1).

Blocking the gaps between the tube and the pipe and between the inner and outer tubes is difficult unless the clearances can be made sufficiently small that the escaping radiation is tolerable. The clearance between the outer tube and the pipe may be decreased if each aluminum tube can be separately introduced through the shield tubes and then welded to the tube sheet or if, in the case of the multi-unit type shield, the shield unit can be slid down over a small number of tubes, (see Sec. IV-B-2), or if the shield, tubes, and tube sheet can be prefabricated into a single unit. This clearance may be further reduced by expanding the tube against the wall of the steel pipe by a rolling procedure. Shrinking the tubes into the pipes is

another means to the same end. Another possibility is that of machining the tube and pipe such that an overlapping step is introduced. Other than making the original clearance between the inner and outer aluminum tubes as small as practicable, no suggestion has as yet been made for shielding this weakly absorbing region. Shielding the clearances inside the inner aluminum tube presents a different problem at each end of the pile. Any blocking scheme at the end through which the rods are charged into and removed from the pile, must provide sufficient room to permit passage of the rod.

A possible scheme which may satisfy these conditions (see Fig. VI + VII, pages) is that of expanding into the aluminum tube, at a position corresponding to the pile face of the shield, a hollow cylinder whose walls will shield the greater part of the water annulus around the active rod, and whose inner diameter will permit passage of the rod. The diameter of the rod extention at this section may be decreased to compensate for the reduced area for water flow. This cylinder, which may extend about one-half the distance through the shield, must be made of, or coated with, aluminum for corrosion resistance. Beyond this cylinder, toward the outer face of the shield, the rod extension itself will increase in diameter until the O. D. is larger than the I. D. of the aforementioned cylinder, thereby completing the blocking of the water annulus around the rod. Sufficient free area for water flow through the rod extension must be provided by using some sort of hollow cylinder for the rod extension at this point. As shown in Figure VI, p. , the central section of the tube may be shielded by a metal plug attached to the end of the active rod. At the opposite end of the pile, the complication of rod removal is eliminated and the shielding becomes more simple. Here an auger or a series of cylinders as above may be used. The physics of these systems has not been investigated to determine their efficacy.

D: Shield Support:

A common feature of end shields on a vertical pile is that they must support a large weight. This consists of their own weight plus the wieght of additional equipment to which they are attached (piping) or which they may support (aluminum tank containing the P-9). Because of the large number of closely spaced pipes emerging from the shields, support around the edges appears most practical. The shield can be supported either by a thick plate extending across the face of the pile, or by a series of individual beams running across the shield between the rows of tubes.

1: Plate Type: The shield was assumed to be either a ten-foot square or a circle, ten feet in diameter, freely supported at the edges.

The approximate stresses in the square plate were calculated by using the equations for a freely supported circular plate whose diameter was that of the circle circumscribed about the square. Square plate stresses calculated in this way are estimated to be high by 50 per cent. In the event that the lower steel plate of the shield must support a weight of W tons, the stress, S(lbs/sq.in.), developed at the center of the plate and on its surface is estimated to be not greater than that given by

$$S = KW$$

where K, a function of t, the plate thickness in inches, is given in the following table:

10 foot square		circle 10 feet in diameter	
t in.	K	t in.	K
2	625	2	398
4	156	4	100
6	70	6	44
8	39	8	25

As stated in Section IV-B-2, to protect the aluminum tubes, steel pipes are made an integral part of the shield (see Fig. I, p.); these may affect the stresses induced, as follows. In the event that the weight, W tons, is supported by the top and bottom plates of the shield, each of thickness t inches, spaced at a distance T inches (center to center), and connected by 456 steel pipes, such that the whole may be considered as one beam, the moment of inertia is so considerably increased that the values of K are appreciably reduced. K is now, however, a function of both t and T. Estimated conservative values are:

10 foot square

T = 36 in.		T = 60 in.	
t in.	K	t in.	K
2	6.2	2	3.6
4	3.1	4	1.8
6	2.3	6	1.3
8	1.8	8	1.0

circle 10 feet in diameter

T = 36 in.		T = 60 in.	
t in.	K	t in.	K
2	3.9	2	2.3
4	2.0	4	1.2
6	1.4	6	0.8
8	1.1	8	0.6

It is apparent from these results, that the connecting of the two plates by the steel pipes is most desirable from the structural point of view. In this system, however, the steel pipes and the aluminum tubes within them are deformed an amount proportional to the deviation of the plates from the horizontal. The stress in the aluminum tube is approximately one fourth that in the steel pipe surrounding it. Using the same formula, S = KW, and tabulating the estimated values of K for the steel pipes we have:

10 foot square

T = 36 in.		T = 60 in.	
t in.	K	t in.	K
2	2.0	2	0.43
4	1.1	4	0.22
6	0.77	6	0.15
8	0.61	8	0.12

circle 10 feet in diameter

T = 36 in.		T = 60 in.	
t in.	K	t in.	K
2	0.87	2	0.18
4	0.46	4	0.09
6	0.32	6	0.06
8	0.26	8	0.05

In order to estimate stresses, the total weight of any proposed system must be calculated. Rough estimates for a shield five feet thick, composed of iron plates and water, and supporting the pile tank and the piping at the bottom, indicate that the shield must be support a weight of approximately 110 tons.

Only in the case where this load is supported by one plate are the stresses high. For example, with a weight of 100 tons, a 4 inch plate would develop a stress of 10-15,000 lbs./sq.in.

In the event that large thick plates are not available or cannot be handled, the support may be either by beams or several thin plates placed one on top of the other.

2: Beam Type: Since there are 24 rows of tubes and the distance between them limits the width of the supporting beams, there will probably be 25 beams used to support the shield (See Fig. V, p. .) Assuming that the beams have a rectangular cross-section, are 10 feet long, and are freely supported at the ends, the stress, S (lb/sq.in.), developed at the center of the beam and on its surfaces may be expressed as

$$S = KW$$

where W is the total load in tons, and K is a function of the number of beams N, the beam thickness t, and the beam width b. Typical values for K are given in the following table:

N = 25, b = 1		N = 25, b = 1.5		N = 25, b = 2	
t in.	K	t in.	K	t in.	K
2	1800	2	1350	2	900
4	450	4	340	4	230
6	200	6	150	6	100
8	110	8	85	8	55

To support 100 tons, for example, the beam thickness should be about six inches. From the table above, this thickness will keep the working stress at 10-20,000 lbs./sq.in. Beams of other cross-sections may also be used, the stresses being the same for equal section moduli.

For example, T-shaped beams might be more convenient in supporting the cast-iron blocks of the thermal shield (see Sect. IV B-3 and Fig. VIII, p.) where the leg of the T might fit into an accommodating slot in the blocks.

E: Heat Removal: The amount of radiant energy incident on the shield has been roughly estimated by Friedman as 3.2 watts/sq.cm. (150KW for each end shield). Practically all of this energy will be converted to heat in the first foot of the shield. In the W pile*, for example, all but about one quarter of one per cent of the incident energy appears as heat in the ten inch blocks of cast iron which comprise the thermal shield. This heat may be removed by the pile cooling water, as is done at W, or by auxiliary cooling water introduced for that purpose. For a given system, whether the heat may be removed by the pile cooling water without developing excessive temperatures, depends on the rate at which heat is generated through the shield and on the overall heat transfer coefficient obtainable from the shield material to the pile cooling water. From the approximate equations given by Woods obtained by initially ignoring radial temperature gradients and later inserting a factor to correct this omission, it appears that, of the two, the overall heat transfer coefficient is the more important factor. Approximate calculations were made for an incident energy of 3.2 watts/sq.cm. being converted to heat exponentially in a cast iron thermal shield. The dimensions assumed for the tubes, etc., were:

	I. D. inches	O. D. inches
Inner tube (Al)	$1.065 \pm .005$	$1.260 \pm .005$
Outer tube (Al)	$1.280 \pm .005$	$1.580 \pm .005$
Bore in iron block	$1.600 \pm .005$	

Overall coefficient, U, PCU/hr.-ft. of tube - $^{\circ}C \cong 4$
(based on conductivities of tube and gap materials)

Since the rate at which the heat will appear in the shield is not definitely known at this time, calculations were made for several cases. Assuming an exponential absorption of the radiant energy according to e^{-bx}, where b is the absorption coefficient and x the distance from the pile face of the shield, the following table gives values of Δt, the maximum temperature difference between the cooling water and the point of highest temperature in the shield for various values of b.

b		Δt at x = o	Δt at x = 3 inches
cm^{-1}	ft^{-1}	$^{\circ}C$	$^{\circ}C$
0.3	9.2	145	
0.5	15.3	153	44
0.7	21.4	157	

These results show that, in addition to a high temperature, a sharp longitudinal temperature gradient will exist in the iron block. If, now, as in the W shield, U the transfer coefficient can be increased to about 20 by decreasing the gap sizes or filling them with materials of higher thermal conductivities, the maximum t at b = 0.3 cm^{-1} is near 60°C. If such high temperatures are allowable on the pile face

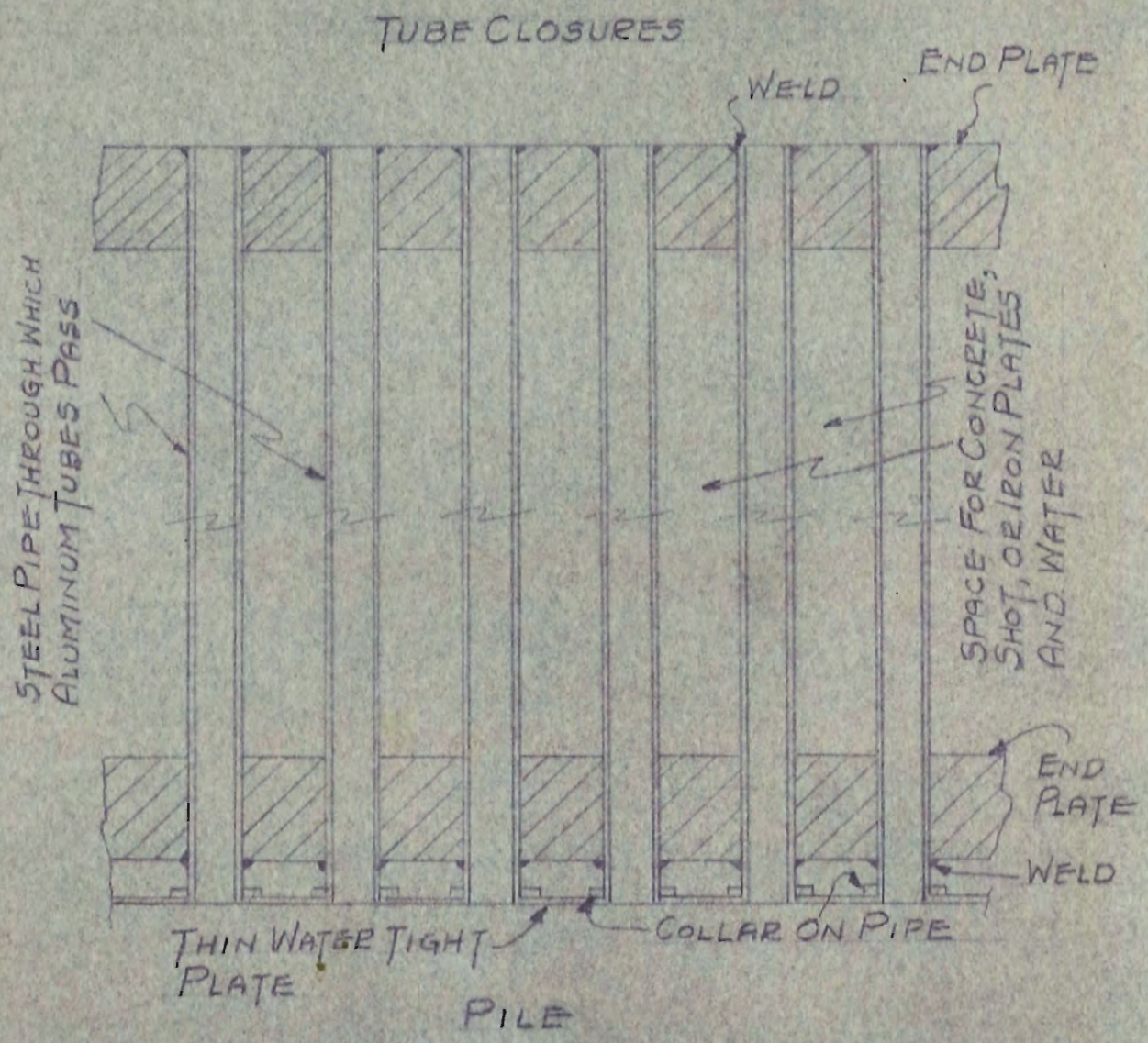
* Memo W. K. Woods to Hood Worthington, "Temperatures at Center of Face Shields of W Pile". 8/24/43

of the thermal shield, provision must be made to insulate this face from the aluminum tank containing the P-9. In the event that a sufficiently high coefficient is not attainable, auxiliary cooling must be provided. This is most easily accomplished in the case of a wet shield in which the hydrogenous liquid could also serve as coolant. In other types, however, cooling water lines would be required at appropriate places. The temperatures developed in a plate or block-type thermal shield, which removed 99% of the incident energy exponentially have been estimated for various methods of cooling. In these calculations, the heat removed by the pipe cooling water was ignored. If only the front face is cooled, the maximum temperature difference developed in the metal is about twice that for the case of cooling both front and rear faces. If only the rear face is cooled, however, the temperature difference is about eight-fold that for the two-faced cooling. Figure I, p. illustrates how the front face of a plate type thermal shield could be cooled.

If sufficient heat is generated in the hydrogenous material of a dry layer type shield, its low thermal conductivity might cause high temperatures to develop. On the basis of the calculations made on the V shield, however, it appears that very small temperature differences will result in that shield. When the heat distribution is definitely known for the P-9 case, this factor must be considered in deciding layer thicknesses and arrangements.

1P01-30

FIG I

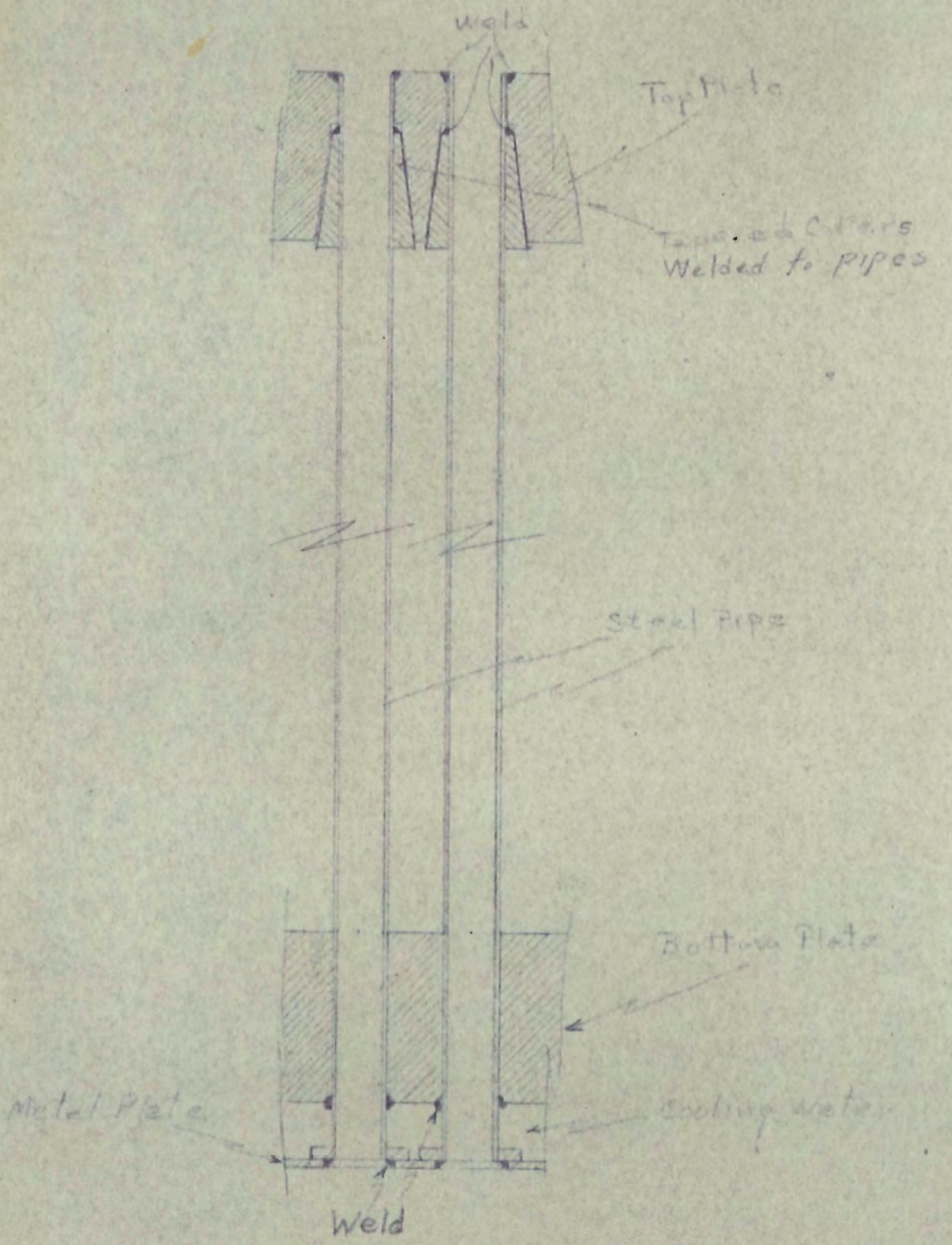


TYPICAL TOP SHIELD

L.B.T - 9-13-43

LZ-A-93

Fig. II

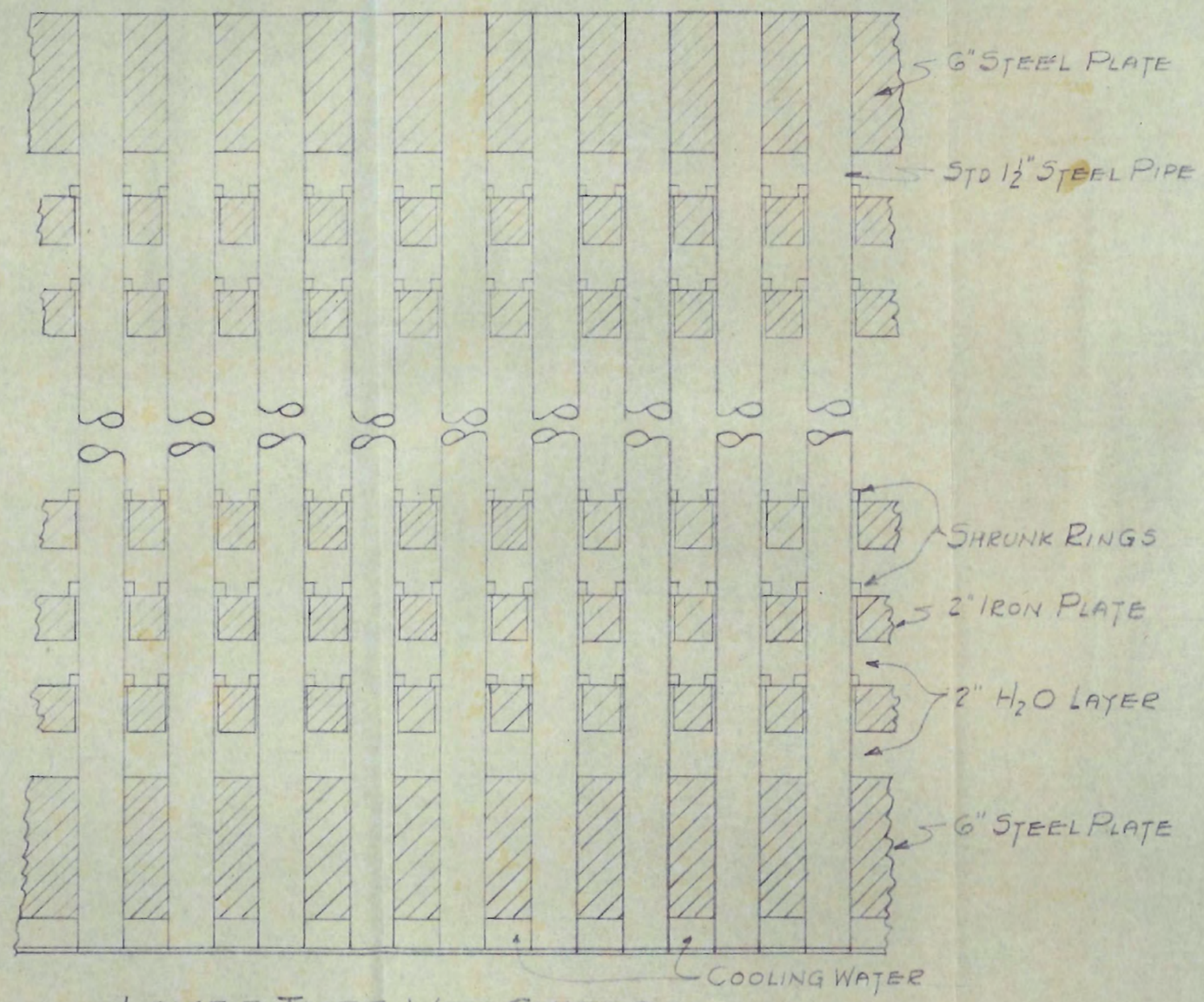


TAPERED COLLAR ON
END SHIELD

LZ-A79

SCALE 3"=1'
LST 12-14-43

FIG III

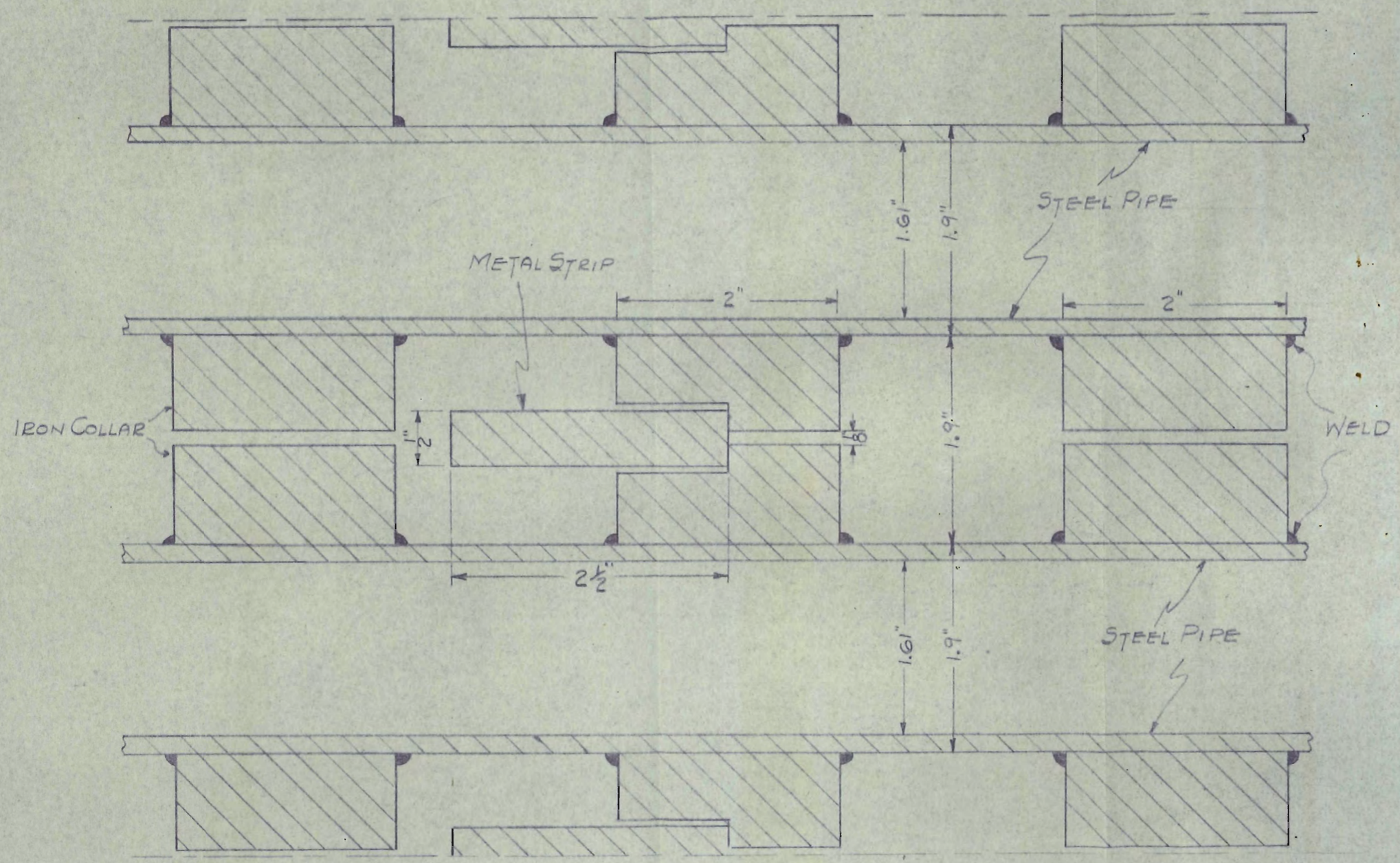


LAYER TYPE WET SHIELD

LZA-100

L.B.T - 10-14-43

FIG IV

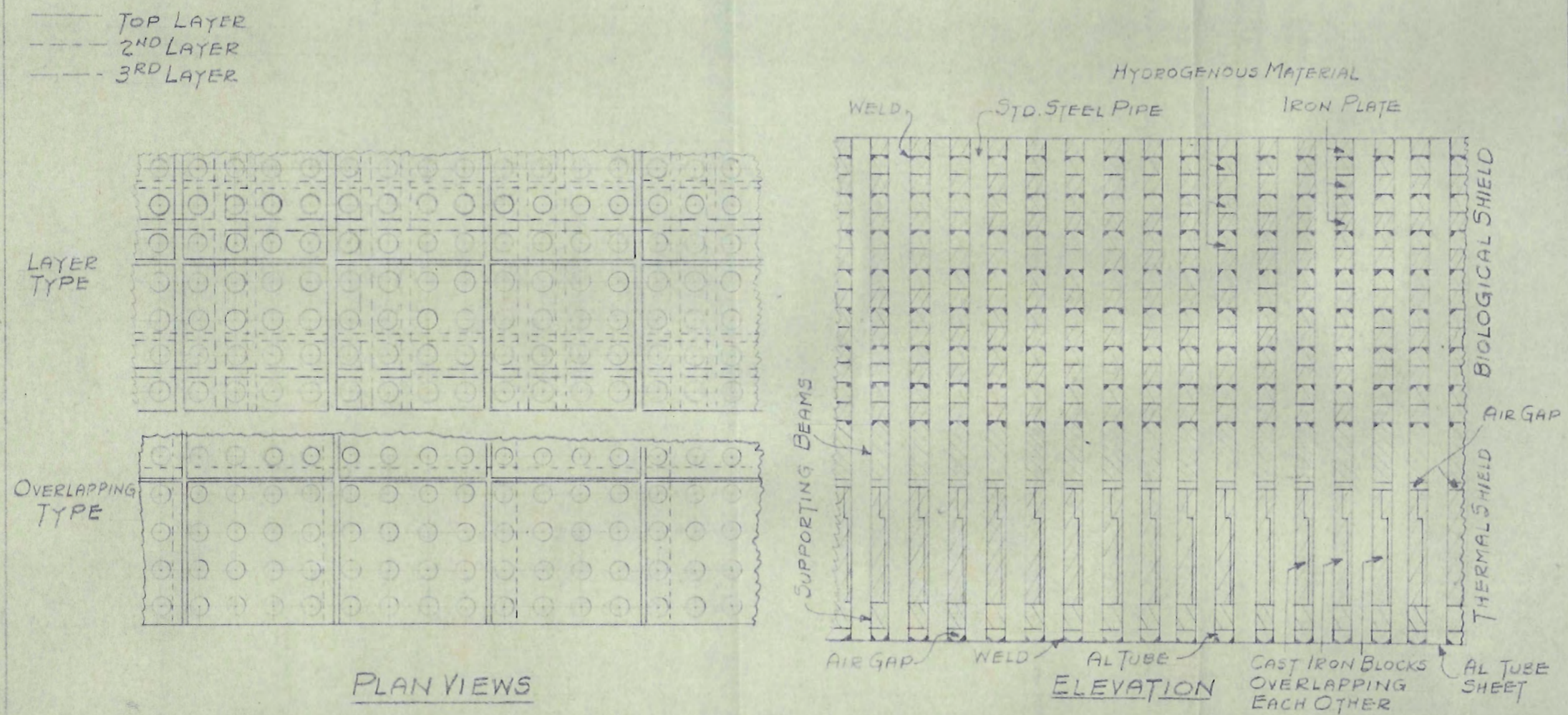


MODIFIED LAYER TYPE WET SHIELD

L.B.T. - 10-14-43

LZ-A-101

FIG V

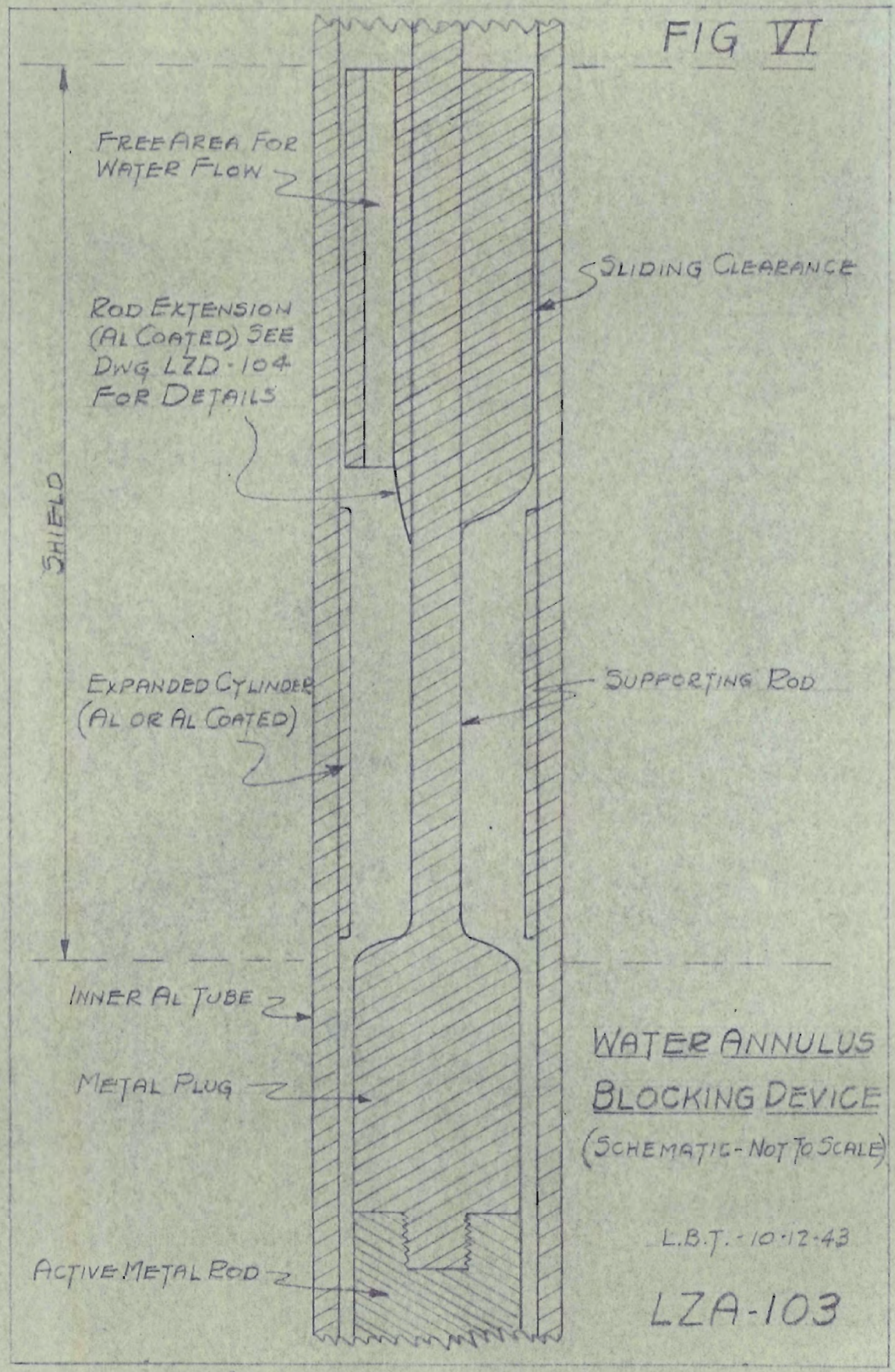


BEAM SUPPORT SHIELD

L.B.T - 9-25-43

LZA-102

FIG VI



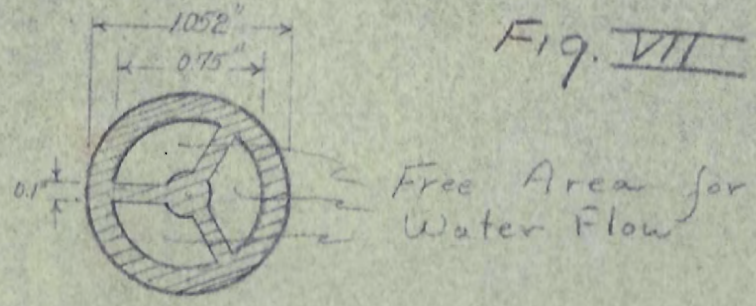
WATER ANNULUS BLOCKING DEVICE

(SCHEMATIC - NOT TO SCALE)

L.B.T. - 10-12-43

LZA-103

Fig. VII

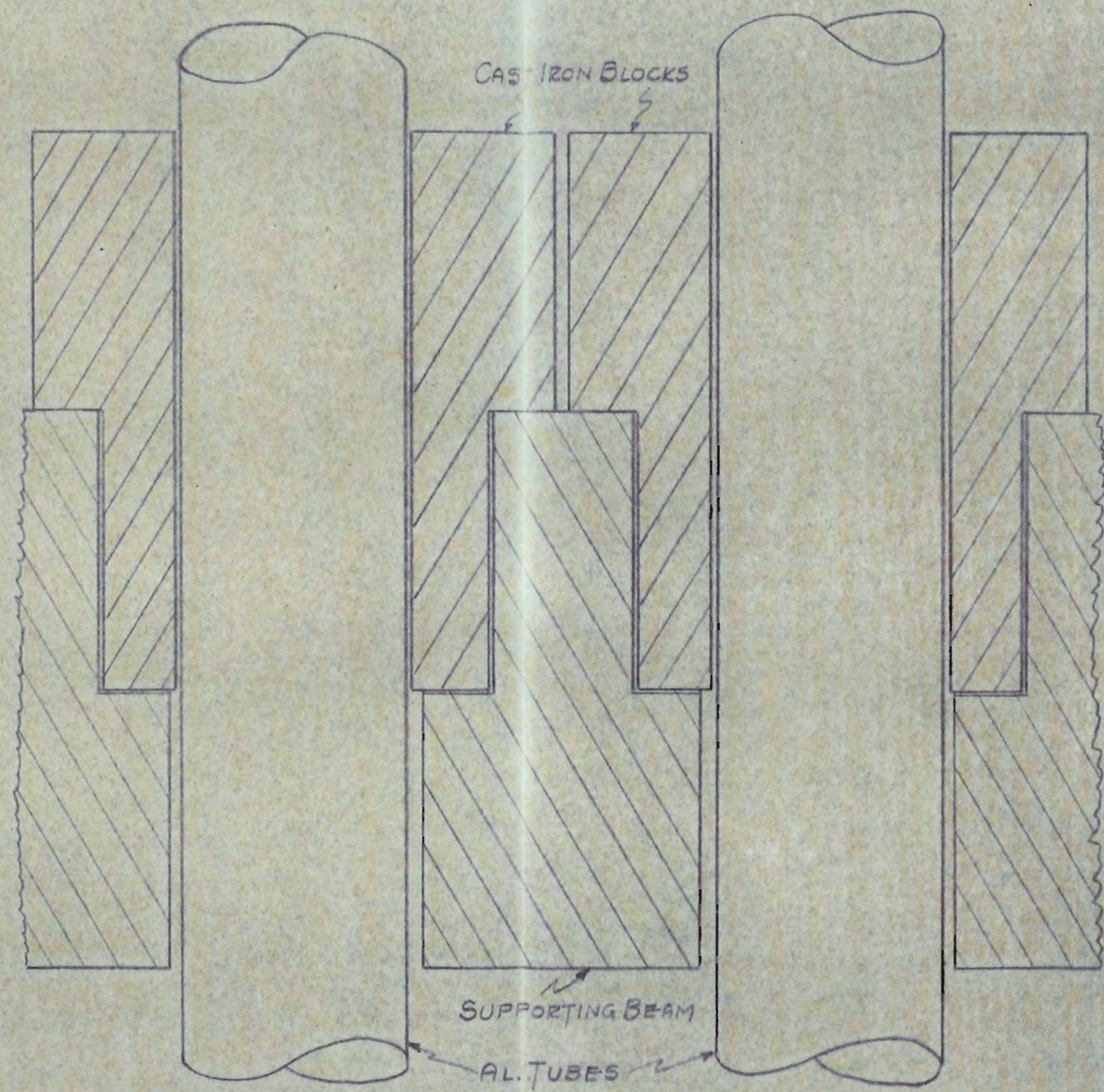


Expanded Rod
Extension

LZ-D104

LBI 9-30-43

FIG VIII



BLOCK TYPE THERMAL SHIELD

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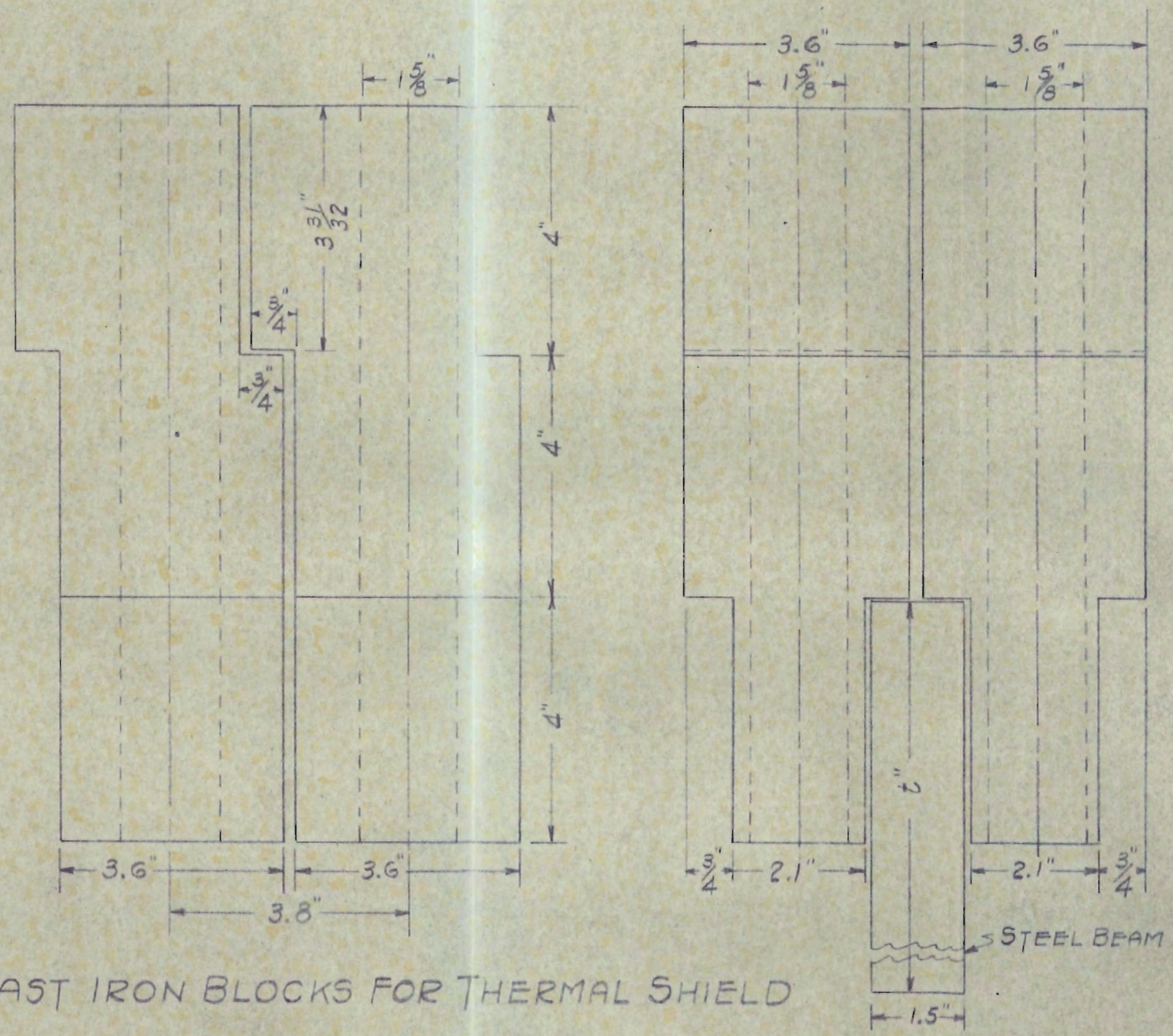
LZ-A-105

CE-1001

FIG IX



CAST IRON BLOCKS FOR THERMAL SHIELD

DIMENSIONS TENTATIVE

G.F.Q - 9-24-43

BLOCK WEIGHT = 38#

LZ-A-106

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