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Edward G. Tirpak

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REPORT ON DESIGN AND PLACEMENT TECHNIQUES OF BARYTES CONCRETE FOR REACTOR BIOLOGICAL SHIELDS

May 1954

Edward G Tirpak

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REPORT ON
DESIGN AND PLACEMENT TECHNIQUES OF
BARYTES CONCRETE FOR REACTOR BIOLOGICAL SHIELDS

This report may be considered to be section 2 of a previous report entitled "Report on the Use of Barytes Aggregates in Concrete for Shielding Purposes" and designated as ORNL Report No 667 Considerable use has been made of barytes concrete at various AEC installations throughout the country, since the earlier report was published It has been very gratifying to the writer that much of the dense concrete that has since been used has been in accordance with the design and recommendations contained in the ORNL Report No 667 Modifications of design and adaptations thereof to meet specific requirements have proven of particular interest. It is with these modifications and adaptations that this report is chiefly concerned.

Time has proven the observations made in the ORNL Report No 667 to be sound, that barytes concrete with a density of approximately 3 52 is highly satisfactory and represents the optimum in concrete shielding material It presents no peculiar construction problems and our experience shows no other material heavy enough to produce concrete of significantly greater density that can compete with it on an economic basis

Barytes deposits occur in may locations throughout the United States Many of these produce satisfactorily sized and graded aggregates of similar quality and density Our experience here at Oak Ridge National Laboratory has been with barytes obtained at Sweetwater, Tennessee, which has proven very satisfactory Some undesirable materials are sometimes found in varying degrees in barytes from certain quarries If it is expedient to use barytes from a new or previously unevaluated source it would be advisable to have samples chemically analyzed and tested for purity Particularly undesirable are opal and chalcedony, and if present in the aggregate in greater quantity than 24% by weight and 5% respectively, low alkaline cements should be used. Small percentages of iron also occur and will have a slight effect on the density obtainable

Metallic aggregates have been used in isolated instances, for very specific purposes and in the main were experimental to a degree High densities were achieved, but at a cost prohibiting consideration for general use One AEC installation used ferrophosphorus as the aggregates for dense concrete, a material which until then was a waste by-product and available in large quantities. For this reason it was obtained for very little more than the freight charges from Mt. Pleasant, Tennessee However, upon placement of a second order for additional amounts, prices were quoted that made the ferrophosphorus more expensive than barytes Some time after this we requested prices for car load lots and were quoted a still higher price of $87.00 per gross ton At this price we saw no justification for further consideration of this material.

An adaptation of barytes concrete for shielding purposes that has proved popular is the solid block used in the construction of temporary shielding walls. Sizes and shapes of the blocks can be varied to suit specific requirements Many space saving uses can be found for this item. ORNL Report No 667 was chiefly concerned with developing a design of dense concrete to be used in mass pours that could be mixed and placed by conventional methods It gave consideration primarily to laboratory cell construction and the resultant specifications were pointed to meeting the requirements for that type of construction

As construction of nuclear energy installations increased, so did the uses for dense concrete. From shielding walls and laboratory cells to nuclear reactors with their massive biological shields was a natural progression Perusal of the design plans of a reactor biological shield made it obvious that previous problems were relatively simple by comparison. Previously we were concerned with designing a concrete of specified density that could be poured from above, pass over a large number of inserted obstructions and recombine into an homogeneous mass with uniform distribution of the large aggregates.

Requirements for reactor biological shields presented some entirely new problems, which necessitated a fresh approach to determine whether barytes concrete

could be adapted to satisfactorily meet these new requirements. Careful study of the design of one* such biological shield showed that we were faced with three major physical problems, and discussions revealed that new functional requirements would necessitate investigations and tests far beyond any we had already made. The compressive strength data seemed to be about the only item of information we already had that would not need further review

The three physical problems were

I Height and Mass

II Inaccessibility Due to Obstructions

III Complex Formwork

Since all three items hinge upon the over-all consideration of achieving an absolutely uniform, calculable shielding value, collectively they constitute the basic problem of placement To evaluate the magnitude of the placement problem it is necessary to analyze each item individually

Item I - Height and Mass

A look at Figure 1*, which shows an horizontal cross-section through the reactor assembly, and Figure 2*, showing a north-south vertical cross-section, will indicate fairly well the dimension and shape of the biological shield (shaded portion approximately a 32-foot hollow cube) and the major inserted fixtures within the forms at their respective planes The thickness of the shield was to be about nine feet, which was established on the basis of using barytes concrete Ordinary concrete would have required a thickness of about 14 feet.

The "forms" in this case were a permanent welded stainless steel shell, which precluded any visual check as to the homogeneity of the concrete after placement Pouring from above meant a 32-foot fall with very little control over segregation, air pockets or honeycombing.

Item II - Inaccessibility Due to Obstructions

Figures 1 and 2 show only the larger of the items embeded in the concrete. Figure 3, showing a view at the top of the shield just before concreteing

*ORNL Report CF-53-12-21 - "Three Declassified Reports on the M T R."

operations began, illustrates well the maze of the smaller sized piping, conduit, etc , contained within the inner and outer steel walls of the biological shield. This condition is typical for the full height of the shield How could concrete be poured from above under these conditions, with any assurance of obtaining the desired uniformity of shielding value, was indeed a 64 dollar question

Item III - Complex Formwork

Note also in Figures 1 and 2 the irregular outlines of the outer shell This created another problem inasmuch as many vertical pockets were created by the shape of the shell, and by the junction of some of the larger inserted objects with the shell Normally very little or no control over prevention of this type of air pocket would be possible

Functional requirements to be made of the biological shield resulted primarily from the fact that the biological shield completely encased the thermal shield on all four sides Figure 1 shows the thermal shield which consists of two 4-inch thick layers of steel, air cooled. These two layers of steel absorb most of the neutrons which otherwise would attack the biological shield, and without which the inside face of the concrete would be exposed to excessively high temperatures Thermal conductivity properties, degree of expansion or contraction, possibility of cracking and degree of possible deterioration from the exposure to the anticipated high temperatures, were some of the questions which required investigation

Results of our tests to determine these characteristics are as follows

TABLE I

PROPERTIES OF PRESSURE GROUTED CONCRETES

Test No	IP-11	IP-22	IP-23	IP-33	NC-11
Coarse Aggregate	Gravel	Barytes	Barytes	Taconite	Gravel
Fine Aggregate	Sand	Barytes	Shot	Shot	Sand
Density - Average	150	215	260	230	150
Comp Strength - 6"x12" Cyl					
42-day	2240	2250	1790	2050	3500
90-day	2280	3470	2610	2750	3810
Density of Grout	132	152	270	260	-
Comp Strength - Grout 4"x8" Cyl - 90-day	4870	3260	3180	3900	-
Thermal Expansion x 10^6	4.39	9 8	10 6	6 9	9 9
Modulus of Rupture					
Preheated Beams	792	461	460	588	714
Unheated Beams	676	463	492	869	642
Comp Strength - 3" Cubes 90-day Average of 8	6310	5870	3615	5290	4370
Thermal Conductivity K = Btu/Hr./Ft ^{2}/^{o}F /in.	7.04	4 60	5 20	8 85	6.02

It is of interest to note that concrete made of barytes gravel and barytes sand shows the lowest thermal conductivity rate of all the materials listed. Although a low conductivity was not desirable, the rate of 4 60 was not considered to be too low

R B. Gallaher and A. S. Kitzes conducted a long series of tests on dense concretes and ably reported their findings in ORNL Report No 1414* Their investigations somewhat paralleled ours which were conducted at the Massachusetts Institute of Technology under the writer's direction Gallaher and Kitzes went farther into the subject of retention of high water content and followed through on experiments with materials some of which we discarded as being impractical for such reasons as high cost, difficulty of preparation and placing, and lack of uniformity of shielding value in the final concrete product due to irregular placement of coarse aggregates

*Summary Report on Portland Cement Concretes for Shielding

In our work at MIT we tried to keep our experimentations pointed towards determining the relative merits of both materials and placement methods Three placement methods were used

1 Conventional

2. Vibrated layers of grout and coarse aggregates

3. Pressure grouting

and the materials tested were

1 Barytes gravel and sand

2 Fine iron shot

3 Fine iron flakes (Master Builders Dispersed Fine Iron)

4. Taconite

5. Hematite and Magnetite

6. Deformed steel balls

7 Iron "stars"

On the basis of the MIT experiments the following conclusions were drawn.

The method of placing and vibrating alternate layers of gravel and grout was not satisfactory. The distribution of coarse aggregate was poor and excessive honeycombing was found. This method might very well be satisfactory for such purposes as blocks having densities greater than 220, but it would be impossible to use in the case of the reactor biological shield.

The other method of placement we tried consisted of first filling the form with coarse aggregate and vibrating internally to attain maximum consolidation and then pumping a dense grout under low pressure to fill the voids. From the very first it became apparent that this method had several advantages over other methods tried, particularly in regard to overcoming problems pertaining to the reactor biological shield enumerated above Professor Murray of MIT, who supervised the work done there for us, and the writer had agreed to enlist the aid of the Prepakt Concrete Company of Cleveland, Ohio, who developed and perfected this method, to assist us in experimenting with it.

The Prepakt Concrete Company had a complete laboratory size unit delivered to MIT, and they sent their field engineer, Mr Bruce Lamberton to operate it With this equipment we were able to try several materials of varying densities, and found that some of the materials that so far had proven difficult of successful placement, could be incorporated into a uniform homogeneous concrete with the Prepakt method. Some materials, such as the Master Builders Company's "Dispersed Fine Iron was found to be not adaptable to this method because it is in a "flake" form which does not make a satisfactory grout for pumping. Fine steel shot was found to be a satisfactory heavy material for a pumpable grout Detailed descriptions of all the tests made with the materials used, analyses of the problems encountered, and conclusions drawn are presented in the MIT report "The Development of High Density, Homogeneous Concrete using Pressure Grouting and Other Methods", dated May 1, 1951. Therefore, to avoid repetition, no mention will be made here of individual tests except to state that using barytes coarse aggregate and barytes sand in the grout a density of 215 lb./ft.^{3} was obtained and using barytes gravel and fine shot a density of 260 lb/ft ^{3} resulted Both materials in proper proportions with "Alfesil"* and "Intrusion Aid"* and cement, proved satisfactory for use as grout in the Prepakt method Comparison of costs shows Barytes available at $18 00 per ton delivered and fine iron shot at about $125.00 per ton F.O.B This is another illustration of our earlier conclusion that from the economic viewpoint barytes is the most satisfactory material for dense concrete

The writer was privileged to have the opportunity to observe the placement of the biological shield of the MTR near Idaho Falls, by the Prepakt Concrete Company Figures 1 and 2 indicate design dimensions, but Figures 3 through 9 clearly show not only the difficulty with which the barytes gravel was placed, but also how placement by any other method would have been well nigh impossible

*Materials used by the Prepakt Company to increase fluidity of grout and control shrinkage.

One advantage of the Prepakt method is that the large aggregate placement is not only uniform throughout but each piece is positioned in the closest possible contact with adjoining pieces, thereby increasing density by reducing the amount of grout required to only that necessary to fill the voids This removes any possibility of either segregation of the large aggregate or massing of the fines. This method also permits positive control of such considerations as slump control, water content, shrinkage and honeycombing. Surface moisture was controlled through complete saturation of the large aggregate. This was accomplished by putting water into the form, to a depth of about 6 inches, after the large aggregate had been placed and before pumping of the grout began. In this manner the water rose atop the grout as the grout was pumped in from the bottom, thoroughly saturating all the gravel and helping to"guide" the grout into every minute crevice Cored samples cut in sections showed remarkable penetrations by the grout of all voids to a degree of perfection. The writer has never seen any corings that approached these samples for absolute homogeneity. This is borne out by the fact that the density achieved was 227 lbs./ft.^{3} It was interesting to note that the operation on a large scale in the field did not involve many of the problems encountered in the laboratory experiments using the small scale equipment. With the exception of interruptions due to a labor union strike, which delayed the placement of the coarse aggregate, the whole Prepakting operation went on in an orderly efficient manner. Mr John C. King and Mr. Lamberton, chief engineer and field engineer, respectively, of the Prepakt Company were in charge and kept the project progressing smoothly to a satisfactory conclusion.

In preparation for the pumping operation, approximately 24 grout pipes had been placed vertically at predetermined locations before the dry aggregate was placed These grout pipes extended the full height of the structure and the grout feeder lines were attached to them at the top The grout mixer and pump assembly was located outside the building The grout was pumped through three main lines to the top of the shield, where each main line divided into two

feeder lines*. Thus the grout was being pumped continuously through the feeder lines to the grout pipes and down through the grout pipes to the bottom of the shield. Close to each grout pipe was placed a sounding well (perforated pipe visible in Figures 4, 5 and 6) and a vent pipe**

During the pumping process, soundings were made periodically and charted. As the grout rose in a given area, the feeder line was disconnected from the grout pipe in that area and connected to another grout pipe where the chart showed the grout at a lower elevation. By this maneuvering of the feeder lines horizontal movement of the grout in the forms was kept at a minimum When the chart showed that the grout had risen three or four feet the grout pipe was withdrawn sufficiently to keep just the bottom end submerged in the grout. The protruding end was cut off of the grout pipe, which was then re-threaded for connection to a feeder line. Continuous sounding, charting, and changing connections between the feeder lines and the grout pipes kept the grout rising at a uniform rate throughout the entire shield. Note in Figure 11 how the grout has penetrated to the top in several locations simultaneously, as the job approached completion.

The volume of grout actually used checked very closely with the estimated amount which was based on the percentage of voids in the large aggregate. The resulting density was determined to be 227 lbs./ft.^{3}.

Having been one of the first to investigate the relative merits of various heavy materials as ingredients in dense concretes, as well as various methods of placement, and after following through from the initial laboratory experiments to the highly successful demonstration of the merits of the Prepakt method as outlined above, it is the writer's firm opinion that different materials both mineral and metallic can be used advantageously for specific purposes. For mass pours, involving large volumes, cost consideration is of prime importance, and materials producing concrete in the 215-230 pound range should be used. In small pours, such as shielding

*See Figure 11
**See Figure 10

blocks, or small slabs to be used as removable plugs, etc., the engineer has a free hand to design for almost any density he may feel is economically justified, and can utilize one of several methods of placement.

For large mass pours, such as hot cells, reactor biological shields and thick wall construction, the method of placement should definitely be given serious consideration If the area within the forms is relatively free of obstructions other than structural and reinforcing steel, so that access from above to all areas (for placing and vibrating) is readily maintainable, conventional placement methods should produce satisfactory results. If, as in the case of the M.T R biological shield, where inserted fixtures occurred in such profusion the Prepakt method is definitely the answer

Positive uniformity of shielding values are assured, and other features also, such as elimination of field controls (both at the jobsite and batching plant) normally required in conventional placement methods

The foregoing is an attempt to briefly describe the history and information formulating the background upon which our conclusions have been drawn, and recommendations made. It is our intention here in the Engineering Department at the Oak Ridge National Laboratory to continue to specify barytes for our dense concrete particularly where large volume is required.

As to placement methods, if no difficulty in pouring or access is foreseen, and the interior of the formwork is reasonably clear of obstructions, conventional methods will be used. If the formwork is fairly free of obstructions, yet is of such complicated shape that access to all areas is difficult, the Prepakt method will be considered. If the quantity or arrangement of inserted fixtures in the forms is such that placement from above is difficult beyond the point of positive control, the Prepakt method will be specified. For reactor biological shields the Prepakt method is automatically specified.

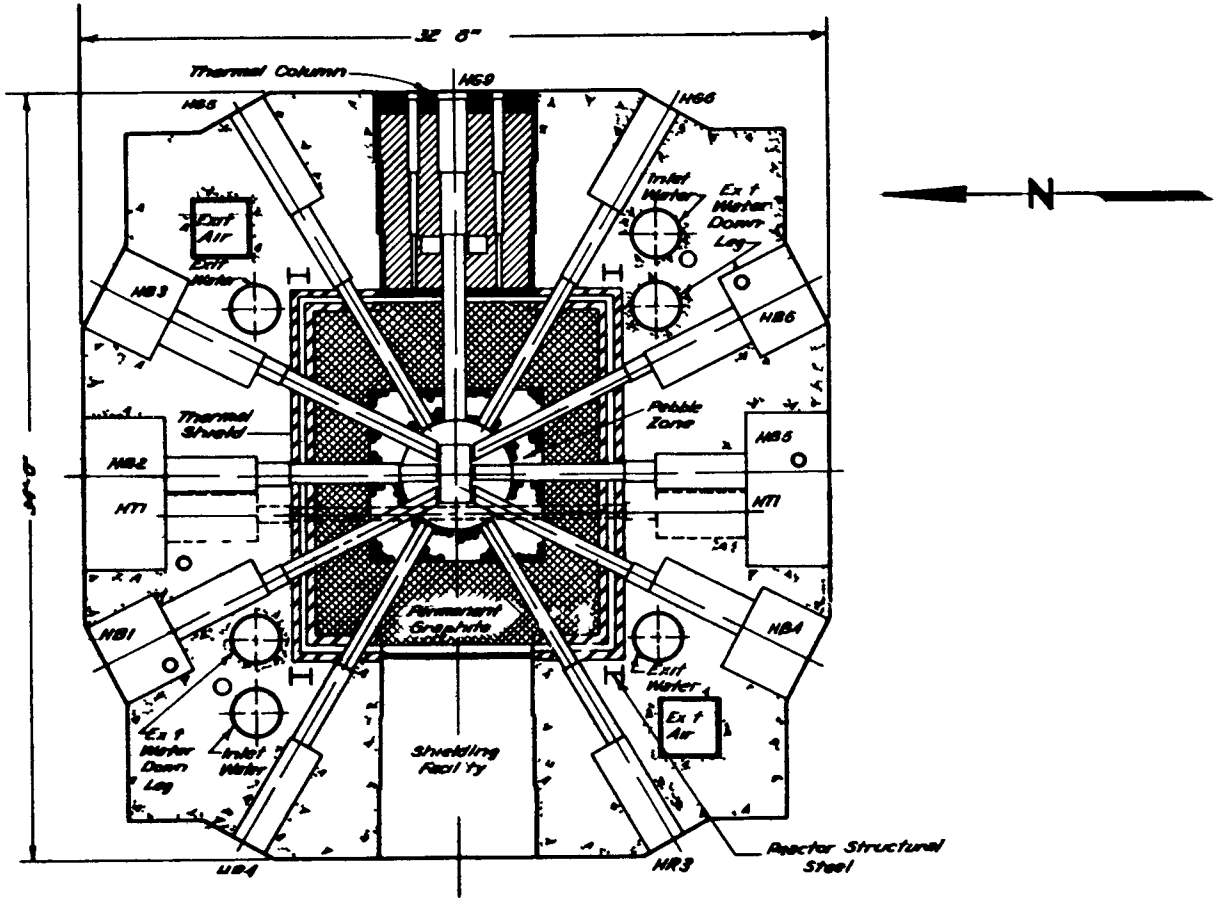

Figure 1 MTR Horizontal Section

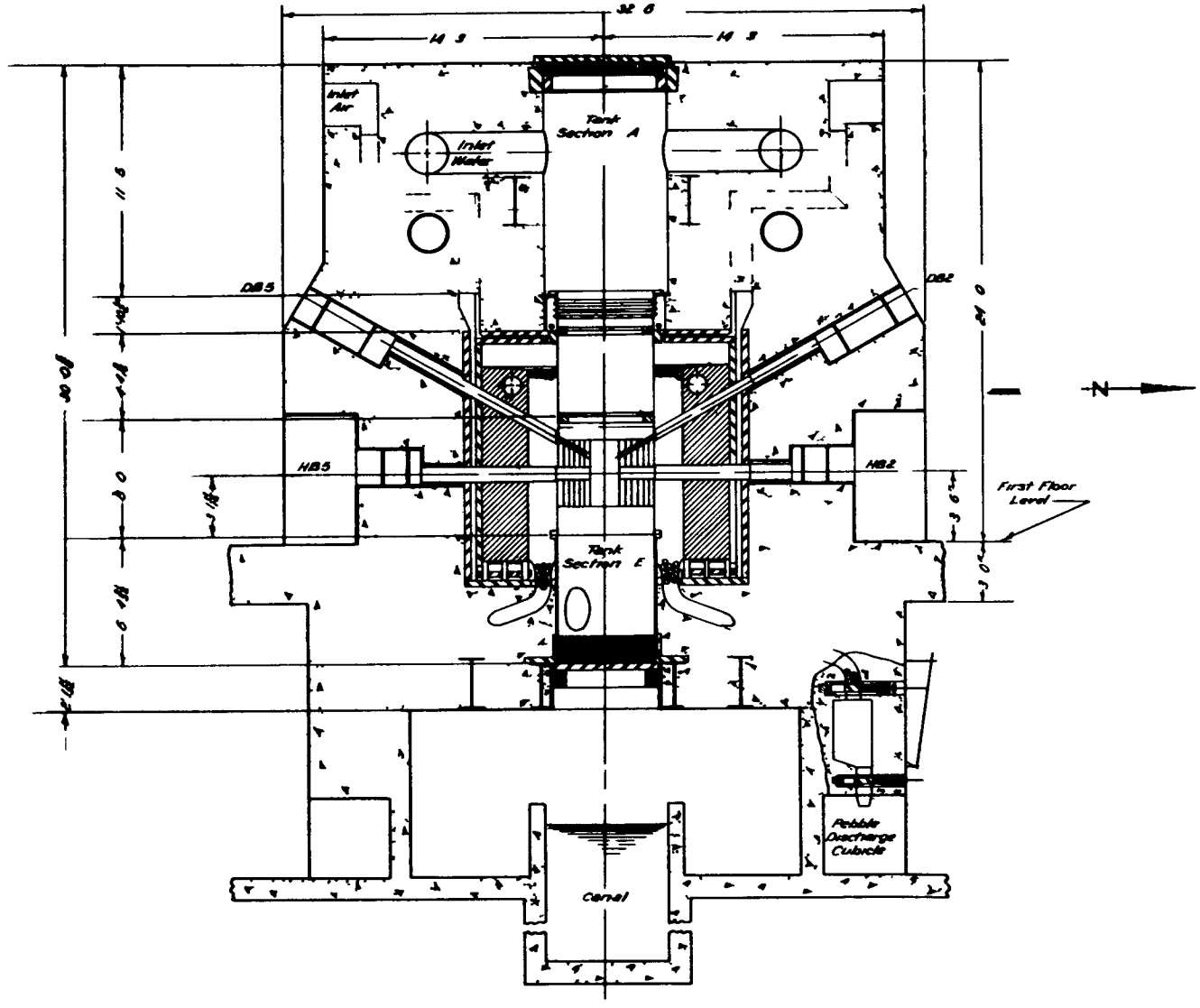

Figure 2 MTR North-South Vertical Section

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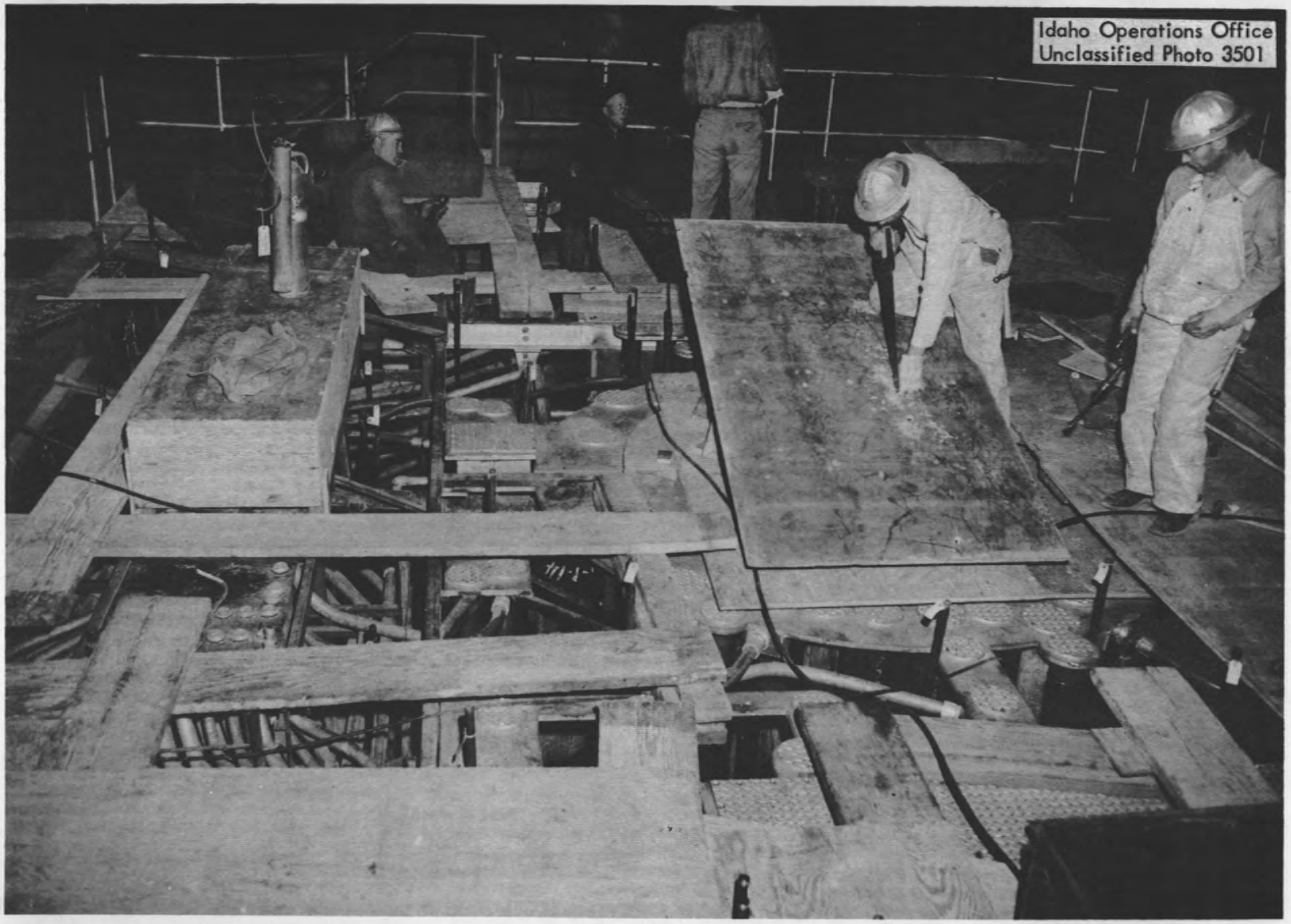
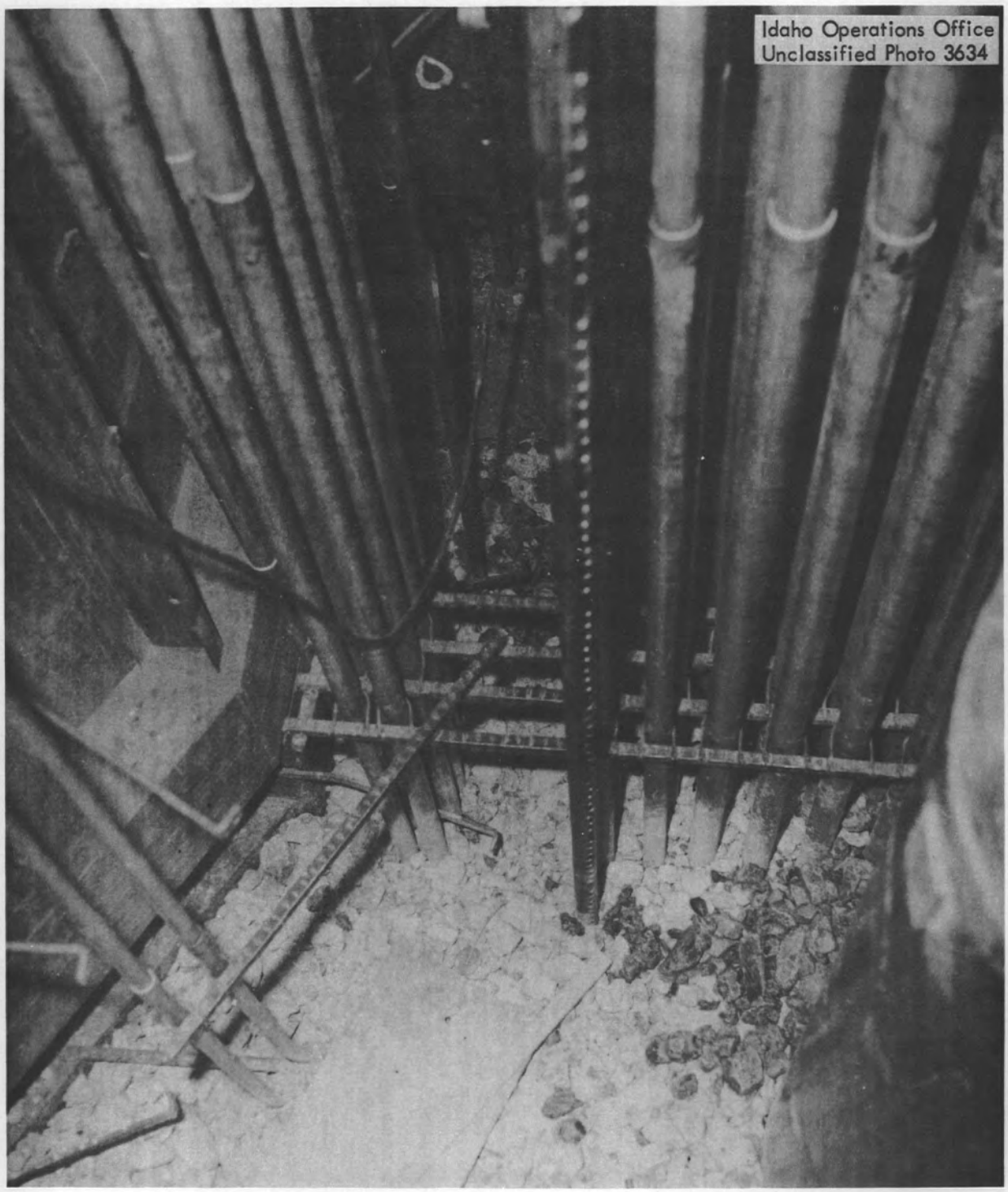


Figure 3.

Figure 4.



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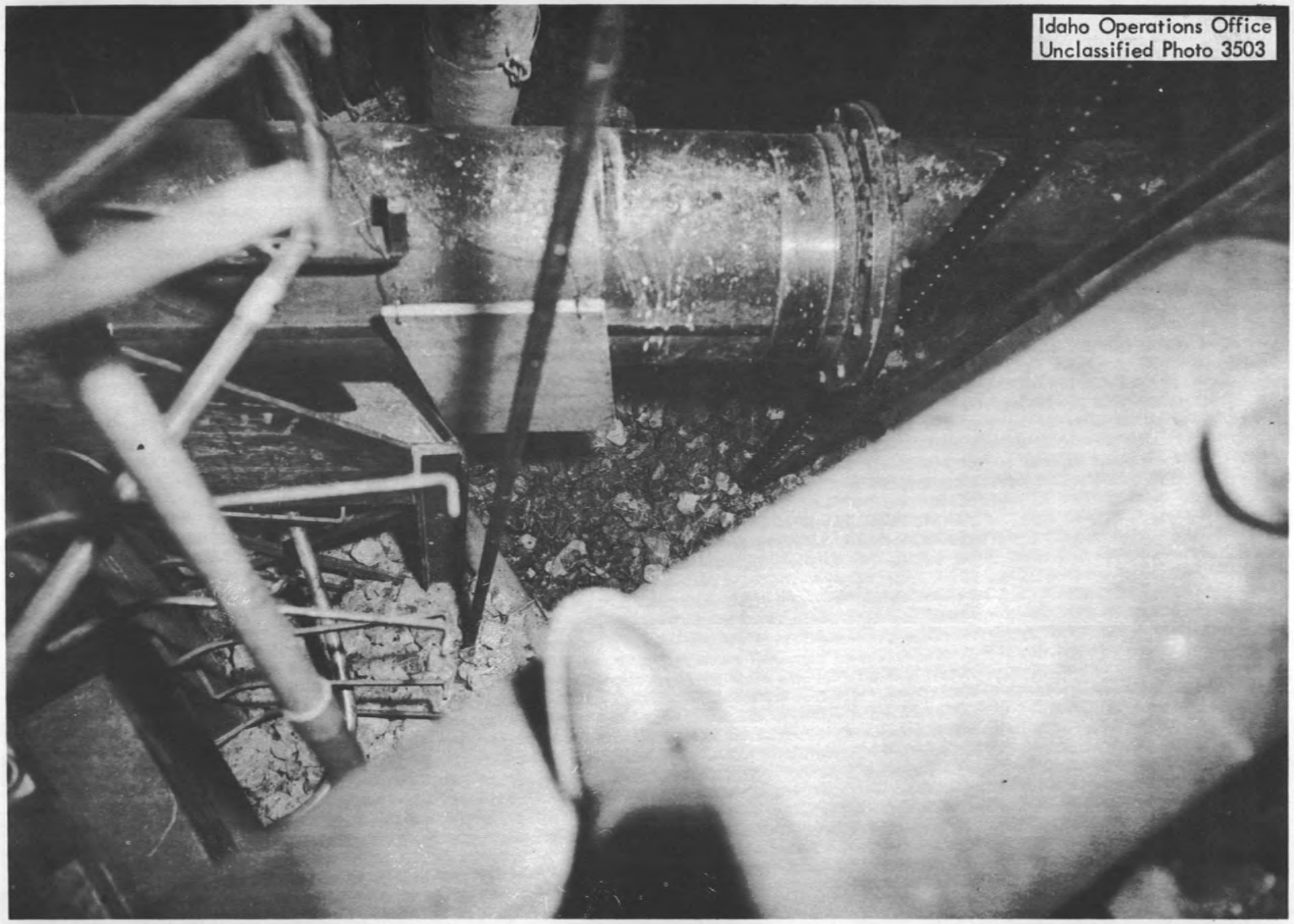
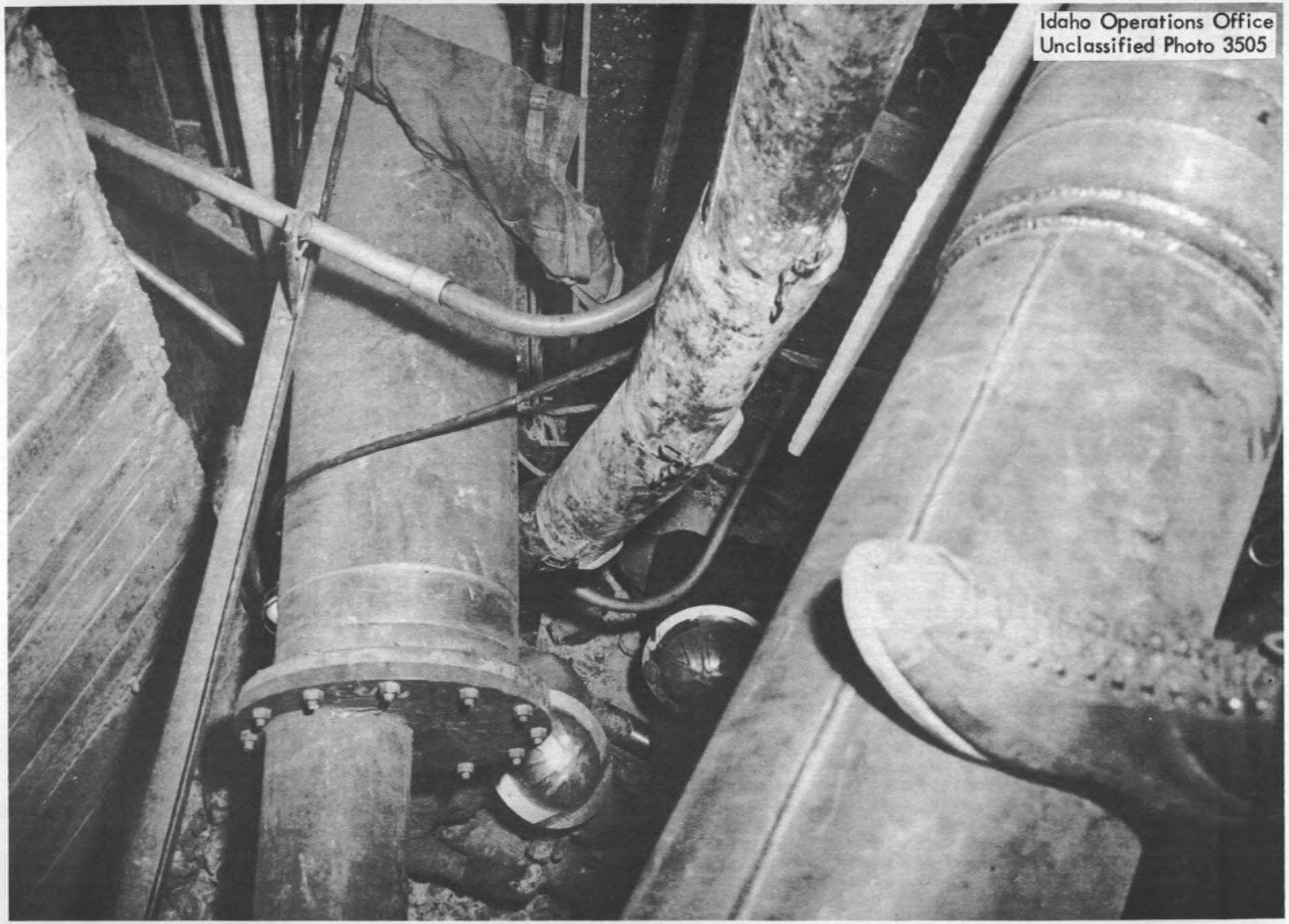


Figure 6.

Figure 7.



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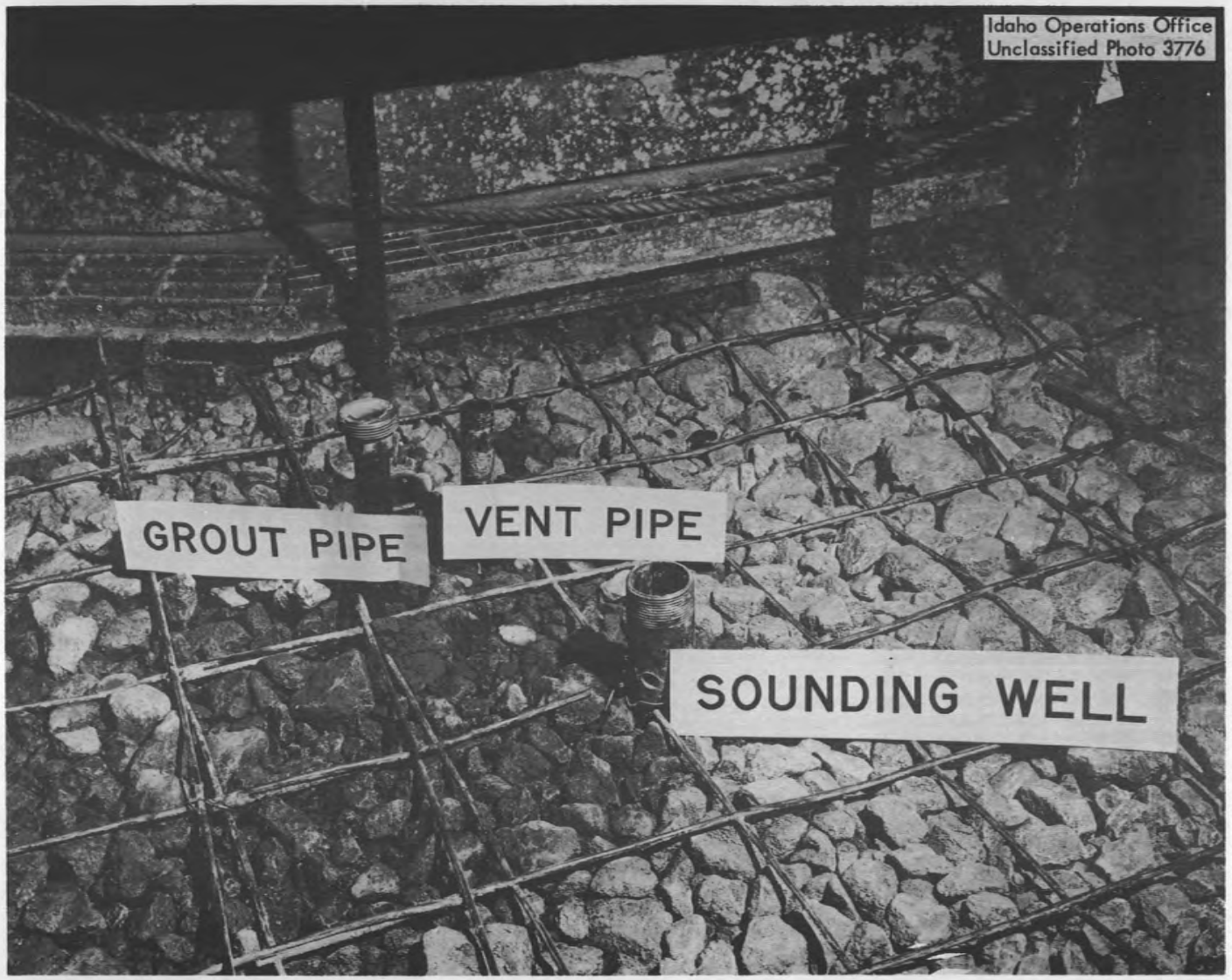
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GROUT PIPE
VENT PIPE
SOUNDING WELL

Figure 10.

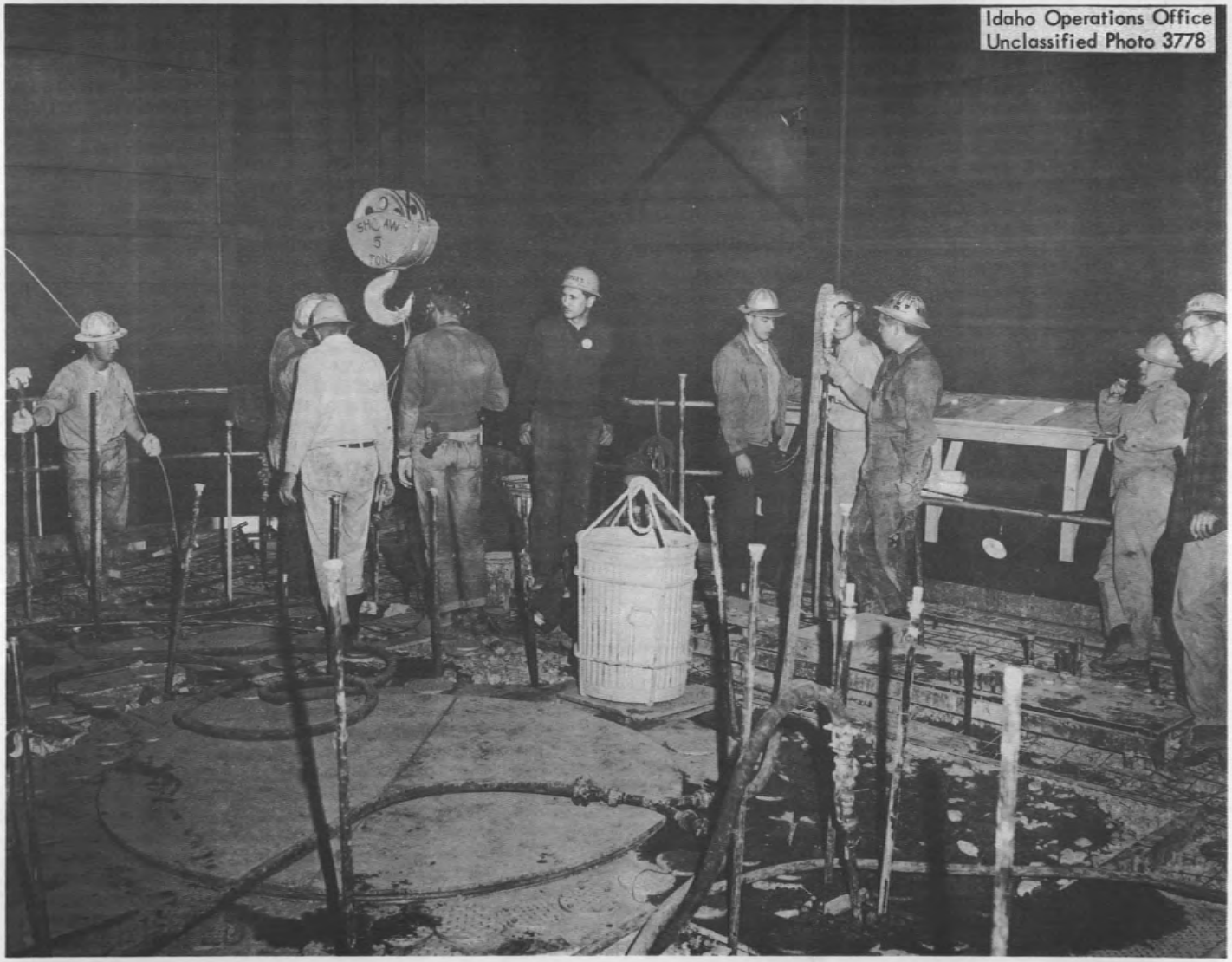

Figure 11.

Acknowledgments

The Master Builders Company, Cleveland, Ohio, and Mr R Kaufman, their chief engineer, for valuable cooperation at MIT

The Prepakt Concrete Company, Cleveland, Ohio, and Mr J C. King, their chief engineer for valuable cooperation at MIT, and Idaho Falls

Photographs courtesy of Idaho Operations Office

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