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REACTOR FUEL CARRIERS - ORSORT LECTURE

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ABSTRACT

This paper was prepared for and presented to an ORSORT Class on December 28, 1959, as a one-hour talk and is a general paper covering the fundamental factors influencing carrier design, such as shielding, criticality, heat transfer and economics. Typical carriers used in the past or currently used are described including the Tucson carrier, MTR, SRP, SRE, and others.

The operation of power reactors will result in the necessity for the recovery of unburned fuel from the expended cores. Transportation of spent fuel elements from the reactor sites to the processing plants as well as at the reactor sites and within the processing plants requires the use of special equipment to permit the safe handling of these highly radioactive materials.

These devices are commonly referred to as carriers, a shortening of the terms slug carriers or product carriers which were applied in the early days of the project to heavily shielded containers used in shipping multicurie quantities of radioactive materials over long or short distances. A slug carrier permitted safe transportation of radioactive uranium slugs discharged from a nuclear reactor, and a product carrier was used to transport a highly radioactive end product such as Ba^{140} and its hard γ emitting daughter, La^{140}, resulting from chemically treating irradiated fuel slugs. Casks or coffins are similar words for referring to the containers for shipment of radioactive materials. The terms include the required shielding, integral means of heat removal and the ancilliary equipment incorporated therein.

The term carrier has a different meaning in the regulations of the AEC, ICC, Bureau of Explosives and other agencies governing the shipment of irradiated fuel elements and is defined as any person who receives special nuclear material for the purposes of transportation. A slug charger is a carrier with additional built in features that allow the slugs to be discharged into a dissolver. Carriers or casks are used for handling liquid fuels as well as solid fuels.

Many factors must be considered in carrier design; the more important of these include:

1. Physical state of the radioactive material, either liquid or solid
2. Shielding
3. Criticality
4. Surface decontamination
5. Heat transfer
6. Carrier handling and transportation
7. Coolant
8. Instrumentation
9. Materials of construction
10. Fabrication and inspection
11. Safety and economics

Physical State of the Radioactive Material

It is difficult to consider any one of these factors by itself since many of them are interrelated. For example, let us consider the first factor or the physical state of the radioactive material; this factor will influence both the size and shape of a carrier as well as its method of construction. In deciding upon the size of the carrier, one must also consider

how much fuel is to be transported at one time, and this in turn must be balanced against other factors such as criticality, heat transfer, available handling facilities and economics. These factors become evident in reviewing the various typical carriers which are described later.

Shielding

Lead is normally employed for carrier shielding because of its high density and low cost. Depleted uranium has been considered for use as shielding - however, the cost of converting the depleted uranium to the metal has made its use prohibitive except for very limited applications.

Criticality

The carriers must be carefully reviewed, studied, and calculations or experiments made to ascertain that there is no chance of the fuel assemblies becoming critical when placed in the carriers. The following assumptions have been proposed by pending AEC regulations[1] for the purpose of evaluating criticality:

1. The shipment will be made with water or antifreeze filling all spaces in and around the elements and with water surrounding the cask even though the elements may be shipped dry.

2. The spacing between fuel elements is that which would give maximum reactivity or the design must assure that the spacing will assure less than maximum reactivity; in such cases, the fuel elements must be supported within the cask so that the fuel elements cannot be rearranged in a configuration more reactive than that for which the carrier is designed.

3. The presence of normal structural material, such as fuel element cladding and cask components, is ignored as nuclear poisons. Poisons, however, can intentionally be built into the carrier, or poisons in the fuel elements may be considered provided there is assurance that the poison cannot change its position relative to the fuel elements; for example, by mechanical shock during normal shipment or credible accident.

4. In any single cask the mass of fuel shipped shall not exceed 75% of that necessary to be critical with credit for the intentionally built in poisons. If geometry is controlling, each controlling dimension shall incorporate a 10% safety factor and in addition an allowance for uncertainties in experiment or calculation.

Determination of criticality shall be based on the following assumptions where applicable.

1. Fuel shall be considered as unirradiated fuel if reactivity decreases with burnup.

2. The fuel shall be considered as irradiated fuel if reactivity increases with burnup at the condition of maximum reactivity.

3. The fuel shall be considered as melted fuel in most reactive array unless it has been demonstrated conclusively that melt-down of the fuel element is impossible.

4. If reactivity increases with loss of coolant, this shall be assumed the condition of maximum reactivity.

5. The fuel shall be considered as wet fuel if reactivity is greatest with water or antifreeze present.

Surface Decontamination

Carriers are designed to permit surface decontamination with the minimum amount of effort involved. For this purpose the majority of the carriers are built from materials such as stainless steel on which strong reagents such as acids may be used for decontamination without damage to the equipment. The carriers are normally designed to minimize pockets or cavities where radioactive materials and contamination could collect and prevent effective decontamination. The carrier components are normally all welded construction and the lead shielding material is completely encased to avoid the possibility of radioactive materials entering between the shell and shielding where decontamination would be impossible. Some carriers have been designed with stainless steel components on the interior surfaces of the carrier only where contamination was most likely and the external parts were constructed of standard carbon or alloy steels and painted.

Heat Transfer

Many of the fuels discharged from the various power reactors require cooling in transit. Many cooling methods have been considered; the following are examples:

1. Forced air circulation around and/or through the casks.

2. An external radiator, similar in principle to the automobile radiator, with a primary cask of water falling through the radiator either by natural convection or forced circulation.

   Under pending AEC regulations, these two methods would be unacceptable since primary gas or liquid coolant coming in contact with the fuel elements shall not be circulated outside of the cask.

3. An external radiator connected to the core inside the cask to permit or provide a secondary circulation system separate from the primary cask water. Again both natural or forced convection circulation can be considered.

4. Mechanical refrigeration.

5. Partial or complete immersion of the cask in a tank of water.

6. Boiling the water in the cask with replacement as necessary.

   This method would also be unacceptable to AEC since the highest liquid temperature inside the cask in the vicinity of the fuel elements is restricted to at least 20°F below the boiling point of the liquid.

7. Use of a high boiling liquid in the cask to achieve a greater temperature difference.

8. Pressure operation of the cask with a higher internal temperature. The pending AEC regulations prohibit the use of a cooling system operating above atmospheric pressure.

9. Extended outside surface of the cask with a natural convection of air. The internal coolant would be at atmospheric pressure with temperature somewhat below the boiling point.

Normally the fuel elements to be shipped off-site should be allowed to undergo radioactive decay for a sufficient period of time to ensure that when the casks are loaded, the maximum temperature of fuel elements and built in poisons will remain at least 180°F below their respective melting points. This determination shall be made assuming a dry air-filled cask.

Carrier Handling Transportation

The carrier handling methods and transportation are important factors in the design. Irradiated fuel transportation from the reactor to the reprocessing plant and return of recovered materials back to the reactor, as in a conventional fuel cycle, presents no great problems when done all on the same site where distances are relatively short and the fuel materials do not leave the plant area. This no longer holds once shipments outside the plant area are involved. The facilities at both the reactor site and the processing plant must have cranes of sufficient capacity to handle the weight of the cask contemplated. A cask must be provided with proper and adequate lifting devices or trunions and lifting attachments to assure safe handling. Shipment may be made by railroad, motor transport, barge, or even air. However, for casks with gross weight above 40 tons, rail shipment or barge are the only practical methods of transportation for any appreciable distance.

Coolant

When coolants are used, the design must have adequate provisions for retaining the coolant since the loss of coolant could result in damage or rupture of the cladding material permitting the release of fission product activity. If the coolant container cannot be made as an all-welded one-piece construction, tight gasketed joints will have to be made.

Instrumentation

The amount of instrumentation required on the cask will vary widely depending on the complexity of the design. In the simplest case, no instrumentation may be required; other cases, thermocouples, pressure gages, level probes and other devices may be necessary.

Materials of Construction, Fabrication and Inspection

Normally, the majority of the carriers are constructed almost entirely from austenitic stainless steels. All welds should be specified to be of ASME Code quality and performed by qualified welders. Full penetration welds are used either for strength on the corners of the container or for heat transfer purposes when fins are attached to outside shell. Welds are normally examined for soundness prior to lead filling by dye penetrant methods. Where heat dissipation is important, the lead shielding is usually specified to be bonded to all surfaces contacted by the internal or external heat transfer media.

Safety and Economics

Long distance shipments by common carriers over publicly used rights-of-way introduce the two very considerable problems of safety and economics. Radioactive fuel elements and liquid radioactive wastes may be shipped via public transportation media only when done in a properly designed container. Recognition of the hazard that would result from improper handling of the shipment during transit, or as a result of an accident during transit, made it necessary that radioactive materials be included in the hazardous materials category subject to the rules and regulations which apply in shipment of these materials via public media. An AEC handbook[2] summarizes useful information pertaining to federal regulations covering radioactive material transportation.

When radioactive materials are transported across state lines, they become subject to the regulations of the Interstate Commerce Commission. Parts 71 through 78 of Title 49, Code of Federal Regulations, govern transportation of explosives and other dangerous articles including radioactive substances. A listing of subject titles for parts 71 through 78 of the above regulations are given below:

Part 71 General information and Regulations
Part 72 Commodity List of Explosives and Other Dangerous Articles Containing the Shipping Name or Description of All Articles Subject to Parts 71-78
Part 73 Regulations Applying to Shippers
Part 74 Regulations Applying Particularly to Carriers by Rail Freight
Part 75 Regulations Applying to Carriers by Rail Express
Part 76 Regulations Applying to Carriers in Baggage Service
Part 77 Regulations Applying to Shipments Made by Way of Common, Contract, or Private Carriers by Public Highway
Part 78 Shipping Container Specifications

The ICC regulations classify radioactive materials as Class D poisons (Class A poisons are extremely dangerous, such as poison gas; Class B are less dangerous, such as Aniline oil, methyl bromide, etc.). Sections 73.391, 73.392, 73.393, and 73.394 of the ICC regulations for dangerous materials contain the rules to be observed by shippers of radioactive materials. These rules permit gamma radiation of not over 200 milliroentgens per hour or equivalent on any readily accessible surface of the container and 10 milliroentgens gamma per hour 3 meters away. In the case of railway cars, this latter is generally interpreted as 10 mr/hr on any outside car surface. The regulations also specify the kinds of labels required on shipments of radioactive materials, precautions needed to prevent mishap during transit, and procedures to be followed in case of emergency.

These regulations are also published by transportation groups directly involved. One of these is the Association of American Railroads' Bureau for the Safe Transportation of Explosives and Other Dangerous Articles (universally called Bureau of Explosives) which published Agent H. A. Campbell's Tariff, No. 10.[3] The Tariff Bureau of the American Trucking Association, Inc., published the Motor Carriers Explosives and Dangerous Articles Tariff No. 9.[4]

Water transportation comes under Coast Guard jurisdiction as contained in Part 146, Title 46 of the Code of Federal Regulations. A Coast Guard publication, CG, 187[5] sets forth the regulations for shipment of dangerous articles within its sphere of responsibility.

Regulation of air transportation of radioactive materials comes under the jurisdiction of the Civil Aeronautics Board.

Economics play an important part in the design of fuel carriers. Weight and distance are the most important factors affecting the economics of irradiated nuclear fuel transportation, since shipping costs are based on these two factors.

As is very well known, gamma shielding is mass dependent, i.e., attenuation of gamma radiation requires very nearly the same weight regardless of the material used. Furthermore, the ratio of shielding weight used per unit weight of fuel has varied from 54:1 in the case of production reactors to 1470:1 in the case of the MTR. Hence, in the latter case, the carrier for transporting 14:28 kg of unburned, irradiated fuel weighed 22,000 lb or a ratio of 1470:1. Admittedly, this is perhaps a special case since the distance from the reactor to the chemical plant was small and the carrier was conservatively designed to handle elements with very short cooling times. It clearly emphasizes the outstanding basic fact, though, that the very large part of a shipment of irradiated fuel is shielding weight. To make matters worse, the empty carrier has to be returned to the reactor for the next shipment.

Some relief from this state of affairs may be gained by permitting the fuel elements to cool as long as possible. The length of cooling time permitted is limited by the optimizing shipping weight with inventory costs since, while it is true that each additional day's cooling will allow a reduced shielding weight, the interest cost on inventory increases with each passing day.

Figure 1 illustrates the weight savings that are possible when the cooling time for the indicated fuel is extended from 15 days to 75 days. In the example shown, one-third of the carrier weight or 4 tons, is saved by the increased cooling time resulting in an 8-ton carrier instead of the 12 tons originally required.

Transportation charge rates change from time to time, and it is necessary to obtain current rates at the time of shipment. Generally, the greater number of elements shipped per cask, the lower the cost of the cask per element shipped. Also, the fewer number of casks that are shipped per core loading results in a reduced shipping cost. These savings, however, must be balanced against other design factors, for example, the handling facilities available at the reactor and processing sites and upon the method of transportation which is to be used, to determine whether or not a large cask is practical.

To illustrate the costs involved in transporting irradiated fuel elements, let us assume a situation similar to the Yankee Atomic Electric Company at Rowe, Massachusetts shipping fuel to Hanford for processing.[6] Assuming a cooling time of 120 days or more, that the weight of the shipping cask is 60,000 lbs and the weight of the uranium in each shipping cask is 2,000 lbs and further assuming that 4 casks are required, but they are used for fuel from one reactor for a total time of only three months each year means that the reactor operator may do well to rent casks rather than to buy them. If one assumes the insurance during shipment as 2% of the value of the special nuclear material from the fuel elements, the following costs may be listed:

Transportation Charges

	$/kg U
Freight, Massachusetts to Hanford	2.80
Freight, Massachusetts to Hanford (return of empty casks)	1.40
Cask Rental	1.30
Courier Charge	0.50
Insurance	4.00
Total	10.00

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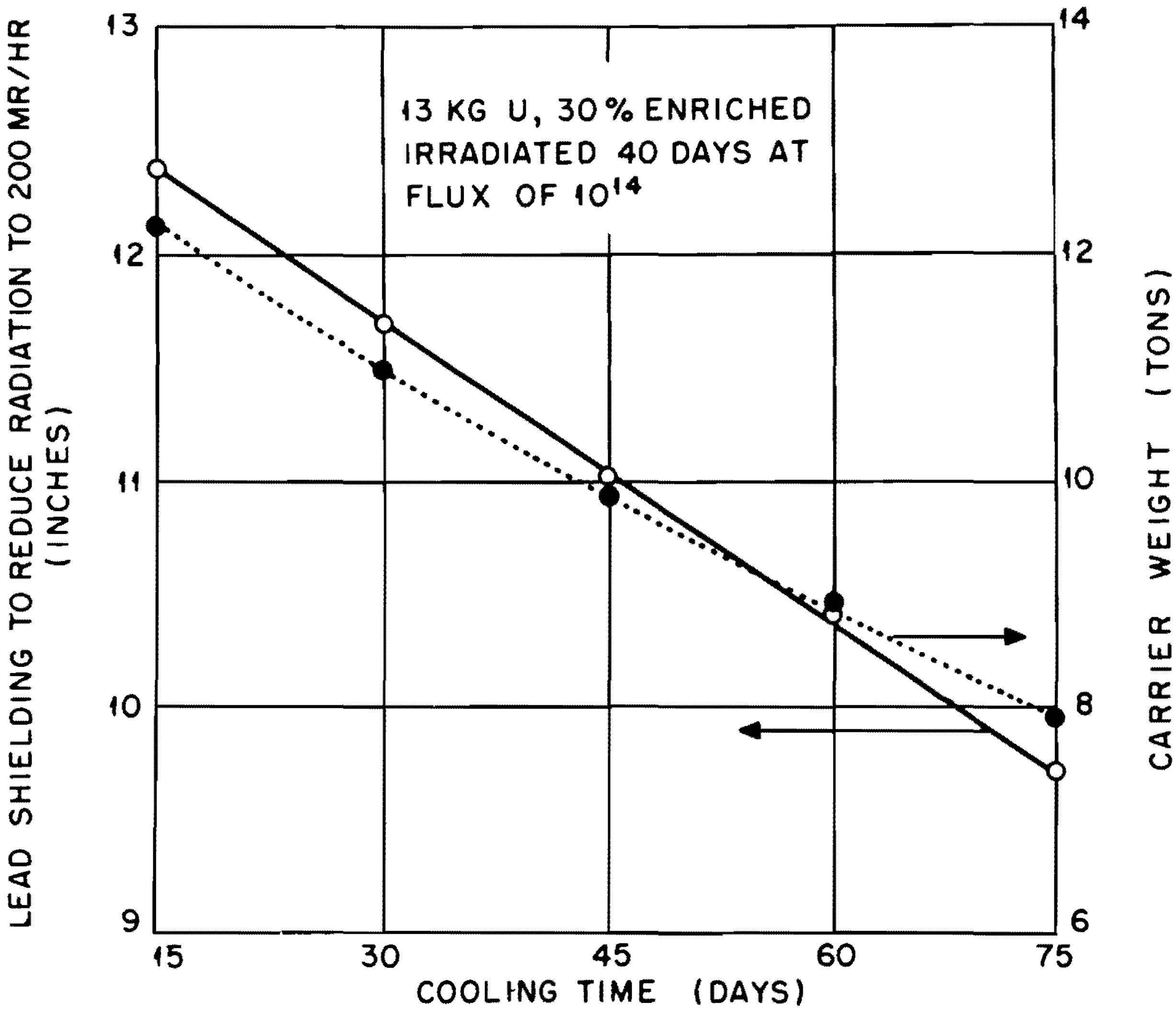

Effect of Cooling Time of Irradiated Fuel on Shielding and Carrier Weight.

Figure 1

The factors that contribute most to the uncertainties in these transportation costs are the amount of insurance, the choice of cask size and weight, cooling time prior to shipment and effect of negotiations on carrier rates.

Tucson Carrier

I will describe several carriers which I believe will be of interest to you. First of the carriers is one which has been in continuous use since 1951. (Fig. 2). The carrier was designed originally to transport irradiated natural uranium slugs from Hanford to ORNL for the isolation and purification of the fission product Ba-140. The carrier has a capacity of 74 8-in. or 149 4-in. natural uranium slugs 1-5/8-in. outside diameter. The size was dictated by the processing requirement as well as the economics since the weight of the shielding per cubic foot of usable volume decreases as the size of the carrier is increased. The Tucson carrier was designed to transfer the heat from the slugs to the external surface of the shipping container by thermal circulation of water. The shipping container (Fig. 3) is a thin-walled tank in which the carrier proper is shipped. External fins on the shipping container dissipate the heat to the ambient air by free convection. The annular space between the carrier and the tank (Fig. 4) serves as a cooling jacket. Water channels at the top and the bottom of the slug cavity communicate with the annular space between the carrier proper and the tank establish a thermal syphon circuit. Water channels are formed by spacers between the carrier body and bottom cover and between the carrier body and top plugs.

The three parts of the carrier proper, the body, the bottom cover, and the top plug, can be readily disassembled and all surfaces exposed to the circulating water made accessible for decontamination if necessary. Deposition of radioactive materials in hard to reach places has been avoided by designing with rounded surfaces in preference to sharp corners or cracks.

The slugs are held in safe position by four cages which are stacked inside the carrier body. The cages are essentially pans with perforated bottoms through which the water passes and are spaced in a triangular pitch so that each slug is positioned in place over a corresponding hole. The slugs are spaced and held in an upright position by means of vertical pins welded to the cage bottom. The bottom cage has a threaded socket at its center to receive the threaded end of a lifting rod passed through the upper three cages permitting simultaneous removal of all of the four cages or removal of one at a time by means of a fixed bail on each cage.

The carrier is loaded under 20 feet of water. The slugs are inserted in the cages with long-handled tongs. The cages are then stacked in the carrier cavity and the top plug is secured in place. The carrier is removed from the water, rinsed with a hose, and lowered into the shipping tank which is filled with water. The shipping tank is closed with a gasketed head to avoid spilling of cooling water which might be contaminated if one of the slug jackets should be ruptured.

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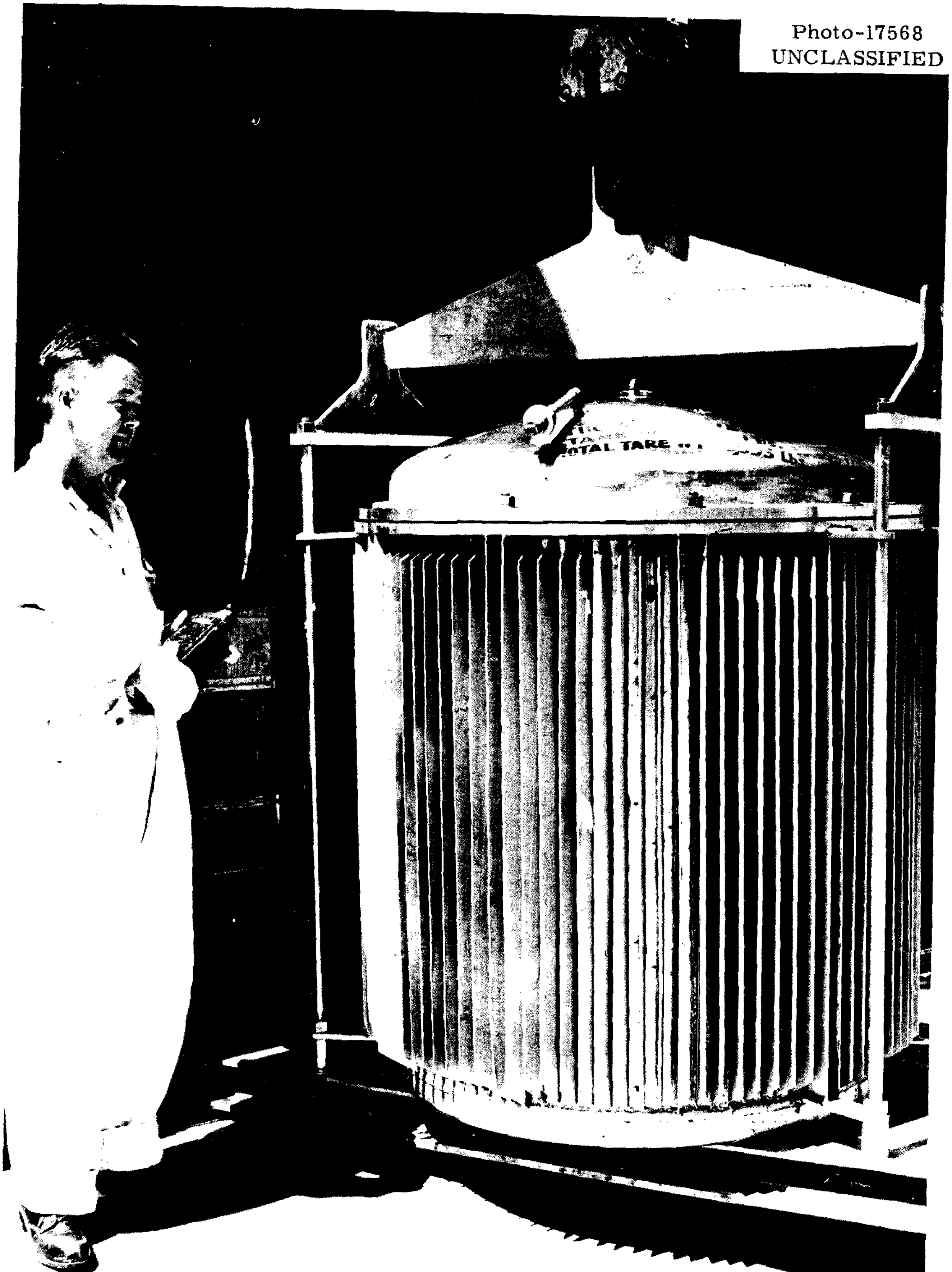

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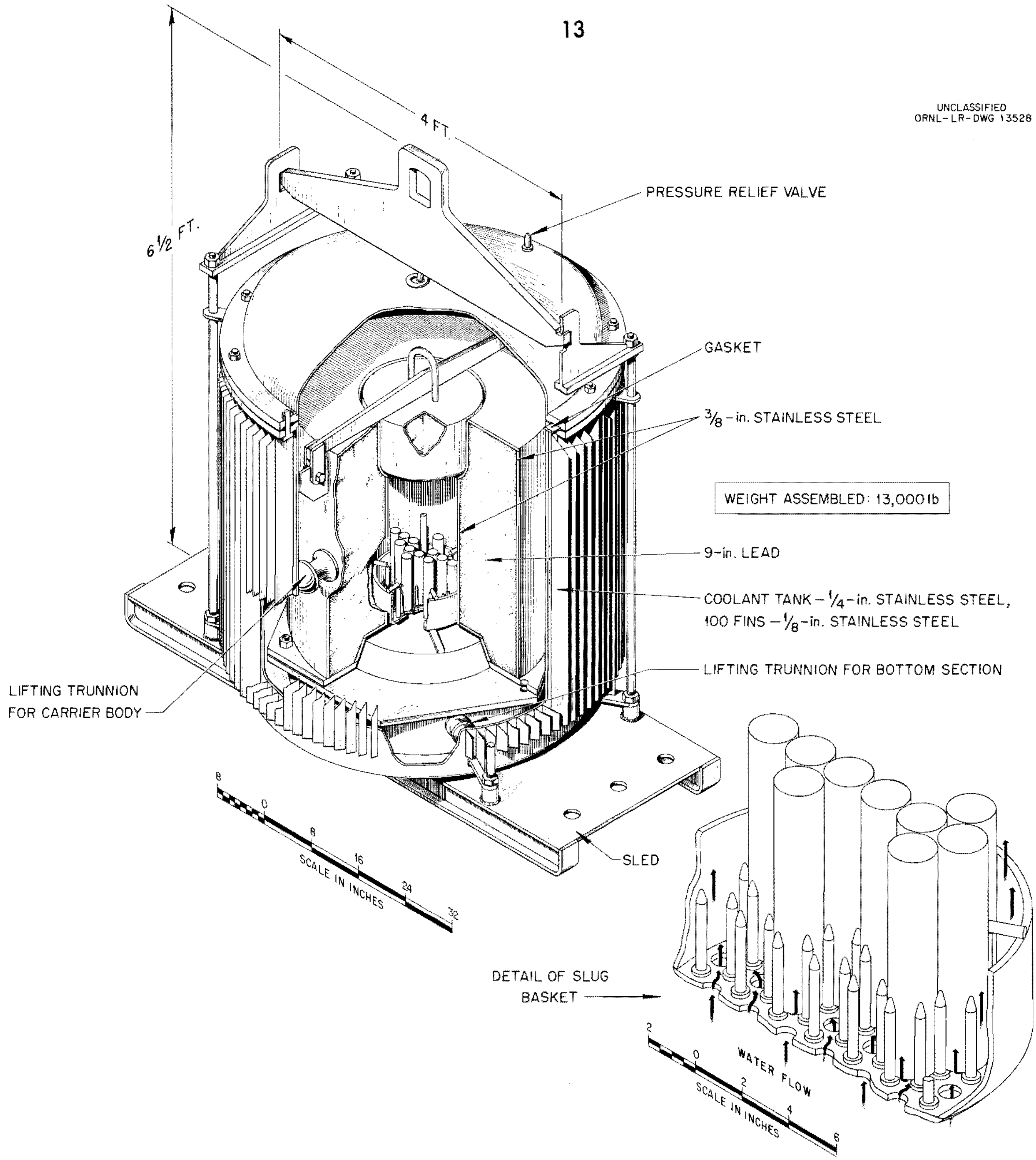

Tucson Carrier

The thin tank was designed to dissipate five kilowatts of heat at an ambient temperature of 32°C. The temperature of the top of the slug chamber reaches 97°C. The calculated temperature at the bottom of the slug chamber for 5 kw heat dissipation is approximately 92°C. Some boiling of the water surrounding the slugs in the cavity occurs initiating the thermal flow of cooling water.

Skids are provided on the shipping tank to facilitate handling and to avoid a concentrated weight which might complicate freight car loading. The entire assembly is built exclusively of type 18-8 stainless steel to facilitate decontamination. The carrier is designed to provide a minimum of 9 in. of lead shielding. The loaded carrier and the thin tank plus the shielding water weigh a total of 6 tons.

Thorex Slug Charger

The Thorex Charger was designed for intraplant transfers of cylindrical, aluminum-sheathed slugs of thorium from the storage canal to the Thorex Pilot Plant dissolver. The charger has six inches of lead radiation shielding and is constructed principally of stainless steel.

An interesting feature of the device is a revolving cylindrical magazine having 40 vertical tubes (Fig. 5). It is designed to be rotated by a crank about its vertical axis so as to position each vertical tube in turn, at 9° intervals, over a radially elongated aperture in the bottom of the magazine cavity. Directly below the aperture and aligned with the dissolver slug chute is a lead shutter rotating within and forming a part of the carrier shielding. (Fig. 6). In the open position a frustrum-shaped hole permits passage of the slugs out of the magazine into the dissolver chute; the closed position permits safe transportation of a loaded carrier.

The disc is rotated by means of a removable radial lever which operates in a slot provided in the carrier wall. Once the lever has been inserted and used to rotate the disc to the open position, a collar fixed on the lever prevents its withdrawal again until the disc has been returned to the closed position, thereby providing a visible means for checking that it is safe to move the carrier.

The charger was normally loaded with 120 6-in. long 1-5/8-in. dia slugs, 3 to a tube, in a canal under 9 feet of water cover. Following placement of the slugs in the magazines, the carrier is closed, hoisted out of the water, and taken to the pilot plant where it is placed on a specially designed pedestal which assures correct alignment of the charger with the slug chute.

MTR Charger

The MTR charger (Fig. 7) was designed and built to transport spent MTR plate and frame fuel elements from the storage canal and unload them into the ICPP dissolver. Four cropped MTR assemblies can be accommodated in the 10-in. by 10-in. by 50-in. internal

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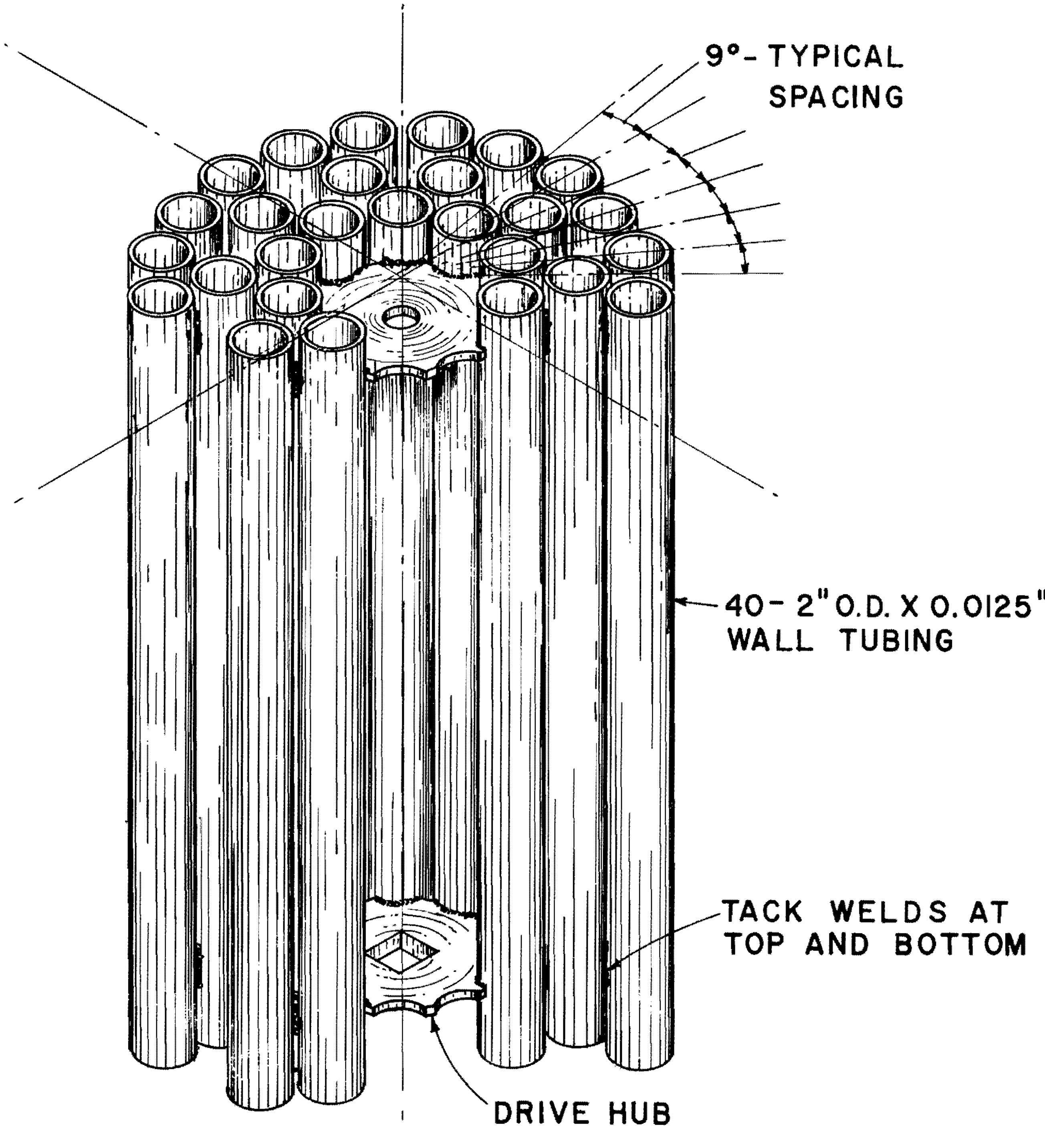

Figure 5

SLUG CHARGER MAGAZINE

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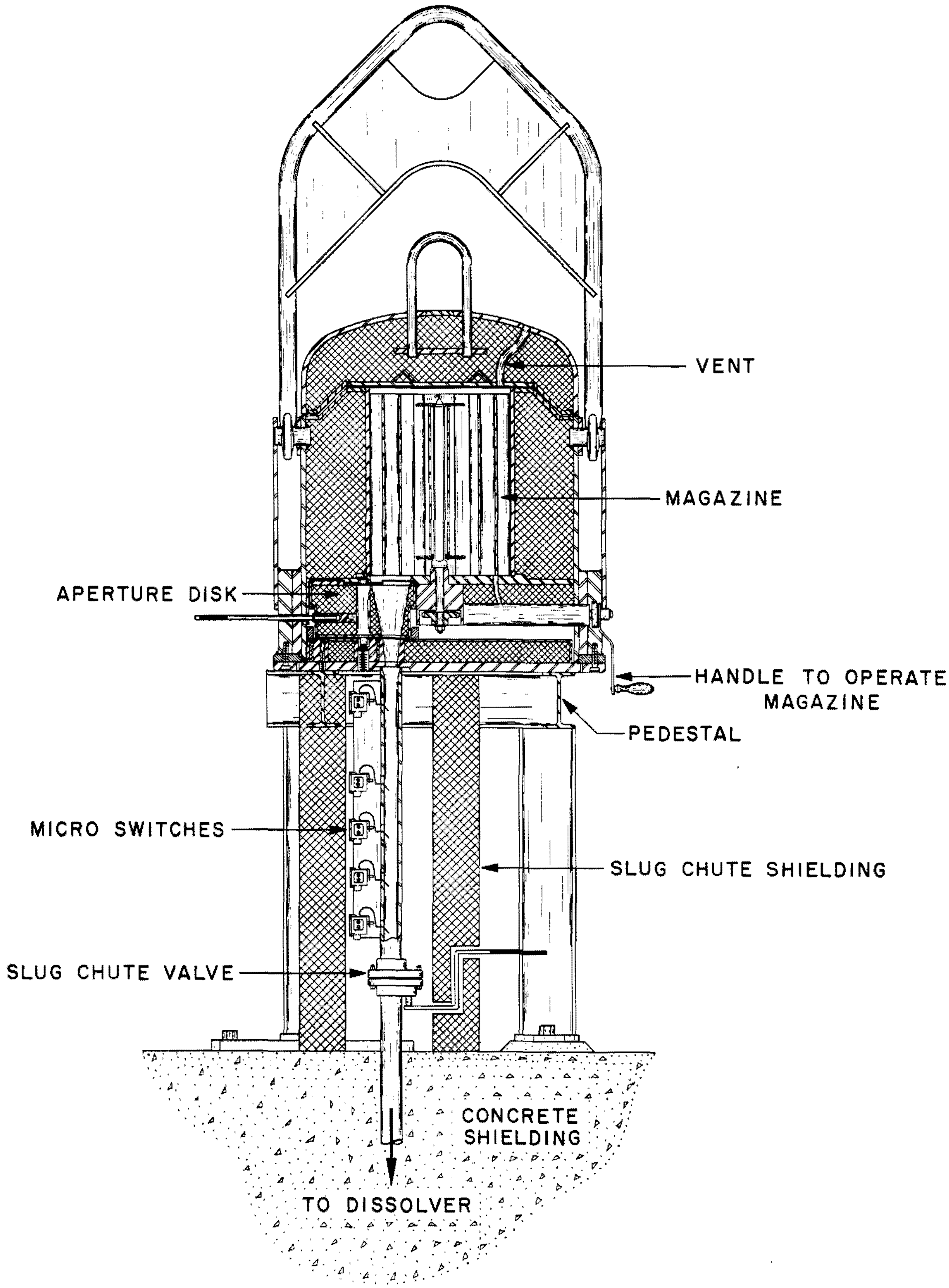

Figure 6

THOREX SLUG CHARGER

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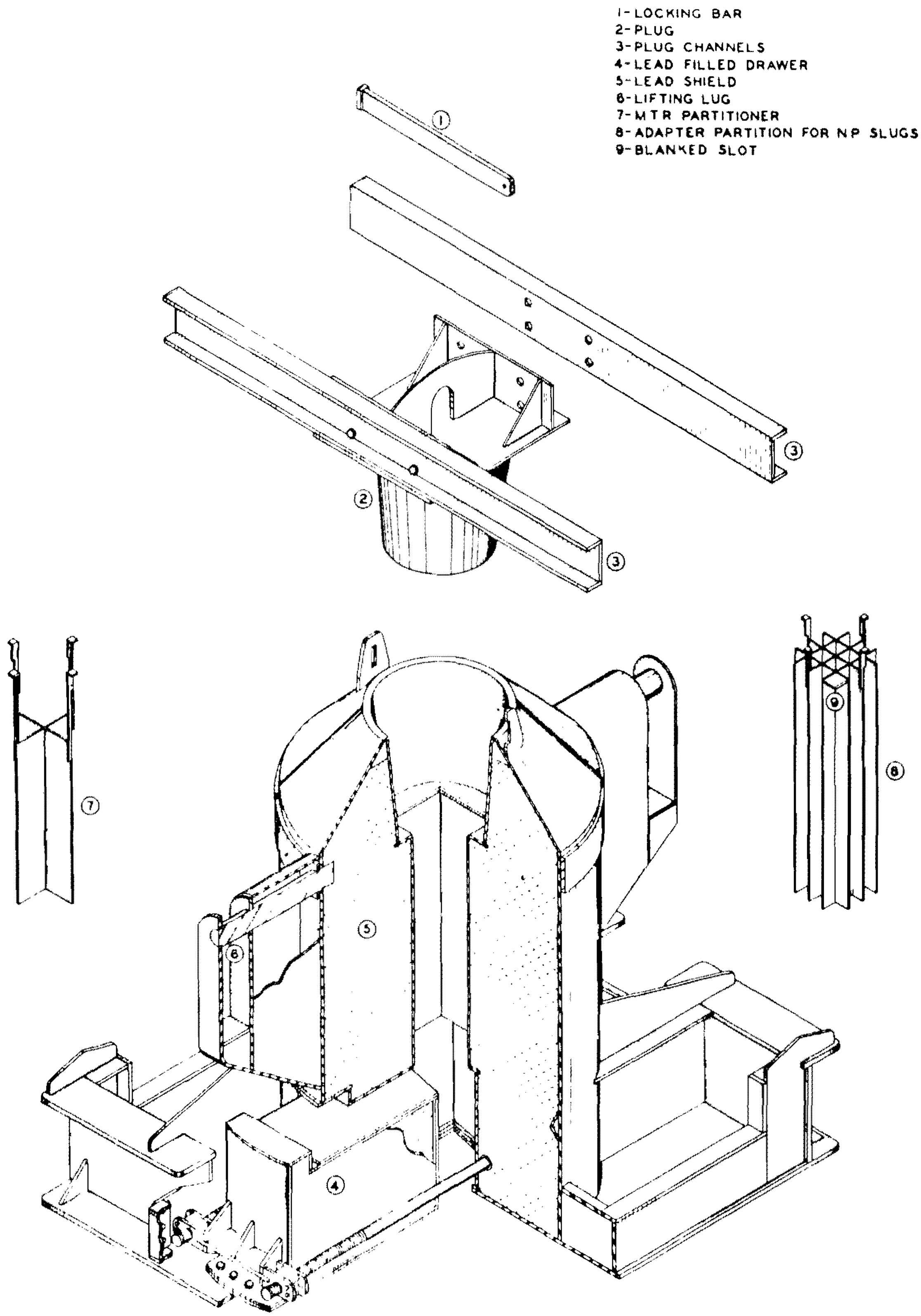

MTR SLUG CHARGER

Figure 7

cavity when the "MTR partitioner" is in place; or, by using the "Adapter portion for NP slugs", slug-type elements can be handled instead. Cropping the fuel elements removes non-fuel-bearing adapters from each end of the fuel element thereby producing savings by shortening the length of shielded cavity necessary. Even so, this charger weighs eight tons because of the need for a 10-in. thickness of lead to provide shielding. The lead was encased in stainless steel which was the principal material of construction used throughout the charger to facilitate decontamination when and if necessary.

Transportation of the charger between the storage canal and the ICPP, a relatively short distance, was by a high chassis straddle carrier (Fig. 8) specially adapted to engage the extension rails on the charger.

A 10-ton overhead crane engages trunnions attached to the carrier's sides for lowering it into a canal where it is loaded under a 20-ft water cover. Rails attached to the top plug engage a rack attached to the canal sides 10-12 ft under water and hold the plug as the charger body continues to descent away from the plug to the 20-ft level. The charger body is then moved horizontally to expose the opening for loading. Manually operated, long-handled tongs are used to load the charger.

After receiving fuel elements, the carrier is horizontally moved back to where it is again under the top plug, then is hoisted vertically, engaging the top plug on the way up.

The top plug rails are removable and the plug is provided with a lifting bail for permitting removal with a crane hook if operation by this method should be more desirable.

The straddle carrier transports the charger to the 5-ft thick concrete roof of the dissolver cell where it is positioned over the dissolver chute. The threaded rods of the charger drawer are engaged by a specially designed motorized unit shown and as the rods are turned, the drawer slowly moves out, permitting the fuel elements to drop into the dissolver.

Production Plant Carrying Casks

Relatively large quantities of fuel elements are routinely handled in a plutonium production plant. Distances that irradiated fuel must be transported in such plants are relatively short and usually all within a controlled area. Fuel handling methods and carrying casks specially suited to these conditions have evolved.

Hanford Slug Carrier

At Hanford slug casks are carried in water-filled vats mounted on a railroad flatcar. Tubes penetrating the sides of the cask into the slug cavity provide a water passage for thermal convection cooling of the slugs. The slugs are contained in a removable, perforated stainless steel bucket that fits in the slug cavity. The cavity has the approximate dimensions of 26-1/2 in. by 22-1/2 in. x 18 in. and is enclosed by shielding walls having 12-1/2-in. thick lead slabs encased in steel. An empty cask weighs around 22 tons.

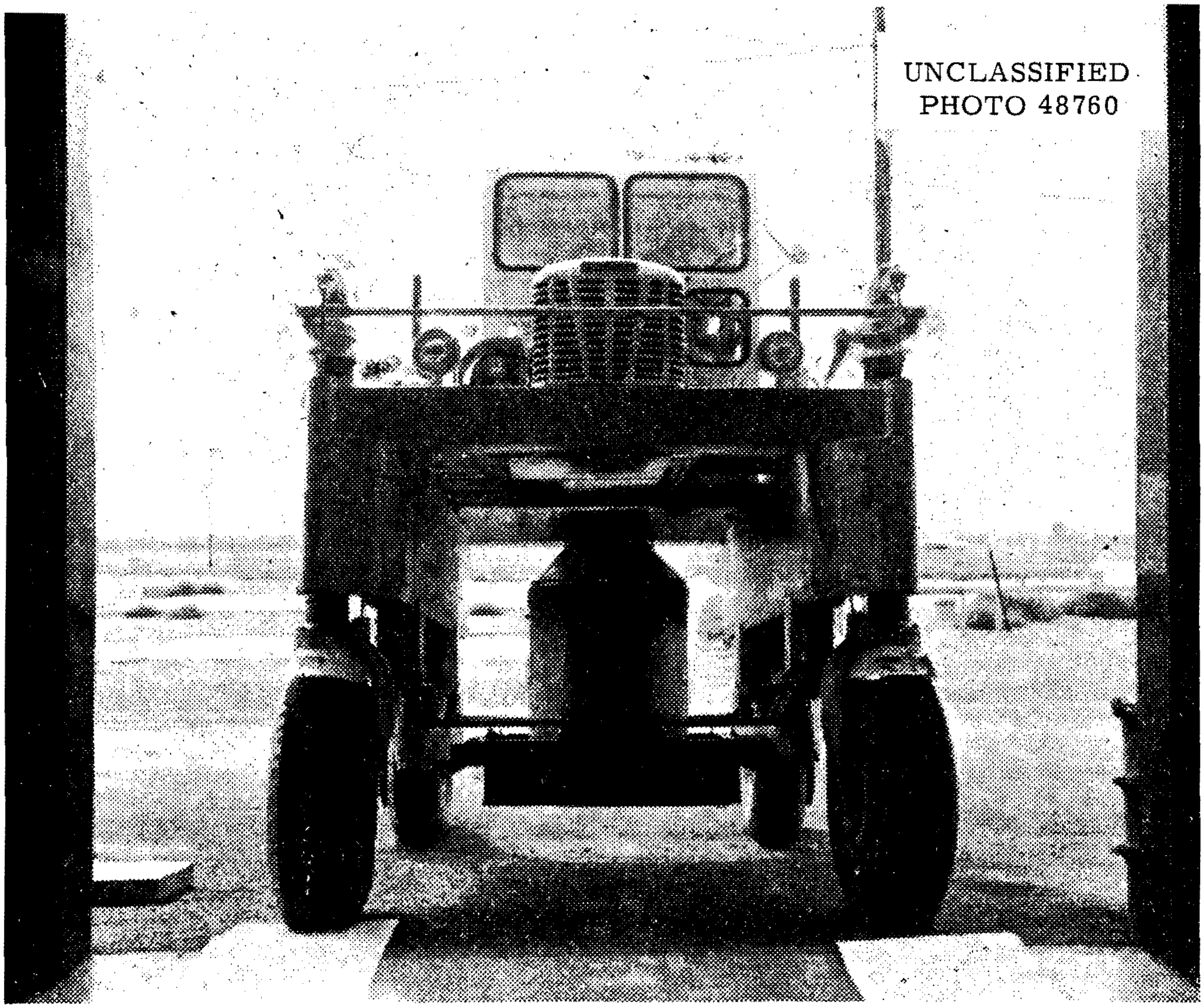

FIG. 8. Gerlinger straddle carrier brings an 8 ton cask into multicurie cell facility of Chemical Processing Plant.

Figure 8

Cask loading is accomplished under 20 ft of water in the slug loading canal. The cask is lowered into the water while supported from a twin hook bridge crane. Extensions on the top plug allow it to be retained on fixed beams 11 ft under water, this depth providing adequate shielding for irradiated fuel. The cask body continues its descent to the 20 ft level where it is moved horizontally to expose the opening for loading. Slugs stored in stainless steel buckets are now transferred into the carrier and the carrier hoisted out of the canal. From there the cask is positioned in the vat on the railway flatcar for transportation to the reprocessing plant. On arrival at the reprocessing plant, remote methods are used to remove the slug bucket from the carrier and empty it into a dissolver funnel.

SRP Slug Carrier

At Savannah River the procedure for handling irradiated fuel slugs is similar to that described for Hanford with one important exception. Instead of immersing the filled cask in a vat of water for transportation to the reprocessing area, the cask is designed with external fins and uses water at atmospheric pressure as an internal coolant to transfer the heat from the slugs to the cask wall. An assembly drawing of this carrier is shown in Fig. 9. Figure 10 is a photograph of the cask fastened in a railroad car for shipment.

SRP 70-Ton Shipping Cask

An externally-finned, water-filled cask with an internal cavity 15 ft long by 2-1/2 ft wide by 2-1/2 feet deep, and weighing about 70 tons was constructed for off-plant shipment of fuel elements, and an assembly drawing is shown in Fig. 11. The cavity was subdivided by separator plates fabricated with 40-mil-thick cadmium sheets enclosed and supported by 1/8-in. thick stainless steel sheets. The compartments were necessary to meet criticality needs; cadmium was incorporated into the separator plates because of its high cross section for thermal neutrons. Filling the void spaces in the cavity with water provides a heat transfer medium between the elements and the cask walls.

For ease in handling, the fuel assemblies are first placed in magazines and the magazines are in turn placed in the compartments formed by the separator plates. The magazines are weldments of minimum weight, designed to expose the maximum element surface for cooling.

Many alternate methods for cask cooling were considered, including immersion in a tank of water described earlier. Greater inherent safety in case of an accident and overturning of the railroad car and its carrying cask was the reason why the externally-finned tank was chosen over other designs.

Figure 12 shows the cask in place on a railroad car.

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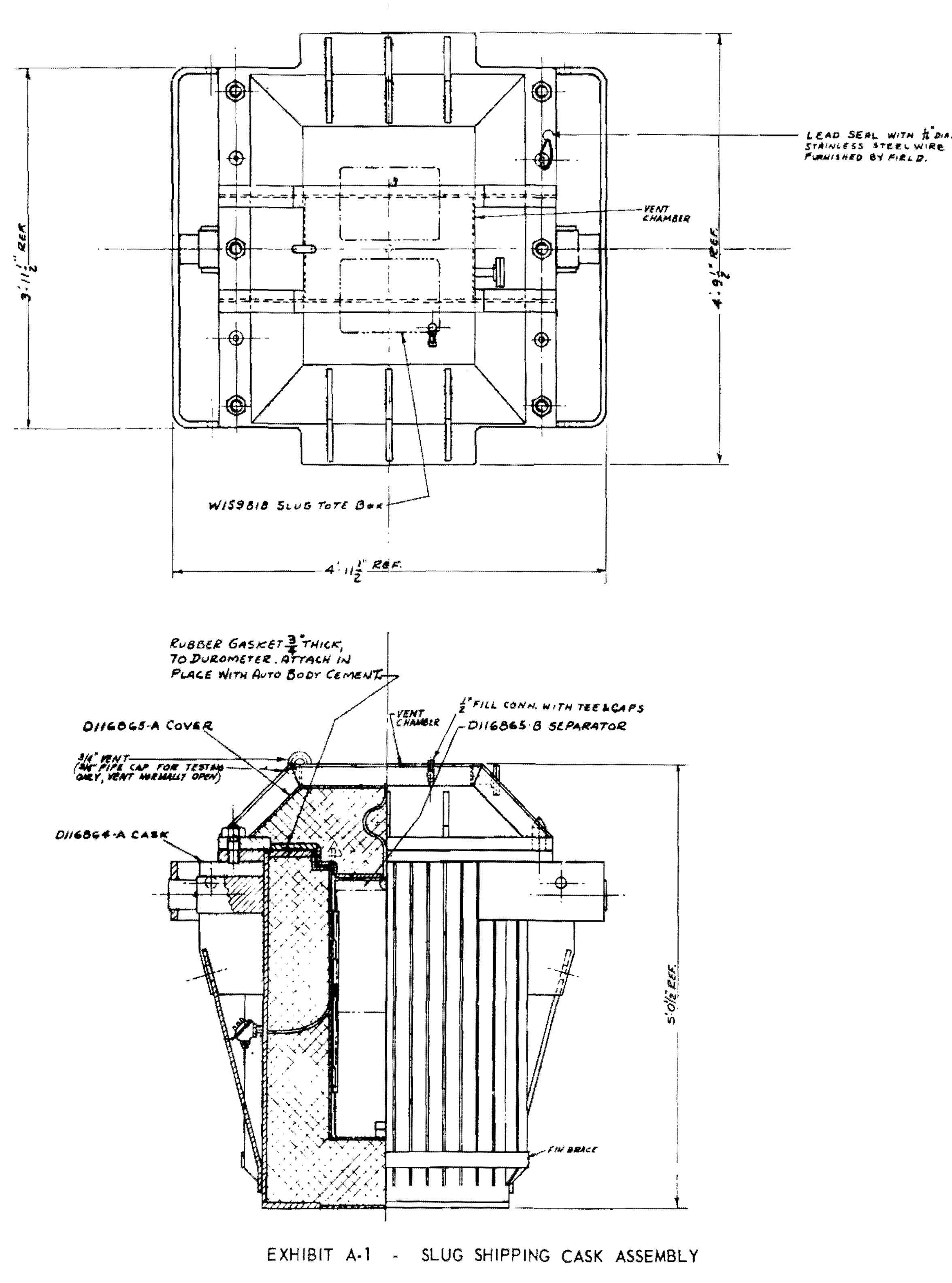

EXHIBIT A-1 - SLUG SHIPPING CASK ASSEMBLY

Fig. 9

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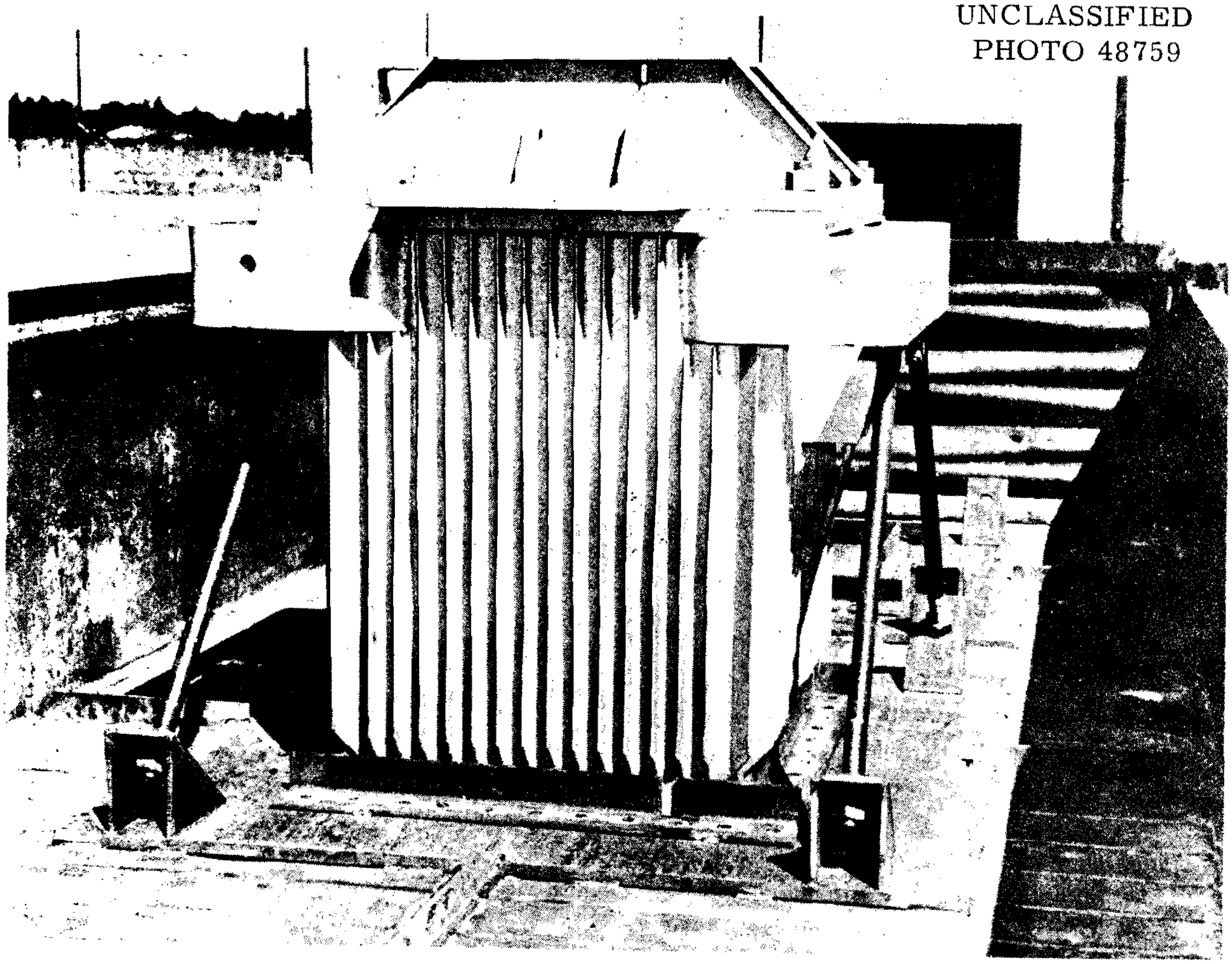

EXHIBIT A-2 - SLUG CASK ON RAILROAD CAR

Figure 10

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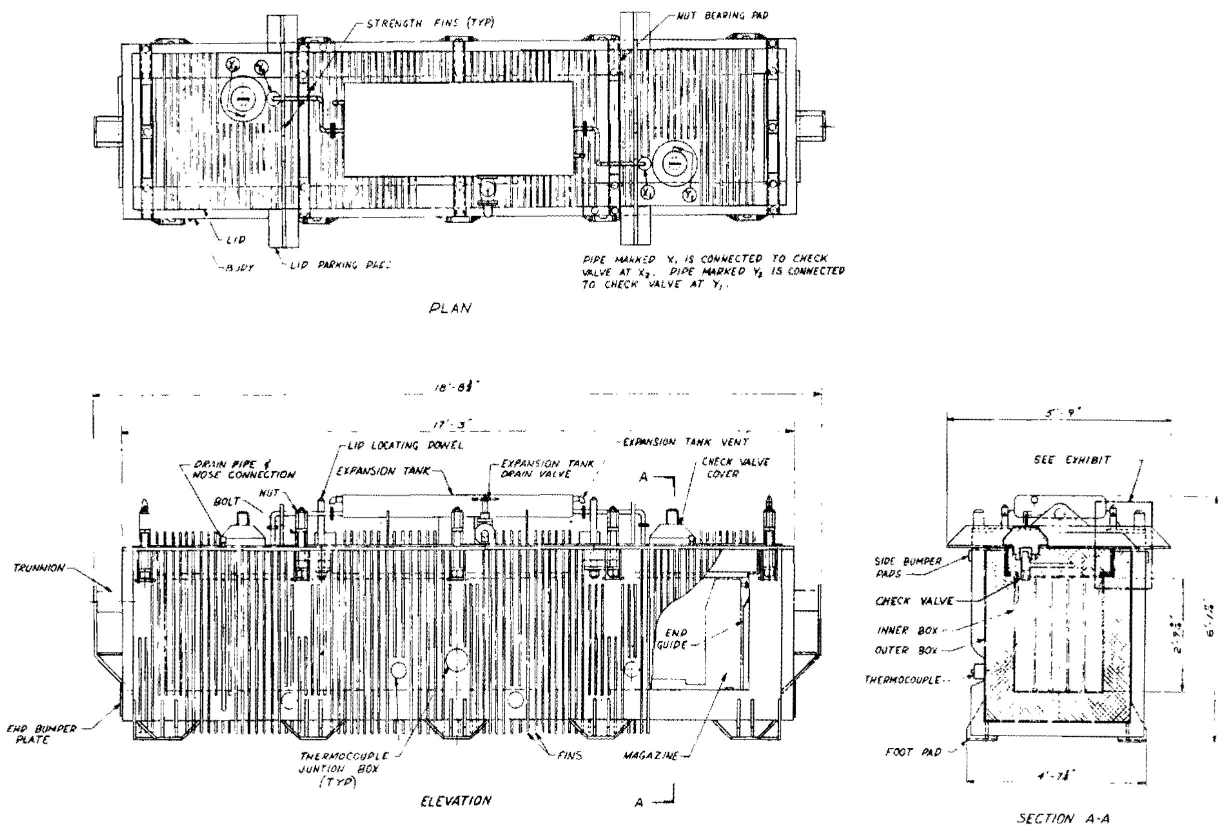

EXHIBIT C-1 - 70-TON SHIPPING CASK NOMENCLATURE AND MAJOR DIMENSIONS

Figure 11

Carriers for Radioactive Liquids

Transportation of liquid radioactive materials requires the carrier to be a tank, preferably spherical, since this configuration provides the minimum surface area for a given volume and hence is important in shielding. Figure 13 shows a carrier for the transcontinental transportation of aqueous wastes from a fuel reprocessing plant to an isotope separation plant where the aqueous waste served as a raw material supply. The 250-gallon carrier shown has a 48-in. dia inner vessel of austenitic stainless steel with walls that 3/8-in. thick. The normal working volume is 210 gallons (Fig. 14). Five and one-half inches of lead surrounds the inner container which in turn is enclosed by a steel shell, 13/16-in. thick, with a stainless steel cladding on the outside surfaces. The empty weight of this carrier is 28,200 lbs; filled with first cycle aqueous waste from solvent extraction fuel processes described earlier, the weight is increased to over 30,000 lbs.

Two pipe connections to the inner tank provide for filling, emptying, and venting the vessel. Filling the vessel is accomplished by first evacuating the tank via the short leg, then allowing the vessel to fill via the long leg to the 210 gallon level as indicated by the conductivity probe. Probes also indicate the 125 and 200-gallon levels. By evacuating the vessel at the start and not running the vacuum pump once filling has started, the risk of overflow is eliminated. Emptying is accomplished by providing air pressure on the short leg with liquid flowing out via the long leg. Each leg is fitted with a teflon-lined plug-cock and a quick opening coupling which automatically seals against pressure from within the tank when couplings are disconnected. Figure 15 is a view of the cylindrical cupola atop the carrier and the disconnects and valves contained therein. The cupola walls are of 2-in.-thick lead for radiation shielding. Protection against leaks is provided by the corrugated stainless steel gasket used with the cupola hatch cover. If for any reason radioactive liquid should escape the inner vessel by means of the connecting lines, the leak proof cupola provides a factor of safety for containment of the hazardous radioactive liquid.

HRT-CPP Waste Carrier

An example of a liquid fuel carrier is that of the HRT-CPP Waste Carrier (Fig. 16). The carrier was designed to remove fuel from the expended fuel from the Homogeneous Reactor Test (HRT) at ORNL. The vessel is about 20 in. dia and 30 in. long and has a capacity of 30 gal; 9-in. thick lead shielding is used on the top and sides and a minimum of 5-in. on the bottom. The radiation at the surface of the carrier is about 80 mr/hr. Additional shielding is provided for the valves and nozzles on the top of the carrier by removable cap that is placed over these fittings whenever the carrier is out of the loading pit. The total weight of the carrier is 9.3 tons.

Figure 17 shows the carrier in position in the loading pit showing how the waste product is pumped into the vessel by opening valves with a long-handled tool under water. Three nozzles are installed on the carrier. One is used for filling the carrier, one for venting and the third for emptying the carrier. All three are flanged.

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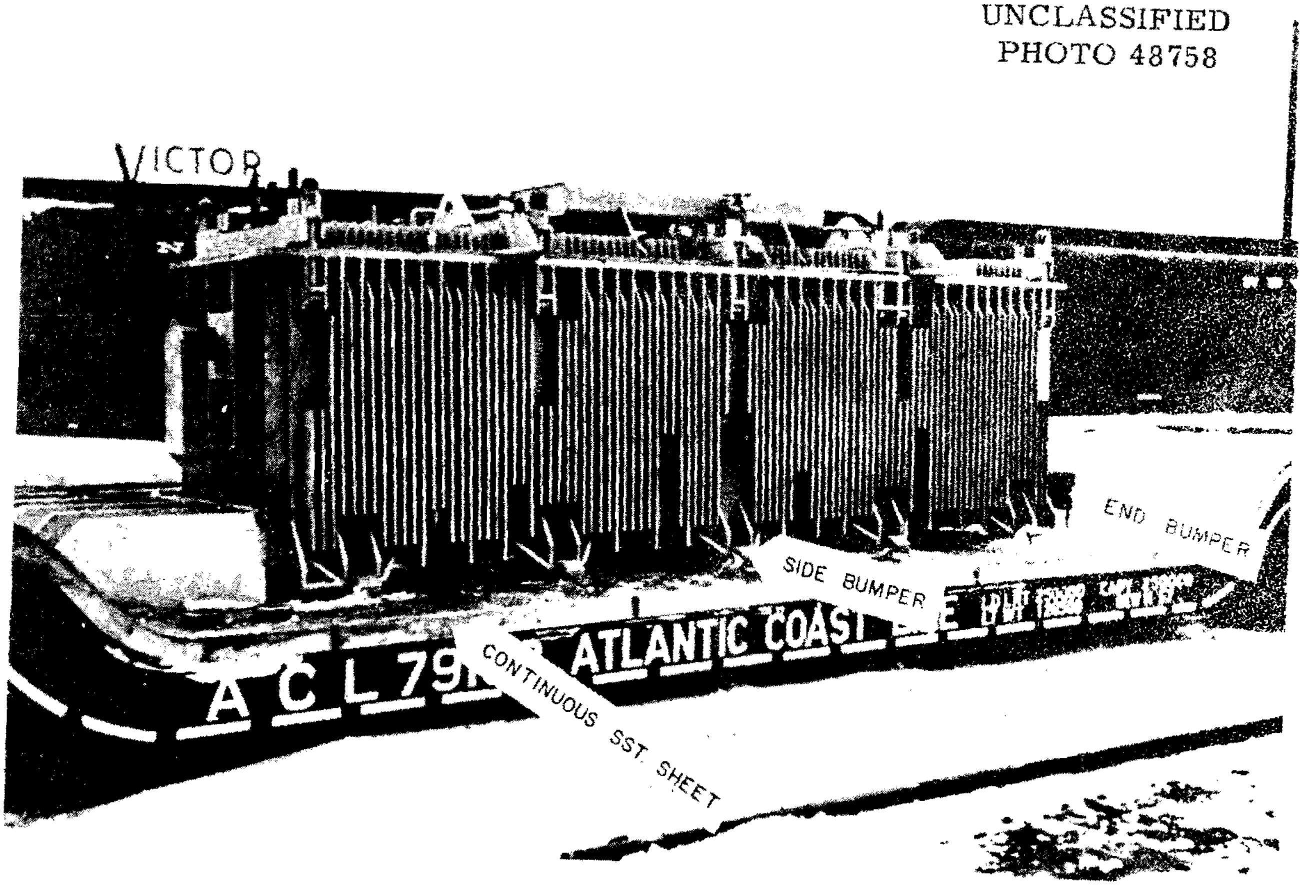

EXHIBIT E-2 · CASK ON RAILROAD CAR

Figure 12

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Figure 13 Shielded Transfer Tank

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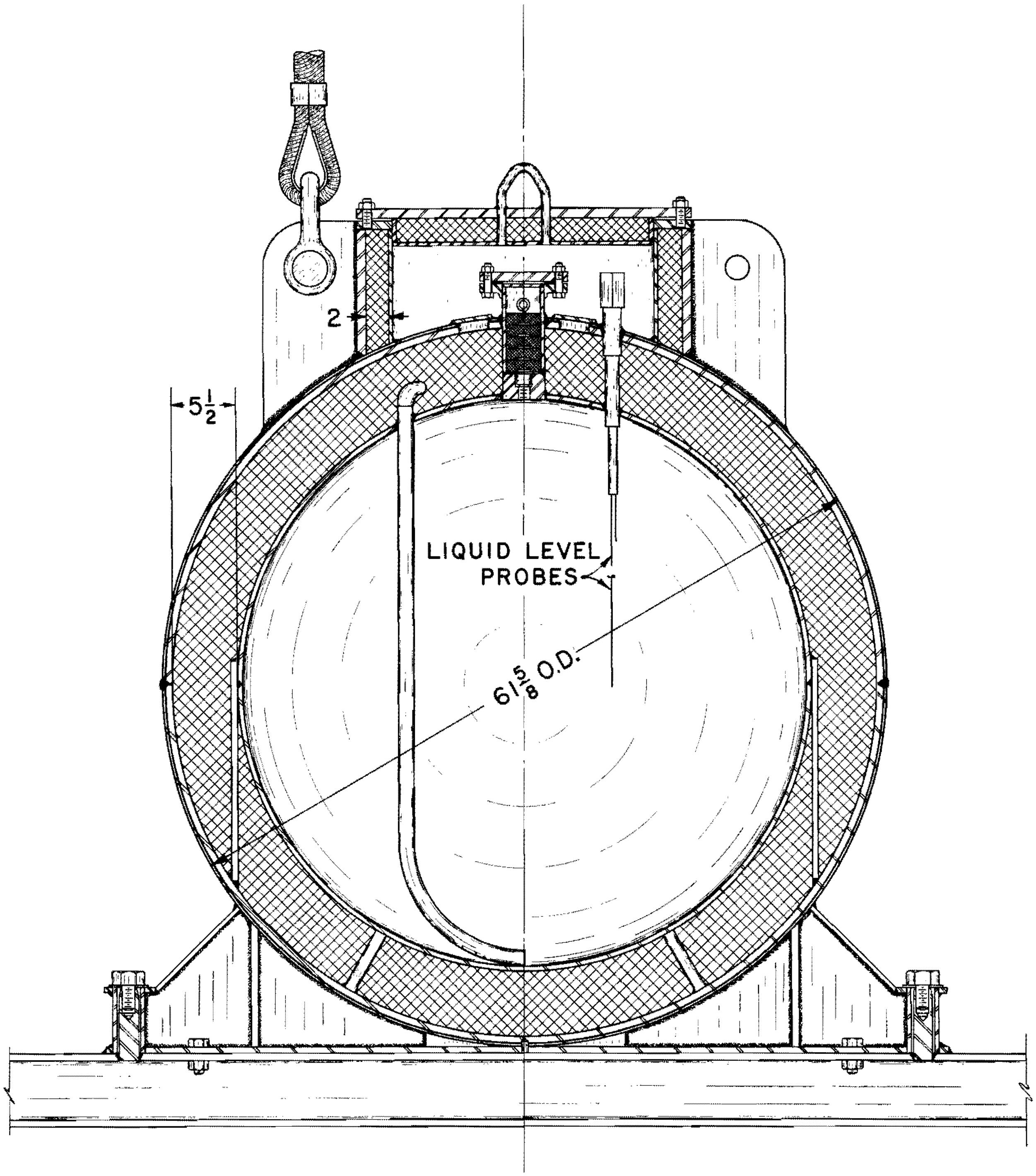

Figure 14

SOLUTION CARRIER

(SHIELDED TRANSFER TANK)

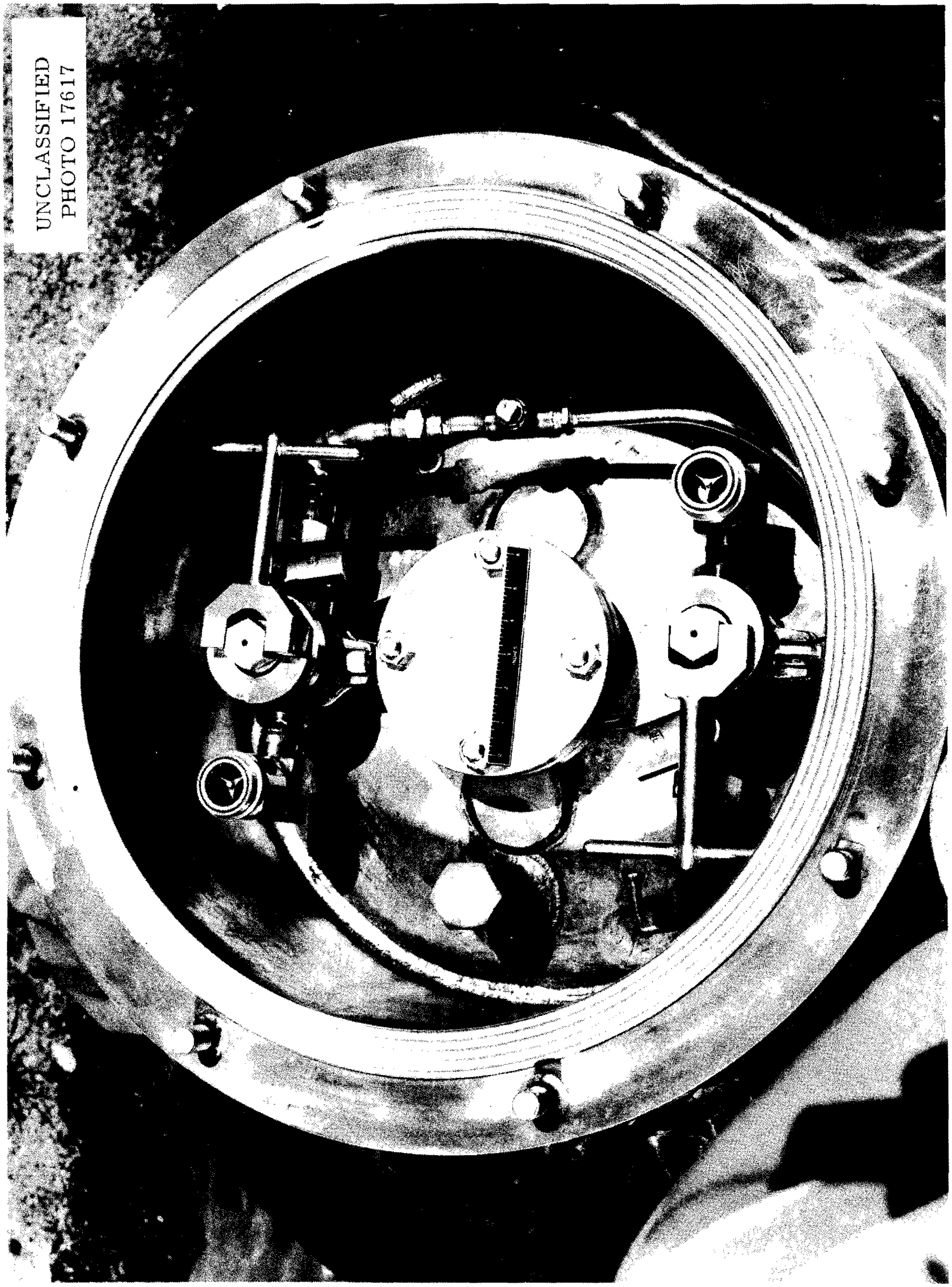

Figure 15

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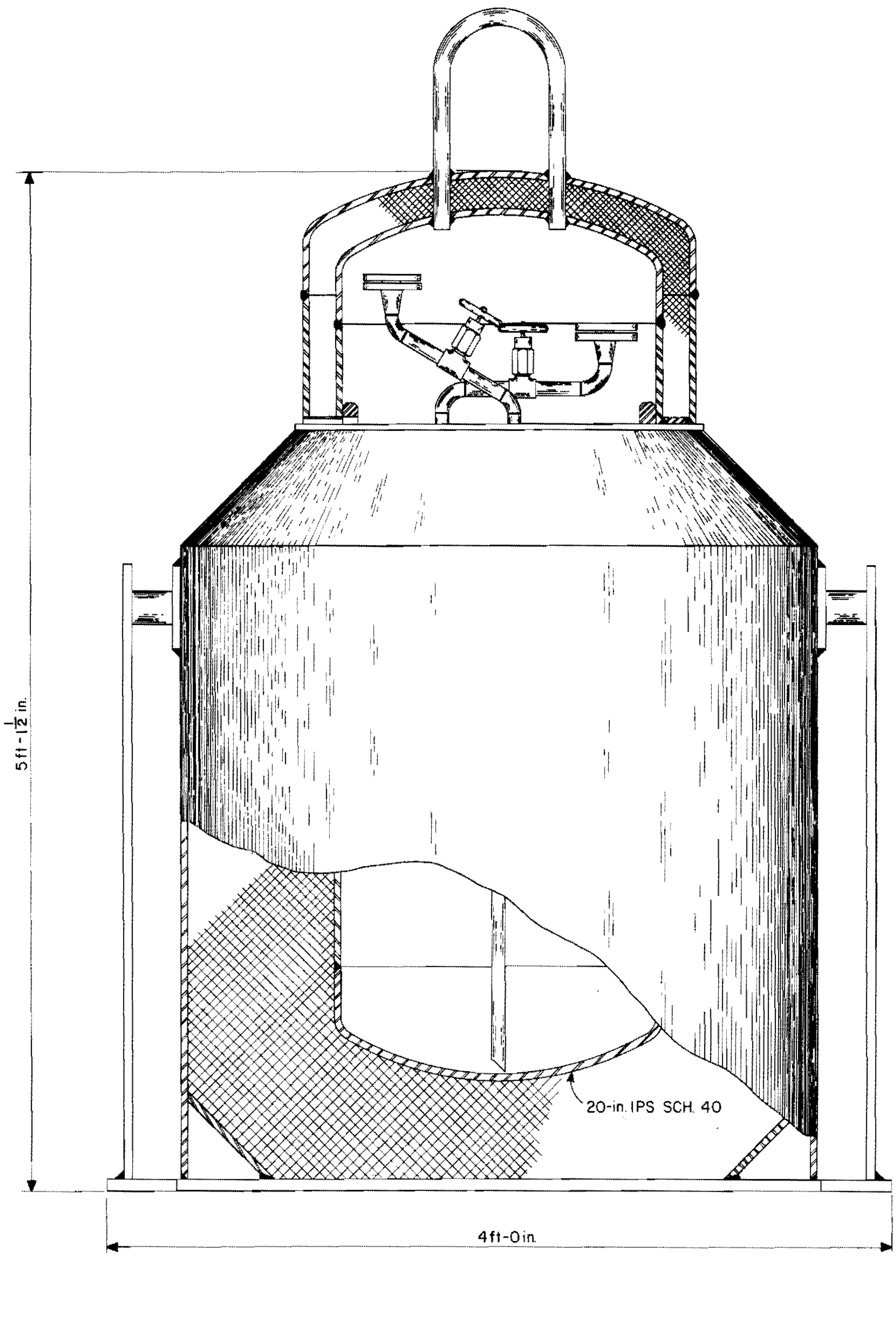

Figure 16

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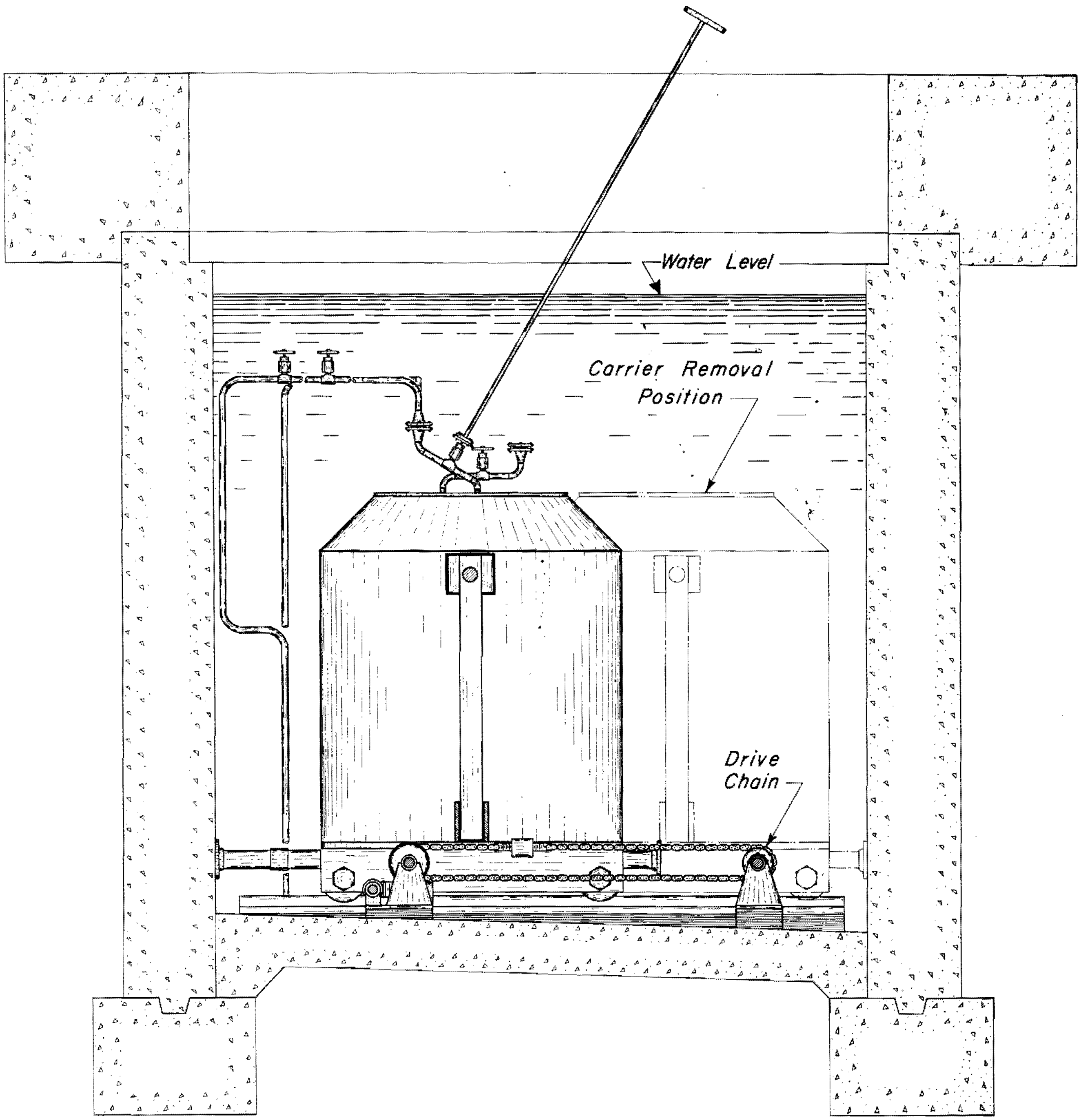

Figure 17

Hydrogen is evolved into waste solution increasing the pressure of the carrier by about .06 psi per hour. This rate is not deemed high enough to justify the use of a recombining mechanism on the carrier since the time in transit is not expected to exceed a few hours. The heat evolved from the waste solution is about 500 Btu/hr which will raise the solution by about 2°F per hour if no heat is lost in the surroundings. Temperature rise is negligible and no provision is made for cooling the carrier in transit. If all the uranium remains in solution, the 20-25 gal charge to the carrier will not contain a critical mass; no mechanism is known by which uranium would precipitate from a 4 molar sulfuric acid solution and the likelihood of such precipitation is considered so remote that a critically safe carrier was not designed. The carrier is designed for 500 psia pressure, the operating pressure is 17 psia and the operating temperature is 129°F.

SRE Carrier

The fuel from the Sodium Reactor Experiment (SRE) of Atomics International at Canoga Park, California, is scheduled to be processed at ORNL during the early part of 1960. An existing carrier was modified at ORNL for the transportation of this fuel. This carrier is shown in Fig. 18. The carrier was originally designed for charging and unloading a large engineering in-pile loop experiment in the ORR reactor. The carrier was designed with a view towards adapting it to other uses. The original design required lead shielding thicknesses of from 6 to 8 inches and was designed for minimum shielding owing to the crane restrictions at the ORR. A special trailer was required to handle the carrier within the ORR Building.

The original carrier had an inside diameter of 27-1/2 in. by 10'-6 in. length. The shielding requirements for the SRE required a lead thickness of 8 in. over the entire length of the carrier. The carrier was modified by inserting a liner with 2 in. of additional lead in the central section of the carrier. A rotating fuel rack was designed for installation within the shield containing space for ten SRE elements. A cross section of the carrier is shown in Fig. 19. Each fuel element is shipped in a gasketed fuel storage can supplied by Atomics International. This can is suitable for handling and shipping ruptured or damaged fuel elements. The can is contained in a sleeve mounted in the rotating rack. Each sleeve is separated by boral sheets for reasons of criticality. A cutaway illustration of the carrier is shown in Fig. 20. Owing to the low burnup in the SRE, no external cooling is required.

The carrier was designed for railroad shipment in a gondola type rail car. The carrier is secured to the car by special linkages mounting on the trunions and the shipping rack (Fig. 21). It is further secured against longitudinal motion by I beams placed transversely on the car against both ends of the carrier. In addition, hold-down chains are provided to prevent the carrier from being dislodged from the rack in the event of a severe rail accident.

The original design contemplated horizontal loading and unloading of the carrier. However, owing to the facilities at Atomics International, vertical loading of the cask was necessary. Additional trunions were added to the carrier to permit this operation. A

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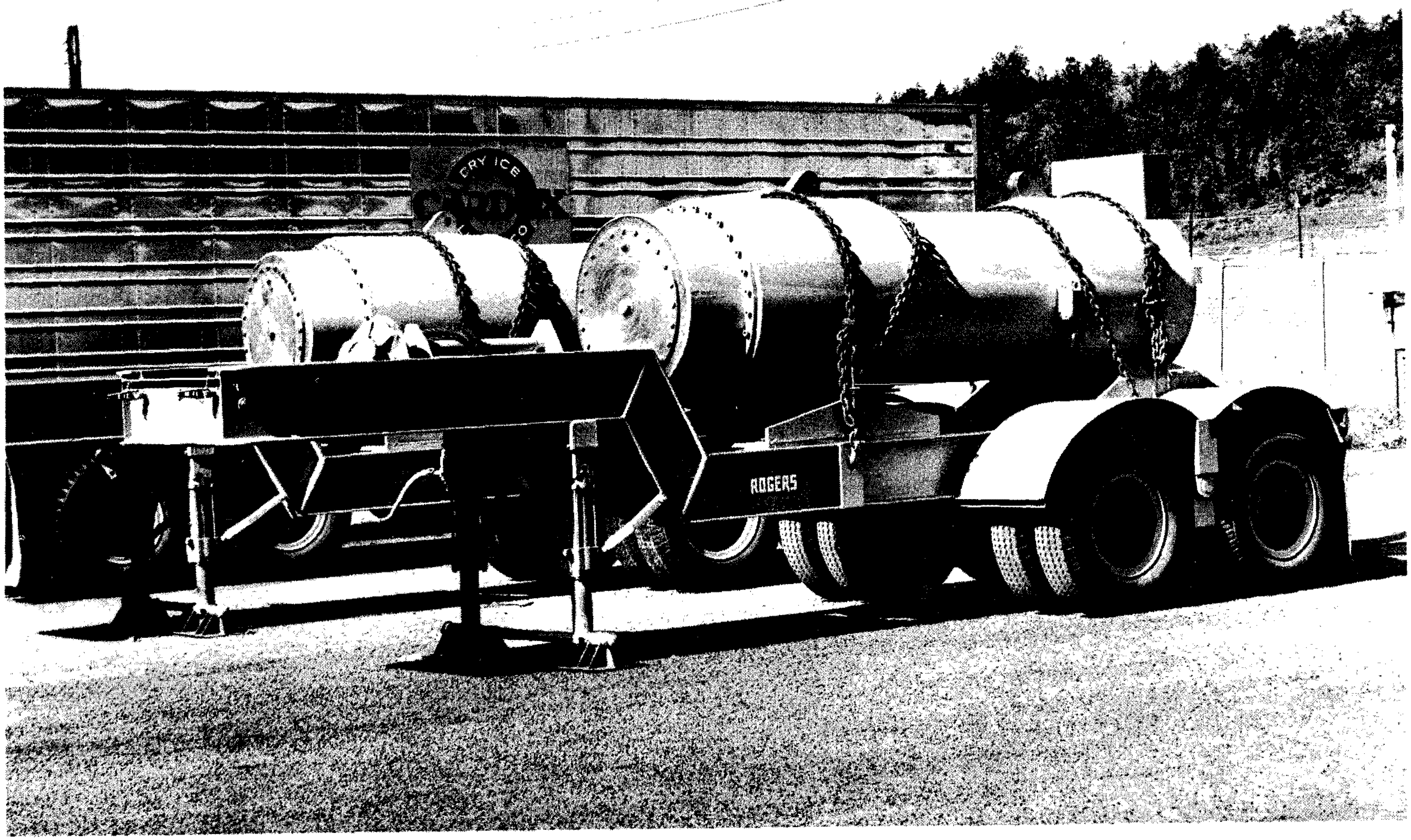
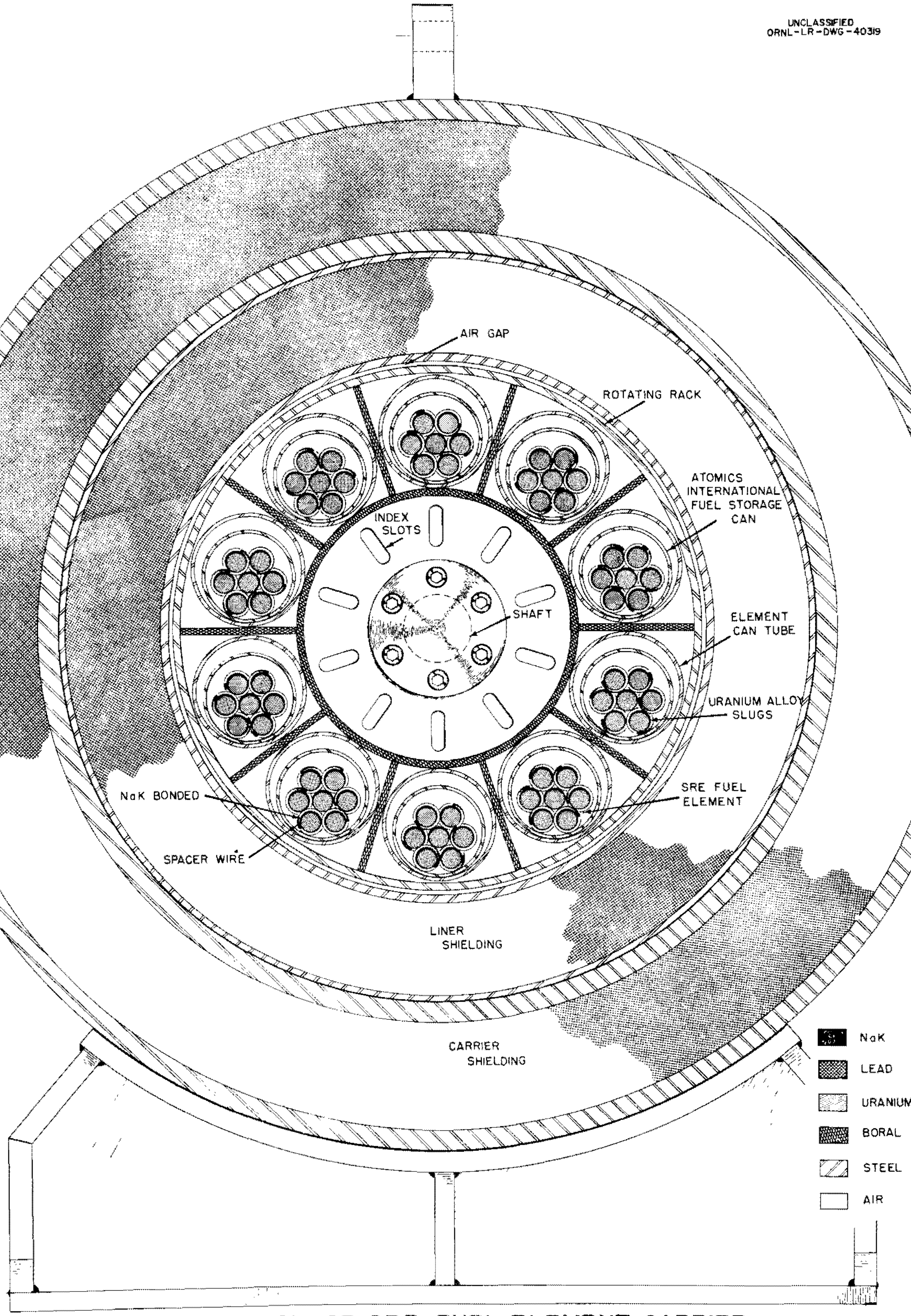


Figure 18



SECTION OF SRE FUEL ELEMENT CARRIER

Figure 19

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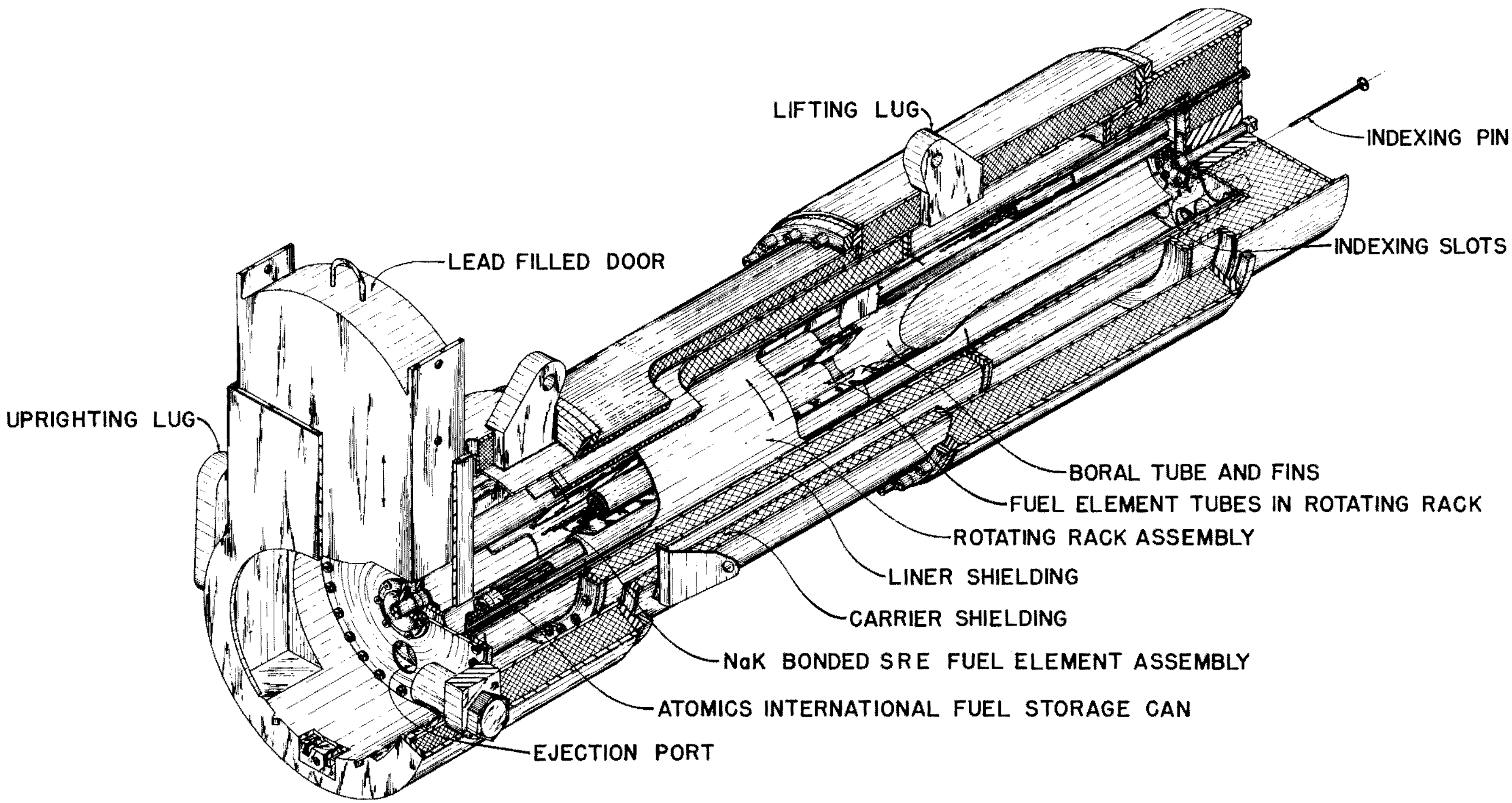

SRE FUEL ELEMENT CARRIER

Figure 20

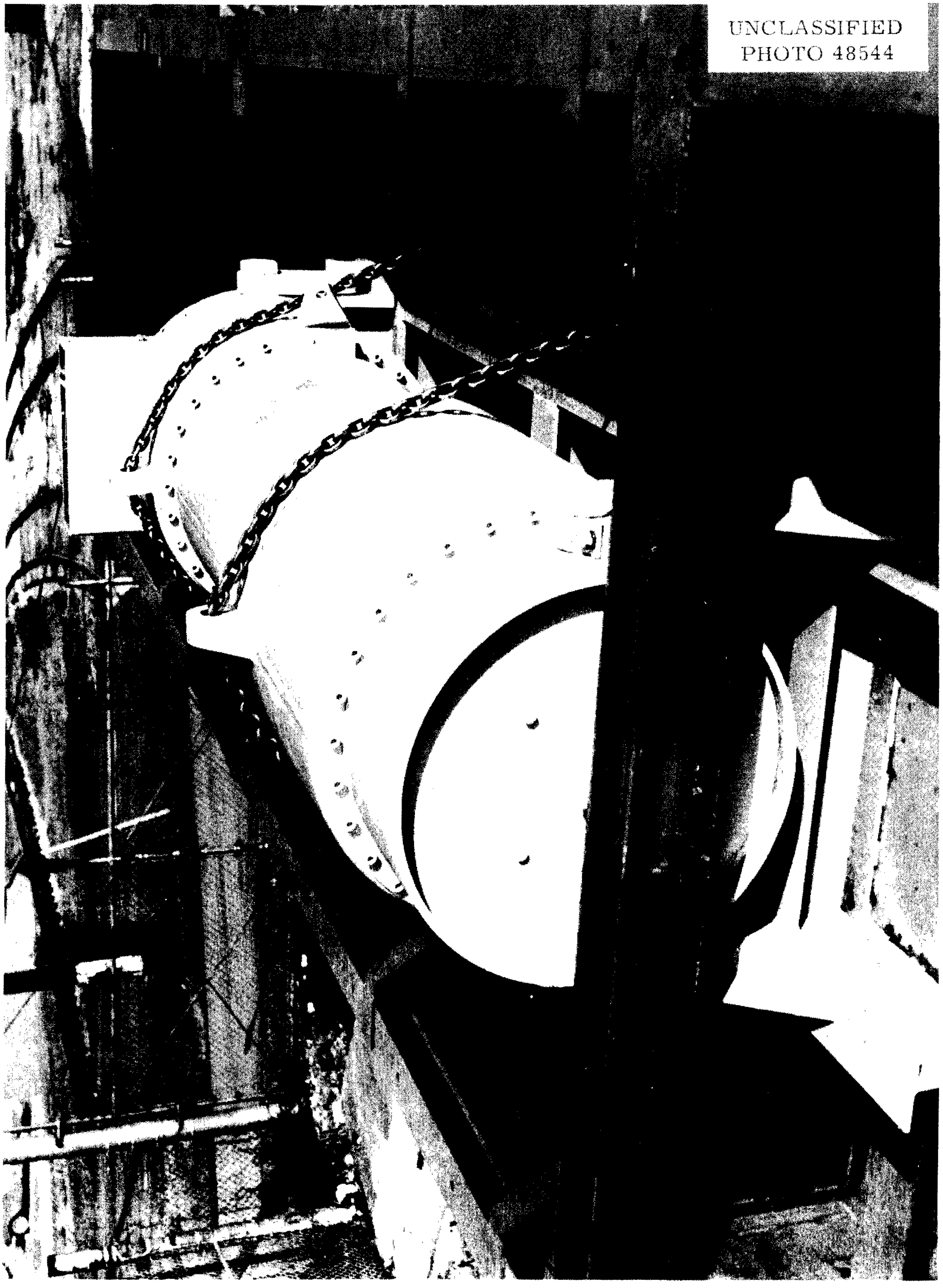

FIGURE 21

smaller charger carrier is used to load the fuel into the SRE carrier when it is placed in a vertical position. This carrier is different from others described later in that the loading and unloading of the carrier is done in air external to a hot cell. Supplementary shadow shielding is used during loading and unloading operations.

The AEC is currently investigating the costs of rail freight versus truck shipment for the SRE carrier. The trucking companies are interested in the business of handling fuel shipments and already have submitted an attractive proposal. Motor freight has several advantages over the rail freight shipment in that the carrier can be delivered directly to the processing facility as well as to the reactor site without the necessity of additional transfer operations as would be necessary in rail shipments. The chance of damage to the fuel enroute is also lessened due to the slower speeds imposed on motor freight shipments. A maximum speed of 35 miles per hour will be enforced owing to various state regulations for handling shipments of this weight. Special permits have already been approved. The severity of an accident may be greater in motor freight shipments owing to the possibility of an accident occurring in a more populated area.

Universal Carriers

Reactor operators have already contacted industry to determine their interest in supplying the casks for shipment of the reactor fuels. A number of companies in this country are interested in performing the service and have submitted proposals to reactor operators. These companies are looking at the problem from a standpoint of developing a universal carrier suitable for a variety of fuel elements. If this goal can be reached, considerable savings will be effected for the nuclear fuel cycle. It is interesting to note even on this basis the cost of transportation amounts to approximately 6% of the total fuel cycle costs based on irradiation levels of 2000 mwd/t; with a higher radiation level up to as high as 14,000 mwd/t, transportation might be reduced to as low as 3%.

To illustrate concepts typical of the thinking of several interested companies, the following information has been taken from a paper[7] presented at the Fuel Transportation Committee Meeting, December 2-3, 1958. Figure 22 shows an over-all view of a universal shipping cask with a cutaway showing the various components. This particular configuration was designed to handle 16 Dresden Station fuel elements. The cask design was made sectional to allow a void height variation from three feet to thirteen feet in one-foot increments. The cask consists of a stainless steel shell with lead shielding and containing cooling coils. The coils in this design are to be connected with a Freon type refrigeration system located on a special car. Figure 23 shows a view of another cask size. The center section of the unit is made in 1, 2, and 3-ft sizes. Thermocouples are located on the inside and outside surfaces of the cask to monitor cask temperature during shipment. Figure 24 shows a typical pressurized liner fuel element separator. The lid is sealed with a cantilevered

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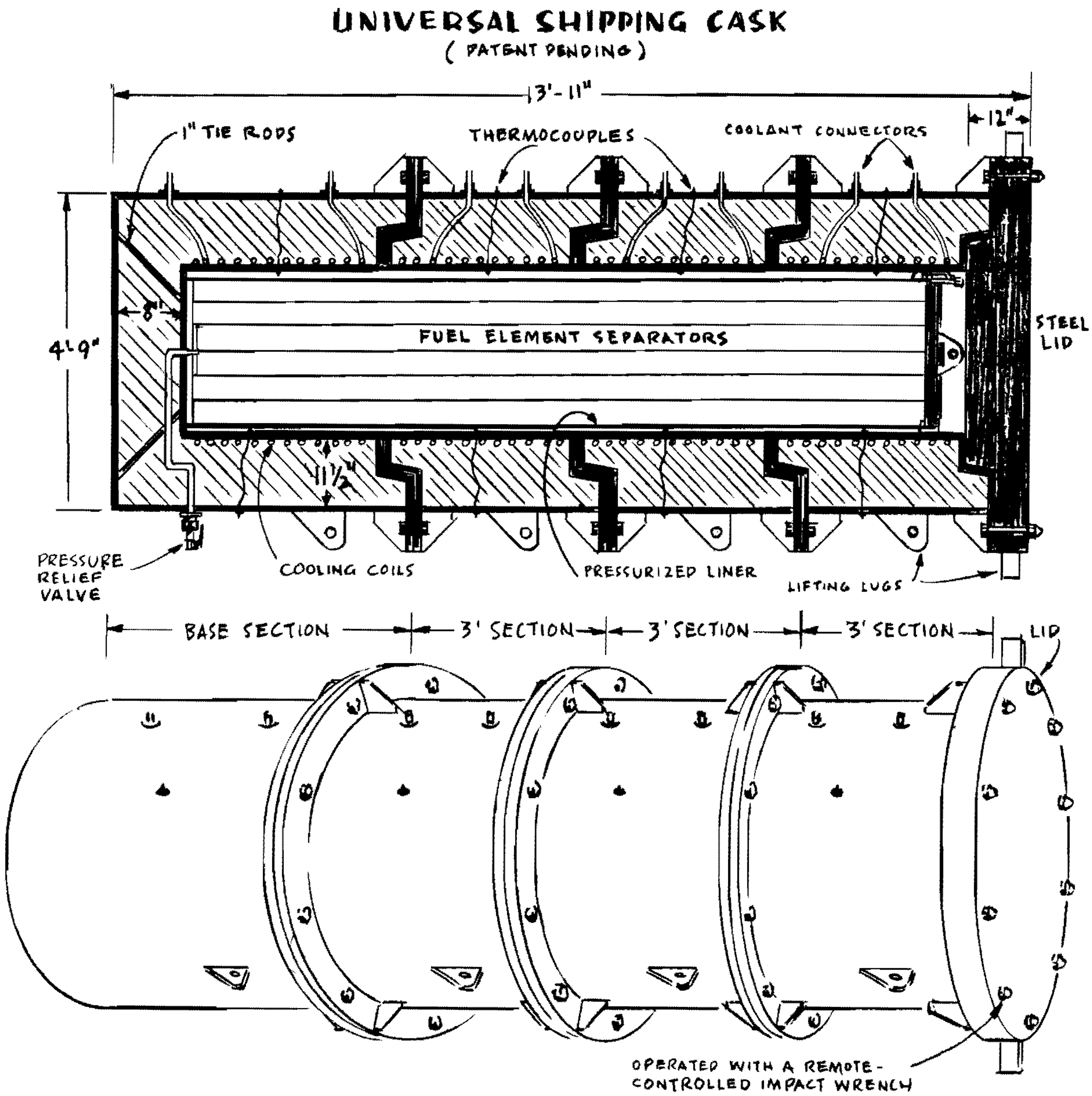

CASK WEIGHT VS SIZE

SHIPPING CASK SIZE (VOID HEIGHT)	WEIGHT (TONS)	SHIPPING CASK SIZE (VOID HEIGHT)	WEIGHT (TONS)
3'	28.4	9'	57.8
4'	34.5	10'	63.9
5'	38.8	11'	68.2
6'	43.1	12'	72.5
7'	49.2	13'	78.6
8'	53.5	14'	82.9

NOTE: OVERALL CASK HEIGHT = VOID HEIGHT + 2 FEET

Figure 22

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