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A STUDY OF MODIFICATIONS FOR ORNL LIQUID WASTE SYSTEM

I. HIGH-LEVEL STORAGE TANKS AND INTERMEDIATE-LEVEL EVAPORATOR

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ABSTRACT

As a means of reducing the quantity of radioactivity released to the environment by radioactive liquid waste discharges at ORNL, it is proposed that two 50,000-gal stainless steel storage tanks and a 600 gph stainless steel, submerged-coil evaporator be installed in the existing excavation for 2527 Building. The tanks, approximately 10 ft in diameter by 85 ft long, will be equipped with cooling coils attached to their outside surfaces for removal of a maximum of 300,000 Btu/hr of decay heat, and will be supported inside a concrete vault for containment. The evaporator and a feed tank will be installed inside a cell shielded with 5 ft of concrete and will process mainly intermediate-level waste from the concrete tank farm, but will be able to evaporate high-level waste as well, if required. Two additional cells for the condenser and other off-gas equipment will be housed with the evaporator cell in a building with an operating area and sampling gallery. The capital cost of this installation is estimated to be $1,226,000.

1.0 INTRODUCTION

A study of the existing ORNL liquid radioactive waste system was undertaken with the objective of determining how the system should best be modified to reduce the quantity of radioactivity released to the environment while retaining the maximum flexibility consistent with safety and economy. It was postulated that this objective could best be achieved by providing new storage capacity for segregation and containment of high-level wastes, an evaporator for concentration of intermediate-level wastes, and a more efficient process than the present lime-soda treatment for decontaminating the low-level wastes. This report summarizes the considerations and bases used in the conceptual design and preliminary cost estimate of the proposed high-level storage tanks and intermediate-level evaporator. The proposed modifications of the low-level waste system are treated in a separate report.

2.0 SUMMARY

It is proposed that two 50,000-gallon stainless steel storage tanks and a 600 gph stainless steel submerged-coil evaporator be installed in the existing excavation for 2527 Building. The tanks, for containment of acidic high-level waste solutions from the Laboratory's hot processing areas, would have dimensions approximately 10 ft in diameter by 85 ft long and will be contained inside a concrete vault. The alternate of neutralizing the wastes and storing in mild steel tanks was rejected because the larger storage volumes and more complex cooling system required for alkaline storage nullified the cost advantage of mild steel.

The high-level waste solutions will be collected from Buildings 3517 and 3019 in existing tanks S-324 and W-19 or W-20, sampled, and routed either directly to the high-level waste tanks or to the evaporator feed tank for concentration before storage. A maximum of 300,000 Btu/hr of decay heat can be removed from each storage tank by water cooling coils attached to their outside surfaces. Air spargers will be provided for agitation and radiolytic hydrogen dilution, and provisions will be made for access, sampling, and solution transfer between tanks. A water-cooled condenser with a heat duty of 450,000 Btu/hr will be provided in the vessel off-gas line to be used in the event of a cooling system failure. The vessel off-gas will be processed by caustic scrubbing and filtration before

release to the 3039 vessel off-gas system. The vessel off-gas equipment will be housed in a cell with inside dimensions about 8 ft x 14 ft x 13 ft deep, shielded with two feet of concrete.

The evaporator, a vessel about 10 ft in diameter by 12 ft high with internal steam coils, will serve mainly to concentrate intermediate-level alkaline wastes from the existing concrete waste tanks, but could be used to concentrate high-level wastes if the occasion demanded. This type evaporator was selected in preference to either the external tube chest or the vapor compression types because of its greater simplicity and lower capital cost. It will be installed with an evaporator feed tank in a cell 14 ft x 26 ft x 20 ft deep, shielded with 5 ft of concrete and with removable roof plugs for access. The vapor from the evaporator will be condensed, monitored, and sent to process waste. The condenser and catch tank will be installed in a cell 8 ft x 14 ft x 13 ft deep shielded with 3 ft of concrete. The condenser cooling water will be circulated to an air-cooled heat exchanger outside the shielded area for heat removal. The evaporator concentrate will be returned to the concrete tank farm for storage. The vessel off-gas will be processed in the same equipment used for the waste storage tank off-gas. The cell off-gas will be filtered before release to the 3039 cell ventilation off-gas system.

A building having dimensions 40 ft x 65 ft x 20 ft high will be constructed over the cells and will contain a 20-ton overhead crane, an operating area, and a sampling gallery.

The capital cost of this installation is estimated to be $1,226,000, and should require $133,600/year operating cost.

3.0 GENERAL CONSIDERATIONS

3.1 Flowsheet and Physical Description

A schematic flowsheet of the high and intermediate-level waste collection system is shown in Fig. 1. High-level waste is assumed to be acidic wastes containing 6-months-cooled fission products. A maximum specific activity of 2800 curies/gallon is assumed for design purposes. The high-level waste comes from Building 3517 via tank S-324 or from 3019 via tanks W-19 or W-20. It is sent to the high-level waste storage tanks, either directly or by way of the evaporator feed tank.

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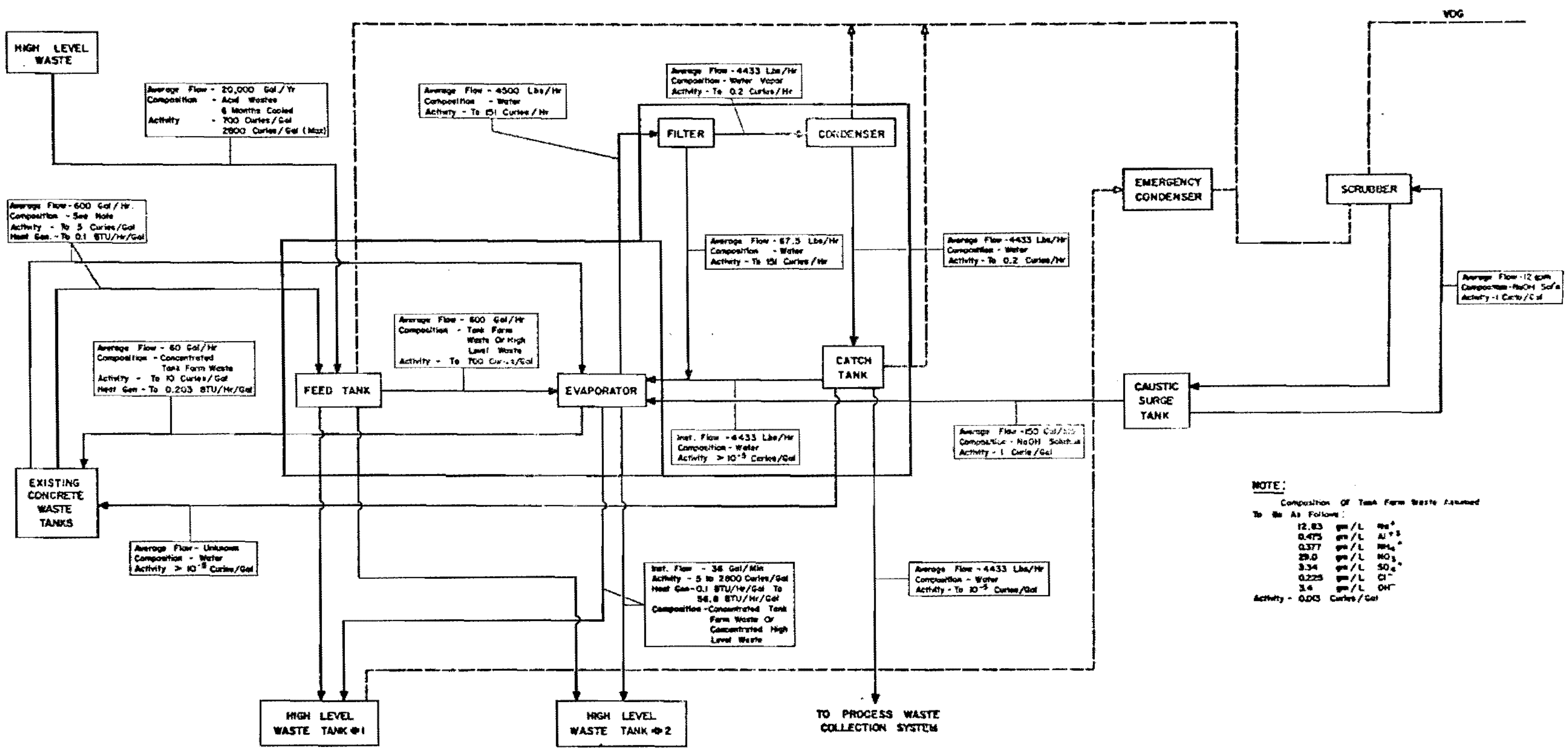

Fig 1 HIGH LEVEL WASTE FACILITY – SCHEMATIC FLOWSHEET

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Intermediate-level waste (which is defined as being waste with a specific activity of between 10 and 10^{-5} curies/gallon) comes from the existing concrete waste tanks and is fed to the evaporator, either directly or through the evaporator feed tank. The concentrated bottoms are returned to the concrete storage tanks; the overhead vapor is condensed, monitored, and discharged to process waste. If the specific activity of the condensate is too high, the condensate can be sent back to the evaporator.

A plot plan showing the proposed location of the waste collection system and the process lines connecting this system to other points of the laboratory waste system is shown in Fig. 2.

Major service requirements are for 5700 lb/hr of steam for the evaporator and about 25 gallons/min of cooling water to each of the waste tanks. The cooling water requirement could be as high as 100 gal/min if wastes of the maximum specific activity were stored.

The shielding requirement for the evaporator cell has been calculated to be 5 ft of concrete. This calculation is based on the assumption that the tank is filled over a 2-1/2-year period with waste solution with an original specific activity of 2800 curies/gal. The shielding requirement for the condenser cell has been calculated to be 3 ft of concrete, based on the assumption that 10% of the Ru^{106} in the evaporator volatilizes during an evaporation. The shielding requirement for the off-gas cell has been calculated to be 2 ft of concrete, based on the assumptions of a 20 cfm off-gas flow, a carry-over of 10 mg of liquid per cubic meter of off-gas, and an emptying of the caustic scrub tank every three weeks.

A one-story change room and an operating area 16 x 55 x 14 ft high will be located on the south side of the evaporator cell. A sample gallery 12 x 25 x 9 ft high will be located on the north side. The cells will have roof slabs opening under a containment cover 18 ft high. This area will be provided with a 20-ton gantry crane for removing roof slabs and equipment. An air-cooled heat exchanger for the closed-cycle cooling water will be located south of the building.

Layouts of the waste collection system are shown in Figs. 3, 4, and 5.

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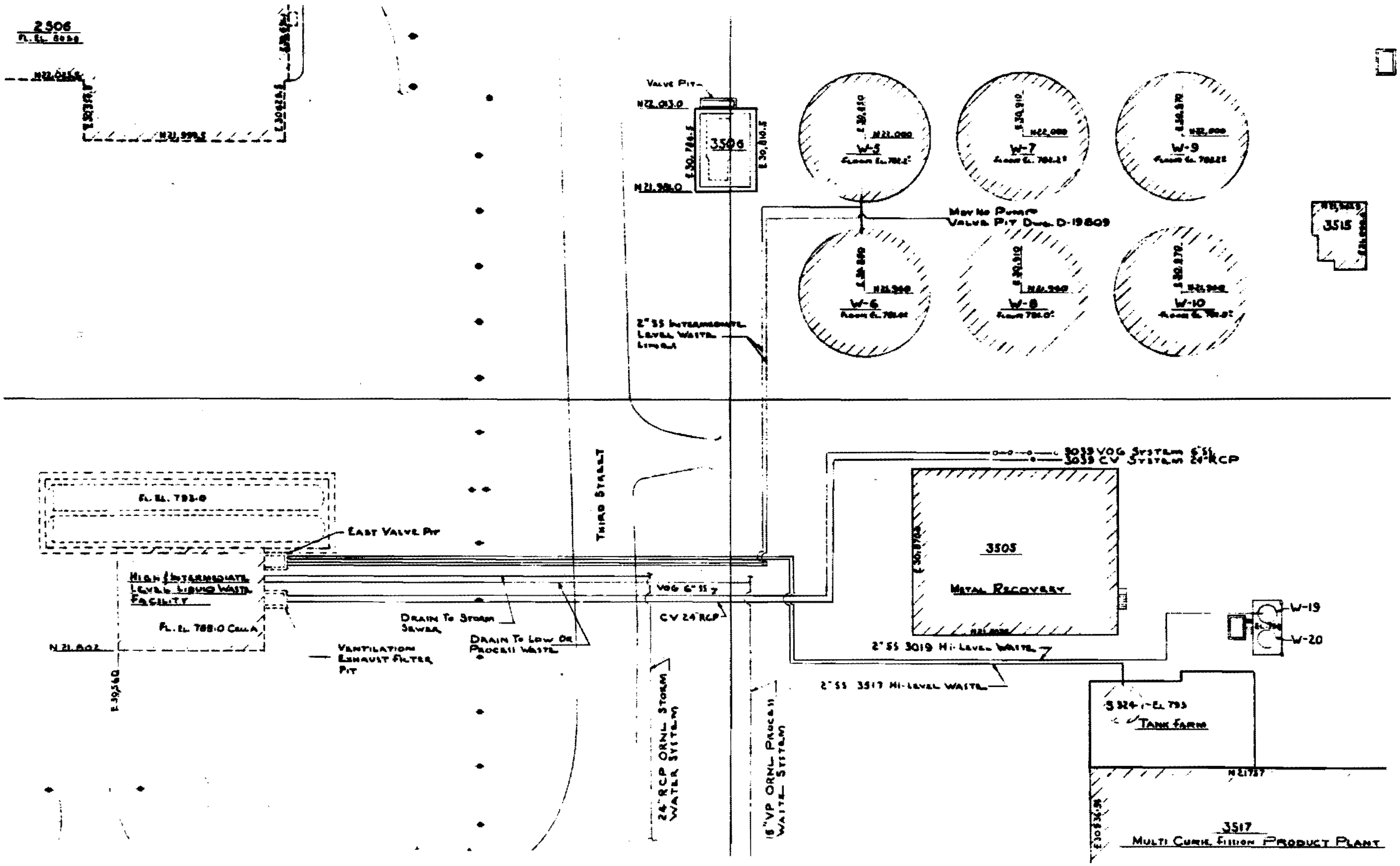

Fig. 2. Site Location of High and Intermediate Level Waste Facility.

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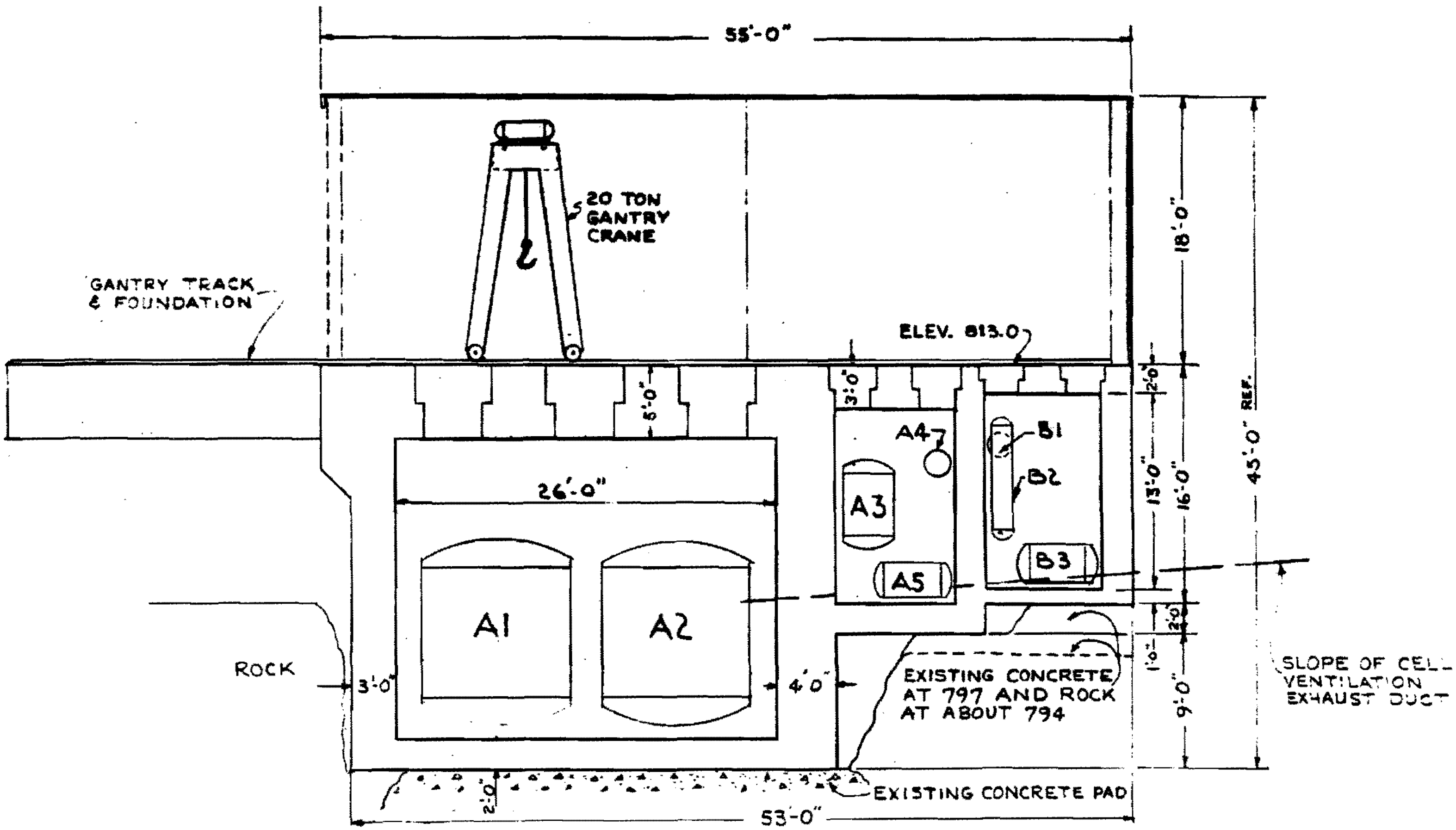

Fig. 3. Cross-section and elevation of evaporator, condenser, and off-gas cells.

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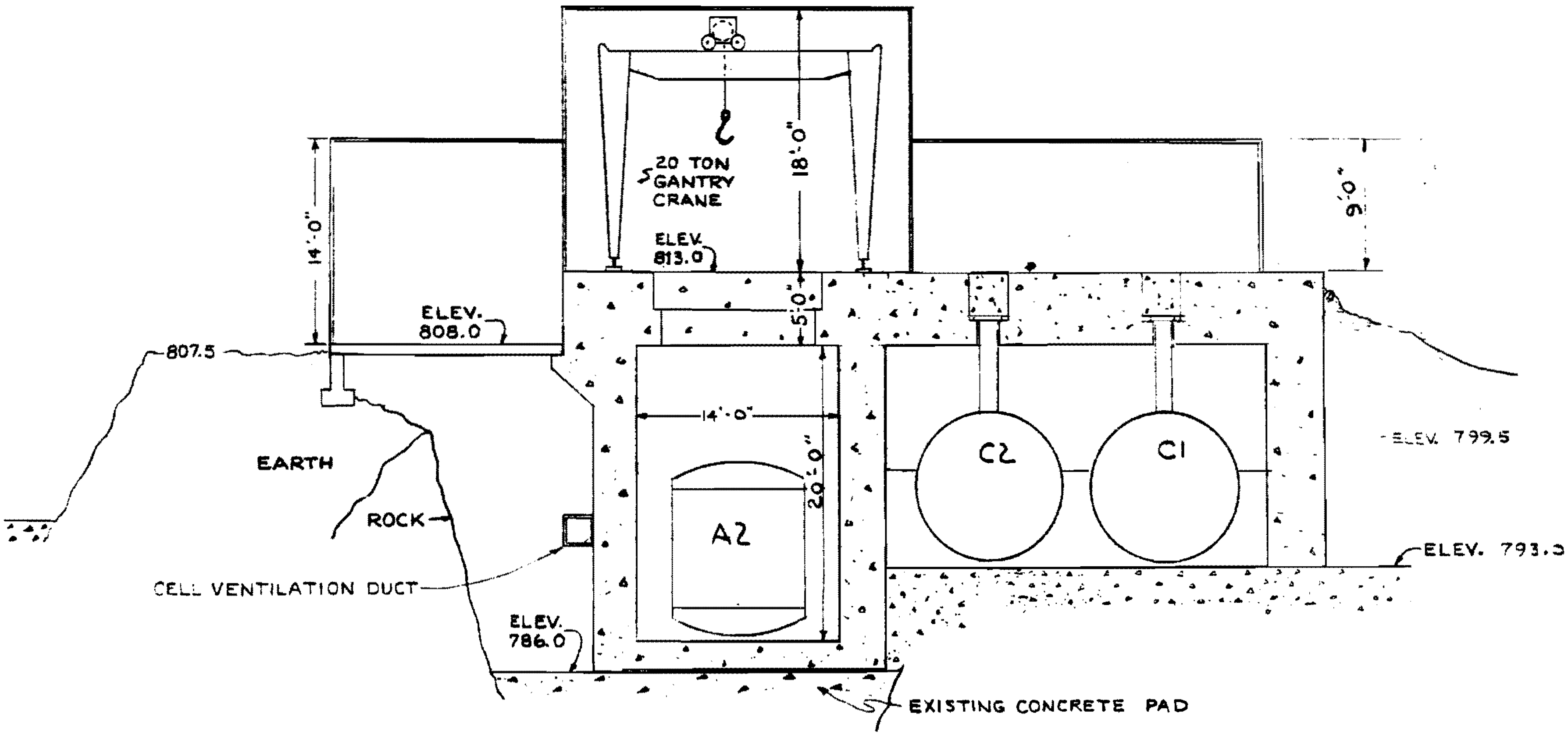

Fig. 4. Cross-section and elevation of evaporator and storage tank cells.

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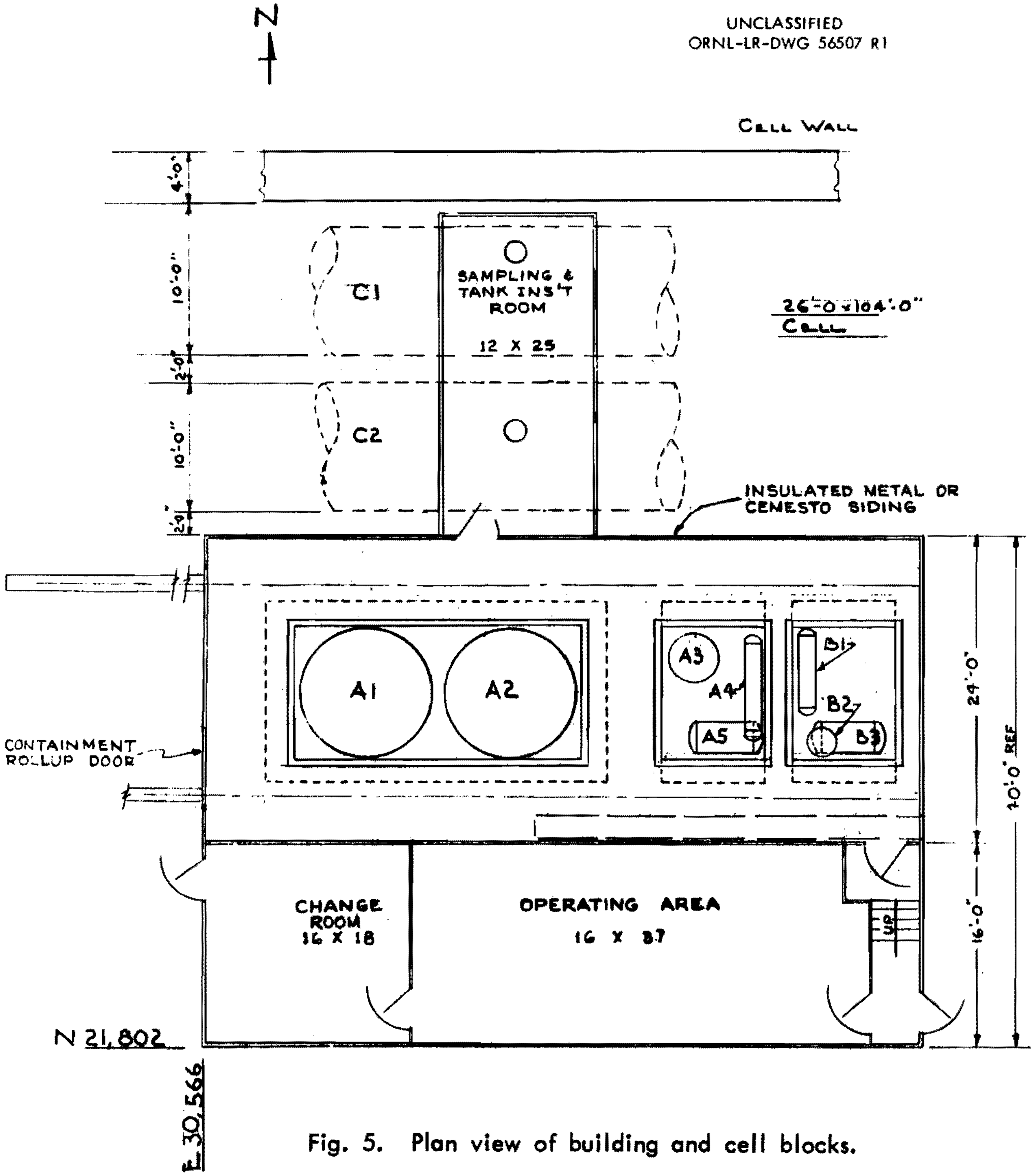

Fig. 5. Plan view of building and cell blocks.

3.2 High-Level Tankage

Since it is not possible to predict with assurance either the characteristics or rate of production of future high-level wastes at the Laboratory, decisions on such matters as tank capacity, material of construction, and cooling requirements must be based primarily on general considerations. It is expected that these wastes will be in the form of nitric acid solutions and can contain a thousand or more curies of mixed fission products, or the equivalent, per gallon. Existing concrete tanks are limited to storage of only very modest amounts of activity because of their poor thermal characteristics. Jury[1] has estimated that these tanks can effectively dissipate by conduction about 17,000 Btu/hr/tank when all six tanks are full and their contents at their boiling point. This is equivalent to 0.1 Btu/hr/gal, or about 10 curies/gal of mixed fission products. The new tankage must contain all wastes of higher radiation levels than this.

A decision of how much storage capacity to install based on predicted requirements at ORNL is difficult to make at present, but a choice based on an economic analysis of capacity vs cost per gallon provides a sound basis for selecting the minimum size tank that should be built. It was decided that two tanks should be installed to provide one empty standby at all times. Figure 6 shows the variation in the unit cost of installed stainless steel tanks in $/gal, with total tank capacity over the range 15,000 to 100,000 gallons. Although the curve does not pass through a minimum, it is apparent that the region of greatest economy is that for tanks of 50,000 gal capacity and greater. This can be seen even more clearly from a plot of the slope of this curve against capacity (Fig. 7). It was concluded that two tanks of 50,000 gallons capacity each were the smallest that could be built and yet be economically justified. A summary of the cost factors used in this analysis is given in the Appendix, Table A-1.

Stainless steel (type 304L) has been specified as the material of construction for the waste tanks. The alternative of using mild steel tanks and neutralizing the wastes before storage was considered but decided against. Neutralization of the wastes would result in a volume increase of about 30%; mild steel tanks would therefore need to be larger

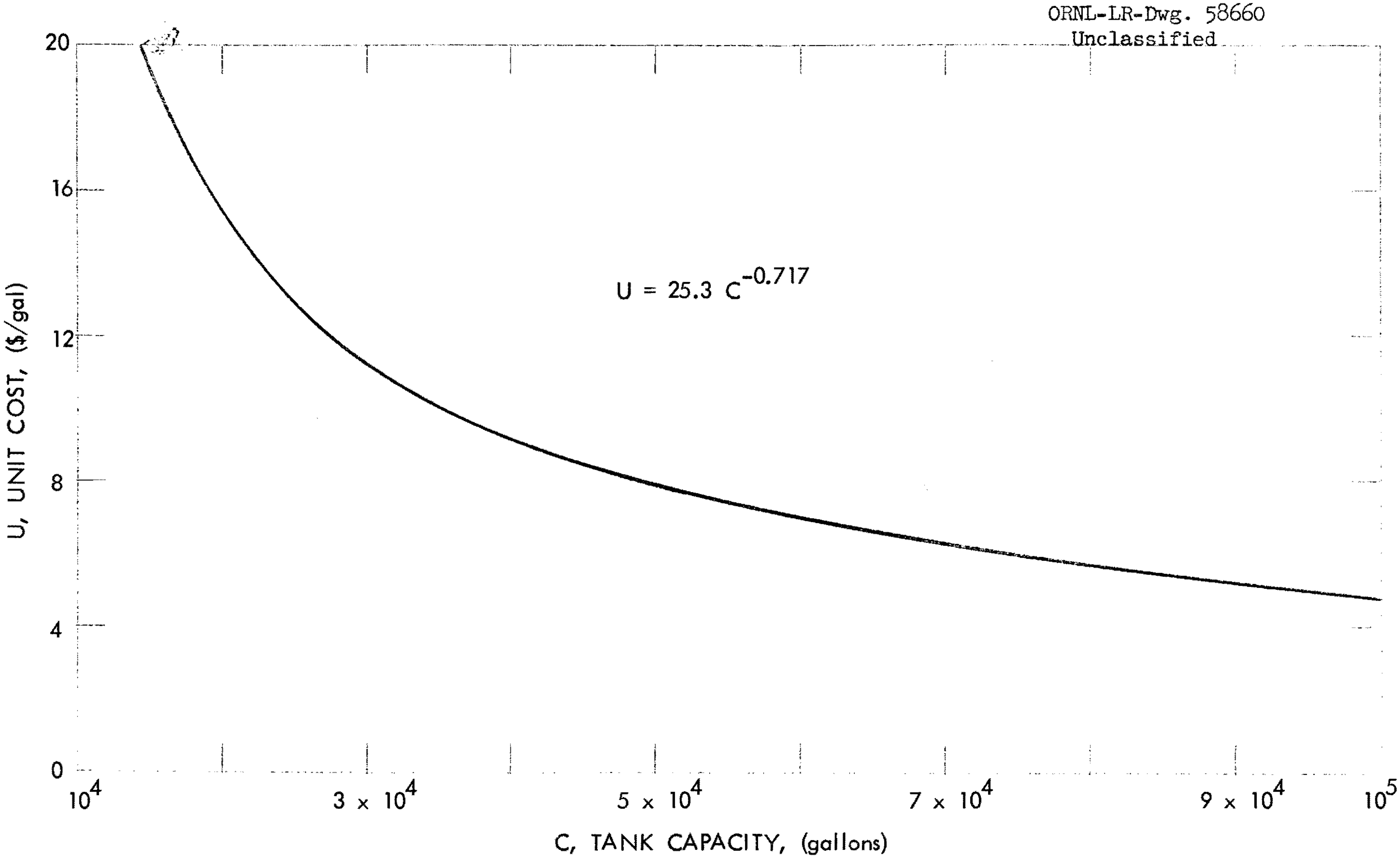

Fig. 6. Variation in unit storage cost with capacity for installed stainless steel tankage.

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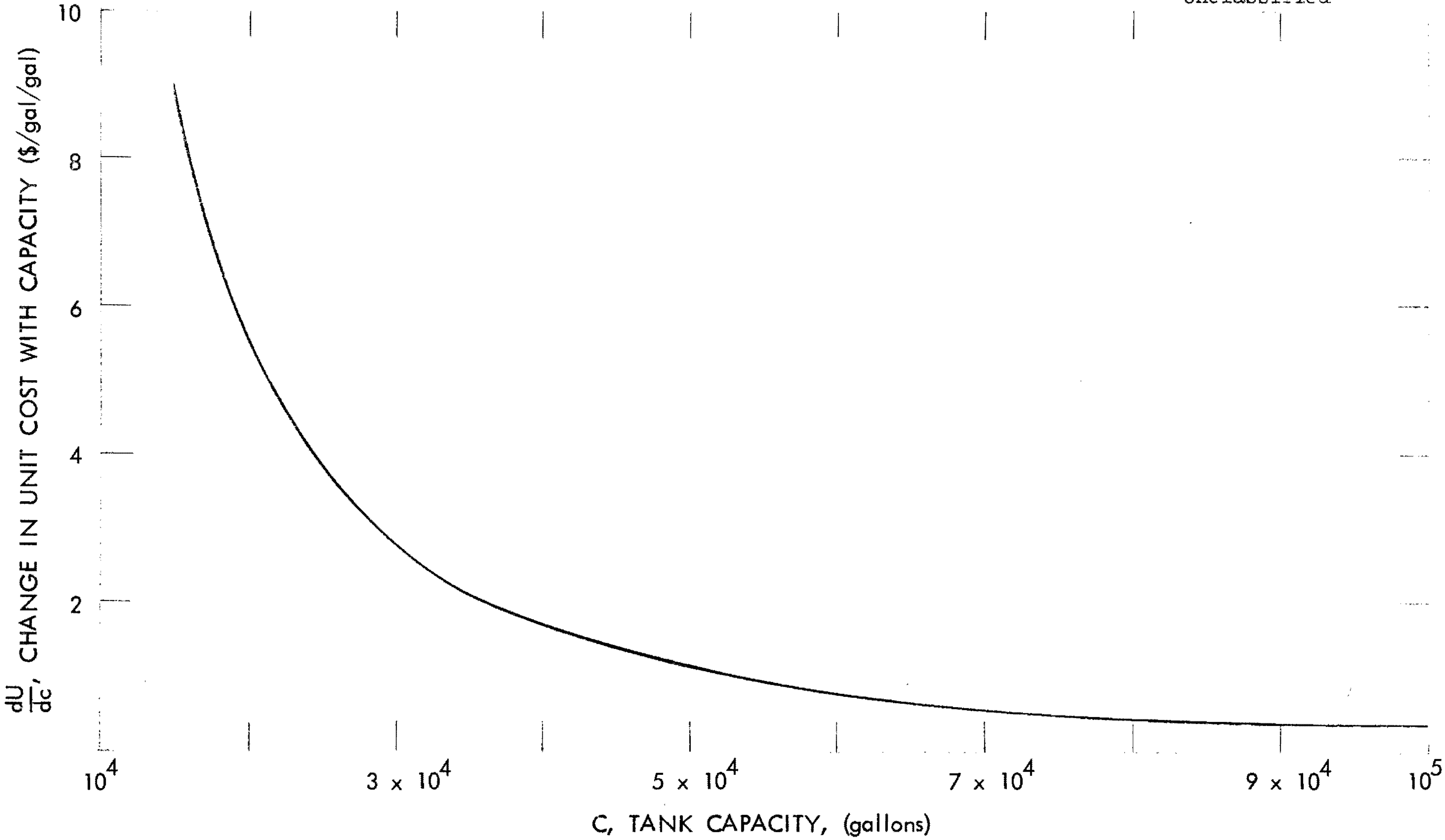

Fig. 7. Change in unit cost with capacity for various tank capacities.

to handle the same quantity of waste as stainless steel tanks. Also, neutralization of the wastes would result in the formation of considerable quantities of sludge, thereby complicating the problem of keeping the wastes cool. If mild steel tanks were used, therefore, either a much more elaborate cooling system would have to be installed or the use of the waste tank facility would have to be restricted to wastes of a lower specific activity. It was concluded that the cost of the required additional capacity and the more complex cooling system would nullify the cost advantage of mild steel.

Three different design configurations were considered for the waste tanks: (1) vertical cylinders with an approximate diameter of 30 ft and a straight side height of 10 ft encased in a concrete vault, (2) horizontal cylinders with an approximate diameter of 10 ft and a length of 85 ft encased in a concrete vault, (3) horizontal cylinders with concentric stainless steel containment jackets and earth shielding. These configurations are shown in Fig. 8. A preliminary cost estimate gave costs of $276,000, $243,000 and $268,000, respectively. The use of mounded earth can reduce the thickness of side shielding required for configurations (1) and (2) and reduce these costs. A breakdown in these estimates is given in the Appendix, Table A-2. The configuration of horizontal cylinders in a concrete vault was chosen for this design on the basis of these estimates and other considerations. First, the horizontal tanks can be shop-fabricated, which in construction for this hazardous service is a definite advantage. Also, the waste solution can be more easily cooled in the horizontal tanks than in the vertical tanks because of their greater surface-to-volume ratio. Finally, the total vertical height of the horizontal tanks is somewhat less than the equivalent dimension of the vertical tanks, thereby easing the shielding problem somewhat.

3.3 Evaporator

The evaporator will have a design capacity of 600 gal/hr and will be operated on a semi-batch basis. The main use of the evaporator will be to concentrate intermediate-level wastes that are currently being collected at the concrete tank farm and subsequently being released to the waste disposal trenches. These wastes will have a specific activity of between 5 curies/gal and 10^{-5} curies/gal. The chemical composition will vary but

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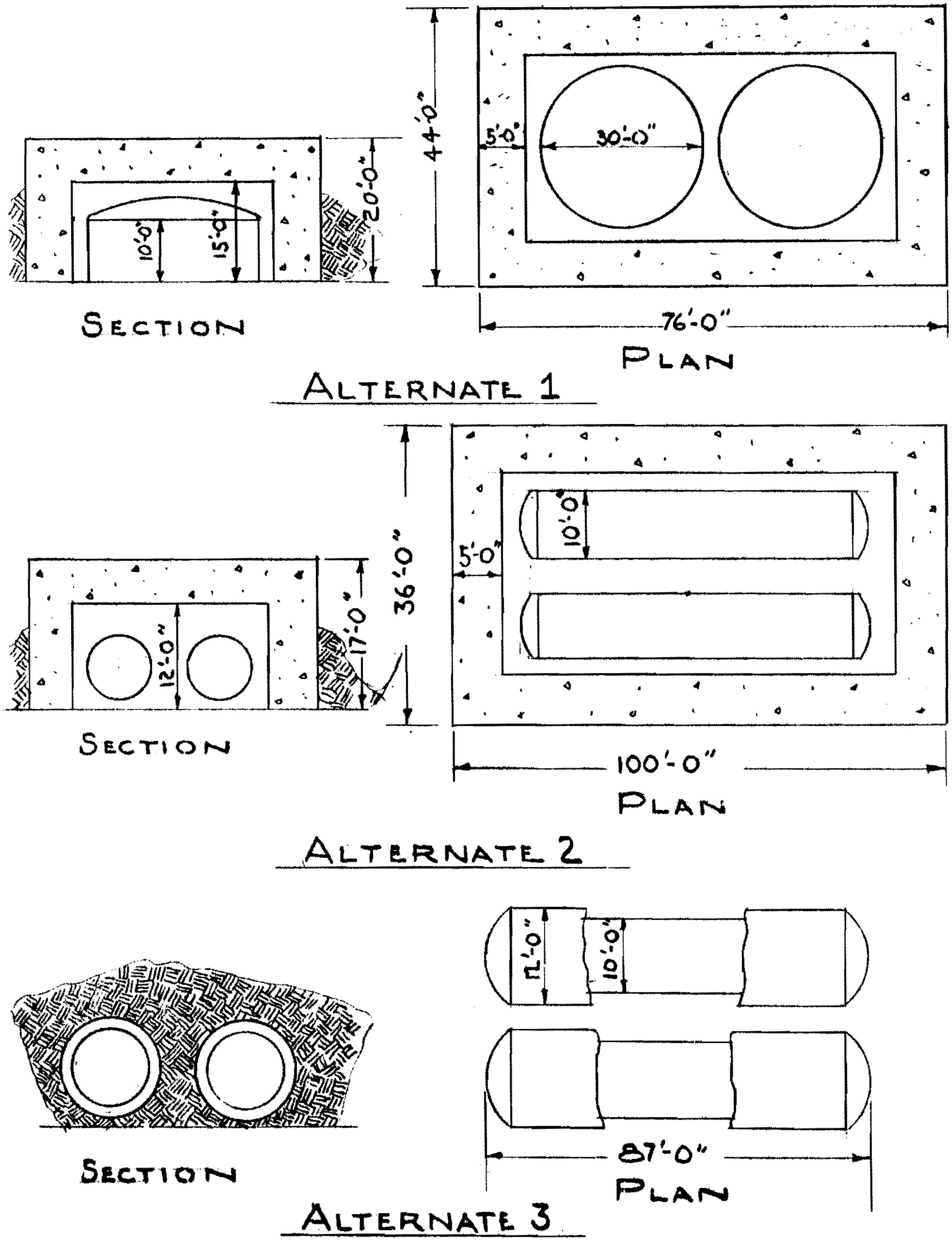

FIG.8 ALTERNATE WASTE TANK DESIGNS

is expected to be approximately 0.3 M $NaNO_3$, 0.2 M NaOH solution. High-level acidic waste solutions can also be concentrated in the evaporator up to 2800 curies/gal.

Laboratory boil-down tests have been made on both actual and synthetic waste solutions. The tests on the actual waste solution indicated that a volume reduction of 40 to 1 was obtainable. The tests on the synthetic waste solution indicated that a volume reduction of 20 to 1 could be achieved, but that large quantities of solids would precipitate when the solution was cooled; a volume reduction of 16 to 1 was recommended.[2] At this concentration the specific gravity of the solution is 1.45, the boiling point is 234°F. The physical properties of this solution measured over a range of concentrations is given in the Appendix.

Since previous experience with this stream using the original ORNL waste evaporator showed that foaming was, at times, a severe problem,[3] a study was made by an MIT Practice School group on the relative suitability of two types of evaporators for use on intermediate-level wastes. An evaporator with an internal coil and an evaporator with an external steam chest were the two types tested. A synthetic solution approximating the average analysis of the waste solution was used for the evaporator feed. A volume reduction of 17 was achieved with the external steam chest type in an extended run with no indication that a further volume reduction would not be possible. The over-all heat transfer coefficient declined by 60% during the course of the run. Over-all heat transfer coefficients with the internal coils were about twice those with the external tube chest. No foaming or scaling was observed with either evaporator type.

Approximate evaporator prices were obtained from fabricators for three types of evaporators: a vapor compression evaporator, a natural circulation evaporator with an external tube bundle, and a natural circulation evaporator with an internal steam chest. The capacity in each case was about 400 gal/hr. The estimated costs were $77,000 for the vapor compression evaporator, $22,500 for the evaporator with the external tube bundle, and $9,000 for the evaporator with the internal steam chest. For concentrating solutions with a high boiling point rise, a vapor compression evaporator must either have an oversize compressor or be limited in the concentration obtainable. This factor and the high cost of the vapor compressor type of evaporator led to the dropping of this type from consideration. The chief advantage of the evaporator with the external tube bundle is the greater accessibility of the heating surface for descaling. This advantage is a dubious one for this application, however, since mechanical descaling would hardly be attemped on an evaporator handling highly radioactive solutions and since scaling does not seem to be a major problem with intermediate-level wastes anyway. For these reasons, this type of evaporator was not considered further. The evaporator with the internal steam chest suffers from the disadvantage - shared with the other two types - that the many welds required in the tube sheet will offer many opportunities for leaks to develop, and a single major leak will necessitate the replacement of the evaporator. For this reason the evaporator with an internal steam chest was dropped from consideration in favor of an evaporator with several submerged coils. This type of evaporator would have a greater freedom from leaks than the other types considered and should be little if any more expensive than the internal steam chest type. The cost is estimated to be in the $8,000-$12,000 range.

4.0 WASTE TANK DETAILS

4.1 Cooling

Because the corrosion of stainless steel by acidic waste solutions is an order of magnitude less rapid at environmental temperatures than it is near its boiling point (several hundredths of a mil/month vs several tenths of a mil/month), it will be necessary to cool the tanks to maintain the walls at or below 130°F. The primary cooling system will consist of a set of stainless steel coils welded to the outside of the tank. The secondary system will consist of a set of titanium coils inside the tank and a standby condenser for emergency use if the primary system for either tank should fail.

The expected maximum heat load of 116,000 Btu/hr occurs when the waste tank is filled with waste with a specific activity of 700 curies/gal when charged. This heat load can easily be removed with the external cooling system only. At higher heat loads (up to about 400,000 Btu/hr) the external cooling system will continue to keep the walls of the tank below 130°F. Heat transfer in the sludge at the bottom of the tank is poor, however, and at these larger heat loads the heat generated in the sludge will not transfer to the walls rapidly enough to prevent local overheating in the sludge. When this overheating becomes severe enough, bumping and spattering of the wastes will result. The function of the internal cooling coil is to remove the excess heat generated in the sludge, thereby preventing bumping and spattering. Calculations indicate that with both the internal and external cooling coils in use a maximum heat load of 480,000 Btu/hr can be handled.

The primary cooling system will consist of lengths of 1-1/2 in. pipe welded to the outside of the tank. Because the pipes carrying the cooling water do not come in direct contact with the waste solution no possibility of contamination exists and a closed cycle cooling water system will not be necessary for containment. The cooling water pipes should be attached at approximately 12-in. intervals on the bottom of the tank where the heat load would be high because of precipitated fission products and heat transfer would be inhibited by any sludge that would be present. Along the sides of the tank the pipes could be spaced at 18-in. intervals. A total of 19 lengths of pipe (~1900 ft) would be required, 9 lengths on the bottom and 5 on each side (see Fig. 9).

The internal coils will consist of a staggered arrangement of 1-1/2-in. pipes at about 1 ft from the bottom of the tank and 1 ft apart. A total pipe length of about 650 ft is required. A maximum of about 80,000 Btu/hr of heat could be removed from a layer of sludge by these coils. Since these coils will not be needed unless unexpectedly high heat loads are encountered, the coil will not be initially connected to a source of cooling water; the ends of the coils will be brought outside the tank and capped off.

Failure of the cooling water service will lead to a temperature rise in the waste tank of at most $1^{\circ}F/hr$ for a heat load of 480,000 Btu/hr. The actual rate of temperature rise will be reduced considerably by the amount of heat removed with the cell off-gas; at least four days and probably many more will be required for the tank contents to reach the boiling point. Should boiling occur before the cooling water system has been repaired, the vapors generated will be condensed in a stand-by reflux condenser and returned to the waste tank.

Some consideration was given to an alternate cooling system using pentane. In this system several jacket segments or "blisters" would be welded to the outside of the waste tank. These blisters would be connected

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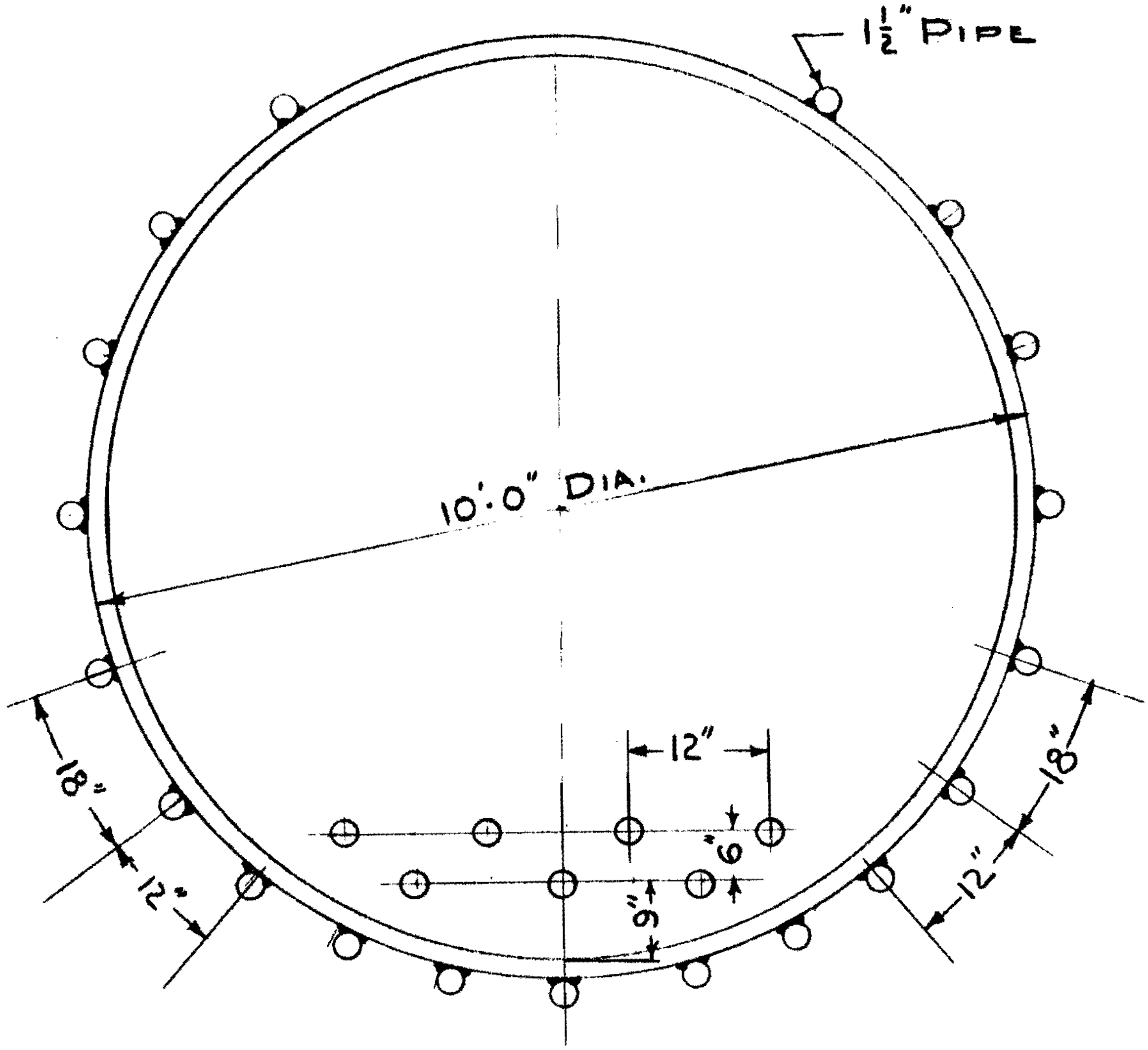

Fig. 9. Arrangement of Internal and External Cooling Coils for High Level Waste Tanks.

to air-cooled condensers above the tank and charged with pentane. Heat generated by waste solution in the tank would be dissipated to the pentane in the blisters. The pentane would boil, be condensed in the condenser above the tank, and returned to the blister. The temperature of the system would be kept at the boiling point of pentane (97°F); an increase in the quantity of heat generated would increase the pentane boilup rate, but not the temperature. The pentane in the system would be replaced periodically (once a month) to prevent by-products of pentane irradiation from accumulating. The pentane system has the advantages of high heat transfer coefficients and the ability to adjust automatically to varying heat loads. The system has not been used in any application dealing with radioactivity, however, and there was considerable reluctance to depend on an untested system for long-term service. The idea of the pentane system was accordingly dropped.

4.2 Tank Auxiliaries

Spargers will be installed in each waste tank at about 9-ft intervals for a total of about 9 spargers per tank. These spargers will be sized to handle a flow of up to 10 cfm per sparger. Under normal operating conditions there will be a flow of 2 cfm into one sparger at each end of the waste tank. This flow will be sufficient to dilute and sweep out the radiolytic hydrogen from the waste tank. The off-gas will be withdrawn from near the top of the access pipe. On those occasions when access to the waste tanks is necessary, a sweep of air down the access pipe will be required to prevent gas-borne activity from being carried out. A flow of ~100 cfm will be required. For this case, the flow will be down the pipe and out a large off-gas line located on top of the waste tank near the access pipe. On those rare occasions when thorough agitation of the contents of a waste tank is necessary (because of impending transfer of its contents) a flow of 10 cfm will be put through each sparger simultaneously. This large flow of off-gas will be withdrawn through the large off-gas line, with a small side flow through the access pipe.

Emergency access to each waste tank will be provided by a 18-in.-pipe riser from the middle of the top of each waste tank to a flange in the roof shield. A removable roof plug will be installed just above the flange. A spray head will be installed just inside the access pipe so that local contamination can be washed down just prior to opening the hatch.

Jets and piping will be installed so that waste solution can be transferred directly from one waste tank to another. Also, solution from the sump of one waste tank pit can be transferred to the other waste tank. Extra jets and nozzles will be installed on each waste tank for possible future need.

Provision will be made to sample each waste tank and the sump of the waste tank pit.

Instrumentation will include level, density, temperature, and pressure measuring devices.

5.0 EVAPORATOR DETAILS

5.1 Evaporator and Evaporator Feed Tank

The intermediate-level waste evaporator and the evaporator feed tank will occupy the same cell. The probable inside cell dimensions will be 14 ft wide, 36 ft long, and 20 ft deep. Shielding equivalent to 5 ft of concrete will be provided. A stainless steel liner will be installed on the bottom of the cell and will extend approximately 4 ft up the sides, enough to contain the contents of either the feed tank or the evaporator if a rupture should occur.

It is expected that the evaporator cell will be installed in the excavation originally intended for Building 2527. The depth of this excavation is such (~ 17 ft in spots) that the evaporator cell will be mostly underground; the bottom of the roof plugs will be about ground level. These roof plugs will be removable to allow access to the cell for major repairs.

The feed tank will be approximately 10 ft in diameter by 12 ft high with a 6000-gallon operating capacity. It will serve both as a feed tank for the evaporator and as a diversion tank for distributing the high-level waste solution between the two waste tanks. Since collection tanks for high-level waste solutions are already in existence, transfers to the high-level waste system can be made in large batches with long intervals between batches. These transfers can be made while the evaporator is shut down between runs; hence there should be little conflict between the two functions that the evaporator feed tank is designed to accomplish. Transfer from the feed tank will be by means of steam jets.

A coil will be welded to the outside of the feed tank so that the temperature of the waste solution in the tank can be kept suitably low (~120°F) and so the tank can be heated for decontamination. With the coils welded to the outside of the tank a leak in a coil will not provide a path for the escape of waste solution outside the cell; hence no secondary cooling system will be needed. Ninety-thousand Btu/hr is the probable maximum heat level that will have to be removed from the tank. Horizontal coils of 1-1/2-in. pipes spaced at 18-in. intervals will suffice.

A sparger will be installed to permit agitation of the tank prior to sampling or emptying. An air flow rate of 25 cfm will provide good agitation. The system will be sized to handle this flow rate although lesser flow rates will probably be adequate for most requirements.

Instrumentation will include level and density measurements, pressure, and temperature.

Other connections to the feed tank will include a vent connection to the vessel off-gas system and an addition line for reagent addition.

The evaporator will be made of 304L stainless steel and will be about 10 ft in diameter by 12 ft high. Internal steam coils with a heat transfer area of about 600 sq ft will be used, and a steam coil will be provided in the vapor phase to break foam. The evaporator will be operated on a semi-batch basis. At the beginning of a run the evaporator will be charged with about 2200 gallons of waste solution from the concrete tanks. During the run fresh waste solution will be added at the same rate as vapor is withdrawn overhead. The solution in the bottom of the evaporator will therefore gradually become more concentrated until the point is reached at which further concentration is no longer feasible, probably at a concentration factor of between 10-to-1 to 15-to-1. At this point the evaporator will be shut down and the concentrated waste solution will be cooled and then transferred either back to the concrete waste tanks (if the specific activity is less than 5 curies/gal) or to either of the two stainless steel waste tanks (if the specific activity is greater than 5 curies/gal). The length of a run will be about 40 hours.

The concentrated evaporator bottoms will be transferred by a submerged steam jet. A type of jet specifically designed to handle sewage and sludge will be used. It will be necessary to cool the concentrated evaporator bottoms to about 190°F prior to jetting; this will be done by circulating cooling water through the steam coils. There will be no bottom opening to the evaporator. The evaporator will not be designed for the removal and replacement of a coil in the event of a leak. There will be six separate coils provided so that in the event of a leak in one coil that particular coil can be shut off without seriously reducing the capacity of the evaporator. If further leaks develop and other coils must be shut off, the entire evaporator vessel will be replaced.

A sparger will be installed to permit agitation of the tank prior to sampling or emptying. An air flow rate of 25 cfm will provide good agitation; the system will be sized to handle this flow rate although lesser flow rates will probably be adequate for most requirements.

The evaporator heat load will be approximately 6,000,000 Btu/hr.

Instrumentattion will include level and density measurements, pressure and temperature. A device to indicate foam level will also be installed; this device will probably be a multi-point conductivity probe, since such a device has worked well in the past.

5.2 Foam Breaker

As a means of control of foaming in the evaporator, should it occur, a high-pressure steam coil will be provided within the vapor space above the boiling liquid. It is expected that this coil will be composed of approximately 80 ft of 1-in. pipe bent in the form of a spiral (Fig. 10).

5.3 De-entrainer

The function of the de-entrainer is to remove the large entrained liquid droplets, thereby reducing the quantity of radioactive particles that reach the filter and simplifying maintenance on the filter and related equipment.

The de-entrainer will be mounted just above the evaporator and will be of the impingement type (Fig. 11, Ref. 5). Vapor leaving the evaporator will undergo two abrupt changes of direction at high velocity; this will remove entrained particles that are larger in diameter than about 6 microns. The de-entrainer will be about 36 inches in diameter. The expected pressure drop will be 5 inches of water.

5.4 Filter

The function of the filter is to remove the micron and submicron sized entrained liquid droplets from the vapor stream. The filter will be mounted outside the evaporator cubicle and will consist of a thick bed of Yorkmesh made from small diameter wire. It will be similar to the filter used by

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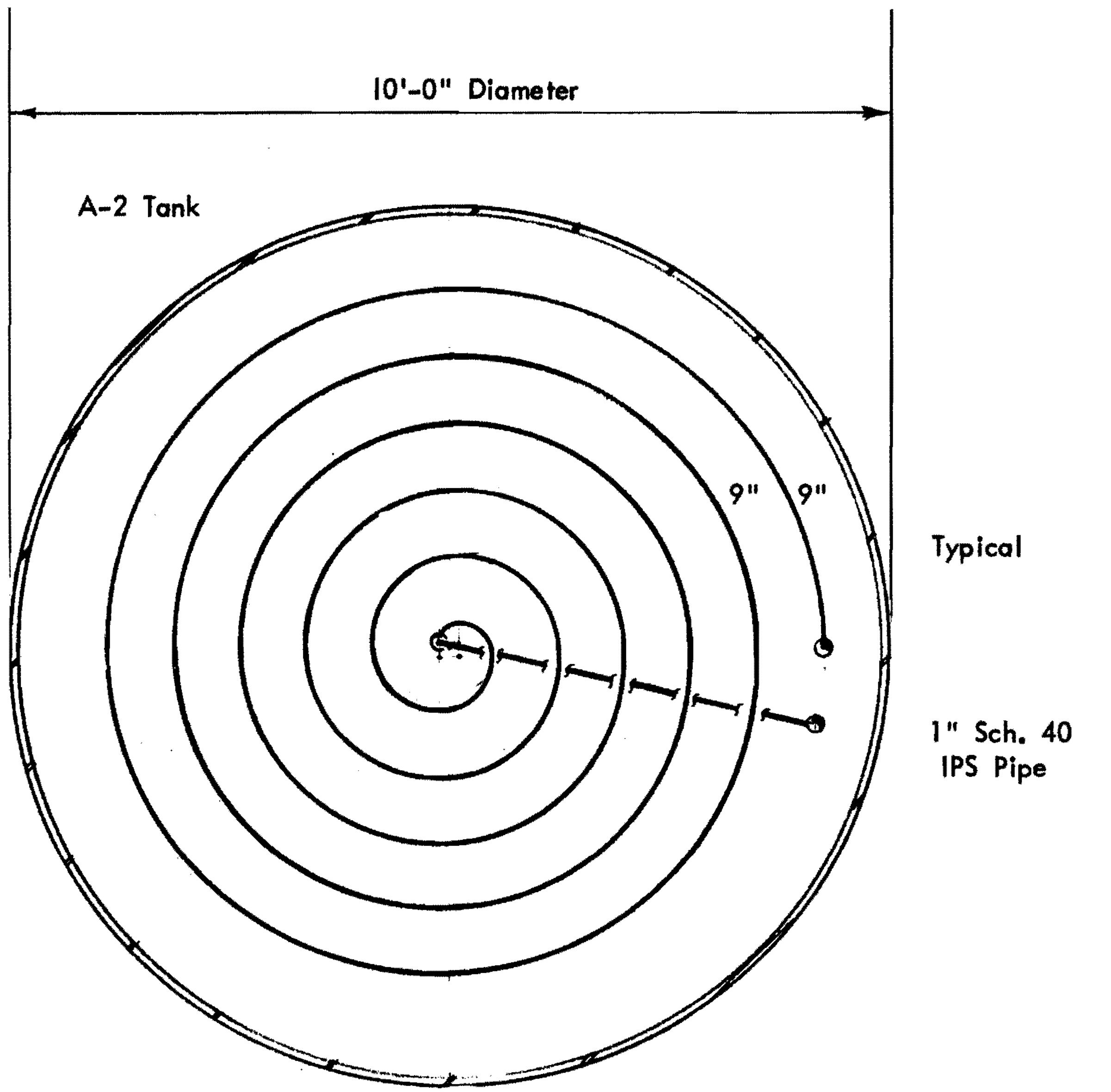

Fig. 10. Steam Coil Foam Breaker for Evaporator.

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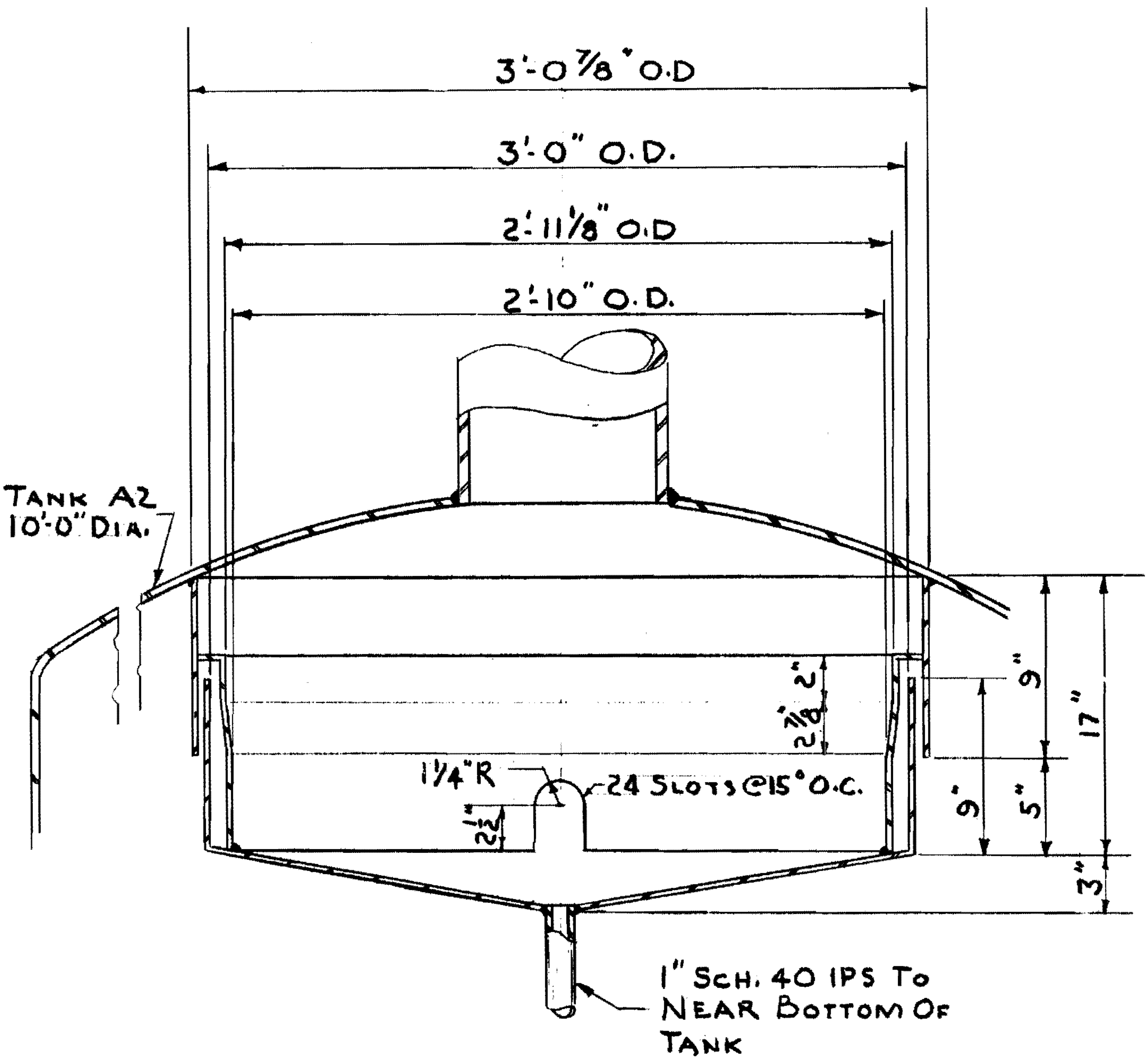

FIG. 11 IMPINGEMENT BAFFLE FOR EVAPORATOR

BNL on their low-level waste evaporator. The filter bed will be approximately 4 ft in diameter and 3 ft thick and made of stainless steel mesh. This mesh will be made of 0.0045-in. wire packed to a density of 15 lb per cu ft. From results obtained with the BNL filter, a filter decontamination factor of approximately 1000 is expected. Heat losses from the filter assembly should be great enough to condense a small fraction (1 to 2%) of the vapor flowing through it, thereby providing a continuous washdown of the mesh and preventing any buildup of solids. The filter assembly will be designed for easy replacement of the mesh. The expected pressure drop is 15 in. of water.

5.4 Condenser

The condenser will be sized for a heat load of 5×10^6 Btu/hr. Such a heat load will require a considerable quantity of cooling water and, rather than overload the plant process water system, a recirculating cooling water system will be used. This will consist of a 700-gal surge tank, a 350-gal/min pump, with a spare, and an air-cooled heat exchanger. The heat exchanger will be approximately 12 ft x 13 ft x 10 ft high. The recirculating system will not require shielding.

5.4 Catch Tank

Condensate from the condenser will be collected in the 300-gal catch tank and from there will normally drain to the process water drain. A monitor will measure the activity of the condensate going to the catch tank and, if this activity exceeds a pre-set value (10^{-5} curies/gal) will actuate an alarm and close a valve in the process water drain line. The catch tank will then be drained back to the evaporator until the upset that caused the high condensate activity level has been corrected.

When high-level waste is being evaporated, the condensate will contain too much activity to be discharged to the process water drain even under the best of conditions (a d.f. of 10^7). In this case the condensate will be jetted to the concrete waste tanks.

6.0 OFF-GAS SYSTEM

6.1 Vessel Off-gas System

The vessel off-gas will normally consist of a 1 cfm flow from the evaporator feed tank, a 1 cfm flow from the evaporator condenser, a 1 cfm flow from the condensate catch tank, and a 4 cfm flow from each of the two waste tanks with a total pressure drop of 24 in. H_2O. The flow from the waste tanks can be much higher upon occasion--up to a maximum of 100 cfm from one tank with a ΔP of about 5 in. H_2O. The off-gas flows from these various sources will be combined and sent through a scrubber, a small heater (to reduce relative humidity and prevent condensation in the filter), and a 100% RH absolute filter or equivalent efficiency deep-bed Hanford-type filter, and discharged into the plant off-gas system.

The condenser will be sized to condense all vapor from a waste tank should a failure of the cooling system occur and the tank contents boil. This load is assumed to be 450,000 Btu/hr, but would probably be considerably less. With a ΔT of 50°F and a U of 100, a surface area of ~100 ft^2 will be required. Since the condenser is intended for emergency use only, it will not normally be operated.

The scrubber will consist of a packed column 7 ft high and 12 in. in diameter with a counter-current flow of caustic solution. The liquid flow rate would be ~ 10 gal/min. A liquid storage tank of about 150 gal capacity would be required.

The heater will be sized to heat the air leaving the scrubber about 5°F and thereby reduce the relative humidity to about 85%. A steam jacket on a 3-ft length of pipe will suffice.

An absolute filter capable of handling 150 scfm will be installed. In normal operation the filters will be changed before the level of activity becomes high enough to make direct maintenance infeasible. The filters will be installed behind shielding, however, in case a surge of activity should occur and the filters should become quite hot.

The vessel off-gas will be tied into the 3039 VOG system near Building 3505.

6.2 Cell Off-Gas

The cell ventilation exhaust will be sent through absolute filters preceded by AAF FG-25-50 prefilters to the off-gas header near Building 3505. The approximate flows through the various cells will be as follows: 900 cfm for the evaporator cell, 2600 cfm for the waste tank cell, 250 cfm for the condenser cell, and 250 cfm for the vessel off-gas treatment area. In general, flow will be from non-radioactive to potentially radioactive to known radioactive areas. The flows will be regulated to maintain ~3/4-in. of water negative pressure in the cells and ~0.1-in. of water in the secondary containment zone. This system will be tied in to the 3039 cell ventilation exhaust system near Building 3505.

7.0 SAMPLING

A Thorex sampler system, modified to provide mechanical movement of sample bottle, will be installed in the sample gallery. This station will include positions for fifteen sampling points of which eleven will initially be connected. The carrier loading station will be designed to transfer the sample bottles to a shielded carrier using a viewing window and ball joint manipulator.

8.0 COST ESTIMATE

The capital cost of the evaporator and storage tank installation has been estimated as follows:

Evaporator Cell and Building	$172,000
Services	24,000
Equipment	140,000
High-Level Storage Tanks w/Equipment	324,000
Off-gas System	90,000
Subtotal	$750,000
Construction Overhead	$220,000
Engineering	145,000
Contingency	111,000
Total	$1,226,000

The cost of evaporator and waste farm operation is estimated as follows:

Steam* (140,000 lbs/day, 300 days/yr)	$ 33,600
4 MY Operators	100,000
	$133,600

*Based on 80% steam efficiency, $0.80 per 1000 lbs of steam cost.

HOW:JOB:WGS/nr

8.0 REFERENCES

1. S. H. Jury, "Steady State Heat Losses from Radioactive Waste Storage Tanks in Oak Ridge National Laboratory Tank Farm," ORNL CF-60-5-40 (May 5, 1960).

2. R. R. Holcomb, "Evaporation of a Synthetic Intermediate-Level Waste," ORNL-CF-61-3-33 (March 7, 1961).

3. E. M. Shank, "ORNL Radiochemical Waste Evaporator Performance Evaluation, December, 1949 through December, 1950," ORNL-1513 (June 26, 1953).

4. J. C. McClymont, Jr., W. R. Alcorn, and J. A. Lauber, Jr., "Evaporation of Radioactive Waste Solutions," KT-530 (May 3, 1960).

5. C. S. Schlea and J. P. Walsh, "De-entrainment in Evaporators," Preprint No. 28, Forty-second National Meeting, AIChE, Feb., 1960.

APPENDIX

Process Design Calculations

Table A-1. Installed Costs of High-level Waste Tanks of Various Capacities in Concrete Cells

Capacity (gal)	Dimensions (ft)		Vol. Concrete (cu. yd)	Cost ($)				
	d	h		Concrete	Tank[1]	Fixed[2]	Total	$/gal
15,000	20	8	266	53,200	36,500	200,000	289,700	19.30
25,000	25	8	344	68,800	52,500	200,000	321,300	12.80
50,000	35	10	563	112,600	85,000	200,000	397,600	7.95
75,000	35	14	639	137,800	113,000	200,000	450,800	6.00
100,000	40	12	714	142,800	138,000	200,000	480,800	4.81

[1]Based on $85,000 estimate for a 50,000-gal stainless steel tank by Chicago Bridge and Iron, and assumes cost varies to 0.7 power with capacity.

[2]Fixed costs for the purposes of this study include off-gas system, cooling system, emergency reflux condenser, piping, sampling, instrumentation, and engineering.

Table A-2. Estimated Costs of Alternate Waste Tank Designs

Alternate 1

Concrete; 1230 cu yds at $15/cu yd*	$141,500
Tanks and Pans; 2 at $67,000 each	134,000
	$275,500

Alternate 2

Concrete: 1226 cu yds at $100/cu yd	$122,600
Tanks: 2 at $50,000 each	100,000
Stainless Steel Pan: 2572 ft^2 at $8/$ft^2$	20,000
	$242,600

Alternate 3

Tanks: 2 at $130,000 each	$260,000
Extra Backfill: 1538 cu yd at $5/cu yd	7,700
	$267,700

*Higher concrete cost per cu yd because of longer roof span.

Table A-3. Evaporation of Synthetic Intermediate-Level Waste*[2]

Vol. Reduction %	Factor	95°C	70°C	26°C	Specific Gravity at Room Temperature
5	--	--	0.81	1.18	1.0357
10	--	--	0.87	1.27	1.0413
15	--	--	0.85	1.21	1.0439
25	--	--	0.84	1.17	1.0489
37.5	--	--	0.84	1.21	1.0592
50	2:1	--	0.81	1.17	1.0734
75	4:1	--	0.96	1.44	1.1364
80	5:1	0.86	1.02	1.61	1.1758
85	6.6:1	0.87	0.99	1.90	1.2323
90	10:1	--	1.32	2.90	1.3355
92.5	13.3:1	--	1.76	5.50	1.4036
95	20.1	2.70	--	--	--

*This waste initially had the composition: 12.83 g/liter Na^+, 0.475 g/liter Al^{+3}, 0.377 g/liter NH_4^+, 29.0 g/liter NO_3^-, 3.34 g/liter SO_4, 0.225 g/liter Cl^-, and 3.4 g/liter OH^-.

I. Heat Buildup in Waste Tanks

Basis: 50,000-gal tank filled at constant rate in 2½ yrs. with waste containing mixed fission products 6-months-decayed. The fission product mixture shall have a heat evolution of 8 Btu/hr/gal, equivalent to 670 curies β-activity/gal.

Using ORNL-2127 and assuming $\phi = 3 \times 10^{13}$ n/cm²/sec

$\tau = 3 \times 10^{7}$ sec

$N_{25}^{o} = 1.5 \times 10^{22}$ atoms/gal

Decay Time, t	Watts/gal	Btu/hr/gal	Curies/gal.
1.6×10^{7} sec. (½ yr)	2.34	8	670
3.2×10^{7} s. (1 yr.)	1.05	3.6	320
4.8×10^{7} s. (1½ y.)	0.61	2.1	204
6.4×10^{7} s. (2 y.)	0.41	1.4	142
8×10^{7} s. (2½ y.)	0.29	0.99	110
9.6×10^{7} s. (3 yr.)	0.23	0.78	91
1.3×10^{8} s. (4 yr.)	0.16	0.55	67
1.6×10^{8} s. (5 yr.)	0.12	0.41	53
1.9×10^{8} s. (6 yr.)	0.10	0.34	44
3.2×10^{8} s. (10 yr.)	0.066	0.23	29
4.8×10^{8} s. (15 yr.)	0.056	0.19	22
6.4×10^{8} s. (20 yr.)	0.050	0.17	19

The above data are plotted in Fig. 1 A.

Heat Buildup, continued.

Tank filled at rate of:

$$\frac{50000 \text{ gal}}{(2.5 \text{ yrs})(365 \text{ days/yr})} = 54.8 \text{ gal/day}$$

Numerically integrating under curve, Fig. 1A, yields following table.

Heat Evolution, Btu/hr/50,000 gal tank.

Increment	Time From Start of Filling, Years												
	0.1	0.2	½	1	1½	2	2½	3½	4½	5½	9½	14½	19½
1			50,900	27,000	16,500	11,500	8600	5700	4,300	3600	2400	1900	1700
2				50,900	27,000	16,500	11,500	6900	4900	3800	2400	1900	1700
3					50,900	27,000	16,500	8600	5700	4000	2500	2000	1700
4						50,900	27,000	11,500	6900	4900	2600	2000	1700
5							50,900	16,500	8600	5700	2800	2000	1800
Total	14,400	26,300	50,700	77,900	94,400	105,900	114,500	49,200	39400	22,000	12,700	9800	8600

The total heat buildup and decay from this table is plotted in Fig A-2.

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ORNL-LR-DWG 57129

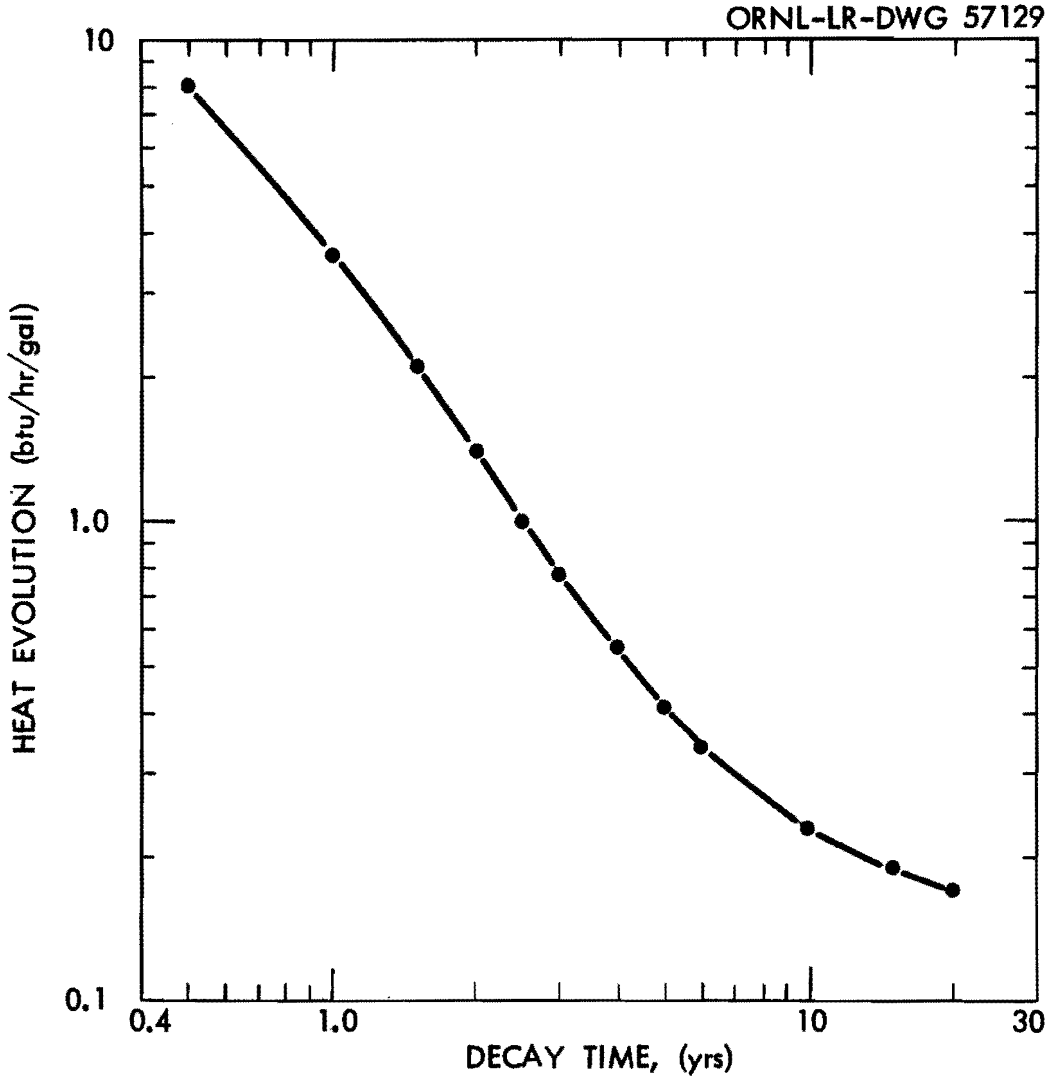

Fig. A-1. Variation in heat evolution with decay time for waste containing 6-month-decayed fission products.

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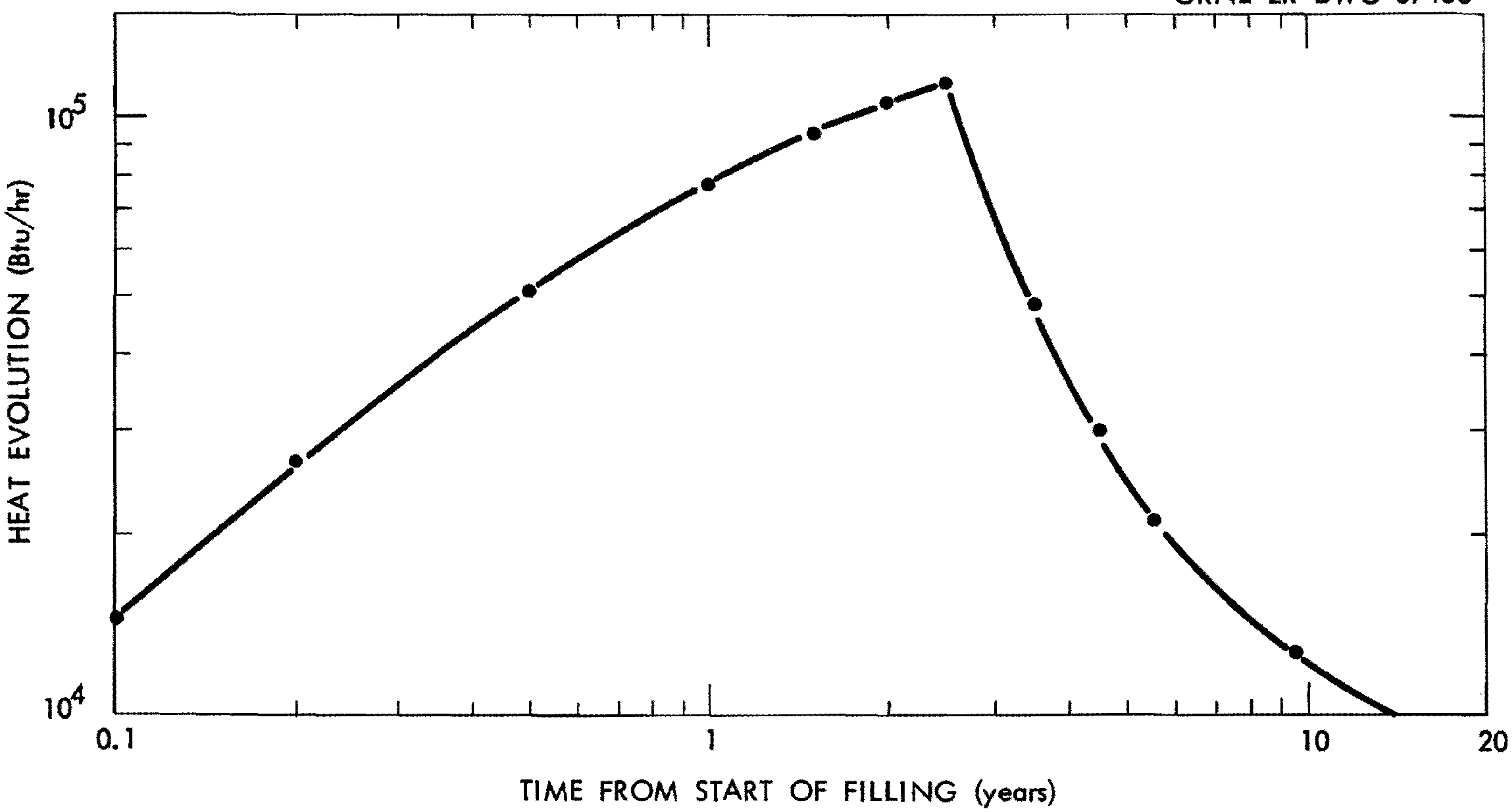


Fig. A-2. Heat evolution in 50,000-gal. waste tank as a function of time.

II. Shielding Calculations

SUMMARY

Evaporator cell:

Shielding thickness is determined by $Ce\text{-}Pr^{144}$ chain
With 2800 curies/gal (6.85 curies/gal of 2.2 mev γ emitting Pr^{144})

dose = 0.96 mr/hr with 5 feet of concrete
0.06 mr/hr with 6 feet of concrete

[Computer code gives 0.1 mr/hr with 65 inches of concrete]

Condenser cell:

Shielding thickness is determined by $Ru\text{-}Rh^{106}$ chain
If 10% of the Ru^{106} in a batch of 2800 curie/gal waste is volatilized and is carried over to the 150 gal condensate tank:

dose = 0.868 mr/hr with 3 feet of concrete
= 0.0406 mr/hr with 4 feet of concrete

[Computer code gives 0.1 mr/hr with 38 inches of concrete]

Off-Gas cell:

Assuming: Ru does not volatilize
20 cfm off-gas flow
Liquid particle carry-over = 10 mg/M^3
All carry-over collects in scrub liquor tank

With 2 feet of concrete, for a dose of 0.1 mr/hr the scrub liquor tank must be emptied every 22 days.

Waste Tank:

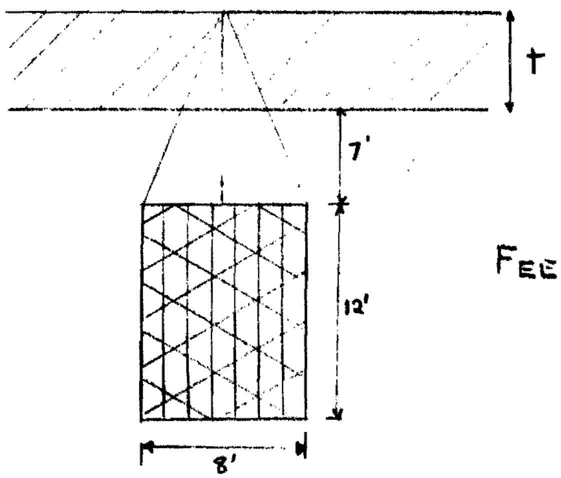
Shielding thickness is determined by $Ce\text{-}Pr^{144}$ chain.
With 2800 curies/gal feed

dose = 0.75 mr/hr with 5 feet of concrete

[Computer code gives 0.1 mr/hr with 63 inches of concrete]

Shielding Calculations

Evaporator Cell



Feed Tank

Assumptions:

(1) Feed tank is filled with 2800 curie/gal waste solution. This solution is made of mixed fission products and is 6 months cooled.

(2) Complete mixing of tank contents.

(3) Shielding thickness will be determined by activity of Ce - Pr^{144} chain.

For solution with
- flux = 3×10^{13} n/cm² - sec
- irradiation time = 3×10^{7} sec
- decay time = 1.6×10^{7} sec

From ORNL - 2127:

Curies / original atom U^{235} = 4.7×10^{-20} (pp 329)

N_s / N°_{25} = 3.9×10^{-2} (pp 57)

N_τ / N_s = 0.563 (pp 115)

N_t / N_τ = 0.7 (pp 194)

Original atoms of U^{235} / gal = $\frac{2800}{4.7 \times 10^{-20}}$ = 5.95×10^{22}

$$N_t / N^{\circ}_{25} = N_s / N^{\circ}_{25} \left(\frac{N_\tau}{N_s} \right) \left(N_t / N_\tau \right)$$

$$= 3.9 \times 10^{-2} (0.563)(0.7) = 1.54 \times 10^{-2} \text{ atoms } Ce^{144} / \text{atom } U^{235}$$

atoms Ce^{144} = $(1.54 \times 10^{-2})(5.95 \times 10^{22})$ = 9.17×10^{20} atoms / gal

$N\lambda = 9.17 \times 10^{20} (2.76 \times 10^{-8}) = 2.53 \times 10^{13}$ d/sec - gal

1% of Pr^{144} disintegrations give a 2.2 mev γ; only these are of interest
$= 2.53 \times 10^{11}$ d/sec - gal

$$E_A = \frac{\mu S_v B}{2\nu}\left[F_1(\sigma t) - F_1(\sigma t + \nu h) + \frac{F_1[(\sigma t + \nu h)\sec\phi_1]}{\sec\phi_1} - \frac{F_1(\sigma t \sec\phi_1)}{\sec\phi_1}\right]$$

$$S_v = \frac{(2.53 \times 10^{11} \text{ d/sec - gal})(2.2 \times 10^6 \text{ ev/d})}{(231 \times 16.4 \text{ ml/gal})} = 2.41 \times 10^{14} \text{ ev/sec - ml}$$

$\mu = 3.5 \times 10^{-5}$

$\nu = 0.05$ cm^{-1}

$\sigma = 0.25$ IN^{-1}

$\sec\phi_1 = \frac{\sqrt{144+16}}{12} = 1.05$ (for t = 5')

$h = 366$ cm

For t = 5 ft, expression becomes:

$$E_A = \frac{3.5 \times 10^{-5}(2.41 \times 10^{14})}{2(.05)}\left[F_1(15) - F_1(88) + \frac{F_1[91]}{1.05} - \frac{F_1(15.75)}{1.05}\right]18$$

$$= 1.52 \times 10^{12}\left[19.5 \times 10^{-9} - \text{neg} + \text{neg} - 7.8 \times 10^{-9}\right]$$

$$= 1.78 \times 10^4 \text{ ev/sec - cc}$$

Dose $= 1.78 \times 10^4 (5.4 \times 10^{-8})(10^3) = \underline{0.96 \text{ mr/hr}}$

For t = 6 ft:

$$E_A = \frac{3.5 \times 10^{-5}(2.41 \times 10^{14})(23)}{2(.05)}\left[F_1(18) - \frac{F_1(18.85)}{1.05}\right]$$

$$= 1.94 \times 10^{12}\left[8.1 \times 10^{-10} - 2.05 \times 10^{-10}\right]$$

$$= 1.175 \times 10^3$$

Dose $= 1.175 \times 10^3 (5.4 \times 10^{-8})(10^3) = 0.0633$ mr/hr

Consideration of other isotopic chains:

$\underline{Zr - Nb^{95}}$

yield - 6.4%
half lives - 63d, 35d
γ energy - 0.75 mev [Too low to be significant]

$Ba \cdot La^{140}$

yield - 6.3%

half-lives - 12 days, 40 hours [Will have decayed to a low level in 6 mo]

$Ru \cdot Rh^{106}$

yield - 0.38%

half-lives - 1 yr, 30 sec

γ energy - 2.41 mev (0.25%)

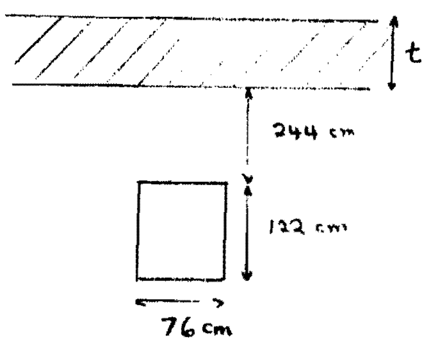
relative # of high energy γ from Pr^{144} and Rh^{106}

$$\frac{\# Pr\ \gamma}{\# Rh\ \gamma} = (\text{yield ratio})(\text{decay ratio})(\text{ratio of high energy yield})$$

$$= \frac{6.1}{0.38}\left(\frac{2.76 \times 10^{-8}}{2.20 \times 10^{-8}}\right)\left(\frac{1}{0.25}\right) = 80$$

The Ru-Rh^{106} chain can therefore be ignored except where Ru might volatilize.

Condensate cell



Assume D.F. of 10^7 for all fission products except Ru^{106}. Assume that 10% of the Ru in the evaporator bottoms is carried over

Shielding, then, will be determined by the Ru^{106}-Rh^{106} chain

S_v = the same as in the evaporator, since the catch tank is 10% of the volume of the evaporator bottoms and collects 10% of the Ru.

$$= \frac{2.41 \times 10^{14}}{80} = 3 \times 10^{12} \text{ ev/sec-ml}$$

For t = 3 FT

$\sigma t = (0.24)(36) = 8.65$

$\sigma t + \nu h = 8.65 + 6.1 = 14.75$

$\sec \phi_1 = 1.005$

$B = 9$

$$E_A = \frac{\mu S_v B}{2\nu}\left[F_1(Gt) - \frac{F_1(Gt\sec\phi_1)}{\sec\phi_1}\right]$$ other terms are negligible

$$= \frac{3.5\times10^{-5}(3\times10^{12})(9)}{2(0.05)}\left[1.73\times10^{-5} - 1.565\times10^{-5}\right]$$

$$= 1.61\times10^{4} \text{ ev/sec-cc}$$

Dose $= (1.61\times10^{4})(5.4\times10^{-8})(10^{3}) = 8.68\times10^{-1} = 0.868$ mr/hr

For $t = 4$ ft

$Gt = (.24)(48) = 11.5$

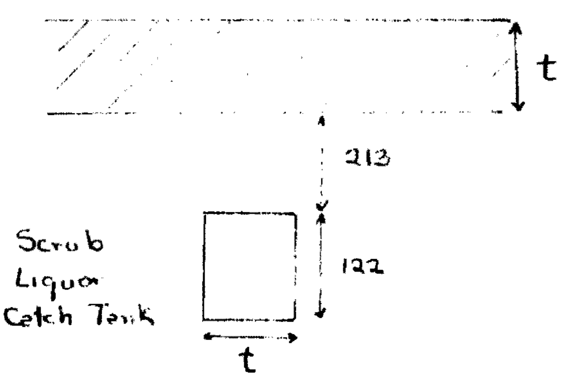
$B = 13$

$$E_A = \frac{3.5\times10^{-5}(3\times10^{12})(13)}{2(0.05)}\left[7.48\times10^{-7} - 6.93\times10^{-7}\right]$$

$$= 7.5\times10^{2} \text{ ev/sec-cc}$$

Dose $= 7.5\times10^{2}(5.4\times10^{-8})(10^{3}) = 0.0406$ mr/hr

OFF - GAS CELL



Assume: (1) Ru does not volatilize
(2) Off gas flow of 20 cfm
(3) Liquid particle concentration in off gas is 10 mg/cu meter

Liquid carry-over $= (20 \text{ ft}^3/\text{min})(28,300 \text{ cm}^3/\text{ft}^3)\left(\frac{1}{10^6 \text{ cm}^3/\text{M}^3}\right)(10 \text{ mg/M}^3)$

$= 5.67$ mg/min

$= .00567$ gm/min $= 0.00567$ cc/min

For dose $= 0.1$ mr/hr and $t = 2$ ft:

$E_A = (0.1)(10^{-3})\left(\frac{1}{5.4\times10^{-8}}\right) = 1.85\times10^{3}$ ev/sec-cc

$Gt = (.25)(24) = 6$

$B = 7$

$\sec\phi_1 = 1.005$

$$F_1(Gt) - \frac{F_1(Gt \sec \phi_1)}{\sec \phi_1} = 30 \times 10^{-6} - 28.4 \times 10^{-5} = 1.6 \times 10^{-5}$$

$$S_v = \frac{E_A \, 2\nu}{\mu B \left[F_1(Gt) - \frac{F_1(Gt \sec \phi)}{\sec \phi}\right]}$$

$$= \frac{1.85 \times 10^{3} (2)(.05)}{3.5 \times 10^{-5} (7)(1.6 \times 10^{-5})} = 4.7 \times 10^{10} \text{ ev/sec - cc}$$

curies of Pr^{144} in tank = $\frac{(4.7 \times 10^{10})(150 \text{ gal})(3785 \text{ cc/gal})}{(2.2 \times 10^{6} \text{ ev/d})(3.7 \times 10^{10})}$

= 0.328 curies

Activity of liquid carried over = $\frac{2.53 \times 10^{11}}{3.7 \times 10^{10}}$ = 6.85 curies/gal of 2.2 mev γ emitting Pr^{144}

= 0.82 curies /#

= 1.81×10^{-3} curies / gm

Rate of activity carry-over

= 0.00567 gm/min (1.81×10^{-3} curies/gm) = 1.025×10^{-5} curies/min

= 1.48×10^{-2} curies/day

If all activity carried over is caught in the scrub liquor, this tank must be emptied when 0.328 curies of 2.2 mev γ Pr^{144} have accumulated. This will be in $\frac{0.328}{0.0148}$ = 22 days

With thinner shield, less energetic γ emitters may be significant. Check with assumption that liquid carried over is 2800 curies/gal of 1 mev γ emitter.

$Gt = 0.38(24) = 9.13$

$B = 20$

$$F_1(Gt) - \frac{F_1(Gt \sec \phi_1)}{\sec \phi_1} = 1.1 \times 10^{-7} - 1.03 \times 10^{-7} = 7.6 \times 10^{-9}$$

$$S_v = \frac{1.85 \times 10^{3} (2)(.07)}{3.5 \times 10^{-5} (20)(7.6 \times 10^{-9})} = 4.87 \times 10^{13} \text{ ev/sec - cc}$$

Total curies in tank = $\frac{(4.87 \times 10^{13})(150 \text{ gal})(3785 \text{ cc/gal})}{(1 \times 10^{6} \text{ ev/d})(3.7 \times 10^{10})}$

= 747 curies

Activity of liquid carried over = 2800 curies/gal

= 336 curies/#

= 0.74 curies/gm

Rate of activity carried over

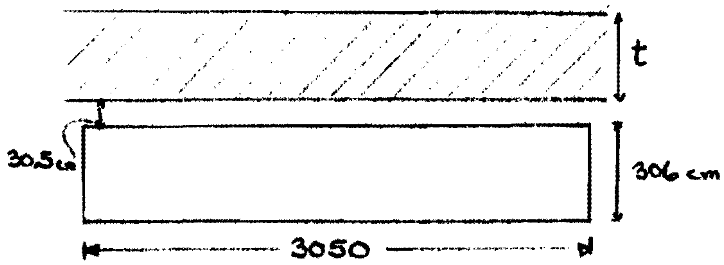
= 0.00567 gm/min (0.74 curies/gm) = 4.2×10^{-3} curies/min

= 6.05 curies/day

Operating days before emptying is required = $\frac{747}{6.05}$ = 124

Pr^{144} chain is still controlling, therefore.

WASTE TANK



Assume ① Tank contains 50,000 gal

② Tank is full

③ Pr^{144} is controlling

④ Tank is filled with waste with an initial activity of 2800 curies/gal (6.85 curies/gal of 2.2 mev γ emitting Pr^{144})

$$S_v = (1 \times 10^{11}\ d/\text{sec-gal})(2.2 \times 10^6\ ev/d)\left(\frac{1}{231}\right)\left(\frac{1}{16.4}\right)$$

$$= 5.57 \times 10^{13}\ ev/\text{sec-cc}$$

R = 153 cm

R^2 = 2.34×10^4

a = 30.5 + t

z = 54

$$E_A = B \frac{\mu S_v R^2}{2(a+z)} \mathcal{F}(\phi\, B^*)$$

For t = 5 ft: μt = 15, B = 24

$$E_A = \frac{3.5 \times 10^{-5}\ (5.57 \times 10^{13})(2.34 \times 10^4)}{2\ (236)}(24)(6.0 \times 10^{-9})$$

$$= 1.39 \times 10^4\ ev/\text{sec-cc}$$

dose = $(5.4 \times 10^{-8})(10^3)(1.39 \times 10^4)$ = 0.75 mr/hr

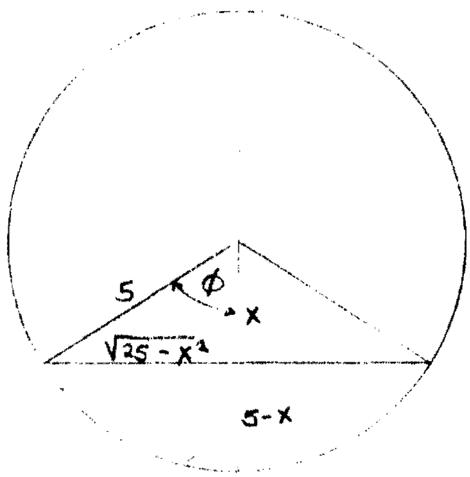
II. HEAT REMOVAL FROM HIGH LEVEL WASTE TANKS

Assume: (1) Solids in the high level waste will be 15% by volume
(2) 75% of the fission products will be with the solids.
(3) There is no heat transfer by convection in the solids
(4) K for conduction in solids = 0.3 BTU/hr - ft² - °F / ft

Mud volume = $50{,}000 \text{ gal} \left(\frac{1}{7.48} \text{ gal/ft}^3\right)(0.15) = 1000 \text{ cu ft}$

Assume tank is 10' I.D. x 105' long

Mud x-sectional area = $\frac{1000}{105} = 9.5 \text{ ft}^2$



Mud x-sectional area:

$$= \frac{\pi}{4}(10^2)\left(\frac{2\phi}{360}\right) - x\sqrt{25 - x^2}$$

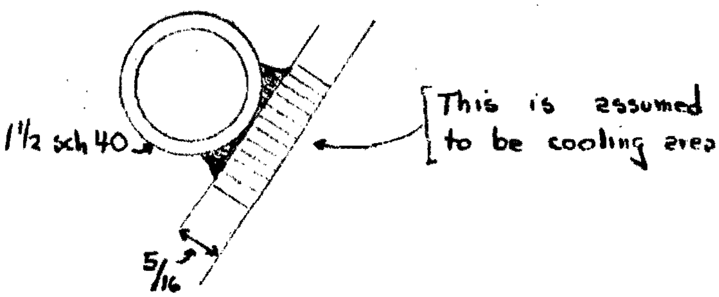
X	$x\sqrt{25-x^2}$	φ	A
1	4.9	78.5	29.3
2	9.18	66.4	19.7
3	12	53.2	11.2
4	12	37	4.1

Depth of mud = ~ 2 feet

CASE I - Total heat generation = 120,000 BTU/hr
90,000 BTU/hr in mud
30,000 BTU/hr in solution

Heat removal from solution:

There are 4 1½" pipes on each side of the tank between the levels of the mud and the top of the liquid. Assume (conservatively) that there is no heat conducted along the tank wall, that only the tank surface immediately adjacent to a coil serves for heat transfer.



Total Area = $\frac{1.9}{12}(105 \text{ ft})(8 \text{ coils})$
= 133 ft²

h (water side) $= 150$ BTU/hr·ft²·°F (assumed)

$$\frac{K}{X} = \frac{130}{.313 + .145} = 284$$

h (solution side):

From eq (7-4a) in McAdams

$$\frac{h_c L}{K_f} = 0.13\left[\frac{L^3 \rho_f^2 g \beta_f \Delta t}{\mu_f^2}\left(\frac{c_p \mu}{K}\right)_f\right]^{1/3}$$

$\mu_f = 0.75$ cp $= 1.82$ #/ft-hr

$K = 0.36$ BTU/hr-ft²-°F/ft

$$\beta = \frac{\frac{V_2 - V_1}{T_2 - T_1}}{V_1} = \frac{\frac{.01620 - .01613}{20}}{.01613} = 0.000217\ /°F$$

$$h_c = \frac{0.13(0.36)}{6}\left[\frac{(6)^3(3.89\times10^3)(4.18\times10^8)(2.17\times10^{-4})(\Delta t)(5.06)}{3.31}\right]^{1/3}$$

$$= \frac{0.13(0.36)}{6}\left[1.17\times10^{11}\ \Delta t\right]^{1/3}$$

$$= 38.1\ \Delta t^{1/3}$$

Assume cooling water at 70°F

Δt between water and solution side of wall $= \dfrac{30{,}000}{(133\ \text{ft}^2)\left(\frac{1}{\frac{1}{150} + \frac{1}{284}}\right)}$

$= 2.3$ °F

Δt between wall and solution $\dfrac{30{,}000}{133\,(38.1\ \Delta t^{1/3})}$

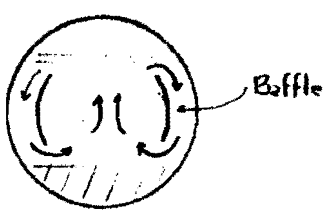
$\Delta t^{4/3} = 5.92$

$\Delta t = 3.8$ °F

Overall $\Delta t = 6.1$ °F

This shows that solution near the wall will be adequately cooled. It remains to be shown that convection currents will transfer heat from near the center of the tank to the outer walls

For purposes of calculation assume a baffle is in the tank as shown.



Flow between baffle and wall = upward flow in center

$\Delta p_{baffle} + \Delta p_{center} = (\rho_1 - \rho_0)\,h$

$$\Delta p_{baffle} = \frac{12 \mu G L}{z_1^2 g_c \rho} \qquad \text{McAdams eq (6-6a)}$$

z_1 = clearance = 2 ft

$G = \frac{w}{2 \times 105} = \frac{w}{210}$ where w = #/hr flowing

$$\Delta p = \frac{12(1.82)(w/210)(5)}{(2)^2(4.18 \times 10^8)(62)} = 5.02 \times 10^{-12} w \ \#/ft^2$$

Δp center is assumed to be the same

total $\Delta p = 1 \times 10^{-11} w = (\rho_1 - \rho_2) 5$

$\rho_1 = 62.3$

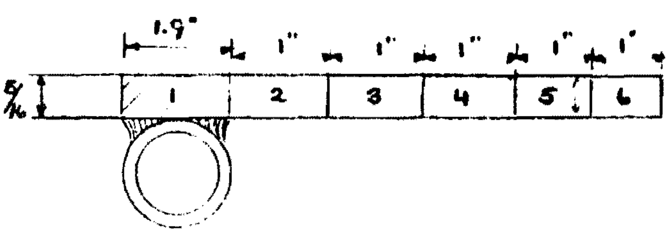
$$w = \frac{15{,}000 \text{ BTU/hr}}{t_{center} - t_{baffle}}$$

$$1 \times 10^{-11} \left[\frac{15{,}000}{t_{center} - 76}\right] = (62.3 - \rho_2) 5$$

$$\frac{6 \times 10^{-8}}{t_2 - 76} = 62.3 - \rho_2$$

t_2 is so near t_1 that the equation cannot be solved. This indicates that convection currents will keep the solution at a nearly uniform temperature, even at much higher heat loads.

Heat removal from mud:



There are 9 pipes welded to the lower part of the tank. Take as the worst case the bottommost pipe. Pipes are spaced 12 inches apart, so peak wall temperature would be 6 inches from pipe midpoint.

Depth of mud above bottom = 1.8 feet

Solution above mud will be at 76°F, bottom wall will be about the same. Therefore, about ½ the heat produced in the mud is given up to the solution and about ½ is given up to the bottom.

q_{total} = 90,000 BTU/hr

heat to bottom = 45,000 BTU/hr

midpoint temperature in mud: - $45{,}000 \text{ BTU/hr} = \frac{0.3(8 \times 105)(t - 76)}{0.9/2}$

$$t - 76 = \frac{45{,}000\,(.45)}{(.03)(840)} = 80.5$$

$$t = 156\,°F$$

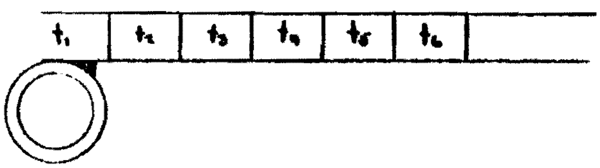
Heat generated in mud between midpoint and bottom over one of the unit areas (1" × 1') shown above:

$$\text{Heat generated}/ft^3 = \frac{90{,}000}{1000}\ BTU/hr = 90\ BTU/hr\text{-}ft^3$$

$$\text{Heat generated per unit volume} = 90\left(\frac{1}{12} \times 1 \times .9\right)$$

$$= 6.75\ BTU/hr$$

If it is assumed that the temperature variation of the tank bottom is small compared to the overall Δt, then the quantity of heat removed by each segment of the tank bottom will be the same and will be ~ 6.75 BTU/hr.



Heat flow between segments 5 + 6 = 6.75 BTU/hr = $\frac{130}{1}\left(1 \times \frac{.313}{12}\right)(t_6 - t_5)$

Heat flow between segments 5 + 4 = 13.5 BTU/hr = $3.39\,(t_5 - t_4)$

Heat flow between segments 4 + 3 = 20.25 BTU/hr = $3.39\,(t_4 - t_3)$

Heat flow between segments 3 + 2 = 27 BTU/hr = $3.39\,(t_3 - t_2)$

Heat flow between segments 2 + 1 = 33.75 BTU/hr = $3.39\,(t_2 - t_1)$

$$t_1 - 70 = \frac{45{,}000\ BTU/hr}{\frac{1}{\frac{1}{150} + \frac{1}{284}}\left(\frac{1.9}{12} \times 105 \times 9\right)} = 3.07\,°F$$

$$t_1 = 73\,°F$$

and

$t_2 = 83°$

$t_3 = 91°$

$t_4 = 97°$

$t_5 = 101°$

$t_6 = 103°$

Since this temperature variation is not great compared to the overall Δt, [83°], more exact calculation seems unnecessary.

Summary for total heat generation = 120,000 BTU/hr:

Heat removed from solution = 30,000 + 45,000 = 75,000 BTU/hr

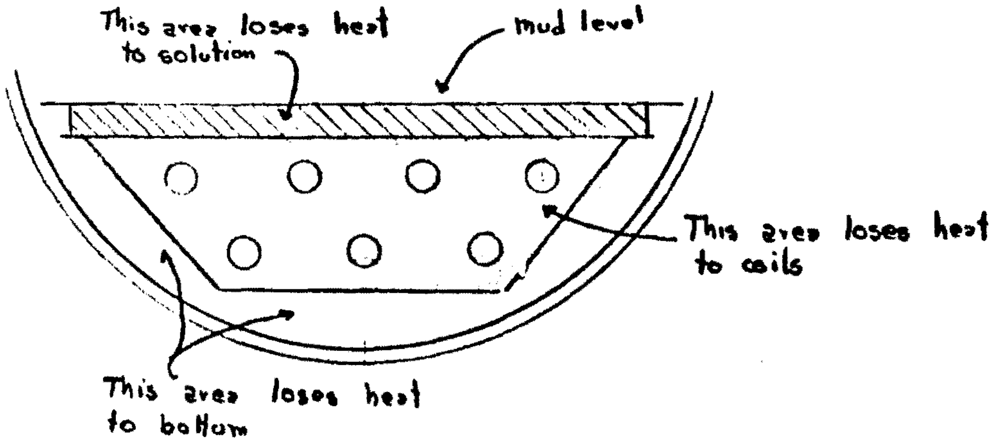
Solution temperature = ~ 80°F

Heat removed from bottom wall = 45,000 BTU/hr
Maximum wall temperature = 103°F
Maximum mud temperature = 156°F

CASE II - Total heat generation = 400,000 BTU/hr
300,000 BTU/hr in mud
100,000 BTU/hr in solution

Calculations of Case I have indicated that:

internal coils will be needed to remove heat from mud for case II
solution temperature will be uniform
A considerable quantity of heat will be removed from the mud by the solution.



Approximate volume losing heat to solution = $\frac{(3.5'')(84'')}{144}(105')$
= 214 cu ft

Approximate heat loss to solution = $\frac{214}{1000}(300,000)$ = 64200 BTU/hr

Approximate volume losing heat to coils = $\frac{13.5''}{2}(36''+48'')(\frac{105}{144})$
= 414 cu ft

Approximate heat loss to coils = $\frac{414}{1000}(300,000)$ = 124,200 BTU/hr

Approximate volume losing heat to bottom = 1000 - 414 - 214 = 372 cu ft

Approximate heat loss to bottom = 300 000 - 64,200 - 124,200
= 111,600 BTU/hr

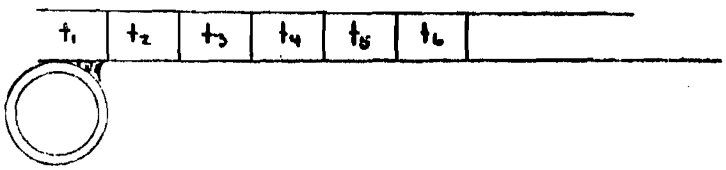
Depth of mud from which is being lost to bottom
= $\frac{372}{105}\left(\frac{1}{8.52}\right)$ = 0.4 ft = 4.8 inches

Heat removal from bottom:

As before, the bottommost pipe is taken.

Heat generated in segment 1" × 1 ft × 5" deep

$$= \left(\frac{1}{12} \times 1 \times \frac{5}{12}\right)\left(300 \ BTU/hr\text{-}ft^3\right) = 10.4 \ BTU/hr$$



Heat flow between segments 5 + 6 = 10.4 BTU/hr = $\frac{130}{1}\left(1 \times \frac{.313}{12}\right)(t_6 - t_5)$

Heat flow between segments 4 + 5 = 20.8 BTU/hr = $3.39\,(t_5 - t_4)$

Heat flow between segments 3 + 4 = 31.2 BTU/hr = $3.39\,(t_4 - t_3)$

Heat flow between segments 2 + 3 = 41.6 BTU/hr = $3.39\,(t_3 - t_2)$

Heat flow between segments 2 + 1 = 52 BTU/hr = $3.39\,(t_2 - t_1)$

$$t_1 - 70 = \frac{111,600 \ BTU/hr}{\dfrac{1}{\frac{1}{150} + \frac{1}{284}}\left(\frac{1.9}{12} \times 105 \times 9\right)} = 7.63°F$$

$t_1 = 78°F$

and

$t_2 = 93.4$

$t_3 = 105.7$

$t_4 = 114.9$

$t_5 = 121.1$

$t_6 = 124.2$ This is still below the 130° temperature, which is the maximum desirable wall temperature.

Heat removal by coils:

Heat removed by 1 ft of coil $= \frac{124,200}{7\,(105)} = 169$ BTU/hr

Maximum distance from coil to uncooled mud ≅ 6 inches

Maximum mud temperature:

$$\frac{Q}{2\pi L}\left[\frac{1}{2} - \frac{r_1^2}{r_2^2 - r_1^2} \ln \frac{r_2}{r_1}\right] = K\,(T_2 - T_1)$$

$$\frac{169}{2\pi}\left[\frac{1}{2} - \frac{(.079)^2}{(.579)^2 - (.079)^2} \ln \frac{.579}{.079}\right] = 0.3\,(T_2 - 70)$$

$T_2 = 114.3\ °F$

Heat removal from solution:

$Q = 164,200$ BTU/hr

Δt between water and solution side of wall $= \dfrac{164,200}{(133\ ft^2)\left(\dfrac{1}{\frac{1}{150}+\frac{1}{264}}\right)}$

$= 12.6°F$

Δt between wall and solution $= \dfrac{164,200}{133\,(38.1)\,\Delta t^{1/3}}$

$\Delta t^{4/3} = 32.3$

$\Delta t = 13.6°F$

overall $\Delta t = 26.2°F$

solution temperature $= 96.2°F$

Summary for total heat generation = 400,000 BTU/hr:

Heat removed from solution = 164,200 BTU/hr.

Solution temperature = ~96°F

Heat removed from bottom wall = 111,600 BTU/hr

Maximum wall temperature = 124°F

Maximum mud temperature = ~184°F

Heat removed from coil = 124,200 BTU/hr

IV. Miscellaneous

Hydrogen evolution in waste tank

Assume tank contains 50,000 gal of waste solution that generates 480,000 BTU/hr of heat

Solution activity = $480{,}000 \left(\frac{1}{3413\ \text{BTU/hr-Kw}}\right)\left(6.25 \times 10^{21}\ \text{ev/sec-Kw}\right)$

$= 8.78 \times 10^{23}$ ev/sec

Assume G value for hydrogen evolution = 0.1 molecules/100 ev

Rate of generation = $\left(8.78 \times 10^{23}\ \text{ev/sec}\right)\left(0.1\ \text{molecules/100 ev}\right)\left(\frac{1}{6.06 \times 10^{23}}\right) = 1.45 \times 10^{-3}\ \frac{\text{gm n}}{\text{sec}}$

$= 1.45 \times 10^{-3} \left(22.4\ \text{L/gm mol}\right)(3600)\left(\frac{1}{28.3}\ \text{L/ft}^3\right) = 4.13\ \text{ft}^3/\text{hr}$

If hydrogen is to be diluted to 2%

Off gas flow = $\frac{4.13}{.02}\left(\frac{1}{60}\right) = 3.44$ cfm

Off-gas scrubber

Design basis: 150 cfm of off-gas [from

Recommended flow in scrubber = 500 #/hr-ft²

Gas density = $0.0808\left(\frac{492}{540}\right) = 0.0737$ #/ft³

X-sectional area needed = $\frac{(150\ \text{ft}^3/\text{min})(0.0737)(60)}{500} = 1.33\ \text{ft}^2$

Scrubber diameter = 15.6 inches

Liquid flow rate = $4000\ \text{\#/hr-ft}^2\ (1.33)\left(\frac{1}{8.33}\right)\left(\frac{1}{60}\right) = 10.6$ gal/min

Evaporator sizing

Boil-up rate = $(600\ \text{gal/hr})(0.9)(8.33\ \text{\#/gal}) = 4500$ #/hr

BNL reports (BNL-121) an evaporator D.F. of 10^5 with an evaporator boil-up rate of ~ 60 #/hr-ft², a D.F. of 10^4 with a boil up rate of ~ 100 #/hr-ft². A boil-up rate of ~ 60 #/hr-ft² has been chosen as the basis for this evaporator design.

Diameter required for 60 #/hr-ft² = 10 ft.

Filter Design

BNL data reports a pressure drop of ~10" of water for a 1 ft/sec vapor velocity in a 3 foot filter thickness, a Δp of 14" of water for a 2.9 ft/sec vapor velocity in a 2.5 foot filter thickness.

These data indicate that the Δp varies linearly with G. For a filter thickness of 3 feet the Δp can be expressed approximately by

$$\Delta p = 5.8\,V$$ where V is velocity in ft/sec.

For a vapor flow of 4500 #/hr = 121,000 ft³/hr = 33.5 ft³/sec

D	A	V	Δp
3.5'	9.64 ft²	3.48 ft/sec	20.2"
4	12.6	2.66	15.4"
4.5	15.9	2.1	12.2"

Δp greater than 15" of water is undesirable, hence a 4 foot filter diameter is chosen. BNL data indicate that a filter D.F. of 10^3 can be expected with a 3 foot thick filter bed and a vapor velocity of 2.66 ft/sec.

Distribution

1-3. DTIE, ORO
4. M. J. Skinner
5-6. Central Research Library
7. Document Reference Section
8. F. E. Harrington