MARTIN MARIETTA ENERGY SYSTEMS LIBRARIES
3 4456 0361441 7

CENTRAL RESEARCH LIBRARY
DOCUMENT COLLECTION

ORNL-2873
UC-70 – Waste Disposal and Processing
TID-4500 (43rd ed.)

THE COSTS OF PERMANENT DISPOSAL OF POWER-REACTOR FUEL-PROCESSING WASTES IN TANKS

J. O. Blomeke
E. J. Frederick
R. Salmon
E. D. Arnold

OAK RIDGE NATIONAL LABORATORY
operated by
UNION CARBIDE CORPORATION
for the
U.S. ATOMIC ENERGY COMMISSION

CENTRAL RESEARCH LIBRARY
DOCUMENT COLLECTION
LIBRARY LOAN COPY
DO NOT TRANSFER TO ANOTHER PERSON
If you wish someone else to see this document, send in name with document and the library will arrange a loan.

Printed in USA. Price $4.00. Available from the Clearinghouse for Federal Scientific and Technical Information, National Bureau of Standards, U.S. Department of Commerce, Springfield, Virginia

LEGAL NOTICE

This report was prepared as an account of Government sponsored work. Neither the United States, nor the Commission, nor any person acting on behalf of the Commission:

A. Makes any warranty or representation, expressed or implied, with respect to the accuracy, completeness, or usefulness of the information contained in this report, or that the use of any information, apparatus, method, or process disclosed in this report may not infringe privately owned rights; or

B. Assumes any liabilities with respect to the use of, or for damages resulting from the use of any information, apparatus, method, or process disclosed in this report.

As used in the above, "person acting on behalf of the Commission" includes any employee or contractor of the Commission, or employee of such contractor, to the extent that such employee or contractor of the Commission, or employee of such contractor prepares, disseminates, or provides access to, any information pursuant to his employment or contract with the Commission, or his employment with such contractor.

ORNL-2873

Contract No. W-7405-eng-26

CHEMICAL TECHNOLOGY DIVISION

THE COSTS OF PERMANENT DISPOSAL OF POWER-REACTOR FUEL-PROCESSING WASTES IN TANKS

J. O. Blomeke
E. J. Frederick
R. Salmon
E. D. Arnold

SEPTEMBER 1965

OAK RIDGE NATIONAL LABORATORY
Oak Ridge, Tennessee
operated by
UNION CARBIDE CORPORATION
for the
U.S. ATOMIC ENERGY COMMISSION

MARTIN MARIETTA ENERGY SYSTEMS LIBRARIES
3 4456 0361441 7

CONTENTS

Page

Abstract 1

Introduction 2

Alternatives to Storage in Tank Farms 2

Background of Present Economic Analysis 3

Scope of Present Study 4

Acknowledgements 5

Basis of Study 5

Description of Cladding Wastes 7

Description of Solvent Extraction Raffinate Wastes 9

Expected Volumes 9

Compositions 10

Fission Product Levels 12

Products of Radiolysis 12

Corrosivity of the Wastes, and Measures To Lessen It 14

Description of Facility 14

Tanks 16

Cooling System 18

Operations Building 21

Piping and Ventilation 22

Provisions for Emergencies 25

Capital Costs 26

Operating Costs 28

Labor 28

Overhead 30

Services 30

Maintenance 30

Waste Transfer 30

Property Taxes 31

Insurance 31

Economic Model 31

Accumulation and "Dead" Periods 31

Permanent Fund 31

CONTENTS (Continued)

Page

Sales Income 32

Construction Schedule 33

Federal Income Taxes 33

Price Escalation and Inflation 34

Total Costs 34

Raffinate Waste Storage 34

Cladding Wastes 41

Appendix A 47

Appendix B 64

References 101

THE COSTS OF PERMANENT DISPOSAL OF POWER-REACTOR FUEL-PROCESSING WASTES IN TANKS

J. O. Blomeke R. Salmon
E. J. Frederick E. D. Arnold

ABSTRACT

The costs of permanent storage of reactor fuel processing wastes are estimated for a 22,400-Mwe nuclear power economy. The wastes arise from chemical dissolution of the fuel cladding and solvent extraction purification of a combination of uranium and thorium converter fuels. The economics are examined for three representative types of financing: government ownership, private ownership, and a combination of government and private ownership. In each case, it is assumed that a permanent tax-free fund is established during a 20-yr period of waste accumulation of such size that the annual tax-free interest will be sufficient to provide for periodic replacement of tanks and for the annual operating expenses of the facility.

Tank farms were designed for storage of high-level wastes in both acid and alkaline forms, and in tanks ranging in capacity from 200,000 to 5,000,000 gal. Capital costs were estimated for each case, then used in a computer code to estimate total costs for each method of financing as a function of tank size, tank life, and fission product concentration in the waste.

Total costs for storing raffinate waste, in terms of the cost of electricity generated, were least for storage of acid wastes in tanks of 75-yr life with government ownership, and greatest for storage of alkaline wastes in tanks of 25-yr life with private ownership. For acid wastes, the optimum tank capacity is about a million gallons, and minimum total costs range from 0.0165 to 0.0272 mill/kwh. For alkaline wastes, the optimum tank capacity is 2.5 million gallons, and minimum total costs range from 0.0177 to 0.0294 mill/kwh. Doubling the concentration of fission products in the wastes, as stored, reduced the total costs between 15 and 30%.

Total costs for storing cladding wastes ranged from 0.0215 to 0.0398 mill/kwh. These costs were greater than those for raffinate storage because of the greater volumes of cladding wastes.

1. INTRODUCTION

In the course of reclaiming irradiated nuclear fuels, nearly all the fission products formed during reactor operation appear in the various waste-effluent streams of the recovery process. Historically, those wastes which are too radioactive for safe release to the environment have been stored as liquids in tanks on an indefinite basis at the chemical-processing-plant sites. Since the radiotoxicity of the wastes will persist for many centuries, it can be expected that they will either have to be transferred periodically to new tanks as the life expectancies of the old containers are reached, or provisions must at some point in time be made for their permanent disposal in an entirely different manner. Consideration of the long-term safety and surveillance requirements for tank farms has led to a consensus that safer, more practical methods of ultimate disposal than tank storage must be developed. The problem must be resolved not only for existing AEC production wastes but also for the effluents to be produced by a civilian nuclear power economy of the future. However, until such time as suitable alternatives have been developed, storage in tanks must be considered.

Whether the responsibility for permanent disposal of the wastes produced by a nuclear power industry be delegated to private enterprise or retained by the Government, the choice of the disposal method eventually adopted will depend on the allowable hazards and on the cost. The hazards are strongly dependent on many properties characteristic of the particular site under consideration as well as on details of the construction and operation of the facility. They are, consequently, difficult, if not impossible, to evaluate quantitatively for a general case. The cost of any proposed disposal method, on the other hand, is easier to assess, provided the scientific and engineering technology exists.

Alternatives to Storage in Tank Farms

Alternatives to permanent tank storage being considered for AEC production wastes include conversion of the liquid wastes to a granular solid by fluidized-bed calcination and storage of this solid in annular bins (Idaho Chemical Processing Plant);[1] partial separation and encapsulation

of the major heat-producing fission products, followed by in-tank solidification of the remaining residues (Hanford);[2] and storage of aged liquid wastes in tunnels mined out of crystalline bedrock, 1300 ft or more beneath the ground (Savannah River Plant).[3] As to power reactor fuel wastes, processes are under development for fixation of the fission products in stable, solid media, which could be permanently stored in salt mines, concrete vaults, or natural caves.[4] These approaches were selected mainly because they are expected to offer greater long-term safety than can be achieved by tank storage; but, in some cases, savings in cost are expected as well.

Background of Present Economic Analysis

Over the past several years, a series of economic studies has been made to estimate waste-management costs as they might pertain to a nuclear power economy.[5,6,7,8,9,10,11] Although the accuracy of these estimates is tempered by the fact that much of the work on which they are based is still in the developmental stage, they nevertheless serve as an indication that the proposed new techniques should not cost more than a competitive nuclear power economy could support. These studies also show that substantial savings in costs could probably be achieved by storing the wastes as liquids for several years, or even several decades, before converting them to solids for ultimate disposal. Thus, tank storage could be a first step toward final disposal.

The experience gained in tank-farm operations over the last 20 years provides firm evidence that tank storage can be applied with safety to future wastes for comparable periods of time, and affords a firm basis for estimating probable costs. The costs of long-term storage of these wastes can serve, therefore, as an indication of the contributory cost that might be expected should it prove necessary or desirable to postpone ultimate disposal until some time in the distant future. They also serve as a basis for comparison with costs estimated for alternative methods of permanent disposal.

Waste-storage costs depend on many factors such as the volumes and characteristics of the wastes, the degree of safety and surveillance

required, and the method used to finance the project. The costs of long-term tank storage were estimated by Campbell et al.[12] for current production waste and by S. M. Stoller Associates[13] for waste to be produced at the Western New York Nuclear Service Center, and a preliminary examination of the costs was made at ORNL.[14] The approach used in each case was to add to the initial cost of tank-farm construction and operation, a cost for establishing a fund, which when invested at a given rate of compound interest, would pay for tank replacement and operating expenses on a continuing or "perpetual" basis. The results of none of these studies were generally applicable to cases other than those specifically considered; however, the method used to arrive at the results is similar to that adopted for the present study.

Scope of Present Study

The present study examines the economics of permanent tank storage for three representative types of financing: government ownership, private ownership, and a combination of government and private ownership. The case of government ownership includes only depreciation and interest on the investment capital; whereas, in the case of private ownership, costs reflect a reasonable return on the initial investment, as well as allowances for depreciation, insurance, taxes, and interest. In the third case, private ownership is assumed during a 20-yr period of waste accumulation, after which the government will assume responsibility for perpetual care of the tank farm. In each case, it is assumed that a permanent tax-free fund is established during the filling period of such size that the annual tax-free interest will be sufficient to provide for periodic replacement of tanks and for the annual operating expense of the facility.

The tank farms were designed for storing high-level wastes in both acid and alkaline forms, and in tanks ranging in capacity from 200,000 to 5,000,000 gallons. Capital costs were estimated for each case and then used in a computer code to estimate total costs for each method of financing as a function of tank size, tank lifetime, and fission product concentration in the waste. Although no attempt was made to determine

the hazards quantitatively, the concept of double containment of radioactivity was applied throughout, and, in all instances, the philosophy of design and operation that was stipulated emphasized safety over any potential savings in costs.

Only summaries of the design basis and cost analysis are given in the main body of this report; additional details are included in Appendix A. A detailed description of the computer program used in the study and the computer output for one example case is given in Appendix B.

Acknowledgements

The authors wish to express their appreciation to S. J. Beard of Hanford, and R. M. Girdler and B. S. Johnson of the Savannah River Plant, for making available many details of tank farm design and operational experience at Hanford and Savannah River; to W. G. Stockdale and P. L. Robertson, ORNL, for developing the capital costs; and to J. T. Roberts, ORNL, for many helpful comments and suggestions during the course of this study.

2. BASIS OF STUDY

As a basis for this study, a fuel processing plant having a nominal capacity of six tons* of fuel per day is assumed, handling the fuel from an installed capacity of 22,400 electrical megawatts (70,000 thermal megawatts). It has been predicted that a nuclear power economy of this size might be reached in the United States during the period, 1975 to 1980.[15] The plant processes 1500 tons/yr of uranium converter fuel irradiated to 10,000 Mwd/ton and 270 tons/yr of thorium converter fuel irradiated to 20,000 Mwd/ton (Table 1). The uranium converter fuels consist of Zircaloy-clad and stainless-steel-clad UO_2, 2% enriched in ^{235}U. The thorium converter fuels are 95% ThO_2--5% enriched (93%) UO_2, clad with Zircaloy. All the fuel is in the form of 1/4-in.-diam rods with Zircaloy cladding 0.025 in. thick, or stainless steel cladding 0.015 in. thick.

In processing these fuels, 120 days after discharge from the reactors, wastes of two general categories are produced, each requiring essentially permanent containment. The claddings are removed chemically, yielding

*Tons in this report refers to metric tons.

Table 1. Reactor and Fuel Characteristics for 22,400-Mw (electrical) Power Economy

	Uranium Converter		Thorium Converter
Fuel Type	Zr-Clad UO_2	SS-Clad UO_2	Zr-Clad ThO_2--5% UO_2
^{235}U enrichment, %	2	2	93
Processing rate, tons/yr	918	582	270
Burnup, Mwd/ton	10,000	10,000	20,000
Power level, Mw/ton	28	28	56
Thermal efficiency, %	32	32	32
Installed capacity, Mw (electrical)	1.006×10^4	6.39×10^3	5.93×10^3
Reactor capacity factor, %	80	80	80
Power generated, kwhr/yr	7.05×10^{10}	4.45×10^{10}	4.15×10^{10}

wastes less radioactive than those from recovery of the fuel cores, but which as acid solutions are so corrosive to ordinary structural materials that they are neutralized for storage. After the cladding has been removed, the fuel cores are processed by organic-aqueous solvent extraction. The aqueous raffinates from these processes contain nearly all the fission products, other than krypton and xenon, and storage under both acid and alkaline conditions is considered. The tank farm accumulates wastes over 20 years of plant operation, following which it is maintained for their containment on a "perpetual" basis.

Description of Cladding Wastes

The compositions of the cladding wastes were idealized for this study but are fairly representative of what to expect, considering site-to-site and even day-to-day fluctuations in plant operations.

Zircaloy cladding is removed by the Zirflex process,[16] which entails dissolution in a 5.5 M NH_4F--0.5 M NH_4NO_3 solution. The resulting solution averages 1.7 gal per kg of uranium or thorium processed, and is produced at a rate of 2×10^6 gal/yr (Table 2). It is adjusted to a pH of 10 with 50% caustic, resulting in a volume for storage of 2.15×10^6 gal/yr. On neutralization, a precipitate or sludge forms and occupies 30 to 40% by volume of the waste.

Stainless steel cladding is removed by the Sulfex process,[17] which consists of dissolution in 4 M H_2SO_4. The resulting waste, averaging in volume 1.34 gal per kg of uranium declad, contains 45 g/liter of the dissolved constituents of stainless steel, and is produced at a rate of 7.8×10^5 gal/yr (Table 2). After adjustment with caustic to pH 12, 1.14×10^6 gal/yr of waste, containing 20 to 30% solids by volume, is produced for storage.

The radionuclide contents of the decladding wastes are estimated from results obtained from decladding irradiated UO_2 pellets in radiochemical hot cells,[17] and from calculations of activity induced by thermal neutron capture in the claddings (Table 2). The hot-cell studies have shown that as much as 0.1% of the gross fission products may appear in the cladding wastes, and that 50% of the ^{137}Cs may also be present,

Table 2. Characteristics of Cladding Wastes

	Zirflex	Sulfex
Acid Wastes		
Composition	0.55 M ZrF_6^{2-}	2.2 M H_2SO_4
	0.55 M F^-	45 g/liter SS
	0.07 M NO_3^-	~ 0.03 g/liter U
	1.72 M NH_4^+	
	~ 0.5 g/liter U or Th	
Volume	1.7 gal/kg U or Th	1.34 gal/kg U
Production rate	2×10^6 gal/yr	7.8×10^5 gal/yr
Neutralized Wastes (as stored)		
Sludge	20-30% by volume	20-30% by volume
pH	10	12
Volume	1.8 gal/kg U or Th	2.0 gal/kg U
Production rate	2.15×10^6 gal/yr	1.14×10^6 gal/yr
Radionuclide content[a]		
0.1% of FP's in fuel	2.3 curies/gal	1.9 curies/gal
	0.03 Btu hr^{-1} gal^{-1}	0.02 Btu hr^{-1} gal^{-1}
^{137}Cs and ^{137m}Ba	22.3 curies/gal	16.7 curies/gal
	0.18 Btu hr^{-1} gal^{-1}	0.14 Btu hr^{-1} gal^{-1}
^{95}Zr-Nb	11.2 curies/gal	
	0.18 Btu hr^{-1} gal^{-1}	
^{60}Co		0.5 curie/gal
		0.03 Btu hr^{-1} gal^{-1}
Totals	35.8 curies/gal	19.1 curies/gal
	0.39 Btu hr^{-1} gal^{-1}	0.19 Btu hr^{-1} gal^{-1}

[a]At 120 days decay following reactor shutdown.

probably as a result of its having diffused to the cladding during irradiation at elevated temperatures.[18] The levels of ^{95}Zr-Nb and ^{60}Co in Zirflex and Sulfex wastes, respectively, were computed by using a natural abundance of 17.4% for ^{94}Zr in Zircaloy, and a content of 0.01 wt % ^{59}Co in stainless steel. It is estimated that the neutralized Zirflex waste, as stored 120 days after reactor shutdown, will exhibit a total activity of about 36 curies/gal and a heat generation rate of about 0.4 Btu hr^{-1} gal^{-1}. The Sulfex waste will have about 19 curies/gal and 0.2 Btu hr^{-1} gal^{-1}. They are stored separately in 1.2 x 10^6-gal tanks, the largest cylindrical containers in which it would be possible to store them without providing mechanical means for removing the decay heat.

Description of Solvent Extraction Raffinate Wastes

The expected volumes, compositions, fission-product levels, and radiolysis products are markedly different from those of cladding wastes. Again, we emphasize that the descriptions given below are at best only representative of raffinate wastes. The volumes, radioactivity levels, etc., actually vary widely from site to site.

Expected Volumes

The uranium converter fuels are recovered by a Purex-process flowsheet,[19] which includes dissolution in nitric acid, followed by separation and purification of uranium by solvent extraction and anion exchange. The thorium converter fuels are processed by an Acid Thorex flowsheet,[20] which consists in dissolving the fuel in a nitric - hydrofluoric acid solution and recovering the uranium and thorium by solvent extraction.

As acid solutions, Purex waste is prepared for storage by evaporation to a concentration equivalent to 100 gal per ton of fuel processed, and Thorex waste is evaporated to a 200 gal/ton equivalency. Under alkaline conditions, the wastes are more dilute and are stored at 600 and 1200 gal/ton equivalencies, respectively.

Although there is no experience in storage of wastes of these compositions containing such large concentrations of fission products,

operating experience with existing tank farms indicates that these volumes may be the smallest from which the decay heat can be removed safely and efficiently. On this basis, the plant generates for storage 150,000 gal/yr of acid Purex waste and 54,000 gal/yr of acid Thorex waste, or 900,000 gal/yr and 324,000 gal/yr of neutralized Purex and Thorex waste, respectively.

Compositions

The wastes contain significant concentrations of nonradioactive chemicals (Table 3). For example, before neutralization, Purex waste is a nitric acid solution with significant concentrations of sodium, iron, aluminum, and sulfate. Thorex waste is less concentrated in nitric acid but contains aluminum, sodium, sulfate, borate, and fluoride as major constituents, and lesser amounts of iron, ammonium, and phosphate. Also, about half the original nitrate is converted by radiolysis to nitrite in both wastes. In addition to the soluble constituents, some insoluble materials are present, principally hydrated silica, which settles slowly to occupy about 5% by volume of the waste. Some fission products are associated with these solids, probably as products of hydrolysis, but they are not of such a nature as to constitute a serious heat-removal problem during storage or to be an impediment to intra-tank transfer of the waste when that becomes necessary.

When neutralized with caustic, using 10% excess NaOH over stoichiometric requirements, iron and many of the fission products precipitate. As much as 80% of the fission product radioactivity is associated with these solids which, when settled, occupy 2 to 3% of the waste volume. Similar sludges at Hanford and Savannah River have sometimes posed difficult problems of heat removal, and temperatures in the sludges of 200 to 300°C have been observed. With the waste concentrations used in this study, however, the nonradioactive waste constituents have been diluted to a degree where considerations of heat removal and solids transfer should not pose especially severe problems.

Since Purex and Thorex wastes are chemically compatible with each other in both acid and alkaline form, they are mixed for tank storage. The compositions of the resulting composite wastes are given in Table 3.

Table 3. Compositions of Purex and Thorex Wastes, Separate and Mixed

	Purex		Thorex		Mixed (as stored)	
	Acid	Neutralized	Acid	Neutralized	Acid	Neutralized
Volume, gal/ton U or Th	100	600	200	1200	--	--
Component						
H^+, M	3.7	--	0.93	--	3.0	--
N^+, M	0.4	0.78	0.30	0.39	0.37	0.68
Fe^{3+}, M	0.2	0.03	0.02	0.003	0.15	0.023
Al^{3+}, M	0.1	--	0.22	--	0.13	--
AlO_2^-, M	--	0.02	--	0.04	--	0.016
NH_4^+, M	--	--	0.05	--	0.01	--
NO_3^- & NO_2^-, M	5.0	0.83	1.1	0.18	4.0	0.66
OH^-, M	--	0.03	--	0.02	--	0.027
SO_4^{2-}, M	0.2	0.03	0.26	0.04	0.22	0.033
F^-, M	--	--	0.09	0.02	0.02	0.005
PO_4^{3-}, M	--	--	0.02	0.003	0.01	0.001
BO_3^{3-}, M	--	--	0.22	0.04	0.06	0.011
$SiO_2 \cdot x\ H_2O$, M	~ 0.01	~ 0.002	~ 0.01	~ 0.002	~ 0.01	~ 0.002
Total FP's, M	~ 0.2	~ 0.03	~ 0.2	~ 0.03	~ 0.2	~ 0.03

Fission Product Levels

The concentration of fission products in these raffinates is the same for both types of waste - Purex and Thorex: 23 g/liter in the acid wastes, and 4 g/liter in the alkaline wastes. The radioactivity level of the acid wastes at the time of their production, 120 days after removal of the fuel from the reactor, is 37,000 curies/gal, equivalent to 138 w/gal. When neutralized, they contain 6200 curies gal, or 23 w/gal.

The inventory of radioisotopes in a tank at any time is a function of tank capacity, the rate of filling, and the time elapsed since full. An IBM 7090 computer code was used to estimate the fission-product heat generation rate with time for the tank farm and for individual batches of wastes representing tanks of different capacities (Fig. 1). The calculations showed that during 20 yr of waste accumulation, the total fission-product heat generation rate rises to 1.02×10^8 Btu/hr. Then, assuming no further accumulation after that time, the rate drops by a factor of 4 over the next ten years, and decreases to insignificant levels over the next two to three centuries. Also shown in Fig. 1 are example cases of tanks containing 68,000, 200,000, and 10^6 gal of the composite acid Purex and Thorex waste, or the proportionate amounts of the composite alkaline waste. With the waste production rates used in this study, tanks of these capacities would be filled in 1/3 yr, 1 yr, and 5 yr, respectively, and maximum heat generation rates of 2.3×10^7 Btu/hr, 4.3×10^7 Btu/hr and 7.2×10^7 Btu/hr are obtained when the tanks are first filled. The rates then decrease with time and reach a value of 10^5 Btu/hr after 80 to 200 yr of decay. This is about the rate of heat loss by natural conduction to the environment from each of these tanks.

Products of Radiolysis

Radiolysis of water or aqueous solutions results in the production of H_2 and H_2O_2. For nitrate solutions, the hydrogen yields $[G(H_2)]$, defined as the number of molecules formed per 100 ev of absorbed energy, have been shown to be dependent on the nitrate ion concentration. From the data of Mahlman,[21] it is estimated that $G(H_2)$ for the acid wastes is 0.03, and for the alkaline wastes 0.1. Therefore, for each million Btu

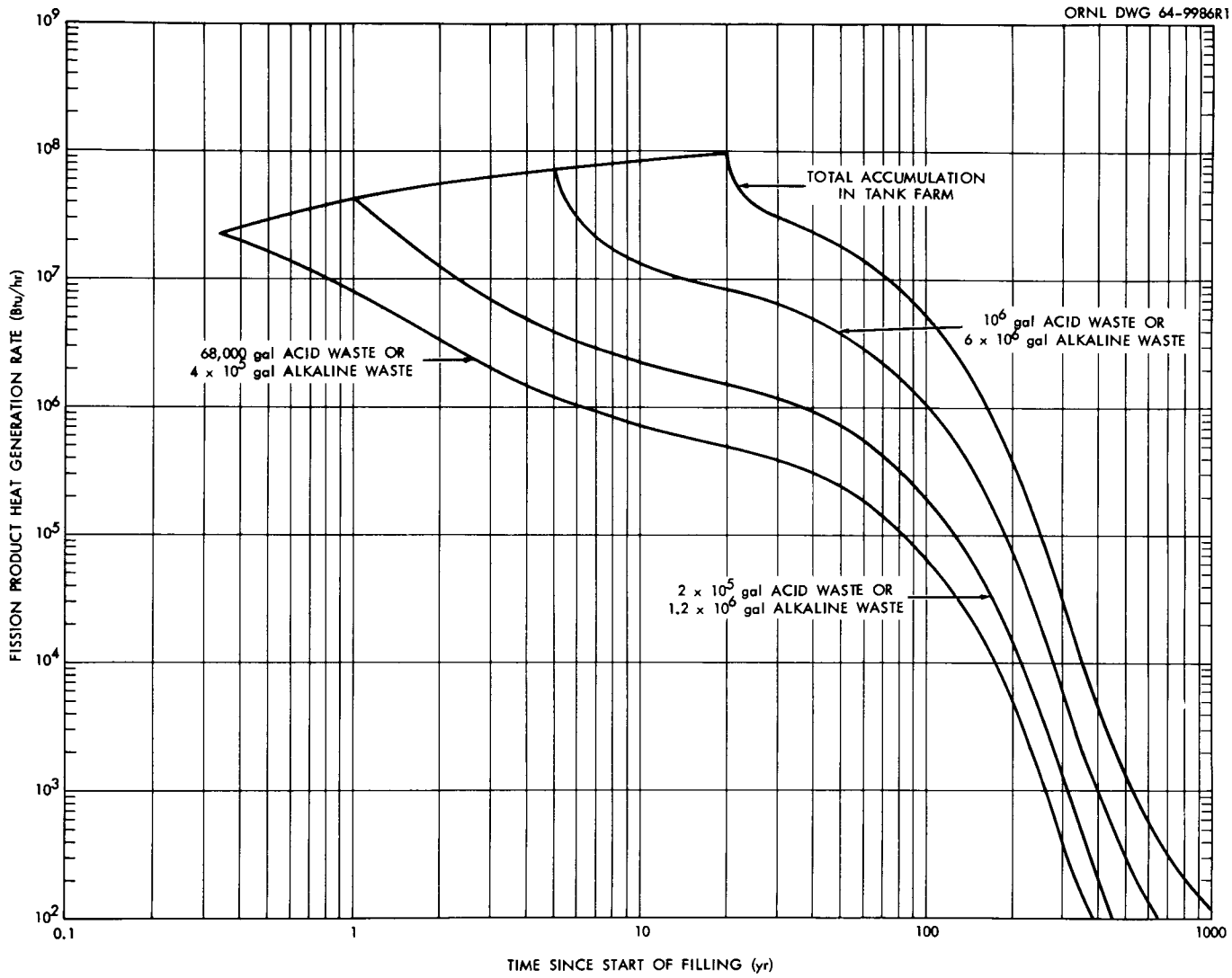


Fig. 1. Variation of Heat Generation Rate with Time for Tanks Containing Purex and Thorex Wastes.

of heat generated in acid waste, about 3 ft^3 of molecular hydrogen is produced, and about 10 ft^3 of hydrogen per million Btu is produced in alkaline waste.

Corrosivity of the Wastes, and Measures To Lessen It

Most of the waste storage tanks that have failed to date were lost because of either pit corrosion or stress corrosion in alkaline systems.[13] Although general corrosion rates for alkaline waste storage in carbon steel are only about 0.02 mil/yr at their boiling points, some pitting has been observed. In other tanks, stress corrosion at the weld-affected areas has indicated the need for additional heat treatment of the tanks, in place, before use. It is believed that annealing for 1 hr at 1000°F will eliminate stress corrosion.[22] Overall corrosion rates of acid wastes in type 304L and 347 stainless steels at about 140°F are a few hundredths of a mil per month, with grain-boundary but no intergranular attack,[23,24] but corrosion rates are accelerated to 30 to 45 mils/yr at temperatures near boiling.[25] Consequently, in this study, neutralized wastes are stored in stress-relieved mild-steel tanks, and acid wastes are stored in type 304L stainless steel tanks at temperatures not exceeding 140°F.

3. DESCRIPTION OF FACILITY

After the desired adjustments of volume and acidity or alkalinity have been made in the fuel processing plant, the wastes are transferred to a tank farm for long-term storage. Figure 2 is a conceptual layout of a "completed" tank farm, containing a 20-yr accumulation of waste. The farm is divided into two areas, one containing tanks of raffinate wastes and their associated cooling and ventilation facilities, and the other containing tanks of cladding wastes. In this farm, the high-level wastes are stored as acid solutions in 10^6-gal tanks grouped around three sides of an operations building that contains many of the major equipment items of the cooling and ventilation systems. A cooling tower and pumps, an emergency water storage tank, a water surge tank, and a stack and fans are also located in this area. The cladding wastes are stored in alkaline form in tanks of about 1.2×10^6-gal capacity. Cooling is not

ORNL-DWG 64-9146

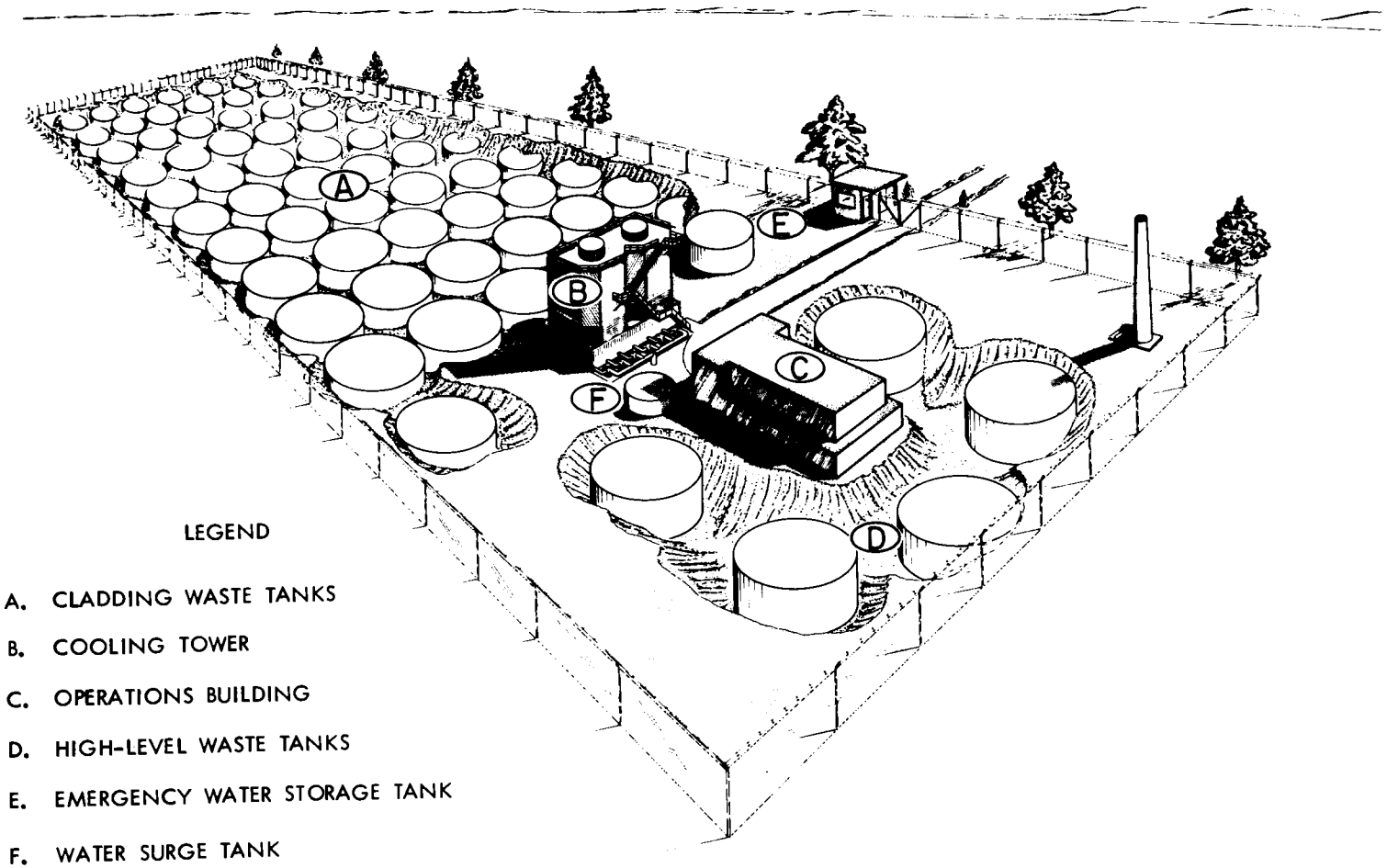


Fig. 2. Layout of Waste Storage Tank Farm.

provided for these wastes. In addition to filled tanks, an empty tank in each area is always maintained on standby to receive the contents of any tank that may have failed.

The tank farm occupies about 52 acres of land, of which 48 are devoted to the cladding wastes, and 4 to the raffinate wastes. The farm is centrally located on one square mile of land (640 acres), which serves as the controlled area and from which the public is excluded. Further details of tank farm layouts and piping can be obtained from Figs. A-1, A-2, and A-3 in the Appendix.

Tanks

The tanks are similar in design to those in use at the Savannah River Plant[26] (Fig. 3). They are cylinders having a diameter-to-height ratio of 3, are made of 1/4- to 2-in.-thick steel plate, and are housed in steel-lined, reinforced-concrete vaults with walls 2 to 4 ft thick, buried under about 10 ft of earth. Stainless steel is used to contain acid wastes; carbon steel is used for alkaline wastes. Dimensions and thicknesses of construction materials for the tanks and vaults used in this study are given in Table A-1 in the Appendix. The tanks are constructed in accordance with the ASME code for unfired pressure vessels, and all welds are completely radiographed. In the case of the mild steel tanks, the welds are stress-relieved by heating at 1000°F for 1 hr. The concrete vaults are constructed according to the recommendations of the Portland Cement Association Bulletin No. ST-57.

For dehumidification, heated air is circulated through the $2\frac{1}{2}$-ft annular space between the tank and vault. The occurrence and severity of leaks are determined by monitoring for both liquid and airborne radioactivity in the annulus. The tanks have steel-lined, internal columns for support and, in the case of high-level waste storage are equipped with cooling coils which serve as the primary means for removing heat due to radioactive decay. A water-cooled condenser located in the operations building serves as the secondary means for heat removal, and steam produced from self-boiling wastes during emergencies is vented to this condenser through a 4-ft-diam off-gas header in the top of the tank.

ORNL-LR-DWG 40043 R-3

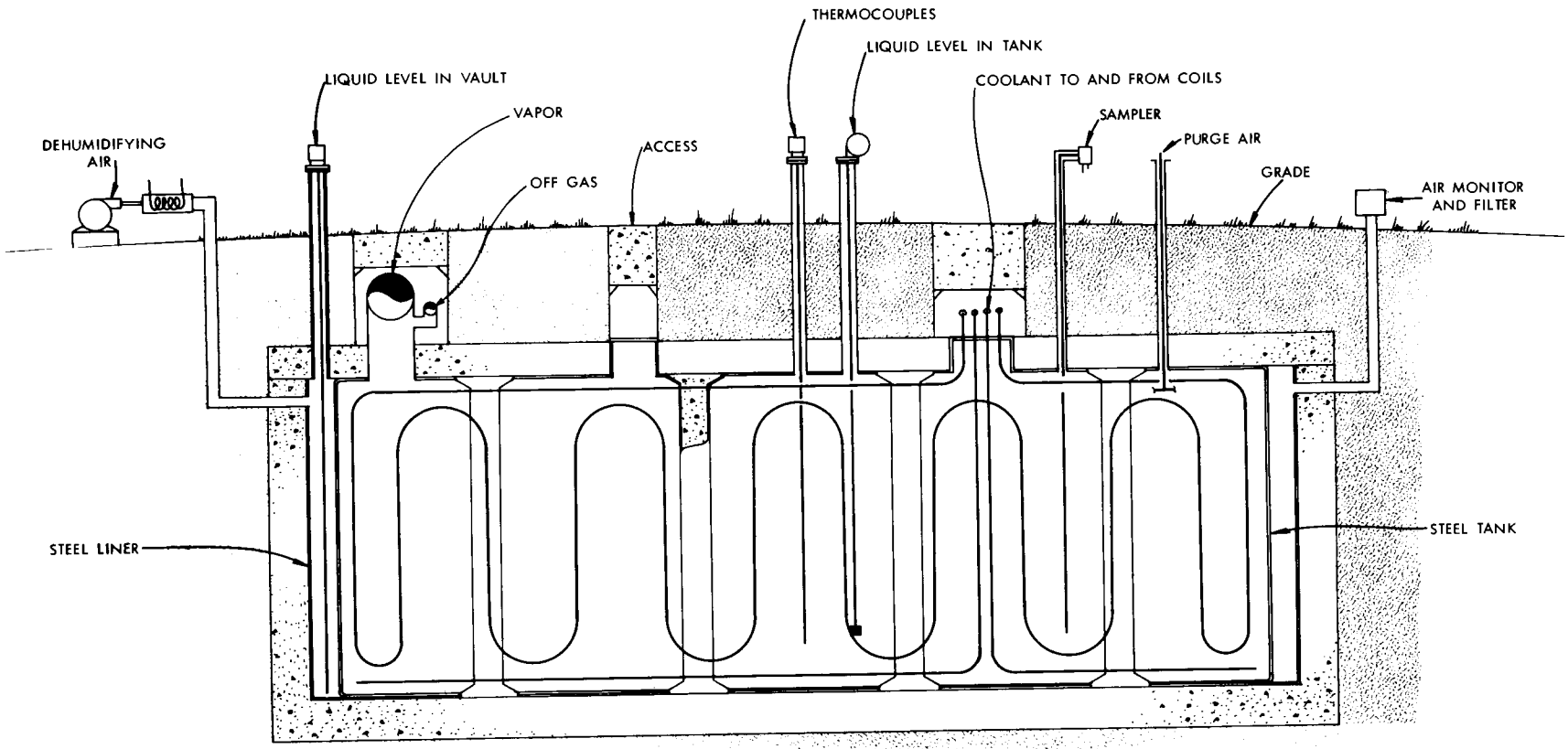


Fig. 3. Waste Storage Tank.

Air, which during normal operation is swept through the vapor space in the tanks at a rate of about 600 cfm to remove radiolytic hydrogen, is likewise vented through the off-gas header. Instruments are provided to measure and record the temperature, density, and liquid level of the tank contents, the concentration of hydrogen in the vapor space above the liquid, the pressure inside the tank, and to detect the presence of liquid and radionuclides in the annulus. The tanks are also provided with access ports for introducing sluicing jets and pumps for removing the wastes when this becomes desirable.

Cooling System

Since heat removal by conduction to the surroundings from tanks with these design features is relatively insignificant (7 to 8 Btu per hour per square foot of tank surface[27]), facilities for removing heat must be provided over the period of time required for the heat generation rate in a tank to decrease to about 10^5 Btu/hr. From Fig. 1 it can be seen that 80 to 200 yr will be required for tanks of the capacities considered in this study. In all cases, several tank lifetimes are probably represented. In this study, a cooling system was designed for the first 20 yr of tank-farm operation (Fig. 4, Table 4). When the wastes are transferred to new tanks from old or defective ones, smaller cooling systems designed to handle the heat loads at those times will be provided.

The contents of the tanks are kept at 140°F by circulating water through vertical and horizontal coils submerged in the waste. To keep the pressure drop inside the coils at an acceptable level, as well as to provide versatility of operation, the coils in each tank are arranged in banks of 1420-ft lengths of 3-inch sched-40 pipe. Each bank is connected to the water supply and discharge headers through valves that allow it to be placed in service or removed, as required. The total lengths of coils and number of banks required for tanks of various capacities are given in Table A-1 of the Appendix.

The water from the coils is passed through external heat exchangers where the heat is transferred to a secondary water-cooling circuit and then recycled through a 2.5×10^5-gal surge tank (5×10^5 gal for an

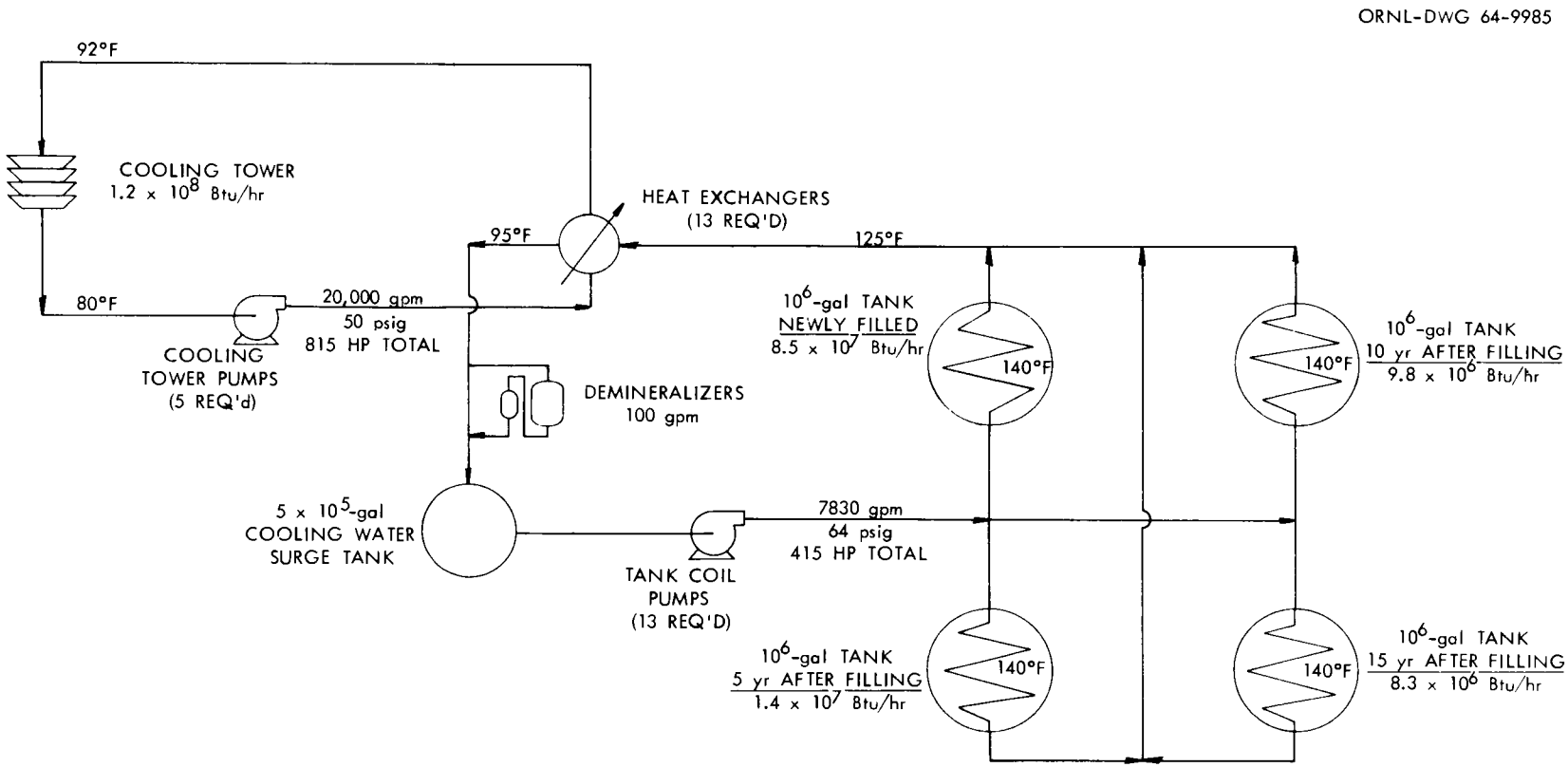


Fig. 4. Schematic of Waste Cooling System for Acid Waste Tank Farm after 20 Years of Operation.

Table 4. Specifications of Cooling System for Tank Farm

Basis: 20 yr of waste accumulation; maximum heat generation rate, 1.0×10^8 Btu/hr

Primary cooling system		
Tank coils	Overall coeff., U	50 Btu hr^{-1} ft^{-2} $°F^{-1}$
	Length 3-in. pipe per bank	1420 ft
	Water velocity	5 fps
	Pressure drop, coils	21 psi
	Pressure drop, total	64 psi
Heat exchangers	Overall coeff., U	200 Btu hr^{-1} ft^{-2} $°F^{-1}$
	Heat transfer area (each)	2000 ft^2
	Length tubing (each)	9750 ft
	Number 15-ft tubes (each)	650
	Diam of exchanger	5 ft
	Flow rate, tube side	600 gpm
	Number of exchangers	13
	Number of spares	1
Tank-coil pumps	Capacity (each)	600 gpm
	Head	150 ft
	Horsepower delivered	23
	Number required	13
	Number of spares	1
Demineralizer system	Anion resin bed volume	51 ft^3
	Cation resin bed volume	25 ft^3
	Regeneration time	255 days
Cooling tower	Water flow rate	17,500 gpm
	Effective area	8000 ft^2
	Fan horsepower	330
Cooling-tower pumps	Capacity (each)	4000 gpm
	Head	113 ft
	Horsepower delivered (each)	114
	Number required	5
	Number of spares	1
Emergency condenser circuit		
Condenser	Overall coeff., U	400 Btu hr^{-1} ft^{-2} $°F^{-1}$
	Heat transfer area	3000 ft^2
	Number 26-ft tubes	2500
	Diam of condenser	6 ft
	Flow rate, tube side	9000 gpm
Condensate surge tank	Capacity	50,000 gal
Condensate pump	Capacity	200 gpm
Total water requirements	Acid tank-farm holdup	$\sim 3.5 \times 10^5$ gal
	Alkaline tank-farm holdup	$\sim 5.5 \times 10^5$ gal
	Makeup rate	525 gpm
Total power requirements		1500 kw

alkaline tank farm) to the tank coils. Thirteen heat exchangers and one spare are provided, each with a rated heat duty of 9×10^6 Btu/hr. They are of the shell and tube type, about 5 ft in diameter and 18 ft long, externally, and with 2000 ft^2 of heat-exchange area. Thirteen centrifugal pumps and one spare are provided for water circulation in this circuit, each with a rating of 600 gpm at 150 ft of water head.

The concentration of ionic impurities in the water of the tank-coil circuit is held at about 1 ppm by passing a 100-gpm sidestream through a double-bed demineralizer system.

Heat is removed from the secondary circuit by passing the water through an induced-draft cooling tower before circulation to the heat exchangers. The cooling tower is rated at 1.0×10^8 Btu/hr at a wet-bulb temperature of 75°F. Cooling water is circulated at a maximum rate of 17,500 gpm by five pumps (plus one spare), each capable of delivering 4000 gpm at 113 ft of water head.

In the event of a shutdown of the primary cooling system, the wastes would self-heat to their boiling point over a period of 10 or more hours. When the water boils, the heat is removed by condensing the vapor in a water-cooled surface condenser located in the operations building. This condenser is sized to handle the maximum heat load of the tank farm, 1.0×10^8 Btu/hr, has dimensions 6 ft by 30 ft, and has a heat-transfer area of 3000 ft^2. Cooling water for the condenser is supplied at a rate of 9000 gpm from the cooling water circuit and the 2×10^6-gal emergency water storage tank, if necessary. The condensate is collected in a 50,000-gal tank adjacent to the condenser and is pumped back to the storage tanks to maintain the proper waste volumes and concentrations.

For the acid tank farms, all equipment and piping in the tank-coil cooling circuit and in the emergency condenser circuit is made of type 304L stainless steel. All equipment and piping in the cooling tower circuit is made of carbon steel. In the alkaline-waste tank farms, both the cooling coil and cooling tower circuits are made of carbon steel; however, the emergency condenser circuit is of stainless steel.

Operations Building

Centrally located in the tank-farm complex, the 90- x 168-ft, two-story operations building contains much of the supporting equipment and

instrumentation for operating the tank farm (Figs. 5 and 6). The building is made of poured concrete below grade level and concrete block above grade, and has a builtup tar-and-gravel roof. The building is divided into "nonregulated and regulated" zones. The nonregulated zone contains the offices, change room, maintenance and supplies storage facilities, and the heating and ventilation equipment. The regulated zone houses the primary-cooling-system demineralizers and operating corridors on the first level; the primary-cooling-system heat exchangers and pumps are in centrally located pits, below grade, covered with steel grating. A 10-ton bridge crane is provided over this area. Valve corridors and the emergency reflux condenser, condensate catch tank, and deep-bed filter, enclosed in concrete cubicles, are also below grade. The regulated zone provides secondary containment for the auxiliary equipment and prevents release of activity to the atmosphere in the event of a series of progressive accidents. Routine access into the regulated zone is through the change room, and an airlock is used to bring equipment into this zone without breach of containment.

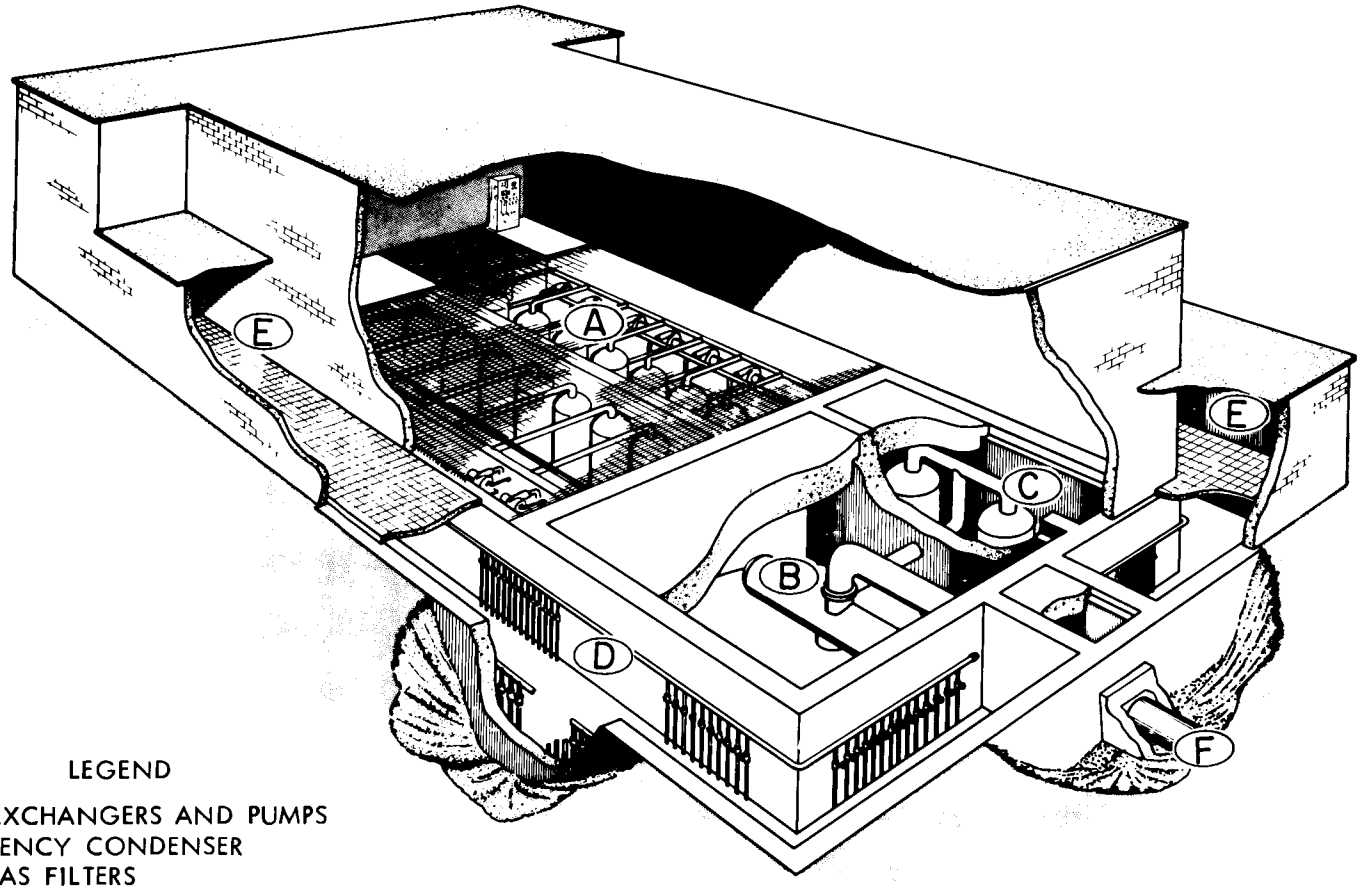
The operations building is ventilated with forced air, with a minimum of six changes per hour in the nonregulated zone and ten per hour in the regulated zone. Pressure areas are regulated to ensure the flow from the cold areas to the potentially contaminated areas. The system flow is downdraft with the air exhausted through the pit and cubicles. The effluent streams are collected and filtered through absolute filters before discharge to the stack.

Additional details of the equipment layout and piping in the operations building are shown in Figs. A-4, A-5 and A-6 in the Appendix.

Piping and Ventilation

As the waste is transferred from the processing plant to the tank farm for storage, it flows through a diversion box which serves as an intermediate valve station and from which it is possible to divert the flow to any of the storage tanks. There are three 3-in. lines from the diversion box to each tank, and these lines can also be used for intratank transfer of waste when required. The lines lie in individual steel

ORNL-DWG 64-9150



LEGEND

A. HEAT EXCHANGERS AND PUMPS
B. EMERGENCY CONDENSER
C. OFF GAS FILTERS
D. COOLING COILS VALVE CORRIDOR
E. OPERATING AREA
F. TANK VAPOR HEADER

Fig. 5. Operations Building.

ORNL-DWG 64-9975

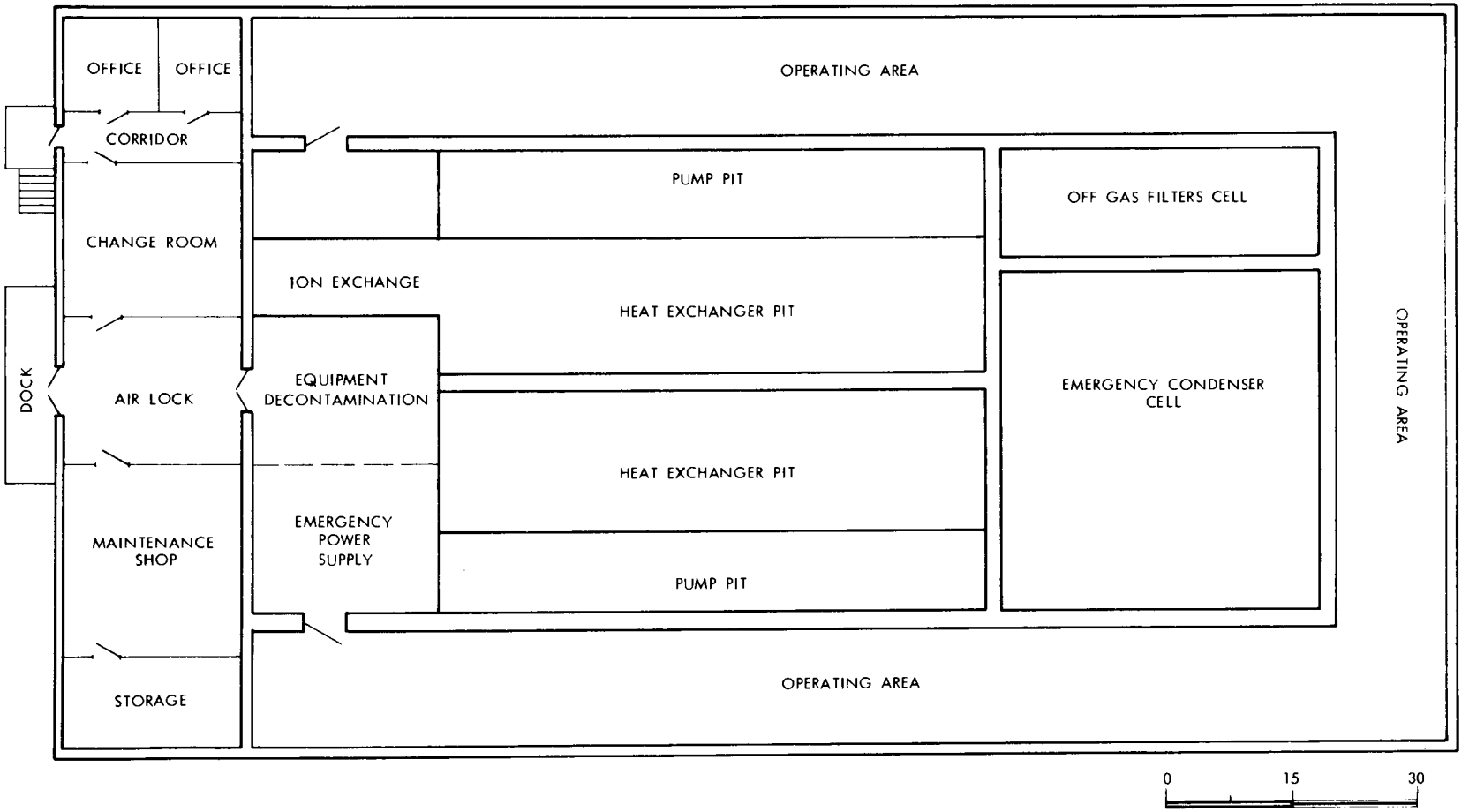


Fig. 6. Plan View of Operations Building.

troughs inside underground concrete trenches, and the troughs are monitored for leaks at appropriate intervals along their lengths.

As a tank fills, the required number of cooling-coil banks, as determined by the decay-heat load, are activated. Valves for this purpose are located in the downcomer lines from the water-supply headers and in the coil exit lines upstream from the return header. Each bank is monitored for water temperature and pressure in the valve-area located beneath the operating corridor in the operations building. In those farms containing more than five raffinate waste tanks, additional valve-areas outside the operations building are required. These valve pits, each sized to handle the coil terminals for as many as four tanks, are located strategically among the tanks (Figs. A-7 and A-2, Appendix).

Each raffinate waste tank is purged continuously with about 600 cfm of air to prevent accumulation of radiolytic hydrogen gas. The purge air leaves the tank through a 48-in.-diam header at the top. This header, terminating at the reflux condenser, is equipped with a liquid pressure seal that can be drained under emergency conditions as described below. During normal operation, the purge air bypasses the seal and condenser through 6- and 12-in.-diam lines, passes through a deep-bed filter in the operations building, and thence to the stack. Control valves located in the purge air by-pass line maintain equal pressure in all tanks. The cladding-waste tanks are vented through 6-in.-diam stainless steel lines to the deep-bed filter.

Provisions for Emergencies

To ensure continuous operation of the tank farm, equipment that is subject to failure or which requires maintenance is "spared" or located in parallel arrays to permit isolating faulty units for repair. Pumps, valves, and heat exchangers can be decontaminated, repaired in the maintenance shop, and placed in standby. Additionally, provision is made for three major emergencies: the failure of a tank, the loss of cooling to one or all tanks, and the loss of electrical power.

If leakage from a tank into a vault is detected, and if it appears desirable to transfer the contents of the defective tank to a standby

tank, a sluice-jet or pump is lowered into the tank through one of the access ports, and the waste is transferred through the diversion box to the new tank. A temporary containment shell may be erected over the tank during this operation to prevent or minimize any release of activity to the atmosphere. This same procedure is followed, although on a less urgent schedule, for all waste transfers between tanks.

The valving of individual cooling-coil banks permits removal of defective coils from service and continued operation with the remainder. In the event of total loss of cooling, the contents may be either transferred to another tank or allowed to self-boil for a limited time. During boiling, the purge air is turned off, its by-pass line closed, and the liquid pressure seal in the 48-in.-diam off-gas header is drained. The vapor passes through this header to the emergency condenser. The condensate is collected and pumped through the diversion box to either the same or to a different tank, and the noncondensable gases are filtered and released through the stack. The cooling water for the reflux condenser can be supplied from either the primary or secondary cooling circuits, or from the emergency water supply.

To ensure the continued operation of the tank farm in the event of a power failure, a standby diesel-powered generator (1500-kw capacity) is provided in a sheltered area outside the operations building.

4. CAPITAL COSTS

Capital costs of tank farms were estimated for storing raffinate wastes as acid solutions in tanks ranging in capacity from 200,000 to 2×10^6 gal, and for storage in alkaline form in tanks from 400,000 to 4.8×10^6 gal capacity (Table 5). In computing construction costs, 27% was allowed for overhead, and an additional 9 to 14% for engineering design and inspection. Engineering design and inspection costs are calculated as the total of 15% of all capital costs exclusive of tank costs, 25% of the cost of the first tank, and 7% of the costs of all additional tanks. A fixed cost for land of $300,000 was assumed, and finally, a contingency of 15% of the total of the above costs was added. The total capital costs for acid raffinate storage ranged from $21,734,000 for

Table 5. Capital Costs of Raffinate Waste Tank Farms

	Acid Raffinate Storage					Alkaline Raffinate Storage					
	Three 2×10^6-gal tanks	Four 1.6×10^6-gal tanks	Five 1×10^6-gal tanks	Eight 6×10^5-gal tanks	Twenty-one 2×10^5-gal tanks	Six 4.8×10^6-gal tanks	Nine 3.2×10^6-gal tanks	Thirteen 2×10^6-gal tanks	Twenty-one 1.2×10^6-gal tanks	Thirty-One 8×10^5-gal tanks	Forty-one 4×10^5-gal tanks
1. Construction costs, $											
A. Site clearance	40,000	40,000	40,000	40,000	40,000	40,000	40,000	40,000	40,000	40,000	40,000
B. Operations building (Table A-2)	819,500	819,500	819,500	819,500	819,500	819,500	819,500	819,500	819,500	819,500	819,500
C. Outside facilities (Table A-3) Elec. substation, cooling tower and pumps, water tanks, stacks, fans, sanitary and storm systems, road, emergency power station, fencing	1,071,000	1,071,000	1,071,000	1,071,000	1,071,000	964,000	964,000	964,000	964,000	964,000	964,000
D. Outside lines (Table A-4) Cooling system piping, waste condensate system, waste distribution system, yard power and lights	387,200	539,500	603,600	645,300	2,156,600	440,000	557,700	750,500	1,147,200	1,671,900	2,759,300
E. Valve pits and pit piping (Table A-5)	–	–	–	697,100	1,226,300	195,000	323,500	425,900	610,900	740,000	1,140,900
F. Equipment and piping inside operations building (Table A-6)	1,136,700	1,221,600	1,272,700	834,800	889,500	696,000	510,000	505,200	500,300	537,100	475,700
G. Waste tanks (Table A-7)	9,449,100	10,814,400	10,618,500	13,724,000	23,032,800	13,721,400	15,152,400	15,553,200	17,637,900	19,644,700	26,248,300
Subtotal	12,903,500	14,506,000	14,415,300	17,831,700	29,235,700	16,875,900	18,367,100	19,058,300	21,719,800	24,417,200	32,447,700
H. Construction overhead, 27%	3,483,900	3,916,600	3,892,100	4,814,600	7,893,600	4,556,500	4,959,100	5,145,700	5,864,300	6,592,600	8,760,900
Subtotal	16,387,400	18,422,600	18,307,400	22,646,300	37,129,300	21,432,400	23,326,200	24,204,000	27,584,100	31,009,800	41,208,600
I. Eng. design and inspection (Table A-8)	2,212,000	2,276,000	2,148,000	2,389,000	3,473,000	2,358,000	2,359,000	2,338,000	2,552,000	2,814,000	3,613,000
Subtotal	18,599,400	20,698,600	20,455,400	25,035,300	40,602,300	23,790,400	25,685,200	26,542,000	30,136,100	33,823,800	44,821,600
2. Land	300,000	300,000	300,000	300,000	300,000	300,000	300,000	300,000	300,000	300,000	300,000
Subtotal	18,899,400	20,998,600	20,755,400	25,335,300	40,902,300	24,090,400	25,985,200	26,842,000	30,436,100	34,123,800	45,121,600
3. Contingency, 15%	2,834,900	3,149,800	3,113,300	3,800,300	6,135,300	3,613,600	3,897,800	4,026,300	4,565,400	5,118,600	6,768,200
Total cost of project, $	21,734,300	24,148,400	23,868,700	29,135,600	47,037,600	27,704,000	29,883,000	30,868,300	35,001,500	39,242,400	51,889,800

storage in three 2 x 10^6-gal tanks, to $47,038,000 for storage in twenty-one 2 x 10^5-gal tanks. Costs for storing the wastes in alkaline form ranged from $27,704,000 for six 4.8 x 10^6-gal tanks to $51,890,000 for sixty-one 4 x 10^5-gal tanks. A spare tank is included in every case.

The capital cost for storing alkaline cladding wastes in a farm consisting of sixty-one 1.2 x 10^6-gal tanks is $52,267,000 (Table 6). The cladding waste farm consists only of tanks without cooling coils, the necessary waste-distribution and tank-vent systems, and electrical services. Engineering and inspection costs for this farm are computed as 15% of all capital costs, including one tank, and 5% of the cost of the additional sixty tanks. No cost for land was allocated.

More-detailed tabulations of the capital costs are given in Tables A-2 through A-8 in the Appendix.

5. OPERATING COSTS

Operating costs are composed of labor costs, labor overhead, services (electricity, water, water-treatment chemicals, and demineralizer resins and regeneration chemicals), maintenance, waste transfer, property taxes, and property and liability insurance. Most of these items increase with the size of the tank farm during the 20-yr waste accumulation period, then decrease as the fission products decay and the cooling requirements are reduced. Also, taxes and insurance costs are dependent on the type of financing assumed, that is, government, private, or a combination of government and private.

Labor

Using as a guide the requirements for tank farms at Hanford and Savannah River, a total of 8 man-years is estimated for the raffinate tank farm at the end of its 20-yr accumulation period. This may be broken down as follows: 1/4 man-year each, for supervision, health physics, security, and analytical; 1 man-year for an engineer; 2 man-years for maintenance; 4 man-years for operators. A cost of $10,000 per man-year is used. The total labor cost is proportional to the total fission-product heat generation rate of the tank farm, and increases from $10,000/yr

Table 6. Capital Costs of Cladding-Waste Tank Farm

1.	Construction costs, $	
	A. Waste tanks	
	Sixty-one 1.2 x 10^6-gal tanks	33,172,700
	B. Waste-distribution system	
	Lines	394,700
	Concrete trenches and earthwork	150,200
	Diversion box	25,000
	C. Tank vent system	134,800
	D. Yard power and lighting	85,500
	Subtotal	33,962,900
	E. Construction overhead, 27%	9,170,000
	Subtotal	43,132,900
	F. Eng. design and inspection	2,325,100
	Subtotal	45,458,000
2.	Contingency, 15%	6,818,700
	Total cost of project, $	52,276,700

at zero heat load to $80,000/yr at 20 yr. It then decreases with the heat load to $10,000/yr and remains fixed at that value thenceforth.

Labor requirements for the cladding-waste tank farm increase with the volume of waste in storage from 1 man-year at startup to 2 man-years at 20 years. It then remains fixed at 1 man-year for perpetuity.

Overhead

Overhead is taken as 50% of labor cost.

Services

The cost of services is considered to be proportional to the total heat-generation rate. Electricity is computed at 8 mill/kwh, and the maximum requirement after 20-yr waste accumulation is 1320 kw, or $92,370/yr. Water requirements are based on 3% blowdown of the water in the secondary (cooling tower) circuit, and the cost is taken as 12¢/1000 gal. For 20 years, at 525 gpm, the maximum annual cost is $33,323. Water-treatment chemicals for the secondary cooling circuit are estimated to be 3% of the cost of the water. Demineralizer resins and regeneration chemicals increase with heat generation rate to a maximum of $3.10/day ($1133/yr) at 20 years, then decrease with cooling requirements. There are no charges for services for cladding wastes.

Maintenance

Maintenance is taken as 1% of the capital investment during the accumulation period. It then decreases with the heat generation rate to 0.2% of the capital investment. For the cladding-waste farm, maintenance is taken as 0.1% of the capital investment.

Waste Transfer

At scheduled intervals corresponding to the assumed lifetime of the tanks, transfer of the waste to new tanks through the existing lines and diversion box, and "moth-balling" of the old tanks is required. For each transfer operation, $50,000 is allocated, regardless of tank size. The moth-balling cost is taken as the cost of the concrete required to fill the evacuated tank.

Property Taxes

For private ownership, property taxes are taken as 1-1/2% of the capital investment during the accumulation period, and this is reduced to 0.1% of the capital investment after that time. For government ownership, property taxes are not included. For private ownership during the accumulation period and government ownership thereafter, taxes are assessed only during the accumulation period.

Insurance

For private ownership, property insurance is taken as 0.2% of the capital investment. There is no experience or schedule on which to base the cost of liability insurance; however, an annual premium of $60,000 is used in this study to provide an estimated $60,000,000 worth of insurance. A liability insurance charge of $10,000/yr is used for cladding wastes. For government ownership, neither property nor liability insurance is included.

6. ECONOMIC MODEL

The capital and operating costs were used in a computer code to calculate the total costs of waste storage for a range of tank sizes, tank lifetimes, fission product concentrations, and for different methods of financing. Details of this computer code are given in Appendix B; however, the economic model used is summarized below.

Accumulation and "Dead" Periods

During the accumulation period of 20 years, waste is accumulated in the tank farm at a constant rate. (See Chap. 2 for volumes of acid and alkaline raffinate and cladding waste streams.) The dead period, of infinite duration, ensues following the accumulation period.

Permanent Fund

To provide for perpetual care of the waste during the dead period, a permanent, tax-free fund is established by making annual deposits during the accumulation period. The size of this fund is calculated so that the

annual tax-free interest will be sufficient to provide for the periodic replacement of tanks, for the replacement of other necessary equipment at 30-yr intervals, and for the annual operating expenses of the facility. The permanent fund also includes a contingency account, equal to the cost of an unscheduled replacement of one tank, transfer of its contents, and filling the defective tank with concrete. No advantage is taken of the accumulation of interest of this part of the permanent fund, since this account may be expended at any time.

Sales Income

Sales income is received only during the accumulation period. The required annual sales income is calculated so as to be just adequate to provide for recovery of investment and return on investment, annual operating expenses (including local taxes), annual deposit into the permanent fund, and federal income taxes.

Capital is derived partly from bonds and partly from stock. The fraction in stock (equity) is assumed to be 35%, and the earning rates on bonds and on stocks for the three cases considered are specified in Table 7. Case 1 assumes government ownership and operation throughout. Case 2 assumes private ownership and operation during the accumulation period, then government ownership and operation thenceforth. Case 3 assumes private ownership and operation during both accumulation and dead periods.

Table 7. Economic Parameters

	Case 1: Government Ownership	Case 2: Private and Government Ownership	Case 3: Private Ownership
Fraction capital invest. in equity	0.35	0.35	0.35
Return on equity	4%	15%	15%
Interest on bonds	4%	5%	5%
Interest on permanent fund	4%	4%	4%
Income tax rate	0	48%	48%

The annual sales incomes are received at the end of each year of the accumulation period and are deemed adequate when the total present value of the sales incomes is equal to the total present value of the investments, expenses, deposits into the permanent fund, and taxes, for the accumulation period. The interest rate used in calculating present values is the weighted average of the earning rates on bonds and stock, corrected for the effect of income taxes. Recovery of investment is complete at the end of the accumulation period.

The total cost in dollars per gallon of waste is obtained by dividing the required annual sales income by the waste accumulation rate, in gallons per year. The cost in mills per kilowatt-hour is obtained by dividing the sales income by 1.570×10^{11}, the kilowatt-hours of electricity generated from the reactor fuel.

Construction Schedule

Since a return must be earned on any investment, it is advantageous to defer all expenditures as long as possible. Consequently, the tank farm construction schedule is fitted to the demand. In those cases where tank capacity exceeds one year's waste accumulation, one tank and spare are installed initially. If the tank capacity is less than one year's accumulation, tankage for one year's requirement, and one spare tank, are installed. Thereafter, new tankage is installed as needed, but no oftener than on an annual basis. The service lives of all tanks are equal. Where practical, other facilities, including heat exchangers, pumps, and piping, also are installed piecemeal according to the demand.

Items that cannot be installed in this manner are built full-size at the start of the project. These include the cooling tower, operations building, emergency water tank and power supply, cooling-water surge tank, the waste condenser and condensate catch tank, stack, fan, filters, and associated piping.

Federal Income Taxes

Federal income taxes are paid only during the accumulation period. The permanent fund is tax exempt, that is, neither deposits into the fund

nor interest drawn by it are taxable. Depreciation for tax purposes is as follows: (1) straight-line depreciation is used throughout; (2) the depreciable life of a tank is equal to its filling time; (3) the remainder of the plant is fully depreciated for tax purposes at the end of the accumulation period.

Price Escalation and Inflation

No attempt is made to take into account the effect of price escalation or inflation; price levels remain constant.

7. TOTAL COSTS

The costs of perpetual storage of raffinate wastes and cladding wastes were computed independently by the computer code TASCO, described in Appendix B. The entire computer output for one example case is given in Table B-2; only summaries of the results are presented below.

Raffinate Waste Storage

Summaries of the total costs of perpetual storage of acid and alkaline raffinate wastes as a function of tank size are presented in Tables 8, 9, and 10 for government ownership (Case 1), combination government and private ownership (Case 2), and private ownership (Case 3), respectively. Tank lifetimes of 25, 50, and 75 years are considered. Total costs are given in terms of dollars per gallon of waste, and mills per kilowatt-hour of electricity generated from the fuel. Also, capital costs, maximum annual operating costs, and the magnitude of the permanent fund and the 20 annual deposits required to establish the fund are given.

Capital costs are independent of tank lifetime and method of financing. For acid waste storage, they ranged from \$22.15 million for storage in 2×10^6- gal tanks, to \$47.63 million for storage in 200,000-gal tanks. For alkaline waste storage, total capital costs varied from \$27.57 million for storage in 4.9×10^6-gal tanks to \$61.16 million for storage in 400,000-gal tanks.

The maximum annual operating cost occurs during the last year of the accumulation period and is independent of tank life. For Case 1, it

Table 8. Total Costs of Acid and Alkaline Waste Storage

Case 1. Government Ownership

Cost Items Related to Various Tank Lives	Number (excluding 1 spare) and Capacity of Tanks													
	Acid Waste Storage						Alkaline Waste Storage							
	Two 2×10^6 gal	Three 1.4×10^6 gal	Four 1×10^6 gal	Five 8×10^5 gal	Ten 4×10^5 gal	Twenty 2×10^5 gal	Four 6×10^6 gal	Five 4.9×10^6 gal	Eight 3.1×10^6 gal	Ten 2.5×10^6 gal	Fourteen 1.8×10^6 gal	Twenty 1.2×10^6 gal	Thirty 8×10^5 gal	Sixty 4×10^5 gal
Tank life, 25 yr														
Capital cost, $\$10^6$	22.15	22.55	23.68	25.27	33.36	47.63	27.86	27.57	28.04	28.92	30.66	34.14	41.50	61.16
Max. operating cost, $\$10^6$/yr	0.469	0.473	0.485	0.501	0.581	0.724	0.526	0.524	0.528	0.537	0.570	0.589	0.663	0.859
Permanent fund, $\$10^6$	34.57	31.61	30.70	30.77	33.67	41.76	45.28	42.95	40.04	39.62	39.67	41.49	46.14	58.65
Annual deposit, $\$10^6$	1.16	1.06	1.03	1.03	1.13	1.40	1.52	1.44	1.34	1.33	1.33	1.39	1.55	1.97
Total cost														
$/gal of waste	15.04	14.26	14.18	14.51	16.91	21.93	2.92	2.87	2.75	2.76	2.82	3.00	3.48	4.71
mill/kwh	0.0195	0.0185	0.0184	0.0188	0.0220	0.0285	0.0233	0.0224	0.0215	0.0215	0.0220	0.0234	0.0271	0.0367
Tank life, 50 yr														
Capital cost, $\$10^6$	22.15	22.55	23.68	25.27	33.36	47.63	27.86	27.57	28.04	28.92	30.66	34.14	41.50	61.16
Max. operating cost, $\$10^6$/yr	0.469	0.473	0.485	0.501	0.581	0.724	0.526	0.524	0.528	0.537	0.570	0.589	0.663	0.859
Permanent fund, $\$10^6$	26.17	24.46	23.91	23.94	25.79	31.03	29.31	27.81	25.88	25.61	25.65	26.65	29.33	36.92
Annual deposit, $\$10^6$	0.879	0.821	0.803	0.803	0.866	0.104	0.984	0.934	0.869	0.860	0.861	0.895	0.985	1.24
Total cost														
$/gal of waste	13.65	13.09	13.06	13.38	15.62	20.17	2.55	2.45	2.36	2.37	2.44	2.59	3.01	4.11
mill/kwh	0.0177	0.0170	0.0170	0.0174	0.0203	0.0262	0.0199	0.0191	0.0184	0.0185	0.0190	0.0202	0.0235	0.0321
Tank life, 75 yr														
Capital cost, $\$10^6$	22.15	22.55	23.68	25.27	33.36	47.63	27.86	27.57	28.04	28.92	30.66	34.14	41.50	61.16
Max. operating cost, $\$10^6$/yr	0.469	0.473	0.485	0.501	0.581	0.724	0.526	0.524	0.528	0.537	0.570	0.589	0.663	0.859
Permanent fund, $\$10^6$	24.12	22.70	22.23	22.24	23.80	28.27	25.37	24.08	22.39	22.15	22.18	22.98	25.17	31.53
Annual deposit, $\$10^6$	0.810	0.762	0.746	0.747	0.799	0.949	0.852	0.809	0.752	0.744	0.745	0.772	0.845	1.06
Total cost														
$/gal of waste	13.32	12.80	12.79	13.10	15.29	19.71	2.44	2.35	2.27	2.28	2.34	2.49	2.90	3.96
mill/kwh	0.0173	0.0166	0.0166	0.0170	0.0199	0.0256	0.0190	0.0183	0.0177	0.0177	0.0183	0.0194	0.0226	0.0309

Table 9. Total Costs of Acid and Alkaline Waste Storage

Case 2. Private and Government Ownership

Cost Items Related to Various Tank Lives	Number (excluding 1 spare) and Capacity of Tanks													
	Acid Waste Storage						Alkaline Waste Storage							
	Two 2×10^6 gal	Three 1.4×10^6 gal	Four 1×10^6 gal	Five 8×10^5 gal	Ten 4×10^5 gal	Twenty 2×10^5 gal	Four 6×10^6 gal	Five 4.9×10^6 gal	Eight 3.1×10^6 gal	Ten 2.5×10^6 gal	Fourteen 1.8×10^6 gal	Twenty 1.2×10^6 gal	Thirty 8×10^5 gal	Sixty 4×10^5 gal
Tank life, 25 yr														
Capital cost, $\$10^6$	22.15	22.55	23.68	25.27	33.36	47.63	27.86	27.57	28.04	28.92	30.66	34.14	41.50	61.16
Max. operating cost, $\$10^6$/yr	0.906	0.917	0.947	0.990	1.21	1.59	1.06	1.05	1.06	1.09	1.15	1.23	1.43	1.96
Permanent fund, $\$10^6$	35.57	31.61	30.70	30.77	33.67	41.76	45.28	42.95	40.04	39.62	39.67	41.49	46.14	58.65
Annual deposit, $\$10^6$	1.16	1.06	1.03	1.03	1.13	1.40	1.52	1.44	1.34	1.33	1.33	1.39	1.55	1.97
Total cost														
$/gal of waste	21.66	20.05	19.47	19.61	21.79	27.03	3.98	3.77	3.53	3.48	3.54	3.67	4.22	5.60
mill/kwh	0.0281	0.0260	0.0253	0.0255	0.0283	0.0351	0.0310	0.0293	0.0273	0.0271	0.0276	0.0286	0.0329	0.0437
Tank life, 50 yr														
Capital cost, $\$10^6$	22.15	22.55	23.68	25.27	33.36	47.63	27.86	27.57	28.04	28.92	30.66	34.14	41.50	61.16
Max. operating cost, $\$10^6$/yr	0.906	0.917	0.947	0.990	1.21	1.59	1.06	1.05	1.65	1.09	1.15	1.23	1.43	1.96
Permanent fund, $\$10^6$	26.17	24.46	23.91	23.94	25.79	31.03	29.31	27.81	25.88	25.61	25.65	26.65	29.33	36.92
Annual deposit, $\$10^6$	0.879	0.821	0.803	0.804	0.866	1.04	0.984	0.934	0.869	0.860	0.861	0.895	0.985	1.24
Total cost														
$/gal of waste	20.28	18.88	18.35	18.49	20.50	25.26	3.54	3.35	3.14	3.09	3.16	3.26	3.76	5.01
mill/kwh	0.0263	0.0245	0.0238	0.0240	0.0266	0.0328	0.0276	0.0261	0.0245	0.0241	0.0246	0.0254	0.0293	0.0390
Tank life, 75 yr														
Capital cost, $\$10^6$	22.15	22.55	23.68	25.27	33.36	47.63	27.86	27.57	28.04	28.92	30.66	34.14	41.50	61.16
Max. operating cost, $\$10^6$/yr	0.906	0.917	0.947	0.990	1.21	1.59	1.06	1.05	1.06	1.09	1.15	1.23	1.43	1.96
Permanent fund, $\$10^6$	24.12	22.70	22.23	22.24	23.80	28.27	25.37	24.08	22.39	22.15	22.18	22.98	25.17	31.53
Annual deposit, $\$10^6$	0.810	0.762	0.746	0.747	0.799	0.949	0.852	0.809	0.752	0.744	0.745	0.772	0.845	1.06
Total cost														
$/gal of waste	19.94	18.59	18.08	18.21	20.17	24.81	3.43	3.25	3.05	3.00	3.06	3.16	3.65	4.86
mill/kwh	0.0259	0.0241	0.0235	0.0237	0.0262	0.0322	0.0268	0.0253	0.0237	0.0234	0.0239	0.0246	0.0284	0.0379

Table 10. Total Costs of Acid and Alkaline Waste Storage

Case 3. Private Ownership

Cost Items Related to Various Tank Lives	Number (excluding 1 spare) and Capacity of Tanks													
	Acid Waste Storage						Alkaline Waste Storage							
	Two 2×10^6 gal	Three 1.4×10^6 gal	Four 1×10^6 gal	Five 8×10^5 gal	Ten 4×10^5 gal	Twenty 2×10^5 gal	Four 6×10^6 gal	Five 4.9×10^6 gal	Eight 3.1×10^6 gal	Ten 2.5×10^6 gal	Fourteen 1.8×10^6 gal	Twenty 1.2×10^6 gal	Thirty 8×10^5 gal	Sixty 4×10^5 gal
Tank life, 25 yr														
Capital cost, $\$10^6$	22.15	22.55	23.68	25.27	33.31	47.63	27.86	27.57	28.04	28.92	30.66	34.14	41.50	61.16
Max. operating cost, $\$10^6$/yr	0.906	0.917	0.947	0.990	1.21	1.59	1.06	1.05	1.06	1.09	1.15	1.23	1.43	1.96
Permanent fund, $\$10^6$	41.56	38.44	37.57	37.80	41.67	51.71	54.23	51.73	48.72	48.38	48.64	51.00	56.76	72.24
Annual deposit, $\$10^6$	1.47	1.36	1.33	1.34	1.47	1.83	1.92	1.83	1.72	1.71	1.72	1.80	2.01	2.55
Total cost														
$/gal of waste	23.17	21.51	20.93	21.10	23.47	29.12	4.30	4.08	3.84	3.79	3.86	4.00	4.60	6.08
mill/kwh	0.0301	0.0279	0.0272	0.0274	0.0305	0.0378	0.0335	0.0318	0.0299	0.0295	0.0301	0.0312	0.0358	0.0474
Tank life, 50 yr														
Capital cost, $\$10^6$	22.15	22.55	23.68	25.27	33.36	47.63	27.86	27.57	28.04	28.92	30.66	34.14	41.50	61.16
Max. operating cost, $\$10^6$/yr	0.906	0.917	0.947	0.990	1.21	1.59	1.06	1.05	1.06	1.09	1.15	1.23	1.43	1.96
Permanent fund, $\$10^6$	32.49	30.69	30.19	30.35	33.05	39.96	36.71	35.09	33.07	32.86	33.08	34.51	38.07	48.05
Annual deposit, $\$10^6$	1.15	1.09	1.07	1.07	1.17	1.41	1.30	1.24	1.17	1.16	1.17	1.22	1.35	1.70
Total cost														
$/gal of waste	21.60	20.17	19.65	19.81	21.98	27.08	3.80	3.60	3.39	3.34	3.41	3.53	4.06	5.38
mill/kwh	0.0281	0.0262	0.0255	0.0257	0.0286	0.0352	0.0296	0.0281	0.0264	0.0260	0.0266	0.0275	0.0316	0.0419
Tank life, 75 yr														
Capital cost, $\$10^6$	22.15	22.55	23.68	25.27	33.36	47.63	27.86	27.57	28.04	28.92	30.66	34.14	41.50	61.16
Max. operating cost, $\$10^6$/yr	0.906	0.917	0.947	0.990	1.21	1.59	1.06	1.05	1.06	1.09	1.15	1.23	1.43	1.96
Permanent fund, $\$10^6$	30.13	28.65	28.23	28.37	30.72	36.74	32.10	30.70	28.95	28.77	28.98	30.15	33.13	41.65
Annual deposit, $\$10^6$	1.06	1.01	0.998	1.00	1.09	1.30	1.14	1.09	1.02	1.02	1.02	1.07	1.17	1.47
Total cost														
$/gal of waste	21.19	19.82	19.31	19.47	21.58	26.52	3.66	3.47	3.27	3.22	3.29	3.40	3.92	5.20
mill/kwh	0.0275	0.0257	0.0251	0.0253	0.0281	0.0344	0.0286	0.0271	0.0255	0.0251	0.0257	0.0265	0.0305	0.0405

varies with tank size from $469,000 to $724,000 for acid wastes, and from $524,000 to $859,000 for alkaline wastes. This variation is due to maintenance costs, which are taken as a fixed percentage of the capital investment. Operating costs for Cases 2 and 3 are identical, and range from $906,000 to $1.59 million for acid wastes, and from $1.05 million to $1.96 million for alkaline wastes. They are higher than for Case 1 because insurance and taxes are included.

The size of the permanent fund and the annual deposit required to establish it during the accumulation period are different for each set of conditions. The size of the fund varies from $22.15 million to $72.24 million. It is least for alkaline waste storage in tanks of 75-yr life with government ownership and greatest for alkaline waste storage in tanks of 25-yr life with private ownership.

Total costs varied in a fashion similar to that of the permanent fund. In terms of the cost of nuclear electricity generated, they were least for storage of acid wastes in tanks of 75-yr life with government ownership and greatest for storage of alkaline wastes in tanks of 25-yr life with private ownership. Total costs, in mill/kwh, are plotted as a function of tank capacity for different tank lifetimes and methods of financing in Figs. 7 and 8. For acid wastes, minima occur at a tank capacity of about 10^6 gal in all cases. These minima range from 0.0165 to 0.0184 mill/kwh for Case 1, from 0.0235 to 0.0253 mill/kwh for Case 2, and from 0.0251 to 0.0272 mill/kwh for Case 3. For alkaline wastes, the optimum tank capacity is about 2.5×10^6 gal, and minimum total costs range from 0.0177 to 0.0215, 0.0234 to 0.0271, and 0.0251 to 0.0294 mill/kwh for Cases 1, 2, and 3, respectively.

One of the least certain aspects of the basis used for this study is the degree of fission product concentration that can be tolerated during storage. The concentrations adopted are based on a careful consideration of Savannah River and Hanford experience and are believed to be as great as practical for wastes of this type. Acid fission product solutions of about twice these concentrations are stored in the United Kingdom;[28] however, the wastes contain less inert salt than is considered to be present in the wastes described in this study, and they are stored in relatively small tanks of 40,000 gal capacity, and less.

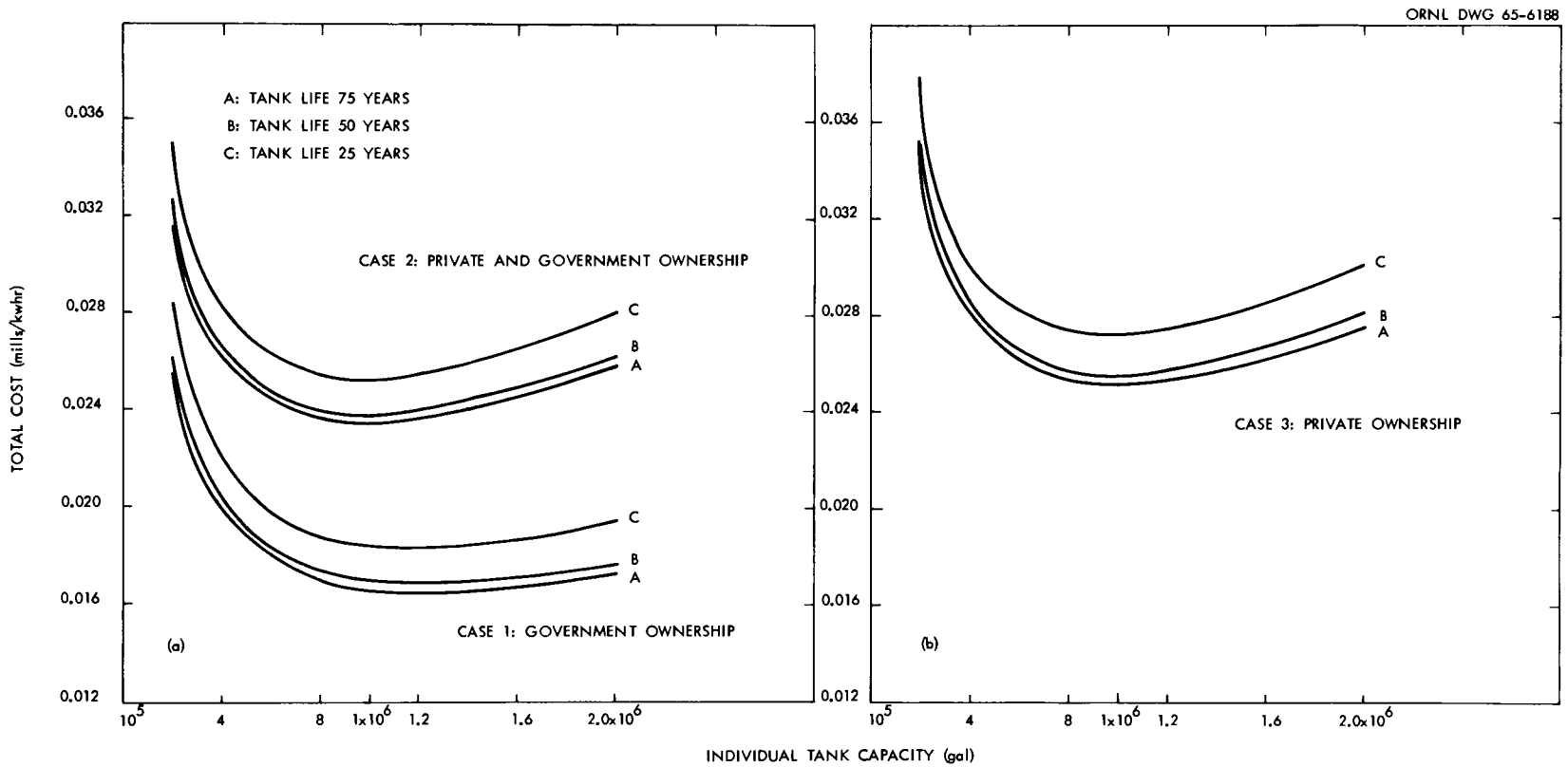


Fig. 7. Cost of Acid Waste Storage as a Function of Tank Capacity, Tank Life, and Method of Financing for (a) Case 1, Government Ownership; Case 2, Private and Government Ownership; and (b) Case 3, Private Ownership.

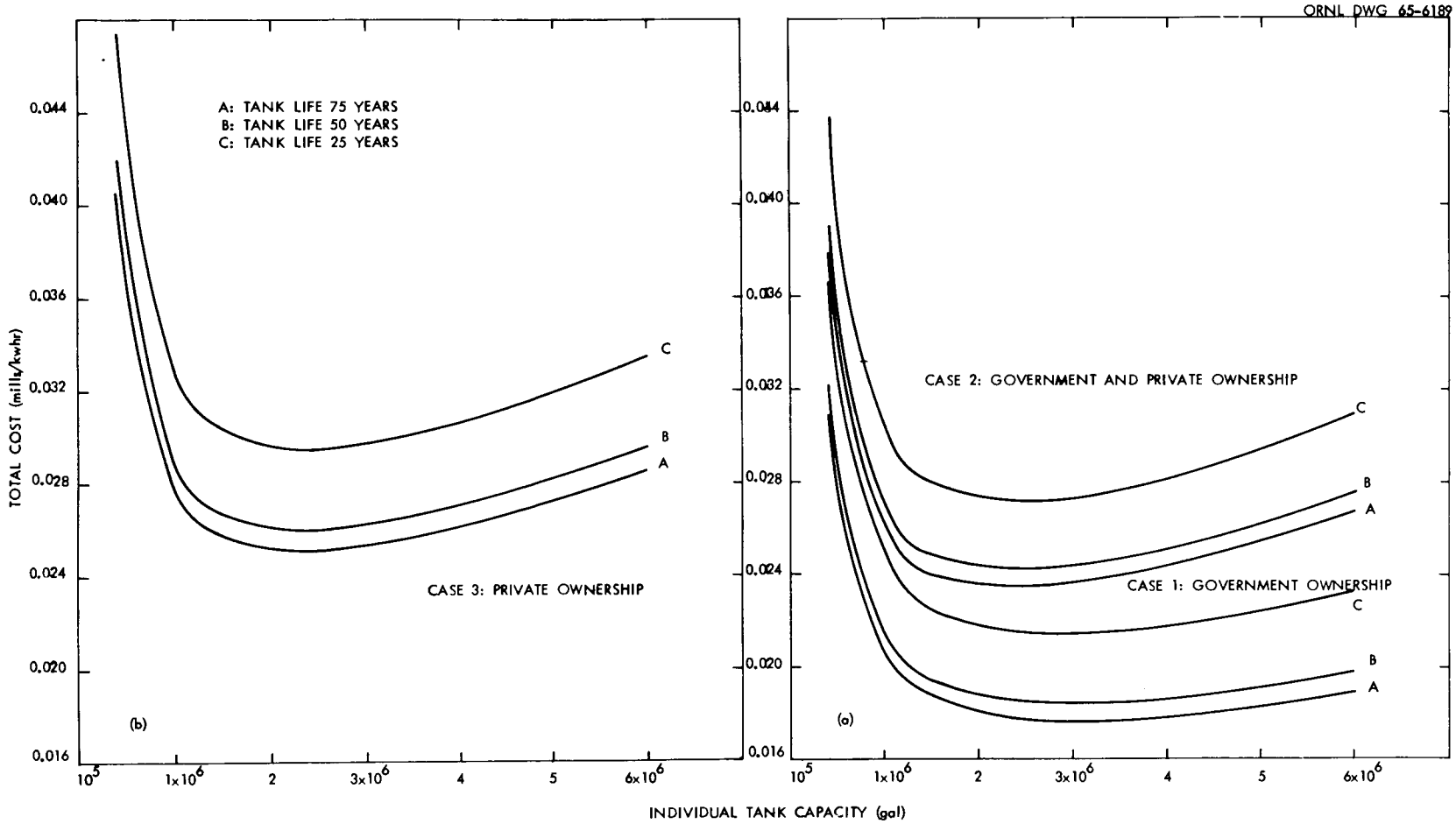


Fig. 8. Cost of Alkaline Waste Storage as a Function of Tank Capacity, Tank Life, and Method of Financing for (a) Case 1, Government Ownership; Case 2, Private and Government Ownership; and (b) Case 3, Private Ownership.

To obtain an indication of the effect of fission product concentration on costs, a second set of costs was computed. Here, it was assumed that the wastes are reduced in volume to one-half those of the original design basis. In this instance, acid Purex and Thorex wastes are stored at 50 and 100 gal/ton of fuel, respectively, and alkaline Purex and Thorex wastes are stored at 300 and 600 gal/ton. This reduction in volumes caused a decrease of between 15 and 30% in total costs (Tables 11, 12, and 13). The optimum tank size for acid waste storage remained about 10^6 gal, whereas the optimum size for alkaline waste storage dropped from about 2.5×10^6 gal to 1.5×10^6 gal.

Cladding Wastes

The costs of cladding-waste storage (Table 14) were compiled independently of those for the raffinates. The capital cost for all cases was $52.27 million, and the maximum annual operating cost was $82,300 for the case of government ownership, and $981,000 for Cases 2 and 3. The permanent fund varied from $17.47 million for storage in tanks of 75-yr life to $65.35 million for storage in tanks of 25-yr life. In Case 3, the fund varied from $24.16 million to $78.26 million. Total costs ranged from 0.0215 mill/kwh for tanks for 75-yr life with government ownership, to 0.0398 mill/kwh for tanks of 25-yr life with private ownership. The total costs of cladding-waste storage, which are in every instance greater than the comparable costs for raffinate storage, are a consequence of their larger volumes.

Table 11. Total Storage Costs for Highly Concentrated Acid and Alkaline Wastes[1]

Case 1. Government Ownership

Cost Items Related to Various Tank Lives	Number (excluding 1 spare) and Capacity of Tanks													
	Concentrated Acid Waste Storage						Concentrated Alkaline Waste Storage							
	Two 1×10^6 gal	Three 7×10^5 gal	Four 5×10^5 gal	Five 4×10^5 gal	Ten 2×10^5 gal	Twenty 1×10^5 gal	Four 3×10^6 gal	Five 2.5×10^6 gal	Eight 1.5×10^6 gal	Ten 1.2×10^6 gal	Fourteen 8.6×10^5 gal	Twenty 6×10^5 gal	Thirty 4×10^5 gal	Sixty 2×10^5 gal
Tank life, 25 yr														
Capital cost, $\$10^6$	17.30	19.05	20.78	22.32	30.59	44.49	18.66	18.88	19.99	21.30	23.85	27.47	34.17	52.83
Max. operating cost, $\$10^6$/yr	0.421	0.438	0.456	0.471	0.554	0.693	0.434	0.437	0.448	0.461	0.502	0.523	0.590	0.776
Permanent fund, $\$10^6$	26.64	26.29	26.50	26.71	30.28	38.23	30.59	29.63	28.64	29.07	30.42	32.70	36.86	48.56
Annual deposit, $\$10^6$	0.895	0.883	0.890	0.897	1.02	1.28	1.03	0.995	0.962	0.976	1.02	1.10	1.24	1.63
Total cost														
$/gal of waste	23.94	24.37	25.09	25.80	31.06	40.91	4.16	4.09	4.06	4.18	4.48	4.89	5.75	8.09
mill/kwh	0.0155	0.0158	0.0163	0.0168	0.0202	0.0266	0.0162	0.0159	0.0158	0.0163	0.0174	0.0190	0.0224	0.0315
Tank life, 50 yr														
Capital cost, $\$10^6$	17.30	19.05	20.78	22.32	30.59	44.49	18.66	18.88	19.99	21.30	23.85	27.47	34.17	52.83
Max. operating cost, $\$10^6$/yr	0.421	0.438	0.456	0.471	0.554	0.693	0.434	0.437	0.448	0.461	0.502	0.523	0.590	0.776
Permanent fund, $\$10^6$	21.83	21.69	21.79	21.95	24.25	29.50	22.09	21.45	20.72	20.95	21.70	23.01	25.56	32.85
Annual deposit, $\$10^6$	0.733	0.728	0.732	0.737	0.814	0.991	0.742	0.720	0.696	0.703	0.729	0.773	0.858	1.10
Total cost														
$/gal of waste	22.36	22.86	23.54	24.23	29.08	38.04	3.70	3.64	3.63	3.73	4.00	4.35	5.13	7.22
mill/kwh	0.0145	0.0148	0.0153	0.0157	0.0189	0.0247	0.0144	0.0142	0.0141	0.0145	0.0156	0.0170	0.0200	0.0281
Tank life, 75 yr														
Capital cost, $\$10^6$	17.30	19.05	20.78	22.32	30.59	44.49	18.66	18.88	19.99	21.30	23.85	27.47	34.17	52.83
Max. operating cost, $\$10^6$/yr	0.421	0.438	0.456	0.471	0.554	0.693	0.434	0.437	0.448	0.461	0.502	0.523	0.590	0.776
Permanent fund, $\$10^6$	20.68	20.56	20.64	20.76	22.71	27.24	19.99	19.43	18.76	18.94	19.55	20.61	22.76	28.94
Annual deposit, $\$10^6$	0.694	0.691	0.693	0.697	0.763	0.915	0.671	0.653	0.630	0.636	0.657	0.692	0.764	0.972
Total cost														
$/gal of waste	21.97	22.49	23.16	23.84	28.57	37.30	3.58	3.53	3.52	3.62	3.88	4.22	4.97	7.01
mill/kwh	0.0143	0.0146	0.0150	0.0155	0.0186	0.0242	0.0140	0.0137	0.0137	0.0141	0.0151	0.0165	0.0194	0.0273

[1] Volumes of waste per ton of fuel processed are one-half those previously assumed.

Table 12. Total Storage Costs for Highly Concentrated Acid and Alkaline Wastes[1]

Case 2. Private and Government Ownership

Cost Items Related to Various Tank Lives	Number (excluding 1 spare) and Capacity of Tanks													
	Concentrated Acid Waste Storage						Concentrated Alkaline Waste Storage							
	Two 1×10^6 gal	Three 7×10^5 gal	Four 5×10^5 gal	Five 4×10^5 gal	Ten 2×10^5 gal	Twenty 1×10^5 gal	Four 3×10^6 gal	Five 2.5×10^6 gal	Eight 1.5×10^6 gal	Ten 1.2×10^5 gal	Fourteen 8.6×10^5 gal	Twenty 6×10^5 gal	Thirty 4×10^5 gal	Sixty 2×10^5 gal
Tank life, 25 yr														
Capital cost, $\$10^6$	17.30	19.05	20.78	22.32	30.59	44.49	18.66	18.88	19.99	21.30	23.85	27.47	34.17	52.83
Max. operating cost, $\$10^6$/yr	0.775	0.822	0.869	0.911	1.13	1.51	0.812	0.818	0.848	0.883	0.968	1.05	1.23	1.73
Permanent fund, $\$10^6$	26.64	26.29	26.50	26.71	30.28	38.23	30.59	29.63	28.64	29.07	30.42	32.70	36.86	48.56
Annual deposit, $\$10^6$	0.895	0.883	0.890	0.897	1.02	1.28	1.03	0.995	0.962	0.976	1.02	1.10	1.24	1.63
Total cost														
$/gal of waste	34.63	34.47	34.66	35.12	40.26	50.64	5.61	5.44	5.30	5.36	5.70	6.06	7.07	9.70
mill/kwh	0.0225	0.0224	0.0225	0.0228	0.0261	0.0329	0.0219	0.0212	0.0206	0.0209	0.0222	0.0236	0.0275	0.0378
Tank life, 50 yr														
Capital cost, $\$10^6$	17.30	19.05	20.78	22.32	30.59	44.49	18.66	18.88	19.99	21.30	23.85	27.47	34.17	52.83
Max. operating cost, $\$10^6$/yr	0.775	0.822	0.869	0.911	1.13	1.51	0.812	0.818	0.848	0.883	0.968	1.05	1.23	1.73
Permanent fund, $\$10^6$	21.83	21.69	21.80	21.95	24.25	29.50	22.09	21.45	20.72	20.95	21.70	23.00	25.56	32.85
Annual deposit, $\$10^6$	0.733	0.728	0.732	0.737	0.814	0.991	0.742	0.720	0.696	0.703	0.729	0.773	0.858	1.10
Total cost														
$/gal of waste	33.05	32.95	33.11	33.55	38.28	47.76	5.15	4.99	4.86	4.92	5.22	5.52	6.45	8.83
mill/kwh	0.0215	0.0214	0.0215	0.0218	0.0249	0.0310	0.0201	0.0194	0.0190	0.0192	0.0203	0.0215	0.0251	0.0344
Tank life, 75 yr														
Capital cost, $\$10^6$	17.30	19.05	20.78	22.32	30.59	44.49	18.66	18.88	19.99	21.30	23.85	27.47	34.17	52.83
Max. operating cost, $\$10^6$/yr	0.775	0.822	0.869	0.911	1.13	1.51	0.812	0.818	0.848	0.883	0.968	1.05	1.23	1.73
Permanent fund, $\$10^6$	20.68	20.56	20.64	20.76	22.71	27.24	19.99	19.43	18.76	18.94	19.55	20.61	22.76	28.94
Annual deposit, $\$10^6$	0.694	0.691	0.693	0.697	0.763	0.915	0.671	0.653	0.630	0.636	0.657	0.692	0.764	0.972
Total cost														
$/gal of waste	32.67	32.58	32.73	33.16	37.77	47.02	5.03	4.88	4.76	4.81	5.10	5.39	6.29	8.62
mill/kwh	0.0212	0.0212	0.0213	0.0215	0.0245	0.0305	0.0196	0.0190	0.0185	0.0187	0.0199	0.0210	0.0245	0.0336

[1] Volumes of waste per ton of fuel processed are one-half those previously assumed.

Table 13. Total Storage Costs for Highly Concentrated Acid and Alkaline Wastes[1]

Case 3. Private Ownership

Cost Items Related to Various Tank Lives	Number (excluding 1 spare) and Capacity of Tanks													
	Concentrated Acid Waste Storage						Concentrated Alkaline Waste Storage							
	Two 1×10^6 gal	Three 7×10^5 gal	Four 5×10^5 gal	Five 4×10^5 gal	Ten 2×10^5 gal	Twenty 1×10^5 gal	Four 3×10^6 gal	Five 2.5×10^6 gal	Eight 1.5×10^6 gal	Ten 1.2×10^6 gal	Fourteen 8.6×10^5 gal	Twenty 6×10^5 gal	Thirty 4×10^5 gal	Sixty 2×10^5 gal
Tank life, 25 yr														
Capital cost, $\$10^6$	17.30	19.05	20.78	22.32	30.59	44.49	18.66	18.88	19.99	21.30	23.85	27.47	34.17	52.83
Max. operating cost, $\$10^6$/yr	0.775	0.822	0.869	0.911	1.13	1.51	0.812	0.818	0.848	0.883	0.968	1.05	1.23	1.73
Permanent fund, $\$10^6$	32.52	32.32	32.72	33.08	37.66	47.50	37.28	36.30	35.37	35.99	37.73	40.58	45.72	60.18
Annual deposit, $\$10^6$	1.15	1.14	1.56	1.17	1.33	1.68	1.32	1.28	1.25	1.27	1.33	1.44	1.62	2.13
Total cost														
$/gal of waste	37.13	37.02	37.28	37.79	43.35	54.52	6.09	5.91	5.77	5.85	6.21	6.61	7.69	10.51
mill/kwh	0.0241	0.0240	0.0242	0.0245	0.0282	0.0354	0.0237	0.0230	0.0225	0.0228	0.0242	0.0257	0.0300	0.0409
Tank life, 50 yr														
Capital cost, $\$10^6$	17.30	19.05	20.78	22.32	30.59	44.49	18.66	18.88	19.99	21.30	23.85	27.47	34.17	52.83
Max. operating cost, $\$10^6$/yr	0.775	0.822	0.869	0.911	1.13	1.51	0.812	0.818	0.848	0.883	0.968	1.05	1.23	1.73
Permanent fund, $\$10^6$	27.36	27.36	27.62	27.91	31.09	37.98	27.96	27.30	26.62	26.99	28.06	29.81	33.17	42.70
Annual deposit, $\$10^6$	0.967	0.967	0.977	0.987	1.10	1.34	0.989	0.965	0.941	0.995	0.992	1.05	1.17	1.51
Total cost														
$/gal of waste	35.34	35.30	35.51	36.00	41.07	51.22	5.55	5.39	5.27	5.33	5.65	5.98	6.96	9.50
mill/kwh	0.0230	0.0229	0.0231	0.0234	0.0267	0.0333	0.0216	0.0210	0.0205	0.0208	0.0220	0.0233	0.0271	0.0371
Tank life, 75 yr														
Capital cost, $\$10^6$	17.30	19.05	20.78	22.32	30.59	44.49	18.66	18.88	19.99	21.30	23.85	27.47	34.17	52.83
Max. operating cost, $\$10^6$/yr	0.775	0.822	0.869	0.911	1.13	1.51	0.812	0.818	0.848	0.883	0.968	1.05	1.23	1.73
Permanent fund, $\$10^6$	26.02	26.05	26.27	26.53	29.31	35.34	25.51	24.93	24.32	24.62	25.51	26.96	29.85	38.07
Annual deposit, $\$10^6$	0.920	0.921	0.929	0.938	1.04	1.25	0.902	0.882	0.860	0.871	0.902	0.954	1.06	1.35
Total cost														
$/gal of waste	34.88	34.84	35.04	35.52	40.45	50.31	5.41	5.25	5.13	5.19	5.50	5.82	6.77	9.23
mill/kwh	0.0227	0.0226	0.0228	0.0231	0.0263	0.0327	0.0211	0.0205	0.0200	0.0202	0.0214	0.0227	0.0264	0.0360

[1] Volumes of waste per ton of fuel processed are one-half those previously assumed.

Table 14. Summary of Total Costs for Cladding Waste Storage

Storage in Sixty 1.2 x 10^6-gal Carbon Steel Tanks, Plus One Spare Tank

	Case 1: Gov't. Ownership	Case 2: Private and Gov't. Ownership	Case 3: Private Ownership
Tank life, 25 yr			
Capital cost, $\$10^6$	52.27	52.27	52.27
Max. oper. cost, $\$10^6$/yr	0.0823	0.981	0.981
Permanent fund, $\$10^6$	65.35	65.35	78.26
Annual deposit, $\$10^6$	2.19	2.19	2.77
Total cost			
$/gal of waste	1.51	1.73	1.90
mill/kwh	0.0317	0.0361	0.0398
Tank life, 50 yr			
Capital cost, $\$10^6$	52.27	52.27	52.27
Max. oper. cost, $\$10^6$/yr	0.0823	0.981	0.981
Permanent fund, $\$10^6$	26.97	26.97	35.47
Annual deposit, $\$10^6$	0.906	0.906	1.25
Total cost			
$/gal of waste	1.12	1.33	1.44
mill/kwh	0.0235	0.0279	0.0302
Tank life, 75 yr			
Capital cost, $\$10^6$	52.27	52.27	52.27
Max. oper. cost, $\$10^6$/yr	0.0823	0.981	0.981
Permanent fund, $\$10^6$	17.47	17.47	24.16
Annual deposit, $\$10^6$	0.587	0.587	0.854
Total cost			
$/gal of waste	1.02	1.24	1.32
mill/kwh	0.0215	0.0259	0.0276

APPENDIX A

DETAILS OF TANK-FARM DESIGN AND CAPITAL COSTS

Table A-1. Materials Specifications for Tanks and Vaults

2-1/2-ft Annulus Between Sides of Tank and Vault

		Tanks					Cooling Coils, 3-in. Sched-40 Pipe		Vault Liners		Vaults		
			Metal Thickness (in.)								Concrete Thickness (ft)		
Storage Capacity (gal)	Material of Construction	Diam. x Ht. (ft)	Top	Upper Side	Lower Side	Bottom	Length (ft)	No. of 1420-ft Banks	Diam. x Ht. (ft)	Metal Thickness (in.)	Top	Sides	Bottom
200,000	Stain. Steel	52 x 17	5/16	5/16	3/8	5/16	42,000	30	57 x 17	1/4	3.75	2.00	2.50
600,000	Stain. Steel	72 x 24	3/8	3/8	5/8	3/8	61,000	43	77 x 24	5/16	3.75	2.50	2.50
1,000,000	Stain. Steel	85 x 28	7/16	7/16	13/16	3/8	68,000	48	90 x 28	5/16	3.75	2.75	3.00
1,600,000	Stain. Steel	98 x 32	1/2	1/2	1	7/16	76,000	53	103 x 32	3/8	4.00	3.00	3.50
2,000,000	Stain. Steel	105 x 35	5/8	5/8	1-1/4	1/2	80,000	56	108 x 35	3/8	4.00	3.25	3.50
400,000	Mild Steel	63 x 21	3/8	3/8	1/2	3/8	22,000	16	68 x 21	5/16	3.75	2.25	2.50
800,000	Mild Steel	78 x 26	3/8	3/8	11/16	3/8	34,000	25	83 x 26	5/16	3.75	2.50	2.50
1,200,000	Mild Steel	89 x 29	1/2	1/2	13/16	3/8	42,000	30	94 x 29	3/8	3.75	2.75	3.00
2,000,000	Mild Steel	105 x 35	1/2	1/2	1-1/8	3/8	51,000	36	108 x 35	3/8	4.00	3.25	3.50
3,200,000	Mild Steel	122 x 40	3/4	3/4	1-1/2	1/2	59,000	42	127 x 40	7/16	4.00	3.50	4.00
4,800,000	Mild Steel	138 x 46	3/4	3/4	1-7/8	1/2	65,000	46	143 x 46	1/2	4.00	3.75	4.00

Table A-2. Summary of Operations Building Costs

Item	Materials and Labor Cost ($)
Excavation and backfill	23,200
Concrete	255,700
Walls, structural steel, roof, windows	97,300
Doors, tile, ceiling, painting	159,100
Stainless steel gratings, misc. steel	23,500
Electrical	82,600
Piping (building only)	30,200
Ventilation (building only)	73,700
Misc., including cranes	74,200
Total	819,500

Table A-3. Summary of Costs of Outside Facilities

Item	Materials and Labor Cost ($)	
Electrical substation	64,500	
Cooling tower and pumps	407,600	
Water surge and storage tanks	210,000	(107,000 for alkaline-waste farms)
Stack, fans, ducts	60,100	
Sanitary and storm system	35,000	
Roadway	18,800	
Standby power equipment	244,000	
Fencing	31,000	
Total	1,071,000	(964,000 for alkaline-waste farms)

Table A-4. Summary of Costs of Outside Lines

Item	Acid Raffinate Storage					Alkaline Raffinate Storage					
	Three 2×10^6-gal tanks	Four 1.6×10^6-gal tanks	Five 1×10^6-gal tanks	Eight 6×10^5-gal tanks	Twenty-one 2×10^5-gal tanks	Six 4.8×10^6-gal tanks	Nine 3.2×10^6-gal tanks	Thirteen 2×10^6-gal tanks	Twenty-one 1.2×10^6-gal tanks	Thirty-one 8×10^5-gal tanks	Sixty-one 4×10^5-gal tanks
Cooling-water headers between building and storage tank	48,500	48,500	48,500	48,500	48,500	13,100	13,100	13,100	13,100	13,100	13,100
Cooling-water headers between building and cooling tower	56,000	56,000	56,000	56,000	56,000	56,000	56,000	56,000	56,000	56,000	56,000
Cooling-water lines (3-in.) between building and/or valve pits and tanks (inc. 18-in. headers)	150,400	189,700	214,700	198,200	451,200	66,300	82,900	113,900	150,800	216,000	300,600
Condensate system											
Piping	37,200	87,600	96,800	119,600	315,400	129,200	143,900	199,000	304,800	517,600	707,200
Concrete	23,600	42,700	31,500	55,600	223,400	80,100	94,300	146,800	212,900	330,200	462,200
Excavation	2,100	4,800	3,000	5,900	21,100	7,300	8,300	12,600	21,100	28,000	39,300
Total condensate system	62,900	135,100	131,300	181,100	559,900	216,600	246,500	358,400	538,800	875,800	1,208,700
Waste Lines											
Piping	26,000	43,700	76,400	89,900	610,600	24,800	66,800	93,600	183,200	245,400	588,700
Concrete trenches	11,300	31,100	38,800	28,100	344,600	22,400	42,200	55,500	119,500	155,700	388,200
Excavation	600	1,700	2,000	2,100	19,000	3,400	6,500	8,400	19,000	24,100	61,300
Diversion box	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000
Total for waste-line system	62,900	101,500	142,200	145,100	999,200	75,600	140,500	182,500	346,700	450,200	1,063,200
Yard power (at tanks)	3,000	4,000	5,000	7,600	18,900	5,700	8,600	12,000	18,900	27,900	54,900
Yard lighting (at tanks)	3,500	4,700	5,900	8,800	22,900	6,700	10,100	14,600	22,900	32,900	62,800
Total, $	387,200	539,500	603,600	645,300	2,156,600	440,000	557,700	750,500	1,147,200	1,671,900	2,759,300

Table A-5. Summary of Valve-Pit and Pit-Piping Costs

Item	Acid Raffinate Storage		Alkaline Raffinate Storage					
	Eight 6×10^5-gal tanks	Twenty-one 2×10^5-gal tanks	Six 4.8×10^6-gal tanks	Nine 3.2×10^6-gal tanks	Thirteen 2×10^6-gal tanks	Twenty-one 1.2×10^6-gal tanks	Thirty-one 8×10^5-gal tanks	Sixty-one 4×10^5-gal tanks
Valve-pit structural costs	15,600	15,600	15,600	15,600	15,600	15,600	15,600	15,600
Piping headers	18,300	18,300	7,800	7,800	7,800	7,800	7,800	7,800
Cooling-coil circuits (outside tanks)								
Piping	297,500	199,400	153,200	121,500	104,200	86,800	72,300	46,300
Instrumentation	17,200	12,000	18,400	16,800	14,400	12,000	10,000	6,400
Total cooling coil circuits	314,700	211,400	171,600	138,300	118,600	98,800	82,300	52,700
Total single valve-pit cost	348,600	245,300	195,000	161,700	142,000	122,200	105,700	76,100
Number of valve pits required	2	5	1	2	3	5	7	15
Total valve-pit cost, $	697,100	1,226,300	195,000	323,500	425,900	610,900	740,000	1,140,900

Table A-6. Summary of Operating Equipment and Piping Costs Inside Operations Building

Item	Acid Raffinate Storage					Alkaline Raffinate Storage					
	Three 2×10^6-gal tanks	Four 1.6×10^6-gal tanks	Five 1×10^6-gal tanks	Eight 6×10^5-gal tanks	Twenty-one 2×10^5-gal tanks	Six 4.8×10^6-gal tanks	Nine 3.2×10^6-gal tanks	Thirteen 2×10^6-gal tanks	Twenty-one 1.2×10^6-gal tanks	Thirty-one 8×10^5-gal tanks	Sixty-one 4×10^5-gal tanks
Equipment											
Heat exchangers	302,500	302,500	302,500	302,500	302,500	118,700	118,700	118,700	118,700	118,700	118,700
Demineralizer system	157,000	157,000	157,000	157,000	157,000	143,200	143,200	143,200	143,200	143,200	143,200
Instrumentation	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000
Total for Equipment	484,500	484,500	484,500	484,500	484,500	286,900	286,900	286,900	286,900	286,900	286,900
Cooling-coil circuits											
Piping	285,100	365,600	413,900	none	51,700	192,600	30,000	25,800	21,500	53,800	11,400
Instrumentation	16,800	21,200	24,000	none	3,000	27,600	4,200	3,600	3,000	7,500	1,500
Total for cooling-coil circuits	301,900	386,800	437,900	none	54,700	220,200	34,200	29,400	24,500	61,300	12,900
Piping, stainless steel	280,800	280,800	280,800	280,800	280,800	none	none	none	none	none	none
Piping, carbon steel	69,500	69,500	69,500	69,500	69,500	188,900	188,900	188,900	188,900	188,900	188,900
Total, $	1,136,700	1,221,600	1,272,700	834,800	889,500	696,000	510,000	505,200	500,300	537,100	475,700

Table A-7. Summary of Costs of Individual Waste-Storage Tanks

Item	Acid Raffinate Tanks					Alkaline Raffinate Tanks					
	2×10^6 gal	1.6×10^6 gal	1×10^6 gal	6×10^5 gal	2×10^5 gal	4.8×10^6 gal	3.2×10^6 gal	2×10^6 gal	1.2×10^6 gal	8×10^5 gal	4×10^5 gal
Tank (Table A-1)	850,000	597,700	383,800	238,400	94,300	416,000[a]	295,400[a]	154,900[a]	99,800[a]	64,600[a]	39,000[a]
Liner (Table A-1)	317,900	275,100	175,200	138,400	54,900	148,000	101,000	65,300	46,900	30,700	20,500
Coils (Table A-1)	1,265,800	1,213,100	1,123,800	1,023,600	758,900	335,300	305,200	267,500	223,500	187,200	125,700
Concrete (Table A-1)	586,000	496,600	345,300	234,100	120,600	1,207,200	827,700	582,100	374,000	270,500	175,800
Excavation and backfill	61,500	52,600	39,400	28,700	15,800	109,500	83,400	61,500	42,900	33,700	22,300
Appurtenances	58,500	58,500	46,200	42,300	42,300	60,900	60,900	55,100	42,800	37,000	37,000
Instrumentation	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000
Total cost, $	3,149,700	2,703,600	2,123,700	1,715,500	1,096,800	2,286,900	1,683,600	1,196,400	839,900	633,700	430,300

[a]An additional 15% is included for stress relief of carbon-steel tanks.

Table A-8. Summary of Engineering Design and Inspection Costs

Engineering and inspection costs for cladding-waste farm are computed as 15% of construction and overhead costs of all items, including one tank, and 5% of cost of remaining 60 tanks

	Acid Raffinate Storage				
	Three 2×10^6-gal tanks	Four 1.6×10^6-gal tanks	Five 1×10^6-gal tanks	Eight 6×10^5-gal tanks	Twenty-one 2×10^5-gal tanks
15% of construction costs, excluding tanks	652,000	697,000	719,000	776,000	1,175,000
25% of first tank cost	1,000,000	858,000	674,000	545,000	348,000
7% of remainder of tanks	560,000	721,000	755,000	1,068,000	1,950,000
Total, $	2,212,000	2,276,000	2,148,000	2,389,000	3,473,000

	Aklaline Raffinate Storage					
	Six 4.8×10^6-gal tanks	Nine 3.2×10^6-gal tanks	Thirteen 2×10^6-gal tanks	Twenty-one 1.2×10^6-gal tanks	Thirty-one 8×10^5-gal tanks	Sixty-one 4×10^5-gal tanks
15% of construction costs, excluding tanks	615,000	627,000	682,000	792,000	923,000	1,181,000
25% of first tank cost	726,000	535,000	380,000	267,000	201,000	137,000
7% of remainder of tanks	1,017,000	1,197,000	1,276,000	1,493,000	1,690,000	2,295,000
Total, $	2,358,000	2,359,000	2,338,000	2,552,000	2,814,000	3,613,000

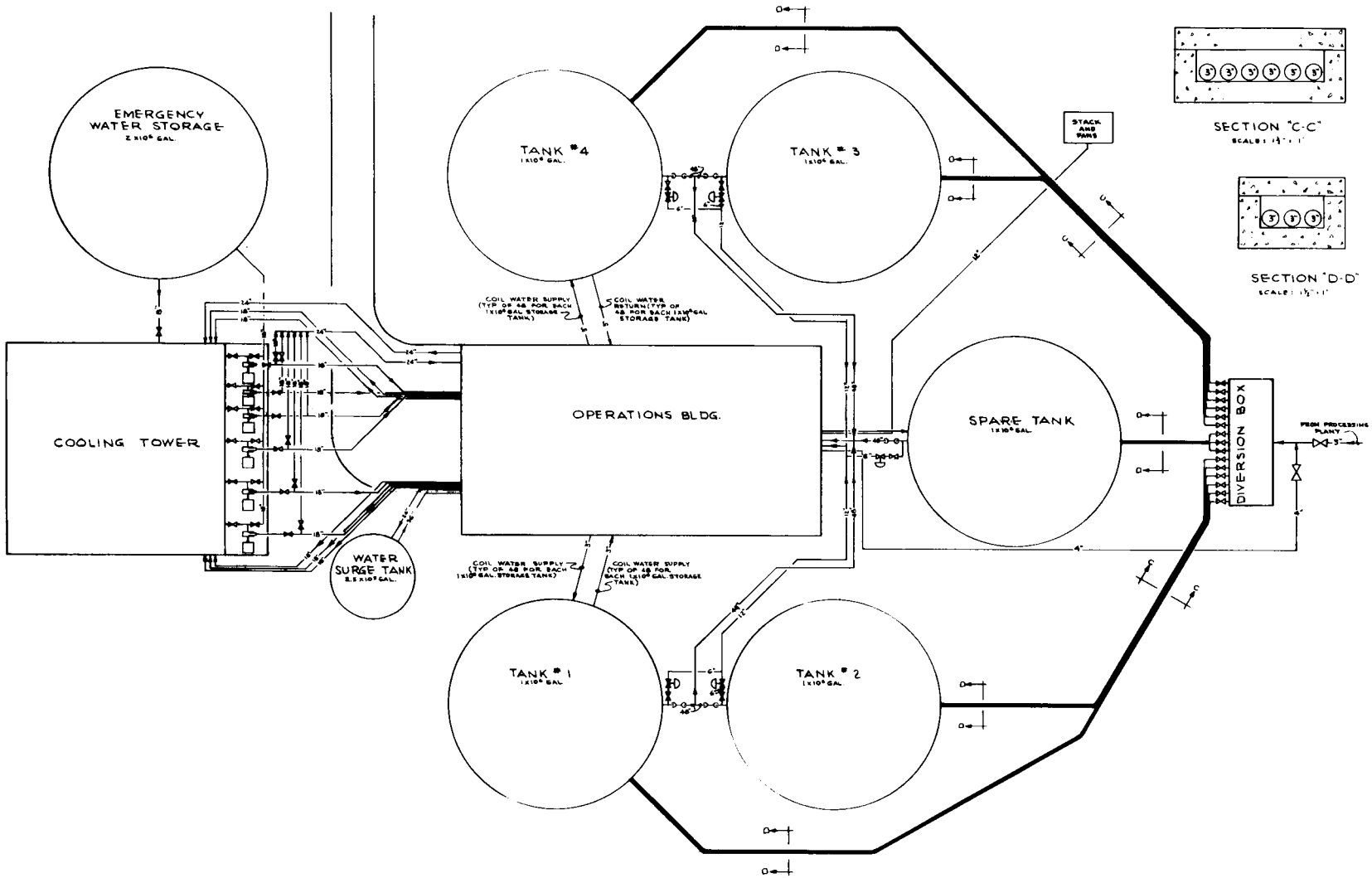


Fig. A-1. Tank Farm Piping Plan - Acid Waste Storage. Taken from Dwg. D-57721.

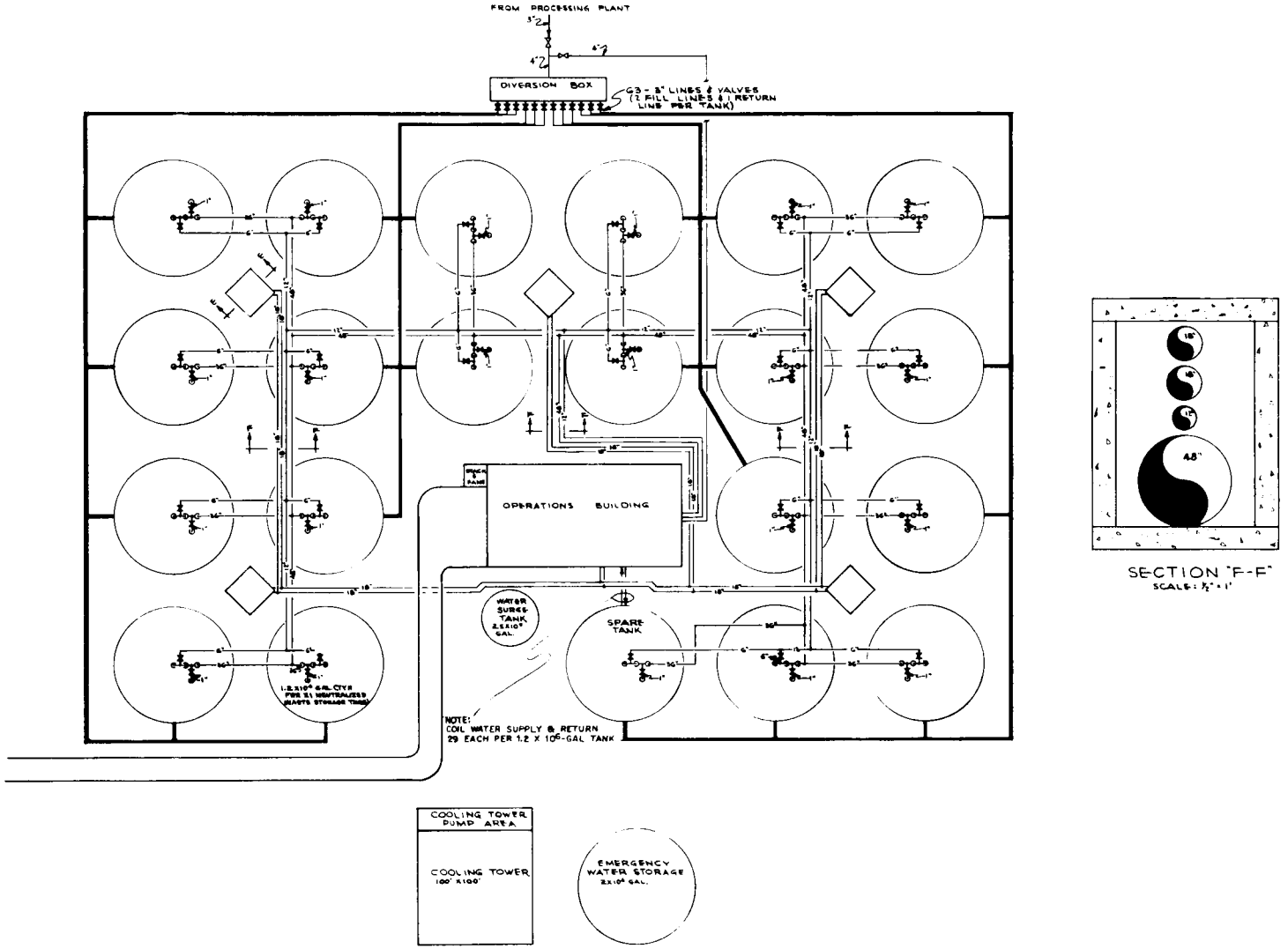


Fig. A-2. Tank Farm Piping Plan - Neutralized Waste Storage. Taken from Dwg. D-57725.

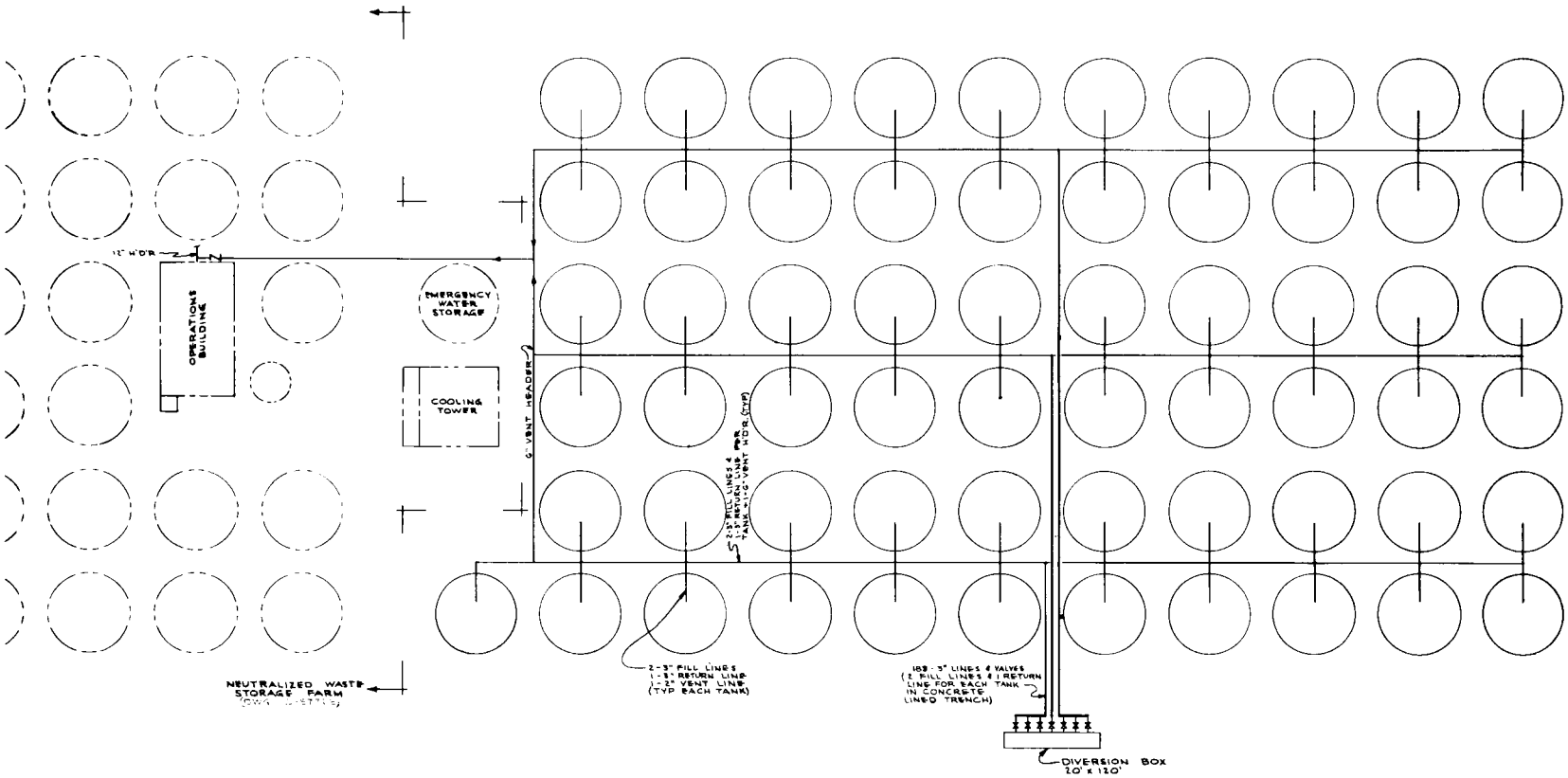


Fig. A-3. Tank Farm Piping Plan - Decladding Waste Storage. Taken from Dwg. D-57927.

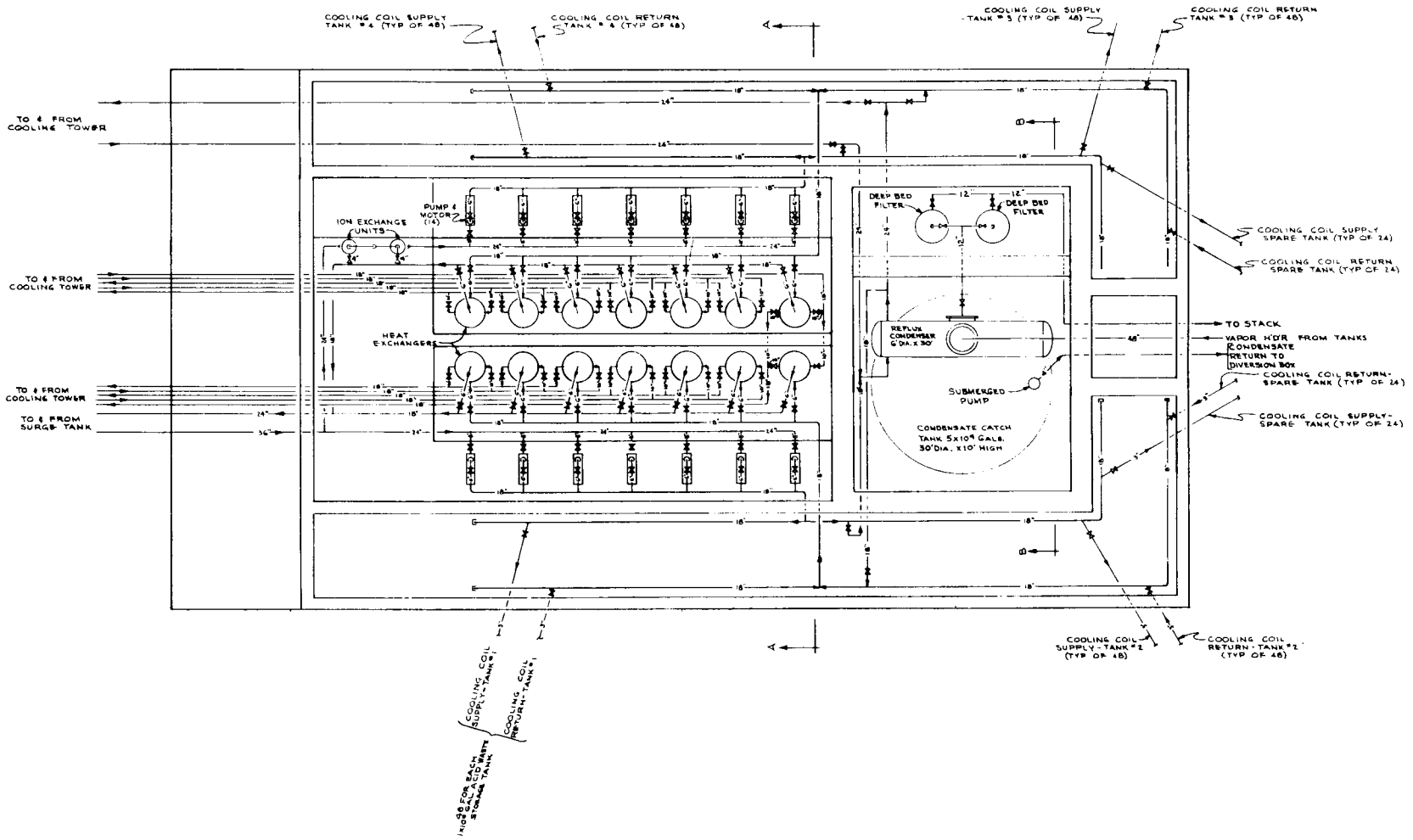


Fig. A-4. Operations Building Equipment Plan and Piping Diagram. Taken from Dwg. D-57718.

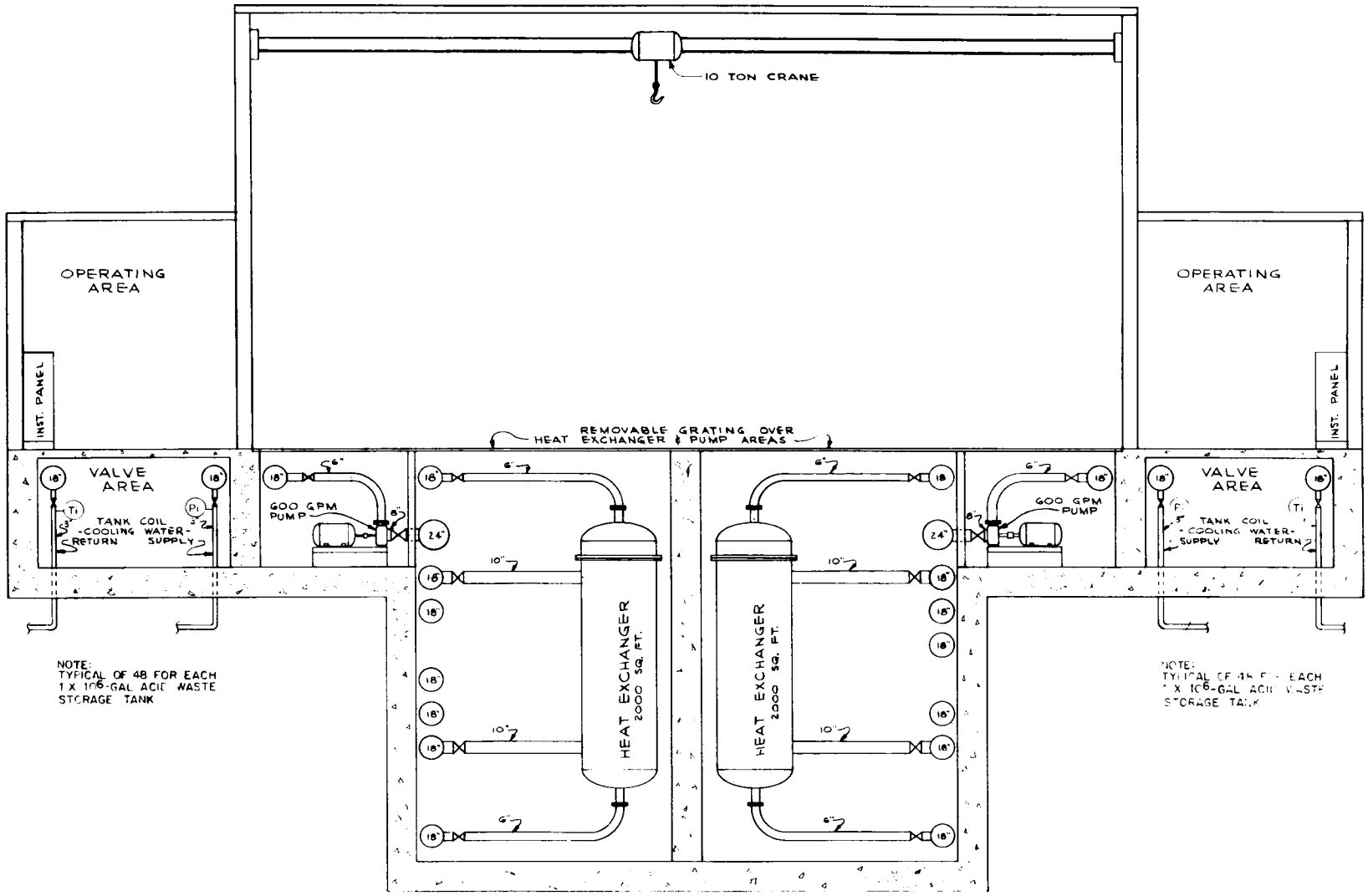


Fig. A-5. Operations Building Section "A-A". Taken from Dwg. D-57720.

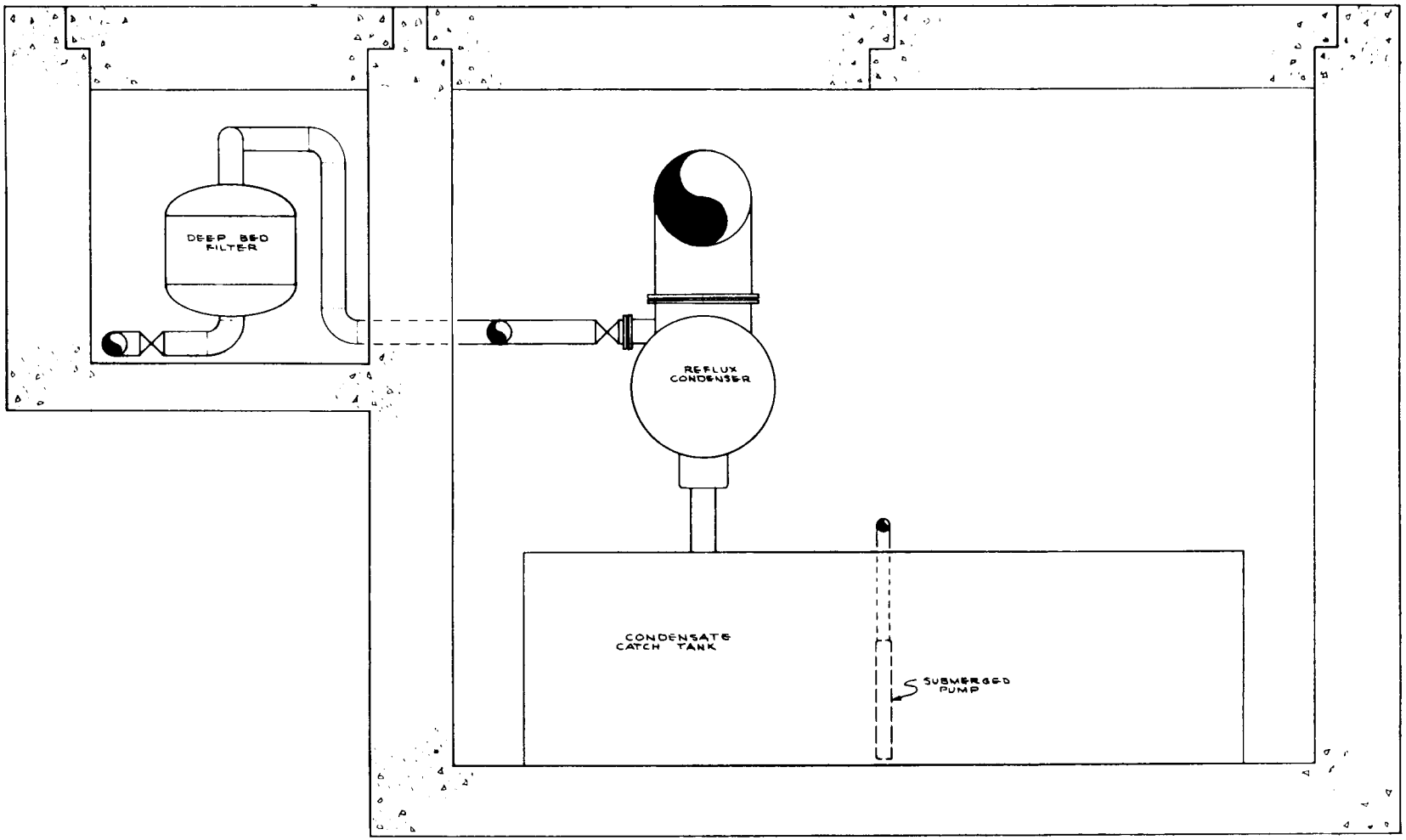


Fig. A-6. Operations Building Section "B-B". Taken from Dwg. D-57722.

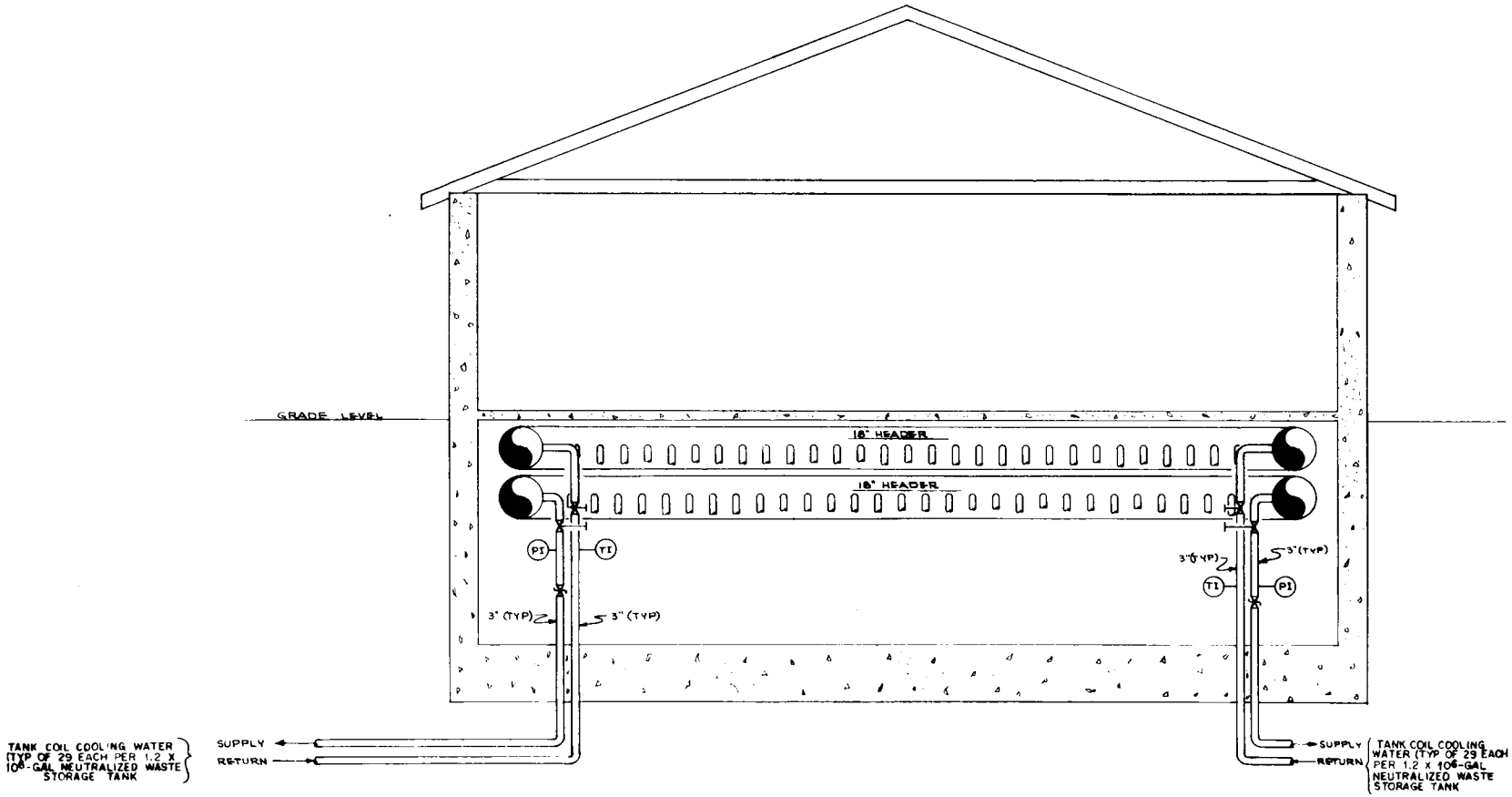


Fig. A-7. Section "E-E" Tank Farm Valve Pit. Taken from Dwg. D-57926.

APPENDIX B

DESCRIPTION OF COMPUTER PROGRAM TASCO

The economic calculations for this study were made by means of a computer program, TASCO. TASCO was written in FORTRAN-63 for the CDC-1604A computer. The program calculates the required equipment capacities, estimates the capital and operating costs, and performs the economic calculations necessary to determine the waste-storage cost in dollars per gallon and in mills per kilowatt-hour. The program is given in Table B-1.

The following sections describe the required input data, the sequence of calculations performed by the code, the output data obtained, and the details of the preparation of input data cards. The final section gives some of the details of the present-worth economic calculations used in calculating the size of the permanent fund and the waste storage cost.

Input Data

The input data required are as follows:

1.	W	waste rate, gal/yr
2.	T	accumulation period, yr
3.	THM	nuclear capacity, Mw (thermal)
4.	Z	tank life, yr
5.	ZAR	average life of other equipment, yr
6.	EMW	nuclear capacity, Mw (electrical)
7.	B3	interest rate on permanent fund
8.	B4	interest rate on bonds
9.	B5	earning rate on equity
10.	BAE	fraction of capital in equity
11.	TXR	Federal income-tax rate
12.	AINS	annual liability insurance

In addition, various permanent data (design and cost constants) are needed, as described later.

Table B-1. Listing of FORTRAN Deck for TASCO Code

```
      PROGRAM TASCO
C A PROGRAM FOR CALCULATING THE COST OF STORING HIGH LEVEL
C LIQUID WASTE IN TANKS, WITH PERPETUAL CARE PROVIDED BY AN
C ESCROW FUND.
      DIMENSION HQ(35),TAL(100)
      DIMENSION DATA(70),DES(8)
      DIMENSION DATAC(70),DATAN(70)
      COMMON/BLK18/TN,W,T,THM,E,ZAR,BLA,JJJ,TXR,Y,B3,
     1B4,B5,BAE,Z,HTU,AINS,EMW
      COMMON/BLK19/HL,HQ,YEAR
      COMMON/BLK21/DATA,LL1,LL2,LL3,LL4,LL5
C READ PERMANENT DATA CARDS
      READ(50,401)(HQ(N),N=1,28)
      READ(50,408)(HQ(N),N=29,34)
      READ(50,401)(DATAC(N),N=1,70)
      READ(50,401)(DATAN(N),N=1,70)
  401 FORMAT(7E10.0)
C READ DATA CARDS FOR PROBLEM
    1 READ(50,402)LL1,LL2,LL3,LL4,LL5,(DES(K),K=1,8)
  402 FORMAT(5I2,8A7)
  403 FORMAT(I4,E16.0)
      IF(LL3)7,7,10
    7 DO 8 N=1,70
    8 DATA(N)=DATAC(N)
      GO TO 15
   10 DO 11 N=1,70
   11 DATA(N)=DATAN(N)
   15 IF(LL1)2,4,2
    2 DO 3 K=1,LL1
    3 READ(50,403)M,DATA(M)
    4 READ(50,401)W,T,THM,Z,ZAR,EMW
      READ(50,401)B3,B4,B5,BAE,TXR,AINS
      READ(50,401)(TAL(K),K=1,LL2)
C WRITE ALL INPUT DATA
      WRITE(51,100)(DES(K),K=1,8)
      WRITE(51,105)LL1,LL2
      WRITE(51,407)
      WRITE(51,101)W,T,THM
      WRITE(51,102)Z,ZAR,EMW
      WRITE(51,103)B3,B4,B5
      WRITE(51,104)BAE,TXR,AINS
      WRITE(51,106)(TAL(K),K=1,LL2)
      WRITE(51,406)
      WRITE(51,405)(HQ(N),N=1,34)
      WRITE(51,404)
      WRITE(51,405)(DATA(N),N=1,70)
  404 FORMAT(38H0PERMANENT DATA (AFTER CHANGES,IF ANY)/)
  405 FORMAT(1H ,7E16.6)
  406 FORMAT(29H0HEAT GENERATION RATES,BTU/HR/)
  407 FORMAT(35H0PERMANENT DATA CHANGE CARDS,IF ANY,
     118H,COME AFTER CARD 1)
  408 FORMAT(3E20.0)
  100 FORMAT(11H1INPUT DATA,4X,8A7)
  101 FORMAT(15H0CARD 2  GAL/YR,F10.0,8H   YEARS,F6.0,8H   TH MW,F9.0)
  102 FORMAT(1H ,8X,9HTANK LIFE,F7.0,13H   EQUIP LIFE,F7.0,
     111H    MW ELEC,F9.0)
```

(Continued)

Table B-1 (Continued)

```
  103 FORMAT(20H0CARD 3  INT ON FUND,F8.4,10H  BOND INT,F8.4,7X,
     116HRETURN ON EQUITY,F8.4)
  104 FORMAT(1H ,8X,15HFRACT IN EQUITY,F8.4,11H   TAX RATE,F8.4,
     116H   ANN INSURANCE,F10.0)
  105 FORMAT(28H0CARD 1  PERM DATA CHANGES  ,I2,16H   NO OF CASES  ,I2)
  106 FORMAT(23H0CARD 4  NO OF TANKS   ,25F3.0)
      YEAR=T
      CALL HEAT
      HTU=HL*THM/56000.
C SET UP DO LOOP IN WHICH EACH TRIAL REPRESENTS A PLANT THAT
C HAS A DIFFERENT TOTAL NUMBER OF TANKS. TN IS THE TOTAL
C NUMBER OF TANKS (EXCLUDING SPARES). IN EACH TRIAL,TN=TAL(K).
      DO 44 K=1,LL2
      TN=TAL(K)
C CALCULATE PLANT DESIGN AND COSTS, AND WRITE RESULTS
      CALL DESIGN
C CALCULATE ECONOMICS AND COST IN DOLLARS PER GALLON,
C AND WRITE RESULTS
      CALL WACO
   44 CONTINUE
C READ DATA FOR NEW PROBLEM, IF ANY.
      GO TO 1
      END TASCO
```

(Continued)

Table B-1 (Continued)

```
      SUBROUTINE HEAT
      DIMENSION DATA(70)
      DIMENSION HQ(35)
      COMMON/BLK19/HL,HQ,YEAR
      COMMON/BLK21/DATA,LL1,LL2,LL3,LL4,LL5
      IF(LL5)11,10,11
   11 HL=0.
      RETURN
   10 IF(YEAR-1.)4,4,5
    4 HL=HQ(1)*YEAR**.523
      RETURN
    5 IF(YEAR-10.)6,6,8
    6 K=YEAR
      T=K
      HL=EXPF(LOGF(HQ(K+1))-LOGF(HQ(K+1)/HQ(K))*
     1LOGF((T+1.)/YEAR)/LOGF((T+1.)/T))
      RETURN
    8 IF(YEAR-100.)7,7,9
    7 K=(YEAR-10.)/5.+10.
      KA=YEAR/5.
      KB=5*KA
      T=KB
      HL=EXPF(LOGF(HQ(K+1))-LOGF(HQ(K+1)/HQ(K))*
     1LOGF((T+5.)/YEAR)/LOGF((T+5.)/T))
      RETURN
    9 K=(YEAR-100.)/100.+28.
      KA=YEAR/100.
      KB=100+KA
      T=KB
      HL=EXPF(LOGF(HQ(K+1))-LOGF(HQ(K+1)/HQ(K))*
     1LOGF((T+100.)/YEAR)/LOGF((T+100.)/T))
      RETURN
      END
```

(Continued)

Table B-1 (Continued)

```
      SUBROUTINE DESIGN
      DIMENSION LV(100),V(100),NV(100)
      DIMENSION DATA(70)
      DIMENSION C1(100),C2(100),AA(200),HQ(35),HTL(100),HE(100)
      COMMON/BLK18/TN,W,T,THM,E,ZAR,BLA,JJJ,TXR,Y,B3,
     1B4,B5,BAE,Z,HTU,AINS,EMW
      COMMON/BLK19/HL,HQ,YEAR
      COMMON/BLK20/C1,C2,AA,PE,CTK,PC,AADM,XAAD
      COMMON/BLK21/DATA,LL1,LL2,LL3,LL4,LL5
      COMMON/BLK24/LV
  201 FORMAT(43H0TANK SIZE,GALLONS                          ,F12.0)
  202 FORMAT(43H1TOTAL NUMBER OF TANKS (EXCL. SPARE)        ,F12.0)
  203 FORMAT(43H YEARS BETWEEN INSTALLATIONS                ,F12.4)
  204 FORMAT(12H0TANK DESIGN)
  205 FORMAT(43H0DIAMETER,FT.                               ,F12.4)
  206 FORMAT(43H HEIGHT,FT.                                 ,F12.4)
  207 FORMAT(43H THICKNESS,INCHES,TOP                       ,F12.4)
  208 FORMAT(43H                    BOTTOM                  ,F12.4)
  209 FORMAT(43H                    LOWER SIDE              ,F12.4)
  210 FORMAT(43H                    UPPER SIDE              ,F12.4)
  211 FORMAT(43H                    SAUCER                  ,F12.4)
  212 FORMAT(43H CONCRETE THICKNESS,FT,TOP                  ,F12.4)
  213 FORMAT(43H                         SIDES              ,F12.4)
  214 FORMAT(43H                         BOTTOM             ,F12.4)
  215 FORMAT(43H0HEAT LOADS                                 )
  216 FORMAT(54H0STAGE  DESIGN YEAR     TOTAL BTU/HR      ADDED BTU/HR/)
  217 FORMAT(1H ,I3,F13.4,2F18.0)
  219 FORMAT(43H0COOLING COILS,$                            ,F12.0)
  220 FORMAT(43H TANK AND SAUCER,$                          ,F12.0)
  221 FORMAT(43H CONCRETE ENCASEMENT,$                      ,F12.0)
  222 FORMAT(43H EXCAVATION AND BACKFILL,$                  ,F12.0)
  223 FORMAT(43H INSTRUMENTATION,$                          ,F12.0)
  224 FORMAT(43H0TOTAL TANK COST                            ,F12.0)
  225 FORMAT(43H APPURTENANCES, $                            ,F12.0)
  226 FORMAT(43H WEIGHT,TANK,LB                             ,F12.0)
  227 FORMAT(43H WEIGHT,SAUCER,LB                           ,F12.0)
  228 FORMAT(43H TOTAL CONCRETE,CU,YDS,                     ,F12.0)
  300 FORMAT(13HISTAGE NUMBER,42X,1HI)
  301 FORMAT(31H0INITIAL INSTALLATION (2 TANKS))
  302 FORMAT(43H INSTALLED AT YEAR                          ,F12.0)
  303 FORMAT(43H DESIGNED FOR HEAT LOAD AT YEAR             ,F12.0)
  304 FORMAT(50H0ITEMS INSTALLED FULL SIZE AT START OF PROJECT     )
  305 FORMAT(43H0FILTERS                                    ,F12.0)
  306 FORMAT(43H STACK                                      ,F12.0)
  307 FORMAT(43H SEPTIC TANK AND FIELD                      ,F12.0)
  308 FORMAT(43H DEMINERALIZERS                             ,F12.0)
  309 FORMAT(43H ELECTRICAL SUBSTATION                      ,F12.0)
  310 FORMAT(43H DIVERSION BOX                              ,F12.0)
  311 FORMAT(43H COOLING TOWER                              ,F12.0)
  312 FORMAT(43H OPERATING BUILDING                         ,F12.0)
  313 FORMAT(43H LAND                                       ,F12.0)
  314 FORMAT(43H EMERGENCY WATER TANK                       ,F12.0)
  315 FORMAT(43H WATER SURGE TANK                           ,F12.0)
  316 FORMAT(43H CONDENSER AND CONDENSATE TANK              ,F12.0)
  317 FORMAT(43H VENTILATING EQUIPMENT                      ,F12.0)
  318 FORMAT(43H0TOTAL                                      ,F12.0)
```

(Continued)

Table B-1 (Continued)

```
319 FORMAT(43H1STAGE NUMBER                                  ,I12)
321 FORMAT(43H0TANK,COMPLETE                                 ,F12.0)
322 FORMAT(43H SPARE TANK                                    ,F12.0)
323 FORMAT(43H OTHER ITEMS LISTED ABOVE                      ,F12.0)
324 FORMAT(43H HEAT EXCHANGERS                               ,F12.0)
325 FORMAT(43H PUMPS                                         ,F12.0)
326 FORMAT(43H PIPING,VALVES,AND FITTINGS                    ,F12.0)
327 FORMAT(43H TOTAL                                         ,F12.0)
328 FORMAT(43H0REPLACEMENT TANK COSTS                        )
329 FORMAT(43H COOLING COILS                                 ,F12.0)
330 FORMAT(43H TRANSFER AND FILL WITH CONCRETE               ,F12.0)
331 FORMAT(43H TOTAL REPLACEMENT COST                        ,F12.0)
332 FORMAT(43H0OPERATING COSTS,$/YEAR                        )
333 FORMAT(43H LABOR                                         ,F12.0)
334 FORMAT(43H OVERHEAD                                      ,F12.0)
335 FORMAT(43H ELECTRICITY                                   ,F12.0)
336 FORMAT(43H FRESH WATER                                   ,F12.0)
337 FORMAT(43H WATER TREATING                                ,F12.0)
338 FORMAT(43H OTHER CHEMICALS                               ,F12.0)
339 FORMAT(43H MAINTENANCE (EXCL LABOR)                      ,F12.0)
340 FORMAT(43H PROPERTY TAXES                                ,F12.0)
341 FORMAT(43H PROPERTY INSURANCE                            ,F12.0)
342 FORMAT(43H TOTAL OPERATING COST                          ,F12.0)
343 FORMAT(43H LIABILITY INSURANCE                           ,F12.0)
344 FORMAT(43H ARCHITECT-ENGINEER                            ,F12.0)
345 FORMAT(43H CONTINGENCY                                   ,F12.0)
601 FORMAT(43H0NUMBER OF TANKS INSTALLED                     ,I12)
    IF(TN-T)90,90,91
 90 Y=T/TN
    JJJ=TN
    DO 92 J=1,JJJ
 92 LV(J)=1
    LV(1)=2
    GO TO 94
 91 JJJ=T
    DO 95 J=1,JJJ
    V(J)=(J*TN+T-1.)/T
 95 NV(J)=V(J)
    LV(1)=NV(1)
    DO 96 J=2,JJJ
 96 LV(J)=NV(J)-NV(J-1)
    LV(1)=LV(1)+1
    Y=1.
 94 YEAR=T/TN
    CALL HEAT
    GCL=8.075E-09*HL*THM
    DA=0.
  1 GAL=W*T/TN+GCL+17.62*DA*DA
    D=.79936*GAL**.333333
    ZEL=(D-DA)*(D-DA)
    DA=D
    IF(ZEL-.0001)13,13,1
 13 H=.333333*D
    P=.433*H*DATA(1)
    THA=6.*D*P/(DATA(2)*DATA(3))+DATA(4)
    IF(D-65.)30,30,31
```

(Continued)

Table B-1 (Continued)

```
30 TMN=.3125
   GO TO 32
31 TMN=.375
32 IF(THA-TMN)2,3,3
 2 THA=TMN
 3 THB=.5*THA
   IF(THB-TMN)4,5,5
 4 THB=TMN
 5 THC=THB
   THD=THC-.0625
   IF(THD-TMN)6,7,7
 6 THD=TMN
 7 THE=THD-.0625
   IF(THE-.3125)33,33,34
33 THE=.3125
34 FT3=.1309*D*H*(THA+THB)+.06545*D*D*(THC+THD)
   FT4=.06545*THE*(D+5.)*(D+5.)+.2618*(D+5.)*H*THE
   WT3=FT3*DATA(5)
   WT4=FT4*DATA(5)
   CT=WT3*DATA(44)+WT4*DATA(46)
   EX=1270000.*(DATA(47)+DATA(48)*(.000001*W*T/TN)**DATA(49))
   EC=DATA(9)+D*DATA(10)
   CCA=DATA(41)*SQRTF(H)
   CCB=DATA(42)*CCA
   CCT=DATA(43)*D
   IF(CCT-DATA(45))8,9,9
 8 CCT=DATA(45)
 9 FTC=3.1416*(D+8.)*(H+CCB+CCT)+.7854*(D+5.)*(D+5.)*(CCB+CCT)
   FTCY=FTC/27.
   TC=FTC*DATA(6)
   DO 11 J=1,JJJ
   YEAR=J*Y
   CALL HEAT
11 HTL(J)=HL*THM/56000.
   HE(1)=HTL(1)
   DO 12 J=2,JJJ
12 HE(J)=HTL(J)-HTL(J-1)
   IF(HTL(1)-DATA(58))44,44,45
44 CL=1.27*(DATA(50)+DATA(51)*HTL(1))*(1-LL5)
   GO TO 46
45 CL=1.27*(DATA(59)+DATA(60)*HTL(1))
46 G6=DATA(52)+DATA(53)*W*T*.000001/TN
   IF(G6-DATA(54))50,50,51
50 G6=DATA(54)
   GO TO 53
51 IF(G6-DATA(55))53,53,52
52 G6=DATA(55)
53 G6=G6*12700.
   CTK=CL+CT+TC+EX+EC+G6
   YEAR=Z
   CALL HEAT
   HA=HL
   YEAR=Z-T/TN
   CALL HEAT
   HB=(HA-HL)*THM/56000.
   IF(HB-DATA(58))54,54,55
```

(Continued)

Table B-1 (Continued)

```
 54 PE=1.27*(DATA(50)+DATA(51)*HB)*(1-LL5)
    GO TO 56
 55 PE=1.27*(DATA(59)+DATA(60)*HB)
 56 WRITE(51,202)TN
    WRITE(51,201)GAL
    WRITE(51,203)Y
    WRITE(51,204)
    WRITE(51,205)D
    WRITE(51,206)H
    WRITE(51,207)THC
    WRITE(51,208)THD
    WRITE(51,209)THA
    WRITE(51,210)THB
    WRITE(51,211)THE
    WRITE(51,226)WT3
    WRITE(51,227)WT4
    WRITE(51,212)CCT
    WRITE(51,213)CCA
    WRITE(51,214)CCB
    WRITE(51,228)FTCY
    WRITE(51,215)
    WRITE(51,216)
    DO 15 J=1,JJJ
    YEAR=J*Y
 15 WRITE(51,217)J,YEAR,HTL(J),HE(J)
    WRITE(51,219)CL
    WRITE(51,220)CT
    WRITE(51.221)TC
    WRITE(51,222)EX
    WRITE(51,223)EC
    WRITE(51,225)G6
    WRITE(51,224)CTK
    IF(LL5)72,73,72
 72 AKA=0.
    AKB=0.
    AKC=0.
    AKD=0.
    AKE=0.
    AKG=DATA(63)
    BTR=0.
    BLD=0.
    BLA=DATA(70)
    BWW=0.
    BWQ=0.
    BRC=0.
    BVE=0.
    GO TO 74
 73 HTU6=HTU**.6
    AKA=HTU6*DATA(16)
    AKB=HTU6*DATA(17)
    AKC=HTU6*DATA(18)
    AKD=HTU6*DATA(19)
    AKE=HTU6*DATA(20)
    AKG=HTU6*DATA(13)
    BTR=HTU6*DATA(21)
    BLD=HTU6*DATA(22)
```

(Continued)

Table B-1 (Continued)

```
      BLA=DATA(23)
      BWW=HTU6*DATA(24)
      BWO=HTU6*DATA(25)
      BRC=HTU6*DATA(26)
      BVE=HTU6*DATA(27)
   74 DLT=0.
      DIN=0.
      DYM=0.
      PAN=AKA+AKB+AKC+AKD+AKE+AKG+BTR+BLD+BLA+BWW+BWO+BRC+BVE
      PC=GAL*DATA(14)+DATA(15)
      IF(LL5)75,76,75
   75 BPG=1.27*DATA(35)
      GO TO 77
   76 IF(LL3)60,60,61
   61 IF(TN-8.)62,62,63
   62 BPG=1.01-.02*(8.-TN)
      GO TO 80
   63 IF(TN-20.)64,64,65
   64 BPG=1.01+.07225*(TN-8.)
      GO TO 80
   65 IF(TN-30.)66,66,67
   66 BPG=1.877+.0691*(TN-20.)
      GO TO 80
   67 BPG=2.568+.047567*(TN-30.)
      GO TO 80
   60 IF(TN-3.)68,68,69
   68 BPG=1.147-.237*(3.-TN)
      GO TO 80
   69 IF(TN-7.)70,70,71
   70 BPG=1.147+.104*(TN-3.)
      GO TO 80
   71 BPG=1.563+.1612*(TN-7.)
   80 BPG=BPG*1270000.*HTU6/(64225.*(TN+1.))
   77 DO 40 J=1.JJJ
      BHX=HE(J)*DATA(28)
      BPQ=HE(J)*DATA(29)
      IF(J-1)18,17,18
   17 ARCH=.15*(PAN+BHX+BPQ+LV(J)*BPG)+DATA(66+LL5)*CTK+
     1  DATA(68+LL5)*LV(J)*CTK
      CONT=.15*(LV(J)*CTK+PAN+BHX+BPQ+LV(J)*BPG+ARCH)
      C1(1)=LV(J)*CTK+PAN+BHX+BPQ+LV(J)*BPG+ARCH+CONT
      C2(1)=(LV(J)-1)*(CT+TC+EX+EC+PE+PC+G6)
      GO TO 19
   18 ARCH=.15*(BHX+BPQ+LV(J)*BPG)+DATA(68+LL5)*LV(J)*CTK
      CONT=.15*(LV(J)*CTK+BHX+BPQ+LV(J)*BPG+ARCH)
      C1(J)=LV(J)*CTK+BHX+BPQ+LV(J)*BPG+ARCH+CONT
      C2(J)=LV(J)*(CT+TC+EX+EC+PE+PC+G6)
   19 YR=(J-1)*Y
      YR2=YR+Y
      DYE=HTL(J)*DATA(11)*DATA(31)
      DYW=HTL(J)*DATA(12)*DATA(32)
      DYT=DYW*DATA(33)
      DYX=HTL(J)*DATA(34)
      DYM=DYM+C1(J)*DATA(64+LL5)
      IF(LL5)78,79,78
   78 DYL=10000+(10000*J)/JJJ
```

(Continued)

Table B-1 (Continued)

```
      GO TO 85
 79   DYL=DATA(36)+DATA(37)*HTL(J)
 85   DLT=DLT+DATA(38)*CT(J)
      DIN=DIN+DATA(39)*CT(J)
      DYH=DATA(40)*DYL
      AA(J)=DYL+DYH+DYE+DYW+DYT+DYX+DYM+DYT+DIN+AINS
      IF(J-1)25,24,25
 24   WRITE(51,300)
      IF(TN-T)82,82,83
 83   WRITE(51,601)LV(J)
      GO TO 84
 82   WRITE(51,301)
 84   WRITE(51,302)YR
      WRITE(51,303)YR2
      WRITE(51,304)
      WRITE(51,305)AKA
      WRITE(51,306)AKB
      WRITE(51,307)AKC
      WRITE(51,308)AKD
      WRITE(51,309)AKE
      WRITE(51,310)AKG
      WRITE(51,311)BTR
      WRITE(51,312)BLD
      WRITE(51,313)BLA
      WRITE(51,314)BWW
      WRITE(51,315)BWQ
      WRITE(51,316)BRC
      WRITE(51,317)BVE
      WRITE(51,318)PAN
      WRITE(51,321)CTK
      WRITE(51,322)CTK
      WRITE(51,323)PAN
      GO TO 28
 25   WRITE(51,319)J
      WRITE(51,601)LV(J)
      WRITE(51,302)YR
      WRITE(51,303)YR2
      WRITE(51,321)CTK
 28   WRITE(51,324)BHX
      WRITE(51,325)BPQ
      WRITE(51,326)BPG
      WRITE(51,344)ARCH
      WRITE(51,345)CONT
      WRITE(51,327)CI(J)
      WRITE(51,328)
      WRITE(51,220)CT
      WRITE(51,221)TC
      WRITE(51,222)EX
      WRITE(51,223)EC
      WRITE(51,225)G6
      WRITE(51,329)PE
      WRITE(51,330)PC
      WRITE(51,331)C2(J)
      WRITE(51,332)
      WRITE(51,333)DYL
      WRITE(51,334)DYH
```

(Continued)

Table B-1 (Continued)

```
      WRITE(51,335)DYE
      WRITE(51,336)DYW
      WRITE(51,337)DYT
      WRITE(51,338)DYX
      WRITE(51,339)DYM
      WRITE(51,340)DLT
      WRITE(51,341)DIN
      WRITE(51,343)AINS
      WRITE(51,342)AA(J)
40    CONTINUE
      IF(LL5)86,87,86
86    AADM=10000.+10000.*DATA(40)+DIN*DATA(61)+AINS*DATA(62)*
     1  CI(JJJ)*DATA(56)+DYM
      XAAD=AADM/B3
      RETURN
87    XAAD=0.
      DISFAC=1.
      BRAC=1./(1.+B3)
      NXG=400.*T
      DO 41 N=1,NXG
      YEAR=T+N
      CALL HEAT
      HDM=HL*THM/56000.
      DYL=DATA(36)+DATA(37)*HDM
      AADM=DYL+DYL*DATA(40)+HDM*DATA(11)*DATA(31)+(HDM*DATA(12)*
     1DATA(32))*(1.+DATA(33))+DYX+DIN*DATA(61)+AINS*DATA(62)+CI(JJJ)*
     2DATA(56)+DATA(57)*CI(JJJ)+HDM*(DATA(64)+DATA(57))*CI(JJJ)/HTU
      DISFAC=DISFAC*BRAC
41    XAAD=XAAD+AADM*DISFAC
42    XAAD=XAAD+DISFAC*AADM/B3
      RETURN
      END
```

(Continued)

Table B-1 (Continued)

```
      SUBROUTINE WACO
      DIMENSION LV(100),CM(100)
      DIMENSION DATA(70)
      DIMENSION VDL(100),C1(100),C2(100),AA(200),HQ(35),DISC(100),
     1AC(100),VA(100),VB(100),VC(100),VD(100),VE(100)
      COMMON/BLK18/TN,W,T,THM,E,ZAR,BLA,JJJ,TXR,Y,B3,
     1B4,B5,BAE,Z,HTU,AINS,EMW
      COMMON/BLK20/C1,C2,AA,PE,CTK,PC,AADM,XAAD
      COMMON/BLK21/DATA,LL1,LL2,LL3,LL4,LL5
      COMMON/BLK24/LV
      C3=C2(1)/(LV(1)-1)-PE
      VAP=(1.+B3)**T
      VAY=(1.+B3)**Y
      VAN=(1.+B3)**Z
      VUM=(1.+B3)**ZAR
      B1=B4*(1.-TXR)*(1.-BAE)+B5*BAE
      SUM=0.
      WE=.5**(.04*Z)/VAN
      WL=VAP/VAN
      DO 5 K=1,10
      SUM=SUM+WL
    5 WL=WL*WE
      C4=PE*SUM
      C5=0.
      DENOM=1.
      DO 70 J=1,JJJ
      C5=C5+C4*LV(J)/DENOM
   70 DENOM=DENOM*VAY
      C5=C5-C4
      UAR=0.
      VEC=VAN/(VAN-1.)
      VET=0.
      VER=0.
      DO 2 J=1,JJJ
      UAR=UAR+C1(J)
      VA(J)=Z-T+(J-1)*Y
      VB(J)=(1.+B3)**VA(J)
      VC(J)=1./VB(J)
      VD(J)=VC(J)*VEC*C2(J)
      VET=VET+VD(J)
      VE(J)=VC(J)*VEC*C3*LV(J)
    2 VER=VER+VE(J)
      VET=VET+VD(1)
      VETC=C5+VER+C4
      ULA=UAR-BLA-(TN+1.)*CTK
      UMA=ULA*VUM/(VUM-1.)
      VEE=UMA*VAP/VUM
      UCA=VET-VETC
      UAB=XAAD
      E=VETC+VEE+UAB+CTK+PC
      VDE=B3/(VAP-1.)
      DE=E*VDE
      EL=.000001*E
      UABL=.000001*UAB
      VEEL=.000001*VEE
      ULAL=.000001*ULA
```

(Continued)

Table B-1 (Continued)

```
      VETCL=.000001*VETC
      UCAL=.000001*UCA
      VETL=.000001*VET
      C2L=.000001*C2(1)/(LV(1)-1)
      WAL=DE*.000001
      DO 25 J=1,JJJ
      CM(J)=.000001*C2(J)
   25 VDL(J)=.000001*VD(J)
      WRITE(51,301)
      WRITE(51,319)
      WRITE(51,302)
      WRITE(51,303)
      WRITE(51,304)
      WRITE(51,305)C2L,VA(1),VB(1),VEC,VD_(1)
      DO 31 J=1,JJJ
   31 WRITE(51,306)J,CM(J),VA(J),VB(J),VEC,VDL(J)
      WRITE(51,307)VETL
      WRITE(51,308)UCAL
      WRITE(51,309)VETCL
      WRITE(51,310)ULAL
      WRITE(51,311)VEEL
      WRITE(51,312)C2L
      WRITE(51,313)UABL
      WRITE(51,314)EL
      WRITE(51,315)WAL
      KT=T
      IF(B1)4,3,4
    3 PFVAH=T
      GO TO 6
    4 PFVAH=(1.-(1.+B1)**(-T))/B1
    6 DISC(1)=1./(1.+B1)
      DO 8 K=2,KT
    8 DISC(K)=DISC(1)*DISC(K-1)
      PVINV=C1(1)
      IF(JJJ-1)9,13,9
    9 DO 12 J=2,JJJ
      KG=(J-1)*Y
   12 PVINV=PVINV+C1(J)*DISC(KG)
   13 GDEP=0.
      DO 14 J=1,JJJ
   14 GDEP=GDEP+C1(J)/T
      ATE=(1.-TXR)*DE-TXR*GDEP
      PVATE=ATE*PFVAH
      PVE=0.
      DO 16 K=1,KT
      J=1+(K-1)/Y
   16 PVE=PVE+(1.-TXR)*AA(J)*DISC(K)
      TPV=PVINV+PVATE+PVE
      SALES=TPV/((1.-TXR)*PFVAH)
      SLS=SALES*.000001
      SLD=GDEP*.000001
      DO 30 N=1,KT
   30 AC(N)=0.
      DO 32 J=1,JJJ
      K=(J-1)*Y+1
   32 AC(K)=C1(J)*.000001
```

(Continued)

Table B-1 (Continued)

```
      WRITE(51,600)
      WRITE(51,601)
      BAER=1.-BAE
      ZZZ=0.
      SLSL=0.
      SLSH=0.
   27 YAE=0.
      YAB=0.
      YBC=0.
      YBN=0.
      YMX=0.
      YMY=0.
      YMZ=0.
      DO 40 K=1,KT
      NO=(K-1)/Y+1
      YAO=AA(NO)*.000001
      YAE=YAE+AC(K)*BAE-YBC
      YAB=YAB+AC(K)*BAER-YBN
      YBB=YAB*B4
      YER=YAE*B5
      YTE=YBB+YAO+WAL+SLD
      YTR=SLS-YTE
      YTX=TXR*YTR
      IF(YTX)35,35,36
   35 YTX=0.
   36 YGC=SLS-YBB-YER-YAO-WAL-YTX
      YBC=YGC*BAE
      YBN=YGC-YBC
      YMX=YMX+AC(K)
      YMY=YMY+YBC
      YMZ=YMZ+YBN
      IF(ZZZ)39,40,39
   39 WRITE(51,602)K,AC(K),YAE,YAB,YBB,YER,SLS,YAO,WAL,SLD,
     1YTE,YTR,YTX,YGC,YBC,YBN
   40 CONTINUE
      IF(ZZZ)42,42,60
   42 ERR=YMX-YMY-YMZ
      ZER=ERR*ERR
      IF(ZER-1.0E-10)44,45,45
   44 ZZZ=1.
      GO TO 27
   45 IF(ERR)47,44,46
   46 SLSL=SLS
      ERRA=ERR
      IF(SLSH)49,48,49
   48 SLS=SLS+1.2*ERR/(T*(1.-TXR))
      GO TO 27
   49 SLS=SLSL+(SLSH-SLSL)*ERRA/(ERRA-ERRB)
      GO TO 27
   47 SLSH=SLS
      ERRB=ERR
      IF(SLSL)50,48,50
   50 SLS=SLSH+(SLSH-SLSL)*ERRB/(ERRA-ERRB)
      GO TO 27
   60 WRITE(51,603)YMX,YMY,YMZ
      WRITE(51,604)
```

(Continued)

Table B-1 (Continued)

```
      WRITE(51,701)
      WRITE(51,702)
      WRITE(51,703)
      WRITE(51,704)
      WRITE(51,705)B4
      WRITE(51,706)B5
      WRITE(51,707)
      WRITE(51,708)
      WRITE(51,709)
      WRITE(51,710)
      WRITE(51,711)
      WRITE(51,712)
      WRITE(51,713)TXR
      WRITE(51,714)
      WRITE(51,715)BAE
      WRITE(51,716)BAER
      DGAL=SLS*1000000./W
      EKWC=SLS*114.1/EMW
      WRITE(51,316)SLS
      WRITE(51,317)W
      WRITE(51,318)DGAL
      WRITE(51,290)B1
      WRITE(51,291)EKWC
  290 FORMAT(43H0EFFECTIVE TAX-CORRECTED RATE OF RETURN      ,F12.6)
  291 FORMAT(43H0COST IN MILLS/KWHR ELECTRIC POWER           ,F12.4)
  301 FORMAT(43H1CALCULATION OF TOTAL PERMANENT FUND          )
  302 FORMAT(43H0    TANK REPLACEMENT FUND                    )
  303 FORMAT(34H0STAGE REPLAC    INTEREST    ACCUMUL.
     122H    PERPET      REQUIRED)
  304 FORMAT(33H  NO.    COST      YEARS      FACTOR,
     120H     FACTOR       FUND)
  305 FORMAT(6H0SPARE,F8.4,3F10.4,F11.4)
  306 FORMAT(1H ,I3,4F10.4,F11.4)
  307 FORMAT(44H01   TOTAL TANK REPLACEMENT FUND (UNCORR)     ,F11.4)
  308 FORMAT(44H 2   CORRECTION FOR HEAT LOAD REDUCTION       ,F11.4)
  309 FORMAT(44H 3   CORRECTED TANK REPLACEMENT FUND          ,F11.4)
  310 FORMAT(44H 4   EQUIPMENT OTHER THAN TANKS AND LAND      ,F11.4)
  311 FORMAT(44H 5   REPLACEMENT FUND FOR ITEM 4              ,F11.4)
  312 FORMAT(44H 6   EMERGENCY TANK FUND                      ,F11.4)
  313 FORMAT(44H 7   FUND FOR ANNUAL OPERATING EXPENSES       ,F11.4)
  314 FORMAT(44H 8   TOTAL PERMANENT FUND (3+5+6+7)           ,F11.4)
  315 FORMAT(44H09   ANNUAL DEPOSIT INTO PERMANENT FUND       ,F11.4)
  316 FORMAT(44H REQUIRED ANNUAL SALES INCOME                 ,F11.4)
  317 FORMAT(43H0GALLONS PER YEAR                            ,F12.0)
  318 FORMAT(43H DOLLARS PER GALLON                          ,F12.2)
  319 FORMAT(43H (ALL FIGURES IN MILLIONS OF $)               )
  600 FORMAT(1H1,PAYOUT OF INVESTMENTS DURING ACCUMULATION PERIOD
     1 (ALL FIGURES IN MILLIONS OF $).)
  601 FORMAT(1H0,2X,1H1,4X,1H2,6X,1H3,6X,1H4,7X,1H5,6X,1H6,6X,
     11H7,6X,1H8,6X,1H9,5X,2H10,5X,2H11,5X,2H12,5X,2H13,5X,
     22H14,5X,2H15,5X,2H16//)
  602 FORMAT(1H ,I3,15F7.3)
  603 FORMAT(1H0,3X,F7.3,84X,2F7.3)
  604 FORMAT(1H0,30HEXPLANATION OF COLUMN HEADINGS)
  701 FORMAT(1H0,40H 1   YEAR                                 )
  702 FORMAT(1H ,40H 2   NEW INVESTMENT MADE AT START OF YEAR)
```

(Continued)

Table B-1 (Continued)

```
703 FORMAT(1H ,40H 3  EQUITY OUTSTANDING AT START OF YEAR )
704 FORMAT(1H ,40H 4  BONDS OUTSTANDING AT START OF YEAR  )
705 FORMAT(1H ,24H 5  INTEREST ON BONDS AT,F7.4)
706 FORMAT(1H ,24H 6  RETURN ON EQUITY AT ,F7.4)
707 FORMAT(1H ,40H 7  INCOME FROM SALES                   )
708 FORMAT(1H ,41H 8  OPERATING EXPENSE INCLUDING INSURANCE)
709 FORMAT(1H ,40H 9  ANNUAL DEPOSIT TO PERMANENT FUND    )
710 FORMAT(1H ,40H10  ANNUAL DEPRECIATION                 )
711 FORMAT(1H ,40H11  TOTAL DEDUCTIBLE EXPENSE (5+8+9+10) )
712 FORMAT(1H ,40H12  TAXABLE INCOME (7-11)               )
713 FORMAT(1H ,17H13  INCOME TAX AT,F7.4)
714 FORMAT(1H ,43H14  TOWARD REDUCTION OF DEBT (7-5-6-8-9-13))
715 FORMAT(1H ,30H15  TOWARD REDUCTION OF EQUITY,F7.4,
   115H    OF COLUMN 14)
716 FORMAT(1H ,30H16  TOWARD REDUCTION OF BONDS ,F7.4,
   115H    OF COLUMN 14//)
    RETURN
    END
```

Sequence of Calculation

The calculations performed by the program are as follows:

1. Read data.
2. Make changes in permanent data as required.
3. Set number of tanks.
4. Design facility.
5. Calculate capital and operating costs.
6. Calculate tank replacement costs.
7. Calculate size of permanent fund.
8. Calculate required annual sales income and waste cost in dollars per gallon.
9. Print out results.
10. Change number of tanks and repeat.

Output Data

A complete set of output data is printed for each tank size tried. This includes a detailed design and cost breakdown, a summary of the permanent fund, and a table showing the payout of investment during the accumulation period. Table B-2 shows the output sheets of an example problem for one tank size.

INPUT-DATA PREPARATION

For the execution of a problem or problems, cards are fed to the computer in the following order:

1. Binary deck of machine-language instructions.
2. Permanent-data cards.
3. Problem data assemblies.

Permanent-Data Cards

There are 24 permanent-data cards. The first four contain the heat-generation rates. The others contain the design and cost constants, 10 cards for acid waste and 10 for neutralized waste. A listing of the permanent data is given in Tables B-3 and B-4.

Table B-2. Computer Output for Example Problem

```
INPUT DATA      CASE 2A50RS  PRIVATE-GOVT OWNED,ACID,204000 GAL/YR

CARD 1  PERM DATA CHANGES   2   NO OF CASES   2

PERMANENT DATA CHANGE CARDS,IF ANY,COME AFTER CARD 1

CARD 2  GAL/YR    204000   YEARS    20   TH MW    56000
        TANK LIFE     50   EQUIP LIFE     30    MW ELEC    17920

CARD 3  INT ON FUND   .0400  BOND INT   .0500       RETURN ON EQUITY   .1500
        FRACT IN EQUITY   .3500   TAX RATE   .4800   ANN INSURANCE     60000

CARD 4  NO OF TANKS     4  5

HEAT GENERATION RATES,BTU/HR

    4.330000E+07    5.650000E+07    6.360000E+07    6.840000E+07    7.220000E+07    7.540000E+07    7.830000E+07
    8.080000E+07    8.320000E+07    8.540000E+07    9.490000E+07    1.030000E+08    1.100000E+08    1.163000E+08
    1.220000E+08    1.269000E+08    1.310000E+08    1.347000E+08    1.381000E+08    1.412000E+08    1.439000E+08
    1.463000E+08    1.484000E+08    1.502000E+08    1.518000E+08    1.531000E+08    1.542000E+08    1.550000E+08
    1.619500E+08    1.624780E+08    1.625312E+08    1.625423E+08    1.625463E+08    1.625483E+08

PERMANENT DATA (AFTER CHANGES,IF ANY)

    1.200000E+00    1.150000E+04    9.000000E-01    1.250000E-01    4.960000E+02    6.115000E+00    1.500000E-02
    2.000000E-01    1.270000E+04               0    8.000000E-03    1.200000E-01    3.898000E-01    1.500000E-01
    5.000000E+04    9.887100E-01    8.502000E-02    6.921000E-01    4.352000E-01    6.101500E+00    9.532100E+00
    1.620860E+01    4.031830E+05    1.186400E+00    2.966000E+00    1.050100E+00    1.042600E+00    3.729000E-03
    1.083400E-03    7.200000E+00    1.121000E-01    2.695000E-03    3.000000E-02    1.100000E-05    1.254400E+04
    1.000000E+04    6.797100E-04    1.500000E-02    2.000000E-03    5.000000E-01    7.200000E-01    1.100000E+00
    5.240000E-02    1.270000E+00    4.920000E+00    1.207000E+00    4.544000E-03    3.490000E-02    7.017300E-01
    1.970700E+05    1.297500E-02    3.250000E+00    1.508000E+00    4.230000E+00    6.850000E+00    1.000000E-03
    2.000000E-03    6.370000E+07    3.118020E+05    1.117050E-02               0               0    2.500000E+04
    1.000000E-02    1.000000E-03    1.800000E-01    1.000000E-01    7.000000E-02    5.000000E-02               0
```

(Continued)

Table B-2 (Continued)

TOTAL NUMBER OF TANKS (EXCL. SPARE)	4
TANK SIZE,GALLONS	1178242
YEARS BETWEEN INSTALLATIONS	5.0000
TANK DESIGN	
DIAMETER,FT.	84.4278
HEIGHT,FT.	23.1426
THICKNESS,INCHES,TOP	.4203
BOTTOM	.3750
LOWER SIDE	.8407
UPPER SIDE	.4203
SAUCER	.3125
WEIGHT,TANK,LB	378579
WEIGHT,SAUCER,LB	183257
CONCRETE THICKNESS,FT,TOP	4.9200
SIDES	3.8196
BOTTOM	4.2015
TOTAL CONCRETE,CU.YDS.	2523

HEAT LOADS

STAGE	DESIGN YEAR	TOTAL BTU/HR	ADDED BTU/HR
1	5.0000	72200000	72200000
2	10.0000	85400000	13200000
3	15.0000	94900000	9500000
4	20.0000	103000000	8100000

COOLING COILS,$	1420256
TANK AND SAUCER,$	701987
CONCRETE ENCASEMENT,$	416515
EXCAVATION AND BACKFILL,$	50714
INSTRUMENTATION,$	12700
APPURTENANCES, $	60810
TOTAL TANK COST	2662981

(Continued)

Table B-2 (Continued)

STAGE NUMBER	1
INITIAL INSTALLATION (2 TANKS)	
INSTALLED AT YEAR	0
DESIGNED FOR HEAT LOAD AT YEAR	5
ITEMS INSTALLED FULL SIZE AT START OF PROJECT	
FILTERS	63500
STACK	5460
SEPTIC TANK AND FIELD	44450
DEMINERALIZERS	27951
ELECTRICAL SUBSTATION	391867
DIVERSION BOX	25035
COOLING TOWER	612197
OPERATING BUILDING	1040993
LAND	403183
EMERGENCY WATER TANK	76196
WATER SURGE TANK	190491
CONDENSER AND CONDENSATE TANK	67442
VENTILATING EQUIPMENT	66961
TOTAL	3015725
TANK, COMPLETE	2662981
SPARE TANK	2662981
OTHER ITEMS LISTED ABOVE	3015725
HEAT EXCHANGERS	269234
PUMPS	78221
PIPING, VALVES, AND FITTINGS	317753
ARCHITECT-ENGINEER	1451957
CONTINGENCY	1516491
TOTAL	12393097
REPLACEMENT TANK COSTS	
TANK AND SAUCER, $	701987
CONCRETE ENCASEMENT, $	416515
EXCAVATION AND BACKFILL, $	50714
INSTRUMENTATION, $	12700
APPURTENANCES, $	60810
COOLING COILS	311248
TRANSFER AND FILL WITH CONCRETE	226736
TOTAL REPLACEMENT COST	1780710
OPERATING COSTS, $/YEAR	
LABOR	59075
OVERHEAD	29538
ELECTRICITY	64749
FRESH WATER	23358
WATER TREATING	701
OTHER CHEMICALS	794
MAINTENANCE (EXCL LABOR)	123931
PROPERTY TAXES	185896
PROPERTY INSURANCE	24786
LIABILITY INSURANCE	60000
TOTAL OPERATING COST	572828

(Continued)

Table B-2 (Continued)

STAGE NUMBER	2
NUMBER OF TANKS INSTALLED	1
INSTALLED AT YEAR	5
DESIGNED FOR HEAT LOAD AT YEAR	10
TANK, COMPLETE	2562981
HEAT EXCHANGERS	49223
PUMPS	14301
PIPING, VALVES, AND FITTINGS	317753
ARCHITECT-ENGINEER	243600
CONTINGENCY	493179
TOTAL	3781037
REPLACEMENT TANK COSTS	
TANK AND SAUCER, $	701987
CONCRETE ENCASEMENT, $	416515
EXCAVATION AND BACKFILL, $	50714
INSTRUMENTATION, $	12700
APPURTENANCES, $	60810
COOLING COILS	311248
TRANSFER AND FILL WITH CONCRETE	226736
TOTAL REPLACEMENT COST	1780710
OPERATING COSTS, $/YEAR	
LABOR	68047
OVERHEAD	34024
ELECTRICITY	76587
FRESH WATER	27629
WATER TREATING	829
OTHER CHEMICALS	939
MAINTENANCE (EXCL LABOR)	161741
PROPERTY TAXES	242612
PROPERTY INSURANCE	32348
LIABILITY INSURANCE	60000
TOTAL OPERATING COST	704756

(Continued)

Table B-2 (Continued)

STAGE NUMBER	3
NUMBER OF TANKS INSTALLED	1
INSTALLED AT YEAR	10
DESIGNED FOR HEAT LOAD AT YEAR	15
TANK, COMPLETE	2662981
HEAT EXCHANGERS	35426
PUMPS	10292
PIPING, VALVES, AND FITTINGS	317753
ARCHITECT-ENGINEER	240929
CONTINGENCY	490107
TOTAL	3757488
REPLACEMENT TANK COSTS	
TANK AND SAUCER, $	701987
CONCRETE ENCASEMENT, $	416515
EXCAVATION AND BACKFILL, $	50714
INSTRUMENTATION, $	12700
APPURTENANCES, $	60810
COOLING COILS	311248
TRANSFER AND FILL WITH CONCRETE	226736
TOTAL REPLACEMENT COST	1780710
OPERATING COSTS, $/YEAR	
LABOR	74504
OVERHEAD	37252
ELECTRICITY	85106
FRESH WATER	30702
WATER TREATING	921
OTHER CHEMICALS	1044
MAINTENANCE (EXCL LABOR)	199316
PROPERTY TAXES	298974
PROPERTY INSURANCE	39863
LIABILITY INSURANCE	60000
TOTAL OPERATING COST	827684

(Continued)

Table B-2 (Continued)

STAGE NUMBER	4
NUMBER OF TANKS INSTALLED	1
INSTALLED AT YEAR	15
DESIGNED FOR HEAT LOAD AT YEAR	20
TANK, COMPLETE	2562981
HEAT EXCHANGERS	30205
PUMPS	8776
PIPING, VALVES, AND FITTINGS	317753
ARCHITECT-ENGINEER	239919
CONTINGENCY	488945
TOTAL	3748578
REPLACEMENT TANK COSTS	
TANK AND SAUCER, $	701987
CONCRETE ENCASEMENT, $	416515
EXCAVATION AND BACKFILL, $	50714
INSTRUMENTATION, $	12700
APPURTENANCES, $	60810
COOLING COILS	311248
TRANSFER AND FILL WITH CONCRETE	226736
TOTAL REPLACEMENT COST	1780710
OPERATING COSTS, $/YEAR	
LABOR	80010
OVERHEAD	40005
ELECTRICITY	92370
FRESH WATER	33323
WATER TREATING	1000
OTHER CHEMICALS	1133
MAINTENANCE (EXCL LABOR)	236802
PROPERTY TAXES	355203
PROPERTY INSURANCE	47360
LIABILITY INSURANCE	60000
TOTAL OPERATING COST	947206

(Continued)

Table B-2 (Continued)

CALCULATION OF TOTAL PERMANENT FUND
(ALL FIGURES IN MILLIONS OF $)

TANK REPLACEMENT FUND

STAGE NO.	REPLAC COST	INTEREST YEARS	ACCUMUL FACTOR	PERPET FACTOR	REQUIRED FUND
SPARE	1.7807	30.0000	3.2434	1.1638	.6389
1	1.7807	30.0000	3.2434	1.1638	.6389
2	1.7807	35.0000	3.9461	1.1638	.5252
3	1.7807	40.0000	4.8010	1.1638	.4316
4	1.7807	45.0000	5.8412	1.1638	.3548

1	TOTAL TANK REPLACEMENT FUND (UNCORR)	2.5894
2	CORRECTION FOR HEAT LOAD REDUCTION	.0495
3	CORRECTED TANK REPLACEMENT FUND	2.5399
4	EQUIPMENT OTHER THAN TANKS AND LAND	9.9621
5	REPLACEMENT FUND FOR ITEM 4	9.7300
6	EMERGENCY TANK FUND	1.7807
7	FUND FOR ANNUAL OPERATING EXPENSES	8.7459
8	TOTAL PERMANENT FUND (3+5+6+7)	23.9056
9	ANNUAL DEPOSIT INTO PERMANENT FUND	.8028

(Continued)

Table B-2 (Continued)

PAYOUT OF INVESTMENTS DURING ACCUMULATION PERIOD (ALL FIGURES IN MILLIONS OF $)

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	12.393	4.338	8.056	.403	.651	3.744	.573	.803	1.184	2.962	.782	.375	.940	.329	.611
2	0	4.009	7.445	.372	.601	3.744	.573	.803	1.184	2.932	.813	.390	1.005	.352	.653
3	0	3.657	6.791	.340	.549	3.744	.573	.803	1.184	2.899	.845	.406	1.075	.376	.699
4	0	3.280	6.092	.305	.492	3.744	.573	.803	1.184	2.864	.880	.422	1.150	.402	.747
5	0	2.878	5.345	.267	.432	3.744	.573	.803	1.184	2.827	.918	.440	1.229	.430	.799
6	3.781	3.771	7.004	.350	.566	3.744	.705	.803	1.184	3.042	.703	.337	.984	.344	.639
7	0	3.427	6.364	.318	.514	3.744	.705	.803	1.184	3.010	.735	.353	1.052	.368	.684
8	0	3.059	5.680	.284	.459	3.744	.705	.803	1.184	2.976	.769	.369	1.125	.394	.731
9	0	2.665	4.949	.247	.400	3.744	.705	.803	1.184	2.939	.805	.387	1.203	.421	.782
10	0	2.244	4.167	.208	.337	3.744	.705	.803	1.184	2.900	.844	.405	1.287	.450	.836
11	3.757	3.109	5.773	.289	.466	3.744	.828	.803	1.184	3.103	.641	.308	1.051	.368	.683
12	0	2.741	5.090	.255	.411	3.744	.828	.803	1.184	3.069	.675	.324	1.124	.393	.731
13	0	2.347	4.359	.218	.352	3.744	.828	.803	1.184	3.032	.712	.342	1.202	.421	.781
14	0	1.927	3.578	.179	.289	3.744	.828	.803	1.184	2.993	.751	.360	1.286	.450	.836
15	0	1.477	2.743	.137	.222	3.744	.828	.803	1.184	2.952	.793	.381	1.375	.481	.894
16	3.749	2.308	4.286	.214	.346	3.744	.947	.803	1.184	3.148	.596	.286	1.148	.402	.746
17	0	1.906	3.539	.177	.286	3.744	.947	.803	1.184	3.111	.633	.304	1.228	.430	.798
18	0	1.476	2.742	.137	.221	3.744	.947	.803	1.184	3.071	.673	.323	1.313	.459	.853
19	0	1.017	1.888	.094	.153	3.744	.947	.803	1.184	3.028	.716	.344	1.404	.491	.912
20	0	.525	.976	.049	.079	3.744	.947	.803	1.184	2.983	.762	.366	1.501	.525	.976
	23.680													8.288	15.392

EXPLANATION OF COLUMN HEADINGS

1 YEAR
2 NEW INVESTMENT MADE AT START OF YEAR
3 EQUITY OUTSTANDING AT START OF YEAR
4 BONDS OUTSTANDING AT START OF YEAR
5 INTEREST ON BONDS AT .0500
6 RETURN ON EQUITY AT .1500
7 INCOME FROM SALES
8 OPERATING EXPENSE INCLUDING INSURANCE
9 ANNUAL DEPOSIT TO PERMANENT FUND
10 ANNUAL DEPRECIATION
11 TOTAL DEDUCTIBLE EXPENSE (5+8+9+10)
12 TAXABLE INCOME (7-11)
13 INCOME TAX AT .4800
14 TOWARD REDUCTION OF DEBT (7-5-6-8-9-13)
15 TOWARD REDUCTION OF EQUITY .3500 OF COLUMN 14
16 TOWARD REDUCTION OF BONDS .6500 OF COLUMN 14

REQUIRED ANNUAL SALES INCOME	3.7444
GALLONS PER YEAR	204000
DOLLARS PER GALLON	18.35
EFFECTIVE TAX-CORRECTED RATE OF RETURN	.069400
COST IN MILLS/KWHR ELECTRIC POWER	.0238

Table B-3. Heat Generation Rates

	Time (yr)	Heat Load (10^8 Btu/hr)
HL(1)	1	0.433
HL(2)	2	0.565
HL(3)	3	0.636
HL(4)	4	0.684
HL(5)	5	0.722
HL(6)	6	0.754
HL(7)	7	0.783
HL(8)	8	0.808
HL(9)	9	0.832
HL(10)	10	0.854
HL(11)	15	0.949
HL(12)	20	1.030
HL(13)	25	1.100
HL(14)	30	1.163
HL(15)	35	1.220
HL(16)	40	1.269
HL(17)	45	1.310
HL(18)	50	1.347
HL(19)	55	1.381
HL(20)	60	1.412
HL(21)	65	1.439
HL(22)	70	1.463
HL(23)	75	1.484
HL(24)	80	1.502
HL(25)	85	1.518
HL(26)	90	1.531
HL(27)	95	1.542
HL(28)	100	1.550
HL(29)	200	1.6195
HL(30)	300	1.6248
HL(31)	400	1.6253
HL(32)	500	1.6254
HL(33)	600	1.62546
HL(34)	700	1.62548

Table B-4. Design and Cost Constants

	Where Used	Acid Waste	Neutralized Waste
DATA(1)	Specific gravity	1.20	1.05
DATA(2)	Allowable stress	11500.	13750.
DATA(3)	Joint efficiency	0.90	0.90
DATA(4)	Corrosion allowance	0.125	0.125
DATA(5)	Metal density	496.	484.
DATA(6)	Concrete cost, $\$/ft^3$	6.115	6.115
DATA(7)	Not used	0.	0.
DATA(8)	Not used	0.	0.
DATA(9)	Instruments	12700.	12700.
DATA(10)	Instruments	0.	0.
DATA(11)	Electricity, $/kwh	0.008	0.008
DATA(12)	Water, $/1000 gal	0.12	0.12
DATA(13)	Diversion box	0.3898	0.3898
DATA(14)	Transfer cost	0.15	0.15
DATA(15)	Transfer cost	50000.	50000.
DATA(16)	Filters	0.98871	0.98871
DATA(17)	Stack	0.08502	0.08502
DATA(18)	Septic tank, storm drains	0.6921	0.6921
DATA(19)	Demineralizers	0.4352	0.4352
DATA(20)	Electric substation	6.1015	6.1015
DATA(21)	Cooling tower	9.5321	9.5321
DATA(22)	Building	16.2086	16.2086
DATA(23)	Land	403183.	403183.
DATA(24)	Emergency water tank	1.1864	1.1864
DATA(25)	Water surge tank	2.966	0.8503
DATA(26)	Condensate system	1.0501	1.0501
DATA(27)	Ventilating equipment	1.0426	1.0426
DATA(28)	Heat exchangers	0.003729	0.0014631
DATA(29)	Pumps	0.0010834	0.0009005
DATA(30)	Piping	7.2	7.2
DATA(31)	Electricity usage	0.1121	0.1121
DATA(32)	Fresh water usage	0.002696	0.002696
DATA(33)	Water treatment	0.03	0.03
DATA(34)	Ion exchange resin	0.000011	0.000011
DATA(35)	Piping (decladding waste)	-	12544.
DATA(36)	Labor	10000.	10000.
DATA(37)	Labor	0.00067971	0.00067971
DATA(38)	Property taxes	0.015	0.015
DATA(39)	Property insurance	0.002	0.002
DATA(40)	Overhead	0.50	0.50
DATA(41)	Concrete design	0.72	0.72
DATA(42)	Concrete design	1.1	1.1
DATA(43)	Concrete design	0.0524	0.0524
DATA(44)	Metal cost, $/lb	1.27	0.2921

(Continued)

Table B-4, Continued

	Where Used	Acid Waste	Neutralized Waste
DATA(45)	Concrete	4.92	4.92
DATA(46)	Saucer, $/lb	1.207	0.254
DATA(47)	Excavation	0.004544	0.004544
DATA(48)	Excavation	0.0349	0.0349
DATA(49)	Excavation	0.70173	0.70173
DATA(50)	Cooling coils	197070.	12931.
DATA(51)	Cooling coils	0.012975	0.00492356
DATA(52)	Appurtenances	3.25	2.50
DATA(53)	Appurtenances	1.508	1.508
DATA(54)	Appurtenances	4.23	3.70
DATA(55)	Appurtenances	6.85	6.09
DATA(56)	Tax rate in dead period	0.001	0.001
DATA(57)	Minimum maintenance rate in dead period	0.002	0.002
DATA(58)	Cooling coils	63700000.	35400000.
DATA(59)	Cooling coils	311802.	28339.
DATA(60)	Cooling coils	0.0111705	0.0044883
DATA(61)	Property insurance factor for dead period	1.0	1.0
DATA(62)	Liability insurance factor for dead period	1.0	1.0
DATA(63)	Diversion box	25000.	25000.
DATA(64)	Maintenance	0.01	0.01
DATA(65)	Maintenance (decladding)	0.001	0.001
DATA(66)	Architect-engineer	0.18	0.18
DATA(67)	Architect-engineer	0.10	0.10
DATA(68)	Architect-engineer	0.07	0.07
DATA(69)	Architect-engineer	0.05	0.05
DATA(70)	Land (decladding)	0.	0.

Problem-Data Assembly

Card 1. This is a control and identification card. Columns 1 and 2 contain a two-digit number indicating the number of data-change cards to follow. Columns 3 and 4 contain a two-digit number designating the number of tank sizes to be investigated. Columns 5 and 6 indicate whether acid or neutralized storage is desired, 00 for acid and 01 for neutralized. Columns 9 and 10 indicate type of waste, 00 for raffinate waste and 01 for decladding waste. Columns 11 through 65 contain any desired problem-identification symbols, which will appear on the output sheets.

Data Change Cards. One card is needed for each item of permanent data to be changed. Columns 1 through 4 contain the data number; columns 5 through 20 contain the new value. Format is I4, E16.0.

Problem Data Cards. There are three cards, with format 7 E 10.0. Card 1 contains W, T, THM, Z, ZAR, and EMW. Card 2 contains B3, B4, B5, BAE, TXR, and AINS. Card 4 tells how many tanks (excluding the spare) are to be used in each of the cases investigated. For example, if it is desired to try 1, 2, 4, 5, and 10 tanks, this card would read:

1. 2. 4. 5. 10.

If more than seven cases are desired, the additional numbers are placed on cards following card 4.

Additional Problems. If several problems are to be run, the control card of the next problem comes at this point. Any changes in permanent data that have been made will remain in force throughout the run until changed again.

Economic Calculations

The purpose of this section is to give the basis for some of the economic calculations. The method of calculating the permanent fund and the required annual sales income are described in detail. The nomenclature used is listed in Table B-5.

Permanent Fund

The total permanent fund E, to be established at the end of the accumulation period, is given by:

$$E = VEE + VETC + UAB + CTK + PC,$$

Table B-5. Nomenclature

AINS	Annual liability insurance cost
B1	Weighted average earning rate, corrected for tax effects (fract.)
B3	Interest rate on fund (fract.)
B4	Interest rate on bonds (fract.)
B5	Earning rate on equity (fract.)
B6	Weighted average earning rate (fract.)
BAE	Fraction of capital in equity
C3	Cost of a tank without coils, $
C4	Fund for replacement of coils in spare tank, $
C5	Fund for replacement of coils in other tanks, $
CL	Cooling coil cost per tank, $
CTK	Cost of complete tank, installed, $
DE	Annual deposit into permanent fund, $
DGAL	Waste storage cost, $/gal
E	Total permanent fund established at end of accumulation period, $
EC	Instrumentation cost per tank, $
EMW	Nuclear capacity, Mw (electrical)
EX	Excavation and backfill cost per tank, $
F2	Amount to which tank replacement fund grows
PC	Cost of emergency transfer, $
PE	Cost of first replacement cooling coil, $
SALES	Required annual sales income, $/yr
T	Accumulation period, years
TC	Concrete encasement cost per tank, $
THM	Nuclear capacity, Mw (thermal)
TN	Number of tanks, excluding spare
TXR	Federal income tax rate (fract.)
UAB	Operating expense fund, $
ULA	Equipment replacement cost, $
UMA	Value to which VEE has grown at time ZAR years
VAN	(1 + B3) * * Z
VAP	(1 + B3) * * T
VEE	Equipment-replacement fund, $

(Continued)

Table B-5, Continued

VETC	Tank-replacement fund, $
VER	Tank-replacement fund without cooling coils, $
VE(1)	Spare-tank-replacement fund, $
VE(J)	Replacement fund for Jth tank, $
VUM	(1 + B3) * * ZAR
W	Waste rate, gal/yr
Y	Tank filling time, yr
Z	Tank life, yr
ZAR	Other equipment life, yr

where

VEE = fund for replacement of equipment other than tanks and their cooling coils,

VETC = fund for replacement of tanks, including cooling coils,

UAB = fund for annual operating expenses, including insurance premiums,

CTK = fund for one new tank, in case of emergency,

PC = fund for emergency waste transfer and filling leaky tank with concrete.

Equipment-Replacement Fund VEE

ULA represents the cost of replacing all equipment other than tanks and coils. This replacement will occur ZAR years after the start of the project, and every ZAR years thereafter. A fund VEE is established at time T and will grow to an amount UMA at the time just before the first replacement. Upon making the first replacement, the fund will be diminished to UMA - ULA. This amount will then accumulate interest for ZAR years until the time just before the second replacement. At this point, it will have grown back to UMA because the fund must be restored to the same value before each replacement. Therefore,

$$(UMA - ULA) * (1 + B3)^{ZAR} = UMA.$$

Defining $VUM = (1 + B3)^{ZAR}$,

$$UMA = \frac{ULA * VUM}{VUM - 1}$$

The value of VEE is obtained by using the fact that VEE must grow to UMA in ZAR - T years:

$$(VEE) * (1 + B3)^{ZAR - T} = UMA$$

or

$$VEE = UMA * (1 + B3)^{T - ZAR}$$

Defining $VAP = (1 + B3)^{T}$,

$$VEE = UMA * \frac{VAP}{VUM},$$

$$VEE = \frac{ULA * VAP}{VUM - 1}.$$

Tank-Replacement Fund VETC

The equation for calculating VETC is as follows:

$$VETC = VER + VE(1) + C4 + C5,$$

where

VER = total fund for replacing tanks, excluding cooling coils, and excluding spare tank,

VE(1) = fund for replacing spare tank, excluding coils,

C4 = fund for replacing cooling coils in spare tank,

C5 = fund for replacing coils in all tanks except spare tank.

Calculation of VER. - Letting "present" time denote the time at the end of the accumulation period (time = T years), present value will mean value at the end of the accumulation period. All present values will be at the interest rate B3, which is the interest rate drawn by the permanent fund. Then VER will be the sum of the present values of the replacement funds for each of the TN tanks built during the accumulation period. Let C3 denote the cost of a tank without cooling coils. Then C3 will be given by:

$$C3 = CT + TC + EX + EC + PC.$$

For the Jth original tank (J goes from 1 to TN), let VA(J) be the number of years of accumulation of interest, starting at time T and going to the time of the first replacement of the tank. VA(J) will then be given by:

$$VA(J) = Z - T + (J - 1) * Y.$$

Let VE(J) be the required fund to be established at time T for the perpetual replacement of the Jth tank. At the time just before the first replacement, this fund will have grown to F2, where

$$F2 = VE(J) * (1 + B3)^{VA(J)}.$$

Or, defining $VB(J) = (1 + B3)^{VA(J)}$,

$$F2 = VE(J) * VB(J).$$

To make the first replacement, the amount C3 will be withdrawn from the fund, leaving F2 - C3. This will then accumulate interest for Z years, until the time just before the second replacement. Since the fund must

be self-renewing, the amount of the fund at that time must again be equal to F2. The equation expressing this requirement is:

$$(F2 - C3) * (1 + B3)^{Z} = F2,$$

which gives for the required value of F2, defining $VAN = (1 + B3)^{Z}$:

$$F2 = C3 * \frac{VAN}{VAN - 1} .$$

And, since F2 = VE(J) * VB(J),

$$VE(J) = \frac{C3}{VB(J)} * \frac{VAN}{VAN - 1} .$$

Since VE(J) is the present value of the fund required for perpetual replacement of the Jth tank, VER is the summation of VE(J) for all values of J from 1 to TN.

Calculation of VE(1). - This has been covered in the preceding discussion.

Calculation of C4. - PE is the cost of the first replacement coil, based on the heat load at the time of the first replacement. The cost of the Nth replacement coil is given by the approximate formula:

$$Cost = PE * (0.5)^{0.04\, Z(N - 1)} .$$

The first replacement occurs at year Z. To get its present value at year T, it is multiplied by the present worth factor, which is:

$$\left(\frac{1}{1 + B3}\right)^{Z-T} .$$

The present worth factor for the Nth replacement coil is:

$$\left(\frac{1}{1 + B3}\right)^{(N * Z)-T} .$$

Since the heat load eventually becomes small enough so that coils are no longer needed, the assumption is made that ten replacements are adequate. The total present value C4 will then be given by:

$$C4 = \sum_{N=1}^{N=10} PE * \left(\frac{1}{1 + B3}\right)^{(N * Z)-T} .$$

Calculation of C5. - The present value of the replacement fund for the coils in the first tank is the same as that for the spare tank, that is, C4. To obtain C5, it is necessary to add up the present values of

the corresponding funds for all of the tanks. In doing this, it should be noted that the physical sizes of the replacement-coil series are identical for each of the TN tanks, because the heat loads of all tanks are identical when filled. Therefore, C5 is the summation of a series of TN terms, where each term can be thought of as consisting of C4 dollars but displaced in time by Y years from the preceding term. The first term has a present value of C4. The present value of the second term is:

$$C4 * \left(\frac{1}{1 + B3}\right)^{Y} ,$$

and the present value of the Jth term is:

$$C4 * \left(\frac{1}{1 + B3}\right)^{(J-1)*Y} .$$

Making use of the fact than TN * Y = T, the summation can be reduced to the form:

$$C5 = C4 * \frac{(VAY) * (VAP - 1)}{(VAY - 1) * (VAP)} ,$$

where $VAY = (1 + B3)^{Y}$.

Operating Expense Fund UAB

The fund UAB must draw annual interest equal to the total of the annual operating expenses and is therefore equal to the latter divided by the interest rate B3.

Annual Deposit Into Permanent Fund

An amount DE is deposited at the end of each year of the accumulation period. Using the interest rate B3, the total fund must grow to E at the end of the accumulation period. Using the sinking-fund formula, the value of DE is given by:

$$DE = E * \frac{B3}{VAP - 1} .$$

Waste-Storage Cost

The objective is to calculate DGAL, the waste-storage cost in dollars per gallon. The annual cash income during the accumulation period will be: SALES = DGAL * W.

Redefining "present" as the time at the start of the project, the total present value of the annual cash incomes must be equal to the total present value of the investments, expenses, deposits into the permanent fund, and actual income taxes for the accumulation period. The payout of the investment is complete at the end of this period. The interest rate used in calculating present values for this application is:

$$B6 = B4 * (1 - BAE) + B5 * BAE.$$

This interest rate is the weighted average of the earning rate on bonds and on stock and can be used because the ratio of outstanding capital in bonds and in stock is kept constant over the life of the project.

The present values of the incomes, investments, expenses, deposits, and income taxes can be obtained by multiplying each term by an appropriate present-worth factor, depending on the time at which the payment is made. For a payment made M years after the start of the project, the present-worth factor is:

$$\left(\frac{1}{1 + B6}\right)^{M} .$$

The method outlined above can be used to determine the required value of SALES. However, the calculation is not a convenient one because of the difficulty in determining the actual income tax paid each year. The annual income tax is equal to the tax rate times the taxable income. The taxable income is equal to the SALES minus the sum of operating expenses, deposits into the permanent fund, bond interest, and depreciation. The bond interest, however, varies from year to year, depending on the amount of capital paid off. Thus, the income tax and the value of SALES are related in such a way that a trial-and-error solution is required.

A better procedure for determining SALES is to use a corrected weighted earning rate, as described by Vondy.[29] This rate is given by:

$$B1 = B4 * (1 - TXR) * (1 - BAE) + B5 * BAE.$$

Using B1 as the interest rate for all present-worth factors, the same calculation as previously described can be made, excepting that now the bond interest is not subtracted when determining the taxable income. This change makes possible a direct solution for the value of SALES. The annual income taxes thus obtained are not actual but pseudo taxes. A subsequent calculation must be made to find the actual taxes paid.

As the final step in the output display, a payout table is constructed. This shows the amount of capital outstanding in bonds and in stock at the start of each year of the accumulation period. The outstanding capital declines to zero at the end of this period. Also shown for each year are the amounts invested, the interest on bonds, earnings on stock, operating expenses, deposit into permanent fund, depreciation, total tax-deductible expenses, taxable income, actual income tax, and amount of income used to recover capital in bonds and in stock.

REFERENCES

1. J. A. Buckham and J. A. McBride, "Pilot-Plant Studies of the Fluidized-Bed Waste Clacination Process," pp. 233-254 in Treatment and Storage of High-Level Radioactive Wastes, IAEA, Vienna (1963).

2. R. E. Tomlinson, "Hanford High-Level Waste Management," pp. 93-118 in Treatment and Storage of High-Level Radioactive Wastes, IAEA, Vienna (1963).

3. R. J. Christl, Storage of Radioactive Wastes in Basement Rock Beneath the Savannah River Plant, DP-844 (March 1964).

4. W. G. Belter, "Advances in Radioactive Waste Management Technology - Its Effect on the Future U.S. Nuclear Power Industry," Third UN Intern. Conf. Peaceful Uses Atomic Energy, Geneva, P/868 (1964).

5. R. L. Bradshaw et al., Evaluation of Ultimate Disposal Methods for Liquid and Solid Radioactive Wastes. I. Interim Liquid Storage, ORNL-3128 (August 1961).

6. J. J. Perona et al., Evaluation of Ultimate Disposal Methods for Liquid and Solid Radioactive Wastes. II. Conversion to Solid by Pot Calcination, ORNL-3192 (September 1961).

7. J. O. Blomeke et al., Evaluation of Ultimate Disposal Methods for Liquid and Solid Radioactive Wastes. III. Interim Storage of Solidified Wastes, ORNL-3355 (October 1963).

8. J. J. Perona et al., Evaluation of Ultimate Disposal Methods for Liquid and Solid Radioactive Wastes. IV. Shipment of Calcined Solids, ORNL-3356 (October 1962).

9. J. J. Perona et al., Evaluation of Ultimate Disposal Methods for Liquid and Solid Radioactive Wastes. V. Effects of Fission Product Removal on Waste Management Costs, ORNL-3357 (June 1963).

10. J. J. Perona et al., Comparative Costs for Final Disposal of Radioactive Solids in Concrete Vaults, Granite, and Salt Formations, ORNL-TM-664 (October 1963).

11. J. I. Stevens, An Economic Evaluation of Ultimate Disposal of Liquid Radioactive Wastes by the Fluidized Bed Calcination Process, IDO-14595 (October 1962).

12. B. F. Campbell et al., "Current Practice in the Management of High-Level Radioactive Wastes in the United States of America," pp. 23-40 in Treatment and Storage of High-Level Radioactive Wastes, IAEA, Vienna (1963).

13. The Perpetual Care of High-Level Radioactive Liquid Wastes in New York State. A Technological and Cost Study, S. M. Stoller Associates, New York, N.Y. (October 1962).

14. Chemical Technology Division Annual Progress Report for Period Ending August 31, 1960, ORNL-2993, pp. 95-96.

15. Civilian Nuclear Power, Appendices to a Report to the President - 1962, pp. 64-67, U.S. Atomic Energy Commission, Washington, D.C. 20545.

16. P. W. Smith, The Zirflex Process Terminal Development Report, HW-65979 (August 20, 1960).

17. J. H. Goode et al., Demonstration of the Zirflex and Sulfex Decladding Processes and a Modified Purex Solvent Extraction Process, Using Irradiated Zircaloy-2 and Stainless-Steel-Clad Urania Specimens, ORNL-3404 (May 1963).

18. J. H. Goode, ORNL, unpublished information, July 1964.

19. E. R. Irish, Description of Purex Plant Process, HW-60116 (May 19, 1959).

20. R. H. Rainey and J. G. Moore, "Laboratory Development of the Acid Thorex Process for Recovery of Thorium Reactor Fuel," Nuclear Sci. and Eng. 10, 367-71 (1961).

21. H. A. Mahlman, "Hydrogen Formation in the Radiation Chemistry of Water," J. Chem. Physics 32, No. 2, 601-603 (1960).

22. R. M. Girdler, Savannah River Plant, personal communication, Dec. 5, 1963.

23. D. N. Hess et al., Corrosion of Stainless Steel in Acidic Nitrate Waste Solutions From Processing Stainless Steel Reactor Fuels, ORNL-3474 (Sept. 30, 1963).

24. T. L. Hoffman, Corrosion Evaluation of Stainless Steels Exposed in ICPP High-Level Radioactive Waste Tanks, IDO-14600 (Dec. 1962).

25. Processing of Power Reactor Fuels, Eighteenth Quarterly Progress Report, January 1 to April 1, 1962, A. T. Clark, Jr., compiler, DP-740 (June 1962).

26. E. E. Wilson, "Design Considerations of Storage Tanks for Radioactive Wastes," Nuclear Eng., Chem. Eng. Prog. Symposium Series 52, No. 19 153-157 (1956).

27. J. I. Stevens, "Treatment, Processing and Future Disposal of Radioactive Wastes at the Idaho Chemical Processing Plant," pp. 483-508 in Disposal of Radioactive Wastes, Vol. 1, IAEA, Vienna (1960).

28. D. W. Clelland, "Concentration and Storage of Highly-Active Wastes," Treatment and Storage of High-Level Radioactive Wastes, pp. 63-91, IAEA, Vienna (1963).

29. M. W. Rosenthal et al., A Comparative Evaluation of Advanced Converters, ORNL-3686 (August 1964).

ORNL-2873
UC-70 — Waste Disposal and Processing
TID-4500 (43rd ed.)

INTERNAL DISTRIBUTION

1. Biology Library
2-4. Central Research Library
5. Reactor Division Library
6-7. ORNL — Y-12 Technical Library
Document Reference Section
8-27. Laboratory Records Department
28. Laboratory Records, ORNL R.C.
29. E. D. Arnold
30. S. I. Auerbach
31. J. O. Blomeke
32. W. J. Boegly
33. R. L. Bradshaw
34. R. E. Brooksbank
35. W. H. Carr
36. W. L. Carter
37. W. E. Clark
38. K. E. Cowser
39. F. L. Culler
40. W. Davis, Jr.
41. D. E. Ferguson
42. E. J. Frederick
43. H. E. Goeller
44. C. E. Guthrie
45. H. W. Godbee
46. F. E. Harrington
47. J. Holmes
48. W. H. Jordan
49. C. E. Larson
50. H. G. MacPherson
51. R. P. Milford
52. J. T. Roberts
53. J. B. Ruch
54. R. Salmon
55. M. J. Skinner
56. E. M. Shank
57. E. G. Struxness
58. J. C. Suddath
59. J. W. Ullmann
60. C. D. Watson
61. G. M. Watson
62. H. Weeren
63. A. M. Weinberg
64. M. E. Whatley
65. Gale Young
66. P. H. Emmett (consultant)
67. J. J. Katz (consultant)
68. C. W. J. Wende (consultant)
69. C. E. Winters (consultant)

EXTERNAL DISTRIBUTION

70. E. L. Anderson, Atomic Energy Commission, Washington
71. W. G. Belter, Atomic Energy Commission, Washington
72. H. Bernard, Atomic Energy Commission, Washington
73. W. H. Regan, Atomic Energy Commission, Washington
74. W. L. Lennemann, Atomic Energy Commission, Washington
75. J. A. Lieberman, Atomic Energy Commission, Washington
76. M. W. Rosenthal, Atomic Energy Commission, Washington
77. R. L. Hervin, Oak Ridge Operations Office
78. J. W. Nehls, Oak Ridge Operations Office
79. C. R. Cooley, Pacific Northwest Laboratory, Richland, Washington
80. E. R. Irish, Pacific Northwest Laboratory, Richland, Washington
81. A. M. Platt, Pacific Northwest Laboratory, Richland, Washington
82. G. Rey, Pacific Northwest Laboratory, Richland, Washington
83. W. H. Swift, Pacific Northwest Laboratory, Richland, Washington
84. C. H. Ice, Savannah River Laboratory
85. J. F. Proctor, Savannah River Laboratory
86. R. M. Girdler, Savannah River Laboratory
87. H. L. Hull, Du Pont, Wilmington

88. W. A. Roger, Nuclear Fuel Services, West Valley, New York
89. Oliver Townsend, New York State Atomic Development Authority, 230 Park Avenue, New York, New York
90. R. W. Kupp, S. M. Stoller Associates, 201 Park Avenue South, New York, New York
91. W. A. Nixon, J. D. Dart and Associates, Washington, D.C.
92. L. Silverman, Harvard Graduate School of Public Health
93. C. P. Straub, USPHS, Taft Sanitary Engineergin Center, Cincinnati, Ohio
94. S. Lawroski, Argonne National Laboratory
95. L. P. Hatch, Brookhaven National Laboratory
96. S. J. Beard, Pacific Northwest Laboratory, Richland, Washington
97. R. E. Tomlinson, Pacific Northwest Laboratory, Richland, Washington
98. J. I. Stevens, Infilco, Tucson, Arizona
99. J. A. Buckham, Phillips Petroleum, Idaho Falls, Idaho
100. Eurochemic, Mol, Belgium, Attn: F. Marcus
101. R. H. Burns, AERE, Harwell, England
102. K. D. B. Johnson, AERE, Harwell, England
103. D. W. Clelland, UKAEA, Risley, Warrington, England
104. L. Thiriet, CEA, Fontenay-aux-Roses, France
105. J. Sauteron, CEA, Fontenay-aux-Roses, France
106. F. N. Browder, IAEA, Vienna
107. K. M. Chandra, Trombay, India
108. Atou Shimozato, Hitachi, Ltd., Hitchi-Shi, Itaraki-Ken, Japan
109. Librarian, AAEC Research Establishment, Private Mail Bag, Sutherland, N.S.W., Australia, Attn: R. C. Cairns
110. Research and Development Division, AEC, ORO

111-425. Given distribution as shown in TID-4500 (43rd ed.) under Waste Disposal and Processing category (75 copies – CFSTI)