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AN APPRAISAL OF THE HANFORD
HIGH-LEVEL WASTE PROGRAM
(Comment Issue)

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AN APPRAISAL OF THE HANFORD
HIGH-LEVEL WASTE PROGRAM
(Comment Issue)

By

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Work performed under Contract #AT(45-1)-1350
between the Atomic Energy Commission and the General Electric Company

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TABLE OF CONTENTS

AN APPRAISAL OF THE HANFORD
HIGH-LEVEL WASTE PROGRAM

	<u>Page</u>
I. INTRODUCTION	4
II. SUMMARY	4
III. RECOMMENDATIONS	6
IV. DISCUSSION	7
A. <u>Selection of Alternative Routes</u>	8
B. <u>Study Basis</u>	9
1. Waste Streams	9
2. Throughput	10
3. Timing	10
4. Terminal Period of Cost Accrual (Present Worth)	10
C. <u>Alternative Cases</u>	11
1. Case Identification and Unit Costs	12
2. Facilities and Cost Factors	14
a. Liquid Storage	14
b. Calcination	16
c. Solids Containment	17
d. Solids Storage	19
1) Interim Storage Basin	21
2) Transport Channel & Final Storage Vaults	23
e. Disposition of Coating Waste and Organic Wash Wastes	26
f. Extended Tank Storage	27
1) Waste Composition	27
2) Cost of Storage Tanks	27
3) Frequency of Tank Replacement	28
4) Total Period of Liquid Storage	28
5) Solidification	28
g. Present Worth Translation of Costs	29
3. Qualitative Considerations	30
a. Extended Tank Storage versus the Calcination Concept	31
b. Direct versus Aged Waste Calcination	31
D. <u>Related Programs and Activities</u>	32
1. Fission Product Recovery	32
2. Storage Tank Design	33
3. Research and Development Activities	33

DECLASSIFIED

	<u>Page</u>
V. CONCLUSIONS	35
VI. ACKNOWLEDGMENTS	36
VII. REFERENCES	36
VIII. APPENDIX (Tables and Figures)	37

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AN APPRAISAL OF THE HANFORD
HIGH-LEVEL WASTE PROGRAM

I. INTRODUCTION

As set forth in the CPD Waste Management Program (HW-63958), new and improved methods of waste processing are planned to be initiated at Hanford. A major part of this program is concerned with the high-level wastes from the Purex Plant, with major objectives being the control of long-term hazards, the insurance of production continuity, and the attainment of positive waste accountability at reasonable over-all costs.

Specific plans for the disposal of Purex wastes are based on the use of high temperature calcination for immobilization and volume reduction of the solvent extraction raffinates (LWW). Four major steps are involved, each of which is of basic importance to the program objectives. These are: (1) interim LWW storage and removal for calcination, (2) calcination, (3) primary containment of the calcined waste, and (4) long-term storage. Immobilization of coating wastes and organic wash wastes is also planned, either by tank solidification methods or possibly by inclusion in the calcination feed stream.

These steps are interrelated to the extent that decisions on one will influence the stepwise costs accrued during each subsequent step in the over-all program. This is especially true of the decisions that will soon be required on the provision of interim solution storage. An early economic perspective on the role of each major element in the high-level waste program is, therefore, needed to help insure the best start in obtaining optimum long-term results.

It is the purpose of this report to provide such perspective. The objectives are: (1) to summarize and compare alternative processing routes on which decisions will be necessary, (2) to review the current program status in light of the alternatives; to indicate R&D needs and integrated timing, and (3) to stimulate new concepts, alternatives, and ideas on high-level waste processing.

Emphasis has been placed on developing a cost comparison between the direct and aged feed calcination routes. In addition, brief analysis has been made of an extended tank storage scheme to provide a basis for comparison and better understanding of the economic position of high-temperature calcination as a long-term waste processing concept. Because of the long-term nature and varying time schedules of the expenditures involved, present worth economics was employed to translate capital and operating expenses in terms of comparative unit costs.

II. SUMMARY

The comparative unit costs of four calcination alternatives and an extended tank storage method, resulting from the processing of future Purex wastes,

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HW-66618 RD

-5-

produced from FY 1965 through FY 1984 are summarized below:

	High Temperature Calcination				Extended Tank Storage Case III
	2-Year Aged Waste		90-Day Aged Waste		
	Case I-A	Case I-B	Case II-A	Case II-B	
Present Worth Basis (Dollars/TU)	406	385	346	332	359
50 Year Constant Dollar Basis (Dollars/TU)	545	516	474	452	570

Each case comprises the total processing requirements for the three high-level waste streams: solvent extraction raffinates (LWW), coating wastes and organic wash wastes. In Case I-A and Case III, organic wash wastes are assumed to be solidified with the LWW stream, whereas in the other cases, they are processed in combination with coating wastes by submerged calcination. Case I-A and Case I-B, both include a new \$5,500,000 tank farm for routine decay cooling of alkaline waste. New alkaline waste storage of two-year capacity is required for Case II-A, but is provided at a lower cost (\$1,050,000) since reuse is unnecessary. In Case II-B calcination is initiated one year earlier than in the other calcination cases which, in combination with extended use of the 241-A Tank Farm, obviates any additional capital investment for alkaline waste storage. Case III assumes continued use of tank storage for 125 years, followed by tank solidification. Capital costs for this case are based on a useful tank life of 15 years at a unit cost of \$150/TU for each tank. A water cooling concept, comprising interim storage basins and long-term storage vaults, and integrated with the 221-B calcination facility, is employed for the storage and control of calcined waste.

Unit costs are shown on the basis of two economic methods of analysis. The present worth method is considered most suitable for analyzing long-term patterns of expenditure, since it recognizes the time value of money. It represents the present funding required for all expenditures necessary for processing and control of the wastes for an indefinite period of time. The constant dollar, pay-as-you-go, evaluation representing the summation of expenditures over the first 50 years of the study period, is included for comparison.

The present worth economic differences between cases derive from changes in major parameters on which decisions will soon be required. Case I-A is representative of the current Waste Management Program basis. In comparison with Case I-B, the cost differential of \$21/TU indicates the relative disadvantage of including organic wash wastes in the calcination stream. Direct calcination, on the basis of existing schedules (Case II-A), minimizes new tank farm expenditures, and could result in an over-all present worth savings of \$39/TU in respect to the comparable aged waste calcination route. A further present worth cost reduction of \$14/TU could be gained with direct calcination (Case II-B) by extending

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HW-66618 RD

-6-

the use of the 241-A Tank Farm and accelerating the calcination program to avoid new tank farm construction.

A constant dollar comparison does not greatly alter the relative differences between calcination cases because of similarity in their expenditure patterns. Erroneous perspective could develop, however, in evaluating cases having widely different expenditure patterns if the time value of money is neglected. This is illustrated by comparing Case III with Case I-A or Case I-B on the two economic bases, which shows an actual reversal in their economic positions.

Qualitative considerations of hazards control and of the feasibility of some operations are potentially more significant than the conceptually-based economic differences. In general, the qualitative differences between cases favor processing and waste handling methods that minimize reliance on tank storage of alkaline wastes. The undefined problems of sludge temperature control and sludge removal, attendant to alkaline storage, appear more formidable than the problems that may be introduced by direct calcination.

Even though future technological developments and clarification of problems of long-term waste processing will modify some of the assumptions of this study, certain conclusions appear justified:

1. High temperature calcination, as a general concept for the long-term processing of high-level wastes, not only offers the advantages of improved hazards control, positive waste accountability and better adaptability to ultimate disposal, but is also economically competitive with extended tank storage methods.
2. Within the framework of the calcination concept, an integrated processing route, based on the direct calcination of Purex solvent extraction raffinates, results in minimum long-term costs and, more importantly, is less dependent on the successful resolution of major undefined problems.
3. Because of the significant influence of containment and storage of calcined solids on total costs, minimization of solids volume, as can be achieved by excluding coating wastes and organic wash wastes from the calcination stream, will likely improve the economics of any calcination route.

III. RECOMMENDATIONS

1. Orient the Hanford high-level waste program toward the direct calcination of acidic LWW with reasonable effort to accelerate the program.

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2. Continue to devote R&D effort to the removal and calcination of existing alkaline waste in the 241-A Tank Farm and, secondarily, the Redox first cycle wastes.
3. Parallel initial program planning with technological and engineering studies directed toward more conclusive identification of the relative position of each alternative, or of others that may merit investigation. (In general, such work would be a continuation or amplification of current effort.) Specifically:
 - a. Characterize actual waste sludges as necessary to appraise feasibility, costs, and hazards of sludge removal from the 241-A storage tanks.
 - b. Continue to evaluate the stability, corrosivity and other characteristics of calcined solids to gain insight on containment and storage criteria.
 - c. Initiate studies to determine the feasibility and hazards potential of applying submerged combustion to the solidification of coating wastes in combination with organic wash wastes. Compare submerged combustion with an alternate method such as Bentube evaporation.
 - d. Review the potential of concentrating organic wash wastes in the Purex Plant. If this is feasible, evaluate the economics of such pre-concentration in comparison with the increased boil-off requirements that would otherwise be required of the tank solidification facilities.

IV. DISCUSSION

Decisions on the early steps involved in long-term waste processing may not be fully measurable for decades in the future, yet may well set the pattern and even be the basis for later steps in an integrated program. The waste calcination program at Hanford has now progressed to a point where perspective on such early decisions is necessary for continued effectiveness of planning and development work.

Toward gaining this perspective, analysis of the over-all processing route, even though requiring highly conceptual evaluation of later steps in the program, was considered necessary. Major processing routes responsive to current interests at Hanford were selected from which the study bases and specific study cases, illustrative of the parameters significant to early decisions, were defined. The facility requirements for each of the alternative cases, including capital and operating costs, were evaluated. In addition, for broader perspective, the effects of related programs and activities were briefly reviewed.

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A. Selection of Alternative Routes

In support of the CPD Waste Management Program, major effort is being applied to the development of high-temperature calcination methods for waste solidification. This work is motivated primarily by the promise of calcination to produce a reasonably stable, minimum volume solid at acceptable costs. For this reason also, high-temperature calcination has been generally accepted as an integral part of the final disposal route to be adopted at Hanford. Decisions on the specific calcination methods to be used, whether spray, fluid-bed or batch calcination, will primarily be dependent on the relative technological advantages each affords. It is further expected that economic differences between these methods may prove to be minor and have little influence on evaluating the worth of integrated processing routes.

Considered more important for establishing perspective within the framework of the calcination concept are those factors relating to the characteristics of the waste established prior to calcination. These can conceivably set the general level of costs that would be accrued in the over-all program. One of the first major decisions of this nature is concerned with the timing and purpose of additional liquid waste storage for the Purex Plant. This can involve a significant capital expenditure and also establish certain waste characteristics derived from the limitations of the storage system. The design and magnitude of additional tank storage will vary considerably depending on the choice between direct or aged waste calcination. Such a determination, in turn, will influence the cost of containment and storage of calcined solids, as related to specific volume and heat dissipation requirements. Also of interest is tank solidification of coating wastes and organic wash wastes, which could be avoided or minimized in scope if advantages are found in using these wastes as a diluent in the calcination of solvent extraction wastes.

Early decisions of a definite nature will also help define the research and development needs of the calcination program. Once the incentives of the many factors influencing the choice of processing routes are known, broad exploratory work can be reduced and specific process and equipment criteria can more effectively be developed. For example, depending on the purpose of new liquid waste storage, whether to provide a 2- to 3-year decay period or to serve only as a short-term holdup prior to calcination, desired timing of the R&D program and its emphasis relative to waste characteristics would be significantly clarified.

Consequently, two major routes for the long-term processing of Purex wastes were selected for study as being most illustrative of the parameters currently of interest. These are: (1) direct calcination with a minimum liquid holdup between the Purex Plant and the calcination process, and (2) calcination of aged feed after a 2- to 3-year

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decay period in liquid storage. Both of these routes involve activation of the 221-B facility for calcination and the provision of a long-term storage system for the calcined waste.

A third route for long-term waste processing, that of extended tank storage with eventual in-tank solidification, was also included for brief review. This concept, which represents a logical extension of present high-level waste handling methods, is of interest primarily as a basis on which to compare and identify the economic position of calcination as a long-term waste processing concept. Basic differences in long-term hazards control, reversibility of final storage and waste accountability would require difficult philosophical discrimination rather than economic analysis if extended tank storage were to be seriously considered a competitive processing route.

B. Study Basis

To insure reasonable consistency in the treatment of each case, and to gain simplicity but still retain appropriate realism in regard to the purpose of the study, the following bases were established:

1. Waste Streams

Because of the major role of Purex in the CPD production complex and the immediacy of project action associated with the disposition of its wastes, the study was confined to the future processing needs for Purex high-level waste streams. The waste program will eventually be expanded, or perhaps initially designed, to encompass methods for the long-term disposition of Redox wastes and other presently stored wastes. Inclusion of these wastes in the study, however, was not believed to be necessary since the attendant costs would be equally incremental to each case, or would involve capital expenditures unique to their own disposition.

The waste streams included in the category of high-level Purex wastes and their assumed chemical compositions are shown in the following table. The LWW stream composition is based on the routine use of the formaldehyde-kill process for nitrate destruction.

<u>PUREX HIGH LEVEL WASTES</u>			
<u>Significant Constituents</u>	<u>Acidic LWW 41 gal./ton</u>	<u>Organic Wash 450 gal./ton</u>	<u>Coating Waste 210 gal./ton</u>
Na	0.5 <u>M</u>	0.35 <u>M</u>	3.71 <u>M</u>
Fe	0.75	--	--
Cr N_1	0.06	--	--
K	--	0.012	--
PO_4^{3-}	0.01	--	--
SO_4	1.00	--	--
NO_2 NO_3	0.95	0.102	1.81
CO_3	--	0.123	--
OH	--	--	0.58
AlO_2	--	--	1.15
Mn	--	0.012	--
Al	0.10	--	--

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Radiochemical composition, and hence heat generation rates, were derived from Blomeke-Todd data⁽²⁾ assuming an irradiation history of 800 MWD/T exposure at a power level of 7 MW/T. Heat generation and decay with time is shown in Figure 1.

2. Throughput

The average production rate of the Purex Plant was taken to be 7,000 TU/year, with processing needs and cost derivations based on a 20-year production period. The requirements for handling only the new wastes generated during this period were considered. This span of time was believed necessary to minimize any disparities that could exist over shorter periods. Although existing waste in underground storage will also necessitate long-term disposition, their inclusion in the case studies was not considered warranted as long as the processes employed are adaptable to them.

3. Timing

Common to each case is the need for additional underground tank storage for Purex 1LW. Based on current assumptions on the depletion and reserve philosophy of existing storage space in the 241-A Tank Farm⁽¹⁾, this need was assumed to occur during the last quarter of FY 1964. Of equal importance is the timing of calcination facilities which, in reflection of current assumptions on development program needs, project timing, and start-up requirements, was assumed to be July 1966. Alteration of these dates was considered possible due to the flexibility inherent in the assumptions from which they were derived. Significant changes, however, such as acceleration of the calcination program by, say a year, would entail certain risks in achieving an optimum design basis, therefore, must appropriately balance with the incentives that are involved. Except for this flexibility in timing, a consistent basis for the economic analysis of direct and aged waste calcination routes was considered necessary to gain a realistic perspective for such incentives.

4. Terminal Period of Cost Accrual

Because of the long-term need for control of the hazards associated with radioactive waste storage, a significant period of surveillance and repetitive annual expenses will be required subsequent to final disposition of the wastes. Assignment of a specific time period for this requirement would be presumptuous since it could conceivably be for centuries due to the long half-lives of the biologically hazardous isotopes that are present. The present worth method of economic analysis (used herein) conveniently, yet justifiably, results in essentially self-termination of such expenditures. For example, based on an annual compound interest rate of 3 percent, the present worth significance of an annual expenditure made over a period of 50 years increases only 23 percent if continued for 100

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years and only 29.7 percent, or an increment of 6.7 percent, if continued indefinitely. Present worth translation of capital expenses incurred under differing expenditure patterns, as in this study, is also necessary for realistic comparison. Again based on annual compound interest rate of 3 percent, the present worth of a capital expenditure planned for 50 years in the future would be only 23 percent of the future dollars required. This would further be reduced to 5 percent if the investment is planned 100 years in the future. For purposes of this study, therefore, long-term surveillance costs were accrued for an indefinite period of time, whereas major capital expense items were included only if envisioned to be required within the next 100 years or so.

C. Alternative Cases

The comparative economic position of five alternative cases for the processing of high-level Purex waste was developed, including the evaluation of facility requirements and an analysis of the cost factors involved. A schematic diagram of the cases is presented in Figure 2. Four of the alternatives are variations of the major concepts - direct and aged waste calcination. These were developed primarily to show the influence of pre-calcination decay and organic wash disposition, and to indicate the incentives for altering established program schedules. Unit costs, presented in the following table, were derived from present worth translation of the estimated capital and operating costs associated with the major steps of each case.

PRESENT WORTH UNIT COSTS OF WASTE PROCESSING ALTERNATIVES
(DOLLARS/TU)

Function	Calcination Alternatives				Extended
	Aged Waste		90-Day Waste		Tank Storage
	Case I-A	Case I-B	Case II-A	Case II-B	Case III
Tank Storage and Pump-out	79	79	18	6	346
Calcination	173	173	173	169	-
Containers for Calcined Waste	78	48	69	69	-
Interim Solids Storage	16	14	18	18	-
Long-term Vault Storage	48	41	38	39	-
Submerged Com- bustion	12	30	30	30	12
Bentube Evap- oration	-	-	-	-	1
Total	406	385	346	332	359
(Constant Dollar Unit Cost)	(545)	(516)	(474)	(452)	(570)

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The economic advantages of one case over another, whereas believed to be sound in qualitative significance, cannot be translated directly in terms of actual unit costs because of their present worth derivation and the differing expenditure patterns of major cost factors. In terms of actual cost accruals, neglecting the time value of money; the unit cost differences would be somewhat greater. The order of magnitude of this increase may be derived from the figures in parenthesis, which represent constant dollar unit costs over a 50-year operational period.

1. Case Identification

The study cases were defined as follows, each encompassing the complete processing of waste produced during the period July 1964 through July 1984:

a. Case I-A

Storage of alkaline LWW and organic wash waste in reusable stainless steel tankage, followed by calcination and solids storage, after an effective decay period of two years. Solidification of coating waste by submerged combustion.

The concept of calcining the combined solvent extraction raffinates from the Purex Plant after a decay period of about two years is the basis of current budget planning for high-level waste processing. In the formation of these earlier plans, this route was selected as the principal alternative because pre-calcination decay of the short half-lived fission products was expected to provide a significant advantage in reducing the heat dissipation required from the solid, calcined waste. In addition, the possible need for new tank storage for Purex waste regardless of the calcination route offered the potential of achieving the desired pre-calcination decay at a reasonable incremental cost by designing the new tank farm to function as a reusable, integral part of the calcination program.

b. Case I-B

Storage of alkaline LWW only, in stainless steel, reusable tankage, followed by calcination and solids storage after an effective decay of two years. Solidification of coating wastes and organic wash wastes by submerged combustion.

This case is of interest because of the conflict between the simplicity and economy of the present method of concentrating dilute organic wash wastes in the 241-A Tank Farm, and the added bulk volume organic wash wastes

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-13-

contributes to the calcined solids. A gain of \$21/TU is indicated as a result of excluding organic wash wastes from the calcination stream.

c. Case II-A

Storage of alkaline LWW produced during the first two years of the study period, as necessary, to span the interval between calcination start-up in July 1966 and the need for additional storage in July 1964. Direct calcination and storage of acidic LWW for 18 years, followed by calcination and storage of the previously accumulated alkaline LWW. Solidification of coating wastes and organic wash wastes by submerged combustion. (Since no cost advantage was introduced, calcination and solids storage costs for the last two years were based on continuation of acidic feed, thereby simplifying calculations.)

As the major alternative to high-temperature solidification of aged waste, direct calcination of LWW from the Purex Plant offers two advantages of economic significance. First, it has the potential of reducing the over-all cost of future tank storage. The extent of this savings, however, is related to the timing of calcination in relation to the need for additional waste storage (depletion of 241-A Tank Farm capacity) for continuity of production in the Purex Plant; the earlier calcination can be started, the greater the advantage. Second, the small liquid hold-up involved in direct calcination will permit economical storage of LWW in the acidic state without significant corrosion, resulting in a minimum of sludge problems in comparison with those expected under alkaline storage conditions. This also provides the potential of achieving a minimum volume in calcined solids and thus favorably influences final storage costs. Disadvantages having a compensating trend are introduced, however, by the effect of shifting major heat dissipation requirements from tank storage to the solids storage area. Increased shielding and off-gas decontamination requirements will also result but are believed to be of minor significance. The net effect of this route is a savings, in terms of present worth dollars, of \$39/TU over the preceding case of aged waste calcination.

d. Case II-B

Acceleration of the calcination program to permit production use of these facilities in July 1965, coupled with extension of the 241-A Tank Farm capacity to avoid new tank farm construction. Direct calcination and storage of acidic LWW, reflecting cost considerations similar to Case II-A, for the

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initial production of alkaline waste. Solidification of coating wastes and organic wash wastes by submerged combustion.

By virtue of this alteration in the 241-A fill limitations and calcination program timing, a comparative unit cost advantage of \$14/TU can potentially be realized over the second most economical route, Case II-A.

Case III

Extended tank storage of combined alkaline LWV and organic wash wastes for an over-all decay period of approximately 125 years, followed by solidification in large underground tankage.

2. Facility Requirements and Cost Factors

The results of this study were based largely on conceptual engineering and preliminary cost estimations and are, therefore, especially sensitive to the many unproven assumptions employed. The facility requirements and limitations for each processing route, however, are believed to be responsive to the major philosophies of CPD waste management and to existing technological considerations. A more detailed discussion of the facilities and cost factors involved is presented below.

a. Liquid Storage

For Cases I-A and I-B, a capital expenditure of \$5,500,000 was assumed necessary to provide high integrity, reusable tanks for decay storage. Differentiation between the storage of alkaline LWV and the combined wastes containing organic washes was not endeavored due to the potential that factors having a major bearing on costs, such as sludge temperature control, sluicing requirements for sludge removal, and specific volume limitations, will not be significantly different for the two cases. For estimating purposes, however, a change of \$1,000,000 in this expenditure will influence present worth unit costs by about \$7/TU.

The storage concept employed was the same as that developed for the CPD Waste Management Program, namely, nine 150,000-gallon, horizontal, stainless steel vessels each enclosed in a cylindrical concrete vault. The net working capacity of these vessels would be about 900,000 gallons assuming a 75 percent fill level and a maximum of eight tanks full at any one time, as necessary to provide for pump-out time to the calcination facility. At a specific volume of 50 gallons/TU and the assumed production rate of 7,000 TU/year, a complete

DECLASSIFIED

-15-

filling, decay, and pump-out cycle would extend for 2.5 years. Sufficient reuse of the tanks was assumed possible for an effective tank farm life of 20 years. Personnel requirements and operating costs, Figure 4, Tables IV and V (Appendix), for the early surveillance period and pump-out period were based on current practices in the 241-A Tank Farm and past experience in the Metal Recovery Program.

On the basis that the previously established need date for additional tank storage is a valid assumption (July 1964), and calcination facilities are not available for production use until July 1966, Case II-A would not obviate the need for storage to span this interval of time. Because of the singular purpose of such storage, however, it was assumed that tank design could be simplified to approach the type provided by the present 241-A Tank Farm. For this purpose a cost of \$1.50 per gallon, for a total capital investment of \$1,050,000, was assigned.

The two years' production of neutralized LWW represents a unique feed stream for the direct calcination route. For case comparison, it was assumed that this material would be calcined during the last two years of the 20-year period. Operating costs associated with the removal of this neutralized increment of waste from storage were related to the removal costs assigned to the aged waste calcination routes.

Case II-B, though obviating the need for new storage of this type, requires a one-year extension of the need date to July 1965. It is believed that with adequate incentive, this can be accomplished either by increasing the 241-A fill limitation based on sound evaluation of hazards involved, or by moving portions of the 241-A tank contents to the older, "non-boiling" tankage available in 200 East Area. For consistency of treatment, operating costs of Case II-B were developed to reflect the inclusion of a one-year quantity of aged, alkaline LWW collected between the start of the base period and the accelerated production use date of the calcination facilities, July 1965.

To handle the primary calcination stream, acidic LWW direct from the Purex Plant, the provision of buffer storage in the 221-B canyon was considered necessary. For this purpose, the installation of three new "bath tub" tanks providing a hold-up of about one month was evaluated. The cost of such an installation, complete with agitators, pumps and cooling coils, was estimated to be \$660,000 - to be incurred in FY 1964 coincidental with the calcination project. (This represents all new equipment, therefore does not reflect the savings possible if 221-U equipment could be used.) Because of the corrosion potential under these storage conditions,

DECLASSIFIED

-16-

an expenditure of a magnitude adequate to cover the cost of new tanks was assumed necessary in 10 years. Operating costs were developed primarily on the basis of pump and agitator replacement needs; manpower requirements were assumed to be covered by the calcination operating crews.

Tank storage costs are of significance in the economic analysis for two major reasons. First, they are primarily responsible for the unit cost differences between the aged waste and direct calcination routes. Second, they occur earliest in the time schedule; consequently, they are of major importance for immediate financial planning.

b. Calcination

Capital expenditures in the amount of \$4,000,000 were estimated to be required to convert the 221-B canyon for calcination purposes and to provide a cross-country transfer line from the Purex Plant. The cost estimate was derived from prior analysis of the conversion of B Plant for recovery of gross fission products. The full cost of B Plant utilization was ascribed to waste calcination for derivation of the costs in this study.

Annual operating costs of \$1,363,000 were derived from consideration of the functional steps and cell layout schematically shown in Figure 3. The acidic waste storage cells were included in this layout to show the probable maximum in-cell utilization for a waste calcination program. The particular arrangement and choice of cells were made in recognition of the possible use of the remaining cells for fission product recovery. Use of the batch calcination process was arbitrarily assumed. Within the accuracy limits of the capital and operating cost estimations, differences that may result by using the spray or fluid bed calcination process are not believed to be significant. A total work force of 44-1/2 operating and service personnel was assumed to be required. Primary containment costs (discussed later) were not included under general calcination costs because of their magnitude and sensitivity to feed stream characteristics.

For present worth evaluation, the capital outlay for calcination was timed in FY 1964. The plant was assumed to be available for production use, however, at the start of FY 1967 for Cases I-A, I-B, and I-C. Annual operating costs were incurred at the same rate as for production for a period of 1-1/2 years prior to production use of the facility, reflecting the need and duration of the start-up and shakedown phase of operation. For Case II-B, acceleration in the production use of the facility was assumed to be achieved by intensifying and expanding hot demonstration on a development scale so the start-up phase could be reduced to a period of six months.

DECLASSIFIED

Capital and operating costs associated with the calcination of fresh waste were considered the same as for the aged waste calcination route. Except, perhaps, for the thickness of view windows installed as an aid to operation of the mechanically-oriented cells, shielding requirements are met equally well for the two cases by virtue of using an existing process building. Because of the increased off-gas decontamination requirement, equipment costs in this area may be increased somewhat for the direct calcination route. Compensating differences in equipment costs could be expected, however, because of the reduced volume of acidic wastes.

The relatively large and stable unit cost contribution of the calcination step (capital depreciated over 20 years) tends to minimize the significance of cost variations in the other steps involved. Therefore, this should be borne in mind when comparing the differences between calcination cases on the basis of total unit costs.

c. Solids Containment

The containment of calcined waste in a manner that will insure long-term integrity is a subject which is yet to receive extensive technological definition. In certain measure, it will be dependent on the calcination scheme employed since batch calcination will pose more severe initial conditions than, say, the subsequent melting of powders produced from continuous calcination processes. High temperature corrosion of various materials of construction in contact with calcined wastes is not too well known, though preliminary data indicate the need for stainless steel. For this study, container costs were developed on the assumed need for 304L stainless steel with a wall thickness of one-half inch.

Other factors influencing container design, quantity, and hence container costs are:

- 1) The reduced volume of calcined waste per ton of uranium processed in the parent plant.
- 2) Heat generation rate of the calcined waste as determined by age and reduced volume.
- 3) Thermal conductivity of the calcined waste.
- 4) Temperature criteria on which container sizing is based.

The first three of these items are inherent properties of the waste, whereas the temperature criteria are a matter of philosophy on the storage conditions to be tolerated. For comparing

DECLASSIFIED

two differently characterized wastes, especially relative to heat generation, the establishment of a temperature criterion poses a difficult problem for insuring consistency of treatment. Comparison of a green waste with an aged waste on the basis of limiting the initial storage temperature to a common value does not appear to be a fair assumption since the rapid decay rate of the green waste would soon result in a significantly lower temperature after the first few months of storage, and an obvious inequity would exist. On the other hand, recognition must be given the need to limit initial container temperature to a reasonable value. Temperature criteria will also be somewhat influenced by the container handling methods and the cooling environment involved. These considerations, illustrated in Figure 5, led to the establishment of two temperature criteria for this study:

- 1) Based on free convection and radiation in air, core temperature of the waste must not exceed the calcination temperature (assumed to be 1650 °F), representing the potential condition during the interval between calcination and initial water storage.
- 2) Under conditions of water cooling, the temperature drop in the waste core must not exceed 100 °F at the end of a two-year interim storage period (resulting in a skin temperature less than 300 °F in final storage for retarding corrosion).

The general assumption was also made that the final solid would be produced as a melt so advantage could be taken of such characteristics as high density and relatively high thermal conductivity as contrasted to the properties of a powder product. Specific values assigned to the various factors influencing container costs, container size, and the constant dollar cost assigned to this item for each of the study cases, were as follows:

	<u>Case I-A</u>	<u>Case I-B</u>	<u>Cases II-A and B</u>
1. Density of Melt (gm/cc)	2.5 gm/cc	2.5 gm/cc	2.5 gm/cc
2. Thermal Conductivity of Melt (BTU/hr. - Ft. °F)	0.6	0.6	0.6
3. Specific Volume (Gallons per ton of uranium processed)	12.5	5.5	3.5

DECLASSIFIED

DECLASSIFIED

HW-66618 RD

-19-

cont. -

	<u>Case I-A</u>	<u>Case I-B</u>	<u>Cases II-A & B</u>
4. Initial heat generation rate (BTU/hr.Ft. ³)	310	710	19200
5. Container Dimensions - Length (ft.)	10	10	10
I.D. (inches)	36	24	10 O.D. - 9 I.D. (Inner component of Annulus)
O.D. (inches)	37	25	21 O.D. - 20 I.D. (Outer component of Annulus)
6. Fill Level (ft.)	8	8	8
7. Number of Containers required per year	415	410	500
8. Constant Dollar Unit Cost - Dollars/TU	115	71	98

As noted above, the solid product resulting from direct calcination will have a significantly greater heat generation rate than that produced by aged waste calcination. To adhere to the temperature criteria, this requires an increase in the effective ratio of container surface area to volume which may be achieved by reducing the container diameter, using an annular cross section or resorting to other more complex design innovations. Annular containers were considered most optimum for use in direct calcination because they would provide not only a lower cost than ordinary cylinders but would also minimize the total number of containers required. Handling frequency would, therefore, be reduced to a level comparable to the aged waste calcination route.

d. Solids Storage

The storage system adopted for calcined waste holds the key to realization of the objectives of the waste calcination program. Herein lies the major burden of providing for long-term hazards control. Complementary to this basic need are the elements of accountability and reversibility which must inherently be provided in the system until an acceptable state of ultimate disposition is achieved.

DECLASSIFIED

DECLASSIFIED

HW-66618 RD

-20-

Without qualification, however, it is believed that ultimate disposition should not be a criterion for the development of initial storage systems until the definition of "ultimate disposition", its worth and its hazards, can more clearly and confidently be stated. Rather, the storage of calcined waste should be provided by a system that basically is reversible. It should have a potential for ultimate storage in itself, but, more importantly, it should not result in the inability of management to respond to the increased knowledge and improved understanding that can be expected in the next 25 to 50 years, or so.

In support of philosophical needs, therefore, the specific requirements of: 1) outgassing control, 2) minimization of long-term storage temperatures, 3) reliability of the cooling environment, and 4) adequacy of radiation control, were considered essential. It is possible these requirements could be met by the use of either air or water cooling as the basic heat dissipation method. A number of considerations, primarily qualitative, led to the selection of water cooling as possibly offering greater advantages.

- Temperature Control and Efficiency - Recent data point to the need for assuring relatively low temperatures in storage to inhibit corrosion. Water can effectively maintain the skin temperature of the storage container to near the boiling point. Air cooling, however, would result in considerable variation in container skin temperatures (and would necessitate smaller containers), depending on the age and distribution of the material in storage. This would require overdesign of the air system to insure a low temperature for the most active containers. Contributing further to the inefficiency of air cooling would be the potential of temperature variations over the surface of individual containers.
- Hazards Control - Shielding, also, is inherently provided by the use of water for cooling, whereas an air system may necessarily require the massive construction of present canyon buildings for workable access to and from the vault area. Water cooling concepts would permit safe and convenient transport of containers between the calcination facility and the storage areas by the use of water channels. Air cooling methods, however, could essentially limit vault construction to an extension of the calcination facilities, or would require cask transportation if a more remote location would be desirable - with its attendant transfer and radiation control problems. Also, as a control measure, periodic inspection of containers could more readily and simply be accomplished in a water system.

DECLASSIFIED

- Design and Construction Complexities - Water storage of highly radioactive materials has undergone extensive development and has been matured by many years of production experience in the handling of reactor fuel elements. Much of this knowledge should be directly translatable to the storage of calcined waste. Comparable experience with air cooled storage systems is not available, and considerable development would be required. It is believed that such development would reveal the need for complex innovations to obtain a workable system.

The concept employed consists of: 1) an interim, water-cooled storage basin, 2) a water transport channel, and 3) a system of water-cooled storage vaults. Figure 6 shows a plot plan of the system adapted for use adjacent to the 221-B canyon building. A second group of final storage vaults would be required for the 20-year production period of the study.

1) Interim Storage Basin (Figures 7a and 7b)

The interim storage basin was planned as an annex to the 221-B canyon. Its main purpose is to serve as a hold station in which close surveillance over the waste containers can be maintained, controlled outgassing can be accomplished and the integrity of the containers can be established. In the event of container failure, return to the canyon building can readily be accomplished. The basin was sized for a container residence time of 2 years.

The basin proper is constructed of concrete with its depth essentially the same as the canyon building. It is housed in a steel and transite structure. Facilities include a water pumping station, a heat exchanger and a cooling tower, an inspection station for examination of containers, a remotely operable overhead crane for movement and positioning of the containers, and a movable maintenance platform extending across the water basin. The basin is divided into sections, each of which can be isolated by means of bulkheads in the event container leakage should occur. Piping connections are provided to the canyon waste system to accommodate the handling of contaminated water. The pumping station provides cooling water to both the interim basin and the final storage vault. The flow is divided between the two storage areas in accordance with the relative heat generation involved. Water from the final storage vaults is returned to the pump pit via the transport channel and the interim basin. Movement of containers to the basin and return to the canyon, if need be, is accomplished with an underwater dolly through a water passage linking cell 20R with the

DECLASSIFIED

basin. Should outgassing of the containers be necessary, it is envisioned that each container would be provided with an off-gas control attachment, such as a snorkle tube and filter device, incorporated as part of the final closure on the container. After positioning in the interim storage basin, the snorkle would be attached by flexible connection to a vent header located along the walls of each basin section. Following the two-year residence period, during which close surveillance is maintained, each container would be given a final inspection and then transported via the water transport channel to its final storage vault.

To realistically differentiate between the storage basin needs for each of the study cases, four parameters of major significance were considered:

- a) Heat generation rate - This was assumed to be 9,000,000 and 40,000,000 BTU/hr. for the aged waste and direct calcination routes, respectively. These rates include the heat dissipation requirements, in terms of waterflow and heat exchange equipment sizing, of the long-term storage vaults.
- b) Basin Floor Area Utilization - Based on remote operational needs, it was assumed that a minimum spacing of six inches must be maintained between containers. In addition, to provide access to individual containers it was assumed that for each two rows a free area equal to the width of a container must be provided.
- c) Shielding Requirements - This was based on the criterion of 1 Mr/hr. at the surface of the water. Changes in water depth with age of the waste were evaluated and found to be insignificant in their effect on basin costs.
- d) Residence Time (or Total Floor Area) - As previously mentioned, this was assumed to be 2 years, representing a nominal period during which confidence in container integrity and adequate outgassing can be achieved prior to final storage.

In regard to this last assumption, arguments can be advanced for either increasing or decreasing the hold-up time for 90-day aged waste as compared to two-year aged waste. For example, the higher internal temperatures under which the 90-day aged waste is stored (Figure 5) during the two-year period would tend to insure that

DECLASSIFIED

maximum out-gassing will occur early in the storage period and result in a stable solid prior to the two-year period. Conversely, the increased radiation intensity and higher terminal heat generation rate at the end of the two-year period may indicate the need for more prolonged interim storage for assurance of container integrity and stability of the waste. Until better definition of the behavior of wastes in storage is obtained, however, the assumption of equal residence time in interim storage was considered most equitable.

The variation in capital cost due to the factors of heat dissipation and total floor area requirements are estimated in Figure 9. For Cases I-A, I-B, and the direct calcination cases, the capital costs for interim storage were \$1,160,000, \$980,000, and \$1,100,000, respectively. In each case it was assumed that the major expenditure for this purpose would occur in FY 1965.

Operation costs were based on a total personnel need of 2-1/2 man-years comprised of both operating and maintenance labor. Utilities and chemical costs for water treatment resulted in a total annual operating expenditure of \$78,000 and \$100,000 for Cases I-A and B, and Cases II-A and B, respectively.

The present worth unit cost contribution of interim storage is based on complete amortization of the facility over the study period. From the preceding unit cost table, it will be noted that this contribution is small, with a maximum unit cost difference between cases of \$4/TU. Modifications in the above assumption, therefore, can be expected to have only a minor effect on the overall analysis.

2. Transport Channel and Final Storage Vaults

To insure radiation control and minimize the hazards of moving waste containers to a more remote final storage area, an underground water channel was believed more suitable than aboveground transport in shielded casks. In addition, it will provide a convenient, functional link between interim and final storage if water cooling is used. The primary limitation in its use is that of distance since the final storage vaults must be located relatively close to the interim storage area. Cost estimates for this study assumed the suitability of the location shown in Figure 6, for which a channel run of about 400 feet would be required. The advantage of more remote location of the final storage area, however, is not readily apparent. Further distance, if desired,

DECLASSIFIED

DECLASSIFIED

HW-66618 RD

-24-

could be gained for an additional investment of about \$350 per lineal foot. Transportation of the container in the channel could be provided by an electrically driven dolly incorporating a lift mechanism of sufficient power to suspend the waste container during movement.

The final storage vaults were sized for a capacity of one year at the assumed production rate. An illustration of the conceptual vault is shown in Figure 8. It was designed for water cooling during the first several years of storage. Provisions were also included to permit changing over to a forced air cooling system after sufficient decay has taken place, and at which time complexities in air cooling could more easily be avoided. The vault is provided with an inlet roughing filter and a CWS outlet filter section that would be designed for periodic replacement.

The cost estimate was based on providing a forced air system of 30,000 CFM capacity for a system of ten vaults. Preliminary theoretical calculations indicate that such an air flow would permit progressive change-over from water cooling after the contents of each vault decayed for an effective period of about 25 years. A maximum exit air temperature of 250 °F and a maximum container skin temperature of about 300 °F was assumed. To effect the change-over, each vault entrance is double keyed to receive bulkheads, thus facilitating water removal from an individual vault. If found desirable, this would also allow permanent isolation of a vault from the transfer channel with concrete.

The assumption was made that forced draft cooling would continue for 50 to 100 years, during which time it is expected that steps would be taken to achieve a state of ultimate containment requiring essentially no surveillance or control. This could conceivably take the form of merely sealing off each vault and relying on natural heat dissipation to the ground and atmosphere. An alternative, in keeping with more popularized concepts, would be to transfer the individual containers to prepared or natural cavities far below the water table.

Prior to ultimate disposal steps, reliance on a forced draft system could possibly be obviated by resorting to a natural draft system. Application could be made to the above described vaults by use of an adapter and stack on the end of each vault if draft and heat dissipation requirements were sufficiently low. The effectiveness of a natural draft system, as previously reported(3), is

DECLASSIFIED

sensitive to the filtering requirements because of pressure drop limitations. This method of cooling could conceivably be compatible with the system described after decay of about 50 years and possibly sooner if filter requirements could justifiably be minimized or eliminated.

The differences in longer-term storage of waste calcined at an initial age of 90 days and 2 years are minor from a total heat dissipation standpoint. This is shown in Figure 10 where the integrated heat generation of a ten-year quantity of waste aged between 2-1/4 years and 12-1/4 years is compared with an equal quantity of waste aged between 4 and 14 years. The difference amounts to about 3,000,000 BTU/hr. It would result in, at the most, a slight but economically insignificant change in the size of piping providing cooling water to the basins. As aging progresses further, the heat generation difference becomes smaller since the remaining isotopes of significance (Sr^{90} and Cs^{137}) have relatively long half lives.

As a result, the significant difference in vault costs for each of the study cases is reduced to the change in floor area required to accommodate the waste containers. The criteria employed for floor area utilization in final storage were the same as used for the interim storage basin (a six-inch spacing between containers), except that the provision of access to individual containers was assumed to be unnecessary.

The estimated capital cost of a ten unit long-term vault system and its variation with useful storage area is also shown in Figure 9. Each vault was sized for a capacity of one year; therefore, for the 20-year production period, two systems consisting of 20 vaults were used as a cost basis. For each ten-year production period, the capital costs amounted to \$5,840,000, \$4,600,000, and \$4,160,000 for Cases I-A, I-B, and the direct calcination cases, respectively. Initial capital costs were assumed to be incurred two years after interim storage basin expenditures. On the basis of assumed construction feasibility, the total capital investment required for the 20-year production period was timed in five-year increments of approximately equal magnitude.

Operating costs during the period of vault filling were estimated at \$58,000/yr. as required for container transfer, gantry operation, and general maintenance. After filling and during the period of continued water cooling, surveillance costs were assumed to be \$20,000 per year for each 10-year vault system, based on a labor require-

DECLASSIFIED

ment of 200 manhours per year, and includes water, power and instrument maintenance. In the belief that continued water cooling for a prolonged period may be undesirable, air cooling was assumed to be initiated with each vault 25 years after filling. Surveillance costs during this period were increased to reflect average filter replacement requirements of \$900 per year for each vault; this expenditure basis, a total of \$58,000 annually, was then continued indefinitely. Neither the cost for natural draft provisions nor the cost for achieving a state of ultimate disposal were included because of the doubtful timing and need of such expenses, in addition to the effect of present worth analysis to minimize their significance.

e. Disposition of Coating and Organic Wash Wastes

For consistency in the bases used for comparing the majority of calcination alternatives, coating and organic wash wastes were assumed to be combined and processed together. Such treatment, though not resulting in any change in the differences between these cases, serves to better identify the total unit costs that may be incurred in future high-level waste processing. In addition, it established a base from which other alternatives (such as Case I-A) involving the addition of these wastes to the calcination feed stream could be evaluated.

The long-term processing route selected was that of in-tank evaporation by submerged combustion. This operation, assumed to be carried out in existing storage tanks, is the method currently planned for coating waste disposal, the feasibility of which has been defined by past development work.⁽⁴⁾ An innovation not evaluated on a development basis, however, is the combination of organic wash wastes with the coating waste. The assumption was made that this will not create any significant problems or hazards in the submerged combustion operation. The long-term applicability of this disposal method is based on the theory that, following evaporation, the waste solution would cool by natural dissipation of heat to the environment and solidify, thereby immobilizing the tank contents. The heat generation rate from contained fission products would be less than that assumed to be lost to the environment at solidification temperatures.

In considering the boil-off required for both coating wastes and organic wash wastes, it was assumed that a 5,000,000 BTU/hr. submerged combustion facility operating at 75 to 80 percent efficiency, 24 hours a day would be suitable for these streams. The capital expenditure required was estimated at \$250,000 made in 1964. Except for burner replacement once per year, the equipment

DECLASSIFIED

involved was assumed to require replacement after 10 years of operation. Operating costs were estimated to be \$95,000 per year, reflecting a total crew of 7-1/2 operation and service personnel, including the variable costs of evaporator operation. Operating costs were divided between coating wastes and organic wash wastes on the basis of boil-off required, or about 30 and 70 percent, respectively.

The relative advantage of excluding organic wash waste from the calcination stream (difference between Case I-A and Case I-B, of \$21/TU) indicated in this study is believed to be a minimum. Other alternative procedures such as the use of a steam evaporator (Bentube) for tank solidification, or preconcentration of organic wash waste in the Purex Plant, may well increase this difference.

f. Extended Tank Storage (Case III)

The concept of extended tank storage of high-level wastes involves primarily the evaluation of costs for prolonged retention of the waste in a liquid state. The culminating step is expected to be eventual volume reduction by evaporation and solidification of the waste in large storage tanks after sufficient decay in the heat generation rate has occurred. The parameters considered important to the economics of this scheme, and the assumptions employed for the study, are as follows:

1. Waste Composition

Organic wash waste was assumed to be combined with alkaline LWW for this case because of the long-term benefit of high inert solids content toward minimizing the volumetric heat generation rate of the final solid. (Coating wastes were assumed to be processed by submerged combustion at the present worth cost, \$12/TU, previously ascribed to this stream.)

2. Cost of Liquid Storage

Storage of the combined wastes prior to solidification was assumed to take place under boiling conditions for a majority of the period involved, with repeated transfer of liquid and slurry from tank to tank required at a frequency dependent on the assumed useful life of the vessel. Storage under these conditions was based on a waste volume of 100 gallons per TU in large-diameter carbon steel vessels provided at a cost of \$1.50 per gallon of waste. The increase in waste volume, from that assumed in other cases, was considered necessary because of the many transfers and the consequent need to achieve some simplification in solution and sludge removal. If storage could be at a lower initial

DECLASSIFIED

volume, the further assumption that subsequent dilution would occur, to effect solubilization or otherwise aid sludge removal, would seem to be justified. Capital expenditure timing was based on the provision of tankage in five-year increments of capacity.

3. Frequency of Tank Replacement

The assumed useful life of each of the above vessels is a key factor in determining the cost of this waste disposal route since it governs the rate of accrual of the major capital investment. For this study, useful life was assumed to be 15 years, reflecting a degree of pessimism, yet giving reasonable weight to the need to minimize the risk of significant tank leakage.

4. Total Period of Liquid Storage

On the basis of theoretical study of heat transfer from a large mass of solidified waste in an underground storage vessel, it is postulated that a reduction in heat generation rate to a level of about 1 BTU/hr. Ft.³ will be required to avoid excessive temperatures within the waste mass and at the base of the tank. Assuming that solidification can be accomplished by evaporation to a reduced volume of 25 gallons/TU, a decay period of about 125 years would be necessary to achieve this heat generation rate. The maximum wall temperature expected under these conditions was estimated to be 200 - 250 °F at the base of the tank, further assuming a waste depth of 10 feet. Figure 11 correlates solid waste temperature, under tank storage conditions, with key parameters from which the effect of alterations in storage conditions can be evaluated.

The addition of other inert solids could be made to shorten the period of liquid storage, although optimization of the process at this point probably would not materially affect the over-all economics of the scheme. Consequently, the use of such additives was not investigated.

5. Solidification

Volume reduction and final storage of the combined waste was assumed to be accomplished at the end of the 125-year decay period by evaporation and transfer to a new and final set of storage vessels. The capital investment for this final step was made equal to that for a similar facility, recently completed by SRP, which is suitably sized to retain the total volume represented by a 10-year production

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of combined waste. This includes a "Bentube" evaporation facility and four 85-foot diameter tanks. The project cost of this installation was \$2,350,000.

Operating costs associated with this case were divided into four phases. First, tank farm surveillance costs were estimated to be the same as developed for surveillance of boiling tanks in Case I-A and B (\$74,000 per year). Second, pump-out costs at the end of useful tank life were derived from the same labor and material requirements developed for Case I-A and B. The timing of this cost item was based on the division of each 5-year tankage increment into a set of seven tanks; each vessel was assumed to require a pump-out time of about one month. Consequently, pump-out costs, once started, were incurred over a period of 7 months every five years. Third, the operating costs associated with volume reduction of the waste were based on labor and material requirements adapted to steam evaporation, equivalent to that required for submerged combustion operation. The further assumption was made that the maximum boil-off rate would be about nine gallons per minute, similar to the Savannah River evaporation facilities. And finally, fourth, long-term surveillance requirements of 100 manhours per year, following solidification, were assumed to be continued indefinitely. These last two cost items, because of their occurrence so far in the future, would have very little significance on a present worth basis. Consequently, considerable latitude exists in making final processing assumptions without significantly changing the over-all economics. Even completion of the solidification step 25 years earlier than assumed in Case III would reduce the present worth unit cost only \$8/TU, or about 2 percent.

Altering the useful life of the liquid storage tanks, however, will have a significant effect, as shown by the curve of Figure 14. This approximate relationship indicates that Case II-B, direct calcination on an accelerated basis, would economically be equivalent to Case III, assuming a useful tank life of about 17 years. The other major factors, tank costs, would have essentially a direct effect on present worth unit costs since this capital investment accounts for a majority of the total cost of the extended tank storage concept.

g. Present Worth Translation of Capital and Operating Costs

Basically, present worth analysis is a method of evaluating economic situations with recognition given to the time value of money. Perhaps in organizations where routine investment of surplus capital is not a common practice, such analysis does not carry

DECLASSIFIED

full quantitative meaning. Yet, it appears to be the only way in which widely different expenditure patterns, extending over long periods of time, can be compared on an equitable basis.

Interest Rate

A compound interest rate of 3 percent, which may be thought of as being discounted for normal escalation, was assumed in the study. A higher rate would reduce the present worth unit economic advantage of cases in which major expenditures occur early in the study period (Cases II-A and B), especially calcination. A lower rate would reduce the economic advantage of a long-term distribution in major expenditures, such as occur in Case III, for extended tank storage.

Capital Cost Translation

Table II (representing Case III) illustrates the procedure followed in translating constant dollar capital costs to their present value, or more accurately, their value related to the base year, FY 1963. The number of years between the base year and the year of expenditure determines the applicable present worth factor; the factor being equivalent to the amount of money necessary to invest in FY 1963 to cover the expenditure of one dollar at the future date. As can be seen, the major requirement is establishment of the expenditure pattern. For each case the time of expenditure was assumed to be the budget year in which funds should be provided. Table III shows the budget pattern assumed and present worth translation of each of the other cases.

Operating Cost Translation

The procedure for determining the FY 1963 value of the operating costs associated with each case was similar to the capital cost treatment, except for the greater detail involved. Expenses of constant value, and annually repetitive for long periods, were evaluated on a net cumulative basis, whereas others more unique and less regular were translated individually. For simplicity, replacement equipment expenditures were included as a part of operating costs in the present worth calculations. Tables IV and V summarize the operating costs, their time patterns of application and their present worth value for each of the study cases.

3. Qualitative Considerations

The foregoing analysis gives a perspective on the economic position of each of the alternatives; however, it does not reflect the impact of other qualitative factors that will have

DECLASSIFIED

an important bearing on the final decision to be made.

a. Extended tank Storage Versus the Calcination Concept

Comparison of these general concepts for high-level waste processing only on a quantitative, economic basis cannot be a conclusive analysis. Rather, the degree to which each may be expected to meet the philosophical objectives of high-level waste management, such as hazards control and accountability, assumes a major role in their evaluation. In the case of extended tank storage, long-term mobility of the waste as a liquid certainly increases the risk of environmental contamination because of leakage induced by corrosion, stress failure or unusual natural occurrences such as earthquakes or floods. In addition, the multiplicity of tankage and frequency of transfers would tend to give statistical credence to the potential for hazardous situations to develop.

Because of limitations to be expected in sludge removal, each tank required in the over-all program would likely contain a heel of significant magnitude. Such quantities, even though small in bulk and heat generation, could be a potential biological hazard if control was lost. As an example of a related difference, the effective acreage dispersal of fission products in Case III is forty times greater than in the calcination cases. Hazards reduction could be achieved in the event of leakage by providing secondary containment for the primary vessel. This provision would further aid in maintaining accountability over the system; however, its inclusion is not reflected in the cost assumptions used in evaluating Case III. Therefore, economic disadvantages would result if extensive backup measures were provided.

Then, too, the final step of achieving solidification of the waste in large-volume storage vessels is essentially an irreversible process. Consequently, the degree to which this condition satisfies the criteria of ultimate containment can seriously be questioned. The containment achieved seems final, but may fall short of responsible ultimate disposition which demands, essentially, no further risk. Under the envisioned conditions of calcined waste storage, reversibility and accountability are major features of the system, by virtue of which, advantage can be taken of the most sound philosophy of ultimate containment prevalent at almost any time in the future.

b. Direct Versus Aged Waste Calcination

The aged waste calcination route comprises certain undefined problems and hazards which could largely be obviated by

DECLASSIFIED

DECLASSIFIED

HW-66618 RD

-32-

direct calcination. These are the problems of waste storage and the subsequent need to remove the stored waste as feed to the calcination facility. Future tank storage design must recognize the need for flexibility to adapt to changing process conditions in the Purex Plant and the anticipated fission product program. In addition, such design must further recognize the desirability, if not the need, for essentially complete removal of sludge and the need to insure control of sludge temperature during the storage period. Each of these requirements is dependent on waste compositions and their resultant sludges, which may not adequately be characterized until the problems are encountered on an operational scale. As a consequence, optimization of new tank design may be difficult to achieve and the alternative of providing added integrity and utility, to what may now be expected as a requirement, may be the only course to follow. The high capital cost assumed for liquid storage in Cases I-A and I-B is believed to reflect this philosophy, although the hazards potential of such an actively operated tank farm and the feasibility of sludge removal remain undefined in their quantitative significance.

On the other hand, direct calcination comprises undefined and unique problems because of the increased fission product activity and heat generation rate prevalent during the calcination and early solids storage phases of operation. These problems suggest the possibility of more direct analysis, however, and are believed to be less formidable than those attendant to the storage and transfer of the alkaline wastes.

Common to both of these major routes, however, is the eventual need to remove wastes from the existing 241-A tanks, and possibly the 241-SX tanks (Redox first cycle wastes) as the initial step for calcination or other long-term methods of disposal. This need would not be a continuing one, nor would it be a necessary one for production continuity, as in the case of routine, aged waste calcination.

D. Related Programs and Activities

Several programs currently in progress have an important bearing on this study. Fission product recovery will result in some indirect effects, whereas storage tank design and waste processing development activities can directly alter some of the assumptions employed.

1. Fission Product Recovery

The full costs of B Plant operation were ascribed to the waste calcination alternatives. It is true, however, that the fission

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product program will share in absorbing some of these costs. Common usage of waste transfer lines and equitable distribution of canyon activation costs should result in a capital reduction to waste calcination of about \$450,000. Operating costs may also be reduced as much as \$100,000 annually because of common usage of some of the canyon facilities. Revaluation of the present worth unit costs on this basis reduces the cost of each calcination case about \$12/TU. Assurance that this reduction would be realistic, however, is dependent on the over-all effect of large-scale fission product recovery - now largely indeterminant - in such areas as the containment and storage of the calcined solids due to changes in waste composition.

2. Storage Tank Design

For all practical purposes the economic difference between calcination cases resides in the cost of providing solution storage. (An exception would be Case I-A which reflects the net increase in costs due to the inclusion of organic wash wastes in the calcination feed stream.) Tank design in relation to over-all containment costs, therefore, becomes a major factor in deciding between the direct and aged waste calcination routes on an economic basis.

Presently, studies are in progress to determine the economics of a relatively broad range of tank designs suitable for various conditions of waste storage. The results of these studies may indicate the need to adjust the tank storage costs assumed in this report. The selection of a particular tank design will, however, be dependent on the success parallel studies may have in determining what the conditions of storage may be.

Design requirements in particular are sensitive to two major aspects of liquid waste handling for which better definition is needed. These are the areas of sludge removal and sludge temperature control, clarification of which depends on improved characterization of waste sludge. Sludge removal feasibility must first be established, followed by optimization of design requirements to facilitate such removal. Parameters influencing sludge temperature under liquid storage conditions are also important but may not be fully understood by the time decisions are required. Two basic choices exist in methods of temperature control. One is the use of operational controls, such as maintenance of appropriately dilute supernate concentration coupled with the circulation of tank contents. The other would be the provision of intrinsic methods of sludge heat dissipation as part of the tank design.

3. Research and Development Activities

In the area of high-level waste management the research and development effort at Hanford has been maintained broad in scope, yet has been invaluable in the technological clarification of many specific

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problems attendant to the definition of the waste program. Waste storage needs have been explored from the standpoint of simulated waste characteristics. Studies on the corrosivity of acidic waste at elevated temperatures have led to the orientation of future tank design to the storage of alkaline wastes. The characterization of simulated waste sludges under various conditions of waste composition and concentration has provided some insight to the problems that may be encountered under the actual storage environment. Also brought out by these studies is the potential for storage under conditions approximating zero "free" acid being the optimum balance between corrosivity and sludge problems. Further examination of wastes in this sensitive state of neutralization would be necessary, however, before its adoption as a process criterion could be made. A basic problem is inherent to the use of simulated waste data, however, stemming from the difficulty with which such information can reliably be extrapolated to the conditions of actual tank storage; consequently, characterization of actual plant wastes may be the next logical step.

A major portion of development work has been directed toward the definition of the fluid bed, spray and batch calcination processes. The results of this appraisal of Hanford's high-level waste program are not expected to have a direct bearing on the choice between specific calcination processes. Indirectly, however, the definition of incentives that may lead to limitations in potential waste stream compositions, and those that may be attendant to the achievement of certain product characteristics, should facilitate the calcination development work.

Waste streams, for the main part, may comprise the acidic conditions of direct calcination, but the need for flexibility to adapt to the characteristics of existing stored wastes, fission product recovery wastes, and the unknown effect of other process innovations must also be recognized. Toward achieving optimum calcined solids characteristics, the parameters of reduced volume, thermal conductivity, and corrosivity of calcined product are important considerations. Preliminary insight on the economic significance of these parameters is provided by the theoretical correlations of Figures 9, 12, and 13, which are based on the criteria and feasibility requirements discussed above for analysis of the specific alternative routes. Figure 13 relates thermal conductivity and reduced volume to container size for 90-day and 2-year aged calcination feed. Figure 12 shows the variation in container costs with diameter and provides an estimate of the equivalence of annular and cylindrical containers. The influence of corrosivity on container costs may be roughly estimated within the cost range of 304-L stainless steel and carbon steel, also shown in Figure 12. The total bulk of waste, in conjunction with container size and heat dissipation requirements, influences storage costs to an extent that can be derived from the curves of Figure 9.

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As an example, and to clarify a point of interest, the effect of including coating wastes in the calcination feed stream, assuming a melt product of 34 gallons/TU and 2-year aging of the combined waste, is estimated in the following comparison with Case I-A. Only capital dollars were used for computing storage costs.

	Constant Dollar Unit Costs Dollars/TU	
	Case I-A	Coating Wastes Included
Containers	115	220
Interim Storage	8	12
Final Storage	40	61
	<hr/>	<hr/>
Total	163	293

The increase in costs (\$133/TU) due to the inclusion of coating waste in the calcined wastes does not reflect the savings that would result by avoiding the need for tank storage of this stream. To carry the analysis this far, however, present worth unit costs must be evaluated. Neglecting any change that may occur in the operating costs for calcination and storage, the present worth increase over Case I-A would be about \$80/TU.

V. CONCLUSIONS

1. High temperature calcination, as a general concept for the processing of high-level wastes, not only offers the advantages of improved hazards control, better waste accountability and adaptability to ultimate disposal, but also has promise of being economically competitive with extended tank storage methods.
2. Within the framework of the calcination route, direct calcination without an intervening liquid decay period tends to provide the lowest costs in proportion to the savings achieved in expenditures for new solution storage. Because of the significant influence of containment and storage of the calcined solids in total costs, minimization of solids volume - such as obtained by excluding organic wash wastes from the calcination feed stream - results in further cost advantages.

Final decisions on the relative merits of calcination alternatives should be made soon, perhaps within a year, for the most effective direction of the waste program. This relates primarily to the important role new alkaline waste storage has in current budget plans and the potential of direct calcination to significantly alter these plans.

DECLASSIFIED

VI. ACKNOWLEDGEMENTS

Acknowledgment is given to D. W. Hoba for his work on programming the problem of heat dissipation from tank stored solids on the IBM 709 digital computer, and to R. P. Omberg for his help in heat transfer calculations and in the preparation of graphical material.

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DECLASSIFIED

VIII. APPENDIX

<u>Tables</u>	<u>Page</u>
I Present Worth Summary of Capital and Operating Costs	38
II Capital Requirements and Detailed Present Worth Summation For Extended Tank Storage	39
III Capital Requirements and Present Worth Summation For Calcination Routes	41
IV Estimated Annual Operating Costs For Functional Steps in Waste Processing Alternatives	42
V Present Worth Translation Of Operating Costs For Waste Processing Alternatives	44
VI Capital Cost Estimate - Interim Storage Basin	46
VII Capital Cost Estimate - Transport, Channel and Storage Vaults	47

<u>Figures</u>	<u>Page</u>
1. Fission Product Heat Generation and Decay	48
2. Schematic of Alternative Routes	49
3. 221-B Canyon Cell Utilization	50
4. Estimated Personnel Requirements for High Level Waste Processing	51
5. Temperature History of Calcined Waste	52
6. Plot Plan - 200-E Waste Storage Concept	53
7a. Conceptual Water Cooled Storage Basin For Calcined Waste	54
b. " " " " " " " "	55
8. Plan Perspective - Long-Term Storage Vaults	56
9. Estimated Capital Cost For High-Activity Solid Waste Storage Facilities	57
10. Heat Generation Rate During Storage of High-Level Calcined Waste	58
11. Estimated Temperature Of Solid Waste If Stored In Hanford Underground Tanks	59
12. Estimated Cost Of Calcined Waste Containers (304L and Carbon Steel	60
13. Effect Of Thermal Conductivity And Fission Product Con- centration of Calcined Waste On Container Diameter	61
14. Present Worth Cost Of Extended Tank Storage	62

DECLASSIFIED

-38-

TABLE I

PRESENT WORTH SUMMARY OF
CAPITAL AND OPERATING COSTS
(Millions of Dollars)

	<u>Case I-A</u>		<u>Case I-B</u>		<u>Calcination</u> <u>Case II-A</u>		<u>Case II-B</u>	
	<u>Cap.</u>	<u>Oper.</u>	<u>Cap.</u>	<u>Oper.</u>	<u>Cap.</u>	<u>Oper.</u>	<u>Cap.</u>	<u>Oper.</u>
Tank Storage	5.50	5.51	5.50	5.51	1.71	0.74	0.66	0.32
Calcination	3.88	20.38	3.88	20.38	3.88	20.38	3.88	19.79
Containers	-	10.98	-	6.80	-	9.62	-	9.62
Interim Storage	1.09	1.14	0.84	1.14	1.04	1.46	1.04	1.50
Final Storage	4.33	2.36	3.34	2.36	3.02	2.36	3.10	2.37
Submerged Combustion	0.31	1.35	0.31	3.95	0.31	3.95	0.31	3.95
Total	<u>15.11</u>	<u>41.72</u>	<u>13.87</u>	<u>40.14</u>	<u>9.96</u>	<u>38.51</u>	<u>8.99</u>	<u>37.55</u>
Dollars/TU	108	298	99	286	71	275	64	268
Total Dollars/TU	406		385		346		332	

Case III (Extended Tank Storage)

	<u>Cap.</u>	<u>Oper.</u>	<u>Total</u>
Storage	46.22	2.22	48.44
Solidification and Surveillance	0.12	0.03	0.15
Submerged Combustion	0.31	1.35	1.66
Total	<u>46.65</u>	<u>3.60</u>	<u>50.25</u>
Total Dollars/TU	333	26	359

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TABLE II
CAPITAL REQUIREMENTS AND DETAILED
PRESENT WORTH SUMMATION FOR EXTENDED TANK STORAGE
(CASE III)

<u>Budget Year</u>	<u>Number of Years From Base Date</u>	<u>Present Worth Factor</u>	<u>Purpose</u>	<u>Constant Dollar Value Of Capital Expense (Millions Of \$)</u>	<u>Present Worth OF Capital Expense</u>
FY 1963	0	1.000	1st set, 0-5 yr. tks.	5.25	5.25
68	5	0.853	1st set, 5-10 yr. "	5.25	4.53
73	10	0.744	1st set, 10-15 yr. "	5.25	3.90
78	15	0.642	1st set, 15-20 yr. " +2nd set, 0-5 yr. "	10.50	6.74
83	20	0.554	2nd set, 5-10 yr. "	5.25	2.91
88	25	0.478	2nd set, 10-15 yr. "	5.25	2.51
93	30	0.412	2nd set, 15-20 yr. " +3rd set, 0-5 yr. "	10.50	4.32
98	35	0.355	3rd set, 5-10 yr. "	5.25	1.86
FY 2003	40	0.307	3rd set, 10-15 yr. "	5.25	1.61
08	45	0.264	3rd set, 15-20 yr. " +4th set, 0-5 yr. "	10.50	2.77
13	50	0.228	4th set, 5-10 yr. "	5.25	1.20
18	55	0.197	4th set, 10-15 yr. "	5.25	1.03
23	60	0.170	4th set, 15-20 yr. " +5th set, 0-5 yr. "	10.50	1.78
28	65	0.146	5th set, 5-10 yr. "	5.25	0.77
33	70	0.126	5th set, 10-15 yr. "	5.25	0.66
38	75	0.109	5th set, 15-20 yr. " +6th set, 0-5 yr. "	10.50	1.14
43	80	0.094	6th set, 5-10 yr. "	5.25	0.49
48	85	0.081	6th set, 10-15 yr. "	5.25	0.43
53	90	0.070	6th set, 15-20 yr. " +7th set, 0-5 yr. "	10.50	0.74
58	95	0.060	7th set, 5-10 yr. "	5.25	0.32
63	100	0.052	7th set, 10-15 yr. "	5.25	0.27

(cont. page 40)

DECLASSIFIED

-40-

TABLE II, cont.

<u>Budget Year</u>	<u>Number of Years From Base Date</u>	<u>Present Worth Factor</u>	<u>Purpose</u>	<u>Constant Dollar Value Of Capital Expense (Millions Of \$)</u>	<u>Present Worth Of Capital Expense</u>
FY 2068	105	0.045	7th set, 15-20 yr. tks. +8th set, 0-5 yr. "	10.50	0.47
73	110	0.038	8th set, 5-10 yr. "	5.25	0.20
78	115	0.033	8th set, 10-15 yr. "	5.25	0.17
83	120	0.029	8th set, 15-20 yr. "	5.25	0.15
83	120	0.029	Evaporator & Storage Facilities - 10-year Capacity	2.40	0.07
93	130	0.021	Evaporator & Storage Facilities - 10-year Capacity	2.40	0.05
TOTAL				172.80	46.34

DECLASSIFIED

DECLASSIFIED

-41-

TABLE III

CAPITAL REQUIREMENTS AND PRESENT WORTH
SUMMATION FOR CALCINATION ROUTES

Budget FY	Purpose	Millions of Dollars							
		Case I-A		Case I-B		Case II-A		Case II-B	
		Present Worth	Con- stant \$	Present Worth	Con- stant \$	Present Worth	Con- stant \$	Present Worth	Con- stant \$
63	Alkaline Waste Storage	5.50	5.50	5.50	5.50	1.05	1.05	-	-
64	Calcination	3.88	4.00	3.88	4.00	3.88	4.00	3.88	4.00
	Submerged Com- bustion	0.24	0.25	0.24	0.25	0.24	0.25	0.24	0.25
	Acid Storage		-		-	0.58	0.60	0.58	0.60
65	Interim Solids Storage	1.09	1.16	0.84	0.98	1.04	1.10	1.04	1.10
66	Long-Term Solids Storage (1st Increment)		-		-		-	0.99	1.08
67	Long-Term Solids Storage (1st Increment)	1.35	1.52	1.10	1.24	0.96	1.08		-
71	Long-Term Solids Storage (2nd Increment)		-		-		-	0.79	1.00
72	Long-Term Solids Storage (2nd Increment)	1.17	1.40	0.81	1.06	0.78	1.00		-
74	Submerged Combustion - replacement	0.07	0.10	0.07	1.10	0.07	0.10	0.07	0.10
	Acid Storage Tank - replacement		-		-	0.08	0.11	0.08	0.11
76	Long-Term Solids Storage (3rd Increment)		-		-		-	0.73	1.08
77	Long-Term Solids Storage (3rd Increment)	1.01	1.52	0.82	1.24	0.71	1.08	0.59	1.00
81	Long-Term Solids Storage (4th Increment)		-		-				
82	Long-Term Solids Storage (4th Increment)	0.80	1.40	0.61	1.06	0.57	1.00		-
Total -		15.11	16.85	13.87	15.43	9.96	11.37	8.99	10.32

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TABLE IV

ESTIMATED ANNUAL OPERATING COSTS FOR FUNCTIONAL STEPS
IN WASTE PROCESSING ALTERNATIVES

	Salaries and C/S	Supplies & Equip. (1)	Service Charges (2)	Overheads (4.7%)	Variable Costs (3)	Process Technology	Additives (16%)	Total
1. Boiling Tank Surveillance	25,000	9,500	4,000	18,000	0	7,500	10,000	74,000
2. Alkaline Waste Pump-Out	87,000	45,000	8,000	66,000	0	37,000	39,000	282,000 (5)
3. Acidic Waste Storage	0	6,000	1,500		3,500	0	2,000	13,000
4. Calcination - 221-B Interim Solids	398,000	144,000	158,000	330,000	25,000	120,000	188,000	1,363,000
5. Storage - Case I	21,000	18,000	6,500	21,500	0	0	11,000	78,000
- Case II	21,000	25,000	12,500	27,500	0	0	14,000	100,000
6. Long-Term Vault Filling	21,000	10,000	3,000	16,000	0	0	8,000	58,000
7. Long-Term Vault Surveillance	6,500	3,500	2,000	5,500	0	0	2,500	20,000
Water Cooling (Per 10-yr. system air cooling)	6,500	8,500	2,000	8,000	0	0	4,000	29,000
8. Submerged Combustion (6)	66,500	15,500	8,500	42,500	95,000	7,500	37,500	273,000
9. Tank Solids Surveillance (per 10 yr. Tank Farm)	3,000	1,000	0	2,000	0	0	1,000	7,000
10. Bentube Evaporation	66,500	15,500	8,500	42,500	30,000	7,500	27,500	198,000

(See Page 43 for footnotes)

DECLASSIFIED

TABLE IV - Notes:

- (1) Equipment replacement costs - based on conventional depreciation rates - varies between 5 to 10 percent.
- (2) Includes Bus and Road, Laundry, Vehicle Rental, Utilities and Landlord.
- (3) Primarily chemical additives (calcination), propane (submerged combustion), and steam (Bentube evaporation). Calcination variable excludes container costs.
- (4) Includes 10 percent contingency plus 6 percent escalation to FY 1963.
- (5) Pump-out from each set of 5-year tanks in Case III assumed to require 7 months, or \$165,000.
- (6) Total cost for coating waste plus organic wash. Total for Coating waste only - \$95,000.

DECLASSIFIED

-44-

TABLE V

PRESENT WORTH TRANSLATION
OF
OPERATING COSTS FOR WASTE PROCESSING ALTERNATIVES
(FY 1963 Basis)

Case	Purpose	Period of Application	Annual Operating Cost (FY 63 \$)	Present Worth Total (\$)
I-A	1. Boiling Tank Surveillance	FY 65 to FY 87	74,000	1,150,000
	2. Boiling Tank Pump-out	FY 67 to FY 87	282,000	4,360,000
	4a. Calcination (shakedown)	mid FY 65 to FY 67	1,363,000	1,880,000
	4b. Calcination (Production)	FY 67 to FY 87	1,363,000	18,500,000
	5. Interim Solids Storage	FY 67 to FY 89	78,000	1,140,000
	6. Long-Term Vault Filling	FY 69 to FY 89	58,000	740,000
	7. Vault Surveillance - water	FY 69 to FY 79	20,000	150,000
	- "	FY 79 to FY 94	40,000	430,000
	- air	FY 95 → Indef.	58,000	1,040,000
	8. Submerged Combustion	FY 65 to FY 85	95,000	1,350,000
	9. Tank Solids Surveillance	FY 85 → Indef.	7,000	130,000
Total Case I-A -				30,870,000
I-B	(Items 1 through 7 and 9, same as Case I-A)			29,520,000
	8. Submerged Combustion	FY 65 to FY 85	273,000	3,950,000
Total Case I-B -				33,470,000
II-A	(Items 4, and 6 through 9, same as Case I-B)			26,820,000
	1. Boiling Tank Surveillance	FY 65 to FY 87	18,000	280,000
	2. Boiling Tank Pump-out	FY 85 to FY 87	282,000	290,000
	3. Acid Waste Storage	FY 67 to FY 85	13,000	165,000
	5. Interim Solids Storage	FY 67 to FY 89	100,000	1,460,000
Total Case II-A -				29,015,000
II-B	(Items 7, 8, and 9 same as Case I-B)			5,980,000
	2. Alkaline Waste Pump-out	FY 85	282,000	145,000
	3. Acidic Waste Storage	FY 66 to FY 85	13,000	175,000
	4a. Calcination (shakedown)	1/2 FY 65	1,363,000	640,000
	4b. Calcination (Production)	FY 66 to FY 86	1,363,000	19,150,000
	5. Interim Solids Storage	FY 66 to FY 88	100,000	1,500,000
	6. Long-Term Vault Filling	FY 68 to FY 88	58,000	765,000
Total Case II-B -				28,355,000

(cont. page 45)

DECLASSIFIED

TABLE V, cont.

<u>Case</u>	<u>Purpose</u>	<u>Period of Application</u>	<u>Annual Operating Cost (FY 63 \$)</u>	<u>Present Worth Total (\$)</u>
III	1. Boiling Tank Surveillance	FY 64 to FY 2014	52,000	1,340,000
	2. Pump-out	(Every 5 years FY 78 to FY 2083 except approx. double rate every 15 years FY 93 to FY 2069)	165,000	880,000
	3. Submerged Combustion	FY 65 to FY 85	95,000	1,350,000
10.	Bentube Evaporation	FY 2083 to FY 2085	198,000	12,000
		FY 2093 to FY 2095	198,000	9,000
9.	Long-Term Surveillance	FY 2093 Indef.	14,000	10,000
Total Case III -				6,201,000

DECLASSIFIED

-46-

TABLE VICAPITAL COST ESTIMATE
INTERIM STORAGE BASIN(Basis: 90-Day aged feed, 2750 Ft.² useful storage area)

<u>Construction Operation</u> (Hot tie-ins, etc.)		\$ 50,000
<u>Fixed Price Contractor</u>		
Building and Structure	171,000	
Electrical	18,000	
Piping	27,000	
Ventilation	23,000	
Instrumentation	26,000	
Equipment	235,000	
Radiation Services and Inspection	15,000	
		\$ 515,000
<u>Construction Additives</u>		
Supervision	20,000	
Start-up	25,000	
Contingency & Escalation	170,000	
General Overhead	28,000	
		243,000
<u>Management Services</u>		32,000
<u>Design Services</u>		160,000
Total Project Cost	-	\$1,000,000

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TABLE VII

CAPITAL COST ESTIMATE
TRANSPORT, CHANNEL AND STORAGE VAULTS
 (10 yr. Capacity - 10,000 Ft.² Storage Floor Area)

Fixed Price Contractor

Water Transportation Channel (640 LF)

Excavation and Backfill	\$ 10,000
Structure	210,000
Equipment	43,000

Storage Vaults (10' - 50' x 20')

Excavation and Backfill	20,000
Structure	728,000
Equipment	77,000

<u>Vault Ventilation System (30,000 CFM)</u>	65,000
--	--------

<u>Outside Facilities</u> (Water, Power, Fencing, Roads, etc.)	75,000
---	--------

Radiation Services and Inspection	65,000
-----------------------------------	--------

\$1,293,000

Construction Additives

Supervision	45,000
Start-up	10,000
Contingency & Escalation	410,000
General Overhead	62,000

527,000

<u>Management Services</u>	60,000
----------------------------	--------

<u>Design Services</u>	120,000
------------------------	---------

Total Project Costs -	\$2,000,000
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FIGURE 1

FIGURE 2

SCHEMATIC OF ALTERNATIVE ROUTES

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FIGURE 3

221 B CONCEPTUAL CELL UTILIZATION
FOR WASTE CALCINATION

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Note

In addition, Cells 6L and 6R to be used for waste reconcentration system. Sections 5 & 9 to be reactivated for cell drainage and waste handling.

FIGURE 3

-51-
FIGURE 4

ESTIMATED PERSONNEL REQUIREMENTS
FOR
HIGH-LEVEL WASTE DISPOSAL

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FIGURE 4

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Page 52 HW 66618 RD

FIGURE 5

TEMPERATURE HISTORY
OF
CALCINED WASTE
(ILLUSTRATING DIFFERENCES IN TEMPERATURE CRITERIA)

FIGURE 5

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FIGURE 6

PLOT PLAN- 200-E WASTE STORAGE
CONCEPT

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FIGURE 6

FIGURE 7a

CONCEPTUAL WATER COOLED STORAGE BASIN
FOR SOLID WASTE
221-B ANNEX

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FIGURE 7b

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CONCEPTUAL WATER COOLED STORAGE BASIN
FOR SOLID WASTE
221-B ANNEX

FIGURE 7b

FIGURE 8

FIGURE 8

PLAN VIEW (PERSPECTIVE)

LONG TERM STORAGE VAULTS

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HW-57515 10

-57-

FIGURE 9

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FIGURE 10

HW-66618 RD

-58-

HEAT GENERATION RATE DURING STORAGE OF HIGH-LEVEL SOLID WASTE

BASIS: 1. TEN YEAR PRODUCTION PERIOD

2. THERADIATION HISTORY - 800 MW/10

3. RATE: 7000 T/U/YR

LEGEND: (AGE OF WASTE PRIOR TO CALCINATION)

90 DAYS

2 YEARS

HISTORY AND
INTERIM STORAGE BASIN
CAPACITY)

FILL → DECAY

FILL AND DECAY HISTORY FOR
LONG TERM STORAGE VAULTS
(10 YR CAPACITY)

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YRS SINCE START OF 10 YR CALCINATION RUN

FIGURE 10

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FIGURE 10

HEAT GENERATION RATE DURING STORAGE OF HIGH LEVEL SOLID WASTE

TOTAL HEAT GENERATION - 10^6 BTU/HR

YRS SINCE START OF 10 YR CALCINATION

FIGURE 10

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FIGURE 11

-59-

ESTIMATED TEMPERATURE

HW-66618 RD

OF
SOLID WASTE IF STORED IN HANFORD
UNDERGROUND TANKS
(75 FT. DIAM.)

ASSUMPTIONS:

$K_{(WASTE)} = 0.33 \text{ BTU/HR-FT}^2\text{-F}$

$K_{(SOIL)} = 0.33 + 0.66 \text{ BTU/HR-FT}^2\text{-F}$

BOUNDARY CONDITIONS

FIGURE 11

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-60-

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FIGURE 13

-61-

FIGURE 13

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END

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12/23/93