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IN-TANK SOLIDIFICATION OF
INTERMEDIATE-ACTIVITY WASTES

By

B. F. Campbell

Advance Process Development
Research and Engineering Operation
Chemical Processing Department

April 3, 1961

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IN-TANK SOLIDIFICATION OF
INTERMEDIATE-ACTIVITY WASTES

I. INTRODUCTION

Solidification of intermediate-activity wastes is a major goal of the CPD Waste Management Program.⁽¹⁾ Plans are to reduce the wastes, by evaporation, to salt cakes in existing tanks, thereby insuring safe, long-term storage of contained fission products regardless of tank integrity. Initiation of these plans at an early date is necessary to offset the expected increase in tank failures and to provide space for future wastes.

Major decisions of the program relate to selection of the evaporative method to be employed. The requirements of in-tank solidification were therefore reviewed to determine if the choice of evaporative systems can be made at this time. The relative potential of Bentube evaporation and submerged combustion for meeting these requirements were analyzed on the basis of available information, including actual performance of the Bentube facility at the Savannah River Plant (SRP).⁽²⁾

II. SUMMARY AND RECOMMENDATIONS

The major requirements of the Hanford in-tank solidification program are early timing, capability for a high degree of concentration, reasonably effective condensate decontamination, general safety of the system, adaptability of the system to existing tank farms, and adequate capacity for reasonable cost.

Bentube evaporation may have an advantage over submerged combustion only in the areas of condensate decontamination and general safety of the system. Submerged combustion can produce condensate in the MPC range; this concentration should be adequate for disposal at Hanford. Safety considerations of submerged combustion relate to the potential for a propane explosion. Appropriate controls are available to reduce this hazard to an acceptable level.

In all other areas of required performance, submerged combustion promises to be the most capable system. Scaling, line pluggage, and tank filling methods would probably impose concentration limitations on the Bentube evaporator (resulting in inadequate immobilization), but would be less significant to the operability of a submerged combustion system. No real timing advantage can be assumed from adopting a production-tested system such as Bentube evaporation since conditions for the Hanford program will require additional development work regardless of the type of concentration used. Because of equipment simplicity and minimum procurement and construction time, a submerged combustion system can be expected to provide greater concentration capability at the earliest date. Capital cost requirements clearly favor a submerged combustion system with an over-all

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advantage of at least \$1,500,000 to be expected for projects in East and West Areas. Other considerations unique to the existing tank farm system, such as the wide-spread distribution of tankage and the sludge heels in many of the tanks, also favor the portability of submerged combustion systems as compared to the permanency of a Bentube evaporator facility.

Sufficient incentive exists to proceed as soon as possible with a prototype submerged combustion unit. It is therefore recommended that the proposed prototype⁽³⁾ be installed in East Area and be relied upon to alleviate the non-boiling storage pinch in East Area. It would also serve to firm up design parameters for the production systems. Fundamental to the program concept, regardless of evaporation methods, is the structural adequacy of existing tanks. Expert evaluation of structural limitations in respect to the parameters of temperature, specific gravity and fill level should consequently be obtained as an initial step in the program.

III. REQUIREMENTS OF THE IN-TANK SOLIDIFICATION PROGRAM

The goal for in-tank solidification is essential immobilization of intermediate activity wastes to the extent that tank integrity is not a long-term concern. The program must also provide space for current wastes and meet the Department's objectives of safety and reasonable cost.

- A. Early Timing - In view of the tank leakage potential, early timing of this program must be considered a must. Even if no leakers occurred in the next several years, forecast waste volumes indicate a need for new space by January, 1964, in East Area (this analysis assumes the fission product recovery wastes are added to old farms during FY 1962 through FY 1965 - otherwise, the need date is about March 1965). Two leakers would advance this need date to about September, 1963.

West Area needs are less urgent; however, delay would also involve some risk due to tank failure potential. Though existing space in West Area theoretically should be adequate well beyond FY 1970, a need date of July, 1964, would develop if 11 - 12 new leakers occurred. Each leaker in West Area (large tank) would result in about a one-year change in the need date.

- B. High Degree of Concentration - To meet the intent of the program, concentration of the various wastes must be carried sufficiently far to result in essentially no residual liquid after the concentrate temperature has dropped to ambient, or in the case of significant heat generation, to what may be defined as the effective steady-state temperature.

Heat dissipation rates from our underground tanks is not well established, but are probably low enough to require a cooling time of 8 to 12 months for the tank contents to reach ambient temperature. If heat generation is significant (as with the case

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of mixes including solvent extraction waste supernates), self-heating may maintain a relatively high end-point equilibrium temperature in the waste mass and introduce the need for a higher degree of concentration to obtain effective solidification.

The chemical - physical nature of the numerous wastes is also varied and will further influence the specific concentration desired. From laboratory work, appropriate solidification may be expected at a solids concentration of 70 percent for most wastes. Inconsistencies in laboratory data and the other factors mentioned, however, point to the need for a system capable of considerable insensitivity to the degree of concentration that may be necessary.

- C. Effective Condensate Off-Gas Decontamination - We have not as yet established a point-of-discharge control limit for ground disposal at Hanford. A specific guide for establishing required decontamination factors of the condensate streams is consequently not available. Determination of limiting activity has in the past been a complex function of opinion and data relating ground storage capacity to long-term responsibilities and cost of alternatives. In general, once the cribbing practice is established, justification of significant expenditures to reduce activity levels is difficult.

In-tank solidification merely generates a new process effluent to be cribbed. Some justification may therefore exist to insure a low-activity level at the outset in keeping with long-term trends and the growing influence of conservatism on ground disposal practices. It is proposed to use the MPC values for industrial exposure as a design limit for contamination levels in the condensate from this program.

Consideration must also be given to the potential of atmospheric contamination from the chosen system. For example, a high proportion of non-condensibles can give rise to a high carryover of sub-micron particulate contamination. Assurance that radiological limits can be met is essential.

- D. Safety - Radiological, chemical and structural safety must be assured with the concentration method chosen. Tank operating limits perhaps represent the most crucial unresolved variable in the program. Preliminary discussions⁽⁴⁾ on this subject indicate that the conditions of storage may limit fill height to an effective volume of about 500,000 gallons and 300,000 gallons for the 750,000-gallon and 500,000-gallon tanks, respectively. This limit would be based on an anticipated specific gravity in the range of 1.9, a maximum temperature of 210 to 220 °F, and thermal gradients yet to be defined. The nominal design temperature of the old tanks has been listed as 210 °F. Higher temperatures could probably be tolerated but in any case would require expert analysis of structural limitations.

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E. Adaptability of the Chosen System to Existing Tank Farms - The chosen system must have the flexibility to adapt to our tank farm system since all of the tanks and essentially all of the waste already exist. Some of the considerations unique to our situation are as follows:

1. Methods of concentrate generation and delivery must be compatible with a widespread system of tanks, not particularly designed or oriented for receipt of waste with high solids content.
2. Most of our existing tanks contain significant quantities of sludges of varying density and mobility. Most of these sludges may have to be left in the tanks (feasibility of incorporating them in feed to an evaporator is doubtful). Inability to pump out sludges, however, does not necessarily mean they are sufficiently immobile to be left in the tanks without further dehydration.
3. The concentrating system must be capable of handling a variety of feeds of different solids and fission product content and of different scaling and freezing point characteristics. In addition, variation in feed characteristics may be encountered (due to stratification) during pump-out of a single tank.

F. Adequate Capacity for Reasonable Cost - Considering the consequences of failure to inaugurate an in-tank solidification program, relatively high costs can be justified for the project. Yet, significant cost differences between alternatives cannot be ignored. Aside from differences in alternatives, costs will be dependent on capacity needs.

Capacity of the evaporator system, like program timing, cannot be derived from forecast production rates alone since the potential of tank failures must also be recognized. A conclusion can be reached, however, that the East Area situation will probably be the controlling one.

To keep current with fresh wastes in East Area and provide 1,000,000 gallons/year for leakers, a heat duty of about 5,000,000 BTU/hr. would be required at nominal operating efficiencies. (The leaker allowance represents two of the 500,000-gallon tanks or one and one-half of the larger tanks.) This capacity does not allow for continued storage of dilute fission product wastes in the old areas on the assumption that pre-concentration would eventually be accomplished elsewhere (evaporator in B Plant or self-concentration in 241-A). It does assume the storage of concentrated organic wash wastes at about

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50 gallons per ton in the non-boiling tank farms. Similar capacity in West Area would provide a leaker allowance of 2,500,000 to 3,000,000 gallons/year, or be capable of handling 3 to 6 leakers a year, depending on tank size.

The significance of evaporative capacity can also be related to the time required to effectively immobilize all intermediate-activity waste in each area. A 5,000,000 BTU/hr. system in East Area would immobilize all the intermediate-activity wastes to a current basis by the third quarter of FY 1962, if the prototype unit is installed in FY 1962 and no further increase in capacity is made. The addition of another 5,000,000 BTU/hr. unit during FY 1964 would result in a "completion" date of the third quarter, FY 1966. Assuming a starting period of FY 1964 in West Area, 5,000,000 BTU/hr. and 10,000,000 BTU/hr. systems would result in solidification being current by the third quarter of FY 1970 and the second quarter of FY 1967, respectively.

IV. CHARACTERISTICS OF WASTES INVOLVED

Table I on page 20 presents some of the more significant waste data that are indicative of the job to be done by the program. In the referenced table, the characteristic numbers for Cs content, concentration factor, and heat generation rate are qualitative but believed to be reasonably close to actual conditions. Concentration factors are difficult to estimate without laboratory and analytical data since supernate - sludge distribution of soluble salts, hydration effect, etc., are relatively unknown. A comprehensive analytical and laboratory buildown program would be required in support of actual operations.

Proportions of coating wastes and high-activity supernates (Redox and Purex) were selected to give a heat generation rate in the vicinity of 0.5 BTU/hr. ft.³ of solidified waste to avoid excessive temperatures in the salt cake. This is probably a conservative limit, and a factor of 2 increase may be found to be tolerable, contingent upon better understanding of heat flow from underground tanks.

The criterion of 0.5 BTU/hr. ft.³ is based on numerical analysis of heat flow from a 15-foot layer of solidified waste in a typical Hanford storage tank. The method employed was similar to relaxation treatment of heat flow problems dealing with an irregular, non-homogenous geometrical system with multiple boundary conditions. At a soil conductivity value of 0.66 BTU/hr.-ft.-°F and at the 0.5 BTU/hr.ft.³ heat generation rate, a maximum cake temperature (low-center of waste mass) of about 210 °F was obtained. At this temperature, the waste would of course still be liquid. The temperature profile of the hypothetical solid, however, indicates that the top surface of the waste mass would cool to about 130 °F and the sides to about 130 to 160 °F, increasing in temperature toward the bottom of the tank. The final form of the contained waste may therefore be a liquid core capped by a solidified layer; the proportions of the two

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phases would be dependent on the temperature - solidification characteristics of the final concentrate.

The Sr^{90} contribution to heat generation rate was included only in standard coating wastes since coating waste sludge would eventually be incorporated in the concentrate; otherwise only Cs^{137} was assumed to contribute. The low cesium content of TBP supernates may be misleading, but it represents the only analytical data available. The TBP waste solution represented by this data has been scavenged and would be useful for dilution of high-activity waste. Unscavenged TBP waste probably contains 50 - 60 $\mu\text{c}/\text{ml}$ of Cs^{137} in addition to the accompanying Sr^{90} .

Other wastes are expected to be innocuous as far as fission product content is concerned. In regard to potential for boil-down, evaporator bottoms are probably at their peak concentration, whereas First and Second Cycle waste sludges could perhaps be dewatered by a factor of 1 or 2.

The relative abundance of the various wastes is also significant in regard to blending requirements and limitations. The approximate current status in East and West Areas is shown below.

Percentage of Total in Each Area

	<u>East</u>	<u>West</u>
103-A Supernate (factor of 10 dilution req'd.)	3	-
SX - Supernate (factor of 3 dilution req'd.)	-	22
Aged Redox Waste	-	30
Coating Waste	34	8
BiPO_4 - First and Second Cycle*	21	14
Evaporator Bottoms	14	14
TBP Waste	28	12
	100	100

*Principally sludges from First Cycle scavenging and "settling-cribbing" of Second Cycle wastes.

As indicated, no problems should exist in East Area on the availability of low-activity waste to blend with the 103-A supernates. Downgrading of 241-A supernates should not be carried out (other than possibly 103-A) without pre-treatment for cesium removal.

In West Area, blending of SX Tank Farm supernates (which continually increase in proportion to the total of other wastes available) may become a problem. Two considerations, however, may reduce the apparent difficulty: First, the average cesium content of the SX supernates is probably a factor of two smaller than that listed in the table, page 20, (since the extreme situation was selected to indicate D.F. requirements), resulting in a probable blend ratio need of 2:1 rather than 3:1. Second, the

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SX volume represents sludge as well as supernate, and the volume to be blended may consequently be less than the indicated 22 percent of total volume. Considerable detail must be investigated before conclusions can be reached. The indications are strong that blending may become a problem in West Area if concentrated SX Farm supernates are included in the program without a pre-treatment step to reduce the Cs¹³⁷ content.

V. HISTORY AND DESCRIPTION OF EVAPORATIVE METHODS

In view of timing needs of the program, the choice of Bentube evaporation or submerged combustion must be based largely on past experience and development status, or on a reasonable assurance that an expanded development program will confirm current beliefs. Herein lies the major advantage of the Bentube evaporator since it has been in production use at SRP for approximately one year. Submerged combustion application to radioactive waste concentration has been confined to pilot-plant and laboratory definition at Hanford. In industry, however, it is a standard concentration method and is routinely applied to systems inoperable with other types of concentrators.

- A. Bentube Evaporation - Preceding project action on the Bentube evaporator at SRP, waste characterization studies were carried on by BNL(5) to define boil-down characteristics of SRP wastes and the feasibility of concentrating them in existing tanks. The plan was to use the tank coils for heating in addition to decay heat.

Later these studies were reoriented to support the present Bentube program, directed to the evaporation of low-activity salt wastes, and containment of concentrate in new and cheaper tanks. The reason for reorientation is not clear in the literature available but may have been due to the more favorable economics of using cheaper tanks for concentrate storage. This permitted continued use of the high-cost tanks for fresh high-activity wastes. There is no indication from BNL work that concentration in existing tanks was not feasible.

Parallel with later BNL characterization studies, other contractors for SRP were assigned the equipment development job, resulting in a system centered about the Bentube evaporator. The mechanical descaling feature of the Bentube evaporator, effected by thermal cycling of the tube bundle, was apparently the major reason for its selection.

The attached equipment sketch (Figure 1) and plot plan of the SRP facility (Figure 2) show other important aspects of the overall system. Concentrate removal (by steam lift) from the apex of the inverted cone base of the evaporator minimizes solids accumulation in the pot. Feed rate is controlled by varying the recycle stream from a steam jet. A three-plate bubble cap tower provides effective de-entrainment.

DECLASSIFIED

-9-

The evaporator building houses the evaporator, condenser and condensate receiver tanks. It is important to note that the evaporator is located to minimize the run of concentrate discharge lines (steam traced). The unit is expected to be used only with the four new storage tanks which were oriented specifically to receive the concentrate.

Some of the design criteria of the Bentube evaporator are listed below.

Feed Capacity	- 9 gpm
Feed Concentration	- 30 - 35% Solids
Evaporative Duty	- 3000 lbs. H ₂ O/hr.
Boil-Up Mass Velocity	- 60 lbs./hr.-ft. ²
Bottoms Concentration	- 60 - 70% Solids
Condensate DF	- Approx. 1×10^6
Design Steam Flow	- 4500 lbs/hr. at 125 psi inlet pressure (SRP reports indicate this should be as high as 5500 lbs/hr.)

Present Control Point	- Sp.Gr. of bottoms 1.50
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The waste tank design criteria of significance are as follows:

Maximum Temperature	- 210 °F
Fill Rate	- 50 to 75 gpm at 125 °F or 12 gpm at 275 °F with an 18-inch heel at 100 °F.
Sp.Gr. Limit	- 1.8

The SRP system has been in operation since March 15, 1960. Actual performance through December 23, 1960, is summarized below. Feed composition was not available.

Total Feed Processed	- 2,520,000 gallons
Average Feed Rate	- 6.1 gpm
Average Boil-Up	- 4.25 gpm
Percent Design Boil-Up	- 68
Average Vol. Reduction	- 3.3
Vol.Reduction Range	- 2.8 to 6.6
Steam Flow Range	- 4000 to 2000 lbs/hr.
Condensate DF	- (estimated in vicinity of 1×10^6)
No. of Shutdowns for descaling	- 10
No. of Shutdowns for unplugging Conc. Discharge Line	- 2

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The wide variation in volume reduction is due to an apparent change in feed composition with dilute feed being processed in November and December. Steam flow variation is due to scaling with the lower flow rate experienced just before descaling was effected. Scaling tendency has varied with feed conditions. Descaling was required once a week during the earlier operating period. The expected maximum steam flow (5500 lbs/hr.) was not reported to have been attained. During September, the available steam pressure was increased from 125 psi to 150 psi to make up for this deficiency. During October, however, the actual boil-up rate during operating hours averaged only 2530 lbs/hr., or about 85 percent of design.

- B. Submerged Combustion - In industry, submerged combustion has widespread application and finds special favor in natural gas areas where significant economy can be achieved. It is recommended for concentrating jobs entailing corrosive environment, high solids content, severe scaling potential, high viscosity, and in applications where boil-off is desired at a lower temperature than that required for normal evaporator operation. Typical applications in industry are heating and/or evaporating various acid and salt solutions such as sulfuric and nitric acids, sulfates, carbonates, nitrates, and hydroxides. Other uses include dewatering clay suspensions, heating and oxidizing asphalt, concentrating and neutralizing alkaline wastes (carbonation), and dehydrating sewage sludge.

The history of submerged combustion, as applied to waste concentration, is essentially confined to the work of Sloat and Rey, documented in two reports: (1) HW-54624, "Proposal for Plant-Scale Submerged Combustion Test", Reference 3, and (2) a thesis by G. Rey titled, "Entrainment From A Submerged Combustion Unit". The major contribution of this work was in the area of entrainment, resulting in a good definition of its relation to the temperature of the gas contacting the liquid. Satisfactory de-entrainment was shown to be feasible when concentrating coating wastes.

The sketch of the proposed prototype design (Figure 3) shows that it will act as a gas lift and consequently circulate large quantities of liquid during evaporation. The major purpose of the gas lift design, however, is to effect a 40 - 50 percent transfer of heat through the burner wall to minimize gas temperature at the point of liquid - gas contact. By so doing, entrainment is reduced, yet the capacity of the system is maintained.

Performance expected of the prototype design is as follows:

DECLASSIFIED

-11-

Burner Capacity	- 5,000,000 BTU/hr.
Boil-Up Rate	- Approx. 5000 lbs/hr. Maximum, or 11 gpm.
Net Boil-Up	- 3,600,000 gal./yr. at 70% efficiency.
Volume Reduction	- Approx. 4 for coating waste - limit not known.
Condensate D.F.	- 4×10^5 (possibly 1×10^6) at burner gas temp. of 1000 °F.

VI. COMPARISON OF METHODS

The two methods of concentrating intermediate-activity wastes may best be compared by viewing their potential for meeting the requirements of the program. Recognition is necessary that complete factual data on all aspects of the total job to be done is not available and considerable opinion is necessary for an analysis of reasonable scope.

A. Timing - Without considering the need for special development of the Bentube evaporator for Hanford application, it appears that this system could be installed for production use in the least amount of time. If performance of the prototype submerged combustion unit is viewed with moderate optimism, however, its contribution to the concentration of East Area waste would more than make up for the development time necessary to optimize the final production system. The following schedules illustrate this point. Differences in procurement and construction time are based on the relative complexity and materials of construction of the two systems.

	<u>Submerged Combustion</u> (Months)	<u>Bentube Evaporator</u> (Months)
A. <u>Prototype</u>		
1. Design	1	
2. Bids	1	
3. Procurement & Construction	9	
4. Shake-down	1	
5. Development Run	5	
	<hr/>	
Total	17	

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-12-

	<u>Submerged Combustion</u> (Months)	<u>Bentube Evaporator</u> (Months)
<u>B. Production Unit</u>		
1. Design	3	3
2. Bids	1	1
3. Procurement & Construction	10	17
4. Shake-down	1	2
	<hr/>	<hr/>
Total	15	23
Cumulative Total Time	32	23
Boil-off at end of 32 months	approx. 4,300,000 gallons	approx. 2,700,000 gallons

The boil-off accredited to submerged combustion assumes continued operation of the prototype unit until completion of the production system at an over-all efficiency of 50 percent. Boil-off from the Bentube evaporator during the 9 months of active operation prior to completion of the submerged combustion production system assumes a boil-off capacity equal to submerged combustion at an efficiency of 70 percent. (This actually represents an efficiency of 86 percent if the SRP design capacity is employed.) Except for reliance on a prototype system, therefore, net timing advantages may well lie in the submerged combustion route. In view of the relative simplicity of the prototype submerged combustion system, the risk of achieving the indicated boil-off appears small. Operation to a high degree of concentration, beyond the development period of 5 months, need not be a criterion for later use of the prototype system if design deficiencies (relative to circulation and solids deposition) should become apparent. Consequently, the continuing value of the prototype as a boil-off device is believed to be assured.

- B. Degree of Concentration - The effectiveness with which an immobile solid can be produced in our waste tanks will be primarily dependent on the degree of concentration routinely obtained. High concentration will carry with it some problems of a limiting nature, such as scaling and concentrate transfer (possibly unfavorable convection and solids deposition in the case of submerged combustion), and will have some relation to the degree of carbonation obtained.

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-13-

Especially with Bentube evaporation, scaling, carbonation, and other solubility characteristics of the waste may all contribute to the concentration limit. Even without carbonation, SRP scaling experience is not encouraging. Their actual experience is difficult to analyze, however, since feed compositions and degree of concentration were not available. The poor performance encountered during early operation, in which case scaling occurred weekly, suggests that we would experience difficulty in concentrating the variety of feeds we have to the degree of concentration we would like to achieve. Carbonation in the Bentube system appears feasible only in the evaporator itself. This can generate (under certain conditions) aluminum oxide of a particularly adherent and insoluble nature in sodium aluminate feeds. Scaling problems under such a potential could become a major limitation.

Concentration limits appear more significant for insuring operability of a Bentube evaporator than a submerged combustion unit. The assurance of producing a final concentrate that will solidify to an adequate extent is therefore less with the Bentube system. At Hanford the desirability of carbonation (to reduce deliquescence) and the longer concentrate transfer distances involved would impose additional limits on Bentube evaporator operation. In addition, final concentration of the tank concentrate would be about 5 percent lower than the evaporator bottoms because of the tank heel necessary to limit thermal stress during filling.

A maximum concentration of 65 to 70 percent solids appears to be the objective of the SRP program. BNL work indicates that without carbonation this will result in a two-phase system at room temperature, consisting of about 33 volume percent solid phase (predominantly salts at a specific gravity of 1.9) and a supernatant solution (specific gravity of 1.55). Work at Hanford indicates that with carbonation and slightly less water removal, the entire concentrate will solidify at room temperature. More work is necessary on defining the relation of solidification temperature and degree of concentration. Concentrations in excess of 70 percent solids may be desirable for waste mixes having significant heat generation to assure solidification at the higher equilibrium temperatures involved.

The specific limit of concentration with submerged combustion is not known though, with some conjecture, it is expected to be adequately high. Further development is required to study the effects of concentration (and carbonation) on scaling and plugging tendencies, and to evaluate the influence of tank geometry (in respect to burner location) on solids deposition patterns and the potential for localized concentration.

DECLASSIFIED

-14-

As noted under industrial uses, one of the strong points for submerged combustion is its resistance to scaling since scale cannot form on a bubble. The Hanford application requires the air-lift feature to reduce gas - liquid contact temperature, however, and the potential for scaling is introduced. From the design of the systems (high liquid and gas velocities) scaling may not be a problem. Although development runs did not reveal scaling tendencies, the degree of concentration was low (about 2.5) and cannot be considered conclusive. If scaling should occur on the air-lift wall, the heat transfer balance between gas to liquid and metal to liquid would be altered toward higher gas - liquid contact temperatures. Toleration of an increase in entrainment, a reduction of heat input, or an increase in the temperature control air volume would be required.

As with scaling, the problem of potentially irregular solids deposition and poor convection during final stages of a submerged combustion run cannot easily be predicted on a theoretical basis and must also be investigated on a prototypical scale. That a problem really would exist is doubtful, however. If necessary, two smaller burners could be operated from the edge sluicing pits, rather than one centrally located burner. This option would also permit greater control over gas - liquid contact temperatures without reducing boil-off rates below the desired capacity since, in effect, a greater metal to gas heat transfer area is made available.

A scale drawing comparing these two burner arrangements is shown in Figure 4. The qualitative indications of convection suggest a non-interfering pattern of solids deposition during the course of evaporation. Rate of flow through the single prototype unit is estimated to be a minimum of 1000 gpm. This would circulate the tank volume once in about 8 hours.

- C. Condensate and Off-Gas Decontamination - It is logical to assume that a higher condensate D.F. can routinely be achieved with the Bentube evaporator. The D.F. of both systems can fluctuate however and at times could be expected to yield poor performance. Bentube D.F. could be upset due to foaming during start-up with a dilute pot. Control of foaming is possible by reducing boil-up rates and, to a degree, by antifoam addition during such periods. BNL data indicate that at concentrations between 30 and 60 percent solids, coating-type wastes will foam at boil-up mass velocities in excess of about 10 lbs. per hr. ft.². Above 60 percent solids, foaming does not normally occur below a mass velocity of 60 lbs. per hr. ft.² (the design basis for SRP's evaporator).

The expected D.F. of 4×10^5 for submerged combustion is satisfactory for in-tank solidification since this would produce condensate

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-15-

at less than MPC. A factor of 10 lower performance could be tolerated with most feeds. Problems could arise (as previously discussed) due to scaling and increased gas temperatures. It is doubtful, however, that condensates from low-activity wastes (TBP, coats, and Bismuth Phosphate wastes) would become uncribbable. Concern over D.F. with submerged combustion may arise only when processing wastes containing a significant proportion of Redox or Purex extraction waste supernates.

Off-gas non-condensibles in the submerged combustion system could possibly result in undesirable atmospheric contamination. It is doubtful that MPC values would be exceeded, but a more stringent limit may be desirable because of the uncontrolled nature of atmospheric releases. Prototypical development will have to answer questions relative to filter and condenser D.F. and evaluate the need to recycle non-condensibles as dilution air.

- D. Safety - In the area of safety, the normal conclusion is to favor steam evaporation since the explosion hazard of using propane for heating cannot be neglected. Hanford has had experience with propane heating in the operation of the Lucky Pots for calcination and no incidents or near misses were experienced. Manufacturers of commercial submerged combustion systems have, of course, been acutely aware of this objection and have generated the necessary controls for essentially eliminating the hazard. The Sloat - Rey proposal also includes an explosimeter in the vapor space of the tank as a further control measure. In addition, the contemplated volume of dilution air is sufficient to reduce the concentration of propane below handbook values for the explosive limit. The aspect of safety by concentration could be further improved if considered necessary.

Structural safety of the tanks appears to be a problem of equal significance to both evaporation methods. Rate of tank heating will be the major control required. Maximum temperature limitation is not known but is expected to be in the vicinity of 220 °F, and could possibly be higher if fill level is reduced.

A controlled rate of temperature rise and uniformity of tank heating appear more assured with submerged combustion. In both cases, temperature gradients in the structure are controlled by rate of temperature rise of the tank contents. Tank volume remains constant for submerged combustion, whereas volume increase relates directly to temperature rise for the Bentube evaporator system. In the latter case, the concentrator bottoms, at essentially the boiling point, are continually introduced on top of a heel, initially at ambient temperature.

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Maximum tank temperature may be somewhat less with the Bentube system, assuming that about an 18-inch heel is initially in the tank. Filling with bottoms at 250 °F to the 15-foot level would result in a maximum temperature (assuming uniform convection and mixing) of about 180 °F. This further assumes an average heat loss of 60,000 BTU/hr. and a fill rate of 3 gpm.

Partial pressure of the water vapor in the submerged combustion off-gases results in a maximum temperature of 220 °F at about 70 percent solids concentration. Under these conditions, the tank contents are more concentrated than for the Bentube case. For equal final concentrations, the difference in maximum tank temperature for the two systems would probably be negligible. Of significance is the consideration that any maximum tank temperature limit in the vicinity of 200 °F is a parameter that can be met by adjusting submerged combustion design to meet the required balance of partial pressures at the concentration required. For the Bentube system adherence to a maximum tank temperature criterion is also influenced by the limitation on rate of temperature rise. Control must be exercised over the size of the cold heel initially in the tank, degree of concentration (or temperature of evaporator bottoms), and the rate of tank filling.

- E. Adaptability to Existing Tank Farms - Hanford application of the Bentube evaporator presents a considerably different relationship between the concentrator unit and the storage system than at Savannah River. This relates primarily to the permanency of the installation and the need to transfer bottoms considerable distances to the existing tanks. Figure 5 shows the transfer distances that would be involved for typical installations in East and West Areas. To serve the BX and BY Tank Farms in East Area, the length of concentrate discharge lines would vary between 130 and 430 feet. In West Area, the evaporator is shown located to serve primarily the TX Tank Farm only, in which case the transfer distance would vary between 40 and 230 feet. These situations compare with a transfer line length of about 40 feet for the SRP installation.

Of course, unless a new facility were constructed, transfer distances would be considerably increased at Hanford when a given tank farm is filled. At the 5,000,000 BTU/hr. capacity, this would not be a serious objection in the case of the BX - BY arrangement since initial filling of the two tank farms would take about 6.5 years. Filling of the TX Farm would be complete in about 5 years. Increasing the boil-off rate would correspondingly decrease the time utility of a permanent installation. By contrast, submerged combustion equipment could be moved from one area to another as the need arises with minimum expense and interruption of service.

DECLASSIFIED

-17-

Low-density sludges existing in most of the storage tanks would contribute to dilution of concentrate from a Bentube evaporator and may also require development of removal methods from failed tanks remote from a permanent evaporator facility. Submerged combustion could dehydrate these sludges in the course of concentrating the tank contents.

The filling of tanks that have evidenced minor leakage would be possible with either concentrating system on the precept that concentrate could be introduced in increments, allowing time for solidification between the additions. A Bentube facility could only service leakers that were located relatively close to the installation (to reduce transfer distances). Because of its portability, submerged combustion could be used to first concentrate waste in a tank adjacent to the leaker (wherever it may be). Concentrate could then be transferred by steam lift to the failed tank.

- F. Capacity and Cost - Capital costs will be in favor of the submerged combustion system, whereas operating costs can most fairly be assumed equal in both cases. Single installations in East and West Areas, similar to the SRP Bentube facilities, may entail project costs of about \$1,500,000. This is based on an estimate of \$750,000⁽⁶⁾ for the SRP evaporator installation. Each such facility would be capable of an average boil-up of 2,200,000 gallons per year at 70 percent efficiency. The capital cost for submerged combustion facilities, based on a CEO estimate derived from the Sloat - Rey proposal, may be about \$400,000 for both areas. Each would be capable of a 3,600,000 gallon per year boil-off, also at 70 percent efficiency and allowing for heat loss from the tank.

Requirements of the Hanford program indicate that the rate capability of a 5,000,000 BTU/hr. submerged combustion unit is probably the minimum capacity need for each area. Consequently, the capital cost of Bentube facilities could range up to \$2,000,000 for comparable capacity. The potential capital cost difference in favor of submerged combustion is therefore about \$1,500,000. If the capacity in each area is doubled, capital requirements would increase to about \$3,000,000 and \$600,000 for Bentube and submerged combustion, respectively.

Neglecting capital depreciation, annual operating costs are estimated to be about \$300,000 for each area, as shown in the following table:

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ANNUAL OPERATING COSTS

		<u>Submerged Combustion</u>	<u>Bentube Evaporator</u>
1. Salaries, Continuity of Service, Supplies and Overhead (5 operators, 0.5 supervisor, 1.5 maintenance personnel, and 0.5 RMO)	-	\$250,000	\$250,000
2. Propane	-	45,000	
3. Steam	-		25,000
4. Carbon Dioxide	-		30,000
		<hr/>	<hr/>
Total	-	\$295,000	\$310,000

Carbonation costs associated with Bentube evaporation would about balance the increased cost of fuel (propane) for the submerged combustion unit. No difference has been ascribed to either case for maintenance costs, although such costs could be expected to be higher for the Bentube facility.

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V. REFERENCES

1. Campbell, B. F., CPD Waste Management Plant Improvement Program, HW-68099. March 1, 1961. (SECRET)
2. SRP Monthly Progress Reports, Separations Technology Section, DPSP-60-1-3S through DPSP-61-1-12S. (SECRET)
3. Rey, G., and Sloat, R. J., Proposal for Plant-Scale Submerged Combustion Test, HW-54624. September, 1958. (SECRET)
4. Personnel Communication, H. W. Stivers to B. F. Campbell, February, 1961.
5. Feasibility of Concentrating Savannah River Plant Wastes In Existing High-Level Storage Tanks - Summary Report No. 1, BNL-343. May, 1955. (SECRET)
6. Letter, E. R. Irish to V. R. Cooper, SRP - HAPC Waste Disposal Information Exchange, March 1960. (UNCLASSIFIED)

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TABLE IRADIOACTIVITY CONTENT OF SELECTED WASTES

The following table presents some of the more significant data indicative of the job to be done in the waste dewatering program.

<u>Waste</u>	<u>Cs¹³⁷ μc/ml</u>	<u>Concentration Factor - 70% Solids</u>	<u>D.F. Required for 2x10⁻³ μc Cs¹³⁷ in Condensate</u>	<u>Heat Generation Rate of Concentrate BTU/hr.-Ft.³</u>
Coating Waste	1 - 3	4	2x10 ³ - 6x10 ³	0.008 - 0.02
TBP Waste Supernates	0.05	4	1x10 ²	0.0001
103-A Super- nate	4000	3	6x10 ⁶	5.0
104-A Super- nate	5300	3	8x10 ⁶	7.0
SX Farm Super- nate	1300	3	2x10 ⁶	1.7
Aged Redox Supernate	130	3	2x10 ⁵	0.17
C.W. plus 103-A (10-1 mix)	370	4	8x10 ⁵	0.65
C.S. plus SX (3-1 mix)	330	4	7x10 ⁵	0.58
C Farm (Sloat-Rey Basis)(3)	20	4	4x10 ⁴	0.04

Others - (1st and 2nd Cycle BiPO₄ sludges and evaporator bottoms) -
/ 10 μc Cs¹³⁷/ml.

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FIGURE 1

-21-

E. I. DU PONT DE NEMOURS AND COMPANY
Explosives Department-Atomic Energy Division
Savannah River Plant

OPERATING
PROCEDURE

BLDGS 241-F and 242-F

DPSOP. 137

DPSOP REV

DATE

TPD DRAWING NO.

TITLE

Orig

4/60

137-5

DO NOT REMOVE
FROM SRP WITHOUT APPROVAL

DRAWN BY

WASTE FARM EVAPORATOR - FIGURE 1

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FIGURE - 2

PLOT PLAN
SRP LOW LEVEL WASTE EVAPORATOR

FIGURE - 2

(SLOAT - REY PROPOSAL)

TYPICAL SUBMERGED COMBUSTION
INSTALLATION IN BY (750,000 GAL) TANK

FIGURE-3

FIGURE -4

SUBMERGED COMBUSTION
SIZE RELATIONSHIP BETWEEN TANK & BURNERS

FIGURE -4

FIGURE-5

CONCENTRATE TRANSFER DISTANCES FOR
HANFORD EVAPORATOR INSTALLATIONS

FIGURE-5

DATE

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END