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DISPOSAL OF TRANSURANIC SOLID WASTE
USING
ATOMICS INTERNATIONAL
MOLTEN SALT COMBUSTION PROCESS

ERDA Research and Development Report

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Rockwell International

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USING
ATOMICS INTERNATIONAL
MOLTEN SALT COMBUSTION PROCESS

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ABSTRACT

The Atomics International Molten Salt Combustion Process for disposal of transuranic solid waste utilizes a molten salt to combust organic materials, to trap inorganic substances including transuranics, and to react chemically with acidic gases formed during combustion. Subsequent processing of the melt in an aqueous system produces three products: (1) ash, which includes the transuranics, (2) salt, which is recycled to the combustor, and (3) solid sodium chloride for disposal. The transuranics are readily leached from the ash and separated via ion exchange techniques. The leached ash is the second solid process product requiring disposal. No liquid wastes are produced in the process. The reductions in weight and volume are 82 and 98% respectively, if one considers the products from the process only.

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I. SUMMARY

The Atomics International Molten Salt Combustion Process for the treatment of transuranic solid waste is a closed-cycle process which recovers plutonium and produces two solids, ash and sodium chloride, for ultimate disposal. No liquid wastes are produced. The purpose of this report is to summarize the bench-scale experiments confirming the process, and to describe the results of a preliminary engineering and cost study for a 200 lb/hr disposal plant.

In the Molten Salt Combustion Process, shredded waste and air are introduced below the surface of a molten salt, consisting primarily of sodium carbonate, at $\sim 800^{\circ}\text{C}$. Combustion occurs, with scrubbing of gaseous products by the salt. The off gas consists of carbon dioxide and steam. Acidic gases react with the salt and are retained, along with the ash, in the melt. A sidestream of salt is processed to remove those products which build up in the salt, primarily ash and sodium chloride (from the polyvinyl chloride in the waste). In this aqueous processing step, sodium carbonate is separated for recycle, and plutonium, in an easily leachable form in the ash, is recovered. Thus, the final products for disposal are the two solids, ash and sodium chloride.

The process has been investigated on a bench scale (~ 12 lb of melt). The combustion of nonradioactive simulated waste at steady-state conditions yields an off-gas containing <10 ppm hydrocarbons, $<0.05\%$ CO, <20 ppm NO_x , and ~ 0.11 gr/scf of particulates (which are 90+% NaCl). The aqueous salt processing was also demonstrated, with good separation of salt and ash, precipitation of sodium carbonate for recycle, precipitation of sodium chloride for disposal, and leaving a recycle solution which is returned to the sidestream dissolving step. Weight and volume factors (not including facility equipment, such as HEPA filters) of 6.2 and 62 respectively, were calculated for the process; and reductions of 5.7 and 57 were experimentally obtained. Since disposal of the product ash and sodium chloride as bulk powders was assumed, an additional improvement factor of almost two in volume could be realized by a final melting step, in which the ash is slurried into the molten sodium chloride and the mass solidified.

The plutonium tests involved heating various plutonium compounds, with salt of the expected steady-state composition, to the molten state, and then passing through an air-CO₂ gas mixture. It was established, by difference, that 99.9% of the plutonium was associated with the water-insoluble ash; by direct analysis, at least 98% of the original plutonium was found with the ash. In addition, the plutonium was in an easily leachable form. Combustion experiments with actual plutonium waste are currently being carried out.

A preliminary engineering design of a 200-lb/hr waste treatment plant has been completed. The plant was assumed to be at an existing Energy Research and Development Administration (ERDA) site, and in an existing facility. The waste treatment involved manual sorting, shredding, and combustion on a continuous basis. The aqueous processing of the salt was assumed to be done on a batch basis, in order to increase equipment size to larger-than-laboratory scale. As a result, the salt processing portion of the plant can handle a feed corresponding to ~1000 lb/hr. Current safety practices were incorporated, including operation of the facility and all equipment at negative pressures. An overall schedule of 18 months was assumed for design, construction, and activation. A summary of estimated capital costs, which total \$2,050,000, is given in Table 1. The cost of a second plant would be reduced by about \$500,000 associated with the engineering of a first plant.

TABLE 1
CAPITAL COST SUMMARY OF 200-lb/hr TREATMENT PLANT

	Dollars (\$000)
Management and Engineering (1st Plant)	735
Equipment	523
Electrical, Instrumentation, Control	382
Installation, Miscellaneous	241
Plant Activation	<u>169</u>
Total	2,050

Assuming a load factor of 70% and capital depreciation of 12%, the total operating expenses for the process are \$1,029,000/yr, which corresponds to \$0.85/lb or about \$5.92/ft³ of waste processed (a burial cost of \$8/ft³ was used for produced waste).

A "system effectiveness" was estimated, based on a comparison of burial of the original waste and burial of the waste produced by the process and by the processing plant itself. As much plastic as feasible (pumps, piping, vessel linings) was used in the plant, so that it could be destroyed by the combustion process. Assuming a 10-year operating period for the plant, the weight reduction was ~80%, [i. e., the weight of the process product (ash + sodium chloride)], the discarded components requiring replacement, and the decommissioned plant was about one-fifth of the weight of the original waste. The volume reduction was ~98%, or a factor of 57. The estimated cost saving, assuming \$8/ft³ burial costs, associated with building the processing facility, operating it for 10 years, and then finally disposing of it, is \$2,300,000 over the 10-year period, or approximately \$230,000/year. At \$30/ft³ burial costs, the cost saving is about \$3,800,000/year.

In summary, the Molten Salt Combustion Process provides a nonpolluting treatment process for transuranic waste, with good volume and weight reduction and simple plutonium recovery capability. Criticality considerations show that waste with up to 0.4 gm Pu/lb of waste can be treated on a steady-state basis without recourse to special measures. The closed cycle produces no liquid waste, and has low water makeup requirements. The process has excellent safety features, in that there is no open flame and the salt stabilizes the combustion process. Bench-scale combustion experiments with actual plutonium-contaminated waste are currently being carried out. Also, combustion experiments in Atomics International's 70-lb/hr pilot plant, using depleted uranium as a stand-in for plutonium, are being performed. If these experiments satisfy the proposed objectives, then the 18-month schedule for the design, procurement, and construction of a 200-lb/hr plant can begin.

II. INTRODUCTION

The high toxicity, high specific activity, and long body half-life (300 years) of plutonium require special handling of plutonium-contaminated wastes. In spite of the known very limited migration of plutonium in soil, the Energy Research and Development Administration has been storing plutonium wastes, on a temporary basis, since 1970, until ultimate disposal techniques are developed. The waste, contained in polyethylene-lined 55-gal. drums, is stored so as to be retrievable without external contamination. Approximately 1600 kg of plutonium are associated with the waste currently in interim storage. In addition, the various ERDA facilities generate $\sim 350,000 \text{ ft}^3$ of additional transuranic waste per year. Since current storage costs are about $\$8/\text{ft}^3$, and are likely to increase, there is an economic incentive to reduce the waste volume. Also, the recovery of plutonium is a desirable aspect, because of both its hazardous nature and its monetary value.

The majority of this waste is made up of combustible material, such as rags, paper, plastic, and rubber. However, because of the high proportion of chlorinated plastic and the danger from plutonium carryover in the particulate, a conventional incinerator is not wholly satisfactory for the combustion of this material to reduce its volume. Instead, complex incinerators or special combustion methods must be used.

For several years, Atomics International has been developing a combustion process which is carried out in a molten salt medium containing a catalytic oxidizing agent. In this process, organic materials are rapidly and completely oxidized to carbon dioxide and steam, and the molten salt traps the chlorine, sulfur, and phosphorus compounds and the ash formed during combustion. The process, including salt treatment and recovery, has been developed and tested to show its applicability to the disposal of pesticides, scrap rubber tires, hazardous chemicals, and several other difficult-to-burn wastes. In this report, the application of the process to the disposal of solid waste contaminated with transuranic elements or compounds (transuranic waste) is described.

In Section III, a flow diagram is given which shows how the process can be arranged to carry out the disposal of transuranic waste with recovery of plutonium. The experimental work in support of this process development is

outlined in Section IV. The preliminary engineering associated with a plant with a capacity of 200 lb of waste/hr is described in Section V, and an estimate of the cost of this plant is given in Section VI. In the concluding section of the report, the recommendations for further work on the process are discussed.

III. DESCRIPTION OF THE MOLTEN SALT COMBUSTION PROCESS

A. GENERAL DESCRIPTION

In the Atomics International concept, the shredded waste and air are fed into a molten salt furnace containing a pool of 90wt% sodium carbonate and 10wt% sodium sulfate at a temperature in the range of 750 to 1000°C. The sodium carbonate serves as a heat transfer medium for the combustible material, and also as a neutralizing agent for any acidic gaseous combustion products [e.g., hydrochloric acid (HCl) and sulfur dioxide (SO₂)]. The sodium sulfate catalyzes the combustion reaction. The waste and air are fed continuously below the surface of the salt, so that all the gases formed during combustion are forced to pass through the melt before being safely released into the atmosphere. Thus, CO₂ and water vapor are the only evolved combustion products. The metal content of the waste is oxidized and retained in the salt, principally as an insoluble ash. The temperatures of combustion are too low to permit any significant amount of nitrogen oxides to be formed by fixation of the nitrogen of the air.

All of the heat of combustion of the waste is released into the melt. A part of this heat is removed as sensible heat of the off-gas and the discharged melt, and the remainder must be rejected through the walls of the molten salt furnace to an external heat sink (air or water), to allow control of the melt temperature within the desired 750 to 1000°C range. The ash and other inorganic combustion byproducts increase in the melt, and eventually must be removed to retain the efficient nonpolluting features of the combustion process. In certain applications with low throughput, the salt-ash mixture is removed batchwise and discarded, and fresh salt added to the furnace. However, when the throughput is sufficiently large, a sidestream of the melt is removed, either batchwise or continuously, and processed to remove ash for disposal and to recover salt for recycle. The initial step in this processing is to separate the soluble melt from the ash by dissolving in water. Subsequent processing depends upon the inorganic components of the feed to the furnace.

As a summary general statement of its functions, the molten salt acts as a heat transfer agent to stabilize temperature throughout the furnace, as a source of oxygen to enable rapid combustion to take place at moderate

temperatures, and as a scrubbing agent to react with acidic gases (other than CO_2) and to retain ash in the furnace.

B. THE MOLTEN SALT COMBUSTION PROCESS FOR DISPOSAL OF TRANSURANIC SOLID WASTE

A summary of the characteristics of the solid waste to be disposed of is given in Table 2. The numerical values represent averages, and variations can be expected on an hour-by-hour basis. In the case of the plutonium content, the listed value corresponds to a concentration of 0.1 gm/ft^3 of waste. The requirements for processing this waste include the maximum practical volume reduction, the minimum air, water, and solid waste pollution, and the option of the recovery of transuranics, particularly plutonium. The Molten Salt Combustion Process meets these requirements to a great degree.

A flow diagram for the process is shown in Figure 1. The waste, after a manual sorting, is shredded, and fed with air to the molten salt furnace. The steady-state composition of salt in the furnace is $\sim 50 \text{ wt } \%$ sodium carbonate, $10 \text{ wt } \%$ sodium sulfate, $20 \text{ wt } \%$ sodium chloride, and $20 \text{ wt } \%$ ash. The sodium chloride and ash result from the polyvinyl chloride (whose chloride content is converted to sodium chloride) and the ash contents of the feed. From processing and viscosity considerations, an upper limit has been set for the ash concentration of $\sim 20 \text{ wt } \%$ at the operating temperature of 800°C (1475°F). The ash concentration in the furnace charge is kept below this value by periodic (or overflow) draining of a portion of the melt and addition of recycle carbonate and sulfate from the aqueous processing system.

The melt-ash mixture from the furnace is quenched, crushed, and re-fluxed with recycle solution to dissolve the soluble sodium salts. After filtration and precipitate washing to separate the insoluble ash, the filtrate is treated in two evaporative crystallizer steps, at two different temperatures, to remove first a sodium carbonate - sodium sulfate fraction and then a sodium chloride fraction. The carbonate-sulfate is recycled to the furnace, and the sodium chloride is sent to disposal. The solution from the second crystallizer is diluted with condensate and ash filter-cake wash solution, and recycled to the dissolver as the "recycle solution." The plutonium is present in the ash fraction as plutonium oxide. The plutonium values are recovered by acid

TABLE 2
CHARACTERISTICS OF TYPICAL
TRANSURANIC SOLID WASTE
(Reference: Energy Research
and Development Administration)

Composition (wt %)	
Paper	55
Rags	5
Plastic (PVC, PE)	30
Rubber	10
Bulk Density (lb/ft ³)	7
Ash Content (%)	8
Plutonium Content (gm/lb)	0.014
Heating Value (Btu/lb)	11,000 to 12,000

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Figure 1. Flow Diagram for Disposal of Transuranic Solid Waste,
Using Atomics International Molten
Salt Combustion Process

leaching of the ash to dissolve the plutonium. The resulting plutonium solution is then returned to the plutonium process stream. The ash fraction is sent to disposal.

In overall concept, the process is a closed cycle. The off-gas consists of essentially carbon dioxide and steam. There is no liquid waste, and two solid products are formed — ash and sodium chloride. These can be consolidated by melting the sodium chloride, adding the ash, and solidifying the mass; or they can be kept separate for different disposal options. The experimental work in support of the process is described in Section IV.

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Figure 2. Bench-Scale Molten Salt Combustion Unit

IV. EXPERIMENTAL VERIFICATION OF THE PROCESS

A. INTRODUCTION

Each step of the process shown in Figure 1 has been verified. Combustion tests were made to determine combustion parameters with the "steady-state" melt composition. Several samples of the ash-melt mixture from the combustion tests were taken through the aqueous reprocessing cycle to determine separation efficiencies. Four 100-gm ash-melt samples were contaminated with 10 mg of four different plutonium and uranium compounds; these mixtures were then fused, and gas was bubbled through the melt for several hours to determine whether the plutonium and uranium would remain in the melt during "simulated combustion. A few tests were made to determine whether the plutonium could be extracted from the ash remaining after the salt was dissolved from the "simulated" combustion melt-ash mixture. Results of these experiments are discussed in Section IV-B.

B. COMBUSTION TESTS WITH SIMULATED TRANSURANIC WASTE

Two different ash-melt mixtures were used in these combustion tests. The first mixture consisted of 16 wt % ash, 16 wt % NaCl, 10 wt % Na₂SO₄, and 58 wt % Na₂CO₃; the second consisted of 20 wt % ash, 20 wt % NaCl, 10 wt % Na₂SO₄, and 50 wt % Na₂CO₃. The two mixtures are the concentration extremes anticipated in actual radwaste combustion.

Paper-plastic mixtures were made up having essentially the same heating value, ash content, ash composition, and chloride content found in "typical transuranic waste." This typical composition was originally obtained from Los Alamos Scientific Laboratory.

Four combustion tests, using this synthetic waste, were made in the bench-scale molten salt combustion apparatus shown in Figure 2. This combustion unit consists of a 6-in. alumina tube inside a metal liner in a tube furnace. In these tests, the furnace is used to melt the salt initially; once combustion begins, the furnace is turned off, and all heat is generated by the internal combustion of the waste in the salt. The temperature of the

TABLE 3

PARTICULATE LOADING OF OFF-GAS FROM COMBUSTOR,
USING STEADY-STATE SALT COMPOSITIONS*

(Feed Rate $\approx$ 3 to 7 gm/min, Air Flow $\approx$ 2.5 scfm)

Salt Composition (wt %)				Temperature (°C)	CO ₂ (%)	Particulate Loading (gr/scf)
Na ₂ CO ₃	Na ₂ SO ₄	Ash	NaCl			
58	10	16	16	840	6.0	0.167
				815	5.4	0.111
				790	5.3	0.085
				765	5.0	0.070
50	10	20	20	840	5.8	0.224
				820	4.0	0.158
				810	4.5	0.127
				780	3.5	0.085
				785	3.5	0.104
				745	2.8	0.056

*NO_x <20 ppm, and CO and HC below limit of detection (i.e., <0.05% and <10 ppm)

salt is controlled by adjusting the feed rate of the combustible material. Combustion air and simulated waste are fed to the salt through the alumina feed tube. The waste and combustion air are introduced below the surface of the molten salt, where rapid and complete combustion of the organic material to CO_2 and H_2O is obtained. The catalytic action and high temperature of the salt assures complete oxidation of the organics instantaneously upon contact with the salt. Therefore, the noncombustible ash components are formed beneath the melt surface, which assures complete retention of the ash in the melt. Hydrogen chloride and any other acidic gaseous species (except, of course, CO_2) react chemically with the basic sodium carbonate melt, and are retained in the melt.

The off-gas from combustion was monitored for N_2 , O_2 , CO , HC , and NO_x , to determine completeness of combustion. Isokinetic particulate samples were collected to determine the particulate loading and composition of the particulates. The off-gas was scrubbed with aqueous sodium hydroxide, to determine whether any gaseous chloride escaped from the melt and passed through the particulate filter; in these tests, none could be found. The results of these tests are given in Table 3. Nitrogen oxide emissions were <20 ppm, and CO and HC emissions were less than the detection limits of the instruments i.e., $<0.05\%$ and <10 ppm, respectively). Particulate emissions were ~ 0.1 gr/scf*. The particulate loading measurements in the off-gas at constant combustion temperature show that particulates increase only slightly with increasing CO_2 content. However, the amount of particulates was directly related to sodium chloride vapor pressure and mole fraction of sodium chloride in the melt. Analysis of the particulates indicates that, at 800°C , they are almost entirely sodium chloride crystallites.

C. AQUEOUS REPROCESSING

The volume and weight of contaminated waste can be further reduced after combustion by processing the melt-ash mixture to recover the sodium carbonate and sulfate for recycle to the combustor, and to produce an ash and sodium chloride fraction for disposal (see flow diagram, Figure 3). This is

* The EPA standard for particulate emissions from incinerators is 0.1 gr/scf. One grain is 1/7000 of a pound.

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Figure 3. Material Balance of Reprocessing Cycle (lb/hr)

accomplished by leaching the soluble sodium carbonate, sulfate, and chloride from the quenched melt-ash mixture by a 2-hr refluxing followed by filtration. Subsequently, the sodium carbonate and sulfate are separated from a concentrated brine solution by fractional crystallization at the solution boiling point (106°C). The sodium carbonate and sulfate crystals are dried, and fed back into the molten salt combustor. Sodium chloride is removed from the concentrated brine solution by further concentrating the brine in a multiple-effect evaporator at reduced pressure and temperature (~35°C). The sodium chloride crystals are filtered from the brine and sent to disposal; the mother liquor filtrate is diluted with the water removed by distillation in the two crystallization steps, and recycled to the dissolver in the closed-cycle process.

These crystallizations are commercial procedures used in the recovery of minerals from certain dry lake bed deposits. The major concern in the evaporative crystallization procedures is the purity of crystals obtained in each crystallization (i. e., separating Na_2CO_3 - Na_2SO_4 from NaCl in the first crystallization, and crystallizing essentially pure NaCl from the Na_2CO_3 - Na_2SO_4 solution in the second step). To demonstrate the purity of crystals obtained in these two crystallizations, six different samples were taken through these two steps.

Table 4 gives the compositions of the crystals expected from solubility calculations, and the compositions observed in the tests. Since the crystals were not washed, the difference was due primarily to mother liquor retention on the crystal surfaces. Based on weight changes when the crystals were dried and the composition of the solution from which the crystals were separated, it was found that ~80 wt % of the undried crystal weight was mother liquor in the first crystallization, and ~40 wt % in the second crystallization. The use of a centrifuge instead of a filter to separate the crystals will reduce the liquor retention in the crystals, and thus improve the crystal purity.

A small amount of water is evaporated in the second crystallization, but most of the sodium chloride precipitates as a result of the temperature change when the solution is cooled from 106 to 35°C. The solution is cooled by evaporation at the reduced pressure required in the filtration step. Sufficient water is carried off in this evaporative cooling to crystallize the additional sodium chloride required in the sodium chloride removal step. Even without further

TABLE 4
COMPOSITION OF CRYSTALS OBTAINED IN
AQUEOUS PROCESSING TESTS

Crystallization	Composition	
	Flowsheet (Calculations)	Experimental Results
1st	84% Na_2CO_3 16% Na_2SO_4	80% Na_2CO_3 12% Na_2SO_4 8% NaCl
2nd	100% NaCl	96% NaCl 4% Na_2CO_3 0.2% Na_2SO_4

purification, adequate separation was obtained to verify process feasibility. The only effects caused by impure crystals are that the melt is slightly higher in sodium chloride content, and that a small amount of sodium carbonate is discarded with the sodium chloride. This is shown in Figure 3, where the aqueous reprocessing material balance is given. With impure crystals, the salt recycled to the combustor will contain some sodium chloride. If this same distribution occurs in the scaled-up process, as was found in the bench-scale tests, the furnace salt composition would run somewhat higher in sodium chloride content than is shown in Table 3.

Table 5 shows the minimum theoretical product possible from the molten salt combustion of 200 lb of transuranic waste which contains 8 wt % ash and 4.9 wt % chloride in plastics. If it is assumed that the most economical way of avoiding HCl emissions from incineration is by tying up the chloride through the formation of sodium chloride, then the minimum amount of waste possible from 200 lb of feed is 16 lb of ash and 16 lb of NaCl . Through molten salt combustion and subsequent reprocessing of the melt to recover and recycle the unused salt, essentially the minimum amount of waste is generated. This is seen by comparing Columns 2 and 3 in Table 5. The only differences are that the NaCl extracted from melt reprocessing is contaminated with a small amount of unused carbonate and sulfate (which could be removed with subsequent

TABLE 5
COMPARISON OF SALT COMPOSITIONS FROM
FLWSHEET AND EXPERIMENTAL
RESULTS*

Process Product	Flowsheet Calculations (lb)	Experimental Results (lb)
Ash Disposal	16 Ash	18 Ash + Na ₂ O 8 H ₂ O
Furnace Recycle	40 Na ₂ CO ₃ 8 Na ₂ SO ₄ 6 H ₂ O	40 Na ₂ CO ₃ 8 Na ₂ SO ₄ 4.3 NaCl 13 H ₂ O 1.6 Ash
NaCl Disposal	16 NaCl	16 NaCl 1 Na ₂ CO ₃ -Na ₂ SO ₄ 5.5 H ₂ O
Recycle/Solution	15 NaCl 14 Na ₂ CO ₃ 1 Na ₂ SO ₄ 60 H ₂ O	15.2 NaCl 13.6 Na ₂ CO ₃ 0.7 Na ₂ SO ₄ 63 H ₂ O 0.4 Ash

* Assumes 200 lb of typical waste with 8 wt % and 4.9 wt % chloride content

TABLE 6
WEIGHT AND VOLUME REDUCTIONS FOR
VARIOUS PROCESSING
OPTIONS*

	Weight		Volume	
	lb	Reduction Factor	ft ³	Reduction Factor
Original Waste	200†		28.6	
Option 1 (No Processing)	80	2.5	1.14	25
Option 2 (Theoretical Maximum with Disposal of Chloride + Ash)	32§	6.2	0.46	62.5
Option 2 Experimental	35	5.7	0.5	57.1

* Note: The reduction factors are process estimates; they do not take into account the waste generated by normal operation of the facility and the air cleaning train. Some of these wastes would probably also be processed through the salt.

† Assumes 200 lb of waste containing 8 wt % ash and a bulk density of 7 lb/ft³.

§ Assumes a density of one-half that of the solid crystalline density, or 70 lb/ft³.

recrystallization, if desired), and some silica in the ash has tied up some sodium oxide.

Table 6 gives the weight and volume reduction expected on using the molten salt combustion process. The calculated reductions do not include facility wastes, such as HEPA filters, etc. If the melt is not reprocessed to recycle the unused salt (Line 2) (i. e., if the melt-ash cake is sent to disposal), weight and volume reductions of 2.5 and 25, respectively, are obtained. However, with the described reprocessing cycle (Line 4), experimentally verified reductions of 5.7 and 57, respectively, were realized. Furthermore, both the ash (primarily insoluble silica and alumina) and the sodium chloride reprocessing fractions that must be disposed of are solids — the best state for storage and ultimate disposal. If plutonium recovery is involved, the plutonium values can be leached from the ash prior to disposal.

The sodium carbonate is readily soluble in the diluted aqueous recycle solution. Essentially no dissolution advantage is gained by breaking the ash-melt mixture in chunks finer than 1/4 in. Approximately 95% of the sodium is dissolved in the refluxing solution in 1 to 2 hr. Additional refluxing does not increase the sodium recovery, since the remaining sodium is tied up as the silicate, which is very insoluble in concentrated sodium carbonate solutions. The insoluble ash is easily filtered from the solution, and can be washed without difficulty. However, a second refluxing of the insoluble ash, after the concentrated carbonate solution is withdrawn, is not recommended, since a voluminous unfilterable colloidal silicate suspension is formed.

D. DISPOSITION OF TRANSURANICS IN THE PROCESS

The transuranics are retained in the melt during combustion, and can readily be extracted in the aqueous reprocessing cycle, if recovery of plutonium and other transuranics is desired. To study this, four different plutonium and uranium compounds were added, as solutions, to separate ash-melt mixtures prepared from combustion tests (Table 7). The ash-melt mixtures were melted, and simulated combustion gases were bubbled through the mixtures for over 2 hr. Analyses, after the tests, of the ash-melt mixtures, the off-gas condenser condensate, and the HEPA filters showed that >99% of the plutonium and uranium were retained in the melt during simulated combustion. Experimental details of these tests are given in the following paragraphs.

TABLE 7
PREPARATION OF SALT-ASH MIXTURES
CONTAINING PLUTONIUM AND URANIUM

Test No.	Compound Used *		Melt Temperature (°F)	Time Gas Sparged Through Melt-Ash Mixture (min)	Gas Composition (%)				Gas Superficial Velocity Through Melt (ft/sec)
	U	Pu			O ₂	N ₂	CO ₂	H ₂ O	
1	UO ₂ Cl ₂	PuCl ₃	1170† - 1490	303	16	63	9	12	4 to 2
2	UO ₂ SO ₄	Pu(SO ₄) ₂	1490 - 1500	200	16	63	9	12	1
3	UO ₂ (NO ₂) ₂	Pu(NO ₂) ₄	1450 - 1500	150	17	66	9	8	2
4	U(SO ₄) ₂	Pu ₂ (SO ₄) ₃	1450 - 1480	125	17	66	9	8	2

* Aqueous solution of compound containing 10 mg of uranium metal and 10 mg of plutonium metal added to 100 gm of ash-melt mixture No. 5.

† Note ash melt mixture not molten at this time. Before crushed ash-melt mixture melted, a high-velocity gas stream of 4 acfs was inadvertently directed at crushed ash-melt mixture containing Pu and U. This caused some of the Pu & U to move to the condenser and HEPA filter downstream of the furnace.

TABLE 8
DISPOSITION OF PLUTONIUM AND URANIUM IN PROCESSING FRACTIONS AND COMPONENTS

Test No.	Disposition of Plutonium (wt %)					Disposition of Uranium (wt %)				Super- ficial Gas-Melt Velocity (ft/sec)
	Reflux Solution	Heat Exchanger	HEPA Filter	Ash		Reflux Solution	Heat Exchanger	HEPA Filter	Ash	
				Found	By Difference				By Difference	
1	0.22	0.05	0.05	-	99.7	16	0.05	0.08	83.9	4-2
2	0.012	0.002	0.003	98±2*	99.98	<0.5	0.03	<0.05	99.5	1
3	0.099	0.006	0.008	-	99.89	0.8	0.08	<0.05	99.1	2
4	0.046	0.0036	0.003	-	99.95	10	0.003	<0.05	90.0	2

*Plutonium was determined coulometrically in this sample - other plutonium determinations were by counting

Metallic plutonium and uranium were dissolved in acids (i.e., HCl for Pu, and HCl and HNO₃ for U). Aliquots (2 ml of 100) of these acid solutions were fumed with other acids (i.e., HNO₃ and H₂SO₄ for Pu, and H₂SO₄ for U) to produce plutonium and uranium chloride, nitrate, and sulfate. A second aliquot (2 ml) of the initial acid solution was fumed with sulfuric acid and reduced with ferrous sulfate to form the lower-valent sulfate species of plutonium and uranium.

One hundred grams of crushed ash-salt mixture was placed in a 1-in. ID alumina tube, and the plutonium compound (~2 ml) and corresponding uranium compound (~2 ml) were placed in the center of the ash-salt mixture. Gas was bubbled through the melt to simulate the agitation present during combustion, and to determine possible uranium and plutonium evolution from an ash-melt mixture during combustion. Test conditions are given in Table 7.

After each test, the ceramic tube was transferred to the analytical glove box train. The large ceramic tube was cracked away from the solidified ash-salt mixture, which was subsequently crushed (<about 4 mesh). About 1/8 of the salt-ash mixture (12.2 gm) was placed in a reflux flask, and 25 gm of recycle solution (dilute sodium chloride-carbonate-sulfate solution, obtained in solution recycle in aqueous processing of the ash melt mixture) was added. The ash-melt mixture was refluxed with the recycle solution for 2 hr. The refluxed mixture was then filtered to separate the ash from solution. Ash from one reflux test (No. 2) was subsequently treated with fuming H₂F₂-HNO₃ solution to dissolve the plutonium away from the predominantly silica and alumina ash. The plutonium in the ash dissolved readily.

Aliquots of the reflux filtrate, the water used to wash any particulates out of the condenser, and sections of the HEPA filter were counted to determine whether plutonium or uranium were carried out of the melt during simulated combustion. The plutonium dissolved from the ash with H₂F₂-HNO₃ was determined quantitatively, using a coulometric technique. The uranium in the various fractions was determined by a fluorometric procedure.

The disposition of plutonium and uranium in the various processing fractions and components is given in Table 8. The percent of the original in the ash fractions was obtained by difference. One test was made to determine

whether the plutonium dissolved from the ash fraction. The plutonium was determined coulometrically; the results roughly confirmed the percent calculated by difference.

The results in Table 8 show that 99.9 wt % of the plutonium was present in the ash fraction. Only a small percentage of the plutonium (generally, <0.1 wt %) was present in the reflux solution. Negligible plutonium was found in the wash from the heat exchanger and in the HEPA filter (generally, <0.01 wt %). The high activity on the HEPA filter in Test No. 1 (0.05 wt % of the plutonium) was undoubtedly due to the high-velocity gas blowing through the crushed solid salt before the mixture was melted. Essentially no difference in the particulate evolution was obtained when gas-melt superficial velocities of 1 and 2 ft/sec were used. In actual combustion tests of plutonium wastes, superficial velocities of 0.5 to 2 ft/sec (generally, ~ 1.5 ft/sec) are contemplated.

The uranium results as shown in Table 8 are similar to those for plutonium. As with plutonium, only trace amounts of uranium were found in the condenser and HEPA filter used when the uranium and plutonium compounds were heated in contact with the melt-ash mixture (i. e., during the simulated combustion step, uranium can be used as a stand-in for plutonium in pilot-scale combustion tests. However, unlike plutonium, it appears that a small fraction of the uranium may dissolve in the reflux solution; at least, in tests 1 and 4, up to 16 wt % of the uranium was found in the reflux solution. By far the majority of the uranium was present in the ash (as was the plutonium).

We do not understand the different results of Tests 1 and 4 vs Tests 2 and 3 (Table 8). We would expect that the uranium would be present in the same chemical form in the molten salt, regardless of its initial chemical form. Therefore, these uranium dissolution tests should be repeated.

Extraction of plutonium from the ash fraction is much easier than the dissolution of refractory plutonium oxide in hydrofluoric-nitric acid digestions. This may be due to the formation of a different species (e. g., a plutonate); or it may be that, at these temperatures in this melt, the refractory oxide does not form. This could be expected, since a sodium carbonate fusion of the plutonium and uranium compounds was performed during combustion. Partial dissolution of the Pu was obtained by refluxing the ash with dilute HCl, HNO₃,

and NH_4Cl for 30 min in exploratory tests. Therefore, it appears that the Pu is at least partially soluble in a number of solvents, and additional tests are planned to determine the optimum conditions for recovering the Pu from the ash.

TABLE 9
DESIGN BASIS FOR TRANSURANIC SOLID
WASTE DISPOSAL PLANT

Waste Feed Characteristics

Feed Rate	200 lb/hr
Plutonium Content	0.014 gm/lb
Waste Composition	
Paper	55 wt %
Plastic (polyethylene-polyvinyl chloride)	30 wt %
Rubber	10 wt %
Rags	5 wt %
Noncombustible Content	
Ash	8 wt %
Heating Value	12000 Btu/lb

Output Products

Plant designed for minimum volume of wastes for ultimate disposal, including plant-generated materials

Ash and chloride separated for disposal

Plutonium separated for recovery as a solution

Process salts recycled to molten salt combustor

Off-gases scrubbed and filtered to provide a product without impact on environment

Plant Site

Site and building furnished by ERDA

Safety

Dual containment of plutonium

 Facility operated under slight vacuum (-0.3 in. H₂O)

 Process equipment operated under vacuum (-1 in. H₂O)

 Airlock entrance and exit

 HEPA filtration of all exhaust gases

Fire Protection

 Fire, smoke, and heat detectors and alarms located in feed system, storage, and work areas

 Fire-resistant plastic used for viewports

 Automatic nonaqueous fire extinguishing equipment installed

Plutonium Control

 Rigid accountability of plutonium required

 Waste and equipment scanner used to determine plutonium input and equipment inventory

 Plutonium recovery determined by ERDA plutonium processor

Reliability

Provided by plant simplicity, flexibility, and redundancy

Maintenance

High-maintenance equipment enclosed in glove-box type enclosures

Component interfaces designed for ease of removal and replacement

V. TREATMENT PLANT DESIGN DESCRIPTION

This section describes a treatment plant for processing transuranic solid wastes and reducing their volume by 98%, using the Molten Salt Combustion Process. First, the design basis for the treatment plant is discussed. This is followed by descriptions of the two major systems comprising the disposal plant — the Molten Salt Combustion System and the Aqueous Reprocessing System.

A. PLANT DESIGN BASIS

The design basis for the treatment plant is summarized in Table 9. The plant was designed for a feed rate of 200 lb/hr of a mixture of paper, plastic, rubber, and rags, of which 8% is noncombustible and ends up in the form of ash. The feed rate and composition of the waste were selected by consultation with the Waste Management and Transportation Division of ERDA. The heating value of 12,000 Btu/lb is a computed value, based on the average upper heating values for the components of the waste mixture. The feed rate, heating value, and amount of noncombustibles are major criteria for sizing and design of the process equipment.

The quantity and form of output products from the plant are important design considerations for a transuranic waste disposal system. In addition to the basic contaminated feed material, wastes are generated during operation and maintenance of the disposal plant itself. Major potential contributors to the plant-generated waste are contaminated liquid streams associated with the process, and contaminated parts and bulky equipment replaced during maintenance activities. A primary objective is to design the plant for minimum volume of all contaminated waste, including plant-generated materials. The disposal plant was designed to minimize sources of plant-generated waste by selecting a process flow arrangement that minimizes liquid wastes of any kind, and by selecting materials of construction that can be destroyed along with the basic waste material.

The two major output products for ultimate disposal are the noncombustible ash and sodium chloride. The treatment plant was designed for separation and collection of these materials as dry products. The plant was also

designed to recycle the potentially contaminated process salts and water, in order to minimize wastes products and reduce process salt and water makeup requirements.

Another major objective for a transuranic solid waste disposal system is recovery of valuable plutonium. With this in mind, the treatment system is designed for recovery of the plutonium as a solution which could be accepted into an existing plutonium processing operation.

The only other product leaving the treatment facility is the off-gases from the combustion process. The plant was designed with an off-gas treatment system to remove particulates before release to the atmosphere.

A specific location for the plant was not selected. It was assumed that the plant would be installed on a site and in a building supplied by the ERDA.

Safety is of utmost concern; therefore, equipment associated with plutonium containment, fire prevention, and plutonium accountability must be included in the disposal plant design. The facility and process equipment were designed for reduced-pressure operation, to assure air leakage into the building and into the equipment, thereby preventing leakage of plutonium out of the equipment and the facility. Off-gases from process equipment were filtered through HEPA-type filters before release to the atmosphere.

Reliability and maintainability of the plant are important considerations in the design of a transuranic waste treatment plant. Reliability is inherently provided by keeping the process as simple as possible, by designing for flexibility in operations, and by installing redundant equipment. Regularly scheduled maintenance of equipment is required to reduce downtime of the treatment facility. Equipment with high maintenance requirements may require glove-box type enclosures with air locks, to permit access without potential contamination of the entire facility.

These considerations formed the general basis for the design of the treatment plant. Early in the engineering evaluation, it became apparent that it was desirable to operate the Molten Salt Combustion System continuously around the clock, whereas the Aqueous Reprocessing System should be operated on a batchwise basis. Continuous operation of the Molten Salt Combustion

System is preferred, because the high operating temperature of the molten salt combustor necessitates a significant period of time (several hours) for startup and shutdown.

On the other hand, the Aqueous Reprocessing System is a low-temperature system, and requires short periods (<1 hr) for startup and shutdown. The major reason for selecting a batch-type operation for this system is associated with utilizing commercially available process equipment. The size requirements for continuous processing of the melt-ash streams were found to be too large for laboratory-scale equipment, and too small for commercial-size equipment. Therefore, a batch-type operation was selected. Economic reliability and maintenance considerations led to selecting sizes of equipment, so that the aqueous processing could be completed during four single shifts per week, with the fifth day allocated to maintenance, restocking waste feed material, and disposing of the noncombustible waste material. This results in almost independent operation of the Aqueous Reprocessing System and the Molten Salt Combustion System.

The following sections describe the process flow arrangements and design characteristics of the two major systems comprising the disposal plant.

B. MOLTEN SALT COMBUSTION SYSTEM

1. Process Flow Description

The Molten Salt Combustion System operates to prepare, feed, and burn transuranic wastes in a molten salt combustor. Off-gases are scrubbed and filtered before release through a stack to the atmosphere. The entire system is operated under negative pressure, to assure containment of plutonium. Periodically, an ash-containing melt sidestream is removed for processing in the Aqueous Reprocessing System. The cleaned melt is recycled, along with fresh salt makeup, to restore the melt level in the combustor.

The process flow diagram for the combustion system is shown in Figure 4. The waste is first sorted manually in a "glove-box" type enclosure. Metallic and noncombustible materials are removed. The waste is then conveyed by a rubber belt to a shredder, where it is reduced in size. A

Figure 4. Waste Combustion System Process Flow Diagram

vacuum system is then used to transfer the waste to a storage hopper, from which a screw feeder feeds the wastes, at a nominal rate of 200 lb/hr, into a fluidizing air stream.

The waste and air are continuously introduced into the refractory-lined molten salt combustor, through multiple feed passages located near the bottom of an 800°C (1472°F) pool of molten Na_2CO_3 , Na_2SO_4 , and NaCl . The combustor is operated with 100% excess air, over that theoretically required for complete oxidation of the combustible materials. Operation with 100% excess air assures complete oxidation to CO_2 and H_2O , and contributes to removal of the exothermic heat of reaction from the molten salt pool.

Ash, chlorides, and plutonium are retained in the molten salt. After an initial period to achieve steady state, the ash builds up to ~20 wt % over a 12-hr period. When this happens, ~1000 lb of the ash-containing molten salt is removed for processing in the Aqueous Reprocessing System. Na_2CO_3 and Na_2SO_4 are recycled from the aqueous system to replenish the salt removed every 12 hr. Fresh Na_2CO_3 is also added to make up that sodium which has reacted to form NaCl , which is ultimately separated for disposal.

The off-gases (633 scfm) from the combustion process and small amounts of entrained melt and particulates first pass through a mist eliminator, where entrained droplets are removed. The gases are then cooled to 600°F in a direct-contact water cooler. Further cooling to ~140°F, and scrubbing of the gases, are performed in an aqueous venturi scrubber, where 99% of the particulates are removed and sent to the Aqueous Reprocessing System.

Since the gases leaving the scrubber are saturated with water vapor, a natural gas reheater is provided to increase the temperature ~20°F, to 160°F. Final cleanup is accomplished as the gases are passed through two 99.95% efficient HEPA filters before discharge to the stack. The maximum plutonium released is over two orders of magnitude below the maximum permissible concentration.

2. Design and Performance Characteristics

Table 10 summarizes the design and performance characteristics of the major equipment items making up the Molten Salt Combustion System.

TABLE 10
MOLTEN SALT COMBUSTION SYSTEM
DESIGN CHARACTERISTICS
(Sheet 1 of 2)

Waste Feed	
Total Feed Rate	200 lb/hr
Plutonium Content	0.014 gm/lb
Ash	16 lb/hr
Chloride	9.8 lb/hr
Heating Valve	12,000 Btu/lb
Feed Hopper and Belt Conveyor	
Waste Sorted in Hooded Enclosure	
Hopper Volume	15 ft ³
Conveyor Length	10 ft
Materials	
Hopper	Carbon Steel
Conveyor	Rubber
Motor	5 hp
Shredder	
Hopper and Surge Bin Volume	25 ft ³
Type	Hammermill
Rotor Diameter	10 in.
Rotor Length	10 in.
Motor	40 hp
Storage Hopper and Feeder	
Hopper Volume	200 ft ³
Hopper Dimensions	5 ft diameter by 10 ft high
Feeder Type	Screw
Feed Rate	5 to 30 ft ³ /hr
Material	Carbon Steel
Motors	
Hopper Vibrator	2 hp
Screw Feeder	5 hp
Air Compressor	
Capacity	1000 scfm
Pressure	8 psig
Motor	25 hp
Molten Salt Combustor	
Waste Feed Rate	200 lb/hr
Air Feed Rate	670 scfm (100% excess)
Off-Gas Produced	633 scfm
Temperature	800°C (1472°F)
Ash Buildup	16 lb/hr
NaCl Formation	16 lb/hr
Melt Withdrawal	1000 lb (twice/day)
Recycle Salt Makeup	48 lb/hr

TABLE 10
MOLTEN SALT COMBUSTION SYSTEM
DESIGN CHARACTERISTICS
(Sheet 2 of 2)

Fresh Salt Makeup	17 lb/hr
Heat Produced	2.4×10^6 Btu/hr
Heat Removal	
Off-Gas	1.17×10^6 Btu/hr
Vessel Walls	1.20×10^6 Btu/hr
Salt and Waste Feed	0.03×10^6 Btu/hr
Vessel Diameter	6-ft OD
Vessel Height	10 ft
Refractory Lining Thickness	4 in.
Materials	
Vessel	Type 304 SS
Lining	Cast Alpha Alumina
Off-Gas Cooler	
Gas Flow	633 scfm
Inlet Temperature	1472°F
Outlet Temperature	600°F
Water Flow	1.1 gpm
Off-Gas Scrubber	
Inlet Gas Flow	842 scfm
Inlet Temperature	600°F
Outlet Temperature	140°F
Recirculating Water Flow	30 gpm at 50 ft
Total Water Vapor in Gas	0.28 lb/lb of gas (1.68 gpm)
Outlet Gas Flow	922 scfm
Particulate Removal Efficiency	99%
Motor	1 hp
Reheater	
Inlet Temperature	140°F
Outlet Temperature	160°F
Gas Flow	927 scfm
Natural Gas Flow	<1 cfm
HEPA Filter	
Number of Filter Systems	2
Efficiency of Each Filter	99.98%
Efficiency of Each Filter System	99.95%
Dimensions	2 x 2 x 1 ft
Pressure Drop	10 in. H ₂ O
Exhaust Blower	
Flow	1000 scfm
Head	40 in. H ₂ O
Motor	15 hp

a. Waste Feed Equipment

The waste is removed from 55-gal. drums by extracting the thick polyethylene bag from the drum, up through a sphincter port into a glove box. The bags are opened, and the waste is poured out on a belt conveyor. The waste is sorted manually to remove large metallic and noncombustible objects. These are placed in thick-walled polyethylene bags, and returned through a sphincter port into a polyethylene-lined 55-gal. drum. The combustible waste passes to a hopper system and belt feed into a shredder.

In the shredder, the waste is reduced in size for even flow and steady chemical reaction in the melt. A size reduction to 3/8 in. has been specified for the process. Although a smaller-size feed was used in the tests described in Section IV, bench-scale and pilot plant scale (100 lb/hr) experiments with similar materials have been done with 3/8 in. size feed or larger. The latter experiments were carried out at Atomics International's Molten Salt Pilot Plant Facility. A greater depth of melt exists in the large-scale furnace, which provides greater residence time for combustion.

The equipment presently planned for shredding the feed is a large capacity, high-speed hammermill, such as a Williams Rocket Grinder, or a Williams hammermill specially modified for shredding. Actual equipment selection will follow demonstration of equipment capability by the manufacturer, using a typical waste blend. A similar hammermill has been found satisfactory for similar wastes at Atomics International's pilot plant facility.

The hammermill is fed by an enclosed conveyor belt which picks up the waste from a bin. The feed hoppers for both conveyor belt and hammermill are provided with exhaust hoods which are ducted to a radioactive-service exhaust system. The waste bin for the conveyor belt hopper is sized large enough to accommodate a waste drum tilted into position by a drum hoist. An air system is provided to purge the shredding chamber and convey the shredded material into a surge bin.

The shredded waste is lifted under vacuum into a cyclone receiver, and dropped via a rotary airlock into a storage hopper, which is sized for a storage capacity of one shift's supply of feed material at rated plant capacity.

The hopper is ~ 5 ft in diameter and 10 ft high, and it is modified from standard hopper design to assure positive continuous discharge into a screw feeder.

The screw feeder drops the shredded waste at a controlled rate into the stream of compressed air flowing to the molten salt combustion furnace. The air carries the shredded waste into the furnace, where both the solids and the air are injected below the surface of the melt.

Compressed air for conveying and oxidizing the contaminated waste is supplied by a compressor capable of delivering ~ 1000 scfm of air at a pressure of 8 psig. This pressure provides for the hydrostatic head of the melt in the combustion furnace and the pressure drop through the feed line to the furnace.

b. Combustion Furnace

Oxidation of the radioactive waste and primary treatment of the initial products of reaction take place in the molten salt combustion furnace. This furnace is a Type 304 stainless steel vessel, ~ 6 ft OD and ~ 10 ft high, which contains ~ 4700 lb of salt. The inside of this vessel is lined with 4 in. (6 in. on the floor) of fused-cast alpha-alumina (Monofrax A). Vessel inside dimensions are 5 ft ID by 8 ft internal height. The outside of the vessel is water jacketed; water cooling is required to maintain the temperature of the melt in the desired operating range of $800 \pm 25^\circ\text{C}$. Approximately one-third of the heat generated in the process is removed by the water; the remainder is removed via the off-gases and through periodic discharge of the melt. External cooling of the vessel provides a temperature gradient across the thickness of the alumina lining, and lowers the temperature of the lining to below the freezing point of the melt (700°C) within a short distance from the hot interior surface of the lining. Any melt which penetrates into joints or cracks in the lining is thus frozen before it reaches the inner surface of the stainless steel furnace shell.

The waste and air feed are introduced into the combustion furnace from a circular manifold, located around the furnace, through four to six feeder lines penetrating the combustion furnace shell. The feeder lines are evenly spaced around the furnace periphery, to provide uniform distribution of the waste and air feed into the melt. Each of these feeders is lined with alumina.

The key operating parameters which control the physical size of the molten salt combustion furnace are the flowrate of the off-gas (the reference design value for the superficial velocity of the off-gas is 2 ft/sec) and the heat which must be removed through the walls of the furnace to maintain the temperature of the melt within the range of $800 \pm 25^\circ\text{C}$. Present furnace design concepts limit this heat removal rate to a maximum heat flux of 7000 to 8000 Btu/hr-ft².

The heat of oxidation of the waste exceeds the heat removed from the furnace as sensible heat of the off-gas stream and of the periodic melt discharge stream. The excess heat must be rejected to an outside heat sink — in this case, the cooling jacket around the furnace shell. The reference design was conservatively based on the use of 100% excess air for process flexibility, and heat transfer surface requirements were conservatively calculated on the basis of upper heating values for components of the typical waste blend. Calculations showed that 200 lb/hr of the "typical" waste will generate $\sim 2,400,000$ Btu/hr. The off-gases from the combustion furnace will remove 1,165,000 Btu/hr, and the melt discharge stream an additional 30,800 Btu/hr, leaving 1,204,000 Btu/hr to be rejected to the furnace shell cooling jacket.

The amount of melt discharged from the furnace at 12-hr intervals is ~ 1000 lb; it is limited by the location of the discharge tap on the side of the furnace, which allows only about one fifth of the salt to flow from the vessel. After discharge, the tap is sealed until the next withdrawal. Thus, the quiescent melt level in the furnace varies between 2 and 2-1/2 ft. As the melt height builds up, more heat will be rejected through the vessel walls, and the system will tend to cool. Since excess combustion air is always present, the excess heat rejection will be overcome by increasing the waste feed slightly, and thus increasing the amount of heat generated in the combustor to match the heat rejected. This feed control system will automatically be adjusted by the molten salt combustor temperature.

c. Combustor Off-Gas Treatment Equipment

The main requirement of the off-gas treatment equipment is to prevent any radionuclides from escaping in the off-gas. This is insured by the use of HEPA filters. The gas must be cooled to prevent damage to the prefilter

and HEPA filters; therefore, a water spray injector is provided in the line. In order to prolong the service life of the HEPA filters, a venturi scrubber removes the NaCl particulates, and a prefilter removes particulates not removed in the scrubber.

The off-gases first pass through a mist eliminator section, which is a refractory-lined chamber located directly above the combustion furnace head. The mist eliminator section has provision for electric resistance heating to insure a constant temperature in excess of 800°C. The mist eliminator traps salt droplets which are entrained in the off-gas stream, and, being maintained at a temperature above the melting point of salt, allows it to drain back to the melt bed. The off-gas line leading from the mist eliminator section is refractory lined, up to the point of the water spray system. The injected water spray cools the off-gas to ~600°F. The off-gas is then conveyed in a low-alloy steel line to a venturi scrubber, where 99% of the remaining particulates are removed. These particulates are primarily NaCl and, possible, tiny melt droplets which dissolve in the water. A bleed stream from the venturi scrubber to the aqueous reprocessing dissolver tank prevents buildup of NaCl and melt in the venturi scrubber.

The off-gas from the venturi scrubber is saturated with water. In order to prevent water from coming out on the prefilter and HEPA filter, the off-gas is reheated slightly (~20°F). Reheat is accomplished by steam or gas, depending on availability. Alternately, a small amount of hot gas could bypass the venturi to provide reheat capability. Further design trade-offs will determine the best reheat technique.

After reheat, the gas passes through a prefilter and a HEPA filter. The prefilter is made of combustible materials, and will probably require infrequent (semiannual) changing. The HEPA filter system removes ultra-fine particulates, down to the submicron range. If the scrubber and prefilter operate as planned, the HEPA filter will require very infrequent changing.

The pressure-regulating fan, located downstream of the HEPA filter, keeps the entire system under slight vacuum to prevent escape of radioactive materials. All off-gas from the entire system is passed through the HEPA filters, to measure activity in the off-gas system and in the stack.

d. Startup-Standby Heating System

An auxiliary heat source is required for combustion furnace heatup, salt melting, and standby heating during non-operating hours. Melt startup is initiated with a prefused, low-melting-point eutectic salt, followed by the addition of sufficient Na_2CO_3 and Na_2SO_4 to make up the initially required melt bed. Heat for melt startup and standby heating is supplied as hot gas from a natural-gas-fired combustion heater, rated at 1×10^6 Btu/hr output and capable of generating a 1300°C exit gas temperature. The hot gas is ducted into the combustion furnace via the feed ports, or through a nickel-alloy downcomer which supplies heat directly to the salt bed zone, as well as to the gas disengagement zone of the furnace. In the event of interruption of the waste feed during operation, natural gas or fuel oil can be injected directly into the molten pool and burned, to sustain operation until the waste feed is restored.

C. AQUEOUS REPROCESSING SYSTEM

1. Process Flow Description

The Aqueous Reprocessing System is operated on a batch basis, in order to utilize commercially available process equipment. This size of equipment also offers greater reliability at a reduced capital cost per unit throughput. Operation on a continuous basis for a 200-lb/hr plant leads to equipment too small for reliable and economic operation.

The melt reprocessing system is operated in two distinct batch processing sections. The first section involves the separation and processing of the insoluble ash from the furnace melt sidestream. The second section involves the separation of recyclable salt and sodium chloride by crystallization from the aqueous solution. The two operating sections are separated by a large holdup or surge tank, to enable independent operation of the two sections and to allow flexibility in system operability. A process flow diagram of the system is shown in Figure 5. A summary of the process cycle for a week of operation is presented in Figure 6.

a. Ash Processing

The first operating section (upper left portion of Figure 5) involves ash separation and processing; it is composed of five unit operations:

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Figure 6. Process Cycle Summary

- 1) Melt drain and solidification
- 2) Formation of aqueous slurry solution
- 3) Insoluble ash separation
- 4) Acid-ash reaction
- 5) Acid-ash separation.

A melt sidestream of ~1000 lb is drained from the combustion vessel, on a batch basis, every 12 hr of continuous operation (assuming a waste feed rate of 200 lb/hr). The melt is drained from the combustion furnace, and distributed in a 1/4-in. thick layer on a water-cooled steel conveyor belt, where it is solidified as it travels along with the moving belt. When the solidified melt reaches the end of the belt, it is broken into small pieces by a knife, and discharged into the dissolver tank. The solidified melt pieces are treated for 2 hr in the tank with a solution of make-up water and recycle solution from the (NaCl) crystallization section of the process, to dissolve the soluble constituents. This dissolving step is expedited by means of a stirring agitator, and by heating the tank to maintain the solution at refluxing temperature (107°C).

The resulting 400 gal. of crude liquor slurry in the tank is pumped (30 gpm) to a rotary vacuum drum filter. Here, the insoluble material, which contains plutonium, is separated from the solution, and discharged as an ash cake into a cake collector. The filtrate from the operation still contains, in solution, the various salts from the furnace. This solution (380 gal.) is collected in a vacuum receiver, from which it is pumped to a heated holdup tank, sized for 10 batches, or 5 days of operation. The wash solution (1 to 3 gpm) from the filter accumulates in its own vacuum receiver, from which it is pumped back to the dissolver tank to be used as make-up water. Approximately 1/2 hr is required for the filtering operation.

A recycle solution of dilute acid from a plutonium recovery facility (not shown in Figure 5) is pumped through the filter cake collector, forming a slurry with the ash. This slurry is transferred to the acid-ash reactor, where a stream of concentrated acid is added to the slurry as it is stirred for 1 hr in the heated vessel. At the conclusion of this stirred batch reaction, the resulting slurry is pumped (25 gpm) to a screening centrifuge, where the inert ash solids are separated in a few minutes and conveyed to interim storage.

The acid centrifugate is pumped to a storage tank, to await transfer to a plutonium recovery facility. This step completes the first phase of the Aqueous Reprocessing System; it requires ~4 hr/cycle, with 2 cycles/day.

b. Solution Processing

The second process section (lower right portion of Figure 5) involves separating the salt solution into three fractions ($\text{Na}_2\text{CO}_3 \cdot \text{Na}_2\text{SO}_4$, NaCl , and recycle solution), and is composed of four unit operations, done on a batch basis with only two major pieces of equipment. The four unit operations are:

- 1) Evaporative crystallization of sodium carbonate monohydrate and burkeite
- 2) Centrifugal separation of the preceding solids and mother liquor
- 3) Vacuum crystallization of sodium chloride
- 4) Centrifugal separation of the preceding solids from the mother liquor.

The feed stream for this process is pumped from the heated holdup tank into the crystallizer loop, where it is circulated by the loop recycle pump through a heat exchanger and the evaporator section of the crystallizer. During this first initial charge for evaporative crystallization, the loop heat exchanger is operated at full capacity to heat the incoming feed, and later the recycle mother liquor, to 107°C (225°F). The initial charge of feed is 475 gal. When this amount has been charged to the system from the holdup tank, the flow from the holdup tank is stopped, and the crystallizer is seeded with Na_2CO_3 nuclei. The recycle pump in the loop continues to circulate the overflow mother liquor from the crystallizer to maintain metastable conditions for the crystallizer.

As the recycle solution is pumped through the recycle loop, the mother liquor is heated to its boiling point at atmospheric pressure. Since the solution is under pressure, it will not boil until it reaches the evaporator section of the crystallizer, where it flash evaporates, at or slightly below atmospheric pressure. When the water evaporates from solution, the resulting mother liquor becomes supersaturated. This supersaturated mother liquor flows down the downcomer section to the crystallizer, where the supersaturation is relieved as the solution grows on the crystal nuclei.

As the solvent is evaporated from solution, the holdup tank pump furnishes new feed to the loop. In this manner, the unit operates on a continuous feed basis, with the addition of a small amount of needed seed crystal nuclei. After a sufficient concentration of crystals have grown in the bottom of the crystallizer, the drain is opened, and a batch is pumped to the centrifuge for separation. This allows operation of the process on continuous feed and batch discharge, until the heated holdup tank is drained or a maximum of 3800 gal. of feed have been fed through the loop. At this time, the holdup pump is stopped, and the last batch of feed is allowed to grow to crystals of >100 mesh. The final batch is then drained to the centrifuge for separation, and the crystallizer is empty.

During centrifuging, the solids discharge is composed primarily of sodium carbonate monohydrate ($\text{Na}_2\text{CO}_3 \cdot \text{H}_2\text{O}$) and burkeite ($\text{Na}_2\text{CO}_3 \cdot \text{Na}_2\text{SO}_4$). This material is conveyed to the salt feeder for recycle to the furnace. The centrifugate is pumped to a holdup tank to be stored, and later fed to the crystallizer loop as feed for NaCl crystallization. This crystallization and centrifugal separation requires 6 hr, during 2 days of the week.

For the next operation, the same crystallizer is utilized in the loop as a vacuum crystallizer. For this process, the loop heat exchanger is operated at a level sufficient to maintain a temperature of 95°F in the evaporating mother liquor. However, the steam booster and vacuum pump at the top of the evaporator section are used to produce a vacuum in the evaporator of 1.6 in. Hg absolute pressure. This will allow the solvent water to evaporate at the 95°F temperature to create supersaturation of the mother liquor.

This process operates in much the same manner as the previous process, except that the feed is drawn from the first centrifugate holdup tank, and the crystallizer is seeded with NaCl nuclei instead of Na_2CO_3 nuclei. Process operation involves the same continuous feed, batch withdrawal, format to separate NaCl crystals in the centrifuge, which will be conveyed to storage for ultimate disposal. The resulting centrifugate will be pumped to the holdup tank provided; or, if the situation warrants, it can either be transferred to the surge tank or directed back to the dissolver tank as make-up water and

recycle solution for the dissolver tank. This NaCl separation requires 4 hr, during 2 days of the week.

The condensate from the evaporator condenser is recycled to the dissolver tank as make-up water. This closes the system in a continuous loop, with no liquid waste discharge. The only products from the loop are the salt for recycle to the furnace, the NaCl crystals for ultimate disposal for further processing, the dry inert ash for interim storage, and the acid solution for ultimate plutonium recovery. All aqueous solutions are recycled to the dissolver tank for reuse in the loop. The aqueous regeneration system is also totally enclosed for plutonium containment.

2. Design and Performance Characteristics

A piping and instrumentation diagram for the Aqueous Reprocessing System is shown in Figure 7. Table 11 summarizes design and performance characteristics.

a. Ash Processing Section

(1) Steel Belt Conveyor

The purpose of the water-cooled endless belt is to freeze the salt, and to convey it to a breaker that discharges the melt in small chunks into the dissolving tank. The reason the salt is frozen before it contacts water in the dissolving tank is to eliminate a possible explosion hazard when molten salt is dispersed in water. Although an explosion is very unlikely, even with molten salt, it is essential to remove all possible hazards when handling radioactive materials.

The endless belt was designed to cool 1000 lb of melt from 1500°F to 500°F in 3 min. The 6.0 ft³ of salt per batch is frozen into a 1/4-in. thick layer by allowing the salt to flow onto the endless belt moving at a rate of 2.4 ft/sec. The belt is 8 in. wide by 8 ft long, and is cooled by means of a water spray on its underside. Melt-water contact is avoided by means of side rails on the belt. A secondary heat exchanger maintains the coolant below the boiling point. The secondary and primary coolants are separated by a heat exchanger to avoid contamination of the secondary coolant stream.

(2) Headbox

The purpose of the headbox is to handle the melt surge, so that the melt can be evenly distributed over the endless belt. The headbox has a 3 ft³ capacity with a 2-in. diameter inlet and a pyramid frustrum discharge. The headbox is made of high alloy steel, and is mounted so it can be swung out of the way for easy access to the belt.

(3) Dissolver Tank

The 600 gal. glass-fiber-reinforced plastic (FRP)-lined carbon steel tank is heated, and the solution agitated to reflux and to insure rapid dissolution of the soluble salts. The agitator also insures an evenly dispersed ash content in the slurry during filtration. A reflux condenser above the dissolver tank prevents water from boiling off during refluxing. The agitator-stirrer is equipped with a 3 ft blade, turning at 60 rpm. A Monel heat exchanger in the tank maintains the solution near its reflux temperature (228°F) during melt dissolution.

(4) Rotary Drum Vacuum Filter

The plastic-lined rotary drum filter has an active surface area of 5.6 ft², and is ~ 1 ft in diameter by 1 ft long. The drum is equipped with a spray cake wash system, discharging 1 to 3 gal. of wash water, and is equipped with a cake squeeze roller. The drum is operated at ~ 1 rpm, with the cake forming for ~ 20 sec/revolution at a vacuum of 10 psig. The cake is removed from the drum with a side discharge knife, and deposited in a cake box for subsequent ash processing.

(5) Holdup Tank

The FRP-lined carbon steel holdup tank has a 4000 gal. capacity, and is used to store the filtrate from the rotating drum filter until sufficient volume has been accumulated to warrant processing (i.e., ~ 3000 to 3500 gal.). The holdup tank is equipped with Monel heating coils to maintain the solution temperature at ~ 212°F.

(6) Acid Reactor

The 300-gal. glass-lined acid reactor is used to dissolve the plutonium from the ash. This unit is equipped with a 2 ft blade stirrer, turning at 60 rpm,

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TABLE 11
AQUEOUS REPROCESSING SYSTEM
DESIGN CHARACTERISTICS
(Sheet 1 of 2)

Ash Processing Section	
Melt Feed Characteristics	
Total Flow	1000 lb in ~ 3 min. (twice/day)
Ash Content	200 lb
Sodium Chloride Content	200 lb
Plutonium	35 gm
Temperature	1472°F
Steel Belt Conveyor	
Belt Dimensions	8 in. wide by 10 ft long
Water Cooling Flow	20 gpm
Melt Discharge Temperature	500 °F
Melt Thickness on Belt	1/4 in.
Type of Melt Discharge	knife
Belt Drive	1/2 hp Variable Speed
Dissolver	
Operating Temperature	225°F
Dissolving Time	2 hr/1000 lb Melt
Capacity	600 gal.
Materials	FRP-Lined Carbon Steel
Water Flow	400 gal. / 1000 lb Melt
Agitator	3 ft blade at 60 rpm
Motor	15 hp
Rotary Vacuum Drum Filter	
Active Filter Area	5.6 ft ²
Operating Pressure Differential	10 psig
Vacuum Pump	25 in. Hg at 40 cfm
Filtrate Withdrawal Rate	20 gpm
Drum Wash Water Flow	1 to 3 gpm
Feed	400 gal.
Filter Cycle	30 min
Filtrate Flow	380 gal.
Ash Removed	192 lb
Materials	FRP, Monel, Carbon Steel, and Polypropylene
Acid Reactor	
Capacity	300 gal.
Operating Temperature (externally heated)	212 °F
Acid Feed	15 ml / gm Ash
Reaction Time	60 min.
Material	Glass-Lined Steel
Agitator	2-ft diameter blade at 60 rpm
Motor	7-1/2 hp
Acid Slurry Feed Pump	5 gpm at 10 ft

TABLE 11
 AQUEOUS REPROCESSING SYSTEM
 DESIGN CHARACTERISTICS
 (Sheet 2 of 2)

Ash Centrifuge		
Speed	1500 rpm	
Active Surface	4.8 ft ²	
Centrifugate Removal Rate	25 gpm	
Ash for Disposal	192 lb	
Plutonium Dilutor Acid Solution	300 gal.	
Solution Processing Section		
Holdup Tank		
Capacity	4000 gal.	
Operating Temperature	212°F	
Material	Carbon Steel	
Vacuum Crystallizer		
Capacity	500 gal.	
Equipment	Steam Booster, Vacuum Pump, Heat Exchanger, Recycle Pump	
Materials		
Heat Exchanger	Monel	
Vessel	Carbon Steel	
Cycle Time	~ 90 min/500 gal.	
Operating Mode	<u>Evaporative</u>	<u>Vacuum</u>
Temperature	195 to 220 °F	95°F
Operating Period	6 hr - Twice/week	2 hr - Twice/week
Crystal Formation	560 lb/hr Na ₂ CO ₃ ·H ₂ O 112 lb/hr Na ₂ CO ₃ ·Na ₂ SO ₄	450 lb/hr NaCl
Water Vaporation	1960 lb/hr	1064 lb/hr
Steam Flow	400 lb/hr	1100 lb/hr
Salt Centrifuge		
Speed	1500 rpm	
Active Surface	3.5 ft ³	
Salt Recycled to Molten Salt	560 lb/hr Na ₂ CO ₃ H ₂ O (480 lb/1000 lb drain)	
Combustion System	112 lb/hr Na ₂ CO ₃ Na ₂ SO ₄ (96 lb/1000 lb drain)	
NaCl for Disposal	450 lb/hr (192 lb/1000 lb drain)	

is externally heated, and is equipped with a reflux-condenser off-gas system to maintain the desired concentration in the reactor during dissolution of the plutonium.

(7) Screening Centrifuge

The plutonium solution is separated from the insolubles by means of a high-speed, 1500-rpm screening centrifuge. The active surface area is 4.8 ft². The centrifuge is automatically controlled to wash the ash prior to discharge by a knife and screw conveyor. The ash is conveyed to a plastic bag, which is deposited in a plastic-lined drum through a sphincter port when it is full. The solution is conveyed to a holdup tank, from which a bleed stream is fed to the plutonium recovery facility.

b. Solution Processing Section

(1) Vacuum Crystallizer

The same crystallizer is used for both of the salt extraction steps (i. e., $\text{Na}_2\text{CO}_3 \cdot \text{Na}_2\text{SO}_4$ crystallization for recycle to the combuster, and NaCl crystallization for disposal). The crystallizer has a capacity of 500 gal. and is constructed of RFP-lined carbon steel. The unit is equipped with a steam-heated heat exchanger and a recycle pump, for operation in the evaporation mode. A steam ejector, vacuum pump, and condenser are provided for operation in the vacuum mode. The crystallizer is designed to remove ~ 1960 lb of $\text{H}_2\text{O/hr}$ at 225°F in the evaporative mode, and ~ 1064 lb of $\text{H}_2\text{O/hr}$ at 95°F in the vacuum mode. Crystal retention time in the crystallizer is ~ 90 min. After the first batch of crystals has been formed, the crystallizer is operated in the continuous mode for the rest of the day, by feeding in solution at the rate of 5 gal./min and discharging crystal magma periodically to the centrifuge.

(2) Screening Centrifuge

The centrifuge is a high-speed (1500-rpm) screening centrifuge with controlled speed drive. It has 3.5 ft² of active screening surface, with a knife and screw conveyor discharge system. The $\text{Na}_2\text{CO}_3 \cdot \text{Na}_2\text{SO}_4$ crystals are collected, and recycled to the furnace. The NaCl crystals are collected in plastic bags for disposal.

c. Miscellaneous Process Equipment

Miscellaneous process equipment is listed in Table 12. As far as practical, fibre-glass reinforced plastic (FRP) piping, pumps, and tank linings were used to minimize the noncombustible portion of the components, so that waste generated during plant maintenance could be disposed of in the melt. This would optimize effectiveness of the plant in waste reduction.

TABLE 12
MISCELLANEOUS EQUIPMENT FOR MOLTEN SALT
PROCESS TREATMENT PLANT FOR TRANSURANIC WASTE
(Sheet 1 of 2)

Item	Size	Function
Filtrate Vacuum Receiver	30 gal.	Surge storage for filtrate from ash filter
Wash Water Vacuum Receiver	10 gal.	Surge storage for filter wash water
Moisture Trap	To be determined	Keep moisture from vacuum pump
$\text{Na}_2\text{CO}_3 \cdot \text{H}_2\text{O}$, Burkeite Holdup Tank	2000 gal. Carbon Steel	Hold centrifugate solution of $\text{Na}_2\text{CO}_3 \cdot \text{H}_2\text{O}$ and burkeite
NaCl Holdup Tank	1500 gal. Carbon Steel	Hold centrifugate solution of NaCl
Recycle Solution Holdup Tank	4000 gal. Carbon Steel	Hold solution for recycle to dissolver
Crystal Seed Screw Feeder	2 lb/min	Feed seed crystals into crystallizer
Recycle Salt Screw Feeder	30 lb/min	Feed recycle salt to storage Feed NaCl to disposal
Pumps		
Filter Feed	30 gpm at 25 ft (1 hp)	Transfer solution from dissolver to filter
Filter Wash	3 gpm at 25 ft (0.1 hp)	Provide wash water for filter
Filter Wash Recycle	3 gpm at 20 ft (0.1 hp)	Transfer wash water to dissolver
Filtrate	20 gpm at 50 ft (1 hp)	Transfer filtrate to holdup tank
Filter Vacuum	40 cfm at 25 in. Hg vacuum (4 hp)	Places vacuum on filter
Dilute Acid Slurry	15 gpm at 30 ft (1/2 hp)	Circulate dilute acid and ash to acid reactor
Concentrated Acid	5 gpm at 10 ft (0.1 hp)	Adds acid to acid reactor
Centrifuge Feed	25 gpm at 30 ft (1 hp)	Transfer slurry from acid reactor to centrifuge

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TABLE 12
 MISCELLANEOUS EQUIPMENT FOR MOLTEN SALT
 PROCESS TREATMENT PLANT FOR TRANSURANIC WASTE
 (Sheet 2 of 2)

Item	Size	Function
Acid Centrifugate	20 gpm at 20 ft (1/2 hp)	Transfer dilute acid centrifugate to storage
Crystallizer Feed	75 gpm at 100 ft (7.5 hp)	Transfer solution from holdup tank to crystallizer
Crystallizer Magma	30 gpm at 20 ft (1 hp)	Transfer crystals and solution to centrifuge
Centrifugate Solution	50 gpm at 100 ft (5 hp)	Transfer solution from centrifuge to solution storage tanks
Recycle Solution	75 gpm at 120 ft (7.5 hp)	Transfer recycle solution to dissolver

VI. ECONOMIC EVALUATION

Capital and operating cost estimates were based on the following assumptions:

- 1) The plant would be located at an ERDA-selected site.
- 2) The ERDA laboratory would supply the building for the plant.
- 3) The plant would treat 200 lb/hr of raw waste at a 70% load factor, or 1,218,000 lb/year (174,000 ft³/year).
- 4) The plant would generate 20,000 lb/year of wastes from operations and maintenance.
- 5) A design and construction program, through pre-operational tests, would require 18 months.

The cost evaluation includes all manpower, materials, equipment, sub-contracts, and management needed to design, build, and activate the plant. The schedule for this 18-month project is shown in Figure 8; it consists of four major tasks: (1) engineering and design, (2) procurement (3) installation, and (4) plant activation. Engineering and design of the plant would be accomplished during the first 6 months. Procurement of components would extend over a 9-month period. Some components have delivery times of several months, and would be ordered early in the engineering phase. Installation of the components would require 6 months to complete, and would start 8 months after the start of the project. During the installation, plans would be developed for activation of the plant, and crews would be trained. Activation of the plant would officially begin at the end of construction, and would require 4 months.

The total capital investment for this program would be \$2,050,000, including general expense and fee. Capital costs are summarized in Table 13. These costs are for the first plant; significant cost reductions can be made for later units of the same design. Engineering and design costs of \$735,000 include 140 man-months of effort in management, engineering, design, procurement, and field activities. The management activities extend over the 18-month duration of the program.

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Figure 8. Transuranic Solid Waste Treatment Plant Schedule

TABLE 13
CAPITAL COSTS FOR A 200 lb/hr TRANSURANIC SOLID WASTE
TREATMENT PLANT

Item	Estimated Cost (\$ 000)
Engineering and Design	735
Equipment	
Combustion System	
Major Components	193
Instrumentation, Controls, and Electrical	102
Aqueous Reprocessing System	
Major Components	330
Instrumentation, Controls, and Electrical	280
Installation	
Combustion System	46
Aqueous Reprocessing System	90
Plant Activation	169
Miscellaneous	<u>105</u>
Total	2,050

A total of \$523,000 would be required for major equipment; \$193,000 for the Molten Salt Combustion System, and \$330,000 for the Aqueous Reprocessing System. A further breakdown of equipment costs is presented in Table 14. Instrumentation, control, and electrical equipment would cost \$382,000; these include safety equipment for fire, smoke, and heat sensors, automatic fire extinguishing systems, and radioactivity sensing and alarm equipment.

Subcontracts totalling \$136,000 would be required for installation of the equipment. This includes setting the equipment and installing piping, valves, instrumentation, controls, and electrical equipment.

Estimated costs of \$169,000 would be required to start up the plant. This includes a team of AI personnel to train and assist in the startup and initial operation.

TABLE 14
EQUIPMENT COSTS FOR 200 lb/hr TRANSURANIC
SOLID WASTE TREATMENT PLANT

Item	Estimated Cost (\$)
Combustion System	
Waste Conveyor - Shredder System	12,500
Storage Hopper - Vacuum Feed System	12,000
Combustion Air Feed Compressor	16,800
Startup Hot Gas Heater	13,200
Molten Salt Combustion Furnace	93,000
Off-Gas Treatment Equipment	20,300
Contingency	<u>25,200</u>
Subtotal	193,000
Melt Processing System	
Melt Feed - Freeze Conveyor	21,200
Dissolver Tank	13,300
Rotary Vacuum Drum Filter	48,200
Acid Reactor	24,200
Vacuum Crystallizer	90,400
Certrifuges (2)	60,300
Pumps, Tanks	29,400
Contingency	<u>43,000</u>
Subtotal	330,000
Total Equipment	523,000

Utilities and materials requirements and costs are listed in Table 15. The major utility requirement is for electrical power (90 kw). Of this, 78% is used by the 24 hr/day operation of the waste preparation and feed equipment. The shredder alone utilizes ~ 30 kw. The intermittent operation of the aqueous reprocessing equipment consumes only 6% of the electrical power. The annual costs are based on operation of the plant at the design throughput, at a plant load factor of 70%.

TABLE 15
UTILITIES AND MATERIAL REQUIREMENTS FOR A 200 lb/hr TRANSURANIC
SOLID WASTE TREATMENT PLANT

	Average Continuous Requirement	Rate	Annual Cost*
Electricity	90 kw	20 mills/kwh	\$ 11,038
Natural Gas	2×10^3 Mcf/year	\$1.00/Mcf	2,000
Makeup Water	102 gph	\$1.00/Mgal.	625
Cooling Water	96 gph	\$0.10/Mgal.	60
Steam	40 lb/hr	\$1.00/Mlb	250
Carbonate	17 lb/hr	\$0.03/lb	3,127
Acid, Crystal Seed, Contingency (15%)			<u>2,565</u>
Total			\$ 19,665

* Assumes a load factor of 70%

TABLE 16
TRANSURANIC SOLID WASTE TREATMENT PLANT
ANNUAL OPERATING COSTS

	Annual Cost (\$000)	Unit Cost	
		\$/lb	\$/ft ³
Utilities and Materials	20	0.016	0.115
Direct Labor at \$8 to \$10/hr	347	0.285	1.995
Payroll Benefits at 25% Labor	87	0.071	0.500
Maintenance at 3% Capital	63	0.052	0.362
Supplies at 1% Capital	21	0.017	0.121
Indirect Costs at 50% Labor, Maintenance and Supplies	215	0.176	1.236
Disposal Cost of Process Waste at \$8/ft ³	24	0.023	0.138
Operating Cost, Except Capital	777	0.640	4.47
Capital Cost at 12%	252	0.207	1.45
Total Operating Cost	1,029	0.847	5.92

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Operating costs of the treatment plant are listed in Table 16, and are expressed as annual costs, and unit costs/lb and/ft³ of waste processed. The utilities and materials costs of Table 16, and capitalization costs at 12%, are included. Labor requirements were estimated at 18 man-years, consisting of a shift supervisor and three operators for around-the-clock operation of the Molten Salt Combustion System, and 2 operators for day shift operation of the Aqueous Reprocessing System. A cost of \$8/ft³ of waste was included for disposal of the waste (i.e., ash, NaCl, metal parts and equipment, etc). The total annual costs are \$1,029,000, or 85¢/lb and \$5.92/ft³ of raw waste feed.

Estimates of the annual weight, volume, and cost benefits provided by the treatment plant were made, as a means of calculating its "system effectiveness." The results are outlined in Table 17, where annual quantities of these parameters are compared, with and without the molten salt waste treatment plant. Waste generated by the plant is presented separately, to show its influence on the overall benefits. The ultimate decommissioning and disposal of the treatment plant at the end of its useful life is not included in Table 17, but is discussed later in this section.

For this study, it was assumed that 20,000 lb/year (~200 ft³) of additional contaminated waste would be generated by operation and maintenance of the plant. Plant-generated waste is composed of plastic bags, prefilters and HEPA filters, and replaced parts and equipment, some of which can be processed through the treatment plant. This amount is equivalent to replacing ~10% of the equipment every year, and is considered conservative, in that the melt reprocessing equipment operates <30% of the time. At that rate, this equipment would be expected to have a very long replacement period.

This evaluation shows that installation of the treatment plant would result in an annual reduction of 80% in the weight, and 98% in the volume, of the waste for long-term disposal-storage. The waste generated by the plant itself has a very small impact on the weight and volume benefits.

The cost analysis was based on a long-term disposal-storage cost of \$8/ft³ of waste, and an operating cost of \$5.92/ft³ of waste processed by the plant.

TABLE 17
MOLTEN SALT WASTE TREATMENT SYSTEM EFFECTIVENESS

	Without Treatment Plant	With Treatment Plant	Δ	Effectiveness
<u>Weight (lb/year)</u>				
Raw Waste	1.21×10^6	0.21×10^6	-1.0×10^6	82% Reduction
Plant-Generated Waste	-	0.02×10^6	$+0.02 \times 10^6$	
Total	1.21×10^6	0.23×10^6	-0.98×10^6	80% Reduction
<u>Volume (ft³/year)</u>				
Raw Waste	1.73×10^5	0.030×10^5	-1.70×10^5	>98% Reduction
Plant-Generated Waste	-	0.002×10^5	$+0.002 \times 10^5$	
Total	1.73×10^5	0.032×10^5	-1.70×10^5	98% Reduction
<u>Cost (\$/year)</u>				
Raw Waste	1.39×10^6	1.054×10^6	-0.336×10^6	24% Reduction
Plant-Generated Waste	-	0.002×10^6	$+0.002 \times 10^6$	
Total	1.39×10^6	1.056×10^6	-0.334×10^6	24% Reduction

Therefore, the total annual disposal cost, without the treatment plant, is \$8/ft³ of raw waste. With a treatment plant, the annual cost is the sum of the operating cost of the plant (\$5.92/ft³) plus the disposal cost (\$8/ft³) associated with the process product (ash and sodium chloride) and the waste generated by the plant. As shown in Table 17, an annual savings of \$334,000 (24%) would be achieved by utilizing a molten salt treatment plant, based on a feed rate of 200 lb/hr.

Consideration was also given to the ultimate decontamination and decommission of the disposal plant at the end of its useful life. For this analysis, a conservative operating life of 10 years was assumed. The most effective

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Figure 9. Effect of Disposal Cost on Savings of a Molten Salt Process Plant for Treatment of Transuranic Waste

way of disposing of the equipment would be to break up and burn as much of the combustible material as possible (e. g., plastic piping, pumps, and equipment lining). Some equipment may be uncontaminated, and disposable by conventional means. The contaminated equipment would have to be packaged and stored, using methods consistent with the regulations in effect at the time.

The weight of the plant was estimated at 100 tons. With an assumed effective density of 100 lb/ft^3 , the quantity of material for ultimate disposal would be 2000 ft^3 . Decommissioning costs were assumed to be $\$1 \times 10^6$. Disposal would cost an additional \$16,000. Therefore, over the 10-year period, the net savings, including final disassembly and disposal, would be \$2,344,000.

The savings derived by the treatment plant are sensitive to the disposal cost. Figure 9 shows the effect of disposal cost on the annual savings and on the total savings for the assumed 10-year operating life and decommissioning cost. Some estimates of disposal cost in the immediate future are as high as $\$30/\text{ft}^3$, in which case, the annual savings would be about \$4,000,000 before decommissioning, and a total savings of about \$38,000,000 if the plant were decommissioned after 10 years.

These results show that the Molten Salt Combustion Process provides significant weight, volume, and cost benefits for the nonpolluting treatment of transuranic solid waste.

VII. RECOMMENDATIONS FOR FUTURE WORK

Further work is needful in two areas — plutonium behavior through the complete process cycle, and scale-up information for the combustion system. These two needs are discussed here.

The combustion of actual plutonium-contaminated waste is a part of the presently funded development program. A bench-scale combustor has been installed in Atomics International's Plutonium Facility to carry out these combustion tests, and results will be available shortly. Additional work, planned in the GFY 1976 program, is needed to determine how to minimize the actual plutonium content of the two waste products from the process — the ash and sodium chloride. Although the plutonium contamination of these wastes will be very low, from the monetary value point of view, the level of contamination will strongly affect the cost of their disposal. Therefore, the actual plutonium contamination of these wastes will be established, and procedures to decrease contamination to a value as low as practical will be investigated. Also the behavior of other transuranic elements (also GFY 1976 program) should be investigated, to assess the value of the process for their recovery.

An experiment in Atomics International's Molten Salt Combustion Pilot Plant is also a part of the presently funded development program. Uranium has been shown to be suitable as a stand-in for plutonium through the combustion step, so depleted uranium will be used in this test, to establish feed parameters, off-gas characteristics, etc. An assessment of plutonium carryover in the off-gas will also be obtained from this test. A feed rate of ~ 70 lb/hr (i. e. $\sim 1/3$ of the plant design) is anticipated in this test.

The results from the preceding investigations will provide the information and confidence needed to initiate design, procurement, and construction of the described 200 lb/hr plant.