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THE THERMALT PROCESS FOR
IMMOBILIZATION OF RADIOACTIVE WASTES

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INTRODUCTION

The ultimate disposition of the fission product wastes from plutonium production has been and yet remains a problem of primary importance. To uncover possible alternatives, the philosophy of the management of radioactive wastes was considered with particular attention to the logic involved in the practices used. This produced some guidelines or points perhaps best identified as lemmas that project new thinking in response to the problem of the ultimate disposition of radioactive waste. One outcome has been the innovation of a new process called Thermalt. Preliminary evidence indicates that this process provides a highly effective means of rendering Hanford wastes insoluble, nonvolatile and nondispersible thereby eliminating the dependency of their immobilization from the integrity of containers.

SUMMARY

The Thermalt process involves an exothermic, thermite-like reaction of aluminum metal with basalt, quartz sand and radioactive waste. The resulting melt when solidified is a silicious stone-like material that is similar in chemical composition to basalt. The process utilizes low cost ingredients: basalt rock, which occurs naturally in the Hanford region, inexpensive aluminum metal such as aluminum scrap which need not be pure, and the waste which is predominately sodium nitrate salt. The waste itself along with the basalt provides the oxygen necessary for the reaction. The exothermic reaction provides the necessary heat to melt the ingredients thus eliminating the need for external heat

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sources such as furnaces which are necessary with most other melt methods. The final product is highly stable and essentially nonleachable; leach rates appear as low or lower than other melt products described in the literature. Initial studies indicate the process is effective for both low-level and high-level wastes.

DISCUSSION

A. The Logic

Consideration of the steps to meet the requisites for ultimate storage of Hanford wastes lead to the following lemmas:

1. Radioactive wastes must be prevented from dispersion into the biosphere. The biosphere involves the atmosphere, the hydrosphere, and the upper level of the lithosphere. Although these zones are used for storage for limited time periods, they are not considered as satisfactory for ultimate storage of radionuclides because of the potential for accidental or malicious release.
2. Radionuclides are processed and used in the biosphere with safety. This safety is provided in part by adequate monitoring, shielding, isolation, precautions against accidental release, and by confinement and transport in suitable containers of high integrity.
3. All containers no matter how complex have a finite life which is small compared to the half-life of plutonium (24,400 years). For maximum safety of future generations of humans and other life forms, immobilization during decay of the radionuclides and

ultimate storage should be independent of the integrity of the container walls.

4. That portion of the lithosphere out of contact with ecosystems is the best suited zone of the earth for the long-term storage of radioactive wastes during their decay. Such zones may be in arid terranes, deep underground salt deposits or dense lava flows deep underground.
5. During ultimate storage, assurance of the prevention of release of radionuclides to the atmosphere is possible if the wastes are stored in nonvolatile, nondispersible form. Volatile radionuclides, such as cesium and ruthenium, should be rendered nonvolatile and nondispersible. Gaseous fission products, such as tritium and the noble gas radionuclides, may require separate consideration. Preliminary inspection indicates that noble gas radionuclides may be stored in complex silicate zeolites as clathrates.
6. Assurance of the prevention of release of radionuclides to the upper hydrosphere during ultimate storage is possible if the wastes are stored in an insoluble and nondispersible form. Assurance against release to the atmosphere and upper hydrosphere and storage at an adequate depth below the upper lithosphere removes radionuclide wastes from the biosphere. Storage in an insoluble, nonvolatile, nondispersible form eliminates the dependency on the integrity of containers.

7. The radionuclide cations, in particular Cs^+ , Sr^{++} , Pu^{++++} , plus others, constitute the major portion of the radioactivity in stored wastes. Immobilization of the cations is of primary importance in considering ultimate disposal of radioactive wastes.
8. All cations in periodic Group II through VIII, inclusive, form insoluble silicates and insoluble complex silicates. Group I cations form insoluble complex alumino-silicates and, in the case of cesium, an insoluble complex iron silicate. Conversion of all radionuclide cations from soluble salts, such as nitrates, to highly insoluble complex silicates, storage of these insoluble complex silicates at a suitable depth in the lithosphere, preferably in an equilibrated silicate environment such as deep basalt, provide one means of fulfilling the criteria above.
9. The properties of basalt rock include high pH connate water, secondary mineralization (low permeability clay minerals) along joints and in fractures, and impermeable discontinuities wherever fractures have resulted from tectonic activity including folding and faulting. Thus, basalt has self-sealing features which may be augmented by chemical injections.

Considerations based on the philosophy of the points enumerated above lead to the preliminary study of three new alternatives for the ultimate disposition of Hanford wastes. Two of the concepts involve conversion of soluble nitrate salts to insoluble complex silicates,

in one case by a hydrothermal process as discussed in "A STOPPER for Radioactive Wastes" (ARH-1658 and ARH-IR-168), and in the other case by an exothermic reaction producing a silicate melt (ARH-IR-173) and discussed in this document. The third concept "Phaser" (unpublished report by L. E. Brownell, January 1971), involves a process which could be utilized for removing sodium from the stored waste thereby reducing the volume of waste requiring ultimate storage.

The Thermalt reaction differs from most exothermic reactions in that it involves basalt. It differs markedly from other melt techniques used for waste in that no external heat source is required and also in that the time for conversion may be controlled and can be reduced to a very short period. Based on preliminary evidence, the Thermalt process appears most promising as a means to immobilize radioactive wastes.

B. Preliminary Tests of Thermalt Process

Three key ingredients have been used in preliminary testing. These are: (1) simulated waste (primarily as nitrate and carbonate salts); (2) "therm", the fuel as powdered aluminum metal, and (3) "alt", a mixture (about 50-50) of pulverized basalt and quartz sand. Each component has a specific function in the Thermalt reaction. The driving force and source of heat for the reaction is derived from the oxidation of the metallic solids in the "therm" fraction. Table I from the Kirk-Othmer Encyclopedia of Chemical Technology, lists the heats of combustion for selected metallic solids.

TABLE IHEATS OF COMBUSTION OF SELECTED METALLIC SOLIDS

<u>Material</u>	<u>Heat of Combustion</u>		<u>Material</u>	<u>Heat of Combustion</u>	
	<u>Cal/cu.cm</u>	<u>Cal/gram</u>		<u>Cal/cu.cm</u>	<u>Cal/gram</u>
Boron	38,300	16,300	Zirconium	18,100	2,800
Beryllium	26,000	15,000	Silicon	14,400	7,200
Titanium	20,500	4,600	Zinc	10,800	1,500
Aluminum	18,900	7,000	Magnesium	10,400	6,000

As listed in Table I, the elements boron, beryllium, aluminum, and silicon have the greatest heating values in calories per gram. Beryllium is toxic and elemental boron, titanium and silicon are significantly more costly. This leaves aluminum as the most practical metal for use in the Thermalt reaction. The oxidation of aluminum requires a high ignition temperature of 1300 °C or more. Magnesium metal has a slightly lower heat of combustion than aluminum metal but can be ignited more easily and continues oxidizing in a limited supply of oxygen with a temperature sufficient to give point reignition to aluminum metal. Magnesium metal turnings were used in early Thermalt formulations for this purpose and to give continuity in the burning of the Thermalt premix.

The oxidation of the aluminum metal used as fuel in the Thermalt reaction results in the production of a large amount of heat which varies depending upon the oxidizing agent used. During initial experiments, a metal oxide was added as an oxidizing agent for the aluminum metal. Table II (also from the Kirk-Othmer Encyclopedia) lists the heat of reaction of aluminum and various oxidizing agents.

TABLE II
HEATS OF REACTION OF ALUMINUM
AND VARIOUS OXIDIZING AGENTS

<u>Material</u>	<u>Heats of Reaction</u>	
	<u>Cal/cu.cm of solid</u>	<u>Cal/gram</u>
Al + O ₂ (air)	18,900	7,000
Al + KClO ₄	6,100	2,400
Al + KNO ₃	4,000	1,800
Al + Fe ₃ O ₄	3,400	800

The reaction between aluminum and iron oxide at the bottom of Table II is the classic "thermite" reaction that has been used for many years for welding steel. The aluminum metal reduces the iron oxide to molten iron. Other metal oxides may be used for recovery of these metals. Table III lists a number of exothermic reactions between aluminum and metal oxides.

TABLE III
EXOTHERMIC REACTIONS BETWEEN ALUMINUM
AND METAL OXIDES

<u>Reaction</u>					<u>Theoretical Temperature</u>
3Fe ₃ O ₄	+	8Al	→	9Fe + 4Al ₂ O ₃	3090 °C
3FeO	+	2Al	→	3Fe + Al ₂ O ₃	2500 °C
Fe ₂ O ₃	+	2Al	→	2Fe + Al ₂ O ₃	3070 °C
3CuO	+	2Al	→	3Cu + Al ₂ O ₃	4870 °C
3Cu ₂ O	+	2Al	→	6Cu + Al ₂ O ₃	3140 °C
3NiO	+	2Al	→	3Ni + Al ₂ O ₃	3170 °C
Cr ₂ O ₃	+	2Al	→	2Cr + Al ₂ O ₃	2980 °C
3MnO ₂	+	2Al	→	3Mn + Al ₂ O ₃	1870 °C
3MnO ₂	+	4Al	→	3Mn + 2Al ₂ O ₃	4990 °C

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The reactions listed in Table ~~III~~ are all nonexplosive and regardless of size of the reacting mass normally require less than one minute for the reaction to be completed. However, the rate may be controlled to much slower values. No fire hazard is involved with the materials listed in Table ~~III~~ since an ignition temperature for these reactions in excess of 1480 °C is required to start the reaction. Special ignition powder is used on top of the thermite charge that can be ignited with a hot wire, a piece of magnesium ribbon or a spark. Some commercial ignition powders can be ignited with a match. An example is barium dioxide and aluminum powder which has been used successfully for ignition in the Hanford field tests with Thermalt.

The thermite reactions were used as a point of beginning in the Thermalt tests at Hanford. Thermalt mix Number 1 consisted of thermite made from chemical grades of aluminum powder and ferric oxide (Fe_2O_3) diluted with 10 percent basalt and fortified with 10 percent manganese dioxide thermite (see Table III). The reaction produced a porous lava-like silicate product plus a slug of metal. In Thermalt Number 2 the oxidizer was changed from ferric oxide to manganese dioxide with the objective of increasing the temperature and thereby permitting better gas removal and producing a denser product. This change was incorrect as the manganese dioxide decomposed below the burning front with excessive gassing. The released oxygen lifted the burning zone as a fluidized bed that rose 15 to 20 feet in the air above the charge. The charge consisted of two pounds aluminum powder, 4.4 pounds manganese dioxide, and 2.4 pounds basalt.

Better results were obtained in Thermalt tests Numbers 3 through 9. The products in these tests had greater density, the reaction rates were decreased, and the percent of simulated waste was increased; in some cases the Fe_2O_3 was omitted and the simulated waste was the principle source of oxygen. For example in Thermalt test Number 9 the burn lasted for over 20 minutes and the product had a high density. The charge consisted of 26 percent simulated waste, 20 percent therm (17.5 percent aluminum, 2.5 percent magnesium) and 54 percent alt (30 percent basalt and 24 percent silica sand). The simulated waste contained 270 grams of NaNO_3 , 130 grams of Na_2CO_3 , 5 grams each of Cs_2CO_3 , $\text{Ce}(\text{NO}_3)_3$, $\text{Sr}(\text{NO}_3)_2$ and $\text{Zr}(\text{NO}_3)_4$ plus 210 grams of SiO_2 (as simulated inerts). Thermalt Number 16 was formulated to contain a very high percentage of cesium in the waste portion. This charge consisted of 24 percent waste (22 percent CsNO_3 and 2 percent as KNO_3 and NaNO_3), 16 percent therm (15 percent aluminum, 1 percent magnesium), 46 percent alt (23 percent basalt, 23 percent silica sand), and 14 percent CuO as an additional oxidizer.

Thermite tests 11, 12, and 13 were each premixed into three layers. The top layer was formulated to be a gentle Thermalt reaction which covers the main charge containing the radioactive waste (layer two). The first, or top layer melts first and the molten liquid acts, it is believed, as a physical barrier to escape of cesium or other volatile radionuclides. The second layer, containing the highest concentration of radionuclides, was formulated to be a slightly hotter reaction than the first layer. The third layer is the finishing layer and is the hottest of the three layers to insure a complete, sustained melt, of the final portion of the charge. The formulations used for Thermalt 13 are shown in Table IV.

TABLE IV
FORMULATION OF THERMALT 13 PREMIX

	<u>Layer 1</u> <u>(grams)</u>	<u>Layer 2</u> <u>(grams)</u>	<u>Layer 3</u> <u>(grams)</u>	<u>Total</u>
NaNO ₃	720	860	360	1940
Na ₂ CO ₃	360	430	180	610 970
Sand	2140	2500	1270	5910
Al	660	850	600	2110
Mg	80	90	60	230
Basalt	1860	2000	1420	5280
T. Salts*	-	500	-	500
CuO	<u>-</u>	<u>-</u>	<u>750</u>	<u>750</u>
Total	5820	7230	4640	17690

*Trace Salts

100 Na₂Cr₂O₄
 100 Cs₂CO₃
 100 Zr(NO₃)₄
 100 Sr(NO₃)₂
 100 Co(NO₃)₂ · 6H₂O

An original feature of the Thermalt process is the use of basalt in the reaction. Basalt contains a significant amount of iron in the oxidized state and in combination with silica. Although there is considerable range in analyses, a typical basalt in the Hanford area may contain 50 percent silica and 14 percent iron as FeO. The heats of formation of all iron oxides FeO, Fe₂O₃ are less than that of Al₂O₃. If the amount of oxygen from salt cake oxidizers is not sufficient for oxidation of the metallic aluminum used in the Thermalt premix, the aluminum will obtain oxygen from the iron oxides present

in basalt. Thermalt burn Number 6 demonstrated this feature. Premix Number 6 contained no iron compounds other than those present in the basalt. The metal fuel in the therm fraction contained 164.5 grams of aluminum powder and 8 grams of magnesium turnings. The oxidizer was cupric oxide CuO of which 220.7 grams were used. Supplemented oxygen was provided by 55.2 grams of MnO_2 , 14.6 grams of KNO_3 , 7.3 grams of Na_2CO_3 and 2 grams each of Cs_2CO_3 , $\text{Ce}(\text{NO}_3)_3$, $\text{Zr}(\text{NO}_3)_4$ and $\text{Sr}(\text{NO}_3)_2$. The alt fraction of the premix contained 264.4 grams of powdered basalt and 166.5 grams of silica sand. This produced a premix of about 2 pounds considered to be about 5 percent simulated waste, 40 percent therm, 55 percent alt. The mix was reacted in a graphite crucible to prevent contamination. The product from burn Number 6 was a dense silicate with little sign of residual gassing. The crucible contained a metal slug at the bottom.

The metal slug from Thermalt Number 6 was analyzed by atomic absorption. The results are given below:

TABLE V
METAL PHASE FROM THERMALT NUMBER 6

<u>Metal</u>	<u>Weight Percent</u>
Copper	60.4
Iron	10.1
Manganese	9.1
Aluminum	4.6
Silicon	3.4

Note: It was necessary to use HF to complete the above metal dissolution. Some silicon was probably lost as volatile SiF_4 .

The analysis shows 10.1 percent iron. This iron could only have resulted from an exothermic reaction involving basalt. Thus, the Thermalt reaction between basalt and the reduction metals aluminum and magnesium has been demonstrated. The process has been reduced to practice on a laboratory scale using simulated In-Tank Solidified (ITS) salt cake.

Thermalt products from tests 7, 9, 10, 11, 12, 13 and 16 have been subjected to several laboratory experiments to help establish product composition, crystallinity, and the effectiveness in containment of the radionuclides.

Product compositions were determined of portions of the solidified melts resulting from ignition of the Thermalt mixtures. The compositions were determined by fusion of the product with lithium metaborate, dissolution of the fusion in dilute hydrochloric acid and subsequent analysis by atomic absorption. These data are shown in Table VI. The composition of a typical Hanford basalt also is shown in Table VI for comparison.

TABLE VI
ANALYSIS OF THERMALT PRODUCT

	Hanford Basalt A-1009	No 7 Wt. %	No. 9 Wt. %	No. 10 Wt. %	No. 11 Wt. %	No. 12 Wt. %	No. 13 Wt. %	No. 16 Wt. %
SiO ₂	51.0	48.0	53.0	53.5	54.0	55.0	53.0	56.0
Fe ₂ O ₃	13.0	11.2	11.0	3.0	5.7	2.4	4.4	1.2
Al ₂ O ₃	12.1	34.8	15.0	34.0	23.6	26.3	24.0	27.2
Na ₂ O	2.4	3.14	2.67	9.1	8.4	8.4	8.0	2.0
K ₂ O	1.16	0.54	0.1	0.1	3.8	1.5	0.80	1.4
CaO	8.8	2.15	10.3	2.1	2.4	1.3	1.9	1.9
MgO	4.6	3.16	6.3	5.7	3.2	2.4	4.5	3.8
SrO	0.031	0.063	0.019	0.13	0.56	0.57	0.26	0.06
Cs ₂ O	-	0.13	<.02	0.12	0.72	1.5	0.39	8.1

Thermalt Number 7 was a gray dense product showing some crystallinity as verified by X-ray diffraction data. Thermalt Number 9 was very dense and glassy appearing. It was remelted in a furnace to increase the density. Thermalts Number 10 and 12 were dense and glassy. Thermalts Number 11 and 13 were slightly porous products showing considerable crystallinity.

To explore the leach rate, the Thermalt products were crushed and wet screened to retain particles between 250 and 420 microns. The total surface areas of the particles were determined and the particles were leached with deionized water during agitation. Leach solutions were filtered and examined for the various trace metals by atomic absorption. The preliminary measurements on leach rates are listed in Table VII. The values are less than leach rates reported for other immobilized mixed radionuclide solid by an order of magnitude.

TABLE VII

LEACH RATES

	<u>Bulk Rate*</u> <u>Gm/cm²/day</u>	<u>Cesium</u> <u>Gm/cm²/day</u>	<u>Strontium</u> <u>Gm/cm²/day</u>
Thermalt No. 7	1.6×10^{-7}	5.2×10^{-9}	$<3.8 \times 10^{-9}$
Thermalt No. 9	1.4×10^{-7}	$<3.6 \times 10^{-9}$	$<3.6 \times 10^{-9}$
Thermalt No. 10	1.4×10^{-7}	$<4.2 \times 10^{-9}$	$<4.2 \times 10^{-9}$
Thermalt No. 11	1.4×10^{-7}	$<2.3 \times 10^{-9}$	$<2.3 \times 10^{-9}$
Thermalt No. 12	1.7×10^{-7}	$<4.3 \times 10^{-9}$	$<4.3 \times 10^{-9}$
Thermalt No. 13	2.0×10^{-7}	$<5.2 \times 10^{-9}$	$<3.9 \times 10^{-9}$
Thermalt No. 16	1.2×10^{-6}	8.7×10^{-7}	-

*From total grams of all elements found in leach solution

Several other analytical studies are planned on the Thermalt products and include the determination of proper reaction mixtures for optimum product quality; a detailed off-gas study to determine the amounts and methods for containment of radioactive off gases; studies on thermal stability, heat capacity, density, and thermal conductivity of the products. Other near future work includes laboratory-scale hot cell demonstrations using actual candidate wastes and subsequent evaluation of the melts.

C. Suggested Application of Thermalt Process to Hanford Wastes

1. Processing of Wastes in Contaminated Cribs

The Hanford 200 Area contains a number of "crib" sites into which solutions of radionuclides were discharged during the early days of plutonium production. The contaminated soil in crib sites involves millions of cubic yards of material. The cost of removing,

loading and interstate shipping of such a large quantity of contaminated material in heavily shielded containers will be large and involve some hazards during transit. One alternate procedure considered to involve less hazard, less time and less cost is the Thermalt conversion of such waste material to insoluble, nonvolatile and nondispersible solids. The final solid product could be in the form of a large number of silicate blocks of regular geometry to permit easy handling, stacking, transport and burial. With the high degree of immobilization possible in this process the use of containers is believed to be unnecessary except for interstate shipments. One or a few large monolithic silicate blocks are an alternate form possible if these immobilized Thermalt products were stored on the Hanford site. The storage might be in the vadose zone of an arid terrane at a depth sufficient to assure essential decay before any reasonable postulated event could cause the material to reach the active environment. A third alternate would be the storage of the Thermalt either as blocks or as large monolithic casts in an underground basalt cavern.

The formulation of batch Thermalt premixes with controlled rates of burning has involved the use of about 1/3 silica sand and 1/3 crushed basalt in the premix. The sand and gravel in the crib sites are of glaciofluvial origin and are composed of sand and basalt gravel. As a result, it is possible that crib waste might be used as about 60 percent of the Thermalt mix. The balance would involve about 12

percent aluminum scrap plus a source of oxygen such as sodium nitrate or salt cake from the ITS operation. If cesium contamination is small, lime as CaCO_3 may be substituted as an oxygen source for a portion of the sodium nitrate. Field tests will involve the following:

- a. adaptation of Thermalt formulation to use of sand and gravel of typical crib;
- b. demonstration of immobilization of larger batches, perhaps as large as 10 cubic yards of soil, in one operation; and,
- c. study of physical and chemical characteristics of Thermalt products such as density, strength, coefficient of thermalt expansion, melting point, solubility, crystallinity, thermalt conductivity, etc.

2. Immobilization of Plutonium in Contaminated Soil Waste

A major problem yet to be resolved is that of immobilization of unrecoverable plutonium in crib soil and other dry wastes burial grounds. Plutonium silicate (PuSiO_4) is isostructural with the mineral zircon (ZrSiO_4). Silicates of this type can be formed hydrothermally for the nuclides Pa, Np, Pu, Am, Th and U from the reaction at elevated pressure and temperature between the hydroxides and silica gel. Good yields of the green PuSiO_4 crystals are obtained by hydrothermal reaction at 500 °C.

According to Keller* no reaction occurs between PuO_2 and SiO_2 nor between UO_2 and SiO_2 in a dry heat in the temperature range between 800 °C and 1600 °C. Thus if conversion of PuO_2 to PuSiO_4 is desired a hydrothermal aftertreatment of the Thermalt product may be required. On the other hand, molten basalt is itself a solution of fused oxides, hence plutonium oxide may be adequately immobilized in Thermalt without hydrothermal processing. Tests required to explore these considerations will include:

- a. laboratory preparation of Thermalt melts with PuO_2 included in the premix;
- b. determination of the degree of immobilization of plutonium in Thermalt; and,
- c. evaluation of hydrothermal processing of Thermalt product containing plutonium contamination.

3. Conversion of Salt Cake to Thermalt

The bulk of the Hanford radioactive chemical wastes are stored in the underground tanks in the 200 Area tank farms. These wastes are being converted from aqueous alkaline nitrate slurries to salt cake by

*Keller, C., "Investigations of Type ABO_4 Germanates and Silicates of Tetravalent Elements Thorium to Americium," Nukleonik 5, No. 2, p. 41-48, 1963.

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evaporating the water using "In-Tank Solidification" (ITS)* methods. The ITS salt cake is soluble, dispersible and certain radionuclides will volatilize at elevated temperatures, thus these wastes are candidates for possible immobilization by the Thermalt Process.

Solids resulting from pot or spray calcination of Purex process high level liquid waste are also potential candidate feeds for some of the permanent disposal concepts considered here. Commercial reprocessing plants will likely produce substantial amounts of such solid radioactive wastes in future years. Only limited studies of the applicability of the high temperature disposal processes to calcined Purex waste are anticipated in the Hanford program. For such studies the synthetic calcine used will be simulated Purex process waste.

Some of the questions to be resolved are:

- a. solution to problems of extreme temperature (measured at values as high as 2300 °C);
- b. size and configuration of large batch operation;
- c. comparison of batch versus continuous procedures and selection of most feasible;
- d. demonstration of pilot operation of conversion of ITS solids to Thermalt; and,
- e. Handling of process gases.

*Godfrey, W. L., and P. W. Smith, "Evaluation and Status of In-Tank Solidification," ARH-905, November 1, 1968.

4. Immobilization of Buried Solid Waste

Miscellaneous solids contaminated with radionuclides have been handled at the Hanford site since the early days of operation. Procedures have involved storage in burial gardens. The nature of the wastes have ranged widely and include combustibles such as rubber and cellulosic products, broken pieces of ceramic, glass and concrete plus various metal wastes. The nature of contamination has varied from short half-lived fission products to plutonium. High-level activity from fresh fission-product waste has decayed to very low levels in much of the buried waste reducing the problem of radiation shielding. However, residual amounts of longer-lived fission products such as strontium and cesium and contamination with plutonium necessitates continued surveillance and monitoring of these burial sites. Burial under soil has resulted in some contamination of soil in contact with buried waste.

Restoration of these burial gardens will require the immobilization of radionuclides in both the solid wastes and the contaminated soil. If these wastes are to be removed, consolidation of the random waste into compact, insoluble, nonvolatile and nondispersible solids with suitable shape for handling, shipping and storage is essential. The Thermalt process offers a possible solution to this need.

Application to wastes in the burial gardens might involve the following operations:

- a. oxidation of residual combustibles in recovered waste by incineration to produce a contaminated ash as a product;
- b. reaction in a Continuous Thermalt Furnace of contaminated ash and contaminated soil to immobilize radionuclides in these wastes; and,
- c. addition of metal wastes to Thermalt melt to evaluate transfer of surface contamination to Thermalt with release of decontaminated metal scrap to the base of the liquid separator.

5. Development of Continuous Processes

The use of the Thermalt process to immobilize recovered solid wastes as proposed above necessitates the use of a Continuous Thermalt Furnace. This equipment presently exists in concept only, as all Thermalt tests to date have been conducted using a batch process. The following phases are considered important to recovery and immobilization of buried solid wastes by the Thermalt process.

- a. development of Continuous Thermalt Furnace;
- b. combination of radionuclide incinerator with continuous furnace;
- c. combination of continuous furnace with metal melt furnace;
- d. demonstration of 3 stage process with typical waste; and,
- e. production of Thermalt blocks and metal slugs.