SOLIDIFICATION OF HAZARDOUS AND MIXED RADIOACTIVE WASTE AT THE IDAHO NATIONAL ENGINEERING LABORATORY[a]

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ABSTRACT

EG&G Idaho has initiated a program to develop treatment options for the hazardous and mixed wastes generated at the Idaho National Engineering Laboratory (INEL). This program includes development of solidification methods for some of these wastes. Testing has shown that toxic wastes can be successfully solidified using cement, cement-silicate, or ENVIROSTONE binders to produce nontoxic stable waste forms for safe, long term disposal. This paper presents the results of the solidification development program conducted at the INEL by EG&G Idaho.

INTRODUCTION

In response to the need for disposal methods for hazardous and mixed waste, EG&G Idaho has initiated a program to investigate the following: hazardous and mixed wastes at the INEL that are candidates for solidification; treatment options available for each waste; available commercial solidification methods and their applicability to INEL wastes; lab-scale testing of solidification methods for development of waste formulas (binder-to-waste ratios); and testing of solidified samples to verify that they meet EPA toxicity criteria.

An inventory of hazardous and mixed wastes generated at the INEL identified the amounts of waste stored and awaiting disposal, annual generation rates, storage location/generating facility, hazardous constituents, and contamination levels. The identified wastes are considered hazardous because of their ignitable, corrosive, reactive, or toxic characteristics, or because they are an EPA listed waste. The major hazardous constituents of the toxic wastes have been determined to be cadmium, chromium, lead, and mercury.

Investigation of available commercial solidification systems has included literature review, contacting various companies involved in waste solidification, visiting operating waste solidification facilities, and performing comparative evaluations of the various systems and their applicability to INEL wastes.

Using lab-scale solidification methods and actual or representative waste samples, binder-to-waste ratios for optimization of set time, minimal volume increase, monolith characteristics, and leachability were developed. The solidified samples were subjected to EP toxicity testing to verify that they meet toxicity criteria. This paper presents the results of the solidification program development conducted at the INEL by EG&G Idaho.

WASTE CHARACTERIZATION

The initial phase of the solidification program was to determine waste volumes and characterize identified waste.

An inventory of hazardous and mixed wastes generated at the INEL was prepared and used as a basis for waste characterization. The inventory included amounts of the waste stored and awaiting disposal, annual generation rates, the basis for the hazardous listing, and the storage location and/or generating facility.

An investigation of the characteristics of each waste was initiated. This entailed performing a waste analysis or documenting analyses already completed for each waste, defining the waste stream, verification of the data in the inventory listing, refining volume estimates, eliminating one-time wastes that have already been dispositioned, and adding other waste streams and their characteristics as they were identified. Analysis performed to determine waste characteristics included radiological analysis, and evaluation of the waste using EPA procedures for determination of its hazardous constituents. The results of this investigation are contained in Table I.

The treatment options considered are not normally influenced by the radioactivity of the waste. Chemical analyses will be performed on both hazardous and mixed waste when the chemistry of the waste is unknown or the chemistry will affect the solidification formula. Radiological analyses will be used to establish handling limitations during the processing of mixed waste.

The chemical characteristics of concern in the wastes include; ignitability, corrosivity, reactivity, and toxicity. The ignitability of a material is established by the Penske-Martens Closed Cup Tester, but a complete chemical analysis will be performed on organic chemical wastes to identify constituents and help determine if a Penske-Martens should be performed.

Corrosivity is an indication of the acidity or alkalinity of a waste and is routinely established by simple pH measurement techniques.

Reactive wastes are those which tend to react spontaneously, to react vigorously with air or water, to be unstable to shock or heat, to generate toxic gases or to explode. These wastes should be identified as such by the generator, and will be treated separately.

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TABLE I

Waste Treatment Analysis and Options Evaluation

Description of Waste	Chemical and Radiological Composition	Quantity Generated Annually	Basis for Hazard Listing	Waste Location and Contact	Processing Location	Is Further Analysis Required	Treatment Options
Hazardous Waste							
HW-1. Spent solvent from degreasing	Stoddard solvent	860 gal	Ignitable	CFA	Off site	--[a]	Recycling
HW-2. Degreasing sludge	1, 1, 1-Trichloroethane	500 gal	Toxic	CFA	On site	--[a]	Incineration
HW-3. Paint shop wastes(thinners, strippers and paint solids)	Mineral spirits, xylene, toluene, acetone	440 gal	Ignitable Toxic	Various	On site	--[a]	Incineration
HW-4. De-inking solvent/sludge	Tetrachloroethylene, petroleum naptha	15-20 gal	Ignitable Toxic	WCB	On site	--[a]	Incineration
HW-5. Hydrazine solution	Hydrazine	30 gal[b]	Corrosive	LOFT	Off site	--[c]	Waste has been dispositioned
HW-6. Gadolinium nitrate solution	60% gadolinium nitrate	150 gal[b]	Ignitable	PBF	Off site	--[c]	Waste has been dispositioned
HW-7. Miscellaneous	Ignitable	650 gal	Ignitable	Various	Undecided	--[d]	Incineration
HW-8. Miscellaneous	Corrosive	425 gal	Corrosive	Various	Undecided	--[d]	Neutralization
HW-9. Mixed organic waste generated from fuel processing pilot plant	Solvents with cadmium	200 gal	Ignitable	CPP	On site	--[a]	Incineration
HW-10. Corrosive wastes generated from fuel processing plant	Acids, including hydrofluoric, nitric, hydrochloric, and traces of sulfuric	5,500 gal	Corrosive	CPP	Undecided	--[e]	Neutralization
HW-11. Fluorinel pilot plant waste	Cadmium, chromium, mercury	275 gal	Corrosive EP Toxic	CPP	Undecided	--[e]	Neutralization Solidification
HW-12. Photographic wastes from chemical analyses	Silver compounds	934 gal	Corrosive	NRF	On site	--[f]	Solidification
HW-13. Silver nitratefrom chemical analyses	Silver nitrate	700 gal	EP Toxic	NRF	On site	--[f]	Solidification
HW-14. Mercuric nitrate from chemical analyses	Mercuric nitrate	770 gal	EP Toxic	NRF	On site	--[f]	Solidification
HW-15. Potassium chromate as corrosion inhibitor in process water	Potassium chromate	1240 gal	EP Toxic	NRF	On site	--[g]	Solidification
HW-16. Phosphoric acid from chemical lab	Phosphoric acid	1240 gal	Corrosive	NRF	Off site	--[a]	Neutralization
HW-17. Sulfuric acid spill residues	Sulfuric acid	1240 gal	Corrosive	NRF	Off site	--[a]	Neutralization
HW-18. Sodium hydroxide from lab operations	Sodium hydroxide	1240 gal	Corrosive	NRF	Off site	--[a]	Neutralization
HW-19. Ammonium hydroxide from lab operations	Ammonium hydroxide	55 gal	Corrosive	NRF	Off site	--[a]	Neutralization
HW-20. Mixed formaldehyde and mercuric nitrate from chemical analysis	Formaldehyde, mercuric nitrate	110 gal[b]	EP Toxic Ignitable	NRF	On site	--[f]	Solidification Incineration
HW-21. Formaldehyde from chemical analysis	Formaldehyde	495 gal	Ignitable	NRF	On site	--[a]	Incineration
HW-22. Paint thinners from paint shop	Stoddard solvent; Amercoat -12 (acetone, xytol); lacquer thinner (toluol, ketones, alcohol); petroleum, distillates and paint thinner--UN-1255	550 gal	Ignitable	NRF	Off site On site	--[a] --[a]	Recycling Incineration
HW-23. Laboratory packs	Varies	605 gal	Varies	NRF	Undecided	--[d]	Undecided

TABLE I (continued)

Description of Waste	Chemical and Radiological Composition	Quantity Generated Annually	Basis for Hazard Listing	Waste Location and Contact	Processing Location	Is Further Analysis Required	Treatment Options
HW-24. Sulfuric acid	Sulfuric acid	<55 gal	Corrosive	NRF	Off site	--[a]	Neutralization
HW-25. Potassium hydroxide	Potassium hydroxide	<55 gal	Corrosive	NRF	Off site	--[a]	Neutralization
HW-26. Solvent cleaning	Trichloroethylene	200 gal	Toxic	NRF	Off site On site	--[a] --[a]	Recycling Incineration
HW-27. Degreasing of reactor components	Acetone	5 gal/ 4 years	Ignitable	NRF	On site	--[a]	Incineration
HW-28. Paint stripping	Methylene chloride	Irregular	Toxic	NRF	On site	--[a]	Incineration
HW-29. Laboratory packs	Organic solvents, acids, caustics, heavy metal solutions	4-55 gal	Varies	NRF	Undecided	--[d]	Undecided
HW-30. Simulated calcine from pilot plant operation	Cadmium-contaminated calcine (inert organic)	60-15 gal[b] drums	EP Toxic	CPP Gary Simpson	On site	NO,[h]	Disposition by CPP
HW-31. Lead shop waste	Lead dross and dust	500 lb	EP Toxic	CFA Ruel Dye	On site Off site	--[g] NO	Solidification Recycling
Radioactive Mixed Waste							
RMW-1. PCB oil (V-2 oil)	680 ppm PCB, contaminated oils, 90 mRem/hr beta-gamma near contact, uranium 0.65 mg/L, TRU 0.12 nCi/g	60 gal[b]	TSCA regulated	TAN-647 Dick Meservey	On site	NO	Incineration
RMW-2. Flyash	Cd, Cr, Pb, low-level radioactivity	5 drums[b] 8 drums	EP Toxic Toxic	WERF Dan Bartel	On site	NO,g	Solidification
RMW-3. Mercury-contaminated pipe	Mercury, low-level radioactivity	420 lb[b]	EP Toxic	TAN-IET Wyndell Banister	On site	NO	Undecided
RMW-4. Mercury	Mercury, Cs-137 2 mRem/hr	1 liter[b]	EP Toxic	TAN/Hot Cells Garry Fife	On site	NO	Recycling Solidification
RMW-5. Paint and rags	Lead-based paint, solvent on rags, low-level radioactivity	1 drum[b]	Ignitable EP Toxic	ANL-W Mike Holzemer	On site	NO	Incineration
RMW-6. Paint stripper and rags	Methylene chloride, paint, rags, low-level radioactivity	2 drums[b]	Toxic	ANL-W Mike Holzemer	On site	NO	Incineration
RMW-7. Combustible wastes	Paper, sample bottles, gloves, etc., low uranium and cadmium	25-30 drums[b] 50 bags	EP Toxic	CPP Bob Nebeker	On site	--[a]	Incineration
RMW-8. PCB dirt	15 ppm PCB, Cs-137 187 counts/min	10 drums	TSCA regulated	CPP Susan Cooper	Off site	--[c]	Waste has been dispositioned
RMW-9. Silver zeolite	Silver, zeolite, variable radioactivity	3,600 lb 1,200 lb 1,500 lb	EP Toxic	TAN/TSF-Armel Cates TRA-Derrill Sparks PBF-Fred Stoll	On site	NO	Recycling Solidification
RMW-10. Miscellaneous lab wastes	Water, organics (30%), heavy metals, variable radioactivity	10 gal	EP Toxic	TRA Janine Jessup	On site	--[a]	Incineration Solidification
RMW-11. Organic radiological leaching solutions from labs	CCl_4, Hexane, Cr, Pb, low-level radioactivity	3 gal[b]	Ignitable EP Toxic	TRA Janine Jessup	On site	--[a]	Incineration
RMW-12. Potassium chromate	Potassium chromate, low-level radioactivity	500 mL	EP Toxic	NRF Lucy Schweiss	On site	NO,g	Solidification
RMW-13. Silver nitrate	Silver nitrate	1 liter	EP Toxic	NRF Lucy Schweiss	On site	NO	Solidification
RMW-14. Freon decontamination still bottoms and disposable filters	Freon, metals, intermediate radioactivity	2 drums	Toxic EP Toxic	TRA-Tolan Whitlock WERF-Dan Bartel	On site	--[a]	Solidification
RMW-15. Lab wastes	Water, acids, heavy metals with variable radioactivity	120 gal	Corrosive EP Toxic	TRA Janine Jessup	On site	--[a]	Neutralization Solidification
RMW-16. Scintillation fluids	Xylene, C-14, H-3, (minor amounts of Ni-63, Fe-55, Fe-59), <0.25 nCi/mL	14 gal[b] 1 gal	Ignitable	CPP/ILF Caroline Filby	On site	NO	Incineration

TABLE I (continued)

Description of Waste	Chemical and Radiological Composition	Quantity Generated Annually	Basis for Hazard Listing	Waste Location and Contact	Processing Location	Is Further Analysis Required	Treatment Options
RMW-17. Scintillation fluids	Xylene, toluene, C-14, H-3	18 gal[b] 3 gal	Ignitable	TRA Janine Jessup	On site	NO	Incineration
RMW-18. Ion exchange resins	Potassium chromate on IE resins, low-level radioactivity	200 gal[h]	EP Toxic	Various	On site	--[a]	Solidification
RMW-19. IET waste	Mercury, radioactivity	100 gal sludge plus pipe[b]	EP Toxic	IET Wyndell Banister	On site	--[j]	Solidification
RMW-20. Shield tank water	2500 ppm Cr, Cr-51 1×10^{-4} μCi/mL	18,000 gal[b]	EP Toxic	LOFT Bob Montgomery	On site	NO[g]	Solidification
RMW-21. Lead	Lead, various levels of radioactivity	1,094,200 lb[b] 50,000 lb	EP Toxic	Various	On site	NO	Refining
RMW-22. Incinerator ash	Lead, low-level radioactivity	6 drums[b] 7,500 lb	EP Toxic	WERF Dan Bartel	On site	NO[k]	Solidification
RWM-23. Baghouse bags	Cadmium lead, low-level radioactivity	300 bags[b] 300 bags/ 2-3 years	EP Toxic Dan Butel	WERF	On site	NO	Undecided

a. Waste will require analysis prior to implementation of treatment option.

b. Quantity generated and awaiting disposal.

c. Waste has been shipped off site for disposal.

d. Analysis requirements and treatment options will be evaluated once the waste is generated.

e. Waste stream requires further analysis before sampling decision is made.

f. Waste has been sampled and is undergoing analysis.

g. Development work is being conducted.

h. This is a classified waste and will be dispositioned by CPP.

i. Up to 200 gal may be generated on an emergency, infrequent basis.

j. Waste is presently being analyzed to determine if it is a mixed or low-level waste.

k. Analysis has been completed on presently stored ash, this ash has not shown any hazardous constituents. Ash from burn No. 10 has shown lead in levels above the EP Toxic limit.

Extraction Procedure (EP) toxic wastes are those wastes whose constituents have a tendency to leach or migrate when disposed of in an improperly designed sanitary landfill. A solid waste exhibits the characteristic of EP Toxicity if the extract obtained (through the EP toxicity procedure) from a representative sample of the waste is analyzed and found to exceed the maximum concentrations specified for the following elements/compounds: Arsenic--5.0 mg/L; Barium--100.0 mg/L; Cadmium--1.0 mg/L; Chromium--5.0 mg/L; Lead--5.0 mg/L; Mercury--0.2 mg/L; Selenium--1.0 mg/L; Silver--5.0 mg/L; Endrin--0.02 mg/L; Lindane--0.4 mg/L; Methoxychlor--10.0 mg/L; Toxaphene--0.5 mg/L; 2,4-Dichlorophenoxyacetic acid--10.0 mg/L; and Trichlorophenoxypropionic acid--1.0 mg/L. The EPA toxicity tests were used to determine toxic constituents of the waste. It is these wastes that are generally assumed to be candidates for solidification.

DECISION ANALYSIS

The second phase of the program was to perform a decision analysis for each waste listed in Table I. This involved an evaluation of the waste characteristics and determination of treatment options. Treatment options considered were: incineration, solidification, neutralization, recycling, refining, or storage of the waste until processing technology can be developed. Commercial disposal offsite was also considered an option for the hazardous wastes.

Other factors which influenced treatment decision analysis included: waste form, future DOE liability for the waste, on-site incinerator availability, safety considerations, and cost of on-site versus off-site processing. Any hazardous waste that is processed on-site that is still a hazardous waste after processing will be disposed of offsite (an example would be a process that provides an enhanced waste form, such as solidification, to minimize the perpetual liability of the generator of the hazardous waste). No hazardous waste will be disposed of at the INEL.

In general, the decision analysis determined that ignitable organic and other combustible wastes will be incinerated, acid and caustic wastes will be neutralized, and EP Toxic wastes solidified. Only those wastes which are considered candidates for solidification and development activities conducted with those wastes are reported in this paper.

SOLIDIFICATION SYSTEMS EVALUATION

The next phase of solidification development consisted of investigation of available commercial solidification methods which included literature review, contacting various companies involved in waste solidification, visiting operating waste solidification facilities and performing comparative evaluations of the various systems and their applicability to INEL wastes. Evaluations have included: investigation of the Delaware Custom Material (DCM) cement-silicate process; solidification systems by Stock, Chem Nuclear, General Electric, Associated Technologies Incorporated, Koch Process Systems Incorporated, ATCOR Engineered Systems Incorporated; and solidification processing using the following waste binders: Fujibeton products, PQ Corporation silicates, FASTCRETE, and United States Gypsum Company's (USGC) ENVIROSTONE.

In evaluation of the above listed solidification systems/binders, with regard to their applicability to INEL wastes, it was determined that the most functional systems for INEL waste were the DCM cement-silicate process and solidification using ENVIROSTONE. The DCM cement-silicate and ENVIROSTONE can be used very efficiently for processing relatively small volumes of waste; they also provide acceptable waste monoliths for a wide variety of waste streams. These processes were also chosen because of their short implementation time, ease of operability, and cost effectiveness.

SOLIDIFICATION PROCESS DEVELOPMENT

The next phase of the solidification program involved lab-scale testing of actual or representative samples of the wastes determined to be candidates for solidification to develop optimum binder-to-waste ratios. Lab-scale testing has been conducted on lead refining dross, baghouse dust, photochemical waste, and potassium chromate solution using cement, silicate, ENVIROSTONE, water, and various combinations of these.

Procedures were developed which provide instructions for solidification of waste samples. The procedures contain recipes for the solidification of the samples which vary the amounts of waste, water, and binder in each monolith. The procedures also ensure the safety of the personnel performing the solidification, provide a method of ensuring repeatability of samples, provide documentation of the work performed, ensure that all required methods are properly and accurately performed, and ensure that all regulations are met.

Variables considered in development of optimum binder-to-waste ratios include: optimization of set time; minimizing volume increase; leachability; monolith characteristics, including compressive strength, uniformity of waste distribution within the monolith, the presence of free liquid, and variations of pH; and use of various available waste binders. Figure 1 shows representative solidified samples. Table II shows the binder-to-waste ratios used for each waste tested.

In considering set time, comparisons were made of stirring times required, time required for the monolith to solidify, and with the cement-silicate, if solidification was instantaneous. The ENVIROSTONE samples required a longer stirring time (4-5 minutes), than the cement-silicate (soft set within 10 seconds of silicate addition). The ENVIROSTONE samples set into a single, hard block without void space, whereas the cement-silicate samples had void space in them due to their instantaneous soft set. The set time of the ENVIROSTONE samples to a hard set was faster than that of the cement-silicate samples.

Monolith characteristics considered were: compressive strength--did the monolith set up into one solid sample or did it crumble, crack, or stay moist and flexible; was there free liquid remaining on top of the sample; and variations of pH. The ENVIROSTONE samples set into a single solid sample, but the cement-silicate samples seemed to remain crumbly or moist and flexible. Some of the samples had free liquid standing on top, but it was absorbed within 48 hours. The pH of the potassium chromate solution and the lead dross solidified with ENVIROSTONE ranged from 6 to 9, and those done with cement-silicate ranged from 11.8 to 12.6.

Following development of binder-to-waste ratios, the solidified samples were sent to laboratories for leach testing using the EP Toxicity procedure. The EP Toxicity test is presently undergoing modification by the EPA and will be called the Toxicity Characteristic Leaching Procedure (TCLP). The TCLP is considered to be a more stringent test; therefore the new method was used as a worst case. The method was also used to ensure that process results will meet the new method and requirements. The concentration limits for the elements and compounds evaluated in the TCLP are the same as those in the EP Toxicity test. The TCLP test does,

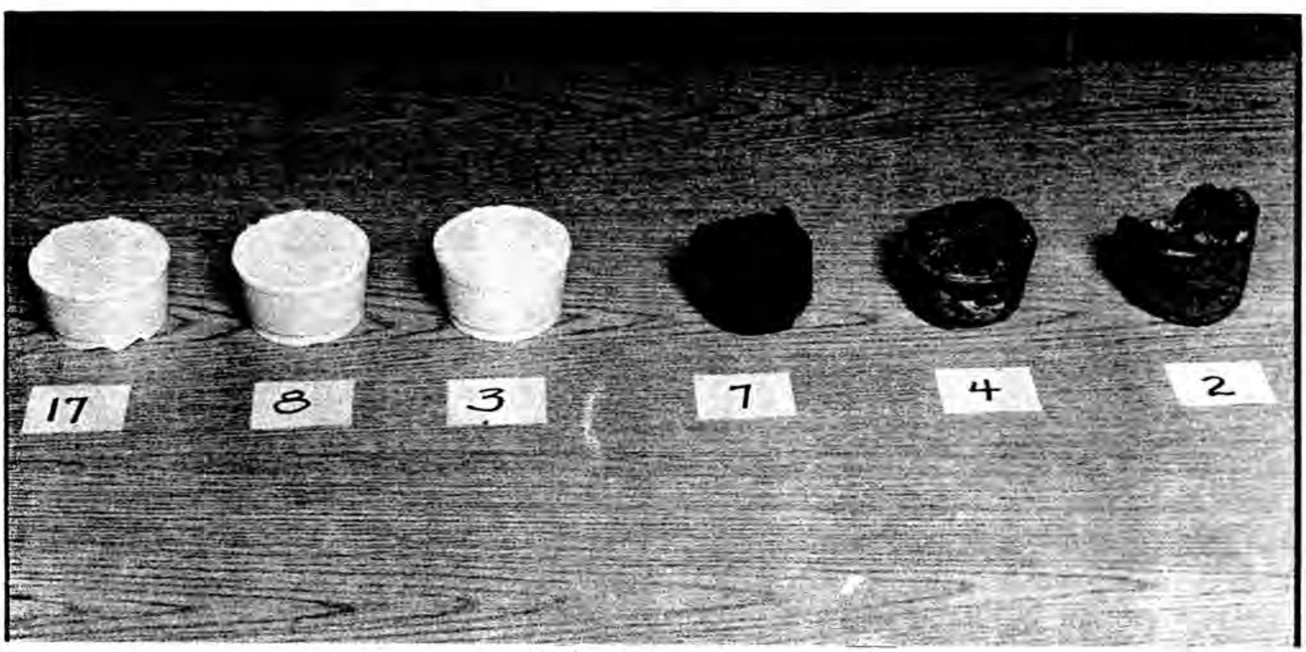

Fig. 1. Solidification Samples.

TABLE II.

Sample Formulations

Sample #	Waste[a] Specie	Water (mL)	Cement (g)	Silicate (mL)	Envirostone (g)
2	A - 100 mL	--	96	32	--
3	A - 100 mL	--	--	--	100
4	A - 100 mL	--	72	24	--
7	A - 100 mL	--	48	16	--
8	A - 100 mL	--	--	--	87.5
17	A - 100 mL	--	--	--	75
1/2 C1	B - 75 mL	--	54	18	--
1/2 E1	B - 75 mL	--	--	--	56.25
1/2 C2	B - 50 mL	--	72	24	--
1/2 C3	B - 50 mL	--	96	32	--
1/2 E2	B - 50 mL	--	--	--	100
1/2 E3	B - 50 mL	25	--	--	125
1/5 C1	C - 50 mL	--	36	12	--
1/5 E1	C - 50 mL	--	--	--	50
1/5 C2	C - 50 mL	--	72	24	--
1/5 C3	C - 50 mL	--	96	32	--
1/5 E2	C - 50 mL	--	--	--	100
1/10 C1	D - 50 mL	--	36	12	--
1/10 E1	D - 50 mL	--	--	--	50
1/10 C2	D - 50 mL	--	72	24	--
1/10 C3	D - 50 mL	--	96	32	--
1/10 E2	D - 50 mL	--	--	--	100
SC	E - 50 g	50	51	17	--
SC 1	E - 50 g	100	120	40	--
SC 2	E - 50 g	100	150	50	--
SC 3	E - 50 g	50	72	--	--
SE	E - 50 g	50	--	--	75
SE 1	E - 50 g	100	--	--	200
SE 2	E - 50 g	125	--	--	250
SE 3	E - 50 g	100	--	--	129
D1 A	F - 50 g	140	--	--	--
D1 B	F - 50 g	100	36	--	--
D1 C	F - 50 g	100	36	12	--
D1 D	F - 50 g	100	--	--	50
D1 E	F - 50 g	100[b]	--	--	--
D1 F	F - 50 g	100[b]	72	--	--
D1 G	F - 50 g	100[b]	36	12	--
D1 H	F - 50 g	100[b]	72	24	--
D1 I	F - 50 g	100[b]	--	--	50
D1 J	F - 50 g	100[b]	--	--	100
D2 A	F - 50 g	100	--	12	--
D2 B	F - 50 g	100	48	--	--
D2 C	F - 50 g	100	48	16	--
D2 D	F - 50 g	100	--	--	75
D2 E	F - 50 g	100[b]	--	24	--
D2 F	F - 50 g	50 + 100[c]	96	--	--
D2 G	F - 50 g	25 + 100[c]	72	24	--
D2 H	F - 50 g	25 + 100[c]	96	32	--
D2 I	F - 50 g	25 + 100[c]	--	--	100
D2 J	F - 50 g	25 + 100[c]	--	--	150
PW 1	G - 50 mL	--	100	34	--
PW 2	G - 50 mL	--	72	24	--
PW 3	G - 50 mL	--	96	32	--
PW 6	G - 50 mL	--	--	--	100
PW 7	G - 50 mL	--	--	--	125

a. Waste species:

A = Potassium Chromate 2500 ppm
B = Potassium Chromate 5000 ppm
C = Potassium Chromate 12,500 ppm
D = Potassium Chromate 25,000 ppm
E = Lead Dross
F = Flyash
G = Photochemical Waste

b. Potassium Chromate 2500 ppm was used instead of demineralized water.

c. In these samples, 100 mL of 2500 ppm potassium chromate solution was used and an additional amount of water was required to provide enough liquid to facilitate thorough mixing of the sample.

however, expand the list of toxic organic compounds evaluated in the test from 6 to 44. Wastes containing concentrations of these elements and compounds that are above the limits are considered toxic.

Potassium Chromate Test Results

The sample used in development work was a 2500 ppm potassium chromate solution made in the laboratory to simulate the actual waste stream. The waste stream is 18,000 gallons of a 2500 ppm potassium chromate solution that was used as shield tank water around a reactor; the potassium chromate is added to the water as a corrosion inhibitor.

Testing was also conducted with solutions of increased potassium chromate concentration. Potassium chromate solution was evaporated in ratios of 2 to 1, 5 to 1, and 10 to 1 to provide solutions of 5000 ppm, 12,500 ppm and 25,000 ppm respectively. The evaporation procedure was conducted to determine if potassium chromate solutions of higher concentrations could be successfully solidified. Successful solidification of the concentrated solutions would allow evaporation to be used to minimize the volume of waste requiring disposal and to reduce disposal costs.

Leach testing results, see Table III, have shown that the 2500 ppm potassium chromate solution requires, as a minimum amount for successful solidification, 72 grams of cement and 24 mL of silicate, or 87.5 grams of ENVIROSTONE per 100 mL of solution. The 5000 ppm potassium chromate solution required 72 grams of cement and 24 mL of silicate, or 100 grams of ENVIROSTONE per 50 mL of solution for successful solidification, and the 12,500 ppm potassium chromate solution required 96 grams of cement and 32 mL of silicate. A successful solidification of the 12,500 ppm potassium chromate solution using ENVIROSTONE was not obtained. The 25,000 ppm potassium chromate solution was not successfully solidified using either the cement-silicate or the ENVIROSTONE.

TABLE III.

Test Results of Solidified Potassium Chromate Solution Samples

Sample #[a]	Chromium Concentration Detected (mg/L) Lab #1	Lab #2	Lab #3
2,500 ppm solution			
K_2CrO_4	627[b]	673[b]	620[b]
2	2.05	2.4	1.03
3	6.82	4.5	1.45
4	2.85	2.9	1.39
7	3.57	16.3	5.52
8	5.08	4.9	72.1
17	7.2	6.9	31.7
5,000 ppm solution			
1/2 C1	18.4	18.4	6.72
1/2 E1	37.8	16.6	54.6
1/2 C2	3.22	--	--
1/2 C3	2.72	--	--
1/2 E2	4.49	--	--
1/2 E3	3.91	--	--
12,500 ppm solution			
1/5 C1	29.0	56.1	22.5
1/5 E1	--	32.4	--
1/5 C2	4.97	--	--
1/5 C3	3.11	--	--
1/5 E2	11.7	--	--
25,000 ppm solution			
1/10 C1	62.6	79.0	38.8
1/10 E1	235	80.1	178
1/10 C2	15.3	--	--
1/10 C3	26.9	--	--
1/10 E2	10.0	--	--

a. See Table II for sample formulations.

b. Unsolidified Sample.

This testing has shown that potassium chromate solution of concentrations up to 12,500 ppm can be successfully solidified using the cement-silicate binder, providing a safe, efficient, and cost-effective method of disposal for this waste stream.

Lead Dross Test Results

The lead dross used in development work was obtained from a refining firm, and is an actual sample of the dross generated in the refining process. Development is being conducted on this waste because the INEL has waste lead which must be dispositioned, and refining may be the most viable option.

Testing of the lead dross (see Table IV for results) has not, using the most conservative results, shown a successful solidification. Four of the samples analyzed showed lead concentrations below the 5.0-mg/L limit set by the EPA. However, duplicate samples analyzed at another Laboratory showed lead concentrations greater than the limit. Further testing is required to determine the differences in results from the various laboratories.

Flyash Test Results

The flyash used was obtained from the Waste Experimental Reduction Facility. The flyash is off-gas dust collected in the baghouse during the facility's metal melting and incineration operations. The constituents of concern in the flyash from a toxicity standpoint, are cadmium and lead. Testing of the flyash also included solidification of samples which used the 2500 ppm potassium chromate solution instead of demineralized water. This testing was performed to investigate the possibility of combining these waste streams for disposal thereby reducing the total waste volume, labor, and burial costs associated with the disposal of these wastes.

TABLE IV

Test Results of Solidified Lead Dross Samples

	Lead Concentration Detected (mg/L)		
Sample #[a]	Lab #1	Lab #2	Lab #3
Lead Dross	8,340[b]	33,233[b]	4,600[b]
SC	230	144	1.28
SC1	2.0	27.6	--
SC2	4.5	32.9	--
SC3	813	189	--
SE	174	96	1.04
SE1	174	46.8	--
SE2	93.9	--	--
SE3	294	--	--

a. See Table II for sample formulation.

b. Unsolidified sample.

Testing of the flyash has shown that successful solidification requires 36 grams of cement as a minimum, (see Table V for results). Addition of the silicate with the cement had the effect of reducing the amount of lead which leached from the sample. A successful solidification of the flyash using the ENVIROSTONE binder was not obtained.

In testing of the flyash using potassium chromate solution instead of water, successful solidification was obtained when 36 grams of cement and 12 mL of silicate were used as a minimum. Again in these samples the silicate reduced the amount of lead that leached from the sample, but in these samples the silicate was required for successful solidification. A successful solidification of the flyash and potassium chromate using the ENVIROSTONE binder was not obtained.

TABLE V

Test Results of Solidified Flyash and Flyash/Potassium Chromate Samples

	Cadmium, Chromium, and Lead Concentrations Detected (mg/L)					
	Lab #1			Lab #3		
Sample #[a]	Cd	Cr	Pb	Cd	Cr	Pb
#1[b]	32.0	0.42	443	80.2	3.68	381
#2[b]	37.0	0.73	332	.079	2.52	90
#3[b]	0.7	0.02	5.7	2.46	1.34	32.7
D1A[c]	46.0	1.10	407	--	--	--
D1B	<0.001	0.41	2.91	--	--	--
D1C	<0.001	0.13	0.30	--	--	--
D1D	25.0	0.41	114	--	--	--
D1E	35.0	3.35	255	--	--	--
D1F	<0.001	4.06	14.7	--	--	--
D1G	0.23	2.01	0.09	--	--	--
D1H	<0.001	5.28	14.7	--	--	--
D1I	26.0	3.09	34.7	--	--	--
D1J	21.0	0.43	61.3	--	--	--
D2A[d]	29.0	0.09	399	--	--	--
D2B	<0.001	0.59	8.71	--	--	--
D2C	<0.001	0.53	<0.01	--	--	--
D2D	20.0	0.30	63.7	--	--	--
D2E	19.0	0.12	268	--	--	--
D2F	<0.001	1.18	4.79	--	--	--
D2G	<0.001	3.33	<0.01	--	--	--
D2H	<0.001	1.99	<0.01	--	--	--
D2I	16.0	0.31	45.5	--	--	--
D2J	13.7	0.27	34.2	--	--	--

a. See Table II for sample formulations.

b. Unsolidified Sample.

c. Samples with a D1 designation were taken from the same drum as sample #1.

d. Samples with a D2 designation were taken from the same drum as sample #2.

The results of the flyash testing have shown that the flyash can be successfully solidified using the potassium chromate solution with the cement-silicate binders. This will provide a safe, efficient, cost-effective method of long term disposal for both the flyash and potassium chromate waste streams.

Photochemical Waste Test Results

The photochemical waste used in development work was obtained from a drum of this waste located at the Hazardous Waste Storage Facility. This waste stream is generated at the Naval Reactor Facility during chemical analysis procedures. The constituent of concern in this waste, from a toxicity standpoint, is silver.

Testing conducted on the photochemical waste, (see Table VI for results), has shown that successful solidification of this waste can be obtained using either cement-silicate or ENVIROSTONE. The mimimum amounts of binder required for successful solidification were 72 grams of cement with 24 mL of silicate, or 125 grams of ENVIROSTONE per 50 mL of the photochemical waste.

PLANNED ACTIVITIES

In addition to the development work contained in this report, testing and analysis is being conducted on the following wastes: silver nitrate; mercuric nitrate; mixed formaldehyde and mercuric nitrate; mercury; mercury-contaminated sludge; mercury-contaminated charcoal; and other wastes determined to be candidates for solidification as they become available. The work conducted on these wastes will be performed in the same manner as that which is presented in this paper.

TABLE VI

Test Results of Solidified Photochemical Waste Samples

Sample #[a]	Silver Concentration Detected (mg/L) Lab #1	Lab #2
PW	3.4[b]	93.8[b]
PW1	.09	--
PW2	.03	.08
PW3	.01	.38
PW6	.30	5.89
PW7	.29	3.94

a. See Table II for sample formulation.

b. Unsolidified sample.

After an optimum binder-to-waste ratio has been developed and tested, and verification that it meets disposal criteria conducted, the ratio will be used for solidification of a drum of waste. A drum of waste will be solidified to verify that the binder-to-waste ratio developed in the small samples will provide successful solidification of the waste in production-scale. The drum monolith will be sectioned and each section subjected to toxicity testing to verify homogeneity.

The drum solidifications will be conducted using simple mixing systems such as the DCM sacrificial blade system or a drum rotator. These are shown in Figures 2 and 3.

The EPA requires facilities treating hazardous waste to have a RCRA Part B permit. EG&G has submitted an application for this permit. Activities will be conducted to support this application, and production-scale solidification of hazardous waste will not be conducted until the permit has been granted.

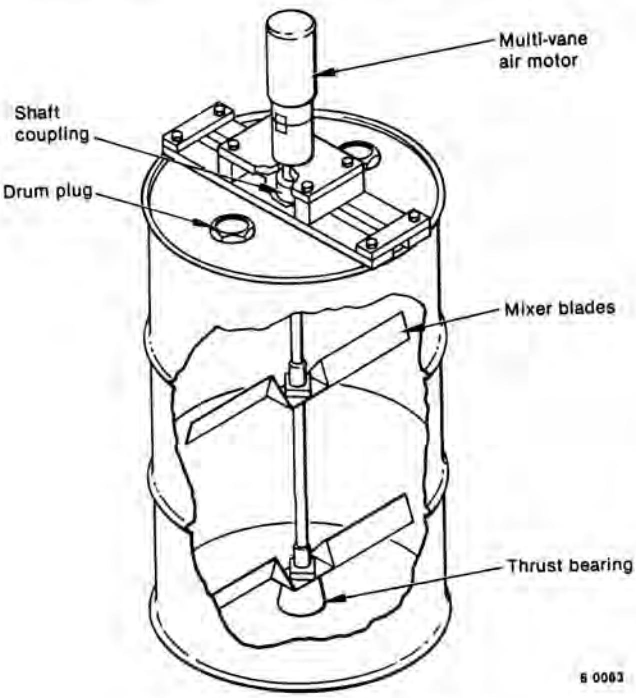

Fig. 2. DCM Drum System.

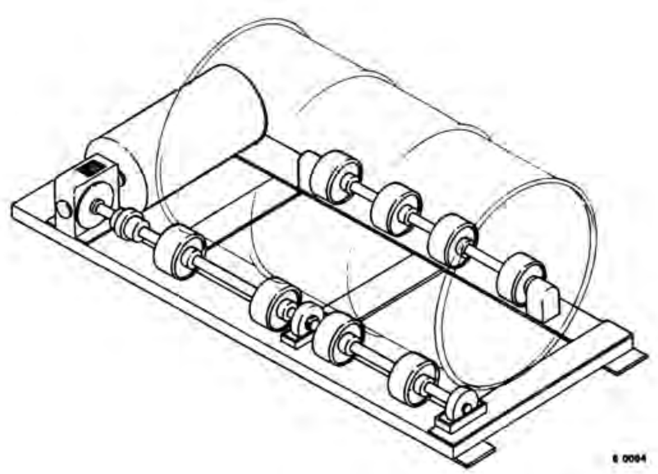

Fig. 3. Drum Rotator.

After drum-scale tests have verified acceptable monoliths for disposal, solidification of wastes awaiting disposal will begin. The first waste scheduled for solidification is the WERF-incinerator ash and flyash.

Solidification of waste at the INEL will be an ongoing activity and each waste, as it is identified, will be subjected to waste characterization, lab-scale testing for development of binder-to-waste ratios, and toxicity testing of solidified samples before implementation of production-scale solidification methods for disposal of the waste.

A problem that was not anticipated but must be addressed is the inconsistency between laboratory results. Three independent laboratories performed EP toxicity testing on identical solidified samples, and yet the data received varied considerably. Evaluation of the data did not reveal any trend which could be used to explain the differences in results.

In addressing this problem, the following activities are planned: (a) preparation of standard solutions containing specific known amounts of the toxic metals listed in the EP toxicity tests; (b) continued analysis of each sample by three independent laboratories; and (c) effects of particle size, temperature, tumbler speed, and other procedural variables on results. Evaluation of the data obtained from these activities should aid in understanding the discrepancies and further evaluation will be performed as required. In all cases, the most conservative (the highest numerical) leaching result will be used in evaluating whether or not the sample passed the TCLP requirements.

CONCLUSIONS

The purpose of the solidification development program is to provide a safe and effective method of disposal for the hazardous and mixed wastes generated at the INEL. The steps taken in the program thus far are: waste characterization; decision analysis; lab-scale testing for development of waste formulas; and testing of solidified samples to verify that they meet EPA toxicity criteria.

The development work conducted and reported in this paper shows that solidification does provide a safe and effective method for treating hazardous and mixed waste so that the resulting form is nontoxic, will satisfy EPA regulations, and can be dispositioned as a nonhazardous or low-level waste.