United States
Environmental Protection
Agency

Industrial Environmental Research
Laboratory
Cincinnati OH 45268

Research and Development

EPA-600/S2-83-030 June 1983

EPA

Project Summary

Analysis of Geothermal Wastes for Hazardous Components

E.L. Hagmann, D.D. Minicucci, and C.D. Wolbach

Proposed regulations governing the disposal of hazardous wastes led to an assessment of geothermal solid wastes for potentially hazardous content. The final regulations, published May 19, 1980, exempt geothermal wastes from designation as hazardous. Samples were collected from three active geothermal areas in the western United States: The Geysers, Imperial Valley, and northwestern Nevada. Approximately 20 samples were analyzed for corrosivity, EP toxicity (as determined by a specific "Extract Procedure" defined in the regulations), radioactivity, and bioaccumulation potential. The samples were further characterized by analysis for cations, anions, moisture content, priority pollutants, and additional trace metals in the leachate. In addition, an aqueous extraction was conducted at ambient pH and similar chemical analyses were performed.

None of the samples collected at The Geysers or in northwestern Nevada could be classified as hazardous as defined by the RCRA regulations published May 19, 1980 in the Federal Register. However, several samples from the Imperial Valley could be classified as hazardous in one or more of the categories of pH, radioactivity, EP toxicity, and bioaccumulation. These hazardous properties appear to be related to the high salinity of the associated geothermal fluids.

This study characterized samples from a limited geographical area and results cannot be broadly extrapolated to other geothermal resource areas.

This Project Summary was developed by EPA's Industrial Environmental Research Laboratory, Cincinnati, OH, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Introduction

On December 18, 1978, EPA proposed the initial set of regulations under the Resource Conservation and Recovery Act of 1976 (RCRA), for managing hazardous solid wastes. The cornerstone of these regulations was the Agency guidance on how to determine whether a solid waste is hazardous. Candidate criteria were introduced which formed the basis for identifying hazardous wastes. Of these, four were potentially applicable to solid wastes produced by geothermal energy development operations: corrosivity, toxicity, radioactivity, and bioaccumulation potential. In anticipation of Congressional action to exclude geothermal wastes from the RCRA hazardous waste management regulations while requiring that studies be undertaken to define the nature of these wastes, EPA initiated a research program to evaluate geothermal solid waste against these hazardous waste criteria.

The objectives of this project were (1) to sample and analyze solid wastes representing a broad spectrum of geothermal resource areas and type of exploration and development activities, and (2) to preliminarily determine, using the RCRA analytical protocols, whether such solid wastes meet the criteria for being hazardous.

Technical Approach

Site Selection

Sampling sites were selected on the basis of (1) solid wastes actually being produced, (2) representing the variety of

Table 1. *Geothermal Waste Sampling and Analysis Sites*

Sample Number*	*Sample Description*	*Location*	*Site Owner/Operator*
Imperial Valley, California			
G-1	*Flash tank sediment*	*East Mesa, Geothermal Test Facility*	*Department of Energy/Westec Services*
G-3	*Brine handling pond sediment*	*East Mesa, Geothermal Test Facility*	*Department of Energy/Westec Services*
G-6	*Mud pit sediment*	*East Mesa, Sperry Well*	*Republic Geothermal*
G-7	*Fluid pit brine*	*East Mesa, Sperry Well*	*Republic Geothermal*
G-8	*Reactor clarifier sludge*	*Niland, Geothermal Loop Experimental Facility*	*Department of Energy/Magma Power*
G-9	*Mud pit sediment*	*Niland, Fee #1 well*	*Republic Geothermal*
G-10	*Brine pit brine*	*Niland, Fee #1 well*	*Republic Geothermal*
G-12	*Landfill sediment*	*Brawley, Class II-2 landfill*	*Imperial County Dept. Public Works*
G-14	*Baker tank brine*	*Westmorland Courier #1 well*	*MAPCO, Inc.*
G-16	*Mud pit sediment*	*Westmorland Courier #1 well*	*MAPCO, Inc.*
The Geysers, California			
G-19-2	*Centrifuge sludge*	*Power generating unit 12*	*Pacific Gas & Electric Co.*
G-20-1	*Cooling tower sediment*	*Power generating unit 9*	*Pacific Gas & Electric Co.*
G-22-1	*Centrifuge sludge*	*Power generating units 5 and 6*	*Pacific Gas & Electric Co.*
G-23-1	*Cooling tower sediment*	*Power generating units 7 & 8*	*Pacific Gas & Electric Co.*
G-24-1	*Drilling sump sediment*	*Beigel #1 well near unit 18*	*Union Oil of California*
G-26-1	*Sedimentation pond sediment*	*Power generating unit 12*	*Union Oil of California*
G-27-1	*Drilling sump sediment*	*Aminoil #1 well, near unit 13*	*Aminoil, USA*
Northwestern Nevada			
G-30	*Drilling sump sediment*	*Steamboat Springs, Steamboat #1 well*	*Phillips Petroleum*
G-31	*Drilling sump sediment*	*Humbolt House well*	*Phillips Petroleum*
G-32	*Drilling sump sediment*	*Desert Peak well*	*Phillips Petroleum*

**Samples taken were numbered consecutively from G-1 through G-33. Resource limitations prevented analysis of all samples. Only those analyzed are listed here.*

wastes being produced, (3) the waste's potential for containing hazardous components, and (4) the extent to which the wastes may be indicative of commercial operations. A priority list of sites was thus developed and contacts were made with site owners/operators regarding types of wastes generated, status of waste-producing processes, and access procedures. The resulting sites selected, for which sampling and analyses were performed, are shown in Table 1.

Sample Collection

All samples were stored in half-gallon, wide-mouth, polyethylene bottles. Sampling equipment was simple: for brines and pond bottom sediment, a 1-liter polyethylene beaker attached to the end of an 8-foot extension rod and, for dry sediments an ordinary metal trowel and pipe scale was removed with a hammer and chisel.

Sample Analysis

All samples were analyzed in accordance with the analytical scheme shown in Figure 1. The following four tests were performed on each original sample (before extraction or separation):

- moisture content (or total suspended solids)
- radioactivity (radium 226)
- bulk composition (major cations and anions)
- corrosivity (pH of slurry or brines)

Major cations and anions in the bulk composition analyses included the following:

Anions	*Cations*
Chloride	Aluminum
Fluoride	Calcium
Silica	Iron
Sulfate	Magnesium
Sulfide	Potassium
	Sodium

Phase separation and extraction were performed. The liquid phase and the extract (under acid pH with acetic acid and "ambient" pH with deionized water) were combined for further analyses of both extracts. These analyses included bulk composition for major cations and anions listed above, RCRA EP toxicity, and bioaccumulation potential.

The eight inorganic elements in the EP toxicity test are arsenic, barium, cadmium, chromium, lead, mercury, selenium, and silver. Eight additional elements included in water quality standards were also measured - antimony, beryllium, boron, copper, lithium, nickel, strontium, and zinc.

Organic (priority pollutant) analyses and bioaccumulation tests were performed on both the acid and base/neutral fractions of three samples (G12, G22-1 and G24-1) known or suspected to have had organic additives introduced.

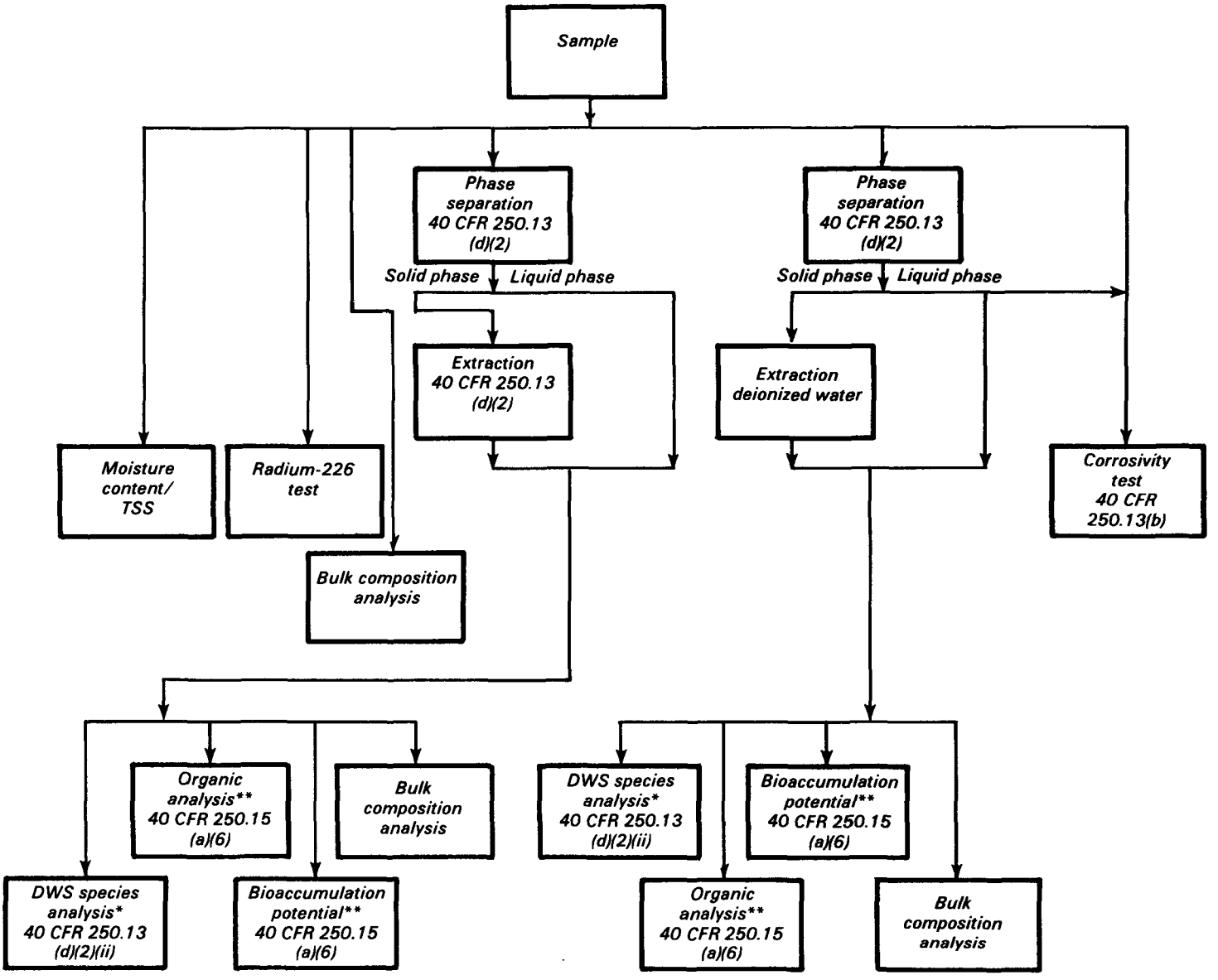
Results

The results of the total sample bulk composition analyses are shown in Table 2.

Corrosivity was determined by measuring the pH of a 5-weight-percent slurry of each solids sample or, in the case of brine samples, by measuring the pH of the brine directly. The values are listed in Table 3, which also lists the Radium 226 values of the same samples.

Table 4 lists the analyses of the eight RCRA trace elements of the EP toxicity test for both the acid and the ambient pH extracts. Table 5 lists the analyses of the additional eight water quality standards constituents.

Table 6 presents the results of the organic analyses of the three samples



*Plus additional water quality criteria trace elements.
**For those samples with organic additives only.
40 CFR references were those published 12/18/78. These references were, in general, replaced by final regulations dated 5/19/81.
40 CFR 250.13(b) became 40 CFR 261.22.
40 CFR 250.13(b)(2)(ii) became 40 CFR 261.24, Appendix II.
40 CFR 250.15(a)(6) became part of 40 CFR 260.22.

Figure 1. Analytical scheme.

selected for these tests. The analyses include priority pollutant screening and tests for bioaccumulation potential.

A comparison of the analytical results with the RCRA criteria shows that five of the samples analyzed exceed one or more of the criteria and thus could be defined as hazardous wastes. The comparison is summarized in Table 7. Note that all of the samples which exceed the criteria came from the Imperial Valley and that two of them were brine samples.

Conclusions

1. This study cannot be used to generalize about the hazardous character of geothermal wastes outside the sites studied, without considerable qualification. Data from this study support the con-

Table 2. Bulk Composition of Total Sample

	% Silica	Approx. % Na, K, Ca Salts	Approx. % Fe, Mg, Al Oxides
Imperial Valley			
G-1	2	70	
G-3	15		
G-6	61	10	10
G-7 (brine)			
G-8	23	35	10
G-9	77	10	10
G-10 (brine)			
G-12	49	10	15
G-14 (brine)			
G-16	61	15	20
The Geysers			
G-19-2	Trace		60
G-20-1	Not analyzed	Not analyzed	Not analyzed
G-22-1	Trace		40
G-23-1	12		50
G-24-1	41		20
G-26-1	Trace		70
G-27-1	59		15
Northwestern Nevada			
G-30	33		10
G-31	31	10	10
G-32	32		

Table 3. Corrosivity (pH) and Radium 226 Concentrations (radium on moisture-free basis, except as noted [a])

Sample No.	pH	Radium 226 (pCi/g)
Imperial Valley		
G-1	8.8	3.0
G-3	8.8	1.5
G-6	12.0	1.0
G-7 (brine)	8.7	.0[a]
G-8	6.1	78.
G-9	8.4	2.1
G-10 (brine)	1.6	0.4[a]
G-12	10.0	1.1
G-14 (brine)	3.8	1320[a]
G-16	8.8	5.9
The Geysers		
G-19-2	6.2	0
G-20-1	3.7	0
G-22-1	6.6	0
G-23-1	5.1	0
G-24-1	10.1	0.5
G-26-1	4.2	0
G-27-1	9.6	0.4
Northwestern Nevada		
G-30	9.3	1.0
G-31	9.8	1.6
G-32	9.1	3.8

[a]- not moisture-free basis; shown as pCi/L.

clusions of other studies that each geothermal resource must be considered unique in its chemical and physical character.

2. None of the samples of waste materials collected at the commercial power plant operations in The Geysers geothermal steam fields and at the northern Nevada exploration sites could be classified as hazardous as defined by the criteria in the Hazardous Waste regulations published May 19, 1980 in the Federal Register.
3. Several samples, including brines, drilling wastes, and settling pond solids from geothermal exploration and development sites in the Imperial Valley could be classified as hazardous waste, with characteristics exceeding the Hazardous Waste criteria in one or more of the categories of pH, radioactivity, EP toxicity, and bioaccumulation.
4. The principal source of the hazardous characteristics in the Imperial Valley is the geothermal brine itself. Imperial Valley brines generally have considerably higher salinities than do geothermal fluids elsewhere. Hazardous waste characteristics appear to be directly related to salinity.
5. Since salinity is site-dependent, it can be concluded that the hazardous waste character of geothermal solid wastes will be site-dependent.
6. Higher heavy metal concentrations were always associated with low ambient pH, but low pH did not guarantee high heavy metal content.
7. High radioactivity (Radium 226) values were generally associated with higher metals content.

The significance of the high bioaccumulation potential in one sample has not been determined. The bioaccumulating compounds were not identified.

Table 4. *RCRA Trace Elements in Acid Extracts and Ambient pH Extracts (mg/l)*

Sample Number	Arsenic		Barium		Cadmium		Chromium		Lead		Mercury		Selenium		Silver	
	AEP	NEP	AEP	NEP	AEP	NEP	AEP	NEP	AEP	NEP	AEP	NEP	AEP	NEP	AEP	NEP
Imperial Valley																
G-1	0.036	0.033	10.5	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
G-3	0.045	0.065	3.8	0.60	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
G-6	ND	ND	1.4	ND	ND	ND	0.03	ND	ND	ND	ND	ND	ND	ND	ND	ND
G-7	--	0.31	--	ND	--	ND	--	ND	--	ND	--	ND	--	ND	--	ND
G-8	0.23	0.23	5.0	5.4	NR	NR	ND	ND	0.20	ND	ND	ND	0.18	0.22	ND	ND
G-9	0.063	ND	1.8	ND	0.006	ND	ND	ND	ND	ND	ND	ND	0.03	0.02	ND	ND
G-10	--	ND	--	363	--	0.07	--	0.98	--	NR	--	INT	--	ND	--	NR
G-12	0.10	NR	1.0	1.4	ND	ND	0.023	0.42	ND	0.20	ND	INT	ND	NR		
G-14	--	14	--	22	--	4	--	ND	--	83	--	ND	--	5.1	--	ND
G-16	0.049	0.047	13	6.8	0.02	ND	ND	ND	0.06	ND	ND	ND	0.10	0.12	ND	ND
The Geysers																
G-19-2	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
G-20-1	0.087	0.068	ND	ND	0.01	0.01	0.029	0.023	0.14	0.18	ND	ND	ND	ND	ND	ND
G-22-1	ND	ND	ND	ND	ND	ND	ND	ND	0.02	0.05	ND	ND	ND	ND	ND	ND
G-23-1	0.110	0.15	ND	ND	NR	NR	ND	ND	0.07	0.05	ND	ND	ND	ND	ND	ND
G-24-1	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
G-26-1	0.02	0.034	ND	ND	0.008	0.007	0.053	ND	ND	ND	ND	ND	0.03	0.04	ND	ND
G-27-1	ND	0.32	1.4	ND	ND	ND	0.07	ND	ND	ND	ND	ND	ND	ND	ND	ND
Northwest Nevada																
G-30	0.06	0.26	0.60	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
G-31	ND	0.14	0.06	0.50	0.006	0.005	ND	0.027	0.70	0.50	ND	ND	ND	ND	ND	ND
G-32	ND	ND	0.50	ND	ND	ND	ND	0.039	ND	ND	ND	ND	0.03	ND	ND	ND

AEP - Acid Extraction Procedure
NEP - Ambient pH (neutral) extraction procedure
ND - Not detected
NR - Not reported
-- - Not applicable
INT - Interference

Table 5. *Additional Metals (Water Quality Standards) in Acid Extracts and Ambient pH Extracts (mg/l)*

Sample Number	Antimony		Beryllium		Boron		Copper		Lithium		Nickel		Strontium		Zinc	
	AEP	NEP	AEP	NEP	AEP	NEP	AEP	NEP	AEP	NEP	AEP	NEP	AEP	NEP	AEP	NEP
Imperial Valley																
G-1	0.18	0.18	ND	ND	ND	ND	0.15	ND	0.22	0.14	ND	ND	ND	ND	0.70	ND
G 3	ND	ND	ND	ND	ND	ND	ND	ND	0.17	0.13	ND	ND	8.3	ND	0.11	ND
G-6	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	2.2	ND	0.15	ND
G-7	--	ND	--	ND	--	ND	--	ND	--	2.8	--	ND	--	ND	--	0.03
G-8	ND	ND	ND	ND	12.0	13.0	0.15	ND	5.8	ND	0.50	ND	12.0	15.0	6.4	4.0
G-9	ND	ND	ND	ND	ND	0.20	ND	ND	1.30	1.10	ND	ND	5.4	1.5	1.3	ND
G-10	--	ND	--	ND	--	660	--	7.4	--	NR	--	0.30	--	1290	--	NR
G-12	ND	ND	ND	ND	ND	0.34	ND	0.23	0.13	0.34	ND	ND	2.4	ND	0.25	1.4
G-14	--	ND	--	ND	--	230	--	ND	--	0.24	--	ND	--	1400	--	6000
G-16	ND	ND	ND	ND	0.25	3.10	ND	ND	3.3	3.1	ND	ND	23.0	20.0	7.0	ND
The Geysers																
G-19-2	ND	ND	ND	ND	7.6	0.52	ND	ND	ND	ND	ND	ND	ND	ND	0.20	0.05
G-20-1	ND	ND	ND	ND	23.0	16.0	2.2	1.8	ND	ND	0.90	0.70	ND	ND	6.2	6.0
G-22-1	ND	ND	ND	ND	28.0	27.0	ND	ND	ND	0.10	0.20	ND	ND	ND	0.06	0.03
G-23-1	ND	ND	ND	ND	7.70	0.88	60	33	ND	ND	ND	ND	ND	ND	7.5	6.0
G-24-1	ND	ND	ND	ND	0.87	15.0	ND	ND	ND	ND	0.30	0.50	0.60	ND	0.30	ND
G-26-1	ND	ND	ND	ND	19.0	30.0	ND	ND	ND	ND	0.40	0.40	ND	ND	9.0	14.0
G-27-1	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	3.5	ND	0.08	ND
Northwest Nevada																
G-30	ND	0.07	ND	ND	0.30	0.57	ND	ND	0.50	0.40	ND	ND	1.0	ND	0.12	ND
G-31	ND	ND	ND	ND	ND	ND	ND	0.10	0.05	ND	ND	ND	3.0	ND	0.42	0.28
G-32	ND	ND	ND	ND	0.23	0.47	0.20	0.10	0.30	0.20	ND	ND	2.6	ND	0.14	0.05

AEP - Acid Extraction Procedure
NEP - Ambient pH (neutral) extraction procedure
ND - Not detected
NR - Not reported
-- - Not applicable
IT - Interference

Table 6. *Organic Analyses*

Sample No.	Extract	Bioaccumulation Potential: % of peak area Log > 3	Bioaccumulation Potential: Potential	Priority Pollutants: Compounds	Priority Pollutants: Concentration (µg/1)
G-12	Acid	0	Negative	Phenol	4
G-12	Neutral	72	Positive	Phenol	2
				4,6-dinitrocresol	8
				anthracene/ phenanthrene	
G-22	Acid	0	Negative	Phenol	0.4
				Benzo (k) flouranthene	14
G-22-1	Neutral	0	Negative	None detected	
G-24-1	Acid	0.39	Negative	Phenol	3
				2-nitro phenol	2
G-24-1	Neutral	1.8	Negative	Phenol	640

Table 7. *Comparison of Analytical Results with RCRA Criteria for Hazardous Wastes*

Sample Number	Waste Criteria: Sample Type	Constituent Analyzed: RCRA Limits:	Corrosivity: pH ≤2 or ≥12.5	Radioactivity: Radium-226 ≥5 pCi/g or ≥50 pCi/L[b]	EP Toxicity[a] (mg/L): As 5.0	Ba 100.0	Cd 1.0	Cr 5.0	Pb 5.0	Hg 0.2	Se 1.0	Ag 5.0	Bioaccumulation potential: Log P>3 positive peaks
G8*	Sludge			78 pCi/g									
G10*	Brine		1.6			363							
G12*	Solids												Positive
G14*	Brine			1,320 pCi/L	14		4		83		5.1		
G16*	Mud			5.9 pCi/L									
All Others **	Various		3.7 - 12	0 - 3.8 pCi/g 0 pCi/L	<0.020 0.31	<0.3 22	<0.005 0.07	<0.020 0.98	<0.020 0.70	<0.001	<0.020 0.18	<0.020	Not analyzed or zero

* *Values presented only for exceedences of RCRA limits.*
** *Ranges presented for highest and lowest values (all within RCRA limits).*
[a] *Acid extracts and liquid sample filtrate.*
[b] *Radioactivity criteria proposed 12/18/78; not promulgated.*

E. L. Hagmann, D. D. Minicucci and C. D. Wolbach are with Acurex Corporation, Energy and Environmental Division, 485 Clyde Avenue, Mountain View, CA 94042
***Robert P. Hartley** is the EPA Project Officer (see below).*
The complete report, entitled "Analysis of Geothermal Wastes for Hazardous Components," (Order No. PB 83-188 680; Cost: $13.00, subject to change) will be available only from:
National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
Telephone: 703-487-4650
The EPA Project Officer can be contacted at:
Industrial Environmental Research Laboratory
U.S. Environmental Protection Agency
Cincinnati, OH 45268

United States
Environmental Protection
Agency

Center for Environmental Research
Information
Cincinnati OH 45268

Postage and
Fees Paid
Environmental
Protection
Agency
EPA 335

Official Business
Penalty for Private Use $300

RETURN POSTAGE GUARANTEED

Third-Class
Bulk Rate