TREATING RADIOACTIVE CONTAMINATED SOIL BY THE PROCESS OF EXTRACTION – PART II

W. Alam, E.C. Donaldson, N. Begum, R. Hossain, R. Bouwkamp
Tetrahedron, Inc.

N. Fatherly, R. Livermore, C. Hallam
U.S. Army Corps of Engineers, Baltimore District

ABSTRACT

A bench scale study was conducted to develop a cost effective method for treating low-level radioactive contaminated soil from a Formerly Utilized Sites Remedial Action Program (FUSRAP) site located in Maryland. The contaminants of concern (COC) are thorium, radium and uranium. Primary Remediation Goals (PRGs) were established for thorium-232, radium-226, radium-228, uranium-234, and uranium-238 based on risk assessment. The method of treatment consisted of a variation of solvent extraction of metals from soil. The results indicate that a multi-stage extraction system will lower COC concentrations to below PRGs in most cases and the treated soil may not require off-site disposal. The concentrated COC in the leachate can be removed by ion exchange process, thus providing a comprehensive waste management system. This treatment system has the potential to significantly lower waste disposal costs.

INTRODUCTION

Low-level radioactive contaminated sites have often been remediated using the "dig and haul method". Though the process works in cleaning a contaminated site, it does have certain disadvantages such as: (i) accumulating of large volumes of contamination at the disposal location, (ii) high exposure risk from high volume and long haul transportation, (iii) reluctance from the public to allow high volume shipment through their communities, and (iv) high cost of transportation and disposal. For most sites, however, "dig and haul" remains the only choice for remediation as other alternatives are not feasible due to waste and site characteristics.

A FUSRAP site in Maryland has a disposal area containing Low Level Radioactive Waste (LLRW) generated from the process of extracting Thorium from Monazite sand. A Remedial Investigation (RI) and Feasibility Study (FS) were conducted by the US Army Corps of Engineers, Baltimore District (USACE) for the site. The PRGs for COC were established during the RI were thorium-232, radium-226, radium-228, uranium-234, and uranium-238 for which PRGs were identified in the Baseline Risk Assessment (BRA). During the evaluation of remedial alternatives for the FS, it was observed that soil characteristics identified during the RI indicated that "Soil Washing" was a viable alternative. A bench scale treatability study was designed and conducted by Tetrahedron to provide site-specific information needed to complete the alternative analysis for the FS. The method of treatment consisted of acid wash of radionuclides from the contaminated soil. The results indicate that treating the soil with a multi-stage extraction system would lower the concentration of the COC to below PRGs in most cases. As a result, a large volume of soil may not require off-site disposal. The remainder of the soil still above PRGs can be reprocessed through the system or disposed off-site at lower concentrations of COC. The treatment system could provide substantially lower disposal costs for the site.

STUDY DESIGN

The study was conducted in two phases, as described below:

Phase I: The objective of this phase of the study was to determine: (i) characteristics of soil and COC, and (ii) preliminary evaluation of treatment processes. Soil samples were collected from eight locations that had indicated significantly elevated concentrations of COC during the RI. The soil was then characterized in terms of: concentrations of COC by grain size, grain size distribution, Cation Exchange Capacity (CEC), pH, Total Organic Carbon (TOC), and moisture content. The initial concentration of radioactive constituent was determined to establish a baseline for treatment comparisons. Parameters analyzed included gross alpha, beta & gamma spectroscopy and isotopic U and Th.

Soil samples were treated with nitric acid under variable conditions to determine the most efficient method for extracting the COC from the soil matrix. Soil samples were composited for this phase of the study. Variables studied for the acid treatment system included: (i) concentrations of nitric acid ranging from 5% to 25% acid strength, (ii) contact times varying between 2 minutes and 10 minutes, (iii) effect of heat, and (iv) effect of common ion (sodium nitrate). Results were measured in terms of Total Activity for screening purposes.

Phase II: The objective of this phase of the study was to determine: (i) optimum concentration of the acid required for treating COC in the soil from the different locations (not composited) to below PRGs using a simulated countercurrent flow, and (ii) efficiency of ion exchange resins to treat leachate produced from treating of soil.

Figure 1 presents a flow diagram of the study design

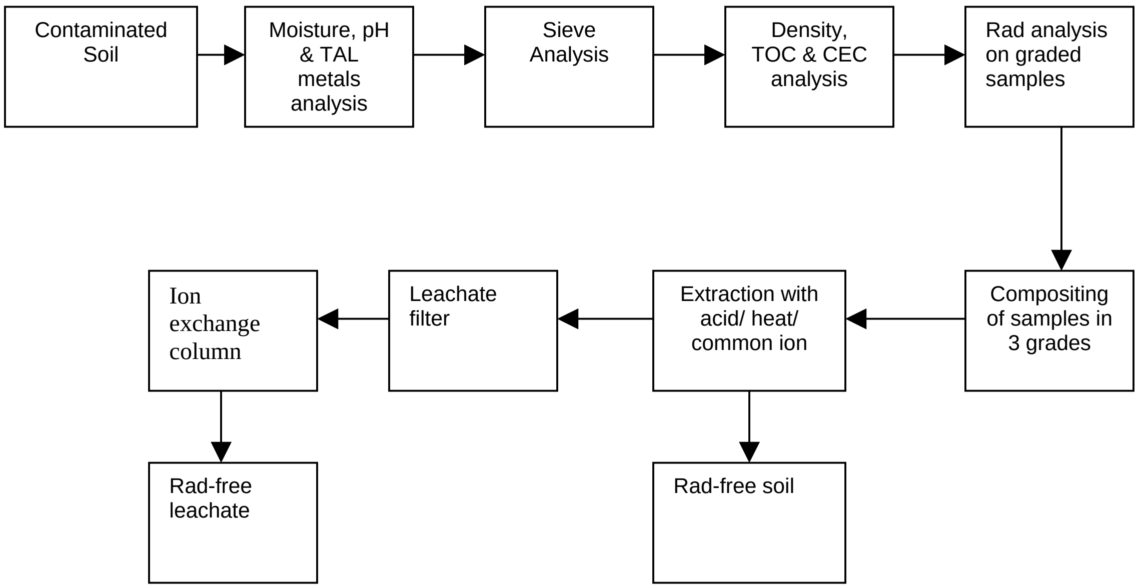

Fig. 1. Flow diagram showing the bench scale treatability system

RESULTS

Results of Phase I Study

Results of the Phase I study were presented in WM'04 conference (paper WM-4043). A synopsis of the results is given here.

The study showed that there was no significant correlation between the concentration of COC and grain size and that the CEC was moderately low (~25 Meq/100gm). In addition, the TOC was low (~1%) and the pH was slightly on the acidic side. Nitric acid leaching tests for extraction of metals (for reducing Total Activity) were conducted on soils to evaluate the effectiveness of treatment under various conditions including: (i) strength of the acid, (ii) addition of heat, (iii) addition of common ion salt, and (iv) multi-stage extraction. Higher concentrations of acid improved extraction, but the increased efficiency diminished with concentration. Heat and common ion salts had an insignificant effect on treatment efficiency. However, multi-stage acid extraction of the soil significantly increased the treatment efficiency. The tests indicated that a 15% acid solution could reduce the Total Activity of the soil by approximately 85% in a 3-stage system compared to about 40% in single stage system.

Results of Phase II Study

Soil Treatment Efficiency: The Phase I study results showed that the treatment system has the potential of lowering the Total Activity of the soil substantially. In order to determine if the treatment would meet the PRGs established for the site, soil treatment efficiency also was evaluated in terms of the concentrations of the various COC for which PRGs have been established. Tables I through IV and Figures II through IV show the results of this evaluation. It should be noted that in this phase of the evaluation, field conditions expected in an actual remediation were duplicated by treating each location separately and without drying or separating the soil by grain size.

Leachate Treatment Efficiency: The spent acid (leachate) resulting from extracting the COC, has high concentrations of metals. In order to reuse the acid and minimize generation of acid waste, the acid is treated by passing it through ion exchange resins. Based on the COC, the contaminants would appear to be simply metal cations; therefore, cation exchange resins should be able to remove most of the COC from the leachate. However, in a solution the COC can also form an anion with nitrates that would require an anion exchange resins for its treatment. Therefore, both types of resins were tested.

In order to maximize the efficiency for treating the leachate, various types of resins were used in different combinations and sequence. Table V shows the results of ten types of tests that were conducted for this study.

Table I. Three - Stage Treatment with 15% Nitric Acid

Parameter	PRG Conc. (Surface/Sub) (pCi/gm)	Location L-1 Conc. before treatment (pCi/gm)	Location L-1 After 3-stage treatment (15% HNO3)	Location L-1 Actual % Reduction	Location L-2 Conc. before treatment (pCi/gm)	Location L-2 After 3-stage treatment (15% HNO3)	Location L-2 Actual % Reduction	Location L-3 Conc. before treatment (pCi/gm)	Location L-3 After 3-stage treatment (15% HNO3)	Location L-3 Actual % Reduction	Location L-4 Conc. before treatment (pCi/gm)	Location L-4 After 3-stage treatment (15% HNO3)	Location L-4 Actual % Reduction	Mean % Reduction (positive data)
Rad Alpha Spec Analysis														
Thorium-228		27.3	4.35	84%	9.76	0.6	94%	93.6	3.97	96%	29.7	25.2	15%	72
Thorium-230		4.06	0.824	80%	6.22	0.88	86%	16.6	0.731	96%	3.83	2.34	39%	75
Thorium-232	2.99/4.76	13.9	1.9	86%	5.28	0.31	94%	50.4	1.58	97%	13.6	12.9	5%	71
Uranium-234	1492/6219	1.43	0.273	81%	2.94	0.621	79%	13.5	0.503	96%	1.86	0.745	60%	79
Uranium-235/236		0.17	0.0157	91%	0.667	0.0674	90%	2.01	0.0629	97%	0.274	0.313	-14%	93
Uranium-238	288/1346	1.62	0.264	84%	2.31	0.459	80%	13	0.659	95%	1.2	0.623	48%	77
Rad Gamma Spec Analysis														
Bismuth-212		11	2.33	79%	1.52	0.445	71%	25.9	1.37	95%	17.4	18.2	-5%	81
Bismuth-214		8.16	0.519	94%	1	0	100%	13.2	0.231	98%	48.2	67.9	-41%	97
Radium-226	5./15	8.16	0.519	94%	1	0.372	63%	13.2	0.231	98%	48.2	67.9	-41%	85
Radium-228	5./15	12.4	0	100%	2.09	0	100%	26.6	1.55	94%	19.8	24.7	-25%	98
Thorium-234		0	2.26		1.61	2.04	-27%	20.5	1.09	95%	6.45	0.597	91%	93
Uranium-235		0.0289	0.491	-1599%	0.135	0.0379	72%	1.29	0.312	76%	0.547	0.181	67%	72

Samples used for this phase of the test were not separated by size and were not dried. They represent the actual field conditions better.

Table II. Three - Stage Treatment with 25% Nitric Acid

		Location L-1			Location L-2			Location L-3			Location L-4			
Parameter	PRG Conc. (Surface/Sub) (pCi/gm)	Conc. before treatment (pCi/gm)	After 3-stage treatment (25% HNO3)	Actual % Reduction	Conc. before treatment (pCi/gm)	After 3-stage treatment (3X25% HNO3)	Actual % Reduction	Conc. before treatment (pCi/gm)	After 3-stage treatment (25% HNO3)	Actual % Reduction	Conc. before treatment (pCi/gm)	After 3-stage treatment (25% HNO3)	Actual % Reduction	Mean % Reduction (positive data)
Rad Alpha Spec Analysis														
Thorium-228		30	2.97	90%	5.28	0.407	92%	40	2.95	93%	398	24.4	94%	92
Thorium-230		4.19	0.53	87%	3.53	1.04	71%	12.4	0.566	95%	28.5	2.2	92%	86
Thorium-232	2.99/4.76	12.6	1.35	89%	3.35	0.274	92%	20.2	1.2	94%	173	13.2	92%	92
Uranium-234	1492/6219	1.92	0.245	87%	3.57	0.297	92%	13.8	0.745	95%	2.93	0.691	76%	87
Uranium-235/236		0.118	0.0569	52%	0.238	0.161	32%	1.71	0.138	92%	0.0808	0.12	-49%	59
Uranium-238	288/1346	1.65	0.342	79%	3.41	0.258	92%	12.8	0.319	98%	3.39	0.893	74%	86
Rad Gamma Spec Analysis														
Bismuth-212		6.92	1.36	80%	2.57	0.0892	97%	23.4	3.05	87%	75.6	7.28	90%	89
Bismuth-214		5.75	0.311	95%	1.74	0.279	84%	5.34	0	100%	212	15	93%	93
Radium-226	5./15	5.75	0.311	95%	1.74	0.279	84%	5.34	0.543	90%	212	15	93%	90
Radium-228	5./15	7.16	0	100%	1.85	0	100%	24.5	3.38	86%	79.6	9.07	89%	94
Thorium-234		0.541	2.65	-390%	1.79	1.49	17%	9.91	0	100%	0	0.39	#DIV/0!	58
Uranium-235		0.499	0.228	54%	0	0	#DIV/0!	0.134	0.204	-52%	1.71	0.64	63%	58

Samples used for this phase of the test were not separated by size and were not dried. They represent the actual field conditions better.

Table III. Six - Stage Treatment with 15% Nitric Acid

Parameter	PRG Conc. (Surface/ Subsurf.) (pCi/gm)	Location L-1 (15% HNO3) Conc. before treatment (pCi/gm)	L-1 After 2-stage treatment	L-1 After 4-stage treatment	L-1 After 6-stage treatment	L-1 Actual % Reduction	Location L-2 (15% HNO3) Conc. before treatment (pCi/gm)	L-2 After 2-stage treatment	L-2 After 4-stage treatment	L-2 After 6-stage treatment	L-2 Actual % Reduction	Location L-3 (15% HNO3) Conc. before treatment (pCi/gm)	L-3 After 2-stage treatment	L-3 After 4-stage treatment	L-3 After 6-stage treatment	L-3 Actual % Reduction	Location L-4 (15% HNO3) Conc. before treatment (pCi/gm)	L-4 After 2-stage treatment	L-4 After 4-stage treatment	L-4 After 6-stage treatment	L-4 Actual % Reduction	Mean % Reduction (positive data)
Rad Alpha Spec Analysis																						
Thorium-228		21.9			2.17	90%	7.87			0.643	92%	39.2			6.1	84%	84.5			22.6	73%	85%
Thorium-230		3.22			0.701	78%	5.11			0.769	85%	9.62			1.02	89%	7.96			1.65	79%	83%
Thorium-232	2.99/4.76	11.7			0.512	96%	4.13			0.575	86%	21.4			1.98	91%	37.2			8.42	77%	87%
Uranium-234	1492/6219	1.39			0.418	70%	3.84			0.199	95%	10.3			0.276	97%	2.21			0.497	78%	85%
Uranium-235/236		0.045			0.0756	-68%	0.254			0.0549	78%	0.537			0.107	80%	0.426			0.0568	87%	82%
Uranium-238	288/1346	1.27			0.0473	96%	3.05			0.207	93%	10.7			0.276	97%	1.95			0.593	70%	89%
Rad Gamma Spec Analysis																						
Bismuth-212		13	9.92	17.4	0.845	94%	3.97	0.73	3.33	1.39	65%	24.5	6.56	12.1	2.48	90%	42.5	19.8	26.7	10.9	74%	81%
Bismuth-214		8.16	3.66	3.29	0	100%	1.19	0.263	0.511	0	100%	7.43	2.44	1.54	0	100%	92.7	49.6	41.8	20.6	78%	94%
Radium-226	5./15	8.16	3.66	3.29	0.438	95%	1.19	0.263	0.511	0.226	81%	7.43	2.44	1.54	0.443	94%	92.7	49.9	41.8	20.6	78%	87%
Radium-228	5./15	13.4	6.68	2.7	0	100%	3.52	1.08	0	0.705	80%	27.2	11.6	9.54	1.7	94%	41.2	27.2	19.1	9.5	77%	88%
Thorium-234		2.27	6.26	3.56	0	100%	2.61	0.92	1.15	1.38	47%	14.4	0.709	0.523	-0.318	102%	2.16	2.2	0.175	1.05	51%	75%
Uranium-235		-0.178	0.0322	0.113	0.2	212%	0.0321	0.181	0.324	0.0743	-131%	0.688	0.0302	-0.103	0.303	56%	1.14	1.06	0.612	0.38	67%	61%

Samples used for this phase of the test were not separated by size and were not dried. They represent the actual field conditions better.

Table IV. Six - Stage Treatment with 25% Nitric Acid

		Location L-1 (25% HNO3)					Location L-2 (25% HNO3)					Location L-3 (25% HNO3)					Location L-4 (25% HNO3)					
Parameter	PRG Conc. (Surface/ Subsurf.) (pCi/gm)	Conc. before treatment(pCi/gm)	After 2-stage treatment	After 4-stage treatment	After 6-stage treatment	Actual % Reduction	Conc. before treatment(pCi/gm)	After 2-stage treatment	After 4-stage treatment	After 6-stage treatment	Actual % Reduction	Conc. before treatment(pCi/gm)	After 2-stage treatment	After 4-stage treatment	After 6-stage treatment	Actual % Reduction	Conc. before treatment(pCi/gm)	After 2-stage treatment	After 4-stage treatment	After 6-stage treatment	Actual % Reduction	Mean % Reduction (positive data)
Rad Alpha Spec Analysis																						
Thorium-228		39.1			1.28	97%	5.86			3.16	46%	27.5			5.65	79%	100			21.6	78%	75%
Thorium-230		5.71			0.8	86%	4.71			1.13	76%	17.9			1.09	94%	9.96			1.7	83%	85%
Thorium-232	2.99/4.76	18.5			0.524	97%	3.08			1.45	53%	14.4			1.87	87%	40.6			8.75	78%	79%
Uranium-234	1492/6219	1.61			0.217	87%	4.64			0.548	88%	17.9			0.273	98%	5.02			0.591	88%	90%
Uranium-235/236		0.326			0.0368	89%	0.204			-0.00742	104%	1.19			0.00136	100%	0.372			0.0468	87%	95%
Uranium-238	288/1346	1.58			0.123	92%	3.95			0.28	93%	17.4			0.298	98%	4.5			0.842	81%	91%
Rad Gamma Spec Analysis																						
Bismuth-212		19.3	5.1	10.7	0.894	95%	2.87	1.93	1.39	2.05	29%	17.5	5.36	11.5	2.12	88%	42.4	23.5	20	4.69	89%	75%
Bismuth-214		16.4	1.78	0	0.165	99%	1.69	0	0.234	0.052	97%	11.3	1.28	0	0	100%	96.2	20.4	21.9	12.1	87%	96%
Radium-226	5./15	16.4	1.78	2.48	0.165	99%	1.69	0.619	0.234	0.052	97%	11.3	1.28	0.8	0.473	96%	96.2	20.4	21.9	12.1	87%	95%
Radium-228	5./15	21.2	3.22	3.84	0.377	98%	3.47	0.375	1.13	0	100%	16.4	6.98	6.36	1.49	91%	43.5	14.6	10.9	4.64	89%	95%
Thorium-234		1.33	0	0	1.14	14%	2.24	1.23	1.53	0.534	76%	13.3	0.543	5.65	1.4	89%	5.58	2.3	2.38	0.972	83%	66%
Uranium-235		0.642	0.273	0	0.0257	96%	0.412	0.22	0.142	0.143	65%	1.43	0.0836	0.316	0.226	84%	0.888	2.03	0.845	0.374	58%	76%

Note: Samples used for this phase of the test were not separated by size and were not dried. They represent the actual field conditions better.

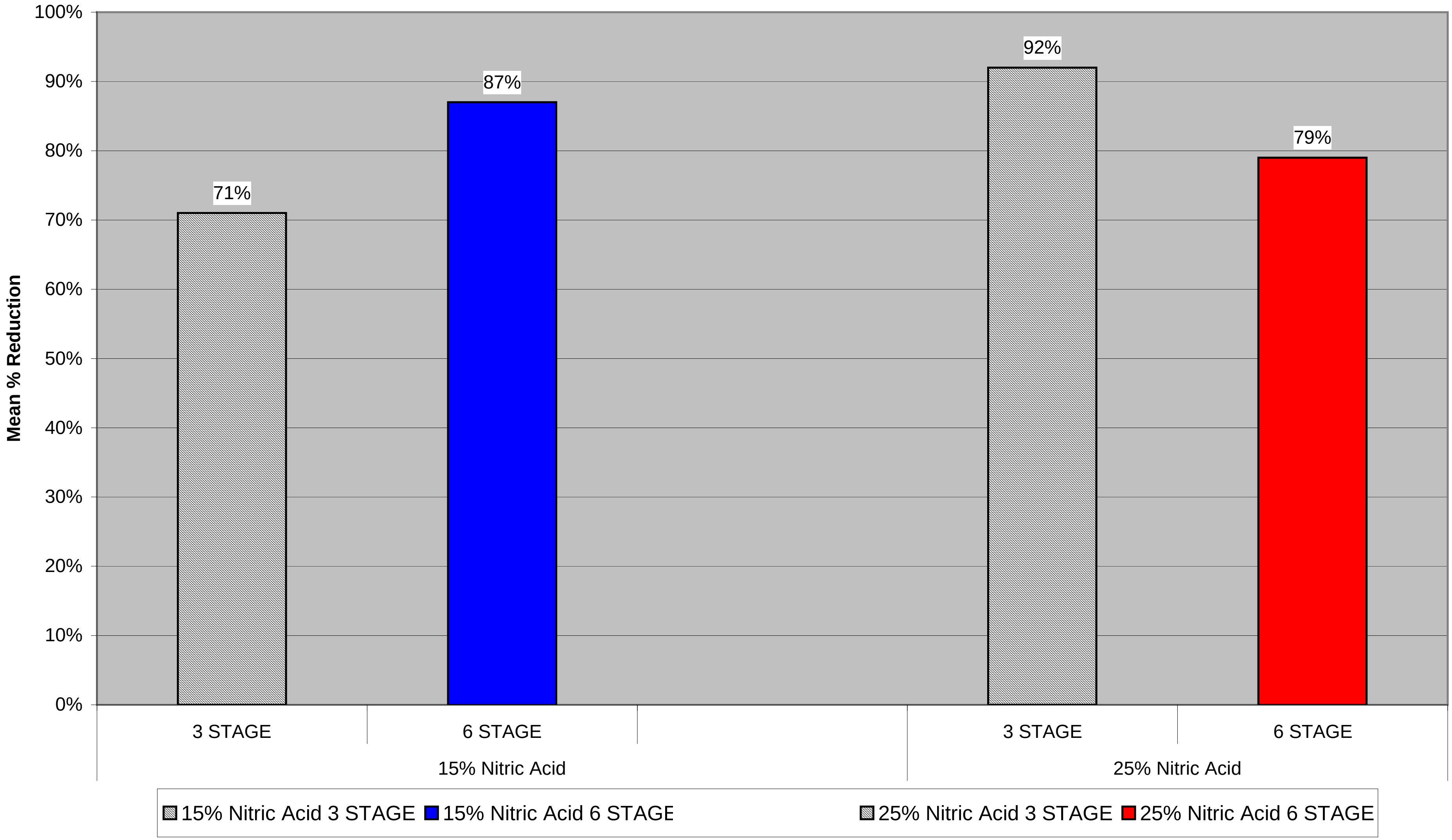

Fig. 2. Treatment efficiency of Thorium-232 in soil as a function of acid concentrations and number of stages

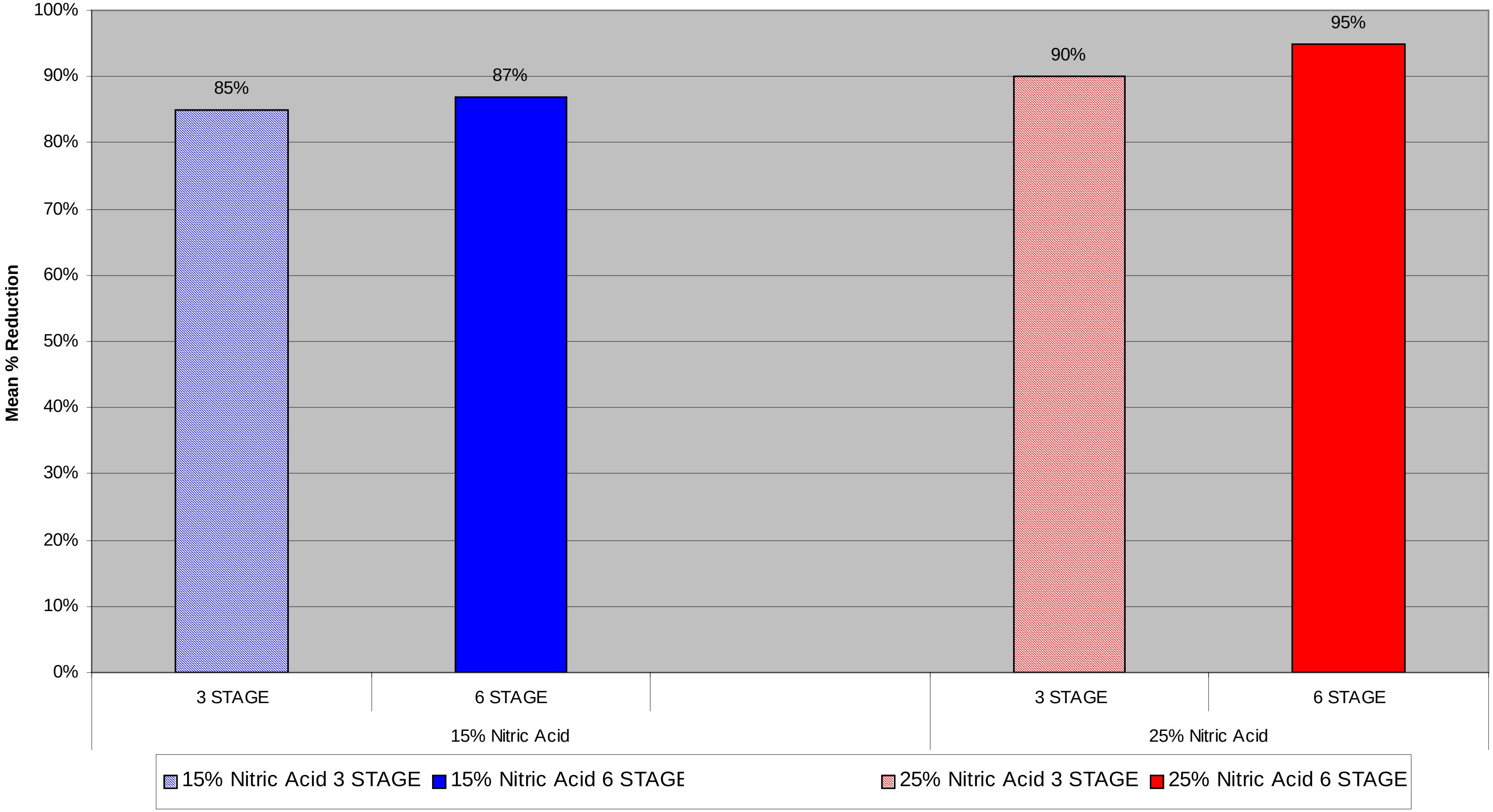

Fig. 3. Treatment efficiency of Radium 226 in soil as a function of acid concentrations and number of stages

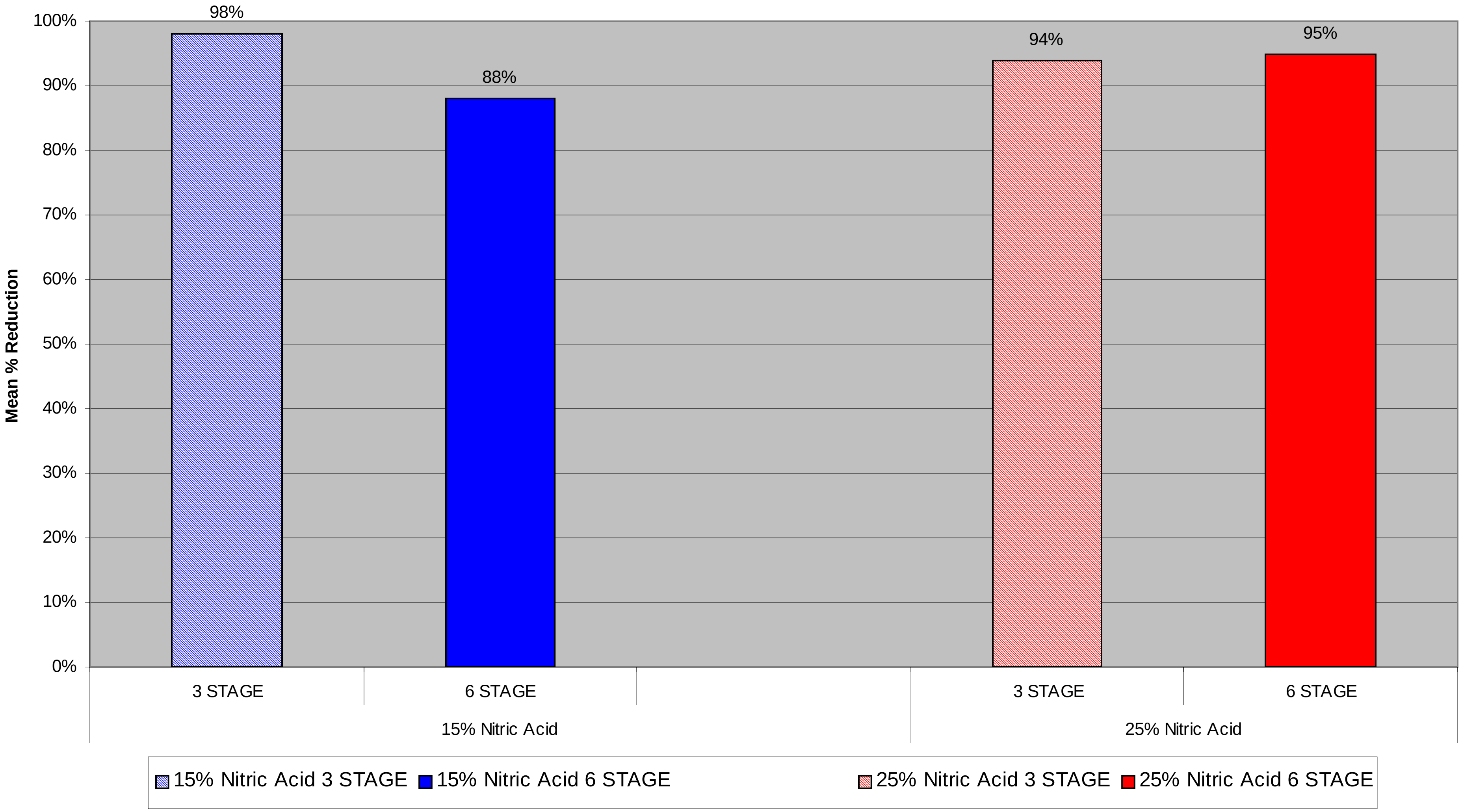

Fig. 4. Treatment efficiency of Radium-228 in soil as a function of acid concentrations and number of stages

Table V. Leachate Treatment Efficiency of Various Combinations of Resins

Resin Combination	Stage 1 Treatment	Stage 2 Treatment	Stage 3 Treatment	% Removal of Total Activity
I	Cation (Type A)			33
II	Cation (Type A)	Cation (Type B)		93
III	Cation (Type A)	Anion (Type B)		69
IV	Anion (Type C)			40
V	Cation (Type D)			43
VI	Anion (Type C)	Cation (Type D)		85
VII	Mixed Bed (Type E)			57
VIII	Anion (Type C)	Cation (Type D)	Cation (Type B)	79
IX	Mixed Bed (Type E)	Cation (Type A)		85
X	Mixed Bed (Type E)	Cation (Type A)	Cation (Type B)	98

DISCUSSIONS OF THE RESULTS

Soil Treatment Efficiency

It is noted generally that there has been substantial reduction in the concentrations of all species using both 15% nitric acid and 25% nitric acid. The reduction in concentration has been almost consistent across all COC. Though the six-stage process seems to provide a slightly greater reduction in the concentration, its difference from the three-stage process is minimal.

A small percentage (about 5%) of the samples show that the reduction in the concentrations do not conform with the other results – in some cases they are even higher than the initial concentration. This could have resulted from the non-homogenous nature of the soil. Soil taken for the initial concentration was subject to both alpha and gamma spectroscopic analysis and was destroyed in the process. It could not be used for conducting subsequent tests. Another aliquot was taken from the same batch of soil for conducting the subsequent tests, which in some cases may have had different concentrations.

- **Reduction in the Thorium-232 Concentration**

It was observed that the average reduction in the concentration of thorium-232 is approximately 71% using 15% nitric acid in a three-stage system. In a six-stage system the reduction was about 87%. Similarly using 25% nitric acid, the reduction in a three-stage system was 92% and in a six-stage system was 79% (apparent lower efficiency in the six-stage system can be attributed to non-homogenous nature of the soil – it is suspected that the initial concentration of Th-232 in the soil aliquot used for treatment was higher than that in the aliquot used for analyzing initial concentrations).

- **Reduction in the Radium-226 Concentration**

It was observed that the average reduction in the concentration of radium-226 is approximately 85% using 15% nitric acid in a three-stage system. In a six-stage system the reduction was about

87%. Similarly using 25% nitric acid, the reduction in a three-stage system was 90% and in a six-stage system was 95%.

- **Reduction in the Radium-228 Concentration**

It was observed that the average reduction in the concentration of radium-228 is approximately 98% using 15% nitric acid in a three-stage system. In a six-stage system the reduction was about 88%. Similarly using 25% nitric acid, the reduction in a three-stage system was 94% and in a six-stage system was 95%. (Slight aberrations in efficiency of the systems can again be attributed to non-homogenous nature of the soil – it is suspected that the initial concentration of the soil aliquot used for treatment in some cases was higher than in the aliquot used for analyzing initial concentration).

- **Reduction in Uranium-233/234 Concentration**

The initial concentrations of all U-234 samples were lower than the PRG. Subjecting the soil to treatment, it was observed that the average reduction in the concentration of U-234 is approximately 79% using 15% nitric acid in a three-stage system. In a six-stage system the reduction was about 85%. Similarly using 25% nitric acid, the reduction in a three-stage system was 87% and in a six-stage system was 90%.

- **Reduction in Uranium-238**

The initial concentrations of all U-238 samples were lower than the PRG. Subjecting the soil to treatment, it was observed that the average reduction in the concentration of U-238 is approximately 77% using 15% nitric acid in a three-stage system. In a six-stage system the reduction was about 89%. Similarly using 25% nitric acid, the reduction in a three-stage system was 86% and in a six-stage system was 91%.
(Note: results are taken from alpha spec analysis because of its greater accuracy).

- **Selection of Acid and Stage Combination for Pilot Study**

Considering all the COC, the average treatment efficiencies for the various combinations of treatment are given below:

Three-stage treatment with 15% nitric acid = 82% reduction
Three-stage treatment with 25% nitric acid = 90% reduction
Six-stage treatment with 15% nitric acid = 87% reduction
Six stage treatment with 25% nitric acid = 90% reduction

In order to optimize the system in terms of reduction in COC, cost and operational safety, a **three-stage system with 15% nitric acid** was selected as an optimum system. A higher number of stages and acid concentrations improve efficiency only marginally but cost more in terms of equipment and chemicals. A higher concentration of acid also increases health hazards.

Estimated Volume of Soil that can be Treated Using the System

Considering, an average of 82% reduction in concentration of the COC, the treatment system should be able to treat soils that have concentrations given in Table VI and be able to reduce the concentrations of the treated soils to below PRGs.

Table VI. Concentration Upper Limits for Three-Stage, 15% Nitric Acid Treatment System

Parameter	PRG Conc. (Surface/Sub) (pCi/gm)	Concentration Upper Limit (pCi/gm)
Thorium-232	2.99/4.76	16.6
Uranium-233/234	1492/6219	8,288
Uranium-238	288/1346	1,600
Radium-226	5./15	27.8
Radium-228	5./15	27.8

For this treatability study, soil samples were taken from locations with the highest COC concentration, according to the RI report. Table 7 shows expected treatment results at these locations using mean soil concentrations.

Table VII. Expected Treatment Results Using Three-Stage System with 15% Nitric Acid

(Treatment Efficiency = 82% reduction in the concentrations of the COC)

Concentrations in pCi/gm

		Location L-1			Location L-2			Location L-3			Location L-4		
Parameter	PRG Conc. (Surface/Sub)	Conc. before treatment (Mean)	Conc. after Expected Reduction of 82%	Below PRG?	Conc. before treatment (Mean)	Conc. after Expected Reduction of 82%	Below PRG?	Conc. before treatment (Mean)	Conc. after Expected Reduction of 82%	Below PRG?	Conc. before treatment (Mean)	Conc. after Expected Reduction of 82%	Below PRG?
Thorium-232	2.99/4.76	14.2	2.56	Yes	2.96	0.533	Yes	26.6	4.79	No	66.1	11.90	No
Uranium-233/234	1492/6219	1.6	0.29	Yes	3.75	0.675	Yes	13.8	2.48	Yes	3	0.54	Yes
Uranium-238	288/1346	1.5	0.27	Yes	3.18	0.572	Yes	13.5	2.43	Yes	2.76	0.50	Yes
Radium-226	5./15	9.6	1.73	Yes	1.41	0.254	Yes	6.81	1.23	Yes	112.3	20.21	No
Radium-228	5./15	13.5	2.43	Yes	2.73	0.491	Yes	23.7	4.27	Yes	46	8.28	No

Leachate Treatment Efficiency

Results show that resins can treat the leachate for recycling into the system. The process of leachate treatment will concentrate the COC into a small volume in resin columns. A two-stage treatment can reduce concentration Total Activity in the leachate by 93% and a three-stage system can reduce it by 98%. *Total Activity is a liquid scintillation screening procedure that is used to measure radioactivity in a sample. The measurement taken is for all energy levels available for the liquid scintillation counter. Alpha and beta radiation are detected at screening levels and detection limits are not as sensitive as specific isotopic analysis. One advantage of the technique is that all low and high energy beta emitters, volatile and non-volatile, can be detected.*

CONCLUSION

Acid leaching tests for extraction were conducted on soils to evaluate the effectiveness of treatment under various conditions including: strength of the acid, addition of heat, addition of common ion salt, multi-stage extraction and grain size. Tests were also conducted to evaluate the efficiency of treating leachate using ion exchange resins. It was observed that:

- Nitric acid is able to effectively remove the radionuclides from the soils.
- A treatment efficiency of over 80% can be achieved using 15% nitric acid in a 3-stage system.
- A treatment efficiency of over 85% can be achieved using 15% nitric acid in a 6-stage system.
- A treatment efficiency of over 90% can be achieved using 25% nitric acid in a 3-stage system.
- A treatment efficiency of over 90% can be achieved using 25% nitric acid in a 6-stage system.
- A 2-stage leachate treatment process using ion exchange can reduce the total activity by 93%.
- A 3-stage leachate treatment process using ion exchange can reduce the total activity by 98%

REFERENCES

1. EPA. 1989. Innovative Technologies: Soil Washing, OSWER Directive 9200.5-250FS.
2. EPA. 1989. Soils Washing Technologies for: Comprehensive Environmental Response, Compensation, and Liability Act, Resource Conservation and Recovery Act, Leaking Underground Storage Tanks, Site Remediation.
3. EPA, 1990. Soil Washing Treatment. Engineering Bulletin, EPA, OERR, Washington, D.C. EPA/540/2-90/017. Available from NTIS, Springfield, VA. Order No. PB91-228056.
4. EPA, 1991. Biotrol Soil Washing System. EPA RREL, series includes Technology Evaluation Vol. I, EPA/540/5-91/003a, PB92-115310: Technology Evaluation Vol. II, Part A, EPA/540/5-91/003b, PB92-115328: Technology Evaluation Vol. II, Part B, EPA/540/5-91/003c, PB92-115336: Applications Analysis, EPA/540/A5-91/003; Technology Demonstration Summary, EPA/540/A5-91/003; and Demonstration Bulletin, EPA/540M5-91/003.
5. EPA, 1992. Bergmann USA Soil/Sediment Washing System, EPA RREL, Demonstration Bulletin, EPA/540/MR-92/075.
6. EPA, 1997. Best Management Practices (BMPs) for Soil Treatment Technologies: Suggested Operational Guidelines to Prevent Cross-media Transfer of Contaminants during Clean-up Activities, EPA OSWER, EPA/530/R-97/007.
7. Raghavan, R., D.H. Diez, and E. Coles.1988. Cleaning Excavated Soil Using Extraction Agents: A State of the–Art Review, EPA Report, EPA 600/2-89/034.
8. INEL-96/0273. 1997. Biagi, C. Integrated Non-thermal Treatment System Study.
9. Krstich, M.A. 1995. The Integration of Innovative Technologies into a Physical-Separation-Based Soil Washing System. Fernald Environmental Restoration Management Corporation Report No. FEMP-2410, U.S. DOE.
10. Musich, M.A. 1997. Systems Analysis of Environmental Management Technologies. DOE/MC/31388-5766.

11. Baylock, B. P. 1995. U. S. Department of Energy Worker Health Risk Evaluation Methodologies for Assessing Risks Associated with Environmental Restoration and Waste Management. ORNL 6833.

12 DOE/EM-0282. 1995. Description of recommended non-thermal mixed waste treatment technologies: Version 1.0.

13. ORNL/TEM –13201. Evaluation of the Act-De-Con^R Process for Treating tank Sludge, NTIS, Springfield, VA.

14. DOE/MC/30097. 1997. W.E. Schwinkendorf . Comparison of Alternative Treatment System for DOE Mixed Low-Level Waste. Idaho National Engineering Laboratory. Lockheed Martin Idaho Technology Company. Idaho.

15. DOE/MC/30097-5162. 1996. Rindt, J. R. Mixed Waste: Topical Report : April 1994-Sept.1995.

16. Technical Reports from Argonne National Laboratory, Environmental Assessment Division, Chicago.

17. Technical Reports from National Council on Radiation Protection and Measurement.

18. Technical Reports from Nuclear Regulatory Commission.*Directives and Orders from U.S. Department of Energy.

19. Perry, R.H., and C. H. Chilton (Eds). Chemical Engineers’ Handbook, Fifth Ed. McGraw-Hill Book Company, New York.

20. Corbitt, R. A. (Ed.). Standard Handbook of Environmental Engineering. McGraw-Hill Book Company, New York.

21. Rossiter, A.P. (Ed.). Waste Minimization through Process Design. McGraw-Hill Book Company, New York.