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Particle size separation via soil washing to obtain volume reduction

Ron Anderson [a,*], Elizabeth Rasor [b], Frank Van Ryn [b]

[a] *Bechtel Jacobs Co., P.O. Box 4699, Oakridge, TN 37831-7583, USA*
[b] *Lockheed Martin Energy Systems, USA*

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Abstract

A pilot-plant study was performed using a soil washing pilot plant originally designed by the Environmental Protection Agency (EPA) to demonstrate scale-up and potential full-scale remediation. This pilot plant named VORCE (Volume Reduction/Chemical Extraction) was modified to meet the specific requirements for treatment of the Formerly Utilized Sites Remedial Action Program (FUSRAP) and a Department of Energy site soils. After a series of tests on clean soils to develop operating parameters and system performance, the machine was used to treat soils, one contaminated with Thorium-232 and the other with Cesium-137. All indicate that soil washing is very promising for volume reduction treatment. In addition, cost data was generated and is given herein. © 1999 Published by Elsevier Science B.V. All rights reserved.

Keywords: Soil washing; Contaminants; Volume reduction

1. Introduction

The Department of Energy's (DOE) Formerly Utilized Remedial Action Program (FUSRAP) consists of 46 sites in 14 states. These sites were originally used for manufacture or processing of ores and metals for support of the nation's early atomic energy programs. FUSRAP sites contain large volumes of soils (and other media) contaminated by low-level radioactive contaminants particularly, thorium, radium and uranium, and in some instances, metals and other hazardous contaminants. Two sites were selected for soil pilot testing based upon successful laboratory studies [1].

* Corresponding author.

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The Maywood site includes an 11.7 acres site and 87 vicinity properties contaminated by the processing of thorium ores by the Maywood Chemical Works. The Maywood Interim Storage Site also contains the Maywood pile, which was generated by the clean-up of 25 vicinity properties. The original pile contained 35 000 $yard^3$ of contaminated soil.

The Oak Ridge Y-12 soil consists of 250 tons of railroad ballast contaminated with Cesium-137 (Cs-137) as it was removed from the railroad tracks near the DOE's Y-12 plant in Oak Ridge, as part of the environmental restoration effort for the reservation. This material comprised of local soils, gravel, and ballast is commonly referred to as CSX soil. It has been stored in B-25 boxes awaiting disposal.

Treatment options for these contaminated soils are limited. Options are: (1) leave in place with either institutional controls and/or engineered controls, (2) remove and dispose in an approved disposal facility or (3) treat to reduce the volume. The first option has potential for community resistance; option two is expensive; and option three has only limited data to support its selection. From characterization studies of site soils, several of the large volume sites have been identified as potential candidate sites amenable to treatment using soil washing technology.

The original concepts of soil washing have their history in the mining and metals industries. Mining processes have been used for years to concentrate metal particles for extraction as metal concentrates. Much of this equipment, i.e. trommels, screw classifiers, attrition mills, hydrocyclones, etc. originated in the mining industry [2].

Soil is comprised of various particle size fractions and most often, the contaminants are concentrated in one size fraction. In many situations, this fraction is the finer silts and clays (50 μm or less). Removal of this fraction facilitates the potential for volume reduction and cheaper disposal costs. Increased surface area, cationic exchange potential, and the innate shape of these particles are important in the attraction of contaminants to the fine fraction.

Soil washing separates soils by particle sizes producing clean and contaminated fractions, using water as the fluidizing media. The clean fractions can be recombined, augmented if required and used as backfill. The contaminated fraction concentrated in a smaller volume can be shipped to an approved disposal facility for final disposition. Clean streams, by FUSRAP standards, are normally site-dependent, but 5/15 pCi/g above background is normally accepted, with 5 pCi/g for residential area soils and 15 pCi/g for industrial area soils. Soils contaminated by Cs-137 were not considered a significant hazard if below 50 pCi/g, and were left on-site with unrestricted use. Results obtained from the two test campaigns are discussed in this article.

2. Soil washing process and description

The term soil washing is most often used to describe a series of treatment operations that either separate soils into their various particle size fractions using water (or chemicals as the carrier medium) or chemically extract the contaminant from the soil matrix. The VORCE soil washing pilot plant is strictly physical particle size separation

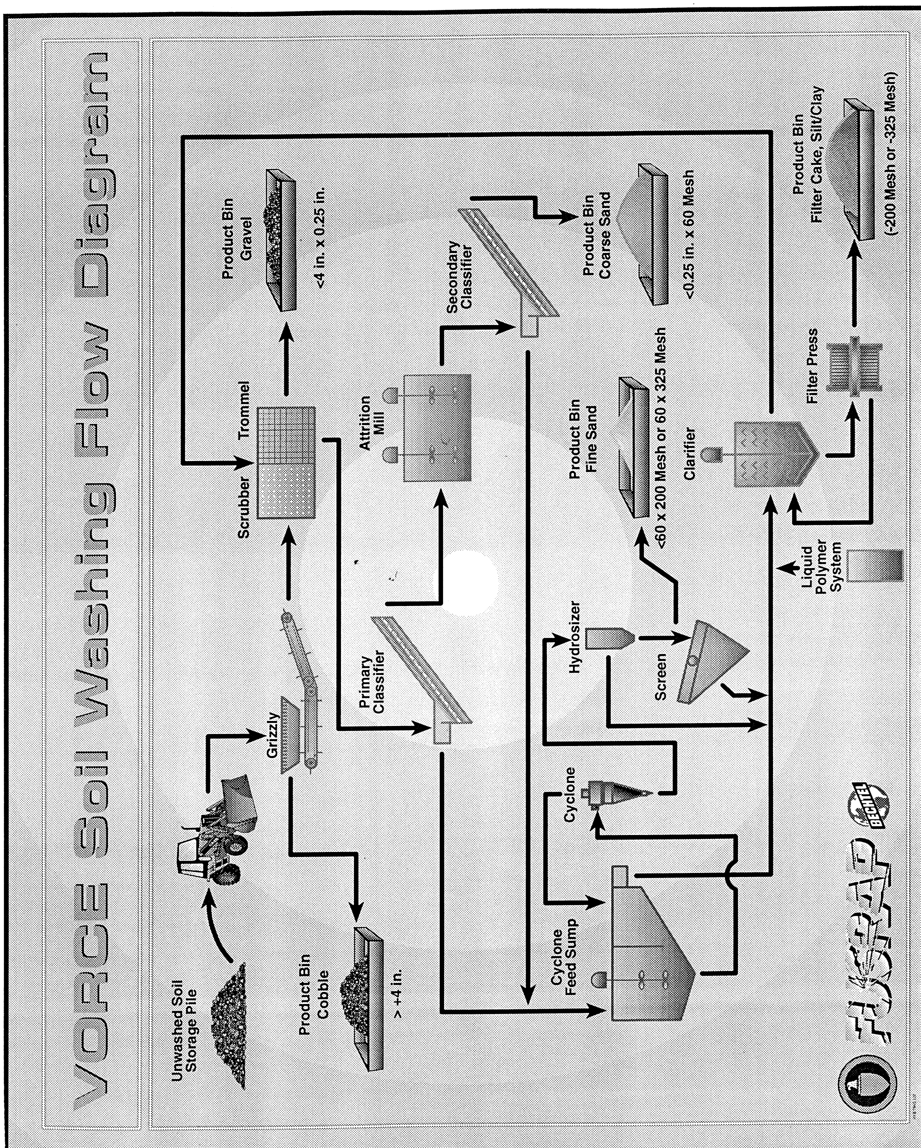

Fig. 1. Schematic of the soil washing process.

using water as the carrier medium. The VORCE plant uses a series of unit operations to physically deagglomerate the soil and separate it into specific size fractions.

Fig. 1 shows a schematic of the process. A description of the process is as follows: soil is loaded onto either a 2-in. or 4-in. grizzly. The oversize material is removed by hand; the undersize passes through the grizzly into a feed hopper. The material in the feed hopper is fed, by a drag flite conveyor, to a trommel. In the trommel, deagglomeration of the soil particles occurs, and soil containing contaminants is washed from the large oversize particles. Soil particles (gravel) between 1/4-in. and 2 or 4 in. are washed clean using high-pressure sprays, and report to a discharge chute as a clean fraction. The undersize material reports to a screw classifier. The screw classifier separates soil particles based on Stokes Law [4]. Stokes Law states that a particle in a fluid settles at a rate that is the function of the particle's diameter. The smaller particles (with lower settling rates) overflow and are collected in a sump. A size cut of approximately 60 mesh (250 μm) is performed at the screw classifier. The larger particles are removed by a screw and dewatered. The 'coarse' sand is sent to an attrition mill where the action of the mill causes interparticle abrasion to remove adhered fines from the coarse sand particles. The soil discharges from the attrition mill to another screw classifier where another 60-mesh particle size cut is made. The overflow from the second screw classifier reports to the sump, and the underflow reports to a discharge bin as a clean fraction.

The fine products from the coarse size operations collected in the sump are pumped to a hydrocyclone. The hydrocyclone is used for two purposes: (1) to make a fine cut of 200 mesh (75 μm), and (2) to dewater the feed to the next unit operation. The fines overflow is collected in another sump, and the coarse underflow is fed to the hydraulic classifier. The hydraulic classifier is used for performing a fine cut between 200–325 mesh (75–45 μm). The hydrocyclone performs separations based upon centrifugal force, while the hydraulic classifier uses a combination of Stokes Law and hindered settling to make the cuts. The fines collected from the hydraulic classifier are collected in the same sump as those from the hydrocyclone. The coarse underflow fraction is fed to a dewatering screen. The screen oversize is collected as a clean product. The fines and water from the screen are collected in the same sump as the other fines fractions. These fines are flocculated using polymer and fed to a clarifier. The flocculated fines are collected in the bottom of the clarifier and the clear water overflows into the process make-up water tank, thus providing recycling of the water.

The sludge in the bottom of the clarifier is then pumped to a holding tank prior to feeding to a filter press for final dewatering. The filter cake contains the contaminated fines, and the filtrate is recycled back to the clarifier for reuse.

3. Soil characterization studies

As noted above, two soils were characterized to show if volume reduction by soil washing was viable. These soils were obtained from the Maywood Interim Storage Site pile and the Wayne Interim Storage Site pile. The data, shown in Fig. 2 for Maywood and Wayne show that volume reduction by particle size could produce volume reduc-

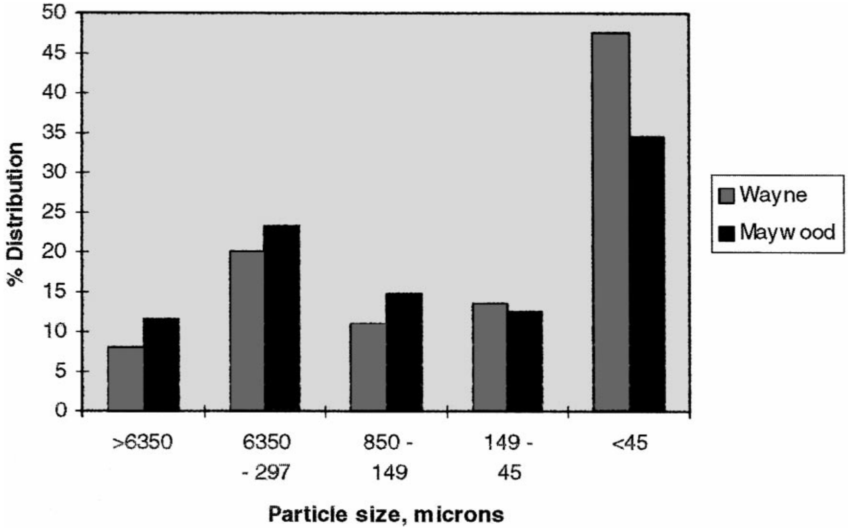

Fig. 2. Comparison of Maywood and Wayne soils.

tions in the 60–80% range depending upon the size fraction removed. Due to estimated total waste volumes, the Maywood site soils were selected for the demonstration.

Further studies performed by Oak Ridge National Laboratory (ORNL) also provided a soil sample from within the Oak Ridge reservation that also provided a soil with properties that would support soil washing as a volume reduction technology. This soil, the CSX soil, was railroad ballast and gravel contaminated with cesium from spills near

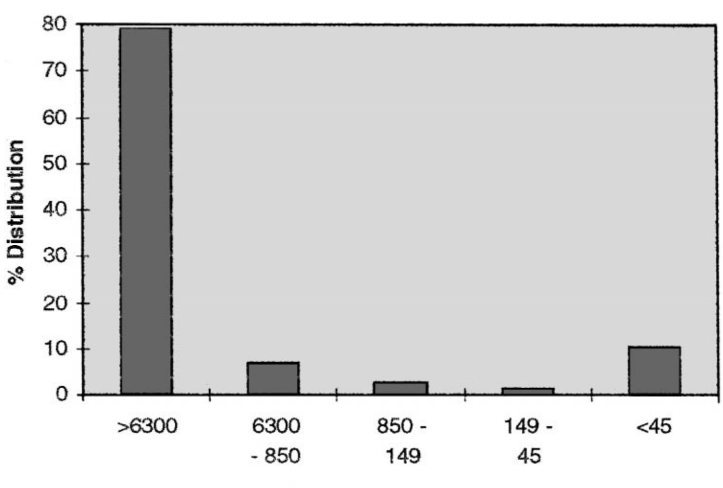

Fig. 3. Particle size distribution of CSX soils.

the rail yards on the Oak Ridge reservation. Fig. 3 shows the potential volume (mass) reduction that could be obtained with the CSX soil.

4. Pilot testing

In order to demonstrate soil washing on Maywood pile soil, approximately 100 tons of soil from the pile was loaded into six intermodal containers and shipped to Tennessee for testing. No intent was made to test all 100 tons, but contingency amounts were built into the quantity ordered. The test consisted of operational settings based upon ‘real-time’ experience, and allowing the machine to reach steady state prior to collecting samples of the feed and four output streams. Field adjustments were made as necessary to ensure proper performance. Four different series of samples were collected and analyzed for radiological content, and particle size. Isotopes of concern were Ra-226, Th-232, and U-238.

Soil was fed to the hopper using a front-end loader (Fig. 1). Oversize material, greater than 6 in., was removed by hand, as was any material collected on top of the grizzly. The feed soil sample was collected from each bucket for later compositing and mixing.

The feed rate was set at 704 lb/h vs. the design value of 2 tons/h for VORCE. This low rate was due to the mismatch in sizes of equipment, which limited the maximum quantity that can be fed to the machine without causing ‘sanding-out’ of the primary classifier. When ‘sanding-out’ occurs, the separation efficiency for that particular unit process is reduced from lack of settling height.

The processed material was collected and volumes recorded, as was feed, for mass balance information. Fractions collected were as follows: (1) $>1/4$-in., (2) $1/4$-in. to 60 mesh, (3) 60–200 mesh, and (4) <200 mesh.

Upon completion of the New Jersey soil tests, the VORCE machine was decontaminated and the test was repeated using the CSX soil. The CSX soils operations essentially duplicated the Maywood work. The process was identical and only minimal adjustments

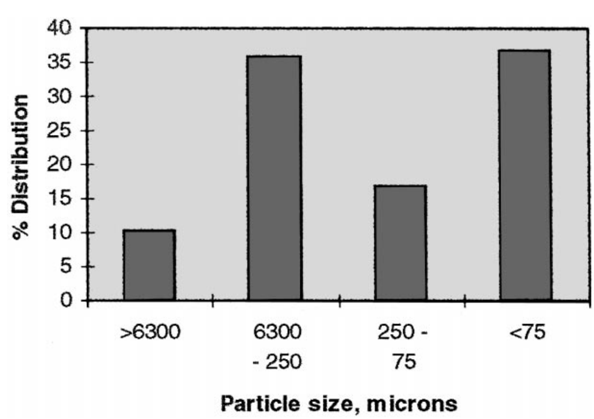

Fig. 4. Maywood test feed soil.

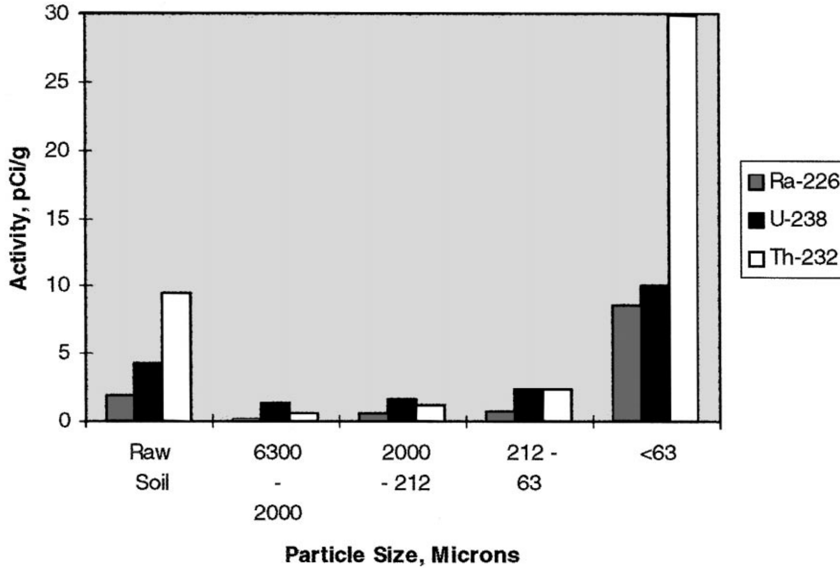

Fig. 5. Treated Maywood soil fractions.

were required on the process to obtain the desired cuts. Because of the greater quantity of coarse size fraction ($> 1/4$-in.), the feed rate was greater than twice that of the Maywood soils, without 'sanding-out' becoming a problem.

5. Results

Studies to date have been performed on the Maywood pile soils and the CSX soils. The studies incorporated running the machine at a steady state condition and collecting

Table 1
Mass balance Maywood soils

Stream	Mass (g)	Ra-226 activity (pCi/g)	Thorium-232 activity (pCi/g)	Combined Ra + Th (pCi/g)	Total activity (pCi)
Feed (input)	12 864 544.00	1.97	9.43	11.40	146 655 801.60
Gravel (output)	1 322 002.60	0.20	0.63	0.83	1 097 262.16
Sand (output)	4 563 154.00	0.54	1.22	1.76	8 031 151.04
Fine sand (output)	2 137 432.00	0.69	2.43	3.12	6 668 787.84
Silt/Clay (output)	4 670 979.00	8.57	29.80	38.37	179 225 464.23
Total outputs	12 693 567.60				195 022 665.27
Mass reduction	63.69%				
Mass recovery	98.67%				
Activity recovery	132.98%				

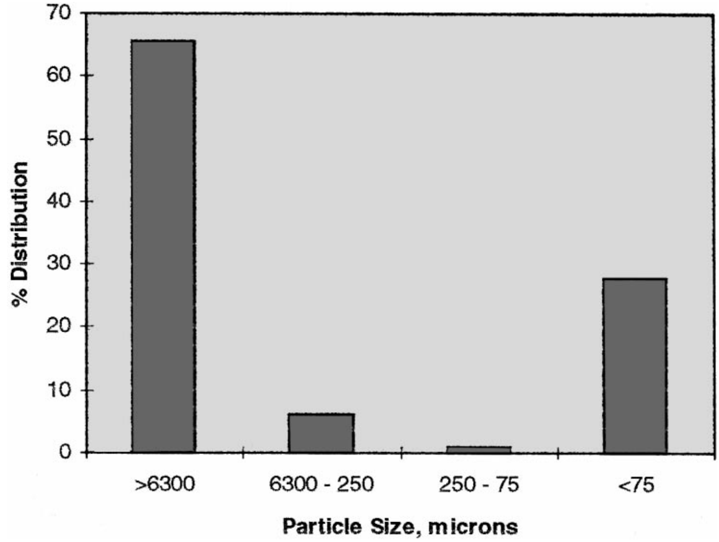

Fig. 6. CSX feed soil particle size distribution.

samples of the feed and all output streams; analyzing for radionuclides of concern and particle size. Data from the feed indicate a variation from the soil characterized in the previous bench scale work [1]. Fig. 4 shows the particle size distribution average for the feed soil to the plant during the Maywood study. Fig. 5 shows the average rad

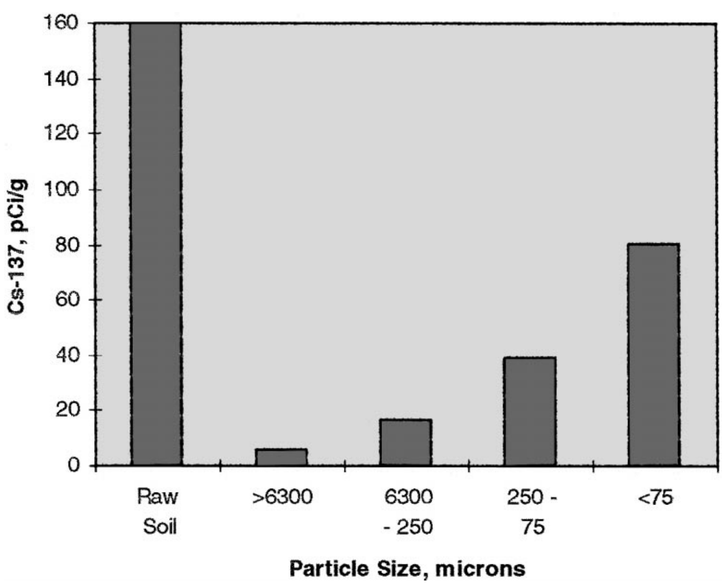

Fig. 7. Cs-137 distribution in treated fractions.

concentration by isotope for the feed soil and the mass reduction generated by the machine. The results of 98.67% mass recovery and 63.69% mass reduction track well with the theoretical results of the feed soil. Table 1 shows the mass balance and activity balance for the Maywood soils.

The CSX soil results data from the actual tests have shown that a 70% mass reduction is obtainable. A formal mass balance was not developed for the CSX soil as the mass reduction was determined from bin volumes. Fig. 6 shows the particle size distribution for the CSX feed soil. Fig. 7 shows the Cs-137 concentration of the feed soil and in the various fractions after treatment. One of the more surprising findings was that the Cs-137 was not water-soluble, especially since the cause of contamination was a soluble cesium spill.

Cost data was recorded and an order of magnitude estimate based for a 20 tons/h unit based upon volumes to be treated are shown in Table 2. Costs were projected using data collected from the VORCE tests and published information on soil washing costs [3]. The cost estimate is based upon treatment of 50 000 tons of contaminated material.

Table 2
Costs for full-scale remediation using soil washing

Item	20 tons/h (full-scale)
Utilities	US$222 950
Equipment rental	US$251 000
Labor	US$1 060 200
Health physics technician	US$216 000
Sample analysis	US$78 000
Consumables	US$155 256
Mob/Demob/Equipment	US$150 000
Shipping/disposal of wastes	US$4 702 800
Treated soil preparation for disposal	US$20 000
Site preparation	US$90 000
Subtotal	US$6 946 206
Total including 25% contingency	US$8 682 758
Cost/ton (including disposal)	US$134

Assumptions:
- A health and safety representative is assigned to the project.
- Treated clean soil will be disposed on-site by others.
- Treated contaminated soil will be transported by rail at a commercial radioactive disposal facility.
- Soil density is 1.3 tons/yard^3.
- On-line percentage of 90% (20 h/day) using a 20-ton/h machine
- Permit requirements are minimal.
- Three samples will be collected per week for the duration of the project.
- National Pollutant Discharge Elimination System (NPDES) permit exists at the site, allowing the process water to be disposed at a publicly owned treatment works at project completion.
- Power will be supplied by a source at the site by others.
- Mobilization and Demobilization will require two weeks each.
- Extra equipment shall be necessary, i.e., front-end loader, fork truck, and crane.
- Costs do not include excavation.

Bergmann [3].

It should be noted that this estimate is applicable for only the waste streams discussed herein, using simple particle size separation for volume reduction. No implication should be made that these costs hold true for other waste streams.

6. Conclusions

Initial tests indicated that soil washing is promising for certain FUSRAP sites, and the Y-12 CSX soils. Sites with characteristics that show particle size separation and can produce volume reduction are amenable to this treatment process, and could produce cost savings over direct disposal.

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