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Full-scale and pilot-scale soil washing

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Abstract

The purpose of this paper is to describe soil washing and to present results obtained from pilot-scale and full-scale projects. The soil washing system to be described is a water-based physical separation process which relies on traditional physical and chemical extraction and separation processes for removing a broad range of organic, inorganic, and radioactive contaminants from soil. Although soil washing is becoming more accepted as a treatment technology in the United States, limited experience in field application still appears to be a barrier to more widespread implementation. This paper will attempt to overcome some of those barriers by describing the system and its applications, and providing case histories of successful experiences in full-scale and pilot-scale field operations. Both levels of operations have been very successful, and confirm the viability of soil washing for treating contaminated soils. © 1999 Published by Elsevier Science B.V. All rights reserved.

Keywords: Soil; Washing; Remediation; Metals; Radionuclides; Organics; Inorganics

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1. Introduction

The ART Division (formerly Alternative Remedial Technologies) was formed in 1990 as a joint venture of Geraghty and Miller, and Heidemij Realisatie of The Netherlands (now ARCADIS Geraghty and Miller and ARCADIS Heidemij Realisatie). The mission of the joint venture was to introduce the Heidemij soil washing technology to the USA. ARCADIS Geraghty and Miller is the U.S. operations of ARCADIS, NV (Arnhem, Netherlands), a global, full-service, environmental and infrastructure consulting, engineering and contracting firm.

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In 1992 ART signed its first contract for a soil washing remediation project at the King of Prussia Superfund site in Winslow, NJ. The contract called for remediation of 20 000 tons of soil contaminated with heavy metals. The project began in January 1992 with a soil washing treatability study, progressed to a demonstration run, a pilot run, and to full-scale operations, which began in July 1993, and were completed in October of the same year. That project was followed by more full-scale and pilot-scale soil washing projects for both private industry and government agencies.

2. The soil washing process

The soil washing process is a physical–chemical approach based on mining and mineral processing principles. For environmental/hazardous waste applications, this approach is very logical because the contaminants of concern will exist in specific particle fractions in reasonably predictable ways.

Soil is a natural mixture of mineral and organic particles and their weathered derivatives. Soils can be characterized quantitatively by constructing a particle-size distribution curve by simple wet sieving. A typical particle-size distribution curve is shown in Fig. 1a.

Three specific 'fractions' are important to soil washing: the *oversize* fraction consisting of materials larger than 5 mm, the *sand* fraction consisting of materials less than 5 mm and larger than approximately 63 μm (0.063 mm), and the *fines* consisting of materials smaller than 63 μm. In most cases, the contaminants will reside and be concentrated in the fines, while lower concentrations of the key contaminants often exist in the *sands* and the *oversize*.

To understand whether a particular contaminated soil is amenable to soil washing, representative samples from the site will be collected, wet sieving size classification performed, and the particle-size distribution curve constructed. Next, the materials retained on each of the sieves will be chemically analyzed for the contaminants of concern, as shown in Fig. 1b. The analytical results from this step are then overlain on the particle-size distribution curve. This information, coupled with existing site background information, will provide significant insight into the possible treatment scenarios, and thus the configuration of a soil washing system.

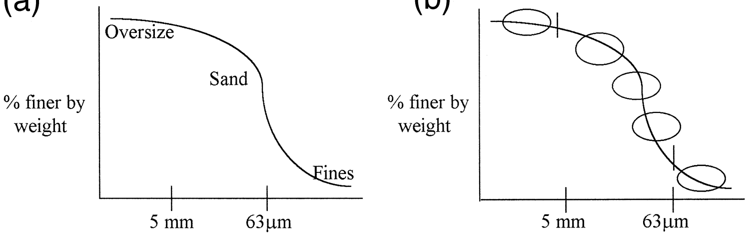

Fig. 1. (a) Particle size distribution curve. (b) Fractions for analysis.

2.1. Operations overview

The performance objectives are to treat the entire volume of contaminated soil at the site. Oversize materials are removed by various mechanical techniques, and the sand separated from the fines using hydrocyclone combinations. The sand is then treated, as necessary, with attritioners, flotation, and spiral concentrators, prior to dewatering. The oversize and the sand fractions are sampled and analyzed according to site-specific protocols, and after attainment of the treatment standards is confirmed, returned to the site as clean backfill. Concurrently, the fines are consolidated, and either dewatered into a sludge cake, or further treated using bioslurry or extraction methods.

The performance of a soil washing system will typically be measured by the volume reduction attained, and calculated by weighing by the clean products (the oversize and the sand) that meets the specified cleanup standards. Where:

$$\text{volume reduction }(\%) = 1 - \left(\frac{\text{feed soil (tons)} - \text{clean products (tons)}}{\text{feed soils (tons)}} \right)$$

The soil washing system is constructed of standard mining and material handling equipment. ART owns a 15 ton/h (tph) pilot plant, and a 25-tph production plant. Both plants are modular, and are therefore easily transported and erected. The pilot plant has a footprint of approximately 10 m × 15 m, while the full-scale plant has a corresponding footprint of approximately 20 m × 30 m. In both cases, these dimensions do not include the process feed pile or the product staging areas.

2.2. Site and feed preparation

In preparation for placement of the plant, the site will be graded and a process pad will be constructed where the full-scale plant is to be erected. A pad may not be required for the pilot plant, and in many cases existing pads can be modified for a cost-saving application. The process pad will include central sump and pump systems to control any process leaks or spills, and a curb to prevent runon or runoff. Commercial electrical power is normally the most effective way to run the plants, but mobile generators can be used if necessary. The 25 tph plant has approximately 1000 connected hp, requiring 3-phase, 440-V service. Process make-up water is required at approximately 50 to 100 l/min to support the plant, and can be provided from commercial service, from an installed well, or from stand-alone storage.

The plant is delivered to the site as the support systems are installed. The plants are modular, and are unloaded and erected using a standard 25-ton crane with extension boom. The pilot plant can be unloaded and erected in 2 days, and the full-scale plant can be unloaded and erected in 5 days.

3. Basic process concepts

The soil washing system is based upon proven principles and equipment from the mining and mineral processing businesses. The key to successful soil washing is partially in the arrangement and configuration of unit processes, but more importantly in the characterization and understanding of the soil matrix/contaminant relationship.

The approach to soil washing is simple: separate and treat the oversize and sand fractions so that they may be re-used as clean backfill, while concentrating the contaminants in the fines for further treatment or disposal. To accomplish this, the plants (both pilot and full-scale) consist of four major subsystems (Fig. 2):

- Mechanical and wet screening,
- Separation using hydrocyclones in circuits,
- Sand handling and treatment,
- Fines handling and treatment.

3.1. Mechanical and wet screening

A working pile is excavated in the field. The management of the excavation is extremely important, so that only contaminated soil is fed to the plant. This concept is called 'selective excavation'. This working pile must first be pre-screened to remove the Gross Oversize fraction. This will usually be accomplished using a hopper mounted with a vibrating 'grizzly', and a trommel screen to produce a plant feed pile of material $< 2''$ in diameter. Gross Oversize material is periodically removed from the hopper area and staged for recycling after meeting specified testing requirements. The plant feed is loaded into the apron feed hopper and weighed on the feed conveyor.

The feed soil is fed to the plant by conveyor and then to the wet screening module. Six high-pressure water spray headers are directed at the influent stream, breaking up small clods, rejecting the 'process oversize', and forming a < 2 mm slurry that is pumped to the separation sub-system. The process oversize, material > 2 mm, is staged outside the plant for confirmatory analysis that the treatment standard(s) are met before being returned to the site as backfill.

3.2. Separation using hydrocyclones in circuits

The heart of the soil washing system, and the area where extensive experience has been developed, is the creative use of hydrocyclones. Conceptually, the use of hydrocyclones is simple: the influent soil/water slurry is pumped to the cyclone and the slurry enters tangentially. In the cyclone, open to atmospheric pressure, the coarse-grained sands exit from the bottom, while the fine-grained materials and water are discharged from the top of the unit.

The hydrocyclones are manufactured with field-adjustable cones, barrels, and vortex finders such that the 'cut-point' interface between coarse and fine-grained materials can be modified to be consistent with treatment needs. This is extremely important in achieving the smallest possible volume of sludge cake requiring off-site disposal. The hydrocyclones can be arranged in many flow-path configurations, depending upon cut-point requirements and the objective of minimizing misplacement.

Depending upon the type of soil to be treated, it may also be beneficial to utilize gravity separation on either or both of the coarse/fines fractions. Typical applications might include the removal of a floating organic layer or, at the other end of the density spectrum, removing lead from the sand stream.

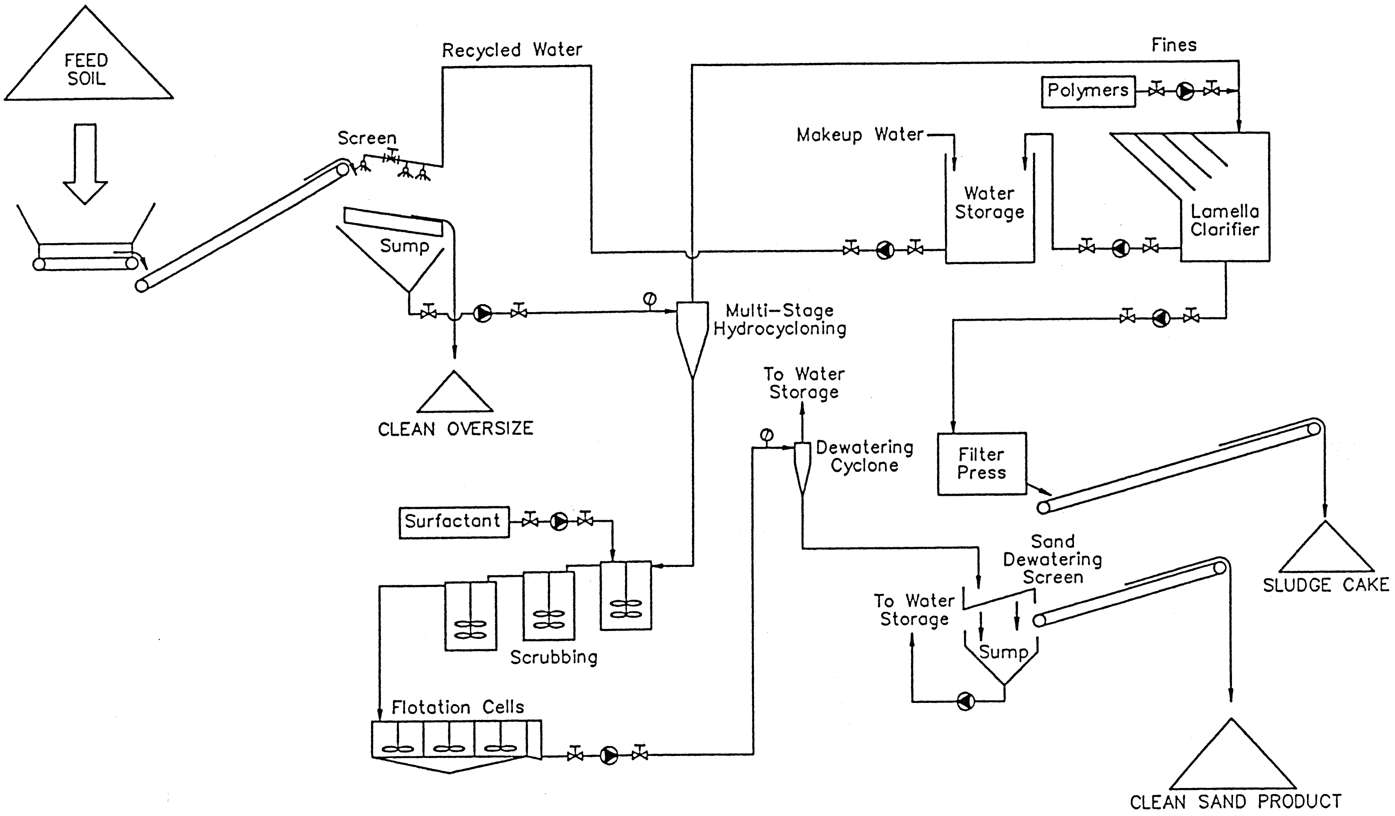

Fig. 2. Basic soil washing process flow diagram.

3.3. Sand handling and treatment

The underflow from the hydrocyclones contains the coarse-grained materials. When treatment is required for this fraction, it is typically accomplished using froth-flotation treatment units and/or gravity concentration. The decision to treat this fraction will be based upon the mode of contamination in the sand, either existing or as a particulate or coating. There may be a significant density difference between the contaminant and a sand particle. If so, spiral concentrators may be used to make this separation. If further treatment is required, froth flotation will be considered. If flotation is considered, the selection of a flotation surfactant is an important decision. The selection, made from scores of alternatives, has one objective: the surfactant, when contacted properly with the contaminant/soil mass, must reduce the surface tension binding the contaminant to the sand, render the contaminant/micelle structure hydrophobic, and allow the contaminants to ‘float’ into a froth which is then removed from the surface of the flotation cell. The selection of the appropriate surfactant is made during the treatability study, at the bench-scale level.

The froth flotation tank is a long, rectangular tank that uses mechanical aerators and diffused air for mixing. Retention time is typically about 30 min, but can be adjusted. The flotation units require operator experience to obtain optimal performance. Primary control parameters are surfactant dosing, slurry flow rate, air flow rate, and the sand retention time.

Two streams, the overflow froth, and the underflow sand, are the effluents from the treatment unit. The froth is concentrated and usually directed to the fines management subsystem. The underflow from the flotation unit (the sand) is directed to sand dewatering screens. The dry sand represents the ‘clean’ material that will be reused, with the water being recycled back to the wet screening section. The sand product is staged outside the plant where it is sampled and analyzed to confirm attainment of the treatment standards.

3.4. Fines handling and treatment

The overflow from the hydrocyclone, consisting of fine-grained materials and water, is now pumped to the fines management sub-system. The fines represent the most difficult fraction to treat, as a result of complex binding and speciation. It is normally feasible to simply treat the fines in a manner similar to a wastewater sludge by polymer addition, sedimentation, thickening, and dewatering. In some cases, it may be necessary to consider more sophisticated treatment. Upgraded treatment will depend upon the contaminants of concern, but may include biological degradation in slurry units or metals extraction.

In the primary case, the hydrocyclone overflow is pumped to the sludge thickeners consisting of lamella clarifiers. An appropriate polymer is selected in lab jar testing, and is dosed prior to introduction to the lamella. The clarified solids are thickened to approximately 15% dry solids, while the water overflow is returned to the wet screening area for reuse. The thickened solids are then pumped to a pressurized belt filter press. This unit is one of the most important in the entire process in terms of selection. The

15–20% solids influent is converted to a 45–55% dry solids filter cake. This cake contains the target contaminants and therefore must be managed by disposal at a properly permitted off-site disposal facility, depending upon the specific contaminants and their status in regard to current land bans.

3.5. Residuals management

An important decision that must be made in selecting a soil washing system is the manner in which the residuals from the treatment system will be managed. There are four primary residuals to be handled:

- Gross oversize (cobbles and debris $> 2''$);
- Process oversize (gravel $< 2''$ but > 2 mm);
- Clean coarse-grained material (the sand);
- Fine-grained material (the sludge cake).

Special efforts will be taken to reuse or recycle the gross oversize fraction. Wood and wood products can be shredded, and in many areas this material can be used as a supplemental fuel in co-generation facilities. Steel scrap may be sold to mini-mills, and concrete rubble can be crushed for use as aggregate in concrete production or as roadway sub-base.

The process oversize will normally be returned to the site, with the clean sand, as backfill.

The clean sand can be used as select backfill, and returned directly to the area of excavation. If the site conditions do not require the area of excavation to be filled or regraded, the clean material can be used as a construction-grade material for other development uses onsite, such as roadways or concrete. In some states, with California leading the way, the ‘clean’ material can be sold for off-site uses after meeting specific re-use criteria.

The fine-grained material, either before or after treatment, will require disposal off-site at a permitted facility. When the project is initially evaluated, determinations are made regarding the type of disposal or treatment facility that will be required for the specific fine-grained residuals from the site. Options will usually be limited to a decision between further treatment, a hazardous waste landfill, a non-hazardous waste landfill, or a fixed-base incinerator. This decision will hinge upon the determination of the status of the specific waste(s) with regard to the definition of the waste stream relative to RCRA and to the Land Disposal Restrictions, commonly known as the land bans.

4. Quality control sampling and analysis

Any decisions in both the selection, qualification, handling, and disposal of treated residuals will be made using analytically quantified information. The specific parameters to be quantified, and the analytical methods to be employed will be made on a site-specific basis. This decision will be made after an understanding of the previous work performed, the nature of the regulatory requirements at the site, and the client/contractor strategy to be followed.

In most cases, excavation and process control analyses will be performed on the project site relying on gas chromatography and X-ray fluorescence techniques. Periodic sampling and analyses will be performed on the treated residuals to verify product quality and the compliance with treatment objectives.

5. Operations and staffing

The soil washing plant is relatively easy to operate. The flexibility of the plant is such that it need not be kept running 24 h per day, as is the case with an incinerator, for example. Generally, the plant can be operated on a 5-days-per-week/1 shift-per-day basis. Preventive and routine maintenance is performed on Saturday and the plant is shut down on Sunday. If schedule or production requires, however, 5 days per week/2 shifts per day or 7 days per week/3 shifts per day schedules can be arranged.

The field operation is led by a Site Operations Manager, who is supported by a Plant Manager, Site Safety Officer, and a mechanical/electrical technician, the four of whom work the day shift. The shift crews (two or three depending upon production requirements) each consist of a shift foreman, a flotation unit operator, a belt filter press operator, and two laborers. All plant personnel are Health and Safety trained as required by OSHA 29 CFR 1910.120 and all participate in the routine medical monitoring program.

6. Project implementation

Every project requires specific information developed through a treatability study. The purpose of the study is to understand the particle-size/contaminant relationship, to confirm a process for the treatment of the waste of concern, and to define the costs. The treatability study generally consists of three phases.

6.1. Phase I

Representative samples need to be collected from the site. The determination of representativeness is important to the client and the contractor because this agreement is the basis of treatment and pricing decisions. Whenever possible, it is very useful for the client and the contractor to participate mutually in this representativeness decision. The analyses to be performed include, first, the sieve analysis and the construction of the particle-size distribution curve. The retained particle-size fractions are then chemically analyzed for the required contaminant menu. These Phase I results represent a good ‘go/no go’ point, for this information will allow a reasonable decision to be made regarding the feasibility of soil washing.

6.2. Phase II

If the results of the Phase I study are positive, a bench-scale investigation is recommended to confirm specific unit operations. Screening, hydrocycloning, froth flotation, and filtration studies will be conducted to select treatment units, screening points, cut points, and to determine surfactant, polymer, flow rate, and throughput requirements. This study will generally take about 6–8 weeks to conduct, and will result in the confirmation of a process flow diagram and treatment capabilities.

At the completion of the studies, a report will be prepared documenting the investigation and providing conclusions regarding the findings. The report will provide the confirmed process flow diagram, general specifications for the actual facility, will commit to a unit treatment price, and specify any particular contractual qualifications. The document is intended to provide all the technical information required to negotiate a services agreement.

6.3. Phase III

If necessary, a pilot study can be conducted to run the specified treatment train with actual site soils. The pilot plant facilities consist of the full range of required treatment units, and has the capacity to run studies at the level of 5–15 ton/h. The scope of the pilot study and the location where it will be conducted depend directly on the size and complexity of the project. When a site situation matches closely to current experience, it may not be necessary to conduct a pilot-level study.

For a successful soil washing project, here are some of the key issues to consider.

1. An open relationship between client and contractor should exist. Initial project understanding will certainly change during the conduct of the work. It is extremely important that a relationship of reasonable trust exists at the beginning of the job and is nurtured through the ensuing work.

2. The size of the project should be considered. On-site technology applications are directly dependent upon volume as an economic fact. For full-scale soil washing to compete economically in a project where all ‘conventional’ remedial alternatives are available, a volume of more than 5000 tons is required. On projects where ‘conventional’ alternatives are limited by unusual site conditions or wastes, the minimum volume may decrease. Smaller volumes can be cost-effectively handled with the pilot plant in some situations.

3. Particle size/contaminant relationship. The better the natural distribution of coarse and fine-grained materials, the more economical soil washing becomes. Soil washing is not a set, rigid treatment train, but is modified specifically for the actual waste streams to be treated. Very substantial volume reductions can be obtained by understanding the particle-size/contaminant relationship, and merely screening and separating wastes for the most appropriate treatment.

3. Contaminants. Primary candidate contaminants for soil washing are heavy metals, semi-volatile organics, polynuclear aromatics, pesticides, PCBs, and low-level radioactive waste.

4. The regulatory situation. The United States Environmental Protection Agency (USEPA) strongly supports innovative, on-site technologies. That does not mean that any special consideration or permitting support emerges from this position. The position of the state regulators is very important in selecting on-site approaches, and this position must be factored directly into the client's remedial strategy.

7. Benefits of soil washing

- The system is exceptionally cost-effective because it focuses treatment only on the appropriate fractions, rather than treating the entire waste stream.
- The system can treat both organics and inorganics in the same treatment stream.
- The soil washing system is a true volume reduction option, and directly supports the recycle and reuse of site materials.
- The system is consistent with the current USEPA directives and policies requiring on-site, innovative treatment.
- Because there is no air emission or wastewater discharge, the system is easier to permit than traditional remedial alternatives.

8. Project summary

CLIENT : The King of Prussia PRP Cooperating Group
CONTAMINANTS : Chromium, Copper, Nickel
PROJECT PHASE : Full-Scale
QUANTITY OF SOIL : 19200 tons
OPERATIONS PERIOD : August 1995–Ongoing

8.1. Background

The King of Prussia (KOP) Technical Site is located in Winslow Township, NJ, about 50 km southeast of Philadelphia. The site is situated on approximately 4 ha within the Pinelands National Reserve, and adjacent to the State of New Jersey's Winslow Wildlife Refuge. The KOP Technical purchased the site in 1970 to operate an industrial waste recycling center. The operation was not successful, and in 1985 the site was placed on the National Priorities List. In 1990 a Record of Decision (ROD) was issued for the site, and soil washing was specified as the cleanup technology to be used for remediating the soils. A group of Potentially Responsible Parties was issued a unilateral Administrative Order to implement the requirements of the ROD.

8.2. Preliminary activities

Two major preparatory steps were taken prior to beginning full-scale soil washing activities: (1) a treatability study to determine the applicability of soil washing to the site, and (2) a ‘demonstration run’ of actual site soils prior to final design of the soil washing plant.

8.2.1. The treatability study

During the treatability study, site soils were separated into particle-size fractions and particle-size distribution curves were constructed. Each resulting fraction was analyzed for the six inorganic contaminants, and bench-scale studies were conducted to determine the treatment unit operations to be implemented in the full-scale operation.

8.2.2. The demonstration run

Because this was a new technology to the U.S. Environmental Protection Agency (USEPA), some questions were left from the treatability and bench-scale studies. Therefore, to fully confirm the effectiveness of the technology on KOP soils, a ‘demonstration run’ was planned and implemented for actual KOP site materials at the ARCADIS full-scale fixed facility in Moerdijk, Netherlands. With USEPA and VROM (the equivalent Dutch agency) approval, 165 tons of KOP site soils were shipped to Moerdijk. A 1-day treatment operation was performed with the equipment configured as recommended in the preliminary design for the KOP soil washing plant. The operation was successful in demonstrating the effectiveness of soil washing in treating the site soils. Soils were remediated to levels well below the ROD-specified standards (Table 1).

8.3. Preparation for full-scale operations

Following the demonstration run, the firm of SALA International was contracted by ART to manufacture a 25-ton/h soil washing plant, and the plant was delivered to the site in May 1993. After erection of the plant on-site, a pilot run was conducted on 1000 tons of contaminated soils excavated from the site. The pilot run was successful, again with cleanup levels well below the ROD-specified standards. As a result, USEPA granted prompt approval to proceed with full-scale remediation.

8.4. Full-scale operations

Full-scale operations at the KOP site began on June 28, 1993. The project was performed with full USEPA oversight and in accordance with the approved Site Operations Plan. The process and products were controlled by on-site X-ray fluores-

Table 1
Analytical results, King of Prussia site soil washing

Contaminant	Feed range (mg/kg)	Average concentration (mg/kg)		
		ROD standard	Clean product	Residual product
Nickel	300–3500	1935	25	2300
Chromium	500–5500	483	73	4700
Copper	800–8500	3571	110	5900

cence using previously prepared site matrix-matched standards, and confirmed by off-site certified laboratory analysis. Correlation between the approaches was excellent. The soil washing operation was completed on October 10, 1993, and the facility was disassembled and removed from the site. The project treated 19 200 tons of soil, and achieved a volume reduction of greater than 90% on a dry solids basis. The overall analytical results are shown in Table 1.

9. Project summary

CLIENT : City of Montreal, Quebec, Canada
CONTAMINANTS : Copper, Lead, Zinc
PROJECT PHASE : Full-Scale
QUANTITY OF SOIL : 22 300 tons
OPERATIONS PERIOD : August 1995–July 1996

A joint venture of Cintec Environnement, and ART performed full-scale soil washing on soils from various locations throughout the City of Montreal, Québec. Cintec is located in Montreal, Québec, and owns and operates various remediation capabilities, including thermal treatment units, and the only permitted contaminated soil landfill in

Table 2
Contaminant levels and remediation standards, City of Montreal

Site	Contaminants	Estimated feed concentration (ppm)	Remediation standard (ppm)
1	Copper	10 000	500
	Lead	1000	1000
	Zinc	5000	1500
4	Lead	700	500
6	Copper	500	100
	Lead	1500	500
	Zinc	1000	500
7	Nickel	500	100
	Lead	1000	500
	Zinc	1500	500
	Copper	150	100
	Oil and Grease	1500	1000
8	PAHs	50	1
	Oil and Grease	4000	1000
9	Copper	200	100
	Lead	8000	500
	Zinc	8000	500
10	Copper	7000	100
	Lead	3000	500
	Zinc	2000	500
	Tin	1000	50

the eastern provinces of Canada. This project combined the soil washing capability of ART with the disposal services of Cintec. The soils were contaminated principally with copper, lead and zinc, and with smaller amounts of oil, grease and polynuclear aromatic hydrocarbons. They originated from a former industrial sector of Montreal. Remediation of these soils was part of a program funded by the City of Montreal in cooperation with the Province of Québec, Ministry of the Environment, to remediate government-owned sites, while developing technologies that will assist in effectively returning impacted properties to productive use.

Cintec/ART established the soil washing plant as a fixed, commercial facility inside an existing factory building in southwest Montreal. The 30-ton/h plant was mobilized to the site in November 1995, and shakedown was completed by January 1996.

Soils from seven sites throughout the city were excavated, pre-screened in the field, transported, and stockpiled inside the building. Prior to treatment, treatability studies were performed on soils from each site to determine the appropriate treatment train. Following completion of the treatability studies, full-scale operations began in January 1996. Soils from each site were remediated individually, and clean soils returned to the appropriate site as backfill. Contaminated residuals from the operation were disposed in the Cintec landfill. The key contaminants for each site, contaminant levels, and remediation standards are shown in Table 2.

10. Project summary

CLIENT	:	Westinghouse-Hanford
CONTAMINANTS	:	Uranium, Metals, Organics
PROJECT PHASE	:	Pilot study
QUANTITY OF SOIL	:	380 tons
OPERATIONS PERIOD	:	March 1994–July 1994

The objective of this soil washing pilot study was to evaluate the capability and effectiveness of soil washing on soils contaminated with low-level uranium, metals and organics at the 300-FF-1 Operable Unit (OU) at the U.S. Department of Energy (USDOE) Hanford Site, WA. Contamination originated from nuclear weapons production operations at the site from World War II until 1975. This was the first soil washing pilot study performed at this site. ART was responsible for all phases of the pilot study including the following:

- Mobilization and set-up of the pilot plant;
- Plant shakedown;
- Preparation of site manuals including:
  - Site Operations Manual
  - Quality Assurance Project Plan
  - Test Procedures;
- Performance of the three phases of the soil washing pilot test;
- Pilot plant decommissioning and decontamination;
- Project Technical Report.

The goals of the pilot study were to demonstrate the ability of soil washing to reduce the mass of contaminated material by more than 90%, and to meet the specified treatment standards. The results of the soil washing operation were to be incorporated into the Phase III Feasibility Study in the context of evaluating soil washing for full-scale remediation at specified areas of the site.

Soils from two areas within the OU were processed, (1) 300 tons of soil containing metals, organic materials and low-level uranium and, (2) 80 tons of soil containing elevated concentrations of copper and uranium.

Project activities included shipment of the soil washing pilot plant to the site, setup in the designated area, performance of the tests, and report preparation. On-site operations began on March 15, 1994 and were completed on April 15, 1994.

The tests for the 300 tons of soil were conducted in three segments: (1) the pre-test run, (2) the verification run, and (3) the replication run, as follows.

(1) The pre-test run provided for startup of the equipment and initial processing of soil. Adjustments and fine-tuning to the plant were made, based on the results of the pre-test run. During this run, 50 tons of soil were processed.

(2) The verification run was to demonstrate that the equipment and process could achieve the specified 90% reduction by weight of contaminated material, and to meet the treatment standards. During this run 125 tons of soil were processed.

(3) The replication run confirmed that the results achieved in the verification run could be replicated. During this run, an additional 125 tons of soil were processed.

ART also performed a test on 80 tons of soil containing significantly higher levels of uranium due to the presence of a uranium–copper carbonate precipitate. Attrition scrubbing was also tested for achieving improved treatment performance.

The ART pilot plant utilized at this site had a throughput capacity of 10–15 ton/h in a mobile, easily erectable configuration. The plant consisted of a feed hopper, a double-decked wet screen, hydrocyclones, attrition scrubber, sand dewatering screen, sludge thickening and dewatering units, and the required supporting peripheral equipment.

The pilot study was successful in meeting the goal of $>90\%$ reduction by weight, and was also successful in achieving the specified test performance standards. Results are presented in Table 3.

Upon completion of the pilot study, ART submitted a written report to Westinghouse-Hanford for incorporation into the Feasibility Study.

Table 3
Analytical results of soil washing at the Hanford Site, 300-FF-1 operable unit

Contaminant	Test performance standard	Concentration			
		Feed	Process oversize (clean)	Sand (clean)	Fines (residual)
Cu (ppm)	11 840	2800	199	1180	22 000
U-238 (pCi/g)	50	132	5.5	28.5	1660
U-235 (pCi/g)	15	4.5	0.3	1.4	58
Cs-137 (pCi/g)	3.0	0.13	0.05	0.3	0.68
Co-60 (pCi/g)	1.0	0.08	< 0.04	< 0.06	0.93

11. Project summary

CLIENT : RMI Titanium and U.S. Department of Energy
CONTAMINANTS : Uranium
PROJECT PHASE : Bench-scale, pilot-scale, full-scale
QUANTITY OF SOIL : 20 000 tons (Phase I, full-scale)
OPERATIONS PERIOD : August 1995–Ongoing

11.1. Background

The RMI Titanium (RMI) Extrusion Plant is located in Ashtabula Township, approximately one mile south of Lake Erie, in the northeast corner of the State of Ohio. The property is privately owned by the RMI Titanium. RMI held contracts with the U.S. Department of Energy (USDOE) and its predecessor agencies to process uranium metal into forms for use in nuclear and non-nuclear weapons production at the Ashtabula site. A decontamination and decommissioning (D and D) plan for the site has been approved by the U.S. Nuclear Regulatory Commission.

During uranium extrusion operations from 1962 to 1988, particulate uranium was discharged from roof vents and stacks to the surrounding soil. The USDOE owns half the buildings on the site and is responsible for funding the cleanup of all contamination associated with work performed under its contracts with RMI Titanium.

The cleanup of the site is being conducted under the RMI Decommission Project (RMIDP) sponsored by the USDOE Office of Environmental Restoration (EM-40). EM-40 established the Innovative Treatment Remediation Demonstration (ITRD) Program to help accelerate the adoption and implementation of new and innovative soil and groundwater remediation technologies.

11.2. Technical summary

The RMI site generally consists of high clay-content soils, which added to the complexity of the project. Because the contaminants tend to bind to the fine soil fractions, and because these fractions make up a high percentage of the Ashtabula soils, typical soil treatment technologies, such as physical separation, are not effective at this site because they do not result in significant volume reduction of the contaminated soils.

In 1996, the ITRD Program sponsored a bench-scale treatability study on RMIDP soils to explore alternatives to a baseline remediation approach of excavation, transport, and off-site disposal. After extensive experimentation, the processing approach narrowed on a carbonate–bicarbonate process which demonstrated a viable technical and cost-beneficial alternative. Efficiencies of up to 90% were attained, and the treatment standard of 30 pCi/g, as established in the D and D plan for the site, was met. The potential benefit of the process is its ability to treat the fine fractions of the soil matrix and separate the uranium contamination from the soil matrix, thereby significantly reducing the volume of contaminated soil requiring off-site disposal.

To validate the results of the treatability study, the USDOE Ashtabula Environmental Management Project (AEMP) office and the ITRD program co-sponsored a pilot project in January and February 1997. The primary objectives of the pilot project were to prove that soil washing/chemical extraction could be successful on a large scale, and to obtain operational data to support full-scale soil remediation.

The equipment was erected and operated in a portion of an on-site building. The design consisted of an innovative mix of existing processes. During the pilot project, 38 batches (approximately 64 tons) of soil were processed. The soil was loaded into a rotary batch reactor with a heated carbonate–bicarbonate solution to form a 30% solids slurry. The leaching solution was allowed to contact the soils for 1– 2 h. A wet screening process separated oversize material (>1 mm), and the remaining slurry was transferred into sequential thickeners to separate soils from the uranium-bearing liquids. The soil fraction was dewatered by filter press and underwent no further treatment. The radiological activity of these treated soils was measured by X-ray fluorescence (XRF) and verified by alpha spectroscopy to determine the effectiveness of the chemical extraction process. An ion-exchange system was used to remove the uranium from the liquid. The uranium eluted from the ion exchange resin, and a ‘yellowcake’ product was recovered by chemical precipitation. Key parameters that were varied included feed-soil type and activity, reaction temperature, and leaching time. Important information that was studied for full-scale operations included leaching performance, ion exchange performance, resin loading, resin regeneration, and uranium precipitation. The system is close looped, and no adverse air or water problems were created as a result of the process.

11.2.1. Results

- Ashtabula soils can be effectively treated for uranium by using a sodium carbonate extraction process.
- Removal efficiencies of up to 94% were achieved, with a volume reduction of up to 95%.
- All soils selected for treatment met the free release standard of 30 pCi/g.
- Full-scale implementation of the process would result in significant schedule reduction and cost savings for the USDOE over the baseline approach.
- As a result of the pilot project, planning and design to initially process 20 000 tons is underway.
- This was the first time that this process had been successfully implemented on a USDOE site with uranium contamination.

Table 4
Results of RMI pilot study

Pile	Area	Uranium activity of feed by alpha spec (pCi/g)	Leaching time (h)	Treated soil		Removal efficiency	
				XRF (pCi/g)	Alpha spec (pCi/g)	XRF (%)	Alpha spec (%)
2	Run 1 Area D	129	1	8	12	94%	91%
3	Run 2 Area D	90	2	11	12	88%	87%
4	Run 1 Area C	133	1	10	13	92%	90%
5	Run 2	145	1	17	4	88%	90%
					Average	90%	89%

11.2.2. Benefits

Cleanup of RMIDP soils is a component of the D and D plan for the site. Full-scale implementation of the soil washing/chemical extraction process will result in significant cost savings and acceleration of schedule over the planned remedy of excavation and off-site disposal of the soil. Soil meeting the 30 pCi/g cleanup level for total uranium, expected to equal 90 + % of the processed soil, will be released as clean material for backfill on the site, thus minimizing the volume of soil requiring off-site disposal, and avoiding purchase of backfill material.

Because of a unique combination of facility resources, operating experience of the participants, and deployment strategies, the site is positioned to be an excellent candidate for success in a new mission built around providing processing services for contaminated media for USDOE and other sites in the future. Results are shown in Table 4.

12. Project summary

CLIENT	:	The Monsanto Company
CONTAMINANTS	:	Bis (2-ethylhexyl) phthalate (BEHP) Phthalic anhydride process residues (PAPR) containing Naphthalene
PROJECT PHASE	:	Full-scale
QUANTITY OF SOIL	:	9600 tons
OPERATIONS PERIOD	:	May 1996–November 1996

The Monsanto Company operated a chemical plant at this 84-acre brownfields site from the mid-1800s to 1992. Manufacturing activities resulted in soil impacted with Naphthalene, BEHP arsenic, lead and zinc. Since operations ceased, the plant facilities have been dismantled or demolished, and the site remediated for construction of a 650 000-ft^2 shopping mall. Monsanto performed the cleanup at this site under the Massachusetts Contingency Plan. Preparations for soil treatment operations began in May 1996 with a treatability study to provide data for design of the plant. The study showed that the fines fraction (< 2 mm) contained BEHP, and the oversize fraction (> 2 mm) contained PAPR. The process flow diagram design included a trommel, feed hopper, double-decked wet screen, hydrocyclones, attritioning, secondary hydrocycloning, sand dewatering, fines thickening and consolidation, sludge dewatering, and jig. The fines stream was further treated in bioslurry reactors.

The ART 15 ton/h soil washing plant was mobilized to the site and configured in accordance with the optimized process flow diagram. Soils consisting primarily of oversize and coarse material, with less than 20% silt and clay, including construction debris, demolition rubble and other fill, were excavated from several areas around the site and delivered to the plant for processing. The soil was field-screened to remove gross oversize material, producing a plant feed $< 2''$. This material was fed into the plant and through the wet screening unit, producing a process oversize > 2 mm, and a wet slurry < 2 mm. The process oversize, containing PAPR, was staged outside the

Table 5
Results of soil washing at the Monsanto site, Everett, MA

PAPR soils	Feed range (mg/kg)	Treated soil mg/kg			Treatment goal (mg/kg)
		Oversize	Sand	Fines[a]	
Naphthalene	5000–40 000	22.000	520	2900	3000
BEHP	–	–	–	–	–

BEHP soils	Feed soil (mg/kg)	Treated soil mg/kg Oversize	Sand	Fines[a]	Treatment goal (mg/kg)
Naphthalene	< 3000	160	39	3300	3000
BEHP	5000	2700	390	10 000	3000

[a] Fines treated in bioslurry reactors.

plant for further treatment. The wet slurry was fed to the hydrocyclone separation unit, producing a coarse sand fraction and a fines fraction. The coarse sand fraction was directed to a dewatering screen and, after testing, was returned to the site as clean backfill. The fines fraction was degraded in a bioslurry system operated by another contractor. The oversize material $> 2''$ contaminated with naphthalene concentrations higher than treatment targets was further treated by attritioning. Results attained are shown in Table 5.

13. Conclusions

In conclusion, soil washing has been proven at the full-scale commercial level to be a cost-effective treatment process for certain remediation requirements. Physical separation, combined with chemical treatment, can produce impressive results.