United States
Environmental Protection
Agency

Office of Research and
Development
Washington DC 20460

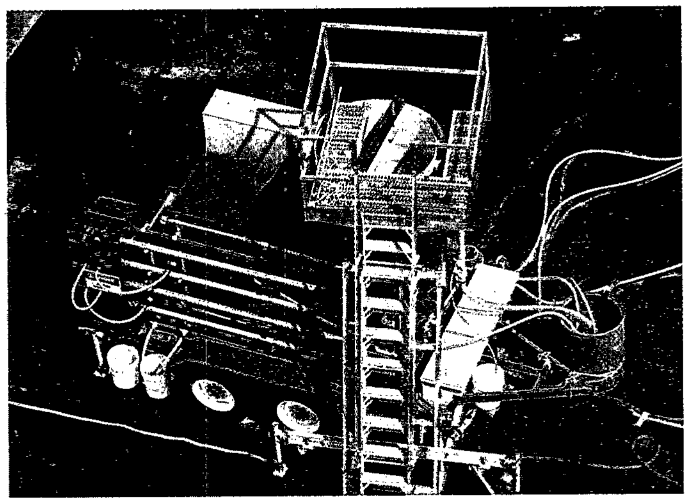
EPA/540/R-96/502
September 1998

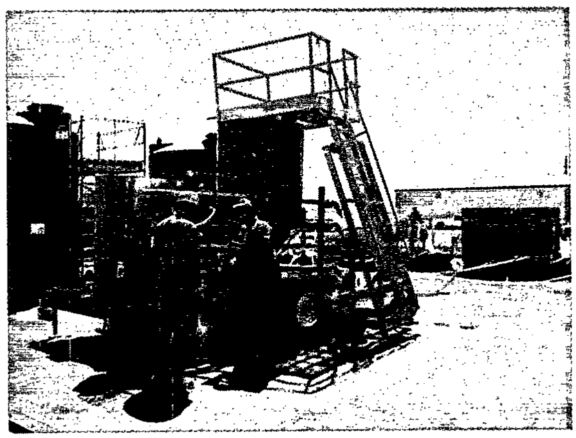
EPA

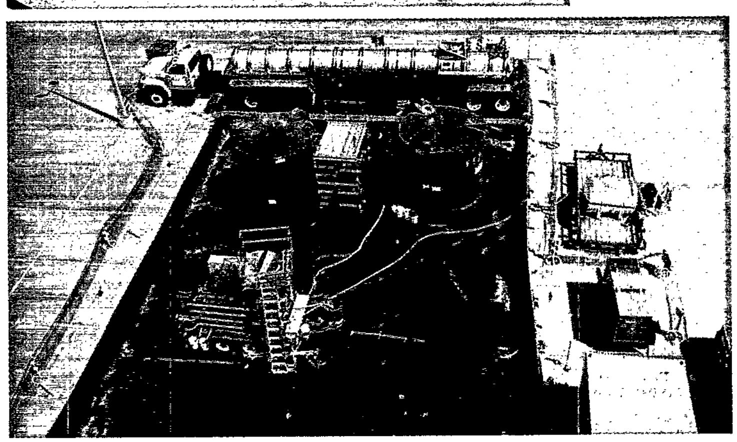
General Environmental Corporation

CURE Electrocoagulation Technology

Innovative Technology Evaluation Report







SITE

SUPERFUND INNOVATIVE
TECHNOLOGY EVALUATION

EPA/540/R-96/502
September 1998

General Environmental Corporation

CURE Electrocoagulation Technology

Innovative Technology Evaluation Report

National Risk Management Research Laboratory
Office of Research and Development
U.S. Environmental Protection Agency
Cincinnati, Ohio 45268

Printed on Recycled Paper

Notice

The information in this document has been funded by the U. S. Environmental Protection Agency (EPA) under Contract No. 68-C5-0037 to Tetra Tech EM Inc. (formerly PRC Environmental Management, Inc.). It has been subjected to the Agency's peer and administrative reviews and has been approved for publication as an EPA document. Mention of trade names or commercial products does not constitute an endorsement or recommendation for use.

Foreword

The U. S. Environmental Protection Agency (EPA) is charged by Congress with protecting the Nation's land, air, and water resources. Under a mandate of national environmental laws, the Agency strives to formulate and implement actions leading to a compatible balance between human activities and the ability of natural systems to nurture life. To meet this mandate, EPA's research program is providing data and technical support for solving environmental problems today and building a science knowledge base necessary to manage our ecological resources wisely, understand how pollutants affect our health, and prevent or reduce environmental risks in the future.

The National Risk Management Research Laboratory is the Agency's center for investigation of technological and management approaches for reducing risks from threats to human health and the environment. The focus of the Laboratory's research program is on methods for the prevention and control of pollution to air, land, water and subsurface resources; protection of water quality in public water systems; remediation of contaminated sites and groundwater; and prevention and control of indoor air pollution. The goal of this research effort is to catalyze development and implementation of innovative, cost-effective environmental technologies; develop scientific and engineering information needed by EPA to support regulatory and policy decisions; and provide technical support and information transfer to ensure effective implementation of environmental regulations and strategies.

This publication has been produced as part of the Laboratory's strategic long-term research plan. It is published and made available by EPA's Office of Research and Development to assist the user community and to link researchers with their clients.

E. Timothy Oppelt, Director

National Risk Management Research Laboratory

Abstract

The CURE electrocoagulation system was evaluated for removal of low levels of the radionuclides uranium, plutonium, and americium as well as other contaminants in wastewater. Economic data from the Superfund Innovative Technology Evaluation (SITE) demonstration are also presented, and the technology is compared to the nine criteria that the U. S. Environmental Protection Agency (EPA) uses to select remedial alternatives for Superfund sites.

The CURE electrocoagulation technology was developed by General Environmental Corporation, Inc. (GEC), of Denver, Colorado. The technology induces the coagulation and precipitation of contaminants by a direct-current electrolytic process followed by settling with or without the addition of coagulation-inducing chemicals. Treated water is discharged from the system for reuse, disposal, or reinjection. Concentrated contaminants in the form of sludge are placed in drums for disposal or reclamation.

The CURE technology was demonstrated under the SITE Program at the U.S. Department of Energy's (DOE) Rocky Flats Environmental Technology Site (formerly the Rocky Flats Plant) near Golden, Colorado. Approximately 4,500 gallons of wastewater containing low levels of the radionuclides uranium, plutonium, and americium were treated in August and September 1995. Water from the solar evaporation ponds was used in the demonstration. Six preruns, five optimization runs, and four demonstration runs were conducted over a 54-day period.

The demonstration runs lasted 5.5 to 6 hours each, operating the CURE system at approximately 3 gallons per minute. Filling the clarifier took approximately 2.5 hours of this time. Once the clarifier was filled, untreated influent, and effluent from the clarifier were collected every 20 minutes for 3 hours. Because of the shortened run times, there is uncertainty whether the data represent long-term operating conditions.

Results indicated that removal efficiencies for the four runs ranged from 32 to 52 percent for uranium, 63 to 99 percent for plutonium, and 69 to 99 percent for americium. Colorado Water Quality Control Commission (CWQCC) standards were met for plutonium and americium in some, but not all cases. However, CWQCC standards for uranium were not met. Arsenic and calcium concentrations were also decreased by an average of 74 and 50 percent, respectively for the two runs for which metals were measured.

Evaluation of the CURE electrocoagulation technology against the nine criteria used by the EPA in evaluating potential remediation alternatives indicates that the CURE system provides both long- and short-term protection of the environment, reduces contaminant mobility and volume, and presents few risks to the community or the environment.

Potential sites for applying this technology include Superfund, DOE, U.S. Department of Defense, and other hazardous waste sites where water is contaminated with radionuclides or metals. Economic analysis indicates that remediation cost for a 100-gallon-per-minute CURE system could range from about $0.003 to $0.009 per gallon, depending on the duration of the remedial action.

Contents

Contents (continued)

Contents (continued)

Figures

Tables

Acronyms, Abbreviations, and Symbols

A	Ampere
A/B decant water	Water removed from A and B solar pond sludge
AEA	Atomic Energy Act
ARAR	Applicable or relevant and appropriate requirements
ATTIC	Alternative Treatment Technology Information Center
BOD	Biological oxygen demand
C	Degrees Celsius
CDPHE	Colorado Department of Public Health and the Environment
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CERI	Center for Environmental Research Information
CFR	Code of Federal Regulations
CRE	Contaminant removal efficiency
CWA	Clean Water Act
CWQCC	Colorado Water Quality Control Commission
DOE	U.S. Department of Energy
Eh	Oxidation/reduction potential
EPA	U.S. Environmental Protection Agency
GEC	General Environmental Corporation
gpm	Gallons per minute
HSWA	Hazardous and Solid Waste Amendments
ITER	Innovative Technology Evaluation Report
kWh	Kilowatt-hour
LANL	Los Alamos National Laboratory
LLRW	Low level radioactive waste
Lpm	Liters per minute
MCL	Maximum contaminant level
mg/kg	Milligrams per kilogram
mg/L	Milligrams per liter
mS	MilliSiemens
mS/cm	MilliSiemens per centimeter
MS/MSD	Matrix spike and matrix spike duplicate

Acronyms, Abbreviations, and Symbols (continued)

NCP	National Oil and Hazardous Substance Pollution Contingency Plan
NPDES	National Pollutant Discharge Elimination System
NPL	National Priorities List
NRC	Nuclear Regulatory Commission
NRMRL	National Risk Management Research Laboratory
O&M	Operation and maintenance
ORD	Office of Research and Development
OSHA	Occupational Safety and Health Administration
OSWER	Office of Solid Waste and Emergency Response
PA	Protected area
pCi/L	PicoCuries per liter
POTW	Publicly owned treatment works
PPE	Personal protective equipment
ppm	Parts per million
PRC	PRC Environmental Management, Inc.
psi	Pounds per square inch
QA/QC	Quality assurance and quality control
QAPP	Quality assurance project plan
RCRA	Resource Conservation and Recovery Act
RFETS	Rocky Flats Environmental Technology Site
SARA	Superfund Amendments and Reauthorization Act
SDWA	Safe Drinking Water Act
SEP	Solar evaporation pond
SITE	Superfund Innovative Technology Evaluation
SWDA	Solid Waste Disposal Act
TCLP	Toxicity Characteristic Leaching Procedure
TDS	Total dissolved solids
TER	Technical Evaluation Report
TOC	Total organic carbon
TRU	Transuranic
TSS	Total suspended solids
TTU	Transportable treatment unit
µg/L	Micrograms per liter
µm	Micrometer (micron)
µS/cm	MicroSiemens per centimeter
V	Volts
VISITT	Vendor Information System for Innovative Treatment Technologies

Conversion Factors

	To Convert From	*To*	*Multiply By*
Length	inch	centimeter	2.54
	foot	meter	0.305
	mile	kilometer	1.61
Area:	square foot	square meter	0.0929
	acre	square meter	4,047
Volume:	gallon	liter	3.78
	cubic foot	cubic meter	0.0283
Mass:	pound	kilogram	0.454
Energy:	kilowatt-hour	megajoule	3.60
Power:	kilowatt	horsepower	1.34
Temperature:	(°Fahrenheit - 32)	°Celsius	0.556

Acknowledgments

This report was prepared under the direction of Ms. Annette Gatchett, the U.S. Environmental Protection Agency (EPA) Superfund Innovative Technology Evaluation (SITE) project manager at the National Risk Management Research Laboratory (NRMRL) in Cincinnati, Ohio. This report was prepared by Dr. Theodore Ball, Mr. Jon Bridges, Ms. Barbara DeAngelis, Mr. David Harr, Ms. Doreen Hoskins, Ms. Jennifer Jones, and Mr. David Walker of PRC Environmental Management, Inc. (PRC). Contributors and reviewers for this report were Ms. Gatchett, Mr. Sam Hayes of EPA, and Mr. Carl Dalrymple of General Environmental Corporation. The report was formatted by Ms. Melissa Fajt, edited by Mr. Christopher Pytel, and technically reviewed by Ms. Pauline LeBlanc of PRC.

Executive Summary

This executive summary of the CURE electrocoagulation technology discusses its applications, evaluates costs associated with the system, and describes its effectiveness.

The CURE electrocoagulation technology has been evaluated under the Superfund Innovative Technology Evaluation (SITE) program. The SITE program was developed by the U.S. Environmental Protection Agency (EPA) to maximize the use of alternative treatment technologies. To this end, reliable performance and cost data on innovative technologies are developed during demonstrations where a technology is used to treat a specific waste.

After the demonstration, EPA publishes an Innovative Technology Evaluation Report (ITER) designed to aid decision makers in evaluating the technology for further consideration as an applicable cleanup option. This report includes a review of the technology application, an economic analysis of treatment costs using the technology, and the results of the demonstration.

The CURE electrocoagulation technology induces the coagulation and precipitation of contaminants by a direct-current electrolytic process followed by flocculent settling with or without the addition of coagulation-inducing chemicals. The water is pumped through concentric tubes made of iron or aluminum that act as electrodes. A direct current electric field is applied to the electrodes to induce the electrochemical reactions needed to achieve the coagulation. Treated water is discharged from the system for reuse, disposal, or reinjection. Concentrated contaminants in the form of sludge are placed in drums for disposal or reclamation.

The CURE electrocoagulation process involves the following basic steps: (1) contaminated water is pumped through the CURE electrocoagulation tubes; (2) treated water is pumped to a clarifier to allow solids to settle out; (3) clarified water is discharged from the system for reuse, disposal, or reinjection; (4) solid waste is stored for disposal or reclamation.

The technology demonstration had two primary objectives: (1) document 90 percent contaminant removal efficiencies (CRE) for uranium, plutonium, and americium to the 95 percent confidence level; and (2) determine if CURE could treat the waste stream to radionuclide contaminant levels below Colorado Water Quality Control Commission (CWQCC) standards at the 90 percent confidence level.

In addition, the technology demonstration had several secondary objectives. These were to (1) evaluate anode deterioration; (2) demonstrate CREs for arsenic, boron, cadmium, calcium, lithium, magnesium, total organic carbon (TOC), total dissolved solids (TDS), and total suspended solids (TSS) of 90 percent or higher at the 90 percent confidence level; (3) document production of hydrogen and chlorine gases; (4) determine power consumption by the CURE electrocoagulation system; (5) determine optimum system operating parameters for treatment of the demonstration treatment water; (6) document selected geochemical parameters (pH, oxidation/reduction potential [Eh], specific conductivity, and temperature) that may affect the effectiveness of the CURE electrocoagulation system; (7) determine uranium, plutonium, americium, and toxicity characteristic leaching procedure (TCLP) metals leachability from the flocculent by TCLP; and (8) estimate capital and operating costs of building a single treatment unit to operate at the rate of 100 gallons per minute (gpm).

For the demonstration, approximately 4,500 gallons of water containing up to 2,933 micrograms per liter (g/L) uranium, 33.1 picoCuries per liter (pCi/L) plutonium, and 83.5 pCi/L americium were treated in four test runs. Due to operating constraints at the demonstration site, no long-term evaluation of the treatment system was conducted. Each run was initiated by running process water through the CURE system until the clarifier was full (approximately 2.5 hours). Sampling of clarifier effluent was conducted for 3 hours thereafter. These tests may not be representative of actual operating conditions.

The CURE technology was evaluated against nine criteria used for decision making in the Superfund remedy selection process. This evaluation indicates that the CURE system can provide short- and long-term protection of human health and the environment by removing radionuclide contamination from water and concentrating it in a solid form.

Operation of the CURE electrocoagulation system must also comply with several statutory and regulatory requirements. Among these are the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), Resource Conservation and Recovery Act (RCRA), Safe Drinking Water Act (SDWA), Clean Water Act (CWA), Occupational Safety and Health Administration (OSHA) requirements, radioactive waste regulations, and mixed waste regulations. These statutes and regulations should be considered before use of any remedial technology.

Using information obtained from the SITE demonstration, an economic analysis was conducted to examine 12 different cost categories for the CURE system treating contaminated groundwater at a Superfund site. The analysis examined three cases in which the system treated water for 1, 5, and 10 years. For all treatment durations, a 100 gpm system was used in the cost calculations. Costs are summarized below.

Fixed costs for all three scenarios were the same. Therefore, for the 1-year treatment scenario capital equipment and site preparation dominate costs. Estimated costs ranged from $0.003 to $0.009 per gallon of water treated. These costs are estimates, and actual costs will vary with site conditions, materials and labor costs, and treatability of the wastestream.

Based on the SITE demonstration, the following conclusions may be drawn about the effectiveness of the CURE technology:

- Results of chemical analysis of waters collected during the four 3-hour demonstration runs showed that the CURE system removed 32 to 52 percent of uranium, 63 to 99 percent of plutonium, and 69 to 99 percent of americium from solar evaporation pond water. However, CWQCC standards could not be attained reliably for plutonium and americium, and were not met for uranium.

- Solid waste generated by the CURE treatment system during this demonstration is resistant to leaching of the radionuclides uranium, plutonium, and americium.

- The volume of waste generated is substantially less than the volume of water treated.

Section 1
Introduction

This section provides background information about the Superfund Innovative Technology Evaluation (SITE) program, discusses the purpose of this innovative technology evaluation report (ITER), and describes the CURE electrocoagulation technology. For additional information about the demonstration site, this technology, and the SITE program, key contacts are listed at the end of this section.

1.1 Background

In August and September of 1995, the General Environmental Corporation (GEC) CURE electrocoagulation system was evaluated at the Rocky Flats Environmental Technology Site (RFETS), near Golden, Colorado. The technology demonstration was conducted as a cooperative effort between the U.S. Environmental Protection Agency (EPA) and the U.S. Department of Energy (DOE) which manages the site.

The CURE system was evaluated as a transportable, trailer mounted unit that uses a series of concentric iron or aluminum tubes, a power supply to control the electrical current across the interior and exterior tube, and a clarifier to remove floccules formed in the tubes. The demonstration evaluated the ability of the system to remove uranium, plutonium, and americium from solar evaporation pond (SEP) water at RFETS.

1.2 Brief Description of the SITE Program and Reports

The Superfund Amendments and Reauthorization Act (SARA) of 1986 mandates that the EPA select, to the maximum extent practicable, remedial actions at Superfund sites that create permanent solutions (as opposed to land-based disposal) for contamination that affects human health and the environment. In response to this mandate, the SITE program was established by EPA's Office of Solid Waste and Emergency Response (OSWER) and Office of Research and Development (ORD). The SITE program promotes the development, demonstration, and use of new or innovative technologies to clean up Superfund sites across the country.

The SITE program's primary purpose is to maximize the use of alternatives in cleaning hazardous waste sites by encouraging the development and demonstration of new, innovative treatment and monitoring technologies. It consists of the Demonstration Program, the Emerging Technology Program, the Monitoring and Measurement Technologies Program, and the Technology Transfer Program. These programs are discussed in more detail below.

The Demonstration Program develops reliable performance and cost data on innovative treatment technologies so that potential users may assess the technology's site-specific applicability. Technologies evaluated are either currently available or close to being available for remediation of Superfund sites. SITE demonstrations are conducted on hazardous waste sites under conditions that closely simulate full-scale remediation, thus assuring the usefulness and reliability of information collected. Data collected are used to assess the performance of the technology, the potential need for pre- and post-treatment processing of wastes, potential operating problems, and the approximate costs. The demonstrations also allow for evaluation of long-term risks and operating and maintenance (O&M) costs.

The Emerging Technology Program focuses on successfully proven, bench-scale technologies which are in an early stage of development involving pilot- or laboratory-scale testing. Successful technologies are encouraged to advance to the Demonstration Program.

Existing technologies which improve field monitoring and site characterization are identified in the Monitoring and Measurement Technologies Program. New technologies that provide faster, more cost-effective contamination and site assessment data are supported by this program. The Monitoring and Measurement Technologies Program also formulates the protocols and standard operating procedures for demonstrating methods and equipment.

The Technology Transfer Program disseminates technical information on innovative technologies in the Demonstration, Emerging Technology, and Monitoring and Measurements Technologies Programs through various activities. These activities increase the awareness and promote the use of innovative technologies for assessment and remediation at Superfund sites. The goal of technology transfer activities is to develop interactive communication among individuals requiring up-to-date technical information.

Technologies are selected for the SITE Demonstration Program through annual requests for proposals. ORD staff review the proposals, including any unsolicited proposals that may be submitted throughout the year, to determine which technologies show the most promise for use at Superfund sites. Technologies chosen must be at the pilot- or full-scale stage, must be innovative, and must have some advantage over existing technologies. Mobile technologies are of particular interest.

Once EPA has accepted a proposal, cooperative agreements between EPA and the developer establish responsibilities for conducting the demonstrations and evaluating the technology. The developer is responsible for demonstrating the technology at the selected site and is expected to pay any costs for transport, operations, and removal of the equipment. EPA is responsible for project planning, sampling and analysis, quality assurance and quality control (QA/QC), preparing reports, disseminating information, and transporting and disposing of treated waste materials.

The results of the CURE electrocoagulation technology demonstration are published in two documents: the SITE technology capsule and the ITER. The SITE technology capsule provides relevant information on the technology, emphasizing key features of the results of the SITE field demonstration. In addition to the ITER, EPA prepares an unbound technical evaluation report (TER) for each demonstration. The TER contains raw analytical and quality assurance data and other operating information collected during the demonstration. The TER is prepared to document the quality of the demonstration data upon which the ITER is based.

1.3 Purpose of the Innovative Technology Evaluation Report

The ITER provides information on the CURE electrocoagulation technology and includes a comprehensive description of the demonstration and its results. The ITER is intended for use by EPA remedial project managers, EPA on-scene coordinators, contractors, and other decision makers for implementing specific remedial actions. The ITER is designed to aid decision makers in evaluating specific technologies for further consideration as an applicable option in a particular cleanup operation. This report represents a critical step in the development and commercialization of a treatment technology.

To encourage the general use of demonstrated technologies, EPA provides information regarding the applicability of each technology to specific sites and wastes. Therefore, the ITER includes information on cost and site-specific characteristics. It also discusses advantages, disadvantages, and limitations of the technology.

Each SITE demonstration evaluates the performance of a technology in treating a specific waste. The waste characteristics of other sites may differ from the characteristics of the treated waste. Therefore, successful field demonstration of a technology at one site does not necessarily ensure that it will be applicable at other sites. Data from the field demonstration may require extrapolation for estimating the operating ranges in which the technology will perform satisfactorily. Only limited conclusions can be drawn from a single field demonstration.

1.4 Technology Description

The following sections overview coagulation theory, the electrocoagulation technology, and the CURE electrocoagulation system.

1.4.1 Theory of Coagulation

It has long been known that contaminants are dissolved or suspended in aqueous solutions due to small, electrostatic charges at the surface of the molecules or particles. If the surface charges are similar, the molecules or particles will repel one another. Competing with this repulsion is van der Waals' force, a weak intermolecular force that results in the attraction of molecules to one another. However, van der Waals' force is very small and decreases rapidly with increasing distance between particles. If the repulsion caused by the stronger like charges can be overcome, the van der Waals' force will cause the particles to coagulate. The addition of electrolytes which have bivalent or, more effectively, trivalent cations is the conventional means for overcoming the repulsive force of the charges and causing coagulation into particles large enough to precipitate out of solution (Sawyer and McCarty 1978).

In conventional coagulation and precipitation, a chemical amendment is added to the contaminated solution. The amendment is generally alum (aluminum sulfate), lime (calcium oxide), ferric iron sulfate, or charged synthetic or natural organic polymers (polyelectrolytes). In each case, the charged portion of the chemical additive destabilizes and binds with the oppositely-charged contaminants in solution, causing them to coagulate and, when of sufficient mass, to precipitate (Sawyer and McCarty 1978; Barkley and others 1993). This method of contaminant removal has the disadvantages of requiring frequent and expensive chemical additions to the solution; leaving high concentrations of the anionic components of the additive in solution; and increasing the volume of sludge formed by subsequent precipitation of the coagulated contaminant. Some chemical amendments may form stable hydroxide compounds. Others may be less resistant to degradation and may not pass the requirements of the EPA's toxicity characteristic leaching procedure (TCLP) (SW-846 Method 1311, [EPA 1994]). Failure to pass the TCLP will result in the sludge being characterized as hazardous waste, increasing sludge disposal costs, and reducing disposal options.

1.4.2 Theory of Electrocoagulation

In electrocoagulation, alternating or direct current electricity is applied to a cathode-anode system in order to destabilize any dissolved ionic or electrostatically suspended contaminants. During the electrolytic process, cationic species from the anode metal dissolve into the water (Equation 1). These cations react with the destabilized contaminants creating metal oxides and hydroxides which precipitate. If aluminum anodes are used, aluminum oxides and hydroxides form; if iron anodes are used, iron oxides and hydroxides form. The formation of the oxides and hydroxides, and their subsequent precipitation, are similar to the processes which occur during coagulation (or flocculation) and precipitation using alum or other chemical coagulants. The differences are the source of the coagulant (in electrocoagulation it is the cations produced by electrolytic dissolution of the anode metal [Barkley and others 1993]), and the activation energy applied promotes the formation of oxides (Renk 1989). The oxides are more stable than the hydroxides, and thus, more resistant to breakdown by acids (Renk 1989). Oxygen gas is also produced at the anode by the electrolysis of water molecules (Equation 2), and chlorine gas can be produced from chloride ions if they are present in the solution to be treated (Equation 3).

During the electrolytic production of cations, simultaneous reactions takes place at the cathode producing hydrogen gas from water molecules (Equation 4). Other important cathodic reactions include reduction of dissolved metal cations to the elemental state (Equation 5). These metals plate on to the cathode. The chemical reactions taking place during electrocoagulation using iron anodes are shown below (Vik and others 1984; Jenke and Diebold 1984; Renk 1989; Barkley and others 1993; Hydrologics, Inc. 1993).

At the anode:

$$Fe(s) \rightarrow Fe^{3+}(aq) + 3e^- \quad (1)$$

$$2H_2O \rightarrow 4H^+ + O_2(g) + 4e^- \quad (2)$$

$$2Cl^-(aq) \rightarrow Cl2(g) + 2e- \quad (3)$$

At the cathode:

$$2H2O + 2e- \rightarrow H2(g) + 2OH- \quad (4)$$

$$MN+ + Ne- \rightarrow M(s) \quad (5)$$

Where:
$Cl^-(aq)$ = Chloride ion in aqueous solution
$Cl_2(g)$ = Chlorine gas

$Fe(s)$	=	Iron solid
$Fe^{+3}(aq)$	=	Ferric ions in aqueous solution
$H^+(aq)$	=	Hydrogen ion in aqueous solution
$H_2(g)$	=	Hydrogen gas
H_2O	=	Water
$M^{N+}(aq)$	=	Metal ion in aqueous solution
$M(s)$	=	Metal solid
$OH^-(aq)$	=	Hydroxide ion in aqueous solution
$O_2(g)$	=	Oxygen gas
e^-	=	Electron
N^+	=	Charge of metal ion

In solution, the ferric ions supplied by dissolution of the anode participate in further spontaneous reactions to form oxides and hydroxides (Drever 1988; Renk 1989; Barkley and others 1993; Hydrologics, Inc. 1993). Renk (1989) found that oxides preferentially formed in electrocoagulation experiments because the energy supplied by the system exceeded the activation energy for their formation. These reactions incorporated dissolved contaminants into the molecular structure forming acid resistant precipitates. These precipitates are typically capable of passing the TCLP. This can significantly reduce solid waste disposal costs. Similar reactions occur when aluminum anodes are used.

1.4.3 System Components and Function

The CURE electrocoagulation technology is designed to remove contaminants including dissolved ionic species such as metals; suspended colloidal materials such as carbon black or bacteria; and emulsified oily materials from groundwater or wastewater. The CURE system induces coagulation of contaminants by means of a direct-current electrolytic process. Floccules formed by this process are allowed to settle in a clarifier. Treated water is discharged from the clarifier for reuse, disposal, or reinjection; contaminants are concentrated in flocs that are dewatered and discharged to drums for ultimate disposal or reclamation.

A schematic diagram of the CURE system is shown in Figure 1-1. The major components of the system include the following:

- **Influent Storage Tank.** This tank collects influent to be processed by the CURE system in batch mode or to provide surge capacity during continuous operation.

- **Influent pH Adjustment Tank.** The influent pH can be adjusted in these tanks if required to bring the influent pH into the range for optimum operation of the electrocoagulation tubes.

- **Electrocoagulation Tubes.** The electrocoagulation tubes consist of a tube-shaped anode material that concentrically surrounds a tube-shaped cathode material leaving an annular space between the anode and cathode. Contaminated water passes through the center of the cathode tube, then through the annular space between the cathode and anode tubes. Several electrocoagulation tubes may be used in series.

- **Clarifier.** The clarifier is designed to allow floccules (flocs) to continue to form in the treated water and to settle. Treated water exits the clarifier as the overflow. The settled flocs form a sludge that is removed in the underflow.

- **Bag Filter.** Heavy duty polypropylene bag filters are used to remove sludge from the underflow. Spent bag filters and sludge are periodically removed for disposal. Filtrate from the bag filters is recycled through the electrocoagulation tubes.

- **Transfer Pumps.** Transfer pumps are used to pump water from the system influent storage tank through the electrocoagulation tubes to the clarifier. Overflow from the clarifier is pumped from a lift station to discharge. Sludge is pumped from the bottom of the clarifier through the bag filter.

Several operating parameters can be varied on the CURE treatment system. These are:

- Length of electrocoagulation tubes
- Spacing between the inner and outer tubes
- Number of electrocoagulation tubes
- Tube material, either iron or aluminum
- Treatment sequence
- Number of passes through each electrocoagulation tube

Entering

1 Influent

2 NaOH for pH Adjustment

5 Iron from Anodes

Leaving

3 Dewatered Sludge and bag Filters

4 Treated Water

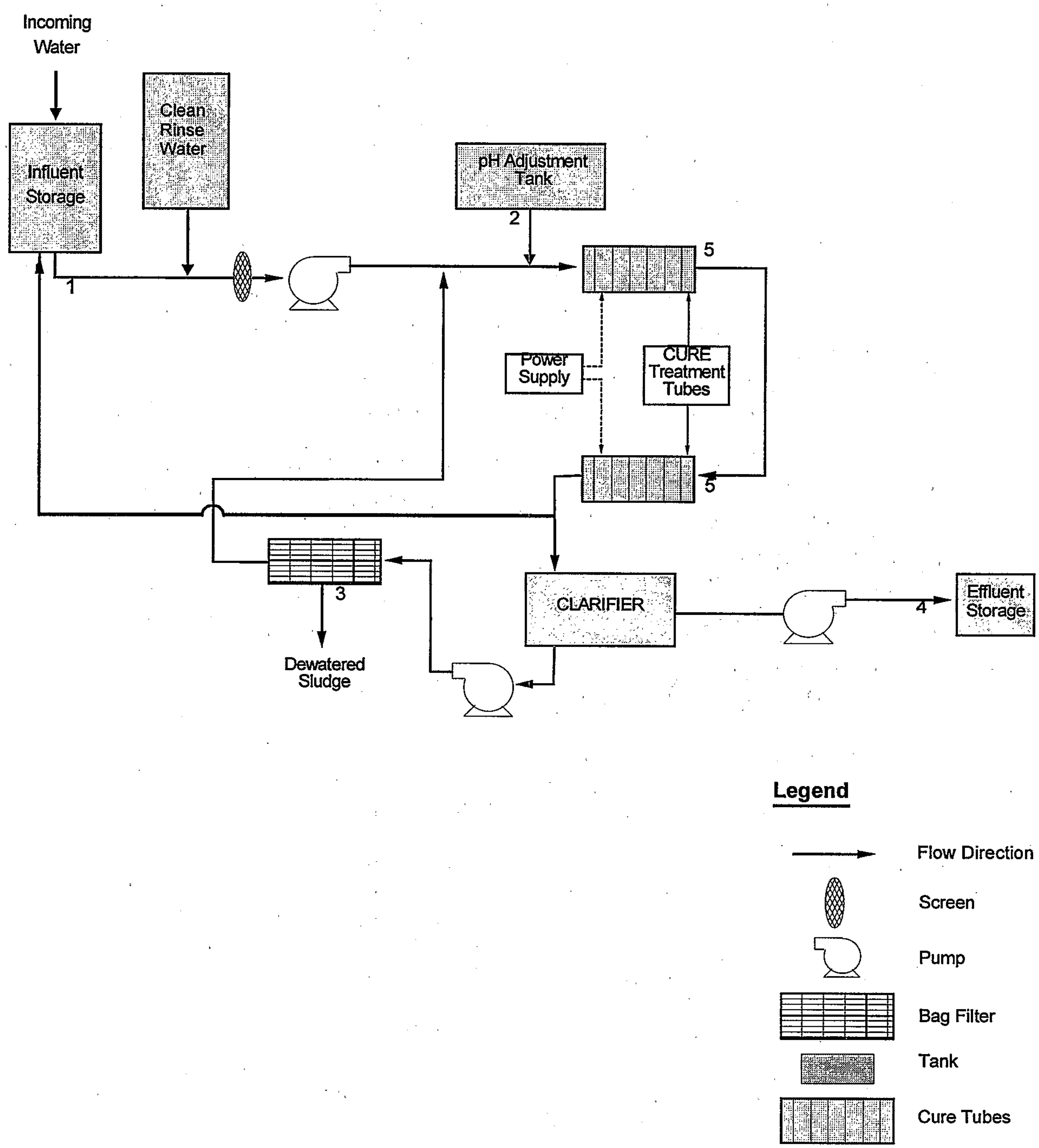


Figure 1-1. CURE schematic diagram.

- Flow rate and associated residence time for water in the electrocoagulation tubes and clarifier

- Amperage and accompanying voltage

1.5 Key Contacts

Additional information on the RFETS, the CURE technology, and the SITE program can be obtained from the following sources:

Rocky Flats Environmental Technology Site
Michael Konczal
Community Relations
U.S. DOE Rocky Flats Field Office
Rocky Flats Environmental Technology Site
P.O. Box 928
Golden, CO 80402-0928
303-966-5993

Jill Paukert
Community Relations
Kaiser-Hill Company, L.L.C.
P.O. Box 464
Golden, CO 80402-0464
303-966-6160
FAX: 303-966-4255

CURE Technology
General Environmental Corporation
c/o Daniel Eide
CURE International, Inc.
1001 U.S. Highway One, Suite 409
Jupiter, FL 33477
516-575-3500
FAX: 516-575-9510

SITE Program
Robert A. Olexsey
Director, Superfund Technology Demonstration Division
U.S. Environmental Protection Agency
26 West Martin Luther King Drive
Cincinnati, OH 45268
513-569-7861
FAX: 513-569-7620

Annette Gatchett
EPA SITE Project Manager
U.S. Environmental Protection Agency
26 West Martin Luther King Drive
Cincinnati, OH 45268
513-569-7697
FAX: 513-569-7620

Information on the SITE program is available through the following on-line information clearinghouses:

- The Alternative Treatment Technology Information Center (ATTIC) System is a comprehensive, automated information retrieval system that integrates data on hazardous waste treatment technologies into a centralized, searchable source. This database provides summarized information on innovative treatment technologies. Information is available on-line at *www.epa.gov/attic/attic.html.*

- The Vendor Information System for Innovative Treatment Technologies (VISITT) (Hotline: 800-245-4505) database contains information on 154 technologies offered by 97 developers.

- The OSWER CLU-In electronic bulletin board contain information on the status of SITE technology demonstrations. The system operator can be reached at 301-585-8368.

Technical reports may be obtained by contacting the Center for Environmental Research Information (CERI), 26 W. Martin Luther King Drive in Cincinnati, OH 45268 or by calling 800-490-9198.

Section 2
Technology Application Analysis

This section of the ITER evaluates the general applicability of the CURE system to contaminated waste sites based on the SITE demonstration results. A detailed discussion of the demonstration results is presented in Section 4 of this report. In addition, the developer's claims regarding the applicability and performance of the CURE system appear in Appendix A and several case studies provided by the developer appear in Appendix B.

2.1 Key Features of the CURE Electrocoagulation Technology

According to the vendor, the CURE system is an ex situ technology that allows on-site treatment of contaminated surface or groundwater with limited site preparation. The technology is unique in that it can remove radionuclides and metals from water without the addition of chemicals.

Operation of the CURE technology utilizes electricity to liberate ferric iron ions from the electrocoagulation tubes as the contaminated water passes through the tubes. The ferric ions combine with dissolved or colloidal contaminants in the water forming flocs which are removed in a clarifier. Use of the CURE system can substantially reduce the volume of contaminated media from the volume of contaminated water to the volume of the dewatered flocs. In addition, the mobility of the waste is reduced. The developer claims that the resulting floc can pass the EPA's TCLP.

2.2 Technology Performance

According to the technology developer, electrocoagulation systems have been used to treat wastewaters for over 85 years (Dalrymple 1994). The CURE electrocoagulation differs from those previously used by using concentric pipes as electrodes. This section summarizes the CURE electrocoagulation technology.

2.2.1 Historical Performance

Electrocoagulation technology using concentric tubes has been demonstrated as an effective process for the removal of metals from properly conditioned electroplating wastewaters. Removal levels appear to be better than those achieved by conventional hydroxide or carbonate precipitation using caustic soda, soda ash, or lime. Also, according to the developer, the metals can be precipitated at a lower pH as compared to these other commonly used methods (Dalrymple 1994).

Dalrymple (1994) reports that treatment of electroplating waste by electrocoagulation using concentric tubes in conjunction with pH adjustment reduced concentrations of cadmium, chromium, nickel, and zinc by 99.5 percent or more for all four metals. These results were compared with treatment of the same waste stream by pH adjustment only. Electrocoagulation treatment was 48 percent more effective than pH adjustment alone for cadmium, and 99.5 percent better for nickel. Chromium removals were similar for both tests, and zinc removal was 85 percent higher for pH adjustment alone.

A cadmium plating waste solution was also treated using the concentric tube electrocoagulation. The cadmium concentration was decreased by 99.5 percent from 12.0 milligrams per liter (mg/L) to 0.057 mg/L, the copper concentration was decreased by 96.4 percent from 8.94 mg/L to 0.32 mg/L, the zinc concentration decreased by 86.8 percent from 3.02 mg/L to 0.40 mg/L, and the silicon concentration decreased by 91.1 percent from 4.49 mg/L to 0.40 mg/L (Dalrymple 1994).

A truck manufacturing plant installed a concentric tube electrocoagulation system that reduces the chromium concentration in their discharge water from 400 mg/L to 0.17 mg/L (99.9 percent removal). The treated water complies with their discharge requirement of 1.0 mg/L (Dalrymple 1994).

Treatment of waste streams from acid mine drainage, can manufacturing, foundries, city sewage, rendering facilities, food processing, and synthetic fuel manufacturing has also been tested with concentric tube electrocoagulation. Metals concentration reductions for metals have ranged from 31 percent for a river water containing 12.0 mg/L magnesium to 99.9 percent for zinc and chromium in electroplating wastewater containing 221 mg/L zinc and 169 mg/L chromium. Dissolved anion concentration reductions have ranged from 33 percent for sulfate in an oil brine to 99 percent for phosphate in city sewage. In addition, biochemical oxygen demand (BOD), oil and grease concentration, total organic carbon (TOC), and total suspended solids (TSS) were reduced by 32 to 99 percent (Dalrymple 1994).

2.2.2 Bench-Scale Study Results

A treatability study was conducted for the CURE electrocoagulation technology prior to the SITE demonstration (EPA 1995a). In addition, RFETS conducted tests of the CURE system prior to the tests done by EPA. Water from the SEPs at RFETS was used for the tests. The primary objectives of the treatability study were as follows:

- Evaluate the effectiveness of the CURE technology for removing uranium, plutonium, and americium to meet Colorado Water Quality Control Commission (CWQCC) standards
- Determine removal efficiencies for boron, calcium, magnesium, the inductively coupled plasma metals suite, nitrate, nitrite, total dissolved solids (TDS), TSS, and TOC
- Evaluate the sludge produced by the CURE technology for leachability using the TCLP

Results of the treatability study indicate that the CURE treatment system is capable of consistently reducing radionuclide concentration by more than 90 percent, and CWQCC standards were met for radionuclides in all tests conducted. Only three other metals (cadmium, chromium, and boron) exceeded CWQCC standards in the test water. Cadmium and chromium concentrations were consistently reduced to below the CWQCC standard, but boron removal was insignificant. Manganese and molybdenum concentrations remained the same or increased slightly. Iron and aluminum concentrations increased during some of the tests due to dissolution of the anode material. This may indicate that the applied potential (voltage) was higher than necessary for effective coagulation, resulting in excess dissolution of the anodes.

Results of the TCLP analysis of the dewatered sludge produced by the CURE technology indicate that the metals barium, cadmium, chromium, selenium, and silver concentrations in the resultant leachate from the solids were all below regulatory limits. Sludge production was estimated to be approximately 2.5 cubic centimeters per liter of influent.

2.2.3 SITE Demonstration Results

The primary objectives of the CURE technology demonstration were to determine contaminant removal efficiencies (CREs) for the radionuclides uranium, plutonium-239/240, and americium-241; and determine if CWQCC standards for these contaminants could be met with 90 percent confidence. The mean CREs were calculated for each of four runs which were conducted after five optimization runs had been completed. The CRE for uranium ranged from 32 to 52 percent; the CRE for plutonium-239/240 was 63 to 99 percent; and the CRE for americium-241 was 69 to 99 percent.

The CWQCC discharge standards are 15 micrograms per liter (g/L) for uranium, 0.05 picoCuries per liter (pCi/L) for plutonium-238/239, and 0.05 pCi/L for americium-241. The CWQCC standard for uranium was not met during the demonstration. Some of the tests achieved the CWQCC standard for plutonium-239/240, but not all, and the CWQCC standard was met for americium-241 in one test only.

The CRE for arsenic was determined to be 78.5 percent, and at 0.02 mg/L, the effluent arsenic concentration was below the CWQCC standard of 0.05 mg/L. The results for aluminum and cadmium were inconclusive because their concentrations were below the detection limit in both the influent and the effluent. Boron, lithium, magnesium, TOC, and TDS showed little or no removal. TSS and iron concentrations increased due to the formation of flocculent from the dissolving anodes.

The results of the optimization portion of the demonstration indicated that three electrocoagulation tubes with an annular space of 0.1 to 0.5 inches should be used. Each tube was 10-feet long, and the water was pumped through the system at 3.0 to 3.1 gallons per minute (gpm). One pass through the system is all that was required. The current was set at 150 amperes, and the resulting potential was 20 to 57 volts.

2.3 Evaluation of Technology Against RI/FS Criteria

The CURE technology's applicability was also evaluated based on the nine criteria used for decision making in the Superfund feasibility study process. Results of the evaluation are summarized in Table 2-1.

2.4 Factors Influencing Performance

Three factors affect the performance of the CURE electrocoagulation technology. These are (1) influent water chemistry, (2) operating parameters; and (3) maintenance of the equipment. The following sections discuss these factors.

2.4.1 Influent Water Chemistry

The CURE electrocoagulation technology can treat a wide variety of wastewaters to remove dissolved and suspended contaminants. The chemistry of the wastewater, including the pH, the oxidation/reduction potential (Eh), dissolved oxygen, TDS, TSS, and the chemical form of the contaminants can affect formation of floccules, thereby affecting the ability of the technology to remove the contaminants of interest. Therefore, pretreatment such as filtering, aeration, or pH adjustment may be necessary. In addition, the system should be optimized to the influent characteristics and the contaminants to be removed.

The SEP water used to demonstrate the CURE electrocoagulation technology contained high levels of alkalinity, bicarbonate, carbonate, chloride and total dissolved solids, as shown in Table 2-2. CWQCC and EPA standards are provided for reference.

2.4.2 Operating Parameters

Use of the CURE technology is waste-specific with several of the operating parameters requiring optimization for the specific waste stream to be treated. Adjustable CURE system operating parameters include:

- Tube length
- Annular space between the concentric tubes
- Number of tubes
- Tube material
- Sequence of tube materials
- Number of passes through the system
- Flow rate (residence time)
- Applied potential that controls the electricalcurrent

2.4.3 Maintenance of Equipment

Routine maintenance of the CURE electrocoagulation equipment is required for smooth operation. Maintenance frequency depends on the electrical current applied and the sizes of the tubes used. The electrocoagulation tubes must be cleaned periodically to prevent clogging by solids. Cleaning is accomplished by flushing the system with clean water. After flushing is complete, the tubes may be disassembled and inspected for corrosion. Periodic replacement of the tubes will be required due to deterioration from the electrocoagulation process. Filter bags used for dewatering flocs also require periodic replacement.

2.5 Applicable Wastes

According to the developer of the CURE electrocoagulation technology, the technology can be applied to many contaminants dissolved and suspended in water including metals, uranium, radium, selenium, phosphates, bacteria, oils, clays, dyes, carbon black, silica, as well as hardness (calcium carbonate). Waste streams that the developer claims can be effectively treated by the technology are:

- Plating plant effluent
- Landfill leachates
- Petrochemical waste
- Bilgewater
- Mine process and wastewater

2.6 Site Requirements

The main requirement of the trailer-mounted CURE electrocoagulation system is electricity to operate the electrocoagulation tubes and the pumps that bring water into and out of the system. The maximum power required for the electrocoagulation system as demonstrated is 48 amperes at 480 volts, 3 phase or 96 amperes at 240 volts, 3 phase. The system distributes the power to the power

Table 2-1. Evaluation of CURE Process Based on Nine Criteria of Superfund Feasability Study Process

Criteria	Evaluation
1. Overall protection of Human Health and the Environment	The CURE technology is capable of removing heavy metal contaminants from groundwater and therefore prevents further migration of those contaminants.
2. Compliance with Federal Applicable or Relevant and Appropriate Requirements (ARARs)	Compliance with chemical-, location-, and action-specific ARARs must be determined on a site-specific basis.
3. Long-Term Effectiveness and Permanence	In waste streams with trace levels of contaminants, a high percentage of the contaminants are permanently removed. Involves some residuals treatment (sludge, wastewater) or disposal. Treatment is a well documented process.
4. Reduction of Toxicity, Mobility, or Volume Through Treatment	Significantly reduces toxicity, mobility, and volume of contaminants through treatment. Volume of technology residuals is small compared to the treated water volume.
5. Short-Term Effectiveness	Presents few short-term risks to workers and community. Some personal protective equipment is required to be worn by workers. Technology involves rapid reduction of contaminants in the waste stream.
6. Implementability	Involves few administrative difficulties. Utility requirements are water and electricity. Access for a 1-ton trailer is required and a 2,000 square feet flat area is required.
7. Cost	Costs range from $0.009 per treated gallon for a one year operation to $0.003 per treated gallon for a ten year operation.
8. Community Acceptance	Minimal short-term risks presented to the community make this technology favorable to the public.
9. State Acceptance	State regulatory agencies may require permits.

Table 2-2. Metals and Water Quality Parameters for RFETS Solar Evaporation Pond Water and Corresponding Treatment Standards

Metal	Units	Tank 029[a]	Tank 031[a]	Colorado Water Quality Control Commission (CWQCC)[b]	EPA MCL[c]
Aluminum	mg/L	<0.10	<0.10	0.15	0.05 - 0.2[e]
Antimony	mg/L	<0.05	<0.05	--	0.006
Arsenic	mg/L		0.21[d]	0.05	0.05
Barium	mg/L	<0.05	0.08	1.0	2
Beryllium	mg/L	<0.005	<0.005	0.004	0.004
Boron	mg/L	1.9	2.0	0.75	--
Cadmium	mg/L	0.011	0.057	0.0015	0.005
Calcium	mg/L	7.1	35	--	--
Chromium	mg/L	0.014	0.087	0.05	0.1
Cobalt	mg/L	0.006	0.013	--	--
Copper	mg/L	0.10	0.23	0.023	1.0[e]
Iron	mg/L	0.09	1.4	0.3	0.3[e]
Lithium	mg/L	2.1	2.3	--	0.25
Magnesium	mg/L	130	140	--	--
Manganese	mg/L	0.015	0.064	0.56	0.05[e]
Molybdenum	mg/L	0.070	0.10	--	--
Nickel	mg/L	0.04	0.06	0.125	0.1
Potassium	mg/L	550	560	--	--
Selenium	mg/L	<0.05	<0.05	0.01	0.05
Silver	mg/L	0.006	0.012	0.59	0.10[e]
Sodium	mg/L	2400	2600	--	--
Thallium	mg/L	<0.5	<0.5	0.012	0.002
Vanadium	mg/L	0.009	0.046	--	--
Zinc	mg/L	0.073	0.14	0.35	5[e]
Alkalinity Total	mg/L ($CaCO_3$)	5900	6300	--	--
Bicarbonate	mg/L (HCO_3^-)	5700	5000	--	--
Carbonate	mg/L ($CO_3^=$)	730	1300	--	--
Hydroxide	mg/L (OH^-)	<5	<5	--	--
Nitrate	mg/L	<0.05	0.09	10.0	10
Nitrate plus Nitrite	mg/L	<0.05	0.09	10.0	10
Nitrite	mg/L	<0.05	<0.05	0.50	1
TDS	mg/L	8200	8500	--	500[e]
TOC	mg/L	440	350	--	--
TSS	mg/L	130	120	--	--
pH	pH units	9.1	9.1	6.5-9.0	6.5 - 8.5[e]

Table 2-2. Metals and Water Quality Parameters for RFETS Solar Evaporation Pond Water and Corresponding Treatment Standards (continued)

Notes:

— No standard exists
mg/L Milligrams per liter

[a] Concentration, based on data collected during the CURE treatability study, April 1995 (EPA 1995a).

[b] Standards adopted through the Rocky Flats Interagency Agreement - the effluent treatment standard governing the demonstration (EPA 1991. Federal Facility Agreement and Consent Order. Denver, Colorado. January).

[c] Code of Federal Regulations, Title 40 (40CFR) Part 264.94 Resource Conservation and Recovery Act Subpart F Maximum Contaminant Levels (MCL).

[d] Concentration based on data collected from the solar evaporation ponds in 1991 (EG&G Rocky Flats 1991. Pond Sludge and Clarifier Sludge Waste Characterization Report).

[e] Secondary Maximum Contaminant Levels.

supply for the electrocoagulation tubes and the pump, and reduces it to supply the instrumentation and air compressor at 120 volts. The compressor is used to supply air to a diaphragm pump which is used to move the flocs through the bag filter.

An area of approximately 2,000 square feet is required for setup of the CURE system, and includes space for influent and effluent storage tanks. The area should be relatively flat and should be paved or gravel covered. Site access requirements for the CURE system are minimal. The site must be accessible to a one-half ton pickup truck pulling a trailer. The roadbed must be able to support such a vehicle and trailer delivering the system.

2.7 Materials Handling Requirements

The waste stream is delivered to the CURE electrocoagulation system using a pump and either piping or hose. In cases where the distance from the waste source to the treatment system exceeds 100 feet, additional pumps may be required to maintain a sufficient delivery rate. After treatment, effluent water may be recirculated through the CURE system, stored for further treatment by another method, discharged directly to another treatment system, or discharged as treated wastewater in an approved manner if treatment is sufficient to meet permit requirements.

Dewatered sludge and filter bags must be stored until disposal. Storage in 55-gallon drums is common practice. These drums can be easily handled with a fork lift equipped with a drum attachment. In most cases the solid waste generated by the CURE electrocoagulation system meets nonhazardous classification. However, confirmation may be required prior to disposal as such.

2.8 Personnel Requirements

Two persons are required for the CURE electrocoagulation system operation. The pumps and electrode potentials are controlled by the system operator while the maintenance technician monitors the system for leaks and treatment effectiveness. Both personnel are required for routine maintenance procedures such as cleaning the tubes and replacing filter bags.

2.9 Potential Community Exposures

The CURE electrocoagulation may produce chlorine, oxygen, and hydrogen gases that may be released to the atmosphere. However, operations during both the treatability study and the demonstration did not produce detectible levels of hydrogen or chlorine emissions. It is assumed that these gases were primarily dissolved in the effluent and their release to the atmosphere was slow. Oxygen emissions were not measured, but dissolved oxygen measurements in the effluent indicate that the oxygen produced from hydrolysis is used up in the coagulation reactions. Hydrogen and chlorine emissions from the effluent water are not expected to be hazardous to the general public or site personnel under open air conditions.

Solid wastes typically pass TCLP requirements for disposal as nonhazardous waste. Therefore, the solid waste generated by the CURE electrocoagulation system does not generally present an exposure problem to site personnel or the community. Treatment of wastewaters containing uranium, plutonium, and americium could produce low-level radioactive waste sludge. The sludge will be wet and contained, and will not present a dust hazard. Potential community exposure to radioactive solid waste is minimal.

The most significant exposure would be through a rupture in the system. Containment of such a spill is achieved by conducting the treatment operations in a lined bermed area. Should a rupture occur, the pumps can be turned off, and the system can be shut down immediately. These precautions will mitigate any potential community exposure due to system failure.

2.10 Potential Regulatory Requirements

Under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), as amended by SARA, remedial actions taken at Superfund sites must comply with federal and state environmental laws that are determined to be applicable or relevant and appropriate requirements (ARARs). This section discusses specific environmental regulations that will most likely be pertinent to operation of the CURE system, including the transport, treatment, storage, and disposal of wastes and treated residuals, and analyzes these regulations in view of the demonstration results. Regulatory requirements must be addressed by remedial managers on a site specific basis. Table 2-3 presents ARARs as they relate to the process activities conducted during the demonstration.

2.10.1 Comprehensive Environmental Response, Compensation, and Liability Act

CERCLA authorizes the federal government to respond to releases or potential releases of any hazardous substance into the environment, as well as to releases of pollutants or contaminants that may present an imminent or significant danger to public health and welfare or the environment.

As part of the requirements of CERCLA, EPA has prepared the National Oil and Hazardous Substance Pollution Contingency Plan (NCP) for hazardous substance response. The NCP is codified in Title 40 CFR Part 300 and delineates the methods and criteria used to determine the appropriate extent of removal and cleanup for hazardous waste contamination.

SARA amended CERCLA, directing EPA to do the following:

- Use remedial alternatives that permanently and significantly reduce the volume, toxicity, or mobility of hazardous substances, pollutants, or contaminants
- Select remedial actions that protect human health and the environment, are cost-effective, and involve permanent solutions and alternative treatment or resource recovery technologies to the maximum extent possible
- Avoid off-site transport and disposal of untreated hazardous substances or contaminated materials when practicable treatment technologies exist (Section 121(b)).

In general, two types of responses are possible under CERCLA: removals and remedial actions. If necessary, the CURE technology would be part of a CERCLA remedial action.

Remedial actions are governed by the SARA amendments to CERCLA. As stated above, these amendments promote remedies that permanently reduce the volume, toxicity, and mobility of hazardous substances, pollutants, or contaminants.

On-site remedial actions must comply with federal and more stringent state ARARs. ARARs are determined on a site-by-site basis and may be waived under six conditions: (1) the action is an interim measure, and the ARAR will be met at completion; (2) compliance with the ARAR would

Table 2-3. Federal and State ARARs for the CURE System

Process Activity	ARAR	Description	Basis	Response
Waste Processing	RCRA 40 CFR Part 264.190 to Part 264.200 or state equivalent.	Standards that apply to the treatment of hazardous wastes.	The treatment process occurs in a series of pipes.	CURE system integrity must be monitored and maintained to prevent leakage or failure; the system must be decontaminated when processing is complete.
Storage after Processing	RCRA 40 CFR Part 264.190 to Part 264.199 or state equivalent.	Standards that apply to the storage of hazardous wastes in drums.	The treated waste will be placed in drums.	The drums will be maintained in good condition in a secured area.
Waste Characterization	RCRA 40 CFR Part 261 Subparts C & D or state equivalent.	Standards that apply to waste characteristics.	Need to determine if treated material is a RCRA hazardous waste or mixed waste.	Testing will be conducted prior to disposal.
On-site Disposal	RCRA 40 CFR Part 264.300 to Part 264.317 or state equivalent.	Standards that apply to landfilling hazardous waste.	If left on-site, the treated waste may still be a hazardous waste or mixed waste subject to land disposal restrictions.	Contact EPA for on-site hazardous waste disposal; also, disposal will be in accordance with DOE RFETS requirements.
Off-site Disposal	RCRA 40 CFR Part 300.	Requirements for the off-site disposal of wastes from a Superfund site.	The waste is being generated from a response action authorized under SARA.	Wastes must be disposed of in an approved manner consistent with the waste classification.
Transportation for off-site Disposal	RCRA 40 CFR Part 262 or state equivalent.	Manifest requirements and packaging and labeling requirements prior to transporting.	The used health and safety gear must be manifested and managed as a hazardous or mixed waste. An identification number must be obtained from EPA.	Wastes and used PPE are being stored at RFETS.
Treated Water Discharge	SDWA, CWA, 40 CFR Part 440	Standards that apply to discharge of treated water	Wastewater containing metals and radionuclides is treated and ultimately discharged to a stream.	Waters discharged from the CURE system are collected for further treatment at RFETS.

pose a greater risk to health and the environment than noncompliance; (3) it is technically impracticable to meet the ARAR; (4) the standard of performance of an ARAR can be met by an equivalent method; (5) a state ARAR has not been consistently applied elsewhere; and (6) ARAR compliance would not provide a balance between the protection achieved at a particular site and demands on the Superfund for other sites. These waiver options apply only to Superfund actions taken on site, and justification for the waiver must be clearly demonstrated.

The CURE electrocoagulation technology demonstration at RFETS met all of the SARA criteria. The system significantly reduced the volume and mobility of contaminants. In addition, it provided a cost effective, permanent solution to the treatment of contaminated water at the site.

2.10.2 Resource Conservation and Recovery Act

The Resource Conservation and Recovery Act (RCRA), an amendment to the Solid Waste Disposal Act (SWDA), was passed in 1976 to address how to safely dispose of the large volume of municipal and industrial solid waste generated annually. RCRA specifically addressed the identification and management of hazardous wastes. The Hazardous and Solid Waste Amendments of 1984 (HSWA) greatly expanded the scope and requirements of RCRA.

The presence of RCRA defined hazardous waste determines whether RCRA regulations apply to the CURE technology. RCRA regulations define hazardous wastes and regulate their transport, treatment, storage, and disposal. Wastes defined as hazardous under RCRA include characteristic and listed wastes. Criteria for identifying characteristic hazardous wastes are included in 40 CFR Part 261 Subpart C. Listed wastes from nonspecific and specific industrial sources, off-specification products, spill cleanups, and other industrial sources are itemized in 40 CFR Part 261 Subpart D.

The CURE electrocoagulation system treated SEP water collected at RFETS. The SEPs have begun RCRA closure operations. Although wastes have not been disposed in the ponds since 1986, the ponds are currently regulated under RCRA. Water in the SEPs has been declared a RCRA waste. Therefore, the sludge collected in the bag filters during the demonstration were RCRA derived-waste and were treated as such by RFETS personnel.

Requirements for corrective action at RCRA-regulated facilities are provided in 40 CFR Part 264, Subpart F (promulgated) and Subpart S (proposed). These subparts also generally apply to remediation at Superfund sites. Subparts F and S include requirements for initiating and conducting RCRA corrective actions, remediating groundwater, and ensuring that corrective actions comply with other environmental regulations. Subpart S also details conditions under which particular RCRA requirements may be waived for temporary treatment units operating at corrective action sites.

2.10.3 Safe Drinking Water Act

The Safe Drinking Water Act (SDWA) of 1974, augmented by the Safe Drinking Water Amendments of 1986, requires EPA to establish regulations to protect human health from contaminants in drinking water. The legislation authorizes national drinking water standards and a joint federal-state system for ensuring compliance with these standards.

The National Primary Drinking Water Standards, maximum contaminant levels (MCLs), are found in 40 CFR Parts 141 through 149. In addition, the CWQCC has set basin specific discharge standards for the streams that drain the area of RFETS. Table 2-2 presents MCLs and CWQCC standards. Water treated by the CURE system must meet these standards in order to be discharged directly to the drainage. However, water treated by the CURE system was returned to a receiving tank for subsequent treatment at RFETS. Wash water from the decontamination was collected and stored in a tank before being collected by RFETS for treatment.

2.10.4 Clean Water Act

The CWA is designed to restore and maintain the chemical, physical, and biological integrity of the nation's waters. To reach this goal, effluent limitations of toxic pollutants from point sources were established. Publicly owned treatment works (POTW) can accept wastewaters with toxic pollutants from facilities; however, pretreatment standards must be met and a discharge permit may be required. A facility wanting to release water to a navigable waterway must apply for a permit under the National Pollutant Discharge Elimination System (NPDES). When a NPDES permit is issued, it includes waste discharge requirements.

Three options are available for the water treated by the CURE system: off-site disposal at a RCRA treatment facility; discharge through a sanitary sewer under an industrial pre-treatment permit; and discharge to the waterways of the U.S. under a NPDES permit. During the demonstration, water treated by the CURE system was stored and treated at RFETS.

2.10.5 Occupational Safety and Health Administration Requirements

CERCLA remedial actions and RCRA corrective actions must be performed in accordance with OSHA requirements detailed in 20 CFR Parts 1900 through 1926, especially Part 1910.120, which provides for the health and safety of workers at hazardous waste sites. On-site construction activities at Superfund or RCRA corrective actions sites must be performed in accordance with Part 1926 of OSHA, which provides safety and health regulations for constructions sites. State OSHA requirements, which may be significantly stricter than federal standards, must also be met.

All technicians operating the CURE system must complete an OSHA training course and must be familiar with all OSHA requirements relevant to hazardous waste sites. For most sites, minimum personal protective equipment (PPE) for technicians includes gloves, hard hats, steel toe boots, and coveralls. Depending on contaminant types and concentrations, additional PPE may be required. The CURE system and support equipment was mounted and operated on the bed of a trailer truck. All equipment on the system meets OSHA requirements for safety of operation.

2.10.6 Radioactive Waste Regulations

The CURE electrocoagulation technology may be used to treat water contaminated with radioactive elements. The primary agencies that regulate the cleanup of radioactively contaminated sites are EPA, the Nuclear Regulatory Commission (NRC), the DOE, and the states.

The SDWA has established MCLs for alpha- and beta-emitting radionuclides which may be appropriate in setting cleanup standards for radioactively contaminated water. Discharge of treated effluent from the CURE electrocoagulation system could also be subject to radionuclide concentration limits established in 40 CFR Part 440 (Effluent Guidelines for Ore Mining and Dressing). These regulations include effluent limits for facilities that extract and process uranium, radium, and vanadium ores. In addition, several states have set more stringent standards for surface waters discharged from nuclear facilities within their jurisdiction.

NRC regulations cover by licenses the possession and use of source, by-product, and special nuclear materials. These regulations apply to sites where radioactive contamination exists and cover protection of workers and public from radiation, discharges of radionuclides in air and water, and waste treatment and disposal requirements for radioactive waste. In evaluating requirements for treating radiologically contaminated waters, consideration must be given to the quality of the raw water, the final effluent, and any process residuals, specifically the dewatered flocs. If the CURE technology is effective for radionuclides, these radioactive contaminants will be concentrated in the dewatered flocs. This could affect disposal requirements, as well as health and safety considerations.

DOE requirements are included in a series of internal DOE orders that have the same force as regulations at DOE facilities. DOE orders address exposure limits for the public, concentration or residual radioactivity in soil and water, and management of radioactive wastes.

2.10.7 Mixed Waste Regulations

Use of the CURE electrocoagulation technology at sites with radioactive contamination may involve the treatment or generation of mixed waste. As defined by Atomic Energy Act (AEA) and RCRA, mixed waste contains both radioactive and hazardous components and is subject to both acts. When the application of both regulations results in a situation inconsistent with the AEA, AEA requirements supersede RCRA requirements.

EPA's Office of Solid Waste and Emergency Response (OSWER), in conjunction with the NRC, has issued several directives to assist in the identification, treatment, and disposal of low-level radioactive mixed waste. If high-level mixed waste or transuranic mixed waste is treated, DOE internal orders should be considered when developing a protective remedy.

2.11 Availability, Adaptability, and Mobility of Equipment

The system used for the demonstration is mounted on a 18-foot long by 6 °-foot wide trailer. This system can easily be transported to a site for operation. The trailer has a process pump, four CURE electrocoagulation tubes of different materials, control panel, power supply, air compressor, a small clarifier, and a bag filter for dewatering sludge.

The throughput of this system is adjustable as there is a variable frequency drive on the process pump. The flow can be set from 0.5 to 5 gpm. The clarifier is a simple design that utilizes the settled floc as a filtering system. The retention time in the clarifier is 2.3 hours at a flow rate of 1 gpm. The retention time required depends on the characteristic of the floc.

The trailer process pump can pump up to 5 gpm effectively. The retention time of the clarifier may not be long enough at this high flow rate. If higher flow rates are required, the clarifier may be modified or a larger clarifier may be used. The trailer unit was built as a test and demonstration unit and is available for use on short notice.

As an alternate to the demonstration trailer unit, GEC is manufacturing a larger transportable system. This system is called a Transportable Treatment Unit (TTU). The TTU trailer is 42 feet long and 8 ° feet wide and is pulled by a semitractor. The TTU is self-contained, requiring only diesel fuel to operate the generator. The throughput is up to 50 gpm. The TTU contains a clarifier and filter press for dewatering the sludge.

2.12 Limitations of the Technology

Electrocoagulation does not tend to remove inorganic contaminants that do not form precipitates, such as sodium and potassium. If a contaminant does not tend to form a precipitate or sorb to solids, electrocoagulation will not be a reliable treatment method. Although certain large organic compounds can be removed such as tannins and dyes, electrocoagulation is not effective in removing light-weight organic materials, such as ethanol, methylene chloride, benzene, toluene, or gasoline.

Section 3
Economic Analysis

This section presents cost estimates for using the CURE technology to treat groundwater. Three cases are presented based on treatment time. These cases are based on 1-year, 5-year, and 10-year treatment scenarios. The CURE technology can be operated at several different flow rates, but 100 gpm was assumed for this economic analysis because groundwater is typically treated in large quantities.

Cost estimates presented in this section are based primarily on data compiled during the SITE bench-scale study and field-scale demonstration at RFETS. Costs have been assigned to 12 categories applicable to typical cleanup activities at Superfund and RCRA sites (Evans 1990).

Costs are presented in November 1995 dollars and are considered estimates. This economic analysis is designed to conform with the specifications for an order-magnitude estimate. This level of precision was established by the American Association of Cost Engineers for estimates having an expected accuracy within +50 percent and -30 percent. In this definition, these estimates are generated without detailed engineering data.

Table 3-1 breaks down costs for the 12 categories for all three cases. The table also presents total one-time costs and annual O&M costs; the total costs for a hypothetical, long-term groundwater remediation project; and the costs per gallon of water treated.

3.1 Basis of Economic Analysis

A number of factors affect the estimated costs of treating groundwater with the CURE system. Factors affecting costs generally include flow rate, type and concentration of contaminants, groundwater chemistry, physical site conditions, geographical site location, availability of utilities, and treatment goals. Ultimately, the characteristics of residual wastes produced by the CURE system also affect disposal costs because they determine whether the residuals require either further treatment or off-site disposal. GEC claims that the CURE technology can be used to treat several types of liquid wastes, including contaminated groundwater and industrial wastewater. Groundwater containing radionuclides was selected for this economic analysis because radioactive wastewater was used in this demonstration, and groundwater remediation involves most of the cost categories. The following text presents the assumptions and conditions as they apply to each case.

For each case, this analysis assumes that the CURE system will treat contaminated groundwater at 100 gpm on a continuous flow cycle, 24 hours per day, 365 days per year. Based on this assumption, the CURE system will treat about 52.6 million gallons of water a 1-year period. Over a 5-year period, this number will rise to 263 million gallons, and over 10 years, to 526 million gallons.

This analysis assumes that treated water for each case will be discharged to surface water, and that specified discharge levels will be achieved with one pass through the electrocoagulation tubes.

The following assumptions were also made for each case in this analysis:

- The site is located near an urban area within 500 miles of Denver, Colorado, the home office of GEC.
- Water contamination at the site resulted from mining or nuclear operations.
- Contaminated water is located in an aquifer within 150 feet of the surface.
- Access roads exist at the site.

Table 3-1. Costs Associated with the CURE System at a Treatment Rate of 100 gpm

Cost Categories	Scheduled Treatment Time					
	1 year		5 years		10 years	
Fixed Costs						
Site Preparation	$18,000		$18,000		$18,000	
Administrative		$8,000		$8,000		$8,000
Bench-scale study		$7,000		$7,000		$7,000
Mobilization		$3,000		$3,000		$3,000
Permitting and Regulatory Compliance	$5,000		$5,000		$5,000	
Capital Equipment	$353,700		$353,700		$353,700	
Extraction wells, pumps, and piping		$158,000		$158,000		$158,000
Treatment equipment		$181,200		$181,200		$181,200
Storage tank purchase (2 tanks)		$4,500		$4,500		$4,500
Portable berm purchase		$10,000		$10,000		$10,000
Startup	$5,000		$5,000		$5,000	
Demobilization	($31,000)		($31,000)		($31,000)	
Decontamination/reconstruction		$5,000		$5,000		$5,000
Salvage value		($36,000)		($36,000)		($36,000)
Variable Costs						
Labor	$35,000		$175,000		$350,000	
Consumables and supplies	$12,400		$62,000		$124,000	
Replacement components		$10,000		$50,000		$100,000
PPE		$1,300		$6,500		$13,000
Disposable drums for PPE		$100		$500		$1,000
Miscellaneous		$1,000		$5,000		$10,000
Utilities	$26,480		$132,400		$264,000	
Water		$200		$1,000		$2,000
Electricity		$26,280		$131,400		$262,800
Effluent treatment and disposal	$0		$0		$0	
Residual and waste shipping and handling	$8,100		$40,500		$81,000	
Solids disposal		$6,700		$33,500		$67,000
PPE disposal		$1,400		$7,000		$14,000
Analytical services	$27,000		$135,000		$270,000	
Maintenance and modifications	$40,000		$200,000		$400,000	
Total fixed costs	$350,700		$350,700		$350,700	
Total variable costs	$138,980		$609,900		$1,192,800	
Total cost per gallon treated	$0.009		$0.004		$0.003	

Note:
Costs are based on 1995 dollars and are rounded to the nearest $100.

- Utility lines, such as electricity and telephone lines, exist on site.

- Water will be treated at a rate of 100 gpm and will be stored at the site.

- Floc will be treated and then disposed of off site as low level mixed waste; wash water will be stored and then disposed of off site.

- GEC will sell the CURE system to the site owner.

- One treated water sample and one untreated water sample will be collected and analyzed weekly to monitor system performance. Analyses will include gross alpha, uranium, and metals.

- One full-time equivalent operator will be required to operate the equipment, collect all required samples, and conduct equipment maintenance and minor repairs.

- Labor costs associated with major equipment repairs or replacement are not included.

3.2 Cost Categories

Cost data associated with the CURE technology have been assigned to one of the following 12 categories: (1) site preparation; (2) permitting and regulatory requirements; (3) capital equipment; (4) startup; (5) demobilization; (6) labor; (7) consumables and supplies; (8) utilities; (9) effluent treatment and disposal; (10) residual and waste shipping and handling; (11) analytical services; and (12) maintenance and modifications.

Costs associated with each category are presented in the following sections. Each section presents the costs that are identical for each case. If applicable, differences among the costs of the three cases are then discussed. Some sections end with a summary of the significant costs within the category. All direct costs associated with operating the CURE system are identified as CURE direct costs; all costs associated with the hypothetical remediation and auxiliary equipment are identified as groundwater remediation costs.

3.2.1 Site Preparation Costs

Site preparation costs include administration, bench-scale testing, and mobilization. This analysis assumes a total of about 2,000 square feet will be needed to accommodate the skid-mounted CURE system, support equipment, and treated and untreated water storage areas. A solid gravel (or ground) surface is preferred for any remote treatment project. Pavement is not necessary, but the surface must be able to support a portable unit weight of approximately 45,000 pounds during operation. This analysis assumes adequate surface areas exist at the site and will require minimal modifications.

A bench-scale test series will be conducted to determine the appropriate specifications of the CURE system for the site. Cost of the bench-scale study is estimated at $7,000 for tests which include analytical work and a site visit. Administrative costs, such as legal searches and access rights, are estimated to be $8,000.

Mobilization involves transporting the entire CURE system from Denver, Colorado, delivering all rental equipment to the site, and connecting utilities to the skid. For this analysis, the site is assumed to be located within 500 miles of Denver, Colorado, to minimize transportation costs. In addition, equipment vendors are assumed to be situated nearby the site. The total estimated mobilization cost will be approximately $3,000.

For each case, total site preparation costs are estimated to be $18,000.

3.2.2 Permitting and Regulatory Requirements

Permitting and regulatory costs vary depending on whether treatment is performed at a Superfund site or a RCRA corrective action facility and on the disposal method selected for treated effluent and any solid wastes generated. At Superfund sites, remedial actions must be consistent with ARARs of environmental laws, ordinances, regulations, and statutes, including federal, state, and local standards and criteria. In general, ARARs must be determined on a site-specific basis. RCRA corrective action facilities require additional monitoring records and sampling protocols, which can increase permitting and regulatory costs. For this analysis, total permitting and regulatory costs are estimated to be $5,000.

3.2.3 Capital Equipment

Capital equipment costs include installing extraction wells; purchasing and installing the complete CURE treatment system including a portable air compressor; and purchasing two storage tanks, one for treated water and one for rinse water. Extraction wells were included in the scenario because they are usually required in pump and treat groundwater remediation systems.

Extraction well installation costs associated with a groundwater remediation project include installing the well and pump connecting the pumps, piping, and valves from the wells to the CURE system. This analysis assumes that four 150-foot extraction wells with 4-inch polyvinyl chloride (PVC) casings will be required to maintain 100 gpm flow rate. Extraction wells can be installed at about $150 per foot per well. Total well construction costs for each case will be about $90,000. Alternatively, secondary wastewater can be inexpensively pumped directly from holding tanks to the system.

Pumps, piping, and valve connections associated with a groundwater remediation project will depend on the following factors: the number and size of extraction wells needed, the material selected, the flow rate, the distance of the extraction wells from the treatment system, and the climate of the area. This analysis assumes that four extraction wells are located within approximately 200 feet from the CURE system. Four 25-gpm pumps will be required to maintain a 100-gpm flow rate, at a total cost of about $20,000. Schedule 80 PVC piping and valve connection costs are about $60 per foot, including underground installation. Therefore, total piping costs will be an additional $48,000.

The complete CURE treatment system includes a 16-foot skid equipped with a power supply, electrocoagulation tubes, a clarifier, a filter press, transfer pumps, and electrical control panel. The clarifier and filter press are each on stand-alone skids. The cost of fabricating a skid mounted CURE system capable of treating flow rates of up to 100 gpm is approximately $181,200. The system includes a redundant set of electrocoagulation tubes to allow for cleaning and maintenance.

A 6,500-gallon high density polyethylene storage tank should be used to store the treated water for analytical testing prior to off-site discharge or reuse. An additional 1,000-gallon polyethylene water storage tank, costing $1,000, will be used for equipment washdown and decontamination rinse waters. It is assumed that a 6,500-gallon tank will be purchased for a cost of $3,500 and a 1,000-gallon tank for $1,000.

One 46- by 64-foot portable containment berm was costed to provide secondary containment under the CURE system and storage tanks. It is assumed that the berm will be purchased for $10,000. For this analysis, total capital costs are estimated at $353,700.

3.2.4 Startup

GEC will provide trained personnel to assemble and optimize the CURE treatment system. GEC personnel are assumed to be health and safety trained for the site of operations. Therefore, training costs are not incurred as a direct startup cost in this analysis. This analysis assumes that startup will take two people approximately 40 hours each to complete and has a total cost of $5,000.

3.2.5 Demobilization

Site demobilization costs include berm cleaning and equipment decontamination, plus site restoration and confirmation. Site restoration activities include regrading or filling excavation areas, and demobilization and disposal of all fencing. Total demobilization costs are estimated to be approximately $5,000.

A lifespan of 15 years is assumed for the CURE system and a salvage value of approximately 20 percent of the original cost, or $36,000.

3.2.6 Labor

Labor costs include a full-time equivalent technician to operate and maintain the CURE system. Once the system is functioning, it is assumed to operate continuously at the designed flow rate. One technician will monitor the system and equipment, make any required operational adjustments, conduct routine sampling, and provide administrative services associated with system operations.

This analysis assumes a 40-hour work week, 52 weeks per year, at an hourly rate of $16.83. Annual labor cost will be approximately $35,000.

3.2.7 Consumables and Supplies

The consumables and supplies associated with CURE system operations include replacement components for the CURE system, disposable personal protection equipment (PPE), drums for disposing used PPE, and miscellaneous items.

Replacement components include electrocoagulation tubes, fittings, and other miscellaneous parts on the CURE system. This analysis assumes an annual cost of these items of $40,000.

Disposable PPE includes Tyvek coveralls, gloves, and booties. The treatment system operator will wear PPE when required by the health and safety plan during system operation. This analysis assumes the PPE will cost approximately $25 per day, be required approximately 1 day per week, 52 weeks per year for the duration of the project. Total annual PPE costs are estimated to be about $1,300.

Three 55-gallon open-headed, plastic-lined drums are estimated to be needed for disposing of used disposable health and safety and sampling gear, as well as for storing nonhazardous wastes for disposal. Total disposal drum costs are estimated to be about $100 per year.

Miscellaneous costs of $1,000 were included for the purchase of miscellaneous small parts and supplies.

3.2.8 Utilities

Utilities used by the CURE system include electricity and water. The CURE treatment system requires about 200 gallons of potable water per week. This water is used for cleaning and decontamination of the CURE system and operators. This analysis estimates water to cost $0.02 per gallon. Total water costs will be about $4 per week, for a total of approximately $200 per year. This cost can vary by as much as 100 percent depending on the geographic location of the site, availability of water, and distance to the nearest water main.

Electricity to operate the process equipment, field laboratory equipment, and air compressor is assumed to be available at the site. Electricity is assumed to cost $3 per hour, or about $26,280 per year. This analysis assumes that electricity costs about $0.06 per kilowatt-hour (kWh). Electricity costs can vary by as much as 50 percent depending on the geographical location and local utility rates. No estimate of kWh per 1,000 gallons of water treated has been calculated.

3.2.9 Effluent Treatment and Disposal

The analysis assumes that the effluent stream will have a pH from 7.0 to 8.3, and will not contain regulated pollutants exceeding EPA and state discharge limits; hence, no further treatment should be needed. Local regulations may require discharge to a POTW, which may result in additional charges to the CURE system operator. For this analysis, effluent treatment and disposal costs are estimated at $0 per year.

3.2.10 Residual Waste Shipping and Handling

This analysis assumes that approximately 50 cubic feet per year of dewatered floc. Disposal of the floc typically involves mixing the dewatered floc with a powdered commercial chemical stabilizing material in 55-gallon drums. During the SITE demonstration, these drums were stored at an EPA- and DOE-approved storage facility. This estimate assumes the drums will be classified as low-level mixed waste and disposal costs for 14 drums of stabilized floc are estimated at $6,700.

Drummed PPE will be screened for radioactivity and disposed of in accordance with state and federal requirements. This analysis assumes that approximately two drums per year must be disposed of and will be classified as low level mixed waste. This analysis estimates a cost of $1,400 for this disposal.

Decontamination and wash water generated during CURE system operation are returned to the CURE system for treatment.

3.2.11 Analytical Services

Analytical costs associated with a groundwater remediation project include laboratory analyses, data reduction and tabulation, QA/QC, and reporting. For each case, this analysis assumes that one sample of untreated water and one sample of treated water will be analyzed for gross alpha radioactivity, uranium, and metal concentrations each week, along with QA samples. Monthly laboratory analyses are estimated at $1,500; data reduction, tabulation, QA/QC, and reporting are estimated to cost about $750 per month. Total annual analytical services costs for each case are estimated to be about $27,000 per year.

3.2.12 Maintenance and Modifications

Annual repair and maintenance costs apply to all equipment involved in every aspect of groundwater remediation with the CURE treatment system. No modification costs are assumed to be incurred. Based on information from GEC, total annual maintenance costs are estimated to be about $40,000 per year.

Section 4
Treatment Effectiveness

The following sections describe the CURE electrocoagulation demonstration that was conducted at RFETS during August and September 1995. The demonstration was conducted as a cooperative effort between the DOE, EPA, and Colorado Department of Public Health and the Environment (CDPHE).

4.1 Background

RFETS is located in northern Jefferson County, Colorado, approximately 16 miles northwest of downtown Denver (Figure 4-1). The 400-acre plant site is located within a restricted area of approximately 6,550 acres, which serves as a buffer zone between the plant and surrounding communities. The immediate area around RFETS is primarily agricultural or undeveloped land. Population centers within 12 miles of the facility include the cities of Boulder, Broomfield, Golden, and Arvada.

RFETS began operations in 1952, and was a key facility in the federal government's nationwide nuclear weapons research, development, and production program. The mission of the plant has now changed from production to decontamination and decommissioning of facilities, environmental restoration, and waste management.

The source of water for the demonstration is the RFETS SEPs. This series of five evaporation ponds is located in the central portion of the RFETS, inside the protected area (PA). This series of ponds was initially placed into service from August 1956 to June 1960. These ponds were used to store and treat liquid process wastes having less than 100,000 pCi/L of total long-lived alpha activity (DOE 1980). These process wastes also contained high concentrations of nitrates, and treated acidic wastes, including sanitary sewer sludge, lithium chloride, lithium metal, sodium nitrate, ferric chloride, sulfuric acid, ammonium persulfates, hydrochloric acid, nitric acid, hexavalent chromium, tritium, and cyanide solutions (Rockwell 1988).

Placement of process waste material in the SEPs ceased in 1986 due to changes in waste treatment operations. In 1994, the sludge and liquid remaining in the A and B ponds were removed and placed in storage tanks inside temporary structures erected on the 750 Pad. Water decanted from this sludge and liquid (A/B decant water) was used for the demonstration.

4.2 Review of SITE Demonstration

The SITE demonstration was divided into three phases (1) site preparation; (2) technology demonstration; and (3) site demobilization. The following paragraphs discuss these activities.

4.2.1 Site Preparation

A total of about 5,500 square feet of asphalt paved parking lot was used to set up the containment berms, portable generator, waste storage container, and support facilities. Site preparation required 10 days to complete. Site preparation consisted of setting up the containment berm used to contain the CURE system, unloading two 6,500-gallon tanks used to store effluent, setting up a second berm to contain the tanker truck delivering the water to be treated by the system, and setting up the hoses required to bring the water from the tanker truck to the CURE system and then to the storage tanks.

4.2.2 Technology Demonstration

Prior to conducting the demonstration, GEC conducted six preruns and five optimization runs over an 11- day period. The preruns allowed for testing of the system integrity and confirmation that all equipment was functioning properly.

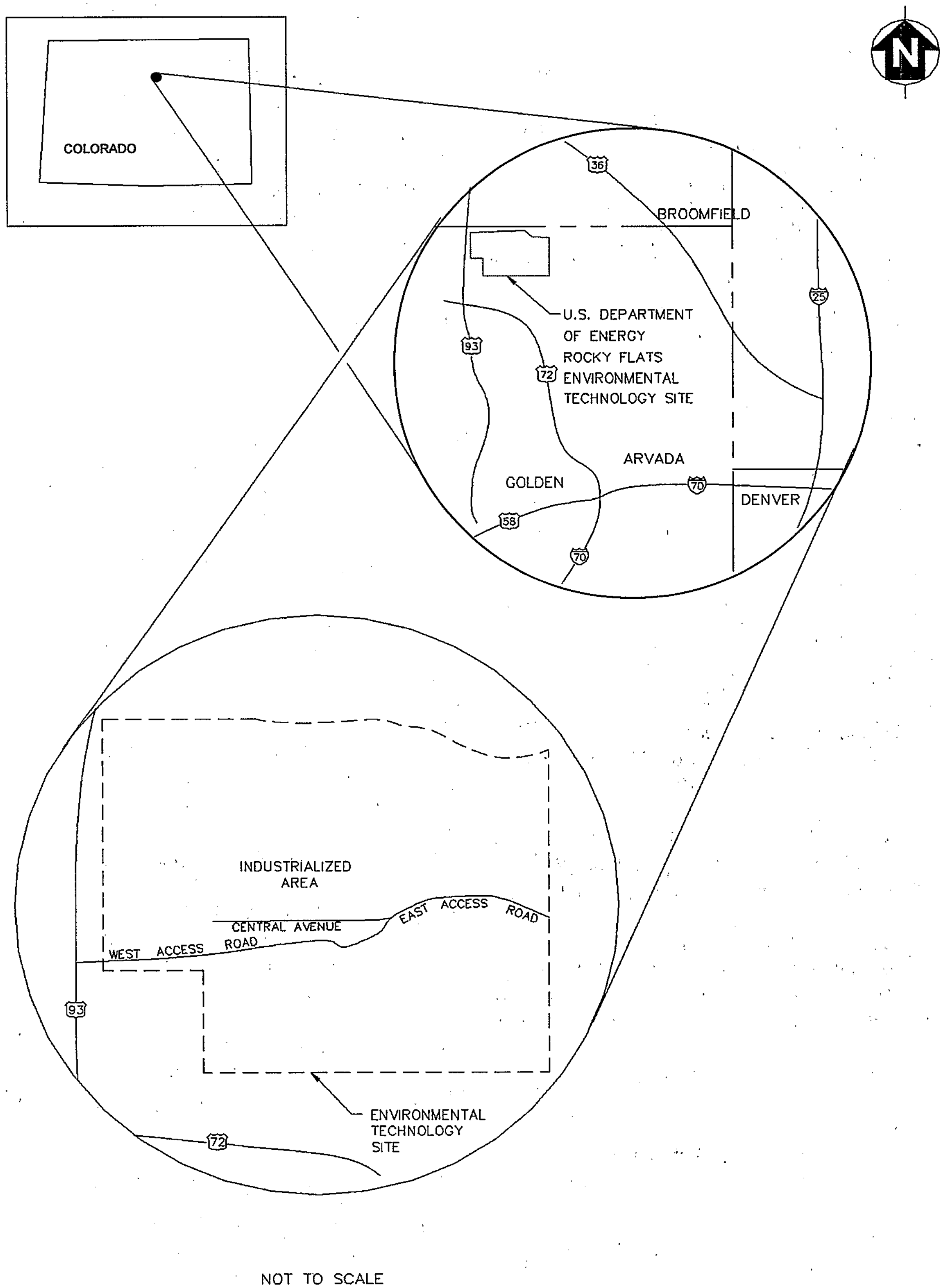


Figure 4-1. Site location map.

Clean process water was used in all of the preruns. The optimization runs were used to configure the CURE electrocoagulation system for optimal removal of contaminants from the process influent. Parameters that were adjusted include the annular space between the tubes, the diameter of the tubes, the number of tubes, the tube material and the sequence, electrical potential, electrical current, and flow rate.

Approximately 4,500 gallons of contaminated water were treated by the CURE system during four demonstration runs conducted over a 2-week period. The run schedule was set up to allow alternating days for demonstration runs and system cleanup due to the operating schedule at RFETS.

All four runs were conducted using the same operating parameters. These parameters were set on the basis of the optimization run results. The demonstration runs were conducted to assess the ability of the CURE system to consistently produce treated water meeting the demonstration goals. Sampling activities were performed in two phases for each run. Each run was initiated by running process water through the CURE electrocoagulation system to the clarifier. The field parameters specific conductance, pH, dissolved oxygen and temperature of the effluent from the CURE tubes were measured every 5 minutes for 30 minutes after pumping commenced. Filling the 450-gallon clarifier took approximately 2.5 hours. Once the clarifier was full, samples of untreated influent, effluent from the clarifier, and effluent from the clarifier that was filtered through a 40-micron filter were collected every 20 minutes for 3 hours. These samples were analyzed for the radionuclides uranium, plutonium, and americium. The field parameters were also measured at the two sample locations at the time of sample collection. Samples were also collected for total metals analysis at the two sampling locations in runs 1 and 3. The runs were terminated after the last samples were collected. Dewatered sludge samples were collected after each run and analyzed for uranium, plutonium, and americium. The TCLP was also performed on the sludge. Sludge samples from runs 1 and 3 were also analyzed for total metals.

4.2.3 Site Demobilization

Site demobilization activities began after the demonstration was complete. Demobilization activities included draining the two 6,500-gallon process water tanks; disconnecting the portable generator; and decontaminating and removing the treatment system, the two 6,500-gallon storage tanks, and the two temporary berms.

The CURE system was decontaminated with high-pressure steam at the RFETS decontamination pad. RFETS personnel decontaminated the two 6,500-gallon storage tanks while they were inside the berm by spraying the tank interiors with water. This wastewater was pumped to a tanker truck and taken to Building 374 for final treatment. Rinsate samples were collected and analyzed for attainment of the performance standards in Part VIII of the Rocky Flats RCRA permit. EPA decontaminated the larger of the two temporary berms with non-phosphate detergent and water.

The CURE system, the two 6,500-gallon tanks, and the berm were screened for radioactive contamination by RFETS personnel. The CURE system and the berm were released by RFETS personnel after the analytical results indicated that the decontamination procedures were successful.

Because RFETS personnel decided that additional analyses of the tank rinsate wastewater was necessary, the removal schedule for the tanks and the smaller inflatable berm was delayed. Both of the tanks and the inflatable berm, on which the tanks were setting, remained on-site for three weeks after the demonstration. After the tanks were picked up by the vendor, the smaller, inflatable berm was decontaminated with non-phosphate detergent and water by EPA.

4.3 Demonstration Methodology

The technology demonstration was designed to address two primary and eight secondary objectives. The primary objectives were to document 90 percent CREs for uranium, plutonium, and americium to the 95 percent confidence level; and to determine if CURE could treat the waste stream to radionuclide contaminant levels below CWQCC standards at the 90 percent confidence level. The data required to achieve these objectives are called the critical parameters. They include uranium, plutonium, and americium concentrations in the influent and effluent.

The secondary objectives were as follows:

- Evaluate anode deterioration

- Demonstrate CREs for arsenic, boron, cadmium, calcium, lithium, magnesium, TOC, TDS, and TSS of 90 percent or higher at the 90 percent confidence level

- Document production of hydrogen and chlorine gasses

- Determine power consumption by the CURE electrocoagulation system

- Determine optimum system operating parameters for treatment of A/B decant water

- Document selected geochemical parameters (pH, Eh, specific conductivity, and temperature) that may affect the effectiveness of the CURE electrocoagulation system

- Determine uranium, plutonium, americium, and TCLP metals leachability from the flocculent by TCLP

- Estimate capital and operating costs of building a single treatment unit to operate at the rate of 100 gpm

Secondary objectives provide information that is useful, but not critical, to the evaluation of the system. Data required to achieve the secondary objectives are called noncritical parameters. These parameters include:

- Periodic visual inspection of the electrodes and documentation of their replacement

- Influent and effluent concentrations of arsenic, boron, cadmium, calcium, lithium, magnesium, TOC, and TSS

- Air monitoring results for chlorine and hydrogen gas at the point where the treated water leaves the electrocoagulation tubes

- Documentation of the quantity of fuel used by the CURE electrocoagulation system and the volume of water treated

- Documentation of the length of the electrocoagulation tubes, the annular space between them, the number of tubes, the tube material, the number of passes through the tubes, the flow rate, the electrical current, and the applied potential throughout the demonstration, including the optimization runs

- Periodic measurement of pH, Eh or dissolved oxygen, specific conductance, and temperature of both the influent and effluent

- Concentrations of TCLP metals and radionuclides in the resultant leachate from a TCLP performed on a sample of the flocculent

- Documentation of all costs associated with the demonstration and an estimation of construction costs

4.3.1 Testing Approach

The CURE electrocoagulation demonstration consisted of six preruns, five optimization runs, and four demonstration runs. The preruns were conducted using clean process water to test the fittings, piping, and overall integrity.

The optimization runs were used to determine the best operating conditions for the system. Parameters such as the tube material, annular space between the tubes, the flow rate, and the electrical current were adjusted during these runs. These parameters were adjusted in response to observations of the technology developer and the water quality parameters pH, dissolved oxygen, specific conductivity, and temperature. Operating parameters were also adjusted based on results from quick turn around of gross alpha analysis of treated water samples.

Four demonstration runs were completed to achieve the primary objectives as stated in Section 4.3. Influent and effluent water samples were obtained from sampling ports L1 and L2 (Figure 4-2). Sample results of influent and effluent were compared to evaluate the CRE of the CURE system. During each 3-hour test run, composite samples of influent and effluent were collected each hour from grab samples taken at 20-minute intervals. Composite samples were collected to reduce variability in radionuclide concentrations due to inherent system changes.

QA/QC samples including matrix spikes and matrix spike duplicates (MS/MSD), duplicates, process equipment blanks, and sample bottle blanks were collected to evaluate the variability associated with the analytical and sampling procedures.

SAMPLE COLLECTION OR MEASUREMENT LOCATION	LOCATION IDENTIFIER	MATERIAL	MONITORING ACTIVITY	PARAMETERS
Influent from Solar Pond Decant Water	L1 M1	Untreated Water Untreated Water	Sample Collection Measurement	Water Chemistry Flow Rate, Pumping Period, Water Characteristics
Effluent from CURE Treatment System	L2 M2	Treated Effluent Treated Effluent	Sample Collection Measurement	Water Chemistry Water Characteristics
Filter Cake	S1 M3	Filter Cake Filter Cake	Sample Collection Measurement	Solids Chemistry and Characteristics Volume
Power Supply	M4 M5	None	Measurement Measurement	Voltage, Amperage Voltage, Amperage

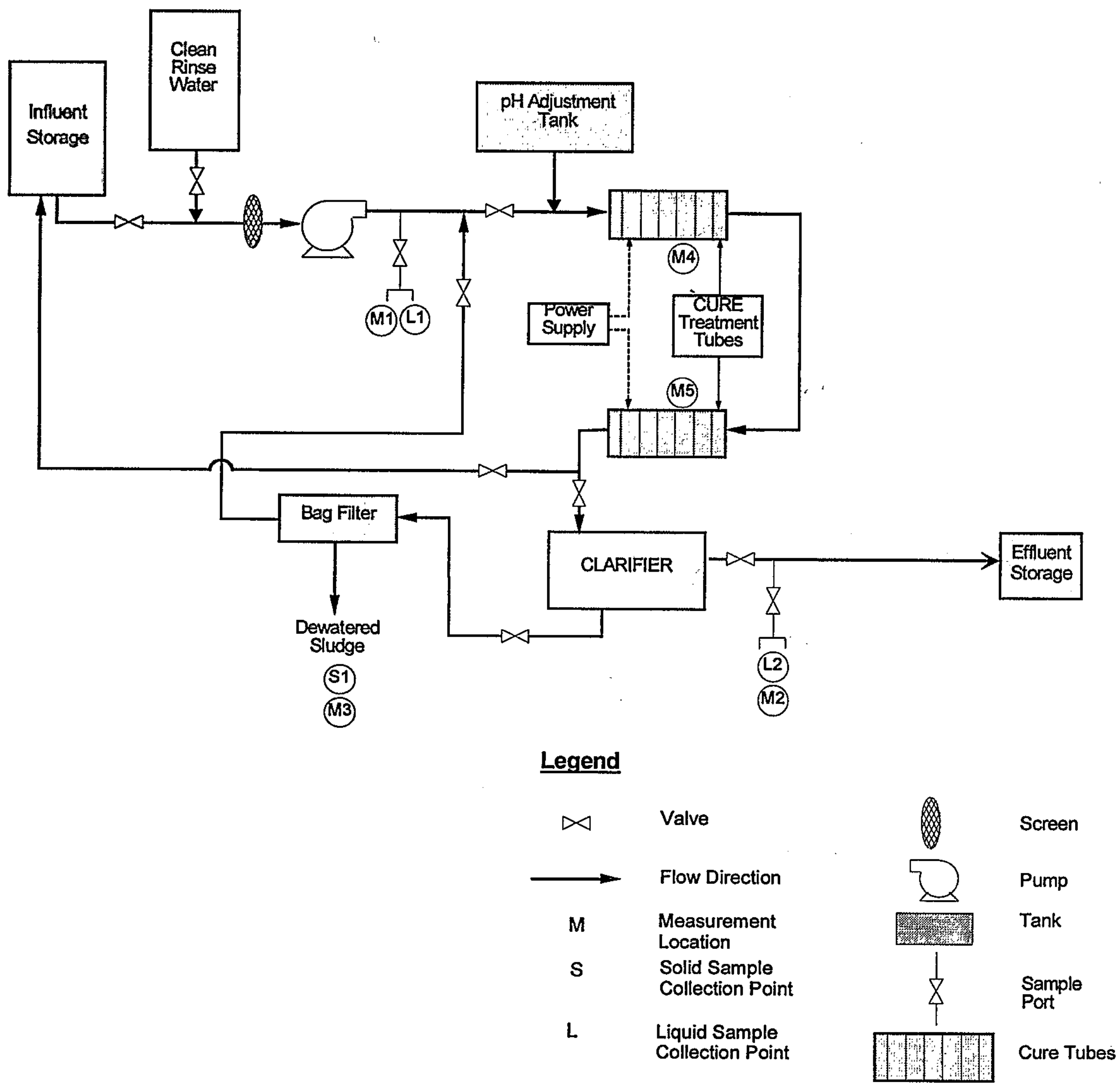


Figure 4-2. Sampling and measurement locations.

The following approaches were used to achieve the demonstration's secondary objectives:

- Samples were analyzed to demonstrate the CREs for metals, TOC, TDS, and TSS and to evaluate anode deterioration
- Field parameter and water quality measurements were obtained every 20 minutes throughout each run to confirm system stability for the duration of each run.
- Samples of dewatered sludge were obtained to determine metals leachability (including radionuclides) from the flocculent by TCLP for waste characterization.
- The volume of sludge generated by the treatment process was measured.
- All costs associated with each phase of the demonstration were documented.

4.3.2 Sampling Analysis and Measurement Procedures

Water samples were submitted for total uranium, plutonium-239/240, and americium-241 analysis. Water samples from test runs 1 and 3 were also analyzed for total metals, TOC, TDS, and TSS. Samples of influent and effluent were obtained at locations L1 and L2 shown in Figure 4-2. In addition, sludge samples were submitted for total uranium, plutonium-239/240, and americium-241 analysis. Sludge samples from test runs 1 and 3 were also analyzed for total metals, TOC, bulk density, and moisture content. Sludge samples were collected after test runs 1 and 3 for TCLP analysis.

In addition to sampling and analysis for chemical parameters, the operating conditions of the treatment system were evaluated using the measurement data collected at locations L1 and L2 shown in Figure 4-2. For runs 1 through 4, pH, specific conductivity, dissolved oxygen, and temperature were measured at sampling ports L1 (influent) and L2 (effluent). Voltage and amperage measurements were taken from gauges installed on the treatment system (M1, M4, and M5). These sampling locations are shown in Figure 4-2. Flow rate was calculated from time and volume measurements for each demonstration run. Power consumption was measured by the amount of diesel fuel used by the portable generator.

4.3.3 Operational and Sampling Problems and Variations from the Work Plan

Originally, the CURE SITE demonstration was scheduled to be completed in 35 days. The SITE team, consisting of EPA's contractors and DOE's operating contractor at RFETS, experienced several operational problems during the demonstration. Some of these problems resulted in changes in the demonstration schedule, while others required making decisions in the field to solve the problem. Some of these changes also resulted in deviations from the work plan contained in the quality assurance project plan (QAPP) (EPA 1995b). As a result of these operational problems, the demonstration was completed over a period of 53 days. Site preparation was completed in 10 days; the preruns, optimization runs, and demonstration runs were completed in 14 days; and decontamination and demobilization was completed in 29 days. The problems encountered during the demonstration and their solutions are presented below. Deviations from the work plan are also presented.

- Pressure buildup within the treatment system due to an accumulation of floc in the electrocoagulation tubes and clogging of bag filters resulted in leaks within the system. These problems led to delays in the original demonstration schedule and resulted in several additional optimization runs and a retrofit of the treatment system. The inner pipes were replaced with smaller diameter pipes to allow for more annular space between the tubes. In addition, nylon screws were placed along the length of each tube to keep the inner tube centered within the outer tube. This allowed flocculent to pass more easily through the annular space. However, the tubes still required cleaning after each run to prevent pressure buildup and to allow data from all runs to be comparable.
- As dictated by the CURE demonstration health and safety plan (EPA 1995c), screening of all personnel for alpha and beta radiation by RFETS radiation control technicians was required upon exiting the bermed area. Therefore, the SITE team was constrained by the radiation control personnel work schedule which also resulted in shorter work days.

- The bag filters attached to the clarifier filled with flocculent and clogged very easily. The bag filter size was changed from 1 micron which was used during preruns and optimization runs, to 25 microns for demonstration runs 1, 2, and 4. In addition, a 50- micron bag filter was used during run 3 to allow for increased flow.

- Samples obtained during demonstration runs were alkaline, with a pH range of 7.7 to 9.6. Large quantities of acid were required to bring the sample pH to 2.0 for preservation, as stated in the work plan. The addition of large quantities of acid led to generation of gases in the samples. Therefore, acid was added in small increments to each sample to control effervescence. This procedure took much more time.

- The work plan stated that two 6,500-gallon tanks would be used during the demonstration. One tank to contain untreated water removed from A and B solar pond sludge (A/B decant water) and the other to contain treated water. However, both tanks were used to contain treated water. The untreated A/B decant water remained in the tanker truck used to transport water to and from the demonstration site. The tanker truck was parked inside an inflatable berm to contain any potential spills.

- The work plan stated that the length and diameter of the electrocoagulation tubes and the type of metal tubes used (Al or Fe), were to be determined before bringing the treatment system on site. The work plan also stated that only flow rate and amperage would be changed during the preruns and optimization runs. However, because of pressure buildup in the system, flow rate, amperage, and tube diameter were changed during the preruns and optimization rums. Iron was the only tube material used.

- An effluent process blank was added before commencement of run 1 to evaluate the flushing efficiency of the treatment system. This additional sample was not included in the original work plan.

- As stated in the work plan, treated effluent was to be routed to the clarifier to allow for the settlement of flocculent generated by the treatment system. However, the developer was concerned that the small-capacity clarifier would not be able to handle the flow rates used during the treatment process. Therefore, samples obtained would not represent the treatment capability of a larger capacity clarifier, as originally proposed. Because of this issue, two samples of effluent water were obtained from sampling port L2. One sample remained unfiltered and the other sample was filtered after collection into the composite container. This sample was filtered using a 40-micron filter to mimic settling within a larger capacity clarifier as originally proposed in the work plan. Samples were filtered during transfer from the composite sample collection container to individual sample bottles.

- The work plan stated that a constant flow rate of 5 gpm would be used throughout runs 1 through 4. As a result of the optimization runs, the flow rate used for runs 1 through 4 was 3 gpm.

During the field QA audit of the demonstration, it was noted by the EPA auditor that the reality short operating runs required by the operating conditions at the site may not be representative of the typical use of the CURE system. Therefore, long-term operating efficiency of the CURE system should be extrapolated with caution from the limited data collected during the demonstration.

4.4 Review of Demonstration Results

This section discusses demonstration results in terms of the optimization runs and results for critical and noncritical parameters. The system optimization was performed to determine the most effective configuration of the system for treatment of the A/B decant water from the SEPs at RFETS.

4.4.1 Summary of Results for Optimization Runs

Five optimization runs were conducted to determine the most effective configuration of the CURE electrocoagulation system for treating A/B decant water at RFETS. Variable parameters included tube material, diameter, length, and number; annular space between tubes; flow rate; number of passes through the system; and applied potential (and associated electrical current).

The configuration used for the demonstration are as follows:

- Iron tube material
- Three pairs of concentric tubes
- 0.1- to 0.5-inch annular space
- One pass through each tube
- Flow rate of 3.0 to 3.1 gpm
- Applied potential of 20 to 57 volts and accompanying current of 135 to 168 amperes

4.4.2 Summary of Results for Critical Parameters

A comparison of the first two test runs with the last two runs indicates that CWQCC standards for plutonium and americium are most likely to be met when the influent concentrations of plutonium and americium are low, while the CREs are greatest when concentrations of these contaminants are higher. However, higher concentrations of plutonium and americium may be associated with suspended solids, and a significant portion may be removable by prefiltering or settling of the treatment water prior to treatment.

CREs for Uranium, Plutonium, and Americium

Samples for uranium, plutonium, and americium analysis were collected from the inflow to the treatment system and the outflow of the clarifier during each run. Both filtered and unfiltered samples were collected at the outflow of the clarifier. The filtered samples were passed through a 40 micrometer (*u*m) nominal pore size filter. CREs were calculated for each test run using composite data from influent and both the filtered and unfiltered effluent concentrations. The results are presented in Table 4-1.

Analytical results from the four runs indicate that the source water contained similar concentrations of uranium throughout the demonstration. However, the plutonium and americium concentrations varied. Plutonium and americium tend to sorb to particulates. Therefore, the variation in influent concentrations for these metals is likely an artifact of positioning of the tanker truck supplying the source water resulting in different amounts of sediment being pumped into the system. The first two runs were conducted with mean influent concentrations of 0.221 and 0.197 pCi/L of plutonium, and 0.202 and 0.172 pCi/L americium. Plutonium and americium concentrations for runs 3 and 4 were more than 100 times these values.

CREs were calculated for each run based on mean influent and effluent concentrations (see Table 4-1). The mean CREs for uranium were 43 percent for unfiltered effluent and 44 percent for filtered. While these results indicate that uranium concentrations were reduced considerably, the objective of 90 percent contaminant removal was not achieved. Uranium removal was not as high as expected based on results of the bench-scale treatability study. Results from the treatability study indicated at least 94 percent removal efficiency for uranium, with an influent uranium concentration that was comparable to the influent concentration in the demonstration.

It is likely that the operational parameters used in the demonstration were not optimal for uranium removal. More complete system optimization and treating wastewater with multiple runs through the CURE system may improve uranium removal efficiencies.

The removal efficiencies for plutonium and americium were much higher than for uranium. Results from run 1 are comparable to those of run 2, and results from runs 3 and 4 are comparable. However, results from runs 1 and 2 are very different than results from runs 3 and 4. Therefore, the results from the first two runs are presented separately from the results of runs 3 and 4. The reason for such different results appears to be related to the higher influent concentrations of plutonium and americium in runs 3 and 4.

The average CRE for plutonium in the first two runs was 72 percent for the unfiltered effluent and 83 percent for the filtered effluent. Average CREs for americium were 74 percent for unfiltered and 70 percent for filtered effluent. These results are below the 90 percent removal objective, although significant removal was observed.

Higher influent concentrations of plutonium, americium, and TSS were observed in the influent for runs 3 and 4. A change in the orientation of the tanker truck supplying the system with influent was likely responsible for this. The increased concentration of TSS, along with the sorptive nature of these two radionuclides, suggests that the plutonium and americium were primarily in the solid or sorbed state, and that prefiltering may have reduced these influent concentrations considerably. The CREs for plutonium and americium in runs 3 and 4 were all 97 percent or better. However, the treated effluent concentrations of these contaminants for both runs was higher than the influent concentration for runs 1 and 2.

Table 4-1. Radionuclide Concentrations in Wastewater

	Parameters Units	Uranium µg/L	Plutonium pCi/L	Americium pCi/L
Run 1	Influent	2,800	0.221	0.202
	Effluent (unfiltered)	1,900	0.082	0.051
	CRE	32%	63%	75%
	Effluent (filtered)	1,900	0.041	0.062
	CRE	32%	82%	69%
Run 2	Influent	2,900	0.197	0.172
	Effluent (unfiltered)	1,600	0.039	0.049
	CRE	44%	82%	72%
	Effluent (filtered)	1,600	0.032	0.051
	CRE	44%	84%	71%
Run 3	Influent	2,600	33.1	83.5
	Effluent (unfiltered)	1,400	1.03	2.49
	CRE	46%	97%	97%
	Effluent (filtered)	1,400	0.434	0.755
	CRE	47%	99%	99%
Run 4	Influent	2,600	26.6	60.5
	Effluent (unfiltered)	1,300	0.706	1.46
	CRE	51%	98%	98%
	Effluent (filtered)	1,300	0.199	0.342
	CRE	52%	99%	99%

Notes:

pCi/L PicoCuries per liter
µg/L Micrograms per liter
CRE Contaminant removal efficiency

Confidence limits cannot be calculated for these results because results for more than two tests are required for the calculations.

CWQCC Standards for Uranium, Plutonium, and Americium

CWQCC discharge standards are 15 g/L for uranium, and 0.05 pCi/L for both plutonium-239/240 and americium-241. CWQCC standards for uranium were not met during the CURE demonstration. The lowest average effluent concentration of uranium for any run was 1,270 g/L, more than 250 times the CWQCC standard. However, a minimum CRE of 99.8 percent would be required to achieve the CWQCC standard with the influent water used in this demonstration.

CWQCC standards for plutonium were met for the filtered effluent of run 1 and both the unfiltered and filtered effluent of run 2, and the CWQCC standard for americium was met in the unfiltered effluent of run 2. The highest average effluent concentration of both contaminants in runs 1 and 2 was 0.0817 pCi/L, which is 63.4 percent higher than the CWQCC standard. The CWQCC standard for these contaminants was exceeded by 398 percent or more in both runs 3 and 4.

4.4.3 Summary of Results for Noncritical Parameters

Anode Deterioration

Examination of the electrocoagulation tubes revealed severe thinning of the tube walls, indicating that extensive anode deterioration had occurred during the demonstration runs. Sludge and effluent iron concentrations from test runs 1 and 3 suggest that nearly all of the tube material precipitates. These results are presented in Tables 4-2 and 4-3.

CREs for Other Contaminants

Table 4-4 lists the influent and effluent metals, TOC, TDS, and TSS concentrations for runs 1 and 3. These constituents were not analyzed in runs 2 and 4. Arsenic removal was the most significant with an average CRE for the two runs of 77 percent. Calcium removal was unexpected, but averaged approximately 50 percent. Magnesium and TOC removals were slight with 15 and 12 percent averages, respectively. No significant removal of boron, lithium, or TDS was observed, and iron concentrations in the effluent increased by more than an order of magnitude in both runs. CREs could not be

Table 4-2. Metal Content in Dewatered Sludge

Parameter	Units	Run 1	Run 3
Aluminum	mg/kg	<10.0	33.0
Arsenic	mg/kg	5.5	17.8
Boron	mg/kg	<10.0	15.6
Cadmium	mg/kg	<0.50	0.65
Calcium	mg/kg	282	2,400
Iron	mg/kg	19,800	49,800
Lithium	mg/kg	<5.0	<5.0
Magnesium	mg/kg	1,120	1780

Notes:

mg/kg milligrams per kilogram
< less than reported detection limit

Table 4-3. Metals Concentrations in Wastewater

Parameter	Units	Run 1			Run 3			CWQCC* Standards
		Avg Influent	Avg Effluent (Unfiltered)	Avg Effluent (Filtered)	Avg Influent	Avg Effluent (Unfiltered)	Avg Effluent (Filtered)	
Aluminum	mg/L	<0.20	<0.20	NA	0.29	<0.20	<0.20	0.1
Arsenic	mg/L	0.11	0.026	0.0237	0.1367	0.0343	0.0287	0.05
Boron	mg/L	2.6	2.53	2.47	2.47	2.43	2.5	0.75
Cadmium	mg/L	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.0015
Calcium	mg/L	16.3	9.73	10.4	42.6	19.1	19.3	NS
Iron	mg/L	NA	12.5	6.4	0.257	12.1	5.27	0.3
Lithium	mg/L	2.3	2.27	2.27	2.1	2.07	2.13	NS
Magnesium	mg/L	122	100	99.4	126	110	112	NS
TOC	mg/L	128	78.7	108	106	111	113	NS
TDS	mg/L	8,410	8,330	8,270	8,510	8,460	8,360	NS
TSS	mg/L	10.5	32.4	18.4	50.4	54.23	31.2	NS

Notes:

mg/L milligrams per liter
< less than reported detection limit
NA not analyzed
NS no standard

Table 4-4. Radionuclide Content in Dewatered Sludge

Parameter	Units	Run 1	Run 2	Run 3	Run 4
Uranium	mg/kg	77	120	120	96
Plutonium	pCi/g	0.189	0.178	34.0	23.0
Americium	pCi/g	0.182	0.115	95.8	66.4

Notes:

mg/kg milligrams per kilogram
pCi/L picoCuries per liter

determined for aluminum or cadmium because the concentrations were too low in both the influent and the effluent. Changes between influent and effluent concentrations of TSS are inconsistent, suggesting that residence time in the clarifier was not sufficient to adequately remove the solids from suspension.

Hydrogen and Chlorine Gas Production

Chlorine and hydrogen gases were possible by-products of the electrocoagulation process. Results of air monitoring over the open clarifier during the test runs did not indicate a hazard due to emission of these gases under the conditions of the demonstration.

Power Consumption

The CURE treatment system was operated using a diesel powered 50-kilowatt generator. Fuel consumption during the demonstration was approximately 8 gallons per hour of operation of the CURE treatment system.

Optimum Operating Parameters

The results of the five optimization runs indicated that the following operating parameters would be adequate for treating the A/B decant water with the CURE system:

- Iron tube material for all tubes
- 10-foot long electrocoagulation tubes
- 0.1 to 0.5 inch annular spacing between inner and outer tubes
- Three 10-foot long tube sets (concentric pairs)
- One pass through each tube
- Flow rate of 3.0 to 3.1 gpm
- Applied potential of 20 to 57 volts to achieve an electrical current of 135 to 168 amperes

These are the conditions used for all four demonstration runs.

Geochemical Characteristics

The four water geochemical characteristics—pH, specific conductivity, dissolved oxygen, and temperature—were measured at 20-minute intervals throughout the four test runs. Measurements were taken for both the influent and effluent waters. Table 4-5 summarizes these parameter measurements.

Influent and effluent pH were similar throughout the demonstration. Generally, pH varied between 8.5 and 9.5, although extremes of 7.77 and 9.66 were recorded. Average specific conductivity at L1 was 10.9 millisiemens per centimeter (mS/cm), and that at L2 was 11.4 mS/cm. These results suggest that some ions in solution were replaced with more conductive ones by the CURE system,

Table 4-5. Geochemical Characteristics Summary

Run	Sample Port	pH	Specific Conductivity (mS/cm)	Dissolved Oxygen (mg/L)	Temperature (°C)	Potential (V)	Current (Amp)	Flow (gpm)	Pressure (psi)
					Parameter Range				
1	L1	8.73-8.86	10.2-10.6	1.90-3.60	28.2-30.2	20-57	135-160	3.0-3.1	73-83
	L2	8.55-9.48	9.5-11.9	ND*-8.69	29.6-36.3	20-57	135-160	3.0-3.1	74-83
2	L1	8.88-9.21	11.2-11.8	1.70-2.54	27.2-29.2	23-57	138-158	2.8-3.1	43-59
	L2	7.86-9.66	10.7-11.4	ND-3.10	27.7-35.4	22-57	138-158	2.8-3.1	43-59
3	L1	8.70-8.92	9.54-11.9	1.11-2.44	28.1-30.5	25-50	140-168	3.0	29-43
	L2	8.23-9.60	11.0-12.3	ND-2.38	27.1-35.7	25-50	140-168	3.0-3.1	29-43
4	L1	8.56-8.73	10.9-11.5	1.58-2.81	26.2-27.0	25-52	150-162	3.0-3.1	21-23
	L2	7.77-8.95	10.6-11.9	ND-3.06	27.7-33.8	25-52	150-162	2.9-3.1	21-23

*ND = Not detectible, detection limit approximately 1 mg/L

Notes:

mS/cm	millisiemens per centimeter
mg/L	milligrams per liter
°C	degrees Celsius
V	volts
A	amperes
gpm	gallons per minute
psi	pounds per square inch

although TDS did not change. This may occur by breaking bonds in uncharged complexed ions in the influent solution.

The influent typically contained between 2.0 and 3.0 mg/L dissolved oxygen, indicating slightly reducing conditions. Dissolved oxygen content of the effluent during the first 30 minutes of operation indicate that oxygen is depleted from the process water by the formation of the floc in the CURE system. Effluent between the CURE system and the clarifier did not contain measurable concentrations of oxygen during this time. Later measurements were collected at the outlet from the clarifier. These measurements indicated similar reducing conditions to the influent. These results suggest that oxygen is the limiting reagent in the formation of the flocculent, and that aerating the influent may increase the removal efficiency of the system by precipitating more of the iron in the effluent.

Temperature of the influent during the three hours after the clarifier had filled was similar to the temperature of the effluent during the first 30 minutes of operation, but measurements made after the clarifier had filled were as much as 6°C higher than the influent. These results suggest that the water in the clarifier had been warmed by the warm days. Temperature comparisons are inconclusive since temperature measurements of the influent were not made during the first 30 minutes of operation, and heating of the process water in the tanker truck may have occurred during the day.

TCLP Results

Tables 4-2 and 4-4 show the metals and radionuclides content in the dewatered sludge. Results indicate that the radionuclides were highly concentrated in the dewatered sludge, especially plutonium and americium in sludge from runs 3 and 4. Table 4-6 presents TCLP results for radionuclides. Although no TCLP regulatory limits exist for uranium, plutonium, and americium, these radionuclides were analyzed to characterize the leachability of the waste.

Analyses of the TCLP leachate indicate that uranium concentrations in the leachate exceed the CWQCC standard of 15 g/L by as much as a factor of 30, while plutonium and americium concentrations are below or near their standard of 0.05 pCi/L. For comparison, it should be noted that the maximum concentration for the toxicity characteristic for the TCLP metals is typically 100 times that of the EPA MCLs for groundwater (EPA 1995a and 1995b).

TCLP results indicate that metals were not detected above TCLP detection limits. These results suggest that the sludge is stable and metals are resistant to leaching.

Operation Costs

A detailed cost analysis is presented in Section 3 of this report. The analysis examined costs for a 100 gpm treatment system operating for 1, 5, and 10 years. Costs ranged from $0.009 per treated gallon for the 1-year

Table 4-6. Radionuclide Concentration in TCLP Leachate

Parameter	Units	Run 1	Run 2	Run 3	Run 4
Uranium	mg/L	0.44	0.21	0.32	0.25
Plutonium	pCi/L	0.014	0.022	0.055	0.081
Americium	pCi/L	0.0049	0.022	0.160	0.270

Notes:

mg/L Milligrams per liter
pCi/L PicoCuries per liter

operation to $0.003 per treated gallon for the 10-year operation. Actual costs will vary based on type and location of installation.

4.5 Conclusions

The primary objectives of the CURE electrocoagulation demonstration were not met. However, removal of radionuclides in the A/B decant water at RFETS was significant, and CWQCC standards were met for plutonium and americium in some cases, but the target confidence level of 95 percent was not met.

Significant removal was also observed for arsenic (74 percent) and calcium (50 percent) indicating that CURE effectively reduces concentrations of these elements.

TCLP analyses of sludge produced by the CURE technology during this demonstration indicate that the solid wastes may be classified as nonhazardous.

Section 5
Technology Status

The CURE technology has been installed in many industrial locations. According to the technology developer, installed applications include metals removal from plating companies and manufacturing operations, steam cleaning, bilge water treatment, drilling fluids, groundwater, mine waters, paint booths, and food industry wastes. Additional testing has been performed on many other industrial wastewaters.

The treatment unit used in this demonstration is trailer mounted and ready for use. It can be mobilized to any site on short notice for testing. GEC is currently constructing a transportable treatment unit that will be capable of treating wastewater at a rate of approximately 50 gpm. The unit will be mounted on a trailer that can be transported by a semitractor. It is not known when this unit will be available for service. Waste streams greater than 50 gpm will require a larger CURE system. These systems are custom designed for the application.

Section 6
References

Barkley, N.P., C.W. Farrell, and T.W. Gardner-Clayson. 1993. Alternating Current Electrocoagulation for Superfund Site Remediation. J. Air & Waste Mgmt. Assoc. Volume 43, Number 5. Pages 784-769.

Dalrymple, C.W. 1994. Electrocoagulation of Plating Wastewaters. American Electroplaters and Surface Finishers Society Environmental Protection Agency 15th Conference on Pollution Prevention and Control. January.

Drever, James I. 1988. The Geochemistry of Natural Waters. Prentice Hall. Englewood Cliffs, NJ. Second edition.

EG&G Rocky Flats, Inc. (EG&G). 1991. Pond Sludge and Clarifier Sludge Waste Characterization Report.

Evans, G. 1990. Estimating Innovative Technology Costs for the SITE Program. Journal of Air and Waste Management Association, 40:7, pages 1047 through 1055.

Hydrologics, Inc. 1993. CURE - Electrocoagulation Wastewater Treatment System, USEPA Superfund Innovative Technology Evaluation (SITE) Program, Proposal No. SITE-008,05.

Jenke, Dennis R. and Frank E. Diebold. 1984. Electroprecipitation Treatment of Acid Mine Wastewater. Water Research. Volume 18, Number 7. Pages 855-859.

Office of Federal Register. 1993. Code of Federal Regulations Title 40, Protection of Environment. U.S. Government Printing Office. Washington, D.C. July 1993.

Renk, R.R. 1989. Treatment of Hazardous Wastewaters by Electrocoagulation. Proceedings Ninth National Symposium on Food Processing Wastes, Denver, Colorado, Page 264. EPA-600/2-78. August.

Rockwell International. 1988. Rockwell International Corporation, Resource Conservation and Recovery Act, Post Closure Care Permit Application, Appendix 1-2, Solar Evaporation Ponds. July. Golden, CO.

Sawyer, Clair N. and Perry L. McCarty. 1978. Chemistry for Environmental Engineering. McGraw-Hill Book Co. New York. Third edition.

U.S. Department of Energy (DOE). 1980. U.S. Department of Energy, Rocky Flats Plant, Final Environmental Impact Statement, DOE/EI5-0064.

U.S. Environmental Protection Agency (EPA). 1991. Federal Facility Agreement and Consent Orders. Denver, Colorado. January.

EPA. 1994. Test Methods for Evaluating Solid Waste, Volumes IA-IC: Laboratory Manual, Physical/Chemical Methods; and Volume II: Field Manual, Physical/Chemical Methods, SW-846, Third Edition (revision 3), Office of Solid Waste and Emergency Response, Washington, D.C.

EPA. 1995a. Superfund Innovative Technology Evaluation Program CURE Electrocoagulation Technology Treatability Study Report. July 10.

EPA. 1995b. Final Quality Assurance Project Plan for General Environmental Corporation CURE Electrocoagulation Technology Demonstration at the Rocky Flats Environmental Technology Site, Golden, Colorado. July.

EPA. 1995c. Final Health and Safety Plan, CURE SITE Demonstration, Rocky Flats Environmental Technology Site, Golden, Colorado. August.

Vik, Eilen A., Dale A. Carlson, Arild S. Eikum, and Egil T. Gjessing. 1984. Electrocoagulation of Potable Water. Water Research. Volume 18, Number 11. Pages 1355-1360.

Appendix A
Vendor Claims for the Technology

This appendix presents the claims made by the vendor, General Environmental Corporation (GEC), regarding the CURE technology under consideration. This appendix was written solely by GEC, and the statements presented herein represent the vendor's point of view based on demonstrations and commercial operation performed since 1990. Publication here does not indicate EPA's approval or endorsement of the statements made in this section; EPA's point of view is discussed in the body of this report.

The demand for improved methodologies and technologies to remove metallic pollutants from water has increased dramatically during the past few years due in part to expanded waste management activities; stricter National Pollutant Discharge Elimination System (NPDES) and publicly owned treatment works (POTW) discharge permit limits; the federal government's commitment to remediate National Priorities List (NPL) radioactive sites; increased public awareness of environment; economic factors; and legal liability issues. The U.S. Department of Energy (DOE) has outlined a long-term plan committing the agency to clean up 45 years worth of accumulated contamination at nuclear weapons sites and facilities. As a result, DOE has scheduled environmental remediation activities for more than 3,700 radionuclide and hazardous chemical waste sites. These DOE sites taken together with the thousands of Superfund sites with metal (and sometimes radionuclide) contamination represent a massive remediation problem that will present a tremendous fiscal and technological challenge in the future.

At an estimated two-thirds of the DOE and Superfund sites, groundwater, stored water, pond water, or sludges and soils are contaminated by metals. DOE's 26 NPL radioactively contaminated sites essentially all have metals and radionuclide problems. They range from uranium and thorium, to low-level radioactive wastes (LLRW), to nuclear weapons production and processing wastes representing uranium, enriched uranium, and transuranic (TRU) materials. Federal statutes require that remediation restoration of these federal sites be carried out in compliance with the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) and the Superfund Amendments and Reauthorization Act (SARA).

CERCLA as amended by SARA establishes a cleanup program intended to:

- Encourage the use of cost-effective methods
- Promote remedial actions that should yield permanent solutions
- Minimize secondary waste streams
- Use alternative treatment technologies
- Conform to applicable or relevant and appropriate requirements (ARAR)
- Protect human health and the environment

The chemistry of heavy metal and radionuclide pollutants varies from site to site, presenting a remediation challenge for achieving strict discharge standards. Conventional filtration, sorption, and ion exchange methods have proved useful for removing macro- to micro-particle inorganic metallic forms from water, but are limited by performance and cost when large volumes of trace metals and radionuclides must be removed. Particle filtration is not efficient for removing trace micromolecular and ionic metallic forms from water. Microfiltration readily removes 0.025- to 10-micron particles from water, but has generally been limited in the molecular to ionic range.

Ultrafiltration is widely used for treating small volumes of liquids containing low total suspended solids (TSS) concentrations, but is limited in throughput and capacity for most metals and radionuclide remedial applications. Ion exchange methods have broad utility for the removal of anionic and cationic soluble metallic ions, but have microchanneling, bed, and residual problems, higher operational costs, and higher disposal costs for radionuclide-contaminated spent bed material. Reverse osmosis is highly efficient for removing a wide range of soluble inorganic metallic ions, but can be expensive to operate and may not remove trace metals and radionuclides existing as complexed, chelated forms. In addition, the salt brine waste produced by this methodology contributes to the waste disposal problem.

A.1 CURE System

The CURE treatment system is a refinement of electrocoagulation technology that has existed since the early 1900s. Electrocoagulation uses electricity to destabilize contaminants and allow van der Waals' force to coagulate and precipitate the contaminants. In conventional coagulation and precipitation, a chemical amendment is added to the contaminated water. The amendment destabalizes and binds with oppositely charged contaminants in solution, causing them to coagulate and precipitate. By eliminating the chemical additives, the residual wastes are reduced.

The CURE system, a patented electrocoagulation process, allows continuous water flow through concentric electrocoagulation tubes. The system circumvents some of the performance limitations of conventional methods used to remove metals and radionuclide pollutants from water, allowing higher flow rates and greater removal efficiencies. In addition, residual wastes produced by treatment are reduced and less subject to leaching that other methods.

Electrocoagulation does not remove materials that do not form precipitates, such as sodium and potassium. If a contaminant does not form a precipitate, electrocoagulation will not cause it to flocculate. Therefore, electrocoagulation will not remove highly soluble contaminants, such as benzene, toluene, or similar organic compounds.

General Environmental Corporation (GEC) has refined this system for commercial applications. The trailer mounted system is self contained and capable of installation in limited space areas and the configuration can be customized to specific applications by altering the tube materials used and flow sequencing.

A.2 Design and Product Improvements

The Rocky Flats Environmental Technology Site (RFETS) SITE demonstration of the CURE system in August and September 1995 showed that the basic engineering and system design configuration were adequate. Still, several system refinements are planned to improve the equipment for higher flow rates (up to 100 gallons per minute [gpm]), improve system reliability, increase performance efficiency, and reduce operational costs. Examples of planned improvements to the CURE SITE demonstration configuration are outlined below.

- Commercial applications can be custom designed with additional banks of electrocoagulation tubes which will allow for increased flow rates.

- A redundant set of electrocoagulation tubes can be installed allowing tube servicing and replacement with no operational down time.

- The clarifier will be replaced with one engineered to meet specific requirements of the application and anticipated flow rates. Due to time and budget limitations an existing conical clarifier was used for the CURE demonstration in place of the slant-plate clarifier engineered for the system. Smaller clarifier volumes and increased clarifier performance will result from the future replacement.

- The bag filter used during the CURE demonstration will be replaced by a filter press which will increase the system capacity and reduce delays associated with the bag filter.

A.3 Applications of the System

The CURE system can be used as an in-line system mounted on a trailer of skid. Examples of commercial and government project applications are provided below.

- Remediation of metals and radionuclides from groundwater, wastewater, and washing operations

- Treatment of manufacturing wastewater containing metals and oil

- Oil and water separation from process wastewaters
- Removal of metals and oil from waters

Several case studies discussing these application are presented in Appendix B.

A.4 Factors that Decrease Performance

Bench- and pilot-scale testing should be carried out at each project to achieve high percent removal efficiency for identified pollutants. These tests enable system operators to optimize the system parameters and identify the presence of competing or inhibiting chemical or physical factors. For the CURE system, several factors have been identified that can limit the technology's performance and increase treatment costs.

Operation of the CURE electrocoagulation system may be affected by wastewater characteristics such as hydrogen ion concentration (pH), oxidation/reduction potential (Eh), specific conductance, temperature, and the amount of total dissolved and suspended solids (TDS and TSS). Solution characterization is therefore important to establish maximum contaminant precipitation, minimize power use, reduce sludge formation, curtail tube scaling, and limit anode deterioration.

A.5 Advantages of Methodology

The CURE system offers several advantages over conventional filtration, ion exchange, reverse osmosis, and chemical coagulation methods for the treatment and remediation of metallic cater pollutants. Examples of advantages include:

- Efficient equipment design allows versatile system installation in space limited areas.
- Generation of substantially lower quantities of residual waste per unit volume of water treated than other methods which translates to lower land disposal costs for hazardous and radioactive wastes.
- Residual wastes capable of passing the EPA toxicity characteristic leaching procedure (TCLP) allowing for less expensive disposal costs.
- System capable of operating without additional additives which results in less residual waste production.
- Demonstrated ability to treat a variety of contaminants including metals, colloids, suspended solids, oils, dyes, and organics.

Appendix B
Case Studies

This appendix contains representative examples provided by the technology developer, GEC, of the cleanup and recovery (CURE) electrocoagulation technology. Analytical test data for estimating performance are also presented by GEC, where available. Additional documentation on these studies may be obtained from GEC. Publication here does not indicate EPA's approval or endorsement of the statements made in this section; EPA's point of view is discussed in the body of this report.

The following are case studies that represent a wide spectrum of metals and radionuclide treatment conditions for industrial wastewater and U.S. Department of Energy (DOE) facility wastes.

B.1 Municipal Wastewater Treatment

An Iron Ore Treatment Plant near Denison, Texas, employs approximately 13,000 people. The plant uses orbital aeration basins for primary treatment of municipal wastewater, followed by clarification and aerobic digestion. The resulting sludge is dried in open air beds then removed for disposal.

The plant had difficulty operating within the scope of its permit due to an increase in influent volume due to growth. The facilities inability to treat additional influent also affected the economic growth of Denison.

The CURE system was tested at the Iron Ore Treatment Plant. It treated effluent at approximately 200 gallons per minute. The treated waste stream was allowed to settle in a 27,000-gallon vertical clarifier for approximately 2 hours. Clear water was then drawn off and discharged to the second ring of the plant's orbital system. A very high quality and low water sludge was passed directly to the drying beds, bypassing polymer application and treatment in anaerobic digestors. The CURE system reduced the suspended solid levels by 98 percent, to a range of 1,300 to 5,000 parts per million (ppm).

Treatment goals were achieved by running the CURE system for approximately 12 hours per day, five days a week. In a 24-hour period, the CURE system processed an average of 144,000 gallons of effluent. At this level of processing, the plant operated at the required level of efficiency.

The CURE system increased the capacity of the plant while bringing plant effluent into compliance with discharge standards. The CURE system reduced capital expense, enhanced treatment capability, and improved throughput. The CURE system was used until a new, larger capacity wastewater treatment plant was built.

B.2 Treatment of Manufacturer Wastewater

A tractor manufacturer generated approximately 30,000 gallons of wastewater per day from the production of approximately 30 to 50 units annually. The waste stream consisted of water-borne contamination including zinc, chrome, oil and grease, paint sludge, and a material similar to cosmoline which is used for temporary protection of unfinished metals. Because of this wide range of contaminants, a multiple pass CURE system treatment was designed using anodes of different materials.

Following treatment by the CURE system, the effluent flowed to a dual clarifier. Approximately 2 to 3 ppm of polymer was added to enhance the settling characteristics of the sludge.

The clear water effluent was discharged to the publicly owned treatment works. The sludge was passed through a filter press, then transported to a permitted disposal facility. The system performed as designed, with all levels of contaminants reduced to or below target values. Zinc, the primary constituent in the effluent stream, was consistently measured at 0.15 to 0.2 ppm, well below discharge limits.

The CURE system replaced the manufacturer's chemical precipitation system, which was extremely labor intensive and costly at approximately $0.125 per gallon. The CURE system, including labor, capital amortization, maintenance, and consumable materials, was treating the wastestream for approximately $0.055 per gallon.

B.3 Oil and Water Separation of Steam Cleaner Wastewater

Several CURE systems have been installed in facilities that use steam equipment to remove oil, dirt, grease, and other materials from oil field equipment. The system is particularly valuable where there is a problem with the separation of oil and water containing concentrations of metals.

At these facilities, the CURE system is the central treatment element, with pH adjustment preceding and clarification following electrocoagulation. The following results presented in Table B-1 show the effectiveness of the CURE process on this type of waste. Cost reductions of up to $3,000 per month are not unusual.

B.4 Treatment of Ship Bilgewater

In August 1992, the U.S. Coast Guard (USCG) approved the use of the CURE system for the treatment of 176,200 gallons of ship bilgewater at Kodiak Island near Anchorage, Alaska. The ship bilgewater was contaminated with high concentrations of oil and metals. A summary of contaminant removal efficiencies for raw and treated bilgewater samples is shown in Table B-2. The CURE process was effective in removing oil and metals with removal efficiencies ranging between 71 and 99 percent.

Effluent samples were taken following treatment by the CURE system and prior to entering the 300- gallon clarifier. Because of the small clarifier and limited retention time, an anionic polymer was added to the sedimentation as a coagulant aid. Following retention in the clarifier, the effluent passed through activated carbon filters for final polishing and removal of any trace hydrocarbons.
The volume of the waste was reduced by 98 percent, from 46,500 gallons of bilgewater to less than 600 gallons of sludge.

The mobility of the CURE equipment eliminated the need to transport the bilgewater for treatment off the island resulting in an estimated cost savings of $185,000. The average cost of treating the bilgewater on-site, estimated at $0.45 per gallon was approximately 10 percent of the cost for treatment on the island.

B.5 Los Alamos National Laboratory Treatability Study

In November 1994, GEC tested the CURE system on wastewater at the Los Alamos National Laboratory (LANL) in Los Alamos, New Mexico. The primary objective of the tests was to compare the CURE electrocoagulation process with the conventional methods of chemical treatment.

The wastewater treated was a grab sample from the influent to LANL hazardous wastewater treatment plant and contained plutonium, americium, and various other metals. The focus of the treatability study was on the radionuclides.

The CURE process was more efficient than the chemical treatment process in one of three test runs. However, LANL was pleased with the results and requested additional testing of the CURE system. Table B-3 summarizes the results of the testing.

B.6 Rocky Flats Environmental Technology Site Treatability Study

In April 1995, a bench-scale study was conducted by GEC testing the ability of the CURE system to remove uranium, plutonium, and americium from water derived from the U.S. Department of Energy's Rocky Flats Environmental Technology site solar evaporation ponds (SEPs).

As part of the manufacturing processes at RFETS near Golden, Colorado, wastes were produced that contained uranium, plutonium-239/240, americium-241, and other contaminants. Some of this waste was collected in SEPs. The SEPs stored and treated liquid process waste having less than 100,000 picoCuries per liter of total long-lived alpha activity. Water decanted from the sludge and liquid from the A and B SEPs was treated for this bench-scale study.

Testing of the CURE system using decant water from the SEPs indicated that the technology is capable of consistently removing more than 95 percent of the uranium, plutonium, and americium.

Table B-1. Treatment of Steam Cleaner Wastewater

Element	Before Treatment (ppm)	After Treatment (ppm)	Percent Removal (%)
Antimony	<0.01	0.014	99
Arsenic	0.30	<0.01	97
Barium	8.0	<0.10	99
Beryllium	<0.01	<0.01	0
Cadmium	0.141	0.031	78
Chromium	7.98	0.05	99
Cobalt	0.13	<0.05	62
Copper	6.96	<0.05	99
Lead	7.4	1.74	76
Mercury	0.003	<0.001	67
Molybdenum	0.18	0.035	81
Nickel	0.4	<0.05	87
Selenium	<0.005	<0.005	0
Silver	<0.01	<0.01	0
Thallium	<0.10	<0.10	0
Vanadium	0.23	<0.01	96
Zinc	19.4	1.20	94

NOTES:

ppm parts per million

Table B-2. Contaminant Removal Efficiencies

	Concentration (mg/L)		
	Untreated	**Treated**	**% Removal**
Contaminant			
Petroleum hydrocarbons	72.5	ND(0.2)	99.0
Heavy Metals			
Aluminum	4.16	0.74	82.0
Boron	4.86	1.41	71.0
Iron	95.4	ND (1.0)	99.0
Zinc	3.41	ND (0.5)	99.0
Dissolved Cations			
Calcium	293	137	53.2
Magnesium	943	300	68.2
Manganese	0.93	ND	99.0
Sodium	8,690	5,770	33.6
Potassium	287	222	23.0
Dissolved Anions			
Phosphorus	5.38	1.43	73.4

NOTES:

mg/L milligrams per liter
ND not detected

Table B-3. Analytical Results for Radionuclides in LANL Wastewater

Sample No.	Plutonium pCi/L	After Treatment pCi/L	% Removal	Americium pCi/L	After Treatment pCi/L	% Removal
Raw	15,560	N/A	N/A	1,970	N/A	N/A
Elec-4	3.2	0.0006	99.98	2.8	0.00392	99.86
Elec-5	32.8	0.0688	99.79	12.4	0.07812	99.37
Elec-6	10,400	6,990	32.98	1,670	1,423	15.00
Jar-1	18.6	0.0223	99.88	6.9	0.0241	99.65
Jar-2	35.4	0.0814	99.77	1.9	0.00190	99.90
Jar-3	4,310	1,190	72.31	783	311	60.23

NOTES:

PCi/L picocuries per liter
N/A not applicable

☆U.S. GOVERNMENT PRINTING OFFICE: 1998-653-686

United States
Environmental Protection Agency
Center for Environmental Research Information
Cincinnati, OH 45268

Please make all necessary changes on the below label, detach or copy, and return to the address in the upper left-hand corner.

If you do not wish to receive these reports CHECK HERE ☐; detach, or copy this cover, and return to the address in the upper left-hand corner.

BULK RATE
POSTAGE & FEES PAID
EPA
PERMIT No. G-35

EPA/540/R-96/502