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Colloid Polishing Filter Method - Filter Flow Technology, Inc.

Innovative Technology Evaluation Report

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Notice

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Foreword

The Superfund Innovative Technology Evaluation (SITE) program was authorized by the Superfund Amendments and Reauthorization Act of 1986. The program is administered by the U.S. Environmental Protection Agency (EPA) Office of Research and Development. The purpose of the SITE program is to accelerate the development and use of innovative cleanup technologies applicable to Superfund and other hazardous waste sites. This purpose is accomplished through technology demonstrations designed to provide performance and cost data on selected technologies.

This project consisted of a demonstration conducted under the SITE program to evaluate the Colloid Polishing Filter Method technology developed by Filter Flow Technology, Inc. The technology demonstration was conducted at a U.S. Department of Energy site. This Innovative Technology Evaluation Report provides an interpretation of the data and discusses the potential applicability of the technology.

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E. Timothy Oppelt, Director
Risk Reduction Engineering Laboratory

Abstract

This report evaluates the Colloid Polishing Filter Method (CPFM) technology's ability to remove uranium and gross alpha contamination from groundwater. This report also presents economic data from the Superfund Innovative Technology Evaluation (SITE) demonstration and compares the technology against the nine criteria the U.S. Environmental Protection Agency (EPA) uses to select remedial alternatives for Superfund sites.

The CPFM technology was developed by Filter Flow Technology, Inc. (FFT), of League City, Texas. The technology uses an inorganic, insoluble, oxide-based compound (Filter Flow [FF] 1000) to remove radionuclide and heavy metal pollutants from water by a combination of sorption, chemical complexing, and filtration. The FF 1000 is contained within filter packs in a filter press unit. After use, the filter packs are dewatered with compressed air. The end products are water with reduced contaminant concentrations and spent filter cake (FF 1000) that contains the contaminants.

The CPFM technology was demonstrated under the SITE program at the U.S. Department of Energy's (DOE) Rocky Flats Environmental Technology Site (RFETS) (formerly the Rocky Flats Plant) near Golden, Colorado. Over a 3-week period in September and October 1993, about 10,000 gallons (37,850 liters) of uranium- and gross alpha-contaminated groundwater were treated in the CPFM system. For the SITE demonstration three tests, consisting of a total of five runs, were conducted. For the first test, consisting of three runs conducted at the same operating conditions, the CPFM system removed 58 to 91 percent of uranium and 33 to 87 percent of gross alpha contamination from groundwater that had no pretreatment. For the second test, consisting of one run using groundwater pretreated with sodium sulfide, the removal efficiency was improved to 95 percent for uranium and 94 percent for gross alpha contamination. Results for the third test were inconclusive.

The average CPFM system discharge for the first test did not meet the Colorado Water quality Control Commission standards for uranium and gross alpha concentrations (7 micrograms per liter and 7 picoCuries per liter) in waters to be discharged from RFETS.

Evaluation of the CPFM technology against the nine criteria used by the EPA in evaluating potential remediation alternatives indicates that the CPFM 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 heavy metals. Economic data indicate that the groundwater remediation cost for a 100-gallon-per-minute CPFM system could range from about $2 to $7 per 1,000 gallons, depending on contaminated groundwater characteristics and duration of the remedial action (Table 4-1).

This report was submitted in fulfillment of Contract No. 68-C0-0047 by PRC Environmental Management, Inc. under the sponsorship of the U.S. Environmental Protection Agency. This report covers a period from November 1991 to October 1993, and work was completed as of April 1995.

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Acronyms and Abbreviations

AA	Atomic absorption
APHA	American Public Health Association
ARARs	Applicable or relevant and appropriate requirements
ASTM	American Society of Testing and Materials
ATTIC	Alternative Treatment Technology Information Center
AWWA	American Water Works Association
CDPHE	Colorado Department of Public Health an Environment
CDH	Colorado Department of Health
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CERI	Center for Environmental Research Information
CFR	Code of Federal Regulations
CPFM	Colloid Polishing Filter Method
CWQCC	Colorado Water Quality Control Commission
DOE	U.S. Department of Energy
Eh	Oxidation potential
EPA	U.S. Environmental Protection Agency
FF	Filter Flow
FFT	Filter Flow Technology, Inc.
FS	Feasibility study
g/cc	Grams per cubic centimeter
gpm	Gallons per minute
HSWA	Hazardous and Solid Waste Amendments
IAG	Interagency agreement
ICP	Inductively coupled plasma
IM/IRA	Interim measure/interim remedial action
ITER	Innovative Technology Evaluation Report
ITPH	Interceptor Trench Pump House
kg	Kilogram
kg/cm^2	Kilograms per square centimeter
kWh	Kilowatt-hour
LLRW	Low-level Radioactive Waste
Lpm	Liters per minute
$\mu g/L$	Micrograms per liter
MCL	Maximum contaminant level
mg/L	Milligrams per liter
mL/min	Milliliters per minute
MOU	Memorandum of understanding
mS	MilliSiemens

NCP	National Oil and Hazardous Substance Pollution Contingency Plan
NORM	Naturally occurring radioactive materials
NPDES	National Pollutant Discharge Elimination System
NPL	National Priorities List
O&M	Operation and maintenance
ORD	Office of Research and Development
OSHA	Occupational Safety and Health Act
OSWER	Office of Solid Waste and Emergency Response
OU	Operable unit
pCi/g	PicoCuries per gram
pCi/L	PicoCuries per liter
PFLT	Paint filter liquids test
POTW	Publicly owned treatment works
ppb	Parts per billion
PPE	Personal protective equipment
ppm	Parts per million
psig	Pounds per square inch, gauge
PVC	Polyvinyl chloride
QA/QC	Quality assurance/quality control
r^2	Correlation coefficient
RCRA	Resource Conservation and Recovery Act
RFETS	Rocky Flats Environmental Technology Site
RI	Remedial investigation
RREL	Risk Reduction Engineering Laboratory
SDWA	Safe Drinking Water Act
SEP	Solar evaporation ponds
SARA	Superfund Amendments and Reauthorization Act
SITE	Superfund Innovative Technology Evaluation
SOP	Standard operating procedure
SWDA	Solid Waste Disposal Act
TCLP	Toxicity characteristic leaching procedure
TDS	Total dissolved solids
TOC	Total organic carbon
TRU	Transuranic
TSS	Total suspended solids
μg/g	Microgram per gram
VISITT	Vendor Information System for Innovative Treatment Technologies
WEF	Water Environment Federation

Acknowledgments

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Section 1
Executive Summary

This executive summary overview of the Colloid Polishing Filter Method (CPFM) technology discusses its applications, evaluates costs associated with the system, and describes its effectiveness.

1.1 Introduction

The CPFM 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) in response to the mandate of the Superfund Amendments and Reauthorization Act (SARA) of 1986. The program's primary purpose is to maximize the use of alternative treatment technologies. To this end, reliable performance and cost data on innovative technologies are developed during demonstrations where the 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 CPFM technology uses a proprietary compound (Filter Flow [FF] 1000) that consists of inorganic, oxide-based granules. FF 1000 is formulated to remove heavy metals and radionuclides from water through a combination of sorption, chemical complexing, and filtration. The technology developer, Filter Flow Technology, Inc. (FFT), states that sorption on the FF 1000 accounts for the majority of the removal action.

The CPFM process involves the following basic steps: (1) contaminated water is pumped to a mixing tank for chemical preconditioning (pH adjustment or sodium sulfide addition), if necessary, to induce formation of colloidal forms of pollutants; (2) suspended solids are then removed by an inclined plate miniclarifier; (3) overflow water from the miniclarifier is pumped through a microfiltration bag filter where particles greater than 10 microns in diameter are removed; (4) the water is pumped from the bag filters to the colloid filter press units where heavy metals and radionuclides are removed by the FF 1000; and (5) treated water is pH adjusted prior to discharge. Following treatment, sludge in the miniclarifier is dewatered in the small sludge filter press using compressed air. The filter packs are also dewatered using compressed air to form a cake containing 60 to 70 percent solids. These two solid wastes are combined for disposal.

1.2 Technology Applications Analysis

The technology demonstration had one primary objective: to assess the technology's ability to remove uranium and gross alpha contaminants to levels below Colorado Water Quality Control Commission (CWQCC) standards (7 micrograms per liter [μg/L] for uranium and 7 picoCuries per liter [pCi/L] for gross alpha). In addition, the technology demonstration had several secondary objectives. These are to (1) document the operating conditions and identify operational needs, such as utility and labor requirements, for the treatment system; (2) estimate costs associated with operation of the CPFM technology; (3) assess the technology's ability to remove other radionuclides (plutonium, americium, and radium); and (4) evaluate the disposal options for prefiltered solids, including miniclarifier and bag filter solids and spent filter cake from the colloid filter unit.

For the demonstration, approximately 10,000 gallons (37,850 liters) of water containing about 100 μg/L of

uranium and 100 pCi/L of gross alpha contamination were treated in three tests. The first test consisted of three runs of 4 hours each, treating about 5 gallons per minute (gpm) (18.9 liters per minute [Lpm]). For the second test, also run for 4 hours at 5 gpm (18.9 Lpm), the influent water was pretreated with sodium sulfide. The third test was a 15-hour run designed to determine the amount of contamination each filter pack is capable of treating. Results of the tests are discussed in detail in Section 5.0, Treatment Effectiveness.

The CPFM technology was evaluated against nine criteria used for decision making in the Superfund remedy selection process (see Section 3.2). This evaluation indicates that the CPFM system can provide short- and long-term protection of human health and the environment by removing radionuclide contamination from water and concentrating it in spent filter cake.

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

1.3 Economic Analysis

Using information obtained from the SITE demonstration, an economic analysis was conducted to examine 12 separate cost categories for the CPFM 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 (378 Lpm) 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, the costs are dominated by capital equipment and site preparation. This scenario resulted in a cost of approximately $7 per 1,000 gallons (3,785 liters) of water treated. Costs for the longer treatment duration scenarios decreased to $2 per 1,000 gallons (3,785 liters) for 5 or 10 years of treatment. The chemical costs are estimated by FFT to be in the range of $0.50 to $1.10 per 1,000 (3,785 liters) gallons depending on the site, duration of the project and gpm treated.

1.4 Treatment Effectiveness

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

- Results of chemical analysis for groundwater samples collected from the Rocky Flats Plant (RFETS) site show that the CPFM system removed from 58 to 91 percent of uranium and from 33 to 87 percent of gross alpha contamination from groundwater that had not been pretreated. However, this effluent did not achieve the CWQCC standards for waters discharged from RFETS.

- For one run conducted using groundwater pretreated with sodium sulfide the removal efficiency was improved to 95 percent for uranium and 94 percent for gross alpha contamination. However, these results are based on single, rather than duplicate composite samples. This effluent did achieve the CWQCC standards for waters discharged from RFETS.

- The CPFM treatment system's performance was found to be inconsistent at constant operating conditions.

- Treatment residuals (spent filter cake) do not require treatment to meet toxicity characteristic leaching procedure (TCLP) limits for metals.

Results from 15 additional tests, conducted independently by the developer at a variety of facilities, are discussed in Appendix B. In summary, results from these additional tests indicate that the CPFM system is capable of removing heavy metals from waste streams and groundwater, and of producing effluent with less than 1 milligram per liter (mg/L) of several heavy metals.

Section 2
Introduction

This section provides background information about the SITE program, discusses the purpose of this ITER, and describes the CPFM technology. For additional information about the SITE program, this technology, and the demonstration site, key contacts are listed at the end of this section.

2.1 Brief Description of the SITE Program and Reports

SARA mandates that 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 up hazardous waste sites by encouraging the development and demonstration of 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 objective of the Demonstration Program is to develop 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 are 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 evaluation of long-term risks and operating and maintenance (O&M) costs.

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

Existing technologies that 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 Measurement 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 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 musthave 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, site preparation, sampling and analysis, quality assurance and quality control (QA/QC), preparing reports, disseminating information, and transporting and disposing of untreated and treated waste materials.

The results of the CPFM 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. The ITER is discussed in the following section. Both the SITE technology capsule and the ITER are intended for use by remedial managers making a detailed evaluation of the technology for a specific site and waste.

2.2 Purpose of the Innovative Technology Evaluation Report

The ITER provides information on the CPFM 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 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.

2.3 Technology Description

In October 1991, a bench-scale study of the CPFM technology was conducted at the U.S. Department of Energy (DOE) RFETS in Golden, Colorado, where water is contaminated with radionuclides. In September 1993, a full-scale demonstration was also conducted at this site based on a cooperative effort involving the EPA Risk Reduction Engineering Laboratory (RREL), DOE, the Colorado Department of Public Health and Environment (CDPHE), (formerly the Colorado Department of Health [CDH]) and EPA Region 8. The evaluation of the CPFM technology is based on the results of the SITE demonstration and the bench-scale study at the RFETS site.

2.3.1 Treatment Technology

The CPFM technology is designed to remove trace to moderate levels of nontritium radionuclides and heavy metal pollutants from water. Specially designed filter plates are used to support filter packs that contain FF 1000, the active ingredient in the CPFM technology. FF 1000 is an insoluble, inorganic, oxide-based, granular material that removes radionuclides and heavy metals from moderately contaminated water through a combination of chemical and physical processes. End products include the spent filter pack that contains contaminants and treated water with reduced concentrations of heavy metals or radionuclide pollutants.

According to the technology developer, removal of contaminants by FF 1000 is achieved through a combination of chemical complexing, adsorption, absorption, and filtration. By optimizing the water pH to favor contaminant insolubility, contaminant colloids and colloidal aggregates can be formed upstream of the filter beds and then removed by the FF 1000. The

reaction mechanisms active within the filter pack are described by FFT as follows:

- **Chemical Complexing**. Heavy metal and radionuclide pollutants in water form charge-dependent, stable complexes with certain inorganic compounds. These complexes associate with the inorganic, oppositely charged FF 1000 to form insoluble colloids, colloidal aggregates, or larger precipitating particles. An estimated 10 percent of the reaction mechanism is attributable to chemical complexing.

- **Adsorption**. Adsorption refers to the replacement of positively charged ions on mineral surfaces by metal cations in solution. The sorption of inorganic ions is largely determined by complex chemical equilibria involving the charge and size of the element or complex ion, the nature of the sorbing material, and the pH of the aqueous solution. The properties of the surface that influence inorganic sorption include net surface charge, the presence and configuration of binding sites, and the pH dependence of those sites. The structure of the solid, whether crystalline or amorphous, may also affect adsorption reactions. FF 1000 is formulated to maximize adsorptive reactions with metals and radionuclides. During CPFM system operation, radionuclides adsorb to FF 1000 to form colloids. The adsorbed colloids and ions electrostatically attach to the surface of the filter bed material where they remain. An estimated 75 percent of the reaction mechanism is attributable to adsorption.

- **Absorption**. Absorption refers to the incorporation of ions or compounds into the crystal lattice of the absorbing material. It is estimated that less than 10 percent of the reaction mechanism is attributable to absorption.

- **Filtration**. The FF 1000 filter medium forms a compact but porous bed that may filter out micromolecular particles. An estimated 5 percent of the reaction mechanism is attributable to filtration.

The principal operating parameters for the CPFM technology are influent pH, chemical pretreatment dose, and flow rate (which determines hydraulic retention time). The optimum operating parameters for each application are selected based on results of bench-scale studies.

The influent pH level controls the formation of insoluble contaminant complexes and colloids that are available for retention by the FF 1000. Increasing or decreasing the pH will affect the CPFM system by altering contaminant chemistry. Typically, optimum pH for contaminant removal is in the range of pH 8 to 9. Flow rate through the CPFM system will determine hydraulic retention time. Increasing or decreasing the flow rate will affect treatment efficiency by changing the time available for colloid formation and retention. A flow rate of approximately 5 gpm (18.9 Lpm) has been determined to be optimal for the existing, trailer-mounted system.

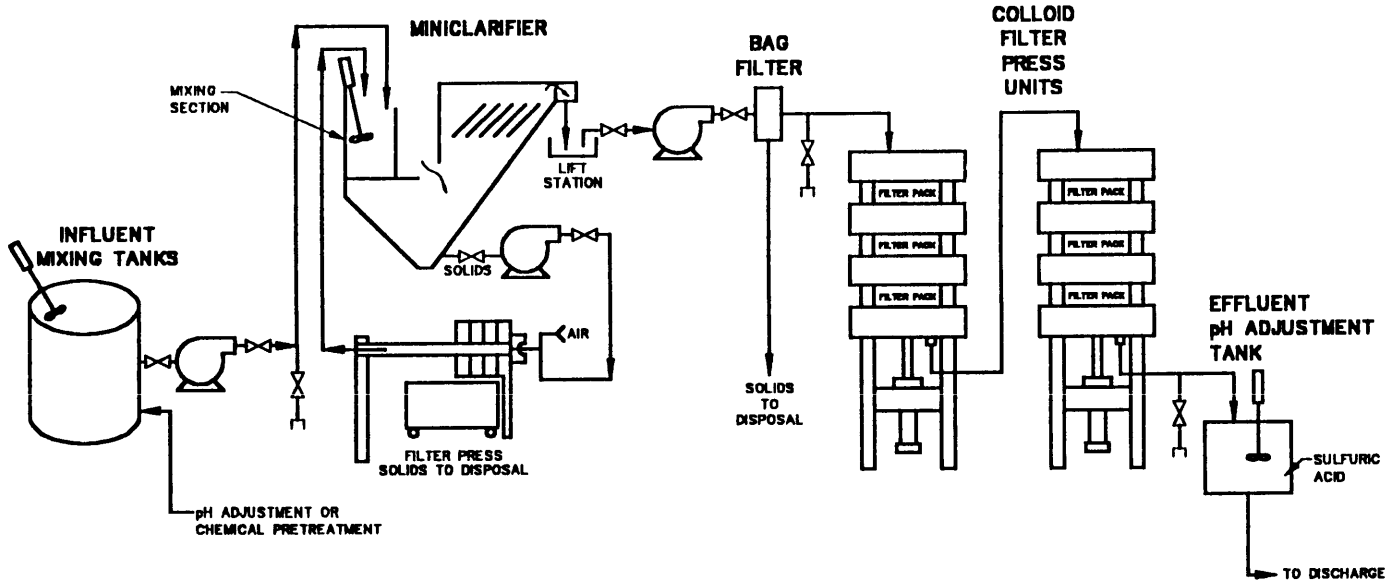
2.3.2 System Components and Function

The CPFM system has several components: an influent mixing tank, a miniclarifier with a filter press, a bag filter, transfer pumps, colloid filter units, and an effluent pH adjustment tank. All components of the CPFM system that come in direct contact with the contaminated water and filter cake are made of stainless steel, Teflon, or plastic to minimize contamination of the process stream by the construction materials. All process equipment is mounted and operated on a trailer bed.

A schematic diagram of the CPFM system is shown in Figure 2-1. The major components of the system include the following:

- **Influent Mixing Tank**. The tank is constructed of polyethylene and has a capacity of 200 gallons (757 liters). It is also equipped with a mixer to promote adequate mixing of influent and pH adjustment or pretreatment chemicals (such as sodium sulfide).

- **Miniclarifier**. The miniclarifier has a nominal volume of 500 gallons (1,892 liters) and is designed to allow bulk solids to settle out of the influent prior to treatment in the CPFM system. It is equipped with a mixer in the mixing section should chemical addition be required. The settling section of the clarifier is equipped with inclined plates that improve particle settling.



LEGEND

VALVE

FLOW DIRECTION

PUMP

MIXER

SAMPLE PORT

NOTE: COLLOID FILTER UNITS CAN BE OPERATED IN SERIES OR PARALLEL MODES. (ONLY SERIES MODE SHOWN HERE)

Figure 2-1. CPFM Treatment System

- **Bag Filter**. Heavy duty filter cloths act as an in-line screen to remove particles larger than 10 microns. The separated particles can be removed from the bag filter for disposal. Spent bag filters can also be disposed of with the prefilter solids (miniclarifier and bag filter solids).

- **Colloid Filter Unit**. This is the principal component of the CPFM system. The unit is 5 1/2 feet (1.67 meters) high and 3 feet (0.91 meters) square. A schematic drawing of the unit is presented in Figure 2-2. It is preassembled, and has few moving parts. It is equipped with influent and effluent polyvinylchloride (PVC) piping and valves. The filter plates are positioned on vertical supporting bars and pressed together using a hand-controlled hydraulic pump to approximately 50,000 pounds per square inch (psi) (3,515 kilograms per square centimeter) of pressure. Filter plates are 26 inches (0.66 meters) square, 2 inches (5 centimeters) thick, and are constructed of plastic. A schematic drawing of a filter plate is shown in Figure 2-3. Each filter pack is constructed of a durable, fibrous, polymer material (Pulplus). Each pack contains a premeasured amount of FF 1000 (approximately 0.364 cubic feet) (0.01 cubic meters). The filter packs are placed horizontally between facing plates. Each pack is equipped with edge tabs for handling.

- **Effluent pH Adjustment Tank**. This tank is constructed of polyethylene and has a capacity of 200 gallons (757 liters). It is also equipped with a mixer to promote adequate mixing of sulfuric or hydrochloric acid solution and effluent.

- **Chemical Feed Systems**. The CPFM system also includes two 20-gallon (75.7 liter) buckets, each equipped with a small (less than 5 gpm) (18.9 liters per minute [Lpm]) metering pump used to store and pump the sodium hydroxide and acid solutions for pH adjustment, if necessary.

- **Transfer Pumps**. Transfer pumps are required for pumping water from: (1) the source to the influent mixing tank; (2) the influent mixing tank to the miniclarifier; (3) the miniclarifier to the bag filter and colloid filter unit; and (4) the pH adjustment tank to discharge. These diaphragm pumps have a rated capacity of 25 gpm (95 Lpm). The transfer pump to the colloid filter unit is controlled with an air pressure gauge that operates between 5 and 100 psi (0.35 to 7.03 kilograms per square centimeter). (The other pumps are equipped with a rotameter downstream of the discharge side to monitor flow.)

During system operation, water is pumped to a 200-gallon (757 liter) mixing tank for pH adjustment and chemical pretreatment, if necessary, to adjust water chemistry to the optimum range for contaminant removal by the FF 1000 in the colloid filter packs. After pretreatment, the water is pumped to a miniclarifier that removes suspended solids. Settled solids from the bottom of the clarifier are dewatered in a small filter press attached to the clarifier. The solids are then collected and stored in a solids disposal container. Effluent from the miniclarifier is pumped through a bag filter to remove additional solids greater than 10 microns in size. Effluent from the bag filter is routed to the colloid filter press unit. Each colloid filter press unit is made up of a series of four filter plates containing three colloid filter packs. One filter pack is located between each set of plates within the filter press unit. Once the filter packs have been inserted between the filter plates, hydraulic pressure is applied to the plates. Pressure seal O-rings contained in the plates form a water tight seal between the plates, holding water within the unit.

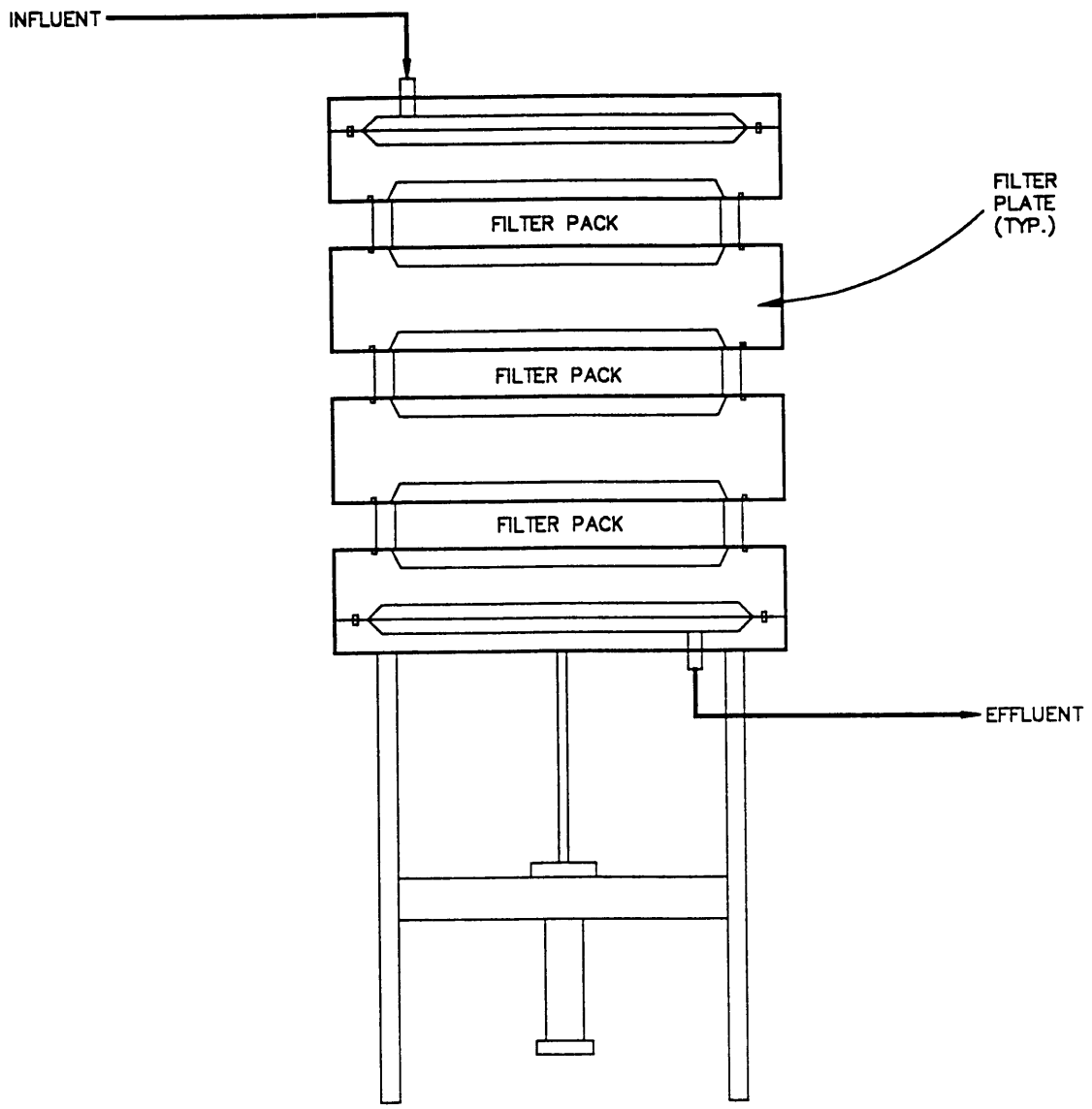
The pretreated water is dispersed throughout the filter packs, where physical and chemical mechanisms remove contaminants.

Water passing through the filter packs is pumped to a final pH adjustment tank. If necessary, effluent from the colloid filter packs is treated in this tank to reduce the effluent pH before discharge.

2.3.3 Key Features of the CPFM Technology

Several unique features of the CPFM technology distinguish it from most small-size particle removal methods such as ion exchange, reverse osmosis, and ultrafiltration. According to FFT, the CPFM technology leads to:

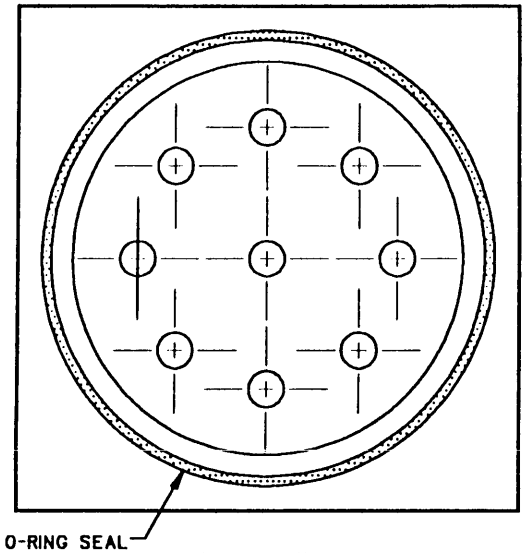
- Reduced capital costs through higher throughput and simpler and cheaper equipment



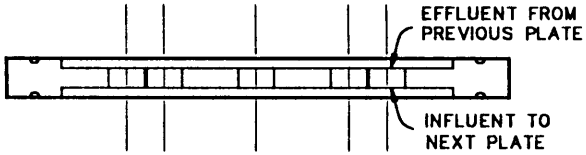
NOT TO SCALE

NOTE:
THIS CONFIGURATION EMPLOYS THREE FILTER BEDS, EACH WITH ONE FILTER PACK, OPERATING IN SERIES, CONFIGURATION A (SEE SECTION 2.3.2. FOR FURTHER DISCUSSION CONCERNING BED CONFIGURATIONS).

Figure 2-2. Schematic of Modified Colloid Filter Unit

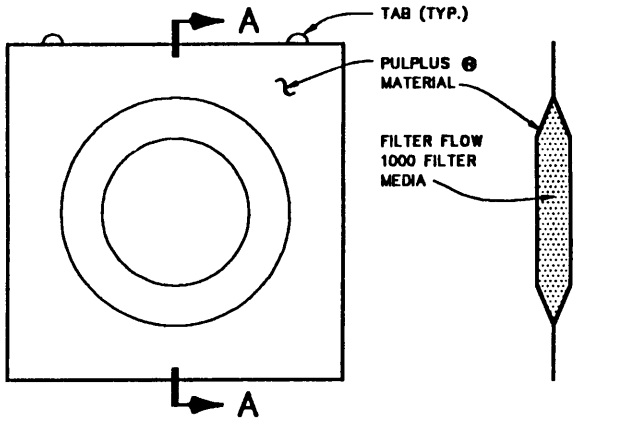


TOP VIEW



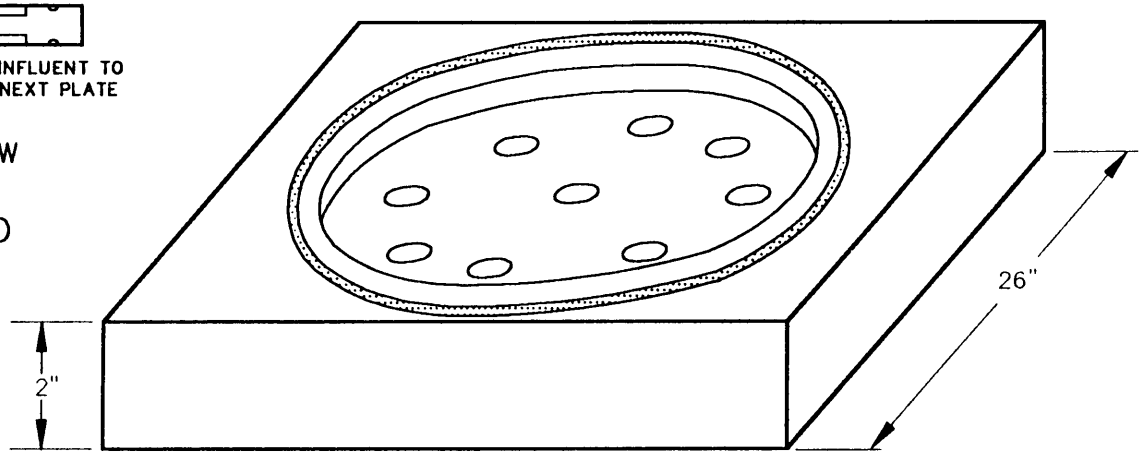
FRONT AND PROFILE VIEW

TYPICAL TWO-SIDED
FILTER PLATE
SCALE: 1 = 10



PLAN SECTION A-A

TYPICAL FILTER PACK
NOT TO SCALE



TYPICAL TWO-SIDED
FILTER PLATE
NOT TO SCALE

Figure 2-3. Schematic of Typical Filter Plate and Filter Pack

- Reduced operation and maintenance costs through reliability and simplicity of the system

- Reduced quantity of solids for disposal generated due to the small-volume and potentially regenerable filter bed

- Improved removal efficiencies for multivalent, chelated, or complexed metals and radionuclides

2.4 Key Contacts

Additional information on the FFT CPFM technology and the SITE program can be obtained from the following sources:

The FFT CPFM Technology

Tod Johnson
Filter Flow Technology, Inc.
122 Texas Avenue
League City, TX 77573
713-332-3438
FAX: 713-332-3644

The 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) (operator: 301-670-6294) is a comprehensive, automated information retrieval system that integrates data on hazardous waste treatment technologies into a centralized, searchable source. This data base provides summarized information on innovative treatment technologies.

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

- The OSWER CLU-In electronic bulletin board contains 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 West Martin Luther King Drive, Cincinnati, Ohio 45268, at 513-569-7562.

Section 3
Technology Application Analysis

This section of the report evaluates the general applicability of the CPFM technology to contaminated waste sites. The analysis is based primarily on the SITE bench-scale study and demonstration results because limited information was available on other applications of the technology. A detailed discussion of the demonstration results is presented in Section 5.0 of this report. The developer's claims regarding the applicability and performance of the CPFM technology are included in Appendix A. Several case studies provided by the developer are presented in Appendix B.

3.1 Technology Evaluation

The objectives of the CPFM technology demonstration, conducted under the SITE Program, were to:

- Assess the technology's ability to remove uranium and gross alpha contaminants to levels below CWQCC standards
- Document the operating conditions and identify operational needs, such as utility and labor requirements, for the treatment system
- Estimate costs associated with operation of the CPFM technology
- Assess the technology's ability to remove other radionuclides (plutonium, americium, and radium)
- Evaluate the disposal options for prefiltered solids (miniclarifier and bag filter solids) and spent filter cake from the colloid filter unit

The effectiveness of the CPFM technology is summarized below. The assessment of the technology's effectiveness is based on the results of the bench-scale study and the SITE demonstration.

3.1.1 Bench-Scale Study Results

FFT conducted a bench-scale study of the CPFM technology at RFETS between September 30 and October 2, 1991. The equipment for this study included a single-flanged filtering vessel representing one filter bed (0.36 cubic feet) (0.008 cubic meters). FF 1000 was slurried into a polypropylene filter mesh within the vessel. Approximately 40 gallons (151 liters) of groundwater from the interceptor trench pump house (ITPH) were treated using this configuration for this study. Flow rates during this bench-scale study varied from 75 to 460 milliliters per minute (mL/min). The study used interceptor trench water spiked with up to 30 pCi/L of plutonium 239, americium 241, and radium 226. The water was spiked so that removal efficiencies could be more easily determined for plutonium, americium, and radium since their concentrations in the ITPH water were relatively low. The trench water contained about 100 pCi/L uranium and 100 pCi/L gross alpha and so did not require spiking for these components. Eight test runs were conducted to treat the spiked interceptor trench water. During the tests, several parameters including influent pH, flow rate through the FF 1000, and chemical pretreatment using sodium sulfide or sodium bisulfite were varied to determine optimum operating conditions for the CPFM technology.

The results of the test runs demonstrated that the system effectively removed uranium, plutonium, and americium from the ITPH water at ambient pH without chemical pretreatment. However, the system did not effectively remove radium from water under any circumstances. Test results also show that chemical

pretreatment with sodium sulfide versus no pretreatment provided some improvement in removal efficiencies. In addition, reduced flow rates, resulting in increased interaction time for water and FF 1000, improved removal efficiencies.

3.1.2 SITE Demonstration Results

The SITE demonstration of the CPFM technology was conducted at RFETS over a 3-week period in September and October 1993. During the demonstration, the CPFM system treated about 10,000 gallons (37,850 liters) of groundwater contaminated with radionuclides. The principal groundwater contaminant, uranium, was present at a concentration of about 100 μg/L. Other radionuclides were present at concentrations of about 0.02 pCi/L for plutonium, 0.02 pCi/L for americium, and 0.10 pCi/L for radium.

Contaminated water was pumped from the ITPH house to 500,000-gallon (1,892,500 liters) tanks used by RFETS to store ITPH water, one of which stored influent for the CPFM system. Treated effluent was routed back to a second 500,000-gallon (1,892,500 liter) tank.

The demonstration consisted of three tests conducted in five test runs. The first test consisted of three runs of 4 hours each, treating about 5 gpm (18.9 Lpm). For the second test, also run for 4 hours at 5 gpm (18.9 Lpm), the influent water was treated with sodium sulfide in the pretreatment tanks to change the oxidation state of the radioactive metals in the water. The third test was a 15-hour run designed to determine the amount of contamination each filter pack is capable of treating.

During the demonstration, samples were collected of untreated influent, pretreated water after passing through the miniclarifier and bag filters, and effluent that had passed through the filter packs. Samples were analyzed to determine the technology's effectiveness. Adjustment of the pH was not required at RFETS because the influent water was within the optimum pH range (7.5 to 9) for the technology. The pH of the effluent water was monitored in the effluent pH adjustment tank and treated to reduce the pH to its original level.

Section 5.0 of this report discusses the results of the demonstration in greater detail. Key findings of the demonstration are summarized as follows:

- For the first test of three runs, the CPFM system demonstrated a range of removal efficiencies for uranium (58 to 91 percent) and gross alpha (33 to 87 percent). These removal efficiencies did not achieve CWQCC standards for off-site discharge. Variation in removal efficiency during the demonstration is not explained by operational data.

- For the second test, consisting of one run using sodium sulfide chemical pretreatment of influent, the CPFM system achieved removal efficiencies of 95 percent for uranium and 94 percent for gross alpha contamination. Using chemical pretreatment, the CPFM system was capable of meeting applicable CWQCC standards.

- The concentrations of plutonium, americium, and heavy metals in influent were near detection limits. Therefore, the ability of the CPFM system to remove these contaminants could not be evaluated. The system was not successful in removing radium from RFETS groundwater.

- Results from the toxicity characteristic leaching procedure (TCLP) evaluation of the spent filter packs without stabilizing agent showed that the packs did not contain leachable metals, uranium, or gross alpha contamination.

3.2 Evaluation of Technology Against RI/FS Criteria

Nine evaluation criteria have been developed by EPA to address the requirements of CERCLA and additional technical and policy considerations that have proven important for selecting among potential remedial alternatives. These criteria serve as the basis for conducting bench-scale testing during the remedial investigation (RI) at a hazardous waste site, for conducting the detailed analysis during the feasibility study (FS), and for subsequently selecting an appropriate remedial action. Each SITE technology is evaluated against the nine EPA criteria because these technologies may be considered as potential remedial alternatives.

The nine evaluation criteria are:

- Overall protection of human health and the environment

- Compliance with applicable or relevant and appropriate requirements (ARARs)
- Long-term effectiveness and permanence
- Reduction of toxicity, mobility, or volume
- Short-term effectiveness
- Implementability
- Cost
- State acceptance
- Community acceptance

Table 3-1 presents the results of this evaluation. The evaluation presented in the table indicates that the CPFM system is capable of providing both short- and long-term protection of the environment by removing contaminants from groundwater and concentrating them in the filter packs.

3.3 Factors Influencing Performance

Several factors influence the performance of the CPFM technology. These factors can be grouped into three categories: (1) influent characteristics, (2) operating parameters, and (3) maintenance requirements. This section discusses these factors.

3.3.1 Influent Characteristics

The CPFM technology is capable of treating a range of contaminated waters containing radionuclides or heavy metals. Under a given set of operating conditions, contaminant removal is a function of the chemical form of the contaminant, with removal efficiencies being highest for radionuclides and metals that form colloids or colloidal aggregates.

Contaminant concentrations also affect treatment system effectiveness. The system is designed to remove trace to moderate levels (less than 1,000 parts per million [ppm]) of radionuclides and heavy metal pollutants from water that has been prefiltered and has low total organic carbon (TOC) and low total dissolved solids (TDS) content. The CPFM system is most effective when operated as a polishing filter for strict heavy metal and radionuclide discharge limitation situations. High levels of contaminants may overload the filter packs and require a significant increase in filter pack replacement or regeneration costs.

Liquid phase organic compounds at concentrations in excess of a few ppm are also known to reduce the CPFM treatment system's ability to remove metals and radionuclides by occupying sorption sites in the FF 1000. The concentrations of organic compounds in the interceptor trench water are well below this level. Therefore, interference due to organic compounds was not anticipated during the demonstration.

3.3.2 Operating Parameters

Operating parameters can be varied during the treatment process to achieve desired removal efficiencies. The principal operating parameters for the CPFM system are influent pH, chemical pretreatment dose, and flow rate.

Influent pH and chemical pretreatment affect contaminant speciation, solubility, and colloid formation. The underlying assumption in using the CPFM system is that heavy metal and radionuclide pollutants in water exist as colloids, colloidal aggregates in association with inorganic or organic particles, and as inorganic ions. By optimizing the water pH and chemistry conditions to favor particle attraction, it is possible to shift the equilibrium toward formation of colloids and colloidal aggregates. These forms of the contaminants can then be removed by the FF 1000 through chemical complexing, sorption, and filtration.

Flow rate through the CPFM system determines the residence time for water within the filter packs. As shown in bench-scale testing, decreasing the flow rate from 460 to 75 mL/min improved treatment efficiency. If residence times are long enough, equilibrium conditions would be approached and increased residence time would not further improve removal efficiencies. Flow rates for the demonstration were based on results of the bench-scale studies and were not investigated further during the demonstration.

3.3.3 Maintenance Requirements

The maintenance requirements for the CPFM system summarized below are based on discussions with FFT during and after the SITE demonstration. Regular maintenance by trained personnel is essential for the successful operation of the CPFM system. Overall, the construction of the CPFM system is mechanically simple and requires minimal maintenance. The only major

Table 3-1. Evaluation Criteria for the CPFM System

	Criteria								
	Overall Protection of Human Health and the Environment	**Compliance with Federal Applicable or Relevant and Appropriate Requirements (ARARs)**	**Long-Term Effectiveness and Permanence**	**Reduction of Toxicity, Mobility, or Volume Through Treatment**	**Short-Term Effectiveness**	**Implementability**	**Cost[a]**	**State Acceptance**	**Community Acceptance**
Performance	Provides short- and long-term effectiveness by permanently eliminating human exposure to contaminants in groundwater.	Effluent complies with federal, but not state, discharge limits for uranium and gross alpha.	Residual risk from stabilized filter pack material is low.	Reduces volume of contamination by concentration in spent filter pack material.	Minimal potential for community exposure to contaminants during implementation of the technology.	Technically feasible to implement technology using reliable, preassembled unit.	$7 per 1,000 gallons to $2 per 1,000 gallons depending on treatment duration.	If remediation is conducted as part of RCRA corrective actions, state regulatory agencies may require permits.	Minimal short-term risks presented to the community make this likely to be accepted by the public.
		Spent filter pack material requires compliance with RCRA land disposal regulations.	Residuals adequately controlled by RCRA land disposal restrictions.	Reduces mobility of contaminants by stabilization in spent filter packs.	Workers protected during implementation of the technology.	Effectiveness of the technology can be monitored on a daily basis.	Capital costs vary from $1,000 per day for rental to $150,000 for purchase of 100 gpm unit.		
				Mass of contaminants not changed by the process.	No adverse environmental impacts during implementation of technology.	Few activities required for implementation of portable treatment unit.			
					System designed to treat up to 100 gpm of contaminated water.	Services and materials required for operation are widely available.			

Notes:

[a] Actual cost of remediation technology is site-specific and depends on the initial contaminant levels and target cleanup level, groundwater characteristics, and volume of water. Cost data presented in this table are for treating groundwater at 100 gpm for 1 year.

system component that requires regular maintenance is the filter packs within the colloid filter press unit, which require periodic replacement or regeneration.

Filter packs will require replacement with new or regenerated packs on a regular basis depending on the size of the packs, the flow rate, and contaminant load. Replacement frequency cannot be calculated until contaminant concentrations, flow rate, and required discharge limits are known.

Other system components, such as the influent chemical pretreatment feed system, the effluent acidification feed system, the miniclarifier sludge removal system, and interconnecting piping and appurtenances should be checked on a daily basis. Sludge from the base of the miniclarifier may need to be pumped to the filter press for dewatering and containerized on a weekly basis depending on influent quality. In addition, the feed pumps should be checked at least once a month for proper operation and calibration.

3.4 Site Characteristics

Site characteristics are important when considering the CPFM technology because they can affect system application. All site characteristics should be considered before selecting the technology to remediate a specific site. Site-specific factors include support systems, site area and preparation, site access, climate, utilities, and services and supplies.

3.4.1 Support Systems

To clean up contaminated water, a piping system from the source of the water to the CPFM system must be constructed. However, for small quantities of water, a tanker truck may be employed to transport contaminated water to the system. The CPFM system may operate in continuous flow-through or batch mode during site remediation. Therefore, an equalization tank may be required for continuous mode to contain water if flow rates are too low or during filter pack changeout.

If on-site facilities are not available for office and laboratory work, a small building or shed may be required near the treatment system. The on-site building should be equipped with electrical power to run laboratory equipment and should be heated or air-conditioned, depending on the climate. The onsite laboratory should contain equipment needed for simple analysis such as pH, oxidation potential (Eh), conductivity, and temperature.

3.4.2 Site Area and Preparation

At the present time, the CPFM system is available in only one size. This unit treated 5 gpm (18.9 Lpm) during the demonstration. According to the technology developer, this system may be refitted with larger pumps that may treat water at flow rates of up to 25 gpm (94.6 Lpm). An area of approximately 2,000 square feet (185.8 square meters) is required for setup of the 25-gpm (94.6 Lpm) CPFM system, and includes space for influent and effluent storage tanks and a small office. The area should be relatively flat and should be paved or gravel covered.

3.4.3 Site Access

Site access requirements for the CPFM system are minimal. The site must be accessible to a 1-ton pickup truck pulling a 30-foot (9.1 meter) trailer. The roadbed must be able to support such a vehicle and trailer delivering the CPFM system.

3.4.4 Climate

The CPFM system is not designed to operate at temperatures near or below freezing. If such temperatures are anticipated, the CPFM system and associated storage tanks should be kept in a heated shelter, such as a building or shed. In addition, piping to the system must be protected from freezing.

3.4.5 Utilities

The CPFM system requires potable water, electricity, and compressed air for operation. Potable water is required for a safety shower, an eye wash station, personnel decontamination, and cleaning sampling equipment. Electrical power for the CPFM system and support facilities can be provided by portable generators or 220-volt, 3-phase electrical service. Total power usage is expected to be less than 1 kilowatt per day for operation. Compressed air at 100 psi (7 kilograms per square centimeter) is required to operate the diaphragm pumps used by the system. Compressed air can be provided by a portable, gas powered compressor.

A telephone connection or cellular phone is required to order supplies, contact emergency services, and provide normal communications.

3.4.6 Services and Supplies

The main service required by the CPFM system is replacement or regeneration of the filter packs. FFT provides replacement filter packs and the system required for filter pack regeneration. Additional chemicals such as sodium hydroxide and sulfuric acid for influent and effluent pH adjustment and sodium sulfide for chemical pretreatment can be supplied by FFT or local vendors.

Complex laboratory services, such as metals and radionuclide analyses, that cannot be conducted in an on-site laboratory during monitoring programs require contracting, preferably with a local, off-site analytical laboratory.

3.5 Material Handling Requirements

The CPFM system generates spent filter cake as a treatment residual that will require further processing, handling, and disposal. Depending on the regulatory requirements, the system effluent may also require storage for analysis before it can be released or retreated if required. Sodium hydroxide or sulfuric acid used for influent and effluent pH adjustment and sodium sulfide used for chemical pretreatment will also require proper storage and handling.

The spent filter cake and sludge removed from the miniclarifier filter press will be dewatered, containerized, and analyzed to determine disposal requirements. Acidic solutions resulting from filter pack regeneration will be containerized and analyzed to determine disposal requirements. Handling chemicals such as sulfuric acid and sodium sulfide should not create any waste streams that require disposal.

3.6 Personnel Requirements

Based on observations during the SITE demonstration, the CPFM system will require two technicians and one supervisor during operation. These personnel should be capable of conducting the following activities: (1) filling chemical feed tanks and adjusting system flow rates; (2) operating the control panel on the CPFM system; (3) collecting liquid samples and performing simple chemical analysis (for example, pH, Eh, conductivity, and temperature); (4) troubleshooting minor operational problems; (5) collecting samples for off-site analysis; and (6) changing out spent filter packs.

All personnel should have completed an OSHA initial 40-hour health and safety training course and an annual 8-hour refresher course, if applicable, before operating the CPFM system at hazardous waste sites. They should also participate in a medical monitoring program as specified under OSHA requirements.

According to FFT, long-term operation of the system may be automated for approximately $20,000. Operator time could then be reduced to approximately half time for one technician.

3.7 Potential Community Exposures

The CPFM system does not generate chemical or particulate air emissions. Therefore, the potential for on-site personnel or community exposure to airborne contaminants is low. The CPFM system is designed to sound an alarm and shut down automatically should a malfunction occur, further reducing risk to on-site and off-site personnel.

3.8 Potential Regulatory Requirements

This section discusses specific environmental regulations pertinent to operation of the CPFM system, including the transport, treatment, storage, and disposal of wastes and treatment residuals, and analyzes these regulations in view of the demonstration results. State and local regulatory requirements, which may be more stringent, also must be addressed by remedial managers. ARARs include the following: (1) CERCLA; (2) RCRA; (3) SDWA; and (4) OSHA regulations. These four general ARARs are discussed below; specific ARARs must be identified by remedial managers for each site. Some specific federal and state ARARs that may be applicable to the CPFM technology are identified and discussed in Table 3-2.

3.8.1 Comprehensive Environmental Response, Compensation, and Liability Act

CERCLA, as amended by SARA, authorizes the federal government to respond to releases or potential

Table 3-2. Federal and State ARARs for the CPFM 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 in tanks.	The treatment process occurs in a series of tanks.	Tank integrity must be monitored and maintained to prevent leakage or failure; the tank 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 tanks.	The treated waste will be placed in the interim measure/interim remedial action (IM/IRA) tank.	The tanks will be maintained in good condition. The tanks will be operated in accordance with on-site requirements (the applicable RCRA Part B permit).
Waste Characterization	RCRA 40 CFR Part 261.24 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 Region 8 for on-site hazardous waste disposal; also, disposal will be in accordance with DOE RFP requirements.
Off-site Disposal	SARA Section 121(d)(3).	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 at a RCRA-permitted hazardous waste facility.
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.

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 Code of Federal Regulations (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 and directed 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. The CPFM technology is likely to 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 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.

3.8.2 Resource Conservation and Recovery Act

RCRA, an amendment to the Solid Waste Disposal Act (SWDA), was passed in 1976 to address the problem of how to safely dispose of the enormous 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 CPFM 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 CPFM demonstration system treated groundwater collected in operable unit (OU) 4 interim measure and interim remedial action (IM/IRA) storage tanks. These tanks receive water collected in the ITPH. The ITPH is part of the system of interceptor trenches constructed around the solar evaporation ponds (SEP). The SEPs have begun RCRA closure operations. Although wastes have not been disposed of in the ponds since 1986, the ponds are regulated under RCRA. However, water collected in the interceptor trenchs and channeled to the ITPH has not yet been declared a RCRA waste. In addition, the spent filter packs were subjected to the TCLP and the leachate analyzed for the characteristic metals plus uranium and gross alpha. The leachate did not contain detectable metal or radionuclide contamination. Therefore, the spent filter packs generated during the demonstration were not RCRA wastes.

3.8.3 Safe Drinking Water Act

The SDWA of 1974, as most recently amended 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, CWQCC has set basin-specific discharge standards for the streams that drain the area of RFETS. MCLs and CWQCC standards are presented in Table 3-3. Water treated by the CPFM system must meet these standards to be discharged directly to the drainage. However, water treated by the CPFM system during the demonstration will be returned to a second IM/IRA receiving tank for subsequent treatment by the RFETS water treatment system before being discharged. Wash water from decontami-nation was collected and stored in a 1,000-gallon (3,785 liter) storage tank. This water was also routed to the IM/IRA receiving tank for treatment.

3.8.4 Occupational Safety and Health Act

CERCLA remedial actions and RCRA corrective actions must be conducted in accordance with OSHA requirements detailed in 29 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 action sites must be conducted in accordance with 29 CFR Part 1926, 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 CPFM system are required to have completed 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 will include gloves, hard hats, steel toe boots, and coveralls. Depending on contaminant types and concentrations, additional PPE may be required.
The CPFM unit and support equipment can be mounted and operated on the bed of a trailer. All equipment on the system meets OSHA requirements for safety of operation.

3.9 Availability, Adaptability, and Transportability of Equipment

Currently, only the one trailer-mounted CPFM system used for the demonstration is available. This unit is capable of treating water at up to 25 gpm (94.6 Lpm) using larger pumps than are currently fitted and is leasable from FFT for $1,000 per day for short-term projects. The cost of building a similar system is estimated to be about $75,000 to $100,000. At present, FFT plans to build additional systems as required to fill project orders. Additional systems may be built in 10 to 12 weeks, including testing. According to FFT, a skid-mounted system that treats water at flow rates up to 100 gpm (378.5 Lpm) could be built for approximately $150,000 to $200,000.

The CPFM system may be used to treat water with a low total suspended solids (TSS) content (surface or groundwater), as in the demonstration. Alternatively, the system may be used to treat industrial wastewater in a treatment train downstream from other technologies such as soil washing, organic oxidation, or conventional wastewater treatment using flocculation and solids removal to lower the TSS content. For each site, preconditioning chemistry and pH must be optimized using bench-scale testing.

As discussed in Section 3.4.3, the trailer-mounted system is easily transported by a 1-ton pickup truck. In addition, the trailer-mounted unit requires minimal site preparation. Skid-mounted units will require significantly more site preparation.

3.10 Limitations of the Technology

In general, the CPFM technology is designed to remove trace to moderate levels (less than 1,000 ppm) of nontritium radionuclides and heavy metal pollutants present in water. The CPFM system removes these contaminants to ppm or parts per billion (ppb) levels and is most efficiently employed as a polishing filter in situations where extremely strict discharge standards apply. The CPFM system will not remove tritium (radioactive hydrogen) because tritium is incorporated with oxygen in water molecules and is therefore not retained by FF 1000.

High organic compound concentrations, greater than a few ppm, may interfere with the chemical and physical reactions occurring between FF 1000 and charged contaminants. Therefore, water with high organic compound concentrations is not treated as effectively by the CPFM technology.

Table 3-3. Treatment Standards and Influent Concentrations for CPFM SITE Demonstration

Element	Influent Concentration[a]	Colorado Water Quality Control Commission (CWQCC)[b] Effluent Standard	EPA MCL[c]
Radionuclides (pCi/L)			
Uranium	68	5	10
Gross Alpha	98.7	7	--
Americium	0.03	0.05	15
Plutonium	0.03	0.05	--
Radium-226	31	5	5
Metals (mg/L)			
Aluminum	0.03U	5.0	5.0
Arsenic	0.04U	0.05	0.05
Antimony	0.05U	---	0.06
Barium	0.10	1.0	1.0
Beryllium	0.001	0.1	0.1
Cadmium	0.005U	0.01	0.01
Chromium	0.005	0.05	0.05
Cobalt	0.003	---	0.05
Copper	0.004	0.2	1.0
Calcium	162	---	---
Iron	0.04	0.3	1.0
Lead	0.03U	0.05	0.05
Magnesium	277	---	---
Manganese	0.003	0.05	0.05
Molybdenum	0.008U	0.1	0.1
Nickel	0.02U	0.2	0.32
Potassium	55	---	---
Silver	0.004U	0.05	0.05
Selenium	0.056U	0.01	0.01
Sodium	359	---	---
Strontium	2.1	---	0.382
Thallium	0.07U	---	0.01
Vanadium	0.003U	0.1	0.024
Zinc	0.003	2.0	0.05

Notes:

[a] Average concentration based on data collected for Runs 1-3 during the demonstration.

[b] Standards adopted through the Rocky Flats Interagency Agreement, the effluent treatment standard governing the demonstration

[c] Maximum contaminant level (MCL)

---- No standard exists
pCi/L PicoCuries per liter
mg/L Milligrams per liter
U Undetected at this value

3.11 Applicable Wastes

According to the developer, potential applications also include remediation of contaminated liquid wastes from industrial operations, oil-drilling production water contaminated with naturally occurring radioactive materials (NORM), in situ uranium mine effluent water, and transuranic and low-level radioactive wastes from nuclear-related facilities. FFT also states that the CPFM system is designed to treat a wide range of inorganic, metallic pollutants in water. Several case studies of the CPFM system in various applications are presented in Appendix B.

Section 4
Economic Analysis

This section presents cost estimates for using the CPFM technology to treat groundwater. Three cases, based on treatment time, are presented. These cases are based on 1-year, 5-year, and 10-year treatment scenarios. The CPFM 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 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 September 1993 dollars and are considered estimates, with an accuracy of plus 50 percent and minus 30 percent.

Table 4-1 presents a breakdown of costs for the 12 categories for all three cases. The table also presents total one-time costs and total annual O&M costs; the total costs for a hypothetical, long-term groundwater remediation project; and the costs per gallon of water treated.

4.1 Basis of Economic Analysis

A number of factors affect the estimated costs of treating groundwater with the CPFM 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 CPFM system also affect disposal costs because they determine whether the residuals require either further treatment or off-site disposal. FFT claims that the CPFM 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 it is commonly found at Superfund and RCRA corrective action sites. Groundwater remediation also 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 CPFM system will treat contaminated groundwater on a continuous flow cycle, 24 hours per day, 7 days per week. Based on this assumption, the CPFM system will treat about 52.4 million gallons (198 million liters) of water during a 1-year period. Over a 5-year period, this number will rise to 262 million gallons (991 million liters), and over 10 years, to 524 million gallons (1.98 billion liters). Although it is difficult in practice to determine both the volume of groundwater to treat and the actual duration of a project, these figures are used to conduct this economic analysis.

Further assumptions about groundwater conditions and treatment for each case include the following:

- Any suspended solids present in groundwater are removed before entering the CPFM system.
- The influent has an optimum pH of 8 to 9.
- The ambient temperature is between 20° and 35° Celsius.

This analysis assumes that treated water for each case will be discharged to surface water, and that MCLs specified in the SDWA are the treatment target levels. The CPFM system should achieve these levels based on results of the SITE demonstration.

Table 4-1. Costs Associated with the CPFM System[a]

Cost Categories	Scheduled Treatment Time					
	1 year		5 years		10 years	
Fixed Costs						
Site Preparation[b]	$15,000		$15,000		$15,000	
Administrative		*10,000*		*10,000*		*10,000*
Bench-scale Study		*3,000*		*3,000*		*3,000*
Mobilization		*2,000*		*2,000*		*2,000*
Permitting and Regulatory Requirements[b]	5,000		5,000		5,000	
Capital Equipment[b]	291,500		291,500		291,500	
Extraction Wells, Pumps, and Piping		*138,000*		*138,000*		*138,000*
Treatment Equipment		*150,000*		*150,000*		*150,000*
Storage Tank Purchase		*3,500*		*3,500*		*3,500*
Startup[b]	1,000		1,000		1,000	
Demobilization[b]	(20,000)		(20,000)		(20,000)	
Decontamination/Reconstruction		*10,000*		*10,000*		*10,000*
Salvage Value		*(30,000)*		*(30,000)*		*(30,000)*
Variable Costs						
Labor[c]	28,000		60,000		100,000	
Operations Staff		*8,000*		*40,000*		*80,000*
Automated Monitoring		*20,000*		*20,000*		*20,000*
Consumables and Supplies[c]	11,900		52,100		102,500	
PPE		*6,000*		*30,000*		*60,000*
Disposable Drums for PPE		*100*		*200*		*400*
Filter Flow 1000		*4,000*		*20,100*		*40,300*
Storage Tank		*800*		*800*		*800*
Miscellaneous		*1,000*		*1,000*		*1,000*
Utilities[c]	800		3,800		7,600	
Water		*300*		*1,300*		*2,600*
Electricity		*500*		*2,500*		*5,000*
Effluent Treatment and Disposal[c]	0		0		0	
Residual and Waste Shipping and Handling[c]	24,700		123,500		247,000	
Solids Disposal		*22,500*		*112,500*		*225,000*
PPE Disposal		*2,200*		*11,000*		*22,000*
Analytical Services[c]	24,000		120,000		240,000	
Maintenance and Modifications[c]	5,000		25,000		75,000	
Total Fixed Costs[b]	$292,500		$292,500		$292,500	
Total Variable Costs[c]	$94,400		$384,400		$772,100	
Total Cost Per Gallon Treated	$0.007		$0.002		$0.002	

Notes:

[a] Costs are based on September 1993 dollars and rounded to the nearest $100.
[b] Fixed costs for demonstration tests would decrease as the water volume and time formulae were optimized.
[c] Variable costs

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

- The site is located near an urban area within 500 miles (805 kilometers) of Houston, Texas, the home office of FFT.
- Water contamination at the site resulted from mining or nuclear operations.
- Contaminated water is located in an aquifer within 150 feet (45.7 meters) of the surface.
- Access roads exist at the site.
- Utility lines, such as electricity and telephone lines, exist on site.
- The water to be treated contains 5,000 ppm radionuclides.
- The treatment goal for the site will be to reduce the contaminant level to 2,000 ppm.
- Water will be treated at a rate of 100 gpm (378.5 Lpm) and will be stored at the site.
- Filter cake will be treated and then disposed of off site; wash water will be stored and then disposed of off site.
- FFT will sell the CPFM treatment system to the site owner.
- One treated water sample and one untreated water sample will be collected daily to monitor system performance.
- One part-time operator will be required to operate the equipment, collect all required samples, and conduct equipment maintenance and minor repairs. FFT will train this operator to operate its equipment as part of the purchase price.
- Labor costs associated with major equipment repairs or replacement are not included.

4.2 Cost Categories

Cost data associated with the CPFM 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) labor; (6) consumables and supplies; (7) utilities; (8) effluent treatment and disposal; (9) residual and waste shipping and handling; (10) analytical services; (11) maintenance and modifications; and (12) demobilization. Costs associated with each category are presented in the sections that follow. 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 CPFM system are identified as CPFM direct costs; all costs associated with the hypothetical remediation and auxiliary equipment are identified as groundwater remediation costs.

4.2.1 Site Preparation Costs

Site preparation costs include administration, bench-scale testing, mobilization, and miscellaneous utility connection costs. This analysis assumes a total of about 2,000 square feet (185.8 square meters) will be needed to accommodate the CPFM unit, 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 mobile unit weight of 24,000 to 30,000 pounds (10,839 to 13,605 kilograms) 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 CPFM system for the site, as well as the amounts of chemicals and reagents needed for optimal performance. FFT estimates the cost of this study to be about $3,000 for tests and a site visit. Administrative costs, such as legal searches and access rights, are estimated to be $10,000.

Mobilization involves transporting the entire CPFM treatment system from Houston, Texas, delivering all rental equipment to the site, and connecting utilities to the trailer. For this analysis, the site is located within 500 miles (805 kilometers) of Houston, Texas, to minimize transportation costs. In addition, equipment vendors are assumed to be situated nearby the site. The total estimated mobilization cost will be about $2,000.

For each case, total site preparation costs are estimated to be $15,000.

4.2.2 Permitting and Regulatory Requirements

Permitting and regulatory costs will vary, depending on whether treatment is performed at a Superfund or a RCRA corrective action site 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 sites 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.

4.2.3 Capital Equipment

Capital equipment costs include installing extraction wells; purchasing and installing the complete CPFM treatment system including a portable air compressor; and purchasing a wastewater holding tank. Extraction wells were included in the scenario because they are almost always required in pump and treat groundwater remediation systems.

Extraction well installation costs associated with a groundwater remediation project include installing the well and pump and connecting the pumps, piping, and valves from the wells to the CPFM system. This analysis assumes that four 150-foot (45.7 meter) extraction wells will be required to maintain the 100 gpm (378 Lpm) 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.

Pumps, piping, and valve connection costs associated with a groundwater remediation project will depend on the following factors: the number of extraction wells needed, 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 about 200 feet (20.9 meters) from the CPFM system. Four 25-gpm (94.6 Lpm) pumps will be required to maintain a 100-gpm (378 Lpm) flow rate, at a total cost of about $20,000. Piping and valve connection costs are about $60 per foot ($180 per meter), including underground installation. Therefore, total piping costs will be an additional $48,000.

The complete CPFM treatment system includes a 30-foot (9.1 meter) trailer equipped with reaction tanks, a miniclarifier, a filter press, bag filters, transfer pumps, two CPFM units, effluent pH adjustment tank, and electrical and electronic control subsystems. The cost of building a skid-mounted CPFM that treats flow rates of up to 100 gpm (378 Lpm) is approximately $150,000.

A high density polyethylene storage tank should be used to store the treated water for analytical testing prior to off-site discharge or reuse. It is assumed that a 5,000-gallon (18,925 liter) tank will be purchased for a cost of $3,500.

4.2.4 Startup

FFT will provide trained personnel to assemble and begin to operate the CPFM system. FFT personnel are assumed to be trained in health and safety procedures. Therefore, training costs are not incurred as a direct startup cost. If the CPFM system is being purchased rather than leased, the owner/operator will be trained at no cost. This analysis assumes that startup will take about 8 hours to complete and has a total cost of $1,000.

4.2.5 Labor

Labor costs include a part-time technician to operate and maintain the CPFM system. Once the system is functioning, it is assumed to operate continuously at the designed flow rate. One technician will monitor the equipment, make any required chemical adjustments, and conduct routine sampling. Under normal operating conditions, an operator will be required to work only a few hours per week. The system could be automated for an approximate $20,000 capital cost. For long-term projects such as the one analyzed here, it has been assumed that the system would be automated, and that staff costs would be approximately $8,000 per year (one quarter of a $32,000 full time employee).

4.2.6 Consumables and Supplies

Most consumables and supplies used during CPFM operations, including all chemicals for pre- and post-treatment, are included in the price of retaining the CPFM service. The consumables and supplies costs applicable to this analysis include disposable PPE, drums for disposing of used PPE, FF 1000, a water storage tank, and miscellaneous items.

Disposable PPE includes Tyvek coveralls, gloves, booties, and air purifying respirator cartridges. The treatment system operator will wear PPE when required by health and safety plans during system operation. PPE will cost about $25 per day. This analysis assumes the PPE will be needed daily for the duration of the project. Total annual PPE costs are estimated to be about $600.

Three 55-gallon (208 liter), open-head, 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.

FF 1000 is necessary for the operation of the CPFM system. FFT estimates that approximately 23 cubic feet (0.65 cubic meters) of FF 1000 at $175 per cubic foot are needed to operate the 100 gpm (378 Lpm) system for 1 year, for a total cost of $4,000 per year.

One 1,000-gallon (3,785 liter) polyethylene water storage tank, costing $800, will be used for equipment washdown and decontamination rinse waters. Miscellaneous costs of $1,000 were included for the purchase of small parts and other supplies.

4.2.7 Utilities

Utilities used by the CPFM system include water, electricity, and compressed air.

The CPFM treatability system requires about 250 gallons (946 liters) of potable water per week. This water will be used for operation of the CPFM system and decontamination of operators. This analysis estimates water to cost $0.02 per gallon. Total water costs will be about $5 per week, for a total of approximately $300 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. When the project is completed, the remaining wash water will be stored in a tank prior to off-site disposal.

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 about $500 per year. This analysis assumes that electricity costs about $0.07 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 (3,785 liters) of water treated has been calculated.

4.2.8 Effluent Treatment and Disposal

The analysis assumes that the effluent stream will have a pH from 7 to 8.3, and will not contain regulated pollutants exceeding EPA drinking water standards; hence, no further treatment should be needed. Final pH adjustment of effluent, if required, is included in miscellaneous consumables costs. Local regulations may require discharge to a publicly owned treatment works (POTW), which may result in additional charges to the CPFM system operator. For this analysis, effluent treatment and disposal costs are estimated at $0 per year.

4.2.9 Residual Waste Shipping and Handling

This analysis assumes that approximately 23 cubic feet (0.65 cubic meters) per year of dewatered, spent FF 1000 would be generated. In addition, 350 cubic feet (9.9 cubic meters) per year of filter cake would be generated from the filter press. Disposal of the FF 1000 typically involves mixing dewatered FF 1000 and filter press filter cake solids, followed by stabilization with a powdered commercial chemical (ChemSorb-500) and storing the stabilized material in 55-gallon (208 liter) drums. During the SITE demonstration, these drums were stored at an EPA- and DOE-approved storage facility. Assuming disposal costs similar to those observed at RFETS, total disposal costs for 47 drums of stabilized filter cake are estimated to be about $22,500 per year.

Drummed PPE will be screened for radioactivity and disposed of in accordance with state and federal requirements. This analysis assumes that about three drums per year must be disposed of. Based on observations at RFETS, this analysis estimates a cost of about $2,200 for this disposal. For remediation projects, there would be no wastewater drummed because the wastewater would be treated to remove the contaminants and discharged to surface water.

Decontamination water generated during system operation is returned to the CPFM system for treatment.

4.2.10 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 and metal concentrations each week, along with trip blank, duplicate, and matrix spike/matrix spike duplicate samples. Monthly laboratory analyses will cost about $1,250; 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 $24,000 per year.

4.2.11 Maintenance and Modifications

Annual repair and maintenance costs apply to all equipment involved in every aspect of groundwater remediation with the CPFM system. No modification costs are assumed to be incurred. Based on information from FFT and its fabrication subcontractor, total annual maintenance costs are assumed to be about $5,000 a year for the first 5 years, and $10,000 a year for every year after that.

4.2.12 Demobilization

Site demobilization costs include berm cleaning and equipment decontamination, plus site restoration and checkout. Site restoration activities include regrading or filling excavation areas, and demolition and disposal of all fencing. Total demobilization costs are estimated to be about $10,000.

The CPFM system has a life span of approximately 15 years. Therefore, this analysis also assumes that there will be a salvage value for the equipment of approximately 20 percent of the original price, or $30,000.

Section 5
Treatment Effectiveness

In January 1991, DOE, CDH, now CDPHE, and EPA signed an interagency agreement (IAG) to govern environmental restoration activities at RFETS. Under the terms of the IAG, DOE has agreed to conduct a number of treatability studies at RFETS. Once DOE and the EPA agreed that RFETS would be an appropriate site for technology demonstrations, a memorandum of understanding between DOE and EPA Headquarters was signed. After signing the memorandum of understanding, a cooperative effort involving DOE, EPA, CDPHE, and FFT allowed the CPFM technology to be demonstrated at RFETS. This section briefly describes the demonstration activities and results.

5.1 Background

RFETS is located in northern Jefferson County, Colorado, approximately 16 miles (25.7 kilometers) northwest of Denver. 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, waste management, and to allow private industry to use portions of the site.

In the past, waste generated by RFETS included hazardous, radioactive, and mixed hazardous and radioactive wastes. Like many industries at that time, RFETS used accepted methods of disposal for these wastes, such as SEPs, that do not meet today's disposal standards.

Contaminated liquids stored in SEPs at RFETS have leaked to groundwater beneath the ponds. This groundwater is collected by a intercepter trench system downgradient of the SEPs and pumped from the ITPH to three open-top 500,000-gallon (1,892,500 liter) tanks. Water from these tanks was used as the source of contaminated water for the demonstration. Treated effluent from the demonstration was routed back to a second 500,000-gallon (1,892,500 liter) tank. The contaminated groundwater contained low levels of radioactivity with a concentration of about 100 pCi/L of gross alpha and 100 μg/L of uranium.

5.2 Review of SITE Demonstration

The SITE demonstration was divided into three phases: (1) site preparation; (2) technology demonstration; and (3) site demobilization. These activities are reviewed in the following paragraphs, including variations from the work plan, and the CPFM system performance during the technology demonstration phase is assessed.

5.2.1 Site Preparation

A total of approximately 2,000 square feet (185.8 square meters) of relatively flat ground was used for the CPFM trailer unit and support facilities, such as generators, air compressors, clean water storage tank, office and field laboratory trailer, and parking area. Site preparation required 1 day to complete. Most of the equipment required to operate the CPFM system is included as part of the trailer-mounted unit. Site preparation was minimal because generators and portable compressors were used. Toilet facilities were available near the demonstration area. Drinking water was transported to the site in portable coolers. Telephone service was provided by cellular phone. Support items required for the demonstration included the following:

- One 1,000-gallon (3,785 liter) closed-top polyethylene tank used to contain potable water

- One 50-gallon (189.2 liter) tank containing concentrated sulfuric acid used to acidify system effluent

- Two gas-powered, portable generators used to power the CPFM system and office trailer

- One gas-powered, portable air compressor used to power compressed air pumps on the CPFM system trailer

- A forklift with operator for moving drummed wastes

- Sampling equipment for collecting aqueous media and solids samples

- Analytical equipment for measuring field parameters at the demonstration site

- Health and safety-related equipment, such as a first-aid kit and protective coveralls, latex or similar inner gloves, nitrile outer gloves, steel-toe boots and disposable overboots, and safety glasses

- A vehicle for transporting personnel and equipment to the site

5.2.2 Technology Demonstration

Approximately 10,000 gallons (37,850 liters) of contaminated groundwater were treated by the CPFM system over a 3-week period. Prior to the tests, a half-day system check using clean water was conducted to check the CPFM system for leaks.

The experiments were divided into three tests: test one (runs 1 through 3) was designed to evaluate the technology at constant operating conditions; test two (run 4) evaluated the system using pretreatment of influent with sodium sulfide; test three (run 5) was designed to determine the saturation rate of the filter media (breakthrough). Only one operating parameter, pretreatment condition, and one equipment set-up parameter, bed configuration, were varied during the demonstration. Other process parameters, such as operating pressure and flow rate, were held constant. Runs 1 through 3 were conducted at a flow rate of 5 gpm (18.9 Lpm), with no pretreatment, to assess the CPFM system's ability to consistently produce treated water meeting effluent goals. Run 4 was conducted at the same operating conditions but using sodium sulfide pretreatment. This run provided data indicating the effect of pretreatment on effluent quality. The CPFM system was operated for 4 hours during each of the first four runs. In addition, to induce high removal efficiencies within the system, all four runs were conducted using two colloid filter units operated in series with three filter packs per colloid unit. The filter packs were changed for each run. Run 5 evaluated the time required to reach breakthrough in the filter packs. Breakthrough was defined as the point at which effluent goals for radionuclides were no longer achieved. Run 5 was conducted using two parallel colloid filter units with one filter pack in each and a flow rate of 2.5 gpm (9.5 liters) per colloid filter unit. This run was conducted for 15 hours.

During the demonstration, samples were collected of untreated influent, pretreated water after passing through the miniclarifier and bag filters, and treated effluent that had passed through the filter packs. Samples were analyzed to determine the technology's effectiveness. Pretreatment adjustment of the pH was not required at RFETS because the influent water was within the optimum pH range (8 to 9) for the technology. The pH of the effluent water was monitored in the effluent pH adjustment tank and treated to reduce the pH to its original level.

5.2.3 Operational and Sampling Problems and Variations from the Work Plan

The SITE team, consisting of EPA's contractors and EG&G, DOE's operating contractor at RFETS, experienced a few operational and sampling 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. Problems encountered during the demonstration and their solutions are described below.

- The five runs of the demonstration were scheduled to be completed in 1 week. Due to problems with pump sizing, a second, larger, pump had to be ordered after the leak test at the end of the first week of the demonstration. The pump did not arrive until Monday of the next week. Therefore, only four tests were conducted during the second week of the demonstration; the last test, the breakthrough run, was conducted during the third week of the demonstration. Decontamination was completed in the remaining days of the third week. Therefore, the demonstration was completed in the allotted 3 weeks.

- The work plan stated that power to operate the CPFM system and support facilities during the demonstration were to be provided by EG&G. However, due to power grid limitations at RFETS, power for the demonstra-tion was provided by portable generators. This change did not affect CPFM system performance.

- During the field audit, the method proposed for compositing the spent filter cake was discussed and revised. The revised sampling plan called for each pack to be opened and five scoops, one from each quadrant and the center, removed. After all six packs had been sampled using this procedure, the resulting solid was homogenized in a stainless-steel bowl and samples collected for the required parameters.

- At the request of DOE, to minimize volume the spent filter cake was not stabilized with ChemSorb 500 as was called for in the work plan. After sampling, the spent filter cake and the filter packs were deposited in a lined 55-gallon drum. Therefore, no samples of stabilized filter cake were collected.

- During the demonstration, the bag filter was replaced for each run. However, the filters did not contain enough material to sample. In addition, the miniclarifier sludge was sampled only at the end of the demonstration. This sludge was not stabilized before sampling.

- During run 5 it was discovered that sample port L4 was actually collecting a combination of the flow through both packs, rather than through only a single pack. When this was noticed at time T8 (720 minutes into the run) an additional sample was collected of water that passed through only the single filter pack. This sample was called L4a.

- Duplicate sampling planned for run 4 was not conducted.

5.2.4 Site Demobilization

Site demobilization activities began after the demonstration was completed. Demobilization activities included draining the 1,000-gallon (3,785 liter) potable water tank and disconnecting the portable generators and compressor.

Decontamination was necessary for the trailer-mounted CPFM system. The CPFM system was decontaminated with high-pressure steam at the RFETS decontamination pad. The RFETS decontamination pad is equipped with a system to treat decontamination water. RFETS also disposed of all PPE that had been previously screened for contamination. Spent filter cake is being stored at RFETS pending a decision on its final disposal off site.

5.3 Demonstration Methodology

The technology demonstration had one primary objective: to assess the CPFM system's ability to remove uranium and gross alpha contamination to levels below CWQCC standards. Secondary objectives for the technology demonstration were as follows:

- Document the operating conditions and identify operational needs, such as utility and labor requirements, for the treatment system

- Estimate costs associated with operation of the CPFM system

- Estimate costs associated with operation of the CPFM system.

- Assess the technology's ability to remove other radionuclides (plutonium, americium, and radium)

- Evaluate the disposal options for prefiltered solids (miniclarifier and bag filter solids) and filter cake from the colloid filter unit

Secondary objectives provide information that is useful, but not critical, to the evaluation of the system.

The data required to achieve the primary objectives are called the critical parameters. For this project, the critical parameters are uranium and gross alpha concentrations in water treated by the CPFM system.

The data required to achieve the secondary objectives are called the noncritical parameters. The noncritical parameters for this project are:

- Concentrations and measurements in the influent, intermediate, and effluent of:

- plutonium, americium, and radium
- anions/cations
- metals analyzed by inductively coupled plasma (ICP)
- total suspended and total dissolved solids (TSS and TDS)
- pH, temperature, and electrical conductivity
- total organic carbon (TOC)

- Individual concentrations in the prefiltered solids and filter care for:

  - uranium and gross alpha
  - plutonium, americium, and radium
  - ICP metals

- Individual measurements of the prefiltered solids and filter cake prior to stabilization for:

  - total mass
  - moisture content
  - bulk density

- Measurement of free liquids in prefiltered solids and filter cake solids (as measured by the paint filter liquids test PFLT).

- Flow rate and pumping periods of the:

  - influent
  - sulfuric acid stream
  - sodium sulfide stream

- Pressure loss across the colloid filter unit as a function of operating time (as measured by the differential pressure across each filter bed)

- Electricity usage

5.3.1 Testing Approach

To evaluate the critical parameters in each of the first four runs, the objective of sampling was to determine the concentrations of uranium and gross alpha at three locations (sample ports) in the system: influent (L1), intermediate precolloid filter units (L2), and effluent (L3) (Figure 5-1). The ability to assess the relative difference at each port depends on the precision of measuring concentrations at each location. The precision of these measurements depends on the magnitude of the errors (variability) introduced by system fluctuations and sampling and analytical variations. The goal of the sampling scheme for this type of system is to minimize these errors so that the difference in the concentrations of uranium and gross alpha at each port reflects system performance only.

However, it is rarely possible, and typically cost prohibitive, to eliminate system variability and sampling error completely. Some modifications of sampling procedures and design can reduce the inherent error and allow for the statistical quantification of the remaining data variation. For example, collection of composite samples over the duration of a run instead of a point (grab) sample from a portion of the system that is potentially subject to fluctuations may reduce variability in the uranium and gross alpha concentrations due to inherent system changes and point sampling. For this reason, grab samples taken in the middle of each run were compared with composite samples consisting of several small samples collected throughout the run. Comparison of data for grab samples to data for associated composite samples allowed for an evaluation of the potential variation introduced by a limited "snap shot" type of sampling. This information was used in determining whether grab sampling will be adequate for sampling a full-scale CPFM system in the future. In addition, analytical precision of radionuclide analytical procedures has historically been a problem (especially at low concentrations). Comparison of sample results with laboratory replicate results was used to identify the variability associated with the analytical procedures. A sampling scheme for the critical parameters uranium and gross alpha was designed to reduce introduction of sampling error and to quantitatively evaluate variation due to each of the sources discussed in this section. The unbalanced hierarchical design used during the demonstration is shown in Figure 5-2.

Analytical and measurement data were also collected during the demonstration to address the secondary objectives of the project. These data were not collected using hierarchical sampling schemes. Measurement locations are also shown on Figure 5-1.

5.3.2 Sampling Analysis and Measurement Procedures

Water samples for the critical parameters were collected from the CPFM treatment system at the locations shown in Figure 5-1 using the sampling protocol described in the previous section. Water samples were also collected for the noncritical chemical parameters including metals, plutonium, americium, and

radium concentrations. In addition, solid samples of the spent filter cake removed from the filter packs were collected. Samples for TCLP analysis were also collected from the spent filter cake. These samples were analyzed for the critical and noncritical parameters using the methods listed in Table 5-1.

In addition to sampling and analysis for chemical parameters, the operating conditions of the CPFM system were evaluated using the measurement data collected at several locations shown in Figure 5-1.

For runs 1 through 4 electrical conductivity, temperature, and pH were measured at measurement locations M1 (influent), M4 (intermediate), and M9 (effluent). For run 5 these parameters were measured at measurement locations M1, M4, M18 (effluent from filter pack 1) and M19 (effluent from filter pack 2). Flow rate was measured at locations M1, M4 and M9 for runs 1 through 4 and at locations M1, M4, M18, and M19 for run 5. The differential pressure across the colloid filter packs was measured at locations M5 (first set of filter packs) and M6 (second set of filter packs) for runs 1 through 4 and at locations M7 (first filter pack) and M8 (second filter pack) for run 5. Mass of solid materials was measured at locations M10 through M15 (the individual filter packs), for runs 1 through 4 and at M16 (filter pack 1) and M17 (filter pack 2) for run 5. Power consumption was measured by the amount of gasoline used by the portable generators. The amount of sodium sulfide used during run 4 was measured at location M26 and the amount of sulfuric acid added during runs 1 through 5 was measured at M21.

5.4 Review of Treatment Results

This section summarizes the results of both critical and noncritical parameters for the CPFM system, and evaluates the technology's effectiveness in treating groundwater containing uranium and gross alpha contamination.

5.4.1 Summary of Results for Critical Parameters

Analytical results for uranium and gross alpha from runs 1 through 4 are presented in Table 5-2. Analytical results for run 5 are presented in Table 5-3. Runs 1 through 3 were designed to collect sufficient data to conduct a statistical evaluation of CPFM system capabilities. Therefore, composite, grab, and replicate samples were collected and analyzed. Run 4 was conducted to evaluate the effect of chemical pretreatment on system efficiency.

Assessment of data quality for the critical parameters uranium and gross alpha included evaluation of laboratory method blanks, matrix spike and matrix spike duplicate recoveries, and analytical/field duplicates. No laboratory contamination was indicated by method blank data. Uranium matrix spike recoveries were all within the acceptable range of 80 to 120 percent. However, three out of 20 matrix spike recoveries for gross alpha were outside of these control limits. Duplicate uranium analyses were all well within $\pm$ 20 percent and yield a correlation coefficient (r^2) value from linear regression of 0.99, indicating that reproducibility of uranium analyses is excellent. However, 12 out of 20 duplicate gross alpha analyses exceeded $\pm$ 20 percent and yield an r^2 value from linear regression of 0.15, indicating poor reproducibility of gross alpha data. Therefore, only uranium analyses are considered reliable for assessing the performance of the CPFM system; gross alpha data should be considered with reasonable caution.

Figures 5-3 and 5-4 show uranium and gross alpha concentrations for influent, intermediate, and effluent in runs 1 through 4. Figures 5-5 and 5-6 show gross alpha and uranium concentrations for effluent for the breakthrough assessment in run 5. (Where replicate composites exist, an average value was used.) Where possible, only composite data were used to construct these figures.

Composite gross alpha and uranium concentrations for influent for runs 1 through 4 varied from 65 to 110 pCi/L for gross alpha and 98 to 103 μg/L for uranium. Analytical results for composite samples of intermediate waters from these three runs show a range of 36 to 84 pCi/L for gross alpha and a range of 60 to 94 μg/L for uranium. Analytical results for composite effluent water from runs 1 through 4 show gross alpha values that range from a low of 3.7 pCi/L for run 4 to a high of 50 pCi/L for run 2. Similarly, analytical results for uranium ranged from a low of 5.1 μg/L for run 4 to a high of 38 μg/L for run 2.

Removal efficiencies for runs 1 through 4 were calculated using composite data and are shown in Table 5-4. (Where replicate composites exit, an average value was used.) Overall removal efficiencies for uranium during runs 1 through 3 ranged from a low of 58.4 percent to a high of 90.6 percent. Overall removal efficiencies for gross alpha for runs 1 through 3 ranged

Table 5-1. Summary of Analytical Methods for the CPFM SITE Demonstration

Parameter	Sample Type	Method Number	Method Title	Method Type
Total Uranium	Solid and Liquid	Phosphorimetry[h]/ PACE SOP[i]	Direct detection of trace levels of uranium by laser-induced kinetic phosphorimetry	Kinetic phosphorimetry
Gross alpha	Solid and Liquid	900.0[d]/PACE SOP[i]	Gross alpha	Alpha and beta gas flow proportional counter
Radium 226	Solid and Liquid	903.1[d]/PACE SOP[i]	Alpha emitting radium isotopes in drinking water	Alpha scintillation counter
Plutonium 239, 240	Solid and Liquid	EPA-600/7-79-081[a]/HEA-0018-01[b]	Plutonium 239, 240	Ion exchange, alpha spectrometry
Americium 241	Solid and Liquid	EPA-600/7-79-081[a]/HEA-0018-01[b]	Americium 241	Ion exchange, alpha spectrometry
Fluoride	Liquid	300.0[f]	Ion chromatography determination: chloride, fluoride, nitrate, nitrite, and sulfate	Ion chromatography
Chloride	Liquid	300.0[f]	Ion chromatography determination: chloride, fluoride, nitrate, nitrite, and sulfate	Ion chromatography
Nitrite/nitrate	Liquid	353.1[f]	Nitrogen, nitrite-nitrate	Colorimetric determination
Sulfate	Liquid	300.0[f]	Ion chromatograph determination: chloride, fluoride, nitrate, nitrite, and sulfate	Ion chromatography
Phosphate	Liquid	365.2[f]	Phosphorous (all forms)	Colorimetric determination
Alkalinity	Liquid	310.1[f]	Alkalinity as carbonate	Titration
Ammonia	Liquid	350.3[f]	Ammonia	Ion selective electrode
ICP Metals	Solid and Liquid	3050[c]/3010[c]/6010[c]	Acid digestion of aqueous samples and extracts for total metals analysis by Inductively Coupled Plasma (ICP) spectroscopy	Digestion/ICP
Mercury	Solid and Liquid	7471 and 7470A[c]	Acid digestion of solid and aqueous samples and Toxicity Characteristic Leaching Procedure (TCLP) leachates for mercury by Cold Vapor Atomic Absorption	Digestion/Cold Vapor AA
Strontium	Solid and Liquid	3050[c]/3010[c]/7780[c]	Acid digestion of solid and aqueous samples and TCLP leachates for strontium by flame atomic absorption (AA)	Digestion/Flame AA

Table 5-1. Summary of Analytical Methods for the CPFM SITE Demonstration (Continued)

Parameter	Sample Type	Method Number	Method Title	Method Type
TCLP	Solid	1311[c]	TCLP	Extraction procedure
pH	Liquid	150.1[f]	pH	Electrochemical
Flow rate	Liquid	NA	NA	Rotameter
Pressure	Liquid	NA	NA	Pressure gauge
Temperature	Liquid	2550[g]	Temperature	Thermocouple
Electrical conductivity	Liquid	2510[g]	Conductivity	Specific conductance
Filter cake mass	Solid	NA	Gravimetric	Gravimetric
Free liquids	Semisolid	9095[c]	Paint Filter Liquids Test (PFLT)	Filtration/volumetric
Moisture content	Solid/semisolid	D2216[e]	Moisture content	Gravimetric
Bulk density	Solid/semisolid	D2937-83[e]	Bulk density	Gravimetric and volumetric
Total suspended solids	Liquid	160.2[f]	Residue, nonfilterable	Gravimetric
Total organic carbon	Liquid	9060[c]	Total Organic Carbon	Gravimetric
Total dissolved solids	Liquid	160.1[f]	Residue, filterable	Gravimetric

Notes:

[a] Acid Dissolution Method for Analysis of Plutonium in Soils. U.S. EPA Environmental Monitoring and Support Laboratory, Las Vegas, Nevada. EPA-600/7-79-081. 1979.

[b] Maximum Sensitivity Procedures for Isolation of Plutonium and Americium in Composited Water Samples, Rocky Flats Plant Health and Safety Laboratories, Golden, Colorado. 1990.

[c] 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. Office of Solid Waste and Emergency Response, U.S. Environmental Protection Agency. 1986.

[d] Prescribed Procedures for Measurement of Radioactivity in Drinking Water. Environmental Monitoring and Support Laboratory, U.S. Environmental Protection Agency. EPA-600/4-80-032. 1980.

[e] American Society for Testing and Materials (ASTM). 1980, 1983.

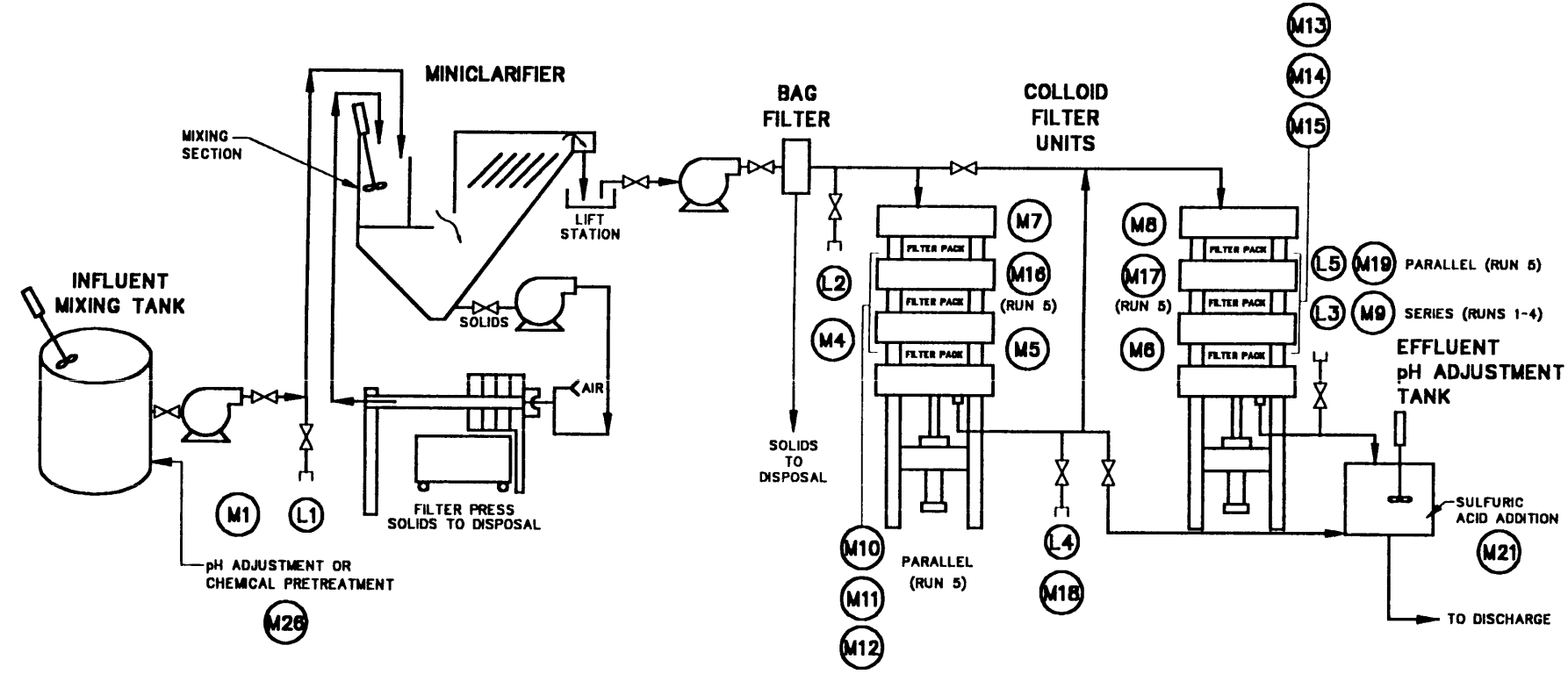
[f] Methods for Chemical Analysis of Water and Wastes. EPA-600/4-79-020, Revised March 1983, Environmental Monitoring and Support Laboratory, Cincinnati, Ohio, U.S. Environmental Protection Agency, 1983, and subsequent EPA-600/4 Technical Additions.

[g] Standard Methods for the Examination of Water and Wastewater, 18th Edition. APHA, AWWA, and WEF, 1992.

[h] Direct Detection of Trace Levels of Uranium by Laser-Induced Kinetic Phosphorimetry, *Analytical Chemistry*, Volume 64, No. 13, pp. 1413-1418. July 1, 1992.

[i] See Appendix A for the appropriate PACE, Inc. laboratory standard operating procedure (SOP).

NA Not applicable



NOTE: COLLOID FILTER UNITS OPERATED FOR RUNS 1 THROUGH 4 IN SERIES WITH THREE PACKS PER UNIT. COLLOID FILTER UNITS OPERATED IN PARALLEL FOR RUN 5 WITH ONE PACK PER UNIT.

LEGEND

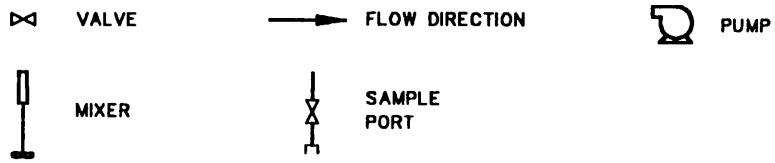


Figure 5-1. CPFM Treatment System Sampling Locations

Table 5-2. Analytical Results for Uranium and Gross Alpha for Runs 1 through 4 of the CPFM SITE Demonstration

Parameter	Run Number	Influent		Intermediate		Effluent		CWQCC[a] Standards
		Composite/ Duplicate	Grab/ Duplicate	Composite/ Duplicate	Grab/ Duplicate	Composite/ Duplicate	Grab/ Duplicate	
Uranium (μg/L)	1	102/104	102	60/60	62	9.5/9.6	3.4	7
Gross Alpha (pCi/L)	1	98/99	94	40/NA	77	13/NA	9.4	7
Uranium (μg/L)	2	89/94	102	92	98/94	38/38	43	7
Gross Alpha (pCi/L)	2	88/62	110	84	68/110	53/47	24	7
Uranium (μg/L)	3	102	96/96	94	94/92	23/25	7.9/8.3	7
Gross Alpha (pCi/L)	3	110	100/110	36	110/57	27/NA	0/25	7
Uranium (μg/L)	4	98	104	64	55	5.1	19	7
Gross Alpha (pCi/L)	4	65	100	71	50	3.7	11	7

Notes:

[a] Colorado Water Quality Control Commmission

[b] CWQCC standard for uranium converted from pCi/L to μg/L using the conversion factor of 0.68 pCi/μg.

NA Not analyzed
μg/L Micrograms per liter
pCi/L PicoCuries per liter

Table 5-3. Analytical Results for Uranium and Gross Alpha for Run 5 of the CPFM SITE Demonstration

Sample Type/ Location	Influent			Intermediate		
	Grab/ Duplicate	Grab	Composite/ Duplicate	Grab	Grab/ Duplicate	Composite/ Duplicate
Time from start of run (minutes)	120	780	120-900	120	780	120-900
Uranium (μg/L)	104/102	100	102/102	87	106/102	96/98
Gross Alpha (pCi/L)	87/77	150	75/76	46	86/110	68/110

Sample Type/Location	Effluent											
	L4	L5	L4	L5	L4/Dup	L5	L4	L5/Dup	L4/Dup	L5	L4	L5/Dup
Time (minutes)	120		240		360		480		540		600	
Uranium (μg/L)	70	75	83	85	94/87	89	92	94	79/81	94	81	98/94
Gross Alpha (pCi/L)	52	79	91	91	87/96	60	--	91	110/40	93	85	84/72

Sample Type/Location	Effluent													
	L4/Dup	L5	L4	L4a	L5/Dup	L4/Dup	L4a	L5/Dup	L4	L4a	L5	L4	L4a	L5
Time (minutes)	660			720			780			840			900	
Uranium (μg/L)	81/94	98/94	77	77	83/77	85	77	85/85	92	70	96	94	83	94
Gross Alpha (pCi/L)	110/86	74	58	81	75/76	81	61	61/55	81	45	100	64	47	110

Notes:

μg/L Micrograms per liter
pCi/L PicoCuries per liter

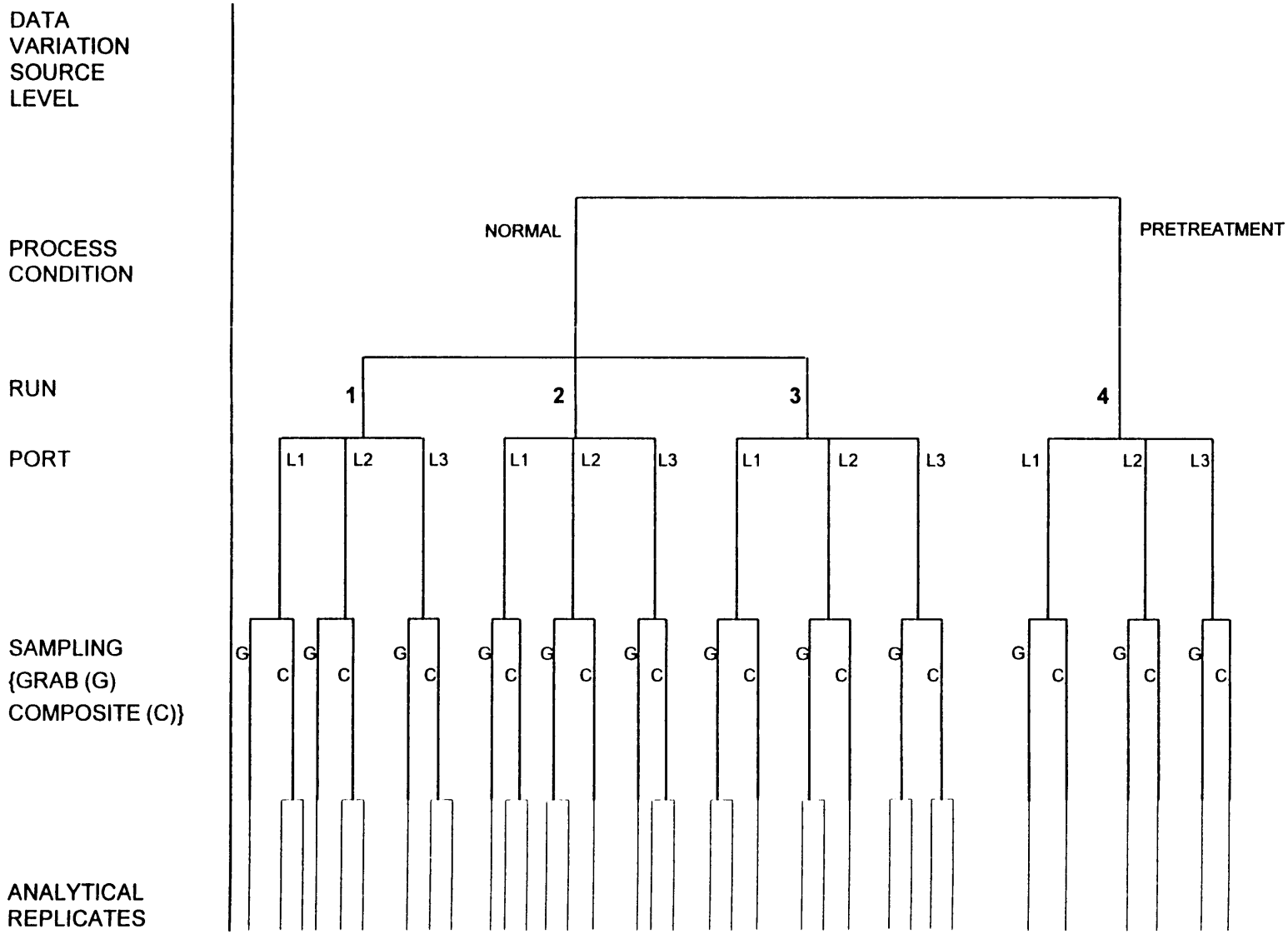


Figure 5-2. Sampling Design for Critical Parameters for Runs 1 through 4

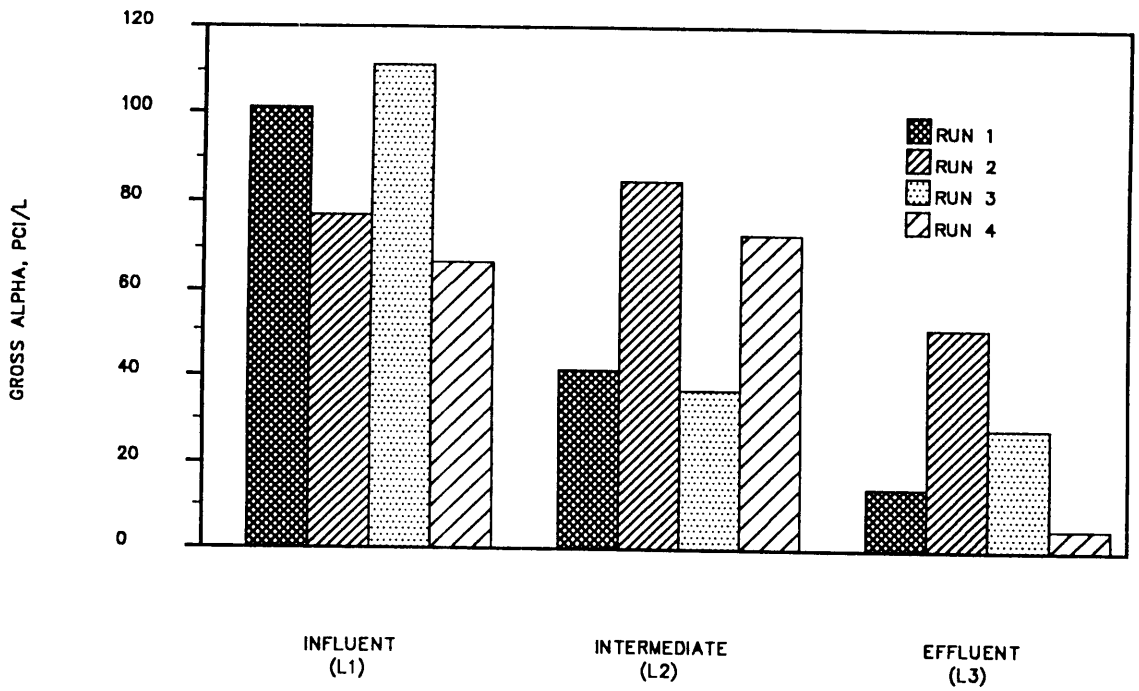


Figure 5-3. Gross Alpha Concentrations for Runs 1 through 4

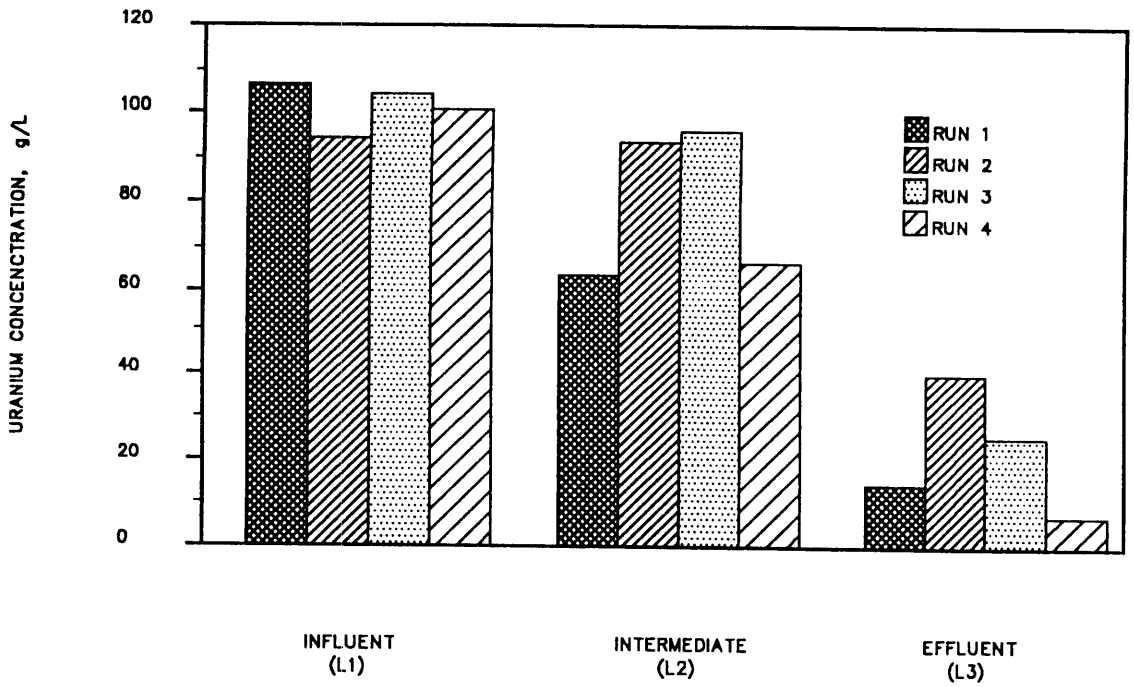
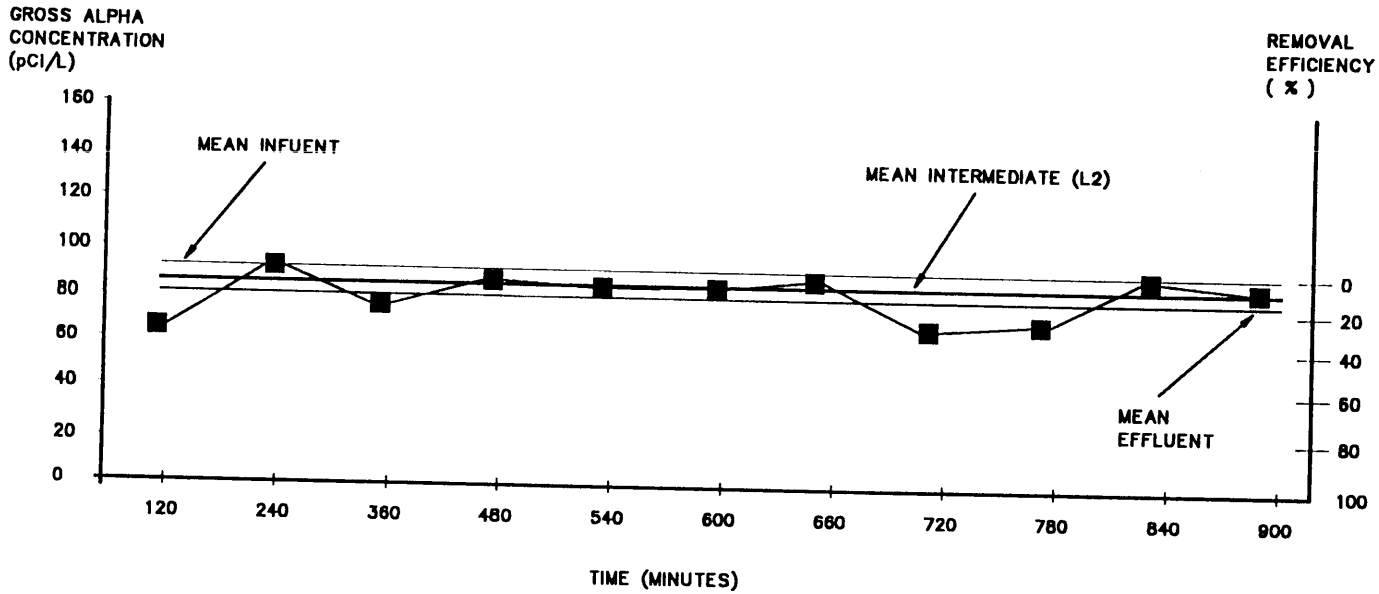
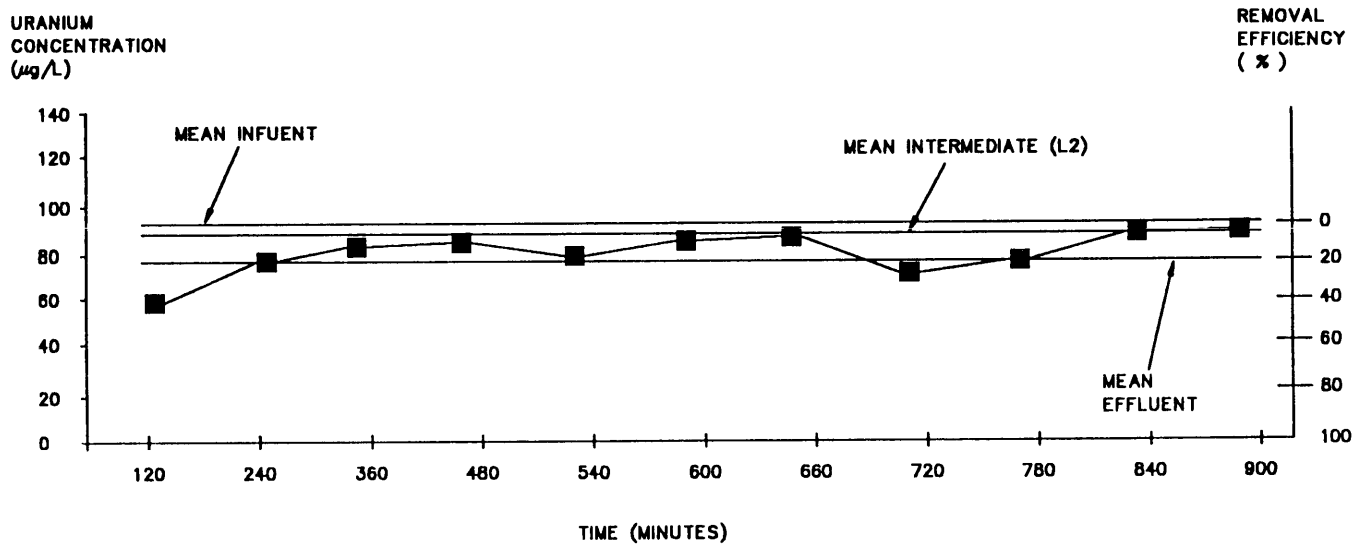


Figure 5-4. Uranium Concentrations for Runs 1 through 4



NOTE: SOLID SQUARES CORRESPOND TO CONCENTRATIONS AND REMOVAL EFFICIENCIES

Figure 5-5. Gross Alpha Concentrations for Run 5 Effluent



NOTE: SOLID SQUARES CORRESPOND TO CONCENTRATIONS AND REMOVAL EFFICIENCIES

Figure 5-6. Uranium Concentrations for Run 5 Effluent

Table 5-4. Removal Efficiency Results for Runs 1 Through 4 for the CPFM SITE Demonstration

Parameter	Run Number	Influent	Intermediate	Effluent	Miniclarifier and Bag Filter Removal Efficiency (percent)[b]	Colloid Filter Unit Removal Efficiency (percent)[c]	Overall Removal Efficiency (percent)[d]	CWQCC Standards[e]
Uranium (μg/L)		103	60	9.6	41.7	84.0	90.6	7
Gross Alpha (pCi/L)	1	98.5	40	13	59.4	67.5	86.8	7
Uranium (μg/L)		91.5	92	38	-0.5	58.6	58.4	7
Gross Alpha (pCi/L)	2	75	84	50	-12.0	40.5	33.3	7
Uranium (μg/L)		102	94	24	7.8	74.5	76.5	7
Gross Alpha (pCi/L)	3	110	36	27	72.5	25.0	75.5	7
Uranium (μg/L)		98	64	5.1	34.7	92	94.8	7
Gross Alpha (pCi/L)	4	65	71	3.7	-9.2	94.8	94.3	7

Notes:

[a] Composite values from Table 5-2 used for all; average taken where applicable

[b] Miniclarifier and bag filter removal efficiency = $\frac{[\text{Influent}] - [\text{Intermediate}]}{[\text{Influent}]} \times 100$

[c] Colloid filter unit removal efficiency = $\frac{[\text{Intermediate}] - [\text{Effluent}]}{[\text{Intermediate}]} \times 100$

[d] Overall removal efficiency = $\frac{[\text{Influent}] - [\text{Effluent}]}{[\text{Influent}]} \times 100$

Where: [ ] equals the concentration of the individual parameters

[e] CWQCC = Colorado Water Quality Control Commission

between 33.3 and 86.8 percent. As stated above, only uranium analyses are considered reliable for assessing the performance of the CPFM system; gross alpha data should be considered with caution. Overall removal efficiencies for run 4 were slightly better than the best of the initial three runs with 94.8 percent removal for uranium and 94.3 percent removal for gross alpha. In addition, only in run 4 were the CWQCC standards met for composite samples. However, this result is based on a single composite rather than a single plus duplicate composite sample.

Although removal is largely attributable to the colloid filter pack, significant removal of uranium occurred in runs 1 and 4 before influent water reached to the colloid filter unit (Table 5-4). Significant precolloid filter removal of gross alpha is also indicated for runs 1 and 3. However, bag filters present between influent and effluent sampling posts did not collect enough material for sampling during any of the runs. The three runs conducted to evaluate the consistency of the CPFM system's ability to remove radionuclide and heavy metal contaminants from water indicate that removal efficiencies are somewhat variable at constant operating conditions. This variability could not be directly related to the operational parameters and so remains unexplained by the demonstration. In addition, a comparison of composite and grab sample analytical results indicates that the composite samples provide a more accurate evaluation of the CPFM system's performance.

The results from run 5 presented in Table 5-3 and shown in Figures 5-5 and 5-6 indicate minimal removal of uranium and gross alpha. This data can be interpreted as showing that breakthrough using a single colloid filter unit occurred prior to the first sampling time at 120 minutes or that the single pack configuration was not capable of removing significant amounts of contamination. Neither result was expected based on the information initially provided by FFT. On average, only a slight reduction in the influent uranium and gross alpha concentrations was observed in run 5. In addition, data for this run are erratic, indicating that performance of the system during discrete time intervals may be unpredictable. In addition, the results indicate that single pack removal efficiencies are considerably less than the series of six packs used in runs 1 through 4. Reduction in removal efficiencies may be due to a variety of factors such as channeling through a single pack, or insufficient residence time within the pack. However, this demonstration was not designed to evaluate such factors.

5.4.2 Summary of Results for Noncritical Parameters

As discussed in previous sections, several noncritical parameters were evaluated during and after the demonstration. The results of these evaluations are discussed below in the order they were presented in Section 5.3.

Results from analysis of composite samples for plutonium, americium, radium, anions, cations, metals, TSS, TDS, pH, temperature, TOC, and electrical conductivity are presented in Tables 5-5 through 5-9. These results show that the radionuclides plutonium, radium, and americium were present at concentrations at or below the detection limit in the influent. Therefore, the ability of the CPFM system to remove them could not be evaluated. Although it was known that these elements were present in the influent at levels near the detection limit of 0.01 pCi/L, assessment of their removal by the CPFM system was retained as a secondary objective of the demonstration because the discharge limit for these elements is 0.05 pCi/L. In addition, several heavy metals that may be removed by the CPFM system were present only at or below the detection limit. Therefore, the ability of the CPFM system to remove them from water could not be evaluated. Most other metals and anions in water showed slight decreases in concentration following treatment by the CPFM system. Aluminum, barium, and carbonate (measured as alkalinity) showed increased concentrations in the effluent relative to the influent. However, these are three of the major components of FF 1000 and so may be expected in the effluent.

The TDS content remained approximately constant from influent to effluent. However, TSS content increased from approximately 10 mg/L in influent to approximately 100 mg/L for effluent. The reason for this increase was not determined. The pH also increased from about 8 in the influent to approximately 11 in the effluent (prior to treatment before discharge). The temperature of water does not appear to systematically increase or decrease from influent to intermediate to effluent. TOC decreased from influent to intermediate to effluent for all runs except run 1. Electrical conductivity was measured by a hand-held probe in the field. However, readings were found to be erratic and did not correlate with the TDS measurements received from laboratory analysis. The electrical conductivity readings are presented in Tables 5-10 through 5-14.

Table 5-5. Analytical Results for Noncritical Parameters from Run 1 of the CPFM SITE Demonstration

Parameter[a]	Influent	Intermediate	Effluent
	Composite	Composite	Composite
Aluminum (μg/L)	38.4	82.0	54.1
Barium (μg/L)	106	85.4	214
Boron (μg/L)	120	69.8	81.2
Calcium (mg/L)	165	99.1	87
Chromium (μg/L)	5.8	6.0	5.4
Copper (μg/L)	3.9	3.4	3.0 U
Iron (μg/L)	41.9	172	24.0
Magnesium (mg/L)	69.7	40.6	10.6
Manganese (μg/L)	2.9	3.6	1.0 U
Potassium (mg/L)	56.4	33.2	26.6
Silicon (μg/L)	1,330	1,800	889
Sodium (mg/L)	364	211	223
Strontium (μg/L)	2,120	1,220	1,090
Zinc (μg/L)	3.8	8.1	2.0 U
Chloride (mg/L)	100	59.3	29.8
Fluoride (mg/L)	0.65	0.44	0.29
Nitrite/Nitrate (mg/L)	473	231	128
Sulfate (mg/L)	142	114	22.7
Alkalinity (mg/L)	1.0 L	1.0 L	301
Radium 222 (pCi/L)	0.17	0.44	0.057
Plutonium 239,240 (pCi/L)	0.02	0.02	0.01
Americium 241 (pCi/L)	0.00	0.03	0.01
TDS (mg/L)	2,530	1,460	1,030
TSS (mg/L)	13	8	51
TOC (mg/L)	15.2	4.10	8.90
Temperature (°C)	18.7	19.9	19.8
pH (pH units)	8.1	8.4	11.1

Notes:

[a] The elements antimony, arsenic, beryllium, cadmium, cobalt, lead, molybdenum, nickel, selenium, silver, thallium, and vanadium were analyzed for, but were not detected, in all samples.

U Undetected at value shown
L Less than the sample concentration recorded
μg/L Micrograms per liter
mg/L Milligrams per liter
pCi/L PicoCuries per liter
°C Degrees Celsius

Table 5-6. Analytical Results for Noncritical Parameters from Run 2 of the CPFM SITE Demonstration

Parameter[a]	Influent	Intermediate	Efluent
	Composite	Composite	Composite
Aluminum (μg/L)	29.0 U	41.9 U	163 U
Barium (μg/L)	101	102	140
Boron (μg/L)	116.0	115.0	95.1
Calcium (μg/L)	161,000	153,000	136,000
Chromium (μg/L)	4.8	8.3	4.0
Copper (μg/L)	5.1	3.0 U	3.1
Iron (μg/L)	48.3	98.6	39.6
Magnesium (μg/L)	67,700	64,400	48,900
Manganese (μg/L)	3.9	3.7	2.2
Potassium (μg/L)	54,400	50,600	48,600
Silicon (μg/L)	1,220.0	1,340.0	1,250.0
Sodium (μg/L)	357,000	339,000	354,000
Strontium (μg/L)	2,010	1,910	1,700
Zinc (μg/L)	3.2	4.3	3.8
Chloride (mg/L)	101	93.6	88.0
Fluoride (mg/L)	0.72	0.69	0.53
Nitrite/Nitrate (mg/L)	318	293	297
Sulfate (mg/L)	174	147	115
Alkalinity (mg/L)	1.0 L	1.0 L	9.7
Radium 222 (pCi/L)	0.24	NA	0.37
Plutonium 239,240 (pCi/L)	0.02	0.00	0.01
Americium 241 (pCi/L)	0.09	0.00	0.02
TDS (mg/L)	2,520	2,280	2,060
TSS (mg/L)	14	11	72
TOC (mg/L)	13.9	11.9	9.46
Temperature (°C)	11.2	11.2	11.45
pH (pH units)	8.4	8.2	10.7

Notes:

[a] The elements antimony, arsenic, beryllium, cadmium, cobalt, lead, molybdenum, nickel, selenium, silver, thallium, and vanadium were analyzed for, but were not detected, in all samples.

U Undetected at this value
L Less than the sample concentration recorded
NA Not analyzed
μg/L Micrograms per liter
mg/L Milligrams per liter
pCi/L PioCuries per liter
°C Degrees Celsius

Table 5-7. Analytical Results for Noncritical Paramters from Run 3 of the CPFM SITE Demonstration

Parameter[a]	Influent	Intermediate	Effluent
	Composite	Composite	Composite
Aluminum (μg/L)	29.0 U	38.1	320
Barium (μg/L)	102	102	282
Boron (μg/L)	105.0	120.0	161.0
Calcium (μg/L)	161,000	158,000	158,000
Chromium (μg/L)	5.0	4.0 U	5.7
Copper (μg/L)	3.0 U	5.8	3.8
Iron (μg/L)	29.8	45.1	72.6
Magnesium (μg/L)	68,100	66,600	27,200
Manganese (μg/L)	1.5	5.0	5.2
Potassium (μg/L)	54,000	52,800	53,100
Silicon (μg/L)	1,210.0	1,200.0	905.0
Sodium (μg/L)	356,000	349,000	367,000
Strontium (μg/L)	2,020	1,980	2,000
Zinc (μg/L)	3.2	4.8	3.8
Chloride (mg/L)	98.9	96.6	55.1
Fluoride (mg/L)	0.74	0.76	0.51
Nitrite/Nitrate (mg/L)	398	378	279
Sulfate (mg/L)	162	159	53.3
Alkalinity (mg/L)	1.0 L	1.0 L	398.0
Radium 222 (pCi/L)	0.47	0.69	0.61
Plutonium 239,240 (pCi/L)	0.06	0.00	0.01
Americium 241 (pCi/L)	0.00	0.02	0.00
TDS (mg/L)	2,440	2,500	1,800
TSS (mg/L)	13	12	126
TOC (mg/L)	14.8	13.4	7.98
Temperature (°C)	11.8	10.8	10.7
pH (pH units)	8.8	8.6	12.2

Notes:

[a] The elements antimony, arsenic, beryllium, cadmium, cobalt, lead, molybdenum, nickel, selenium, silver, thallium, and vanadium were analyzed for, but were not detected, in all samples.

U Undetected
L Less than the sample concentration recorded
μg/L Micrograms per liter
mg/L Milligrams per liter
pCi/L PicoCuries per liter
° Degrees Celsius

Table 5-8. Analytical Results for Noncritical Parameters from Run 4 of the CPFM SITE Demonstration

Parameter[a]	Influent	Intermediate	Effluent
	Composite	Composite	Composite
Aluminum (μg/L)	29.0 U	73.6	724
Barium (μg/L)	107	94.7	135
Boron (μg/L)	123.0	133.0	159.0
Calcium (μg/L)	166,000	148,000	138,000
Chromium (μg/L)	4.0 U	4.2	4.0 U
Copper (μg/L)	5.1	8.2	4.6
Iron (μg/L)	36.4	102	61.4
Magnesium (μg/L)	70,800	65,100	76,400
Manganese (μg/L)	5.2	8.0	5.2
Potassium (μg/L)	56,300	55,700	52,700
Silicon (μg/L)	1,330.0	1,420.0	935.0
Sodium (μg/L)	372,000	435,000	425,000
Strontium (μg/L)	2,100	1,950	1,860
Zinc (μg/L)	2.1	7.0	4.3
Chloride (mg/L)	99.7	99.5	50.4
Fluoride (mg/L)	1.07	1.05	0.71
Nitrite/Nitrate (mg/L)	444	386	229
Sulfate (mg/L)	194	192	67.2
Alkalinity (mg/L)	1.0	1.0	556
Radium 222 (pCi/L)	0.49	1.4	1.7
Plutonium 239,240 (pCi/L)	0.02	0.01	0.04
Americium 241 (pCi/L)	0.05	0.03	0.01
TDS (mg/L)	2,560	2,660	2,120
TSS (mg/L)	10	6	197
TOC (mg/L)	13.9	10.6	7.22
Temperature (°C)	16.1	15.3	15.0
pH (pH units)	8.9	10.0	11.7

Notes:

[a] The elements antimony, arsenic, beryilium, cadmium, cobalt, lead, molybdenum, nickel, selenium, silver, thallium, and vanadium were analyzed for, but were not detected, in all samples.

U Undetected at this value
μg/L Micrograms per liter
mg/L Milligrams per liter
pCi/L PioCuries per liter
°C Degrees Celsius

Table 5-9. Analytical Results for Noncritical Parameters from Run 5 of the CPFM SITE Demonstration

Parameter[a]	Composite of Influent	Composite of Intermediate	Grab of Effluent at 120 minutes into run	Grab of Effluent at 480 minutes into run	Grab of Effluent at 780 minutes into run
Aluminum (μg/L)	29.0 U	29.0 U	59.3	92.5	29.0 U
Barium (μg/L)	103	104	106	107	108
Boron (μg/L)	116.0	116.0	118.0	121.0	118.0
Calcium (μg/L)	165,000	164,000	150,000	159,000	166,000
Chromium (μg/L)	4.4	4.0 U	4.0 U	4.0 U	4.0 U
Copper (μg/L)	3.0 U	3.8	3.0 U	3.0 U	3.0 U
Iron (μg/L)	27.0	21.0	37.9	33.9	20.2
Magnesium (μg/L)	71,200	72,500	62,600	70,300	72,700
Manganese (μg/L)	2.0	2.4	2.0	4.1	1.7
Potassium (μg/L)	56,600	57,600	55,800	56,200	58,900
Silicon (μg/L)	1,470.0	1450.0	1,240.0	1,400.0	1,590.0
Sodium (μg/L)	376,000	393,000	406,000	381,000	390,000
Strontium (μg/L)	2,090	2,120	2,050	2,060	2,150
Zinc (μg/L)	2.1	2.0 U	2.0 U	10.2	3.2
Chloride (mg/L)	104	105	94.4	101	102
Fluoride (mg/L)	0.24	0.34	0.3	0.44	0.47
Nitrite/Nitrate (mg/L)	350	327	277	364	341
Sulfate (mg/L)	168	187	163	174	166
Alkalinity (mg/L)	1.0	1.0	3.3	1.0 L	1.0
Radium 222 (pCi/L)					
Plutonium 239,240 (pCi/L)	0.00	0.01	0.00	0.01	0.01
Americium 241 (pCi/L)	0.00	0.01	0.00	-0.01	0.01
TDS (mg/L)	2,690	2,610	2,450	2,610	2,630
TSS (mg/L)	13	4.0	56	97	17
TOC (mg/L)	14.9	0.50	12.7	16.4	14.8
Temperature (°C)	13.2	13.0	18	12.6	10.8
pH (pH units)	7.8	8.2	10.2	9.0	8.6

Notes:

[a] The elements antimony, arsenic, beryllium, cadmium, cobalt, lead, molybdenum, nickel, selenium, silver, thallium, and vanadium were analyzed for, but were not detected, in all samples.

U Undetected at this value
L Less than the sample concentration recorded
μg/L Micrograms per liter
mg/L Milligrams per liter
pCi/L PioCuries per liter
°C Degrees Celsius

Metals and radionuclides in the spent filter packs and sludge from the miniclarifier (collected at the end of all runs) are shown in Tables 5-15 and 5-16. These results show that the spent filter cake does not contain a significant amount of sorbed radionuclides. However, the sludge from the miniclarifier is quite high in uranium (170 micrograms per gram [μg/g]) and gross alpha activity (320 pCi/L).

Table 5-15 shows that the spent filter cake is mostly aluminum, magnesium, barium, calcium, and silicon. The moisture content, density, weight of FF 1000, and performance on the PFLT are shown in Table 5-17. This table shows that the amount of moisture left in the spent filter packs varied from about 21 percent to 29 percent. Variation was probably due to the duration of dewatering after each run. The dry weight of FF 1000 used for runs 1 through 4 varied from 26.4 kg to 33.2 kg. All spent filter cake samples from runs 1 through 4 passed the PFLT, indicating that they do not contain free liquids.

The flow rates for each run are presented in Tables 5-10 through 5-14. Flow rates for runs 1 through 4 are similar and range from 3.8 to 4.2 gpm (14.4 to 15.9 Lpm). Use of sulfuric acid and sodium sulfide (for run 4) was measured by weight rather than by flow rate and duration. These data are presented in Tables 5-10 through 5-14.

Pressure drop across the colloid filters as a function of time could not be accurately measured because the gauges installed by the developer were not sensitive enough. Electricity usage for each run was measured by the amount of gasoline used by portable generators that powered the equipment. This information is presented in Tables 5-10 through 5-14.

Disposal options for spent filter cake are determined by its radionuclide and leachable metal content. Table 5-16 shows that concentrations of uranium in the filter cake ranged from 2.1 to 5.7 and gross alpha concentrations ranged from not detectable to 10 picoCuries per gram (pCi/g). In addition, Tables 5-18 and 5-19 show TCLP test results indicating that the filter cake does not contain extractable metals and that extractable radionuclides are below federal drinking water standards.

5.5 Conclusions

5.5.1 Primary Objectives

The primary objective of the demonstration was to assess the CPFM system's ability to remove uranium and gross alpha contamination to levels below CWQCC standards. The critical parameters used to achieve this objective were uranium and gross alpha concentrations in the system influent, intermediate, and effluent. Three runs were conducted in this first part of the demonstration to evaluate the reproducibility of the treatment results. These runs (runs 1 through 3) were conducted under the same operating conditions such as influent pH, flow rate, and amount of FF 1000 used in the filter packs. This information has been presented in Tables 5-10 through 5-14. Analytical results for the critical parameters indicate that uranium concentrations provide a reliable assessment of CPFM system performance and that the gross alpha data should be used with caution in evaluating the system.

Although the three runs were conducted at the same operating conditions, removal efficiency for uranium ranged from a low of 58.4 percent for run 2 to a high of 90.6 percent for run 1. Review of operational data does not reveal the cause of this variation. Therefore, the ability of the CPFM system to remove uranium appears to be variable. At optimum operating efficiency without chemical pretreatment, as observed during run 1 of the demonstration, the CPFM system produced effluent with 9.5 μg/L of uranium, compared to the CWQCC standard of 7 μg/L. For run 4, using sodium sulfide pretreatment, the CPFM system produced effluent with 5.1 μg/L of uranium. However this result is based on only a single composite sample rather than a sample and duplicate as for runs 1 through 3.

5.5.2 Secondary Objectives

Four secondary objectives were identified for the demonstration. These are:

- Document operating conditions
- Estimate operating costs
- Assess the ability of the CPFM system to remove other radionuclides
- Evaluate disposal options for spent filter cake

Data on operating conditions are presented in Tables 5-10 through 5-14. These data show that runs 1 through 3 were conducted at nearly the same influent pH, flow rate, and amount of FF 1000 in the filter packs. Therefore, variation in the ability of the CPFM system to remove uranium from influent does not appear to be related to these parameters.

Table 5-10. Field Parameter Data From Run 1 of the CPFM SITE Demonstration

Location	Parameter	Time 1	Time 2	Time 3	Time 4	Time 5	Time 6	Time 7	Average
	Time From Start of Run	(15 min)	(40 min)	(80 min)	120 min)	(160 min)	(200 min)	(240 min)	
M1	pH (pH units)	7.0	8.6	8.0	8.3	8.8	8.1	8.3	8.2
	Conductivity (mS)	4.3	4.3	2.1	4.3	4.3	4.3	4.0	3.9
	Temperature (°C)	16.1	18.9	17.5	17.9	20.0	19.2	21.6	18.7
	Flow Meter Reading (gpm) [Lpm]	5.0 [18.9]	--	5.0 [18.9]	5.0 [18.9]	5.0 [18.9]	4.0 [15.1]	5.0 [18.9]	4.8 [18.2]
	Actual Flow Rate (gpm) [Lpm]	4.0 [15.1]	--	4.0 [15.1]	4.0 [15.1]	4.0 [15.1]	3.2 [12.1]	4.0 [15.1]	3.8 [14.4]
M4	pH	9.0	8.8	8.3	8.4	8.5	7.9	8.3	8.4
	Conductivity	1.5	1.9	2.4	1.6	3.2	3.4	3.6	2.5
	Temperature	17.5	18.9	19.3	19.2	21.7	20.8	21.8	19.9
	Flow Meter Reading	5.0 [18.9]	--	5.3 [20.0]	5.1 [19.3]	4.5 [17.0]	4.8 [18.2]	5.1 [19.3]	5.0 [18.9]
	Actual Flow Rate	3.7 [14.0]	--	3.9 [14.3]	3.8 [14.4]	3.3 [12.5]	3.5 [13.2]	3.8 [14.4]	3.7 [14.0]
M9	pH	10.6	11.9	11.8	11.6	11.2	10.4	10.6	11.1
	Conductivity	2.5	3.6	3.4	1.9	3.1	3.0	3.3	3.0
	Temperature	17.4	18.3	19.4	19.4	21.3	20.8	22.2	19.8
	Flow Meter Reading	--	--	--	--	--	--	--	--
M5	PI-1 (psi) [kg/cm^2]	2 [0.14]	2 [0.14]	9 [0.63]	14 [0.98]	15 [1.0]	18 [1.3]	19 [1.34]	
	PI-2	0	0	0	0	5 [0.35]	10 [0.70]	16 [1.12]	
	Pressure drop	2 [0.19]	2 [0.14]	9 [0.63]	14 [0.98]	10 [0.70]	8 [0.56]	3 [0.21]	
M6	PI-3 (psi) [kg/cm^2]	0	0	0	0	0	5 [0.35]	10 [0.70]	
	PI-4	0	0	0	0	0	0	0	
	Pressure drop	0	0	0	0	0	5 [0.35]	10 [0.70]	
									Total Usage
M21	Sulfuric acid usage (lbs) [kg]								23 [8.58]
	Power consumption (measured as gallons [liters] of gasoline used)								7.5 [28.4]

Notes:

--	No measurement	°C	Degrees Celsius
gpm	Gallons per minute	psi	Pounds per square inch
Lpm	Liters per minute	kg/cm^2	Kilograms per square centimeter
mS	MilliSiemens	kg	Kilograms
lbs	Pounds		

Table 5-11. Field Parameter Data From Run 2 of the CPFM SITE Demonstration

Location	Parameter	Time 1	Time 2	Time 3	Time 4	Time 5	Time 6	Time 7	Average
	Time From Start of Run	(15 min)	(40 min)	(80 min)	120 (min)	(160 min)	(200 min)	(240 min)	
M1	pH (pH units)	8.3	9.1	9.1	7.3	8.4	8.3	8.3	8.4
	Conductivity (mS)	3.5	3.5	3.5	3.4	3.1	3.5	3.4	3.4
	Temperature (°C)	10.5	11.1	11.7	11.8	10.5	11.7	13.3	11.2
	Flow Meter Reading (gpm) [Lpm]	5.0 [18.9]	--	--	5.3 [19.9]	5.0 [18.9]	5.5 [20.8]	5.2 [19.7]	5.2 [19.7]
	Actual Flow Rate (gpm) [Lpm]	4.0 [15.1]	--	--	4.2 [15.9]	4.0 [15.1]	4.4 [16.7]	4.2 [15.9]	4.2 [15.9]
M4	pH	7.3	8.6	8.8	7.8	8.3	8.4	8.4	8.2
	Conductivity	3.2	3.2	3.2	3.4	3.2	3.3	3.4	3.2
	Temperature	10.1	10.8	11.8	11.4	11.0	11.9	13.3	11.2
	Flow Meter Reading	--	--	--	4.8 [18.0]	5.0 [18.9]	5.5 [20.8]	5.2 [19.7]	5.1 [19.3]
	Actual Flow Rate	--	--	--	3.8 [14.4]	4.0 [15.1]	4.4 [16.7]	4.2 [15.9]	4.1 [15.5]
M9	pH	11.9	11.4	10.8	10.3	10.0	9.9	9.7	10.7
	Conductivity	2.9	--	3.0	3.0	3.4	3.2	3.4	3.1
	Temperature	10.7	11.3	12.1	11.3	11.1	12.2	13.1	11.5
	Flow Meter Reading	5.0 [18.9]	--	--	--	5.0 [18.9]	5.5 [20.8]	5.2 [19.7]	5.2 [19.7]
	Actual Flow Rate	4.0 [15.1]	--	--	--	4.0 [15.1]	4.4 [16.7]	4.2 [15.9]	4.1 [15.5]
M5	PI-1 (psi) [kg/cm²]	5 [0.35]	--	--	6 [0.42]	4 [0.28]	4 [0.28]	4 [0.28]	
	PI-2	0	--	--	0	0	0	0	
	Pressure drop	5 [0.35]	--	--	6 [0.42]	4 [0.28]	4 [0.28]	4 [0.28]	
M6	PI-3	0	--	--	0	0	0	0	
	PI-4	0	--	--	0	0	0	0	
	Pressure drop	0	--	--	0	0	0	0	
M21	Sulfuric acid usage (lbs) [kg]								**Total Usage**
	Power consumption (measured as gallons of gasoline used)								20 [7.46]
									10 [37.8]

Notes:

--	No measurement	°C	Degrees Celsius
gpm	Gallons per minute	psi	Pounds per square inch
Lpm	Liters per minute	kg/cm²	Kilograms per square centimeter
mS	MilliSiemens	kg	Kilograms
lbs	Pounds		

Table 5-12. Field Parameter Data From Run 3 of the CPFM SITE Demonstration

Location	Parameter	Time 1	Time 2	Time 3	Time 4	Time 5	Time 6	Time 7	Average
	Time From Start of Run	(15 min)	(40 min)	(80 min)	120 min)	(160 min)	(200 min)	(240 min)	
M1	pH (pH units)	9.0	8.4	8.8	9.2	8.7	8.8	9.0	8.8
	Conductivity (mS)	3.2	3.0	3.3	3.2	3.3	3.4	3.3	3.2
	Temperature (°C)	11.3	11.9	11.5	11.7	12.6	12.5	11.0	11.8
	Flow Meter Reading (gpm) [Lpm]	4.8 [18.0]	5.0 [18.9]	5.0 [18.9]	4.3 [16.1]	5.0 [18.9]	4.0 [15.1]	5.0 [18.9]	4.7 [17.8]
	Actual Flow Rate (gpm) [Lpm]	3.8 [14.4]	4.0 [15.1]	4.0 [15.1]	3.4 [12.9]	4.0 [15.1]	3.2 [12.1]	4.0 [15.1]	3.8 [14.4]
M4	pH	8.7	8.1	8.7	9.1	8.4	8.6	8.8	8.6
	Conductivity	3.1	3.3	3.3	3.2	3.2	11.7	3.5	4.4
	Temperature	10.9	10.9	10.7	11.1	10.9	11.0	10.6	10.8
	Flow Meter Reading	5.0 [18.9]	4.8 [18.0]	5.0 [18.9]	4.8 [18.0]	5.0 [18.9]	4.5 [17.0]	5.0 [18.9]	4.9 [18.5]
	Actual Flow Rate	4.0 [15.1]	3.8 [14.4]	4.0 [15.1]	3.8 [14.4]	4.0 [15.1]	3.6 [13.6]	4.0 [15.1]	3.9 [14.8]
M9	pH	12.8	12.6	12.8	12.	11.6	11.7	11.2	12.2
	Conductivity	5.4	4.3	4.0	3.2	3.0	3.1	3.1	3.7
	Temperature	10.5	10.2	10.7	11.0	10.9	10.9	10.5	10.7
	Flow Meter Reading	--	--	--	--	--	--	--	--
	Actual Flow Rate	--	--	--	--	--	--	--	--
M5	PI-1 (psi) [kg/cm^2]	14 [0.98]	16 [1.1]	18.5 [1.3]	22 [1.5]	17 [1.2]	19 [1.3]	19 [1.3]	17 [1.2]
	PI-2	0	0	0	0	0	0	0	0
	Pressure drop	14 [0.98]	16 [1.1]	18.5 [1.3]	22 [1.5]	17 [1.2]	19 [1.3]	19 [1.3]	17 [1.2]
M6	PI-3	0	0	0	0	0	0	0	0
	PI-4	0	0	0	0	0	0	0	0
	Pressure drop	0	0	0	0	0	0	0	0
									Total Usage
M21	Sulfuric acid usage (lbs) [kg]								20 [7.46]
	Power consumption (measured as gallons [liters] of gasoline used)								7 [26.5]

Notes:

--	No measurement	°C	Degrees Celsius
gpm	Gallons per minute	psi	Pounds per square inch
Lpm	Liters per minute	kg/cm^2	Kilograms per square centimeter
mS	MilliSiemens	kg	Kilograms
lbs	Pounds		

Table 5-13. Field Parameter Data From Run 4 of the CPFM SITE Demonstration

Location	Parameter	Time 1	Time 2	Time 3	Time 4	Time 5	Time 6	Time 7	Average
	Time From Start of Run	(15 min)	(40 min)	(80 min)	120 min)	(160 min)	(200 min)	(240 min)	
M1	pH (pH units)	9.1	9.1	8.9	9.0	8.6	9.1	8.8	8.9
	Conductivity (mS)	0.1	3.4	2.7	3.5	0.2	2.63	3.5	2.2
	Temperature (°C)	13.8	14.2	15.3	17.4	17.2	18.1	16.8	16.1
	Flow Meter Reading (gpm) [Lpm]	5.0 [18.9]	5.0 [18.9]	5.3 [19.9]	5.3 [19.9]	5.3 [19.9]	5.0 [18.9]	5.3 [19.9]	5.1 [19.3]
	Actual Flow Rate (gpm) [Lpm]	4.0 [15.1]	4.0 [15.1]	4.2 [15.9]	4.2 [15.9]	4.2 [15.9]	4.0 [15.1]	4.1 [15.9]	4.1 [15.5]
M4	pH	9.2	9.6	9.8	10.2	10.1	10.4	10.5	10.0
	Conductivity	3.5	0.1	3.5	3.5	3.5	3.6	3.8	3.1
	Temperature	13.2	13.8	14.8	16.4	17.0	16.7	15.2	15.3
	Flow Meter Reading	5.0 [18.9]	5.0 [18.9]	4.8 [18.0]	5.3 [19.9]	5.0 [18.9]	5.0 [18.9]	4.8 [18.0]	5.0 [18.9]
	Actual Flow Rate	4.0 [15.1]	4.0 [15.1]	3.8 [14.4]	4.2[15.9]	4.0 [15.1]	4.0 [15.1]	3.8 [14.4]	4.0 [15.1]
M9	pH	12.6	12.5	12.1	11.6	11.2	11.0	11.0	11.7
	Conductivity	5.8	5.1	4.6	4.0	3.1	3.5	3.7	4.2
	Temperature	13.2	13.7	14.7	16.1	16.1	15.7	15.3	15.0
	Flow Meter Reading	--	--	--	--	--	--	--	
M5	PI-1 (psi) [Kg/cm2]	4 [0.28]	4 [0.28]	6 [0.42]	9 [0.63]	12 [0.84]	13.5 [0.95]	14.5 [1.0]	9.0 [0.63
	PI-2	0	0	0	0	0	0	0	0.0
	Pressure drop	4 [0.28]	4 [0.28]	6 [0.42]	9 [0.63]	12 [0.84]	13.5 [0.95]	14.5 [1.0]	9.0 [0.63]
M6	PI-3	0	0	0	0	0	0	0	0.0
	PI-4	0	0	0	0	0	0	0	0.0
	Pressure drop	0	0	0	0	0	0	0	0.0
M21	Sulfuric acid usage (lbs) [kg]								**Total Usage**
	Power consumption (measured as gallons [liters] of gasoline used)								17.5 [6.53]
	Sodium Sulfide usage (lbs) [kg]								8.0 [75.7]
									14 [6.33]

Notes:

--	No measurement	°C	Degrees Celsius
gpm	Gallons per minute	psi	Pounds per square inch
Lpm	Liters per minute	kg/cm^2	Kilograms per square centimeter
ms	MilliSiemens	kg	Kilograms
lbs	Pounds		

Table 5-14. Field Parameters From Run 5 of the CPFM SITE Demonstration.

Location	Parameter	Time 1	Time 2	Time 3	Time 4	Time 5	Time 6	Time 7	Time 8	Time 9	Time 10	Time 11	Average
	Time From Start of Run	(120 min)	(240 min)	(360 min)	(480 min)	(540 min)	(600 min)	(660 min)	(720 min)	(780 min)	(840 min)	(900 min)	
M1	pH (pH units)	8.13	7.54	7.78	7.93	8.34	8.01	7.84	7.74	7.59	7.57		7.847
	Conductivity (mS)	3.65	3.67	3.62	2.94	2.55	3.74	3.69	3.76	1.772	3.72		3.31
	Temperature (°C)	19.1	17.9	17.1	11.5	12.2	11.7	11.9	11	9.9	10.1		13.24
	Flow Meter Reading (gpm) [Lpm]	4.78 [17.8]	5.0 [18.9]	5.0 [18.9]	5.0 [18.9]	5.0 [18.9]	5.8 [21.9]	5.0 [18.9]	5.2 [19.6]	5. [18.9]	5.5 [20.8]		5.1 [19.3]
	Actual Flow Rate (gpm){Lpm]	3.8 [14.3]	4.0 [15.1]	4.0 [15.1]	4.0 [15.1]	4.0 [15.1]	4.6 [17.4]	4.0 [15.1]	4.2 [15.9]	4.0 [15.1]	4.4 [16.6]		4.1 [15.5]
M4	pH	8.43	8.07	8.11	8.43	8.77	8.26	8.25	7.99	8.13	7.99		8.24
	Conductivity (mS)	3.63	3.67	3.32	3.29	0.22	3.45	3.66	16.24	3.76	3.82		4.51
	Temperature (°C)	18.0	18.1	15.5	11.9	12.2	11.7	11.7	11.1	9.8	10.5		13.055
	Flow Meter Reading	5.0 [18.9]	5.0 [18.9]	4.7 [17.8]	4.7 [17.8]	5.0 [18.9]	5.0 [18.9]	4.6 [17.4]	5.0 [18.9]	5.1 [19.3]	5.0 [18.9]		4.5 [18.9]
	Actual Flow Rate	4.0 [15.1]	4.0 [15.1]	3.8 [14.4]	3.8 [14.4]	4.0 [15.1]	4.0 [15.1]	3.7 [14.0]	4.0 [15.1]	4.1 [15.5]	4.0 [15.1]		3.9 [14.8]
M18=L4	pH	10.18	8.76	8.61	9.03	8.83	8.71	8.56	8.83	8.36	8.49	8.58	8.84
	Conductivity (MS)	3.59	3.66	3.59	3.56	0.23	3.70	3.05	3.61	3.64	3.78	3.80	3.24
	Temperature (°C)	17.2	18.2	15.7	12.6	13.7	12.9	12.8	11.8	10.9	11.00	11.00	13.68
	Flow Meter Reading	--	--	--	--	--	--	3.7 [14.0]	--	3.4 [12.9]	--	--	3.5 [13.2]
	Actual Flow Rate	--	--	--	--	--	--	3.0 [11.2]	--	2.7 [10.3]	--	--	2.8 [10.6]
M19=L5	pH	9.97	9.54	9.42	9.34	9.29	8.98	9.06	9.18	8.60	9.03	8.88	9.24
	Conductivity (mS)	3.62	3.68	3.40	3.47	0.29	3.32	3.39	3.53	3.78	3.76	3.30	3.22
	Temperature (°C)	17.5	19.9	16.5	12.9	13.3	12.6	12.1	11.4	10.8	11.5	10.7	13.85
	Flow Meter Reading	--	--	--	--	--	--	2.3 [8.3]	--	2.2 [8.3]	--	--	2.2 [8.3]
	Actual Flow Rate	--	--	--	--	--	--	1.8 [7.0]	--	1.8 [6.7]	--	--	1.8 [6.7]
M5	PI-1 9 (psi) [kg/cm^2]	5 [0.35]	4 [0.28]	4 [0.28]	4 [0.28]	4 [0.28]	4 [0.28]	3 [0.21]	3 [0.21]	3 [0.21]	2 [0.14]	2 [0.14]	4 [0.28]

Table 5-14. Field Parameters From Run 5 of the CPFM SITE Demonstration. (Continued)

Location	Parameter	Time 1	Time 2	Time 3	Time 4	Time 5	Time 6	Time 7	Time 8	Time 9	Time 10	Time 11	Average
	Time From Start of Run	(120 min)	(240 min)	(360 min)	(480 min)	(540 min)	(600 min)	(660 min)	(720 min)	(780 min)	(840 min)	(900 min)	
M6	PI-2	0	0	0	0	0	0	0	0	0	0	0	0
	Pressure Drop	5 [0.35]	4 [0.28]	4 [0.28]	4 [0.28]	4 [0.28]	4 [0.28]	3 [0.21]	3 [0.21]	3 [0.21]	2 [0.14]	2 [0.21]	4 [0.28]
	PI-3	0	0	0	0	0	0	0	0	0	0	0	0
	PI-4	0	0	0	0	0	0	0	0	0	0	0	0
	Pressure Drop	0	0	0	0	0	0	0	0	0	0	0	0
		Filter 13 Location 1	**Filter 14 Location 2**										
Dry	Total Weight of Pack (kg)	6.24	5.466										
	Weight of Container	0.151	0.145										
	Weight of FF 1000	6.089	5.321										
Wet	Total weight of pack	10.15	11.41										
	Weight of container	0.151	0.145										
	Weight of FF1000	9.999	11.265										

Notes:

--	No measurement	°C	Degrees Celsius
gpm	Gallons per minute	psi	Pounds per square inch
Lpm	Liters per minute	kg/cm^2	Kilograms per square centimeter
mS	MilliSiemens	kg	Kilograms
lbs	Pounds		

Table 5-15. Noncritical Metal Concentrations in Spent Filter Material from the CPFM SITE Demonstration

Analyte	Concentration (μg/kg)						
	Run 1	Run 2	Run 3	Run 4	Run 5 Pack 1	Run 5 Pack 2	Miniclarifier Sludge
Aluminum	6,320	66,500	29,000	64,600	67,500	69,200	1,390
Antimony	6.9U	6.2U	6.1U	6.9U	6.8U	6.5	34.1U
Arsenic	5.3U	4.8U	4.7U	5.4U	5.3U	5.1	26.4U
Barium	3,020	1,180	7,060	237	16.7	33.9	214
Beryllium	0.20	0.30	0.16	0.14U	0.14U	0.13	0.7U
Boron	19.4	28.4	14.1	19.3	18.3	25.1	63.1
Cadmium	0.7U	0.63U	0.62U	0.71U	0.69U	0.66	3.5U
Calcium	3,490	4,470	1,690	1,510	1,860	2,620	226,000
Chromium	2.7	2.8	1.7	2.9	3.0	3.1	9.0
Cobalt	1.8	0.69	4.1	0.42	0.42U	0.40	2.1U
Copper	1.4	0.52	0.37U	0.64	1.1	0.40	16.0
Iron	2,070	938	500	503	536	588	2,890
Lead	12.4	12.4	11.0	4.1	4U	8.7	20.2U
Magnesium	230,000	259,000	101,000	261,000	274,000	279,000	50,300
Manganese	68.7	81.7	41.4	54.2	57.0	59.2	40.2
Molybdenum	3.6	1.5	0.99	1.2	1.3	1.8	5.6U
Nickel	4.9	2.5U	5.3	2.8U	2.8U	7.4	150.0
Potassium	1,350	1,560	855	137U	135U	250	785
Selenium	7.8U	7.1U	6.9U	7.9U	7.8	7.4	38.9U
Silicon	1,730U	3,060	1290	846	1,250	1,190	4610
Silver	0.56	0.51U	0.5U	0.56U	0.55U	0.53	2.8U
Sodium	3,330	1,370	527	238	360	557	3,830
Strontium	144	81.7	99U	4.2	4.9	18.4	1190
Thallium	9.8U	8.9U	8.7U	28.0	17.5	24.2	48.7U
Vanadium	7.9	4.8	2.1	4.9	5.4	5.1	2.1U
Zinc	10.2	8.8	5.7	8.5	9.0	10.1	58.9

Notes:

μg/kg Micrograms per kilogram
U Undetected at this value

Table 5-16. Radionuclide Concentrations in Spent Filter Cake Solids from the CPFM SITE Demonstration

Analyte	Run 1	Run 2	Run 3	Run 4	Run 5 Pack 1	Run 5 Pack 2	Miniclarifier Sludge
Uranium (μg/g)	10.0 ± 0.13	1.0 ± 18	1.6 ± 0.16	1.2 ± 0.05	2.2 ± 0.16	2.7 ± 13	170 ± 5.6
Gross Alpha (pCi/g)	-3 ± 14	12 ± 16	15 ± 14	8 ± 14	11 ± 14	-6 ± 12	320 ± 36
Plutonium (pCi/g)	0.00 ± 0.02	0.04 ± 0.03	0.01 ± 0.02	0.01 ± 0.02	0.01 ± 0.02	0.02 ± 0.03	0.00 ± 0.01
Americum (pCi/g)	0.01 ± 0.02	0.01 ± 0.02	0.02 ± 0.03	0.00 ± 0.01	0.00 ± 0.01	0.00 ± 0.01	0.01 ± 0.02
Radium (pCi/g)	0.37 ± 0.14	0.51 ± 0.15	0.44 ± 0.13	0.02 ± 0.15	0.05 ± 0.16	0.85 ± 0.17	0.07 ± 0.08

Note:

μg/g Micrograms per gram
pCi/g PicoCuries per gram

Table 5-17. Physical Characteristics of Solids from the CPFM SITE Demonstration

Analyte	Run 1	Run 2	Run 3	Run 4	Run 5 Pack 1	Run 5 Pack 2	Miniclarifier Sludge
Percent Moisture (%)	29.2	21.8	20.8	29.8	29.3	27.0	85.7
Bulk Density (g/cc)	1.17	0.98	1.14	1.15	1.15	1.19	1.07
Dry weight of FF 1000 (kg)	29.7	31.8	33.2	26.4	6.1	5.3	NA
Wet weight of FF 1000 (kg)	63.7	52.2	72.5	65.7	10	11.3	NA
Paint Filter Liquids Test	No free liquids	No free liquids	No free liquids	No free liquids	NA	NA	NA

Notes:

kg kilograms
NA Not analyzed
g/cc Grams per cubic centimeter

Table 5-18. Analytical Results for TCLP Extract Solutions for the CPFM SITE Demonstration

Parameter	Run 1	Run 2	Run 3	Run 4	Run 5 Pack 1	Run 5 Pack 2
Uranium (μg/L)	2.1	2.1	3.4	2.6	4.7	5.7
Gross Alpha (pCi/L)	0.0	12	15	8.1	11	0.0

Table 5-19. Analytical Results for TCLP Extract Solutions for the CPFM SITE Demonstration

Parameter	Run 5 Pack 1	Run 5 Pack 2
Uranium (μg/L)	0.1 U	0.1 U
Gross Alpha (pCi/L)	0.0 U	0.0 U
Arsenic (mg/L)	380 U	380 U
Barium (mg/L)	2,840 U	4,780 U
Cadmium (mg/L)	50 U	50 U
Chromium (mg/L)	40 U	40 U
Lead (mg/L)	10 U	10 U
Mercury (mg/L)	10 U	10 U
Selenium (mg/L)	10 U	10 U
Silver (mg/L)	40 U	40 U

Note:

U	Undetected at this value
μg/L	Micrograms per liter
mg/L	Milligrams per liter
pCi/L	PicoCuries per liter

Operating costs have been estimated using standard EPA procedures and indicate that it would cost approximately $7 to treat 1,000 gallons of influent for a system operating at a site for a single year. This cost is reduced to $2 for 1,000 gallons if the system operates at the site for 10 years.

The ability of the CPFM system to remove the radionuclides plutonium, americium, and radium was included as a secondary objective, although influent levels were anticipated to be near the detection limit, because discharge limits are also very low (0.05 pCi/L). However, analysis of influent during the demonstration showed that influents were at or below the 0.01 pCi/L detection limit and always below the discharge limit. Therefore, the ability of the CPFM system to remove these elements could not be evaluated during this demonstration.

Numerous chemical and physical parameters were evaluated for the spent filter cake to provide the information required to determine how the spent filter cake may be disposed of. The filter cake did not contain free liquids and did not contain any metals above the regulatory limit in the TCLP extract. In addition, the spent filter cake contained uranium and gross alpha activity at 1 to 10 μg/g and 0 to 15 pCi/g respectively. This information may assist potential users of the technology evaluate disposal costs. However, at the conclusion of the demonstration, DOE took possession of all waste generated during the demonstration for later disposal. Therefore, actual disposal costs were not determined.

Section 6
Technology Status

The CPFM technology is being considered for several sites. Improvements to the CPFM system to be used at the additional sites are described in the vendors' claims for the technology (see Appendix A). Pilot-scale testing is underway at the DOE Oak Ridge National Laboratory through a joint venture. The pilot test will determine CPFM process effectiveness in treating mixed waste. In another pilot-scale test, funded by the Westinghouse Science and Technology Group, the process is being applied as part of a treatment train for mixed wastewater that has been pretreated to remove organic compounds and solids. The CPFM process is also planned for the commercial arena in the area of metal finishing wastes. FFT is also building a CPFM system for a mining operation in Peru that will treat wastewater containing copper, zinc, lead, and arsenic. A total of 25 commercial projects are planned.

Section 7
References

Evans, G. 1990. Estimating Innovative Technology Costs for the SITE Program. Journal of Air and Waste Management Association, 40:7, pages 1047 through 105.

Appendix A
Vendor Claims for the Technology

A.1 Introduction

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 the 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 heavy metals (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 heavy metals. DOE's 26 NPL radioactively contaminated sites essentially all have heavy 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 heavy metals and radionuclide remediation 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.2 Colloid Polishing Filter Method

The Colloid Polishing Filter was developed to circumvent some of the performance limitations of conventional methods used to remove heavy metals and radionuclide pollutants from water. In addition, there is a need to reduce the disposal costs for generated solid wastes by decreasing the quantity of spent ion exchange resins and miscellaneous solids. Figure A-1 illustrates the wide dynamic range achievable for removing trace heavy metal and nontritium radionuclide pollutants from water using the new methodology. The methodology has application to heavy metals and nontritium radionuclide removal from groundwater, pond water, stored water, and wastewater (such as secondary wastewater from sludge or soil washing, solids dewatering or surface decontamination wastewater streams). Several case studies discussing these applications appear in Appendix B.

Metallic pollutants can be removed from water in colloidal form, ions, in both complexed and chelated forms. Heavy metal and radionuclide pollutants can be efficiently removed from water based on the principles of charge dependent, surface sorption, charge and size related chemical complexing phenomena and, to a lesser extent (less than 10 percent), physical trapping or precipitated forms. Site-specific geochemistry, water chemistry, and the types and the chemical and physical forms of the metals and radionuclides are important operational variables. Therefore, it will be important to optimize the chemical preconditioning and flocculation tank procedures for each site to achieve high performance from the CPFM.

For example, in the U.S. Environmental Protection Agency (EPA) Superfund Innovative Technology Evaluation (SITE) demonstration at the Rocky Flats Plan (RFP), the low TSS, clear, interceptor trench pump house (ITPH) groundwater used in the bench tests was stored in aboveground tanks prior to the demonstration and an algae bloom produced turbidity. Colloidal algae particles from the algae bloom were not removed by the clarifier or 10-micron bag filter upstream of the polishing filters. As a result, excessive TSS collected in the filter packs during testing and interfered with the sorption beds. Generally, when algae are present, these particles should be treated and removed before using the CPFM system. However, removal was not possible at the demonstration due to limited time and a preset demonstration text matrix.

The flow diagram in Figure A-2 illustrates how the CPFM is used for treating heavy metals and nontritium radionuclide water pollutants. The influent water is pumped to a reaction tank and then to a flocculation tank for chemical conditioning. Conditioning shifts the equilibrium of the metallic pollutants toward particle agglomeration (that is, formation of micro- and colloidal particles). The bulk TSS is removed either indirectly (clarifier and bag filter) or directly (high crossflow microfilter) and dewatered into a filter cake for stabilization and disposal. The low-TSS water is then pumped to the Colloid Polishing Filter beds using controlled fluid flow and serial processing to ensure high performance. The pH of the treated water is monitored and adjusted (if necessary) to pH 8 to 8.3 and the water is stored in holding tanks for testing and verification of the metals and radionuclide concentrations before the water is discharged or reused. To date, Filter Flow Technology, Inc. (FFT) has designed CPFM systems ranging from less than 5 to more than 100 gallons per minute (gpm), and is currently working on a 500 gpm skid-mounted system to treat secondary wastewater from soil washing of radionuclide-contaminated soils. The Filter Flow (FF) 1000 sorption bed material (inorganic, insoluble pellets) can be formulated, blended, and produced to match the site-specific problem being treated (that is, groundwater contaminated with uranium, plutonium, and americium radium 226, zinc 65, cesium 137, cobalt 60, or lower valence heavy metals). Filter packs can be loaded with bed material tailored for the various pollutant forms and used in series to first remove one form of pollutant, then subsequently remove the other forms in different filter packs. This versatility should prove useful when using the methodology at a variety of remediation sites having different water chemistry and dissimilar pollutants.

A.3 Design and Product Improvements

The RFETS SITE demonstration in September 1993 showed that basic engineering design and system configuration were adequate. Still, several changes have been made to improve the equipment for higher flow rates (25, 50, and 100 gpm), improve system reliability, increase performance efficiency, and reduce operational

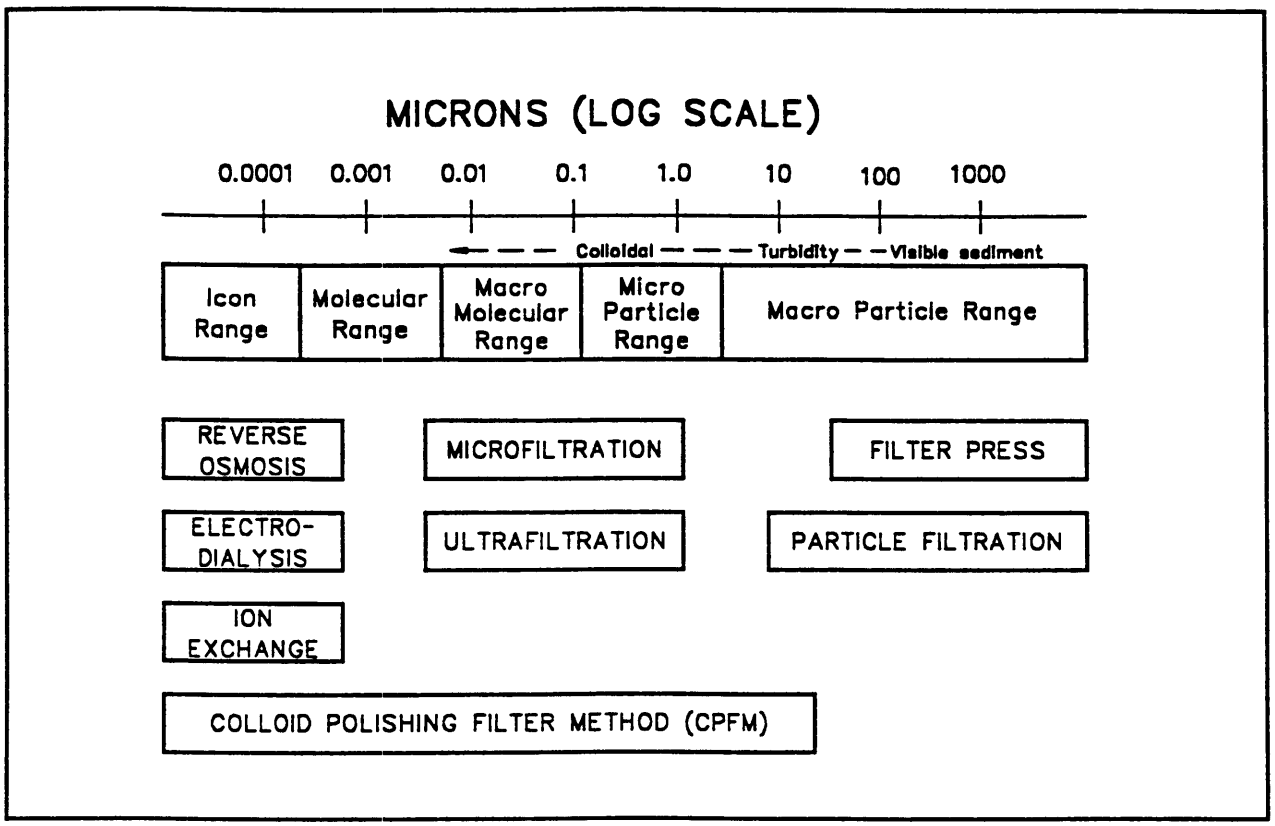


Figure **A-1**. Comparison of the Particle Removal Size Range for Conventional Versus the CPFM

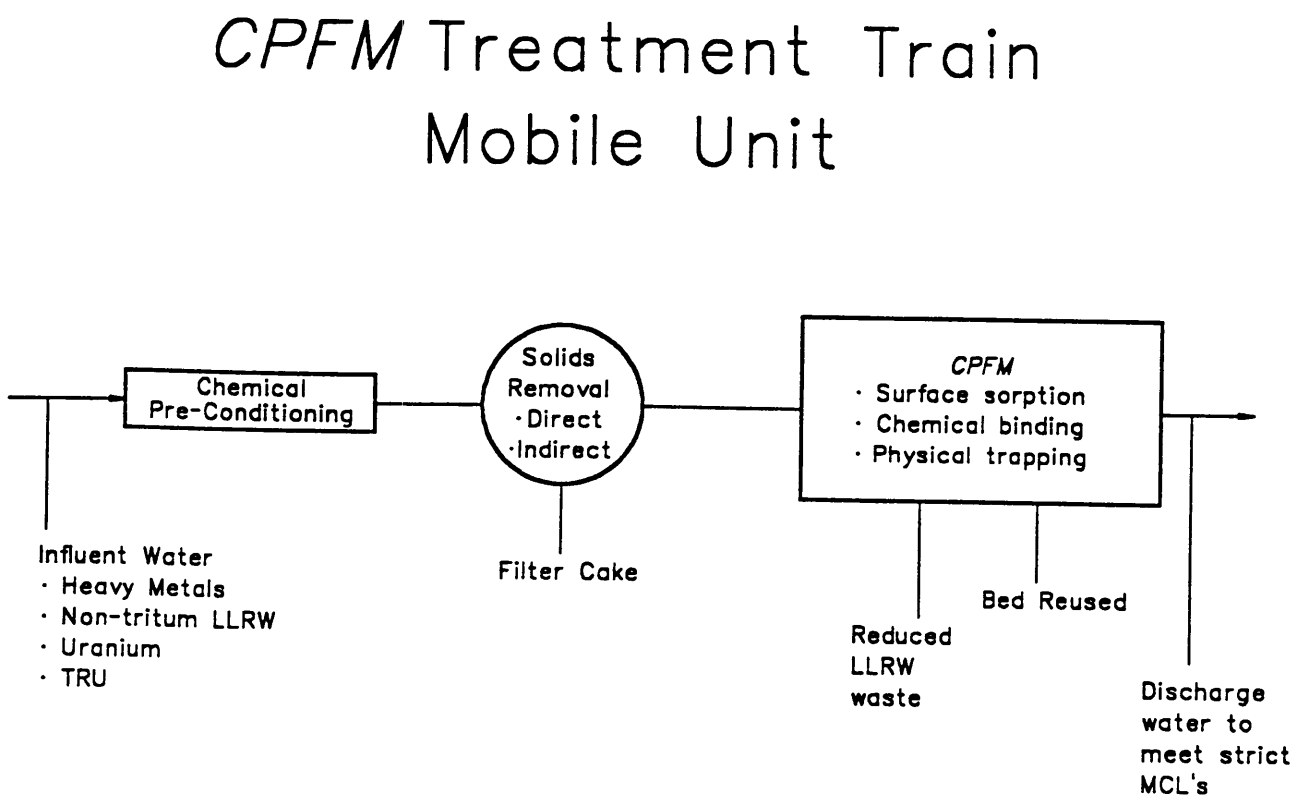


Figure A-2. Flow Diagram Showing the Basic Treatment Train Used for the CPFM

costs. Examples of improvements to the CPFM since the demonstration are outlined below.

- The filter pack compartment has been redesigned to increase the bed volume and capacity by a factor of 8 to 9 and increase the strength of the filter pack material.

- A basic, vertical carbon steel (or stainless steel) and polypropylene Colloid Polishing Filter has been designed with five filter packs totaling 14.5 cubic feet bed volume that will process up to 35 gpm for a wide range of metallic pollutants.

- The hydraulic ram assembly and support plates have been reworked so that the filter packs are loaded (or unloaded) one at a time. This improvement simplifies the changeout procedure, increases the safety factor (particularly for gamma emitting isotopes), and reduces the overall height of the equipment by 25 percent.

- The capability to more efficiently remove heavy metal pollutants with various chemical and physical characteristics has been enhanced by using serial removal of the various species in filter packs loaded with bed material formulated and manufactured with different sorption and chemical affinities for the pollutants.

- An alternative to the clarifier was tested for removing bulk TSS upstream of the Colloid Polishing Filter using direct, high crossflow microfiltration. This new method reduces the capital cost, increases performance, and decreases the weight and area required for the trailer and skid system that holds the CPFM.

- The manufacturing process for FF 1000 sorption material has been improved and is being readied for production in large quantities with quality control documentation for each batch.

- A method has been developed to increase the FF 1000 bedlife, thereby allowing extra backwash and rinse cycles, reducing the operational cost, and decreasing the annual quantity of spent bed material requiring landfill disposal.

A.4 Applications of the System

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

- In-line, trailer-, or skid-mounted polishing filter for the removal of heavy metals from groundwater, wastewater, or soil washing secondary wastewater

- Naturally occurring radioactive materials (NORM)-contaminated production water

- Remediation of NORM-contaminated groundwater, production site, and equipment decontamination and decommissioning wastewater

- Remediation of uranium and thorium mine and milling tailings pond water, groundwater, and wastewater

- Treatment of LLRW-contaminated groundwater and wastewater from nuclear reactors and power plants

- Treatment and remediation of LLMW-contaminated water following pretreatment to remove or destroy Resource Conservation and Recovery Act (RCRA)-regulated organic pollutants

Commercialization of the CPFM started slowly in late 1992 and early 1993 at small industrial plants, treating heavy metals in wastewater. By early 1994, afer the bench and demonstration tests were completed at RFETs and tests at the DOE Hanford Site, Oak Ridge National Laboratory, and Los Alamos National Laboratory, use of the methodology increased substantially. Table A-1 summarizes the types of 1994 projects at FFT. Two-thirds of the 25 projects are directly related to DOE NPL sites and one-third are from the private industrial sector.

A.5 Factors that Decrease Performance

Bench and pilot testing should be carried out at each project site to achieve high percent removal efficiency and decontamination factor values for heavy metals and radionuclide water pollutants. These tests enable system operators to optimize the treatment train parameters and identify the presence of competing or inhibiting chemical or physical factors. For the CPFM, several factors have been identified that can limit the technology's performance and increase treatment costs, and are listed below:

- Water chemistry not optimized
- Moderate to high TSS
- Freezing temperatures
- Hydrocarbon contaminants

Table **A-1**. Summary of the 1994 CPFM Projects at FFT

Treatment Category	CPFM Project Location			
	DOE NPL Site*		Industrial Plant	
	Number of Projects	Percent of Total	Number of Projects	Percent of Total
Wastewater	5	20%	6	24%
Groundwater	4	16%	1	4%
Decontamination and Decommissioning/Soil Washing (Secondary Wastewater)	5	20%	1	4%
Miscellaneous	2	8%	1	4%

Notes:

* NPL SITE refers to National Priorities List for radioactive contaminated sites.

- NH_4-ions for copper and uranium
- Influent pH of less than 6 or more than 10
- Flow rate less than 1 gpm
- Limited bed capacity
- Microalgae or turbidity
- Metallic/radionuclide concentration too high

A.6 Advantages of Methodology

The CPFM offers several advantages over conventional filtration, ion exchange, and reverse osmosis methods for the treatment and remediation of metallic water pollutants. Examples of advantages include:

- Efficient equipment design translates to higher performance capacity in physically less floor-, trailer-, or skid-mounted square footage

- More cost-effective treatment cost per 1,000 gallons of groundwater or wastewater treated than with ion exchange or reverse osmosis

- Removes colloidal and ionic heavy metal and uranium, plutonium, americium, and reactor-produced LLRW to levels not possible using ultrafiltration or microfiltration

- Has application for treating a wide range of mono-, di-, tri- and multi-valent inorganic metallic pollutants (and some complexed and chelated forms) not possible using conventional methodology

- Generates substantially lower quantities of spent bed material per unit volume water treated than ion-exchange resins, which translates to lower land disposal costs for hazardous and radioactive wastes

Appendix B
Case Studies

B.1 Introduction

Representative examples of Colloid Polishing Filter Method (CPFM) case studies are outlined in this section, which also presents analytical test data to provide a basis for estimating performance. Summary data are also provided for capital and operational costs. This section ends with a summary of performance and cost data. These case studies represent a broad spectrum of heavy metals and radionuclide treatment conditions for groundwater, industrial wastewater, and U.S. Department of Energy (DOE) facility projects.

B.2 Representative Case Examples

The following sections describe representative CPFM case studies.

B.2.1 Uranium Wastewater

Wastewater containing high concentrations of nitrate, sulfate, and uranium stored in a wastewater treatment system tank at a major west coast DOE facility has been successfully treated by the CPFM system. The nitrate, sulfate and uranium pollutants in the wastewater exceeded sewer discharge permit criteria. In addition, solidification, drum packaging, and low-level radioactive waste (LLRW) landfill disposal were considered too expensive. To treat this waste, FFT designed a treatment train for on-site pumping and treating based on biological denitrification, primary flocculation, high crossflow microfiltration for solids removal, and use of the CPFM system for uranium removal. This treatment train reduced the remediation cost by one-third to one-half the net cost of the LLRW land disposal option. Treatment using the CPFM also allowed the operation to meet the limits in the existing discharge permit. A total of 11,000 gallons of water were treated in 8 bioremediation days plus 3 CPFM treatment days at this Resource Conservation and Recovery Act (RCRA) facility. Water at this facility was contaminated with 50 to 60 milligrams per liter (mg/L) total uranium. After treatment, the water contained less than 10 mg/L total nitrogen, less than 250 mg/L sodium, and less than 0.10 mg/L total uranium.

B.2.2 Treatment of Strontium-90, Yttrium-90 Contaminated Groundwater

An average 5,000 gallons per day (gpd) of neutral pH groundwater contaminated by strontium 90, tritium-90 (gross beta/gamma about 3,000 picoCuries per liter [pCi/L]), trace heavy metals, and inorganic salts presented a challenge due to intermediate turbidity that inhibited the polishing filter system operation. The National Pollutant Discharge Elimination System (NPDES) permit issues focused on pH, turbidity, and the gross beta/gamma activity, requiring a safe margin for variability in the flow rate of 12 to 30 gallons per minute (gpm). For this project, a specially designed chemical reaction and microfiltration technique was employed for turbidity treatment upstream of the CPFM system. This treatment train removed strontium 90, tritium-90 and trace cesium 137, and cobalt 60 radionuclide pollutants operating at 99.5 percent to more than 99.9 percent removal efficiency.

B.2.3 Treatment of Contaminated Wastewater

A metals reprocessing plant located in Oak Ridge, Tennessee, produced depleted uranium-contaminated wastewater at a flow rate of 10 gpm. The wastewater required treatment prior to discharge under an NPDES permit. High total suspended solids (TSS) wastewater produced in reprocessing the depleted uranium was collected in a sump and stored in an equalization tank for neutralization, flocculation, solids removal, and filtration

prior to discharge. A pilot study was successfully carried out at the plant to evaluate an electrocoagulation method and the CPFM as methods for uranium removal. Problems with the electrocoagulation equipment prohibited use of this method as a primary treatment for the tests. For FFT's portion of the pilot study, the high suspended solids sump water was pumped directly to 10-micron bag filters and into two CPFM units mounted on a trailer. The total uranium concentration was reduced by more than 99.9 percent with the discharge stream activity being less than 0.1 pCi/L.

B.2.4 Treatment of LLRW Wastewater

A LLRW wastewater stream (averaging 12 gpm) at a major DOE facility in the southeastern U.S. contained ionic metal contaminants and less than 100 mg/L of total dissolved solids (TDS), representing a mixture of trace heavy metals and reactor-produced radionuclides. This waste stream required efficient, cost-effective treatment to meet NPDES discharge limits. FFT designed a skid-mounted CPFM system that allowed the customer to achieve the discharge limits for metals and radionuclides, yet reduce the annual operational cost by one-third compared to an ion exchange system. The cost saving was due to the system's higher milli-equivalent per pound of bed material advantage, extended bed-life, and reductions in the quantity of spent bed material requiring land disposal.

B.2.5 Treatment of Oil Production Wastewater Norm

Naturally occurring radioactive materials (NORM) contaminate crude oil via leaching during drilling operations, then partition into the aqueous phase, and so can be detected in the production wastewater subsequent to oil and water separation. Wastewater from oil production generally has low concentrations of NORM and is not covered under the disposal criteria of the original Atomic Energy Commission Act of 1954, the Uranium Mill Tailings Radiation Control Act, or the Nuclear Regulatory Commission's standards. Recently, U.S. Environmental Protection Agency (EPA) draft guidelines have been prepared that may require oil (and gas) production companies to treat the production water prior to discharge. FFT has conducted extensive scientific, technical, and engineering studies into the problem of removing NORM from oil production water. Test data indicate that CPFM has performed in the percent removal efficiency range of 95 to more than 99.9 percent (decontamination factor values of 305 to more than 1,000) based on gamma spectroscopy measurements of radium 226. FFT has completed the design and engineering for an offshore or land-based, skid-mounted system that can treat 25 to 300 gpm of oil production water.

B.2.6 Remediation of Norm-Contaminated Wastewater

A Texas-based oil company is developing alternative strategies for remediation of a major oil and gas production site including tank batteries, sludge pits, drilling pipe, and contaminated groundwater. FFT carried out a series of laboratory and field tests to evaluate the compliance issues and costs for remediating the NORM, representing natural uranium, radium 226/228, and radon gas. CPFM was used to treat the secondary wastewater fractions from liquified and partitioned hydrocarbons and tank bottom sludges containing NORM. The NORM activity in the treated waste was consistently observed to be significantly below EPA's drinking water standards. However, removal efficiencies for the radionuclide radium 226 were less than for other radionuclides.

B.2.7 Molybdenum in Uranium Mine Groundwater

Molybdenum is an inorganic metallic pollutant that exists in a wide range of chemical and physical states in water and is one of the most challenging metals to remediate. A series of tests were conducted at a South Texas uranium mine to compare molybdenum removal by the CPFM versus conventional flocculation methods to determine if the NPDES discharge permit limit could be achieved. The CPFM successfully removed molybdenum from groundwater, reducing the level from 49 mg/L to 0.4 mg/L.

Table B-2 provides an example of in situ uranium groundwater molybdenum removal by CPFM compared to filtration using conventional sorption and water filtration agents. Each method was tested using aliquots from the same groundwater sample at pH 7.1, adjusted to pH 8.5 before rapid filtering through a 1-centimeter-thick filter bed of the test material.

B.2.8 Removal of Selenium from Pit Water

A uranium mining site in the western U.S. routinely employed soil dewatering as part of the mining operation and excavated a large mining pit that stored hundreds of millions of gallons of water contaminated by uranium

Table **B-1**. Summary of Sample Sources and Pollutants for Case Studies

Sample Source and Pollutants	Analytical Method[1]	Untreated Influent (mg/L)	Treated Effluent (mg/L)
Smelting Plant Acid Water			
Arsenic	AA	1640	<0.01
Cadmium	AA	358	<0.01
Chromium^{+3}	AA	1100	<0.01
Copper	AA	1	<0.01
Lead	AA	22	<0.01
Nickel	AA	1	<0.01
Selenium	AA	8	<0.01
Tellurium	AA	<0.1	<0.01
Vanadium	AA	<0.01	<0.01
Zinc	AA	65	<0.01
Industrial Battery Plant			
Lead	AA	1094	<0.10
Chemical Manufacturing Co. Wastewater			
Chromium^{+3}	ICP	23	0.3
Groundwater Contaminated with Chromium			
Chromium^{+3}	ICP	2	<0.05[2]
Chromium^{+6}	ICP	1	<0.03
Food Processing Plant Wastewater			
Chromium^{+3}	ICP	0.06 - 0.10	0.02
Copper	ICP	0.07	0.03
Lead	ICP	0.10	0.04
Zinc	ICP	0.05 - 0.07	0.05
Metals Finishing Plan Clarifier Effluent (Texas) Run 1			
Arsenic	AA	---	<0.01
Cadmium	AA	0.01	<0.01
Chromium^{+3}	AA	1.30	<0.01
Copper	AA	<0.01	<0.01
Lead	AA	Trace	<0.01
Nickel	AA	0.01	<0.01
Tellurium	AA	<0.01	<0.01
Vanadium	AA	<0.01	<0.01
Zinc	AA	--	--

Table B-1. Summary of Sample Sources and Pollutants for Case Studies (Continued)

Sample Source and Pollutants	Analytical Method[1]	Untreated Influent (mg/L)	Treated Effluent (mg/L)
Metals Finishing Plant Clarifier Effluent (Texas) Run 2			
Chromium^{+3}	AA	0.15	<0.05
Zinc	AA	0.08	<0.005
Metals Finishing Plant (Mexico)			
Chromium^{+3}	AA	1350	0.11
Zinc	AA	80	<0.1
Metals Finishing Plant (Mexico)			
Chromium^{+3}	ICP	0.30	0.03
Copper	ICP	0.12	<0.02
Nickel	ICP	4.61	0.06
Lead	ICP	0.07	0.04
Zinc	ICP	0.72	0.03
Oil Refinery Flexicoker Clarifier Effluent			
Cadmium	AA	<0.01	<0.01
Chromium	AA	<0.01	<0.01
Copper	AA	---	<0.01
Lead	AA	<0.01	<0.01
Nickel	AA	0.42	<0.01
Selenium^{+4}	AA	0.75	<0.01
Tellurium	AA	<0.01	<0.01
Vanadium	AA	19.0	<0.01
Zinc	AA	---	<0.01
Oil Refinery DAF Water (Preactivated sludge)			
Arsenic	AA	---	<0.01
Cadmium	AA	<0.01	<0.01
Chromium^{+3}	AA	<0.01	<0.01
Copper	AA	<0.01	<0.01
Nickel	AA	0.15	<0.01
Selenium^{+4}	AA	0.16	<0.01
Tellurium	AA	0.10	<0.01
Vanadium	AA	1.20	<0.01
Oil Refinery Phenolic Sour Water Stream (pH 8.2)			
Selenium^{+4}	AA	0.170	0.005

Table B-1. Summary of Sample Sources and Pollutants for Case Studies (Continued)

Sample Source and Pollutants	Analytical Method[1]	Untreated Influent (mg/L)	Treated Effluent (mg/L)
Carpet Manufacturing Plant Dye Wastewater			
Chromium^{+3}	ICP	0.20	0.02
Copper	ICP	0.07	<0.03
Lead	ICP	0.03	<0.03
Zinc	ICP	0.05	0.03
Organic Dye	Visual	Brown Dye	Clear Water
TSS/TDS	---	High Solids	Low TSS, TDS
Circuit Board Manufacturing Wastewater			
Cadmium	AA	0.06	0.001
Chromium^{+3}	AA	0.02	0.01
Copper	AA	1.45	<0.01
Iron	AA	0.28	0.03
Silver	AA	0.05	0.01
Zinc	AA	0.10	0.01
Printing Ink	Visual	Cloudy Dye	Clear Water
TSS/TDS	---	Moderate	Low
Printing Shop Wastewater			
Copper	AA	0.10	0.01
Zinc	AA	0.71	0.03
Printing Ink	Visual	Black Dye	Clear Water
TSS/TDS	---	Moderate	Low
Textile Dye Wastewater 1			
Arsenic	GF	<0.003	<0.003
Cadmium	GF	0.0014	<0.0005
Copper	GF	0.240	0.140
Lead	ICP	0.030	<0.030
Mercury	CV	<0.001	<0.001
Silver	ICP	0.030	<0.030
Zinc	ICP	0.130	0.030
Organic Dye	Visual	Blue Dye	Clear Water
TSS/TDS	---	High Solids	Low TSS, TDS

Table B-1. Summary of Sample Sources and Pollutants for Case Studies (Continued)

Sample Source and Pollutants	Analytical Method[1]	Untreated Influent (mg/L)	Treated Effluent (mg/L)
Textile Dye Wastewater 27			
Arsenic	GF	0.008	<0.003
Cadmium	GF	<0.0005	<0.0005
Copper	GF	0.0160	<0.003
Lead	GF	0.005	<0.002
Mercury	GF	<0.0002	<0.0002
Nickel	GF	0.003	<0.002
Silver	GF	<0.0005	<0.0005
Zinc	GF	0.130	0.002
Uranium Mining (in situ)			
Boron	ICP	0.51 - 0.80	0.010 - 0.005
Cobalt	ICP	0.01 - 0.06	0.001 - 0.003
Iron	ICP	0.10 - 0.31	<0.001 - <0.005
Molybdenum	ICP	35 - 60	0.050 - 0.5000
Selenium^{+4}	ICP	0.51 - 0.70	0.005 - 0.008
Silicon	ICP	7 - 10	0.010 - 0.020
Silver	ICP	0.01 - 0.02	0.002 - 0.005
Strontium	ICP	0.60 - 0.90	0.015 - 0.020
Thallium	ICP	0.01 - 0.03	0.001 - 0.005
Vanadium	ICP	0.02 - 0.09	0.001 - 0.002
Uranium Mining Pit Water			
Selenium^{+6}	ICP	0.760	0.005

Notes:

1 Analytical Method refers to: Graphite Furnace (GF), Inductivity Coupled Plasma Emission (ICP), Atomic Absorption (AA), or Cold Vapor (CV) Spectroscopy.

2 Represents separate batch runs on different days.

TSS Total suspended solids
TDS Total dissolved solids
-- No result

Table **B-2**. Molybdenum Atomic Absorption Analysis Concentration

Treatment Material/System	Effluent Concentration (mg/L)
Control (unfiltered)	49
Magnesium Oxide	48
Bone Charcoal	40
Activated Alumina	38
Diatomaceous Earth	36
Aluminum Sulfide (Floc/filter)	35
Alum	22
CPFM	0.4

and selenium. A double-blind study was conducted by the geological engineer at the mine to assess technologies for the removal of selenium (Se^{+6}) at concentrations of 500 to 800 mg/L, which constituted 98 percent of the total selenium in the pit water. After reviewing the available methodologies, seven methods were tested that appeared to hold promise as remediation methods for removing Se^{+6}. Based on independent, EPA-certified laboratory analysis of duplicate test runs, the mine engineer determined that CPFM had the best performance at more than 99 percent removal efficiency, with some samples being reduced from an average 0.750 mg/L to the analytical detection limit of 0.002 mg/L, using graphite furnace analysis.

B.2.9 Selenium in Oil Refinery Wastewater

Selenium is commonly found in certain crude oil from the U.S. and the Middle East regions and ultimately is detected in the refinery wastewater. A major west coast oil refinery commissioned a series of tests by an environmental engineering group to evaluate selenium (Se^{+6} and Se^{+4} oxidation states) removal from refinery sour water. (Sour water is wastewater having moderate to high concentrations of phenolic chemical oxygen demand [COD] upstream to the aeration ponds used for biodegradation of the COD.) CPFM successfully removed the Se^{+6}/Se^{+4} in the process waste containing an average phenol concentration of 0.900 mg/L from 0.170 mg/L influent to 0.005 mg/L treated. These results were based on duplicate test runs analyzed for total selenium by an independent commercial laboratory and the consulting engineering group.

B.2.10 Treatment of Chromium in Soil Washing Wastewater

At a chemical products distribution company in New Mexico, leaking storage tanks contaminated an estimated 120 cubic yards of sandy soil with trace hydrocarbons and chromium (Cr^{+3}). Core samples indicated the Cr^{+3} ranged from 16 to more than 1,200 mg/L, representing both a leachable and a nonleachable species. During remediation, the leach water contained moderate to high levels of suspended solids and total chromium ranging from 122 to 450 mg/L, which was used as the influent water to the FFT wastewater treatment system. A primary pH adjustment tank, flocculation tank, and clarifier reduced the total chromium to an average 15 mg/L, which was polished by the CPFM to less than 0.03 mg/L.

B.2.11 Metals Roofing Manufacturer - South Texas

At this facility, trace light oil hydrocarbons containing hexavalent chrome and zinc with high TSS content were being treated using an oil skimmer followed by chrome reduction to Cr^{+3}; primary lime flocculation; and polymer agglomeration. Suspended solids were removed using an inclined plate clarifier and sand filter bed. The discharge stream had a pH 7.8 to 8.2 and consistently contained chromium and zinc concentrations in the 0.10 to 0.80 mg/L range, which exceeded the NPDES discharge permit limits of 0.01 for chromium and 0.05 for zinc. Numerous changes and modifications in the treatment train chemistry failed to correct the problem. Two deep bed-type (6 feet high, back-washable) CPFM tanks were installed to polish the sandfilter water at 6 gpm based on bench test results. The chromium and zinc concentrations detectable in the discharge water downstream from the CPFM were lowered to less than 0.01 mg/L for both metals, meeting permit discharge standards.

B.2.12 Metals Finishing Wastewater Copper and Zinc

A major manufacturing company located in the northeastern U.S. generated 32,000 gpd of heavy metals-contaminated wastewater from copper metal scrubbing, cleaning, and treatment processes. Acidic wastewater contained moderate levels of suspended solids and complexed or chelated copper and zinc. FFT designed a modified treatment train using CPFM that consistently removed the metals to levels not achieved by reverse osmosis or ion exchange methods. In addition, the net cost per 1,000 gallons treated was reduced by one-third compared to the original primary treatment method that was being used.

B.2.13 Hazardous Waste Incinerator Metals Wastewater Treatment

A hazardous waste incinerator plant in South Texas generated rinse water containing arsenic, copper, selenium, nickel, lead, zinc, and antimony at a combined concentration fo 6 to 10 mg/L. This effluent could not meet NPDES discharge permit limits due to intermittent spikes in the concentrations. The spikes resulted from waste from one customer. Assessment of the primary chemistry treatment methods being used indicated that the ferric chloride reaction tank and subsequent flocculation tank were inadequately treating the wastewater. Discharge compliance was achieved by converting the primary reaction tank to a ChemSorb-500

flocculation tank, changing the polymer in the flocculation tank, and then polishing the low-TSS water with the CPFM.

B.2.14 Treatment of Metals Wastewater for Volume Minimization

A small chemical plant manufacturing company in South Texas accumulated 115 cubic yards of metal oxide, magnesium sulfate, and zinc dust sludges containing cadmium, lead, and zinc. These wastes were classified as hazardous by EPA toxicity characteristic leaching procedure (TCLP) standards. Because the sludges contained mainly water-soluble (and leachable) metals, a simple, cost-effective solution to the problem was suggested to the customer in lieu of expensive commercial hazardous metals waste disposal. For about $10,000, a slurry mixing box (second hand) and a gravity sedimentation tank with a sludge pump were purchased and set up at the company for water dilution, mixing, and leaching the metals sludges and sulfates. The sludges were processed in batches as needed and an existing filter press was employed for dewatering the leached solids prior to stabilization with FFT ChemSorb-500 powder. The metals were removed in the filter press wastewater using an FFT mobile unit equipped with pumps, controls, a prefilter, and CPFM. Using this method, the original cost of $700 per ton for the metals sludge was reduced to $10 to $12 per ton and the metals containing wastewater can be discharged to a sewer under an existing publicly owned treatment works (POTW) permit. The concentrations of the heavy metals in the sludge wastewater were in the range of 35 mg/L to 100 mg/L for cadmium, 300 to 100 mg/L for lead, and 50 to 200 mg/L for zinc.

B.3 Performance and Cost Summary

Approximately 90 different groundwater and industrial wastewater sites and 10 secondary wastewater streams from soil washing have been tested using the CPFM since late 1991. Generally, two-thirds of the water samples yielded percent removal efficiencies using the CPFM in the range of 99.4 to 99.9 for 18 different heavy metals representing random, grab samples. The other one-third of the samples required chemical preconditioning or pH adjustment before using the CPFM to achieve 98 to 99 percent removal efficiencies. Uranium and transuranic pollutants (plutonium and americium and other nontritium radionuclides) were efficiently removed directly by the CPFM at 95 to 99.9 percent removal efficiencies, except in situations in which the performance was compromised due to some intrinsic water chemistry or interfering factors that required pretreatment or optimization (for example, high ammonium-ion concentrations for uranium and copper; the presence of high suspended solids such as micro-algae; and micro-aggregated or complexed forms of technetium that require chemical pretreatment).

Bench-scale tests (and pilot tests when feasible) are necessary so that the methodology can be adapted to the specific conditions because each groundwater and wastewater stream is chemically different and the inorganic metallic pollutants can exist in a broad range of chemical, physical, and oxidation state forms. In addition, the CPFM sorption bed formulation can be modified to match the specific contaminated water's characteristics, and multiple sorption bed formulations can be used in series to sequentially remove different organic metallic pollutants.

Information is now available regarding the capital and operational costs for the CPFM. The basic 25 gpm (maximum 35 gpm) vertically configured CPFM unit has been designed with five filter packs totaling 14.8 cubic feet of sorption bed. Extra structural work and lead shielding (averaging 3 inches thick) for this unit costs an additional $10,000. The operational cost will depend to a large extent on the volume of water being treated and the project duration. Generally, for remediation projects, 2 days setup and demobilization time are adequate. Continuous treatment at 1 to 25 gpm is feasible at a daily cost of $1,000 to $1,300 for a trailer-mounted CPFM system and one operator, plus the additional support staff and chemicals and supplies required for the project. The average chemical cost for heavy metals and uranium or transuranic pollutant remediation is in the range of $1.00 to $1.50 per 1,000 gallons treated.

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