INNOVATIVE TECHNOLOGY
Summary Report

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3M Selective Separation Cartridges

Industry Programs and
Subsurface Contaminants Focus Area

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INNOVATIVE TECHNOLOGY
Summary Report

3M Selective Separation Cartridges

OST/TMS ID 1543

Industry Programs and
Subsurface Contaminants Focus Area

Demonstrations and Deployments
R-Reactor Disassembly Basin, Savannah River Site
Aiken, SC
Ashtabula Environmental Management Project
Ashtabula, OH
Brookhaven National Laboratory
Long Island, NY

INNOVATIVE TECHNOLOGY
Summary Report

Purpose of this document

Innovative Technology Summary Reports are designed to provide potential users with the information they need to quickly determine whether a technology would apply to a particular environmental management problem. They are also designed for readers who may recommend that a technology be considered by prospective users.

Each report describes a technology, system, or process that has been developed and tested with funding from DOE's Office of Science and Technology (OST). A report presents the full range of problems that a technology, system, or process will address and its advantages to the DOE cleanup in terms of system performance, cost, and cleanup effectiveness. Most reports include comparisons to baseline technologies as well as other competing technologies. Information about commercial availability and technology readiness for implementation is also included. Innovative Technology Summary Reports are intended to provide summary information. References for more detailed information are provided in an appendix.

Efforts have been made to provide key data describing the performance, cost, and regulatory acceptance of the technology. If this information was not available at the time of publication, the omission is noted.

All published Innovative Technology Summary Reports are available on the OST Web site at http://www.em.doe.gov/ost under "Publications."

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SECTION 1
SUMMARY

Technology Summary

3M has developed a Selective Separation Cartridge that is designed to remove specific radionuclides in aqueous solutions at high flow rates. Many Department of Energy (DOE) sites have radionuclide-containing wastes that were left behind from nuclear weapons production. Much of the waste exists in the aqueous form and additional aqueous waste are continually being generated from groundwater remediation and decontamination and decommissioning (D&D) activities. The Selective Separation Cartridge is an efficient technology for the treatment of these wastes and is capable of removing various radionuclides to EPA drinking water standards.

The Selective Separation Cartridge is based on an innovative membrane technology developed by 3M. The membrane is unique in that it is made up of sorbent particles that are loaded or enmeshed onto a web or membrane. The membrane, termed the WWL™, is fabricated into a spiral-wound, cartridge-filter shown below in Figure 1. Several classes of materials have been successfully incorporated into the 3M membranes, including commercial ion-exchange materials, inorganic adsorbents, unique zeolite structures, and sophisticated macrocyclic molecular recognition compounds.

The Selective Separation Cartridges have the following characteristics:

- high separation efficiencies
- high radionuclide loading
- high flow rates
- fast reaction kinetics
- physical ruggedness
- compact size with small system footprint
- cost effective treatment

Figure 1. Selective Separation Cartridges in nested arrangement.

Membranes have been developed for removal of the following contaminants:

- Cesium (Cs)
- Technetium (Tc)
- Strontium (Sr)
- Cobalt (Co)
- Lead (Pb)

At the time this report was written, membranes for the removal of Uranium (U) and Plutonium (Pu) were under development.

Advantages Over Baseline

3M's selective separation membranes have several advantages over the baseline technology: conventional sorbent columns.

- Small (5-80μm), high surface-area, particles can be incorporated into membranes
  - particles of this size would result in unacceptable back-pressure if used in columns;

- Faster flow rate than standard ion exchange columns while achieving equal extraction efficiencies;

- Channeling, which can be a severe limitation for columns, is absent in the 3M membrane system; and
- The footprint of the cartridge system is small compared to a column system of equivalent capacity

Demonstration Summary

Demonstrations and Deployments of the Selective Separation Cartridges are listed below:

- Argonne National Laboratory (ANL) CP-5 (September 1996): for the removal of Cs-137 and ^{60}Co from storage pool water at 0.5 gpm
- Paducah Gaseous Diffusion Plant, Paducah Kentucky (July 1997): for the removal of Tc-99 form groundwater at 1 gpm (Pilot Scale)
- Brookhaven National Laboratory (BNL) (December 1998): for the removal of Sr-90 frorm 4,000-gallon of tank waste at 1.5 gpm
- Ashtabula Environmental Management Project (AEMP)(Former RMI Titanium Plant), Ashtabula, OH (June 1999): for the removal of Tc-99 from groundwater at 10 gpm
- Savannah River Site (SRS), R-Disassembly Basin, Aiken, SC (May 2000): for removal of Sr-90 and Cs-137 from a 5-millon gallon concrete lagoon at 20 gpm through the Accelerated Site Technology Deployment (ASTD) Program

Future Planned Deployments

- Paducah Gaseous Diffusion Plant
- BNL

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Other

All published Innovative Technology Summary Reports are available on the OST Web site at http://www.em.doe.gov/ost under “Publications.” The Technology Management System (TMS), also available through the OST Web site, provides information about OST programs, technologies, and problems. The OST/TMS ID for Empore™ Membrane Separation Technology is 1543.

SECTION 2
TECHNOLOGY DESCRIPTION

Overall Process Definition

3M's Selective Separation Cartridge is based on the WWL™ membrane separation technology. The trademarked identification WWL™ is used to differentiate the membrane which is used in the Selective Separation Cartridges from a similar membrane used in 3M's Rapid Liquid Sampler™, known as the Empore™ membrane. Both the WWL™ and Empore™ membranes are created by enmeshing surface-active sorbent particles in a web-like matrix. Particles as small as 5-80 microns have been incorporated into these membranes. This new approach incorporates a variety of sorbent particles into membranes that can be fabricated into versatile, highly efficient chemical adsorbing cartridges. It is possible to fabricate membranes from almost any particle provided it is properly sized.

The primary components that make up the Selective Separation Cartridges are described below:

Particles

The Selective Separation Cartridge technology relies on the use of chemically active particles that have the ability to adsorb specific dissolved materials from liquid media. Particles are selected based on the following criteria

- Affinity for analyte: ability to capture and hold the radionuclide of concern;

- Capacity for retention of target analyte: sufficient capacity on a per weight basis;

- Physical stability: ability to be incorporated into a membrane with acceptable functional characteristics (e.g. flow-rate, pressure drop, kinetic performance); and

- Economic feasibility: the particle must be available in a cost range that makes final cost of the complete system competitive with existing technologies.

Particles have been developed for the following contaminants:

- Cs, Tc, Sr, Co, Pb; and
- U and Pu (currently under development).

Membranes

The 3M Selective Separations Cartridges are fabricated from sheet-like, roll-goods membranes. The membranes are comprised of the active particles (described above), fibers, and binder. The fibers are chemically inert and stable over a broad range of aqueous conditions (i.e. pH). In addition, they are very stable in a radioactive field and are not subject to deterioration over prolonged use in such an environment.

Cartridges

Each Selective Separation Cartridge is fabricated by combining a uniform sheet WWL™ membrane with a scrim material, and winding it onto a hollow, perforated core. The article formed is referred to as a spiral-wound cartridge. The ends are then capped – one closed, the other open – to form the final product. The direction of flow through the cartridge is from the outside to in: water surrounds the cartridge in its housing, passes through the layers of the membrane, through the perforated core, and then out the open end. Removal of the target radionuclide takes place as water passes across the active particles in the membrane layers.

Selective Separation Cartridges cartridges may be prepared in a number of different sizes. A typical cartridge designed to process liquid at 1 to 2 gallons per minute measure 2.5 in. in diameter by 10 in. in length, and contains approximately 450 square inches of membrane with 100 to 200 grams of available active particle. Larger cartridges have been designed to handle increased flow rates: an experimental cartridge measuring 6 in. in diameter by 22 in. in length was used to process water at a flow rate exceeding 15 gallons per minute. Cartridge dimensions are predicated both on system requirements with regards to flow and back pressure and industry standard for filter vessels an housings. For instance, the open ends of the cartridges are fitted with o-rings that adapt to one of two industry-standard receptacles for filters, designated as 222 and 226.

Design considerations for the Selective Separation Cartridges are similar to those for ion-exchange systems. Design consideration include:

- Target contaminant(s)
- Concentration of target contaminant(s)
- Concentration of competing ions (ions that will also be removed by the cartridge, therefore; “competing” with target contaminant for adsorption sites)
- Desired effluent quality
- Desired flow rate
- Suspended solids concentration
- Temperature
- pH

System Operation

The Selective Separation Cartridges are deployed in a system that includes a pump, filter vessels, active filter cartridges, plumbing, valves, and gauges. The system is small enough that the components can be carried on small utility carts. A 10-15 gpm system is shown in Figure 2 below. Because the requirement for each application differs, there are a variety of systems that may be provided with the cartridges. The simplest system is an arrangement of vessels in series: water enters at one end and passes through a vessel (or series of vessels) containing prefilters for solids removal, and then through active cartridges for radionuclide removal, exiting the opposite end of the system. Vessels may contain single cartridges or multiple cartridges in a “nested” arrangement. The combination of large, nested cartridges and a redirectable flow system provides high flowrate and continuous operation.

Figure 2. Selective Separation Cartridgesvessels in series.

The spiral-wound construction of the cartridges requires that they be protected from particulates so that they do not become prematurely fouled. 3M has explored several alternative methods for prefiltration of suspended solids. The current design uses a commercially available, high-capacity, radial-pleated 3M particulate filters (2 micron nominal filtration) in front of finer particulate prefilters (rated at 0.2 micron).

When utilizing 3M's Selective Separation Cartridge's for the removal of Cs-137, which emits gama radiation, special safety precautions are required. Adsorption of Cs-137 onto the cartridges can result in radiation levels that are not safe for workers if appropriate safety measures are not taken. Worker exposure to radiation can be minimized to safe levels by radiation monitoring, shielding, and minimizing time spent in close proximity to the cartridge vessel. To minimize worker exposure, the entire cartridge filter-vessel is disposed directly into a waste container rather than removing each cartridge from the vessel. For other contaminants, such as Sr-90 and Tc-99 that emit weaker radiation, the cartridge can be safely handled at maximum capacity.

SECTION 3
PERFORMANCE

Introduction

The Selective Separation Cartridges have been demonstrated at the ANL-East, Paducah, and AEMP. The technology has been deployed at BNL and SRS's R-Basin. This report will present performance information from the small-scale deployment at BNL, the demonstration at the AEMP, and the ASTD project at SRS. The projects are presented in chronological order and each project has increased size and scope. The results of the demonstration at ANL, CP-5 in 1997 are documented in a separate ITSR entitled "Empore^{TM} Membrane Separation Technology" (February 2000).

Brookhaven National Laboratory (BNL)

3M completed a commercial deployment of the Selective Separation Cartridges at BNL for the removal of strontium-90 (Sr-90) from 4,000 gallons of tanked purge water from groundwater sampling activities. Key project information is listed in Table1 below:

Table 1. Key Information, Brookhaven National Laboratory Deployment

Date Performed:	December 1998
Contaminants/Source:	Sr-90 contaminated purge water from groundwater sampling activities (15-700 pCi/L initial Sr-90 concentration)
System Description:	Three single cartridge vessels in series with particulate prefilters
Design Flowrate:	1.5 gpm
Gallons Processed:	4,000 gal

Results

The system successfully reduced the Sr-90 levels in the wastewater to below detection levels of 1-2 pCi/L and also below the discharge limit of 4 pCi/L. BNL is considering utilizing the Selective Separation Cartridges in a trailer-mounted system to remove the Sr-90 from purge water during well development.

Ashtabula Environmental Management Project (AEMP)

The Selective Separation Cartridge was demonstrated at the AEMP, site of the former RMI Titanium Plant, in Ashtabula, Ohio for the removal of technetium-99 (Tc-99) from groundwater. The groundwater, also contaminated with TCE and uranium, was generated from demonstration of an innovative groundwater flushing technology. The goals of this demonstration were to evaluate the removal efficiency, and capacity of the Tc-removal cartridge; gather data for economic evaluation; continue to optimize system performance at higher flow rates; and evaluate the performance of the particulate prefilters under field conditions. Key project information is presented below:

Table 2. Key Information, Ashtabula Demonstration

Date Performed:	May – October 1999
Contaminants/Source:	Tc-99 contaminated groundwater (1,500 - 8,000 pCi/L)
System Description:	Three vessels in series with 9 nested cartridges per vessel and two particulate prefilters.
Design Flowrate:	10 gpm
Gallons Processed:	17,045 gal

The 3M system effectively reduced the Tc-99 concentration to well below the effluent treatment requirement of 900 pCi/L. The portable system used at the AEMP utilized 3 in. by 10 in. cartridges in a nested arrangement. Prefiltration was accomplished by two particulate prefilters in series; a 2 micron radial-pleated filter followed by a vessel containing six 0.1 micron prefilters. Cartridges were replaced when the effluent Tc-99 concentration reached 80% of influent concentration based on laboratory analysis. A simple change in valves redirected flow so the new cartridges became last in the sequence.

Results

The results of the demonstration at AEMP are summarized below:

- Effluent levels ranged from <2.0 - 400 pCi/L surpassing requirement of 900 pCi/L; and
- Each vessel in series, comprised of 9 nested cartridges, processed approximately 3,000 gallons of water before breakthrough.

The presence of nitrate (NO_3^-) in the groundwater at AEMP was found to reduce the adsorptive capacity of the Selective Separation Cartridges for Tc-99. Nitrate is a primary competing ion that also absorbs onto the cartridge. The effect of competing ions can be seen by comparing the results from Ashtabula to results from previous testing at Paducah. At Ashtabula, where nitrate levels in the groundwater were measured to be 3,800 ppm, a single cartridge was able to process an average 330 gallons (based on 3,000 gallons for 9 nested cartridges). At Paducah, where the nitrate level was approximately 30 ppm, a similar Tc-99 cartridge was able to process 22,000 gallons before breakthrough. It is evident that the presence of competing ions has a great effect on cartridge capacity. A comparison of cartridge capacity with respect to nitrate concentration is presented in Figure 3 below.

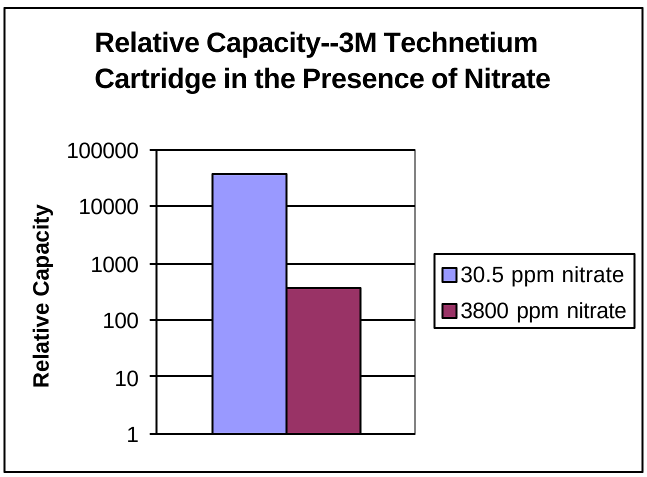

Figure 3. Relative capacity of 3M techetium cartridge in the presence of nitrate.

Savannah River Site, R-Disassembly Basin, ASTD Project

3M's Selective Separation Cartridge system was deployed at SRS in an ASTD project to remove Cs-137 from five-million gallons of water in the R-Reactor Disassembly Basin. Although removal of Cs-137 was the primary focus of the project, a short-term test was also conducted using a Sr-90 removal cartridge. The Sr-removal test lasted approximately 2 weeks, and the formal Cs-removal phase ran for 8 weeks. Based on successful results, the Cs-removal cartridge remained on-line for several months after the formal 8-week project.

The R-Reactor is one of five production reactors at SRS placed into shutdown mode in 1992. The primary contaminants in the basin, present at concentrations above DOE release limits, include tritium, Cs-137 and Sr-90. The baseline technology for treatment of this water is tanking it to another part of the site for treatment. The goal of this deployment was to remove the radionuclides from the basin water, contributing to the basin's closure, using faster and cheaper technology.

During this deployment, the contaminated water was pumped from the basin, treated, and then discharged back into the basin. As part of this ASTD project, another innovative technology that utilized ion-exchange was also operated for treatment of the basin water and also discharging treated water back into the basin. Key project information is provided below in Table 3. A photograph of the system at SRS is provided in Figure 4.

Table 3. Key Information, Savannah River Site ASTD

Date Performed:	5/17 – 5/30/2000 (Sr-90-removal test) 6/16 – 8/28/2000 (Cs-137-removal deployment)
Contaminants/Source:	Sr-90 (23,500 pCi/L initial concentration) Cs-137 (92,800pCi/L initial concentration)
Discharge Limits	1,000 pCi/L Sr-90 [1] 3,000 pCi/L Cs-137[1]
System Description:	1 lead-shielded filter vessel housing 22 nested cartridges (2.5 in. by 20 in cartidges), two particulate prefilters in series (2 micron filter followed by 0.2 micron filter)
Design Flowrate:	20 gpm
***Gallons Processed*:**	30,000 gal. (Sr-90-removal phase) 1.25 million gal. (Cs-137-removal phase)

[1]DOE Order 5400.5 criteria for unrestricted release

Results

Sr-Removal Cartridge

The Sr-removal cartridge worked effectively, reducing the concentration of Sr-90 from an influent concentration of 23,500 pCi/L, to an effluent concentration less than 100 pCi/L. The 22-nested cartridges were replaced after 50 percent breakthrough was observed. Two sets of cartridges were used during the Sr-90-removal phase. The first set of 22 filters processed approximately 11,500 gallons before breakthrough and the second set of filters processed 11,750 gallons before breakthrough. The capacity of the Sr-cartridge was reduced by the presence of Ca, a competing ion. This occurrence was not unexpected based on the concentrations of $CaCO_3$ in the basin.

Figure 4. System at SRS with two particulate pre-filters and lead-shielded cartridge vessel.

The first set of Sr-removal cartridges also adsorbed some Cs-137. This is undesirable since the cartridges were designed to be selective for Sr-90, and different radiation-safety considerations are required for Cs-137, which emits stronger gamma radiation. The second set of Sr-cartridges, which had a slightly different composition, initially adsorbed some Cs-137, but the Cs was eventually displaced by Sr-90. This phenomenon was indicated by observations of an increase and subsequent decrease in radiation levels. 3M has a new particle under development that has demonstrated better selectivity for Sr, and is therefore less affected by competing ions, such as Ca, and other contaminants such as Cs.

Cs-Removal Cartridge

The Cs-removal cartridge, which was the focus of this project, performed successfully and had no problems with competing ions. The water pumped from the basin had an initial Cs-137 concentration of approximately 92,800 pCi/L. After treatment, the water was discharged back into the basin at a concentration less than 200 pCi/L, a removal efficiency of greater than 99.8 percent. After and initial startup period, the Cs-removal cartridges were operated 24 hours per day, 7 days per week. The system was shut down only for change-out of the particulate pre-filters, which was required every 2 to 3 weeks or every 400,000 gallons. During the formal 8-week ASTD project, from 6/21 and 8/28, the system processed 1.25 million gallons of basin water with original set of 22 cartridge filters while maintaining a removal efficiency of greater than 97 percent. This system continued to operate after the formal test period and as of 11/30/2000 the system has processed over 2.4 million gallons with the original filters with no significant decrease in removal efficiency. Based on 3M design projections, one set of 22 Cs Selective Separation Cartridges has the capacity to remove all the Cs that was present in the basin at the beginning of the project. Therefore the cartridges are not expected to breakthrough before the completion of the project.

Two points should be noted regarding the configuration of the system at SRS. First, the system was operated in a recycle mode with the treated water being discharged back into the basin. The 3M system was operated in parallel with another completing innovative technology also removing Cs. Therefore; the influent Cs concentration was not constant, but continually decreasing. The recycle mode of operation is less efficient than a once-through mode in that more than one “basin-volume” will likely be pumped and treated to achieve the desired contaminant reduction. This mode was the most practical for this situation, considering that there was not a suitable, permitted receiver which to discharge the water, at the time of the project. Secondly, the configuration at SRS utilized a single cartridge vessel rather than two vessels in series. Operation of two vessels in series allows for maximum utilization of the cartridge capacity without sacrificing effluent quality. During the Sr-removal phase, the cartridges were changed-out at 50 percent breakthrough, therefore; some of the cartridge’s capacity was not utilized.

Performance Conclusions

3M’s Selective Separation Cartridge performed as designed for the removal of dissolved Tc-99, Sr-90 and Cs-137 from aqueous streams as evidenced by the results presented here. 3M has successfully scaled-up the technology, progressing from a 1.5 gpm system at Brookhaven, to a 10 gpm system at Ashtabula, to a 20 gpm system at SRS. Developmental efforts continue on 50 gpm system, which has been tested in a lab setting. 3M’s compact high-capacity system demonstrated the ability to meet desired removal efficiencies while operating around the clock with little maintenance. In some cases, the presence of competing ions, such as nitrates, and calcium was found to reduce the capacity of the cartridge for the target contaminant. This is a common challenge for treatment systems based on ion-exchange and/or adsorption. Remedies to this issue include pretreatment to remove competing ions or modifications to the particles used in the membranes.

Overall, the performance of the Selective Separation Cartridges, met or exceeded expectations. This innovative treatment technology has proven to be a significant breakthrough in removal of dissolved inorganic contaminants from aqueous streams.

SECTION 4
TECHNOLOGY APPLICABILITY AND ALTERNATIVES

Technology Applicability

The 3M Selective Separation Cartridge is applicable to the removal of specific dissolved radionuclides and heavy metals from liquid streams. This technology is applicable to most situations where ion exchange columns are utilized.

This technology is applicable to the removal of the following radionuclides and selective heavy metals:

- Cs, Tc, Sr, Co, Pb and Cu;
- U and Pu (currently under development)

The Selective Separation Cartridges use a number of known, high performance, chemical adsorbing materials, which previously could not be put into a useful engineered form because of their small particle size. Further, new particles that are developed in the future can be integrated into the WWL™ membrane for use in the Selective Separation Cartridges.

This technology is applicable to treatment of aqueous solutions from the following sources

- Groundwater remediation systems
- Purge-water from groundwater sampling activities
- D&D activities
- Reactor fuel storage and disassembly basins
- Surface water treatment

Rapid Liquid Sampler (RLS)

3M has also developed a similar membrane technology, called Empore™, for aqueous sampling and analysis applications. The RLS is designed for rapid and economical field sampling of heavy metal and radionuclide contaminants. The sampling system is field-portable, rugged and user friendly. A disk from the RLS is pictured in Figure 5. The RLS technology is described in an ITSR entitled Rapid Sampling Using 3M Membrane Technology, January 2000. The RLS has been used during most of the demonstrations and deployments of the Selective Separation Cartridges.

Figure 5. Rapid Liquid Samplers and Empore™ Rad Disks

Competing Technologies

Baseline and competing technologies utilized for the removal of radionuclides from aqueous wastes include ion-exchange columns, evaporation, activated carbon adsorption, and reverse osmosis. In some instances, sites ship bulk liquids off-site for treatment and disposal.

Part of the SRS ASTD project includes a “head to head” comparison between 3M’s technology and a deep-bed ion exchange technology called Highly Selective Nuclide Removal System (NURES) by Selion Technologies, Inc.

Patents/Commercialization/Sponsor

The technology is being developed and marketed by 3M. Support for 3M's research was provided by the DOE's NETL under Contract DE- AD21-96MC33089. The terms Empore™ and WWL™ are trademarked 3M product names. 3M has several patents relating to separation technology materials and/or methods. These include US4,153,661; S 5,071, 10; US 5,147,539; US5,207,916; US 5,618,438; US5,616,407; US 5,328,758; and US 5,115,779.

With regard to commercialization of the technology, 3M's deployment at BNL was considered a commercial deployment. 3M is participating in an ASTD at R-Disassembly Basin of SRS with a 20 gpm system, which will further commercialization efforts. Success at R-Basin could lead directly to additional work treating similar liquids present in other basins at SRS's. 3M is a large international company with a successful track record in commercialization of innovative products.

SECTION 5
COST

Methodology

The following cost analysis is based on the demonstrations and deployments completed to date and includes comparisons to the baseline methods where possible. Cost information for the Selective Separation Cartridge was provided by 3M and baseline technology costs have been obtained from DOE sites and/or drawn from the public record.

The primary cost components associated with 3M's Selective Separation Cartridges include;

- capital cost for system components;
- the Selective Separation Cartridges;
- operation and maintenance (O&M)- includes labor, sampling, and particulate pre-filters; and
- disposal of spent cartridges.

For each demonstration/deployment, relevant cost information is provided following a brief description of the project. In most cases each of the cost components listed above are provided and a unit cost (cost/gallon treated) is also presented. Where possible baseline costs are provided for comparison. The cost information provided for the SRS ASTD is the most extensive since this is the largest deployment to date.

Cost Analysis

Brookhaven National Laboratory (BNL) Deployment

The BNL deployment, during which Sr-90 was removed from 4,000 gallon waste tank, is considered a small volume application. Unit costs tend to be slightly higher for small volume applications. Strontium was reduced from an initial concentration, ranging from 15-700 piC/l, to less than 2 pCi/L. For this fixed volume application, the system cost was incorporated into the unit cost.

- Total processing cost $3.14/gal
  (cost includes: system , cartridges, labor, disposal)

At Brookhaven National Laboratory, off-site disposal costs for fiscal year 1999 averaged $10.20 per gallon for non-concentrated liquids, and $22.50 for concentrates derived from reverse osmosis. Solids disposal is priced at $15.00 per cubic foot. Therefore, the 3M system offers a minimum cost savings of 69 percent compared to the baseline ($10.20 per gallon).

Summary of RMI, Ashtabula OH Costs

The capital and operating costs for the demonstration at AEMP are summarized below. A 10 gpm system was utilized at Ashtabula to remove Tc-99 from 17,045 gallons of contaminated groundwater.

- Capital cost for 10 gpm system $15,000

- Operating costs (labor) $0.02/gal
- Cartridge replacement $2.65/gal
- Disposal of spent cartridges $0.04/gal
- Total cost per gallon for treatment $2.71/gal

As discussed in the Performance Section of this report, the high concentration of nitrate in the groundwater at Ashtabula (approximately 3,800 ppm) contributed to a shortened cartridge life and subsequently higher cost. In comparison, the filter replacement costs for the identical system at Paducah Paducah, where the nitrate concentration was approximately 31 ppm, was predicted to be less than $0.03 per gallon. The baseline cost for Tc removal at Ashtabula is difficult to determine because it is was accomplished as part of the site's wastewater treatment plant. Information on the cost for treatment of the Tc component was not available.

Summary of Savannah River Site ASTD Project Costs

The capital cost for the 20 gpm system at SRS was approximately $12,700. This included a pump, two carts, two particulate prefilter vessels, one cartridge vessel, valves, plumbing and fabrication. The system was modified at SRS by the addition of lead shielding, a stronger cart, and miscellaneous plumbing modifications. The cost for these modifications is not included in the $12,700. Westinghouse Savannah River Company (WSRC), Facilities Disposition Division (FDD) operated the system. Project preparation, O&M labor, capital equipment and material costs for the ASTD project at SRS are summarized in Table 4. The project preparation costs incurred by WSRC include a SRS site overhead fee of 37 percent.

Table 4. Savannah River Site ASTD project cost summary

Description	Cost
Project Preparation	
FDD Planning Costs (included deployment and technical task plans, functional requirements, and travel to 3M's site for equipment inspection)	$9,590
Start-up costs (includes equipment modifications described above, pressure testing, job specific training, Works Clearance Permitting, Job-Specific Radiation Work Permitting, and an ALARA review.)	$62,746
Operation and Maintenance Labor (10 weeks)	$64,390
Capital Equipment and Material Costs	
Capital cost for 20 gpm system (excluding cartridges and on-site modifications)	$12,700
Sr-Removal Selective Separation Cartridges	$12,760/set of 22
Cs-Removal Selective Separation Cartridges	$60,500/set 22
Filter Vessel (replacement cost when Cs-cartridges and vessel require direct disposal)	$3,400 each
2 micron particulate prefilter (3M 740B)	$400 each
0.2 micron particulate prefilter	$550/set of 11

In terms of O&M costs, the most significant costs are for the Selective Separation Cartridges and O&M labor. O&M labor includes general maintenance, engineering, radiation protection support, and sampling and analysis. Other minor costs that contribute to the overall O&M cost include replacement of particulate filters, and disposal of spent cartridges and used filters.

Labor costs for the two-week deployment of Sr cartridges and the eight-week deployment of the Cs cartridges amounted to approximately $64,390. These cost covered the period from May to August 28, 2000, during which time over 1.2 million gallons of basin water was treated. After steady state operation was achieved during the Cs-removal phase, the O&M labor costs averaged $2,000 per week, with approximately 150,000 gallon/week being treated or a unit cost of $0.013/gal.

With the goal of comparing the O&M costs of 3M's system and the baseline technology at SRS, unit costs were calculated for each technology. Some assumptions were applied in calculating the unit costs so the comparison is made on equivalent terms. An explanation of how the unit costs were calculated is provided below.

Because the 3M system was operated in a recycle mode during the ASTD, and the baseline technology involves once-through treatment, the cost per gallon can not be directly compared. The primary reason for this is that in a recycle configuration, the influent concentration decreases over time, while in a once-through configuration, the influent concentration is relatively constant. Since the cartridge utilization rate is a function of influent concentration, the cost per gallon would be lower for the recycle configuration. In simple terms a cartridge will process more water before breakthrough in a recycle configuration, thus lowering the cost per gallon, compared to a once through configuration. To address the situation, the following assumptions were applied to the calculation of unit costs for operation of 3M's system:

- The Selective Separation Cartridges utilization cost is based on 3M projections that one set of 22 Cs-cartridges has the capacity to treat the entire 5 million-gallon basin to required levels
- Costs for cartridge utilization are based on once-through treatment (not recycle) where the influent concentration is relatively constant and the total gallons processed is 5 million gallons.
- O&M labor, sampling, and particulate filter changeouts, are based on costs after steady state operation during the ASTD project

A summary of the unit costs for O&M of the Selective Separation Cartridges is provided in Table 5.

Table 5 O&M Unit Costs	
Description	**Unit Cost**
O&M Labor	$0.013/gal
Cs-Removal Cartridge utlilization[1]	$0.012/gal
Sr-Removal Cartridge utillization[2]	$1.09/gal
Particulate Filter Replacement and Cartridge Filter Vessel Replacement[3]	$0.007gal
Disposal of Spent Cartridges and Particulate Filters[4]	$0.006/gal
Total cost per gallon for removal of Sr	$1.11/gal
Total cost per gallon for removal of Cs	$0.035/gal

[1]Based on projected treatment of 5.0 million-gallons
[2]Based on treatment of 11,750 gallons at which point 50 percent breakthrough occurred
[3]Based on treatment of 400,000 gallons per set of particulate filters
[4]Based on projected disposal of 3 B-25 waste boxes at completion of entire and $5K in characterization costs

The unit cost for O&M of 3M system for Cs removal is very low at 3.5 cents per gallon. The cost for Sr removal stands out as being much higher at $1.11 per gallon. The unit cost for Sr removal is much higher because one set of 22 cartridges processed only 11,750 gallons compared to 5 million gallons projected for the Cs cartridges. As discussed in the performance section, the capacity of the Sr-cartridges was reduced greatly by the presence of Ca in the basin, which is a competing ion. 3M is working on new Sr-removal particle for use in the cartridge that is less affected by Ca.

Comparison to Baseline

The baseline method for treatment of the basin water at SRS is hauling the water to a wastewater treatment plant (F&H Effluent Treatment Facility) at the site. The treatment plant is designed to treat 18,000,000 gal/yr and uses crossflow ceramic filters, activated carbon, and reverse osmosis as the primary treatment systems. Mitsubishi HPK-25 resin is used to remove Cs-137. The operating cost for the plant is approximately $0.96/gal. The water from the R-Basin would have to be trucked via 5,000 gallon tanker to the treatment plant. The treatment plant's uploading station can handle 1-2 shipments per week. At this rate, it would take six to eight years to treat the 5 million gallons from the R-Basin. The baseline cost to ship and treat the 5 million gallons of water from the R-Basin is estimated to be over 5.5 million dollars. This works out to about $1.10 per gallon.

The unit cost 3.5 cents per gallon for Cs removal of is very low compared to the baseline. At 3.5 cents per gallon, the O&M cost for removal of Cs from the 5 million gallons of water in the basin would amount to $175, 000. The unit cost for Sr removal at $1.11 per gallon is about the same cost as the baseline. 3M predicts that this cost could be reduced to $ 0.72 per gallon by using larger, 6 in. by 20 in. Sr cartridges , which are cheaper to make. In comparison to the baseline, treatment using 3M's system is definitely much faster. At 150,000 gallons per week, the entire basin could be treated in just over eight months. This time savings will also result in cost savings.

Cost Conclusions

Based on the cost analysis of the demonstrations and deployment presented here, 3M's Selective Separation Cartridge offers significant cost savings over the baseline technologies. The capital cost for 3M's system is relatively inexpensive, typically under $15,000 without cartridges. The ASTD project at SRS provides the most substantial cost information given the scale of the project. The unit cost for the O&M of the Cs-removal cartridge of approximately 3.5 cents per gallon is very attractive. Although the Sr-removal cartridge did not offer same level of cost savings as the Cs –cartridge, modifications to improve cost efficiency and selectivity may lead to cost savings of similar magnitude.

End users should note that the cost of the system is highly dependent on site conditions. Specifically, the presence of competing ions in a wastewater stream has a significant impact on the useful life of the cartridge, which ultimately affects cost. Therefore, when applying the cost information presented here, the concentration of competing ions must be considered.

SECTION 6
REGULATORY AND POLICY ISSUES

Regulatory Considerations

The primary regulatory considerations related to operation of the 3M Selective Separation Cartridges include:

- Removing contaminant to required effluent concentration (discharge limits vary based on specific contaminant, site, and point of discharge); National Pollution Discharge Elimination System (NPDES) permit or other discharge permits may be required;
- Proper disposal of spent cartridges which may constitute a Low Level Waste (LLW) or hazardous waste depending on the contaminants; and
- Compliance with applicable Occupational Safety and Health Administration (OSHA) regulations for safe operation.

Safety, Risks, Benefits, and Community Reaction

With respect to operational safety issues, the Selective Separation Cartridges involve the same considerations as those for other radioactive liquid treatment technologies. For the removal of Cs-137, special safety precautions a required because cartridge has the capacity to absorb Cs-137 to levels that are not safe to contact-handle. At the SRS ASTD project, lead shielding was placed around the cartridge vessel to reduce worker exposure. Worker exposure was minimized to safe levels by a combination of shielding, distance (staying as far away from the system as possible), and time (spending as little time near the system as possible). Due to the radiation levels, the entire filter vessel was disposed directly into a waste container rather than removing each cartridge from the vessel. For other contaminants such as Sr-90 and Tc-99, radiation exposure is not a safety issue because the cartridge can be safely handled at maximum capacity.

The risk of exceeding discharge limits and releasing contaminants to the environment is low. This risk is minimized by operating the cartridges in series, which provides a level of redundancy in treatment; timely changeout of the cartridges based on regular effluent sampling; and knowledge of the influent characteristics.

The primary benefit of the Selective Separation Cartridges is that it allows the selective removal of radioactive contaminants at increased flow rates when compared to ion exchange or evaporators, while concentrating the contaminants in the compact cartridge. The system has a lower capital cost and smaller footprint than conventional technology. The small footprint and versatility of design enables the 3M System to be retrofitted to existing treatment processes for improvements in speed and quantity of treatment. There has been no negative community reaction to this technology as it is simple and has no adverse environmental or socioeconomic impact.

SECTION 7
LESSONS LEARNED

Implementation Considerations

The presence of competing ions and particulate matter must be considered in implementation of this technology. In some cases, the presence of competing ions such as nitrates, and Ca, was found to reduce the cartridge's capacity for the contaminant of concern. This is a common challenge for liquid treatment systems that are based on ion exchange and/or adsorption.

Protecting the cartridges from premature fouling with particulates is essential due to the significant cost of the 3M cartridges. During the deployment at BNL, prefilter fouling with particulate and bacterial material was a problem. Therefore, an effective particulate prefiltration system is imperative.

Technology Limitations and Needs for Future Development

Areas for future development include:

- reducing the effect of competing ions (positive laboratory results have been achieved for a new Sr-cartridge that minimizes competition from Ca, as experienced at SRS;
- development of Selective Separation Cartridges for other contaminants, such as U and Pu (development of these cartridges is underway); and
- increase flowrate (3M has achieved positive results in the laboratory with a larger cartridge capable of processing 50 gpm)

APPENDIX A
REFERENCES

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APPENDIX B
ACRONYMS AND ABBREVIATIONS

ANL	Argonne National Laboratory
ASTD	Accelerated Site Technology Deployment Program
BNL	Brookhaven National Laboratory
Cs	Cesium
Co	Cobalt
D&D	Decontamination and Decommissioning
DOE	Department of Energy
FDD	Facilities Disposition Division
INEEL	Idaho National Environmental Engineering Laboratory
ITSR	Innovative Technology Summary Report
LLW	Low Level Waste
NPDES	National Pollution Discharge Elimination System
NETL	National Energy Technology Laboratory
O&M	Operation and Maintenance
OSHA	Occupational Safety and Health Administration
OST	Office of Science and Technology
Pb	Lead
Pu	Plutonium
RLS	Rapid Liquid Sampler
Sr	Strontium (Sr)
SRS	Savannah River Site
Tc	Technetium (Tc)
TMS	Technology Management System
U	Uranium
WSRC	Westinghouse Savannah River Company