

Fission Products Separations Testing

Efficient Separations and Processing
Crosscutting Program



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Fission Products Separations Testing

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Efficient Separations and Processing
Crosscutting Program

Demonstrated at
Oak Ridge Reservation
Oak Ridge, Tennessee

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 if 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://ost.em.doe.gov> under "Publications."

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SECTION 1 SUMMARY

Technology Summary

To remove the radioactive fission products strontium-90 (^{90}Sr) and cesium-137 (^{137}Cs) from near-neutral pH wastewater and groundwater, sorbents are needed that rapidly and tightly bind these ions into a stable solid matrix of low volume which is (or can be made) acceptable for disposal.

Wastewater is typically treated by passing the water through columns filled with sorbent, with flow rate adjusted to give sufficient contact time for adsorption of the contaminant ions. Sorption capacity is usually measured by the number of bed volumes of water that pass through the column before effluent concentration of the contaminant reaches 50% of the influent concentration. This point of 50% breakthrough will depend not only on the properties of the sorbent, but also on the relative concentrations of contaminants and competing ions in the wastewater.

^{90}Sr and ^{137}Cs removal will generally be required for the process wastewater associated with tank waste remediation at Hanford, Savannah River, Idaho and Oak Ridge. Certain DOE groundwater sites may also be sufficiently contaminated to require treatment.

Several new sorbent materials have been evaluated for their ability to remove ^{90}Sr and ^{137}Cs from water solution, and were compared to the baseline sorbent used at Oak Ridge National Laboratory (ORNL), chabazite zeolite. One material, Crystalline Silico-Titanate (CST), in its engineered form IonsivTM IE-911, has shown excellent potential with a variety of tested wastewaters. In particular, in comparison to the baseline sorbent, chabazite zeolite, IonsivTM IE-911 CST has the advantages of:

- high selectivity for strontium—the more difficult ion to capture
- very high selectivity for cesium
- ability to function in high-salt media
- greater sorption capacity for strontium, resulting in a substantial (3-30 times) reduction in final waste volume (and disposal cost)
- superior mechanical stability, with no column plugging or fines generation

However, at this stage of technological development, CST has the disadvantage of much higher material cost than zeolite, and at its current cost, is not economic. The cost disadvantage for CST may decrease substantially if and when other uses (notably for cesium removal from tank waste) lead to high-volume production of CST and subsequent reductions in costs of this new material.

Demonstration Summary

This report covers the period October, 1994 through August, 1999. A number of promising sorbents, originally developed for recovery of ^{90}Sr and ^{137}Cs from highly alkaline tank waste, were evaluated for extraction of these ions from process wastewater and groundwater. The studied sorbents included: (a) resorcinol-formaldehyde resin, an organic sorbent developed at Savannah River Laboratory and manufactured by the Boulder Scientific Company; (b) sodium nonatitanate, a strontium sorbent developed by Texas A&M University and Allied Signal Corporation; and (c) CST, in its engineered form IonsivTM IE-911, developed at Sandia National Laboratories and Texas A&M University and prepared in engineering form by UOP, Inc. Characterization of these materials and the ORNL baseline sorbent, chabazite zeolite, using simulant wastewater, showed IonsivTM IE-911 CST to be technically superior to the zeolite and the other materials. These results were confirmed in September, 1998, by small-scale column studies of an actual groundwater (from Seep D at ORNL) that contained calcium ion concentration of 75 ppm—nearly twice that of the process water simulant. Maximum strontium loading on CST was more than 3 times

higher than on zeolite, and strontium was retained on CST rather than being displaced by competing cations as was observed to occur with zeolite.

A field demonstration using a small CST column to treat ^{90}Sr -contaminated groundwater collected at Core Hole 8 (ORNL) operated continuously for five months. No strontium was observed in the effluent until 3200 bed volumes were treated, after which the strontium showed a slow, unsteady increase that peaked at 25% of influent concentration at 22,000 bed volumes. Strontium concentrations then decreased slightly and averaged 24% for the remainder of the run that concluded at 42,000 bed volumes. These data suggest that at least 30,000 bed volumes of this sump water can be treated before column effluent activity exceeds the DOE 5400.5 Derived Concentration Guide of 37 Bq/L ^{90}Sr . As noted in previous CST column studies, the sorption capacity for cesium is so great that no ^{137}Cs was found in the traced effluent, even after treating 42,000 bed volumes of groundwater containing high levels (85 ppm) of calcium. The sorption capacity of CST for cesium is about 15 times the capacity of chabazite zeolite.

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Other

All published Innovative Technology Summary Reports are available on the OST Web site at <http://ost.em.doe.gov> under "Publications." The Technology Management System, also available through the OST Web site, provides information about OST programs, technologies, and problems. The OST reference number for Fission Products Separations is #205.

SECTION 2 TECHNOLOGY DESCRIPTION

Overall Process Definition

The basic principle of ion-exchange sorption is that ions in solution are electrically charged and can be attracted to locations on the solid sorbent that are oppositely charged. A sorbent with high affinity for a particular ion is said to be selective for that ion. This affinity is usually attributed to the good geometric fit of the sorbed ion in the sorbent crystal matrix. When a waste solution contacts a sorbent, ions with low affinity are displaced from the sorbent by ions of high affinity.

Large, singly charged wastewater cations such as potassium and cesium easily shed their waters of hydration and form strong bonds with the ion-exchange sorbent. Cesium-sorbent interactions are often irreversible, with bound cesium displaced from the sorbent only by high wastewater concentrations of potassium. In contrast, doubly charged ions such as strontium, calcium and magnesium are strongly hydrated and therefore form long, weak bonds to sorbents that span the ions' hydration spheres. These weakly sorbed ions are therefore rather easily displaced by competing cations, and require additional time to penetrate and bond to the sorbent.

Most sorbents have a lower selectivity for strontium than for cesium. When both of these contaminants are present, it is generally the breakthrough of radiostrontium, rather than that of radiocesium, that determines the lifetime of an ion-exchange column and thereby drives the economics of the treatment process.

Project studies over the past two years have concentrated on CST, an ion-exchange material developed at Sandia National Laboratory and Texas A&M University for alkaline tank waste remediation. CST is now available from UOP, Inc., in powder and pellet forms. Because water flow through packed powder is extremely slow, only the pellet form, Ionsiv™ IE-911, is suitable for column work. It was evaluated for simultaneous ⁹⁰Sr and ¹³⁷Cs removal in column studies on the following wastewaters:

- a simulant of wastewater from the Process Waste Treatment Plant (PWTP) at Oak Ridge
- an actual seep water from ORNL
- groundwater from Core Hole 8 sump, ORNL

Compositions of these waters are presented in Table 1.

In addition, batch studies not discussed in this report were conducted on two actual wastewater samples:

- wastewater from the washdown of low-level waste (LLW) tanks at ORNL
- wastewater normally treated at the Central Neutralization Facility (CNF) at the East Tennessee Technology Park (formerly K-25)

For these batch studies, CST in both powder and pellet forms was evaluated as a sorbent. Strontium decontamination by less than a factor of 100 was observed, and this was insufficient to allow the product wastewater to be discharged to the wastewater treatment plant. The high concentration of potassium (18 ppm) and the presence of complexing agents in the LLW tanks washdown wastewater were probably responsible for the poor capture of strontium by CST from that waste. CST was more successful in capturing cesium and strontium from the CNF wastewater, and was clearly superior to the chabazite zeolite. Details of these studies can be found in the FY 98-99 report cited in the appendix (Bostick and DePaoli, 1999).

Table 1. Composition of Process Waste Treatment Plant (PWTP) actual and simulant wastewater, Seep D water, and groundwater from Core Hole 8 sump

Component	Concentration (mg/L)			
	PWTP, actual	PWTP, simulant	Seep D water ^a	Groundwater, Core Hole 8 ^{a,b}
Ca ²⁺	35–40	45	76	85
¹³⁷ Cs ⁺	9.4 × 10 ⁻⁸ (3.0 × 10 ² Bq/L)	3.4 × 10 ⁻⁴ (1.12 × 10 ⁶ Bq/L)	3.4 × 10 ⁻⁴ (1.12 × 10 ⁶ Bq/L)	3.4 × 10 ⁻⁴ (1.12 × 10 ⁶ Bq/L)
K ⁺	1–3	1.2	1.6	1
Mg ²⁺	7–8	8.8	9.1	8
Na ⁺	14–30	18.3	8.7	8
Sr ²⁺ (total)	0.1	0.1	0.1	0.1
Sr ²⁺ (rad.)	5.3 × 10 ⁻⁸ as ⁹⁰ Sr (2.70 × 10 ² Bq/L)	1.14 × 10 ⁻⁶ as ⁸⁵ Sr (1.0 × 10 ⁶ Bq/L)	5.33 × 10 ⁻⁶ as ⁹⁰ Sr (2.7 × 10 ⁴ Bq/L)	3 × 10 ⁻⁸ as ⁹⁰ Sr (1.50 × 10 ² Bq/L)
pH	6.7–9	7–8	8	7.2

^aCesium added to these waste waters in tracer levels.

^bCore Hole 8 water collected from Bldg. 2016 sump.

System Operation

Column testing was used to define the sorption characteristics of the different test materials under dynamic flow conditions. Small columns were used in order to limit the amount of materials and time required for testing. Columns were 1 cm in diameter and were packed with 2-4 g of preconditioned sorbent, resulting in a bed volume of 4-5 mL. A peristaltic pump was used to transfer the previously filtered feed solution through a 0.45- μm Supor™ filter membrane into the base of the sorbent column (Fig. 1). The flow rate of feed was maintained at about 1.2 mL/min. Feed was introduced at the bottom of the column to maximize contact of the solution and sorbent within the column.

An automatic fraction collector was used to collect column effluent over 2- to 10-h periods (about 36-190 bed volumes per fraction.) The radionuclide content of each fraction was determined, and intermittent samples were analyzed for all elements using ICP emission spectroscopy.

Gamma scanning equipment was designed and used to locate gamma emitters along loaded columns in post-operation analysis. This system was helpful in column tests in which the loading capacity of the sorbent for a given emitter is so large that unduly long operating times would be required to observe breakthrough. For example, in the case of cesium sorption on CST, an operating time of 17 years was estimated for complete breakthrough using the process wastewater feed and the chosen flow rate. The portable gamma counting system located the position of the cesium mass transfer zone within the CST column, allowing extrapolation of cesium breakthrough parameters from limited column operation.

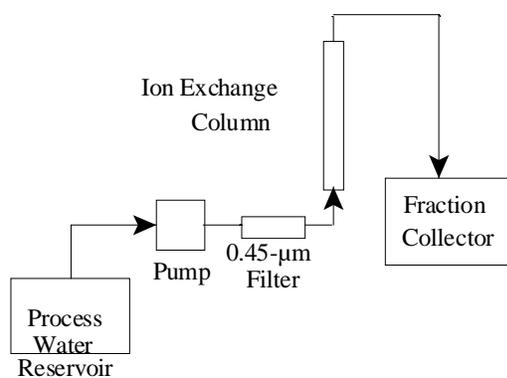


Fig. 1. Flow diagram of column test

SECTION 3 PERFORMANCE

Demonstration Plan

A survey of customers within the Oak Ridge Reservation was conducted in FY1997 to define the critical parameters for removing ^{90}Sr and ^{137}Cs from wastewater. Survey results revealed the following:

- local sites have a limited (and shrinking) budget for treating aqueous waste streams
- process selection will be based on
 - sorbent costs
 - use of existing equipment
 - disposal costs for spent processing materials
- inorganic sorbents are preferred over organic (more disposal options)

Bench-scale evaluation of several new sorbent materials showed that CST had the greatest promise for selective sorption of these contaminants. Small-column tests on a variety of wastewaters and simulants were therefore conducted to provide the parameters necessary to predict the performance of CST in scaled-up systems. Previous studies of the baseline treatment technology—nuclide sorption on chabazite zeolite—using the same wastewaters and treatment conditions, provided the benchmark against which the CST could be compared. The properties of these two sorbents are summarized in Table 2.

Process Wastewater Treatment Plant simulant was formulated to be representative of feed to the Process Waste Treatment Plant (PWTP) at ORNL and also fall within the ranges of concentration found in groundwater. The contaminated seep water (**Seep D**) is notable for its high calcium concentration—about twice that found in PWTP simulant. **Core Hole 8** groundwater was selected for testing because it was contaminated with ^{90}Sr at levels exceeding DOE discharge limits.

Results

Process Wastewater Treatment Plant Simulant

Breakthrough curves for ^{90}Sr and ^{137}Cs on the chabazite zeolite columns (Figure 2) can be compared with those for the CST columns (Figure 3) shown below. The theoretical curves are constructed using a model originally proposed by Rosen (see Bostick and DePaoli, 1999, for details). That model assumes one well-defined ion exchange reaction and a bed length that allows for several mass transfer zones for the reaction. These assumptions hold for cesium, but not for strontium on CST which requires a more complex model (as yet undeveloped.)

Strontium was first observed in the zeolite column effluent at 3000 bed volumes (BV), with fractional breakthroughs of 10% and 50% occurring at 6600 and 15,000 BV, respectively. Under these conditions, cesium breakthrough was 1% after 15,000 BV, 10% after 30,000 BV, and 50% after 50,000 BV. Toward the end of the column test the zeolite began to break down, creating fines that cemented together, causing channeling and scatter in the cesium breakthrough data. Strontium loading for the zeolite was 60 meq/kg at 50% strontium breakthrough, and the cesium loading was 0.2 meq/kg at 50% cesium breakthrough.

The superior performance of CST is demonstrated by the breakthrough curves in Figure 3. The CST column was operated for ten months, processing 120,000 BV during that time. No visual change in the appearance of the CST pellets was noticed, whereas continuous breakdown of zeolite plugged the column after 5 months of operation. Only limited maintenance of the CST system was required. This included the replacement of worn peristaltic tubing, flow lines, and the prefilter that showed evidence of algae growth.

The strontium breakthrough curve on CST is very unusual in shape, showing an initial rise (expected) to 28% breakthrough ($C/C_0 = 0.28$), followed by a decrease/increase succession (unexpected) that drops to

15% breakthrough at 120,000 BV. This phenomenon was also noted in the CST column tests with groundwater. A complex mechanism for strontium sorption and ion exchange (whereby more sorption sites become available with time) is indicated by these data. Linear extrapolation of the curve from the point at which the column test was terminated would give 50% breakthrough of strontium at 175,000 BV. Cesium breakthrough was not observed. Approximately 300 meq/kg strontium and 0.3 meq/kg cesium had been sorbed onto the column when the test was terminated. Gamma scanning results indicated the point of 50% cesium saturation would be 2.1 meq/kg.

Table 2. Physical and chemical parameters of sorbents

	Chabazite zeolite	Crystalline silicotitanate ^a
Source	GSA Resources, Inc.	UOP Molecular Sieves
Form	Naturally occurring, inorganic zeolite	Inorganic, engineered pellets or powder; framework of aluminosilicate
Exchangeable cation	Sodium	Sodium and hydrogen
Cost	\$102/ft ³	\$7200/ft ³
Bulk density, g/cm ³	0.7	1.0
Particle density, g/cm ³	1.73	2.0
Average particle size, μm	480 ± 220	410 ± 110
Moisture content, %	7.71	5.85 (6.07% for IONSIV IE-910)
Order of selectivity in process waste simulant	Na < Mg < Ca < Sr < Cs	Mg < Ca < Na < K < Sr < Cs
Column operating characteristics	Material is friable; tends to break down prior to complete loading, causing column plugging	Material appears to be structurally stable; in column test over 10 months, no noticeable plugging or fines produced
Pretreatment for near-neutral-pH waste treatment	Sieve; wash with 2 M NaCl; wash with H ₂ O; air dry	Sieve, wash with H ₂ O; wash with 0.1 M HCl
Ion-exchange capacity, meq/g	2.2	2.5

^aInformation in table is for engineered form of CST (IonsivTM IE-911)

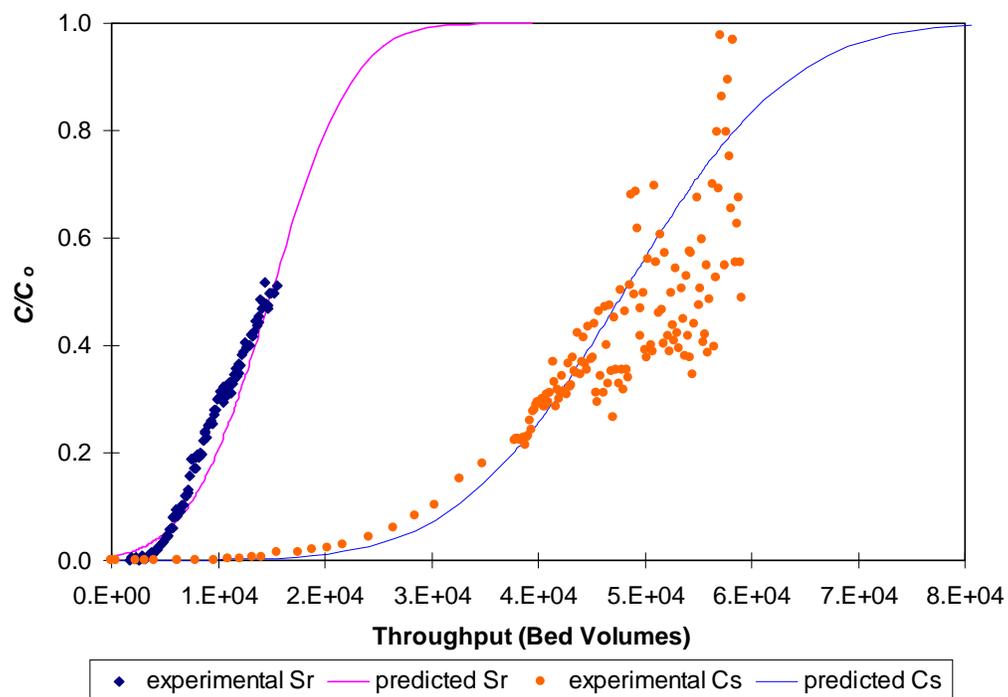


Figure 2. Experimental and theoretical breakthrough of strontium and cesium on chabazite zeolite in PWTP simulant

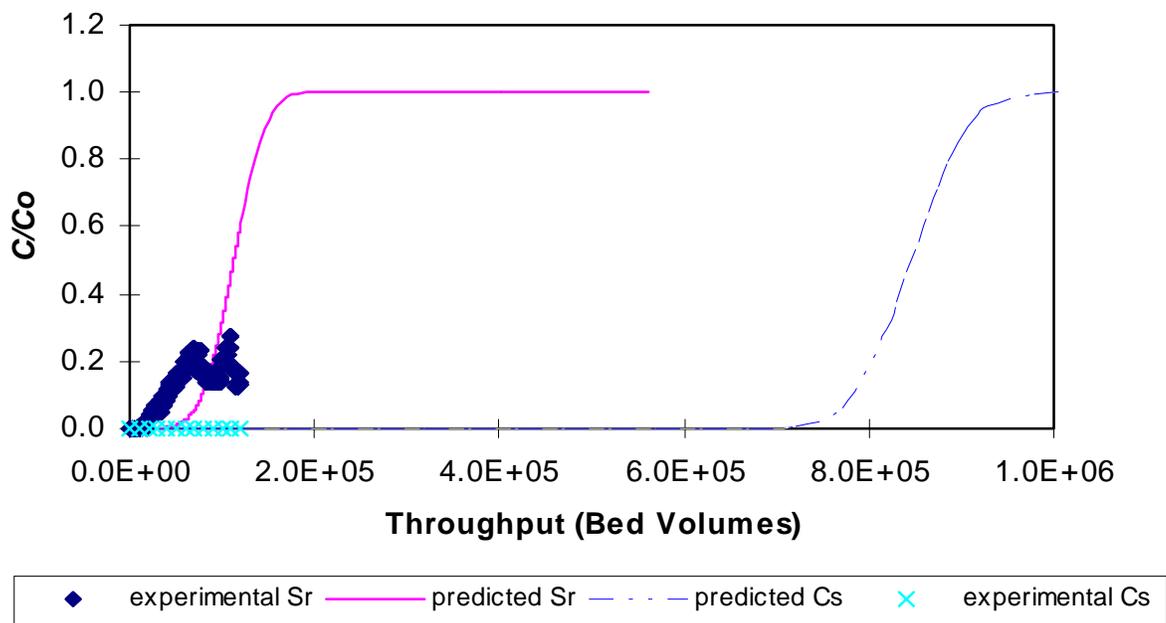


Figure 3. Experimental and theoretical breakthroughs of strontium and cesium on Hydrogen-1 CST in PWTP simulant

Seep D Water

Breakthrough curves for Seep D water were similar in character to those above, with CST again outperforming the zeolite. The most notable difference was the loss of strontium by the zeolite, with more than half of that originally sorbed onto the column being displaced by other cations after 22,000 BV. No such displacement was observed from the CST column, even at a throughput of 60,000 BV.

Core Hole 8 Groundwater

The elevated concentrations of calcium (85 ppm) leached from limestone formations at the Core Hole accelerate strontium breakthrough from CST. Results were otherwise similar to those for PWTP simulant. At least 30,000 BV of water could be treated before the effluent activity level exceeds the DOE 5400.5 Derived Concentration Guide of 37 Bq/L ⁹⁰Sr (original activity in the Core Hole 8 plume is 170 Bq/L.)

SECTION 4 TECHNOLOGY APPLICABILITY AND ALTERNATIVES

Competing Technologies

Current treatment processes for the decontamination of wastewater usually involve the removal of the radionuclides by ion exchange on organic resins or inorganic zeolites. One of the drawbacks in using these technologies is that they are not adequately selective for the removal of these particular radionuclides in the presence of large concentrations of alkaline and alkaline-earth metals typically found in wastewater. Consequently, the sorbents are quickly exhausted and generate large amounts of solid secondary waste. Because the handling and disposal of these secondary wastes can be very expensive, new processes are needed that will minimize the volume of secondary waste produced during wastewater treatment. In addition to the disposal issue, the location of contaminated groundwater sites generally is remote and not easily accessible to treatment and disposal systems. Methods for isolation and on-site treatment of groundwater are needed that can be implemented at these remote sites.

Despite the problems noted above, ion exchange is the compelling choice for wastewater treatment, offering

- simplicity of operation in modular units of equipment
- high waste concentration factors
- well-understood principles of operation
- an acceptable solid waste form

Technology Applicability

CST is now the only technology that has been applied at large scale for removing radioactive cesium from alkaline tank waste, and has been extensively evaluated in engineering studies sponsored by the Tanks Focus Area. Approximately 31,000 gal of Melton Valley Storage Tank (MVST) supernatant at Oak Ridge was processed in a 1997 engineering demonstration, with 1,142 Curies of cesium removed and loaded onto 70 gal of Ionsiv™ IE-911 sorbent. Laboratory tests showed that the loaded sorbent was suitable for disposal at the Nevada Test Site (NTS) and no further stabilization was necessary to meet waste acceptance criteria. Results are summarized in DOE-1999a (see References). Loaded CST can also be vitrified into HLW glass as demonstrated in 1997 (DOE-1999b).

Because CST has the potential to be widely adopted for DOE tank waste cleanup, its simultaneous use as a sorbent for radioactive wastewater treatment offers several advantages, including:

- increased volume demand for CST should lower initial material costs
- worker familiarity with sorbent properties leads to safe and efficient handling

Patents/Commercialization/Sponsor

Chabazite zeolite is a naturally occurring mineral that is available from a number of commercial sources. The sample used in this study was purchased from GSA Resources, Inc.

CST was originally developed under sponsorship of the Efficient Separations and Processing Crosscutting Program by researchers at Sandia National Laboratories and Texas A&M University. The U. S. Patent Office has notified Sandia that a patent has been allowed for CST materials, and issuance is expected in a short time. The technology is jointly owned by Sandia and Texas A&M. Additional patents are pending. The government has retained rights for its use by the government or its contractors.

UOP, Inc., Des Plaines, Illinois, has been granted an exclusive license for commercial use of the CST technology. CST has been made available in powder and engineered (mesh pellets) forms by UOP under the trade names Ionsiv-910 and Ionsiv-911, respectively.

SECTION 5 COST

Methodology

A cost scenario is presented that projects total cost of wastewater remediation and disposal of the loaded sorbent for CST and zeolite. Comparisons are made on the basis of CST having more than seven (7) times the loading capacity of zeolite for ⁹⁰Sr and ¹³⁷Cs. Maintenance and operation costs for the sorption columns are limited to labor costs for changeout of the sorbent, based on prior experience at ORNL. This analysis assumes that the columns exist and there are no new capital costs. For new installations, the capital costs for new columns would be the same for both the new (CST) and baseline (zeolite) technologies. For either sorbent, 100 cubic feet of sorbent would be in use at one time. Identified costs therefore include only:

- sorbent materials
- disposal of the low-activity waste sorbents
- maintenance and operation of the columns

Cost Analysis

The amount of zeolite needed to treat the radioactive process waste at PWTP has been estimated to be 3000 ft³ per year (Berry, 1998). Approximately 422 ft³ of CST IonsivTM IE-911 would be required to match this zeolite treatment capacity and meet DOE 5400.5 regulations for process wastewater.

Disposal costs for spent sorbent are based on a recent ORNL study (Kent, 1998) that estimated transportation (\$93/ft³) and disposal costs (\$30/ft³) at the Nevada Test Site (NTS) for a solid waste containing 25 mCi/L of ¹³⁷Cs.

Comparative costs of these options are summarized in Table 3.

Table 3. Comparative Costs of Zeolite and CST Sorption at PWTP

	Zeolite	CST
Quantity needed per year	3000 ft ³	422 ft ³
Cost of sorbent	\$306,000 (\$102/ft ³)	\$3,038,400 (\$7200/ft ³)
Disposal cost of loaded sorbent	\$369,000 (\$123/ft ³)	\$51,900 (\$123/ft ³)
Operating costs	\$240,000 (\$8000/changeout)	\$33,800 (\$8000/changeout)
Total costs per year	\$915,000	\$3,124,100

Thus, in order to match the total cost per year for zeolite, the sorbent cost of CST would have to be reduced to \$1965/ft³.

Caveats:

- Comparative loading capacities will vary with waste stream composition and should be determined for candidate wastes by experimental small-column testing.
- The higher radioactivity of the loaded CST columns may make their unit disposal costs greater than those for zeolite.
- Changeout costs may be higher for zeolite than for CST, given the tendency for zeolite columns to plug.

Cost Conclusions

The demonstration of this technology used existing equipment (i.e., columns, pumps, valves, etc.). Therefore, this cost analysis assumes that the new technology (CST) replaces the baseline technology (zeolite) and uses the existing equipment. For new installation, the equipment costs would be the same for the new or baseline technologies.

Despite the superior technical performance of CST over zeolite, the present high cost of CST makes it economically unattractive for wastewater treatment. At \$7200/ft³ (vs \$102/ft³ for zeolite), CST is 70 times as expensive, but only 3-30 times more effective than zeolite. Solid waste disposal costs would have to be so large that they become the economic driver for adoption of CST under these conditions.

There is precedent that CST costs will diminish as the demand for larger quantities of the engineered form, IonsivTM IE-911 (for cesium removal from alkaline tank waste) drives the production of larger quantities, with subsequent reduction in unit costs.

SECTION 6 REGULATORY AND POLICY ISSUES

Regulatory Considerations

Ion exchange is a well understood and widely used technology for wastewater cleanup. Regulatory issues therefore are limited to waste discharge and safe practice, and should require no special permits related to adoption of a new technology.

Wastewater discharge is covered by DOE regulation 5400.5 which limits ^{90}Sr discharge to the Derived Concentration Guide of 1×10^{-6} mCi/L (37 Bq/L) and ^{137}Cs to 3×10^{-6} mCi/L (subject to the “sum of product” rule that applies when more than one radioactive species is present; the sum of all species’ concentrations expressed as % of maximum limit must not exceed 100%.) Additional federal and state regulations govern discharge of heavy metals (mercury, lead, etc.) that may also be present in the wastewater.

Sorbent is considered loaded when wastewater discharge approaches acceptable limits. For PWTP, using CST sorbent, limits are governed solely by ^{90}Sr limits (37 Bq/L) because CST sorption capacity for Cs is so great that no ^{137}Cs was detected in wastewater effluent in any of the ORNL tests.

The cesium- and strontium-loaded ion exchange materials must be managed as a low-level radioactive waste. Management of radioactive waste is addressed by DOE Order 5820.2a (to be replaced by DOE Order 435.1.) The revised directive will call for performance-based and risk-based requirements.

The Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) evaluation criteria are addressed for this technology as follows:

- *Overall Protection of Human Health and the Environment.* The technology removes radioactive ^{90}Sr and ^{137}Cs from wastewater to levels acceptable for water discharge to the environment. The radioactive species are sorbed onto solid inorganic pellets and safely disposed in an approved repository.
- *Compliance with Applicable or Relevant and Appropriate Requirements (ARARs).* Compliance with ARARs is required when waste is disposed on site. Loaded ion-exchange solids will be sent to an off-site repository for disposal.
- *Long-term Effectiveness and Permanence.* The low-activity solid waste will be appropriately packaged for safe transport and long-term disposal. Incursion of saline water into the disposal site would create the potential for release of ^{90}Sr into the aqueous environment, especially from loaded zeolite.
- *Reduction of Volume, Mobility or Toxicity.* ^{90}Sr and ^{137}Cs are concentrated and immobilized as sorbed ions in solid inorganic material, with CST volume being about 1/7 that of zeolite.
- *Short-term Effectiveness.* No significant difference in effectiveness between zeolite and CST is forecast during construction and implementation of the ion-exchange treatment system.
- *Implementability.* Full-scale implementation is straightforward. All equipment and reagents are commercially available, and skilled personnel are familiar with the process.
- *Costs.* These have been addressed in Section 5.
- *State and Community Acceptance.* Citizens and regulators are familiar and comfortable with ion exchange sorption technology.

Safety, Risks, Benefits, and Community Reaction

- **Worker Safety.** Changeout of the loaded ion exchange materials can be hazardous to unprotected workers, but safe procedures have been established and implemented for this periodic task. CST offers less risk than zeolite, with fewer changeouts per year and less physical degradation of the solid particles.
- **Community Safety.** Transportation of low-activity waste solids poses some risk to the community, but accidents are of low probability, and shielded trucks and canisters protect the public from radiation.

SECTION 7 LESSONS LEARNED

Implementation Considerations

Ionsiv™ IE-911 CST offers superior performance over chabazite zeolite and other ion exchange materials for capturing ⁹⁰Sr and ¹³⁷Cs from aqueous wastes at near-neutral pH. The chief detraction for using CST is its high initial cost which can be partially offset by the reduced volume of solid waste generated.

Technology Limitations and Needs for Future Development

- CST was not effective for strontium capture when potassium ion concentration exceeded 18 ppm and trace complexing agents were present in wastewater (as from cleaning of LLW tanks)
- The multi-stage capture of strontium is relatively slow, and this could adversely affect application in batch mode operations. (In column mode, this could be advantageous in moderating the onset of breakthrough.)
- Because CST sorption of strontium is difficult to predict, small column testing will be required to evaluate CST treatment of any candidate wastewater. This is particularly true (for CST or any other sorbent) when potassium and/or complexing agents are present in the wastewater.

APPENDIX A REFERENCES

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APPENDIX B ACRONYMS AND ABBREVIATIONS

Bq	Bequerel
BV	Bed Volume
Ci	Curie
C/C ₀	Concentration/Initial Concentration
CNF	Central Neutralization Facility
Cs	Cesium
CST	Crystalline Silico-Titanate (usually in commercial form Ionsiv™ IE-911)
DOE	U. S. Department of Energy
HLW	High-level Waste
ICP	Inductively-coupled Plasma
kg	Kilogram
L	Liter
LAW	Low-activity Waste
LLW	Low-level Waste
mCi	MilliCurie
meq	Milliequivalent
MVST	Melton Valley Storage Tank
NTS	Nevada Test Site
ORNL	Oak Ridge National Laboratory
PWTP	Process Waste Treatment Plant
Sr	Strontium