Pilot Tests of Adsorptive Media Arsenic Treatment Technologies in the Arsenic Water Technology Partnership

Malynda Aragon[1], Malcolm D. Siegel[2], Randy Everett[3], Alicia Aragon[4], William Holub, Jr[5], Jerome Wright[6] and Brian Dwyer[7]

ABSTRACT

As a member of the Arsenic Water Technology Partnership, Sandia National Laboratories has carried out field scale pilot tests to obtain performance data on arsenic removal for eight different adsorptive media. The media include 3 iron oxyhydroxides, two titanium oxides, a zirconium oxide, and 2 resins with active metal oxide surfaces or nanoparticles. Pilot studies have been completed or are in progress at three sites in New Mexico: Socorro, Anthony, and Rio Rancho. Well waters at the sites span a range of chemical and physical characteristics such as temperature, pH, arsenic content and speciation, and silica and dissolved solids concentrations. Each pilot demonstration site has three participants (Sandia National Laboratories, the technology providers, and the site owner) with specific roles and responsibilities.

The results of the studies provide estimates of the capacity (bed volumes until breakthrough at 10 ppb arsenic) of adsorptive media in chlorinated water, information about the durability of the media, and evaluation of performance under different operating conditions. The data from the field tests were supplemented with laboratory studies to allow a more robust evaluation of media performance. The flow experiments (pilot and laboratory columns) are designed to measure the number of bed volumes (BV) of water passing through the media columns until the regulatory limit (10 ppb) is exceeded in the effluent. For batch sorption tests and the flow experiments, the sorption capacity of the media (mg arsenic adsorbed per kg media) when the treated water reached 10 ppb was calculated or measured. For flow experiments, the capacities were calculated from mass balance; for batch tests, a sorption isotherm was fit to the data and a capacity was calculated at 10 ppb.

Sandia National Laboratories Author Information

[1]Malynda Aragon: PO Box 5800, MS0754, Albuquerque, NM 87185-0754; (505) 844-1288; malarag@sandia.gov;

[2]Malcolm Siegel: PO Box 5800, MS0754, Albuquerque, NM 87185-0754; (505) 844-5426; msiegel@sandia.gov

[3]Randy Everett: PO Box 5800, MS0754, Albuquerque, NM 87185-0754; (505) 844-2933; rlevere@sandia.gov

[4]Alicia Aragon: PO Box 5800, MS0754, Albuquerque, NM 87185-0754; (505) 284-5066; ararag@sandia.gov

[5]William Holub Jr.: PO Box 5800, MS0754, Albuquerque, NM 87185-0754; (505) 844-9918; weholub@sandia.gov

[6]Jerome Wright: PO Box 5800, MS0735, Albuquerque, NM 87185-0754; (505) 844-2875; jwrigh@sandia.gov

[7]Brian Dwyer: PO Box 5800, MS0754, Albuquerque, NM 87185-0754; (505) 845-9894; bpdwyer@sandia.gov

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MANUSCRIPT

The Arsenic Water Technology Partnership (AWTP) program is a multi-year program funded by a congressional appropriation through the Department of Energy to develop and test innovative technologies that have the potential to reduce the costs of arsenic removal from drinking water. The AWTP members include Sandia National Laboratories, the American Water Works Association (Awwa) Research Foundation and WERC (A Consortium for Environmental Education and Technology Development). The program is designed to move technologies from bench-scale tests to field demonstrations. The Awwa Research Foundation is managing bench-scale research programs; Sandia National Laboratories is conducting the pilot demonstration program and WERC will evaluate the economic feasibility of the technologies investigated and conduct technology transfer activities.

The objective of the Sandia Arsenic Treatment Technology Demonstration project (SATTD) is the field pilot demonstration testing of both commercial and innovative technologies. The scope for this work includes:

1. Identification of sites for pilot demonstrations
2. Accelerated identification of candidate technologies through Vendor Forums, proof-of-principle laboratory and local pilot-scale studies, collaboration with the Awwa Research Foundation bench-scale research program and consultation with relevant advisory panels
3. Pilot testing multiple technologies at several sites throughout the country, gathering information on:
    a. Performance, as measured by arsenic removal
    b. Costs, including capital and Operation and Maintenance (O&M) costs
    c. O&M requirements, including personnel requirements, and level of operator training
    d. Waste residuals generation

Pilot scale testing provides a cost effective method to optimize a water treatment methodology prior to full-scale implementation. The final water treatment system can be modeled and tested using a pilot scale demonstration that considers the communities long-term needs. More specifically, a pilot scale system is used to vary design process parameters (such as detention time, filtration rate, or mixing energy) and treatment materials (filter media, new chemicals, or chemical doses) to provide the information necessary for the full-scale design.

The New Mexico Environment Department has identified over 90 public water systems that currently exceed the 10 μg/L MCL for arsenic. The Sandia Arsenic Treatment Technology Demonstration project is currently operating pilots at three sites in New Mexico. The cities of Socorro, Anthony, and Rio Rancho vary in population, water chemistry, and source of arsenic. Figure 1 shows the locations of each city.

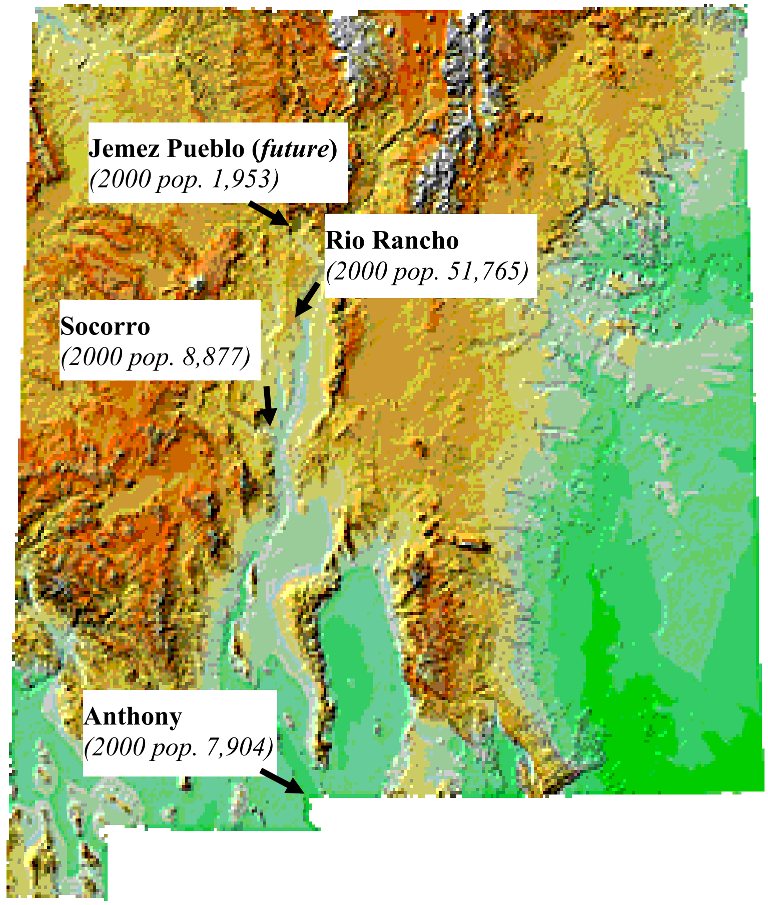

Figure 1. Location of New Mexico Pilots

At each site, the owners (e.g. city utility) provide access to the site, water, electricity, means to discharge treated water, and daily operational checks. Daily checks include filling out a logsheet with information on the flow rates, pressure drops, flow adjustments (when needed), and notification of Sandia personnel if a leak is present.

Sandia owns all equipment and is responsible for the disposal of spent media and other waste streams. Sandia also performs all field tests and collects water samples for laboratory analysis.

Pilot Demonstration Site: Socorro, NM

The first pilot demonstration began in the winter of 2004 at Socorro Springs in Socorro, New Mexico. The verification test site (the "Springs Site") is located off Evergreen Road in Socorro, NM. Socorro and Sedillo springs supply continuous water to the Springs Site. These sources are spring boxes located in the foothills west of the City of Socorro, approximately three-quarters of a mile to the southwest at an elevation approximately fifty feet above the Springs Site. Water from both springs is mixed slightly down gradient of the spring boxes, followed by a shut-off valve. Below the shut-off valve, an eight-inch subsurface, carbon steel line delivers via gravity the approximately 540 gpm, 90^{o}F (xxC) water to the chlorination building where the water is disinfected and oxidized using chlorine gas injection just prior to storage in the Springs Site Storage Tank. Overflow from the Springs Site Storage Tank flows via gravity to a second storage tank located approximately one mile to the east. A summary of the water chemistry and adsorption media tested are shown in Tables 1 and 2.

Table 1. Socorro, NM Water Chemistry

Parameter	Unchlorinated Feed Water
Conductivity (μS)	356-360
Temperature (°C)	30.1-30.5
pH	8.03-8.07
Iron (ppb)	43.3
Turbidity (NTU)	0.1
Total As/As (III), ppb	42.4/<2
Alkalinity (ppm $CaCO_3$)	123
Nitrate (ppm)	0.479
Calcium (ppm)	17.5
Silica (ppm SiO_2)	25.0
Vanadium (ppb)	11.4
Gross Alpha/Beta (pCi/L)	Alpha – 3-6 Beta – 3-4
Sulfate (ppm)	28.7

Table 2. Socorro, NM Adsorption Media

Media Type	Vendor/Media
Iron oxy/hydroxide	Engelhard/ARM 200
Iron-impregnated resin	Purolite/ArsenX^{np}
Titanium Oxide	Hydroglobe/Metsorb
Zirconium Oxide	MEI/Isolux
Iron oxy/hydroxide	AdEdge/AD 33
Iron oxy/hydroxide	AdEdge/AD 33
Iron oxy/hydroxide	AdEdge/AD 33

The pilot test equipment is located in the chlorination building (Figure 2). Phase 1 of this pilot tested five different adsorbent media, including two iron-based sorbents, one zirconium oxide, one titanium oxide, and one resin (Table 2). In addition, a study was performed on the benefits of differing empty bed contact times with a single media (IBS2). The ambient pH (near pH 8.0) was utilized for this phase.

Figure 2. Socorro Springs Chlorination Building

Phase 2a of this pilot evaluated the additional capacity in each media with pH adjustment to 6.8 as well as the effects of flow interruption. Phase 2b will evaluate new media, pH adjustment, and potentially different arsenic removal technologies (i.e. coagulation-assisted filtration).

Other studies completed at the Socorro Springs site not covered in this manuscript are:

- Rapid Small Scale Column Tests (RSSCT) on chlorinated and pH-adjusted water
- Mass Transfer Zone Analysis
- Digestion, TCLP, WET analyses of the spent adsorption media

The breakthrough curves for Phase 1 are shown in Figure 3 below. None of the media were backwashed during the pilot test. "SB" is the chlorinated influent water.

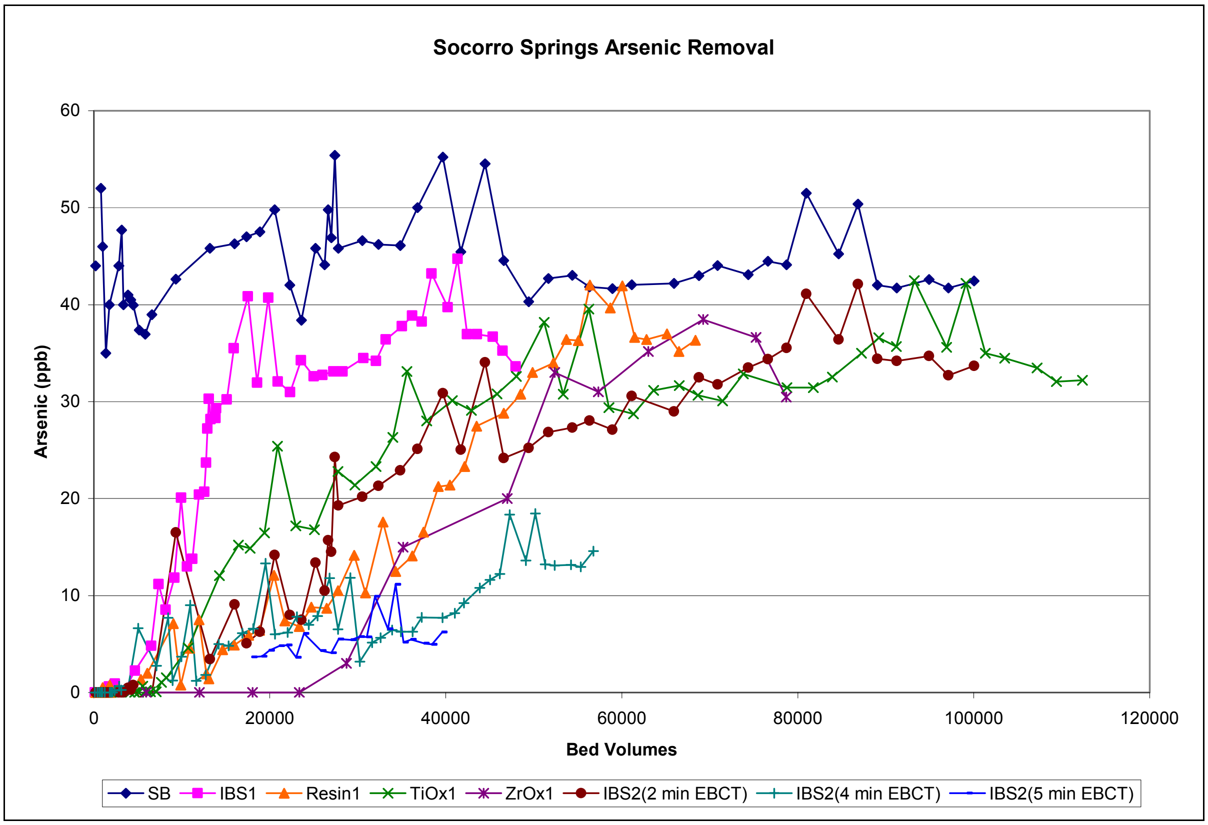

Figure 3. Arsenic Breakthrough Curves for Socorro Springs Pilot – Phase 1

Pilot Demonstration Site: Anthony, NM

The second pilot demonstration began in the summer of 2005 in Anthony, New Mexico. The verification test site is the Desert Sands Mutual Domestic Water Consumers Association (MDWCA) Well Site #3, or simply the "Desert Sands site", located just off I-10 in Anthony, New Mexico. Desert Sands serves a segment of the Anthony population (approximately 1,820) from two wells in a rural community along the New Mexico-Texas line, north of El Paso. It has a new water treatment plant built by Severn Trent Corp. that uses the iron oxide treatment method. The two wells pump 240-270 gpm directly into the distribution system and from it fill two storage tanks located adjacent to each other. The system is operated by radiotelemetry. Typical water production is 2-4 million gallons per month, or 29 million gallons per year.

The EPA is conducting a separate full-scale demonstration study at the site using a Granular Ferric Oxide adsorptive media (E33/AD33/SORB33) system from Severn Trent/AdEdge with chlorinated well water. The EPA study provides full scale performance and cost data and has been in progress for over 18 months. The Sandia study will provide estimates of the capacity (bed volumes until breakthrough at 10 ppb As) of other adsorptive media in the same chlorinated water. Tables 3 and 4 summarize the Desert Sands Well #3 water chemistry and adsorption media being tested. Figure 3 shows the pilot equipment skid.

Table 3. Desert Sands Water Chemistry

Parameter	Unchlorinated Feed Water
Conductivity (µS)	1380
Temperature (^oC)	30.2
pH	7.7
Iron (ppb)	154
Total As/As (III), ppb	23.5/19.7
Alkalinity, as ppm $CaCO_3$	177
Nitrate	ND
Calcium (ppm)	27.2
Silica, as ppm SiO_2	34.3
Vanadium (ppb)	4
Gross Alpha/Beta (pCi/L)	Alpha-3.68, Beta-4.36
Sulfate (ppm)	180

Table 4. Adsorption Media

Media Type	Vendor/Media
Zirconium Oxide	MEI/Isolux
Amended Silicate	ADA/Amended Silicate
Iron oxy/hydroxide	Kemiron/CFH12
Iron oxy/hydroxide	AdEdge/AD33
Iron oxy/hydroxide	Engelhard/ARM200
Iron, Copper oxy/hydroxide	Sandia National Laboratories/SANS
Iron- impregnated resin	Purolite(Solmetex)/ArsenX^{np}
Iron-coated resin	Resin Tech/ASM 10HP
Titanium Oxide	Hydroglobe/Metsorb
Titanium Oxide	Dow/Adsorbsia GTO
La-Coated DE	Eagle Picher/NXT-2
Modified Alumina	Virotec/Bauxsol

Phase 1 started in August of 2005, testing 9 media: Isolux, CFH12, AD33, ARM200, ArsenX^{np}, ASM 10HP, Metsorb, Adsorbsia GTO, and NXT-2. All except for the NXT-2 are still in operation as of December 30, 2005. The Isolux is a patented 42" long cartridge provided by MEI, all other media are installed in 3" diameter columns with a downward flow.

Phase 2 started in December of 2005, testing an additional 4 media: Amended Silicate, SANS, NXT-2 (a new formulation), and Bauxsol. All are still in operation as of December 30, 2005 except for the NXT-2 product. In addition, a new ArsenX^{np} product was loaded into a new column, as the previous product had a manufacturing defect (according to Solmetex). The Amended Silicate and Bauxsol products are installed in 4" diameter columns; all others are in 3" columns with a 0.3 gpm downward flow rate.

Figure 4. Desert Sands Pilot Equipment

Results thus far indicate that only one media has broken through. The results are shown in Figure 5. "SB" is the chlorinated influent water. The media are labeled to match the corresponding media in the Socorro Pilot (i.e. IBS1 is the same media at each pilot). Several of the media have required frequent backwashing (based on a pressure drop greater than 10 psi across the bed), some as often as weekly or twice per month. Larger pressure drop increases seem to affect the media with a smaller particle size.

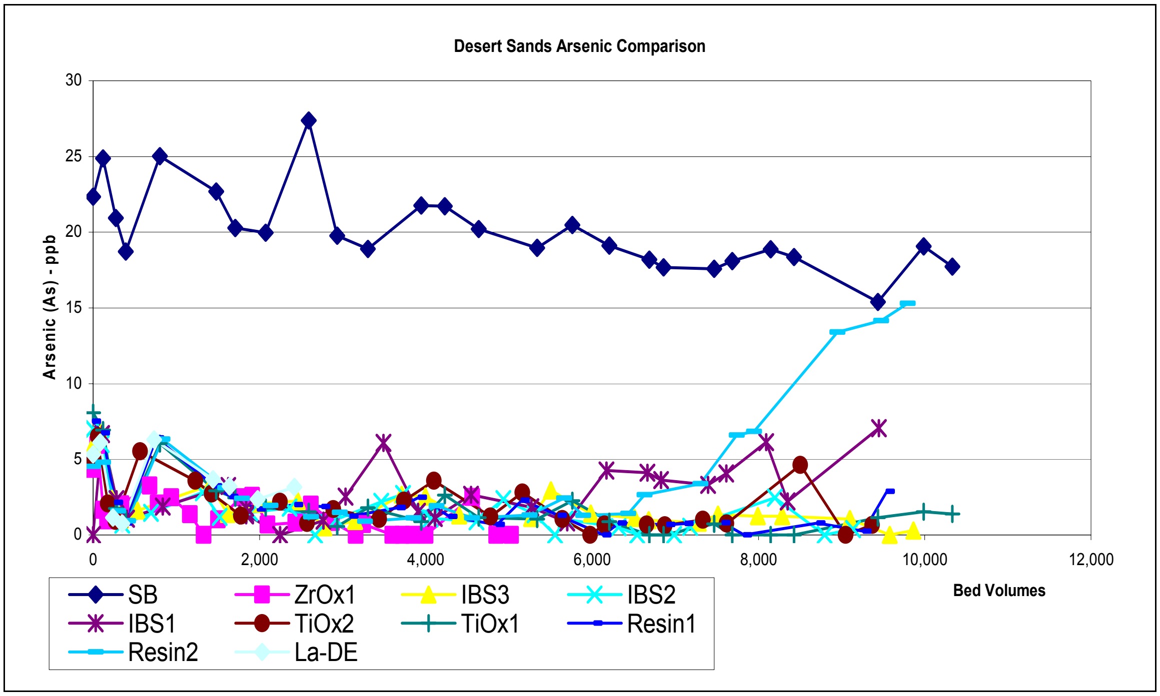

Figure 5. Breakthrough Curves for Desert Sands Pilot

Pilot Demonstration Site: Rio Rancho, NM

The most recent pilot project began in the fall of 2005 at Rio Rancho, NM. The verification test site is Well Site #21, or simply the "Rio Rancho site", located just off Loma Colorado Drive near the city's high school in Rio Rancho, New Mexico. The well pump capacity is 2000 gpm; the water is directed into a distribution system nearby. The pilot equipment is housed within a metal storage transportainer. The transportainer, RRNM Well #21 building, power drop and the RRNM sanitary sewer connection are secured within a six foot chain link fence. The transportainer is heated by a small unit heater, and cooling is not required. Temperatures will be between 50-80^{o}F (10 – 27 C^{o}). Chlorinated water is provided to the pilot test equipment at pressures from 70-80 psi.

The city of Rio Rancho operates multiple wells to serve a growing population near 62,000. The information from the test will help the city of Rio Rancho determine if a cost effective adsorption strategy is viable for their water chemistry. They are currently in the design process for arsenic removal systems at each of their affected wells. Tables 5 and 6 summarize the adsorptive media and reverse osmosis systems being tested at the Rio Rancho Well #21 site. Figure 4 shows the pilot equipment.

Table 5. Rio Rancho Water Chemistry

Parameter	Unchlorinated Feed Water
Conductivity (µS)	605-620
Temperature (^{o}C)	23
pH	7.7-7.9
Iron (ppb)	< 200
Total As/As (III), ppb	18-20/0
Alkalinity (ppm $CaCO_3$)	160
Nitrate	2.3
Calcium (ppm)	23
Silica (ppm as SiO_2)	25-30
Vanadium	15
Gross Alpha/Beta (pCi/L)	NT
Sulfate (ppm)	100

Table 6. Adsorbtion Media

Media Type	Vendor/Media
Zirconium Oxide	MEI/Isolux
Iron oxy/hydroxide	Kemiron/CFH24
Iron oxy/hydroxide	AdEdge/AD33
Iron-impregnated resin	Purolite/ArsenX^{np}
Iron-coated resin	Resin Tech/ASM 10HP
Titanium Oxide	Dow/Adsorbsia GTO
Reverse Osmosis	Watts Premier/KP4
Reverse Osmosis	Watts Premier/ZRO

Figure 6. Rio Rancho Pilot Site and Equipment

Phase 1 started in September of 2005, testing 6 adsorption media and two under-the-sink reverse osmosis units, as listed in Table 6. The Isolux is a patented 42" long cartridge provided by MEI; all other media are installed in 3" diameter columns with a downward flow. The reverse osmosis units are rated to produce up to 25 gallons per day; consumption is simulated by a computer program that opens a solenoid valve, which empties the storage tanks 4 times per day. On December 6, 2005 abnormally low temperatures caused freezing of water in several locations in the pilot, causing the pilot to be shut down until repairs are made and new media loaded into the columns. A mass transfer zone analysis will be performed on each of the spent media.

As of December 6, 2005, only one media had broken through (As greater than 10 ppb). Only two of the media required one backwashing cycle during the entire pilot. The Arsenic curves are shown in Figure 7.

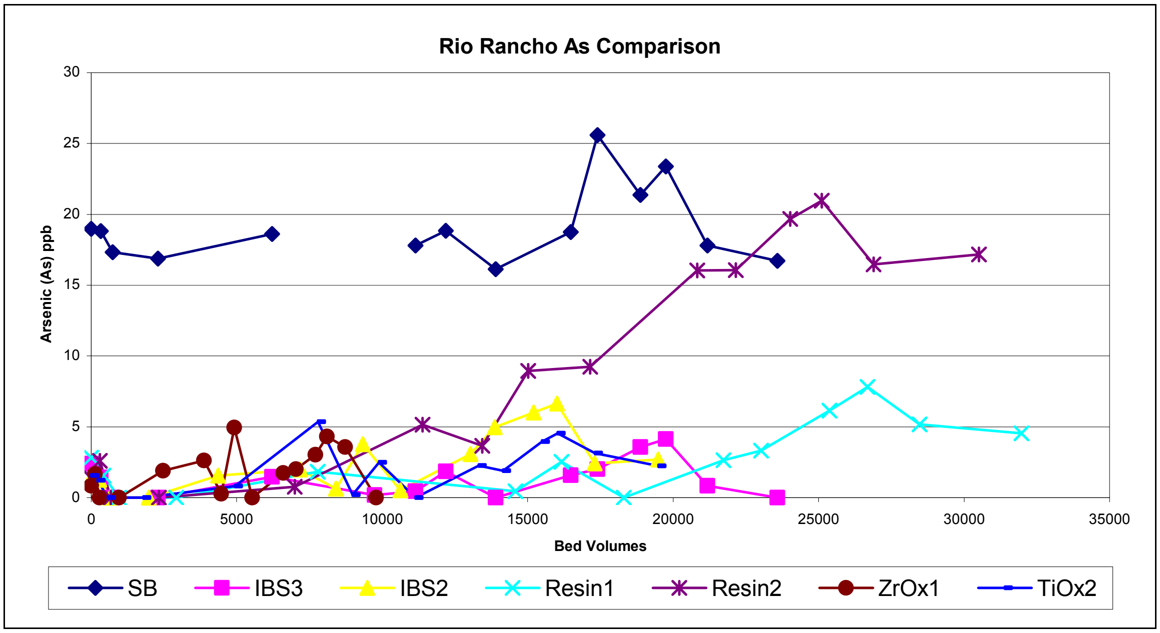

Figure 7. Breakthrough Curves for Rio Rancho Pilot

Summary of Results

As a member of the Arsenic Water Technology Partnership, Sandia National Laboratories has carried out field scale pilot tests to obtain performance data on arsenic removal for eight different adsorptive media. Pilot studies have been completed or are in progress at three sites in New Mexico: Socorro, Anthony, and Rio Rancho. Well waters at the sites span a range of chemical and physical characteristics such as temperature, pH, arsenic content and speciation, and silica and dissolved solids concentrations.

The results of the studies provide estimates of the capacity (bed volumes until breakthrough at 10 ppb arsenic) of adsorptive media in chlorinated water, information about the durability of the media, and evaluation of performance under different operating conditions. Results are summarized in Table 7.

Table 7. Summary of Pilot Demonstration Results

Media	Socorro BV to 10 ppb breakthrough	Desert Sands BV to 10 ppb breakthrough[a]	Rio Rancho BV to 10 ppb breakthrough[b]
IBS1	9,000	>10,000	N/A
IBS2	26,000/43,000/42,000 (2/4/5 min EBCT)	>10,000	>20,000
IBS3	N/A	>10,000	>20,000
ZrOx1	32,000	>10,000	>20,000
TiOx1	13,000	>10,000	N/A
TiOx2	N/A	>10,000	>20,000
Resin1	27,000	>10,000	>20,000
Resin2	N/A	8,000	17,000
La-DE	N/A	*Media broke down at 2,400*	N/A

[a]Phase 1 not yet complete
[b]Phase 1completion data

In general, the smaller the particle size of the media, the more susceptible the media is to incoming iron and particulate matter. These media require more backwashing than others. Each media requires a different loading procedure (e.g. overnight soaking or wet-loading) and can add significant time up front.

Empty bed contact time (EBCT) does have an affect on the relative performance of the media. Most media vendors recommend 3-5 minutes EBCT. We have shown that a 3 minute EBCT is generally sufficient, in that higher bed volumes to 10 ppb breakthrough are demonstrated regularly.

Future Plans

In 2006, the Arsenic Water Technology Partnership will undertake several activities. Rio Rancho will be restarted by early spring 2006, a new pilot will start at the Jemez Pueblo, Phase 1 and 2 operations will continue at Desert Sands, and Phase 2 operations will begin at the Socorro site. In addition, the Partnership will locate several new sites out of New Mexico for pilot demonstrations.

The Jemez Pueblo pilot demonstration site will test coagulation-filtration technology, as well as gather information on the effectiveness of various oxidizers for Arsenic (III). There is a full scale iron and manganese removal plant for comparison to pilot scale results.

Pilot-specific economic analyses will be performed at each site to gain further insight to the relative performance of each of the media. These results will be used to supplement our partner, WERC, in their efforts to build the Comprehensive Arsenic Tool (CoAsT).

REFERENCES

Aragon, A. (2004), *Development of a Rapid Small-scale Column Testing Procedure for the Evaluation of Arsenic Adsorption Media:* Ph.D. Thesis, University of New Mexico, Albuquerque, NM.

Brady, P.V., Teter, D. M., Khandaker, N.R., Krumhansl, J.L. and Siegel, M. D. (2004) *Development of Novel Arsenic Treatment Approaches*. SAND2004-0056, Sandia National Laboratories, Albuquerque, NM.

City-Data.com, *2000 Population Data*, www.city-data.com

Coonfare C., Chen, A., Wang, L., Valigore, J. (2005), *Arsenic Removal from Drinking Water by Adsorptive Media USEPA Demonstration Project at Desert Sands MDWCA, NM Six-Month Evaluation Report:* USEPA, 600-R-05-079

Siegel, M., McConnell, P., Ilges, A., Chen, H, Ghassemi, A., and Thompson, R (2006), *Development and Evaluation of Innovative Arsenic Adsorption Technologies for Drinking Water by the Arsenic Water Technology Partnership:* Proc. 2006 NGWA Naturally Occurring Contaminants Conference, Feb. 6-7, 2006, Albuquerque, NM.

USEPA (2003), *Arsenic Treatment Technology Evaluation Handbook for Small Systems Handbook:* USEPA, 816-R-03-014

USEPA, *Arsenic Virtual Tradeshow Website:* http://www.arsenictradeshow.org/

USGS, *Arsenic in ground water of the United States Website:* http://water.usgs.gov/nawqa/trace/arsenic/

WERC, *Comprehensive Arsenic Tool Website*: http://wercstation.nmsu.edu:8080/arsenic/AsTree.dsb

BIOGRAPHY INFORMATION

Malynda Aragon, M.S., is a Member of the Technical Staff at Sandia National Laboratories. She is the lead engineer for the Arsenic Treatment Technology Pilot Demonstration Program at Sandia National Laboratories. She received a BS in chemical engineering from the University of New Mexico and a M.S. in chemical engineering from UC Davis. She has experience in the fields of industrial water treatment, waste water treatment and water conservation. Ms. Aragon has been involved in several projects including increasing cooling tower water efficiency, reclaim water usage in cooling towers, and implementing the High Efficiency Reverse Osmosis (HERO) system at Sandia. Her current projects include three pilot demonstration projects in New Mexico at Socorro, Anthony, and Rio Rancho New Mexico.

Dr. Malcolm Siegel is a Principal Member of the Technical Staff at Sandia National Laboratories. He received a BA in Chemistry from Columbia University; a Ph.D. in Geological Sciences/Geochemistry from Harvard University, and a Masters in Public Health/Epidemiology from the University of New Mexico. Dr. Siegel has served as Principal Investigator for experimental and modeling studies of radionuclide retardation and hydrogeochemical studies at the Waste Isolation Pilot Plant Site and Yucca Mountain, as the Technical Coordinator of the U.S. DOE Innovative Treatment and Remediation Demonstration program and as the Project Manager for the Sandia Arsenic Treatment Technology Pilot Demonstration Program. He is the author of over 55 scientific articles, book chapters and peer-reviewed reports.

Randy Everett is a Technologist in the Geochemistry department and is currently working to field pilots in the state of New Mexico. Mr. Everett has more than 25 years experience in the field of industrial water treatment, pre-treatment devices, internal process chemical treatment programs, waste water systems, and analytical control instrumentation. His current projects include the design, building, and operation of each of the Sandia pilots.

Alicia Aragon, PhD is a Postdoctoral Appointee in the Geochemistry Department at Sandia National Laboratories. She received a BS in Civil Engineering from the University of New Mexico, an MS in Civil Engineering from the University of Illinois, and a PhD from the University of New Mexico. Ms. Aragon is the lead investigator to the Rapid Small Scale Column Tests (RSSCT) for the Sandia pilots.

William Holub, Jr is a Technologist in the Geochemistry department and is currently working to field pilots in the state of New Mexico. Mr. Holub has more than 25 years experience in the field of mechanical and electrical fields including pipefitting, water distribution, HVAC controls and operation, as well as industrial water treatment. His current projects include the design, building, and operation of each of the Sandia pilots.

Jerome Wright is a Senior Technologist in the Geohydrology Department. Jerome received his BS in Information Technology and MS in Computer Information Systems (CIS) from the University of Phoenix. Jerome served in the United Stated Air Force as a metrologist. Currently Jerome creates innovative monitoring and data collection systems for unique research and development projects. Various systems reside in New Mexico, California, and Arizona.

Brian Dwyer is a Senior Member of Technical Staff at Sandia National Laboratories. Mr. Dwyer has a BSCE, MBA and a Master's in Environmental Engineering from New Mexico State University with over 17 years of experience in Civil and Environmental engineering projects. His areas of expertise include research, design and construction of in-situ and ex situ water treatment systems.