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Revision 0

# Resin Evaluation and Test Report to Support DX Treatment System

Prepared for the U.S. Department of Energy
Assistant Secretary for Environmental Management

Contractor for the U.S. Department of Energy
under Contract DE-AC06-08RL14788

CH2MHILL
Plateau Remediation Company

P.O. Box 1600
Richland, Washington 99352

Approved for Public Release;
Further Dissemination Unlimited

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# Executive Summary

The purpose of this document is to recommend the ion-exchange (IX) resin and regeneration process option for design of the expansion of the groundwater pump-and-treat capacity in the 100-D Area (DX facility) and to document the conduct of resin evaluation and testing at the DR-5 pump-and-treat facility. This report supports Performance Objective 1a.4(a), "Complete the resin testing at DR-5 pump-and-treat system located in the 100-HR-3 [Operable Unit] OU."

## Recommendations

The results of the resin tests indicate that, in general, the performance of two resins, Purolite® A500 (a regenerable resin) and ResinTech® SIR-700 (a single-use, disposable resin), range between a factor of 2 to an order of magnitude more efficient than that of Dowex® 21K. Purolite A500 has been in use at DR-5 since 2004, and the operating experience gained from this resin's performance has been confirmed; however, offsite regeneration capabilities will need to be obtained to make this resin available to support the DX design. ResinTech SIR-700 is a new resin with operational and disposal risks that have been identified but not completely mitigated. Evaluations are ongoing to determine a disposal pathway and optimize requirements for ResinTech SIR-700 to support the DX design.

CH2M HILL Plateau Remediation Company (CHPRC) recommends the following for design and startup of the new DX facility:

- Design the IX vessels so they can use either Purolite A500 or ResinTech SIR-700 without modification. This design is already under way.
- Concurrently, address operational uncertainties and programmatic risks associated with spent resin regeneration for Purolite A500, as well as safe handling and disposal considerations for ResinTech SIR-700.
- Determine whether to initiate a larger-scale test of ResinTech SIR-700 at DR-5 to mitigate scale-up risk.

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Purolite® is a registered trademark of The Purolite Company, Bala Cynwyd, Pennsylvania.
ResinTech® is a registered trademark of ResinTech Inc., West Berlin, New Jersey.
Dowex® is a registered trademark of The Dow Chemical Company, Midland, Michigan.

- Upon completion of the DX design in November 2009, facility modifications needed to optimize the use of ResinTech SIR-700 will be developed.
- Continue evaluation of site-wide resin-handling strategies for the pump-and-treat facilities to reduce the programmatic risk associated with offsite resin regeneration.

To achieve the *Hanford Federal Facility Agreement and Consent Order*[1] (Tri-Party Agreement) milestone M-016-111B to expand the current pump-and-treat capacity at the 100-HR-3 OU to 1,893 L/min (500 gallons per minute [gal/min]) by December 31, 2010, CHPRC recommends that no further design changes be made to the DX facility at this time. As noted above, the current design can accept either Purolite A500 or ResinTech SIR-700 resin, either of which is a marked improvement over Dowex 21K. ResinTech SIR-700 (granular or WBG30-B spherical form) will be used for start up and the facility modified after start-up to optimize the treatment using this resin. In the unlikely event that the operational issues cannot be resolved for ResinTech SIR-700, Purolite A500 will be used; as a result, potential regeneration facilities will be identified.

## Resin Evaluation Program

Resin testing at the DR-5 facility started in March 2009 and is ongoing. Concurrent with the resin tests at DR-5, pre-conceptual-level design and cost evaluations were prepared for four DX process options:

- Offsite regeneration (similar to the current 100-H and 100-K Area facility operations)
- Onsite regeneration (shared with other 100 Area IX plants)
- In-vessel regeneration (similar to the DR-5 process)
- Single-use resin (in this case, ResinTech SIR-700).

Results of the resin tests were incorporated into the design and cost evaluation of process options, and in turn are being incorporated into the DX facility design.

Six resins were selected for evaluation based on demonstrated or reported abilities to remove hexavalent chromium from water. The resins included those currently being used in the existing treatment facilities, single-use resins, and resins that can be regenerated in situ or in a separate regeneration facility (Tables ES-1 and ES-2). Because

[1] Ecology, EPA, and DOE, 1989, *Hanford Federal Facility Agreement and Consent Order*, 2 vols., as amended, Washington State Department of Ecology, U.S. Environmental Protection Agency, and U.S. Department of Energy, Olympia, Washington. Available at: http://www.hanford.gov/?page=91&parent=0

groundwater from the 100-D Area was used in these evaluations, the results are directly applicable to chromium removal at and near this location.

**Table ES-1. Summary of Results from the First Resin Evaluation**

| Parameter | Units | Purolite A100 (pH 7.5) | Purolite A500 (pH 7.5) | Purolite A600 (pH 7.5) | Dowex 21K (pH 7.5) | ResinTech SIR-700 (pH 5) | ResinTech SIR-1200 (pH 7.5) |
|---|---|---|---|---|---|---|---|
| Bed volumes to breakthrough | -- | 724 | 5,787 | 4,626 | 2,925 | See footnote | 4,367 |
| Hexavalent chromium capacity | g/L<br>lb/ft$^3$ | 0.455<br>0.0284 | 3.64<br>0.227 | 2.92<br>0.182 | 1.84<br>0.115 | See footnote | 2.75<br>0.172 |

NOTE: Has not reached breakthrough at the time that this report was issued.

**Table ES-2. Summary of Results from the Second Resin Evaluation**

| Parameter | Units | Purolite A500 (pH 5) | Purolite A600 (pH 5) | Dowex 21K (pH 7.5) | Dowex 21K (pH 5) | ResinTech SIR-700 (pH 5) | ResinTech SIR-1200 (pH 5) |
|---|---|---|---|---|---|---|---|
| Bed volumes to breakthrough | -- | 6,391 | 4,744 | 2,523 | 1,550 | >40,000 on 07/21/09 | 3,542 |
| Hexavalent chromium capacity | g/L<br>lb/ft$^3$ | 4.02<br>0.251 | 2.98<br>0.186 | 1.59<br>0.099 | 0.970<br>0.061 | See footnote | 2.22<br>0.139 |

NOTE: Has not reached breakthrough at the time that this report was issued.

Two resin evaluation tests have been completed at the DR-5 facility and a third test is still under way. The relative performance of the resins was compared based on their breakthrough times and breakthrough curves. "Breakthrough" is defined in this evaluation as two consecutive effluent hexavalent chromium readings above 10 µg/L, signifying that hexavalent chromium has started to exit the column. Continued testing beyond this point defined the shape of the breakthrough curve, which provided information on the rate at which the contaminant approaches equilibrium in the column; i.e., when inlet and outlet concentrations are equal. These comparisons provided technical resin performance data input to SGW-41529, *100-DX Pre-Conceptual Designs and Costs Technical Memorandum*.[2]

2 SGW-41529, 2009, *100-DX Pre-Conceptual Designs and Costs Technical Memorandum*, Draft (in publication), CH2M HILL Plateau Remediation Company, Richland, Washington.

The results of these tests revealed performance differences that were not predictable from vendor-supplied information. The first series of tests showed that Dowex 21K performed as expected, but Purolite A500 performed 2 to 4 times better and ResinTech SIR-700 performed greater than 10 times better than Dowex 21K in terms of capacity and breakthrough time (Tables ES-1 and ES-2).

As shown above, Purolite A500 and ResinTech SIR-700 have superior abilities to remove hexavalent chromium from 100-D Area groundwater, as demonstrated by their higher bed volume to breakthrough values. They fit into the overall site resin-handling strategy as follows:

- Purolite A500: This regenerable resin has the longest breakthrough time and highest capacity of the regenerable resins tested. The DX facility vessels are being designed with in-vessel regeneration capabilities (like DR-5) in the event co-injection becomes viable (the most cost-effective option). Since this option is not currently technically viable, the preferred regeneration option is for ex-vessel regeneration (initially offsite at Siemens but could later be near-site or onsite to mitigate the U.S. Department of Energy's (DOE's) offsite regeneration risk).

- ResinTech SIR-700: This resin is non-regenerable, but has a hexavalent chromium retention capacity projected to be as much as an order of magnitude greater than that of Purolite A500. The high capacity observed in these tests is consistent with operational experience at the U.S. Environmental Protection Agency Boomsnub/AIRCO Superfund Site in Vancouver, Washington. It is anticipated that, once exhausted, this resin will be disposed onsite. However, completion of a waste profile is necessary to confirm disposal characteristics.

Table ES-3 shows a summary of the advantages and disadvantages of these two resins relative to Dowex 21K.

**Table ES-3. Comparison of Key Resin Attributes**

| Resin | Advantages | Disadvantages |
|---|---|---|
| Dowex 21K | Large-scale experience on Site<br>Common operations with HR-3, KR-4, K W, and KX | Offsite shipment for regeneration<br>OR<br>Onsite regeneration waste disposal (liquid and solid)<br>Shortest time between resin changeouts<br>Highest cost resin per cubic foot |
| Purolite A500 | Longer time than Dowex 21K between resin changeouts<br>Process experience onsite (DR-5)<br>More cost-effective regenerable resin than Dowex 21K | Offsite shipment for regeneration<br>OR<br>Onsite regeneration waste disposal (liquid and solid) |
| ResinTech SIR-700 | Longest time between resin changeouts<br>No regeneration waste<br>No offsite shipment<br>Mitigates DOE offsite regeneration liabilities | Routine disposal of spent resin<br>• Waste designation required for the Environmental Restoration Disposal Facility<br>• Boomsnub spent resin is designated extremely hazardous waste (disposal at Arlington, Oregon)<br>Possible requirements for stabilization of waste resin and disposal of stabilization solutions by solidification or co-injection<br>Possible requirement to modify facility design to allow removal of waste resin<br>No experience on Site<br>pH adjustment needed both before and after treatment for best performance |

## Process Options and Lifecycle Costs

The design options for the DX facility are based on a capacity of 2,271 L/min (600 gal/min), similar to that of the KX system, which began operation in the 100-K Area in the fall of 2008. The KX system uses Dowex 21K to remove hexavalent chromium from influent groundwater. Spent resin is sent offsite for regeneration.

Resin performance is an important variable in determining operations and maintenance (O&M) costs for the DX facility. The results of resin testing indicated that Purolite A500 was the most cost-effective regenerable resin tested, and the use of this resin by the DX facility was the basis for the cost analysis of each of the resin regeneration options evaluated. ResinTech SIR-700 has an extremely high capacity but is not regenerable; it was used in the cost analysis of the DX facility for the single-use resin option. Cost analyses are based on a resin regeneration rate of 88 vessels/year for Purolite A500 and a resin changeout rate of 13 vessels/year (40,000 bed volumes) for ResinTech SIR-700.

The process options evaluated in SGW-41529 are:

- Offsite regeneration: IX using Purolite A500 that is sluiced into totes for offsite regeneration at the Siemens facility in Minnesota. This is a continuation of current practices for 100 Area facilities (except DR-5, where in-vessel regeneration is conducted).
- Onsite regeneration: IX using Purolite A500 that is sluiced into totes for onsite regeneration at a central regeneration facility, which would be constructed in the 100 Areas.
- In-vessel regeneration: Exhausted Purolite A500 is treated in the IX vessels with sodium chloride, followed by sodium dithionite (to reduce hexavalent chromium), and then dilute hydrochloric acid. In-vessel regeneration generates wastewater that contains significant quantities of chromium, chloride, and sulfate. Solutions produced from the regeneration process are treated to precipitate chromium, which is filtered out, and to oxidize residual dithionite to sulfate. However, the residual regenerant solution (containing the various salts) would require disposal by co-injection or treatment by vapor compression crystallization (VCC). Use of an evaporation pond is a cost-effective option for in-vessel regeneration, but was not analyzed in detail due to perceived regulatory issues.
- Single-use resin: The IX resin ResinTech SIR-700 requires an acidic pH to achieve its high capacity, according to vendor information. Therefore, influent groundwater is acidified before treatment, and treated groundwater is neutralized before injection. The study addresses potential requirements for in-vessel resin stabilization (converting hexavalent chromium to trivalent chromium before disposal). ResinTech WBG30-B is the bead form of granular SIR-700 and also is being evaluated.

Table ES-4 presents capital and O&M cost estimates for the various resin options. These estimates are feasibility study level (+50%,-30%) and are only to be used for comparative, not budgetary, purposes.

**Table ES-4. DX Facility Option Cost Comparison**

| | Baseline Regeneration[a] | Offsite Resin Regeneration | Onsite Resin Regeneration[b] | In-Vessel Resin Regeneration with Co-Injection | In-Vessel Resin Regeneration with VCC | Single-Use Resin |
|---|---|---|---|---|---|---|
| Estimated capital cost ($ million) | 10.76 | 7.73 | 9.92 | 8.15 | 20.38 | 7.33 |
| Estimated annual O&M cost ($ million) | 3.33 | 2.36 | 2.21 | 1.58 | 1.91 | 1.84 |
| Estimated lifecycle cost[c] ($ million) | 39.60 | 28.15 | 29.12 | 21.86 | 36.95 | 23.25 |

a. Dowex 21K with offsite regeneration.

b. Pro-rated cost for the DX facility includes 56 percent of total central regeneration facility costs.

c. Lifecycle costs based on 11-year lifetime and discount rate of 4.2 percent.

Based on lifecycle cost, Table ES-4 shows that the preferred process options would be, in order:

- In-vessel regeneration with co-injection. Even with the lowest lifecycle cost, this option is not recommended because of the potential for solids precipitation and plugging the aquifer. Preliminary work by Pacific Northwest National Laboratory indicates this is a real risk. Addition of VCC treatment to treat the regenerant stream increases lifecycle cost by 69 percent and makes the option unattractive. Use of an evaporation pond increases the lifecycle cost by 5 percent and is subject to regulatory approval.

- Single-use resin. Lifecycle cost is only 6 percent higher than the lowest lifecycle cost option. Operational and waste disposal concerns must be addressed.

- Offsite regeneration. The lifecycle cost is 29 percent higher than the lowest lifecycle cost option. Offsite regeneration capabilities will be established for Purolite A500 in the unlikely event that a disposal pathway cannot be determined for ResinTech SIR-700, and as a potential alternative for resin changes in other pump and treat facilities.

This result was confirmed in a structured decision analysis in which these three options scored (on an arbitrary scale) 7.64 points, 7.11 points and 6.49 points, respectively, compared to the Dowex 21K option score of 3.21 points.

Estimated O&M costs for the single-use resin option are higher than might be expected because of the need for complete resin replacement after (in this analysis) 40,000 bed volumes. This makes it comparable to the estimated O&M costs for the in-vessel regeneration options; the average of all three is 53 percent of the estimated O&M cost for a Dowex 21K system.

## Impacts, Risks, and Mitigations

Impacts of recommendations, risks, and mitigations to the DX design schedule have been evaluated. The DX facility schedule is summarized by the following milestones:

- Award purchase orders for process equipment — November 2009
- Design to 90 percent (forecast) — December 2009
- Design issued for construction (forecast) — December 2009
- Award purchase order for resin — January 2010
- Process equipment installation start — January 2010
- End of construction/start of acceptance test procedure — September 2010.

Table ES-5 summarizes technical risks and mitigations related to SIR-700.

**Table ES-5. Impacts, Risks, and Mitigations**

| Risk/Issue | Action | Estimated Completion | Comment |
|---|---|---|---|
| Design changes/process optimization | Evaluate IX vessel volume for backwash expansion | August 31, 2009 | These issues have been evaluated in the ARES white paper* on potential design changes for SIR-700; a Soil & Groundwater Remediation Protection documented recommendation is required. Preliminary indications are as follows:<br>• IX vessel volume is only an issue for in vessel regeneration.<br>• Proposed DX materials are compatible with a reduced pH and no change is required.<br>• A sluicing system would need to be designed to remove the spent resin. |
| | Determine material compatibility with reduced pH | | |
| | Evaluate spent resin removal capability | | |

**Table ES-5. Impacts, Risks, and Mitigations**

| Risk/Issue | Action | Estimated Completion | Comment |
|---|---|---|---|
| | Obtain written clarification on SIR-700 temperature limits | August 31, 2009 | ResinTech has provided information to close this issue; a Soil & Groundwater Remediation Protection documented conclusion is required. |
| | Complete WBG30-B resin testing | October 15, 2009 | The estimated completion date is a forecast selection. The WBG30-B test column should break through in about half the time of the SIR-700 test column. The SIR-700 test column has not broken through after about 4 months. |
| Spent resin disposal | Analyze SIR-700 from test skid<br>• Determine analytical parameters in addition to toxic characteristic leaching procedure<br>• Collect sample<br>• Perform analyses (15-day expedited laboratory time) | October 1, 2009 | Resin analysis will be performed on a target analyte list to accelerate resin evaluation. |
| | Determine need for additional treatment before disposal<br>• Evaluate sample analysis results<br>• Document conclusion | October 30, 2009 | – |
| | Perform waste designation for SIR-700 disposal | December 1, 2009 | May require formal data quality objective (30 days) and additional laboratory analyses; will start in parallel with initial sample analysis |

*ARES Corporation, 2009, *Preliminary Assessment of IX Vessel Dimensions and Materials of Construction*, July, Richland, Washington.

## Path Forward

CHPRC is continuing to evaluate options for eliminating the programmatic risk of offsite regeneration by pursuing a site-wide resin management strategy. The options being considered include onsite regeneration, contracted near-site regeneration, in-vessel regeneration, and disposable resin (ResinTech SIR-700). Constraints include evaluations of the ability to cost effectively modify existing facilities, onsite disposal requirements, resin removal and handling, and regenerant co-injection or disposal. This evaluation started with consideration of the central regeneration facility in SGW-41529; completion will be planned for fiscal year 2010. CHPRC believes that the benefits of commonality in

operating facilities (e.g., technical basis, operating procedures, O&M training, equipment, spares) have value, will reduce lifecycle cost, and will be addressed in the evaluation.

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# Terms

| | |
|---|---|
| BV | bed volume |
| CHPRC | CH2M HILL Plateau Remediation Company |
| CRF | central regeneration facility |
| DOE | U.S. Department of Energy |
| Ecology | Washington State Department of Ecology |
| ERDF | Environmental Restoration Disposal Facility |
| gal/min | gallons per minute |
| IX | ion exchange |
| MCL | maximum contaminant level |
| O&M | operations and maintenance |
| OU | operable unit |
| TCLP | toxic characteristic leaching procedure |
| Tri-Party Agreement | *Hanford Federal Facility Agreement and Consent Order* |
| VCC | vapor compression crystallization |
| WSCF | Waste Sampling and Characterization Facility |

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# 1 Introduction

Over the past 12 years, chromium has been removed from contaminated groundwater at the Hanford Site 100-HR-3 and 100-KR-4 Operable Units (OUs) using pump-and-treat facilities. The groundwater is treated by circulation through a series of ion-exchange (IX) resin columns. Two different resin formulations are currently being used in five treatment facilities, which combined have removed over 500 kg (1,102 lb) of hexavalent chromium and competing anions from 3.7 billion L (1 billion gal) of groundwater.

The performance of a resin depends on many factors, including relative affinity for chromate ($CrO_4^{2-}$) and other anions (e.g., nitrate and sulfate), groundwater residence time, and the relative concentration of hexavalent chromium. Performance of the resin typically is determined by the vendor through a series of tests but can vary considerably due to the composition of the water being treated. Thus, further testing with site-specific groundwater is essential to determine the most suitable resin for use.

Selection of the IX resin used in the existing chromium pump-and-treat facilities has been largely based on testing performed in the 1990s. A general discussion of IX resins is presented in Appendix A. Several new resin formulations have the potential to increase efficiency of the existing treatment systems and optimize the design of new facilities. This document provides information on the site-specific tests conducted with various IX resins for removing chromium. These tests were performed using a resin evaluation skid, which was designed and built exclusively for use at the Hanford Site. This testing apparatus is briefly described below and in more detail in SGW-39770, *Hanford Groundwater Chromium Resin Evaluation Plan.*

In addition to resin testing, process facility alternatives, including resin regeneration and disposal processes, were evaluated. Details of these evaluations that are pertinent to the selection of an IX resin for use in the 100-DX facility (DX) are included in this document. Additional information on the process alternatives can be found in SGW-41529, *100-DX Pre-Conceptual Designs and Costs Technical Memorandum.*

## 1.1 Purpose

It is essential to evaluate the hexavalent chromium breakthrough curves of various resins using the actual groundwater that a full-scale system would be treating, as resin performance is affected by the type and abundance of groundwater constituents. Data from IX resin testing and process evaluations will be the primary factors in resin selection for the design of a new pump-and-treat facility in the 100-D Area that will be used to achieve final cleanup of groundwater in this area. The process evaluations provide data for determining the advantages and disadvantages of different operating scenarios.

This document discusses the resin evaluation tests and the process evaluation results for the selection of a resin for use in the DX facility.

## 1.2 Resin Evaluation Skid

The resin skid (Figure 1-1) was designed to simulate conditions typical of the lead vessel in a full-scale Hanford Site treatment facility (e.g., 100-HR-3). Table 1-1 compares the skid-testing conditions with the operating conditions of a full-scale lead vessel. By keeping the linear flow rate similar between the columns, the number of bed volumes (BVs) to breakthrough can be used for resin performance comparisons. The skid can simultaneously evaluate up to six IX resins for their ability to remove chromium from groundwater. During the evaluation, site-specific groundwater is passed through the resin columns from top to bottom, and individual feed streams can be modified (e.g., the pH adjusted) to test

the resins under varying conditions. Groundwater is drawn from sample points at the effluent end of each resin column to determine the resin's current performance. Pumps and valves control flow through each test resin and prevent backflow or cross-contamination between the test resins. More detailed information on the resin skid is presented in the evaluation plan (SGW-39770).

**Figure 1-1. Resin Evaluation Skid Installed in the DR-5 Facility**

For the resin evaluations described in this document, the evaluation skid was located in the 100-DR-5 facility (DR-5) and used groundwater from the 100-D Area. The evaluations were performed to provide technical resin performance data input to the design and cost technical memorandum (SGW-41529). The technical memorandum combines the resin technical performance evaluation results with capital cost, operating cost, waste disposal considerations, and other engineering data to determine the most efficient resin for use in the new treatment facility to be installed in the 100-D Area.

## 1.3 Resins

The resins chosen for evaluation were based on their demonstrated or reported ability to remove hexavalent chromium from water. The resins include formulations currently being used in the site-specific treatment facilities, single-use resins, and resins that can be regenerated in-vessel or in a dedicated onsite regeneration facility. Because site-specific groundwater from the 100-D Area was used in these evaluations, the results are directly applicable to chromium removal at the DX facility.

Table 1-2 provides a comparison of vendor information for six resins tested for use at the DR-5 facility. The table also includes information on theoretical capacity, resin substrate (underlying polymeric type), resin structure (gel or macroporous), type, operating pH range, and ability to be regenerated. Table 1-3 provides additional details on the resins tested and the parameters.

**Table 1-1. Comparison of 100-HR-3 Lead Column with Evaluation Skid**

| | Lead Column | Evaluation Skid |
|---|---|---|
| Resin vessel volume | 104 $ft^3$ | Approx. 40 $in^3$ |
| Resin volume | 80 $ft^3$ | 30 $in^3$ (evaluation #1) |
| Resin height | 60.4 in. | 43 in. (evaluation #1) |
| Resin diameter | 53.5 in. | 0.935 in. |
| Flow rate | 50 gal/min | 0.018 gal/min |
| Linear velocity | 0.42 ft/min | 0.48 ft/min |
| Residence time | 12 min | 5.2 min |
| Feed pH | Approx. 7.5 | Approx. 7.5 |
| Feed temperature | 60 °F | 60 °F |
| Feed pressure | 50 psi | 35 psi |
| Bed differential pressure | 3 psi | <2 psi |

gal/min = gallons per minute
psi = pounds per square inch

**Table 1-2. Properties of Resins Evaluated**

| | Purolite A500 | Purolite A100 | Purolite A600 | ResinTech SIR-1200 | Dowex 21K 16-20 | ResinTech SIR-700 |
|---|---|---|---|---|---|---|
| Estimated cost, $/$ft^3$ | $140 | $175 | $130 | $175 | $266 | $225 |
| Maximum exchange capacity, equivalents/L | 1.15 | 1.3 | 1.4 | 1.4 | 1.2 | 2.7 |
| Calculated hexavalent chromium capacity, g/L | 30 | 34 | 36 | 36 | 31 | 70 |
| Calculated hexavalent chromium capacity, lb/$ft^3$ | 1.87 | 2.11 | 2.27 | 2.27 | 1.95 | 4.38 |
| Calculated hexavalent chromium capacity, lb/vessel (80 $ft^3$) | 149.3 | 168.8 | 181.8 | 181.8 | 155.8 | 350.6 |

**Table 1-2. Properties of Resins Evaluated**

| | Purolite A500 | Purolite A100 | Purolite A600 | ResinTech SIR-1200 | Dowex 21K 16-20 | ResinTech SIR-700 |
|---|---|---|---|---|---|---|
| Calculated hexavalent chromium capacity, kg/vessel | 67.9 | 76.7 | 82.6 | 82.6 | 70.8 | 159.4 |
| Pressure drop, psi/ft[a] | 0.93 | 0.50 | 0.11 | 0.40 | 0.20 | 0.90 |
| Temperature, °C[a] | 20 | 27 | 25 | 27 | 25 | 27 |
| Backwash flow rate, gal/min/ft$^2$ for 50% expansion factor[b] | 2.4 | 1.9 | 2.5 | 2.2 | 5.0 | 2.4 |
| Temperature, °C[b] | 20 | 20 | 20 | 20 | 25 | 27 |
| Substrate | Styrene DVB | Styrene DVB | Styrene DVB | Styrene DVB | Styrene DVB | Epoxy polyamine |
| Structure | Macroporous | Macroporous | Gel | Gel | Gel | Macroporous |
| Shape | Spherical bead | Spherical bead | Spherical bead | Spherical bead | Spherical bead | Granular |
| Active group | Quaternary ammonium | Tertiary amine | Quaternary ammonium | Quaternary amine | Quaternary amine | Proprietary amine |
| Type (anion exchange) | Type 1 strong base | Weak base | Type 1 strong base | Type 1 strong base | Type 1 strong base | Weak base |
| Operational pH | 0 to 11 | 0 to 9 | 0 to 10 | 0 to 14 | 0 to 14 | <6.5 |
| Ability to be regenerated? | Yes | Yes | Yes | Yes | Yes | No |

a. The pressure drop is determined at the temperature in the row below it.

b. The backwash flow rate is determined at the temperature in the row below it.

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DVB = divinylbenzene

gal/min = gallons per minute

The resins were tested at least until hexavalent chromium had been detected in the effluent of the column. In this document, "breakthrough" is defined as the point at which hexavalent chromium has started to exit the column, as indicated by two consecutive effluent concentrations above 10 µg/L. Continued testing beyond this point defines the shape of the breakthrough curve, which provides important information on the rate that the contaminant approaches equilibrium in the column.

**Table 1-3. Resins Tested in Evaluations #1 and #2 and the Parameters of the Tests**

| | Column #1 | Column #2 | Column #3 | Column #4 | Column #5 | Column #6 |
|---|---|---|---|---|---|---|
| **Resin Evaluation #1** | **Dowex 21K** | **Purolite A100** | **Purolite A500** | **Purolite A600** | **ResinTech SIR-700** | **ResinTech SIR-1200** |
| Resin volume | 30 $in^3$ | 30 $in^3$ | 30 $in^3$ | 30 $in^3$ | 30 $in^3$ | 30 $in^3$ |
| Resin height | 43 in. | 43 in. | 43 in. | 43 in. | 43 in. | 43 in. |
| Residence time | 7.5 min | 7.5 min | 7.5 min | 7.5 min | 7.5 min | 7.5 min |
| Feed pH | Approx. 7.5 | Approx. 7.5 | Approx. 7.5 | Approx. 7.5 | 5 | Approx. 7.5 |
| Regeneration Condition | New | New | New | New | New | New |
| **Resin Evaluation #2** | **Purolite A500** | **Purolite A600** | **Dowex 21K** | **Dowex 21K** | **ResinTech SIR-700** | **ResinTech SIR-1200** |
| Resin volume | 13.7 $in^3$ | 13.7 $in^3$ | 13.7 $in^3$ | 13.7 $in^3$ | 30 $in^3$ | 13.7 $in^3$ |
| Resin height | 20 in. | 20 in. | 20 in. | 20 in. | 43 in. | 20 in. |
| Residence time | 3.5 min | 3.5 min | 3.5 min | 3.5 min | 7.5 min | 3.5 min |
| Feed pH | 5 | 5 | Approx. 7.5 | 5 | 5 | 5 |
| Regeneration condition | Regenerated | Regenerated | Regenerated | New | Continuation | Regenerated |

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## 1.4 Process Evaluations

Process alternatives are identified and described in the design and cost technical memorandum (SGW-41529). The primary purpose of the technical memorandum is to present pre-conceptual designs and cost evaluations to facilitate selection of an appropriate treatment system design for the DX facility. Consistent with this overall purpose, the specific objectives of the technical memorandum included the following:

- Develop the design criteria for the proposed DX facility treatment system.
- Develop pre-conceptual design and cost information for the proposed DX facility treatment system with the following four treatment design options:
  - IX using a strong-base resin with offsite regeneration at the Siemens facility in Minnesota
  - IX using a strong-base resin with regeneration at an onsite central regeneration facility (CRF)

- IX using a strong-base resin with in-vessel regeneration
- IX using single-use, weak-base resin with disposal of spent resin.

- Provide a basis for the future detailed design activities for the proposed DX facility treatment system.

Process alternatives identified in the technical memorandum were evaluated in a decision analysis workshop[3] to select the optimal IX regeneration approaches for the proposed DX facility (see Section 5.1). A multi-attribute value analysis approach was used to establish a hierarchy of decision criteria to be used in evaluating various resin management options. The following steps were completed as part of the multi-attribute value evaluation:

1. Provide overview of relevant IX technologies.
2. Develop a list of regeneration alternative options.
3. Develop potential evaluation criteria.
4. Define potential criteria.
5. Screen criteria and retain those considered important for decision making.
6. Identify measurement units for retained criteria.
7. Quantify the metrics for each measurement criterion.
8. Set scoring scales and ranges.
9. Establish weights for the criteria.
10. Score each alternative.
11. Evaluate scores and sensitivity analysis.

[3] Favara, P., 2009, *Decision Analysis for Resin Management Process at the 100-DX Ion-Exchange Treatment Plant*, CH2M HILL, Denver, Colorado.

# 2 Current DX Facility Project Baseline

This chapter presents information on the current project baseline for the DX facility.

## 2.1 Schedule

The current baseline schedule for the DX facility is based on, and driven by, the milestones outlined in Section 2.1.1. In summary, the baseline schedule for the DX facility indicates the following:

- Design: December 2008 to August 2009
- Construction: February 2010 to December 2010
- Acceptance testing: Acceptance test procedure/operational test procedure, to December 2010.

Completion of the 2,271 L/min (600 gallons per minute [gal/min]) DX facility expansion is targeted for December 2010.

### 2.1.1 Tri-Party Agreement Milestones

The Tri-Parties (i.e., the U.S. Department of Energy [DOE], U.S. Environmental Protection Agency, and Washington State Department of Ecology [Ecology]) established a series of *Hanford Federal Facility Agreement and Consent Order* (Tri-Party Agreement) (Ecology et al. 1989) milestones. The milestones that are applicable to this effort included the following:

- Milestone M-016-110-T01: Contain or remediate hexavalent chromium groundwater plumes by December 31, 2012.
- Milestone M-016-110-T02: Remediate hexavalent chromium groundwater plumes by December 31, 2020.
- Milestone M-016-111B: Expand the current pump-and-treat system at 100-HR-3 to 1,893 L/min (500 gal/min) capacity by December 31, 2010.
- Milestone M-016-111C: Expand the current pump-and-treat system at 100-HR-3 to 3,028 L/min (800 gal/min) capacity by December 31, 2011.

### 2.1.2 Contract Performance Incentives

The DOE has established performance objectives that support the above-mentioned Tri-Party Agreement milestones. The pertinent performance criteria are as follows:

- Performance Criterion 1a.1: Expand the current pump-and-treat system at 100-HR-3 OU to 1,893 L/min (500 gal/min) by December 31, 2010.
- Performance Criterion 1a.3: Expand the current pump-and-treat system at 100-HR-3 OU to 3,028 L/min (800 gal/min) by December 31, 2011.
- Performance Criterion 1a.4(a): Complete resin testing at DR-5 by August 31, 2009.

## 2.2 Design Basis

The current DX facility project baseline provides for the design, construction, and operation of the DX facility as follows:

- DX facility design was initially based on the design of the 100-KX system (KX), which has a 2,271 L/min (600 gal/min) capacity. It has six 379 L/min (100 gal/min) IX treatment trains and uses Dowex 21K® resin. The resin is regenerated offsite at the Siemens facility in Minnesota.
- Early in the design process, it became apparent that Purolite® A500 and ResinTech SIR-700 offered better performance at a lower cost, and the design was changed to accommodate both of these resins.

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# 3 Resin Testing and Evaluation

Two sets of tests were performed in the DR-5 facility using the same groundwater influent used in the treatment facility. The influent contains approximately 650 µg/L hexavalent chromium, as well as high levels of nitrate and sulfate. Summaries of the chemistry of the wells that feed this facility are presented in Appendix B. The resin evaluation skid was delivered to the DR-5 facility in late February 2009. The skid was connected to the DR-5 influent tank and was tested for water leaks; proper operation; and calibration of the pumps, valves, and flow meters. The resin columns were then loaded with the appropriate volume of resin. Testing began on March 10, 2009.

The types of resin and the conditions for testing (e.g., influent pH) were chosen after review of vendor-supplied performance data and peer-reviewed literature. Test parameters were reviewed by individuals with expertise in IX resins to ensure that the information produced would meet the design needs for the DX facility. Table 1-3 lists the resins tested in the two evaluations and the testing conditions. In the first test series, ResinTech® SIR-700 was tested at pH 5, as recommended by the manufacturer. The remaining resins were tested at pH 7.5, the normal groundwater pH. In the second test series, pH levels were reduced in all the resins (except Dowex 21K, which was tested at pH 5 and pH 7.5) to investigate the effects of pH on resin behavior.

Effluent from the columns was analyzed onsite twice each day on working days and typically once each day on weekends. The skid was inspected daily for any signs of leakage or malfunction of the pumps and flow meters.

The duration of testing for each resin was determined by breakthrough indications. For example, Purolite A100 resin exhibited complete exhaustion (i.e., effluent concentration equal to influent concentration) after 8 days, but ResinTech SIR-700 still showed no signs of breakthrough after 130 days of testing.

At the conclusion of the first test, five of the resins were removed from the columns. Purolite A100 performed poorly during the test, and was removed from further testing. ResinTech SIR-700 remained on the skid for further testing. The other four resins were regenerated and repacked into columns for the second test. The regeneration procedure consisted of emptying the resin into a container and adding various solutions to remove hexavalent chromium from the resin. This resin regeneration process is discussed in further detail in Section 3.4.

## 3.1 Experimental Design

The resin evaluation parameters were chosen to emulate existing hexavalent chromium treatment systems, specifically the 100-HR-3 treatment facility. This system, as well as those in the 100-KR-4 OU, treats groundwater in trains of four vessels, referred to as a "lead-lag-lag-polish" configuration. Each vessel holds a resin volume of 2.27 $m^3$ (80 $ft^3$, or 600 gal) and is designed for a flow rate of 379 L/min (100 gal/min). Additional details on the treatment parameters (e.g., linear flow rate and residence time) for the 100-HR-3 facility are presented in Table 1-1. The resin evaluation skid was designed to simulate the breakthrough time of a typical Hanford Site lead resin bed, so the resin configuration and flow rates were chosen to see breakthrough for Dowex 21K (the resin used at the 100-HR-3, 100-KR-4, 100-KW (K-West), and KX facilities) in approximately 20 days. This was accomplished by keeping the linear flow rate through the resin (therefore, the contact time with the resin particles) in the evaluation skid close to that of the full-scale vessels.

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Hexavalent chromium was sampled and analyzed onsite at least daily to detect initial breakthrough and accurately establish the breakthrough curve. These tests were performed using a reagent containing an acidic buffer combined with 1,5-diphenylcarbohydrazide, which reacts to give a purple color when hexavalent chromium is present. The sample was then analyzed using a calibrated colorimeter (Hach® DR/4000 portable spectrophotometer), which was operated by a trained technician. The technique has a detection limit of approximately 10 μg/L, with a precision of ±20 percent. Other analyses were performed at the Hanford Site Waste Sampling and Characterization Facility.

The evaluation skid has been designed to emulate conditions typical of the lead vessel in a full-scale Hanford Site treatment facility (e.g., 100-HR-3). Each test column has a feed tank, and all feed tanks are filled from a common supply of groundwater influent. Flow rates for each test column are controlled manually to maintain linear velocities through the test resin beds close to the full-scale operating facility velocities. This control provides equal groundwater-to-resin bead (or granule) contact times and is important to emulate breakthrough time observed in full-scale systems and more accurately compare the performance of different resins.

## 3.2 Test Data

The data discussed in this chapter are from the first two resin evaluations, which were performed from March 10 to May 31, 2009. The primary difference between the two tests was that the first test used only virgin resins, and the second test used smaller volumes of resin, a combination of virgin and regenerated resin, and a reduced pH of the groundwater. The only non-regenerable resin used in the tests, ResinTech SIR-700, ran continuously during both of the tests and has continued to run, without breakthrough, for over 130 days.

The flow rates through the columns averaged 0.064 L/min (0.0170 gal/min), with a standard deviation of 0.0050 L/min (0.00133 gal/min). This is very close to the target rate of 0.068 L/min (0.018 gal/min).

### 3.2.1 Evaluation #1

The first resin evaluation ran for 42 days, from March 10 to April 21, 2009. At that point, two of the six resins had reached complete exhaustion (i.e., the effluent chromium concentration had met, or exceeded, the influent concentration). Three of the resins demonstrated breakthrough but had effluent concentrations at approximately one-half of the influent concentration. Breakthrough curves are sinusoidal; therefore, the remainder of the curve can be predicted once a defining-region of the curve has been identified by testing. The sixth resin, ResinTech SIR-700, demonstrated no signs of breakthrough, so testing continued into the second evaluation.

The breakthrough curves (Figure 3-1) and associated data (Appendix C) show that hexavalent chromium reached breakthrough with Purolite A100 after treating 350 L (92.5 gal) and 724 BVs, and hexavalent chromium reached equilibrium throughout the column at approximately 1,400 BVs. Dowex 21K was the next resin to exhibit breakthrough at 1,416 L (374 gal) and 2,925 BVs; hexavalent chromium reached equilibrium throughout this column at approximately 6,000 BVs. Hexavalent chromium in the Purolite A600 and SIR-1200 resins reached breakthrough at 4,626 and 4,367 BVs, respectively. Neither of these was tested to equilibrium with chromium, but a curve analysis indicates that equilibrium would be achieved at approximately 7,000 BVs. Purolite A500 was the last of the resins to show breakthrough after treating 2,801 L (740 gal) and 5,787 BVs. Total equilibrium with Purolite A500 would be expected at approximately 12,000 BVs. The hexavalent chromium adsorption front could be visually observed

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during the tests. The downward movement of this front corresponded well to detection of breakthrough in the effluent.

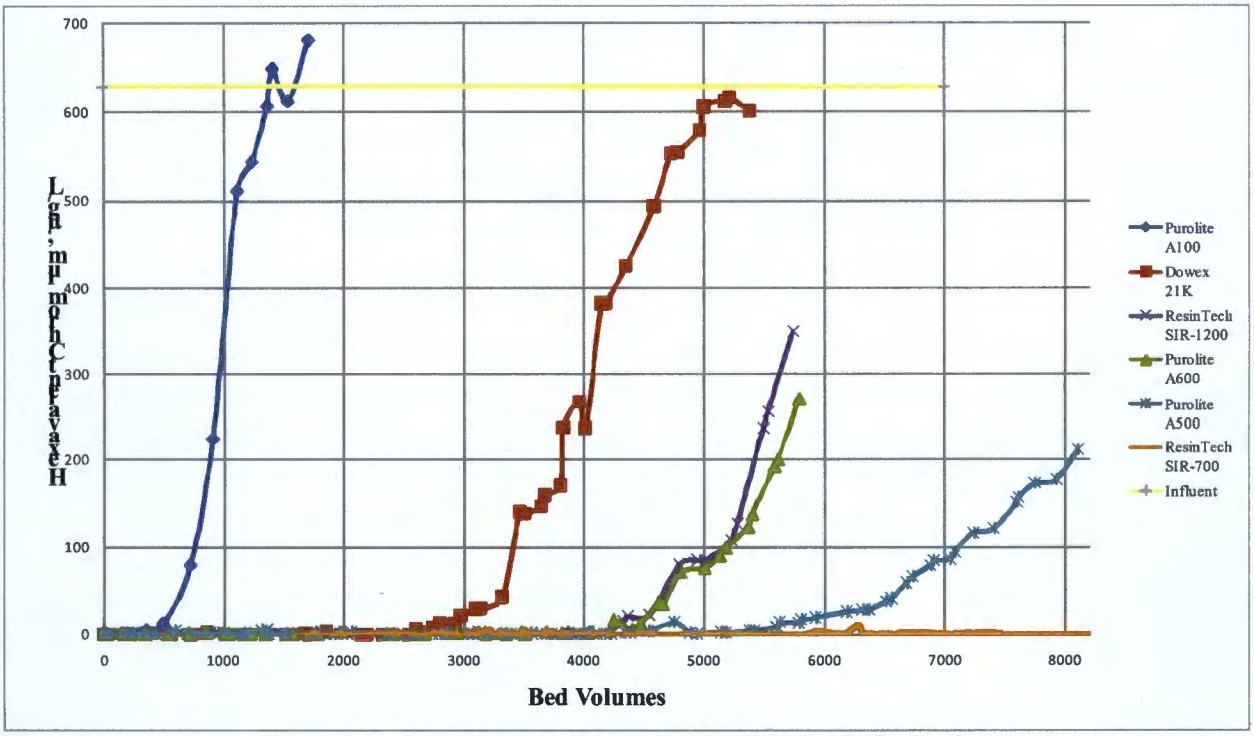


**Figure 3-1. Breakthrough Curves for the First Resin Evaluation**

Table 3-1 lists the amount of hexavalent chromium retained on each column at breakthrough and the amount adsorbed by the resin per BV. A summary of the effluent chemistry for constituents other than hexavalent chromium is presented in Appendix D.

**Table 3-1. Summary of Results from the First Resin Evaluation**

| Parameter | Units | Purolite A100 (pH 7.5) | Purolite A500 (pH 7.5) | Purolite A600 (pH 7.5) | Dowex 21K (pH 7.5) | ResinTech SIR-700 (pH 5) | ResinTech SIR-1200 (pH 7.5) |
|---|---|---|---|---|---|---|---|
| BV | gal | 0.1278 | 0.1278 | 0.1278 | 0.1278 | 0.1278 | 0.1278 |
| Average flow rate | gal/min | 0.0170 | 0.0168 | 0.0170 | 0.0167 | 0.0158 | 0.0167 |
| Volume treated to breakthrough | gal | 92.5 | 740 | 591 | 374 | >2,100 | 558 |
| BVs to breakthrough | -- | 724 | 5,787 | 4,626 | 2,925 | See footnote | 4,367 |
| Total hexavalent chromium in resin at breakthrough | g | 0.22 | 1.76 | 1.41 | 0.89 | See footnote | 1.33 |
| Hexavalent chromium capacity | g/L | 0.455 | 3.64 | 2.92 | 1.84 | See footnote | 2.75 |
| Hexavalent chromium capacity | $lb/ft^3$ | 0.0284 | 0.227 | 0.182 | 0.115 | See footnote | 0.172 |

**Table 3-1. Summary of Results from the First Resin Evaluation**

| Parameter | Units | Purolite A100 (pH 7.5) | Purolite A500 (pH 7.5) | Purolite A600 (pH 7.5) | Dowex 21K (pH 7.5) | ResinTech SIR-700 (pH 5) | ResinTech SIR-1200 (pH 7.5) |
|---|---|---|---|---|---|---|---|

NOTE: Has not reached breakthrough at the time that this report was issued.

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### 3.2.2 Evaluation #2

The second resin evaluation was performed under the same flow conditions as the first evaluation but differed in the bed depth (50.8 cm [20 in.]), the use of regenerated resin, and lower pH in most of the columns. As previously noted, ResinTech SIR-700 continued running from the first test, so only five resins were evaluated under conditions different from those of evaluation #2.

This evaluation ran for 38 days, from April 23 to May 31, 2009. At the end of the test, one resin had complete exhaustion so hexavalent chromium was in equilibrium throughout the entire column. The other four resins had demonstrated breakthrough, but the effluent concentrations were significantly less than the influent concentration. The sixth resin, ResinTech SIR-700, continued to effectively remove hexavalent chromium for over 130 days and has treated approximately 40,000 BVs to date. Table 3-2 presents a summary of the results from the second evaluation.

**Table 3-2. Summary of Results from the Second Resin Evaluation**

| Parameter | Units | Purolite A500 (pH 5) | Purolite A600 (pH 5) | Dowex 21K (pH 7.50) | Dowex 21K (pH 5) | ResinTech SIR-700 (pH 5) | ResinTech SIR-1200 (pH 5) |
|---|---|---|---|---|---|---|---|
| BV | gal | 0.0594 | 0.0594 | 0.0594 | 0.0594 | 0.1278 | 0.0594 |
| Average flow rate | gal/min | 0.0160 | 0.0176 | 0.0167 | 0.0161 | 0.0158 | 0.0163 |
| Volume treated to breakthrough | gal | 380 | 282 | 150 | 92.0 | >2,100 | 210 |
| BVs to breakthrough | -- | 6,391 | 4,744 | 2,523 | 1,550 | >40,000 | 3,542 |
| Total hexavalent chromium in resin at breakthrough | g | 0.90 | 0.67 | 0.36 | 0.22 | See footnote | 0.50 |
| Hexavalent chromium capacity | g/L | 4.02 | 2.98 | 1.59 | 0.970 | See footnote | 2.22 |
| Hexavalent chromium capacity | $lb/ft^3$ | 0.251 | 0.186 | 0.099 | 0.061 | See footnote | 0.139 |
| Virgin or regenerated | -- | Regenerated | Regenerated | Regenerated | Virgin | Virgin | Regenerated |

**Table 3-2. Summary of Results from the Second Resin Evaluation**

| Parameter | Units | Purolite A500 (pH 5) | Purolite A600 (pH 5) | Dowex 21K (pH 7.50) | Dowex 21K (pH 5) | ResinTech SIR-700 (pH 5) | ResinTech SIR-1200 (pH 5) |
|---|---|---|---|---|---|---|---|

NOTE: Has not reached breakthrough at the time that this report was issued.

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The breakthrough curves (Figure 3-2) and associated data (Appendix C) for this evaluation show that the regenerated Dowex 21K that was tested at a nominal pH (approximately 7.5) exhibited breakthrough approximately 15 percent sooner than the virgin Dowex 21K from the first evaluation (2,523 BV versus 2,925 BVs). The virgin Dowex 21K (tested at a pH of 5) reached breakthrough at approximately 1,500 BVs, and the curve was markedly shallower than either test with this resin at nominal pH.

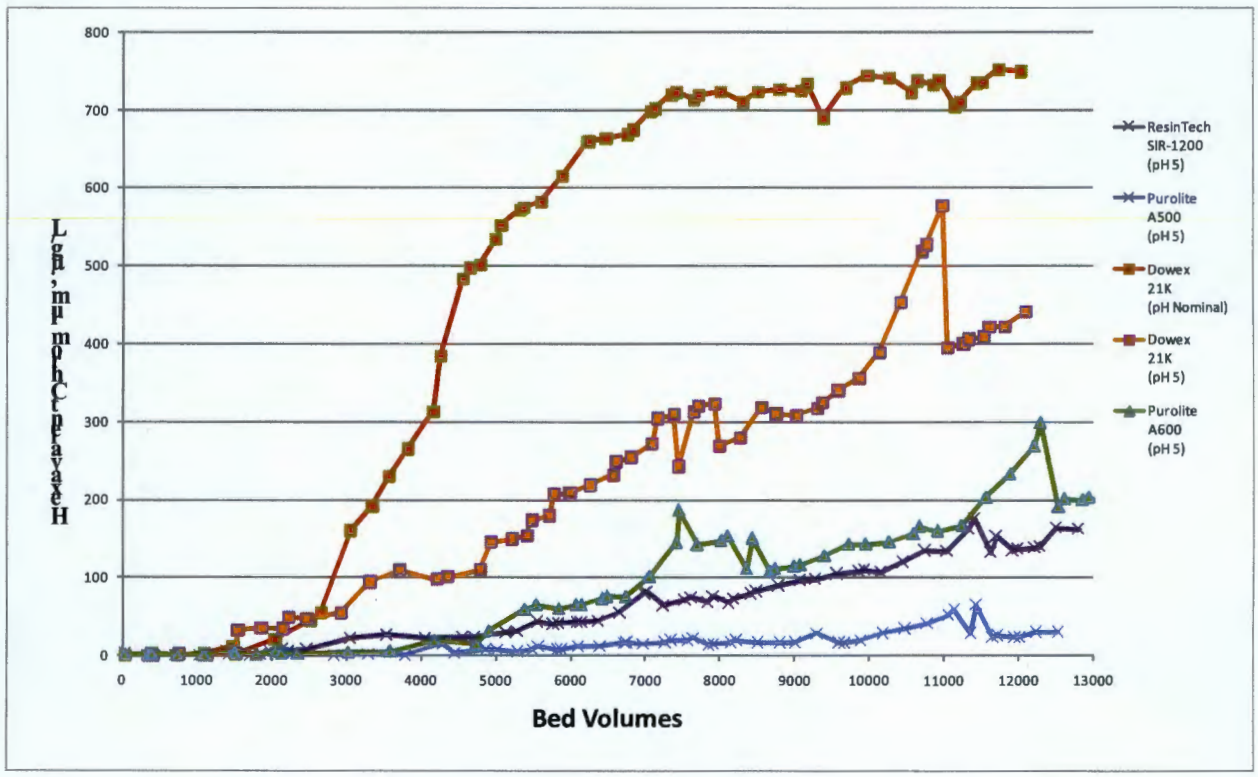


**Figure 3-2. Breakthrough Curves for the Second Resin Evaluation**

Purolite A500, Purolite A600, and ResinTech SIR-1200 all regenerated and tested at a pH of 5, performed similarly to the first test. Dowex 21K and ResinTech SIR-1200 showed a decrease in the number of BVs to the point of breakthrough compared to the first evaluation and the curve had a lower slope. Purolite A600 reached breakthrough at 4,744 BVs compared to 4,626 BVs in the first evaluation, approximately a 3 percent increase. Purolite A500 reached breakthrough at 6,391 BVs compared to 5,787 BVs in the first evaluation, which is an approximate 10 percent increase. ResinTech SIR-1200

reached breakthrough at 3,542 BVs compared to 4,367 BVs in the first evaluation, which is approximately a 20 percent reduction.

## 3.3 Hydrologic Characteristics

All of the resins retained adequate permeability during the evaluations, allowing free flow of water through the columns with little increase in differential pressure between the inlet and outlet.
The non-regenerable resin, ResinTech SIR-700, did show signs of decreasing permeability, which was overcome through the following measures: (1) the influent pressure to the column was increased by diverting more water to the column, (2) the flow meter and valve were removed from the influent line to the column, and (3) the top inch of the resin bed was removed and a 0.45-micron filter was added to the column influent line to remove organic sediments that were causing the increased pressure differential across the resin bed. The column has operated as intended for 6 weeks without problems following these measures.

## 3.4 Resin Regeneration

After the first evaluation, the resin was regenerated and used in the second evaluation to evaluate any change in characteristics due to the regeneration process. The procedure used to regenerate the resin is discussed below.

First, water was drained from each column into a bucket, and then the resin was emptied into an 18.9 L (5-gal) container. Then 200 mL (6.76 oz) of 10 percent sodium chloride solution was added to the resin and swirled periodically for up to 30 minutes. The resin was then drained and treated with 200 mL (6.76 oz) of 14 percent sodium dithionite solution for up to 30 minutes. Finally, the resin was rinsed with water and was ready to load into a column for additional testing. This procedure took approximately 4 hours to perform for all five columns.

This regeneration procedure is based on the in situ regeneration process used in the DR-5 facility. However, because of safety concerns associated with handling acid in uncovered containers, the last step of adding 3 percent hydrochloric acid was omitted in this evaluation. The acid treatment more completely removes some anions and converts the resin from a sulfate form to a chloride form. The chloride form of resin more readily gives up active sites to competing anions, increasing the capacity of the regenerated resin. A primary objective of the second test was to compare the performance of regenerated resin to virgin resin. Since all test resins were regenerated by the same procedure, the effect of the regeneration process can be determined by comparing the results from the first and second evaluations.,

## 3.5 Quality Assurance/Quality Control

Hexavalent chromium at the DR-5 facility is analyzed with a calibrated Hach DR/4000 portable spectrophotometer, which is operated by a trained technician. The practical detection limit of this instrument is 10 μg/L. The spectrophotometer is calibrated periodically and tested with a hexavalent chromium standard. Blank measurements are taken before and after each sample measurement to ensure that the spectrophotometer is operating properly.

Table 3-3 lists the values for hexavalent chromium as measured at DR-5 (i.e., laboratory code "FIELD") and in a fixed laboratory (i.e., laboratory code "WSCF" [Waste Sampling and Characterization Facility]). The largest difference between the two methods is slightly greater than 5 percent, with an average difference less than 3 percent.

**Table 3-3. Comparison of Field and Laboratory Data for Hexavalent Chromium**

| Well | Date/ Time | Hexavalent Chromium | % Difference | Units | Laboratory Code |
|---|---|---|---|---|---|
| 199-D5-20 | 08/24/08 / 08:15 | 197 | 0.5 | µg/L | WSCF |
| 199-D5-20 | 08/25/08 / 06:40 | 196 | | µg/L | FIELD |
| 199-D5-20 | 11/17/08 / 13:20 | 174 | 2.2 | µg/L | FIELD |
| 199-D5-20 | 11/20/08 / 12:02 | 178 | | µg/L | WSCF |
| 199-D5-32 | 08/24/08 / 08:45 | 134 | | µg/L | WSCF |
| 199-D5-32 | 08/24/08 / 08:45 | 133 | 1.1 | µg/L | WSCF |
| 199-D5-32 | 08/25/08 / 06:40 | 135 | | µg/L | FIELD |
| 199-D5-32 | 11/17/08 / 13:20 | 63 | 1.6 | µg/L | FIELD |
| 199-D5-32 | 11/20/08 / 13:02 | 64 | | µg/L | WSCF |
| 199-D5-39 | 11//17/08 / 13:20 | 1,929 | | µg/L | FIELD |
| 199-D5-39 | 11/20/08 / 10:14 | 2,000 | 5.2 | µg/L | WSCF |
| 199-D5-39 | 11/20/08 / 10:14 | 2,070 | | µg/L | WSCF |
| 199-D5-92 | 11/17/08 / 13:20 | 86 | 5.3 | µg/L | FIELD |
| 199-D5-92 | 11/20/08 / 12:30 | 90.8 | | µg/L | WSCF |

NOTE: Average percent difference = 2.7; standard deviation = 2.1.

## 3.6 Deviations from Test Plan and Lessons Learned

The goal of the testing was to gather hexavalent chromium breakthrough curve data for various resins, using actual Hanford Site groundwater, in order to make relative comparisons. The data are directly applicable to the new DX facility and the existing hexavalent chromium pump-and-treat facilities at the Hanford Site.

The test plan made allowances for deviations in the plan, due to the newness of both the evaluation skid and the pilot facility evaluation method. In addition to the stated purpose of the testing, supplementary analyses were added to enhance the overall understanding of the IX process and to confirm the data analyzed in the field.

As allowed by the plan, additional hexavalent chromium analyses were performed as needed to define the hexavalent chromium breakthrough curves, and the collection of a portion of the supplementary data was curtailed. The deviations from the test plan were as follows:

- The normal collection of effluent hexavalent chromium data was increased to twice per day on weekdays and once per day on weekends.
- The analysis for effluent pH, oxidation-reduction potential, and conductivity was stopped after 29 days. No correlation between the data and resin performance was evident.

- The sampling of the influent and effluent for cations, inductively coupled plasma metals, total dissolved solids, total suspended solids, etc., was reduced in frequency after a baseline was established and the daily field hexavalent chromium analyses were confirmed.

These deviations did not compromise the primary goal of comparing breakthrough curves.

## 3.7 Comparison to Operating Facilities

To obtain some measure of data applicability to a full-scale treatment system (which the skid was designed to emulate), one column during the first test was run with Dowex 21K (i.e., the resin currently used at the 100-HR-3 and 100-KR-4 facilities). The hexavalent chromium retention data from this column were compared to similar data obtained during operation of the 100-HR-3 and 100-KR-4 treatment systems. This comparison demonstrates that data from the evaluation skid are comparable to the full-scale treatment facilities. The evaluation skid processes 3.79 L/h (1 gal/h), whereas the full-scale system processes 379 L/min (100 gal/min); however, in both systems, the linear flow rates are comparable. Therefore, the number of BVs of water passing through the resin bed before breakthrough was comparable. The linear flow rate and the number of BVs to breakthrough in the evaluation skid results differed by approximately 10 percent from that of the full-scale systems.

The data obtained from the first two tests were used, along with the process options presented in Chapter 4, to evaluate the economics of the design alternatives and served as guidance for choosing the resin and conditions for the third test, which is ongoing.

# 4 Design and Cost Evaluation of Treatment System Options

This chapter summarizes the designs and costs of four candidate IX systems for the proposed DX facility. Detailed information is provided in SGW-41529. The IX processes are virtually identical. The primary difference in the candidate systems is the approach for regeneration or disposal of spent resin.

The DX system, which is based on the existing KX system, is designed for a maximum design flow rate of 2,271 L/min (600 gal/min), with influent hexavalent chromium concentrations of up to 500 µg/L. Design criteria for the KX system specified use of a modular system in which capacity is increased by adding 379 L/min (100 gal/min) trains rather than using trains with higher capacity. This modular approach has been used for the 100-HR-3, K-West, and 100-KR-4 systems.

The IX train components (including associated vessels, piping, valves, and instrumentation) are skid-mounted as a single unit. Each of the four coated-steel vessels in a skid has a resin BV of 2.27 $m^3$ (80 $ft^3$), with allowance for 50 percent resin expansion during backwash, plus freeboard. The maximum flow rate through each train is 379 L/min (100 gal/min) at full system capacity.

## 4.1 Process Options Considered and Rationale for Selection

This section discusses the process options that were considered and the rationale for selection. Process options include offsite resin regeneration, onsite resin regeneration at a CRF, in-vessel regeneration, and single-use resins.

### 4.1.1 IX with Offsite Resin Regeneration

The design and operation of this IX system with offsite regeneration is virtually identical to that of the KX system, including provision for sluicing depleted resin into totes for shipment to the Siemens facility in Minnesota for regeneration. The proposed resin is Purolite A500. The expected resin capacity[4] (6.6 kg/vessel [14.5 lb/vessel]) is calculated from test data and the design hexavalent chromium concentration (500 µg/L). The expected regeneration rate for Purolite A500 is 88 vessels/year.

#### *4.1.1.1 Process Description*

As shown in Figure 4-1, the system consists of six parallel trains, with four IX vessels per train, and provision for resin sluicing and tote handling. The general layout of the process building (Figure 4-2) is based on the 100-KX Building, except the building has been enlarged to accommodate potential future modifications, including additional trains or pre-treatment systems to accommodate chemical or biological in situ treatment of groundwater with subsequent treatment at the DX facility.

Groundwater from extraction wells is pumped into an influent storage tank where the pH is reduced from ambient to 7.0 with acid (sulfuric or hydrochloric) to reduce the potential for well and column fouling by precipitation of calcium carbonate. Process feed pumps transfer water to the six IX trains. Automated flow-control valves distribute the flow equally to each train. Groundwater flows serially through the vessels in each train, with downward flow through each vessel. A diffuser above the resin bed ensures even coverage of water. Treated groundwater is collected in an effluent storage tank, and then booster pumps transfer the water to injection wells located upgradient of the extraction wells.

[4] Resin capacities in this section are the capacities for hexavalent chromium removal from groundwater.

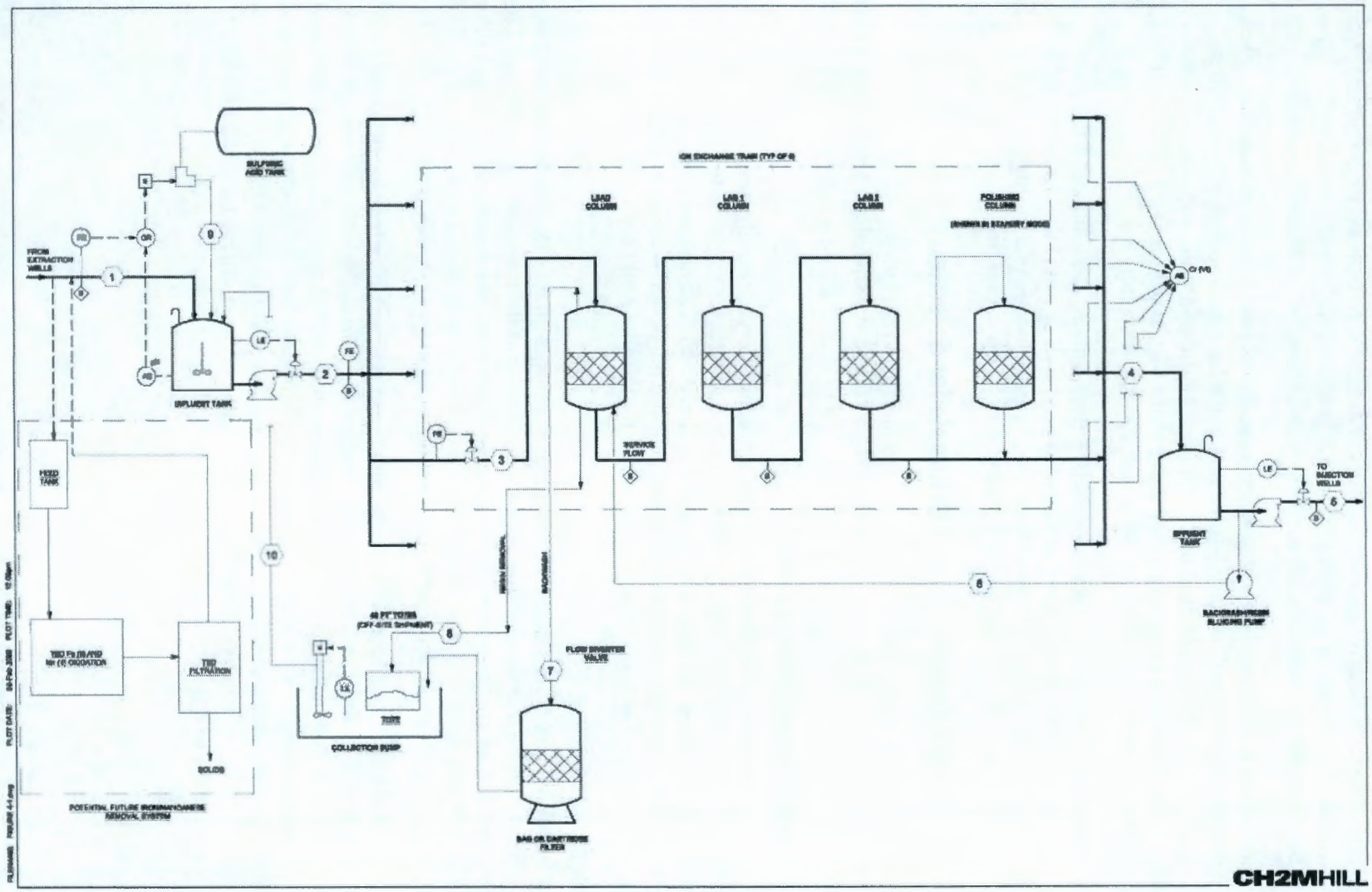


Figure 4-1. IX System with Offsite Regeneration

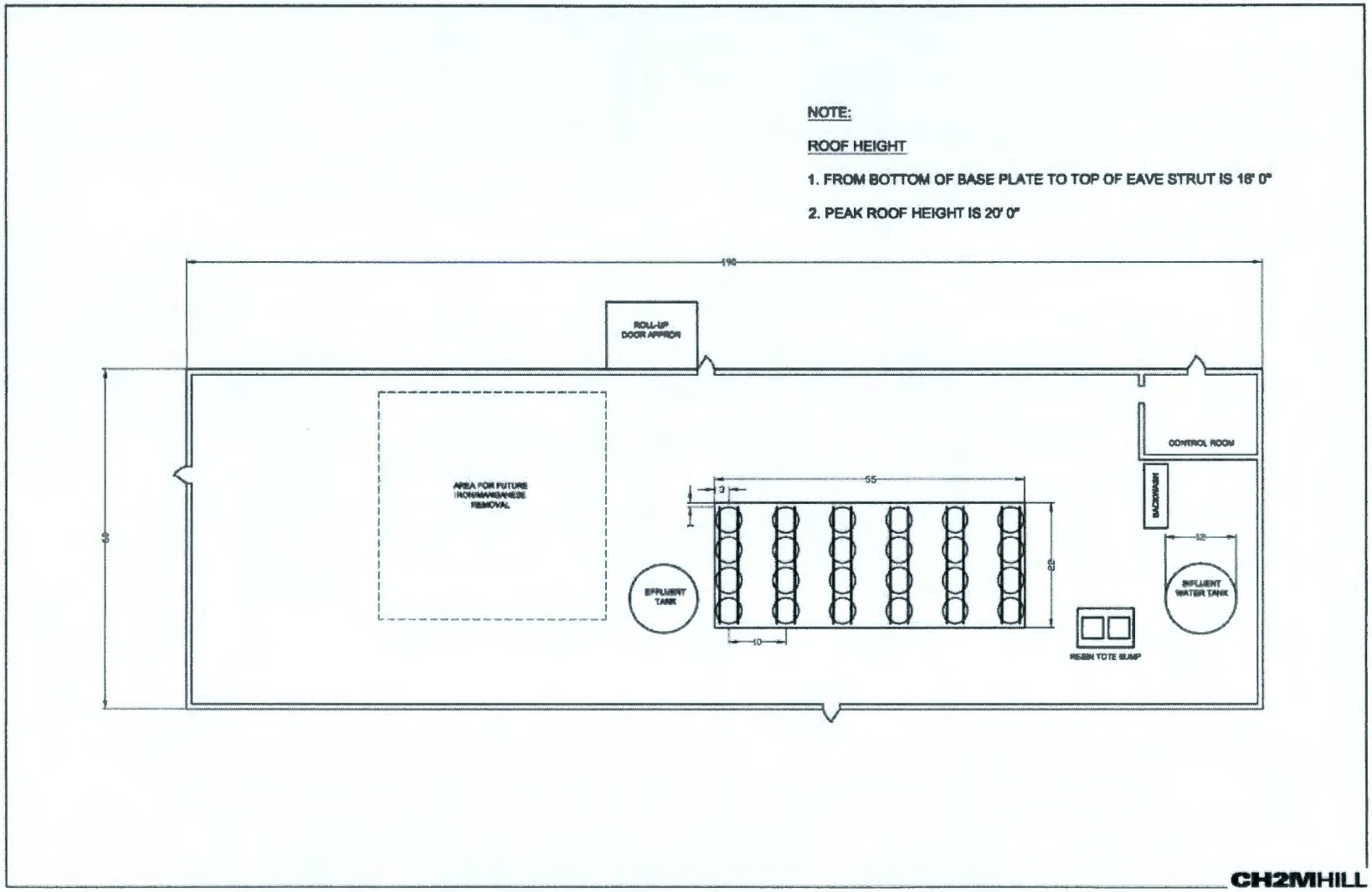


Figure 4-2. Building Layout for IX System with Offsite Regeneration

Spent resin is transferred to totes placed in a tote sump system in the process building. Empty totes (1.13 $m^3$ [40 $ft^3$]) are set on an apron next to the sump to receive spent resin. When hexavalent chromium breakthrough occurs, the lead vessel is backwashed with treated water to remove fines from the resin. The backwash water is filtered before being pumped back to the feed tank to be reprocessed. Treated groundwater also is used to sluice spent resin into the totes. The sluice water drains from the totes into the collection sump before being pumped into the influent tank. Fresh resin is added as required to supplement resin loss. The resin is analyzed for radioisotopes before shipment offsite.

#### *4.1.1.2 Advantages*

The primary advantage of offsite regeneration is that the regeneration process, associated chemical handling, and waste disposal are performed without impact to the Hanford Site. Siemens, the regeneration contractor, has a proven process for regeneration. An authorized limit application is in place to address radionuclide issues.

#### *4.1.1.3 Disadvantages*

Disadvantages of offsite regeneration include the following:

- Possible DOE liability for cleanup of the Siemens process facility and potential contamination of a municipal sewage system because the liquid wastes at Siemens are disposed as domestic waste.
- Transport on public highways during offsite shipment of exhausted resins that potentially contain radionuclides. A replenishment rate of 5 percent per year is assumed to account for resin damage or loss from resin loading and unloading, transportation, and regeneration.
- Cost of the resin shipment and regeneration process, including analysis of radionuclides and preparation of required documents.
- Long turnaround time (120 days), which requires the purchase of additional resin and totes. Based on the pre-conceptual design and cost estimates (SGW-41529) and the estimated regeneration rate (88 vessels/year), the cost for additional resin and totes is about $460,000.

### 4.1.2 IX with Onsite Resin Regeneration

The DOE has expressed concern regarding shipping spent resin offsite because of the possible presence of radionuclides. Onsite regeneration would require the construction of a CRF on the Hanford Site. The estimated capacity for Purolite A500 is 6.6 kg/vessel (14.5 lb/vessel) and the regeneration rate is 88 vessels/year.

#### *4.1.2.1 Process Description*

The operating process for IX with onsite regeneration at the DX facility is nearly identical to the offsite regeneration process. The difference is that totes containing exhausted resin would be transported to the CRF rather than offsite. After regeneration is complete, the totes would be returned to the DX facility for sluicing of regenerated resin back into the IX vessels. Resins would be regenerated at the CRF using the general approach presented in Section 4.1.3.

#### *4.1.2.2 Advantages*

Advantages of IX with onsite regeneration include the following:

- Entire process remains onsite
- Reduced costs associated with turnaround times
- Elimination of radionuclide analysis, document preparation, and resin shipment.

#### *4.1.2.3 Disadvantages*

Disadvantages of IX with onsite regeneration include the following:

- Construction and operation of the CRF
- Treatment of used regeneration solutions (see Section 4.1.3.3 for further discussion).

### 4.1.3 IX with In-Vessel Resin Regeneration

The design for in-vessel regeneration is similar to the offsite regeneration system, except regeneration will take place while the resin is in the IX vessels. The resin regeneration approach presented here is the optimized regeneration approach used for the DR-5 facility. The estimated capacity for Purolite A500 is 6.6 kg/vessel (14.5 lb/vessel) and the regeneration rate is 88 vessels/year.

#### *4.1.3.1 Process Description*

The DR-5 regeneration process uses sodium dithionite ($Na_2S_2O_4$) to reduce hexavalent chromium to trivalent chromium within the IX vessels, and phosphoric acid followed by sodium hydroxide to form insoluble trivalent chromium phosphate in the used regenerant after removal from the vessel. The process underwent significant optimization during 2008 (HNF-37517, *DR-5 Process Optimization Study*) to reduce reagent use and labor requirements, as well as to allow for co-injection of regeneration process water rather than discharge to the in situ redox manipulation pond. Operation of the IX system is identical to that of the offsite and onsite systems.

As shown in Figure 4-3, the system consists of six parallel trains, with four IX vessels per train. Resin regeneration capabilities and a treatment system are used for regeneration solutions. The layout of the process building (Figure 4-4) is similar to the layout of the building used for the offsite regeneration solution, except the building has been enlarged to provide space for regeneration equipment. The IX process is identical to that used in the offsite system.

Regeneration is a multi-step process in which the vessel that contains exhausted resin is treated sequentially with each of three reagents, followed by two series of rinses with treated groundwater (SGW-38494, *DR-5 Performance Assessment of the 100-DR-5 Ion-Exchange System for Removal of Chromium from Groundwater at the 100-D Area*). Each regenerant solution is recirculated upward through the vessel, after which it is recirculated for 15 minutes of each regeneration hour and allowed to soak the resin for the remaining 45 minutes. Regenerant solutions include the following:

- Sodium chloride solution (10 percent) removes adsorbed hexavalent chromium (as $CrO_4^{-2}$) and uranium (as uranyl carbonate) from the resin.
- Sodium dithionite solution (14 percent) reduces residual hexavalent chromium to trivalent chromium.
- Dilute hydrochloric acid (1.1 percent hydrogen chloride) solubilizes residual uranium and trivalent chromium.
- An initial rinse with treated groundwater removes residual chemicals.
- Eight auxiliary rinses with treated groundwater remove residual acidity.

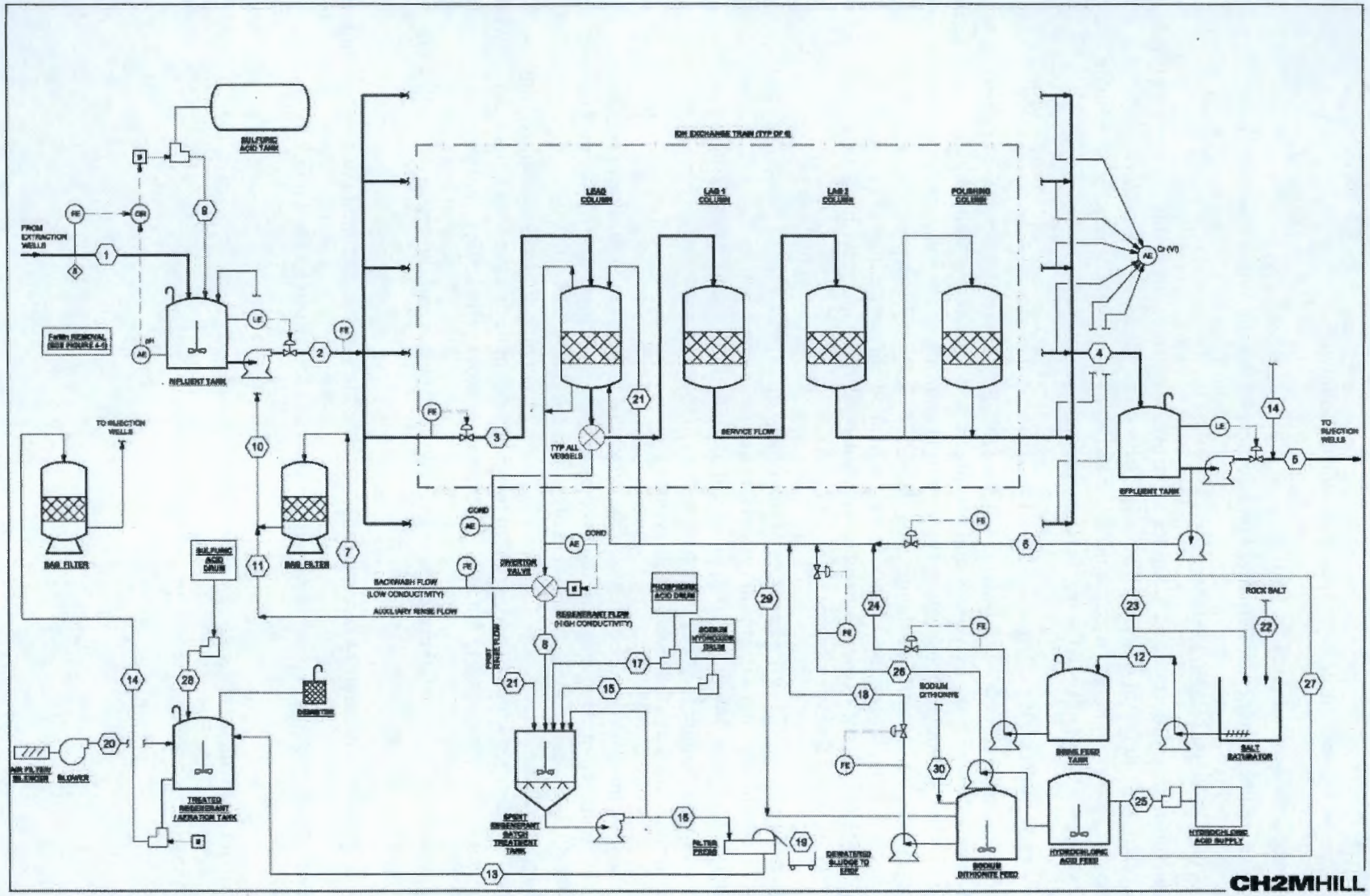


Figure 4-3. IX System with In-Vessel Regeneration

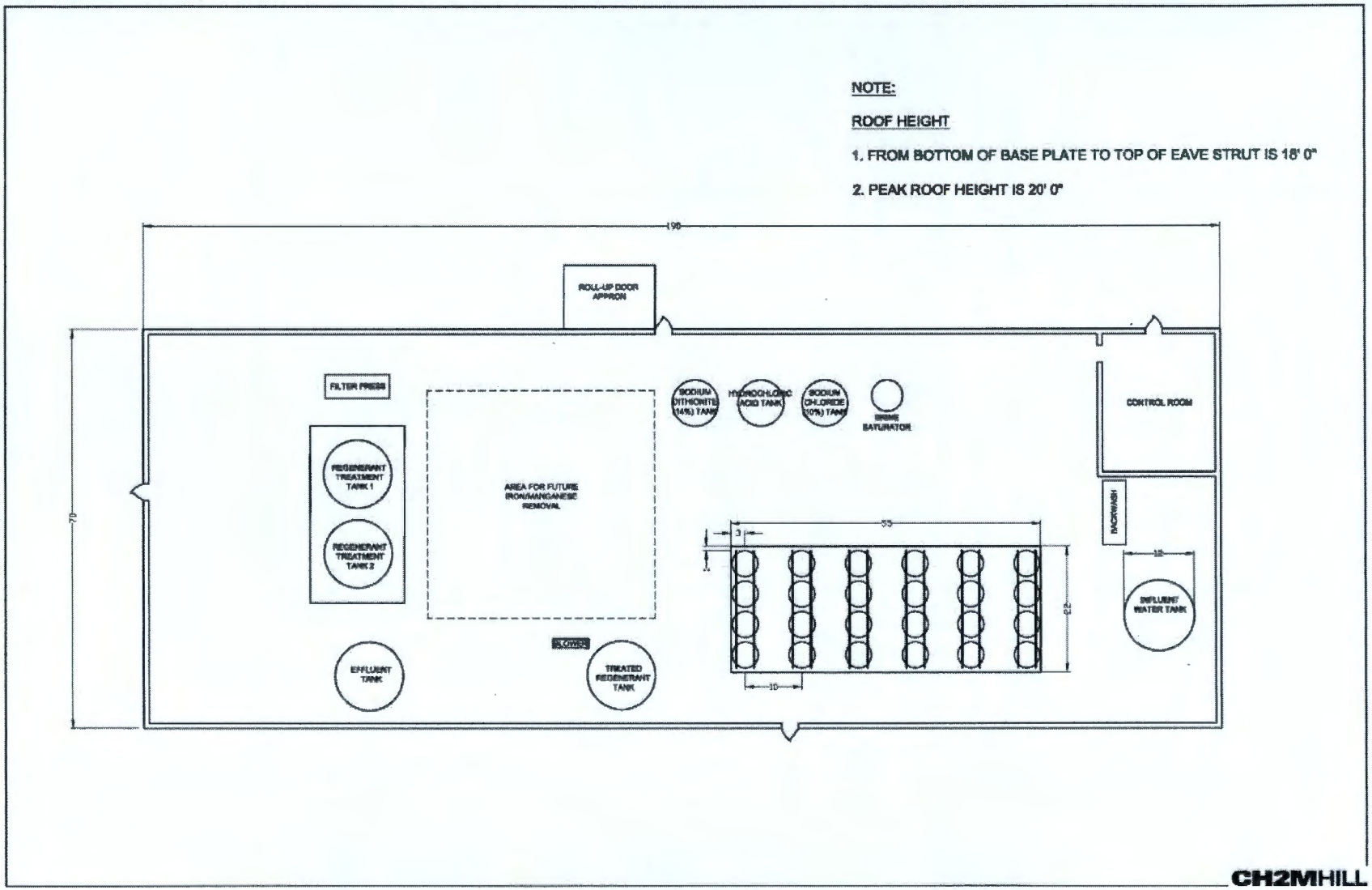


Figure 4-4. Building Layout for IX System with In-Vessel Regeneration

Treatment solutions and the initial rinse are conveyed to a precipitation tank. (Water from the auxiliary rinses is pumped to the influent tank.) In the precipitation tank, a 15 percent stoichiometric excess of 85 percent phosphoric acid ($H_3PO_4$) is added, and the pH is adjusted to 11.0 using sodium hydroxide, which is added over a 15-minute period. These steps generate chromium phosphate hexahydrate [$Cr(PO_4).6H_2O$]. After being allowed to settle for 12 hours, solids are removed in a filter press for disposal at the Hanford Site Environmental Restoration Disposal Facility (ERDF).

The filtrate is routed to the regenerant storage tank where residual dithionite is oxidized to sulfate by atmospheric oxygen provided by a blower.

Finally, the treated regenerant solution is neutralized with acid and metered into treated groundwater for co-injection. The metering rate is designed to ensure that the treated groundwater does not exceed secondary maximum contamination levels (MCLs) for chloride and sulfate. Phosphate does not have a secondary MCL, and its concentration is much lower than the chloride and sulfate concentrations. Therefore, chloride and sulfate concentrations are the deciding factors in the co-injection metering rate.

Use of vapor compression crystallization (VCC) was considered as an alternative to co-injection.[5] This would remove regeneration chemicals from the water and generate a solid waste that could be disposed at ERDF. Another alternative to co-injection is use of an evaporation pond, but regulatory issues may eliminate this option. Preliminary estimates show the lifecycle costs to be 5 percent greater than for co-injection. Table 4-1 shows that lifecycle costs for VCC are approximately 70 percent greater than the cost for co-injection.

**Table 4-1. Cost Comparison of Co-Injection with VCC for the DX Facility**

| | Co-Injection | VCC |
|---|---|---|
| Estimated capital cost ($ million) | 8.15 | 20.38 |
| Estimated annual O&M cost ($ million) | 1.58 | 1.91 |
| Estimated lifecycle costs ($ million) | 21.86 | 36.95 |

O&M = operations and maintenance

### *4.1.3.2 Advantages*

Advantages of IX with in-vessel regeneration include the following:

- Lower operations and maintenance (O&M) costs, which are lower than for offsite and onsite resin regeneration and comparable to that of single-use resin.
- Longer resin life when not subjected to the sluicing process. A five percent per year loss is assumed to account for resin damage or loss from resin loading and unloading, transportation, and regeneration.

[5] Giordano, T., 2009, *Preliminary Evaluation of Vapor Compression Condensation as an Alternative to Co-Injection for Treated Regenerant at 100-DX*, June 23, CH2M HILL, Denver, Colorado.

#### *4.1.3.3 Disadvantages*

Disadvantages of IX with in-vessel regeneration include the following:

- Co-injection of treated regenerant solution is a major concern.
  - Co-injection would introduce a flow of treated regenerant chemicals (chloride, sulfate, and phosphate) to the aquifer for over 10 years.
  - The duration and flow rate of co-injection at DR-5 are insufficient to evaluate potential impacts at the DX facility.
  - Aquifer impacts are uncertain but could be wide-ranging and irreversible.
  - Cost and regulatory issues must be addressed before alternatives to co-injection are feasible.
    - The VCC process is expensive (Table 4-1).
    - Ecology may prohibit use of an evaporation pond.
- The chemical process includes purchasing additional equipment and chemicals.
- Handling of hazardous chemicals is a concern.

### 4.1.4 IX with Single-Use Resin

The single-use design is similar to the offsite regeneration system, except ResinTech SIR-700 (a high-capacity, non-regenerable, weak-base resin) will be used. Exhausted resin is removed from the IX vessels, disposed as a waste, and fresh resin is then used. The minimum resin capacity is 44.5 kg/vessel (98.2 lb/vessel) and is calculated based on test data to date (40,000 BV) and the design hexavalent chromium concentration (500 µg/L). This capacity corresponds to a disposal rate of 13 vessels/year.

#### *4.1.4.1 Process Description*

As shown in Figure 4-5, the IX system consists of six parallel trains, with four IX vessels per train. When the lead vessel becomes exhausted, it is removed from service for resin removal and replacement. The system has the capability for backwash if necessary to reduce flow losses with time and to prepare the resin for removal. The layout of the process building (Figure 4-6) is similar to the layout of the facility proposed for offsite regeneration, with the exception that two sumps are located immediately adjacent to the IX trains to minimize pressure losses during resin removal by reducing the length of transfer lines.

Operation of the IX system is similar to that of the other alternatives, but the pH is reduced to 5.0 rather than 7.0 to optimize resin performance. After treatment, the effluent groundwater is neutralized with sodium hydroxide before injection.

If the exhausted resin does not pass toxicity characteristic leachate procedure (TCLP) testing, a stabilization process would be used to convert residual hexavalent chromium on the resin to trivalent chromium. A potential stabilization process has been incorporated into the design for the single-use resin. A 14 percent sodium dithionite solution will be pumped through the vessel to reduce the hexavalent chromium to trivalent chromium, which is expected to remain bound to the weak-base resin. The waste liquid containing sodium sulfate and residual sodium dithionite could be co-injected with the treated groundwater or mixed with an absorbent to create a solid waste.

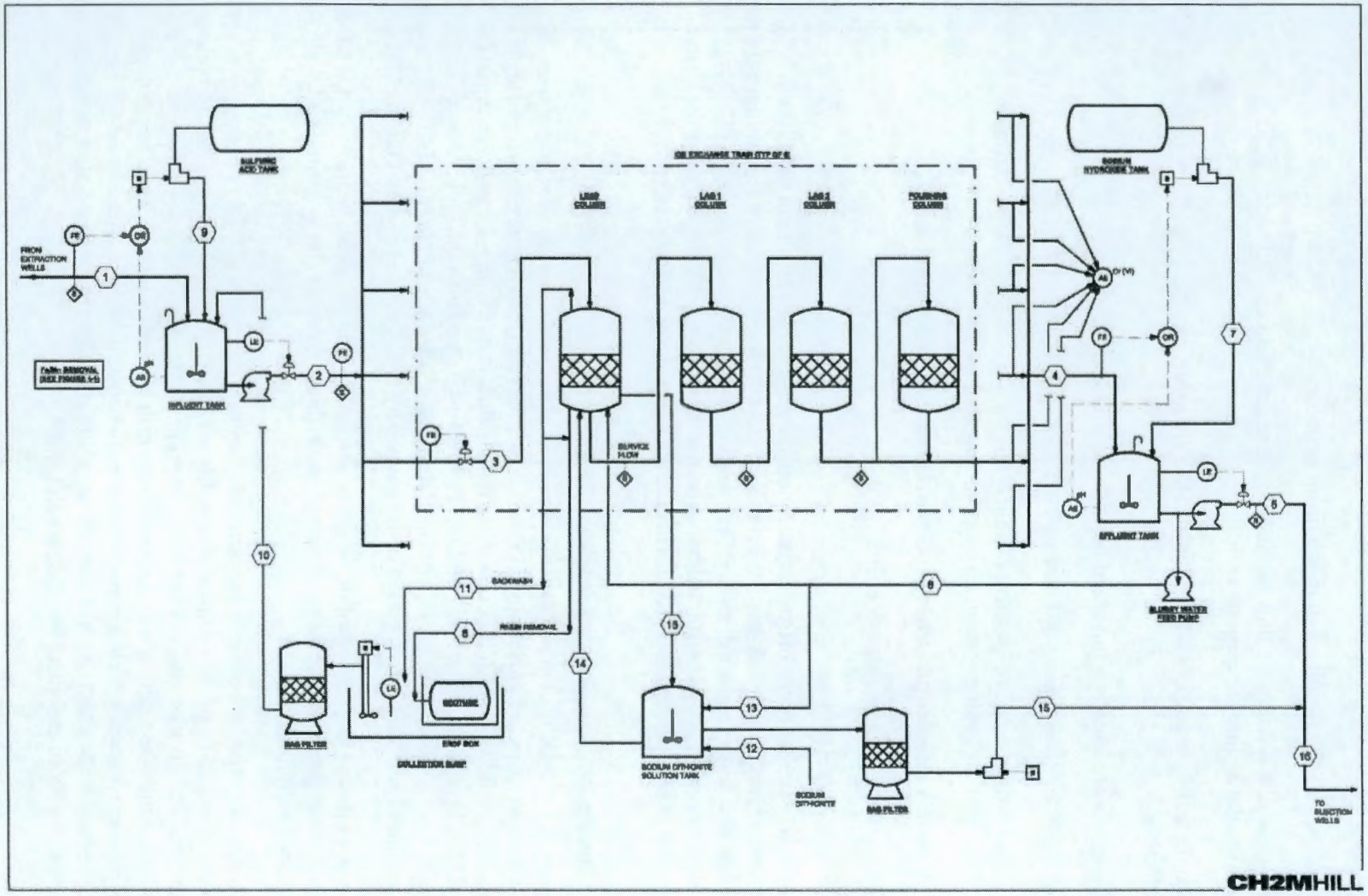


Figure 4-5. IX System with Single-Use Resin

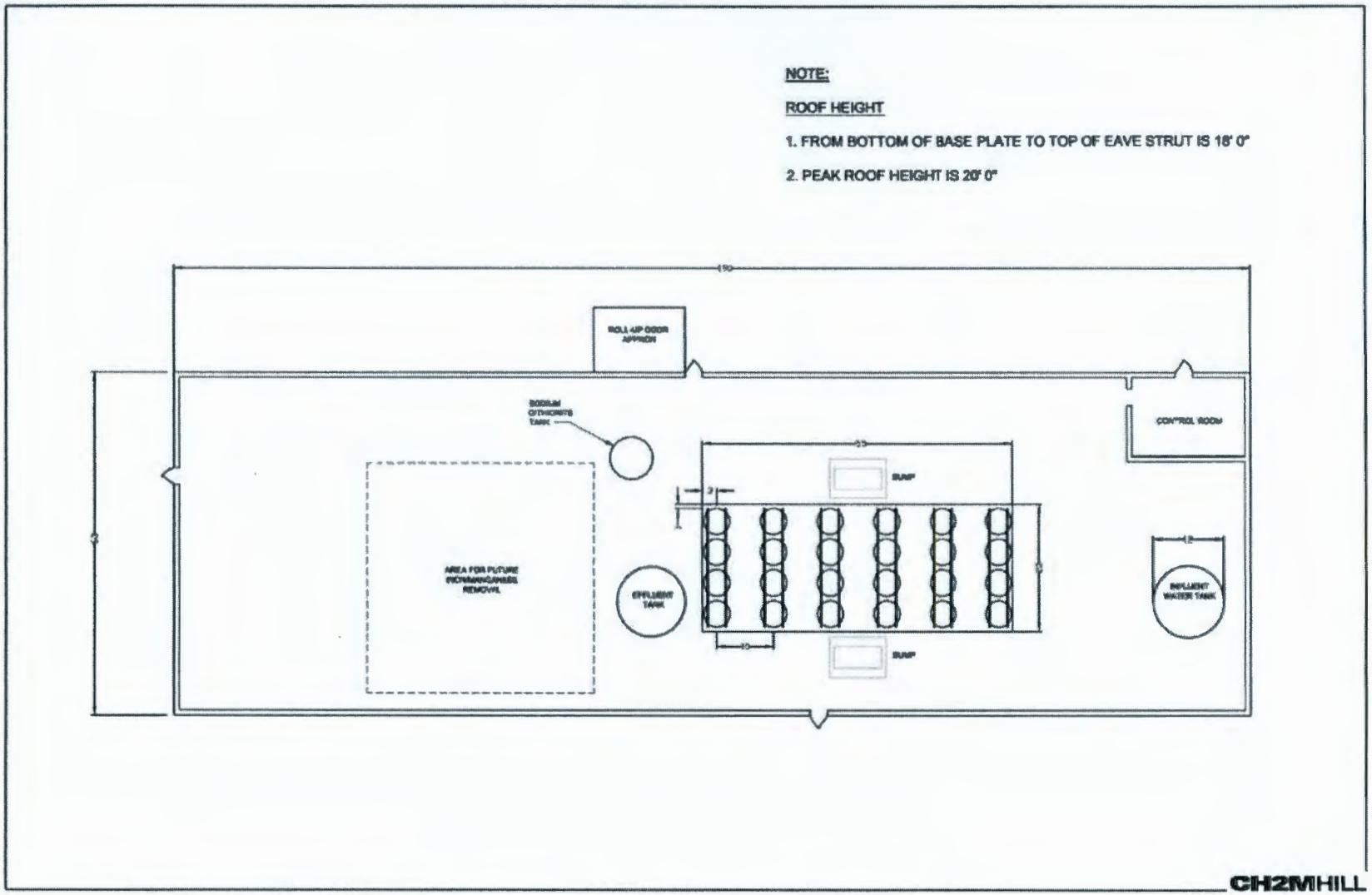


Figure 4-6. Building Layout for IX System with Single-Use Resin

If ResinTech SIR-700 cannot be sluiced in the same manner as Purolite A500 or with air sparging, a resin removal process is proposed that is similar to removal of granular activated carbon. Treated groundwater is added to the lead vessel to create a slurry. The vessel is then pressurized and the slurry is forced from the system, dewatered, and ultimately transferred to ERDF boxes for disposal. This process would require modification of the IX vessel and associated piping. An alternative to modifying the IX system would be use of ResinTech WBG30-B, a spherical equivalent to SIR-700.

#### *4.1.4.2 Advantages*

Advantages of IX with single-use resin include the following:

- Simpler process than the other alternatives, and there is no requirement for regeneration or tote handling
- Comparable costs to in-vessel regeneration and less expensive than offsite and onsite regeneration
- Higher capacity of ResinTech SIR-700 reduces interruption of IX operations typically associated with regeneration.

#### *4.1.4.3 Disadvantages*

Disadvantages of IX with single-use resin include the following:

- Process requirement for acidification before IX and neutralization before groundwater injection
- Uncertainties are associated with ResinTech SIR-700:
  - Possible modification needed of IX system design and operations if resin cannot be sluiced because of its irregular shape. ResinTech has provided advice on resin removal techniques and this information is being incorporated in the DX facility design.
  - Ability of SIR-700 to pass TCLP testing. If SIR-700 cannot pass TCLP testing, a stabilization process must be evaluated. Resin sampling and TCLP analysis are in progress.
  - Ultimate ability to dispose exhausted resin at ERDF. If the spent resin is designated extremely hazardous waste, additional treatment will be required before disposal at ERDF can be approved (RCW 70.105.050, "Disposal at Other than Approved Site Prohibited -- Disposal of Radioactive Wastes"). Other SIR-700 users (e.g., the Boomsnub/AIRCO Superfund Site) have successfully disposed of spent SIR-700 resin in commercial waste disposal sites. Potential radioactive contamination of spent resin from the DX facility would require additional evaluation before considering disposal in a commercial waste disposal site.
  - Potential liquid waste disposal issues associated with a stabilization process.
  - Clarification of operating temperature limits and storage conditions for SIR-700 resin. This clarification has been received from ResinTech, and neither operating temperatures nor storage conditions are reasons for elimination of this resin.

## 4.2 Cost Comparison

This section compares capital, O&M, and lifecycle costs for the four DX facility IX options presented in Section 4.1. A detailed description of the estimating process and the resulting cost tables are provided in SGW-41529. A summary of the costs is provided in Table 4-2. To provide a realistic basis for comparison, 56 percent of the capital and O&M costs were attributed to the DX facility and the remaining

41 percent of the costs to the other pump-and-treat facilities. As shown in Table 4-2, all options are less expensive than offsite regeneration with Dowex 21K (i.e., the design baseline).

Before cost development, system mass balances were calculated based on a design flow rate of 2,271 L/min (600 gal/min), an influent hexavalent chromium concentration of 500 µg/L, and capacities obtained from resin testing (described in Chapter 3). The mass balances were used to size components and were also used to calculate chemical use and resin regeneration rates.

**Table 4-2. Resin Regeneration Option Cost Comparison**

| | Baseline Regeneration[a] | Offsite Resin Regeneration | Onsite Resin Regeneration[b] | In-Vessel Resin Regeneration with Co-Injection | In-Vessel Resin Regeneration with VCC | Single-Use Resin |
|---|---|---|---|---|---|---|
| Estimated capital cost ($ million) | 10.76 | 7.73 | 9.92 | 8.15 | 20.38 | 7.33 |
| Estimated annual O&M cost ($ million) | 3.33 | 2.36 | 2.21 | 1.58 | 1.91 | 1.84 |
| Estimated lifecycle cost[c] ($ million) | 39.60 | 28.15 | 29.12 | 21.86 | 36.95 | 23.25 |

a. Purchased Dowex 21K with offsite regeneration; based on measured capacity.

b. Pro-rated cost for the DX facility includes 56 percent of total CRF costs.

c. Lifecycle costs based on 11-year lifetime and discount rate of 4.2 percent.

### 4.2.1 Capital Cost

Equipment lists and costs were developed by contacting process equipment and resin vendors. Whenever possible, the vendors of the equipment used at the Hanford Site were contacted. After the equipment costs were identified, the capital costs were estimated using standard factors for installation, instrumentation and controls, piping, electrical, yard improvements, service facilities, engineering and supervision, construction expenses, administration and miscellaneous (includes permitting), and contractor's overhead and profit recommended in Peters and Timmerhaus 2003, *Plant Design and Economics for Chemical Engineers*. These factors were modified to obtain site-specific factors after consulting with CH2M HILL Plateau Remediation Company (CHPRC) personnel.[6]

As shown in Table 4-2, capital costs were the highest for in-vessel regeneration with VCC. High capital costs are the result of the additional equipment required to remove dissolved solids from used regeneration solutions. This equipment includes a crystallizer (which is expensive because of the materials of construction required for high-chloride environments), an additional filter press, and a steam generator. Single-use resin had the lowest capital costs (although resin costs are higher) because totes and additional resin are not required to accommodate turnaround.

6 E-mail correspondence from B. A. Gilkeson (CH2M HILL Plateau Remediation Company, Richland, Washington) to T. Giordano (CH2M HILL, Denver, Colorado), "Cost Factors," February 13, 2009.

### 4.2.2 O&M Cost

Mass balances were used to calculate chemical use rates. Chemical costs were determined after consulting with CHPRC personnel. Labor requirements were estimated based on a review of actual labor costs for the DR-5, 100-HR-3, and 100-KR-4 systems for fiscal years 2008 and 2009 (partial). Electrical use rates were estimated based on review of data from the KX system. Maintenance costs were estimated as a percentage of capital costs.

As shown in Table 4-2, O&M costs are the greatest for offsite regeneration because of the cost associated with radionuclide analysis and offsite resin shipment. Onsite resin regeneration costs do not include radionuclide analysis and offsite shipment costs but do include costs for transporting totes and treated regenerant solutions. The O&M cost for the single-use resin is most affected by the cost of replacement resin. The estimated cost is based on an expected capacity, which is based on resin test performance before July 1, 2009. To date (as of July 21, 2009), the resin has not experienced breakthrough; therefore, the estimated O&M cost could be reduced further.

### 4.2.3 Lifecycle Cost

Lifecycle cost is calculated as shown in Equation 4-1:

$$Cost_{lifecycle} = Cost_{capital} + PV_{O\&M} \qquad \textbf{(Equation 4-1)}$$

where $PV_{O\&M}$ equals the present value for O&M costs, assuming a discount rate of 4.2 percent, as recommended by the Office of Management and Budget (OMB Circular No. A-94, *Discount Rates for Cost-Effectiveness, Lease Purchase, and Related Analysis*) and an 11-year lifetime.

As shown in Table 4-2, lifecycle costs are significantly lower for in-vessel regeneration and the single-use resin. The lifecycle cost of the single-use resin could be even lower because the resin has not experienced breakthrough to date.

### 4.2.4 Uncertainties/Assumptions/Trade-Offs

Cost estimates are used for screening and comparing alternative ex situ technologies for treating hexavalent chromium in groundwater. The costs are in April 2009 dollars and do not include future escalation or unusual material cost increases. The cost estimates shown here have been prepared to guide the project in evaluating information available at the time of preparation. The final costs of the project will depend on actual labor and material costs, actual site conditions, productivity, competitive market conditions, final project scope, final project schedule, and other variable factors. As a result, the final project cost will vary from the cost presented above. Because of these factors, funding needs must be carefully reviewed before making specific financial decisions or establishing final budgets.

Table 4-3 provides a comparison for the design options, which are expected to meet the preliminary design criteria developed for the DX facility. Although an IX system in which resin is regenerated may have elevated phosphate, chloride, and sulfate concentrations in the treated regenerant, the concentrations will remain below the secondary MCLs for chloride and sulfate (phosphate has no secondary MCL) when co-injected with treated groundwater, if the co-injection is properly metered. However, co-injection could have significant regulatory concerns and adverse impact on the aquifer.

The technical memorandum (SGW-41529) presents alternatives for eliminating offsite regeneration for all of the 100 Area IX facilities, including constructing a CRF and converting existing facilities (i.e., 100-HR-3, 100-KR-4, KX, and K-West) to in-vessel regeneration. The technical memorandum did not include information about converting existing facilities for single-use resin. Single-use resin will meet the DOE goal to eliminate offsite regeneration and could result in O&M and lifecycle cost savings.

**Table 4-3. IX Hexavalent Chromium Treatment Technology Comparison**

| | Offsite Resin Regeneration | Onsite Resin Regeneration | In-Vessel Resin Regeneration | Single-Use Resin |
|---|---|---|---|---|
| Expect to meet secondary MCL for chloride | Yes | Yes | Yes | Yes |
| Expect to meet secondary MCL for sulfate | Yes | Yes | Yes | Yes |
| Ability to operate continuously at reduced flow rate | Yes | Yes | Yes | Yes |
| Treated regenerant solution management | Not applicable | Co-inject with treated groundwater[a] | Co-inject with treated groundwater | Not applicable[b] |
| Potential regulatory issues | None | Approval for co-injection | Approval for co-injection | Not applicable[b] |
| Solid waste quantity 1,000 kg/yr (tons/yr) | 3.6 (4) | 3.6 (4)[c] | 40 (44) | 29 (32)[d] |
| Potential impact to aquifer | None | Major | Major | Possibly significant |
| Expect to pass TCLP testing | Yes | Yes | Yes | TBD |

a. Performed at CRF.

b. If treatment of spent resin is required before disposal, waste generated from that process must be managed in accordance with applicable regulatory controls.

c. Does not include waste generated at the CRF.

d. Waste resin only. Does not include potential waste from solidification.

TBD = to be determined

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# 5 Impacts, Risks, and Mitigations for DX Facility Design

This chapter presents the impacts, risks, and mitigations for the DX facility design for the four process options presented in Chapter 4. The baseline case (i.e., offsite regeneration with Dowex 21K resin) is included because it was used in the design initiated in March 2009. The information presented in this chapter is incorporated into the recommendations presented in Chapter 6.

## 5.1 DX Process and Resin Selection Decision Analysis

CHPRC conducted a decision analysis workshop on April 29 and 30, 2009, in Richland, Washington, to select and evaluate the candidate processes and, if possible, to select the best one. The evaluation used a multi-attribute value analysis approach to establish decision criteria. Scoring groups used the decision criteria to evaluate the baseline case (i.e., offsite regeneration with Dowex 21K) and the four proposed options for the DX facility.[7]

The scoring teams used the evaluation criteria (Figure 5-1) to score each alternative using a range of 1 through 10 for each category. Raw scores were multiplied by the weight to obtain weighted scores, which were combined for each option and then normalized to 1.0. The scoring results indicate that in-vessel regeneration (0.76) is slightly more favorable than single-use resin (0.71). Offsite regeneration with Purolite A500 (0.65) is somewhat less favorable, but it is much more favorable than onsite regeneration at the CRF (0.47) and offsite regeneration with Dowex 21K (0.32).

Recent information regarding the higher capacity of ResinTech SIR-700 and impacts to the aquifer from co-injection of regenerant solutions favors a single-use resin.

## 5.2 Resin Performance

Resin performance (discussed in detail in Chapter 3) is summarized in Table 5-1. The high cost of the baseline option results from the low capacity and the high cost of Dowex 21K (in comparison to Purolite A500). Purolite A500 is the most favorable regenerable resin because it has more than twice the capacity of Dowex 21K at one-half the cost.

Although ResinTech SIR-700 has the highest capacity, there is a trade-off between the capacity and the high cost of resin replacement compared to regeneration and the cost of additional acid and base required for pH adjustment. The estimated cost advantage of in-vessel regeneration compared to single-use resin has decreased because the capacity of ResinTech SIR-700 is much greater than initially estimated. This is attributed to the reduction of hexavalent chromium to trivalent chromium by reaction with the resin (Sarkar et al. 2008, "Investigation of Extraordinarily High Cr[VI] Removal Capacity by a Weak-Base Anion Exchange Resin: The Mechanism of Reactive Ion Exchange"), as well as indications that the resin had been oxidized (McGuire et al. 2007, *Hexavalent Chromium Removal Using Anion Exchange and Reduction with Coagulation and Filtration*).

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7 Favara, P., 2009, *Decision Analysis for Resin Management Process at the 100-DX Ion-Exchange Treatment Plant*, CH2M HILL, Denver, Colorado.

| Criteria Group | Weight | Criteria | Weight | Metric (Definition) | Units | Range | Scale | Criteria Definition: Alt 0 - D21 - Offsite | Alt. 1A - A500-Offsite | Alt. 1B - A500 - On-Site (CRT) | Alt. 2 - A500 - InVessel | Alt. 3 - SIR700 - Single Use | Scores: Alt 0 - D21 - Offsite | Alt. 1A - A500-Offsite | Alt. 1B - A500 - CRT | Alt. 2 - A500 - InVessel | Alt. 3 - SIR700 - Single Use | Weighted Scores: Alt 0 - D21 - Offsite | Alt. 1A - A500-Offsite | Alt. 1B - A500 - CRT | Alt. 2 - A500 - InVessel | Alt. 3 - SIR700 - Single Use |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Design and Operation | 15 | Resin Durability Based on Process | 5 | Process operation affects resin durability | % loss per year | 0-10 | 0 - >10% resin loss<br>10 - < 2% resin loss | 5-10 | 5-10 | 5-10 | <2 | 0 | 3.60 | 3.20 | 4.40 | 8.90 | 10.00 | 0.18 | 0.16 | 0.22 | 0.45 | 0.50 |
| | | Cycle Time | 10 | Frequency of regeneration or resin replacement | days between cycles (bed volumes) | 0-10 | 0 - 17 days (2600 BVs)<br>10 - 66 days (10,000 BVs) | 17 | 35 | 35 | 35 | 66 | 1.00 | 6.20 | 6.20 | 5.20 | 9.80 | 0.10 | 0.62 | 0.62 | 0.52 | 0.98 |
| Cost (updated post meeting with revised costs - scores changed to linear interpolation) | 50 | Annual O&M | 10 | Annual costs | $MM | 0-10 | 0 - 3.58<br>10 - 1.59 | 3.58 | 2.40 | 2.26 | 1.59 | 2.84 | 0.00 | 5.93 | 6.63 | 10.00 | 3.72 | 0.00 | 0.59 | 0.66 | 1.00 | 0.37 |
| | | Cost Uncertainty through Variables | 10 | labor availability, design changes, resin durability | $MM | 0-10 | 0 - >50% life cylce cost increase<br>5 - >25% life cycle cost increase<br>10 - <10% life cycle cost increase | | | | | | 6.00 | 5.80 | 2.00 | 6.00 | 3.40 | 0.60 | 0.58 | 0.20 | 0.60 | 0.34 |
| | | Capital | 10 | Installed costs | $MM | 0-10 | 0 - 11.3<br>10 - 7.43 | 11.30 | 7.87 | 10.17 | 8.25 | 7.43 | 0.00 | 8.86 | 2.92 | 7.68 | 10.00 | 0.00 | 0.89 | 0.29 | 0.79 | 1.00 |
| | | Life Cycle | 20 | Operating 2009-2020 | $MM | 0-10 | 0 - 42.3<br>10 - 22 | 42.3 | 26.7 | 29.8 | 22.0 | 32.0 | 0.00 | 6.71 | 5.16 | 10.00 | 5.06 | 0.00 | 1.34 | 1.23 | 2.00 | 1.01 |
| Other | 35 | Liquid Disposal Risk | 8 | Potential to negatively impact aquifer through reinjection (geochemical transformations) due to the IX process | frequency of well rehabilitation | 0-10 | 0 - twice per year (per well)<br>5 - once per year (per well)<br>10 - no well rehab needed | 0.5 | 0.5 | 2 | 2 | >2 | 9.10 | 8.90 | 4.80 | 3.60 | 2.60 | 0.73 | 0.71 | 0.38 | 0.29 | 0.21 |
| | | Safety | 3 | Potential to impact extended community (citizen injury or death) | Binary risk (yes or no) | 0-10 | 0 - chance for risk exists<br>10 - no chance for risk | yes | yes | no | no | no | 0.00 | 0.00 | 10.00 | 10.00 | 10.00 | 0.00 | 0.00 | 0.30 | 0.30 | 0.30 |
| | | Transportation Risk | 3 | Potential for offsite release of IX | Binary risk (yes or no) | 0-10 | 0 - chance for risk exists<br>10 - no chance for risk | yes | yes | no | no | no | 0.00 | 0.00 | 10.00 | 10.00 | 10.00 | 0.00 | 0.00 | 0.30 | 0.30 | 0.30 |
| | | Solid Waste Disposal Risk | 5 | Reliability of continuing agreement with offsite resin regeneration; and compliant operation of offsite regeneration facility, and continuing authorization limit | Binary risk (yes or no) | 0-10 | 0 - chance for risk exists<br>10 - no chance for risk | yes | yes | no | no | no | 0.00 | 0.00 | 10.00 | 10.00 | 10.00 | 0.00 | 0.00 | 0.50 | 0.50 | 0.50 |
| | | Regulatory Risk-Central Regeneration Facility | 9 | Permitting a Central Regeneration Facility | Binary risk (yes or no) | 0-10 | 0 - chance for risk exists<br>10 - no chance for risk | no | no | yes | no | no | 10.00 | 10.00 | 0.00 | 10.00 | 10.00 | 0.90 | 0.90 | 0.00 | 0.90 | 0.90 |
| | | Regulatory Risk-Regulatory Acceptance (revised post-meeting based on updated interpretation of criteria and scoring range) | 7 | Risk of regulatory acceptance with chloride, sulfate, total dissolved solids | Binary risk (yes or no) | 0-10 | 0 - regenerent needs to be reinjected<br>10 - reinjection of the regenerant is not necessary | no | no | yes | yes | no | 10.00 | 10.00 | 0.00 | 0.00 | 10.00 | 0.70 | 0.70 | 0.00 | 0.00 | 0.70 |
| Total | | | 100 | | | | | | | | | | | | | | | **3.21** | **6.49** | **4.71** | **7.64** | **7.11** |

SOURCE: Favara, P., 2009, *Decision Analysis for Resin Management Process at the 100-DX Ion-Exchange Treatment Plant*, CH2M HILL, Denver, Colorado.

**Figure 5-1. Alternative Scoring Chart**

**Table 5-1. Resin Test Results**

| Resin | Resin Type | Influent pH | BV to Breakthrough | Relative Capacity[a] | Resin Cost, $/ft$^3$ | Cost Effectiveness[b] |
|---|---|---|---|---|---|---|
| Dowex 21K | Strong-base, regenerable, gel | 7.5 | 2,925 | 1.0 | $266 | 1.0 |
| Purolite A100 | Weak-base, regenerable, macroporous | 7.5 | 724 | 0.2 | $175 | 0.4 |
| Purolite A500 | Strong-base, regenerable, macroporous | 7.5 | 5,787 | 2.0 | $140 | 4.2 |
| Purolite A600 | Strong-base, regenerable, gel | 7.5 | 4,626 | 1.6 | $130 | 3.6 |
| ResinTech SIR-700 | Weak-base, non-regenerable, macroporous | 5.0 | 40,000[c] | 13.7[c] | $225 | 16.2[c] |
| ResinTech SIR-1200 | Strong-base, regenerable, gel | 7.5 | 4,367 | 1.5 | $175 | 2.3 |

a. Relative capacities based on relative number of BVs (BV resin ÷ BV Dowex 21K).

b. Cost effectiveness [(BV resin ÷ BV 21K) × (Cost 21K ÷ cost resin)].

c. Estimated. Breakthrough had not occurred as of July 21, 2009.

ResinTech SIR-700 is a granular resin with a higher pressure drop than spherical resins such as Dowex 21K (ResinTech 2009a, *SIR-700 Ion-Exchange Resin*), and as such is less readily handled by sluicing than bead resins such as Dowex 21K. ResinTech has formulated a spherical weak-base bead resin, WBG30-B (ResinTech 2009b, *WBG30-B Ion-Exchange Resin*), which is reported to be functionally equivalent to SIR-700, and it has a lower pressure drop and could mitigate sluicing problems. WBG30-B is currently being tested with the resin evaluation skid (discussed in Chapter 3), and its feasibility for use as a single-use resin will depend on its capacity and cost compared to SIR-700.

## 5.3 Risks of Resin Regeneration/Disposal

The options presented in Chapter 4 differ regarding the handling of exhausted resins. The highest risks associated with resin regeneration are presented in this section (i.e., those risks that could lead to elimination of an option).

- Offsite regeneration at the Siemens facility: This is a continuation of the current practice, except Purolite A500 would be used in place of Dowex 21K.The risks listed below are the same, whether Purolite A500 or Dowex 21K is shipped to the Siemens facility in Minnesota:
  - An alternative offsite facility has not been identified in the event Siemens were to close their facility or increase prices.
  - Any accident or anomaly during transport or regeneration of resins that potentially contain radionuclides could create a public concern, regardless of the lack of risk to public health.
- Regeneration at the Hanford Site: The risks listed below are generally the same whether the resin is regenerated in-vessel or at the CRF:
  - Co-injection adding significant quantities of chloride (4,490 kg/yr [9,900 lb/yr]), sulfate (12,250 kg/yr [27,000 lb/yr]), and phosphate (168 kg/yr [370 lb/yr]) to the aquifer from regeneration operations at the DX facility based on 88 vessels/year (SGW-41529)
  - The possibility of Ecology prohibiting co-injection because of the larger scale for the DX system (2,271 L/min [600 gal/min]) compared to the DR-5 system (189 L/min [50 gal/min]).
  - Concerns regarding the regeneration impacting the aquifer if VCC is not used.
- Disposal of spent resin: Although any resin could be disposed after a single use, ResinTech SIR-700 is the only option evaluated that is cost-effective as a single-use resin (ResinTech WBG30-B is currently being evaluated). The risks listed below are common to any single-use resin:
  - There is no pathway for hazardous waste disposal if exhausted resin does not pass TCLP testing.
  - In-vessel stabilization before disposal by reducing hexavalent chromium to trivalent chromium with sodium dithionite is feasible, but it has not been evaluated to verify that stabilized ResinTech SIR-700 passes TCLP testing.
  - Used stabilization solution will require solidification or co-injection because liquid waste cannot be disposed at ERDF.
  - The resin has not yet been profiled for disposal at ERDF, although this analysis is under way.

## 5.4 Impacts to DX Design

CHPRC has evaluated impacts of resin and regeneration/disposal options on the DX facility design. Potential design issues included the vessel volume available for resin expansion during backwash and the published operating temperature limits suggested by ResinTech for SIR-700 (38 °C [100 °F]) and WBG30-B (43 °C [110 °F]). ResinTech has evaluated the proposed application at DX and concluded that higher temperature limits [82 °C (180 °F)] were applicable,[8] and there is no requirement for a cooling system.

Potential design changes to address volume for backwash expansion (in-vessel regeneration only) include the following:

- Reducing resin BV in each vessel from 2.27 $m^3$ (80 $ft^3$) to 1.73 $m^3$ (61 $ft^3$) (recommended)
- Increasing vessel diameter from 137 to 158 cm (54 to 62 in.) (not recommended).

The design of the IX vessels currently permits use of Purolite A500 or ResinTech SIR-700 and will not require modification for offsite or in-vessel regeneration of Purolite A500 unless the vessel diameter is increased. However, the overall process and facility design would require modification for in-vessel regeneration to accommodate the regenerant treatment system (reagent storage and handling systems).

While the current IX vessel design will accommodate ResinTech SIR-700 without modification, the IX facility design will require modification for use of ResinTech SIR-700:

- Resin removal: If SIR-700 can be sluiced using the current approach or by adding air sparging, then design changes would be minimal. This is a known design issue and has been addressed in the vessel design.

- Operating pH: Weak-base resins (e.g., SIR-700 or WBG30-B) must be operated at an acidic pH to be effective. Resin testing is being performed at pH 5.0. Operation at this pH requires the addition of neutralizing capability before injecting treated groundwater and evaluating the compatibility of materials used in the current IX to a hydrochloric or sulfuric acid environment. An alternative would be to operate at pH 6.0, if capacity is not significantly reduced. Materials of construction and polymer liners have been selected to accommodate the range of pHs expected for Purolite A500 (both in-vessel and offsite regeneration) and ResinTech SIR-700, including the need for stabilization.

- Stabilization: If SIR-700 requires stabilization, provision will be added to the design to incorporate the necessary equipment in the future. The pre-conceptual design (SGW-41529) includes an alternative resin removal system and provides for stabilization. The IX vessels are provided with nozzles for future use for in-vessel regeneration, stabilization, or air sparging.

## 5.5 Residual Risks and Mitigations

The CHPRC approach for risk mitigation, including issue resolution, creating a decision tree, and developing a risk mitigation plan, has been used to address risks with ResinTech SIR-700 (e.g., disposal of waste resin and the possibility that SIR-700 cannot be readily sluiced). Proposed mitigations include the following:

- Obtain written clarification from ResinTech on the impact of operating at site maximum temperatures (in process).

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8 "SIR-700 Temperature Limits in Chrome Removal and Storage," letter from ResinTech (West Berlin, New Jersey) to S. Wolfe (Columbia Energy, Richland, Washington), July 17, 2009.

- Contact SIR-700 users to determine their level of satisfaction and any problems they have encountered.
- Perform TCLP testing on exhausted SIR-700 resin. If the resin fails TCLP testing, prepare a test plan for evaluating stabilization, including disposal of liquid waste (in process).
- Through discussion with users and the vendor, determine whether SIR-700 can be readily sluiced using current methods or air agitation; if not, evaluate the alternatives.
- Determine the cost of ResinTech WBG30-B to supplement capacity data currently being collected. If the data are favorable, perform TCLP testing on the exhausted WBG30-B resin.
- Prepare a technical memorandum to evaluate conversion of existing 100 Area facilities to single-use resin using the general approach from the technical memorandum (SGW-41529).

## 5.6 Schedule

Table 5-2 summarizes the schedule for resolving the design issues associated with use of ResinTech SIR-700.

**Table 5-2. Impacts, Risks, and Mitigations**

| Risk/Issue | Action | Estimated Completion | Comment |
|---|---|---|---|
| Design changes/process optimization | Evaluate IX vessel volume for backwash expansion | August 31, 2009 | These issues have been evaluated in the ARES white paper* on potential design changes for SIR-700; a Soil & Groundwater Remediation Protection documented recommendation is required. Preliminary indications are as follows:<br>• IX vessel volume is only an issue for in vessel regeneration.<br>• Proposed DX materials are compatible with a reduced pH and no change is required.<br>• A sluicing system would need to be designed to remove the spent resin. |
| | Determine material compatibility with reduced pH | | |
| | Evaluate spent resin removal capability | | |
| | Obtain written clarification on SIR-700 temperature limits | August 31, 2009 | ResinTech has provided information to close this issue; a Soil & Groundwater Remediation Protection documented conclusion is required. |
| | Complete WBG30-B resin testing | October 15, 2009 | The estimated completion date is a forecast selection. The WBG30-B test column should break through in about half the time of the SIR-700 test column. The SIR-700 test column has not broken through after about 4 months. |

**Table 5-2. Impacts, Risks, and Mitigations**

| Risk/Issue | Action | Estimated Completion | Comment |
|---|---|---|---|
| Spent resin disposal | Analyze SIR-700 from test skid:<br>• Determine analytical parameters in addition to toxic characteristic leaching procedure<br>• Collect sample<br>• Perform analyses (15-day expedited laboratory time) | October 1, 2009 | Resin analysis will be performed on a target analyte list to accelerate resin evaluation. |
| | Determine need for additional treatment before disposal:<br>• Evaluate sample analysis results<br>• Document conclusion | October 30, 2009 | – |
| | Perform waste designation for SIR-700 disposal | December 1, 2009 | May require formal data quality objective (30 days) and additional laboratory analyses; will start in parallel with initial sample analysis |

*ARES Corporation, 2009, *Preliminary Assessment of IX Vessel Dimensions and Materials of Construction*, July, Richland, Washington.

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# 6 Recommendations

This chapter presents recommendations for resin selection, DX process-related considerations, and remaining risks.

## 6.1 Resin Selection

ResinTech SIR-700 has shown high capacity in side-by-side resin testing. Although its theoretical capacity is 2.3 times the capacity of Purolite A500, its actual capacity is greater than 5 times that of Purolite A500 under test conditions. The high capacity of SIR-700, which results from its ability to reduce hexavalent chromium to trivalent chromium, compensates for the cost of resin replacement. ResinTech WBG30-B merits consideration because of its spherical bead shape, but cost will need to be determined and capacity testing must be completed. Although there are still some operational concerns to be addressed, CHPRC recommends the use of ResinTech SIR-700 for the initial DX operation recognizing that in order to meeting the Tri-Party Agreement milestone M-016-111B, optimization of the system may have to wait until the milestone is achieved.

Side-by-side resin testing at the DR-5 facility has indicated that Purolite A500 could be used in any process requiring a regenerable resin (offsite, onsite, and in-vessel regeneration). The capacity of Purolite A500 is 2 times that of Dowex 21K at one-half the cost, and it is more cost-effective than the other regenerable resins tested. Purolite A500 has been used at the DR-5 facility since 2004 without necessity for resin replacement or resin addition.

## 6.2 Process Selection

One option for resin regeneration is in-vessel treatment onsite with reinjection of the regenerant waste water. The major advantage of this method is the ability to maintain control of the resin onsite as well as the relatively low cost of processing. However, a negative consequence of this method appears to be a relatively fast rate of precipitation of the regenerant chemicals within the filter pack and aquifer during reinjection. Preliminary evaluations indicate that degradation of the aquifer can be expected. The impact of aquifer degradation is significant in regard to both technical and political aspects. Therefore, co-injection of regeneration solutions into the aquifer will no longer be considered.

The technical memorandum (SGW-41529) (see Chapter 4) and the decision analysis (Section 5.1) indicated that in-vessel regeneration was the most favorable process, with single-use resin as the second choice. As previously noted, CHPRC has eliminated the possibility of co-injection because of the potential for impacts to the aquifer. The use of VCC to remove contaminants from treated regenerant was evaluated as an alternative to co-injection. Table 4-1 shows that the estimated lifecycle cost for a proposed VCC system is 70 percent higher than the cost for co-injection. A significant cost driver is the necessity for expensive construction materials because of the high chloride content of the treated regenerant.

The focus of the third resin test is to confirm ResinTech SIR-700 chromium removal efficiency that was demonstrated in the first test. The single-use SIR-700 column from the first test continued to run through the second and third tests (over 40,000 BVs). To confirm these results, a second, shorter column of SIR-700 is being evaluated in the third test, as well as a column of ResinTech WBG30-B (which is a comparable bead form of the resin). To date, the initial data from the shorter column with SIR-700 and WBG30-B duplicate the original SIR-700 performance through 10,000 BVs.

To achieve the Tri-Party Agreement milestone M-016-111B to expand the current pump-and-treat capacity at the 100-HR-3 OU to 1,893 L/min (500 gal/min) by December 31, 2010, CHPRC recommends

that no further design changes are made to the DX facility at this time. As noted above, the current design can accept either Purolite A500 or ResinTech SIR-700 resin, either of which is a marked improvement over Dowex 21K. ResinTech SIR-700 (granular or WBG30-B spherical form) will be used for start up and the facility modified after start-up to optimize the treatment using this resin. In the unlikely event that the operational issues cannot be resolved for ResinTech SIR-700, Purolite A500 will used; as a result, potential regeneration facilities will be identified.

On the assumption that a single-use resin will be successful in DX, converting the remaining 100 Area facilities for single-use resin should be evaluated.). Converting existing facilities could significantly reduce operating costs and alleviate DOE's concerns regarding offsite regeneration. This approach will be further evaluated in the site-wide analysis.

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"SIR-700 Temperature Limits in Chrome Removal and Storage," letter from ResinTech (West Berlin, New Jersey) to S. Wolfe (Columbia Energy, Richland, Washington), July 17, 2009.

# Appendix A

# Ion-Exchange Resin Background

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# A1 Ion-Exchange Resins

Anion-exchange resins capable of removing hexavalent chromium are of several different types: weak or strong base, gel or macroporous structure, spherical bead or granular shape, as well as regenerable or disposable. All of the resins used in this evaluation are anion resins designed to retain anionic compounds (e.g., hexavalent chromium).

## A1.1 Weak- and Strong-Base Resins

The ion-exchange (IX) resins are classified as cation exchangers (have positively charged mobile ions available for exchange) and anion exchangers (exchangeable ions are negatively charged). Both anion and cation resins are produced from the same basic organic polymers. They differ in the ionizable group attached to the hydrocarbon network. It is this functional group that determines the chemical behavior of the resin. Resins can be broadly classified as strong or weak acid cation exchangers or strong- or weak-base anion exchangers. The following summary of these different types of resins is from EPA 625/-81-007, *Ion Exchange*.

### A1.1.1 Strong Acid Cation Resins

Strong acid resins are so named because their chemical behavior is similar to that of a strong acid. The resins are highly ionized in both the acid ($R\text{-}SO_3H$) and salt ($R\text{-}SO_3Na$) form. The hydrogen and sodium forms of strong acid resins are highly dissociated, and the exchangeable Na+ and H+ are readily available for exchange over the entire pH range. Consequently, the exchange capacity of strong acid resins is independent of solution pH. These resins would be used in the hydrogen form for complete deionization; they are used in the sodium form for water softening (e.g., calcium and magnesium removal). After exhaustion, the resin is converted back to the hydrogen form (i.e., regenerated) by contact with a strong acid solution, or the resin can be convened to the sodium form with a sodium chloride solution.

### A1.1.2 Weak Acid Cation Resins

In a weak acid resin, the ionizable group is a carboxylic acid (COOH) as opposed to the sulfonic acid group ($SO_3H$) used in strong acid resins. These resins behave similarly to weak organic acids that are weakly dissociated.

Weak acid resins exhibit a much higher affinity for hydrogen ions than strong acid resins. This characteristic allows for regeneration to the hydrogen form with significantly less acid than required for strong acid resins. Almost complete regeneration can be accomplished with stoichiometric amounts of acid. The degree of dissociation of a weak acid resin is strongly influenced by the solution pH. Consequently, resin capacity depends, in part, on solution pH. A typical weak acid resin has limited capacity below a pH of 6.0, making it unsuitable for deionizing acidic metal-finishing wastewater.

### A1.1.3 Strong-Base Anion Resins

Like strong acid resins, strong-base resins are highly ionized and can be used over the entire pH range. These resins are used in the hydroxide (OH) form for water deionization. Regeneration with concentrated sodium hydroxide (NaOH) converts the exhausted resin to the hydroxide form.

### A1.1.4 Weak-Base Anion Resins

Weak-base resins are like weak acid resins in that the degree of ionization is strongly influenced by pH. Consequently, weak-base resins exhibit minimum exchange capacity above a pH of 7.0. These resins merely sorb strong acids: they cannot split salts.

In an IX wastewater deionization unit, the wastewater would pass first through a bed of strong acid resin. Replacement of the metal cations (Ni+2, Cu+2) with hydrogen ions would lower the solution pH. The anions ($SO_4^{-2}$, Cl-) can then be removed with a weak-base resin because the entering wastewater will normally be acidic and weak-base resins sorb acids. Weak-base resins are preferred over strong-base resins because they require less regenerant chemical.

The weak-base resin does not have a hydroxide ion form, as does the strong-base resin. Consequently, regeneration only needs to neutralize the absorbed acid; it does not need to provide hydroxide ions. Less expensive weakly basic reagents such as ammonia ($NH_3$) or sodium carbonate can be used.

## A1.2 Resin Structure

The molecular structures of the resins are typically of two types: gel or macroporous. Gel-type resins have no permanent pore structures through which ions can travel. Instead, the pore structures are determined by the distance between the polymer chains and cross-links (i.e., bonds between polymer chain substituents that add strength to the structure), which vary with the cross-link level of the polymer, polarity of the solvent, and operating conditions. These pores are generally considered to be quite small, usually not greater than 3 nm (Rohm and Haas 2009, *Ion Exchange Resins – Industrial Processes, General Frequently Asked Questions*). Macroporous resins have a sintered structure that provides free water channels (in contrast to bound gel water) of about 100 nm diameter, which makes them more resistant to poisoning by small organic molecules and makes more of the active sites accessible for exchange (Rousseau 1987, *Handbook of Separation Process Technology*).

### A1.2.1 Particle Shape

The IX resins are available in spherical or granular shapes. Spherical beads are uniform in shape and size and are packed to create consistent, repeatable void space between beads. Granular resins are prone to packing more densely than spherical beads, often resulting in increased differential pressure across the resin bed.

### A1.2.2 Regeneration

The IX resins can also be characterized by their potential to be regenerated. Non-regenerable resins typically have high capacity and selectivity for the contaminants of concern. For regenerable resins, high overall capacity and selectivity are again desired, but cost-effective regeneration also is important (Green 2008, *Perry's Chemical Engineers' Handbook*).

A comparison of vendor information for six resins tested for use at the DR-5 facility is presented in Table 1-1 in the main text. Information in this table includes theoretical capacity, resin substrate (underlying polymeric type), resin structure (gel or macroporous), type, operating pH range, and ability to be regenerated.

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# Appendix B

# Influent Chemistry

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# Influent Chemistry

A summary of the influent chemistry of the associated wells that feed the facilities is presented in Tables B-1 and B-2.

**Table B-1. Influent Chemistry Collected from Resin Skid During Evaluation**

| **Sample Numbers** | B1YP74 | B1YP77 | B1YP78 | B208Y8 | | | |
|---|---|---|---|---|---|---|---|
| **Influent** | B1YP80 | B1YP83 | B1YP84 | B20916F | | | |
| | B1YP85 | B1YP89 | B1YP95 | B20915 | | | |
| **Date and time** | **3/10/09 7:35** | **3/18/09 9:15** | **3/20/09 13:00** | **4/6/09 14:30** | | | |
| **Analyte** | **Values** | | | | **Units** | **Lab Qualifier** | **AverageValue** |
| Bromide | 137 | 200 | 139 | 131 | ug/L | BD | 151.8 |
| Chloride[1] | 19000 | 24800 | 81300 | 23000 | ug/L | D | 22266.7 |
| Fluoride | 46 | 46 | 59 | 52.1 | ug/L | UD | 50.8 |
| Nitrate | 28900 | 29600 | 27251 | 30400 | ug/L | D | 29037.8 |
| Nitrite | 85.4 | 1840 | 85.4 | 95.6 | ug/L | UD | 526.6 |
| Phosphate | 368 | 368 | 368 | 368 | ug/L | UD | 368.0 |
| Sulfate | 71900 | 69500 | 76800 | 77200 | ug/L | D | 73850.0 |
| Hexavalent Chromium | 641 | 595 | 567 | 635 | ug/L | D | 609.5 |
| Hexavalent Chromium[2] | 653 | 628 | 594 | 669 | ug/L | D | 636.0 |
| pH Measurement | 7.96 | 8.21 | 7.44 | 7.97 | unitless | | 7.90 |
| Total dissolved solids | 300000 | 353000 | 403000 | 285000 | ug/L | | 335250.0 |
| Total suspended solids | 2000 | 2000 | 2000 | 2000 | ug/L | B | 2000.0 |

1. The data from March 20, 2009, reflect high chloride concentrations due to pH adjustments made to the SIR-700 column by adding HCl and are not included in the average value calculation.
2. This row contains values from duplicate hexavalent chromium analyses performed on the influent.

B = analyte less than required detection limit but greater than the minimum detection limit (inorganic)

D = analyte reported at a secondary dilution factor

U = analyzed but not detected above limiting criteria

**Table B-2. Summary of Chemistry of Influent to the DR-5 Treatment Facility**

| Analyte | Influent | Units | Qualifier |
|---|---|---|---|
| Antimony | 56.0 | µg/L | U |
| Arsenic | 1.4 | µg/L | |
| Barium | 62.8 | µg/L | |
| Beryllium | 4.0 | µg/L | U |
| Cadmium | 4.0 | µg/L | U |
| Calcium | 63525.0 | µg/L | |
| Chloride | 19848.1 | µg/L | D |
| Chromium, total | 1009.0 | µg/L | |
| Cobalt | 4.1 | µg/L | B,U |
| Copper | 6.0 | µg/L | U |
| Dissolved oxygen | 9610.0 | µg/L | |
| Fluoride | 65.4 | µg/L | DU |
| Gross alpha | 0.3 | pCi/L | U |
| Gross beta | 2.5 | pCi/L | U |
| Hexavalent Chromium | 635.3 | µg/L | |
| Iron | 25.0 | µg/L | U |
| Magnesium | 14812.5 | µg/L | |
| Manganese | 4.8 | µg/L | B,U |
| Nickel | 4.0 | µg/L | U |
| Nitrate | 30595.8 | µg/L | D |
| Nitrite | 84.1 | µg/L | DU |
| pH Measurement | 7.8 | Unitless | |
| Potassium | 4587.5 | µg/L | |
| Silver | 5.0 | µg/L | U |
| Sodium | 7930.0 | µg/L | |
| Specific Conductance | 450.1 | uS/cm | |
| Strontium | 519.4 | µg/L | |
| Strontium-90 | -1.6 | pCi/L | U |
| Sulfate | 74609.7 | µg/L | D |
| Temperature | 15.8 | Deg C | |
| Tritium | 262.6 | µg/L | |
| Turbidity | 0.5 | NTU | |
| Uranium | 1.7 | µg/L | |
| Vanadium | 13.7 | µg/L | B,U |
| Zinc | 9.4 | µg/L | B,U |

B = analyte less than required detection limit but greater than minimum detection limit (inorganic)

D = analyte reported at a secondary dilution factor

U = analyzed but not detected above limiting criteria

# Appendix C

# Field Hexavalent Chromium and Flow Data

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# Field Hexavalent Chromium and Flow Data

The data obtained during evaluation #1 and evaluation #2 for field hexavalent chromium and flow are presented in Tables C-1 and C-2, respectively.

## Table C-1. Field Hexavalent Chromium and Flow Data from Evaluation #1

| Date-Time | Measure | Units | BV | Purolite 100 | BV | Purolite 500 | BV | Purolite 600 | BV | Dowex 21K | BV | ResinTech SIR-700 | BV | ResinTech SIR-1200 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 3/10/09 10:00 | Cr+6 | ppb | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 3/10/09 14:40 | Cr+6 | ppb | 32 | 0 | 39 | 0 | 35 | 0 | 36 | 0 | 34 | 0 | 31 | 0 |
| 3/11/09 8:48 | Cr+6 | ppb | 156 | 0 | 189 | 0 | 170 | 0 | 176 | 0 | 166 | 0 | 153 | 0 |
| 3/11/09 15:15 | Cr+6 | ppb | 200 | 0 | 242 | 1 | 218 | 0 | 226 | 0 | 213 | 0 | 196 | 0 |
| 3/12/09 8:12 | Cr+6 | ppb | 316 | 0 | 382 | 0 | 344 | 0 | 357 | 0 | 337 | 0 | 310 | 0 |
| 3/12/09 14:45 | Cr+6 | ppb | 361 | 4 | 436 | 0 | 393 | 1 | 407 | 1 | 385 | 1 | 354 | 0 |
| 3/13/09 10:35 | Cr+6 | ppb | 496 | 11 | 600 | 3 | 540 | 0 | 560 | 0 | 530 | 1 | 486 | 0 |
| **3/13/09 11:47** | **Total Thru** | **Gal.** | | **64.5** | | **78** | | **70.2** | | **72.8** | | **68.8** | | **63.2** |
| **3/13/09 11:47** | **Avg Flowrate** | **GPM** | | **0.0146** | | **0.0176** | | **0.0159** | | **0.0164** | | **0.0155** | | **0.0143** |
| **3/13/09 11:47** | **Total Thru** | **Gal.** | | **64.5** | | **78** | | **70.2** | | **72.8** | | **68.8** | | **63.2** |
| **3/13/09 11:47** | **Avg Flowrate** | **GPM** | | **0.0146** | | **0.0176** | | **0.0159** | | **0.0164** | | **0.0155** | | **0.0143** |
| 3/14/09 14:05 | Cr+6 | ppb | 724 | 78 | 797 | 0 | 715 | 1 | 728 | 0 | 699 | 1 | 709 | 0 |
| 3/15/09 10:35 | Cr+6 | ppb | 910 | 223 | 954 | 1 | 856 | 1 | 861 | 2 | 835 | 1 | 890 | 1 |
| 3/16/09 9:30 | Cr+6 | ppb | 1118 | 510 | 1130 | 0 | 1013 | 0 | 1011 | 0 | 987 | 0 | 1093 | 0 |
| **3/16/09 12:37** | **Total Thru** | **Gal.** | | **82** | | **69.5** | | **62** | | **59** | | **60** | | **80** |
| **3/16/09 12:37** | **Avg Flowrate** | **GPM** | | **0.0193** | | **0.0164** | | **0.0146** | | **0.0139** | | **0.0141** | | **0.0188** |
| **3/16/09 12:37** | **Total Thru** | **Gal.** | | **146.5** | | **147.5** | | **132.2** | | **131.8** | | **128.8** | | **143.2** |
| **3/16/09 12:37** | **Avg Flowrate** | **GPM** | | **0.0169** | | **0.0172** | | **0.0154** | | **0.0154** | | **0.0150** | | **0.0167** |
| 3/16/09 15:36 | Cr+6 | ppb | 1239 | 543 | 1171 | 0 | 1049 | 0 | 1046 | 0 | 1024 | 1 | 1057 | 0 |
| 3/17/09 8:53 | Cr+6 | ppb | 1366 | 606 | 1321 | 4 | 1179 | 0 | 1173 | 0 | 1171 | 0 | 1189 | 0 |
| 3/17/09 15:10 | Cr+6 | ppb | 1413 | 648 | 1375 | 0 | 1227 | 0 | 1219 | 0 | 1225 | 0 | 1238 | 0 |
| 3/18/09 8:30 | Cr+6 | ppb | 1541 | 611 | 1525 | 0 | 1358 | 0 | 1347 | 0 | 1372 | 0 | 1370 | 5 |
| 3/19/09 7:40 | Cr+6 | ppb | 1712 | 680 | 1726 | 0 | 1533 | 0 | 1518 | 0 | 1569 | 5 | 1548 | 0 |
| **3/19/09 11:37** | **Total Thru** | **Gal.** | | **66** | | **77.5** | | **67.5** | | **66** | | **76** | | **68.5** |
| **3/19/09 11:37** | **Avg Flowrate** | **GPM** | | **0.0157** | | **0.0185** | | **0.0161** | | **0.0157** | | **0.0181** | | **0.0163** |
| **3/19/09 11:37** | **Total Thru** | **Gal.** | | **222.5** | | **225** | | **199.7** | | **197.8** | | **204.8** | | **201.7** |
| **3/19/09 11:37** | **Avg Flowrate** | **GPM** | | **0.0173** | | **0.0176** | | **0.0156** | | **0.0155** | | **0.0160** | | **0.0158** |
| 3/19/09 15:00 | Cr+6 | ppb | | | 1776 | 0 | 1583 | 0 | 1563 | 0 | 1617 | 0 | 1590 | 0 |
| 3/20/09 8:30 | Cr+6 | ppb | | | 1888 | 0 | 1736 | 1 | 1677 | 1 | 1726 | 1 | 1677 | 0 |
| 3/20/09 14:30 | Cr+6 | ppb | | | 1927 | 0 | 1788 | 0 | 1716 | 0 | 1763 | 0 | 1707 | 0 |
| 3/21/09 12:00 | Cr+6 | ppb | | | 2065 | 2 | 1976 | 2 | 1856 | 3 | 1896 | 2 | 1814 | 2 |
| 3/23/09 8:30 | Cr+6 | ppb | | | 2352 | 0 | 2363 | 0 | 2146 | 0 | 2171 | 0 | 2035 | 0 |
| **3/23/09 12:40** | **Total Thru** | **Gal.** | | **Complete** | | **79** | | **107** | | **80** | | **76** | | **61** |
| **3/23/09 12:40** | **Avg Flowrate** | **GPM** | | **Complete** | | **0.0137** | | **0.0186** | | **0.0139** | | **0.0132** | | **0.0106** |
| **3/23/09 12:40** | **Total Thru** | **Gal.** | | **222.5** | | **304** | | **306.7** | | **277.8** | | **280.8** | | **262.7** |
| **3/23/09 12:40** | **Avg Flowrate** | **GPM** | | **0.0173** | | **0.0164** | | **0.0166** | | **0.0150** | | **0.0152** | | **0.0142** |
| 3/23/09 15:00 | Cr+6 | ppb | | | 2398 | 0 | 2422 | 0 | 2191 | 0 | 2215 | 0 | 2076 | 0 |
| 3/24/09 6:54 | Cr+6 | ppb | | | 2554 | 0 | 2596 | 0 | 2327 | 0 | 2356 | 0 | 2241 | 0 |
| 3/24/09 14:30 | Cr+6 | ppb | | | 2628 | 0 | 2680 | 0 | 2392 | 0 | 2423 | 0 | 2320 | 0 |
| 3/25/09 8:00 | Cr+6 | ppb | | | 2799 | 0 | 2872 | 1 | 2542 | 0 | 2578 | 0 | 2501 | 0 |
| 3/25/09 15:00 | Cr+6 | ppb | | | 2868 | 0 | 2949 | 1 | 2602 | 7 | 2640 | 0 | 2573 | 0 |
| 3/26/09 7:00 | Cr+6 | ppb | | | 3024 | 0 | 3125 | 2 | 2739 | 8 | 2782 | 0 | 2739 | 0 |
| **3/26/09 9:00** | **Total Thru** | **Gal.** | | **Complete** | | **85** | | **95.5** | | **74.5** | | **77** | | **90** |
| **3/26/09 9:00** | **Avg Flowrate** | **GPM** | | **Complete** | | **0.0208** | | **0.0234** | | **0.0183** | | **0.0189** | | **0.0221** |
| **3/26/09 9:00** | **Total Thru** | **Gal.** | | **222.5** | | **389** | | **402.2** | | **352.3** | | **357.8** | | **352.7** |
| **3/26/09 9:00** | **Avg Flowrate** | **GPM** | | **0.0170** | | **0.0172** | | **0.0178** | | **0.0156** | | **0.0158** | | **0.0156** |
| 3/26/09 15:30 | Cr+6 | ppb | | | 3081 | 0 | 3186 | 0 | 2798 | 13 | 2850 | 0 | 2804 | 0 |
| 3/27/09 8:30 | Cr+6 | ppb | | | 3198 | 0 | 3309 | 1 | 2925 | 12 | 3004 | 0 | 2941 | 0 |
| 3/27/09 14:45 | Cr+6 | ppb | | | 3241 | 0 | 3354 | 0 | 2972 | 22 | 3061 | 0 | 2991 | 0 |
| 3/28/09 8:00 | Cr+6 | ppb | | | 3360 | 0 | 3478 | 2 | 3102 | 29 | 3218 | 0 | 3130 | 2 |
| 3/28/09 12:00 | Cr+6 | ppb | | | 3387 | 0 | 3507 | 0 | 3132 | 30 | 3254 | 0 | 3163 | 0 |

## Table C-1. Field Hexavalent Chromium and Flow Data from Evaluation #1

| Date-Time | Measure | Units | BV | Purolite 100 | BV | Purolite 500 | BV | Purolite 600 | BV | Dowex 21K | BV | ResinTech SIR-700 | BV | ResinTech SIR-1200 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 3/29/09 13:00 | Cr+6 | ppb | | | 3559 | 1 | 3686 | 2 | 3320 | 43 | 3481 | 0 | 3364 | 0 |
| 3/30/09 8:00 | Cr+6 | ppb | | | 3690 | 0 | 3823 | 1 | 3462 | 140 | 3654 | 0 | 3517 | 0 |
| **3/30/09 13:00** | **Total Thru** | **Gal.** | | **Complete** | | **87** | | **91** | | **95** | | **115** | | **102** |
| **3/30/09 13:00** | **Avg Flowrate** | **GPM** | | **Complete** | | **0.0146** | | **0.0153** | | **0.0160** | | **0.0194** | | **0.0172** |
| **3/30/09 13:00** | **Total Thru** | **Gal.** | | **222.5** | | **476** | | **493.2** | | **447.3** | | **472.8** | | **454.7** |
| **3/30/09 13:00** | **Avg Flowrate** | **GPM** | | **0.0170** | | **0.0167** | | **0.0173** | | **0.0157** | | **0.0166** | | **0.0159** |
| 3/30/09 15:10 | Cr+6 | ppb | | | 3732 | 0 | 3869 | 2 | 3508 | 138 | 3706 | 0 | 3568 | 0 |
| 3/31/09 10:20 | Cr+6 | ppb | | | 3863 | 1 | 4031 | 1 | 3644 | 146 | 3821 | 0 | 3730 | 0 |
| 3/31/09 14:30 | Cr+6 | ppb | | | 3892 | 0 | 4066 | 2 | 3674 | 159 | 3846 | 0 | 3765 | 0 |
| 4/1/09 8:30 | Cr+6 | ppb | | | 4015 | 0 | 4219 | 4 | 3801 | 170 | 3954 | 0 | 3917 | 0 |
| 4/1/09 12:06 | Cr+6 | ppb | | | 4040 | 2 | 4249 | 16 | 3827 | 238 | 3975 | 0 | 3948 | 0 |
| 4/2/09 7:00 | Cr+6 | ppb | | | 4169 | 0 | 4409 | 5 | 3961 | 268 | 4088 | 0 | 4108 | 0 |
| 4/2/09 14:30 | Cr+6 | ppb | | | 4220 | 0 | 4473 | 12 | 4014 | 237 | 4133 | 0 | 4171 | 0 |
| 4/3/09 8:35 | Cr+6 | ppb | | | 4344 | 1 | 4626 | 36 | 4143 | 382 | 4242 | 0 | 4325 | 14 |
| **4/3/09 9:30** | **Total Thru** | **Gal.** | | **Complete** | | **80** | | **99** | | **83** | | **70** | | **99** |
| **4/3/09 9:30** | **Avg Flowrate** | **GPM** | | **Complete** | | **0.0146** | | **0.0180** | | **0.0151** | | **0.0128** | | **0.0180** |
| **4/3/09 9:30** | **Total Thru** | **Gal.** | | **222.5** | | **556** | | **592.2** | | **530.3** | | **542.8** | | **553.7** |
| **4/3/09 9:30** | **Avg Flowrate** | **GPM** | | **0.0170** | | **0.0163** | | **0.0174** | | **0.0156** | | **0.0159** | | **0.0163** |
| 4/3/09 14:20 | Cr+6 | ppb | | | 4380 | 1 | 4661 | 33 | 4181 | 382 | 4277 | 4 | 4367 | 20 |
| 4/4/09 10:30 | Cr+6 | ppb | | | 4537 | 3 | 4807 | 70 | 4351 | 425 | 4434 | 2 | 4547 | 22 |
| 4/5/09 14:10 | Cr+6 | ppb | | | 4752 | 13 | 5008 | 75 | 4584 | 494 | 4649 | 1 | 4794 | 79 |
| 4/6/09 7:00 | Cr+6 | ppb | | | 4883 | 1 | 5129 | 89 | 4725 | 553 | 4779 | 0 | 4945 | 84 |
| **4/6/09 12:00** | **Total Thru** | **Gal.** | | **Complete** | | **73** | | **68** | | **79** | | **73** | | **84** |
| **4/6/09 12:00** | **Avg Flowrate** | **GPM** | | **Complete** | | **0.0166** | | **0.0154** | | **0.0179** | | **0.0166** | | **0.0190** |
| **4/6/09 12:00** | **Total Thru** | **Gal.** | | **222.5** | | **629** | | **660.2** | | **609.3** | | **615.8** | | **637.7** |
| **4/6/09 12:00** | **Avg Flowrate** | **GPM** | | **0.0170** | | **0.0164** | | **0.0172** | | **0.0158** | | **0.0160** | | **0.0166** |
| 4/6/09 14:45 | Cr+6 | ppb | | | 4939 | 0 | 5182 | 98 | 4783 | 555 | 4830 | 10 | 5009 | 83 |
| 4/7/09 11:00 | Cr+6 | ppb | | | 5140 | 2 | 5367 | 122 | 4964 | 579 | 4970 | 2 | 5232 | 107 |
| 4/7/09 15:00 | Cr+6 | ppb | | | 5180 | 1 | 5404 | 137 | 5000 | 606 | 4998 | 0 | 5276 | 125 |
| 4/8/09 11:00 | Cr+6 | ppb | | | 5378 | 4 | 5588 | 191 | 5179 | 612 | 5136 | 1 | 5496 | 237 |
| 4/8/09 14:30 | Cr+6 | ppb | | | 5413 | 4 | 5620 | 199 | 5211 | 616 | 5160 | 0 | 5534 | 256 |
| 4/9/09 9:30 | Cr+6 | ppb | | | 5602 | 8 | 5794 | 271 | 5381 | 601 | 5291 | 2 | 5744 | 349 |
| **4/9/09 13:30** | **Total Thru** | **Gal.** | | **Complete** | | **92** | | **85** | | **83** | | **64** | | **102** |
| **4/9/09 13:30** | **Avg Flowrate** | **GPM** | | **Complete** | | **0.0211** | | **0.0195** | | **0.0191** | | **0.0147** | | **0.0234** |
| **4/9/09 13:30** | **Total Thru** | **Gal.** | | **222.5** | | **721** | | **745.2** | | **692.3** | | **679.8** | | **739.7** |
| **4/9/09 13:30** | **Avg Flowrate** | **GPM** | | **0.0170** | | **0.0168** | | **0.0174** | | **0.0162** | | **0.0159** | | **0.0173** |
| 4/9/09 14:30 | Cr+6 | ppb | | | 5627 | 13 | 5819 | 274 | 5399 | 619 | 5306 | 2 | 5777 | 346 |
| 4/10/09 11:30 | Cr+6 | ppb | | | 5787 | 12 | 5953 | 303 | 5602 | 623 | 5458 | 1 | 5900 | 413 |
| 4/10/09 14:00 | Cr+6 | ppb | | | 5806 | 16 | 5969 | 327 | 5627 | 626 | 5476 | 0 | 5915 | 421 |
| 4/11/09 5:45 | Cr+6 | ppb | | | 5926 | 18 | 6070 | 395 | 5779 | 617 | 5591 | 0 | 6008 | 461 |
| 4/12/09 15:30 | Cr+6 | ppb | | | 6183 | 25 | 6286 | 459 | 6106 | 628 | 5836 | 2 | 6206 | 517 |
| 4/13/09 8:30 | Cr+6 | ppb | | | 6312 | 27 | 6395 | 568 | 6270 | 625 | 5959 | 1 | 6306 | 592 |
| **4/13/09 10:50** | **Total Thru** | **Gal.** | | **Complete** | | **88** | | **74** | | **112** | | **84** | | **68** |
| **4/13/09 10:50** | **Avg Flowrate** | **GPM** | | **Complete** | | **0.0162** | | **0.0136** | | **0.0206** | | **0.0155** | | **0.0125** |
| **4/13/09 10:50** | **Total Thru** | **Gal.** | | **222.5** | | **809** | | **819.2** | | **804.3** | | **763.8** | | **807.7** |
| **4/13/09 10:50** | **Avg Flowrate** | **GPM** | | **0.0170** | | **0.0168** | | **0.0170** | | **0.0167** | | **0.0158** | | **0.0167** |

## Table C-1. Field Hexavalent chromium and Flow Data from Evaluation #1

| Date-Time | Measure | Units | BV | Purolite 100 | BV | Purolite 500 | BV | Purolite 600 | BV | Dowex 21K | BV | ResinTech SIR-700 | BV | ResinTech SIR-1200 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 4/13/09 14:30 | Cr+6 | ppb | | | 6370 | 27 | | | | | 6012 | 3 | | |
| 4/14/09 9:00 | Cr+6 | ppb | | | 6507 | 37 | | | | | 6132 | 0 | | |
| 4/14/09 15:30 | Cr+6 | ppb | | | 6556 | 40 | | | | | 6175 | 0 | | |
| 4/15/09 8:10 | Cr+6 | ppb | | | 6680 | 58 | | | | | 6283 | 1 | | |
| 4/15/09 15:00 | Cr+6 | ppb | | | 6730 | 65 | | | | | 6328 | 0 | | |
| 4/16/09 11:00 | Cr+6 | ppb | | | 6879 | 78 | | | | | 6458 | 2 | | |
| 4/16/09 14:30 | Cr+6 | ppb | | | 6905 | 83 | | | | | 6481 | 2 | | |
| 4/17/09 9:00 | Cr+6 | ppb | | | 7042 | 85 | | | | | 6602 | 1 | | |
| 4/17/09 14:30 | Cr+6 | ppb | | | 7083 | 93 | | | | | 6638 | 0 | | |
| 4/18/09 11:00 | Cr+6 | ppb | | | 7235 | 115 | | | | | 6772 | 0 | | |
| 4/19/09 10:00 | Cr+6 | ppb | | | 7406 | 120 | | | | | 6922 | 0 | | |
| 4/20/09 11:45 | Cr+6 | ppb | | | 7597 | 150 | | | | | 7090 | 0 | | |
| 4/20/09 13:30 | Cr+6 | ppb | | | 7610 | 156 | | | | | 7101 | 0 | | |
| 4/21/09 7:45 | Cr+6 | ppb | | | 7746 | 172 | | | | | 7220 | 0 | | |
| **4/22/09 8:30** | **Total Thru** | **Gal.** | | **Complete** | | **181** | | **Complete** | | **Complete** | | **159.0** | | **Complete** |
| **4/22/09 8:30** | **Avg Flowrate** | **GPM** | | **Complete** | | **0.0158** | | **Complete** | | **Complete** | | **0.0139** | | **Complete** |
| **4/22/09 8:30** | **Total Thru** | **Gal.** | | **222.5** | | **990** | | **819.2** | | **804.3** | | **922.8** | | **807.7** |
| **4/22/09 8:30** | **Avg Flowrate** | **GPM** | | **0.0170** | | **0.0166** | | **0.0170** | | **0.0167** | | **0.0155** | | **0.0167** |
| 4/22/09 9:30 | | | | | | 176 | | | | | | 3 | | |
| 4/22/09 7:00 | | | | | | 210 | | | | | | 2 | | |
| 4/23/09 14:00 | | | | | | | | | | | | 3 | | |
| 4/24/09 9:30 | | | | | | | | | | | | 11 | | |
| 4/25/09 10:30 | | | | | | | | | | | | 8 | | |
| 4/24/09 12:40 | | | | | | | | | | | | 3 | | |
| 4/25/09 10:15 | | | | | | | | | | | | 0 | | |
| 4/26/09 8:50 | | | | | | | | | | | | 0 | | |
| 4/27/09 8:40 | | | | | | | | | | | | 5 | | |
| 4/27/09 10:30 | | | | | | | | | | | | 7 | | |
| 4/27/09 10:30 | | | | | | | | | | | | 8 | | |

BV = bed volume

gal/min = gallons per minute

ppb = parts per billion

## Table C-2. Field Hexavalent chromium and Flow Data from Evaluation #2

| DateTime | Measure | Units | BV | ResinTech SIR-1200 (pH 5) | BV | Purolite A-500 (pH 5) | BV | Dowex 21K (pH Nom.) | BV | Dowex 21K (pH 5) | BV | ResinTech SIR-700 (pH 5) | BV | Purolite A-600 (pH 5) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 4/23/09 14:00 | Cr+6 | ppb | 40 | 2 | 38 | 0 | 40 | 0 | 41 | 0 | 7806 | 3 | 40 | 1 |
| 4/24/09 9:30 | Cr+6 | ppb | 351 | 0 | 331 | 0 | 351 | 0 | 358 | 0 | 7952 | 11 | 351 | 2 |
| 4/24/09 10:30 | Cr+6 | ppb | 367 | 0 | 346 | 0 | 367 | 0 | 375 | 0 | 7959 | 8 | 367 | 1 |
| 4/24/09 12:40 | Cr+6 | ppb | 401 | 3 | 379 | 3 | 401 | 3 | 410 | 2 | 7975 | 3 | 401 | 2 |
| 4/25/09 10:15 | Cr+6 | ppb | 745 | 0 | 704 | 0 | 745 | 0 | 762 | 0 | 8136 | 0 | 745 | 0 |
| 4/26/09 8:50 | Cr+6 | ppb | 1105 | 0 | 1044 | 0 | 1105 | 3 | 1130 | 3 | 8304 | 0 | 1105 | 0 |
| 4/27/09 8:41 | Cr+6 | ppb | 1485 | 5 | 1403 | 5 | 1485 | 12 | 1518 | 33 | 8482 | 5 | 1485 | 5 |
| **4/27/09 10:30** | **Total Thru** | **Gal.** | | **90.0** | | **85.0** | | **90.0** | | **92.0** | | **128** | | **90.0** |
| **4/28/09 10:30** | **Avg Flowrat** | **GPM** | | **0.0158** | | **0.0149** | | **0.0158** | | **0.0161** | | **0.0174** | | **0.0158** |
| **4/29/09 8:20** | **Total Thru** | **Gal.** | | **90** | | **85** | | **90** | | **92** | | **1086** | | **90** |
| **4/29/09 14:30** | **Avg Flowrat** | **GPM** | | **0.0158** | | **0.0149** | | **0.0158** | | **0.0161** | | **0.0159** | | **0.0158** |
| 4/27/09 10:30 | Cr+6 | ppb | 1516 | 3 | 1432 | 2 | 1517 | 2 | 1550 | 36 | 8496 | 8 | 1516 | 2 |
| 4/28/09 10:30 | Cr+6 | ppb | 1842 | 1 | 1718 | 0 | 2044 | 21 | 1865 | 35 | 8630 | 2 | 1802 | 1 |
| 4/29/09 8:20 | Cr+6 | ppb | 2139 | 9 | 1978 | 5 | 2523 | 45 | 2151 | 49 | 8751 | 0 | 2063 | 5 |
| 4/29/09 14:30 | Cr+6 | ppb | 2223 | 6 | 2052 | 2 | 2659 | 55 | 2232 | 48 | 8785 | 5 | 2136 | 3 |
| 4/30/09 8:38 | Cr+6 | ppb | 2470 | 8 | 2268 | 2 | 3057 | 161 | 2470 | 55 | 8886 | 1 | 2353 | 2 |
| **4/30/09 8:51** | **Total Thru** | **Gal.** | | **57.00** | | **50.00** | | **92.00** | | **55.00** | | **50.00** | | **50.00** |
| **4/30/09 8:51** | **Avg Flowrat** | **GPM** | | **0.0135** | | **0.0118** | | **0.0217** | | **0.0130** | | **0.0118** | | **0.0118** |
| **4/30/09 8:51** | **Total Thru** | **Gal.** | | **147** | | **135** | | **182** | | **147** | | **1136** | | **140** |
| **4/30/09 8:51** | **Avg Flowrat** | **GPM** | | **0.0148** | | **0.0136** | | **0.0183** | | **0.0148** | | **0.0156** | | **0.0141** |
| 5/1/09 11:30 | Cr+6 | ppb | 3056 | 22 | 2830 | 0 | 3341 | 192 | 2931 | 95 | 9089 | 5 | 3028 | 4 |
| 5/2/09 9:10 | Cr+6 | ppb | 3542 | 27 | 3296 | 1 | 3574 | 231 | 3313 | 110 | 9257 | 0 | 3588 | 5 |
| 5/3/09 8:12 | Cr+6 | ppb | 4059 | 22 | 3792 | 0 | 3822 | 266 | 3719 | 98 | 9436 | 0 | 4184 | 19 |
| **5/3/09 11:00** | **Total Thru** | **Gal.** | | **98.00** | | **94.00** | | **47.00** | | **77.00** | | **73.00** | | **113.00** |
| **5/3/09 11:00** | **Avg Flowrat** | **GPM** | | **0.0222** | | **0.0213** | | **0.0107** | | **0.0175** | | **0.0166** | | **0.0256** |
| **5/3/09 11:00** | **Total Thru** | **Gal.** | | **245** | | **229** | | **229** | | **224** | | **1209** | | **253** |
| **5/3/09 11:00** | **Avg Flowrat** | **GPM** | | **0.0171** | | **0.0160** | | **0.0160** | | **0.0156** | | **0.0157** | | **0.0176** |
| 5/4/09 7:00 | Cr+6 | ppb | 4563 | 24 | 4294 | 15 | 4154 | 313 | 4209 | 101 | 9598 | 2 | 4744 | 15 |
| 5/4/09 13:25 | Cr+6 | ppb | 4712 | 24 | 4443 | 3 | 4257 | 385 | 4359 | 110 | 9646 | 1 | 4909 | 32 |
| 5/5/09 7:50 | Cr+6 | ppb | 5142 | 30 | 4873 | 8 | 4551 | 484 | 4789 | 146 | 9783 | 2 | 5384 | 59 |
| 5/5/09 14:00 | Cr+6 | ppb | 5286 | 31 | 5017 | 7 | 4649 | 498 | 4933 | 150 | 9829 | 0 | 5543 | 65 |
| **5/6/09 8:35** | **Total Thru** | **Gal.** | | **95.00** | | **95.00** | | **65.00** | | **95.00** | | **65.00** | | **105.00** |
| **5/6/09 8:35** | **Avg Flowrat** | **GPM** | | **0.0231** | | **0.0231** | | **0.0158** | | **0.0231** | | **0.0158** | | **0.0255** |
| **5/6/09 8:35** | **Total Thru** | **Gal.** | | **340** | | **324** | | **294** | | **319** | | **1274** | | **358** |
| **5/6/09 8:35** | **Avg Flowrat** | **GPM** | | **0.0184** | | **0.0176** | | **0.0159** | | **0.0173** | | **0.0157** | | **0.0194** |
| 5/6/09 14:30 | Cr+6 | ppb | 5561 | 44 | 5292 | 5 | 4787 | 502 | 5216 | 154 | 9873 | 0 | 5847 | 60 |
| 5/7/09 7:30 | Cr+6 | ppb | 5768 | 41 | 5499 | 7 | 4995 | 535 | 5413 | 174 | 9995 | 0 | 6076 | 65 |
| 5/7/09 13:00 | Cr+6 | ppb | 5836 | 42 | 5566 | 12 | 5062 | 553 | 5476 | 180 | 10035 | 0 | 6150 | 65 |
| 5/8/09 9:50 | Cr+6 | ppb | 6090 | 43 | 5821 | 8 | 5316 | 572 | 5718 | 207 | 10185 | 0 | 6431 | 73 |
| 5/8/09 14:30 | Cr+6 | ppb | 6147 | 43 | 5878 | 8 | 5373 | 575 | 5772 | 209 | 10218 | 0 | 6494 | 76 |
| 5/9/09 9:09 | Cr+6 | ppb | 6375 | 45 | 6106 | 12 | 5601 | 583 | 5988 | 219 | 10353 | 0 | 6745 | 75 |
| 5/10/09 8:30 | Cr+6 | ppb | 6660 | 55 | 6391 | 12 | 5886 | 616 | 6259 | 232 | 10521 | 0 | 7060 | 101 |
| 5/11/09 11:27 | Cr+6 | ppb | 6990 | 80 | 6720 | 16 | 6216 | 659 | 6571 | 249 | 10715 | 0 | 7423 | 145 |
| 5/11/09 14:00 | Cr+6 | ppb | 7021 | 82 | 6752 | 17 | 6247 | 660 | 6601 | 255 | 10733 | 0 | 7457 | 187 |
| 5/12/09 8:10 | Cr+6 | ppb | 7243 | 64 | 6973 | 15 | 6469 | 664 | 6811 | 272 | 10864 | 0 | 7702 | 142 |

## Table C-2. Field Hexavalent chromium and Flow Data from Evaluation #2

| DateTime | Measure | Units | BV | ResinTech SIR-1200 (pH 5) | BV | Purolite A-500 (pH 5) | BV | Dowex 21K (pH Nom.) | BV | Dowex 21K (pH 5) | BV | ResinTech SIR-700 (pH 5) | BV | Purolite A-600 (pH 5) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 5/13/09 8:15 | Cr+6 | ppb | 7537 | 72 | 7268 | 17 | 6763 | 669 | 7090 | 304 | 11037 | 0 | 8026 | 147 |
| 5/13/09 14:45 | Cr+6 | ppb | 7616 | 75 | 7347 | 20 | 6842 | 675 | 7166 | 309 | 11084 | 0 | 8114 | 153 |
| 5/14/09 9:16 | Cr+6 | ppb | 7842 | 69 | 7573 | 19 | 7069 | 698 | 7380 | 243 | 11217 | 0 | 8363 | 111 |
| 5/14/09 15:05 | Cr+6 | ppb | 7914 | 76 | 7644 | 22 | 7140 | 702 | 7448 | 312 | 11259 | 0 | 8441 | 151 |
| 5/15/09 8:30 | Cr+6 | ppb | 8126 | 68 | 7857 | 14 | 7353 | 720 | 7650 | 320 | 11384 | 0 | 8676 | 108 |
| 5/15/09 13:30 | Cr+6 | ppb | 8187 | 73 | 7918 | 15 | 7414 | 723 | 7708 | 323 | 11420 | 0 | 8743 | 111 |
| 5/16/09 8:34 | Cr+6 | ppb | 8420 | 80 | 8151 | 17 | 7647 | 713 | 7929 | 269 | 11558 | 0 | 9000 | 114 |
| 5/16/09 14:17 | Cr+6 | ppb | 8490 | 83 | 8221 | 20 | 7716 | 719 | 7995 | 280 | 11599 | 0 | 9077 | 116 |
| 5/17/09 14:35 | Cr+6 | ppb | 8787 | 90 | 8518 | 17 | 8013 | 724 | 8276 | 318 | 11774 | 0 | 9404 | 128 |
| **5/18/09 8:00** | **Total Thru** | **Gal.** | | **195.00** | | **195.00** | | **195.00** | | **185.00** | | **247.00** | | **215.00** |
| **5/18/09 8:00** | **Avg Flowrat** | **GPM** | | **0.0121** | | **0.0121** | | **0.0121** | | **0.0115** | | **0.0153** | | **0.0133** |
| **5/18/09 8:00** | **Total Thru** | **Gal.** | | **535** | | **519** | | **489** | | **504** | | **1521** | | **573** |
| **5/18/09 8:00** | **Avg Flowrat** | **GPM** | | **0.0155** | | **0.0150** | | **0.0141** | | **0.0146** | | **0.0156** | | **0.0166** |
| 5/18/09 14:40 | Cr+6 | ppb | 9081 | 97 | 8812 | 17 | 8307 | 710 | 8556 | 310 | 11947 | NA | 9729 | 143 |
| 5/19/09 7:30 | Cr+6 | ppb | 9287 | 98 | 9018 | 17 | 8513 | 724 | 8751 | 308 | 12068 | NA | 9956 | 143 |
| 5/20/09 7:00 | Cr+7 | ppb | 9574 | 105 | 9305 | 28 | 8800 | 727 | 9023 | 317 | 12237 | NA | 10272 | 146 |
| 5/21/09 7:00 | Cr+8 | ppb | 9867 | 108 | 9598 | 17 | 9093 | 725 | 9301 | 324 | 12410 | NA | 10595 | 156 |
| 5/21/09 13:00 | Cr+9 | ppb | 9941 | 110 | 9671 | 16 | 9167 | 734 | 9371 | 340 | 12453 | NA | 10676 | 166 |
| 5/22/09 7:00 | Cr+10 | ppb | 10160 | 107 | 9891 | 19 | 9387 | 690 | 9579 | 356 | 12583 | NA | 10919 | 160 |
| 5/23/09 7:00 | Cr+11 | ppb | 10454 | 120 | 10185 | 29 | 9680 | 729 | 9858 | 389 | 12756 | NA | 11242 | 167 |
| 5/24/09 7:00 | Cr+12 | ppb | 10747 | 135 | 10478 | 35 | 9973 | 745 | 10136 | 453 | 12928 | NA | 11565 | 203 |
| 5/25/09 7:00 | Cr+13 | ppb | 11040 | 134 | 10771 | 41 | 10266 | 742 | 10414 | 518 | 13101 | NA | 11889 | 233 |
| 5/26/09 7:00 | Cr+14 | ppb | 11333 | 163 | 11064 | 52 | 10560 | 723 | 10692 | 527 | 13274 | NA | 12212 | 269 |
| 5/26/09 13:00 | Cr+15 | ppb | 11407 | 176 | 11137 | 59 | 10633 | 738 | 10762 | 577 | 13317 | NA | 12293 | 299 |
| 5/27/09 7:00 | Cr+16 | ppb | 11627 | 133 | 11357 | 29 | 10853 | 733 | 10970 | 395 | 13447 | NA | 12535 | 191 |
| 5/27/09 13:00 | Cr+17 | ppb | 11700 | 153 | 11431 | 65 | 10926 | 739 | 11040 | 400 | 13490 | NA | 12616 | 201 |
| 5/28/09 7:00 | Cr+18 | ppb | 11920 | 135 | 11651 | 24 | 11146 | 705 | 11249 | 406 | 13619 | NA | 12858 | 200 |
| 5/28/09 13:00 | Cr+19 | ppb | 11993 | 137 | 11724 | 26 | 11219 | 710 | 11318 | 409 | 13663 | NA | 12939 | 203 |
| 5/29/09 7:00 | Cr+20 | ppb | 12213 | 139 | 11944 | 24 | 11439 | 735 | 11527 | 422 | 13792 | NA | 13182 | 199 |
| 5/29/09 13:00 | Cr+21 | ppb | 12286 | 140 | 12017 | 24 | 11512 | 736 | 11596 | 422 | 13835 | NA | 13263 | 200 |
| 5/30/09 7:00 | Cr+6 | ppb | 12506 | 164 | 12237 | 30 | 11732 | 752 | 11805 | 441 | 13965 | NA | 13505 | 234 |
| 5/31/09 7:00 | Cr+6 | ppb | 12799 | 163 | 12530 | 30 | 12026 | 750 | 12083 | 438 | 14138 | NA | 13828 | 237 |
| **5/31/09 14:00** | **Total Thru** | **Gal.** | | **312** | | **312** | | **312** | | **312** | | **NA** | | **312** |
| **5/31/09 13:00** | **Avg Flowrat** | **GPM** | | **0.0179** | | **0.0176** | | **0.0178** | | **0.0178** | | **NA** | | **0.0176** |
| **5/31/09 16:00** | **Total Thru** | **Gal.** | | **870** | | **848** | | **823** | | **838** | | **NA** | | **903** |
| **5/31/09 15:00** | **Avg Flowrat** | **GPM** | | **0.0163** | | **0.0159** | | **0.0154** | | **0.0157** | | **NA** | | **0.0169** |

BV = bed volume

gal/min = gallons per minute

ppb = parts per billion

# Appendix D

# Column Effluent Chemistry

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# Column Effluent Chemistry

Table D-1 provides data on the column effluent chemistry obtained during testing.

**Table D-1. Column Effluent Chemistry**

| Resin | A500 | A600 | 21K | SIR 700 pH5 | SIR 1200 | | |
|---|---|---|---|---|---|---|---|
| **Sample Number** | B20769 | B20770 | B20771 | B20772 | B20773 | **Date and Time:** | 3/26/09 13:00 |
| **Bed Volumes** | 3081 | 3186 | 2798 | 2850 | 2804 | | |
| **Analyte** | **Values** | | | | | **Units** | **Lab Qualifier** |
| Chloride | 21900 | 22100 | 21900 | 82200 | 22000 | ug/L | D |
| Phosphate | 368 | 368 | 368 | 368 | 368 | ug/L | UD |
| Sulfate | 71700 | 72600 | 74800 | 79500 | 74500 | ug/L | D |
| **Sample Number** | B208Y6 | B208Y7 | B20912 | B20913 | B208Y5 | **Date and Time:** | 4/6/09 12:30 |
| **Bed Volumes** | 4939 | 5182 | 4783 | 4830 | 5009 | | |
| **Analyte** | **Values** | | | | | **Units** | **Lab Qualifier** |
| Bromide | 143 | 150 | 163 | 135 | 147 | ug/L | BD |
| Chloride | 23300 | 23100 | 23100 | 86800 | 23100 | ug/L | D |
| Fluoride | 46 | 46 | 46 | 46 | 46 | ug/L | UD |
| Nitrate | 30900 | 31000 | 30100 | 29800 | 30300 | ug/L | D |
| Nitrite | 85.4 | 85.4 | 85.4 | 85.4 | 85.4 | ug/L | UD |
| Phosphate | 368 | 368 | 368 | 368 | 368 | ug/L | UD |
| Sulfate | 77300 | 78900 | 77100 | 81900 | 76700 | ug/L | D |
| pH Measurement | 8.21 | 8.25 | 8.23 | 5.96 | 8.26 | unitless | |
| **Average Sample Value** | | | | | | | |
| **Analyte** | **Values** | | | | | | |
| Chloride | 22600 | 22600 | 22500 | 84500 | 22550 | ug/L | D |
| Phosphate | 368 | 368 | 368 | 368 | 368 | ug/L | UD |
| Sulfate | 74500 | 75750 | 75950 | 80700 | 75600 | ug/L | D |

B = analyte less than required detection limit but greater than minimum detection limit (inorganic)

D = analyte reported at a secondary dilution factor

U = analyzed but not detected above limiting criteria

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