FINAL REPORT

# FIVE-YEAR REVIEW REPORT

Submitted by:

SC&A, Inc.
1625 17th Street, Suite 323
Denver, CO 80202

Submitted to:

Mr. Clint Burklin
Eastern Research Group
P.O. Box 2010
1600 Perimeter Park Drive
Morrisville, NC 27560-2010

In response to:

EPA Contract Number 68-D7-0001

November 12, 1999

## Table of Contents

**Table of Contents**
**(Continued)**

## Tables



## Appendices

# I. Introduction

The purpose of this Work Assignment was to prepare an EPA technical report required by the Superfund five-year review requirements. This report was prepared independently by SC&A, Inc. (SC&A), under subcontract to Eastern Research Group (ERG). Tim Fields, Administrator for the EPA Office of Solid Waste and Emergency Response (OSWER), is the decision-maker to whom the report is directed. This review is one of the major milestones leading toward a Fall 1999 decision to complete the high-level review of the original Region 8 and State of Colorado remedy for the Shattuck site.

The Shattuck site - Operable Unit VIII - is one of the 65 Denver area properties involving operating businesses that required various levels of cleanup, such as excavation and removal of contaminated soil to a permanent disposal site, removal of floors to excavate underlying wastes, and installation of ventilation systems to reduce levels of radon. Cleanup actions at Shattuck included onsite stabilization by cement/flyash solidification, followed by capping with a low-permeability composite clay barrier. About 56,000 cubic yards of contaminated soils have been treated and placed on site in a monolith form. The total final volume of the monolith is about 70,000 cubic yards.

This review considered only the Shattuck site and offsite contamination attributed to the Shattuck site. The resulting Five-Year Review report describes actions required to achieve protectiveness and includes other recommendations for the implementation and maintenance of the remedy and coordination with authorities.

The Five-Year Review report was written after the collection and evaluation of site information and documents the results of the review. It summarizes the adequacy of the implementation of the remedy and changes to applicable or relevant and appropriate requirements (ARARs) and other risk-related factors. It identifies deficiencies, recommendations, and required actions. The report also provides the background information necessary to understand the review analysis and discusses the findings of each review activity.

Although the report is directed to the EPA/OSWER Assistant Administrator, it is also of interest to the other principal stakeholders and the general public. Therefore, the report was written to be understood by someone unfamiliar with the site. The report presents all of the information needed to understand the past activities at the site and the current status of all remedial actions.

The following table summarizes the major components of this report.

**Table 1: Contents of the Five-Year Review Report**

| Report Section | Discussion |
|---|---|
| I. Introduction | Synopsis of who conducted the review, when, and for what site; the purpose of the review; whether the review is required by statute or as a matter of policy; whether it is the first or a subsequent review of the site; and what action triggered the review. |
| II. Site Chronology | Dates of major events such as the initial discovery of contamination, NPL listing, decision and enforcement documents, start and completion of remedial actions, construction completion, and prior five-year reviews. |
| III. Background | Description of the site and threats, including discussions of relevant physical characteristics, land and resource use, contaminants, and initial response. |
| IV. Remedial Actions | Description of the remedial action objectives and the remedy, remedy implementation, O&M requirements, and O&M activities to date. |
| V. Five-Year Review Findings | Description of the results of each of the review tasks: ARARs review, any risk recalculation or new risk assessment, and review of documents and analytical data. |
| VI. Assessment | Discussion of the conclusions reached, including whether conditions external to the remedy have changed since the remedy was selected, whether the remedy has been implemented in accordance with decision documents, and whether any risk or ARARs information has changed. |
| VII. Deficiencies | List of any deficiencies. |
| VIII. Recommendations and Required Actions | List of any recommendations, including required actions to achieve protectiveness, parties responsible for implementation, agencies with oversight authority, and the schedule for completion. |

## I.4_ WHO CONDUCTED THE FIVE-YEAR REVIEW

SC&A furnished the personnel, services, materials, and equipment to assist EPA with the Five-Year Review report in accordance with the draft OSWER Directive 9355.7–03B-P, March 1999, Comprehensive Five-Year Review Guidance.

In planning the review, SC&A established a review team, comprising the following technical experts:

- Construction Representative/Geotechnical Engineer, who reviewed composite clay cover design and construction
- Process Engineer, who reviewed groundwater/leachate collection and treatment

- Civil Engineer, who reviewed stabilized/solidified monolithic waste form and general site conditions
- Hydrogeologist, who reviewed aquifer characterization
- Geochemist, who reviewed fate and transport of radiological contaminants
- Risk Assessor, who reviewed risk assessment

In Section V, the peer review team members are identified and their backgrounds are briefly described.

While the review was conducted independently, SC&A coordinated with the EPA and the Colorado Department of Public Health and Environment (CDPHE) in order to facilitate access to files and confirm the accuracy of data inputs.

The Five-Year Review report includes a peer review record. Individual peer review members' comments are presented in Appendix A.

SC&A was also given the task of deciding whether a recalculation of risk or a risk assessment scoping analysis was needed. SC&A determined that a scoping analysis was indeed needed and it is presented in Appendix B.

Monitoring and sampling data and the documentation of operation and maintenance (O&M) were also examined.

## I.B PURPOSE OF THE REVIEW

The purpose of a five-year review is to determine whether the remedy at a site is protective of human health and the environment. The five-year review does not reconsider decisions made during the selection of the remedy, but evaluates the implementation and performance of the selected remedy. The review includes recommendations to ensure that the future remedy will be protective and to address any deficiencies identified during the review process.

Specific to the situation at Shattuck, the Record of Decision (ROD) specified that, in all likelihood, groundwater monitoring would be the only activity implemented during the long-term remedial action period. The ROD component for groundwater was thus considered a No Action or No Further Action ROD. Rather than to verify the performance of a groundwater restoration or containment remedy, the purpose of the required groundwater monitoring was to ensure that ROD assumptions regarding no action for groundwater were correct. The ROD presumed that the aquifer could not be used. However, statutory five-year reviews are still required in cases where hazardous substances, pollutants, or contaminants remain above levels that allow for unlimited use and unrestricted exposure.

## I.C OTHER REVIEW CHARACTERISTICS

This is the first Five-Year Review for the Shattuck site since the remedy was fully implemented. Two earlier reviews occurred (9/12/94, 11/20/98) prior to and at the completion of the remedy. The triggering action for this statutory review is as follows.

The EPA, through its Technical Assistance Grant Program, has granted funds for residents in Superfund site areas to review EPA studies and cleanup work and to communicate their findings to the community. A local community group, the Overland Neighborhood Environmental Watch Group, has received a Technical Assistance Grant (TAG) from EPA to conduct a review of the Shattuck site. TAG recipients often suggest improvement to the plans for remediation and monitoring. In this case, an interest group from the community organized itself to challenge the findings in the first five-year review and filed a case in the U.S. District Court. The trial date has been postponed until 30 November 1999 to give alternative dispute resolution initiatives an opportunity to work.

Tim Fields, Administrator for the EPA Office of Solid Waste and Emergency Response (OSWER), met the Mayor of Denver on March 11, 1999. During that visit, the City and County of Denver reassured Mr. Fields that it would be making a commitment to work with the EPA and participate in the four-part review process for this site. Theresa Donahue, Manager of Environmental Health for the city, joined the Mayor in expressing an interest in going forward under a spirit of cooperation. On April 23, 1999, Mr. Fields completed his personal initiative to meet with the principals of the stakeholders when he visited with Jane Norton, Director of the Colorado Department of Public Health and the Environment. He gained her commitment to participate in this review. The other parts of the ongoing review include a facilitated process with the principals (convened by the Keystone Center) to address outstanding issues, the National Ombudsman report, and the work product from this Five-Year Review. Mr. Fields was committed to moving forward with these reviews and accomplishing major milestones along the way leading to a Fall 1999 decision to complete his high-level review of the original Region 8 and State of Colorado remedy for the Shattuck site.

## II. Site Chronology

The Shattuck property has been the location of several minerals-processing operations since the early 1900s. These operations included the extraction of molybdenum and vanadium from ores, processing of “radium slimes” for the production of radium salts and uranium compounds, recovery of rhenium as a byproduct of molybdenum production, and processing of depleted uranium. As a result of these activities, the primary site contaminants are radium, thorium, uranium, molybdenum, arsenic, selenium, and some organic compounds. Shattuck’s operations ceased in 1984.

EPA selected an onsite Stabilization and Solidification remedy for this Operable Unit (OU) in a Record of Decision (ROD) dated January 1992. The objectives of this remedy were to prevent (1) radiation exposure due to inhalation of radon gas and its daughter products, (2) radiation exposure due to inhalation and ingestion of long-lived radionuclides, and (3) direct exposure to gamma radiation. The remedy was also ostensibly intended to prevent further groundwater degradation and allow contamination in the groundwater to attenuate over time.

The selected remedy included demolition of existing facilities on the Shattuck property, stabilization and onsite disposal of an estimated 50,000 cubic yards of contaminated soil, and capping the treated soil.

The Shattuck Chemical Company, Inc. was identified as a potentially responsible party and the remedial action proceeded under a Unilateral Administrative Order dated August 1992. An Operation and Maintenance Plan and an Institutional Control Plan were developed to ensure the protectiveness and permanence of the selected remedy.

Table 2 lists all important site events and relevant dates in the site chronology. The identified events are illustrative, not comprehensive.

In response to questions from the City and County of Denver and public concern, EPA formed an independent peer review board to provide input to the Five-Year Review. The peer review board consisted of independent professionals who reviewed the remedy at OU VIII, including ARARs and technical issues, and it made recommendations. The board’s report is incorporated into this Five-Year Review as Appendix A.

## Table 2: Chronology of Site Events

| EVENT | DATE |
|---|---|
| Initial discovery of problem or contamination | 1979 |
| NPL listing | September 1983 |
| Surface Impoundment Closure | 1987 |
| Superfund State Contract or Agreement signature | May 1988 |
| Baseline Risk Assessment | September 1991 |
| RI/FS complete | September 1991 |
| Pre-NPL responses | October 1991 |
| ROD signature | January 1992 |
| Enforcement documents (UAO) | August 1992 |
| Remedial Design start | April 1994 |
| Previous Five-Year Reviews | September 1994, November 1998 |
| Remedial Design complete | June 1996 |
| Construction date (start) monolith | July 1996 |
| Actual RA start | September 1996 |
| Oily Soils Shipped Offsite | 1997 |
| Storm Sewer Remediation Activity | February-March 1997, March-May 1999 |
| Construction completion date monolith | September 1998 |
| Final Close Out Report | February 1999 |
| ROD Amendments or ESDs | None |

# III. Background

## III.A PHYSICAL CHARACTERISTICS

The S. W. Shattuck Chemical Company plant processed minerals for more than six decades (1918-1984). Also called the Denver Radium site, it is located in southwest Denver, northeast of the intersection of Evans Avenue and Santa Fe Drive. The site includes the 5.9-acre S.W. Shattuck Chemical Company, Inc. ("Shattuck") property located at the 1805 South Bannock Street, the 4.3-acre railroad rights-of-way located to the west of the Shattuck property, and nearby ("vicinity") properties located within the area bounded by South Santa Fe drive (U.S. Highway 85), South Broadway, Jewell Avenue, and New Mexico Avenue.

The facilities located on the Shattuck property at the time of the ROD included six permanent buildings, miscellaneous storage sheds, underground storage facilities, above-ground storage tanks, process equipment and piping, and asphalt and concrete paving.

South Santa Fe Drive borders the site west of the railroad rights-of-way. Overland Park Golf Course lies west of South Santa Fe Drive. The South Platte River forms the western boundary of the golf course.

Land use in most of the area, with the exception of the Overland Park Golf Course, is typical urban development, ranging from industrial to residential. The Shattuck property is located in an area of the city designated as commercial/industrial. Land use within two blocks south and east of the Shattuck property is predominantly industrial, although some residential use exists. The industrial/commercial area extends from the Shattuck property north for several blocks following the railroad lines.

Residential areas are located three blocks east of the Shattuck property (east of South Broadway), and south of the golf course and west of South Santa Fe Drive (approximately 600 feet southwest of the Shattuck property). Water for domestic use is supplied to the area by the Denver Water Department.

## III.B LAND AND RESOURCE USE

The site is located within the drainage basin of the South Platte River, which is located approximately 3,000 feet west of the site. A shallow unconfined aquifer exists below the site. The shallow aquifer is perched on bedrock and merges with the alluvial aquifer beneath the floodplain of the South Platte River. The groundwater is not currently used as a drinking water source, however, at least two local residents water their lawns with water obtained from shallow wells.

Studies of potential future use are currently being conducted by another contractor. At present, the area surrounding the site is mixed use - light industrial, recreational, and domestic housing.

## III.C HISTORY OF CONTAMINATION

The Shattuck property has been the location of several mineral-processing operations, including the processing of tungsten ores, carnotite ores (for uranium and vanadium), radium slimes, molydbenum ores, and depleted uranium. The contamination of the site is due to the historical use for those mineral processing operations. Approximate time frames for some of the processing activities at the site are:

| | |
|---|---|
| 1920s - | Treatment of molybdenum ores and extraction of ferric vanadate from vanadium and uranium ores or byproducts |
| 1930s- | Processing of radium slimes for recovery of radium, as well as production of radium salts, uranium compounds, and other rare mineral products from carnotite ores |
| 1940s- | Processing of uranium compounds and molybdenum |
| 1950s- | Processing of uranium ores |
| 1960s- | Unknown |
| 1970-80s- | Processing of uranium compounds, molybdenum and rhenium |

From 1969 to 1984, the operations at the facility consisted primarily of processing molybdenite for the recovery of molybdenum compounds, with recovery of rhenium as a by-product. In addition, a small batch operation for the production of uranium products from depleted uranium existed. Operations at the Shattuck facility ceased in 1984. The Shattuck property is currently fenced, and access is restricted by Shattuck.

The railroad rights-of-way include two rail lines which have been operating since the late 19th century. In addition, a rail spur onto the Shattuck property was in place by 1915. The two rail lines are utilized as main lines through the Front Range and handle a total of about twenty to thirty general freight and coal trains per day. The east rail line is located on property owned by the Atchison, Topeka & Santa Fe Railway Company, and the western line is owned by the Denver & Rio Grande Western Railroad Company.

## III.D INITIAL RESPONSE

The United States Bureau of Mines, in cooperation with private industry, established the National Radium Institute (NRI), which successfully developed radium processing in the Denver area. In 1979, EPA noted a reference to the NRI in a 1916 United States Bureau of Mines Report. Subsequent field research revealed the presence of 31 radioactive sites within the City and County of Denver. After identifying these properties, the Radiation Control Division of the CDPHE notified affected property owners of the presence of radiological contamination. Pursuant to a cooperative agreement with EPA, CDPHE initiated engineering assessments of the majority of the identified properties. In October 1981, the Denver Radium Site was placed on the Superfund Interim Priorities List. The Site was included on the National Priorities List on September 8, 1983.

CDPHE began a remedial investigation in November 1988. Since 1979, CDPHE, the EPA, and Shattuck have conducted various studies of the site media, which have included soil and groundwater sampling. The remedial investigation evaluated the existing data and included collection of additional data to characterize the nature and extent of contamination.

During the remedial investigation, additional radiological contamination was discovered to the east and north of the property at 1805 South Bannock Street. EPA evaluated the extent of this contamination. These areas are referred to as the “vicinity properties” in the Record of Decision and the supporting documentation. In August 1989, EPA conducted an emergency removal action at one of the vicinity properties, which involved installation of an active radon reduction system in order to reduce excessively high levels of radon present at a commercial property.

A subsurface impoundment, utilized as an evaporation pond when the 1805 South Bannock facility was in operation, was excavated and closed in 1987, pursuant to a consent decree between CDPHE and the S.W. Shattuck Chemical Company, Inc.

## III.E CONTAMINATION

Radiologically contaminated soils were identified on the Shattuck property, the railroad rights-of-way, and the vicinity properties. Areas were considered contaminated with radium-226 when radium-226 concentrations in soil exceed 5 pCi/g above background in the top 15 cm of soil or 15 pCi/g above background in any layer below the top 15 cm. Contaminated soil on the Shattuck property, prior to the remediation specified in the ROD, covered approximately 230,000 square feet. The estimated volume of contaminated soil on this property is 38,500 cubic yards.

Radioactive soil contamination covered approximately 34,000 of the 186,000 square foot railroad rights-of-way. The volume of contaminated materials on the railroad rights-of-way was estimated to be greater than 4,500 cubic yards. The volume of contaminated soil on the vicinity properties was estimated to be 6,000 cubic yards.

These estimates were based primarily on radium-226 contamination. Additional metals' contamination including radioactive lead-210, thorium-230, and uranium, as well as non-radioactive metals such as lead and arsenic, was also identified in site soils. The majority of the additional contaminants were co-located with the radium-226 contamination.

### III.E.1 Shattuck Property

Discussion of the pre-remedy Shattuck property condition is divided into three areas: (1) the buildings and process areas that were located in the center of the property; (2) the open space areas to the north and south; and (3) the closed evaporation pond which was located in the north open area of the property.

*Buildings and Process Area*

The soils throughout most of the buildings and process area were contaminated. The highest measured one-meter gamma radiation exposure rate in this area was 2,800 micro-roentgens/hour near the southeast corner of Building 6. Subsurface radiation data indicated contamination depths ranging from one to nine feet, with an average depth of about 40 inches and an average equivalent radium-226 concentration of about 90 pCi/g.

*Open Space Areas*

The open areas of the Shattuck property to the north and south of the buildings and process area generally exhibited contamination throughout the area, with the exception of the southern area near the perimeter of the property, the area near the southwest corner of Building 6, and the areas east and south of the closed evaporation pond. Depth of contamination for these areas ranged from 0.5 to over 14.5 feet, with an average depth of about 39 inches and an average equivalent radium concentration of about 69 pCi/g.

The CERCLA action addressed the underlying soils of the surface impoundment (evaporation pond) that was closed under RCRA. The RCRA closure had removed the pond waste materials and the liner materials, but left the underlying soils to the CERCLA action.

Direct gamma radiation measurements on the asphalt surface of the closed pond indicated no surface contamination in this area. Soil immediately beneath the asphalt cover exhibited background concentrations of radioactive contaminants. However, radium-226 contamination was found from about 6 feet to about 7.5 feet below the surface over the western two thirds of the former pond area. Thorium-230 contamination was also found in this area.

III.E.2 <u>Railroad Rights-of-Way</u>

The 4,500 cubic yard estimate of contaminated soil on the railroad rights-of-way included nearly the full length of the area between the east rail line and the Shattuck property, as well as some limited areas to the west of the rail line. The estimated depth of contamination was 0.5 to 2.5 feet along the southern portion and 5 feet from the northern portion.

Although the soil directly beneath the rail line was not sampled, the data for the surrounding area indicated that radium contamination beneath the line is likely. The highest radium equivalent value measured in the railroad rights-of-way was 570 pCi/g.

III.E.3 Vicinity Properties

EPA performed the assessment of the vicinity properties after surface gamma scans indicated the presence of radioactivity on properties in the vicinity of the Shattuck property. The estimated volume of these materials was 6,000 cubic yards. The following is a summary of the primary deposits found on the vicinity properties:

- The 1860 South Bannock Street property. Radium-contaminated soils were located beneath the floor slab of a building, the concrete driveway and parking area, and beneath an asphalt-covered area extending beyond the property to the north and south. The deposit was approximately 2,700 cubic yards and extended to a depth of over eight feet. In August 1989, an emergency removal action was conducted at this property because of the very high levels of radon gas and decay products measured within the building. The removal action involved radon mitigation measures, including sealing slab joints and installing a vent system. Contaminated source materials were not removed.

- The area adjacent to the west side of South Bannock Street from approximately 1700 to 1830 South Bannock. The contaminated area consisted of uncovered soil, as well as asphalt, concrete, driveways, and parking areas. The deposit included approximately 1,300 cubic yards of material contaminated with radium to a depth of over three feet.

- The 1822 South Bannock Street property. Soil contaminated with radium existed in the fill material beneath the concrete floor slab of a building and adjacent to the east side of the building. The deposit included approximately 250 cubic yards of material and extends to a depth of approximately 2.5 feet.

- The 1788 South Acoma Street residential property. Soil contaminated with radium was limited to exterior soils and ranges to two feet, with an estimated volume of 220 cubic yards.

- In addition, 1,100 cubic yards of soils contaminated with radium were estimated to exist beneath South Bannock Street. This estimate was based on adjacent investigations; investigation into the street was not performed because of the presence of numerous utility lines.

The remedial investigation did not attempt to estimate the extent of possible uranium and thorium-230 contamination for the railroad and vicinity properties. Based on the data from the Shattuck property at the time of the ROD, it was believed that the total amount of radiologically contaminated soils requiring remediation could possibly be higher than estimated because of radiological constituents other than radium-226 or lead-210. However, it was believed that additional materials would not influence the remedy selected in the Record of Decision.

III.E.4 Facilities

The following buildings and tanks have been completely removed.

*Buildings*

Based on procedures outlined in the Nuclear Regulatory Commission (NRC) Guide 1.86, radioactive contamination was identified in five of the six permanent buildings on the Shattuck property. The volume of the radiologically contaminated material associated with the buildings was estimated to be approximately 2,095 cubic yards. This estimate included 100 percent of three of the buildings and the floor slabs of two of the buildings. At least one building was contaminated with depleted uranium.

The contamination of the buildings was associated with radioactive constituents which had been processed on the site. Radium-226 and uranium were identified in building-material samples. Based on visual inspection, radiologically contaminated building materials were also suspected to contain relatively abundant concentrations of asbestos in two of the contaminated buildings, with minor amounts in a third building.

*Tanks*

Direct radiation measurements showed elevated levels of total alpha activity for five tanks, indicating that these tanks were contaminated by the processing operations at the site. The averages of the total alpha activity on the five tanks were greater than the NRC Regulatory Guide 1.86 average. However, no maximum measurements exceeded the NRC maximum. The radioactive contamination associated with the tanks was at relatively low levels, and it was expected that the tanks could be adequately decontaminated.

III.E.5 Air

The following describes the historical air monitoring results during the completed remediation activities.

Atmospheric contaminants of concern at the site consisted primarily of radon, a radioactive gas produced by the decay of radium-226 and airborne thorium-230 particles associated with soil contamination.

Air investigations included indoor and outdoor measurements for radioactive contaminants and organic vapors. Of the six buildings on the Shattuck property, three exhibited concentrations of radon gas and its decay products in excess of the EPA guideline of 0.02 working levels (WL), a measurement unit associated with radon gas. Given the gamma radiation levels associated with two additional buildings, it was expected that these additional two buildings may also have periodically exceeded the EPA guideline.

Monitoring of the outdoor air detected low atmospheric concentrations of radioactive contaminants. Measurements of alpha activity and thorium-230 concentrations were in the $10^{-14}$ to $10^{-15}$ microcuries per milliliter range or lower. Air monitors attached to workers performing the remedial investigation indicated up to $10^{-12}$ microcuries alpha activity per milliliter for activities disturbing the soils.

At a vicinity property, an emergency removal was performed to mitigate very high radon concentrations (up to 4 - 6 working levels). The removal action reduced radon levels; however, gamma radiation still poses a potential risk. Measurements of radon at other vicinity properties where soils contaminated with radium were identified did not exceed the EPA guideline of 0.02 working levels.

Indoor and outdoor measurements of organic vapors were less than the detection limit of approximately one part per million benzene equivalent.

III.E.6 Groundwater

Data from the supplemental monitoring system installed during the remedial investigation was used in conjunction with data from monitoring performed by the Shattuck Chemical Company to characterize groundwater flow and quality for the site. Potentiometric surface maps were prepared during the remedial investigation and indicated that contaminated groundwater from the site flows in a west to northwest direction from the site and is contained beneath the Overland Park Golf Course. The golf course obtains its water from ponds supplied from the South Platte River. At the time of the ROD, EPA believed that there was no current use of alluvial groundwater affected by the site. Groundwater level data also indicated that contaminated groundwater from the site did not flow beneath the residential area located to the south of Overland Park Golf Course. Currently, water for domestic use is supplied to the area by the Denver Water Department. However, there is a historical usage pattern.

The aquifer immediately below the site flows into a larger aquifer associated with the South Platte River. EPA estimated the groundwater velocity to be 0.51 feet/day beneath the site. At this rate, groundwater would take an estimated 2.7 years to reach the eastern edge of Overland Park Golf Course. Beneath the golf course, the hydraulic gradient increases dramatically as the shallow aquifer beneath the site drops into the valley that was carved by the South Platte River during the Pleistocene era. The valley is now filled with alluvial sand and gravel. The velocity of the groundwater increases through this section, with the total elapsed time for groundwater to travel from the site to the South Platte River estimated to be slightly more than three years.

Isolated occurrences if gross alpha and beta radioactivity have been detected in the alluvial aquifer. The primary radioactive contaminant in the groundwater is uranium, which has been detected in excess of the range of proposed standards. The offsite alluvial aquifer downgradient from the site continues to exhibit significant concentrations of radioactivity which were estimated by EPA to diminish to background levels as the aquifer is diluted by the system underlying the Platte River.

Volatile organic compounds were detected in concentrations above MCLs in an upgradient well, onsite wells, and downgradient offsite wells. Data from the upgradient well provide strong evidence that significant offsite sources of volatile organic compounds, specifically 1,1,1-trichloroethane, have affected groundwater. Soil boring data indicate that onsite sources of tetrachloroethene and associated degradation products may impact groundwater quality as well. The semi-volatile compounds phenol, benzoic acid, and phthalates were detected in onsite wells.

The metals arsenic, cadmium, and selenium were measured in levels exceeding MCLs, and very high concentrations of molybdenum were observed in onsite and offsite well samples.

Data submitted by the City and County of Denver, and confirmed by CDPHE, indicate that groundwater associated with the site was infiltrating a storm sewer located along South Santa Fe Drive. The storm sewer discharges into the South Platte River just south of Louisiana Avenue. Data for samples obtained from manhole 23A and the storm sewer outfall showed elevated levels of ammonia, molybdenum, copper, and uranium. Remediation work was conducted on the storm sewer in during February through April 1997 and March through May 1999.

At the time of CDPHE sampling, the manhole upgradient (south) of manhole 23A was dry, indicating the water sampled in manhole 23A was infiltrating the storm sewer at the point between the manholes. Contours on the potentiometric surface measured in 1989 indicate the portion of the storm sewer into which groundwater is infiltrating is located downgradient of the site.

Data for well SHB-3 show elevated levels of ammonia, molybdenum, copper, and uranium. The SHB-3 data are generally higher than the data for the manhole, indicating that some dilution occurs between SHB-3 and the storm sewer.

## III.F SUMMARY OF SITE RISKS

A baseline risk assessment was conducted as part of the remedial investigation/feasibility study to characterize the current or potential threat to human health and the environment that may be posed by the contamination on the site.

The principal health threat posed by the site is the carcinogenic risk related to soils contaminated with radium-226. Risk estimates were calculated based on the concentration of contamination found on the site. The potential pathways of exposure evaluated in the baseline risk assessment include future residential or occupational use of the site. This type of land use was selected based on the past and present use of the site and surrounding area and the site's location within a large metropolitan area. Exposure durations were evaluated in conjunction with the contamination levels identified at the site to estimate the baseline risks. The following potential exposure pathways were considered:

- Inhalation of radon, particulate, and organic compounds
- Direct exposure to gamma radiation
- Ingestion of contaminated soil
- Ingestion of groundwater
- Ingestion of garden produce grown in contaminated soil

In risk analysis, carcinogenic risk is presented in the form of a probability (i.e., the increased chance of contracting cancer over a lifetime attributable to the site). As required by the NCP, the risk range of one in ten thousand to one in one million ($10^{-4}$ to $10^{-6}$) is used as the range to indicate whether the site poses an unacceptable risk. For non-carcinogenic compounds, hazard quotients are calculated by comparing a reference dose (Rfd), which is a dose for which there is a potential for adverse health effects, to the estimated potential dose for a given pathway of exposure.  The hazard quotients for a potential pathway of exposure are summed to obtain a hazard index.  A hazard index greater than one poses an unacceptable risk.

## III.G HUMAN HEALTH RISKS

The following discussion reflects the historical site condition at the time of the 1991 Risk Assessment.

III.G.1 Principal Threats Posed by the Site (Pre-Remedy)

The two major contaminants of concern for radiological exposure at the site were radon gas and gamma radiation, both of which are attributable to the radium-contaminated soil located on the site.  Radon gas, a decay product of radium, was migrating from contaminated soil into the atmosphere.  The risk associated with radon gas results from inhalation of its short-lived decay products which can expose the internal tissue of the lungs to bursts of energy if they decay within the lungs.

Prolonged inhalation of air with a high concentration of radon decay products has been conclusively shown to increase the risk of contracting lung cancer in uranium miners.  When radon gas emanates from soil contaminated with radium, dispersion into the air generally dilutes the radon.  In open spaces, such dispersion usually reduces radon concentrations to low enough levels that outdoor risks of radon exposure are insignificant.  However, radon decay products can accumulate to unacceptable concentrations in buildings built over radium contamination, because structures tend to trap radon gas.

The radioactive decay of radium and its decay products also results in the emission of highly penetrating gamma radiation.  Gamma radiation is continuously emitted from radiologically-contaminated soil.  Gamma radiation is omitted in all directions from a source, and exposure is dependent on proximity to the source and whether physical materials shield the source.  Gamma radiation emitted by unshielded radium-containing soil penetrates the soil to give anyone standing over a contaminated area a radiation dose over the whole body.  The greater the duration and intensity of this exposure, the larger the dose, and hence the greater the risk of adverse health effects.

III.G.2 Radon Conditions (Pre-Remedy)

Seasonally corrected interior radon concentrations of 0.12 working levels were observed on the historic Shattuck property. These concentrations correspond to a 5 x $10^{-2}$ lifetime cancer risk to a future resident for a 30-year exposure, or a 1 x $10^{-1}$ lifetime cancer risk to a future worker with a 20-year exposure.

Dispersion modeling was used to estimate the offsite radon concentrations attributable to the site. The results indicate that the contribution of the Shattuck property to offsite radon concentrations was negligible, with levels estimated to be 0.0002 working levels for the 1800 block of South Acoma (modeled as the nearest residential area) and 0.008 working levels immediately north of the Shattuck property (modeled as the nearest offsite worker location).

III.G.3 Gamma Radiation (Pre-Remedy)

The projected lifetime cancer risk from gamma radiation to an individual working 75 percent indoors and 25 percent outdoors on the Shattuck property for 20 years was 1 x $10^{3}$. The lifetime cancer risk from gamma radiation exposure for a future residential scenario on the Shattuck property was 5.6 x $10^{-3}$, based on a 30-year exposure and the average one-meter gamma radiation measurements in the vicinity of the process buildings. The risks calculated for radon inhalation and gamma radiation were independent of each other. Hence the total risk potentially posed by radium-contaminated soil was the sum of the radon and gamma risks.

The risks represented herein were the calculated risks attributable to the historic site. For comparison, the background gamma risks, based on gamma measurements taken at the Overland Park Golf Course were calculated as 1.2 x $10^{-3}$ for the future onsite residential scenario and 1.9 x $10^{-4}$ for the future onsite worker scenario. A background risk for indoor radon was not calculated. Indoor levels for radon can vary widely, depending on soil compensation and the physical characteristics of a building.

# IV. Remedial Actions

## IV.A REMEDY SELECTION

EPA selected an onsite stabilization and solidification remedy for OU VIII in a Record of Decision (ROD) dated January 1992. The objectives of this remedy were to prevent:

- Radiation exposure due to inhalation of radon gas and its daughter products
- Radiation exposure due to inhalation and ingestion of long-lived radionuclides
- Direct exposure to gamma radiation

The remedy was also designed to prevent further groundwater degradation and allow contamination in the groundwater to attenuate over time.

The Decision Summary for the Record of Decision provides a performance criteria standard of 1,000 years for the remedy as a whole. This standard is based on 40 CFR 192 Subpart A, which states that the design should be for 1,000 years to the extent reasonably achievable, and, in any case, for at least 200 years. This is a functional requirement not a system component. A system component is a physical part of the disposal facility, and each component may be designed to perform a number of functions.

Monolith construction effectively diluted the contaminated soil by 30 percent; thus a degraded monolith source was effected that would no longer be comparable to the original open-site condition prior to onsite disposal. As such, even if the monolith begins to degrade, contaminants will not be released at the same rate as they would have been from the pre-remedy onsite soils because (1) they are diluted, (2) the reactive surface area is considerably reduced, and (3) the chemical form of at least some of the contaminants will have been changed by chemical reactions involving the soil and monolith materials. However, pilot-study leaching tests show that leachates from the monolith often exceed several groundwater standards, notably with respect to heavy metals.

TCLP tests were used to determine potential leachate composition for the monolith. Specifically, the tests showed that the leachably metal content for molybdenum was consistently leached at higher concentrations than the groundwater ARAR limits; cobalt, chromium, and vanadium, leached at concentrations close to or just above the groundwater regulatory limit of 50 μg/L in some samples.

IV.A.1 Groundwater

For groundwater, the remediation requirement is to prevent the ingestion of groundwater with contaminants in excess of ARARs, TBCs, or health-based concentrations if no ARARs exist. Attenuation will improve the groundwater quality after the remedy is complete. Stabilization of the contamination will reduce the mobility of contaminants and reduce the release to the groundwater.

Specific performance standards, used to ensure that the requirements for the groundwater are met, are:

- Groundwater monitoring will be performed to assess the effectiveness of stabilization such that any release to groundwater from the disposal unit will not cause the groundwater to exceed ARARs and TBCs.

- Groundwater monitoring will also be performed to monitor the existing plume of contamination. Design of a network of wells to monitor post-remediation groundwater quality was developed during remedial design. When monitoring indicates that ARARs are being maintained for the contaminated plume, the frequency of the plume monitoring may be reduced or discontinued. However, monitoring of groundwater near the disposal unit will continue.

- Further groundwater remediation may be required if monitoring shows that attenuation of the contamination will not achieve ARARs.

- Corrective action as required to comply with the Clean Water Act and Colorado Water Quality Control regulations (5 CCR 1002-2 Sections 3.1, 3.8, and 6.1 et. sec.) will be undertaken to address the contaminated groundwater infiltrating the storm sewer west of the site. The means of compliance were to be determined during remedial design.

- 5 CCR 1002-8 section 3.12.0, Classifications and Water Quality Standards for Ground Water, is an applicable requirement for groundwater at the site. The regulation sets an interim narrative standard that requires that groundwater be maintained at the less restrictive of: (1) existing ambient quality as of October 30, 1991, or (2) that quality which meets the most stringent criteria set forth in Tables 1 through 4 of "The Basic Standards for Ground Water." The regulation provides that for contaminated groundwater, the intent is not to limit remediation. This requirement will be met by controlling the source of contaminants and attenuation of the groundwater to the contaminant-specific levels set forth in Table 3 of Appendix A of the ROD.

- All other ARARs identified in EPA's ROD for groundwater must also be met.

For concerns related to monitoring design and performance, see Section VII.

## IV.B REMEDY IMPLEMENTATION

The Remedial Action at OU VIII was substantially completed in September 1998. Remedial action operations at OU VIII include the following:

- Demolition of radium-contaminated buildings
- Excavation of radium-contaminated soil from vicinity properties, Bannock Street, the storm sewer located east of Santa Fe Drive, and the Shattuck Chemical property
- Onsite stabilization/solidification of the radium-contaminated soil into a disposal cell
- Capping of the stabilized material
- Installation of monitoring wells to evaluate the effectiveness of the remedy

The remedial action at OU VIII was conducted in two phases, beginning September 1992, and was substantially complete in September 1998. During Phase I, approximately 67,345 tons of building debris were disposed of off site and 8,700 cubic yards of soil were excavated from the vicinity properties. During this phase, approximately 200 cubic yards of asbestos-containing material were removed and disposed of under appropriate regulations. Approximately 400 cubic yards of radiologically contaminated material were excavated from beneath Bannock Street. Stabilization/solidification of the radiologically contaminated material began in July 1996 and was completed in November 1997.

Approximately 65,000 loose cubic yards of radiologically contaminated soil excavated from Shattuck Chemical and the vicinity properties were stabilized/solidified onsite in a disposal cell. Capping of the stabilized material was completed in June 1998. The Draft Construction Completion Report was submitted on September 29, 1998.

A waste form (i.e., monolith) was constructed on site consisting of compacted layers of contaminated soil, cement, fly ash, and water. In the pilot treatability study, the soils were to be mixed at a ratio of 70:20:10 (soils: cement: fly ash), compacted to an ASTM standard value, and a moisture content to maintain a 0.4 ratio of water to cement. The study results indicate that, at least in the near-term, structural strength of the concrete meets the requirements of the EPA in terms of compressibility and permeability. Toxicity Characteristic Leaching Procedure (TCLP) results were consistently close to or just below the groundwater ARAR limits for cobalt, chromium and vanadium, and higher concentrations than the groundwater ARAR limits for molybdenum.

These tests confirm the near-term acceptability of the waste form, but do not address its long-term performance as a part of the remedial system.

The monolith is covered with a surface barrier or cap, which in some form or another has been designed and used throughout the Western United States at Uranium Mill Tailing Remedial Action (UMTRA) sites. The cover ultimately used is a variant of those typically applied for UMTRA; however, the UMTRA caps in use may not have been in place a sufficient amount of time to adequately evaluate their efficiency and long-term performance. The Department of Energy (DOE) is currently conducting long-term surveillance of UMTRA caps under an alternative cap study. Already, concern has been raised about the UMTRA-type caps' long-term performance related to the clay barrier in arid regions and vegetation invasion (Hakonson, 1997).

During the excavation of radiologically contaminated soils, oil-impacted soils were also found onsite. The materials were below the action levels established in the ROD. Approximately 2,000 cubic yards of oil-impacted soil were excavated during Phase II activities from the Shattuck Chemical Property located at 1805 South Bannock Street. This material was covered and transported by truck to Conservation Services Inc. (CSI) in Bennet, Colorado. Bioremediation was used for oil-impacted soils that extended beneath the completed portion of the monolith. A plan addressing the remaining soils contaminated with oil at OU VIII was submitted in August 1998. The bioventing system was approved by EPA and was installed in September 1998.

In 1997, the storm sewer along Santa Fe Boulevard west of the site was remediated. The remediation consisted of using InSituForm to install a lining within the existing sewer lines, manholes, and inlet boxes. The sewer remediation effort was conducted in 1997 in accordance with the EPA-approved design. Based on water quality sampling and water level data obtained in 1998, EPA determined that an additional section of the sewer located to the north of the section previously determined to be located below the shallow groundwater table, also needed to be remediated. This additional section of the storm sewer line was remediated using the InSituForm process in 1999. EPA has requested additional water quality sampling of the storm sewer and a decision is pending.

## IV.C SYSTEM OPERATIONS/OPERATION AND MAINTENANCE

The System Operations/O&M requirements are not identified in a single document. Components may be found in the monolith-monitoring plan, the plume-monitoring plan, and the bioremediation plan.

Security arrangements discussed in this report are based on visual observations during the July 1999 site visit and oral discussions with a Shattuck representative. Site-security arrangements that are temporarily in place and consist of a 24-hour, round-the-clock guard and a controlled access system consisting of a fence and a locked gate. The bioremediation system has operated since 1998 without incident. The existing monolith- and plume-monitoring wells are being sampled quarterly. Annualized costs for the site security arrangements, the bioremediation system, and the monolith- and plume-monitoring system are presented in Table 3. The site engineer has indicated that the security arrangements will most likely be discontinued in the near future and therefore costs associated with site security are not included in Table 3. Apparently, site groundskeeping activities will be maintained and are presented in Table 3.

**Table 3: Current Annual O&M Costs**

| O&M ITEM | DATES | | ESTIMATED ANNUALIZED COSTS |
|---|---|---|---|
| | FROM | TO | |
| Grounds keeping | 1/99 | 12/99 | $10,000 |
| Bioremediation | 1/99 | 12/99 | $15,000 |
| Monolith and plume monitoring | 1/99 | 12/99 | $220,000 |

Additional costs have been incurred to replace the protective fencing around the site. The fence on the western side of the site was taken down by a Regional Transportation Department construction crew during an adjacent construction activity.

In addition, considerable debate is going on with regard to the adequacy of the existing monolith- and plume-monitoring programs. Potential expansion of these programs is under consideration. Expansion could take the form of geoprobes, additional wells, additional constituents to be monitored for, additional surface water and soil sampling, as well as additional testing and monitoring of the monolith itself (coring to evaluate the monolith's intactness, evaluating the cap statistically, setting benchmarks for settlement evaluation, etc.). These activities would require significant capital cost outlays and could also significantly increase the upcoming and future annualized O&M costs.

## IV.D PROGRESS SINCE THE LAST FIVE-YEAR REVIEW

Table 4 itemizes the actions taken since the last Five-Year Review. At the time of the last five-year review, the remedial action for OU VIII had just been completed. This included the excavation and stabilization of the contaminated soil and select vicinity properties, the construction of the cap, and installation of the bioremediation system. Since then, the Operation and Maintenance Plan was developed and implemented, and Shattuck initiated sampling under the plume-monitoring and monolith-monitoring plans.

**Table 4: Actions Taken Since the Last Five-Year Review**

| RECOMMENDATIONS/ REQUIRED ACTIONS | PARTY RESPONSIBLE | ACTIONS TAKEN | DATE OF ACTION |
|---|---|---|---|
| Excavation & stabilization | Shattuck | completed | 1998 |
| Construction of cap | Shattuck | completed | 1998 |
| Bioremediation system | Shattuck | completed | 1998 |
| Monolith | Shattuck | completed | 1998 |
| Sewer System | Shattuck | conducted | 1998 |
| Plume-monitoring plan | Shattuck | developed & implemented | 1998 |
| Monolith-monitoring plan | Shattuck | developed & implemented | 1998 |
| Bioremediation | Shattuck | developed & implemented | 1998 |

The current monolith-monitoring program consists of 10 monitoring wells; five wells on the western side of the monolith and five wells on the eastern side of the monolith.

# V. Five-Year Review Findings

## V.A TEAM MEMBERS

This section briefly describes the technical experts who served on the Peer Review Team.

**Mr. John Darabaris** managed the Peer Review Panel. He is a geologic engineer with extensive experience in EPA-OSW RCRA Corrective Action and Permitting Actions, and Comprehensive Environmental Response Compensation Liability Act (CERCLA) Environmental Restorations. He has served in lead roles on prior peer reviews.

**Mr. Phillip Rogers** was the process engineering representative on the Peer Review Panel. Mr. Rogers is a professional engineer with more than 23 years of experience. His experience includes the development of complex conceptual and numerical models that capture processes such as preferential flow in the vadose zone, the effects of tank waste chemistry on radioisotope mobility, alternative end state configurations, and infiltration. He has extensive experience with CERCLA and RCRA projects, including hazardous and municipal waste landfills, mine waste, mixed wastes, and petroleum contamination at Air Force bases. Mr. Rogers also managed and was the principal author of the hydrogeologic impact sections and sensitivity analysis appendix of the Retrieval Performance Evaluation Methodology for the AX Tank Farm (U.S. DOE, DOE/RL-98-72, April 1999). For that report, he successfully managed and implemented the detailed evaluation of the hydrogeologic impacts of retrieval and closure of high-level radioactive waste tanks at DOE's Hanford Site.

**Dr. Allen Hatheway** was the Construction/geotechnical engineering representative on the Peer Review Panel. Dr. Hatheway has more than 38 years of professional experience in environmental management and geotechnical options; exploration program design; hazardous and special waste management facility siting, design and permitting; site and waste characterization and remedial engineering for uncontrolled sites; seismic risk assessment; hazards mitigation; rock engineering and underground construction; critical facility siting; and expert testimony.

**Dr. John W. Goode** was the Risk Assessment Specialist on the Peer Review Panel. Dr. Goode has a Ph.D. in toxicology. He has 26 years of management, technical, and business-related experience in a broad range of environment, health, and safety areas. Dr. Goode currently represents EPA as the lead inspector in determining compliance of the major nuclear waste sites in the United States that will eventually ship waste to the Waste Isolation Pilot Project outside of

Carlsbad, N.M. Dr. Goode has managed or participated as a senior investigator in major risk assessment and exposure information projects. For example, he has managed a screening level human health-risk assessment for direct and indirect exposure to combustion emissions for chemical agent incinerators located at the Tooele Army Depot in Utah. Dr. Goode has also managed a risk assessment of the closure of the 2101-M pond at Hanford. He validated analytical data generated by U.S. Testing, and provided a risk-assessment model to the Washington Department of Ecology.

**Dr. Steven Schaffer** was the aquatic biologist on the Peer Review Team. Dr. Schaffer has a Ph.D. in Biology/Environmental Health Science from New York University. Dr. Schaffer is a senior scientist responsible for a wide variety of ecological, health, and regulatory activities and has lead responsibilities for SC&A's chemical risk-assessment business. He managed a project that produced the Environmental Impact Statement and Regulatory Analysis in support of NRC's decommissioning standards. He is also responsible for SC&A's technical training business, which offers seminars in risk assessment, environmental chemistry, and quality control to industry and government. Dr. Schaffer has also performed several studies for the EPA concerning the risks and hazards of both chemical and radiological contaminants.

**Mr. David Back** was the Hydrogeologist on the Peer Review Team. Mr. Back has over 14 years of experience reviewing and evaluating hazardous and nuclear waste disposal technologies; performing groundwater contamination assessments; developing and implementing remedial measures and evaluating remedial effectiveness; conducting aquifer tests, geophysical surveys, tracer tests, and soil and water sampling; performing numerical and analytical simulations of groundwater flow and contaminant transport; and implementing quality-assurance and quality-control procedures. Mr. Back has been the lead author of several EPA/DOE/NRC joint guidance documents developed to facilitate the selection and application of groundwater models at Federal facilities, EPA sites, and potential low-level waste sites.

**Dr. Wendy Harrison** was the geochemist expert on the Peer Review Panel. Dr. Harrison is a professor at Colorado School of Mines with more than twenty years of experience, and has participated in numerous peer review panels.

**Dr. Charles Shackelford** was the civil engineer on the Peer Review Panel. Dr. Shackelford is a professor of Civil Engineering at Colorado State University with more than 20 years of experience. He has participated on numerous expert panels, specializing in closure design issues.

## V.B COMMUNITY ACTIVITIES

Members of the Peer Review Panel attended four Shattuck dialogue meetings. The first meeting was held on May 21, 1999, at which time the scope of work was discussed. In a meeting on July 7, 1999, several administrative actions were discussed and it was agreed that another contractor would address a report on development options for the Shattuck site in future meetings. Relative to this work assignment, the Peer Review Panel members were identified and resumes made available. A meeting on July 23-24 discussed decision criteria for use by the EPA/OSWER Administrator and plans for an in-depth discussion of perspectives on costs and benefits at the upcoming August meeting. The City of Denver presented alternatives that address its criteria. A proposed work plan for the remainder of the dialogue was also presented. Progress to date was discussed as was the desired future course of the dialogue in relation to the other Shattuck review tracks. With respect to this review, a need to conduct a scoping analysis of the site's risk assessment was identified. This analysis had been identified in the original work plan as a "to-be-determined" item. All members of the Peer Review Panel attended the dialogue meeting on September 9, 1999. The purpose of this meeting was to receive updates from the major dialogue initiatives. These updates included the redevelopment study, a re-mining feasibility study, the work of the environmental response team, and the expert panel study conducted as part of this assignment.

## V.C TECHNICAL EXCHANGES

No formal interviews were scheduled during this peer review. However, all Panel members had discussions with various members of the dialogue, representatives of EPA Region VIII, the City of Denver personnel, and Shattuck site personnel as necessary. This included attendance by some of the Panel in the monthly Shattuck technical meetings with EPA, the State, the City of Denver, Shattuck Chemical Company, and stakeholder technical staff. Mr. Darabaris attended the majority of the meetings, with participation by Mr. Back, Mr. Rogers, Dr. Goode, Dr. Hatheway, Dr. Shackelford, and Dr. Harrison as needed.

As part of the Technical Exchange process, and to ensure the technical accuracy of the review, each Panel member met with interested parties to discuss their individual findings. In preparation for these meetings, the interested parties had a rough draft of the initial findings, concerns, and assessments of each Panel member as presented in Appendix A. Furthermore, the Working Draft of the Five-Year Review itself was made available for comments from interested parties. Comments were forwarded under an October 15, 1999 deadline. Panel members reviewed the comments and revisions were made to the Five-Year Review as deemed appropriate to ensure technical accuracy and clarity.

## V.D SITE INSPECTION

Expert Panel members Darabaris, Rogers, Schackelford, Hatheway, and Harrison participated in a site inspection on July 6, 1999. Jim Hanley of the EPA and Paul Rosasco of EMSI also accompanied the members of the Peer Review Panel on the site visit.

The Shattuck Site now consists of a fenced rectangular property on which solid waste is disposed in a landfill that occupies the majority of the surface area. The surface of the unit was covered with riprap consisting of large, irregularly shaped rock. The surface topography appeared uneven, with randomly scattered highs and lows, possibly due to the size of the rock and the method of placement. Plate 2 of the Construction Completions Report shows the top the of monolith to be crowned with an overall slope of one percent to the northwest. There appeared to be a “drain” consisting of coarse gravel or rock around the perimeter of the cap. This drain is designed to capture runoff from the cap and divert it to a sump. The cap design and waste monolith characteristics would seem to indicate very little infiltration through the unit.

A system of groundwater monitoring wells could be observed near the landfill. The system appeared to be limited to one row of upgradient wells on the east side of the landfill and one row of downgradient wells on the west side. The wells were located very close to the toe of the landfill cap.

There did not appear to be a reliable system to determine settlement. Based on an inspection performed on behalf of EPA in June 1999, Morrison-Knudsen concluded that there is no indication of an imminent or ongoing threat to the monolith and cover system from potential impacts due to settlement, subsidence, slope movement, or erosion. Expert Panel members also inspected the site and agreed with the Morrison-Knudsen inspection report. However, visual observation of the cap surface is not conclusive. Excessive settlement could occur and not be detected or, conversely, false indications of settlement could be interpreted from the uneven rock surface.

## V.E RISK INFORMATION REVIEW

The 1991 baseline risk assessment for the Shattuck site meets the EPA guidelines that were in place at the time the risk assessment was conducted. In recent years, new guidelines for Exposure Assessment (1992), Carcinogenic Risk (1996), Reproductive Toxicity Risk (1996), and Ecological Risk (1998) have been issued. The newer guidelines do not change the overall approach of the risk-assessment process but continue EPA's risk-development process initiated in the early 1980s. The newer guidelines have increased the emphasis on exposure characterization and provide better guidance for assessing ecological exposure to chemicals and human exposure to radiological agents. These two areas are important in evaluating the applicability of the 1991 risk assessment to the current site circumstances.

The primary agencies with regulatory authority for the cleanup of sites contaminated with radioactivity include the EPA, the Nuclear Regulatory Commission (NRC), the Department of Energy (DOE), and the State of Colorado. National and international scientific advisory organizations provide recommendations related to radiation protection and radioactive waste management but have no regulatory authority. EPA's authority to protect public health and the environment from adverse effects of radiation exposure is derived from several statutes, including the Atomic Energy Act, the Clean Air Act, the Uranium Mill Tailings Radiation Control Act (UMTRCA), the Nuclear Waste Policy Act, and CERCLA. EPA's major responsibilities with regard to radiation include the development of Federal guidance and standards, assessment of new technologies, and surveillance of radiation in the environment. EPA also has lead responsibility in the Federal government for advising all Federal agencies on radiation standards.

The State of Colorado has its own authority and regulations for managing radioactive material and waste. State regulations are potential ARARs.

The following were reviewed to determine changes in ARARs that could affect the Shattuck site.

- 10 CFR Part 20, Standards for Protection Against Radiation
- 10 CFR Part 61, Licensing Requirements for Land Disposal of Radioactive Waste
- 40 CFR Part 190, Environmental Radiation Protection Standards for Nuclear Power Operations
- 40 CFR Part 191, Environmental Standards for the Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Waste

- 40 CFR Part 61, National Emission Standards for Hazardous Air Pollutants
- 40 CFR Part 141, Interim Primary Drinking Water Regulations
- 40 CFR Part 142 National Primary Drinking Water Regulations- Radionuclides
- 40 CFR Part 192, Health and Environmental Protection Standards for Uranium and Thorium Mill Tailings
- 40 CFR Part 300, National Contingency Plan (NCP) and Supporting Guidance
- 10 CFR Part 834, Radiation Protection of the Public and the Environment
- 40 CFR Part 311, Worker Protection
- 40 CFR Part 440, Ore Mining and Dressing Point Source Category
- 40 CFR Part 58, Ambient Air Quality Surveillance
- Colorado Department of Public Health and Environment 6 CCR 1007-2, Regulations Pertaining to Solid Waste Disposal Sites and Facilities
- Colorado Department of Public Health and Environment 7 CCR 261, Identification and Listing of Hazardous Waste
- Colorado Department of Public Health and Environment, Water Quality Control Commission Regulation No. 41, The Basic Standards for Groundwater
- Colorado Department of Public Health and Environment, Air Quality Control Commission Regulation No. 8, Control of Hazardous Air Pollutants
- Colorado Department of Public Health and Environment, Radiation Services Commission, Part 1 General Provisions
- Colorado Department of Public Health and Environment, Radiation Services Commission, Part 3 Licensing of Radioactive Material
- Colorado Department of Public Health and Environment, Radiation Services Commission, Part 4 Standards for Protection Against Radiation General Provisions
- Colorado Department of Public Health and Environment, Radiation Services Commission, Part 14 Licensing Requirements for Land Disposal of Low Level Radioactive Waste

- Federal Guidance Report No. 13, Part I - Interim Version, Health Risks from Low-Level Environmental Exposure to Radionuclides, EPA 402-R-97-014, Office of Radiation and Indoor Air, January 1998

- Risk-Based Concentration Table, USEPA Region III

- Selecting Exposure Routes and Contaminants of Concern by Risk-Based Screen, EPA/903/R-93-001, January 1993

- OSWER Memorandum No. 9200.4-23, Clarification of the Role of Applicable, or Relevant and Appropriate Requirements in Establishing Preliminary Remediation Goals under CERCLA

- OSWER Memorandum No. 9200.4-18, Establishment of Cleanup Levels for CERCLA Sites with Radioactive Contamination

- Regulatory Guide 8.36, Radiation Dose to the Embryo/Fetus, NRC, July 1992

- Effects of Ionizing Radiation on Terrestrial Plants and Animals: A Workshop Report, ORNL/TM-13141, Oak Ridge National Laboratory, December 1995

- The Health Physics and Radiological Health Handbook, Scinta, Inc., 1992, (Bernard Shleien, ed.)

- Environmental Protection Agency, Risk Assessment Guidance for Superfund, Vol. I, Human Health Evaluation Manual (Part A), Office of Emergency and Remedial Response. EPA/540/1-89/002, 1998

- Environmental Protection Agency, Uses of Soil Cleanup Criteria in 40 CFR 192 as Remediation Goals for CERCLA Sites, OSWER Directive No. 9200.4-25, February 12, 1998

It was determined that there were no ARAR changes that materially affected the site. Since the soil was removed and concentrated in the landfill and the current groundwater usage is minimal, the site remedy would not be affected by small changes in ARAR concentration levels. However, there are concerns that the goals of the original remedial design were not stringent enough and could have fallen short of the ARAR requirements in place at the time of the remedy.

The Construction Completion Report states that the soil cleanup levels were based on ARARs developed at the time of the ROD, 1992. The levels for Ra-226, Th-230 and gamma radiation were based upon the uranium mill tailings standard 40 CFR 192. This standard does not specify levels for uranium, so DOE Order 5480.1 was used.

Since the time of the ROD, EPA issued two OSWER Memoranda concerning residual levels of radioactivity left onsite after remediation. An August 22, 1997, OSWER Memorandum (OSWER No. 9200.4-18) states that the maximum concentrations of residual contaminants (including radionuclides) should not exceed the$10^{-4}$ cancer risk. This limit is based on a site-specific risk assessment and depends on the site-specific radionuclides and exposure pathways. A February 12, 1998, OSWER Memorandum (OSWER No. 9200.4-25) further clarifies the use of the soil cleanup criteria in 40 CFR Part 192 as remediation goals for CERCLA Sites. This memorandum specifically addresses subsurface soils and states that the subsurface criterion for radium (15 pCi/g) is only potentially relevant and appropriate if the distribution of subsurface contamination is similar to the 24 UMTRCA Title I sites.

A cursory review of the soil concentrations remaining after cleanup supports the finding that the site may not meet the new EPA cleanup criteria in OSWER No. 9200.4-18, and that the doses may be well above acceptable levels. Table 5 illustrates this point.

**Table 5: Summary of Soil Concentrations Remaining After Cleanup**

| **RADIONUCLIDE** | **SOIL RISK CONVERSION (per pCi/g)** [1] | **SITE SOIL CONCENTRATIONS AFTER CLEANUP (pCi/g)** [2] | | **RISK LEVEL** | |
|---|---|---|---|---|---|
| | | **Mean** | **U-95%** | **Mean** | **U-95%** |
| Ra-226 | $5.6x10^{-5}$ | 5 | 7.6 | $2.8x10^{-4}$ | $4.3x10^{-4}$ |
| Total Uranium | $3.6x10^{-7}$ | 14 | 20 | $5.0x10^{-6}$ | $7.2x10^{-6}$ |
| Th-230 | $1.6x10^{-5}$ | 9 | 13 | $1.4x10^{-4}$ | $2.1x10^{-4}$ |
| TOTAL | | | | $4.2x10^{-4}$ | $6.4x10^{-4}$ |

[1] Taken from *Radiation Site Cleanup Regulations: Technical Support Document for the Development of Radionuclide Cleanup Levels for Soils*, EPA, September 1994, using the commercial industrial exposure without the groundwater pathway.

[2] Calculated from Table 5 of the *Construction Completion Report Vol 1*, Shattuck Chemical Company, Inc., February 8, 1999. Radium-226 background of 1.5 pCi/g subtracted from mean and U-95% concentrations.

The table shows that the average subsurface soil concentration remaining onsite could exceed the EPA's suggested limit by as much as a factor of 6.4. This table was developed using soil risk conversions based upon generic and standardized usage and exposure factors, and chemical equilibrium constants assuming surface soil exposures. It has been our experience that many regulatory agencies, including EPA, assume that subsurface soils can be brought to the surface by human activity thereby creating surface soil exposure scenarios.

If the EPA assumes that the residual contamination remains buried, then OSWER No. 4200.4-25 provides specific guidance. It states that, if the subsurface contamination exists at a level between 5 pCi/g to 15 pCi/g averaged over 100 $m^2$, then conditions at the site are not sufficiently similar to an UMTRCA site to consider the subsurface contamination standard in 40 CFR Part 192 a relevant or appropriate requirement. The EPA recommends that in this situation the 5 pCi/g surface standard might be used as a cleanup goal provided a site-specific risk assessment demonstrates that this level is protective. In addition , when parent radionuclides of radium exist in the soil (Thorium 230 and 232), EPA recommends that the soil should be cleaned to 5 pCi/g concentration for the parent radionuclides too. This prevents future buildup of radium to levels greater than the 5 pCi/g standard.

Again we find that the residual levels of radionuclides in subsurface soils are not relevant and appropriate according to this newer directive. Table 5 shows that the average subsurface values for radium, thorium and uranium are all between 5 and 15 pCi/g. This means that the 15 pCi/g subsurface criterion in 40 CFR Part 192 should not be used as a cleanup goal because it is not relevant and appropriate for this site. Table 5 also shows that the residual levels of Ra-226 and Th-230 are above the 5 pCi/g health based criterion in the UMTRCA standard.

To determine the safe levels for the radionuclides in the residual subsurface soils at the site, a site specific risk assessment needs to be performed. Risks for subsurface soils could be higher or lower than those shown in Table 5. The direct shine dose contribution from Ra-226 and Th-230 would essentially decrease to zero because of the shielding from the soil above, but other exposure mechanisms would become more important. For subsurface exposures, one needs to consider radon migration into dwellings and groundwater contamination from uranium.

Radon in dwellings and subsequent inhalation is one of the critical exposure pathways the EPA sought to mitigate in the UMTRCA regulation. Indoor radon standards under 40 CFR 192(b)(1) and 192.41(b) are potentially relevant and appropriate requirements. Radon gas is a daughter product of the contaminants of concern. Migration through soil is highly variable and can range from a few centimeters to many meters. The average travel distance was about 5 meters. The distance radon travels is dependent on whether the soil media is highly compacted which inhibits movement or contains cracks and conduits that promote migration. It is possible that radon from the subsurface soils and the monolith could travel to nearby buildings through spaces in the soils and conduits created by underground utilities.

Since uranium can readily move into groundwater, the subsurface soils could become an easy source for groundwater uranium contamination.   This is because the contamination is only a short distance above the water table.

## V.F RISK RECALCULATION/ASSESSMENT

The 1991 risk assessment evaluated the level of risk for the underlying aquifer, and found the water unacceptable for drinking.  Of the radioactive contaminants, uranium was the most significant, with a calculated lifetime risk of $6.7 \times 10^{-3}$ based on drinking two liters of water per day for 30 years.  As stated above, this finding (based on 1991 RA) is a cause for concern since uranium has a long half-life (U-234 = 240,000 yrs., U-238 = 4,400,000,000 yrs.) and would not be expected to lose appreciable activity in the proposed 200-year time period.

The 1991 risk assessment information did not address future risk which is a concern at the Shattuck site and surrounding area since hazardous contaminants have been left in place and complete remediation of groundwater may not occur for decades in the future.

The Panel's main concern is the long-term risk potential of the groundwater.  There has been use of the groundwater in the past, and without strict institutional controls, there may be use of the groundwater before the present risk level has been reduced.  A recent M-K sampling report since completion of the monolith still shows constituents, such as molybdenum, above trigger levels. The passive nature of the remedial alternative for groundwater that essentially relies solely on dilution for the long-lived radionuclides places an even greater importance on extensive groundwater monitoring.  Unless a credible understanding of the groundwater flow and contaminant processes can be developed the true environmental impacts may remain unknown. Performance criteria, especially for the groundwater plume, should be developed and monitored. The goal of these criteria should demonstrate that MCLs for all groundwater constituents will be achieved in the regulatory timeframe.  Without this information, the Panel is not convinced that the groundwater will achieve necessary standards required by CFR 40 192 within the 100-year timeframe.
Additional onsite and offsite data is necessary before conducting a risk assessment of the current situation at the Shattuck site and surrounding areas.  Increasing the number of samples and locations of samples will increase the precision and accuracy of results.  More data must be obtained to demonstrate that the site meets the criteria given in 40 CFR 192.

## V.G DATA REVIEW

The Panel concluded that too few samples of media had been taken since remediation to conduct an acceptable risk assessment of the current situation. Quarterly groundwater sampling has been conducted and is the major source of new data. The 1991 baseline risk assessment concluded that the groundwater was a major source of risk, and the ROD concluded that natural flushing was the choice for remediation of the aquifer. Many more data points are necessary to address issues raised by the Panel before a meaningful risk assessment of the current situation at Shattuck can be conducted.

# VI. Assessment

## VI.A CHANGES IN CONDITIONS EXTERNAL TO THE REMEDY

### VI.A.1 Land Use

Land use at the site itself has not changed since the ROD. However, the review has found that the original remedy did not adequately address potential groundwater usage. The reasonably expected land use within the site boundaries is restricted by deed. It is also important to recognize that the land use of the surrounding areas is not restricted by any formal legal means and is, in fact, mixed residential and industrial. Also, the aquifer is considered a potential source of drinking water as a Class II aquifer under the "Guidelines for Groundwater Classification under the EPA Groundwater Protection Strategy, Final Report, November 1986," issued by the EPA's Office of Groundwater Protection.

Given the longevity of the remedy, it is possible that land use downgradient of the site may change with respect to groundwater and surface-water use.

### VI.A.2 Contaminants and Pathways

Currently, the monolith provides an improved waste-management form from the pre-remediation circumstances. In the near term, there is no evidence that the monolith is not performing as expected (i.e., stabilizing the site contaminant source term). The review has identified significant design issues that question the ability of the site to confirm long-term performance of the monolith. From an exposure point of view, the monolith represents a new contaminant source because it changes the external exposure geometry and provides a concentrated source for radon emanation.

Based on the preliminary findings presented in Section V, Table 5, the remaining soils and aquifer materials within the plume could have sufficient metals' loading to act as a source. Data are insufficient to assess the magnitude of this source.

Although there are no currently known downgradient groundwater users, there are groundwater users in the area. Furthermore, while the State of Colorado has not formally classified the Upper Terrace aquifers, the State's position is that aquifers not designated as being of limited beneficial use must be considered as having potential beneficial use to the public. The underlying Denver formation aquifer is classified as a Class I aquifer by the State, equivalent to the Class I aquifer designation found in the 1986 CERCLA Guidance. In addition, surface water is currently being used for recreation (Platte River). There is also an unnamed pond downgradient of the site that may be receiving groundwater recharge from the contaminant plume. Water from this pond may be used for irrigation. The Remedial Investigation Report and the Baseline Risk Assessment removed from consideration the groundwater exposure pathway for human and ecological risk. This review finds that the decision to eliminate the groundwater pathway was based on insufficient data and not supported by regulatory concerns. Likewise, this review finds that the surface-water exposure pathway was eliminated based on minimal data and regulatory support.

### VI.A.3 Hydrologic/Hydrogeologic Conditions

There is no evidence that the hydrologic/hydrogeologic site conditions have changed. However, these conditions may not have been characterized in sufficient detail. The site hydrogeologic conditions presented in the remedial assessment and remedial investigation are not a complete depiction of the actual site conditions.

The review finds that the groundwater plume condition does not meet CERCLA 121(d) standards. The site characterization program does not define site hydrogeologic conditions sufficiently to support natural monitored attentuation. Site geology (upper aquifer soils and underlying bedrock) may exhibit a great deal more variability and channeling characteristics than the simplistic model presented in site documents. There are significant questions regarding the adequacy of the definition of the plume characteristics (lateral extent, vertical extent, fate and transport characteristics).

## VI.B IMPLEMENTATION OF THE REMEDY

### VI.B.1 Health and Safety Plan/Contingency Plan

The project's health and safety requirements, equipment, and procedures required of all contractors and subcontractors at the Shattuck site are described in section 01020 of the Construction Completion Report, February 1999.

VI.B.2 Institutional Controls

An institutional controls program has been developed and implemented to control access to the stabilized materials.  Security measures such as fencing and surveillance are in place. Groundwater monitoring is in place ostensibly to monitor the effectiveness of the stabilized material so that any groundwater loading from the disposal unit will not cause the groundwater to exceed ARARs.  The existing plume of contamination will be monitored.  An air monitoring plan was in place to monitor volatile and semi-volatile and particulate (PM10) and total suspended particulate (TSP) constituents during the construction phase.  Currently, no continuous air monitoring is taking place under the existing site institutional control program.  However, at the end of the cap construction, a gamma flux and radon emission measurement program was conducted as part of the construction completion and will be continued on an annual basis.

This review finds it questionable whether the institutional controls required to restrict the use of contaminated groundwater can ever be implemented.

VI.B.3 Remedy Performance

Currently, the monolith provides an improved waste management form from the pre-remediation circumstances.  In the near term, there is no evidence that the monolith is not performing as expected (i.e., stabilizing the site contaminant source term).  However, there are a number of technical findings that raise doubt about the site's ability to confirm long-term performance of the monolith and control over the contaminated groundwater.

Limited recent-sampling data indicated that contaminants may still be present in soil and groundwater and, if not controlled, may cause harm to humans, the environment, and ecological organisms.

VI.B.4 Adequacy of System Operations

The systems operations requirements appear adequate for the site and are being properly implemented.  The security breaches during construction appear to have been eliminated.

However, as noted above, although there is apparently no groundwater exposure today, the review finds that no institutional controls are in place to prevent offsite groundwater access. Also, the review finds that the surface water was also poorly characterized.  Only one surface-water sample from a runoff catchment basin was analyzed. For this sample, only gamma activity, indicating Ra-226 and/or elevated natural uranium, was determined; other constituents, such as metals and organic compounds, were not determined. Thus, the characterization of the surface-water quality was incomplete.

VI.B.5 Optimization

The determination of the extent of groundwater contamination and the movement of the contaminant plume was incomplete. Thus, the effectiveness of the remedy in protecting human health and environmental quality cannot be fully assessed at this time with respect to the groundwater contamination exposure path. Likewise, analyses of soil metals were perfunctory and sparse. Thus, the review finds that data are insufficient to confirm whether all the metal-contaminated soil was removed, or whether metals loading into the aquifer materials occurred. Inadequate information exists to determine if metal-contaminated soils remain, although apparently radioactive materials were removed properly and adequately to the target levels established at the time of the remedy.

Many more data points are desirable to characterize the plume and to make a meaningful assessment of the current situation at Shattuck. There is not a long enough history of “clean” sampling results for sampling to be reduced. Increased sampling of groundwater and offsite soil is necessary because, as mentioned, site soils and groundwater that exceeded general EPA guidance for radioactive cleanup may have been left in place.

VI.B.6 Indicators of Potential Failure

There is no history of frequent equipment breakdowns or changes in the scope of system operations that indicate potential problems.

VI.B.7 O&M Costs

At the present level of operations, there are no potential problems. However, an increase in necessary offsite institutional controls would increase cost in the near term. The City and County of Denver has the authority to control use of groundwater downgradient from the Shattuck site or anywhere within the service area of the Denver Water Board. Accordingly, an offsite institutional control can be implemented by Denver by enacting an ordinance. The City and County of Denver has indicated that they have no intention to enact such an ordinance. Nor, for that matter, is it clear that the PRP ever approached the City and County to enact such an ordinance.

From a review of the Shattuck documents, it appears that the PRG was set for achieving a risk of $1 \times 10^{-4}$ (industrial). Future risk assessment and performance standards of the Shattuck site should evaluate a more conservative goal. The latter may be more appropriate for the following reasons:

- The surrounding site area presently includes recreational and residential activities.
- Trying to predict the future of land use over the next 200 years for Shattuck and the surrounding area is difficult. However, there is justification for believing that Denver will continue to grow and will have several times its present population in 200 years.
- The contaminants include long half-life radioactive contaminants (up to $10^{10}$ years for U-238), which guarantees that they will retain much of their activity throughout the 200-year period and beyond.
- Shattuck is a unique situation because it is the only radiation waste repository set in a major metropolitan area in the United States
- Security at present does not go beyond the site boundaries, and the EPA has gone on record (FR 1/11/95) as limiting credible maintenance of the site to 100 years.
- Actions at Superfund sites should be based on estimates in the high-end of the intake/dose distribution.

The EPA has generally assumed that cleanups to ARARs are satisfactory because the residual risk will be in the $10^{4}$ to $10^{6}$ range. However, the Agency has clarified that cleanups of radionuclides are governed by the risk range for all carcinogens established in the NCP when ARARs are not available or are not sufficiently protective. That is, cleanup should generally achieve a level of risk within the $10^{-4}$ to $10^{-6}$ range based on the reasonable maximum exposure for an individual. The Peer Review Panel is concerned as to whether the original goal of $1 \times 10^{-4}$ for the Shattuck cleanup is appropriate given the surrounding site circumstances.

# VII. Deficiencies

Table 6 details shortcomings in current site operations, noting which inadequacies currently prevent the remedy from being protective.

**Table 6: Identified Deficiencies**

| DEFICIENCIES | CURRENTLY AFFECTS PROTECTIVENESS (Y/N) |
|---|---|
| Lack of institutional control of plume outside site boundary | Y |
| Vulnerability of cover/monolith design to long-term degradation | Y |
| Monolith-monitoring plan deficiencies | Y |
| Plume-monitoring plan deficiencies | Y |
| Site characterization and modeling deficiencies | Y |
| Risk assessment deficiencies | Y |
| Specific design technical issues that need to be re-evaluated | Y |

A brief discussion of each deficiency follows.

## VII.A LACK OF INSTITUTIONAL CONTROL OF PLUME OUTSIDE SITE BOUNDARY

This review finds that the offsite impact of the degraded groundwater plume has not been covered by any formal institutional control. Shattuck does not consider itself responsible for ensuring offsite land use, and the State/City governments have not provided definitive assurances of institutional controls for the life of the remedy specified in the ROD (200 years).

## VII.B VULNERABILITY OF COVER/MONOLITH DESIGN TO LONG-TERM DEGRADATION

The remedial design is ostensibly based on UMTRA design concepts. However, this review finds that the remedial design does not include performance assessment modeling that is typically used to confirm long-term performance capability. Furthermore, there is great concern that the limited performance analysis that was done (i.e., reduction factor analysis presented in Appendix F of the Remedial Design) does not accurately reflect the anticipated chemical and hydrologic performance (i.e., more uniform flow based on a higher incidence of microfractures; rather than dilution, water passing down the column will acquire more contamination until it reaches the base of the monolith). Specifically, the approach used to calculate the "Reduction Factors" in Appendix F is based on a uniform mixing type approach that is known to be nonconservative when compared against methods that better represent groundwater flow and contaminant transport and predict dilution rates based on vertical and transverse dispersion.

Also, it has been reported that some "high quality concretes made with sulfate-resisting cements have deteriorated prematurely in the field" (Kalousek et al., 1972). Given the required long service life of the monolith and lack of supporting data, it is concluded that the sulfate resistance of the monolith is uncertain. The monolith mixture is described as 70 percent soil and rubble, 20 percent Type I/II cement and 10 percent Class C fly ash. The uncertainty in monolith sulfate resistance stems from (1) the presence of sulfates and potential chlorides, (2) the potential for water to come into contact with the monolith, and (3) the lack of available chemical documentation on the fly ash combined with the type of fly ash used. Most Class F fly ashes improve sulfate resistance of Type II cements and are generally more efficient in improving sulfate resistance (Klieger and LaMond, 1994). This variability has prompted investigators to recommend that Class C fly ashes be individually evaluated if intended for sulfate resistance. Chemical variability in fly ash would not be uncommon from ashes from one source. In this case, it is not known how many sources of fly ash were used for the monolith nor were chemical analyses made available. Guidelines for the use of fly ashes for the improvement of sulfate resistance have been published by several sources. Dunstan 1980 proposes a fly ash "sulfate resistance factor R" and has documented the "drastic" reduction of sulfate resistance due to use of inappropriate fly ashes. Such fly ashes (i.e., those that would not improve sulfate resistance or potentially reduce sulfate resistance) would generally be characterized as being high in calcium oxide content and comparably low in ferric oxide content. Finally, there are no available data on the sulfate resistance of monolith samples as could have been determined by laboratory testing. Several laboratory (and field) tests are in standard use, such as ASTM C 1012, which involves the expansion of mortar specimens in a 5 percent sodium sulfate solution or the Bureau of Reclamation Procedure 4908, Methods A, B, or C.

## VII.C MONOLITH-MONITORING PLAN DEFICIENCIES

The review finds the current monolith monitoring plan deficient. The monolith-monitoring plan (MMP) outlines the approach that was used to place monitoring wells to detect leaks from the monolith. A computer code (i.e., MEMO) was used in a stochastic framework to predict how much of the monolith area would be effectively covered in terms of leak detection by potential monitoring wells. One of the key parameters for this analysis is the transverse dispersivity (i.e., the amount that the plume spreads perpendicular to groundwater flow). The MMP cites a 1985 EPA guidance document indicating that transverse dispersivity can be estimated as 0.33 times the longitudinal dispersivity. In the case of the monolith, the longitudinal dispersivity is estimated to be 10 percent of the travel distance from the monolith to the site boundary or 35 ft. Therefore, a transverse dispersion of 12 ft was assumed (0.33 times the longitudinal dispersivity).

The greater the transverse dispersivity the more likely the plume will intersect a monitoring well. The value for transverse dispersivity cited in the 1985 EPA document was developed prior to the famous tracer tests performed at the Borden test site that indicated considerably lower transverse dispersivity values. More recently, Dr. Len Gelhar, a professor at MIT with considerable knowledge of contaminant transport, has estimated transverse dispersivities in the alluvial aquifer system in the vicinity of Yucca Mountain Nevada to be approximately 10 percent of the longitudinal dispersivity. This system is similar to the one at the Denver Radium site. This would result in a transverse dispersivity of 3.5 ft. The MEMO modeling results indicate that with a transverse dispersivity of 6 ft, the monitoring wells would effectively cover 86 percent of the monolith area. Therefore, we know that this coverage would be reduced if a value of 3.5 were to be used for transverse dispersivity. Furthermore, the transverse dispersivity could be even smaller if preferential pathways exist beneath the monolith.

MEMO should be rerun with smaller, more representative transverse dispersivities. Based on the MEMO results, additional monitoring wells should be placed to offset those that currently exist in order to provide at least a 95 percent confidence that any leaks will be detected. Since the groundwater is estimated to be moving at 0.5 ft/yr and the mean distance is approximately 350 ft, it could take up to two years for the contaminants to move from the monolith to the site boundary. These relatively low velocities would suggest that only every other well would need to be sampled annually.

## VII.D PLUME-MONITORING PLAN DEFICIENCIES

The review finds the Plume-Monitoring Plan deficient and far too limited in scope. As noted in the ROD, the second objective of groundwater monitoring is to monitor the currently existing plume of contamination. An implicit argument in the RI, however, was that plume monitoring does not have to be particularly intensive because concentrations are low once the plume is diluted within the alluvial aquifer and the river. This assertion cannot be supported without a properly designed monitoring program. The actual concentrations in the alluvial aquifer will remain unknown since the downgradient concentrations currently being observed may be on the plume fringes rather than on the centerline.

With respect to monitoring under a monitored natural attenuation remedy, OSWER Directive 9200.4 states (p.22) that the monitoring program should be designed to accomplish the following:

- Demonstrate that natural attenuation is occurring according to expectations;
- Detect changes in environmental conditions (e.g., hydrogeologic, geochemical, microbiological, or other changes) that may reduce the efficacy of any of the natural attenuation processes;
- Identify any potentially toxic and/or mobile transformation products;
- Verify that the plume(s) is not expanding (either downgradient, laterally or vertically);
- Verify no unacceptable impact to downgradient receptors;
- Detect new releases of contaminants to the environment that could impact the effectiveness of the natural attenuation remedy;
- Demonstrate the efficacy of institutional controls that were put in place to protect potential receptors; and
- Verify attainment of remediation objectives.

To address these issues, the groundwater monitoring program needs to be comprehensive. It is important to note that the OSWER Directive, in discussing the monitored natural attenuation alternative for metals/radionuclides, only briefly mentions dilution as a mechanism to be relied upon to lower contaminant concentrations in the groundwater. Only processes such as sorption and oxidation that actually remove the contaminant from solution are discussed.

The passive nature of the remedial alternative for groundwater, which essentially relies solely on dilution for the long-lived radionuclides, makes extensive groundwater monitoring even more important. Unless a credible understanding of the groundwater flow and contaminant processes can be developed, not only will the true environmental impacts remain unknown, but a poor precedent will be set for future monitored natural attenuation remedies.

## VII.E SITE CHARACTERIZATION AND MODELING DEFICIENCIES

This review finds that the site characterization program does not sufficiently define site hydrogeologic conditions to support a passive groundwater remediation strategy. Site geology (upper aquifer soils and underlying bedrock) may exhibit a great deal more variability and channeling characteristics than the simplistic model presented in site documents. There are significant questions regarding the adequacy of the definition of the plume's characteristics (lateral extent, vertical extent, fate and transport characteristics). If one assumes that "institutional control" is plausible and allows for a passive natural remediation process, EPA standards (40CFR192, Groundwater Standards for Remedial Actions at Inactive Uranium Processing Sites, Final Rule) call for a demonstration that the natural remedy can meet groundwater standards within a 100-year timeframe. Specifically,

> for aquifers where compliance with the groundwater standards can be projected to occur naturally within a period of less than 100 years, and where the groundwater is not now used for a public water system and is not now projected to be so used within this period, this rule permits extension of the remedial period to that time, provided institutional control and an adequate verification plan which assures satisfaction of beneficial uses is established and maintained throughout this extended remedial period,

and

> If the Secretary determines that sole reliance on active remedial procedures is not appropriate and that cleanup of the groundwater can be more reasonably accomplished in full or in part through natural flushing, then the period for remedial procedures may be extended. Such an extended period may extend to a term not to exceed 100 years if: (A) The concentration limits established under this subpart are projected to be satisfied at the end of this extended period, (B) Institutional control, having a high degree of permanence and which will effectively protect public health and the environment and satisfy beneficial uses of groundwater during the extended period and which is enforceable by the administrative or judicial branches of government entities, is instituted and maintained, as part of the remedial action, at the processing site and wherever contamination by listed constituents from residual radioactive materials is found in groundwater, or is projected to be found, and (C) The groundwater is not currently and is not now projected to become a source for a public water system subject to provisions of the Safe Drinking Water Act during the extended period.

This review finds that an expanded site hydrogeologic investigation is necessary to adequately define: (1) variability of hydrogeologic regimes, (2) fate and transport characteristics, (3) background, and (4) plume extent. After this investigation, a sufficiently rigorous and sophisticated model could be developed to assess the ability of natural remediation processes to achieve remediation goals within the specified maximum regulatory time period (100 years).

There are questions as to whether the remaining soils and aquifer materials within the plume have sufficient metals loading to act as a source. This review also finds that insufficient data exist to assess the magnitude of this source. Because the groundwater contaminant plume cannot be remediated "instantly," there is a period of time where two possibilities arise: (1) the groundwater remains above standards despite the completion of the remedial action, but comes into compliance over some non-established time period; and (2) the groundwater does not meet standards over any reasonable short term because remaining soil and aquifer material release contaminants previously taken up (adsorbed, precipitated, exchanged, etc.). The re-introduction of contaminants could be caused by the changed water quality resulting from site remediation. Improved contaminant transport models can be used to estimate a duration for plume remediation.

## VII.F RISK ASSESSMENT DEFICIENCIES

The review finds that the remedy did not consider either a groundwater or a surface-water receptor. While land use on the site is restricted by deed, there are no apparent offsite legal land-use restrictions that would prevent Shattuck's neighbors from using the groundwater and surface water. Therefore, a supplemental risk assessment should be performed that includes both groundwater and surface-water receptor scenarios. This supplemental risk assessment should consider maximum groundwater contaminant levels with the understanding that the limited plume-monitoring system may not be sufficient to capture maximum contaminant concentrations. Also, appropriate release models and realistic time-variant infiltration rates through the cap and monolith are required.

Also, no ecological risk assessment has been done for the site. It is now standard practice to complete such assessments.

## VII.G SPECIFIC DESIGN TECHNICAL ISSUES THAT NEED TO BE RE-EVALUATED

Although the remedy has been implemented in accordance with the gist of the decision documents, this review finds that several technical issues apparently were overlooked in the original design.  Since these design-related technical issues may affect the performance of the remedy over the 200-yr design life, these technical issues need to be addressed.  They are:

- Water balance analysis
- Potential for shrinkage cracking of GCL
- Confirmation of hydraulic conductivity of RS/CL slope
- Settlement

## VIII. Recommendations and Required Actions

Table 7 specifies the required and suggested improvements to current site operations. It notes the parties responsible for actions, milestone dates, and the agencies with oversight authority.

### Table 7: Recommendations and Required Actions

| RECOMMENDATIONS/REQUIRED ACTIONS |
|---|
| Institutional Controls |
| Performance Assessment Modeling of Cover/Monolith Design Long-term Performance |
| Monolith-Monitoring Plan Upgrade |
| Plume-Monitoring Plan Upgrade |
| Development of a More Sophisticated Groundwater and Contaminant Transport Model to Assess Natural Attenuation |
| Develop Sufficient Site Characterization Data to Define Plume and Support Risk Assessment |
| Conduct Risk Assessment |
| Specific Design Technical Issues |

The following is a brief discussion addressing all deficiencies that currently affect protectiveness.

### VIII.A INSTITUTIONAL CONTROLS

Protective fencing is currently around the site. However, the western portion was taken down by RTD during their construction of the light rail line on the adjacent property and subsequently replaced by Shattuck. It is important to note that Shattuck does not consider itself responsible for maintaining the site fence and access control. The Record of Decision specifies that the owner will acquire deed restrictions necessary to allow institutional protection of all site development. However, nothing seems to be in place to prevent any vicinity property owners from developing groundwater resources in the time frame it would take to remediate the contaminant plume.

Institutional control agreements should be enacted to control surface and groundwater usage. If the latter is not feasible, the site remedy should be re-evaluated to address groundwater and surface water in a pro-active manner, through both more definitive site characterization and possibly more aggressive remediation strategies.

## VIII.B PERFORMANCE ASSESSMENT MODELING OF COVER/MONOLITH DESIGN LONG-TERM PERFORMANCE

From about 1918 to 1984, the site was used to receive and treat molybdenum ore, carnotite ore, vanadium ore, uranium ore, and radium salts. Other ores may have been received and treated in addition to those documented. Much of the contaminated soils incorporated into the monolith is assumed to consist of ore and ore waste. These ores and ore-related wastes commonly contain various salts, including those of sulfate. The presence of sulfates and perhaps chloride salts in the ore calls into question the long-term acceptability of the waste form. Constructed on site, the waste form (i.e., monolith) consists of compacted layers of contaminated soil, cement, fly ash, and water. In the pilot treatability study, the soils were to be mixed at a ratio of 70:20:10 (soils: cement: fly ash), compacted to an ASTM standard value, and a moisture content to maintain a 0.4 ratio of water to cement. The study results indicate that, at least in the near-term, structural strength of the concrete meets the requirements of the EPA in terms of compressibility and permeability. Toxicity Characteristic Leaching Procedure (TCLP) results were consistently close to or just below the groundwater ARAR limits for cobalt, chromium and vanadium, and higher concentrations than the groundwater ARAR limits for molybdenum. These tests confirm the near-term acceptability of the waste form, but do not address its long-term performance as a part of the remedial system.

A review of concrete longevity in Service Life of Concrete (Clifton and Knab, 1989) and Concrete Longevity Overview (Chang and Hasan, 1990) provide a basis for the concern over the long-term performance of the monolith. Among the most common and destructive factors affecting concrete are sulfates in soil, groundwater, or seawater. The degradation caused by sulfate varies from minor surface erosion to complete loss of structural strength leading to total structural failure of the concrete (Chang and Hasan, 1990). The most commonly found sulfate salts in soils are sodium sulfate, calcium sulfate, and magnesium sulfate. They are found in rocks as well as mineral deposits. Another destructive factor in concrete is the presence of chloride ions. Chloride ions are common in nature, and they exist in soil in the form of chloride salts such as calcium chloride, magnesium chloride, and sodium chloride. They are found in igneous rocks and sedimentary rocks. Particularly high levels of chloride ions are found in evaporates. In arid regions, the soil usually contains high chloride concentrations due to a high evaporation rate. Chlorides such as magnesium chloride and aluminum chloride react with lime to form unstable and water-soluble compounds. Chang and Hasan, in a 1990 report, note that the presence of chloride ions in concrete reduces its resistance to attack by sulfates in soils.

While much of the research has focused on the external effects of sulfates in soil and groundwater, the same deleterious effects are expected when sulfate-rich aggregates are used because all aggregates are, to a certain extent, chemically reactive with the cement paste. Aggregates (in this case the contaminated soil and other material) must conform to certain standards for optimum engineering use. They must be clean, hard, strong, durable particles free from deleterious coatings that could affect hydration and bonding of the cement paste. They must not be easily split and should have high resistance to the effects of weathering.

Suitable aggregates do not contain deleterious substances that react chemically (e.g., sulfates and chlorides) to produce significant volume changes or harmful byproducts, or that interfere with ordinary hydration of cement.

Given the history of the site, the waste quite possibly contains various sulfates and chloride compounds that would interfere with cement reactions. The only available data on sulfate content of the waste mixed into the monolith is related to testing samples used in the Pilot Scale Treat ability Study (Earth Sciences Consultants, 1993). Three test feed materials were developed: 1) one with average radioactivity (sulfate concentration of 1,440 mg/kg), 2) one with elevated radioactivity (sulfate concentration of 2,390 mg/kg), and 3) one with elevated radioactivity containing building rubble (sulfate concentration 4,400 mg/kg). Sulfate concentration data in adjacent soil and groundwater were not reviewed. Various organizations such as the Bureau of Reclamation (Concrete Manual, 1975) and the Portland Cement Association (Kosmatka and Panarese, 1988 and Guide to Durable Concrete, 1992) have developed guidance for the identification of the potential severity of sulfate attack and appropriate precautionary measures but, this guidance is intended for use in concrete construction under ordinary service life conditions and may not necessarily be appropriate for long-term service life, such as required for hazardous waste containment (Klieger and LaMond, 1994 ). Never-the-less, if one applies the guidance (Guide to Durable Concrete, 1992) to the limited data, then a cement formulation that is at least moderately resistant to sulfate attack would be required based on the "average soil" sulfate concentration of 1,440 mg/kg. This does not consider the potential cumulative sulfate attack from the other external sources (i.e., groundwater and leaching from adjacent soil).

The pilot treatability study did not directly address these issues. The Shattuck site may be a very severe environment for long-term cement stabilization of the waste because of the various sulfates and chlorides in the site waste. As noted by Clifton and Knab (1989), “a site with a very severe environment is, undoubtedly, unfit for storing LLW in concrete vaults.” They go on to note that following design recommendations should result in a concrete with acceptable durability for many years, possibly for the 60- to 100-year design life of typical concrete structures. There is no basis (at the time of the report in 1989) for predicting the service life of a concrete exposed to a sulfate environment, especially in the case of a concrete with a design life of hundreds of years.

Also, the record of groundwater levels is relatively short compared to the period over which levels must be predicted; thus, there is not enough information to say with certainty that groundwater levels will remain below the base of the monolith, and the potential impact of changes in groundwater levels should be evaluated via performance assessments.

Calculating the contaminant mass flux that is released from the monolith to the underlying vadose zone requires the development of assumptions concerning (1) how waste is released for the waste form (i.e., the monolith) and (2) the time-variant infiltration rate through the cap and monolith. Appendix F, “Groundwater Evaluation,” from the Shattuck RI design report includes a calculation of a so-called “reduction factor” that is used to demonstrate the effectiveness of the design with respect to contaminant concentrations in the groundwater at the downgradient boundary. Essentially, this approach calculates a potential dilution rate rather than a release rate.

A more standard approach to calculating the mass flux of contaminants to the groundwater is recommended. This approach, called the congruent dissolution release model, has been used by several performance assessments (PAs) and environmental impact statements (EISs) involving the disposal of radioactive waste. The congruent dissolution release approach, combined with realistic time-variant estimates of infiltration rates through the cap, is recommended for reassessment of the Shattuck Site. Recent analyses involving the disposal of radioactive waste that have adopted the assumptions associated with congruent contaminant release include the Retrieval Performance Evaluation Methodology for the AX Tank Farm (DOE 1999), Performance Assessment of Grouted Double-Shell Tank Waste Disposal at Hanford (Kincaid et al. 1995), and Tank Waste Remedial System, Hanford Site, Richland Washington, Final Environmental Impact Statement (DOE 1996).

## VIII.C MONOLITH-MONITORING PLAN UPGRADE

Several monitoring wells surround the monolith, and these wells can be used to assess the elevation of the water table relative to the base of the monolith and to make periodic analyses of contaminants of concern.  In a conservative sense, such monitoring may be adequate. Unfortunately, by the time any radionuclides and metals such as molybdenum and arsenic are detected, the chemical stability of the monolith will have been compromised.  That is, there is no forewarning of incipient chemical failure of the monolith.  A more aggressive monitoring plan would be to expand the list of chemical constituents being analyzed to include sodium, potassium, magnesium, silicon, aluminum, and possibly other elements that might serve as a fingerprint for this particular fly-ash-cement-soil mixture.

This review finds that the site monitoring plan is not clear as to what constitutes a significant release from the monolith and what actions are triggered by such releases.   The monolith-monitoring plan states,  "A review of currently available chemical data suggests that the most reliable indicators of contaminant migration from the monolith are likely to be molybdenum and uranium."   A Morrison-Knudsen (MK) sampling report dated May 7, 1999, indicates that MK compared the averages of the contaminant concentrations in the upgradient wells with those in the downgradient wells and concluded that "At a 95% level of statistical confidence, no difference was found in the average concentrations for radium or thorium.  However, average uranium concentrations exhibit a significant difference between upgradient and downgradient wells at the 95 percent level of confidence."

The report also concludes that, in general, molybdenum concentrations in the terrace wells are greater than the ARAR, while concentrations in alluvial wells are at or below the ARAR.  This last conclusion implies that as long as ARARs will be met in the downgradient monitoring wells, no further action is required.   This is exactly why a remedial alternative based solely on dilution becomes so untenable.  It could be argued that since dilution alone was good enough for the remediation of residual levels of contaminants currently in the groundwater, why not rely on it for releases from the monolith itself.  It should be kept in mind that CERCLA statute 121D2B requires that the ARARs (e.g., MCL) be met at the site boundary.

Trigger levels and remedial alternatives should be developed for addressing potential releases from the monolith, and the number of wells and the spacing of the wells should be re-evaluated per comments made regarding the MEMO program in Section VII.

## VIII.D   PLUME-MONITORING PLAN UPGRADE

The ROD specified that one of the objectives of the groundwater monitoring is to monitor the currently existing plume of contamination.  The ROD goes on to indicate that a network of wells will be established to monitor post remediation groundwater quality. We find that the current network of wells is insufficient to define the currently existing plume of contamination. In correspondence with the EPA, the USGS recommends that additional monitoring wells be installed and supplementary constituents be analyzed. The USGS bases its recommendations on a general lack of site characterization data. It finds that the existing information is insufficient to define critical aspects of the contaminant migration, including vertical and horizontal extent of the contaminant plume, temporal trends in the behavior of the plume, presence of preferential pathways, and the effect that the South Platte River has on migration rates and directions.

The two basic objectives of the groundwater monitoring program are to (1) provide sufficient information from which both downgradient concentrations in groundwater can be established and overall mass-loading rates to the river can be estimated, and (2) assess the degree to which contaminants are confined to the monolith and to detect any statistically significant releases prior to contaminants migrating off site.

In augmenting the existing monitoring well network, the USGS recognized the need to identify the plume centerline as well as the transient behavior of the plume. In so doing, the Survey incorporates three cross sections of wells perpendicular to groundwater flow. Clearly, additional data are needed; the question is, how can data needs be balanced against the overall objectives and the practicality of performing long-term monitoring of numerous wells.

In correspondence with the USGS, EPA posed the question of whether geoprobe sampling could be an alternative to several wells in a row and whether it could be used to define the plume and precisely locate monitoring wells, thereby reducing the number of wells. In response to this suggestion, the USGS indicated that data from exploratory drilling would provide only a "snapshot" of the distribution of contaminants, which probably changes over an annual cycle and with year-to-year variations in recharge of precipitation. Although the points the Survey makes are true, there are a number of advantages to collecting hydropunch samples in order to optimize the locations of future monitoring wells. These advantages including the following:

- Concentrations are far more representative of actual pore-water values, as they are not integrated over the entire screened interval
- Hydropunch samples provide a much better three-dimensional view of the plume morphology
- Hydropunch samples facilitate the identification of preferential pathways

As the USGS notes, the concentrations will change with time; however, it is likely that the overall shape of the plume will remain relatively constant.  Therefore, defining the plume reasonably well by hydropunch sampling would facilitate the optimization of the monitoring well placement.

We recommend that a downgradient geoprobe investigation should be conducted in order to establish the general three-dimensional shape of the plume.

Once the morphology of the plume is established, a numerical modeling study should be performed in order to optimize the placement of the monitoring wells.  Factors that need to be considered include plume dispersion, contaminant velocity, nature of the source release (e.g., pulse or continuous), presence of preferential pathways and sampling frequency.  A number of computer programs are designed specifically for this purpose.

Since metals/radionuclide speciation and mobility are very dependent on the presence or absence of oxygen, dissolved oxygen and Eh should be measured in the monitoring wells.

Once the extent of the existing plume is determined, an assessment should be made as to whether a monitoring well should be placed on the other side of the South Platte River.

The presence of dissolved uranium (in some cases in exceedance of the ARARs) and other contaminants in monitoring wells USE 1 through 5 will make it difficult to ascertain whether releases from the monolith have occured..  The problem is further exacerbated by the means outlined in the Monitoring Plan for determining whether a release has occurred.  The MMP directs that statistical comparisons be made to determine whether there are significant differences in chemical concentrations between downgradient and upgradient monitoring wells.  This method could mask releases if concentrations in the upgradient monitoring wells rise with time.

As noted, the high uranium concentrations in the upgradient wells suggests that water quality in these wells may be impacted by wastes still remaining in place (i.e., beneath Bannock Street). Furthermore, at least two mechanisms exist that could lead to a reversal in groundwater gradients and could place the existing background wells directly downgradient from the source.  First, future recharge through the monolith could create a groundwater mound, in which case flow from the monolith would be in a radial direction.  Second, a rise in the water table could intersect the monolith, which would, in turn, act as a hydraulic barrier and potentially reverse the groundwater gradients.

We recommend that a hydropunch investigation be performed to establish background locations. Additional background wells should be installed. Trends should be assessed statistically, not only against the background wells, but also against the downgradient wells through time.

## VIII.E DEVELOPMENT OF A MORE SOPHISTICATED GROUNDWATER AND CONTAMINANT TRANSPORT MODEL TO ASSESS NATURAL ATTENUATION

The Remedial Investigation presents a very simplistic approach to predicting the amount of dilution in groundwater downgradient from the monolith. This type of analysis is more suited to a scoping type exercise than in support of a full blown risk assessment.

The analysis performed with regard to the large dilution rates attributed to the South Platte River and cited in the Remedial Investigation should be presented. However, metals do not always stay in solution and can precipitate as stream sediment. For example, in studies of molybdenum geochemistry in the stream system draining the Climax area of Colorado, Kaback and Runnels (1980) found that the molybdenum was precipitating out of solution. Furthermore, even if molybdenum stays in solution it tends to accumulate in vegetation and if present in excessive amounts can cause problems for grazing animals (Dye and O'Hara, 1959).

We recommend that a numerical model of the groundwater flow system be constructed in order to obtain more reliable estimates of dilution, and groundwater flow rates and directions.

Stream sediment from the South Platte River should be sampled. Contaminant concentrations in additional monitoring wells placed close to the river could be used to select sampling locations and analytes. The actual origin of any contaminants detected may be difficult to establish. However, if contaminants are not detected, it would eliminate the sediment as an exposure route. The potential effects of bioaccumulation of metals in plant and animal tissue needs to be investigated as part of an Ecological and Human Food Chain Risk Assessment.

The contaminant transport model depends on two fundamental sets of data - hydrogeology and water-aquifer chemical reaction (chemistry of attenuation). In the case of the Shattuck site, neither the hydrogeology nor the nature of the chemical reactions within the aquifer has been adequately characterized. Thus, the contaminant transport model is vastly oversimplified and, as such, is a poor basis for eliminating the groundwater exposure path from the risk assessment. The groundwater exposure path cannot be eliminated based on current information about the contaminant plume.

Multiple problems underlie the hydrologic model for the Shattuck site. Uncertainties in the site hydrogeologic and transport model include (1) incomplete knowledge of quality of infiltrating surface water, including any source that might result from monolith leaching; (2) extent of groundwater interaction with Platte River flow system; (3) seasonal changes in surface water - groundwater interactions in the area including the Overland Golf Course holding ponds, (4) lack of any sensitivity analyses on variables including dispersivity, flow rate, hydraulic conductivity; (5) assumption of a homogeneous aquifer with no allowance for channeling; (6) lack of control points in several key areas; (7) poor understanding of bedrock-alluvial hydrologic interactions; (8) no allowance for contaminant attenuation; (9) no evaluation of the effect of a catastrophic hydrologic event (dam failure, 200-year storm etc.) on plume behavior; (10) lack of prediction of effect of groundwater use on hydrology and contaminant plume; and (11) lack of a consistent set of chemical analyses and a manageable data base for monitoring wells.

Only one surface water sample from a runoff catchment basin was analyzed. For this sample, only gamma activity, indicating Ra-226, and/or elevated natural uranium was determined; other constituents, such as metals and organic compounds, were not determined. Thus, the characterization of the surface water quality was incomplete. Exposure risk from surface water cannot be eliminated if the data base for assessing the water quality is so small.

## VIII.F DEVELOPMENT OF SUFFICIENT SITE CHARACTERIZATION DATA TO DEFINE PLUME AND SUPPORT RISK ASSESSMENT

The Remedial Investigations Report shows that 76 soils (combining surface and subsurface) were analyzed, but only 14 of these were analyzed for a set of metals, including Al, Sb, As, Ba, Be, Cd, Ca, Cr, Co, Cu, Fe, Pb, Mg, Mn, Hg, Ni, K, Se, Ag, Na, Th, V, Zn. No tungsten analyses were included (see above). Surprisingly, only one soil was analyzed for molybdenum (Mo), and the balance were analyzed only for As and Se consistently, and Hg, Ag, V, Cr, Cu, Pb, Cd on occasion. It is unclear why As and Se were selected for such detailed analysis, and why molybdenum was ignored given the plant's history of processing molybdenum ore. An inventory of the data presented in the Remedial Investigations Report shows that 55 samples were used to characterize the radioactive materials, 69 samples were used to characterize the distribution of arsenic and selenium, 29 samples were used to characterize a heavy metal suite including Hg, Ag, V, Cr, Cu, Pb, Cd, and one sample was analyzed for molybdenum. Molybdenum was subsequently eliminated as a metal of concern for the soil exposure pathway. Exposure risk from soil exposure cannot be eliminated if the data base for assessing the soil quality is so small.

The derivation of the list of toxic metals in the Baseline Risk Assessment eliminates copper, cadmium, rhenium, and silver. Given that maximum soil copper concentrations are almost 300 times above background and average copper concentrations are 100 times above background, why was copper eliminated from the Risk Assessment?

Inadequate data have been provided to demonstrate that particular metals or organic compounds are originating from the site. Verbal and written reports that the copper and chromium in groundwater originate from other offsite industrial activities cannot be confirmed from current data. Given the admitted gaps in the site's own waste management history, a more specific identification of other potential contributions to the site groundwater degradation should be conducted.

The Construction Completion Report shows that soil quality was monitored by gamma radiation, with samples taken to confirm that Ra-226 was below 15 pCi/g. However, as discussed, monitoring for only a limited suite of metals took place; thus, the data are inadequate for determining both the original extent of non-radioactive metals contamination as well as the post-remediation distribution of metals.

Although in a gross sense it is true that removing radium contaminated soils would also likely remove other metals, this cannot be stated with certainty (nor do the site documents make such a case). Recognize first, metals in the soils probably did not originate from similar sources: ores of molybdenum and uranium, for example, are geochemically completely different. Second, we are not sure to what degree mine-site enrichment occurred for the ores. Assuming that metal waste was deposited onto the soils over an extended period (tens of years) then it is likely that normal geochemical processes, including aging, surface water infiltration, and natural attention will have dispersed the metals through the soil in a chromatographic-like pattern (as a simple analogy). As such, it is a gross oversimplification to consider that the limited monitoring will provide 100 percent certainty that all metals have been removed. An uncertainty remains with respect to the quality of the remaining soil.

Finally, no deep soil samples were analyzed, nor were any samples recovered from below the water table (i.e., soil and aquifer materials from within the contaminant plume). This is a critical piece of information for assessing the potential of the aquifer itself to act as a source by releasing previously adsorbed/precipitated metals back to the water. Achieving the groundwater remediation goal depends on the natural attenuation of contaminants; that is, contaminated water will deposit metals onto the aquifer materials, thereby removing contaminants from the water.

However, the chemical processes involved in attenuation are all reversible, to a greater or lesser extent. Much of the adsorptive capacity of an aquifer is determined by a combination of water pH and Eh and aquifer mineralogy - notably its clay mineral type and content, the presence of organic material, and the presence of iron and manganese hydroxides. If water pH and Eh change, previously adsorbed metals can be released (see technical notes below).

Aquifer mineralogy is unknown beyond simple visual observations, no attempt has been made to determine total metals loading within the aquifer, and no attempt has been made to determine the partitioning of any metals among the different mineral fractions. Without such data, it is premature to eliminate the aquifer as a source during risk assessment and it is premature to assume that the aquifer has the capacity to attenuate all contaminants effectively over a 100-year period.

Attenuation of a contaminant involves multiple processes, including dilution by simple physical mixing and dispersion and removal from the water by several types of chemical reactions, including adsorption, ion-exchange, solid phase precipitation, and co-precipitation. Because of aquifer heterogeneity with respect to organic matter content and proportions of minerals with significant adsorption and ion-exchange capacities, the normal procedure is to determine an empirical attenuation factor or Kd for a given site. To expect attenuation to be a simple process that has a linear dependence on time is a vast oversimplification.

A pro-active approach is recommended; that is, the better our understanding of the complexities of the groundwater-soil aquifer geochemistry, the higher confidence we will be able to place in the natural attenuation remedy and the less vulnerable to unanticipated plume behavior impacts.

## VIII.G CONDUCT RISK ASSESSMENT

The EPA, DOE, DOD, and NRC have developed a multi-agency approach to performing the final radiation survey to prove that the cleanup criteria at radiation sites are met (see the Multi-Agency Radiation Survey and Site Investigation Manual (MARSSIM), NUREG -1575, EPA 402-R-97-016, December 1997).

Also, EPA has developed new cleanup levels for radionuclides in soil for Superfund sites. An August 22, 1997, OSWER Memorandum (OSWER No. 9200.4-18) states that the maximum radiation dose limit for humans at Superfund sites should be 15 mrem/yr effective dose equivalent

(EDE) from all radionuclides and exposure pathways. This limit is based on a site-specific dose assessment and is dependent on the site-specific radionuclides and exposure pathways.

A cursory review of the soil concentrations remaining after cleanup indicates that the site does not meet the new EPA cleanup criteria, and that the doses could be well above acceptable levels.

There were also some changes in MCLs between the time of the risk assessment and the time of the final remedial design. However, these changes were taken into account before the implementation of the final design. Since 1996, the guideline for arsenic has changed, but the change in magnitude was of no consequence to the RA or remedial design.

A current risk assessment would be appropriate given the design life of the remedy (200 to 1,000 yrs), the potential for recreational use near groundwater discharge points along the Platte River, potential future groundwater use, and the potential for additional surface-water use from nearby ponds. However, at present, data are insufficient to support a credible risk assessment. The necessary steps include a better definition of the aquifer, expansion of monitoring data, collecting additional ecological data, reviewing appropriate conceptual models, calculating contaminant concentrations in groundwater, and calculating risk. An updated assessment should include the following:

- An ecological risk assessment
- A residential groundwater user scenario
- A recreational surface water user
- A release from the monolith under conditions that could include fracturing and degradation of the cap

## VIII.H SPECIFIC DESIGN TECHNICAL ISSUES

Relatively recent studies concerning water balance modeling indicate that commonly used water-balance models, such as the HELP model which was used in the design of the cover system, have a tendency to overpredict overland flow and, thus, underpredict percolation through the cover system, particularly in semi-arid or arid sites subject to snow cover and snow melt (e.g., Khire et al. 1997). This overprediction in overland flow has been attributed, in part, to the inability of the models to accurately reflect the thermal conditions in the soil. This finding is of particular concern for the Shattuck site due to the semi-arid nature of the climate and the large snowfalls that often occur in the spring (i.e., March and April). These snowfalls commonly occur over relatively short durations (24-48 hrs), and are followed by a warming period that results in rapid melting (personal observation).  In this case, the ground may not be frozen, resulting in a large pulse of infiltration into the cover system, even though the annual precipitation may be low.

We recommend that a more extensive water-balance analysis be performed to account for the potential snowmelt problem, possibly using two or more models with reference to the cited publication.

Recent comments by Shattuck (Shattuck Response Document, October 15, 1999) define the Shattuck final cover as "Resistant-Armored" and, as such, it is stated that the cover "...acts as a "one-way" valve in that water can get in but cannot be removed by surface runoff or evapotranspiration."  Maximization of both surface runoff and evapotranspiration would result in minimization of infiltration of water into the underlying monolith, and subsequent leaching of potentially harmful chemical constituents, into the underlying groundwater.  Thus, the above stated inability of the cover system to provide for surface runoff or evapotranspiration of water supports the contention that the cover system is inadequate to sustain the long-term performance of the selected remedy.  Furthermore, Shattuck consultants confirm that "All the models require significant tweaking to accurately present armored final covers." and supports the review comment in that a much more site-specific modeling be conducted.

A key component in the overall performance of the cover system is the GCL.  Research has established that GCLs can maintain their integrity throughout a reasonable magnitude of differential settlement, as well as environmental factors such as wet/dry cycles and freeze/thaw cycles.  However, some evidence indicates that divalent (e.g., calcium) for monovalent (e.g. sodium) ion exchange within the bentonite component of the GCL can lead to cracking of the GCL, resulting in poor performance and even failure of the GCL.

For example, James et al. (1997) investigated the cause of leakage through GCLs that were used in a cover system for brick arches to protect water reservoirs.  The exchange complex of the bentonite in the GCL was initially dominated by sodium with a cation exchange capacity (CEC) of 90.2 meq/100 g.  After leakage was observed in the field, tests on exhumed specimens of the GCL indicated that the $Ca^{2+}$ concentrations on the exchange complex increased substantially, whereas $Na^{+}$ concentrations on the exchange complex decreased substantially.  Based on these data and other tests, James et al. (1997) concluded that calcium from the foundation soil and overlying cover soils had migrated into the GCL and displaced the sodium from the exchange complex, which resulted in subsequent shrinkage and cracking of the bentonite.  Similar results also have been reported elsewhere (Aboveground Tank Update 1992, and Dobras and Elzea 1993).

We recommend that specimens of the GCL in the cover system be exhumed and examined for shrinkage and cracking, tested for exchangeable cations and CEC, and tested for hydraulic conductivity. The results of these tests should be compared to the results of the same tests performed on unexposed specimens of the same GCL. Of course, any place where specimens have been exhumed must be retrofitted to a satisfactory condition. As an alternative to exhumation of intact GCL specimens, complete chemical analyses of all of the materials (riprap, sand, gravel, recompacted soil/clay liner, etc.) used in the cover system should be performed to evaluate the potential for an adverse ion-exchange effect on the GCL. As a minimum, these chemical analyses should include, where appropriate, soluble salts, exchangeable cations, CEC, soil pH, and soil electrical conductance. All of these tests should be performed using unexposed materials, since the materials at the site have undoubtedly already been exposed to some washing from precipitation.

Recent comments provided by Shattuck (Shattuck Response Document, October 15, 1999) regarding the potential for cation exchange in the bentonite of the GCL and the subsequent increase in hydraulic conductivity do not address the washing of soluble salts from the overlying gravel and riprap into the underlying clay that may have occurred during the first wetting event after placement of these materials. Also, the theoretical analyses performed to evaluate the potential for cation exchange do not consider any site-specific data regarding chemical concentrations of pore waters, and no mention is made of the potential for cation exchange resulting from the soluble salts in the pore water of the underlying RS/CL (i.e., as opposed to the underlying monolith). Finally, the value of 25 percent for the porosity of the bentonite in the GCL used in the Shattuck Response Document's theoretical analysis may be significantly in error. For example, Petrov and Rowe (1997) present data that indicate the porosity of GCLs can range from 50 to 80 percent depending on hydration and applied stress conditions. The only way to alleviate the concern with respect to the long-term performance of the GCL is to perform tests that use site-specific materials and conditions as recommended.

The review team perceived two major issues related to the performance and integrity of the recompacted soil/clay layer (RS/CL) used in cover system. First, the RS/CL is relatively thin (15 cm). Benson and Daniel (1994) have shown from case histories that the hydraulic conductivity of compacted clay liners decreases as the thickness of the liner increases from 15 cm (6 in) to 90 cm (36 in), with unacceptably high ($> 10^{-7}$ cm/s) hydraulic conductivities for the thinner liners. This effect of thickness on hydraulic conductivity is usually attributed to continuity of cracks resulting from desiccation and lack of proper construction quality control. Second, the hydraulic conductivity of the RS/CL was based on only laboratory tests using small-scale specimens. However, standard practice for evaluating the hydraulic conductivity of compacted clay barriers requires either field hydraulic conductivity tests performed on test pads (Daniel 1990) and/or laboratory tests performed on large-scale specimens ($\geq$ 30 cm) (Benson et al. 1994) recovered from test pads due to the potential effect of scale on the hydraulic conductivity of the compacted clay. Thus, there is concern about the overall integrity of the RS/CL in the cover system.

We recommend that the hydraulic conductivity and the associated performance of the RS/CL component of the cover system be re-evaluated.

Recent Shattuck comments (Shattuck Response Document, October 15, 1999) neglect the importance of the 6-inch RS/CL layer on the overall performance of the cover system. For example, it is stated that the permeability of the 6-inch thick portion of the RS/CL is considered to be "...of secondary value", yet the permeability of this soil was measured in the laboratory, and we assume the measured value was used in the HELP analysis for the water balance calculations. Also, Shattuck data supports the observation that the hydraulic conductivity of 6-inch (15-cm) compacted clay barriers tend to range from about $10^{-6}$ cm/s to as high as about $10^{-4}$ cm/s, depending on the quality of construction. Thus, the actual field hydraulic conductivity for the 6-inch RS/CL layer may be as much as 10 to 1000 times higher than previously assumed on the basis of the laboratory measured hydraulic conductivity values. Also, the 6-inch RS/CL layer is subjected to a greater potential for infiltration and subsequent leaching of underlying contaminants since the 6-inch layer is on a flatter slope and covers a greater surface area. Thus, prudence dictates that the primary focus of the evaluation be placed on the 6-inch thick RS/CL, not the thicker and steeper side slopes, particularly with respect to the long-term (200+ years) performance of the selected remedy.

Last, given the magnitude of the project and the potential for detrimental environmental consequences resulting from cracking of the monolith over the design life of 200 years, the Review Team recommends that a system of settlement markers be installed to monitor the actual settlement of the monolith.

## IX. Protectiveness Statement(s)

Clearly, the site remedy has significantly improved the overall protectiveness of human health and the environment over the short term. However, there are technical findings that raise doubt about the long-term effectiveness and permanency of the site remedy and the concomitant ability of the site to meet the optimization and institutional control requirements inherent within the remedy.

The review finds that the offsite impact of the degraded groundwater plume has not been covered by any formal institutional control. Shattuck does not consider itself responsible for ensuring offsite land use, and the state/city governments have not provided definitive assurances of institutional controls for the life of the remedy specified in the ROD (200 years).

Also, the review finds that the public's goals were not adequately assessed and reflected in the ROD and the remedy. While some of the stakeholders may be comfortable with long-term restrictions and diminishment of resource usage, the community does not share this sentiment, and the community's views deserve attention.

We recommend re-evaluating the site remediation concept to ensure that community land-use goals are understood and protected. The re-evaluation should be supported by more rigorous performance assessment modeling relative to monolith integrity over the long term. We also recommend that the groundwater pathway be considered a viable pathway and that a risk assessment be completed accordingly to allow for accurate assessment and evaluation of the overall site remediation strategy. This will require a sufficient database of site characterization information (hydrogeology, ecology, soil and groundwater samples, etc.).

## X. Next Review

This Five-Year Review recommends that the remedy be re-evaluated and that additional response actions be considered. Based on the information available, the review finds that it is unclear whether the remedy will meet cleanup levels for contaminants of concern within the specified 100-year period identified as the maximum allotted time for material flushing to achieve clean-up criteria. Thus, the reviewers believe that the remedy must be re-evaluated because the plume and its impact on the groundwater and surface pathways have not been sufficiently addressed.

This report documents findings of inadequacies and inefficiencies in current site operations and design presentations. In particular, it identifies deficiencies that currently prevent the remedy from being considered protective in the future. These deficiencies include changes needed to ensure the proper management of the remedy. They are documented in Section VII, indicating which need to be corrected to achieve protectiveness.

Based on these findings, it is recommended that after additional data become available that address the issues raised in this review, another review be conducted.

# XI.  References

The references cited in the text are given in Appendix A.

# APPENDIX A

# EXPERT PANEL REVIEW

# APPENDIX B

# SCOPING ANALYSIS REPORT ON SITE RISKS