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APR 27 2000

Thomas H. Essig, Chief
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U.S. Nuclear Regulatory Commission
Mail Stop T7J8
Washington, D.C. 20555-0001

Subject: Revised *Long-Term Surveillance Plan for the U. S. Department of Energy Burrell Vicinity Property, Blairsville, Pennsylvania*

Dear Mr. Essig:

Three copies of the revised *Long-Term Surveillance Plan (LTSP) for the U. S. Department of Energy Burrell Vicinity Property, Blairsville, Pennsylvania,* document are enclosed for NRC review. Also enclosed for NRC review are three copies of the document entitled *Plant Encroachment on the Burrell, Pennsylvania, Disposal Cell: Evaluation of Long-Term Performance and Risk.* This companion document forms the basis for the Department of Energy's position for discontinuing vegetation control measures on the surface of the Burrell disposal cell, as presented in the revised LTSP.

Also, please note that the ground water monitoring commitments have been scaled back based on the monitoring results to date.

If NRC has questions about these documents, please contact me at 970/248-6037.

Sincerely,

Russel Edge

Russel Edge
LTSM Program Manager

Enclosures

cc w/o enclosures:
B. Young, DOE-GJO
M. Plessinger, MACTEC-ERS
Project File LBUR 1.1 (H. Salter)

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Long-Term Surveillance and Maintenance Program

# Long-Term Surveillance Plan

for the

**U.S. Department of Energy**
**Burrell Vicinity Property**
**Blairsville, Pennsylvania**

April 2000 Revised

This document supersedes document number
UMTRA-DOE/AL/62350-3F Ver.2, Rev.2

Prepared by
U.S. Department of Energy
Grand Junction Office
Grand Junction, Colorado

Work Performed Under DOE Contract Number DE-AC13-96GJ87335
Task Order Number MAC 00-06
Document Number S00350

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# 1.0 Introduction

## 1.1 Purpose

This Long-Term Surveillance Plan (LTSP) explains how the U.S. Department of Energy (DOE) will fulfill general license requirements of Title 10 *U.S. Code of Federal Regulations* (CFR) Part 40.27 as the long-term custodian of the Burrell vicinity property near Blairsville, Pennsylvania.

## 1.2 Legal and Regulatory Requirements

The Uranium Mill Tailings Radiation Control Act (UMTRCA) of 1978 (42 USC § 7901) as amended, provides for the remediation (or reclamation) and regulation of uranium mill tailings at two categories of mill tailings sites, Title I and Title II. Title I covers former uranium mill sites that were unlicensed, as of January 1, 1978, and essentially abandoned. Title II covers uranium milling sites under specific license as of January 1, 1978. In both cases, the licensing agency is the U.S. Nuclear Regulatory Commission (NRC), or in the case of certain Title II disposal sites, an Agreement State.

The Burrell vicinity property falls under Title I of UMTRCA. Licensing of the Burrell vicinity property site represents a departure from UMTRCA, which requires the licensing only of disposal sites, not vicinity properties. However, given the unusually large volume of waste and the distance from the Canonsburg Title I disposal cell (see Section 2.1) to the Burrell vicinity property, the DOE and the NRC have agreed that a license for a designed disposal cell with surveillance requirements constituted a reasonable and prudent approach in keeping with the spirit of UMTRCA.

Federal regulations at 10 CFR 40.27 provide for the licensing, custody, and long-term care of residual radioactive material disposal sites closed (remediated) under Title I of UMTRCA.

A general license is issued by the NRC for the custody and long-term care, including monitoring, maintenance, and emergency measures necessary to ensure that uranium mill tailings disposal sites will be cared for in such a manner as to protect the public health, safety, and the environment after closure (completion of remediation activities).

The general (long-term custody) license became effective when the previous revision of the site-specific LTSP was accepted by the NRC.

Requirements for the content of the LTSP and general requirements for the long-term custody of the Burrell vicinity property are addressed in various sections of the LTSP (Table 1-1). These requirements are defined in 10 CFR 40.27 and Appendix A of 10 CFR 40.

The plans, procedures, and specifications discussed herein are based upon the *Guidance for Implementing the Long-term Surveillance Program for UMTRCA Title I and Title II Disposal Sites* (Guidance Document) (DOE 2000). The rationale and procedures of the Guidance Document should be considered part of this plan.

*Table 1-1. Content Requirements of the LTSP and for the Long-Term Custodian (DOE) of the Burrell Site*

| **Content Requirements of LTSP** | | |
|---|---|---|
| | *Requirement* | *Location* |
| 1. | Description of final site conditions | Section 2.0 |
| 2. | Legal description of site | Appendix A |
| 3. | Description of the long-term surveillance program | Section 3.0 |
| 4. | Criteria for follow-up inspections | Section 3.5.1 |
| 5. | Criteria for maintenance and emergency measures | Section 3.6.3 |
| **Requirements for the Long-Term Custodian (DOE)** | | |
| | *Requirement* | *Location* |
| 1. | Notification to NRC of changes to the LTSP | Section 3.1 |
| 2. | NRC permanent right-of-entry | Section 3.1 |
| 3. | Notification to NRC of significant construction, actions, or repairs at the site. | Section 3.5 and 3.6 |

## 1.3 Role of the Department of Energy

In 1988, the DOE designated the Grand Junction Office (GJO) to be the program office for long-term surveillance and maintenance of all DOE remedial action project disposal sites, as well as other sites as assigned, and to establish a common office for the security, surveillance, monitoring, and maintenance of these sites. The DOE established the Long-Term Surveillance and Maintenance (LTSM) Program at the GJO to carry out this responsibility.

The LTSM Program is responsible for the preparation, revision, and implementation of this LTSP, which includes site inspection, monitoring, and maintenance. The LTSM Program is responsible for annual and other reporting requirements and for maintaining records pertaining to the site.

# 2.0 Final Site Conditions

## 2.1 Site History

The Burrell vicinity property site was operated as a railroad landfill from the late 1940s through the late 1960s. In the late 1940s, the Pennsylvania Railroad constructed a berm along the bank of the Conemaugh River and began landfill operations. The landfill was believed to be used for typical railroad wastes, such as railroad ties, cinders, and excess coal (Ford, Bacon & Davis, Inc. 1979a and 1979b). From October 1956 to January 1957, 11,600 tons of residual radioactive material (RRM) were shipped from the Vitro Rare Metals Plant in Canonsburg, Pennsylvania to the Burrell site. The Vitro Rare Metals Plant eventually became the Canonsburg UMTRCA Title I site hence the identification of the Burrell site as a vicinity property. The RRM was later excavated and placed in the Burrell vicinity property disposal cell as part of the site remedial action under UMTRCA in 1986 and 1987. The disposal cell was closed in July 1987.

## 2.2 Site Area Description

The Burrell vicinity property is located approximately 40 miles east of Pittsburgh, 1 mile east of the Borough of Blairsville, Indiana County, in southwestern Pennsylvania (Figure 2-1). The Burrell vicinity property is bordered on the south by the Conemaugh River and on the north by the Norfolk Southern Rail Corporation railroad tracks.

The Burrell site is a plateau formed by landfilling. Excavation and landfill operations have disturbed soils at the site. Fill material exists to depths of 50 to 60 feet. The fill consists of gravelly loam and sandy loam mixed with ashes, cinders, gravel, railroad ties, bricks, boards, and sandstone fragments (DOE 1983).

The Burrell site is located in the humid continental climatic region. A succession of low- and high-pressure centers and fronts that migrate through the area during the year dominate the regional climate. The average annual precipitation of 44.4 inches is fairly evenly distributed throughout the year. The summers are generally mild but frequently humid. The winter months can be described as brisk with occasional periods of extreme cold (DOE 1983).

The Burrell vicinity property covers approximately 72 acres. Disposal of the 11,600 tons of RRM removed from the Canonsburg site took place in the western portion of the Burrell vicinity property. The RRM was brought in as fill by the railroad. Excess RRM was placed in a storage location adjacent to the Conemaugh River at Burrell, and this was later added to the disposal area. The disposal area contains a total of 86,000 tons of RRM. Immediately north of the railroad tracks adjacent to the disposal site, an unofficial open dumping area exists.

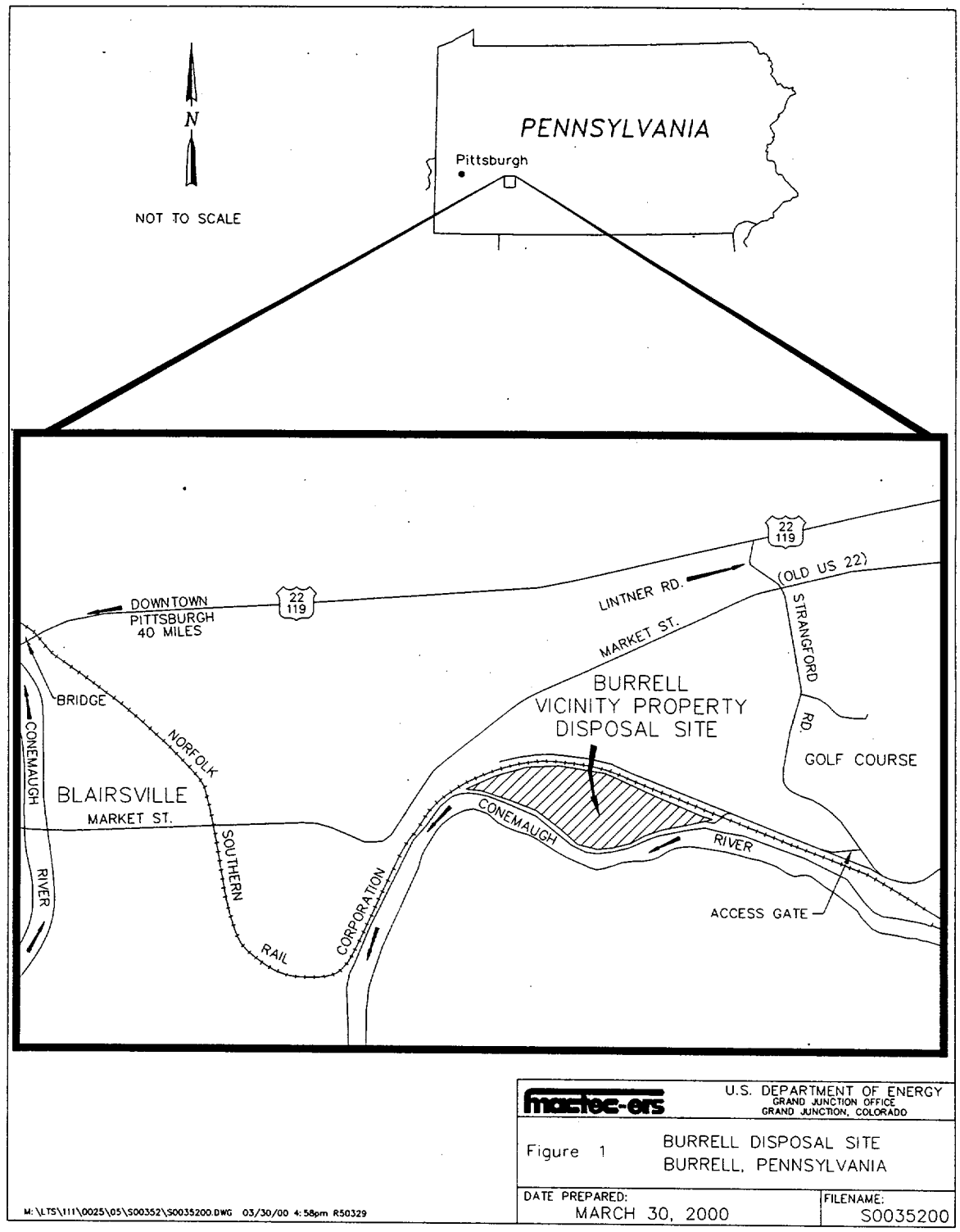


*Figure 2-1. Location of Burrell, Pennsylvania, Vicinity Property Disposal Site*

## 2.3 Disposal Site Description

### 2.3.1 Site Ownership

The Burrell site was acquired by the U.S. Federal Government July 14, 1986 (see Appendix A). Title to the site property, Tract 201 (CA-200), was acquired in fee simple through condemnation proceedings, subject to existing easements for public roads and highways, public utilities, railroads, and pipelines. A perpetual and assignable easement and right-of-way in, on, over, and across Tract 201 E was acquired from the Railroad, subject to existing easement for public roads and highways, public utilities, railroads, and pipelines (Appendix A, Figure A-1). The DOE makes an annual payment of $800.00 to the Railroad for grade crossing privileges.

### 2.3.2 Directions to the Disposal Site

The Burrell vicinity property disposal site can be accessed as follows:

| Mileage | Route |
|---|---|
| 0.0 | East end of U.S. Highway 22 and 119 bridge over the Conemaugh River, proceed eastward. |
| 0.2 | Pass exit to Blairsville, continue travelling eastward. |
| 2.1 | Turn right (south) on Lintner Road. |
| 2.3 | Intersection of Market Street (old U.S. Highway 22) and Strangford Road (to south). Cross Market Street and proceed south and southeast on Strangford Road. |
| 3.2 | Turn right onto site access road. Follow access road across railroad tracks to site entrance gate. |

### 2.3.3 Description of Surface Conditions

Most of the eastern half of the 72-acre site property is grass-covered with small clusters of woody growth. Most of the western half of the site property is wooded, with the exception of the disposal cell itself. The disposal cell is covered with riprap and resides in the northwest "quarter" of the vicinity property. The surface area of the disposal cell is approximately 5 acres. Surrounding the disposal site property is a chain-link fence. Its locked gates provide both vehicle and pedestrian access for authorized persons.

### 2.3.4 Specific Site Surveillance Features

**Survey Monuments**

Three permanent survey monuments were established at the Burrell vicinity property at the locations within the fenced area shown in Plate 1. The monuments were referenced to the nearest U.S. Geological Survey (USGS) or National Geodetic Survey (NGS) control networks by using second-order standards.

The Berntsen Federal iron pin survey monuments are set in concrete. Additional details regarding survey monument construction and installation are provided in the Guidance Document.

**Boundary Monuments**

Seven boundary monuments were placed as shown on Plate 1. The final locations of the boundary monuments were established to second-order standards and linked to the survey monument system. Additional details regarding boundary monument construction and installation are provided in the Guidance Document.

**Site Marker**

The Burrell vicinity property also has one granite site marker that identifies the vicinity property (Burrell, Pennsylvania), indicates the general location of the tailings on the vicinity property (boundary and cell), and shows the date of closure (July 2, 1987), the quantity of tailings (86,000 wet tons) in the disposal area, and the activity of the tailings (4 curies radium-226 [Ra-226]). The site marker was placed at the entrance to the vicinity property inside the fence (see Plate 1).

The site marker was set in a bed of reinforced concrete, extending 12 inches below frost line (approximately 48 inches below grade). The elevation and position of the site marker was determined by a survey of the same precision used in establishing the survey monuments. Additional details regarding site marker construction and installation are provided in the Guidance Document.

**Signs**

Signs displaying the international trefoil symbol that indicates the presence of radioactive materials are attached to the outside of the fence at 500-foot intervals around the perimeter of the vicinity property, starting at the site entrance. The signs indicate that the site is Government property, that it contains uranium mill tailings, and that trespassing is forbidden. A special entrance sign provides the name (DOE) and telephone number (970/248-6070) of the responsible agency. The signs are metal (similar to highway signs). Additional details regarding signs are provided in the Guidance Document.

**Erosion Control Markers**

Due to the proximity of the vicinity property to the Conemaugh River, four sets of erosion control markers were installed: two sets adjacent to the ditch outlet to the river near the southeastern boundary, and two sets at the outfall of the west ditch where it enters the Conemaugh River (Plate 1). If an erosion control marker is removed by high water in the Conemaugh River or by runoff from the disposal cell, the DOE will be alerted to the potential need to exercise mitigative measures in order to protect the integrity of the disposal site.

Berntsen A-1 monuments were used for erosion control markers. Each monument is 5 feet long and was placed 1 foot below frost line, leaving 1 foot exposed above the surface.

### Displacement Monuments

Twenty displacement monuments were installed on the disposal cell during the remedial action to monitor possible differential settlement. The displacement monuments were installed prior to placement of bedding and riprap, where possible, and settlement observations (i.e., surveys to second-order standards) were made weekly until construction was completed. The final locations of the displacement monuments were determined by a survey of the same precision used in establishing the site survey monuments. Maximum settlement measured did not exceed 1 inch and maximum lateral displacements did not exceed 0.7 inch. Analysis of the data indicates that movements were small and compared closely with the limit of the settlement estimates.

It was concluded that future movements will be insignificant and that sagging of the embankment, which could have led to concentration of storm runoff, will not occur. Therefore, continued monitoring of these displacement monuments is no longer required. Displacement monument monitoring settlement plots were originally presented in the *Burrell Vicinity Property Completion Report* (DOE 1988). The displacement monuments still exist on the disposal cell as an artifact of site construction.

### 2.3.5 Site Hydrogeology

The Burrell site is underlain by up to 50 feet of unconsolidated fill and alluvium that overlies claystones and shales of the Pennsylvanian Casselman Formation. Ground water occurring beneath the site is unconfined in the unconsolidated material, and confined by approximately 30 to 40 feet of claystone and shale in the underlying bedrock. Depth to ground water in the unconsolidated material is in excess of 30 feet beneath the land surface. The unconsolidated materials are recharged by direct infiltration of precipitation, and by ground-water flow. Ground-water flow in the unconsolidated material at the site is to the southwest and ground water discharges to the Conemaugh River just south of the site. The predominant ground-water flow direction in the bedrock aquifer is to the south. Ground-water levels appear to vary seasonally, with higher levels occurring in the winter and lower levels occurring in the summer. Seasonal variations range up to 4 feet in the unconsolidated material and up to 3 feet in the shallow bedrock.

## 2.4 Disposal Cell Design

The Burrell disposal cell occupies about 5 acres of the 72-acre site. Contaminated materials are covered by a low-permeability layer of compacted clay, a bedding layer, and a protective rock cover (see Figure 2-2). The clay layer is designed to prevent the escape of radon gas and the infiltration of precipitation. The free-draining bedding layer overlies the clay layer. Precipitation runs down the sloped cell top through the bedding layer and into surrounding rock drains. The cell design promotes runoff of precipitation to minimize infiltration. The surrounding area was graded to promote drainage away from the disposal cell and was vegetated with native species to prevent erosion. The rock cover protects the disposal cell surface against erosion. A security fence to prevent unauthorized access encloses the site.

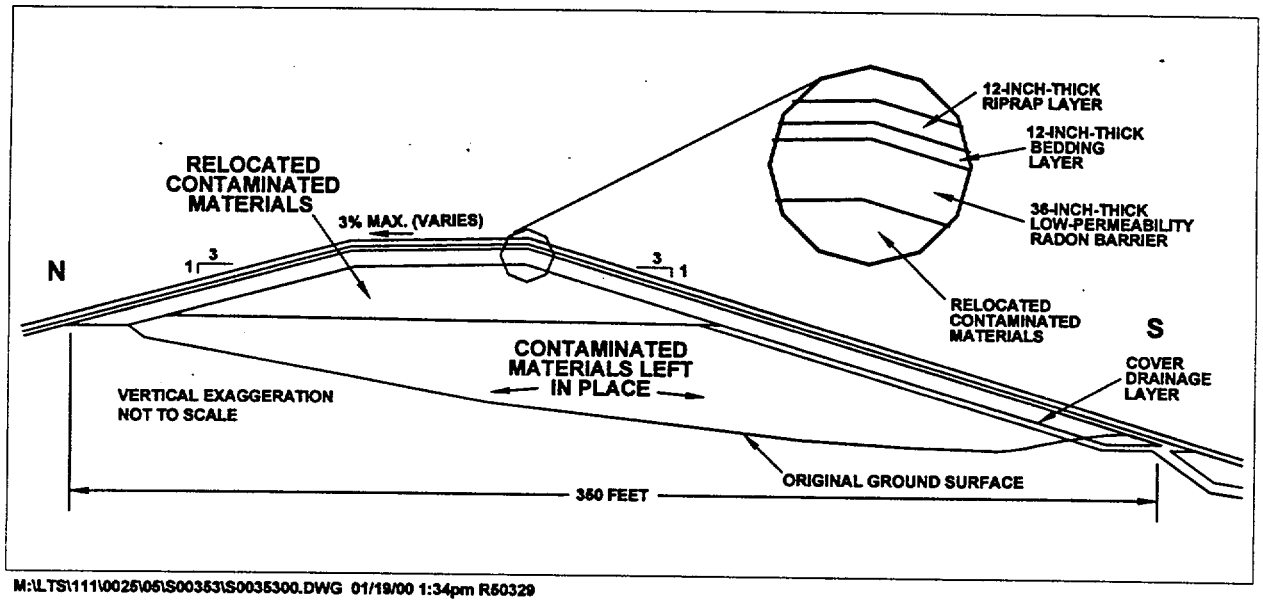


*Figure 2-2. North-South Cross Section of Burrell Vicinity Property Disposal Site*

## 2.5 Ground-Water Conditions

DOE has monitored ground water at the Burrell site since it was completed in 1987. The purpose of monitoring during this period was to demonstrate the *initial* performance of the disposal cell. During this period (1987 through 1998), no contaminant of concern (COC), except lead, exceeded its respective maximum concentration level (MCL) at any well or surface sampling location. (Lead was detected above its MCL in some wells in June 1987, when first sampled. These values were anomalously high compared to subsequent results for lead, all of which have been below the MCL.)

Molybdenum concentrations decreased slightly during the period and uranium concentrations remained essentially the same. Other COCs were present in such small concentrations that they were below laboratory detection limits. The presence of these COCs is attributed to pre-existing contamination from uncontrolled disposal of contaminated materials that occurred in 1956 and 1957. The uncontrolled disposal of contaminated materials predates construction of the Burrell disposal cell.

Ground-water level data also extend back to 1987. Since then, ground-water levels have remained relatively constant at all monitor well locations. The constancy of ground-water levels suggests that ground-water mounding within (or under) the cell, that might indicate that precipitation is flowing through the cell, is not occurring. Equally, there is no evidence of mounding from construction water and subsequent dissipation of this water from within the cell.

# 3.0 Long-Term Surveillance Program

## 3.1 General License for Long-Term Custody

With the NRC acceptance of the previous revision of the LTSP (DOE 1993), the site was included under the NRC's general license for long-term custody (10 CFR 40.27 [b]).

Although sites are designed to last "for up to 1,000 years, to the extent reasonably achievable, and, in any case, for at least 200 years [40 CFR 192, Subpart A, ' 192.02 (a)]," there is no termination of the general license for the DOE's long-term custody of the site (10 CFR 40.27 [b]).

Should changes to this LTSP be necessary, the NRC must be notified of the changes, and the changes may not conflict with the requirements of the general license. Additionally, representatives of the NRC must be guaranteed permanent right-of-entry for the purpose of periodic site inspections. To assure permanent access to the Burrell vicinity property, DOE purchased an access easement from the adjacent property owner (included in Appendix A). The DOE also has obtained a *License Agreement for Private Grade Crossing* from the railroad that provides the legal railroad crossing necessary for site access. A copy of this agreement is also included in Appendix A.

## 3.2 Requirements of the General License

To meet the requirements of the NRC's license at 10 CFR 40, Section 27, and Appendix A Criterion 12, the long-term custodian must, at a minimum, fulfill the following requirements. The section in the LTSP in which each requirement is addressed is given in parentheses.

1. Annual site inspection. (Section 3.3)

2. Annual inspection report. (Section 3.4)

3. Follow-up inspections and inspection reports, as necessary. (Section 3.5)

4. Site maintenance, as necessary. (Section 3.6)

5. Emergency measures in the event of catastrophe. (Section 3.6)

6. Environmental monitoring, if required. (Section 3.7)

## 3.3 Annual Site Inspections

### 3.3.1 Frequency of Inspections

At a minimum, sites must be inspected annually to confirm the integrity of visible features at the site and to determine the need, if any, for maintenance, additional inspections, or monitoring (10 CFR 40, Appendix A, Criterion 12).

To meet this requirement, the DOE will inspect the Burrell vicinity property once each calendar year. The date of the inspection may vary from year to year, but the DOE will endeavor to inspect the site approximately once every 12 months unless circumstances warrant variance. The variance will be explained in the inspection report. At least 30 days in advance of the scheduled inspection date, the DOE will notify the NRC of the inspection schedule.

### 3.3.2 Inspection Procedure

For the purposes of inspection, the Burrell vicinity property will be divided into areas, called *transects*. Each transect will be individually inspected. Transects for the inspection of the Burrell vicinity property are listed in Table 3-1 and shown on Figure 3-1. General inspection procedures can be found in the Guidance Document.

*Table 3-1. Transects Used During Inspection of the Burrell Site*

| Transect | Description |
|---|---|
| Disposal Cell | Surface of disposal cell. |
| Area Adjacent to Disposal Cell | Drainage channels and erosion protection features. |
| Site Perimeter | Site perimeter fencing, boundary monuments, warning signs, site marker. |
| Outlying Area | Area within 0.25 mile of site boundary, access easement, railroad crossing. |

Annual inspections will be a visual walk-over. The primary purpose of the inspection will be to look for evidence of cover subsidence, erosion, structural discontinuity, maintenance of vegetation, and animal or human intrusions that could result in adverse impacts.

In addition to inspection of the site itself, inspectors will note changes and developments in the area surrounding the site. Significant changes within this area could include development or expansion of human habitation, erosion, road building, or other change in land use.

It may be necessary to document certain observations with photographs. Such observations may be evidence of vandalism or a slow modifying process that should be monitored more closely during general site inspections. A sample Field Photograph Log is included in Appendix B.

### 3.3.3 Inspection Checklist

The inspection is guided by the inspection checklist. A sample site-specific inspection checklist for the Burrell vicinity property site is presented in Appendix C.

Included in the inspection checklist is a discussion on the preparation for the inspection, health and safety concerns, and the performance of the inspection itself.

The checklist is subject to revision. At the conclusion of an annual site inspection, inspectors will revise the checklist, if necessary, in anticipation of the next annual site inspection. Revisions to the checklist will include such items as new discoveries or changes in site conditions that must be inspected and evaluated during the next annual inspection. Other revisions may include updating telephone numbers and directions to local medical facilities as part of the health and safety precautions noted in the checklist.

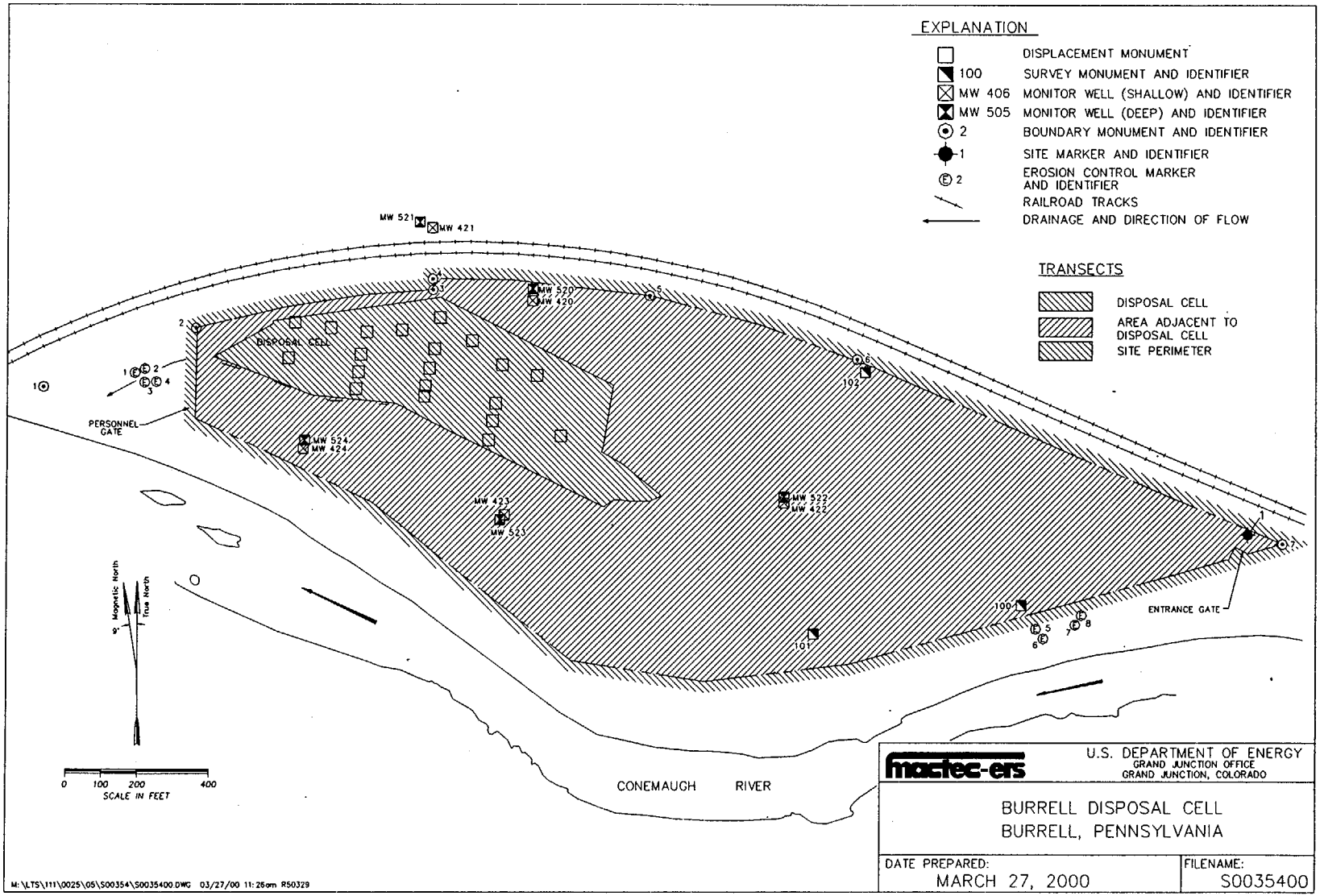


*Figure 3-1. Map of Inspection Transects for Burrell Vicinity Property Disposal Site*

### 3.3.4 Personnel

Annual inspections will typically be performed by a minimum of two inspectors. Inspectors will be experienced engineers or scientists who have been specifically trained for the purpose through participation in previous site inspections.

Engineers will typically be civil, geotechnical, or geological engineers. Scientists will include geologists, hydrologists, biologists, and environmental scientists representing various fields (e.g., ecology, soils, range management). If serious or unique problems develop at the site, additional inspectors, specialized in specific fields, may be assigned to the inspection.

## 3.4 Annual Inspection Reports

Results of annual site inspections will be reported to the NRC within 90 days of the last site inspection of that calendar year (10 CFR 40, Appendix A, Criterion 12). In the event that the annual report cannot be submitted within 90 days, the DOE will notify the NRC.

## 3.5 Follow-up Inspections

Follow-up inspections are unscheduled inspections that may be required (1) as a result of discoveries made during a previous annual site inspection, or (2) as a result of changed site conditions reported by a citizen or outside agency.

### 3.5.1 Criteria

Criteria necessitating follow-up inspections are required by 10 CFR 40.27 (b)(4). The DOE will conduct follow-up inspections should the following occur.

1. A condition is identified during the annual site inspection or other site visit that requires personnel, perhaps personnel with specific expertise, to return to the site to evaluate the condition.

2. The DOE is notified by a citizen or outside agency that conditions at the site are substantially changed.

Once a condition or concern is identified at the site, the DOE will evaluate the information and, on the basis of this evaluation, will decide whether or not to respond with a follow-up inspection. Conditions that may require a routine follow-up inspection include changes in vegetation, compromised slope stability, new or increased erosion, evidence of casual or low-impact human intrusion, minor vandalism, or the need to revisit the site to evaluate, define, or perform maintenance tasks. Conditions that may require a more immediate (nonroutine) follow-up inspection include extreme weather or seismic events and deliberate human intrusion that threatens the integrity of the disposal cell.

The DOE will act responsibly and will exercise flexibility by using a graded approach in scheduling routine follow-up inspections. Urgency of the follow-up inspection will be in proportion to the seriousness of the condition. For example, a follow-up inspection to investigate a vegetation problem may be scheduled for a particular time of year when growing conditions

are optimum. A routine follow-up inspection to perform maintenance or to evaluate an erosion problem might be scheduled to avoid snow cover or frozen ground.

In the event of "unusual damage or disruption" (10 CFR 40, Appendix A, Criterion 12) that threatens or compromises site safety, security, or integrity, including the unlikelihood of an actual breach in cover materials, the DOE will notify the NRC, begin the DOE occurrence notification process (DOE Order 232.1), respond with an immediate follow-up inspection, and begin emergency measures (Section 3.6) to contain or prevent dispersion of radioactive materials from the disposal cell. At any time, the DOE may request the assistance of local authorities to confirm the seriousness of a condition at the site before scheduling a follow-up inspection or initiating other appropriate action.

The DOE establishes liaison with other government agencies that will notify DOE in the event of human intrusion or unusual-to-catastrophic natural events in the vicinity of the site. Notification agreements have been established with the Indiana County Emergency Management Office, the Indiana, Pennsylvania State Police, and the U.S. Geological Survey National Earthquake Information Center in Denver, Colorado. Agency notification agreements are included in Appendix D. These agencies will contact the DOE, or will provide information upon request, should an event occur that might affect the security or integrity of the Burrell vicinity property. Information regarding severe weather events will be obtained via the Internet.

In addition, the warning signs installed at the site display a 24-hour DOE telephone number. The public may use this number to request information about the site or to advise the DOE of problems at the site. The DOE may conduct follow-up inspections in response to information provided by the public.

### 3.5.2 Personnel

Inspectors assigned to follow-up inspections will be selected on the same basis as for the annual site inspection. (See Section 3.3.4.)

### 3.5.3 Reports of Follow-up Inspections

Results of routine follow-up inspections will be included in the next annual inspection report (Section 3.4). Separate reports will not be prepared unless the DOE determines that it is advisable to notify the NRC or other outside agency of a problem at the site.

If follow-up inspections are required for more serious or emergency reasons, the DOE will submit to the NRC a preliminary report of the follow-up inspection within the required 60 days (10 CFR 40, Appendix A, Criterion 12).

## 3.6 Routine Site Maintenance and Emergency Measures

### 3.6.1 Routine Site Maintenance

UMTRCA disposal sites are designed and constructed so that "ongoing active maintenance is not necessary to preserve isolation" of radioactive material (10 CFR 40, Appendix A, Criterion 12).

The disposal cell has been designed and constructed to minimize the need for routine maintenance.

If inspection of the disposal cell reveals degradation of the as-built condition, then repairs will be conducted to reestablish the as-built condition. The DOE will perform routine site maintenance, where and when needed based on best management practices. Reports of routine site maintenance will be summarized in the annual site inspection report.

Vegetation control is no longer required at this site. Screening-level risk assessment by the DOE in 1996 through 1998 determined that plant succession on the disposal cell does not present significant or credible risk to human health or the environment and may, by evapotranspiration, improve the long-term performance of the disposal cell (DOE 1999).

### 3.6.2 Emergency Measures

Emergency measures are the actions that the DOE will take in response to "unusual damage or disruption" that threaten or compromise site safety, security, or integrity. The DOE will contain or prevent dispersal of radioactive materials in the unlikely event of a breach in cover materials.

### 3.6.3 Criteria for Routine Site Maintenance and Emergency Measures

Conceptually, there is a continuum in the progression from minor routine maintenance to large-scale reconstruction of the disposal cell following an unlikely disaster. Criteria, although required by 10 CFR 40.27 (b)(5) for triggering particular DOE responses for each progressively more serious level of intervention, are not easily defined because the nature and scale of all potential problems cannot be foreseen. The information in Table 3-2 will, however, serve as a guide for appropriate DOE responses. The table shows that the difference between routine maintenance and emergency responses is primarily one of urgency and degree of threat or risk. The DOE's priority (urgency) in column 1 of Table 3-2 bears an inverse relationship with the DOE's estimate of probability. The highest priority response is also believed to be the least likely to occur.

### 3.6.4 Reporting Maintenance and Emergency Measures

Routine maintenance completed during the previous 12 months will be summarized in the annual inspection report.

In accordance with 10 CFR 40.60, the DOE will notify:

Uranium Recovery and Low-Level Waste Branch
Division of Waste Management
Office of Nuclear Material Safety and Safeguards
U.S. Nuclear Regulatory Commission

within 4 hours of discovery of any Priority 1 or 2 event in Table 3-2. The phone number for the required 4-hour contact to the NRC Operations Center is (301) 816-5100.

*Table 3-2. DOE Criteria for Maintenance and Emergency Measures*[a]

| Priority | Description | Example | Response |
|---|---|---|---|
| 1 | Breach of disposal cell with dispersal of radioactive material. | Failure of containment dam. | Notify NRC. Immediate follow-up inspection by DOE emergency response team. Emergency actions to prevent further dispersal, recover radioactive materials, and repair breach. |
| 2 | Breach without dispersal of radioactive material. | Partial or threatened exposure of radioactive materials. | Notify NRC. Immediate follow-up inspection by DOE emergency response team. Emergency actions to repair the breach. |
| 3 | Breach of site security. | Human intrusion, vandalism. | Restore security; urgency based on assessment of risk. |
| 4 | Maintenance of specific site surveillance features. | Deterioration of signs, markers. | Repair at first opportunity. |
| 5 | Minor erosion or undesirable changes in vegetation. | Erosion not immediately affecting disposal cell, invasion of undesirable plant species. | Evaluate, assess impact, respond as appropriate to eliminate problem. |

[a] Other changes or conditions will be evaluated and treated similarly on the basis of perceived risk.

## 3.7 Environmental Monitoring

### 3.7.1 Ground-Water Monitoring

DOE monitors ground water at this site as a best management practice to evaluate the initial performance of the disposal cell. Natural background ground-water conditions and DOE's initial post-remediation monitoring program are described in the previous revision of the LTSP (DOE 1993).

Initial post-remediation monitoring included annual water-level measurements and sampling at 10 monitor wells and 2 seeps for standard water-quality indicators and 20 analytes. Eight of these analytes have an MCL at 40 CFR 192, Subpart A and 60 FR 2866, Table 1: gross alpha, lead, molybdenum, radium-226 and radium-228, nitrate, selenium, and uranium.

Of these eight analytes, nitrate and the two radium isotopes have never exceeded their respective MCLs since the disposal cell was completed in 1987. Gross alpha, lead, molybdenum, selenium, and uranium exceeded their respective MCLs occasionally during early monitoring (1987 to 1992). Since then, all eight analytes have been well below their respective MCLs, and most occur at concentrations below laboratory detection limits.

Since there is no indication in the monitoring results to date that seepage from the disposal cell occurs or that it degrades ground-water quality relative to background (contaminant levels that existed in ground water prior to cell construction), the initial performance of the disposal cell is demonstrated: The disposal cell is performing as an effective containment system. DOE will, however, continue the best management practice of monitoring ground water at appropriate intervals with a reduced analyte list, and at one background/upgradient location rather than two.

## Sampling Locations

The ground-water monitoring network will continue to consist of 8 wells (in 4 pairs) and 2 seeps (Table 3-3). Locations of the wells and seeps are indicated on Plate 1.

Each pair of wells consists of a shallow well, completed in unconsolidated fill and alluvium (400-series wells); and a deeper well, completed in the shallow bedrock of the Casselman Formation (500-series wells).

Two seeps at the bottom of the south side slope of the disposal cell are also sampled whenever they yield sufficient water. Sometimes the seeps can not be sampled because they are dry. Flow from these seeps responds to and may be wholly dependent on recent precipitation. Location and number of seeps may vary from year to year. Field personnel sample the two seeps with the freest flows.

*Table 3-3. Ground-Water Monitoring Locations, Burrell Site, Pennsylvania*

| Monitor Wells | Location |
|---|---|
| MW-420 & MW-520 | Upgradient, or background wells |
| MW-422 & MW-522 | Crossgradient, point-of-compliance wells |
| MW-423 & MW-523 | Downgradient, point-of-compliance wells |
| MW-424 & MW-524 | Downgradient, point-of-compliance wells |
| **Seeps** | **Location** |
| 611 | Bottom of disposal cell, south side slope |
| 612 | Bottom of disposal cell, south side slope |

## Frequency of Monitoring

Ground water will be monitored in the fall at 5-year intervals beginning in fall of 1999. The next monitoring will be in fall of 2004 and every 5 years thereafter. After each monitoring event, DOE will review the data and compare them with data from previous monitoring. The purpose of the comparison will be to detect trends and significant changes if any should occur. From time-to-time, DOE will review the need to continue monitoring and may determine to discontinue monitoring or to continue monitoring at appropriate intervals.

## Analytes

For future monitoring (beginning 2004), DOE will continue to monitor for standard water quality indicators and four analytes with MCLs: lead, molybdenum, selenium, and uranium (Table 3-4). The MCLs for these four analytes will be used as indicators for evaluating cell performance. Should future monitoring indicate increasing trends or concentrations that exceed the MCL for these analytes, DOE will conduct confirmatory sampling. If the confirmatory sampling verifies the exceedance, the DOE will develop an evaluative monitoring plan and submit that plan to the NRC for review prior to initiating the evaluative monitoring plan. Results of evaluative monitoring would be used to determine if corrective action is necessary.

*Table 3-4. Ground-Water Samples Will Continue to be Analyzed for the Following 14 Analytes*

| Analyte | MCL | Analyte | MCL |
|---|---|---|---|
| Calcium | None | Potassium | None |
| Chloride | None | Nitrate (as N) | 10.0 mg/L |
| Iron | None | Selenium | 0.01 mg/L |
| Lead | 0.05 mg/L | Sodium | None |
| Magnesium | None | Sulfate | None |
| Manganese | None | Total dissolved solids (TDS) | None |
| Molybdenum | 0.1 mg/L | Uranium | 0.044 mg/L |

## 3.8 Records

The LTSM Program maintains site records in a permanent site file at the GJO. These records are available for inspection by government agencies or the public. Records include disposal site characterization, design, and construction documents. Annual inspection, maintenance, and monitoring results are also part of the permanent site file.

All LTSM Program records are maintained in full compliance with DOE requirements:

1. DOE Order 1324.2A, Records Disposition

2. 36 CFR Parts 1220-1236, National Archives and Records Administration

## 3.9 Quality Assurance

The long-term care of the Burrell vicinity property and all activities related to the annual surveillance and maintenance of the site will comply with DOE Order 414.1A, Quality Assurance (QA) and ANSI/ASQC E4-1994, *Specifications and Guidelines for Quality Systems for Environmental Data Collection and Environmental Technology Programs* (American Society for Quality Control 1994).

QA requirements will be transmitted through procurement documents to subcontractors if/when appropriate.

## 3.10 Health and Safety

Health and safety procedures for LTSM Program activities are consistent with DOE orders, regulations, codes, and standards.

Immediate health and safety concerns are listed in the Inspection Checklist (Section 3.3.3 and Appendix C). Also in the Job Safety Analysis section of the Inspection Checklist are 24-hour emergency phone numbers for fire, hospital and ambulance, and police and sheriff. The checklist is updated before each inspection to advise on-site personnel of new and continuing health and safety considerations. A Job Safety Analysis is reviewed before each inspection. At a

pre-inspection briefing, on-site personnel review the Job Safety Analysis and are instructed on hazards that may be present at the site and health and safety procedures that must be followed.

Subcontractors (for maintenance) are advised of health and safety requirements through appropriate procurement documents. Subcontractors must submit health and safety plans for all actions subject to Occupational Safety and Health Administration (OSHA) requirements. Subcontractor health and safety plans will be reviewed and approved before the contract is awarded. Proposals from subcontractors without an adequate health and safety plan are rejected.

# 4.0 References

U.S. Department of Energy, 2000. *Guidance for Implementing the Long-term Surveillance Program for UMTRCA Title I and Title II Disposal Sites*, prepared by the U.S. Department of Energy, Grand Junction Office, Grand Junction, Colorado.

———, 1999. *Plant encroachment on the Burrell, Pennsylvania, Disposal Cell: Evaluation of Long-Term Performance and Risk*, GJO-99-96-TAR, prepared by the U.S. Department of Energy, Grand Junction Office, Grand Junction, Colorado, June.

———, 1993. *Burrell, Pennsylvania Vicinity Property Long-Term Surveillance Plan.* UMTRA-DOE/AL/62350-3F, prepared by the U.S. Department of Energy, UMTRA Project Office, Albuquerque Operations Office, Albuquerque, New Mexico.

———, 1988. *Burrell Vicinity Property Completion Report, Final*, prepared by Morrison-Knudsen Ferguson for the UMTRA Project Office, Albuquerque Operations Office, Albuquerque, New Mexico.

———, 1983. *Final Environmental Impact Statement, Remedial Actions at the Former Vitro Rare Metals Plant Site, Canonsburg, Washington County, Pennsylvania.* DOE/EIS-0096-F. Albuquerque Operations Office, Albuquerque, New Mexico.

Ford, Bacon & Davis, Inc., 1979a. *Formerly Utilized MED/AEC Sites Remedial Action Program, Engineering Evaluation of the Pennsylvania Railroad Landfill Site, Burrell Township, Pennsylvania, Final Report,* document FBDU 230-003, Salt Lake City, UT.

Ford, Bacon & Davis, Inc., 1979b. *Formerly Utilized MED/AEC Sites Remedial Action Program, Environmental Analysis of the Pennsylvania Railroad Landfill Site, Burrell Township, Pennsylvania,* document FBDU 230-007, Salt Lake City, UT.

End of current text

# Appendix A

# Site Real Estate Documentation and Access

# Real Estate Documentation

# Long-Term Surveillance Plan

# Burrell Disposal Site

# Indiana County, Pennsylvania

## General

Acquisition of the Burrell disposal site was finalized by civil action in the United States District Court for the Western District of Pennsylvania, Case Number 86-1475, July 14, 1986, United States of America, Plaintiff *N*/71.83 acres of land, more or less, situated in Indiana County, Commonwealth of Pennsylvania, and George Wm. Burrow, a/k/a George W. Burrows, et al., defendants. Final disposition of the case is dated December 27, 1988. The real estate associated with the disposal site contains "69.12 acres, more or less, including all of the area of muds, flats, and land under the waters of the Conemaugh River in which all rights, title, and interest extends or should extend by law or custom together with all riparian rights appertaining thereto." The case included 2.71 acres of perpetual right-of-way leading from the southerly side of State Road, Legislative Route 32006, at Strangford to the disposal site.

## Documentation of Acquisition

Disposal site/access

(1) Legal descriptions-See attachment Tracts 201 and 201-E

(2) Filed:
United States of America, Plaintiff v 71.83 acres of land, more or less, situated in Indiana County. Commonwealth of Pennsylvania, and George Wm. Burrow, a/ka George W. Burrows, et al., defendants, Civil Action No. 86-1475, July 14, 1986, United States District Court for the Western District of Pennsylvania.

## Repository

Real estate correspondence and related documents are maintained and filed by the Property Management Branch, Facilities and Property Management Division, Albuquerque Operations Office under the supervision of Corville J. Nohava, (505) 845-6450.

| | |
|---|---|
| Tract: 201 E | UMTRA Project |
| Owner: George Wm. Burrows, et ux | Department of Energy |
| Acres: 2.71 | Burrell Township, Pennsylvania |
| | Road Easement |

**Legal Description**

**Tract No. 201 E**

A certain tract of land situated in the Township of Burrell, County of Indiana and Commonwealth of Pennsylvania, on the southerly side of Legislative Route 32006 at Strangford. Said tract of land is a right-of-way for a proposed haulroad, located partly along an existing private road and more particularly bounded and described as follows:

Beginning at the entrance to said private road on the southerly side of Legislative route 32006 (Strangford Road), said point is located westerly approximately 0.4 mile along Strangford Road from Toms Run and southerly approximately 0.8 mile along said road from Old State Route (Market Street). Said beginning point is also approximately 480 feet right of centerline Station 479+30 of the Consolidated Rail Corporation; thence, from said point of beginning, along the southerly side of said Strangford Road,

South 33° 30' east 110 feet; thence, leaving said Strangford Road, with the southerly line of said haulroad,

North 66° 30' west 90 feet,

South 59° 30' west 415 feet to an iron pin set in the northerly right-of-way line of said Consolidated Rail Corporation; thence, with said right-of-way line,

North 64° 11' west 1,702 feet to a point on the northerly line of said haulroad; thence, leaving said railroad right-of-way line, with the said northerly line of said haulroad,

North 69° 49' east 74 feet,
South 64° 11' east 1400 feet,
South 69° 30' east 150 feet,
North 85° 00' east 200 feet,
North 59° 30' east 160 feet,
North 36° 30' east 100 feet,

North 06° 00' west 98 feet to a point on the said southerly side of Strangford Road; thence, along the southerly side of said road,

South 25° 50' east 127 feet to the point of beginning, containing 2.71 acres, more or less.

It is the intent of the above description to include a part of former railroad property described in the following deeds together with the former river channel riparian thereto:

1. Deed Book A-45, page 250 from Christopher Hill to the Western Pennsylvania Railroad Company, recorded 7 November 1882, in the records of Indiana County.

2. Deed Book 288, page 122 from Alva Forsha, et al. to the Pennsylvania Railroad Company, recorded 1 July 1937, in the records of Indiana County.

3. Deed Book, B-54, page 38 from Jerome Bock, et al. to the Western Pennsylvania Railroad Company, recorded 14 October 1890, in the records of Indiana County.

4. Deed Book 1003, page 380 from Annie Hartman, et al. to the Pennsylvania Railroad Company, recorded 23 October 1937, in the records of Westmoreland County.

Tract: 201 E UMTRA Project

Thereafter, the tracks of the railroad were relocated along with the channel of the Conemaugh River to occupy lands to the south. The said lands occupied by the former roadbed of the railroad and river channel were excepted and reserved in the Deed of the Trustees of the property of the Penn Central Transportation Company to the Consolidated Rail Corporation, dated 30 March 1976 and recorded in Indiana County in Deed Book 751, page 408, the same being depicted on certain railroad valuation maps recorded and made a part of said deed. The same land is a part of the land subsequently described in the first parcel of a deed from the Penn Central Corporation to George Wm. Burrows, and Wilma Gene Burrows, his wife, dated 30 April 1980 and recorded 2 June 1980 in the Office of the Recorder of Deeds of Indiana County, Pennsylvania, in Deed Book Volume 799, page 95.

Tract: 201
Owner: George Wm. Burrows, et ux
Acres: 69.12

UMTRA Project
U.S. Department of Energy
Burrell Township, Pennsylvania
Fee Tract

## Legal Description

**Tract No. 201**

A certain tract of land situated in the Township of Burrell, County of Indiana and Commonwealth of Pennsylvania, on the Conemaugh River, between Blairsville and Strangford. Said Tract is sometimes called the Strangford Dump and is more particularly described as follows:

Beginning at a point 510 feet, more or less, westerly of Milepost 7 and 110 feet left of the monumented centerline of the Consolidated Rail Corporation railroad;

thence, with a curve to the right having a radius of 2,761.43 feet, easterly 1,135.02 feet to a point 110 feet left of said centerline;

thence, north 00° 45' 18" east 30.00 feet to a point 80 feet left of said centerline;

thence, with a curve to the right having a radius of 2,791.43 feet, easterly 1,221.24 feet to a point of 80 feet left of said centerline;

thence, south 64° 11' 00" east 1,300 feet to a point 80 feet left of said centerline;

thence, southwesterly approximately 690.00 feet to the center of the Conemaugh River, a point in the line between Westmorland County and Indiana County;

thence, downstream with said county line and the meanders of said river, westerly approximately 3,070.00 feet;

thence, leaving said county line and river northerly approximately 290.00 feet to the point of beginning, containing 69.12 acres, more or less, including all of the area of muds, flats, and land under the waters of the Conemaugh River in which all right, title, and interest extends or should extend by law or custom together with all riparian rights appertaining thereto.

It is the intent of the above description to include the same land as the first tract described in a deed from Paul Interoligator, et ux to the Pennsylvania Railroad Company, dated 10 September 1943 and recorded in the records of Indiana County in Deed Book 329, page 68. The same was subsequently conveyed as the second parcel in a deed from the Penn Central Corporation to George Wm. Burrows and Wilma Gene Burrows, his wife, dated 30 April 1980 and recorded 2 June 1980 in the records of Indiana County, Pennsylvania in Deed Book 799, page 95.

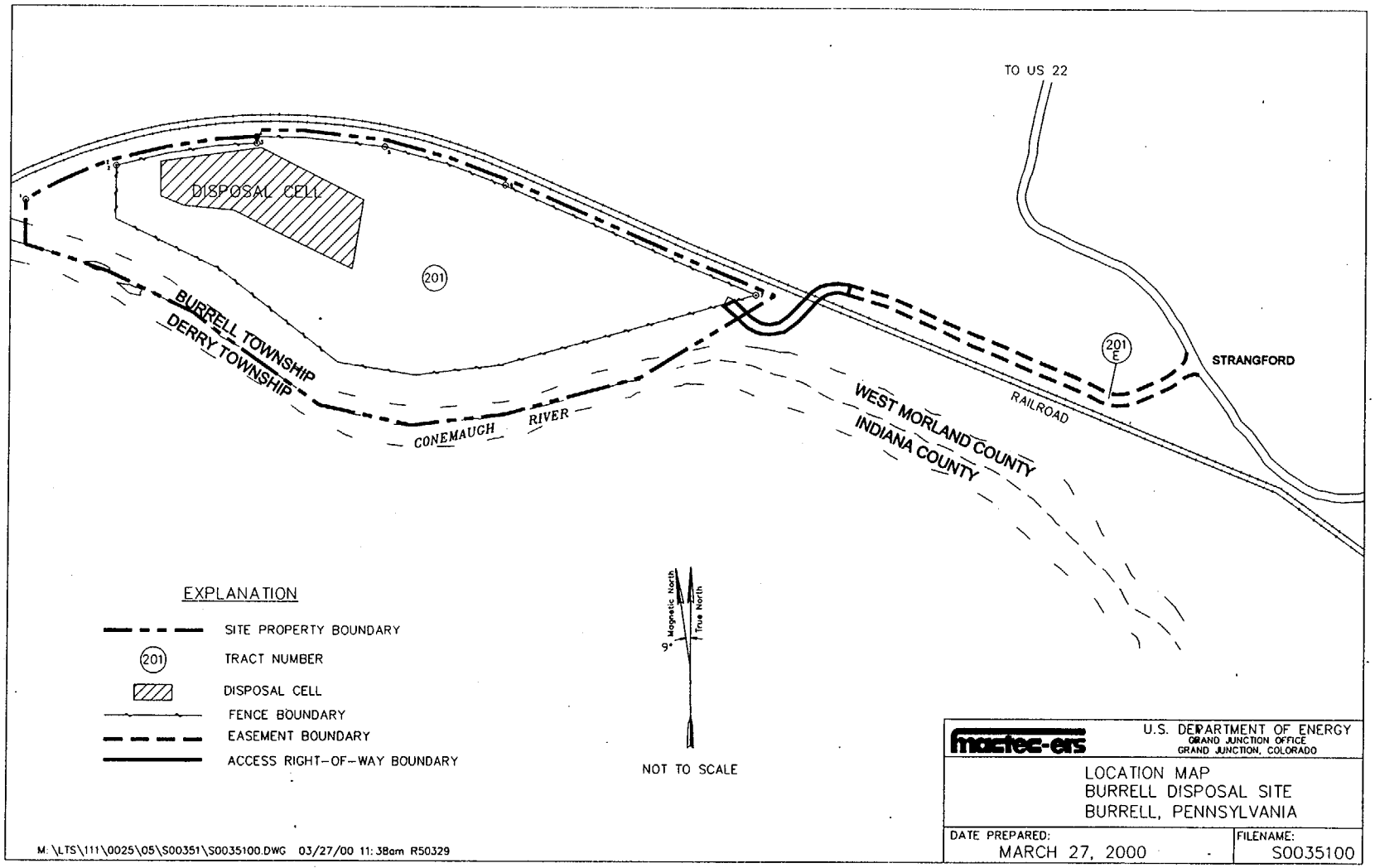


*Figure A-1. Location Map of Burrell Disposal Site, Burrell, Pennsylvania*

End of current text

# Appendix B

# Sample Field Photograph Log

## Field Photograph Log

Site: _____ Roll No. ___ (of ___)

Date: _____

| Frame | Azimuth | PI-Number | Subject/Description |
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Remarks:

Inspector/Photographer: _____

## Field Photograph Log (continued)

Site: _____ Roll No. ___ (of ___)
Date: _____

| Frame | Azimuth | PI-Number | Subject/Description |
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Remarks:

Inspector/Photographer: _____

# Appendix C

# Sample Site Inspection Checklist and

# Job Safety Analysis

# Site Status Report (Checklist) And Job Safety Analysis
# Burrell

Status of Site Inspections

| | |
|---|---|
| Last Update of Status Report: | October 9, 1999 |
| Last Annual Inspection: | October 13, 1998 |
| Inspectors: | Kastens and Plessinger |
| Next Annual Inspection: | Week of October 18, 1999 |
| Inspectors: | Jones and Gardner |
| Last Follow-Up Inspection: | None |

Issues

1. Old business:

- Guard rail has been installed along Strangford Road to deter trespassing on the Burrows property and along DOE's right-of-way.
- Potholes along DOE's right-of-way across the Burrows property have been filled with roadbase.
- Conrail maintenance personnel have a habit of using the DOE access gate at Strangford Road and leaving the gate open and unlocked. Conrail has a nice pole gate closer to the railroad tracks, but it does not use its gate for some reason.
- Trespassing on the Burrows property by dirt bikes and ATV's is a recent problem. The new guard rail is to discourage this use.
- Illegal dumping has occurred, for years apparently, along the railroad track north of the site.
- Vegetation is mowed annually to allow samplers to drive to the monitor wells. Vegetation is also mowed, cleared, and sprayed along the security fence to allow the fence to be inspected and, if necessary repaired, and to prevent trees and large plants from damaging the fence.
- A spring or seep west of perimeter sign P8 may destabilize the security fence.

# Checklist: Burrell
# October 8, 1999

| Feature | Comment |
|---|---|
| Access Gate at Strangford Road | Guard rail installed in 1999 |
| Access Road | Leads from Strangford Road, across DOE Tract 201-E, then across the Conrail tracks to the entrance gate. Potholes filled with roadbase in 1999. |
| Entrance Gate | |
| Pedestrian Gate | West end of site. |
| Entrance Sign | |
| Perimeter Signs | Total: 17 |
| Security Fence | Previous problems include theft of parts of the fence and vandalization of barbed wire. Hunters have been known to bait deer with apples inside the fence.<br><br>Vegetation cleared in 1999.<br><br>Seep 60 feet east of P8 may destabilize of the fence. |
| Survey Monuments | Total: 3 |
| Boundary Monuments | Total: 7<br>BM-1 is hard to find in a thickly wooded area and may be buried by silt from a recent high stand of the Conemaugh River. |
| Site Marker | Only 1, near entrance gate. |
| Erosion Control Markers | Total: 8 (4 pair)<br>Visual examination only. No measurements. |
| Monitor Wells | Total: 10 (5 pair). |
| Displacement Monuments | Artifacts of construction. No longer surveyed or inspected. |
| Biointrusion | |
| Seeps | Base of south side slope. Flow varies with recent precipitation. |
| River Bank | Between security fence and the river. Inspect for seeps and slope instability. |
| "Strangford Dump" | Most waste is household. Look for changes in dumping practices. |

# LTSM Job Safety Analysis

| | | | |
|---|---|---|---|
| Site: Burrell, Pennsylvania | | JSA Number: BUR-99-1 | |
| Task: Annual Site Inspection | | | |
| Prepared by:<br>C. A. Jones | Date: 10/10/99 | Reviewed by: | Date: |

Site Hazards

-Large area of rough, irregular riprap
-October: Rapid weather changes. Rain, freezing rain.
-Locals seem to think there are copperheads in the area.
-Poison Ivy possible.

Protective Clothing Required/Suggested

-Sturdy boots with ankle support are recommended.
-Clothing appropriate for cool days and rain.

Protective Equipment Required/Suggested

-Drinking water
-Personal items such as sunscreen, sunglasses, hat, insect repellant
-First-aid kit

Medical & Emergency Service Information

Fire 911

Hospital (at Indiana, PA) 412-357-7000

Ambulance 911

Police 412-349-2121

# Appendix D

# Agency Notification Agreements

**Department of Energy**
Albuquerque Field Office
P.O. Box 5400
Albuquerque, New Mexico 87185-5400
JUN 0 1 1993

Mr. Paul Beatty, Coordinator
Indiana County Emergency Management
825 Philadelphia Street
Indiana, PA 15701

Dear Mr. Beatty:

The U.S. Department of Energy (DOE) Uranium Mill Tailings Remedial Action (UMTRA) Project is requesting notification in the event of issuance of flash flood, tornado warnings, or hurricane alert in Indiana County, Pennsylvania. We would appreciate notification to the DOE Grand Junction Projects Office's 24-hour phone line at (303) 248-6070 within eight hours of issuance of a warning or episode of warnings.

The purpose of this warning is to assist the DOE in surveying and maintaining the integrity of its radioactive waste disposal site located one mile east of the Borough of Blairsville, Indiana County, in southwestern Pennsylvania. The Burrell vicinity property site is bordered on the south by the Conemaugh River and to the north by the Conrail railroad tracks. The enclosed map provides directions to the site if you are not familiar with its location.

If the notification request discussed above is agreeable to you, please sign and return the enclosed reply letter for our records as soon as possible.

Should you have any questions, please contact Steve Hamp of my staff at (505) 845-5640.

Sincerely,

Albert R. Chernoff
Project Manager
Uranium Mill Tailings Remedial Action
Project Office

2 Enclosures

J. Virgona, GJPO
C. Jones, GJPO
S. Hamp, UMTRA
F. Bosiljevac, UMTRA
E. Artiglia, UMTRA

RECEIVED
SEP 14 1993

Albert R. Chernoff
UMTRA Project Manager
U.S. Department of Energy
Uranium Mill Tailings Remedial Action Project Office
5301 Central Ave., N.E., Suite 1720
Albuquerque, NM 87108

Attention: Steve Hamp

Dear Mr. Chernoff:

This letter is to concur with the U.S. Department of Energy (DOE) request for notification as set forth in the DOE's letter of JUN 01 1993, 1993. As requested in your letter, this office will contact the DOE's Grand Junction Projects Office at (303) 248-6070 within 8 hours of the issuance of a flash flood, tornado warning, or hurricane alert in Indiana County, Pennsylvania. During normal business hours, the warning may also be faxed to (303) 248-6040.

Sincerely,

Paul R Beatty
Name

Director
Title

Indiana County Emergency Management
825 Philadelphia Street
Indiana, PA 15701

Enclosures

cc: JVirgona, GJPO
CJones, GJPO
SHamp, UMTRA
FBosiljevac, UMTRA
EArtiglia, TAC

**Department of Energy**
Albuquerque Field Office
P.O. Box 5400
Albuquerque, New Mexico 87185-5400

MAR 1 6 1993

Mr. Bruce Presgrave
U.S. Geological Survey
National Earthquake Information Center
P.O. Box 25046, Mail Stop 967
Denver Federal Center
Denver, CO 80225

Dear Mr. Presgrave:

The U.S. Department of Energy (DOE) Uranium Mill Tailings Remedial Action (UMTRA) Project Office is requesting notification if a seismic event is recorded in Indiana County, Pennsylvania. The purpose of this request is to assist the DOE in surveying and maintaining the integrity of its radioactive waste disposal site located approximately one mile east of the Borough of Blairsville, (Latitude N40°.3'/Longitude W79°.3') Indiana County, in southwestern Pennsylvania.

We would appreciate notification to the DOE Grand Junction Projects Office's 24-hour phone line at (303) 248-6070 if a seismic event(s) occurs that fits any of the following descriptions:

- Any earthquake of magnitude 3.0 or greater, within 0.3 degrees (about 20 miles) of the disposal site, or
- Any earthquake of magnitude 5.0 or greater, within 1.0 degrees (about 70 miles) of the disposal site.

If the notification request discussed above is agreeable to you, please sign and return the enclosed reply letter for our records as soon as possible.

Should you have any questions, please contact Steve Hamp of my staff at (505) 845-5640. Thank you for your attention in this matter.

Sincerely,

for Albert R. Chernoff
Project Manager
Uranium Mill Tailings Remedial Action
Project Office

2 Enclosures

cc w/o enclosures:
J. Virgona, GJPO
C. Jones, GJPO
S. Hamp, UMTRA
F. Bosiljevac, UMTRA
E. Artiglia, TAC

**Department of Energy**
Albuquerque Field Office
P.O. Box 5400
Albuquerque, New Mexico 87185-5400

SEP : 5 1993

Mr. Bruce Presgrave
U.S. Geological Survey
National Earthquake Information Center
P.O. Box 25046
Mail Stop 967
Denver Federal Center
Denver, Colorado 80225

Dear Mr. Presgrave:

On December 14, 1992, the U.S. Department of Energy (DOE) Uranium Mill Tailings Remedial Action (UMTRA) Project Office received your letter confirming that the following four UMTRA Project sites, Green River, Utah; "Spook" site, Wyoming; Tuba City, Arizona; and Shiprock, New Mexico; have been added to your notification list for earthquakes. These sites were entered into the following selection criteria:

1. Any earthquake of magnitude 3.0 or greater, within 0.3 degrees (about 20 miles) of any of the sites.

2. Any earthquake of magnitude 5.0 or greater, within 1.0 degrees (about 70 miles) of any of the sites.

We appreciate the addition of these sites to your notification system.

The UMTRA Project will have 16 additional radioactive waste disposal sites requiring earthquake notification. The 16 additional site locations are listed below. We would appreciate the inclusion of these sites into your notification system. The DOE requests notification to the DOE Grand Junction Projects Office 24-hour phone line at (303) 248-6070 if any seismic event occurs that fit the criteria listed above. If this notification request is agreeable to you, please sign and return the attached reply letter for our records as soon as possible.

| Disposal Site | Latitude | Longitude |
|---|---|---|
| COLORADO | | |
| Durango (Bodo Canyon) | N37.15 | W107.90 |
| Grand Junction | N38.91 | W108.32 |
| Gunnison (Landfill) | N38.51 | W106.85 |
| Maybell | N40.55 | W107.99 |
| Naturita (Dry Flats) | N38.21 | W108.60 |
| Rifle (Estes Gulch) | N39.60 | W107.82 |
| Slick Rock (Burro Canyon) | N38.05 | W108.87 |

| Disposal Site | Latitude | Longitude |
|---|---|---|
| **IDAHO** | | |
| Lowman | N44.16 | W115.61 |
| **NEW MEXICO** | | |
| Ambrosia Lake | N35.41 | W107.80 |
| **NORTH DAKOTA** | | |
| Bowman | N46.23 | W103.55 |
| **OREGON** | | |
| Lakeview (Collins Ranch) | N42.2 | W120.3 |
| **PENNSYLVANIA** | | |
| Canonsburg | N40.26 | W80.25 |
| Burrell VP | N40.62 | W79.65 |
| **TEXAS** | | |
| Falls City | N28.91 | W98.13 |
| **UTAH** | | |
| Mexican Hat | N37.10 | W109.85 |
| Salt Lake City (Clive) | N40.69 | W113.11 |

If there are any questions or concerns about this request, please contact me at (505) 845-5659 or Linda Ulland, Manager of Environmental Regulations and Compliance with the UMTRA Project Office's Technical Assistance Contactor at (505) 845-5671.

Sincerely,

Russel Edge
for
Clinton C. Smythe
Engineering and Construction Group Leader
Uranium Mill Tailings Remedial Action
Project Office

Enclosure

cc w/o enclosure:
C. Jones, GJPO
J. Virgona, GJPO
F. Bosiljevac, UMTRA
S. Hamp, UMTRA
M. Abrams, UMTRA
W. Woodworth, UMTRA
S. Arp, UMTRA
E. Artiglia, TAC
M. Day, TAC
M. Leaf, TAC
J. McBee, TAC
L. Ulland, TAC
C. Watson, TAC
C. Yancey, TAC

Clinton C. Smythe
Engineering and Construction Group Leader
Uranium Mill Tailings Remedial Action
Project Office
2155 Louisiana NE, Suite 4,000
Albuquerque, NM 87110

Dear Mr. Smythe:

This letter is to confirm that the DOE Grand Junction Projects Office (24-hour phone line, (303) 248-6070 has been added to our notification list for the occurrence of earthquakes near the following locations:

| Disposal Site | Latitude | Longitude |
|---|---|---|
| COLORADO | | |
| Durango (Bodo Canyon) | N37.15 | W107.90 |
| Grand Junction | N38.91 | W108.32 |
| Gunnison (Landfill) | N38.51 | W106.85 |
| Maybell | N40.55 | W107.99 |
| Naturita (Dry Flats) | N38.21 | W108.60 |
| Rifle (Estes Gulch) | N39.60 | W107.82 |
| Slick Rock (Burro Canyon) | N38.05 | W108.87 |
| IDAHO | | |
| Lowman | N44.16 | W115.61 |
| NEW MEXICO | | |
| Ambrosia Lake | N35.41 | W107.80 |
| NORTH DAKOTA | | |
| Bowman | N46.23 | W103.55 |
| OREGON | | |
| Lakeview (Collins Ranch) | N42.2 | W120.3 |
| PENNSYLVANIA | | |
| Canonsburg | N40.26 | W80.25 |
| Burrell VP | N40.62 | W79.65 |
| TEXAS | | |
| Falls City | N28.91 | W98.13 |
| UTAH | | |
| Mexican Hat | N37.10 | W109.85 |
| Salt Lake City (Clive) | N40.69 | W113.11 |

We have entered the following selection criteria into our notification program:

1. Any earthquake of magnitude 3.0 or greater, within 0.3 degrees (about 20 miles) of any site shown above, or

2. Any earthquake of magnitude 5.0 or greater, within 1.0 degrees (about 70 miles) of any site shown above.

Sincerely,

Bruce Presgrave
U.S. Geological Survey
National Earthquake Information Center
P.O. Box 25046
Mail Stop 967
Denver Federal Center
Denver, Colorado 80225

**Department of Energy**
Albuquerque Field Office
P.O. Box 5400
Albuquerque, New Mexico 87185-5400

MAR 1 6 1993

Lt. Tripp
Indiana, Pennsylvania State Police
401 Airport Center
Indiana, PA 15701

Dear Lt. Tripp:

The U.S. Department of Energy (DOE) Uranium Mill Tailings Remedial Action (UMTRA) Project Office is requesting notification of any unusual activities or events in or around the uranium mill tailings disposal cell located approximately one mile east of the Borough of Blairsville, Indiana County, in southwestern Pennsylvania. The purpose of the notification request is to assist the DOE in surveying and maintaining the integrity of its disposal cell and to ensure public safety.

If, during the course of routine activities, anything out of the ordinary is observed by your staff or reported to your office, we would appreciate immediate notification to the DOE Grand Junction Projects Office's 24-hour phone line at (303) 248-6070. The enclosed map provides directions to the site if you are not familiar with its location.

If the notification request discussed above is agreeable to you, please sign and return the enclosed reply letter for our records as soon as possible.

Should you have any questions, please contact Steve Hamp of my staff at (505) 845-5640. Thank you for your attention in this matter.

Sincerely,

for Albert R. Chernoff
Project Manager
Uranium Mill Tailings Remedial Action
Project Office

2 Enclosures

cc w/o enclosures:
J. Virgona, GJPO
C. Jones, GJPO
F. Bosiljevac, UMTRA
S. Hamp, UMTRA
E. Artiglia, TAC

MIS/UMT/0393-0031

Albert R. Chernoff
UMTRA Project Office
U.S. Department of Energy
Uranium Mill Tailings Remedial Action
Project Office
5301 Central Ave., N.E., Suite 1720
Albuquerque, NM 87108

Attention: Steve Hamp

Dear Mr. Chernoff:

This letter is to concur with the U.S. Department of Energy (DOE) request for notification as set forth in the DOE's letter of MAR 1 6 1993, 1993. As requested in your letter, this office will contact the DOE's Grand Junction Projects Office at (303) 248-6070 if any unusual event or anomaly is observed or reported at the Burrell Vicinity Property disposal site.

Sincerely,

James R. Trupp
Name

LIEUTENANT - STATION COMMANDER.
Title

Indiana, Pennsylvania State Police
401 Airport Center
Indiana, PA 15701

cc:
J. Virgona, GJPO
C. Jones, GJPO
F. Bosiljevac, UMTRA
S. Hamp, UMTRA
E. Artiglia, TAC

MAR 1993
RECEIVED

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WM-42

GJO-99-96-TAR

# Plant Encroachment on the Burrell, Pennsylvania, Disposal Cell: Evaluation of Long-Term Performance and Risk

June 1999

U.S. Department of Energy

GRAND JUNCTION OFFICE

*Work Performed Under DOE Contract No. DE–AC13–96GJ87335 for the U.S. Department of Energy*

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GJO-99-96-TAR

# Plant Encroachment on the Burrell, Pennsylvania, Disposal Cell: Evaluation of Long-Term Performance and Risk

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June 1999

Prepared for
U.S. Department of Energy
Albuquerque Operations Office
Grand Junction Office
Grand Junction, Colorado

*Work Performed Under DOE Contract No. DE-AC13-96GJ87335 for the U.S. Department of Energy*
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# Executive Summary

The Burrell, Pennsylvania, disposal cell is a covered landfill constructed by the U.S. Department of Energy (DOE) to isolate soil contaminated with uranium mill tailings. The abundance of plants growing on the Burrell disposal cell has increased each year since closure of the cell in 1987. DOE's original plan for post-closure maintenance included regular herbicide spraying to suppress plant growth for the 200-to-1,000-year life of the disposal cell.

This report completes a two-part study of the effects of plant root intrusion and ecological development on the performance of the disposal cell cover and, as a consequence, on potential changes in risks to human health and the environment. The DOE Long-Term Surveillance and Maintenance (LTSM) Program plans to use the results of this study as the technical basis for choosing one of the following three management options for the Burrell disposal cell:

- Discontinue herbicide spraying if risks of root intrusion are acceptably low.
- Accept the cost and environmental consequences of continued herbicide spraying, or other long-term maintenance, if risks are sufficiently large.
- Modify the disposal cell cover design and, thereby, improve risk management over the long term.

In the first part of the study we evaluated the effects of root intrusion on radon flux and the saturated hydraulic conductivity of the cover. This work resulted in two findings. The first is that root intrusion and associated drying of the cover will not likely increase radon flux above the 20-picocurie-per-square-meter-per-second standard unless the western Pennsylvania climate changes from humid to semiarid. The second is that plant roots do increase the hydraulic conductivity of the radon barrier. We measured a 2-orders-of-magnitude increase in the saturated hydraulic conductivity where plant roots penetrated the radon barrier (or compacted soil layer). At a nearby analog site, the saturated hydraulic conductivity was 3 orders of magnitude above the design specification of $10^{-7}$ centimeter per second. The analog site represents a reasonable future condition of the cover after 200-to-1,000 years of ecological and pedogenic changes.

In the second part of the study, we evaluated possible consequences of increased water movement into the tailings that might result from root intrusion in the cover. The first phase of this screening-level risk assessment evaluated concentrations and mobility of contaminants in tailings pore fluid. Composite tailings samples were retrieved from locations within the disposal cell that had the highest radium levels at the time of construction. Column leach tests conducted using composite samples encompassed a range of current, possible future, and, less likely, extreme chemical conditions. The results suggest that manganese, molybdenum, selenium, uranium, and $^{226}$Ra in pore fluid may exceed either the Uranium Mill Tailings Radiation Control Act (UMTRCA) maximum concentration limit (MCL) or a U.S. Environmental Protection Agency (EPA) risk-based screening level for one or more of the conditions tested. In other words, water extracted directly from the disposal cell, the worst-case exposure pathway, may be unsafe to drink.

The second phase of the risk assessment evaluated groundwater quality beneath the disposal cell for a range of conditions, reasonable and extreme, that could occur during the design life of the cover. We used a combination of historical monitoring data from seeps and wells, soil-water

balance modeling, and groundwater mixing calculations to estimate groundwater quality for a range of possible future conditions, including changes in the ecology of cover soils and changes in the tailings pore water chemistry. No contaminants of concern (COCs) in DOE's historical database for seeps and monitor wells came close to the UMTRCA MCLs or the EPA risk-based screening levels. Estimates of groundwater quality for existing conditions were comparable to the historical monitoring data. Even for extreme conditions, all model-predicted COCs, except $^{226}$Ra, were well below MCLs and EPA risk-based screening levels.

The results suggest that $^{226}$Ra in groundwater could exceed the MCL by at most 10 percent, but only for a highly unlikely combination of conditions: (1) pore water pH of 4.5 or less, (2) a 2-to-3-orders-of-magnitude increase in the saturated hydraulic conductivity of the radon barrier because of root intrusion, (3) 1,000 years of $^{226}$Ra ingrowth, and (4) pore water contamination levels as high as that from the most contaminated tailings. Primarily because a pore water pH of 4.5 is highly unlikely, radium is expected to remain relatively immobile in the disposal cell. The results also suggest that, in the future, because of increased evapotranspiration, contaminant concentrations in groundwater would be substantially lower if native woodlands were allowed to establish. Conversely, regular denuding of the disposal cell with herbicides would reduce evapotranspiration and, in time, may actually increase drainage from the cover and leaching of contaminants into groundwater.

On the basis of the results of this study, we conclude that regular spraying of vegetation on the disposal cell is unwarranted and unjustified. DOE can safely eliminate this requirement from the Burrell long-term surveillance plan. Natural plant succession can be allowed to proceed with no increased risk to human health or the environment. In fact, continued spraying may interfere with the long-term performance of the disposal cell. Because of a much higher evapotranspiration rate, the development of a mature woodland plant community is expected to augment the performance of the disposal cell by limiting drainage through the cover and by reducing the likelihood of contaminant leaching into groundwater below the disposal cell.

# 1.0 Introduction

## 1.1 Purpose

This document presents methods, results, and recommendations of a screening-level risk assessment for the Burrell, Pennsylvania, disposal cell. The risk assessment was conducted to evaluate possible long-term changes in disposal cell performance, human health risks, and environmental risks associated with a documented increase in the permeability of the disposal cell cover caused by plant root intrusion. The U.S. Department of Energy (DOE) Long-Term Surveillance and Maintenance (LTSM) Program plans to use the results of this evaluation as the basis for vegetation management decisions at the site and, if warranted, for revision of the long-term surveillance plan for the Burrell disposal cell.

## 1.2 Current Vegetation Management Plan

The Burrell, Pennsylvania, disposal cell is a covered landfill constructed by DOE under the Uranium Mill Tailings Radiation Control Act (UMTRCA) of 1978 to isolate soil contaminated with uranium mill tailings. The disposal cell was constructed in 1987 (Morrison-Knudsen Engineers, Inc., 1994) and stewardship was transferred to the LTSM Program in 1994. Observations of plants growing on the disposal cell cover, beginning in 1988, raised concerns about effects of root intrusion on the long-term performance of the cell. Within 3 years after construction, a diverse plant community had established on the rock cover. Within 10 years, Japanese knotweed, an exotic perennial, had rooted through the rock layer and an underlying, 90-centimeter (cm)-thick, compacted soil layer (CSL). Of concern was the possibility that root intrusion would increase (1) radon flux from the surface of the disposal cell and (2) water movement through the cover and leaching of underlying tailings. Because of this concern, the long-term surveillance plan for Burrell recommended herbicide applications every 2 to 3 years to suppress plant growth for the design life of the disposal cell (DOE, 1993). Under UMTRCA, disposal cells are intended to last 200 to 1,000 years (EPA, 1983).

## 1.3 Summary of Root Intrusion Study

The LTSM Program recognizes that the costs and associated risks of committing to long-term spraying of herbicide are unjustified unless substantiated by sound technical reasons. Herbicide applications may actually increase human health and environmental risk at the site—the solution may be worse than the problem. Therefore, between 1995 and 1997, the LTSM Program conducted a field study of the consequences of root intrusion and long-term ecological change on the disposal cell cover as the basis for a reasonable vegetation management strategy (Waugh and Smith, 1997, 1998).

Waugh and Smith (1997, 1998) evaluated the effects of plant root intrusion on radon attenuation and water infiltration through the CSL, which is intended to serve as both a radon barrier and a water infiltration barrier. The results indicate that root intrusion will not increase radon flux above the 20-picocuries-per-square-meter-per-second ($pCi \cdot m^{-2} \cdot s^{-1}$) performance standard unless the CSL dries out because of unforeseen and unlikely climatic and ecological changes (see Section 3.0). However, LTSM Program personnel measured a significant increase in the

saturated hydraulic conductivity ($K_{sat}$) where plant roots penetrated the CSL (see Section 4.0). The $K_{sat}$ averaged $3.0 \times 10^{-5}$ centimeter per second ($cm \cdot s^{-1}$) at locations where Japanese knotweed roots penetrated the clay layer compared with $2.9 \times 10^{-7}$ $cm \cdot s^{-1}$ where there were no plants. The average $K_{sat}$ for the cover, calculated using the leaf area index for Japanese knotweed as a weighting factor, was $4.4 \times 10^{-6}$ $cm \cdot s^{-1}$. At nearby Hannastown Historical Park, a site with late-successional vegetation and a soil profile and clay subsoil similar to the Burrell cover, the $K_{sat}$ of the clay subsoil averaged $1.3 \times 10^{-4}$ $cm \cdot s^{-1}$. The Hannastown soil profile was teaming with life. Earthworm holes, root channels, and soil structural planes all contribute to macropore flow of water in the subsoil. The LTSM Program considers Hannastown to be a reasonable analog of the long-term ecology and soil hydrology of the Burrell disposal cell cover.

Burrell and Hannastown data indicate that during the 200- to 1,000-year life of the disposal cell, the hydraulic conductivity of the CSL will likely increase by 3 orders of magnitude in response to ecological and pedogenic changes. This greater capacity to move water through the disposal cell may cause unacceptable leaching of radioactive and other hazardous materials into nearby surface water and groundwater. Section 4.0 addresses the likelihood and risks of increased contaminant leaching.

## 1.4 Management Options

During 1998, the LTSM Program conducted two phases of a possible three-phase assessment of the added risks associated with increased permeability of the cover attributable to plant root intrusion. The goal of the risk assessment was to provide a technically based rationale that will allow DOE to choose among three management options for the Burrell disposal cell:

- Discontinue herbicide spraying if risks are acceptably low.
- Accept the cost and environmental consequences of continued herbicide spraying, or other long-term maintenance, if risks are sufficiently large.
- Modify the disposal cell cover design and, thereby, improve risk management over the long term.

# 2.0 Characterization Data

## 2.1 As-Built Contaminant Concentrations and Distributions

Evaluations of root intrusion effects on water infiltration, radon diffusion, plant uptake, and, ultimately, human health and ecological risks require data on the chemical species, concentrations, and distributions of contaminants in the Burrell disposal cell. Data on concentrations and distributions of radiological ($^{226}$Ra and $^{230}$Th) and other contaminants are available in the *Burrell, Pennsylvania, Vicinity Property Completion Report* (Morrison-Knudsen Engineers, Inc., 1994). The estimated total $^{226}$Ra activity in the 54,000 cubic yards of contaminated material placed in the cell is about 4 curies. The completion report did not contain an estimate of the $^{230}$Th inventory. Table 2–1 provides a summary of as-built $^{226}$Ra and $^{230}$Th data in picocuries per gram (pCi/g) from a grid of 24 boreholes sampled in November 1986 after tailings were placed in the cell but before the cover was constructed.

*Table 2–1. Summary Statistics for $^{226}$Ra and $^{230}$Th Concentrations in Burrell Disposal Cell*

| Depth | $^{226}$Ra (pCi/g) | | | | | $^{230}$Th (pCi/g) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| (cm) | Mean | S.E.(mean)[a] | Min. | Max. | *n*[b] | Mean | S.E.(mean)[a] | Min. | Max. | *n*[b] |
| 0 – 60 | 39.5 | 8.0 | 5.5 | 85.0 | 11 | 416.0 | 154.6 | 55.0 | 1910.0 | 11 |
| 60 – 120 | 26.5 | 5.3 | 8.0 | 83.0 | 12 | 204.1 | 32.1 | 77.0 | 410.0 | 12 |
| 120 – 300 | 79.8 | 18.8 | 28.0 | 280.0 | 13 | 878.5 | 171.9 | 350.0 | 2520.0 | 13 |
| All | 49.6 | 8.2 | 5.5 | 280.0 | 36 | 512.4 | 90.7 | 55.0 | 2520.0 | 36 |

[a]Standard error of tbe mean.
[b]Sample size.

Lateral and vertical heterogeneities of $^{226}$Ra and $^{230}$Th concentrations were high. Overall, concentrations were lower beneath the top slope and higher beneath the side slopes of the cell. Radon emanation fraction data, required for modeling radon flux, were also compiled from the completion report (Table 2–2).

*Table 2–2. Radon Emanation Fraction Data for Burrell Disposal Cell*

| Depth (cm) | Mean | S.E.(mean) | Min. | Max. | *n* |
|---|---|---|---|---|---|
| 0 – 60 | 0.14 | 0.011 | 0.04 | 0.23 | 22 |
| 60 – 120 | 0.13 | 0.014 | 0.01 | 0.27 | 23 |
| 120 – 180 | 0.15 | 0.013 | 0.00 | 0.23 | 23 |
| 180 – 240 | 0.17 | 0.015 | 0.00 | 0.31 | 24 |
| 240 – 300 | 0.16 | 0.016 | 0.02 | 0.29 | 22 |
| All | 0.15 | 0.006 | 0.00 | 0.31 | 114 |

Chemical analyses of soil samples from the Burrell site were performed in 1984. The analyses included pesticides (Methoxychlor, 2,4–D, and 2,4,5–T), metals (As, Ba, Cd, Pb, Hg, Se, and

Ag), sulfide, and cyanide. According to Morrison-Knudsen Engineers, Inc. (1988), no results for pesticides exceeded the U.S. Environmental Protection Agency (EPA) maximum allowable toxicity concentrations in Title 40 *Code of Federal Regulations* (CFR) Part 261.24. Except for one cadmium value, Morrison-Knudsen Engineers, Inc. (1988) also states that no metal results exceeded the maximum EPA toxicity limits for metals in 40 CFR 261.24.

## 2.2 As-Built Cover Design and Material Properties

As-built information on the soil, sand, and rock layer thicknesses; material properties (e.g., liquid limit, plasticity, texture, bulk density); and hydraulic properties (e.g., saturated conductivity and water retention characteristics) were compiled for use in radon flux and water infiltration evaluations.

From the tailings layer up, the Burrell cover consists of a 90-cm-thick radon barrier or CSL, a 30-cm-thick sand-and-gravel drainage layer, and a 30-cm-thick rock (riprap) layer (Figure 2–1). These three layers were designed to function together to meet the regulatory standards for radon releases and erosion for 200 to 1,000 years. A CSL thickness adequate to meet the radon flux standard was calculated using the U.S. Nuclear Regulatory Commission (NRC) RADON model (NRC, 1989). The target hydraulic conductivity for the CSL was $1 \times 10^{-7}$ cm · $s^{-1}$.

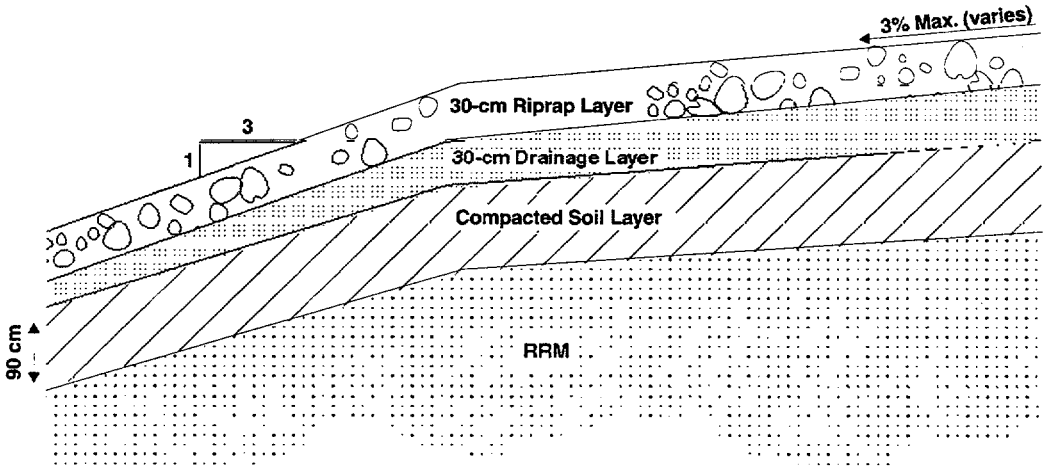


*Figure 2–1. Surface Cover Design for Burrell Disposal Cell*

The sand-and-gravel drainage or filter layer also serves as a bedding layer for the rock armor. The rock armor is sized to prevent erosion of underlying layers given a probable maximum precipitation (PMP) event, the most severe combination of meteorological and hydrological conditions possible at a site (DOE, 1989).

Material property data for the CSL (Table 2–3) were compiled from the Burrell completion report (Morrison-Knudsen Engineers, Inc., 1994). Actual compaction of the radon barrier during construction averaged 96.6 percent of the maximum dry density. Actual average, maximum, and

*Table 2–3. Summary of Engineering Test Results for CSL*

| Soil Type[a] | Specific Gravity | Liquid Limit (%) | Plasticity Index (%) | % Passing 200 Sieve | Silt (%) | Clay (%) | Moisture Content (%) | Proctor Compaction Optimum % Moisture | Proctor Compaction Max. Dry Density |
|---|---|---|---|---|---|---|---|---|---|
| CL[b] | 2.66 | 35.8 | 16.0 | 62 | 38 | 24 | 16.7 | 16.9 | 1.73 g · cm$^{-3}$ |

[a]Unified Soil Classification System.
[b]Silty clay with some coarse fragments.

minimum gravimetric moisture contents of the radon barrier during construction were 17.7 percent, 21.7 percent, and 14.7 percent, respectively. The bedding and rock materials are a greenish gray, calcareous, crossbedded sandstone. Grain-size curves for these materials are available in the Burrell completion report.

## 2.3 Natural Analog Site Selection

A goal of this study was to evaluate both current conditions and possible long-term effects of root intrusion on radon attenuation and water infiltration. Current influences of plants were evaluated by measuring the conditions of the disposal cell cover at locations both with and without plants. We inferred a potential long-term condition of the cover with data from a natural analog site.

Three criteria were used to search for an appropriate natural analog of possible future ecological conditions on the Burrell cover:

- The same soil type as the CSL.
- A soil depth equal to or greater than the CSL.
- A chronosequence of plant community development with the oldest sere (successional stage) at least 50 years old.

Construction records, a series of aerial photographs, and a copy of the U.S. Department of Agriculture (USDA) Soil Survey for Westmoreland County (Taylor et al., 1992) were used to determine that the Burrell disposal cell CSL consisted of Gurnsey silt loam and Westmoreland silt loam series excavated from open pits at a nearby coal mine. Land parcels with Westmoreland silt loam and Gurnsey silt loam series and with mature vegetation were located using USDA soil survey maps. Hannastown Historical Park, an archaeological and historical site owned and managed by the Westmoreland County Historical Society, was selected as the natural analog site (Waugh and Smith, 1998).

A 0.5-hectare (ha) rectangular area near the northeast corner of Hannastown Historical Park was chosen for study. The second-growth, closed-canopy woodland consists primarily of sugar maple with scattered beech and yellow birch and virtually no understory vegetation. This northeast-facing stand has a slope of approximately 5 percent. The soil series, Westmoreland silt loam, formed in residuum derived from interbedded gray calcareous shale, sandstone, and limestone. The soil profile at the study site consisted of a 15- to 20-cm brown, silt loam plow layer over a 80+ cm yellowish-brown silty clay loam subsoil.

## 2.4 Soil Physical and Hydraulic Properties

A field measurement and sampling program was developed to acquire data that best capture near-term and possible long-term influences of ecological development on the performance of the cover. These data were used for analyses of radon flux and water infiltration. Three conditions were compared: (1) the Burrell cover without plant roots (as-built), (2) the Burrell cover with plant roots, and (3) the Hannastown analog of a possible future ecology of the Burrell cover.

### 2.4.1 Soil Water Content, Texture, Bulk Density, and Porosity

Soil samples were retrieved from the Burrell cover and from analog soil profiles at Hannastown to determine seasonal soil water content, texture (particle-size distribution), bulk density (compaction), and porosity. Soil pits were excavated in the Burrell cover at locations both with and without vegetation ($n = 5$). At locations with vegetation, pits were excavated through the root crowns of mature Japanese knotweed, sycamore, black locust, and tree-of-heaven. The surface layer of rock was moved to expose the gravel bedding layer. For water content and textural analyses, loose bedding-layer material was sampled at the contact with the CSL; a bucket auger was used to retrieve CSL samples. Samples were collected early in the growing season and again in midsummer to capture seasonal variation in soil water content. Plow layer and subsoil samples from random soil profiles ($n = 5$) at the Hannastown site were also retrieved with a bucket auger. Bulk density samples of the Burrell CSL and the Hannastown subsoil were retrieved with a double cylinder, hammer-driven core sampler. Table 2–4 presents methods used for analyses of gravimetric water content, soil particle size, dry-weight bulk density, and porosity. Tables 2–5 and 2–6 present the results of these analyses.

*Table 2–4. Summary of Laboratory Methods for Soil Analyses*

| Soil Property and Method | Reference |
|---|---|
| Gravimetric Water Content | Klute (1986), Chapter 21, pp. 493–544 |
| Dry-Weight Bulk Density | Klute (1986), Chapter 13, pp. 363–367 |
| Soil Porosity | Klute (1986), Chapter 18, pp. 444–445 |
| Saturated Hydraulic Conductivity | |
| Falling Head Method | Klute (1986), Chapter 28, pp. 700–703 |
| Moisture-Retention Characteristics | |
| Hanging Column | Klute (1986), Chapter 26, pp. 637–639 |
| Pressure Plate | ASTM D 2325-68 (81) |
| Thermocouple Psychrometer | Klute (1986), Chapter 24, pp. 597–618 |
| Particle-Size Distribution | |
| Sieve | ASTM D 422-63 (90) |
| Hydrometer | ASTM D 422-63 (90) |

*Table 2–5. Particle Size and Bulk Density of Burrell CSL and Hannastown Analog Subsoil*

| Site | Particle Size[a] | | Bulk Density ($g \cdot cm^{-3}$) | | |
|---|---|---|---|---|---|
| | % Clay | % Sand | Mean | S.E.(mean) | *n* |
| Burrell Cover | | | | | |
| With Plants | 27 | 39 | 1.76 | 0.02 | 5 |
| Without Plants | | | 1.77 | 0.02 | 5 |
| Hannastown Analog Site | 29 | 17 | 1.48 | 0.02 | 5 |

[a]USDA soil classification system.

*Table 2–6. Gravimetric and Volumetric Soil Water Content in Burrell Cover and in Analog Soil Profiles at Hannastown*

| Site | Date | Material Type | Depth (cm) | Soil Water Content (% dry-wt) | | Soil Water Content (% vol.)[1] | | *n* |
|---|---|---|---|---|---|---|---|---|
| | | | | Mean | S.E.(mean) | Mean[2] | S.E.(mean) | |
| Burrell Cover Without plants | May 10, 1995 | Drainage Layer | 15 | 4.3 | 0.6 | | | 5 |
| | | Drainage Layer | 30–45 | 4.3 | 0.3 | | | 5 |
| | | Radon Barrier | 15 | 20.3 | 1.0 | 35.9 a | 1.0 | 5 |
| | | Radon Barrier | 45–60 | 19.3 | 0.7 | 34.2 a | 0.7 | 5 |
| Burrell Cover Without Plants | July 28, 1995 | Drainage Layer | 30–45 | 4.7 | 0.2 | | | 5 |
| | | Radon Barrier | 15 | 18.2 | 0.9 | 32.2 a | 0.9 | 5 |
| | | Radon Barrier | 30–60 | 19.2 | 0.5 | 34.1 a | 0.5 | 5 |
| Burrell Cover With Plants | July 28, 1995 | Drainage Layer | 30–45 | 4.8 | 0.2 | | | 5 |
| | | Radon Barrier | 15 | 19.1 | 0.7 | 33.6 a | 0.7 | 5 |
| | | Radon Barrier | 30 | 18.8 | 0.3 | 33.2 a | 0.3 | 5 |
| | | Radon Barrier | 50–60 | 18.3 | 0.2 | 32.2 a | 0.2 | 4 |
| Hannastown Analog Site | July 27, 1995 | A Horizon | 15 | 17.8 | 0.9 | | | 5 |
| | | B Horizon | 60 | 17.0 | 0.6 | 25.1 b | 0.6 | 5 |
| | | B Horizon | 110 | 16.5 | 0.7 | 24.4 b | 0.7 | 5 |

[1]Calculated using bulk density values from Table 2–5.
[2]Means marked with the same letter are not significantly different ($\alpha = 0.05$).

### 2.4.2 Soil Hydraulic Properties

Soil hydraulic properties of the Burrell CSL and the Hannastown subsoil were needed for radon flux and water infiltration analyses. These soil hydraulic-property data were also used as a measure of the value of Hannastown as an analog site. Saturated hydraulic conductivity and water-retention characteristics were determined with standard laboratory methods (see Table 2–4). For those tests, samples were recompacted at bulk densities consistent with field values (Table 2–5). The RETC code (van Genuchten et al., 1991) was used to quantify unsaturated soil-water retention characteristics and curve fitting. Table 2–7 presents a summary of the results. The soil-water retention curves are available in Waugh and Smith (1997).

*Table 2–7. Initial Test Conditions, Laboratory Saturated Hydraulic Conductivity ($K_{sat}$), and Water-Retention Characteristics for Recompacted Burrell CSL and Hannastown Analog Subsoil*

| Material Type | Initial Test Conditions | | | | $K_{sat}$ (cm · s$^{-1}$) | Water Retention Characteristics | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | $\theta_g$ [a] | $\theta_v$ [b] | $\rho_b$ [c] | $S_t$ [d] | | $\theta_s$ [e] | $\theta_r$ [f] | $n$ [g] | $\alpha$ [g] | $r^2$ [h] |
| Burrell CSL 1 | 19.0 | 33.9 | 1.78 | 32.7 | $2.6 \times 10^{-8}$ | 36.4 | 0.10 | 1.524 | 0.0001 | 0.963 |
| Burrell CSL 2 | 18.5 | 33.2 | 1.79 | 32.5 | $3.3 \times 10^{-8}$ | 36.7 | 0.06 | 1.163 | 0.0014 | 0.966 |
| Hannastown 1 | 16.2 | 24.1 | 1.48 | 44.0 | $1.4 \times 10^{-7}$ | 43.1 | 0.02 | 1.312 | 0.0022 | 0.993 |
| Hannastown 2 | 16.0 | 23.8 | 1.49 | 44.0 | $5.1 \times 10^{-7}$ | 40.8 | 0.08 | 1.416 | 0.0008 | 0.999 |

[a]Gravimetric percent water content.
[b]Volumetric percent water content.
[c]Dry-weight bulk density (g · cm$^{-3}$).
[d]Total porosity calculated as $1 - \rho_b/\rho_p$ with an assumed particle density, $\rho_p$, of 2.65 g · cm$^{-3}$.
[e]Saturated water content as % volumetric; the maximum volumetric water content of the soil.
[f]Residual water content; the maximum amount of water in a soil that will not contribute to liquid flow.
[g]The symbols $n$ and $\alpha$ are empirical curve-fitting constants that affect the shape of the water-retention curve using the equation of van Genuchten (1980).
[h]The coefficient of determination is a measure of how well the van Genuchten curve fits the observed data.

# 3.0 Root Intrusion Effects on Radon Flux

The Uranium Mill Tailings Remedial Action (UMTRA) Project designed the Burrell cover to conform to standards promulgated by EPA for the release rate of $^{222}Rn$. The rules in 40 CFR Part 192 require assurance that the release rate will not exceed 20 $pCi \cdot m^{-2} \cdot s^{-1}$ "for a period of 1000 years to the extent reasonably achievable and in any case for at least 200 years when averaged over the disposal area over at least a one-year period." The U.S. Nuclear Regulatory Commission (NRC) accepts cover designs for which radon attenuation is calculated with the computer program RADON (NRC, 1989) or its predecessor program, RAECOM, as a basis for compliance. We used RADON to test a range of possible current and future influences of root intrusion and ecological development on radon flux from the cover. Input data for the tests consisted of a combination of characterization data from the original investigation, field data depicting current conditions at Burrell, and data from the Hannastown site as an analog of possible future conditions (Waugh and Smith, 1998).

The mathematical model implemented in RADON describes one-dimensional, steady-state radon diffusion through a two-phase multilayer system. The model does not address preferential diffusion in soil macropore structure or active transport through the transpiration stream of plants. Therefore, although RADON is the accepted tool for designing UMTRA disposal cell covers, it may underestimate increases in flux rates attributable to root intrusion and soil development.

## 3.1 RADON Program Input Data

The RADON program requires input data on radiological and physical properties of tailings and cover layers. Original design values for parameters that are not expected to change appreciably or in response to root intrusion were held constant (Table 3–1).

*Table 3–1. Constants Input to RADON Program for Calculating Radon Flux From Burrell Cover*

| Constant | Description | Source |
|---|---|---|
| Tailings Layer Thicknesses (from the bottom to top of the tailings) | Layer 1 = 180 cm<br>Layer 2 = 60 cm<br>Layer 3 = 60 cm | Burrell completion report (Morrison-Knudsen Engineers, Inc., 1994) |
| Tailings Dry Bulk Density | 1.46 $g \cdot cm^{-3}$ | Burrell completion report (Morrison-Knudsen Engineers, Inc., 1994) |
| Tailings $^{222}Rn$ Emanation Coefficient (mean) | 0.15 | Table 2–2 |
| Tailings Water Content | 9.0 | Burrell completion report (Morrison- Knudsen Engineers, Inc., 1994) |
| Cover $^{222}Rn$ Emanation Coefficient | 0.00 | NRC (1989) default |
| Cover $^{226}Ra$ Activity | 0.00 | NRC (1989) default |

Radium-226 activity, soil water content, and dry-weight bulk density were selected as RADON test variables because (1) sensitivity analyses have shown them to be important (e.g., Smith et al., 1985), (2) they are expected to change in the long-term, and/or (3) field measurements (Section 2.4) show that they are influenced by root intrusion and long-term ecological change.

### 3.1.1 Radium-226 Activity

The radiological characterization data for Burrell tailings (Table 2–1) underestimate $^{226}$Ra activity during the 200- to 1,000-year design life of the cover. Radium-226 activity is expected to increase over time as a consequence of $^{230}$Th decay. Table 3–2 gives initial ($t = 0$) $^{226}$Ra and $^{230}$Th activity as measured during construction of the cell (from Table 2–1) and the serial decay of $^{226}$Ra and $^{230}$Th through the year $t = 1{,}000$.

*Table 3–2. Serial Decay of $^{226}$Ra and $^{230}$Th (in picocuries per gram) at Three Depths Based on Average Activity From As-Built Characterization Data*

| Time | Depth = 0–60 cm | | Depth = 60–120 cm | | Depth = 120–300 cm | |
|---|---|---|---|---|---|---|
| (years) | $^{226}$Ra | $^{230}$Th | $^{226}$Ra | $^{230}$Th | $^{226}$Ra | $^{230}$Th |
| 0 | 39.5 | 416.0 | 26.2 | 204.1 | 79.8 | 878.5 |
| 50 | 47.5 | 415.8 | 30.0 | 204.0 | 96.8 | 878.1 |
| 100 | 55.4 | 415.6 | 33.7 | 203.9 | 113.5 | 877.7 |
| 150 | 63.1 | 415.5 | 37.3 | 203.8 | 129.8 | 877.3 |
| 200 | 70.6 | 415.3 | 40.9 | 203.7 | 145.8 | 876.9 |
| 250 | 78.0 | 415.1 | 44.4 | 203.6 | 161.4 | 876.6 |
| 300 | 85.2 | 414.9 | 47.8 | 203.6 | 176.7 | 876.2 |
| 350 | 92.2 | 414.7 | 51.1 | 203.5 | 191.7 | 875.8 |
| 400 | 99.1 | 414.6 | 54.3 | 203.4 | 206.3 | 875.4 |
| 450 | 105.8 | 414.4 | 57.5 | 203.3 | 220.6 | 875.1 |
| 500 | 112.4 | 414.2 | 60.6 | 203.2 | 234.5 | 874.7 |
| 550 | 118.9 | 414.0 | 63.7 | 203.1 | 248.2 | 874.3 |
| 600 | 125.2 | 413.9 | 66.7 | 203.0 | 261.6 | 873.9 |
| 650 | 131.3 | 413.7 | 69.6 | 202.9 | 274.7 | 873.5 |
| 700 | 137.4 | 413.5 | 72.4 | 202.9 | 287.5 | 873.2 |
| 750 | 143.3 | 413.3 | 75.2 | 202.8 | 300.0 | 872.8 |
| 800 | 149.0 | 413.1 | 77.9 | 202.7 | 312.2 | 872.4 |
| 850 | 154.7 | 413.0 | 80.6 | 202.6 | 324.2 | 872.0 |
| 900 | 160.2 | 412.8 | 83.2 | 202.5 | 335.9 | 871.7 |
| 950 | 165.6 | 412.6 | 85.8 | 202.4 | 347.3 | 871.3 |
| 1,000 | 170.9 | 412.4 | 88.2 | 202.3 | 358.5 | 870.9 |

The total $^{226}Ra$ activity in picocuries per gram at any time ($N_2$) was calculated as

$$N_2 = \frac{\lambda_2 (N_1)_0}{\lambda_2 - \lambda_1}(e^{-\lambda_1 t} - e^{-\lambda_2 t}) + (N_2)_0 e^{-\lambda_2 t} \quad (1)$$

where

$\lambda_2$ = $8.63 \times 10^{-6}$, the decay constant for $^{226}Ra$,
$(N_1)_0$ = the initial activity of $^{230}Th$,
$\lambda_1$ = $4.32 \times 10^{-4}$, the decay constant for $^{230}Th$, and
$(N_2)_0$ = the initial activity of $^{226}Ra$.

### 3.1.2 Soil Water Content and Dry-Weight Bulk Density

Soil water content and dry-weight bulk density of the CSL are the two RADON input parameters most influenced by root intrusion and ecological development on the cover. Because radon diffusion in soil is elevated when interconnected pore spaces are filled with air, radon flux is most sensitive to the CSL water content and porosity (NRC, 1989). RADON calculates porosity as a function of the dry-weight bulk density, assuming a constant specific gravity (2.65 $g \cdot cm^{-3}$) and the density of water as unity in grams per cubic centimeter.

NRC considers the long-term soil water content of the CSL to be the parameter that introduces the greatest uncertainty in radon attenuation calculations. In the absence of field data, NRC accepts the soil water content at which permanent wilting occurs as a reasonable value of the long-term soil water content. The permanent wilting point used by UMTRA for design calculations is –15 bars (DOE, 1989). Water retention characteristic curves (Waugh and Smith, 1997) indicated that the –15 bar-soil water equivalent is about 23 percent by volume for the Burrell CSL and about 15 percent by volume for the Hannastown subsoil. In situ dry-weight bulk densities were 1.76 $g \cdot cm^{-3}$ for the Burrell CSL and 1.48 $g \cdot cm^{-3}$ for the Hannastown subsoil (Table 2–5). Converting volumetric water content ($\theta_v$) to gravimetric water content ($\theta_w$) as

$$\theta_w = \theta_v(\rho_w / \rho_b) \quad (2)$$

where $\rho_w$, the density of water, is taken as unity in grams per cubic centimeter, gives –15 bar gravimetric water content equivalent values for Burrell and Hannastown of 13.1 percent and 10.1 percent, respectively. RADON requires gravimetric values.

The –15-bar soil water equivalent is a conservative annual average for the humid climate of western Pennsylvania. At the depth of the Burrell CSL, agricultural and woodland soils in western Pennsylvania only rarely dry to –15 bar (Rogowsky, 1995). NRC also accepts in situ measurements of soil water content if samples are obtained below depths influenced by high seasonal variability. Wet and dry season in situ gravimetric water contents of the Burrell CSL for 1995 (Table 2–6) were not significantly different and, therefore, provide a reasonable and still conservative annual average value of 19.0 percent. The 1995 dry-season water content of 17.1 percent for the Hannastown subsoil is a reasonable long-term value.

## 3.2 RADON Test Matrix

A suite of RADON tests were run encompassing a broad range of current and possible future conditions. Table 3–3 provides summaries of the factorial test structure.

*Table 3–3. RADON Model Test Structure*

| Factor | Level | | Description |
|---|---|---|---|
| Year | 0 | | Current conditions |
| | 200 | | Minimum cover design life |
| | 1000 | | Target cover design life |
| $^{226}$Ra Activity ($pCi \cdot m^{-2} \cdot s^{-1}$) in Three Tailings Layers | Layer 1: (0–60 cm) | 39.5 in year 0<br>70.6 in year 200<br>170.9 in year 100 | $^{226}$Ra activity derived from serial decay calculations (Table 3–2) from sampling of three tailings layers during construction of the disposal cell |
| | Layer 2: (60–120 cm) | 26.2 in year 0<br>40.9 in year 200<br>88.2 in year 1000 | |
| | Layer 3: (120–300 cm) | 79.8 in year 0<br>145.8 in year 200<br>358.5 in year 1000 | |
| Soil Water Content (gravimetric) | Burrell CSL | 13.1% | –15 bar equivalent (Waugh and Smith, 1997) |
| | | 19.0% | In situ mean value (Table 2–6) |
| | Hannastown | 10.1% | –15 bar equivalent (Waugh and Smith, 1997) |
| | | 17.1% | In situ mean value (Table 2–6) |
| Dry-Weight Bulk Density ($g \cdot cm^{-3}$) | Burrell CSL | 1.76 | In situ mean value (Table 2–5) |
| | Hannastown | 1.48 | In situ mean value (Table 2–5) |
| CSL Layer Thickness (cm) | 0.0 | | Rn flux calculated given no CSL |
| | 90.0 | | Actual thickness of the Burrell CSL |
| | Optimum | | RADON calculates the thickness required to maintain $^{222}$Rn flux below the 20 $pCi \cdot m^{-2} \cdot s^{-1}$ standard. |

## 3.3 RADON Test Results and Discussion

Table 3–4 presents a summary of the RADON model test results. Given the constraints and assumptions of these tests, $^{222}$Rn flux levels at the surface of the Burrell disposal cell should not exceed the standard within 1,000 years if the CSL remains intact and dries no more than the Hannastown analog subsoil.

*Table 3–4. RADON Model Test Results; Shaded Results Are for Analog Site Conditions*

| | Test Conditions | | | | | | Test Results[a] | |
|---|---|---|---|---|---|---|---|---|
| | | $^{226}$Ra Activity (pCi/g) in Three Tailings Layers[b] | | | CSL | | | |
| Test No. | Time (0 + *t*) | 0–60 cm | 60–120 cm | 120–300 cm | $\theta_w$[c] (wt%) | $\rho_b$[d] ($g \cdot cm^{-3}$) | CSL (cm) | Rn Flux ($pCi \cdot m^{-2} \cdot s^{-1}$) |
| 1 | 0 | 39.5 | 26.2 | 79.8 | – | – | 0.0 | 23.6 |
| 2 | 0 | 39.5 | 26.2 | 79.8 | 19.0 | 1.76 | < 10.0 | 20.0 |
| 3 | 0 | 39.5 | 26.2 | 79.8 | 19.0 | 1.76 | 90.0 | < 0.1 |
| 4 | 0 | 39.5 | 26.2 | 79.8 | 13.1 | 1.76 | < 10.0 | 20.0 |
| 5 | 0 | 39.5 | 26.2 | 79.8 | 13.1 | 1.76 | 90.0 | 0.8 |
| 6 | 200 | 70.6 | 40.9 | 145.8 | – | – | 0.0 | 42.0 |
| 7 | 200 | 70.6 | 40.9 | 145.8 | 19.0 | 1.76 | < 10.0 | 20.0 |
| 8 | 200 | 70.6 | 40.9 | 145.8 | 19.0 | 1.76 | 90.0 | 15.7 |
| 9 | 200 | 70.6 | 40.9 | 145.8 | 13.1 | 1.76 | 25.1 | 20.0 |
| 10 | 200 | 70.6 | 40.9 | 145.8 | 13.1 | 1.76 | 90.0 | 1.3 |
| 11 | 200 | 70.6 | 40.9 | 145.8 | 17.1 | 1.48 | 26.5 | 20.0 |
| 12 | 200 | 70.6 | 40.9 | 145.8 | 17.1 | 1.48 | 90.0 | 6.3 |
| 13 | 200 | 70.6 | 40.9 | 145.8 | 10.1 | 1.48 | 72.3 | 20.0 |
| 14 | 200 | 70.6 | 40.9 | 145.8 | 10.1 | 1.48 | 90.0 | 16.8 |
| 15 | 1,000 | 170.9 | 88.2 | 358.5 | – | – | 0.0 | 101.0 |
| 16 | 1,000 | 170.9 | 88.2 | 358.5 | 19.0 | 1.76 | < 10.0 | 20.0 |
| 17 | 1,000 | 170.9 | 88.2 | 358.5 | 19.0 | 1.76 | 90.0 | < 0.1 |
| 18 | 1,000 | 170.9 | 88.2 | 358.5 | 13.1 | 1.76 | 74.7 | 20.0 |
| 19 | 1,000 | 170.9 | 88.2 | 358.5 | 13.1 | 1.76 | 90.0 | 3.2 |
| 20 | 1,000 | 170.9 | 88.2 | 358.5 | 17.1 | 1.48 | 73.2 | 20.0 |
| 21 | 1,000 | 170.9 | 88.2 | 358.5 | 17.1 | 1.48 | 90.0 | 15.2 |
| 22 | 1,000 | 170.9 | 88.2 | 358.5 | 10.1 | 1.48 | 163.3 | 20.0 |
| 23 | 1,000 | 170.9 | 88.2 | 358.5 | 10.1 | 1.48 | 90.0 | 40.5 |

[a]All test results are output of the RADON code (NRC, 1989).

[b]$^{226}$Ra activity (picocuries per gram) for the years 0, 200, and 1,000 are based on characterization of $^{226}$Ra and $^{230}$Th activity in the cell during construction (Table 2–1) and calculation of their serial decay (Table 3–2).

[c]$\theta_w$ values: 13.1% was derived from the volumetric moisture retention curve for the Burrell CSL at –15 bar matric potential (Waugh and Smith, 1997), 19.0% was the dry-season mean for 1995 (Table 2–6), 17.1% was the dry-season mean for the Hannastown analog subsoil (Table 2–6), and 10.1% was derived from the volumetric moisture retention curve for the Hannastown analog subsoil at –15 bar matric potential (Waugh and Smith, 1997).

[d]$\rho_b$ bulk density values: 1.76 and 1.48 $g \cdot cm^{-3}$ are in situ values for the Burrell CSL and Hannastown analog subsoil, respectively (Table 2–5).

Given current $^{226}$Ra levels in the tailings, it appears there is little need for a CSL in the cover (Tests 1 through 5). Flux rates at the surface of the tailings in the year $t = 0$ barely exceed the standard (Test 1). A CSL less than 10 cm thick would be more than adequate for compliance with the standard (Tests 2 and 4). The 90-cm CSL maintains flux rates below 1.0 $pCi \cdot m^{-2} \cdot s^{-1}$ regardless of root intrusion; present-day plant growth had no significant

effect on CSL water content (Test 3). Even for the unlikely scenario that plant transpiration dries the CSL water content to –15 bar, flux rates remain below 1.0 pCi · $m^{-2} \cdot s^{-1}$ (Test 5).

Tests 6 through 14 results are for $^{226}Ra$ activity levels in the year $t = 200$. Flux rates at the surface of the tailings (Test 6) are more than twice the standard (42.0 pCi · $m^{-2} \cdot s^{-1}$). However, a CSL less than 10 cm thick would be adequate, given in situ soil water data (Test 7). A minimum 25-cm-thick CSL would be needed, assuming the –15 bar water content (Test 9). A 90-cm CSL remains more than adequate to meet the flux standard at the surface of the disposal cell (Tests 8 and 10), even if it degrades and dries to conditions equivalent to the Hannastown subsoil bulk density, porosity, or –15 bar moisture (Tests 11 through 14).

For the 1,000-year $^{226}Ra$ activity levels (Tests 15 through 23), $^{222}Rn$ flux rates at the top of the tailings exceed 100 pCi · $m^{-2} \cdot s^{-1}$ (Test 15). Given the unlikely assumption that in situ bulk density and porosity at Burrell will remain unchanged, a CSL less than 10 cm thick would be adequate if soil water also remains unchanged (Test 16); a minimum 75-cm CSL would be needed if soil water content dropped to the –15 bar equivalent (Test 18). For current Burrell conditions, the 90-cm CSL remains adequate (Tests 17 and 19). A 90-cm CSL on the disposal cell with dry-season field conditions equivalent to the Hannastown analog subsoil is also adequate to meet the standard (Test 21). However, if unforeseen ecological development and changes in climatic conditions caused the CSL to dry to –15 bar (Test 23), annual average radon flux rates, averaged over the surface of a 90-cm CSL, may double the standard (40.5 pCi · $m^{-2} \cdot s^{-1}$). For this unlikely scenario, a minimum CSL thickness of 163 cm would be required (Test 22).

# 4.0 Contaminant-Leaching Risk Assessment

We developed a three-phase approach to evaluate possible consequences of increased water movement into the tailings that could result from root intrusion of the cover.

- **Phase I: Assessment of Tailings Contaminants**

  Phase I evaluated risks of water extracted directly from the disposal cell to human health and the environment. As a simple screening-level measure of risk, this evaluation required a comparison of reasonable estimates of pore-water concentrations of contaminants of concern (COCs) with drinking water standards. Estimates of existing and potential future COC concentrations were derived from a sequence of leaching and pore-fluid extraction tests using samples augered from the disposal cell. The tests were designed to capture a reasonable range of possible future changes in the chemistry of leach water.

  Phase I test results suggested that water extracted directly from the pile could pose unacceptable risk.

- **Phase II: Assessment of Groundwater Contamination**

  The purpose of Phase II was to model the effects of a higher CSL permeability on the leaching of pore-water COCs into groundwater beneath the disposal cell.

  Phase II required the following information:

  - Estimates of drainage from the cover for current and possible future ecological conditions. A simple soil-water balance model was used to estimate drainage for current Burrell conditions and for Hannastown analog site conditions.
  - Physical and hydraulic properties of disposal cell materials and underlying sediments. These properties were estimated from existing data in the Burrell completion report.
  - Existing water quality data for seeps and wells.

  The results of Phase II modeling indicated that a higher CSL permeability, attributable to root intrusion, would not likely cause concentrations of COCs in groundwater beneath the disposal cell to exceed drinking water standards.

- **Phase III: Exposure Assessment**

  If Phase II had reached the opposite conclusion, then the risk assessment would have proceeded with Phase III. Phase III would have followed EPA guidance for risk characterization and assessment, including identification of potential receptors, exposure analysis, effects assessment, and comparison of the risks of contaminant leaching with the risks of long-term herbicide spraying.

  Phase III would have consisted of the following tasks:

  - Compile information on residential and incidental use of surface water and groundwater in the area. Acquire any information on potential future land use. Clarify DOE property boundaries and the duration of DOE institutional controls at the site.

- Characterize aquatic and terrestrial habitats potentially affected by groundwater and surface water.
- Identify human and ecological pathways, potential receptors, and exposure points.
- Evaluate exposure pathways and estimate exposure point concentrations for a reasonable range of possible future site conditions.
- Calculate hazard quotients and indices.

Phase I and Phase II of the risk assessment were completed in 1998. This section provides summaries of the methods and the results of the Phase I and Phase II tasks listed in Table 4–1.

*Table 4–1. Phase I and Phase II Tasks*

| Task | Description |
|---|---|
| Phase I: | Assessment of Tailings Contaminants |
| | • Complete project plans |
| | • Search and evaluate contaminant geochemistry literature |
| | • Sample and analyze disposal cell materials |
| | • Conduct leach studies of disposal cell materials |
| | • Compare leach study results with drinking water standards |
| Phase II: | Assessment of Groundwater Contamination |
| | • Evaluate existing water quality data |
| | • Compile soil physical and hydraulic property data |
| | • Model soil-water balance of cover |
| | • Model groundwater COC concentrations attributable to cover $K_{sat}$ changes |
| | • Compare groundwater COC estimates with drinking water standards |

## 4.1 Phase I: Assessment of Tailings Contaminants

### 4.1.1 Evaluation of Geochemistry Literature

The Burrell completion report (Morrison-Knudsen Engineers, Inc., 1994) and other project files contained no pore-water quality data for tailings materials. A search for literature on contaminant levels in similar geochemical environments did not provide reasonable or transferable estimates of pore-water quality. Therefore, geochemistry data that were needed to model pore-water quality based on solid-phase chemistry were lacking.

### 4.1.2 Sampling and Analysis of Disposal Cell Materials

Because of the lack of sufficient literature on mill tailings geochemistry similar to Burrell conditions, we chose to sample and analyze tailings materials from the Burrell disposal cell.

Drilling and sampling of tailings materials occurred during two trips to western Pennsylvania. A total of six boreholes were drilled on May 13 and 14, 1998. Figure 4–1 shows the borehole locations on the disposal cell. The holes were advanced using a Simco Model 4000 track-mounted drill equipped with 3.5-inch inside diameter hollow stem augers. Samples were collected with a 140-pound sliding hammer using a 30-inch drop. Borehole sites were prepared by removing the riprap and setting it aside for later replacement. Drill cuttings were placed on plastic sheeting to protect the ground from contamination. Radon barrier materials and tailings were segregated on the plastic sheets. Surface radiation levels were monitored continuously during the drilling operation.

Boreholes 1 and 2 (Figure 4–1) were advanced to the target depth of approximately 21.5 and 20 feet, respectively. However, when cuttings with elevated radioactivity were encountered, the on-site health and safety officer terminated drilling of boreholes 3 through 6 before the target depth was reached. Three new boreholes were drilled on July 8 and 9, 1998, at locations 4, 5, and 6 where the May drilling had encountered contaminated tailings (Figure 4–1). These holes were drilled to approximately 50 feet. Drive samples were collected at 5-foot intervals and lithologic logs of the cuttings were recorded (see Appendix A). Soil samples from an upgradient location were also collected to serve as a reference (background).

Boreholes 4, 5, and 6 were located on the west end of the Burrell disposal cell in an area that an earlier characterization study indicated has the highest radium concentrations in the disposal cell (Morrison-Knudsen Engineers, Inc., 1994).

After the samples were removed, all boreholes were backfilled with cuttings in approximately the same horizons from which they were taken, and the riprap layer was replaced. The auguring and sampling equipment was then cleaned with high-pressure washing equipment following completion of the last hole to prevent the potential spread of residual contamination.

### 4.1.3 Column Leach Study of Disposal Cell Materials

A column leach study was conducted by the Environmental Sciences Laboratory (ESL) at the DOE Grand Junction Office. The purpose of the study was to bound a range of possible future COC concentrations in tailings pore water. Precipitation (rainfall and snowfall) at the site was simulated and passed through samples of contaminated tailings materials that had been retrieved from the Burrell disposal cell. ESL personnel believed that small differences in the chemical composition of the simulated precipitation would have only minor effects on the results because the ionic composition will be dominated by interaction with the soils.

Soil chemical conditions may change over time because of plant growth, microbial activity, change in land use, and other factors. Thus, an acidic solution (pH = 4.5), the same as that used for the toxicity characteristic leaching procedure (TCLP) (51 FR 21648), was passed through the column to represent a worst-case scenario. Considering the chemical conditions currently existing in groundwater at the Burrell site (neutral pH, high sulfate, high calcium, and high alkalinity), groundwater chemistry would have to change drastically for TCLP conditions to occur; therefore, TCLP conditions are highly unlikely.

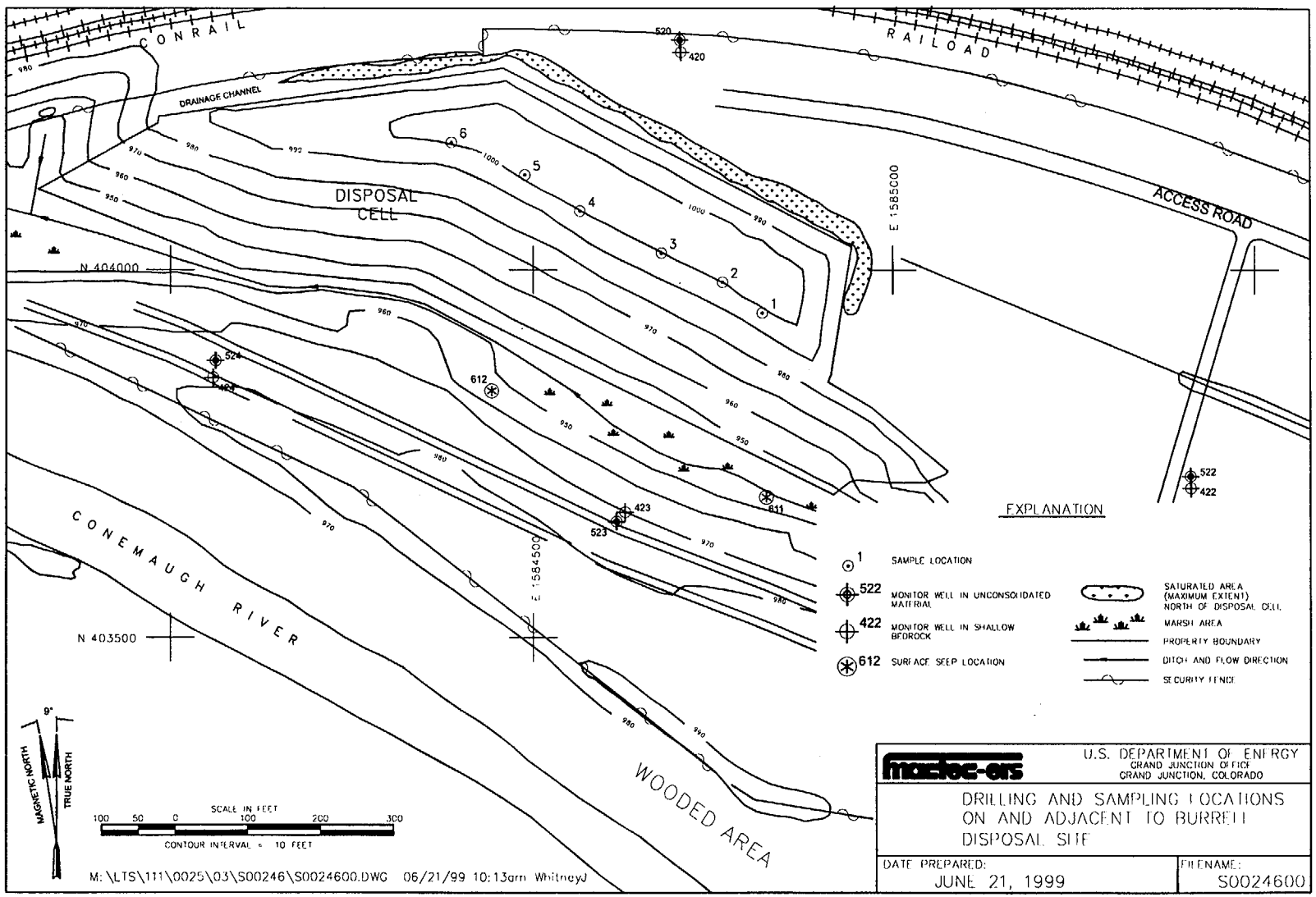


*Figure 4–1. Drilling and Sampling Locations On and Adjacent to Burrell Disposal Site*

A total of five leach tests were performed. Three of the tests used composite samples (a composite consists of material from the entire length of the borings) from each of three borings, boreholes 4, 5, and 6 (see Figure 4–1). Boreholes 4, 5, and 6 were located in an area with the highest radium concentrations in the disposal cell (Section 3.1). A fourth leach test used samples with the highest radioactivity levels. The fifth leach test used background or reference soils collected near, but not influenced by, the Burrell disposal cell. The purpose of the background test was to evaluate if contaminated soils in the disposal cell are likely to release COCs in concentrations above those released by "normal" soils in the area.

The column leach test procedure follows:

1. Borehole cuttings from the disposal cell and the background sample were air dried for 5 days.

2. Columns were constructed of clear acrylic tubing (4-inch inside diameter, 8-inch length). The columns were packed by lightly tamping the sample material. Column designations and sample weights follow:

| Identifier | Sample Weight (g) | Description |
|---|---|---|
| A | 2,099.60 | Composite from borehole 4 |
| B | 2,267.20 | Background sample |
| C | 1,939.40 | Composite from borehole 6 |
| D | 2,203.80 | Composite from borehole 5 |
| E | 536.30 Boreholes 4 (15–16 feet) and 1,821.20 from borehole 6 (15–17 feet) | Hottest (radiological) material from boreholes 4 and 6 |

Composite samples were prepared by spooning nearly equivalent portions from throughout the boreholes. Again, composite samples from boreholes 4, 5, and 6, augered in the area of the disposal cell with highest $^{226}$Ra levels, were selected to bias the tests at the high end of contaminant distribution.

3. Test fluids were passed through the columns from bottom to top with a peristaltic pump. Flow rates were about 1.5 milliliters per minute (mL/min). Samples were collected in a flask placed at the outlet. All fluids were filtered [0.45 micron ($\mu$m)] and submitted to the GJO Analytical Chemistry Laboratory for analyses. Each sample consisted of 1,625 mL divided into 5 separate aliquots for analyses.

Preservation techniques were as follows:

| Container | Preservative | Analyses |
|---|---|---|
| 1 L Nalge | $HNO_3$, pH<2 | $^{226}Ra$, $^{228}Ra$ |
| 250 mL Nalge | NaOH, pH>12 | C, N |
| 125 mL Nalge | $HNO_3$, pH<2 | Pb, Mn, Mo, Se, U, V |
| 125 mL Nalge | None | $SO_4$ |
| 125 mL Nalge | $H_2SO_4$, pH<2 | $NO_3$, $NH_4$ |

4. Deionized water was passed through the columns initially. The first four samples were collected using deionized water as the influent. Then the TCLP fluid was used as the influent. The last two samples were collected using TCLP fluid as the influent. The TCLP fluid was prepared in the GJO Analytical Chemistry Laboratory by combining 5.7 mL of glacial acetic acid, 64.3 mL of 1N NaOH, and diluting the solution to 1L with deionized water. The pH of the TCLP solution is 4.5.

Table 4–2 presents results of the leach study. Appendix B contains several figures that display leachate concentrations for selected constituents.

*Table 4–2. Comparison of the Burrell Site Leach Study Results With Risk-Based Screening Levels and UMTRA Maximum Concentration Limits (MCLs)*

| Constituent (units) | Risk-Based Screening Level[a] | UMTRA MCL | Maximum Deionized Water Concentration | Exceeds Risk Level or MCL? | Maximum TCLP Concentration | Exceeds Risk Level or MCL? |
|---|---|---|---|---|---|---|
| Lead ($\mu$g/L) | N/A[b] | 50 | 1 | No | 38.7 | No |
| Manganese ($\mu$g/L) | 840 | N/A | 1,120 | Yes | 28,300 | Yes |
| Molybdenum ($\mu$g/L) | 180 | 100 | 793 | Yes | 125 | Yes |
| Selenium ($\mu$g/L) | 180 | 10 | 5.8 | No | 24.6 | Yes |
| Uranium ($\mu$g/L) | 110 | 44 | 210 | Yes | 583 | Yes |
| Vanadium ($\mu$g/L) | 260 | N/A | 7 | No | 7 | No |
| Cyanide ($\mu$g/L) | N/A | N/A | 3.9 | N/A | 3.9 | N/A |
| Ammonia ($\mu$g/L) | 1000 | N/A | 233 | No | 419 | No |
| Nitrate ($\mu$g/L) | 58,000 | 44,000 | 2,400 | No | 96 | No |
| $^{226}Ra$ (pCi/L) | N/A | 5[c] | 3.8 | No | 128 | Yes |
| $^{228}Ra$ (pCi/L) | N/A | 5 | <1.4 | No | 6.9 | Yes |
| Sulfate (mg/L) | N/A[d] | N/A | 418 | N/A | 85.5 | N/A |

[a]These are screening-level risks developed by EPA Region III using standard default values. Site concentrations below these levels are generally considered to be protective of human health. Reference "Updated Risk-Based Concentration Table" by Roy L. Smith, Ph.D., Toxicologist, March 17, 1997.
[b]N/A = not available.
[c]Combined $^{226}Ra$ and $^{228}Ra$ level is 5 pCi/L.
[d]Although an official risk-based level has not been developed, proposed levels range from 250 to 2,000 mg/L, depending on site-specific conditions.

### 4.1.4 Comparison of Leach Study Results with Drinking Water Standards

Table 4–2 also presents a comparison of the Phase I leach study results with risk-based screening levels and UMTRA maximum concentration limits (MCLs). The highest leachate concentrations for manganese, molybdenum, and uranium concentrations, using deionized water, exceeded the respective screening threshold and/or the MCL. When leached with the TCLP solution, the COCs manganese, molybdenum, selenium, uranium, $^{226}$Ra, and $^{228}$Ra all exceeded the respective screening threshold and/or the MCL. Risk-based screening threshold values and UMTRA MCLs are shown on the leach study figures in Appendix B.

These Phase I results indicate that water extracted directly from the Burrell disposal cell may pose unacceptable risk to human health and the environment. Therefore, we chose to proceed with Phase II of the risk assessment, Assessment of Groundwater Contamination.

## 4.2 Phase II: Assessment of Groundwater Contamination

The purpose of Phase II was to review existing groundwater quality data and then to model the effects of a higher CSL permeability on the leaching of COCs into groundwater beneath the disposal cell.

### 4.2.1 Summary of Existing Water Quality Data

Groundwater monitor wells and seeps are sampled annually in the fall at the Burrell site (DOE, 1999). The groundwater monitor network consists of two pairs of wells at five locations: two hydraulically downgradient point-of-compliance locations, one hydraulically crossgradient point-of-compliance location, and two hydraulically upgradient point-of-compliance locations. Each well pair consists of a shallow well completed in unconsolidated fill or alluvium and a deeper well completed in shallow bedrock. Seeps along the base of the south side slope of the disposal cell are also sampled. The following 18 constituents are analyzed in the water samples:

| | | |
|---|---|---|
| ammonium | magnesium | selenium |
| calcium | manganese | sodium |
| chloride | molybdenum | sulfate |
| gross alpha | nitrate | total dissolved solids |
| iron | potassium | uranium |
| lead | $^{226}$Ra and $^{228}$Ra | vanadium |

Of the 18 analytes, 7 have exceeded minimum laboratory detection limits since sampling began in 1987, but none exceeded the MCLs in October 1998:

- Gross alpha has occasionally reached detection limits but remains well below the MCL.
- Lead concentrations in samples were anonymously high in 1987, as high as 0.15 mg/L. The MCL is 0.05 mg/L. Lead concentrations have not reached detection limits since then.

- Values for molybdenum (0.06 to 0.08 mg/L) in samples from downgradient locations were also highest in 1987 but below the MCL (0.10 mg/L). Since then, values have dropped by more half but remain higher than samples from upgradient and crossgradient locations.
- Low values for nitrate in samples from downgradient and background locations, barely above detection limits, have persisted.
- Radium-226 and -228 levels in samples from downgradient and background locations have also remained barely above detection limits.
- Selenium concentrations in samples have been at or below laboratory detection limits at all locations since sampling began in 1987.
- Uranium concentrations in samples from downgradient alluvial wells is higher than in background wells. Uranium values increased slightly between 1996 and 1998 but remain below MCLs.

Table 4–3 and Table 4–4 present the analytical results of alluvial and bedrock groundwater samples for October 1998.

*Table 4–3. Summary of Alluvial Groundwater Sample Analytical Results[a]*

| Analyte | UMTRA MCL | Alluvial Groundwater Sample Location | | | | |
|---|---|---|---|---|---|---|
| | | MW-420 (upgradient) | MW-421 (upgradient) | MW-422 (crossgradient) | MW-423 (downgradient) | MW-424 (downgradient) |
| Gross alpha | 15[b] | 9.23 U[c] | 17.14 U | 7.92 U | 24.93 U | 14.57 U |
| Lead | 0.05 | 0.001 U | 0.001 U | 0.001 U | 0.001 U | 0.001 U |
| Molybdenum | 0.10 | 0.001 U | 0.001 U | 0.001 U | 0.0153 | 0.021 |
| Nitrate as $NO_3$ | 44 | 0.0294 | 0.011 U | 0.0245 | 0.0208 | 0.0188 |
| $^{226}Ra$ | 5, combined | 0.15 U | 0.13 U | 0.14 U | 0.51 | 0.13 U |
| $^{228}Ra$ | | 0.93 | 0.62 U | 0.66 U | 0.67 U | 0.64 U |
| Selenium | 0.01 | 0.001 U | 0.001 U | 0.001 U | 0.001 U | 0.001 U |
| Uranium | 0.044 | 0.001 U | 0.001 U | 0.001 U | 0.022 | 0.0019 |

[a]All results in milligrams per liter, except $^{226}Ra$, $^{228}Ra$, and gross alpha are in picocuries per liter.
[b]Excludes contributions from uranium and $^{222}Rn$ decay. Groundwater sample results include uranium and $^{222}Rn$ decay.
[c]U = undetected at respective laboratory reporting limit.

*Table 4–4. Summary of Bedrock Groundwater Sample Analytical Results[a]*

| Analyte | MCL | Bedrock Groundwater Sample Location | | | | |
|---|---|---|---|---|---|---|
| | | MW-520 (upgradient) | MW-521 (upgradient) | MW-522 (crossgradient) | MW-523 (downgradient) | MW-524 (downgradient) |
| Gross alpha | 15[b] | 5.93 U[c] | 10.73 U | 7.37 U | 14.22 U | 9.23 U |
| Lead | 0.05 | 0.001 U | 0.001 U | 0.001 U | 0.001 U | 0.001 U |
| Molybdenum | 0.10 | 0.0014 | 0.0143 | 0.001 U | 0.0138 | 0.0012 |
| Nitrate as $NO_3$ | 44 | 0.0361 | 0.0113 | 0.0194 | 0.0224 | 0.011 U |
| $^{226}Ra$ | 5, combined | 0.15 U | 0.19 U | 0.14 U | 0.14 U | 0.14 U |
| $^{228}Ra$ | | 1.27 | 1.05 | 0.68 U | 0.69 U | 0.66 U |
| Selenium | 0.01 | 0.001 U | 0.001 U | 0.001 U | 0.001 U | 0.001 U |
| Uranium | 0.044 | 0.001 U | 0.001 U | 0.001 U | 0.001 U | 0.001 U |

[a]All results in milligrams per liter, except $^{226}Ra$, $^{228}Ra$, and gross alpha are in picocuries per liter.
[b]Excludes contributions from uranium and $^{222}Rn$ decay. Groundwater sample results include uranium and $^{222}Rn$ decay.
[c]U = undetected at respective laboratory reporting limit.

### 4.2.2 Soil Physical and Hydraulic Property Data for Modeling

Modeling of water movement and drainage from the cover and tailings requires input data on the design, physical properties, and hydraulic properties of cover materials and vegetation.

*Cover Design*

From the tailings layer up, the Burrell cover consists of a 90-cm-thick CSL, a 30-cm-thick sand and gravel drainage layer, and a 30-cm-thick rock layer (Figure 2–1). The specified hydraulic conductivity for the CSL was $1 \times 10^{-7}$ cm · $s^{-1}$. The sand-and-gravel drainage or filter layer in the cover also serves as a bedding layer for the rock armor. The rock armor is sized to prevent erosion of underlying layers given a PMP event, the most severe combination of meteorological and hydrological conditions possible at a site.

*Soil Physical Properties*

Material property data for the CSL were compiled from the completion report for Burrell (Table 2–3). Section 2.4.1 presents soil water content, texture (particle-size distribution), bulk density (compaction), and porosity of samples retrieved from the Burrell cover and from analog soil profiles at Hannastown.

*Soil Hydraulic Properties*

Water retention characteristic data for the Burrell CSL and the Hannastown subsoil, needed to model water movement through the cover, were presented in Section 2.4.2. These data were also used as a measure of the value of Hannastown as an analog site.

At humid sites like Burrell where CSLs have been constructed as the primary barrier to water infiltration, macropore structure in the CSL created by root intrusion and soil development is of greatest concern (Meyer et al., 1996). Root channels and eventually earthworms, burrowing animals, soil structural changes, and other heterogeneities can all combine to promote preferred pathways for flow of water.

At Burrell, given high precipitation and a CSL that is often saturated, the passage of water through the cover is most sensitive to changes in the saturated hydraulic conductivity. Under these conditions, the hydraulic gradient is approximately 1 and water flux through the CSL ($Q^{CSL}$) can be calculated using Darcy's law (Meyer et al., 1996) as

$$Q^{CSL} = K_{sat} \cdot I \tag{3}$$

where

$K_{sat}$ = the vertical saturated conductivity of the CSL,

$I$ = the vertical gradient across the CSL, calculated as $(H + T)/T$

$H$ = the head of water above the CSL, and

$T$ = the thickness of the CSL.

Under saturated conditions, when $H$ is small with respect to $T$, water flux through the CSL is approximated by saturated hydraulic conductivity ($K_{sat}$). Air-entry permeameters (AEPs) (ASTM D5126) were used to estimate in situ changes in $K_{sat}$ and preferential flow attributable to root intrusion and soil development. The AEPs were designed and manufactured by Daniel B. Stephens and Associates, Inc., for use on engineered clay layers and other low-permeability clay soils (Stephens et al., 1988; Havlena and Stephens, 1992).

The AEP tests were designed to capture a reasonable range of current and possible future conditions on the cover. Replicate AEP tests were conducted on the cover in areas without plants ($n = 3$), on the cover where woody plants have rooted into the CSL ($n = 6$), and at the Hannastown analog site ($n = 3$). Permeameter rings were driven into the cover CSL or analog subsoil after removing overlying materials (rock and bedding layers on the cover and plow-layer soil at Hannastown). The CSL-with-plants tests included three Japanese knotweed and three dominant tree species (sycamore, black locust, and staghorn sumac).

Three different methods corresponding to three different conditions encountered during the tests were used to calculate $K_{sat}$:

- Bouwer (1966) method, which assumes initially unsaturated soil, was used for the analog soils;

- Young et al. (1995) method, which assumes initially saturated or nearly saturated soil and deep seepage, was used for most of the cover tests with plants; and

- Young et al. (1995) method that assumes initially saturated or nearly saturated soil and *no* deep seepage. This method was used for cover tests without plants and one test with plants where water moved to the surface after a period of monitoring.

Table 4–5 presents in situ $K_{sat}$ test results. Results for four conditions are presented: (1) the Burrell CSL without plants, (2) the Burrell CSL with Japanese knotweed, (3) the Burrell CSL with trees, and (4) the Hannastown analog subsoil. For all Burrell cover tests, field soil-water content values were at saturation and water was observed ponding in AEP test pits.

- At locations on the disposal cell where plants have *not* rooted (Table 4–5), the in situ $K_{sat}$ of $2.9 \times 10^{-7}$ cm · s$^{-1}$ was about 3 times the CSL design standard ($1 \times 10^{-7}$ cm · s$^{-1}$) (DOE, 1989) and about an order of magnitude higher than laboratory falling-head results for the same soil ($2.6 \times 10^{-8}$ cm · s$^{-1}$).

- Japanese knotweed increased the Burrell CSL $K_{sat}$, within their root zone, by 2 orders of magnitude ($3.0 \times 10^{-5}$ cm · s$^{-1}$). Japanese knotweed taproots grew vertically through the drainage layer of sand and gravel, were diverted laterally at the surface of the CSL, but often turned again deep into the CSL with many secondary laterals and fibrous roots.

- The CSL $K_{sat}$ for the three tree species ($4.8 \times 10^{-7}$ cm · s$^{-1}$; $Q^{CSL}$ = 0.41 millimeter per day) was not significantly different than the control (no plants; Table 4–5). The test trees were taller than Japanese knotweed but had significantly lower foliage density. Tree roots clogged the drainage layer, but only a small percentage of the root biomass was observed in the CSL.

*Table 4–5. Air-Entry Permeameter Tests of In Situ $K_{sat}$ in Burrell CSL and Hannastown Analog Subsoil*

| Conditions Tested | $K_{sat}$ (cm · s$^{-1}$) | $K_{sat}$ (mean) [a] | Calculation Method |
|---|---|---|---|
| Burrell CSL Without Plants | | | |
| Replicate 1 | $1.8 \times 10^{-7}$ | $2.9 \times 10^{-7}$ a | Young et al. (1995)[c] |
| Replicate 2 | $6.0 \times 10^{-7}$ | | Young et al. (1995)[c] |
| Replicate 2 | $1.0 \times 10^{-7}$ | | Young et al. (1995)[c] |
| Burrell CSL With Plants | | | |
| Japanese knotweed | $1.6 \times 10^{-6}$ | $3.0 \times 10^{-5}$ b | Young et al. (1995) |
| Japanese knotweed | $5.8 \times 10^{-5}$ | | Young et al. (1995) |
| Japanese knotweed | $6.1 \times 10^{-4}$ [b] | | Young et al. (1995)[c] |
| Trees | | | |
| Sycamore | $4.0 \times 10^{-7}$ | $4.8 \times 10^{-7}$ a | Young et al. (1995) |
| Staghorn sumac | $7.4 \times 10^{-7}$ | | Young et al. (1995) |
| Black locust | $3.1 \times 10^{-7}$ | | Young et al. (1995) |
| Hannastown Analog Subsoil | | | |
| Replicate 1 | $1.2 \times 10^{-4}$ | $1.2 \times 10^{-4}$ c | Bouwer (1966) |
| Replicate 2 | $1.2 \times 10^{-4}$ | | Bouwer (1966) |
| Replicate 3 | $1.2 \times 10^{-4}$ | | Bouwer (1966) |

[a]Mean values followed by the same letter were not significantly different at $\alpha = 0.05$.
[b]This value was excluded from the mean because water may have seeped along the permeameter wall, resulting in an inflated $K_{sat}$ value.
[c]Shape factors used for calculation were based on the assumption of no deep seepage.

- Measurements of $K_{sat}$ at the Hannastown analog site are considered a reasonable upper range for future conditions on the Burrell cover (Waugh and Smith, 1997). The Hannastown $K_{sat}$ ($1.3 \times 10^{-4}$) was nearly 3 orders of magnitude higher than the Burrell CSL $K_{sat}$ without plants. Dye was used to trace water movement patterns during AEP tests. Excavation of soil profiles following AEP measurements revealed dye on coarse and fine root surfaces, in earthworm holes, and along planes of weakness between soil peds.

### 4.2.3 Ecological Data for Modeling

Plant canopy structure plays a fundamental role in processes involving the interaction of plant communities and their environment such as evapotranspiration (McNaughton and Jarvis, 1983), biomass productivity (deWit,1965), and radiation interception (Ross, 1981) and, therefore, is needed to model these processes. Plant community leaf area index (LAI) was measured at Burrell and Hannastown vegetation with an LAI–2000 Plant Canopy Analyzer (LI-COR, Inc., 1992). The LAI–2000 provides an indirect but accurate estimate of LAI using "fish-eye" lens measurements of canopy gap fractions (the fraction of the sky visible through the canopy) at various angles (Welles and Norman, 1991). Table 4–6 presents a summary of LAI results.

*Table 4–6. Leaf Area Index on Burrell Cover and at Hannastown Site*

| Site | Date | Start Time | Finish Time | LAI[a] | | Visible Sky (%)[b] | $n$[c] |
|---|---|---|---|---|---|---|---|
| | | | | Mean | S.E.(mean) | | |
| Burrell Cover | July 28, 1995 | 19:47 | 20:45 | 0.65 | 0.07 | 57.9 | 100 |
| Hannastown 1 | July 27, 1995 | 19:38 | 19:56 | 4.86 | 0.19 | 1.4 | 25 |
| Hannastown 2 | July 27, 1995 | 18:59 | 19:37 | 5.37 | 0.04 | 1.0 | 25 |

[a]Leaf area index (LAI) is a dimensionless measure of "How much foliage?" LAI can be thought of as square meter of foliage area divided by square meter of ground area. It is also an index of leaf-evaporation surface area.
[b]"Visible sky" is an indicator of canopy light absorption.
[c]The number of sample points ($n$) were located using random points along transects originating at random locations along a baseline.

LAI data for Burrell and Hannastown plant communities provide clues for possible future changes in the plant canopy structure on the engineered cover. Hannastown 1 is a 30-year-old, mixed-deciduous, open-woodland sere in an abandoned pasture. Hannastown 2, a second-growth closed-canopy sugar maple woodland, is perhaps more than 100 years old. A comparison of stands suggests that the Burrell LAI, presently 0.65, may increase sevenfold within 30 years as the community begins to resemble Hannastown 1, resulting in higher evapotranspiration rates that may help dry the soil and reduce the probability of saturated flow events. Lower standard error values for LAI at Hannastown 1 than at Hannastown 2 is an indication of increased uniformity in the canopy over time.

### 4.2.4 Model Soil Water Balance of Cover

Soil moisture data (Table 2–6) suggest that under present-day conditions the Burrell CSL is often saturated. So for present-day conditions, the passage of water through the cover is most sensitive

to changes in the saturated hydraulic conductivity of the CSL. Therefore, for the purpose of modeling present-day groundwater contamination, given saturated conditions, the hydraulic gradient is approximately 1 and water flux through the CSL can be approximated by the saturated hydraulic conductivity.

Hundreds of years from now, assuming Hannastown is a reasonable analog of long-term conditions, the CSL will be significantly drier (Table 2–6). Prediction of water flux through a drier CSL must take into account many factors in the soil water balance and, thus, is more complex. We used a computer model called HELP (Hydrologic Evaluation of Landfill Performance) to predict the water flux or leakage for Hannastown as an analog of a future condition of the Burrell cover.

HELP Version 3.07 (Schroeder et al., 1996) is a quasi two-dimensional hydrologic model of water movement across, into, through, and out of landfills. The model accepts weather, soil, and design data and uses solution techniques that account for surface storage, snowmelt, runoff, infiltration, vegetative growth, evapotranspiration, soil moisture storage, lateral subsurface drainage, leachate recirculation, unsaturated vertical drainage, and leakage through soil, geomembrane, or composite liners. Landfill systems, including combinations of vegetation, cover soils, waste cells, lateral drain layers, barrier soils, and synthetic geomembrane liners, can be modeled. The program was developed to conduct water balance analyses of landfills, cover systems, and solid-waste disposal facilities. The model facilitates rapid estimation of the amounts of runoff, evapotranspiration, drainage, leachate collection, and liner leakage that may be expected to result from the operation of a wide variety of landfill designs.

Tables 4–7, 4–8, and 4–9 present summaries of input parameters, input values, and the source of input values. Table 4–10 presents a summary of average annual water-balance results, averaged for a 10-year simulation.

For Hannastown analog conditions, the HELP simulation indicates that drainage from the Burrell disposal cell cover should not be approximated by the saturated hydraulic conductivity. Water balance changes were most sensitive to LAI. The simulation calculated greater than 60 percent of precipitation lost by evapotranspiration. Approximately 25 percent of the precipitation was lost as leakage from the cover, and the balance was lost as runoff from the disposal cell. Appendix C contains the HELP 3.07 output file for the simulation.

### 4.2.5 Model Groundwater Contaminants of Concern Concentrations

The purpose of this task is to model the effects of the projected increase in the permeability of the CSL on COC concentrations in groundwater beneath the Burrell disposal cell. A range of possible future site conditions are defined based on the root intrusion study (Waugh and Smith, 1998), the column leach study (Section 4.1.3), and cover water-balance modeling (Section 4.2.4).

The following mixing equation from the Summers model (EPA, 1989) was used:

$$Cgw = [QpCp + QaCa] / Qp + Qa \qquad (4)$$

where

$Cgw$ = concentration of contaminant in groundwater after source mixing,

$Qp$ = volumetric flux of source water to aquifer,

$Cp$ = contaminant concentration in source water,

$Qa$ = volumetric flux in aquifer beneath source area, and

$Ca$ = initial contaminant concentration in aquifer.

*Table 4–7. Cover Layer Input Values for HELP Model of Cover Water Balance*

| Parameter | Rock Layer | Drainage Layer | Compacted Soil Layer | Tailings Layer | Data Source |
|---|---|---|---|---|---|
| Layer Type[a] | Lateral drainage | Lateral drainage | Barrier soil | Vertical percolation | HELP user's manual |
| Soil Texture Classification[b] | Sand | Sand | Clay loam | Silty clay loam | Waugh and Smith (1997) |
| Thickness (cm) | 30.0 | 30.0 | 90.0 | 600.0 | Morrison-Knudsen Engineers, Inc. (1994) |
| Porosity (vol/vol) | 0.437 | 0.437 | 0.464 | 0.398 | HELP default value |
| Field Capacity (vol/vol) | 0.062 | 0.062 | 0.310 | 0.244 | HELP default Value |
| Wilting Point (vol/vol) | 0.024 | 0.024 | 0.187 | 0.136 | HELP default value |
| Initial SWC[c] (vol/vol) | 0.188 | 0.127 | 0.464 | 0.274 | HELP calculation |
| Effective $K_{sat}$[d] ($cm \cdot s^{-1}$) | $5.8 \times 10^{-3}$ | $5.8 \times 10^{-3}$ | $6.4 \times 10^{-5}$ | $1.2 \times 10^{-4}$ | Waugh and Smith (1997) |
| Slope (%) | — | 17.0 | — | — | Morrison-Knudsen Engineers, Inc. (1994) |
| Slope Length (meters) | — | 60.0 | — | — | Morrison-Knudsen Engineers, Inc. (1994) |

[a]Selected from options in HELP.
[b]USDA soil texture classification.
[c]SWC = soil water content.
[d]HELP calculated the *effective* $K_{sat}$ for the compacted soil layer from input of Hannastown AEP data. The other $K_{sat}$ values were HELP default values specified for the textural classes selected.

*Table 4–8. Cover Design and Evaporative Zone Data for HELP Model of Water Balance*

| Parameter | Value | Data Source |
|---|---|---|
| Soil Conservation Service runoff curve number | 74.7 | Computed by HELP model based on slope percent, slope length, soil texture, and vegetation |
| Fraction of area allowing runoff | 100.0% | Specified by user |
| Area of landfill surface | 2.5 ha | Morrison-Knudsen, Inc. (1994) |
| Evaporative zone depth | 60.0 cm | HELP override of user input of 150 cm |
| Initial water in evaporative zone | 9.44 cm | Computed by HELP based on weather data |
| Upper limit of evaporative storage | 26.22 cm | Computed by HELP based on soil input data |
| Lower limit of evaporative storage | 1.44 cm | Computed by HELP based on soil input data |
| Initial snow water | 0.0 cm | Computed by HELP based on weather data |
| Initial water in layer materials | 215.41 cm | Computed by HELP based on soil input data |
| Total initial water | 215.41 cm | Computed by HELP based on soil input data |
| Total subsurface inflow | 0.0 cm | Specified by user |

*Table 4–9. Evapotranspiration and Weather Data for HELP Model of Cover Water Balance*

| Parameter | Value | Data Source |
|---|---|---|
| Station latitude | 40.50° | HELP input data for Pittsburgh, Pennsylvania |
| Maximum LAI | 5.37 | Hannastown analog data (Table 4–7) |
| Start of growing season (Julian date) | 114 | HELP weather input data for Pittsburgh |
| End of growing season (Julian date) | 288 | HELP weather input data for Pittsburgh |
| Average annual wind speed | 14 $km \cdot h^{-1}$ [a] | HELP weather input data for Pittsburgh |
| Average first quarter relative humidity | 67% | HELP weather input data for Pittsburgh |
| Average second quarter relative humidity | 63% | HELP weather input data for Pittsburgh |
| Average third quarter relative humidity | 71% | HELP weather input data for Pittsburgh |
| Average fourth quarter relative humidity | 70% | HELP weather input data for Pittsburgh |

[a]$km \cdot h^{-1}$ = kilometers per hour.

*Table 4–10. Output Summary of HELP Simulation of Burrell Cover Water Balance for Hannastown Analog Conditions*

| Water Balance Parameter | Water (cm) | | |
|---|---|---|---|
| | Mean | Std. Dev. | Percent |
| Precipitation | 93.3 | 8.3 | 100.0 |
| Runoff | 9.6 | 7.0 | 10.3 |
| Evapotranspiration | 58.6 | 5.4 | 62.9 |
| Lateral drainage from layer 2 (sand drainage layer) | 1.0 | 0.5 | 1.1 |
| Vertical drainage/leakage through layer 3 (CSL) | 24.1 | 6.1 | 25.8 |
| Average head on top of layer 3 (CSL) | 0.08 | 0.03 | — |
| Vertical drainage/leakage through layer 4 (tailings) | 24.8 | 6.6 | 26.7 |
| Overall change in water storage | –0.8 | 0.2 | –0.1 |

We computed a suite of groundwater COC calculations encompassing a broad range of present-day and possible future conditions. Descriptions of the test conditions follow:

| Factor Descriptions | Level Descriptions |
|---|---|
| 1. **Leach Test.** A range of COC concentrations from results of the column leach tests (Section 4.1). | a. Maximum levels from deionized water tests.<br>b. Maximum levels from TCLP tests.<br>c. Mean levels from TCLP tests. |
| 2. **CSL $K_{sat}$.** Range of $K_{sat}$ values from air-entry permeameter measurements on the Burrell cover and at the Hannastown analog site. | a. Current CSL $K_{sat}$ with no plants.<br>b. Current CSL $K_{sat}$ with Japanese knotweed.<br>c. Analog site $K_{sat}$ and vegetation. |
| 3. **Percent of Maximum $Q_c$.** Percent of the annual precipitation through the CSL; 25% level is based on a HELP simulation (Section 4.0); 100% and 50% levels were sensitivity tests. | a. 100% of precipitation.<br>b. 50% of precipitation.<br>c. 25% of precipitation. |
| 4. **Percent Aquifer $K_{sat}$.** Percent of measured aquifer saturated conductivity. The 10% level was a sensitivity test. | a. 100% aquifer $K_{sat}$.<br>b. 10% aquifer $K_{sat}$. |
| 5. **$^{226}$Ra Ingrowth Time.** A range of $^{226}$Ra concentrations spanning current levels to 1,000 years of ingrowth. | a. Current Ra-226 levels.<br>b. $^{226}$Ra levels after 200 years of ingrowth.<br>c. $^{226}$Ra after 1,000 years of ingrowth. |

### 4.2.6 Results and Discussion of Groundwater Contamination Assessment

The assessment of root intrusion effects on current and possible long-term groundwater quality was based on historical water-quality data and on model simulations of water quality for a range of possible future conditions of the disposal cell cover. Tables 4–11, 4–12, 4–13, and 4–14 present summaries of test conditions and results. Appendix D contains the input and assumptions for the full calculation.

Since monitoring of wells and seeps began in 1987, no COC values have exceeded either the UMTRA MCLs or EPA risk-based drinking water standards (see Table 4–2 and Table 4–3 for MCLs and EPA standards). The maximum historical $^{226}$Ra value (0.5 pCi/L) is an order of magnitude below the MCL (Table 4–11). Concentrations of only 7 of 18 analytes from historical data exceeded minimum laboratory detection limits.

The modeling results suggest that $^{226}$Ra concentrations may slightly exceed MCLs, but only for combinations of the following test conditions (Table 4–11):

- Leaching from the most contaminated areas of the disposal cell.
- pH of 4.5 or less (the TCLP test condition).
- $K_{sat}$ where knotweed rooted through the CSL and at the analog site.
- 100 percent of precipitation percolating through the CSL for current $^{226}$Ra levels or 25 percent of precipitation passing through the CSL for $^{226}$Ra after 1,000 years of ingrowth.
- 100 percent of the measured aquifer $K_{sat}$.

*Table 4–11. UMTRA MCL for $^{226}$Ra, Maximum Value From Historical Monitoring, and Modeling Conditions for Which $^{226}$Ra Exceeded UMTRA MCL*

| Test Condition | | | | | Test Result |
|---|---|---|---|---|---|
| Leach Test | CSL $K_{sat}$ | Percent of Max $Q_c$ | Percent Aquifer $K_{sat}$ | $^{226}$Ra Ingrowth Time (years) | $^{226}$Ra (pCi/L) |
| *UMTRA MCL* | | | | | 5.0 |
| *Maximum Value From Historical Monitoring Data* | | | | | 0.5 |
| Max TCLP | Knotweed | 100 | 100 | 0 | 5.3 |
| Max TCLP | Analog | 100 | 100 | 0 | 5.3 |
| Max TCLP | Analog | 25 | 100 | 1,000 | 5.5 |

*Table 4–12. Groundwater Modeling Test Conditions and Results for Maximum Deionized Water Leaching*

| | Test Condition | | | | | Test Result | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Test No. | Leach Test | CSL $K_{sat}$ | Percent of Max $Q_c$ | Percent Aquifer $K_{sat}$ | $^{226}Ra$ Ingrowth Time (years) | Mn ($\mu$g/L) | Mo ($\mu$g/L) | U ($\mu$g/L) | Se ($\mu$g/L) | $^{226}Ra$ (pCi/L) |
| 1 | Risk screening level | — | 100 | 100 | — | 840 | 180 | 110 | 180 | — |
| 2 | Max DI[a] | No Plants | 100 | 100 | 0 | 9,155 | 3.5 | 1.7 | 1.1 | 0.3 |
| 3 | Max DI | Knotweed | 100 | 100 | 0 | 8,874 | 31.0 | 8.9 | 1.3 | 0.4 |
| 4 | Max DI | Analog | 100 | 100 | 0 | 8,874 | 31.0 | 8.9 | 1.3 | 0.4 |
| 5 | Max DI | No Plants | 100 | 100 | 200 | | | | | 0.3 |
| 6 | Max DI | No Plants | 50 | 100 | 200 | | | | | 0.3 |
| 7 | Max DI | No Plants | 25 | 100 | 200 | | | | | 0.3 |
| 8 | Max DI | Knotweed | 100 | 100 | 200 | | | | | 0.5 |
| 9 | Max DI | Knotweed | 50 | 100 | 200 | | | | | 0.4 |
| 10 | Max DI | Knotweed | 25 | 100 | 200 | | | | | 0.3 |
| 11 | Max DI | Analog | 100 | 100 | 200 | | | | | 0.5 |
| 12 | Max DI | Analog | 50 | 100 | 200 | | | | | 0.4 |
| 13 | Max DI | Analog | 25 | 100 | 200 | | | | | 0.4 |
| 14 | Max DI | No Plants | 100 | 100 | 1,000 | | | | | 0.3 |
| 15 | Max DI | No Plants | 50 | 100 | 1,000 | | | | | 0.3 |
| 16 | Max DI | No Plants | 25 | 100 | 1,000 | | | | | 0.3 |
| 17 | Max DI | Knotweed | 100 | 100 | 1,000 | | | | | 0.8 |
| 18 | Max DI | Knotweed | 50 | 100 | 1,000 | | | | | 0.6 |
| 19 | Max DI | Knotweed | 25 | 100 | 1,000 | | | | | 0.4 |
| 20 | Max DI | Analog | 100 | 100 | 1,000 | | | | | 0.8 |
| 21 | Max DI | Analog | 50 | 100 | 1,000 | | | | | 0.6 |
| 22 | Max DI | Analog | 25 | 100 | 1,000 | | | | | 0.4 |

[a]Max DI = maximum deionized water.

*Table 4–13. Groundwater Modeling Test Conditions and Results for Maximum TCLP Water Leach Tests*

| | Test Condition | | | | | Test Result | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Test No. | Leach Test | CSL $K_{sat}$ | Percent of Max $Q_c$ | Percent Aquifer $K_{sat}$ | $^{226}Ra$ Ingrowth Time (years) | Mn ($\mu$g/L) | Mo ($\mu$g/L) | U ($\mu$g/L) | Se ($\mu$g/L) | $^{226}Ra$ (pCi/L) |
| 23 | Max TCLP | No Plants | 100 | 100 | 0 | 9,241 | 1.6 | 2.8 | 1.2 | 0.7 |
| 24 | Max TCLP | Knotweed | 100 | 100 | 0 | 9,905 | 8.5 | 22.1 | 2.0 | 5.3 |
| 25 | Max TCLP | Analog | 100 | 100 | 0 | 9,905 | 8.5 | 22.1 | 2.0 | 5.3 |
| 26 | Max TCLP | No Plants | 100 | 100 | 200 | | | | | 1.1 |
| 27 | Max TCLP | No Plants | 50 | 100 | 200 | | | | | 1.1 |
| 28 | Max TCLP | No Plants | 25 | 100 | 200 | | | | | 1.1 |
| 29 | Max TCLP | Knotweed | 100 | 100 | 200 | | | | | 10.4 |
| 30 | Max TCLP | Knotweed | 50 | 100 | 200 | | | | | 5.4 |
| 31 | Max TCLP | Knotweed | 25 | 100 | 200 | | | | | 2.9 |
| 32 | Max TCLP | Analog | 100 | 100 | 200 | | | | | 10.4 |
| 33 | Max TCLP | Analog | 50 | 100 | 200 | | | | | 5.4 |
| 34 | Max TCLP | Analog | 25 | 100 | 200 | | | | | 2.9 |
| 35 | Max TCLP | No Plants | 100 | 100 | 1,000 | | | | | 1.9 |
| 36 | Max TCLP | No Plants | 50 | 100 | 1,000 | | | | | 1.9 |
| 37 | Max TCLP | No Plants | 25 | 100 | 1,000 | | | | | 1.9 |
| 38 | Max TCLP | Knotweed | 100 | 100 | 1,000 | | | | | 20.6 |
| 39 | Max TCLP | Knotweed | 50 | 100 | 1,000 | | | | | 10.6 |
| 40 | Max TCLP | Knotweed | 25 | 100 | 1,000 | | | | | 5.5 |
| 41 | Max TCLP | Analog | 100 | 100 | 1,000 | | | | | 20.6 |
| 42 | Max TCLP | Analog | 50 | 100 | 1,000 | | | | | 10.6 |
| 43 | Max TCLP | Analog | 25 | 100 | 1,000 | | | | | 5.5 |

*Table 4–14. Groundwater Modeling Test Conditions and Results for Mean TCLP Water Leach Tests*

| | Test Condition | | | | | Test Result | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Test No. | Leach Test | CSL $K_{sat}$ | Percent of Max $Q_c$ | Percent Aquifer $K_{sat}$ | $^{226}$Ra Ingrowth Time (years) | Mn ($\mu$g/L) | Mo ($\mu$g/L) | U ($\mu$g/L) | Se ($\mu$g/L) | $^{226}$Ra (pCi/L) |
| 44 | Mean TCLP | No Plants | 100 | 100 | 0 | 9,216 | 1.4 | 1.9 | 1.1 | 0.5 |
| 45 | Mean TCLP | No Plants | 100 | 10 | 0 | 9,535 | 5.1 | 9.5 | 1.4 | 2.9 |
| 46 | Mean TCLP | No Plants | 50 | 10 | 0 | 9,535 | 5.1 | 9.5 | 1.4 | 2.9 |
| 47 | Mean TCLP | Knotweed | 100 | 100 | 0 | 9,617 | 6.0 | 11.4 | 1.5 | 3.5 |
| 48 | Mean TCLP | Knotweed | 100 | 10 | 0 | 12,438 | 38.3 | 78.8 | 4.1 | 24.6 |
| 49 | Mean TCLP | Knotweed | 50 | 10 | 0 | 11,077 | 22.7 | 46.3 | 2.8 | 14.4 |
| 50 | Mean TCLP | Analog | 100 | 100 | 0 | 9,617 | 6.0 | 1104 | 1.5 | 3.5 |
| 51 | Mean TCLP | Analog | 100 | 10 | 0 | 12,438 | 38.3 | 78.8 | 4.1 | 24.6 |
| 52 | Mean TCLP | Analog | 50 | 10 | 0 | 11,077 | 22.7 | 46.3 | 2.8 | 14.4 |
| 53 | Mean TCLP | No Plants | 100 | 100 | 200 | | | | | 0.8 |
| 54 | Mean TCLP | No Plants | 50 | 100 | 200 | | | | | 0.8 |
| 55 | Mean TCLP | No Plants | 25 | 100 | 200 | | | | | 0.8 |
| 56 | Mean TCLP | Knotweed | 100 | 100 | 200 | | | | | 6.8 |
| 57 | Mean TCLP | Knotweed | 50 | 100 | 200 | | | | | 3.6 |
| 58 | Mean TCLP | Knotweed | 25 | 100 | 200 | | | | | 1.9 |
| 59 | Mean TCLP | Analog | 100 | 100 | 200 | | | | | 6.8 |
| 60 | Mean TCLP | Analog | 50 | 100 | 200 | | | | | 3.6 |
| 61 | Mean TCLP | Analog | 25 | 100 | 200 | | | | | 1.9 |
| 62 | Mean TCLP | No Plants | 100 | 100 | 1,000 | | | | | 1.3 |
| 63 | Mean TCLP | No Plants | 50 | 100 | 1,000 | | | | | 1.3 |
| 64 | Mean TCLP | No Plants | 25 | 100 | 1,000 | | | | | 1.3 |
| 65 | Mean TCLP | Knotweed | 100 | 100 | 1,000 | | | | | 13.3 |
| 66 | Mean TCLP | Knotweed | 50 | 100 | 1,000 | | | | | 6.9 |
| 67 | Mean TCLP | Knotweed | 25 | 100 | 1,000 | | | | | 3.6 |
| 68 | Mean TCLP | Analog | 100 | 100 | 1,000 | | | | | 13.3 |
| 69 | Mean TCLP | Analog | 50 | 100 | 1,000 | | | | | 6.9 |
| 70 | Mean TCLP | Analog | 25 | 100 | 1,000 | | | | | 3.6 |

The sensitivity tests indicated that $^{226}$Ra levels would exceed the MCL only for TCLP test conditions and if one of the following conditions was met:

- The cover $K_{sat}$ reached $1.2 \times 10^{-4}$ cm · s$^{-1}$ (equivalent to analog site conditions).
- The cover drainage rate was 2 to 4 times greater than that predicted by the HELP model.
- The aquifer $K_{sat}$ dropped to 10 percent of that measured by pump tests.

Model estimates of $^{226}$Ra levels in groundwater at the edge of the disposal cell are considered to be conservative. Radium-226 levels are expected to be much less than the MCL, even after 1,000 years of ingrowth, primarily because radium is relatively immobile in the natural environment. The immobility is due to its strong tendency to substitute with alkaline cations

(particularly Ba, Sr, and Ca) in minerals. Radium also adsorbs to mineral surfaces. While $^{226}Ra$ is the predominant radioactive component at 22 UMTRA sites, it has not migrated any significant distance in the groundwater at these sites.

Because the TCLP leach solution used in the Burrell tests has a low pH (4.5), it is capable of dissolving some of the alkaline cation-bearing mineral phases that would otherwise be stable. Once these minerals are in solution, the radium is released and can migrate. If the conditions changed back to higher pH, the minerals would reprecipitate and the radium would again become immobile. However, it is not likely that the low pH conditions used in the TCLP leach tests will occur in the Burrell tailings. This TCLP leach test was used to represent a worst-case scenario. The chemical conditions of neutral pH, high sulfate, high calcium, and high alkalinity currently existing in groundwater at the Burrell site favor the stability of the radium-bearing minerals. Groundwater chemistry would have to change drastically for these phases to dissolve and mobilize radium.

The results also indicate that high drainage rates from the disposal cell, between 50 and 100 percent of precipitation, would be high enough to leach radium at levels that would exceed the groundwater MCL if TCLP conditions existed. However, such high drainage rates are very unlikely if plant succession progresses unimpeded. Water-balance modeling with the HELP code supports the premise that a combination of runoff and evapotranspiration from native woodland vegetation would limit drainage from the cover to about 25 percent of the precipitation. Therefore, denuding the disposal cell with regular herbicide applications would reduce evapotranspiration and may, in time, actually increase both drainage from the cover and contaminant leaching.

In summary, Phase II modeling results show that a higher CSL permeability attributable to root intrusion would not likely cause concentrations of COCs in groundwater beneath the disposal cell to exceed UMTRA MCLs. Therefore, Phase III, Exposure Assessment, was considered unnecessary.

# 5.0 Summary and Recommendations

This report completes the second part of a two-part investigation of plant root intrusion on the Burrell, Pennsylvania, disposal cell. The first part was a field study of the consequences of plant root intrusion and long-term ecological change on the performance of the disposal cell cover. The second part was a screening assessment of changes in human health and environmental risks associated with existing and potential future changes in cover performance. The LTSM Program planned to use the results of this investigation as the technical basis for choosing one of the following three management options for the Burrell disposal cell and, if warranted, for revision of the long-term surveillance plan for the cell:

- Discontinue herbicide spraying if risks of root intrusion are acceptably low.
- Accept the cost and environmental consequences of continued herbicide spraying, or other long-term maintenance, if risks are sufficiently large.
- Modify the disposal cell cover design and thereby improve risk management over the long term.

## 5.1 Summary

In the first part of the study we evaluated the effects of root intrusion on radon flux and the saturated hydraulic conductivity of the cover. This work resulted in two findings. The first is that root intrusion and associated drying of the cover is not likely to increase radon flux above the 20-pCi $m^{-2} \cdot s^{-1}$ standard unless the western Pennsylvania climate changes from humid to semiarid. The second is that plant roots do increase the hydraulic conductivity of the radon barrier. We measured a 2-orders-of-magnitude increase in the $K_{sat}$ where plant roots penetrated the compacted soil layer (CSL or radon barrier). At a nearby analog site, the $K_{sat}$ was 3 orders of magnitude above the design specification. The analog site represents a reasonable future condition of the cover after 200 to 1,000 years of ecological and pedogenic changes.

The second part of the investigation, the screening-level risk assessment, evaluated possible consequences of increased water movement into the tailings that might result from root intrusion in the cover. Phase I of the risk assessment evaluated concentrations and mobility of contaminants in tailings pore fluid. Composite tailings samples were retrieved from locations within the disposal cell that had the highest radium levels at the time of construction. Column leach tests conducted with the composite samples encompassed a range of current, possible future, and less likely extreme chemical conditions. The results show that manganese, molybdenum, selenium, uranium, and $^{226}Ra$ in pore fluid may exceed either the UMTRCA MCL or an EPA risk-based screening level for one or more of the conditions tested. These results prompted the LTSM Program to proceed with Phase II of the risk assessment.

Phase II estimated groundwater quality beneath the disposal cell for a range of conditions, reasonable and extreme, that could occur during its design life. Phase II combined historical monitoring data from seeps and wells, soil water-balance modeling, and groundwater mixing calculations to estimate groundwater quality for a range of possible future conditions of the cover soils, plant ecology, and tailings pore water chemistry. No COCs in the DOE historical database for seeps and monitor wells came close to the UMTRCA MCLs or the EPA risk-based screening

levels. Modeled groundwater quality estimates for existing conditions were comparable to the historical monitoring data. Even for extreme conditions, all model-predicted COCs, except $^{226}Ra$, were well below the UMTRA MCL and the EPA risk-based screening levels.

The Phase II modeling suggests that $^{226}Ra$ in groundwater would exceed the MCL by, at most, 10 percent, but only for the following unlikely combination of conditions:

- Pore water pH of 4.5 or less,
- A 2 to 3 orders of magnitude increase in the $K_{sat}$ of the CSL because of root intrusion,
- One thousand years of $^{226}Ra$ ingrowth from $^{230}Th$ decay, and
- All pore water leaching from the disposal cell would have contamination levels equal to the most contaminated tailings.

Because a pore water pH of 4.5 is highly unlikely, radium is expected to remain relatively immobile at the Burrell disposal cell. Historical information in the DOE seeps and monitor wells database, and the modeling runs with a pH close to current conditions, support this reasoning. For modeling runs with pH held constant at existing levels, changes in the $K_{sat}$ of the CSL had little effect on $^{226}Ra$ concentrations. Furthermore, contaminant concentrations in groundwater were substantially lower for modeling runs with plant data from the native woodlands at the analog site. LTSM Program personnel concluded that regular denuding of the disposal cell with herbicides would reduce evapotranspiration and, in time, may actually increase drainage from the cover. This increase in drainage could lead to an increase in contaminants leaching into groundwater.

## 5.2 Recommendations

On the basis of the results of this study, we conclude that regular spraying of vegetation on the disposal cell is unwarranted and unjustified. DOE can safely eliminate this requirement from the Burrell long-term surveillance plan. Natural plant succession can be allowed to proceed with no increased risk to human health or the environment. In fact, continued spraying may interfere with the long-term performance of the disposal cell. Because of a much higher evapotranspiration rate, the development of a mature woodland plant community is expected to augment the performance of the disposal cell by limiting drainage through the cover and by reducing the likelihood of contaminant leaching into groundwater below the disposal cell.

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# Appendix A
# Burrell Disposal Cell Borehole Logs
# May 13 and May 14 and July 8 and 9, 1998

**MACTEC-ERS**
2597 B 3/4 Road
Grand Junction, Colorado 81502

Borehole Summary
Page 1 of 2

Facility USDOE GJO LTSM Site Burrell, PA Project LTSM

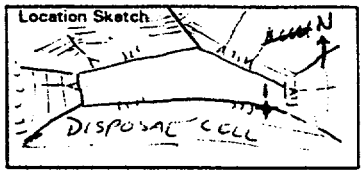
Boring/~~Well~~ No. 1 Location (N) 403900 (E) 1584835

Ground Elev. (Ft.) _____ Bit/Auger Size 6"OD 3 1/4 ID Diameter (inch I. D.) Hole Depth (Ft) 21.5

No. of Completions _____
Stick-Up Height (Ft) _____
Slot Size _____

| | TYPE | Vol. (cf. gal) | Interval (Ft.) |
|---|---|---|---|
| Blank Casing | | | to |
| Screen | | | to |
| Sump/End Cap | | | to |
| Sand Pack | | | to |
| Sealant | | | to |
| Grout | | | to |

Location Sketch




Locking Cover Installed Y / N Padlock No. _____
Drilling Method HSA Truck Mounted (Simco 4000) Sampling Method _____
Date Drilled 5-13-98 Date Developed _____ Fluid Level/Date _____
Sampler(s) M. Kautsky Remarks Sunny, Dry ~70°F

| Depth* (FT) | Blows/ 6" | PID ppm | Sample No.; Interval | WELL CONSTRUCTION | GRAPHIC LOG | DESCRIPTION |
|---|---|---|---|---|---|---|
| | | | | | | **Required Information:** Typical name; Munsell color; percentage sand and gravel; sorting (poor to well); grain angularity; induration or plasticity; moisture content (moist to saturated). |
| 0 | | | | | | MED GY RIP RAP to 12-inch Diam w/D-50 ≈ 8-inches |
| 1 | | | | | | ~~DK~~ Grading finer gravelly @ 1ft-2ft. ~~YEL BRN SILT (ML), MOIST, DENSE~~ (10YR 4/4) |
| 2 | | | | | | DK YEL BRN SILT (ML) 10YR 4/4 MOIST DENSE |
| 3 | | | | | | |
| 4 | | | | | | |
| 5 | | | | | | TURNS BLACK & SANDY @ 6ft depth |
| 6 | 12 35 48 | | | | | BLACK (2.5YR N 2.5/0) SANDY SILT MOIST, DENSE V. LITTLE SAMPLE RECOVERED AT 7ft hit apparent FZ. tie lots of wood frags recovered while drilling out sample interval. Apparently drilled through it at 8ft will sample again. |
| 7 | | | | | | |
| 8 | 11 68 71 100/3 | | | | | (CARBONACEOUS) BLACK SANDY SILTY (ML) MOIST, DENSE w/ WOOD FRAGS (FILL) |
| 9 | | | | | | |

a - All depths measured from ground level. ~~20, 25, 24~~

Completed By M. Kautsky Verified By _____

**MACTEC-ERS**
2597 B 3/4 Road
Grand Junction, Colorado 81502

Borehole No. 1 Date 5-13-98

Borehole Summary
Page 2 of 2

| Depth (FT) | Blows/ 6" | PID ppm | Sample No.: Interval | Well Construction | Graphic Log | DESCRIPTION |
|---|---|---|---|---|---|---|
| | 20 25 24 | | | | | BLACK SILT (ML) (2.5 YR N 2.5/0) MOIST, DENSE SANDY CARBONACEOUS CONTAINS WOOD FRAGS (FILL) |
| 11 | | | | | | |
| 12 | | | | | | |
| 13 | | | | | | |
| 14 | | | | | | |
| 15 | 17 33 40 | | | | | BLACK SANDY CARBONACEOUS SILT (ML) MOIST, DENSE (2.5 YR N 2.5/0) W/ WOOD FRAGS, BOTTLE CAP, RAGS. (FILL) |
| 16 | | | | | | |
| 17 | | | | | | |
| 18 | | | | | | |
| 19 | | | | | | |
| 20 | 75 48 44 | | | | | BLACK SANDY CARBONACEOUS SILT (ML) MOIST DENSE (2.5 YR N2.5/0) W/ WOOD FRAGS (FILL) |
| | | | | | | No Water Encountered. |

All depths measured from ground level.

Completed By Mark Kantsky Verified By

**MACTEC-ERS**
2597 B 3/4 Road
Grand Junction, Colorado 81502

Borehole Summary
Page 1 of 2

Facility US DOE LTSM Site Burrell, PA Project Root Intrusion Study

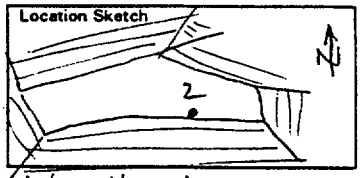
Boring/Well No. 2 Location (N) ~~403580~~ 403580 (E) 1584780

Ground Elev. (Ft.) _____ Bit/Auger Size 6¾ OD 3¼ - ID
Diameter (inch I. D.)

Hole Depth (Ft) _____
No. of Completions _____
Stick-Up Height (Ft) _____
Slot Size _____

| | TYPE | Vol. (cf. gal) | Interval (Ft.) |
|---|---|---|---|
| Blank Casing | | | to |
| Screen | | | to |
| Sump/End Cap | | | to |
| Sand Pack | | | to |
| Sealant | | | to |
| Grout | | | to |

Location Sketch




Locking Cover Installed Y / N Padlock No. _____
Drilling Method Track-Mounted HSA (Simco 4000) Sampling Method Hollow Stem Auger 140# hammer 30"
Date Drilled 5-13-98 Date Developed _____ Fluid Level/Date None
Sampler(s) M. Kautsky Remarks _____

| Depth* (FT) | Blows/ 6" | PID ppm | Sample No.: Interval | WELL CONSTRUCTION | GRAPHIC LOG | DESCRIPTION |
|---|---|---|---|---|---|---|
| | | | | | | **Required Information:** Typical name; Munsell color; percentage sand and gravel; sorting (poor to well); grain angularity; induration or plasticity; moisture content (moist to saturated). |
| 0 | | | | | | MED GY Riprap to 12-inch diam w/ d-50 ≈ 8 inches. (Fill) |
| 1 | | | | | | Finer gravelly riprap w 2-inch d-50 med-gy |
| 2 | | | | | | |
| 3 | | | | | | DK yel-brown (2.5YR N2.5/0) silt (ML) dense, moist radon-barrier cover material |
| 4 | | | | | | |
| 5 | | | | | | Black |
| 6 | | | | | | |
| 7 | | | | | | |
| 8 | | | | | | hard drilling @ 8 ft. – 9½ ft. |

a - All depths measured from ground level.

Completed By Mark Kautsky Verified By _____

**MACTEC-ERS**
2597 B 3/4 Road
Grand Junction, Colorado 81502

Borehole No. 2 Date 5-13-98

Borehole Summary
Page 2 of 2

| Depth (FT) | Blows/ 6" | PID ppm | Sample No.; Interval | Well Construction | Graphic Log | DESCRIPTION |
|---|---|---|---|---|---|---|
| 11 | 21<br>26<br>76/4 | | | | | (2.5 YR N2.5/0)<br>BLACK GRAVELLY SILT (ML), CARBONACEOS (FILL)<br>dense, moist. |
| 12 | | | | | | |
| 13 | | | | | | |
| 14 | | | | | | |
| 15 | 140/4" | | | | | Refusal to sampling (140 blows /4")<br>Black Gravelly Silt (ML) Carbonaceous w/ abundant wood frags. (Fill)<br>dense, slightly moist |
| 16 | | | | | | |
| 17 | | | | | | |
| 18 | 13 | | | | | Grabbed bulk sample of cuttings |
| 19 | 75<br>67 | | 13<br>75<br>67 | | | No recovery (collected bulk cuttings sample) |
| 20 | | | | | | No Water Encountered. |

All depths measured from ground level.

Completed By Mark Hartley Verified By

**MACTEC-ERS**
2597 B 3/4 Road
Grand Junction, Colorado 81502

Borehole Summary
Page 1 of 2

Facility US Dept Energy LTSM Site Burrell Project Weed Intrusion Study

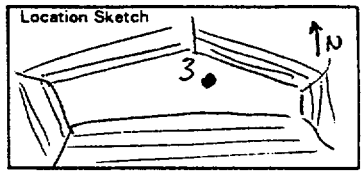
Boring/Well No. 3 Location (N) 404020 (E) 1584680

Ground Elev. (Ft.) _____ Bit/Auger Size 6 1/4" OD ; 3 1/4" ID
Diameter (inch I. D.)

Hole Depth (Ft) 17.5
No. of Completions _____
Stick-Up Height (Ft) _____
Slot Size _____

| | TYPE | Vol. (cf. gal) | Interval (Ft.) |
|---|---|---|---|
| Blank Casing | | | to |
| Screen | | | to |
| Sump/End Cap | | | to |
| Sand Pack | | | to |
| Sealant | | | to |
| Grout | | | to |

Location Sketch




Locking Cover Installed Y / N Padlock No. _____
Drilling Method Track Mounted HSA (Simco 4000) Sampling Method 140# hammer 30 inch drop
Date Drilled 5-13-98 Date Developed _____ Fluid Level/Date No water encountered
Sampler(s) Mark Kautsky Remarks _____

| Depth[a] (FT) | Blows/ 6" | PID ppm | Sample No.: Interval | WELL CONSTRUCTION | GRAPHIC LOG | DESCRIPTION |
|---|---|---|---|---|---|---|
| | | | | | | **Required Information:** Typical name; Munsell color; percentage sand and gravel; sorting (poor to well); grain angularity; induration or plasticity; moisture content (moist to saturated). |
| 0 | | | | | | Dk Gy riprap loose (fill) dry |
| 1 | | | | | | Gray fine gravelly sand (GP) loose, dry (fill) |
| 2 | | | | | | |
| 3 | | | | | | Dk yel-brown (10YR 4/4) silt (ML) moist, dense fill radon barrier cover material |
| 4 | | | | | | |
| 5 | | | | | | Black Silt (ML) dense, moist w/ gravel & wood frags. |
| 6 | | | | | | Rough drilling @ 7 ft |
| 7 | | | | | | |
| 8 | | | | | | |
| 9 | 80 60 50 | | | | | Gray Silty Gravel (GP) dense, moist (fill) |

a - All depths measured from ground level.

Completed By Mark Kautsky Verified By _____

**MACTEC-ERS**
2597 B 3/4 Road
Grand Junction, Colorado 81502

Borehole No. 3 Date 5-13-98

Borehole Summary
Page 2 of 2

| Depth (FT) | Blows/ 6" | PID ppm | Sample No.: Interval | Well Construction | Graphic Log | DESCRIPTION |
|---|---|---|---|---|---|---|
| 11 | | | | | | |
| 12 | | | | | | |
| 13 | | | | | | (2.5 YR N 2.5/0) |
| 14 | 29 | | | | | BLACK (Gravelly) carbonaceous silt (ML) dense, moist |
| | 25 | | | | | w/ wood frags (Fill) |
| 15 | 31 | | | | | |
| 16 | | | | | | |
| 17 | | | | | | Cuttings are contaminated @ > 5000 dpm ( ) |
| | | | | | | terminated drilling @ 17.5 ft. |
| | | | | | | collected bag/grab sample off lead auger |
| 18 | | | | | | |
| 19 | | | | | | |
| 20 | | | | | | |

All depths measured from ground level.

Completed By Mark Kautsky Verified By

**MACTEC-ERS**
2597 B 3/4 Road
Grand Junction, Colorado 81502

Borehole Summary
Page 1 of 2

Facility DOE GJO LTSM Site Burrel Site Project Root Intrusion study

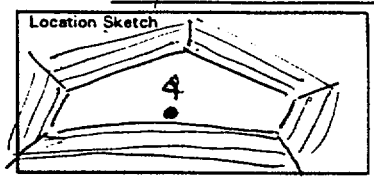
Boring/Well No. 4 Location (N) 404,100 (E) 1584560

Ground Elev. (Ft.) _____ Bit/Auger Size 6 1/4 OD 3 1/4-inch ID
Diameter (inch I. D.)

Hole Depth (Ft) 11.5 ft.
No. of Completions Ø
Stick-Up Height (Ft) Ø
Slot Size Ø

| | TYPE | Vol. (cf. gal) | Interval (Ft.) |
|---|---|---|---|
| Blank Casing | | | to |
| Screen | | | to |
| Sump/End Cap | | | to |
| Sand Pack | | | to |
| Sealant | | | to |
| Grout | | | to |

Location Sketch




Locking Cover Installed Y / N Padlock No. _____
Drilling Method HSA track-mounted (Simco 4000) Sampling Method _____
Date Drilled 5-14-98 Date Developed Ø Fluid Level/Date 54 ft BGL 7-9-98
Sampler(s) Mark Kautsky Remarks _____

| Depth* (FT) | Blows/ 6" | PID ppm | Sample No.; Interval | WELL CONSTRUCTION | GRAPHIC LOG | DESCRIPTION |
|---|---|---|---|---|---|---|
| | | | | | | **Required Information:** Typical name; Munsell color; percentage sand and gravel; sorting (poor to well); grain angularity; induration or plasticity; moisture content (moist to saturated). |
| 0 | | | | | | Gray Riprap to 12-inch diam, loose, dry, (fill) |
| 1 | | | | | | Dk yel-brwn (10YR 4/4) silt (ML) moist, dense (radon cover material) |
| 2 | | | | | | |
| 3 | | | | | | |
| 4 | | | | | | |
| 5 | | | | | | Drilling is harder @ 5 1/2 ft. & black cuttings appearing |
| 6 | | | | | | |
| 7 | | | | | | |
| 8 | 55 26 64 | | | | | Black carbonaceous silt (ML) w/ wood chips, dense, moist. |

* - All depths measured from ground level.

Completed By Mark Kautsky Verified By _____

**MACTEC-ERS**
2597 B 3/4 Road
Grand Junction, Colorado 81502

Borehole No. 4 Date 7-8-98



| Depth (FT) | Blows/ 6" | PID ppm | Sample No.: Interval | Well Construction | Graphic Log | DESCRIPTION |
|---|---|---|---|---|---|---|
| 11 | | | | | | Cuttings are running about 8000 – 9000 |
| 12 | | | | | | dpm through this interval of 10 – 15 ft. |
| 13 | | | | | | Drilling is quite rough at 13 – 15 ft. depth |
| 14 | | | | | | |
| 15 | 30 | | | | | Black Carbonaceous SILT (ML) w/ SLAG, |
| | 100 | | | | | WOOD FRAG, METAL FRAGS Dense, moist |
| 16 | | | | | | Sample material running 600 – 1000 dpm |
| 17 | | | | | | above background. |
| 18 | | | | | | |
| 19 | 200 | | | | | No Recovery will offset to continue boring. Drilling very rough at 18.5 – will try sampling it since we can't drill through it. Ringing blows w/ 140# hammer |
| 20 | 58 | | | | | OFFSET BORING 5 ft east |
| 21 | 53/3 | | | | | BLACK GRAVELLY SILT, ORGANIC, (ML) w/ wood chips & frags of brick, wire steel. ~~etc~~. dense, moist. |
| 22 | | | | | | |
| 23 | | | | | | |
| 24 | | | | | | |
| 25 | 54 | | | | | |
| | 23 | | | | | No Recovery. |
| 26 | 35 | | | | | |
| 27 | | | | | | |
| 28 | | | | | | |

All depths measured from ground level.

Completed By Mark Kantzky Verified By

**MACTEC-ERS**
2597 B 3/4 Road
Grand Junction, Colorado 81502

Borehole No. 4 Date 7-8-98

Borehole Summary
Page 3 of 4

| Depth (FT) | Blows/ 6" | PID ppm | Sample No.: Interval | Well Construction | Graphic Log | DESCRIPTION |
|---|---|---|---|---|---|---|
| 28 | | | | | | |
| 29 | | | | | | |
| 30 | 10 | | | | | Black Carbonaceous Gravelly SILT (ML); Med dense, Moist. (FILL) Radioactivity is at background levels. |
| 31 | 23 38 | | | | | |
| 32 | | | | | | |
| 33 | | | | | | |
| 34 | | | | | | |
| 35 | 18 | | | | | |
| 36 | 12 14 | | | | | WOOD FRAGS IN SAMPLE BARREL CREOSOTE ODOR, RADIATION LEVELS AT BACKGROUND. |
| 37 | | | | | | |
| 38 | | | | | | |
| 39 | | | | | | Drilled to 40ft by COB 7-8-98 |
| 40 | 9 | | | | | WOOD CHIPS & FRAGS IN SAMPLE BARREL BLACK, CREOSOTE ODOR. Rad at background. |
| 41 | 66 37/1 | | | | | |
| 42 | | | | | | |
| 43 | | | | | | |
| 44 | | | | | | |
| 45 | 15 | | | | | BLACK CARBONACEOUS SILT (ML) with wood fragments. Loose, Moist, (Fill) Rad @ Background |
| 46 | 14 | | | | | |

All depths measured from ground level.

Completed By Mark Kautsky Verified By

**MACTEC-ERS**
2597 B 3/4 Road
Grand Junction, Colorado 81502

Borehole No. 4 Date 7-9-98

Borehole Summary
Page 4 of 4

| Depth (FT) | Blows/ 6" | PID ppm | Sample No.: Interval | Well Construction | Graphic Log | DESCRIPTION |
|---|---|---|---|---|---|---|
| 46 | 15 | | | | | |
| 47 | | | | | | Grading Sandier below 46 feet |
| 48 | | | | | | |
| 49 | | | | | | |
| 50 | 8 | | | | | BLACK SILTY SAND (SM) Loose, moist with wood frags (FILL) |
| 51 | 10 20 | | | | | Radiation at background levels |
| 52 | | | | | | |
| 53 | | | | | | |
| 54 | | | | | | |
| 55 | 11 | | | | | water level 54 ft measured. |
| 56 | 11 13 | | | | | No Recovery, Sampler Saturated |
| | | | | | | Borehole 7-9-98 @ 08:35 |
| 57 | | | | | | |
| 58 | | | | | | |
| 59 | | | | | | |
| 60 | | | | | | |
| 61 | | | | | | |
| 62 | | | | | | |
| 63 | | | | | | |
| 64 | | | | | | |

All depths measured from ground level.

Completed By Mark Kantty Verified By

**MACTEC-ERS**
2597 B 3/4 Road
Grand Junction, Colorado 81502

Borehole Summary
Page 1 of 2

Facility DOE GJO LTSM  Site Burrell LTSM Site  Project Root Intrusion Study

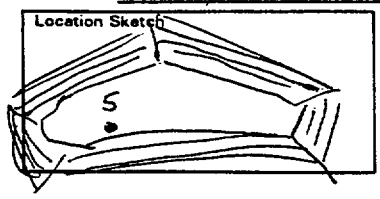
Boring/Well No. 5  Location (N) 404150 (E) 1584480

Ground Elev. (Ft.) _____  Bit/Auger Size 6¼ OD & 3¼ ID
Diameter (inch I. D.)

Hole Depth (Ft) 14.5 ft.
No. of Completions Ø
Stick-Up Height (Ft) Ø
Slot Size Ø

| | TYPE | Vol. (cf. gal) | Interval (Ft.) |
|---|---|---|---|
| Blank Casing | | | to |
| Screen | | | to |
| Sump/End Cap | | | to |
| Sand Pack | | | to |
| Sealant | | | to |
| Grout | | | to |

Location Sketch




Locking Cover Installed Y / N  Padlock No. _____
Drilling Method Hollow Stem Auger (truck mounted) (Simco 4000)  Sampling Method _____
Date Drilled 5-4-98  Date Developed Ø  Fluid Level/Date 60.4 ft. BGL 7-8-98
Sampler(s) Mark Kautsky  Remarks _____

| Depth* (FT) | Blows/ 6" | PID ppm | Sample No.: Interval | WELL CONSTRUCTION | GRAPHIC LOG | DESCRIPTION |
|---|---|---|---|---|---|---|
| | | | | | | **Required Information:** Typical name; Munsell color; percentage sand and gravel; sorting (poor to well); grain angularity; induration or plasticity; moisture content (moist to saturated). |
| 0 | | | | | | Gray Riprap to 12-inch diam (fill) |
| 1 | | | | | | Fine Gravelly (sand) Filter layer (GP) fill ~~DK YEL BRN 10YR 4/4~~ |
| 2 | | | | | | |
| 3 | | | | | | DK YEL BRN (10YR 4/4) SILT (ML) Radon Barrier moist, dense. |
| 4 | | | | | | |
| 5 | | | | | | |
| 6 | | | | | | |
| 7 | | | | | | (2.5YR N2.5/0) |
| 8 | 40 | | | | | Black Λ carbonaceous silt (ML) w/ wood & metal frags (fill) dense, moist. |
| 9 | 47 30 | | | | | |
| 10 | | | | | | |

* - All depths measured from ground level.

Completed By Mark Kautsky  Verified By _____

**MACTEC-ERS**
2597 B 3/4 Road
Grand Junction, Colorado 81502

Borehole No. 5 Date 7-7-98

| Depth (FT) | Blows/ 6" | PID ppm | Sample No.: Interval | Well Construction | Graphic Log | DESCRIPTION |
|---|---|---|---|---|---|---|
| 11 | | | | | | |
| 12 | | | | | | |
| 13 | 40 | | | | | Black (2.5 YR N 2.5/0) Carbonaceous silt (ML) w/ wood frags (fill); dense, moist |
| 14 | 75 | | | | | |
| | 35/3 | | | | | Radiation levels @~7,500 - 8,000 dpm in cuttings |
| 15 | 4 | | | | | |
| | 6 | | | | | |
| 16 | 30 | | | | | Sample @ 15.5 - 16.9 ft Rad levels back down to ~50 counts > bkg |
| | 100/5 | | | | | |
| 17 | | | | | | |
| 18 | | | | | | Cuttings are running ~ 5000 - 6000 dpm Rad. |
| 19 | | | | | | |
| 20 | 8 | | | | | Sample Rad is ~ 60 counts > bkg. |
| | 27 | | | | | Black silt (ML) with brick & RR tie frags dense, moist. (FILL). |
| 21 | 58 | | | | | |
| 22 | | | | | | |
| 23 | | | | | | |
| 24 | | | | | | Drilled to 25 ft depth by CoB 7-7-98 |
| 25 | 35 | | | | | Black organic silt (ML) w/ creosote odor and brick fragments and wood chips; moist, dense (FILL) |
| 26 | 73 | | | | | Rad levels @~600 dpm. |
| 27 | | | | | | |
| 28 | | | | | | |

All depths measured from ground level.

Completed By Mark Kantsky Verified By

MACTEC-ERS
2597 B 3/4 Road
Grand Junction, Colorado 81502

Borehole No. 5 Date 7-7-95

Borehole Summary
Page 3 of 4

| Depth (FT) | Blows/ 6" | PID ppm | Sample No.: Interval | Well Construction | Graphic Log | DESCRIPTION |
|---|---|---|---|---|---|---|
| 29 | | | | | | Gravelly |
| 30 | 4 | | | | | Black Carbonaceous Silt (ML) w/ wood frags |
| 31 | 28 | | | | | dense, moist (FILL); Rad Levels at Background. |
| | 43 | | | | | |
| 32 | | | | | | |
| 33 | | | | | | |
| 34 | | | | | | |
| 35 | 30 | | | | | Contains white powdery material in sample barrel |
| | 100 | | | | | Background Radiation Levels |
| 36 | | | | | | |
| 37 | | | | | | |
| 38 | | | | | | |
| 39 | | | | | | |
| 40 | 7 | | | | | Black Gravelly Silt, Carbonaceous (ML) FILL |
| 41 | 21 | | | | | Radiation levels at Background |
| | 21 | | | | | |
| 42 | | | | | | |
| 43 | | | | | | |
| 44 | | | | | | |
| 45 | 8 | | | | | has become Black silty sand (SM) w/ gravel fragments |
| | 8 | | | | | |

All depths measured from ground level.

Completed By _____ Verified By _____

**MACTEC-ERS**
2597 B 3/4 Road
Grand Junction, Colorado 81502

Borehole No. 5 Date 7-8-98

Borehole Summary
Page 4 of 4

| Depth (FT) | Blows/ 6" | PID ppm | Sample No.: Interval | Well Construction | Graphic Log | DESCRIPTION |
|---|---|---|---|---|---|---|
| 46 | ~~8~~ 8, 14 | | | | | Radiation levels at 20 counts above background or ~ 600 dpm > Background. |
| 47 | | | | | | |
| 48 | | | | | | |
| 49 | | | | | | |
| 50 | 14, 26 | | | | | Black gravelly ~~sandy~~ silty sand (ML) w/ |
| 51 | 14 | | | | | Wood frags (FILL) loose, moist Radiation levels at 600 dpm > Bkg. |
| 52 | | | | | | |
| 53 | | | | | | |
| 54 | | | | | | |
| 55 | 180 | | | | | RR ties, Black, wet, Dense. (Fill) Radiation Levels are at Background. |
| 56 | | | | | | |
| 57 | | | | | | |
| 58 | | | | | | |
| 59 | | | | | | |
| 60 | 21, 25 | | | | | R.R. Ties Black, Saturated, Radiation at Background levels |
| 61 | 26 | | | | | Creosote odor |
| 62 | | | | | | Ground water level at 60.4 ft BG |

All depths measured from ground level.

Completed By Mark Kantsky Verified By

**MACTEC-ERS**
2597 B 3/4 Road
Grand Junction, Colorado 81502

Borehole Summary
Page 1 of 2

Facility DOE GJO LTSM Site Burrell Project Root Intrusion Study

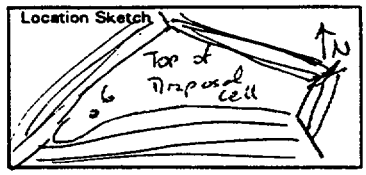
Boring/Well No. 6 Location (N) 404200 (E) 1584400

Ground Elev. (Ft.) _____ Bit/Auger Size 6¼" OD x 3¼" ID HSA
Diameter (inch I. D.)

Hole Depth (Ft) 12.5 feet
No. of Completions _____
Stick-Up Height (Ft) _____
Slot Size _____

| | TYPE | Vol. (cf. gal) | Interval (Ft.) |
|---|---|---|---|
| Blank Casing | | | to |
| Screen | | | to |
| Sump/End Cap | | | to |
| Sand Pack | | | to |
| Sealant | | | to |
| Grout | | | to |

Location Sketch




Locking Cover Installed Y / N Padlock No. _____
Drilling Method Track Mounted Hollow Stem Auger (Simco 4000) Sampling Method _____
Date Drilled 5-14-98 Date Developed _____ Fluid Level/Date _____
Sampler(s) Mark Kantsky Remarks Auger Refusal @ 39.5 ft BGL 7-7-98

| Depth* (FT) | Blows/ 6" | PID ppm | Sample No.; Interval | WELL CONSTRUCTION | GRAPHIC LOG | DESCRIPTION |
|---|---|---|---|---|---|---|
| | | | | | | **Required Information:** Typical name; Munsell color; percentage sand and gravel; sorting (poor to well); grain angularity; induration or plasticity; moisture content (moist to saturated). |
| 0 | | | | | | Riprap, Gray to 12-inch diam. (GP) |
| 1 | | | | | | Fine Gravel / Coarse sand filter blanket (GP) |
| 2 | | | | | | |
| 3 | | | | | | Dk yel-brwn (2.5 YR 4/4) SILT (ML) dense moist, (radon barrier) |
| 4 | | | | | | |
| 5 | | | | | | |
| 6 | | | | | | (2.5 YR N 2.5/0) |
| 7 | | | | | | Black to organic silt. (ML) w/ Abundant wood frags moist, dense |
| 8 | | | | | | |
| 9 | 60 | | | | | |
| 10 | 85 | | | | | No Recovery |

a - All depths measured from ground level.

Completed By Mark Kantsky Verified By _____

MACTEC-ERS
2597 B 3/4 Road
Grand Junction, Colorado 81502

Borehole No. 6 Date 7-7-98

Borehole Summary
Page 2 of

| Depth (FT) | Blows/ 6" | PID ppm | Sample No.: Interval | Well Construction | Graphic Log | DESCRIPTION |
|---|---|---|---|---|---|---|
| | 40/4 | | | | | No Recovery; Sampled again @ 11-12.5 ft |
| 11 | 30 | | | | | |
| | 50 | | | | | Black (2.5 YR N 2.5/0) organic silt (ML), dense, |
| 12 | 25/3 | | | | | moist |
| 13 | | | | | | |
| 14 | | | | | | |
| 15 | 11 | | | | Sloughy | Light Yel Brn sandy clay (CL) @ top of Sample tube is probable slough from cover material |
| 16 | 19 | | | | | |
| | 29 | | | | | Black gravelly silt (ML) organic, dense, moist. |
| 17 | 39 | | | | | ~~Coarse~~ Rad ≈ 9000 dpm. |
| 18 | | | | | | |
| 19 | | | | | | |
| 20 | 9 | | | | | Black gravelly organic silt (ML) med dense, |
| | 17 | | | | | moist |
| 21 | 26 | | | | | Rad ≈ Background |
| 22 | | | | | | |
| 23 | | | | | | |
| 24 | | | | | | |
| 25 | 16 | | | | | Black organic silt w/ wood frags & creosote |
| 26 | 17 | | | | | odor (ML) med dense, moist. (fill) |
| | 18 | | | | | Rad ≈ 2X > Bgd. |
| 27 | | | | | | |

All depths measured from ground level.

Completed by _____ Checked by _____

**MACTEC-ERS**
2597 B 3/4 Road
Grand Junction, Colorado 81502

Borehole No. 6 Date 7-7-98

Borehole Summary
Page 3 of 3

| Depth (FT) | Blows/ 6" | PID ppm | Sample No.: Interval | Well Construction | Graphic Log | DESCRIPTION |
|---|---|---|---|---|---|---|
| 26 | | | | | | |
| 27 | | | | | | |
| 28 | 8 | | | | | |
| 29 | 10 | | | | | |
| 30 | 12 | | | | | |
| 31 | | | | | | WOOD FRAGS, BLACK ORGANIC SILT (ML) FILL, Loose, Moist. Rad ~ 60-100 DPM |
| 32 | | | | | | |
| 33 | | | | | | |
| 34 | | | | | | |
| 35 | 14 | | | | | |
| 36 | 14 | | | | | |
| 37 | 12 | | | | | WOOD DEBRIS & BRICK (FILL) |
| 38 | 180/5" | | | | | WOOD DEBRIS (RR Ties) Hard drilling @ ~~37 ft~~ 37.5 ft Driller says v. hard material. We'll ~~[illegible]~~ sample to see. Rad levels @ Background |
| 39 | | | | | | TD @ 37.5 ft due to auger refusal. |
| 40 | | | | | | |
| 41 | | | | | | |
| 42 | | | | | | |
| 43 | | | | | | |
| 44 | | | | | | |

All depths measured from ground level.

Completed By _____ Verified By _____

# Appendix B
# Leach Study Results for
# Burrell Phase I Screening-Level Risk Assessment

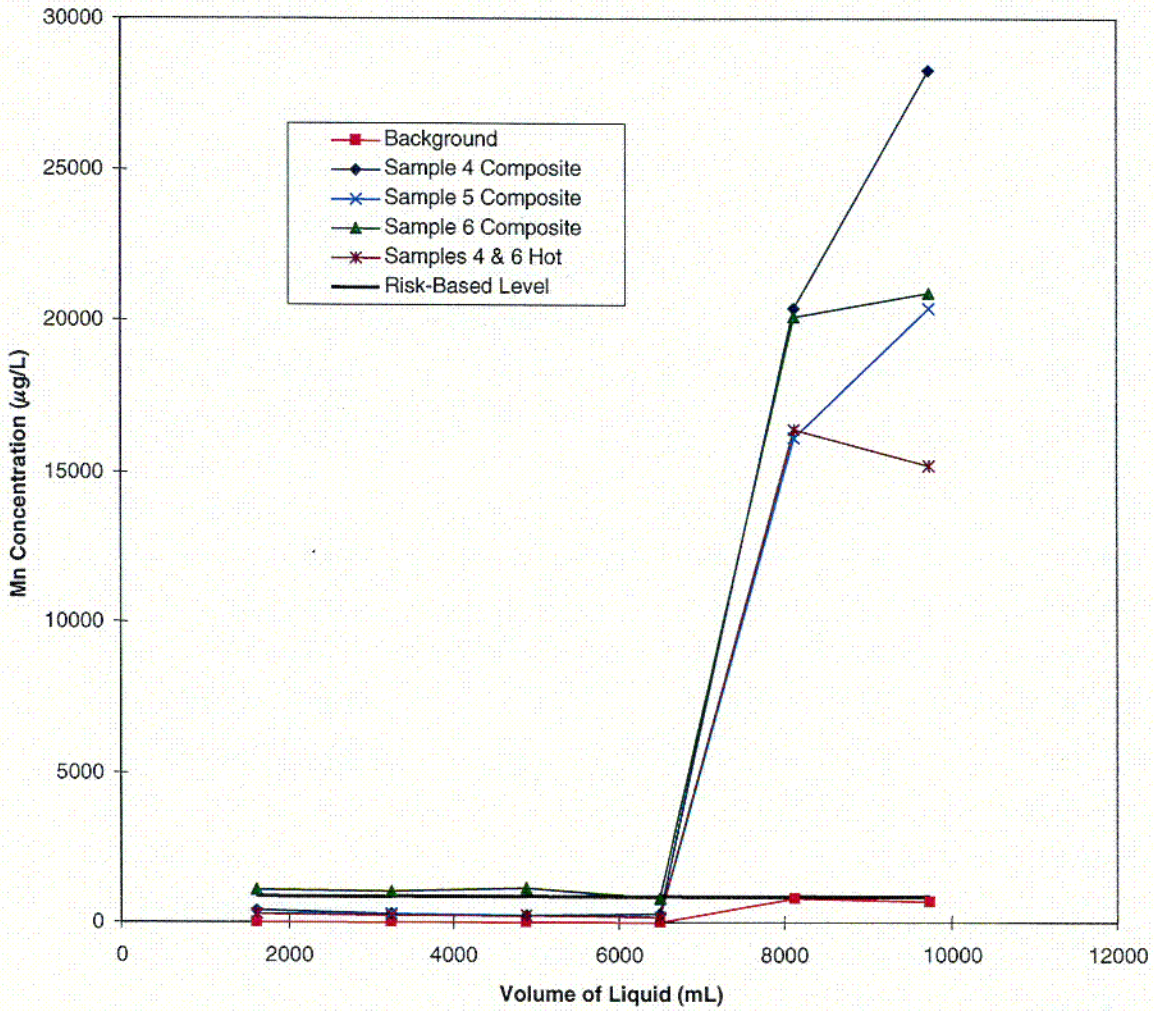



*Figure B–1. Manganese Concentration Results of Leach Study*

C1

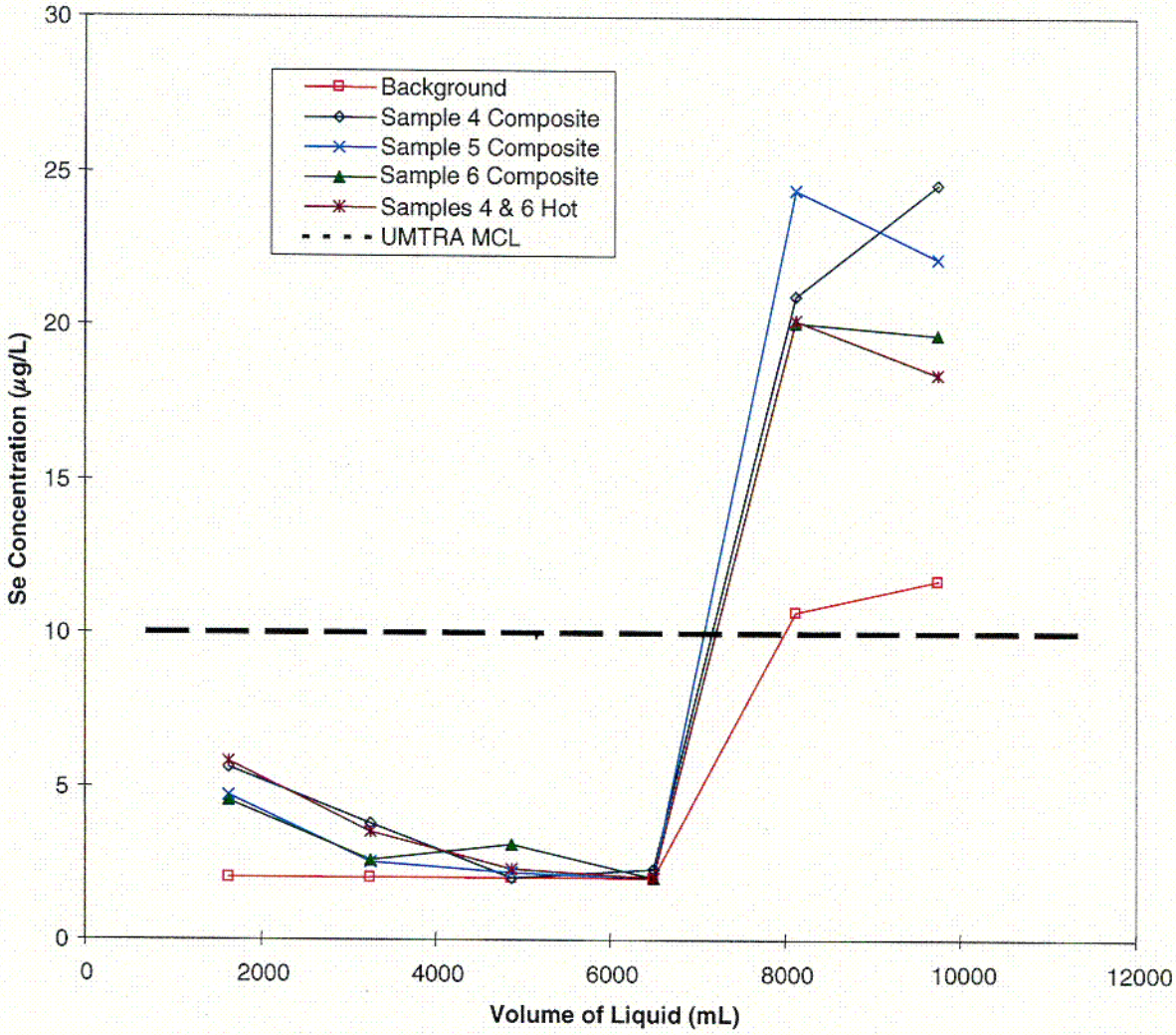



*Figure B–2. Selenium Concentration Results of Leach Study*

C2

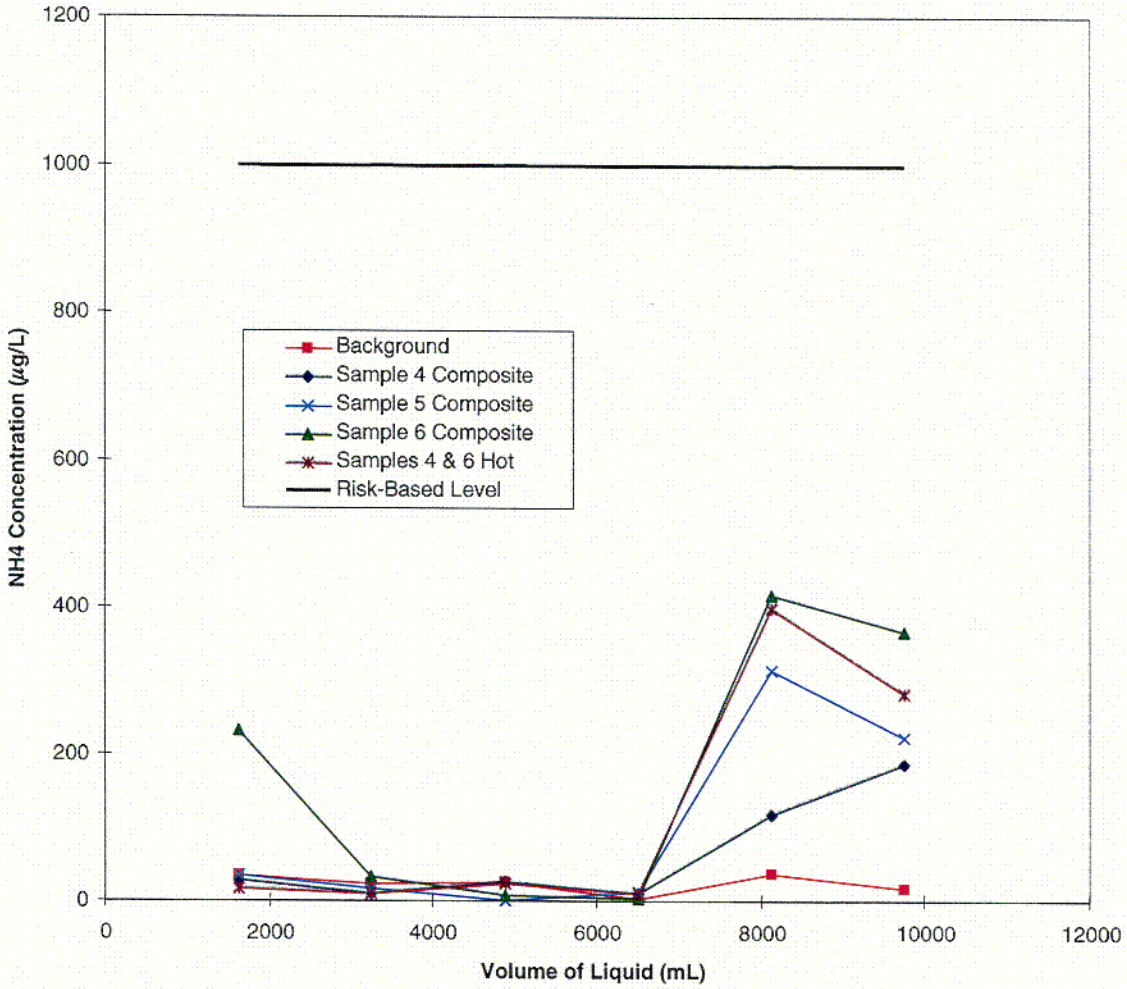



*Figure B–3. Ammonium Concentration Results of Leach Study*

C3

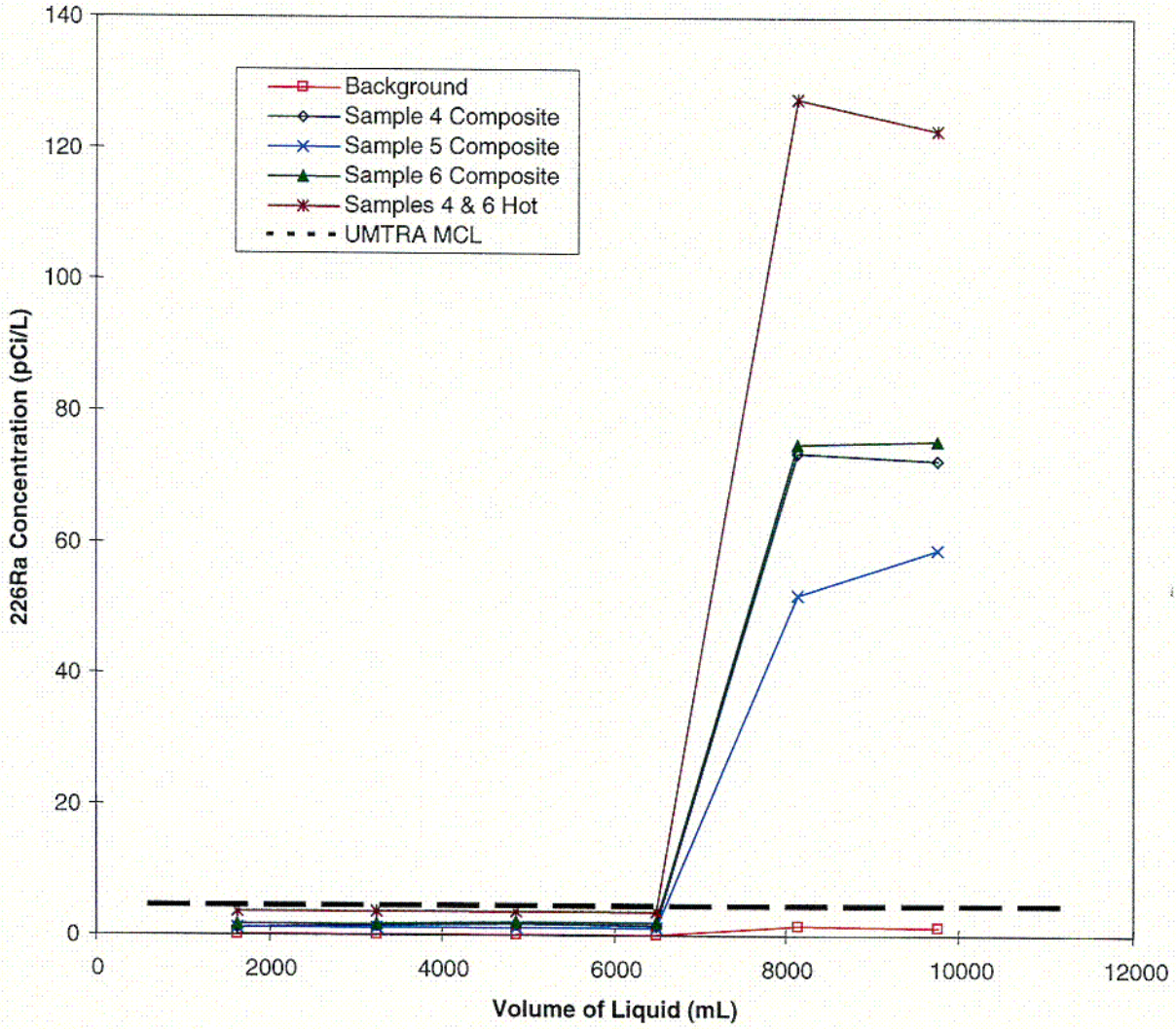



*Figure B–4. Radium-226 Concentration Results of Leach Study*

C4

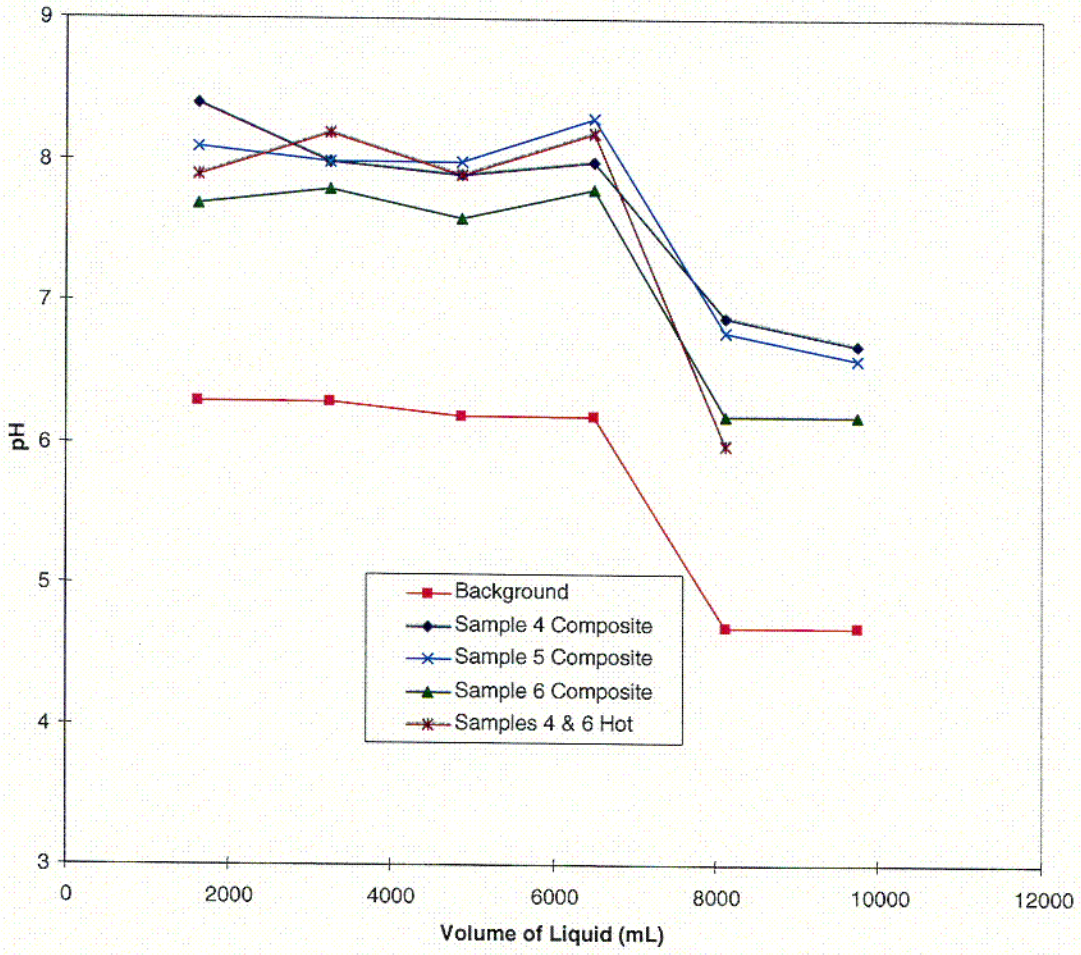



*Figure B–5. pH Concentration Results of Leach Study*

C5

# Appendix C
# HELP Version 3.07 Output File

```
******************************************************************************
******************************************************************************
**                                                                          **
**                                                                          **
**                                                                          **
**              HYDROLOGIC EVALUATION OF LANDFILL PERFORMANCE               **
**                HELP MODEL VERSION 3.07  (1 NOVEMBER 1997)                **
**                  DEVELOPED BY ENVIRONMENTAL LABORATORY                   **
**                    USAE WATERWAYS EXPERIMENT STATION                     **
**             FOR USEPA RISK REDUCTION ENGINEERING LABORATORY              **
**                                                                          **
**                                                                          **
******************************************************************************
******************************************************************************


PRECIPITATION DATA FILE:      C:\HELP\HELP3\BURRELL\DATA4.D4
TEMPERATURE DATA FILE:        C:\HELP\HELP3\BURRELL\DATA7.D7
SOLAR RADIATION DATA FILE:    C:\HELP\HELP3\BURRELL\DATA13.D13
EVAPOTRANSPIRATION DATA:      C:\HELP\HELP3\BURRELL\DATA11.D11
SOIL AND DESIGN DATA FILE:    C:\HELP\HELP3\BURRELL\DATA10.D10
OUTPUT DATA FILE:             C:\HELP\HELP3\BURRELL\Hannas.OUT


TIME:  15:22     DATE:   1/ 6/1999


******************************************************************************

     TITLE:  Burrell LTP Analog

******************************************************************************


     NOTE:  INITIAL MOISTURE CONTENT OF THE LAYERS AND SNOW WATER WERE
              COMPUTED AS NEARLY STEADY-STATE VALUES BY THE PROGRAM.


                                  LAYER  1
                                  --------

                     TYPE 2 - LATERAL DRAINAGE LAYER
                       MATERIAL TEXTURE NUMBER   2
          THICKNESS                    =     30.00   CM
          POROSITY                     =      0.4370 VOL/VOL
          FIELD CAPACITY               =      0.0620 VOL/VOL
          WILTING POINT                =      0.0240 VOL/VOL
          INITIAL SOIL WATER CONTENT   =      0.1875 VOL/VOL
          EFFECTIVE SAT. HYD. COND.    =  0.579999993000E-02 CM/SEC
        NOTE:  SATURATED HYDRAULIC CONDUCTIVITY IS MULTIPLIED BY  5.00
                 FOR ROOT CHANNELS IN TOP HALF OF EVAPORATIVE ZONE.
```

| | | | |
|---|---|---|---|
| SCS RUNOFF CURVE NUMBER | = | 74.70 | |
| FRACTION OF AREA ALLOWING RUNOFF | = | 100.0 | PERCENT |
| AREA PROJECTED ON HORIZONTAL PLANE | = | 2.5000 | HECTARES |
| EVAPORATIVE ZONE DEPTH | = | 60.0 | CM |
| INITIAL WATER IN EVAPORATIVE ZONE | = | 9.444 | CM |
| UPPER LIMIT OF EVAPORATIVE STORAGE | = | 26.220 | CM |
| LOWER LIMIT OF EVAPORATIVE STORAGE | = | 1.440 | CM |
| INITIAL SNOW WATER | = | 0.000 | CM |
| INITIAL WATER IN LAYER MATERIALS | = | 215.409 | CM |
| TOTAL INITIAL WATER | = | 215.409 | CM |
| TOTAL SUBSURFACE INFLOW | = | 0.00 | MM/YR |

## EVAPOTRANSPIRATION AND WEATHER DATA

NOTE: EVAPOTRANSPIRATION DATA WAS OBTAINED FROM
PITTSBURGH PENNSYLVANIA

| | | | |
|---|---|---|---|
| STATION LATITUDE | = | 40.50 | DEGREES |
| MAXIMUM LEAF AREA INDEX | = | 5.40 | |
| START OF GROWING SEASON (JULIAN DATE) | = | 114 | |
| END OF GROWING SEASON (JULIAN DATE) | = | 288 | |
| EVAPORATIVE ZONE DEPTH | = | 60.0 | CM |
| AVERAGE ANNUAL WIND SPEED | = | 14.00 | KPH |
| AVERAGE 1ST QUARTER RELATIVE HUMIDITY | = | 67.00 | % |
| AVERAGE 2ND QUARTER RELATIVE HUMIDITY | = | 63.00 | % |
| AVERAGE 3RD QUARTER RELATIVE HUMIDITY | = | 71.00 | % |
| AVERAGE 4TH QUARTER RELATIVE HUMIDITY | = | 70.00 | % |

NOTE: PRECIPITATION DATA WAS SYNTHETICALLY GENERATED USING
COEFFICIENTS FOR PITTSBURGH PENNSYLVANIA

NORMAL MEAN MONTHLY PRECIPITATION (MM)

| JAN/JUL | FEB/AUG | MAR/SEP | APR/OCT | MAY/NOV | JUN/DEC |
|---|---|---|---|---|---|
| 72.6 | 61.0 | 90.9 | 83.3 | 89.9 | 83.8 |
| 97.3 | 84.1 | 71.1 | 63.2 | 59.4 | 65.3 |

NOTE: TEMPERATURE DATA WAS SYNTHETICALLY GENERATED USING
COEFFICIENTS FOR PITTSBURGH PENNSYLVANIA

NORMAL MEAN MONTHLY TEMPERATURE (DEGREES CELSIUS)

| JAN/JUL | FEB/AUG | MAR/SEP | APR/OCT | MAY/NOV | JUN/DEC |
|---|---|---|---|---|---|
| -2.9 | -1.8 | 3.6 | 10.1 | 15.4 | 20.1 |
| 22.2 | 21.5 | 17.8 | 11.4 | 5.3 | -0.3 |

NOTE: SOLAR RADIATION DATA WAS SYNTHETICALLY GENERATED USING
COEFFICIENTS FOR PITTSBURGH PENNSYLVANIA
AND STATION LATITUDE = 40.50 DEGREES

**********

ANNUAL TOTALS FOR YEAR 1

| | MM | CU. METERS | PERCENT |
|---|---|---|---|
| PRECIPITATION | 979.10 | 24477.496 | 100.00 |
| RUNOFF | 48.960 | 1224.002 | 5.00 |
| EVAPOTRANSPIRATION | 611.612 | 15290.303 | 62.47 |
| DRAINAGE COLLECTED FROM LAYER 2 | 6.9924 | 174.809 | 0.71 |
| PERC./LEAKAGE THROUGH LAYER 3 | 311.337738 | 7783.443 | 31.80 |
| AVG. HEAD ON TOP OF LAYER 3 | 0.8431 | | |
| PERC./LEAKAGE THROUGH LAYER 4 | 293.131042 | 7328.276 | 29.94 |
| CHANGE IN WATER STORAGE | 18.404 | 460.103 | 1.88 |
| SOIL WATER AT START OF YEAR | 2154.090 | 53852.254 | |
| SOIL WATER AT END OF YEAR | 2172.494 | 54312.359 | |
| SNOW WATER AT START OF YEAR | 0.000 | 0.000 | 0.00 |
| SNOW WATER AT END OF YEAR | 0.000 | 0.000 | 0.00 |
| ANNUAL WATER BUDGET BALANCE | 0.0001 | 0.002 | 0.00 |

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ANNUAL TOTALS FOR YEAR 2

| | MM | CU. METERS | PERCENT |
|---|---|---|---|
| PRECIPITATION | 949.50 | 23737.506 | 100.00 |
| RUNOFF | 175.239 | 4380.977 | 18.46 |
| EVAPOTRANSPIRATION | 505.172 | 12629.296 | 53.20 |
| DRAINAGE COLLECTED FROM LAYER 2 | 12.9647 | 324.117 | 1.37 |
| PERC./LEAKAGE THROUGH LAYER 3 | 276.708069 | 6917.702 | 29.14 |
| AVG. HEAD ON TOP OF LAYER 3 | 1.0357 | | |
| PERC./LEAKAGE THROUGH LAYER 4 | 258.220673 | 6455.517 | 27.20 |
| CHANGE IN WATER STORAGE | -2.096 | -52.405 | -0.22 |
| SOIL WATER AT START OF YEAR | 2172.494 | 54312.359 | |
| SOIL WATER AT END OF YEAR | 2170.398 | 54259.953 | |
| SNOW WATER AT START OF YEAR | 0.000 | 0.000 | 0.00 |
| SNOW WATER AT END OF YEAR | 0.000 | 0.000 | 0.00 |
| ANNUAL WATER BUDGET BALANCE | 0.0002 | 0.005 | 0.00 |

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ANNUAL TOTALS FOR YEAR 3

| | MM | CU. METERS | PERCENT |
|---|---|---|---|
| PRECIPITATION | 941.20 | 23530.002 | 100.00 |
| RUNOFF | 200.294 | 5007.351 | 21.28 |
| EVAPOTRANSPIRATION | 538.866 | 13471.652 | 57.25 |
| DRAINAGE COLLECTED FROM LAYER 2 | 17.5808 | 439.519 | 1.87 |
| PERC./LEAKAGE THROUGH LAYER 3 | 165.019241 | 4125.481 | 17.53 |
| AVG. HEAD ON TOP OF LAYER 3 | 1.1729 | | |
| PERC./LEAKAGE THROUGH LAYER 4 | 268.563354 | 6714.084 | 28.53 |
| CHANGE IN WATER STORAGE | -84.104 | -2102.598 | -8.94 |
| SOIL WATER AT START OF YEAR | 2170.398 | 54259.953 | |
| SOIL WATER AT END OF YEAR | 2082.600 | 52065.004 | |
| SNOW WATER AT START OF YEAR | 0.000 | 0.000 | 0.00 |
| SNOW WATER AT END OF YEAR | 3.694 | 92.350 | 0.39 |
| ANNUAL WATER BUDGET BALANCE | -0.0002 | -0.005 | 0.00 |

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ANNUAL TOTALS FOR YEAR 4

| | MM | CU. METERS | PERCENT |
|---|---|---|---|
| PRECIPITATION | 957.00 | 23925.006 | 100.00 |
| RUNOFF | 128.703 | 3217.580 | 13.45 |
| EVAPOTRANSPIRATION | 590.142 | 14753.546 | 61.67 |
| DRAINAGE COLLECTED FROM LAYER 2 | 13.2144 | 330.359 | 1.38 |
| PERC./LEAKAGE THROUGH LAYER 3 | 202.929260 | 5073.231 | 21.20 |
| AVG. HEAD ON TOP OF LAYER 3 | 0.9980 | | |
| PERC./LEAKAGE THROUGH LAYER 4 | 163.453217 | 4086.331 | 17.08 |
| CHANGE IN WATER STORAGE | 61.488 | 1537.190 | 6.43 |
| SOIL WATER AT START OF YEAR | 2082.600 | 52065.004 | |
| SOIL WATER AT END OF YEAR | 2140.796 | 53519.910 | |
| SNOW WATER AT START OF YEAR | 3.694 | 92.350 | 0.39 |
| SNOW WATER AT END OF YEAR | 6.985 | 174.633 | 0.73 |
| ANNUAL WATER BUDGET BALANCE | 0.0000 | 0.001 | 0.00 |

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ANNUAL TOTALS FOR YEAR 5

| | MM | CU. METERS | PERCENT |
|---|---|---|---|
| PRECIPITATION | 962.20 | 24055.006 | 100.00 |
| RUNOFF | 152.428 | 3810.693 | 15.84 |
| EVAPOTRANSPIRATION | 616.114 | 15402.859 | 64.03 |
| DRAINAGE COLLECTED FROM LAYER 2 | 13.3424 | 333.560 | 1.39 |
| PERC./LEAKAGE THROUGH LAYER 3 | 212.949890 | 5323.747 | 22.13 |
| AVG. HEAD ON TOP OF LAYER 3 | 0.9850 | | |
| PERC./LEAKAGE THROUGH LAYER 4 | 198.382782 | 4959.569 | 20.62 |
| CHANGE IN WATER STORAGE | -18.067 | -451.685 | -1.88 |
| SOIL WATER AT START OF YEAR | 2140.796 | 53519.910 | |
| SOIL WATER AT END OF YEAR | 2129.714 | 53242.859 | |
| SNOW WATER AT START OF YEAR | 6.985 | 174.633 | 0.73 |
| SNOW WATER AT END OF YEAR | 0.000 | 0.000 | 0.00 |
| ANNUAL WATER BUDGET BALANCE | 0.0004 | 0.009 | 0.00 |

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ANNUAL TOTALS FOR YEAR 6

| | MM | CU. METERS | PERCENT |
|---|---|---|---|
| PRECIPITATION | 792.00 | 19800.002 | 100.00 |
| RUNOFF | 12.794 | 319.859 | 1.62 |
| EVAPOTRANSPIRATION | 565.461 | 14136.536 | 71.40 |
| DRAINAGE COLLECTED FROM LAYER 2 | 1.5919 | 39.797 | 0.20 |
| PERC./LEAKAGE THROUGH LAYER 3 | 154.971283 | 3874.282 | 19.57 |
| AVG. HEAD ON TOP OF LAYER 3 | 0.2365 | | |
| PERC./LEAKAGE THROUGH LAYER 4 | 188.292969 | 4707.324 | 23.77 |
| CHANGE IN WATER STORAGE | 23.860 | 596.490 | 3.01 |
| SOIL WATER AT START OF YEAR | 2129.714 | 53242.859 | |
| SOIL WATER AT END OF YEAR | 2091.350 | 52283.742 | |
| SNOW WATER AT START OF YEAR | 0.000 | 0.000 | 0.00 |
| SNOW WATER AT END OF YEAR | 62.224 | 1555.608 | 7.86 |
| ANNUAL WATER BUDGET BALANCE | -0.0002 | -0.005 | 0.00 |

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ANNUAL TOTALS FOR YEAR 7

| | MM | CU. METERS | PERCENT |
|---|---|---|---|
| PRECIPITATION | 958.80 | 23969.998 | 100.00 |
| RUNOFF | 131.269 | 3281.722 | 13.69 |
| EVAPOTRANSPIRATION | 570.604 | 14265.103 | 59.51 |
| DRAINAGE COLLECTED FROM LAYER 2 | 12.6456 | 316.140 | 1.32 |
| PERC./LEAKAGE THROUGH LAYER 3 | 304.658539 | 7616.463 | 31.77 |
| AVG. HEAD ON TOP OF LAYER 3 | 1.0521 | | |
| PERC./LEAKAGE THROUGH LAYER 4 | 200.663025 | 5016.576 | 20.93 |
| CHANGE IN WATER STORAGE | 43.618 | 1090.455 | 4.55 |
| SOIL WATER AT START OF YEAR | 2091.350 | 52283.742 | |
| SOIL WATER AT END OF YEAR | 2196.486 | 54912.141 | |
| SNOW WATER AT START OF YEAR | 62.224 | 1555.608 | 6.49 |
| SNOW WATER AT END OF YEAR | 0.706 | 17.662 | 0.07 |
| ANNUAL WATER BUDGET BALANCE | 0.0001 | 0.002 | 0.00 |

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ANNUAL TOTALS FOR YEAR 8

| | MM | CU. METERS | PERCENT |
|---|---|---|---|
| PRECIPITATION | 1049.30 | 26232.498 | 100.00 |
| RUNOFF | 8.389 | 209.731 | 0.80 |
| EVAPOTRANSPIRATION | 698.205 | 17455.135 | 66.54 |
| DRAINAGE COLLECTED FROM LAYER 2 | 1.9622 | 49.054 | 0.19 |
| PERC./LEAKAGE THROUGH LAYER 3 | 306.695312 | 7667.383 | 29.23 |
| AVG. HEAD ON TOP OF LAYER 3 | 0.3481 | | |
| PERC./LEAKAGE THROUGH LAYER 4 | 393.382294 | 9834.558 | 37.49 |
| CHANGE IN WATER STORAGE | -52.639 | -1315.976 | -5.02 |
| SOIL WATER AT START OF YEAR | 2196.486 | 54912.141 | |
| SOIL WATER AT END OF YEAR | 2125.097 | 53127.426 | |
| SNOW WATER AT START OF YEAR | 0.706 | 17.662 | 0.07 |
| SNOW WATER AT END OF YEAR | 19.456 | 486.403 | 1.85 |
| ANNUAL WATER BUDGET BALANCE | -0.0001 | -0.004 | 0.00 |

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ANNUAL TOTALS FOR YEAR 9

| | MM | CU. METERS | PERCENT |
|---|---|---|---|
| PRECIPITATION | 959.40 | 23985.014 | 100.00 |
| RUNOFF | 75.986 | 1899.650 | 7.92 |
| EVAPOTRANSPIRATION | 623.452 | 15586.295 | 64.98 |
| DRAINAGE COLLECTED FROM LAYER 2 | 13.6253 | 340.632 | 1.42 |
| PERC./LEAKAGE THROUGH LAYER 3 | 276.018829 | 6900.471 | 28.77 |
| AVG. HEAD ON TOP OF LAYER 3 | 1.0329 | | |
| PERC./LEAKAGE THROUGH LAYER 4 | 270.685883 | 6767.147 | 28.21 |
| CHANGE IN WATER STORAGE | -24.349 | -608.716 | -2.54 |
| SOIL WATER AT START OF YEAR | 2125.097 | 53127.426 | |
| SOIL WATER AT END OF YEAR | 2110.373 | 52759.332 | |
| SNOW WATER AT START OF YEAR | 19.456 | 486.403 | 2.03 |
| SNOW WATER AT END OF YEAR | 9.831 | 245.780 | 1.02 |
| ANNUAL WATER BUDGET BALANCE | 0.0002 | 0.005 | 0.00 |

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ANNUAL TOTALS FOR YEAR 10

| | MM | CU. METERS | PERCENT |
|---|---|---|---|
| PRECIPITATION | 781.30 | 19532.502 | 100.00 |
| RUNOFF | 27.259 | 681.463 | 3.49 |
| EVAPOTRANSPIRATION | 544.285 | 13607.131 | 69.66 |
| DRAINAGE COLLECTED FROM LAYER 2 | 6.4340 | 160.851 | 0.82 |
| PERC./LEAKAGE THROUGH LAYER 3 | 193.920670 | 4848.017 | 24.82 |
| AVG. HEAD ON TOP OF LAYER 3 | 0.7036 | | |
| PERC./LEAKAGE THROUGH LAYER 4 | 254.105759 | 6352.644 | 32.52 |
| CHANGE IN WATER STORAGE | -50.783 | -1269.586 | -6.50 |
| SOIL WATER AT START OF YEAR | 2110.373 | 52759.332 | |
| SOIL WATER AT END OF YEAR | 2038.710 | 50967.762 | |
| SNOW WATER AT START OF YEAR | 9.831 | 245.780 | 1.26 |
| SNOW WATER AT END OF YEAR | 30.711 | 767.765 | 3.93 |
| ANNUAL WATER BUDGET BALANCE | 0.0000 | 0.000 | 0.00 |

**********

AVERAGES OF MONTHLY AVERAGED DAILY HEADS (CM)

DAILY AVERAGE HEAD ON TOP OF LAYER 3

| | | | | | | |
|---|---|---|---|---|---|---|
| AVERAGES | 0.0056 | 0.0731 | 0.5222 | 0.3199 | 0.0112 | 0.0006 |
| | 0.0000 | 0.0063 | 0.0123 | 0.0102 | 0.0255 | 0.0220 |
| STD. DEVIATIONS | 0.0124 | 0.2304 | 0.4718 | 0.5014 | 0.0106 | 0.0018 |
| | 0.0000 | 0.0084 | 0.0250 | 0.0175 | 0.0227 | 0.0213 |

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AVERAGE ANNUAL TOTALS & (STD. DEVIATIONS) FOR YEARS 1 THROUGH 10

| | MM | | CU. METERS | PERCENT |
|---|---|---|---|---|
| PRECIPITATION | 932.98 | ( 82.781) | 23324.5 | 100.00 |
| RUNOFF | 96.132 | ( 70.3886) | 2403.30 | 10.304 |
| EVAPOTRANSPIRATION | 586.391 | ( 54.4921) | 14659.79 | 62.851 |
| LATERAL DRAINAGE COLLECTED FROM LAYER 2 | 10.03535 | ( 5.42582) | 250.884 | 1.07562 |
| PERCOLATION/LEAKAGE THROUGH LAYER 3 | 240.52086 | ( 60.95679) | 6013.021 | 25.77985 |
| AVERAGE HEAD ON TOP OF LAYER 3 | 0.841 | ( 0.317) | | |
| PERCOLATION/LEAKAGE THROUGH LAYER 4 | 248.88809 | ( 66.38271) | 6222.202 | 26.67668 |
| CHANGE IN WATER STORAGE | -8.467 | ( 1.8194) | -211.67 | -0.908 |

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FINAL WATER STORAGE AT END OF YEAR 10

| LAYER | (CM) | (VOL/VOL) |
|---|---|---|
| 1 | 3.8725 | 0.1291 |
| 2 | 2.4004 | 0.0800 |
| 3 | 41.7600 | 0.4640 |
| 4 | 155.8383 | 0.2597 |
| SNOW WATER | 3.071 | |

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# Appendix D
# Calculation of Groundwater Contamination Resulting From Tailings Leaching

**Problem Statement:** Estimate groundwater concentration resulting from leaching residual radioactive material [RRM] in the Burrell disposal cell. Three scenarios of disposal cell cover integrity are evaluated:
Scenario 1 - Undegraded compacted soil layer [CSL] on cell controls infiltration through underlying RRM [CSL w/o plants scenario]
Scenario 2 - Hydraulic conductivity of the CSL is increased by Japanese knotweed root intrusion [CSL w/knotweed scenario]
Scenario 3 - Hydraulic conductivity of the CSL is increased by mature plant/biotic community intrusion [mature analog site scenario]
Analytes of concern are manganese, molybdenum, selenium, radium, and uranium.

**Method of Solution**: Analytical mixing model [Summers Model, in EPA 1989].

Summers Model Mixing Equation:
Cgw = [QpCp + QaCa] / Qp + Qa; where:

Cgw = concentration of contaminant in groundwater after source mixing [M/L3],
Qp = volumetric flux of source water to aquifer [L3/T],
Cp = contaminant concentration in source water [M/L3],
Qa = volumetric flux in aquifer beneath source area [L3/T].
Ca = initial contaminant concentration in aquifer [M/L3],

## Burrell Site Parameters

| | | Data Source: |
|---|---|---|
| Area of source: | | |
| Cell footprint area | 2.5 hectare = 2.5E+08 cm2 | Waugh & Smith 1997 |
| Cell length perpendicular to groundwater flow direction = 1300 ft [39,624 cm] | | DOE 1993, site map |
| Average annual precipitation: 112cm | Data Source: Waugh & Smith, 1997 | |
| Saturated hydraulic conductivity [Ksat]: | | Data Source: |
| CSL w/o plants | Ksat 1 = 2.9E-07 cm/sec | Waugh & Smith 1997, field measurement |
| CSL w/knotweed | Ksat 2 = 3.0E-05 cm/sec | Waugh & Smith 1997, field measurement |
| Mature analog site | Ksat 3 = 1.3E-04 cm/sec | Waugh & Smith 1997, field measurement |
| Aquifer/fill beneath cell | Ksat aq = 8.6E-02 cm/sec | DOE 1982, documented pump test result |
| Hydraulic gradient: | 0.011 to 0.023 cm/cm | DOE 1994 and 1988, GJO 1998; 9/87, 7/93 data |
| Aquifer saturated thickness: | 25 ft [762 cm] | DOE 1985, thickness estimated from geologic cross-sections |
| | 20 ft [610 cm] | DOE 1982, derived from pump test result |

## Analyte Concentrations in Source Water

| | Max conc in DI water leach | Max conc in TCLP leach | Mean of Max concs in 4 TCLP leach tests, minus background |
|---|---|---|---|
| manganese | 1,120 ug/L | 28,300 ug/L | 20,700 ug/L |
| molybdenum | 793 ug/L | 200 ug/L | 133 ug/L |
| uranium | 210 ug/L | 583 ug/L | 276 ug/L |
| selenium | 5.8 ug/L | 24.6 ug/L | 11.6 ug/L |
| radium 226+228 | 4 pCi/L | 134.3 pCi/L | 86.3 pCi/L |

Data Source: Waugh 1997, column leach test results, composite RRM samples

## Analyte Concentrations in Groundwater

| | Maximum observed concentration in groundwater, background wells; 11/97 | | Maximum observed concentration in groundwater, downgradient wells; 11/97 | |
|---|---|---|---|---|
| manganese | 9180 ug/L | | 9980 ug/L | |
| molybdenum | <1 ug/L | not detected | 26.5 ug/L | |
| uranium | <1 ug/L | not detected | 8.2 ug/L | |
| selenium | <1.1 ug/L | not detected | <1.1 ug/L | not detected |
| radium 226+228 | 0.25 pCi/L | | 0.16 pCi/L | |

Data Source: GJO 1998, November 1997 groundwater sample results.

## Infiltration Water Budget

[1] Estimate maximum volume of water [Qmax] available to infiltrate RRM, where
Qmax = infiltration rate [L/T] x infiltration area [L2]
Assume 100% infiltration of average annual precipitation on disposal cell; therefore,
Qmax = 112cm/yr x 2.5E+08 cm2 = 2.8E+10 cm3/yr [or 0.9 L/sec]

[2] Calculate infiltration [Qc] at variable Ksat for 3 site scenarios
Assume gravity drainage under saturated conditions, and K RRM >= Ksat 1, 2, and 3; therefore,
Qc = Ksat x hydraulic gradient x infiltration area, where

| | | |
|---|---|---|
| Ksat 1 = | 2.9E-07 cm/sec | CSL w/o plants |
| Ksat 2 = | 3.0E-05 cm/sec | CSL w/knotweed |
| Ksat 3 = | 1.3E-04 cm/sec | mature analog site, |

hydraulic gradient = 1, and
infiltration area = 2.5E+08 cm2

Results: Qc 1 = 0.0725 L/sec
Qc 2 = 7.5 L/sec
Qc 3 = 32.5 L/sec

[3] Compare calculated infiltration [Qc] with maximum available infiltration [Qmax = 0.9 L/sec]

| | |
|---|---|
| Qc 1 < Qmax | Qc 1 is valid; use Qc 1 in mixing calculation for CSL w/o plants scenario |
| Qc 2 > Qmax | Qc 2 is not valid; use Qmax in mixing calculation for CSL w/knotweed scenario |
| Qc 3 >> Qmax | Qc 3 is not valid; use Qmax in mixing calculation for mature analog site scenario |

## Mixing Calculation Inputs

| Scenario | Ksat CSL [cm/sec] | Source area [cm2] | Qp [L/sec] | Ksat aquifer [cm/sec] | Hydraulic gradient | Sat thick [cm] | Flow tube width [cm] | Qa [L/sec] |
|---|---|---|---|---|---|---|---|---|
| CSL w/o plants | 2.90E-07 | 2.50E+08 | 0.0725 | 8.60E-02 | 0.011 | 609 | 39624 | 22.8 |
| CSL w/knotweed | Not Applicable | 2.50E+08 | 0.9000 | 8.60E-02 | 0.011 | 609 | 39624 | 22.8 |
| Mature analog site | Not Applicable | 2.50E+08 | 0.9000 | 8.60E-02 | 0.011 | 609 | 39624 | 22.8 |

Mixing calculation assumptions:

[1] Qa = Ksat aquifer x gradient x saturated thickness x width of cell perpendicular to flow.
[2] Instantaneous homogenous source/groundwater mixing.
[3] No retardation of contaminants in subcell vadose zone or in aquifer.
[4] Initial groundwater concentration [Ca] = max concentration in background wells, 11/97 results.
[5] Ca = detection limit for undetected analytes.
[6] Source concentration [Cp] is constant through time except Calculations 4 and 5. See assumption 9.
[7] Aquifer and source flow rates are constant through time.
[8] Calculated groundwater concentrations [Cgw] are in aquifer beneath disposal cell and donwgradient of the site to Conemaugh River.
[9] For Calculation 4 & 5 only, Cp Ra-266 will increase in proportion to Ra-226 ingrowth predicted in Waugh 1997. Therefore, at times = 200 yr and 1,000 yr from present, Cp Ra-226 = 2x and 4x values measured in leach tests, respectively.
[10] For Calculation 5 with Ra-226 ingrowth, Qp = 0.5 x Qmax for plant scenarios, i.e., 50% of mean annual precipitation infiltrates RRM.
[11] For Calculation 6, Ksat aquifer = 0.1 x pump test result, all else same as Calculation 3.
[12] For Calculation 7, Ksat aquifer = 0.1 x pump test result, and Qp = 0.5 x Qmax [plant scenarios only], all else same as Calculation 6.
[13] For Calculation 8 with Ra-226 ingrowth, Qp = 0.25 x Qmax for plant scenarios, i.e., 25% of mean annual precipitation infiltrates RRM.

## Mixing Calculation 1: Cp = Max conc in DI leach

| | Calculated groundwater concentration [Cgw] | | | | |
|---|---|---|---|---|---|
| | CSL w/o plants | CSL w/knotweed | Mature Analog | RSL [ug/L] | MCL |
| Mn [ug/L] | 9154.5 | 8874.3 | 8874.3 | 840 | N/A ug/L |
| Mo [ug/L] | 3.5 | 31.0 | 31.0 | 180 | 100 ug/L |
| U [ug/L] | 1.7 | 8.9 | 8.9 | 110 | 44 ug/L |
| Se [ug/L] | 1.1 | 1.3 | 1.3 | 180 | 10 ug/L |
| Ra [pCi/L] | 0.3 | 0.4 | 0.4 | N/A | 5 pCi/L |

## Mixing Calculation 2: Cp = Max conc in TCLP leach

| | Calculated groundwater concentration [Cgw] | | | | |
|---|---|---|---|---|---|
| | CSL w/o plants | CSL w/knotweed | Mature Analog | RSL [ug/L] | MCL |
| Mn [ug/L] | 9240.5 | 9905.2 | 9905.2 | 840 | N/A ug/L |
| Mo [ug/L] | 1.6 | 8.5 | 8.5 | 180 | 100 ug/L |
| U [ug/L] | 2.8 | 22.1 | 22.1 | 110 | 44 ug/L |
| Se [ug/L] | 1.2 | 2.0 | 2.0 | 180 | 10 ug/L |
| Ra [pCi/L] | 0.7 | 5.3 | 5.3 | N/A | 5 pCi/L |

## Mixing Calculation 3: Cp = Mean of max concs in 4 TCLP leach tests

| | Calculated groundwater concentration [Cgw] | | | | |
|---|---|---|---|---|---|
| | CSL w/o plants | CSL w/knotweed | Mature Analog | RSL [ug/L] | MCL |
| Mn [ug/L] | 9216.5 | 9617.0 | 9617.0 | 840 | N/A ug/L |
| Mo [ug/L] | 1.4 | 6.0 | 6.0 | 180 | 100 ug/L |
| U [ug/L] | 1.9 | 11.4 | 11.4 | 110 | 44 ug/L |
| Se [ug/L] | 1.1 | 1.5 | 1.5 | 180 | 10 ug/L |
| Ra [pCi/L] | 0.5 | 3.5 | 3.5 | N/A | 5 pCi/L |

**Mixing Calculation 4:** Cp Ra-226 = estimate based on Ra-226 ingrowth at 200 yr and 1,000 yr

| | | | Calculated Ra-226 concentration in groundwater [pCi/L] | | |
|---|---|---|---|---|---|
| Ra-226 source | Cp [pCi/L] | Time yr | CSL w/o plants | CSL w/knotweed | Mature analog site |
| Max DI water leach x 2 | 8 | 200 | 0.3 | 0.5 | 0.5 |
| Max DI water leach x 4 | 16 | 1000 | 0.3 | 0.8 | 0.8 |
| Max TCLP leach x 2 | 268 | 200 | 1.1 | 10.4 | 10.4 |
| Max TCLP leach x 4 | 536 | 1000 | 1.9 | 20.6 | 20.6 |
| Mean of max TCLP leach x 2 | 172 | 200 | 0.8 | 6.8 | 6.8 |
| Mean of max TCLP leach x 4 | 344 | 1000 | 1.3 | 13.3 | 13.3 |

**Mixing Calculation 5:** Cp Ra-226 = estimate based on Ra-226 ingrowth at 200 yr and 1,000 yr Qp = 0.5 x Qmax

| | | | Calculated Ra-226 concentration in groundwater [pCi/L] | | |
|---|---|---|---|---|---|
| Ra-226 source | Cp [pCi/L] | Time yr | CSL w/o plants | CSL w/knotweed | Mature analog site |
| Max DI water leach x 2 | 8 | 200 | 0.3 | 0.4 | 0.4 |
| Max DI water leach x 4 | 16 | 1000 | 0.3 | 0.6 | 0.6 |
| Max TCLP leach x 2 | 268 | 200 | 1.1 | 5.4 | 5.4 |
| Max TCLP leach x 4 | 536 | 1000 | 1.9 | 10.6 | 10.6 |
| Mean of max TCLP leach x 2 | 172 | 200 | 0.8 | 3.6 | 3.6 |
| Mean of max TCLP leach x 4 | 344 | 1000 | 1.3 | 6.9 | 6.9 |

**Mixing Calculation 6:** All conditions same as Calculation 3 but Ksat aquifer = 0.1 x pump test result

| | Calculated groundwater concentration [Cgw] | | | | |
|---|---|---|---|---|---|
| | CSL w/o plants | CSL w/knotweed | Mature Analog | RSL [ug/L] | MCL |
| Mn [ug/L] | 9534.6 | 12437.5 | 12437.5 | 840 | N/A ug/L |
| Mo [ug/L] | 5.1 | 38.3 | 38.3 | 180 | 100 ug/L |
| U [ug/L] | 9.5 | 78.8 | 78.8 | 110 | 44 ug/L |
| Se [ug/L] | 1.4 | 4.1 | 4.1 | 180 | 10 ug/L |
| Ra [pCi/L] | 2.9 | 24.6 | 24.6 | N/A | 5 pCi/L |

**Mixing Calculation 7:** All conditions same as Calculation 6 but Qp = 0.5 x Qmax for root intrusion scenarios

| | Calculated groundwater concentration [Cgw] | | | | |
|---|---|---|---|---|---|
| | CSL w/o plants | CSL w/knotweed | Mature Analog | RSL [ug/L] | MCL |
| Mn [ug/L] | 9534.6 | 11077.0 | 11077.0 | 840 | N/A ug/L |
| Mo [ug/L] | 5.1 | 22.7 | 22.7 | 180 | 100 ug/L |
| U [ug/L] | 9.5 | 46.3 | 46.3 | 110 | 44 ug/L |
| Se [ug/L] | 1.4 | 2.8 | 2.8 | 180 | 10 ug/L |
| Ra [pCi/L] | 2.9 | 14.4 | 14.4 | N/A | 5 pCi/L |

**Mixing Calculation 8:** Cp Ra-226 = estimate based on Ra-226 ingrowth at 200 yr and 1,000 yr Qp = 0.25 x Qmax

| | | | Calculated Ra-226 concentration in groundwater [pCi/L] | | |
|---|---|---|---|---|---|
| Ra-226 source | Cp [pCi/L] | Time yr | CSL w/o plants | CSL w/knotweed | Mature analog site |
| Max DI water leach x 2 | 8 | 200 | 0.3 | 0.3 | 0.3 |
| Max DI water leach x 4 | 16 | 1000 | 0.3 | 0.4 | 0.4 |
| Max TCLP leach x 2 | 268 | 200 | 1.1 | 2.9 | 2.9 |
| Max TCLP leach x 4 | 536 | 1000 | 1.9 | 5.5 | 5.5 |
| Mean of max TCLP leach x 2 | 172 | 200 | 0.8 | 1.9 | 1.9 |
| Mean of max TCLP leach x 4 | 344 | 1000 | 1.3 | 3.6 | 3.6 |

RSL = Risk Screening Level, RSLs per Waugh 1997.
MCL = UMTRA Maximum Contaminant Limits.

**Summary**

[1] Presently, no contaminant concentration in groundwater, except manganese, exceeds an MCL or RSL.
[2] Manganese concentrations in background groundwater presently exceed the RSL.
[3] The RRM source is not presently causing MCLs or RSLs to be exceeded.
[4] MCLs or RSLs will not be exceeded by contributions from the RRM under the scenarios evaluated in Calculation 1, 2, and 3.
[5] As a result of Ra-226 ingrowth from Th-230 decay [Calculation 4], the MCL for Ra-226 may be exceeded at approximately 200 yr through 1,000 yr under the root intrusion scenarios [w/knotweed and mature analog site], assuming aggressive leaching [TCLP leach conditions]. However, the predicted future Ra-226 concentrations are not mass conservative with respect to source depletion from Th-230 and Ra-226 leaching.
[6] Predicted Ra-226 concentrations only marginally exceed the MCL at 1,000 yr if infiltration is reduced by 50% [evapotranspirative losses and runoff] and are at or below the standard when infiltration is 25% of mean annual precipitation (Calculations 5 and 8).
[7] Calculation 6 [aquifer Ksat sensitivity analysis] indicates that the MCL for Ra-226 will be exceeded under the root intrusion scenarios assuming aggressive leaching [TCLP leach conditions] and aquifer Ksat = 0.1 x pump test result. However, because the Ra-226 concentration predicted in Calculation 6 no-plant scenario is approximately 18 times greater than presently in groundwater immediately downgradient of the disposal cell [0.16 pCi/L], the aggressive leach conditions or lower Ksat are overly conservative, or Ra-226 is immobile in the aquifer [see assumption 3].

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