Q-ESR-E-00001

Mixed Waste Management Facility (MWMF) Old Burial Ground (OBG) Source Control Technology & Inventory Study

by

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WESTINGHOUSE SAVANNAH RIVER COMPANY

INTER-OFFICE MEMORANDUM

GEO-ENVIRONMENTAL ENGINEERING

June 1, 1994

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FROM: J. P. Kanzleiter, 992-4W (4-6683) JPK
T. E. Rehder, 992-4W

RE: MIXED WASTE MANAGEMENT FACILITY (MWMF) OLD BURIAL GROUND (OBG) SOURCE CONTROL TECHNOLOGY & INVENTORY STUDY

The final version of the above referenced study is attached . This report is the final deliverable for this task.

CC (w/o attachments): B. T. BUTCHER, 992-4W
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Joseph P. Kanzleiter
ADC and Reviewing Official
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6/1/94

Q-ESR-E-00001
Revision 0

MIXED WASTE MANAGEMENT FACILITY (MWMF) OLD BURIAL GROUND (OBG)

SOURCE CONTROL TECHNOLOGY & INVENTORY STUDY (U)

May 1994

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Does Not Contain Unclassified Controlled Nuclear Information (UCNI)

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Prepared for the U. S. Department of Energy under Contract No. DE-AC09-89SR18035

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Revision 0

MIXED WASTE MANAGEMENT FACILITY (MWMF)
OLD BURIAL GROUND (OBG)

SOURCE CONTROL TECHNOLOGY & INVENTORY STUDY (U)

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TABLE OF CONTENTS

1.0 EXECUTIVE SUMMARY

This report has been developed to support information needs for wastes buried in the Burial Ground Complex (BGC). Information discussed is presented in a total of four individual attachments. The general focus of this report is to collect information on estimated source inventories, leaching studies, source control technologies, and to provide information on modeling parameters and associated data deficiencies.

The transport of leached contaminants from buried wastes disposed of in the area has contaminated the groundwater with several RCRA hazardous constituents above regulatory maximum concentration levels (MCLs). In addition, several radionuclides have been detected in a few area groundwater samples indicating that migration from the source has occurred.

This report contains an annotated description of various reports or studies which are related to the the Burial Ground Complex (BGC). The report was prepared in an attempt to collect information relating to source inventories, wasteform lysimeter studies, contaminant partition (Kd) studies, and groundwater detection monitoring. A variety of source control techniques applicable to the subsurface environment at the burial grounds will also be discussed. The discussion will prescribe viable source control technologies that could potentially mitigate contaminant migration (i.e., provide hydraulic control of groundwater from further contaminant leaching) from the buried wastes to the underlying groundwater system.

2.0 INTRODUCTION

The SRS radioactive waste burial ground has been in use since the 1950's for the disposal of radioactively contaminated wastes. The burial grounds, referred to as Burial Ground Complex (BGC), is approximately 330 acres and is located near the center portion of the Savannah River Site (SRS). The southern area of the BGC is referred to as the Old Burial Ground (OBG), designated as building 643-E, and occupies approximately 76 acres. The northern area occupies approximately 254 acres and is apportioned between the following waste units: Mixed Waste Management Facility (MWMF), building (643-28E); the Low-Level Radioactive Waste Disposal Facility (LLRWDF), building 643-7E; the Hazardous Waste/Mixed Waste Disposal Vaults (HW/MWDV); and the E-Area Vaults, building 643-26E (Ref. WSRC-RP-93-848). This discussion will focus mainly on wastes placed in the OBG, MWMF, and LLRWDF trenches.

Most of the waste placed in the burial grounds was enclosed in some sort of container. The designs and materials used for the containers have been numerous. Since placement in the trenches, some of the containers may have already degraded; many are probably still intact. Over time, many more contaners will probably degrade.

Analyses of groundwater samples from monitoring wells in the vicinity of the burial grounds have already indicated the presence of hazardous and radioactive constituents. The presence of these contaminants indicates that there is already some contact between the waste and the groundwater. In the future, there is likely to be more contact between waste and groundwater as the waste containers degrade further.

The contaminantion present in the groundwater is a concern because it has a flow path which outcrops to adjacent wetlands and/or discharges directly to surface water streams.

An estimate of the likely extent of future groundwater contamination will require detailed information on contaminant migration (Kds), source inventories, and groundwater detection monitoring. This report involved gathering and assembling documents relating to this subject matter and organizing the information in an annotated bibliography. In addition, information on viable source control techniques using in-situ technologies commercially available to control contaminant migration are discussed with respect to their use in the BGC. Note that the technologies do not involve remediation or immediate destruction of buried wastes but rather provide time as the governing mechanism for contaminant decay and/or degradation.

3.0 DISCUSSION: SUMMARY OF ATTACHED INFORMATION

Information developed in this report is organized into four topics which are presented as attachments. A summary of the contents discussed in each of the attachments is provided below.

ATTACHMENT ONE: <u>ANNOTATION OF CONTAMINANT MIGRATION STUDIES AND WASTE INVENTORIES</u>

The focus of this effort was to compile a broad list of past documents and/or studies related to the burial grounds. The majority of the documents placed in an annotated format include information relating to the following topics: waste lysimeter studies, contaminant migration/soil distribution (Kd) studies, waste inventory reports, and contaminant detection monitoring reports. Most of the information and data obtained from the list of documents reviewed is illustrated in tabular form.

A table showing the most recent detected maximum groundwater concentrations detected at the facility point of compliance wells is also presented for many organic and inorganic (metal) constituents to show the magnitide of groundwater contamination.

It should be noted that some of the information presented in *Attachment One* may be repetitive. In addition, information mentioned in *Attachment One* is related in many cases to past studies and may not be analogous with current findings. Data presented in *Attachment One* is provided to serve only as a source of information for the BGC.

ATTACHMENT TWO: <u>SOURCE CONTROL TECHNOLOGIES</u>

This disussion describes source control and containment technologies that are commerically available which could potentially mitigate or reduce contaminant migration to groundwater. The bulk of this section focuses on in-situ technologies which have potential for implemented at a burial waste facility.

A variety of potentially viable source term control technologies and/or methods applicable to past burial practices at the Mixed Waste Management Facility (MWMF) and Old Burial Ground (OBG) are discussed. Technologies in this discussion were selected based on their applicability, viability, and ability to reduce the migration of contaminants (i.e., to increase the transit time) so that contaminant decay and/or natural or biological degradion can effectively reduce source term concentrations. A determination of the economic feasibility of the technologies presented is beyond the scope of this effort. However, available information relating to estimated costs associated with a technology are integrated into the discussion.

Although an economic evaluation is not presented, each technology is categorized based on its technical feasability for implementation and is listed as potentially viable, limited, or is eliminated from further discussion for applicability at the BGC.

ATTACHMENT THREE: MODELING INPUT PARAMETERS

The scope of the information developed in this attachment includes basic input requirements for inclusion in a contaminant fate & transport model. Information and suggestions on transport modeling input parameters are presented in an outline format. Information presented also identifies data deficiencies associated with waste source terms and characterization data. Information relating to waste container life expectancy is also mentioned.

ATTACHMENT FOUR: LIST OF REFERENCES AND DOCUMENTS CITED

This attachment contains a large list of documents and studies related to the burial grounds. This is a more comprehensive list of documents than the attachment forwarded to ERD as "MWMF/OBG Source Inventory Index," Inter-Office Memorandum (400:EPD-SGS-94-0007). Most of the contents of the listed references have been summarized in *Attachment One.* Additional references on burial ground activities not included in the annotated bibliography in *Attachment One* are included in this section as potential resources for information.

Attachment One: Annotation of Migration Studies and Waste Inventories

Introduction

Originally, the focus of this effort was to locate data on waste inventories related to the MWMF/OBG and to compare values to inventories currently listed in the 1992 RCRA Part B Permit Application for the MWMF. This focus evolved to an effort to compile a broad list of past documents and/or studies related to the Burial Ground Complex (BGC). The majority of the documents placed on this annotated list relate to the following topics: waste lysimeter studies, contaminant migration/soil distribution (Kd) studies, waste inventory reports, and contaminant detection monitoring reports. The synopsis of each of the reports and/or studies which follow have been placed in chronological order. In addition, most of the information and data obtained from the list of documents reviewed is illustrated in tabular form.

A table showing recent maximum groundwater concentrations detected at BGC point of compliance and/or assessment wells is presented for many constituents to show the magnitide of groundwater contamination.

It should be noted that some of the information presented below may be repetitive because many of these documents reference back to data which are presented in earlier reports. In addition, information mentioned in this effort is related in many cases to past studies or previous results and may not be analogous with current findings. Data presented are provided to serve only as a resource for information on migration and source term studies related to the burial grounds.

The following is a synopsis of data and information reported in the documents reviewed. Data related to distribution coefficient (Kd) values and estimated waste inventories are summarized at the end of this attachment.

1. Adsorption of Radioactive Wastes By Savannah River Plant Soil (Soil Science 86, 13 - 1958).

This report entails the adsorption of radioisotopes affected by the concentration or oxidation state of the ion in question, for both the total concentration of salts present and the pH of the solution. A calculation to predict the arrival time of contaminants to the groundwater is also presented. No data are given in this report to help quantify a source term in the burial ground.

The arrival time of contaminants to the Water Table Aquifer is also discussed and is shown to be calculated using the following equation:

$$t_X = x/R\,(Kd^{*}\rho + \xi)$$

where: t = arrival time, years
x = 100 ft (depth of water table)
R = 30 ft/yr (linear rate of percolation)
ρ = 2 g/ml (density of soil)
ξ = 0.5 (void fraction)

The distribution coefficient, Kd (mL/g), is a practical measure of the relative affinity of ions for the soil and can be used to establish the conditions for the maximum adsorption.
The rate of percolation will depend on the composition of the waste, composition of the soil, and geological structure of the area such as faults, gravel, and rock layers.

Strontium Kd = 9 mL/g; tx = 54 years

Adsorption of strontium is dependent on its concentration and on the pH of the solution. In addition, strontium adsorption is greatly inhibited by the hydrogen ion: adsorption is insignificant at a pH of 2. Maximum adsorption of strontium to kaolinite type clayey soil (20% clay and 80% sand) occurred at a pH of 7. Above pH 8 the competitive effect of sodium (due to pH adjustment with NaOH) predominated and adsorption was reduced (or declined). For maximum adsorption of strontium to be achieved the waste stream (solutions) should be neutralized with NaOH.

Cesium Kd = 280 mL/g; tx = 1600 years

The adsorption of cesium is dependent on its concentration and the pH of the solution. Maximum adsorption occurs near a pH of 8.

2. Mercury In The 643-G Burial Ground (DPST-73-480).

This report indicates that the quantities of mercury buried throughout an estimated 44 acres of low-level beta/gamma waste trenches have not been well recorded. It has been suggested that mercury burial began in 1956 and stopped in 1968. Regardless of the lack of adequate inventory records, it has been estimated that about 10 tons (i.e., 22,000 lbs.) of elemental mercury have been buried. Waste mercury was described as being placed in one-liter polyethylene bottles which were then placed into two polyethylene bags. Several of these bags (2 to 3) were then placed into 5 gallon lard cans.

3. Tritium Release From Crucible and Spent Melt (TA 2-854)

This report indicates that tritium in buried Li-Al melts accounts for more than 30 percent of the total curies of radioactivity in the burial ground. The spent melts are described as being buried in open-top stainless steel extraction crucibles, without secondary containment. No data is given in this report to help quantify a source term for tritium in the burial ground.

4. Exhumation of Canyon Equipment From Burial Ground (TA 2-885).

This report discusses very high-level (failed) canyon equipment that has been buried at the SRP burial ground. This equipment contains dominant long-lived radionuclide species ^{90}Sr, ^{137}Cs, ^{238}Pu, and ^{239}Pu. The ^{137}Cs content for this waste has been estimated at 10,000 curies based on gross gamma radiation measurements of each waste shipment. No measurements can be directly or indirectly related to ^{90}Sr, so it has been assumed that the inventory is approximately 10,000 curies, i.e., similar to that of ^{137}Cs. No data or no direct or indirect inferences can be applied in the case of the TRU isotopes because of the intense penetrating radiation associated with this equipment has made sampling and analysis impractical.

Factors related to the leaching of contaminants from a waste form to the groundwater table are given. Contaminant leaching is rate limited and controlled by:

- radioactive decay or chemical degradation rates;
- soil retention/sorption properties (distribution coefficients, Kds); and
- leach rate of waste from source as a result of percolation rate of infiltrating rainwater.

5. Migration of Tritium from a Nuclear Waste Burial Site (DP-MS-75-25)

This report discusses three spent melt crucibles with an estimated average 125 curies each (375 curies total) which were immersed in water to measure the amounts of tritium released as HTO and HT. Tritium concentration as a function of the percolate volume was measured over a ten year period.

The amounts of tritium released as HTO and HT to the water and to air were 99% HTO remained in the immersion water, and 1% HT that passed into the air. Average concentrations were used to estimate that some 50 Kilocuries of tritium are in the groundwater underlying the 77-acre burial site. Travel time of tritium in the groundwater form the burial ground to a tributary stream 3000 ft away is estimated to be about 60 years. No data is given in this report to help quantify a source term for tritium in the burial ground.

6. Movement of Organically-Bound Plutonium in Soil (DPST-75-377).

This study discusses the potential for migration of plutonium in soil by facilitated transport via an organic spent solvent. The study also postulates a massive leak of solvent containing plutonium from a tank to the subsurface and its ability to transport through the soils. An estimation of the amount of spent solvent containing plutonium released to the ground from leaks in tanks in 1968 is also given. No data is given in this report to help quantify a source term in the burial ground.

7. Storing Solid Radioactive Wastes at the Savannah River Plant (DP-1366), J. H. Horton & J. C. Corey, 6/76

This report describes the methods used for burying wastes in the burial ground. The grid system used to locate wastes placed in the burial ground is also discussed. Radioactive wastes buried from startup through 1974 are also listed.

Waste Classification	Radioactivity (Curies)	Volume (ft^3)
Transuranic Alpha Waste		
Retrievable	500,000	70,000
Nonretrievable	20,000	1,100,000
Low Level	3,200,000	6,700,000
High Level	4,100,000	700,000

The average depth of the trenches was 20 feet. The average depth to the water table is 45 feet. Groundwater in the unsaturated soil above the water table moves at a rate of about 7 feet per year. In the water table the water moves between 29 and 47 feet per year. The shortest path to Four Mile Creek is about 0.5 miles. The travel time for wastes buried is, therefore, about 70 years to the creek. Ion exchange will increase the travel time for strontium by a factor of 16 and cesium by a factor of 200.

A grid of monitoring wells placed at 200 foot centers was placed around the site. Approximately one-third of the wells contained tritium significantly above concentrations for rain recorded in the area. Eight wells recorded levels above 3000 pCi/ml.

8. Radioactivity Trends in Burial Ground Wells - 1975-1976 (DPST-77-495).

This study indicates that an increase in tritium content, inconjunction with at least a 3 year delay time for percolation from the trenches to the water table, is compatible with data from a lysimeter test of leach rate of tritium from spent melts. No data is given in this report to help quantify a source term for tritium in the burial ground.

9. Lysimeter Tests of SRP Waste Forms (DP-1591).

This document is part of an estimated 10 year field study to define leaching and migration rates of radionuclides from SRP buried wastes. The report discusses lysimeter design, physical and radiological characteristics of the waste forms, and the experimental procedure. Predicted rates of migration of various radionuclides in the lysimeter soil are also discussed.

This report mentions that approximately 4000 curies of ^{238}Pu and 400 Ci of ^{239}Pu were encapsulated in trenches during the early years of SRP burial ground operation. This report discusses the lysimeters that were installed at SRP to function as miniature burial grounds. The wastes placed in these lysimeters contained ^{238}Pu, ^{239}Pu, ^{60}Co, ^{90}Sr, ^{14}C, and other miscellaneous fission and activation products. A description of the materials buried in the lysimeters is provided. This report discusses how calculations can be made to determine K_d, but actual data is needed from the field. No data is included in this report because it was written when the lysimeters were just being installed.

10. Shallow Land Burial of Solid Low-Level Radio Active Wastes - 30 Years of Experience at the Savannah River Plan (DP-MS-82-61).

This document gives a summary of Waste Migration Studies for the SRP burial ground. The Water Table was noted to be typically about 14 meters beneath the surface. Annual rainfall at the site is about 1.2 meters, one-third of which was estimated to reaches the water table aquifer as recharge. The flowrate in the unsaturated (Vadose) zone was estimated to be about 2 meters per year. In the saturated zone, an average groundwater velocity has been measured as 14 meters per year for each 1% gradient of the water table. Trenches are generally 6 meters deep, 6 meters wide , and typically 100 - 300 meters long. The trenches were on average filled to within 1.2 meters of the surface and then backfilled with native soil. Total volume of buried waste is about 370,000 cubic meters. 400,000 curies of TRU-Alpha waste is stored retrievably in earthen mounds at the burial site. To monitor the burial grounds performance a "containment factor" (i.e., the ratio of radioactivity buried to that which has reached the water table), was estimated from groundwater monitoring. Tritium showed a containment factor of 50.

Tritium is the predominant radionuclide in buried waste. ^{60}Co, ^{90}Sr, ^{137}Cs are the principal fission products. Likewise, ^{238}Pu, and ^{244}Cm are the primary alpha emitters buried. In addition, large quantities of long-life radionuclides such as ^{99}Tc, ^{129}I, and ^{239}Pu are also buried. Ninety-nine percent of the radioactive waste is believed to represent about 5% of the total waste volume projected to be 370,000 cubic meters; ^{3}H (19,000 cubic meters); Fission products (268,000 cubic meters); and alpha emitters (86,000 cubic meters).

The study indicates that only 2 percent of buried tritium has reached the water table.

The following table lists equilibrium distribution coefficients (Kds) for burial trench water for strontium, cesium, and technetium.

Soil/Water Distribution Coefficients (Kds)

Constituent	Units (mL/g)
Strontium	10 - 30
Cesium	1000
Technetium	(0.1 - 0.3)*

*** corresponds to 41 - 67% of groundwater velocity**

11. Analysis of 643-G and 643-7G Groundwater for Mercury (DPST-82-593).

This report indicates that prior to 1972, up to 10 tons of mercury was disposed of in 643-G in polyethylene bottles. It is believed that 643-7G does not contain any mercury. In March of 1982, 86 wells were tested for mercury. None of the wells tested above the 2 ppb drinking water level. The highest value measured was 1.6 ppb. Fifty-one percent are below detection limits of 0.05 ppb. Seventy-one wells are below 0.1 ppb which is nearly the natural background level for the eastern U. S. This represents 80 percent of the wells which had mercury concentrations less than 0.1 ppb.

12. Groundwater Monitoring in the Savannah River Plant Low Level Waste Burial Ground: A Summary and Interpretation of the Analytical Data, (DPST-83-209).

This report discusses the mechanisms available for various radionuclides to become mobile. It discusses chelating agents and complexes that may be formed as well as the effect that factors such as pH, oxidation potential, ionic strength, concentration of competing ions, etc. could have of the formation of these soluble complexes. There is data on radiation levels detected at various wells in the area, however, this data does not help in determining the source term for the burial ground.

13. Cesium and Strontium Adsorption Out of 643-G Trench Water Onto Soils (DPST-83-272).

This study indicates as one would expect that strontium ions exchange reversibly with calcium and magnesium cations on clay soils. Data in this study shows a correlation between high calcium and magnesium concentrations and low distribution coefficients (Kds) for strontium. Dissolved iron was observed to have somewhat less effect on strontium adsorption. Distribution coefficients (Kds) determined for ^{137}Cs were sensitive to the potassium concentration but were essentially independent of the iron concentration in anoxic tests. No data is given in this report to help quantify a source term in the burial ground.

14. Specific Factors Influencing Cesium Sorption By SRP Soils (DPST-83-490).

This document discusses several ionic species present in burial groundwater which have been shown to increase the migration rate (i.e., decreased Kd) of ^{137}Cs through the SRP soils. The Potassium ion (K^+) was observed to have the largest effect on ^{137}Cs migration (i.e., K^+ appeared to be the controlling species for the migration of cesium). Fe^{+2} (to 85 ppm) was also determined to be an important ion in mobilizing ^{137}Cs nuclide. This study also concluded that cesium adsorption to SRP soil does show a flowrate dependence. The results indicate that ^{137}Cs will migrate furthest from waste trenches that have large quantities of other salts. However, Kd values greater than 100 were inherent which indicates relatively little potential for migration. No data is given in this report to help quantify a source term in the burial ground.

15. Migration Studies At The Savannah River Plant Shallow Land Burial Site (DP-MS-83-89).

Tritium

This study indicates that about 25,000 curies of tritium are estimated to be in the groundwater as of 1983. A containment factor of approximately 100 for tritium was estimated at the burial ground. The contribution of outcropping tritium from the burial ground was estimated to be less than 200 Ci/year and was projected to unlikely ever exceed 500 Ci/year.

Mercury

Mercury concentrations at the burial grounds are noted to have always been less than the 2 ppb drinking water limit and are indicated to be diminishing with time.

Defense Waste Lysimeters

The report describes the 42 lysimeters as being approximately 3 meters deep and 2-3 meters in diameter. Five gamma emitters from the wastes placed in the lysimeters have been detected in the leachate. These gamma emitters are as follows:

Gamma Emitters Measured In Effluents From Defense Waste Lysimeters

Radionuclide	Number of Waste Types Showing Detection	Concentration (pCi/L)*	Typical Detection Limit (pCi/L)
Mn-54	1	4	0.8
Co-60	3	13-100	1
Zn-65	0	-	2
Ru-106	2	56-140	7
Sb-125	2	16-40	2
Cs-134	0	-	0.8
Cs-137	1	2	0.9

***Range of highest concentrations to date in effluents.**

Ru-106

Lysimeters showing ^{106}Ru have reported fractional release rates ranging from 5.0E-06 to 3.0E-04 per year and averaging 9.1E-05 per year. Batch measurements for the Kd of ruthenium with burial ground soil and typical groundwater gave values of 100 - 500 mL/g.

Co-60

Fractional release rates for ^{60}Co were calculated at 2.0E-07 to 4.0E-06 per year.

I-129

Iodine-129 released from spent beryl saddles resulted in a fractional release rate of 1.8E-07 per year. Results for ^{129}I suggest that shallow land burial may not be the best disposal method for the relatively small volumes of spent beryl saddles containing concentrated ^{129}I. This is because ^{129}I is long-lived, mobile (i.e., tends to migrate with the groundwater flow), and appears in concentrations near the 1 pCi/L drinking water limit. Any iodine leaching from the buried waste potentially could be in anionic form and thus have very low soil adherence. Such species might be expected to move with the groundwater just as tritium does.

Tritium

The spent Li-Al melts released most of their tritium after 10 years of lysimeter operation with a rapid initial release rate which tapered off to approximately 5 percent (corrected for decay) of the original rate.

Alpha-Emitter Lysimeters

A set of 12 miniature lysimeters was constructed to study alpha-emitting radionuclides. After two years of operation, no radionuclides had been detected in percolate water. One lysimeter containing ^{239}Pu was removed from service to determine the distribution of the ^{239}Pu in the soil from its source. The ^{239}Pu was determined to have migrated at least 0.1 meter downward.

Trench Water

The quantity of dissolved cations (i.e., calcium, magnesium, potassium, and iron) appear to be correlated to radionuclide mobility because of their effect on varying the Kd value.

16. Strontium Sorption Onto SRP Soils (DPST-84-554)

The purpose of this study was to determine Kd values for ^{90}Sr for SRP burial ground soil as well as compare the results to previous work. Groundwater Kd values for ^{90}Sr previously reported ranged from 1.1 to 10.9 mL/g which are in good agreement with reported Kd values from this study of 1 to 5 mL/g. SRP soil Kd values of 10 to 20 mL/g were also reported. The soil Kd for strontium was found to increase by a factor similar to the percent increase in the percent clay content of the soil. Increasing cation concentrations particularly for Mg^{2+}, Ca^{2+}, and K^{+} were noted to cause a similar decrease in strontium sorption (lower Kd) analogous to the findings for cesium. This report indicates that the estimated inventory of ^{90}Sr in the burial ground is approximately 11,000 curies.

17. Radionuclide Migration Studies at the SRP Humid Shallow Land Burial Site For Low-Level Waste (DP-MS-84-82).

This study indicates that most of the tritium in the study area does not arise from near grid well G-21, but from sources more distant and easterly (perhaps) from the area of well G-34. The study demonstrates that the soil cores are more effective than water table wells for measuring tritium that has migrated far along the groundwater flowpath. The following radionuclides are reported to be analyzed for at the burial grounds: Sr-90 (nonvolatile beta emitter), ^{238}Pu, ^{239}Pu, ^{241}Am, and the gamma emitters: ^{54}Mn, ^{60}Co, ^{106}Ru, ^{125}Sb, and ^{137}Cs. The flux of ^{129}I to the water table is calculated to be about 10E-05 percent per year with a groundwater concentration of about 10E-02 pCi/L. The data does not mention anything that would help determine source term in the burial ground area.

18. Soil Coring in a Plutonium Wasteform Lysimeter (DPST-84-481).

This study reports that plutonium has been observed to have relatively low mobility in SRP Burial Ground Soil. Data indicates that there is greater retention (higher Kd) of plutonium by soil near the source, and less retention (lower Kd) with increasing depth. This suggests that most of the leached plutonium consisted of one or more species having low mobility in the soil, but that a small fraction was a higher mobility species, possibly Pu(VI). A 1978 study of the SRP burial ground, *Wilhite (DP-1511)*, reported that once plutonium is sorbed on soil it is not susceptable to ion-exchange. This study considered the bulk of plutonium on burial ground soil to be immobile except for movement of plutonium-bearing soil particles.

19. Subsurface Monitoring of Groundwater at the SRP Burial Ground: 1984 Summary of Grid Well Assays (DPST-85-353).

This report gives an estimate on the total amount of tritium in the groundwater beneath 643-G (i.e., 643-E) at 38,800 curies during 1984. A soil coring study indicates that 90 percent of the tritium was deeper than the well screen. This indicates that the groundwater tritium plume was being underestimated. The study does not mention anything that would help determine a source term in the Burial Ground Area.

20. 1984 Monitoring of Mercury In The Groundwater At 643-G and 643-7G (DPST-85-407-TL).

This report indicates that grid well A-5 (northwest corner of 643-E) had a detectable concentration of 2.9 μg/L for mercury and has shown elevated mercury concentrations in all years except 1981. This study indicates that no detectable amounts of mercury are migrating from the burial ground to Four Mile Creek. The nearly 10 tons of mercury (metal) believed to be buried in the OBG was placed before 1968. The new burial ground (i.e., MWMF and LLRWDF) should contain no metallic mercury. However, the continued use of small quantities of mercury salts, compounds, and thermometers at SRP and SRL would indicate that small amounts of mercury have continued to be buried. This report concludes that mercury has been monitored since 1977 - because its large source inventory warrants a continued monitoring program.

21. Radionuclide Sorption On Savannah River Plant Burial Ground Soil - A Summary and Interpretation of Laboratory Data, (DP-1702).

The purpose of the paper was to determine the distribution coefficients, K_d, for ^{60}Co, ^{85}Sr, ^{106}Ru, ^{125}Sb, ^{137}Cs, $^{238/239}$Pu, and nonradioactive iodine (^{129}I) for the soil in the burial ground. Factors that would affect these coefficients were also investigated (pH, radionuclide concentration, etc.). Some data were also listed for amounts of radionuclides contained in the burial ground. These data are as follows:

Radionuclide	Curies
^{60}Co	540,000
^{90}Sr	10,000
^{99}Tc	1 to 100
^{129}I	13.5
^{137}Cs	10,000
TRU (total)	4,000
^{239}Pu	500
^{238}Pu	2,600

The report stated that pH has an important effect on the sorption of ^{60}Co, ^{90}Sr, ^{106}Ru, ^{125}Sb, ^{137}Cs, $^{238/239}$Pu. For a given radionuclide, a K_d range of 2 to 5 orders of magnitude occurs. Radionuclide concentration has an important effect on K_d for ^{90}Sr, ^{137}Cs, and to a lesser extent, on ^{129}I. For a given radionuclide, a K_d range of 1 to 2 orders of magnitude occurs. The following values of K_d (mL/g) are given:

Radionuclide	Minimum	Maximum	Typical Groundwater	Trench Water
^{60}Co	3.5	>10,000	10	30-100
^{90}Sr	1.5	3,000	7.5	7-600
^{106}Ru	65	-	175	160-580
^{125}Sb	180	>4,000	3,800	190->4,000
^{137}Cs	330	1,800	500	100-400
$^{238/239}Pu$				
Pu (VI)	7	250	9	-
Pu (IV)	120	7,100	150	-
Pu (III)	800	>10,000	8,000	-
^{99}Tc	-	-	0.5	-
^{129}I	3	10	5	-

22. Results of the Spent Melt Lysimeter Experiment Summary (DPST-85-384).

This report indicates that spent melts containing tritium released an estimated 25 curies via washoff in first year. Other mechanisms account for an additional release of 50 curies of tritium over the next three years and thereafter 20 or less curies per year. The last contribution is continually decreasing as the source is nearing depletion. Estimates indicate that line-2 spent melt/crucibles contain approximately 100 to 150 curies each.

23. Waste Migration Studies At The Savannah River Plant Burial Ground (DP-MS-85-86).

This paper summarizes results for 40 defense waste lysimeters operated 5 to 7 years, a tritium lysimeter operated 12 years, and a plutonium waste lysimeter operated 2 years. Recent results for soil-water chemistry studies, and transport modeling which were being performed during this period at the low-level radioactive waste burial ground, are also reported.

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Radionuclide	Curies
^{60}Co	540,000
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^{99}Tc	1 to 100
^{129}I	13.5
^{137}Cs	10,000
TRU (total)	4,000
^{239}Pu	500
^{238}Pu	2,600

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Radionuclide	Minimum	Maximum	Typical Groundwater	Trench Water
^{60}Co	3.5	>10,000	10	30-100
^{90}Sr	1.5	3,000	7.5	7-600
^{106}Ru	65	-	175	160-580
^{125}Sb	180	>4,000	3,800	190->4,000
^{137}Cs	330	1,800	500	100-400
$^{238/239}$Pu				
Pu (VI)	7	250	9	-
Pu (IV)	120	7,100	150	-
Pu (III)	800	>10,000	8,000	-
^{99}Tc	-	-	0.5	-
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This paper summarizes results for 40 defense waste lysimeters operated 5 to 7 years, a tritium lysimeter operated 12 years, and a plutonium waste lysimeter operated 2 years. Recent results for soil-water chemistry studies, and transport modeling which were being performed during this period at the low-level radioactive waste burial ground, are also reported.

Defense Waste Lysimeters

Radionuclide concentrations in lysimeter effluents with either known or estimated source terms were analyzed for the following: ^{90}Sr, alpha emitters ^{238}Pu, ^{239}Pu, ^{241}Am have known source terms; and analyses for gamma emitters ^{54}Mn, ^{60}Co, ^{106}Ru, ^{125}Sb, ^{137}Cs, ^{234}Th, and ^{235}U. All these gamma emitters appeared to be from the waste except ^{234}Th - a daughter product of ^{238}U or ^{235}U. Source terms were not known for ^{125}Sb.

The following observations were reported: Lysimeters containing laboratory wastes were found to release the fraction and variety of radionuclides to effluent water. There are no apparent differences between the saturated and unsaturated lysimeters in terms of radionuclide releases. Strontium-90 has the highest fractional release rate and highest concentration measured in the effluent; however, less than 0.5 percent of ^{90}Sr originally placed in the lysimeter will ever be released if there is no change in rates or mechanism.

This paper concluded that releases from the burial ground to the groundwater will be significantly lower than those observed from the lysimeters because of the longer soil column through which the water must pass and the longer time for radionuclide decay.

Tritium Lysimeter

Results from a 12-year lysimeter study on stainless-steel crucibles containing spent Li-Al melts with an estimated tritium source of 450 curies was presented . After 12 years, 400 curies were accounted for by decay or release to percolate water. Whereas a remaining 50 curies (decayed to 25 curies) was continuing to slowly release.

The following additional observations were reported:

17 percent of original tritium was released in first year by washoff mechanism;
33 percent of tritium was released at relatively constant rate over the first three years;
25 percent of tritium was released slowly over next 9 years;
19 percent of original tritium was result of decay; and
6 percent of original tritium was estimated to have remained unreleased after 12 years.

Plutonium Lysimeter

An actual SRP soil lysimeter containing 480 microcuries of source ^{239}Pu resulted in no detectable ^{239}Pu in collected rain percolate water over a 24 month period. Approximately 90% of the plutonium found by soil coring indicated migration of less than 3 inches below source and most was within 1 inch of the source. A Kd calculated from the soil core data ranged between 9 and 35 mL/g which is in good agreement with batch studies performed on SRP soils.

Over the 2 year period, 79 liters of percolate water was collected. An upper limit of plutonium released from the waste lysimeter to the percolate water was estimated based on the analyses detection limit of 2.5 pCi/L. This results in 200 picocuries (79 L * 2.5 pCi/L) of plutonium that could have migrated from the lysimeter. This gives a fractional release of less than 4E-07 (200 pCi / 480 µCi).

The results indicate that radial migration was small compared to downward migration. Pu(VI) is mobile at the SRP burial ground, but migration rates are small, 15 cm/yr as determined from the maximum migration distance for plutonium in the lysimeter study.

Radionuclide Distribution Coefficients

Decreased sorption of ^{60}Co, ^{85}Sr, ^{125}Sb, and ^{137}Cs to SRP soil was observed for burial groundwater with elevated levels of total organic carbon (TOC). No direct correlation, however, was observed between TOC and each of the radionuclide's Kd. Distribution coefficients for ^{137}Cs were also determined to range from 90 to 2400 mg/L over the pH range of 3.4 to 7.2 for the burial ground.

24. Lead and Cadmium Measurements of Groundwater Beneath the Low-Level Waste Burial Grounds (DPST-85-969).

This report gives results for the analysis of cadmium, lead, and mercury in groundwater for 79 grid wells at the 643-G and 643-7G burial grounds during November 1984.

LEAD

Twenty of 79 wells were reported in excess of 50 µg/L standard for lead with the highest concentration observed at 398 µg/L. The average lead concentration for all 79 wells is 43 ppb. The estimated source term for lead in the burial grounds is a minimum of 42 tons based on the average year separations facilities disposal amount of 1.5 tons (from 1954-1972). Most of the lead is indicated to be buried with large amounts of paper and plastic wastes, and thus the formation of complexed lead species would not be surprising.

CADMIUM

Fifty-four of 79 wells in excess of 10 µg/L standard for cadmium with the highest concentration observed at 365 µg/L. The average cadmium concentrations for all 79 wells is 39 ppb. The report indicates that the estimated source for cadmium is at least 1 ton (based on shutdown of L and R reactors - cadmium control rods). Cadmium sheet is also likely to have gone to the burial grounds and could add an additional 1 ton to the cadmium source term. Cadmium soil/water Kd of 6 mL/g is consistent with these findings. Cadmium is noted to appear to be less strongly sorbed and only weakly complexed by the soils than is lead, with reported ranges for the Kd of 1 to 25 mL/g.

25. Technetium-99 and Iodine-129 in the Burial Ground Plume (DPST-86-278).

This report suggests that as anionic species, ^{99}Tc and ^{129}I detected in groundwater are expected to be mobile in the soils beneath the burial ground once leached from the waste because of the generally low anion exchange capacity of SRP soils. Maximum concentrations for ^{99}Tc and ^{129}I detected during this study were above background at 22 and 12 pCi/L, respectively. The data also indicates that ^{129}I concentrations may be increasing with time. In addition, the Kds for these anionic species suggest mobility in SRP soils and thus transport with the groundwater is likely. The Kd for ^{99}Tc as the pertechnetate anion (TcO_4^-) were measured at less than 1 mL/g. Measured Kds for iodide on SRP soils ranged from 0.6 to 6.6 mL/g showing slightly lower mobility. The study indicates that the presence of these radionuclides in the groundwater makes them likely to be migrating toward Four Mile Creek. No data is given in this report to help quantify a source term in the burial ground.

26. Mercury In Shallow Savannah River Plant Soil (DPST-86-314).

This report lists mercury concentration data from 999 test sites in and around the 643-G Burial Ground, at the Savannah River Swamp adjacent to the TNX Area, and at a background area. The data does not mention anything that would help determine source term in the burial ground area.

27. Organic Compounds at the SRP Old Burial Ground for Low Level Radioactive Waste (DP-MS-86-138).

This report indicates that a source of organic species was detected in the northwest corner of the facility and is a soluble source of complexing agents including EDTA. These complexing agents enhance mobility of radionuclides in the SRP soils. EDTA is a strong chelating agent for many metals and it is possible for this species to enhance the mobility of a number of radionuclides, particularly the induced activity radionuclides such as ^{63}Ni and ^{60}Co. No data is given in this report to help quantify a source term in the burial ground.

28. Environmental Information Document - Radioactive Waste Burial Grounds (DPST-85-694)

This document does list information on inventories of wastes placed in the burial grounds, however, information listed is not assigned to individual facilities. Information on distribution coefficients is also presented.

29. 1987 Monitoring Report of Special Lysimeters - Humid Site (DPST-87-648).

Ten lysimeters at SRP were monitored from 1/83 until 1987 for this report. The leachate was analyzed for various radionuclides over this time period and is included in this report.

Cobalt-60

The annual fractional releases of ^{60}Co measured ranged from 2E-09 to 2E-06.

Strontium-90

The annual fractional releases of ^{90}Sr measured ranged from 3E-08 to 3E-05. The portland cement wasteforms have released less ^{90}Sr (approximately a factor 10) than the polymer matrix evaluated.

Cesium-137

The annual fractional release of ^{137}Cs from a portland cement lysimeter 44 was measured at 2E-05. The highest ^{137}Cs concentration measured in the leachate of a lysimeter 44 during the year was 431 pCi/L.

These results indicate that low-level waste forms stabilized in either a polymer or portland cement matrix will help retard migration of radioactivity for significant periods of time. In addition, the conclusions reached were that polymer wasteforms are more effective than portland cement in retaining ^{60}Co, ^{134}Cs, and ^{137}Cs. Portland cement was more effective than polymer wasteforms for retaining ^{90}Sr. There is no mention of K_d values or source term.

30. Effect of Organics on Radionuclide Mobility in the SRP Burial Ground (DPST-87-762).

This report concerns an investigation to determine the effects of organics that were disposed of in the burial ground on radionuclide mobility. Nearly 40 percent of the organics detected in groundwater were high molecular weight which strongly suggests that they are humic materials from decomposing waste. Humic materials can form high molecular weight complexes with radionuclides and could increase their mobility; however, no indication of this geochemical process has been obsered at the BGC. The report concluded that the 60 identified organics present in the burial ground are either not strong complexing agents or are present in levels too low to significantly affect radionuclide mobility in the soil/water system. No mention was made of source term or K_d values.

31. Sorption Properties of Carbon-14 on Savannah River Plant Soil (DPST-88-900).

This report discusses batch experiments performed to determine the Kd for ^{14}C from SRP soil, and burial groundwater. Results indicate a value of 2 mL/g after 7 hours equilibration and 55 mL/g after 72 hours. Results obtained were developed for ^{14}C concentrations ranging from 4.2E+06 pCi/L to 40.9E+06 pCi/L. Carbon-14 is a moderately long lived radionuclide having a half life of 5730 years. Carbon-14 disposed of at both 643-E and 643-7E has an estimated inventory as high as 6600 curies.

Recommendations forwarded by this study suggest that all future transport modeling of ^{14}C should be performed using a Kd value of 2 mL/g which conservatively represents conditions present in the SRP burial grounds.

32. Integrated Report on Radionuclide Migration at the Savannah River Sallow Land Burial Site, (DP-1778).

This report lists the following radionuclide inventory for wastes buried in the SRP burial grounds (1952 through 1985):

		Radioactivity (1,000 Ci)	
Radionuclide	**Volume (1000 m^3)**	**Initial Activity**	**Decayed (1985)**
Tritium	24	4090	1830
Fission Products	266	711	19
Activation Products	31	3410	348
Carbon 14	-	6.8	6.8
Cobalt 60	5	1110	413
Nickel 63*	-	350	349
Strontium 90	-	-	~10,000
Cesium 137	-	-	~10,000
Other Alpha Emitters	54	0.093	0.087

*** Included in Activation Products**

Composition of Other Alpha Emitters (Percent of Activity)	
Uranium 233	0.8
Depleted Uranium	62.7
Enriched Uranium	0.3
Natural Uranium	3.3
Plutonium 242	0.002
Americium 241	6.7
Californium 252	25.9
Neptunium 237	0.2
Thorium 242	0.1

Chemicals and Metals	Amount (Kg)
Cadmium	2,000
Lead	100,000
Mercury	10,000
Naphthalene	4,000
Toluene	13,000
Trimethylbenzene	13,000
Xylene	21,000

Note: Data are based upon corrected and updated information retrieved from the Computerized Radioactive Waste Burial Records analysis *COBRA*. Reference is Jaegge 1987. Figures are rounded.

The amount of tritium in the southern plume in 1987 is about 100,000 curies; in the northern plume, about 3000 curies. About 12 curies of ^{129}I are estimated to be in 643-G. About 6,800 curies of ^{14}C have been disposed of in 643-G and 643-7G. An estimated 10,000 curies of ^{90}Sr have been disposed of in 643-G. Approximately 10 tons of mercury have been disposed of in 643-G.

Following are the K_d's for a number of chemicals along with the retardation factor and estimated velocities per year.

Chemical	**K_d (mL/g)**	**Retardation Factor**	**Velocity (feet/year)**	**Time to travel 20 feet (yr)**
Tritium	0.001	1.008	6.9	3
Strontium	7.9	65	0.11	180
Carbon	2	17	0.41	48
Cesium	500	4000	0.0017	11,500
Cobalt	10	81	0.086	230
Iodine	0.2	2.6	2.7	7
Neptunium	10	81	0.086	230
Plutonium	100	800	0.009	2300
Technetium	0.001	1.008	6.9	3
Uranium	40	320	0.022	900
Lead	100	800	0.009	2300
Mercury	>10,000	>80,000	<0.00009	>230,000

The K_d of cesium varies over the pH range of the burial ground from 90 mL/g at pH of 3.4 to 2400 mL/g at a pH of 6.9.

33. Extension of the Defense Waste Lysimeter Program (U) (WSRC-RP-89-1424).

This report recommends that the lysimeter program be continued. It also describes the lysimeters. No useful data for source term or K_d.

34. Radionuclide Inventory of E Area (WSRC-RP-91-709).

This report lists radionuclide inventories in the E-Area at the BBG as of 6/25/91 using COBRA records. Estimated inventories for building 643-E, 643-28E , and 643-7E are as follows:

643-E Inventory

Nuclide	As Variety 1	As Variety 2	Total	Units
Fission Products	561,063	40,145	601,208	Curies
Induced Activity	2,279,612	--	2,279,612	Curies
Other	139	--	139	Curies
Depleted Uranium	18,039	--	18,039	Kg
Enriched Uranium	171,449	--	171,449	g
^{244}Cm	88	--	88	g
Californium	25	--	25	μg
Weapons Grade Plutonium	17,225	--	17,225	g
^{233}U	24	--	24	g
Normal Uranium	8,027	--	8,027	Kg
^{237}Np	128	--	128	g
^{238}Pu	800	--	800	g
Tritium	117	55	172	g
Thorium	194	--	194	Kg

643-28E Inventory

Nuclide	As Variety 1	As Variety 2	Total	Units
Cobalt	1,103,370	73	1,103,443	Curies
Cesium	2,322	15	2,337	Curies
Fission Products	85,878	15,882	101,760	Curies
Induced Activity	1,046,009	--	1,046,009	Curies
Other	137	15,532	15,669	Curies
Strontium	16	1,822	1,838	Curies
Depleted Uranium	141,162	--	141,162	Kg
Enriched Uranium	375,099	--	375,099	g
^{242}Pu	0.4	--	0.4	g
^{241}Am	2.8	--	2.8	g
^{244}Cm	28	--	28	g
Californium	59,905	--	59,905	µg
Weapons Grade Plutonium	975	--	975	g
^{233}U	209	--	209	g
Normal Uranium	317	31	348	Kg
^{237}Np	73	81	154	g
^{238}Pu	67	--	67	g
Tritium	178	41	219	g
Thorium	1.4	93	94.4	Kg

643-7E Inventory

Nuclide	As Variety 1	As Variety 2	Total	Units
Cobalt	35,971	0	35,971	Curies
Cesium	10	0	10	Curies
Fission Products	3,675	90	3,765	Curies
Induced Activity	24,736	--	24,736	Curies
Other	326	73	399	Curies
Strontium	0	0.4	0.4	Curies
Depleted Uranium	7,659	--	7,659	Kg
Enriched Uranium	200,709	--	200,709	g
^{241}Am	0	--	0	g
^{244}Cm	0.2	--	0.2	g
Californium	62,593	--	62,593	µg
Weapons Grade Plutonium	5	--	5	g
^{233}U	0	0	0	g
Normal Uranium	417	80	497	Kg
^{237}Np	0	0	0	g
^{238}Pu	2.7	--	2.7	g
Tritium	14.9	5.8	20.7	g
Thorium	14.5	52.8	67.3	Kg

Waste inventories related to the TRU Pads 1-13 are presented, however, are not included in this discussion because this study is attempting to represent waste inventories for the unlined shallow trench burials at the BGC.

35. Phase II RFI/RI Work Plan for the Burial Ground Complex (U) (WSRC-RP-90-1140) Rev. 1.

This document lists information for chemical and radioactive waste inventories at the BGC. Information presented for the radionuclide inventory in this document was provided by *Cook, 1991* (reference #34). Note, however, that information presented for curium (^{244}Cm is listed at 5 grams in the OBG) in this document was different than that reported by *Cook, 1991* (^{244}Cm estimated at 88 grams). Most of the information related to waste inventories and radionuclide amounts were estimated. Data on projected chemical and metal waste inventory modified from *Cook, 1987* for the OBG is shown as follows:

Inventory Of Metals And Solvents At The OBG (643-E)

Chemicals	**Quantity (lbs.)**
n-Dodecane	3,750
Naphthalene	4,850
Toluene	15,600
Tributylphosphate	1,600
Trimethylbenzene	15,600
Xylene	26,500
Metals	
Cadmium	2,650
Lead	121,000
Mercury	22,000

Data on the total solid radioactive waste inventory at the BGC is presented. Note that this summary table includes information on retrievable TRU Waste.

Solid Radioactive Waste Inventory at the Burial Ground Complex - By Volume

Radioactive Waste	Volume (cubic ft.)	Activity (Ci)
TRU Waste		
Non-Retrievable	160,100	52,000
Retrievable	266,239	809,403
Total	**426,339**	**861,403**
Beta-Gamma Waste		
Total	**21,272,046**	**9,598,559**

36. Cesium in the Savannah River Site Environment (U) (WSRC-RP-92-250).

This document reports that the estimated decay-corrected inventory of cesium at the Solid Waste Disposal Facility (SWDF) as of January 1987 was 1,809 curies. This value was estimated from radiation surveys of packages and by using conversion factors for the estimated fission product content.

There have been few direct detection measurements of cesium radioisotopes in the SWDF groundwater.

37. Assessment of Strontium in the Savannah River Site Environment (U) (WSRC-RP-92-984).

This document reports that the estimated decay-corrected inventory of strontium at the SWDF as of January 1987 was 1,389 curies.

38. Assessment of Technetium in the Savannah River Site Environment (U) (WSRC-TR-93-217).

This document reports that the estimated inventory of Tc-99 at the (SWDF) is 20 curies. In groundwater at SRS, technetium favors the pertechnetate ion (TcO_4^-) species which is soluble, but relatively inert, and thus will travel near-groundwater velocities. Technetium-99 has been measured in groundwater wells surrounding the SWDF. The highest activity detected was 14 pCi/L but for most wells the Tc-99 activity was below detection.

39. Tritium in the Burial Ground of the Savannah River Site (U) (WSRC-TR-93-316), Rev 0

This report reviews the available information on the tritium contaminated material discarded in the burial grounds. The report determined that the amount of tritium in the burial grounds is very uncertain. There are no records of burials before 1961. Tritium burials associated with spent target melts are estimated from a very limited study and have a large uncertainty associated with the estimates. Burials involving discarded equipment are very difficult to estimate. Many of the burials waste casks were simply filled with waste materials of various types without any attempt to specify the contents.

Following is an estimate of the tritium content in typical items that were buried in the burial grounds.

Type Shipment	Tritium (Curies)	Induced Activity (Curies)
Waste Dumpsters	0.1	0
Spent Melts		
Lithium aluminum	100/melt	20/melt
	200/double melt	40/double melt
Lithium Aluminate	1000/melt	20/melt
Mg, U, Z beds	500/bed	0.1/bed

Note: the Mg, U, and Z beds are used to purify and concentrate the tritium and must eventually to replaced. Lithium aluminate has been irradiated only in a few special experimental irradiations.

This report also states that HP data and the COBRA database are often quite different in the values that they report. Data from HP reports tend to show greater amounts of tritium buried than the COBRA database. Data on estimated amounts of tritium buried from 1959 through 1964 from HP reports are presented below. These reports tend to vary quite a bit from COBRA data. For example, in 1963 *COBRA* reported 227,000 curies while the HP reports listed 531,000 curies.

Tritium Burials by Year, from HP Reports

Year	Tritium Buried, kCi
Through 1959	1201
1960	159
1961	615
1962	531
1963	531
1964	559

The total quantity, uncorrected for decay, reported *(Cook, 1991)* was 172 g (1,670,000 Ci) in the OBG and 240 g (2,330,000 Ci) in the new burial ground. This was based on COBRA records which give lower values than the HP estimates. COBRA records also do not include materials placed in the burial ground prior to 1961.

Groundwater Detection Monitoring

The following is a list of groundwater concentrations for several organic and metal constituents which have been detected in groundwater perimeter monitoring wells at the BGC. This table presents previous maximum groundwater contaminant concentrations beginning as early as the fourth quarter 1988 and also lists more recent maximum values for contaminants detected up to the first quarter of 1993.

Constituent	Well ID	Maximum Observed Conc. (ppb)	Monitoring Quarter for Maximum Obs Conc.	Well ID	Current Maximum Result (ppb)	Monitoring Quarter for Current Max.Conc.
Benzene	BGO-01D	46.0	89Q2	----	LT	93Q1
Cadmium	BGO-11D	38.7	89Q3	----	LT	93Q1
Carbon Tetrachloride	BGO-37C	95.0	89Q2	----	LT	93Q1
Chloroethylene	BGO-28D	179.0	92Q2	BGO-28D	86.0	93Q1
Chloroform	BGO-37C	78.0	90Q3	BGO-30D	40.8	93Q1
Lead	BGX-10D	198.0	92Q4	BGO-40D	34.1	93Q1
Mercury	BGO-02D	2.86	88Q4	BGO-33C	1.46	93Q1
Tetrachloroethylene	BGO-48D	78.0	92Q4	BGO-48D	39.9	93Q1
Trans-1,2-Dichloroethylene	BGO-28D	2600.0	89Q3	----	LT	93Q1
Trichloroethylene	BGO-37C	1000.0	90Q4	BGO-28D	245.0	93Q1
Xylene	BGO-16D	9.0	90Q3	BGO-30D	6.5	93Q1

ppb	Parts per billion (μg/L)
N/A	None available
LT	Less than method detection for wells screened

Summary of Data for Distribution Coefficient Values (Kd)

The following tables present a summary of distribution coefficient (Kd) values obtained upon review of the documents covered in this discussion. Document reference numbers are included on this table.

Distribution Coefficient Values (Kd) Developed From Review of SRS Documents

Constituent	Kd Values presented as a Range (mg/L)	Reference #
Metals		
Cadmium	6	24, 28
Lead	1 - 100	24, 28, 32
Mercury	≥10,000	28, 32
Radionuclides		
C-14	2 - 55	31, 32
Cs-137	90 - 2400	1, 10, 14, 21, 23, 32
Co-60	10	21, 28, 32
H-3	0.001	28, 32
I-129	0.2 - 6.6	21, 28, 25
Neptunium	10	28, 32
Plutonium	9-100	23, 28, 32
Ru-106	175	21
Sb-125	3800 - 4000	21, 28
Sr-90	1 - 30	1, 10, 16, 21, 28, 32
Tc-99	0.001 - 0.5	10, 21, 25, 28, 32
Uranium	40	28, 32

Note: This list of reported Kd values was generate based on those documents presented in this discussion.

Summary of Waste Inventories for 643-E, 643-28E, and 643-7E

The following tables illustrates waste inventories for the old and new burial grounds (i.e., buildings 643-E, 643-28E, and 643-7E trenches). *Cook, 1991* (reference #34) is used here as the base reference case upon which radionuclide inventories were compared. In addition, because chemical waste inventories are not well recorded, data reported in the *Phase II RFI/RI Work Plan for the Burial Ground Complex (U) (WSRC-RP-90-1140) Rev. 1.* (reference #35) was assumed to be the best reference case for the chemical inventory at the BGC. Data obtained on waste inventories from the review of annotated documents is integrated with the information from these reference waste inventory estimates. The following tables present a summary from this review on source term estimates. Note that data obtained which differs from waste projections reported in the base reference case estimates are presented as a waste inventory range in **bold** type. Reference numbers are included for those documents from which these ranges of inventory were derived.

The following radionuclide inventory representative of the OBG (643-E) was provided by *Cook, 1991.*

Radionuclide Inventory at Old Burial Ground (643-E)		
Radionuclides	**Amount**	
	Curies	**Grams**
Fission Products	601,208	
Induced Activity	2,279,612	
Other	139	
Depleted Uranium		18,039,000
Enriched Uranium		171,449
U-233		24
Np-237		910
Pu-238		800
Cm-244		**(5 - 88)**[1]
Californium		0.000025
Weapons grade plutonium		17,225
Normal Uranium		8,027,000
Thorium		194,000
Tritium		**(172 - 313)**[2]

[1] Lower limit based on quantity reported in *Phase II RFI/RI Work Plan for the Burial Ground Complex (U) (WSRC-RP-90-1140) Rev. 1.* (reference #35).

[2] Upper limit was estimated based on HP report for estimated tritium buried prior 1961 ≈1,360,000 Ci (or 141 g)-undecayed *Hyder, 1993* (reference #39).

The following table presents estimated inventories of organic solvents buried in the OBG (643-E). Document references numbers from which this data was developed are included on the table.

Inventory Of Metals And Solvents at Old Burial Ground (643-E)

Chemicals	Quantity (lbs.)	Reference #
n-Dodecane	3,750	35
Naphthalene	4,850 - 8,820*	32, 35
Toluene	15,600 - 28,660*	32, 35
Trimethylbenzene	15,600 - 28,660*	32, 35
Xylene	26,500 - 46,300*	32, 35
Metals		
Cadmium	2,650 - 4,410*	32, 35
Lead	84,220 - 220,460*	32,35
Mercury	22,000	2, 11, 20, 32, 35

*Upper limit of each estimated inventory range may include contributions from 643-28E and 643-7E (see following note).

Note: Document *DP-1778* (reference #32) does not delineate nor segregate the amount of waste sent to each individual burial unit (i.e., 643-E, 643-28E , or 643-7E); therefore, the upper limit of the estimated waste inventory range for each chemical listed could be a summation of estimated inventories from each of the burial units (i.e., the estimated inventory for the entire burial ground).

The following table illustrates estimated inventories for several individual radionuclides buried in the burial grounds (i.e., 643-E, 643-28E, and 643-7E). Amounts presented are not corrected for decay.

Radionuclides Buried at the Burial Grounds

Radionuclide	**Amount (Ci)**	**Burial Unit**	**Reference**
Carbon-14	6800	643-E and 643-7E	32
Cesium-137	10,000	643-E	4, 21
Iodine-129	12 - 13.5	643-E	21, 32
Strontium-90	10,000 - 11,000	643-E	4, 16, 21, 32
Technetium-99	1 - 100	643-E	21, 28

Note: This data on estimated inventories was based only on the documents presented in this discussion.

No additional radionuclide inventory data which could be related directly to the MWMF (643-28E) or LLRWDF (643-7E) was discovered during this review which would add to the data provided from *Cook, 1991.*

The following table lists the radionuclide inventory at the MWMF (643-28E). This information is reported from *Cook, 1991*:

Inventory Of Radionuclides At The MWMF (643-28E)		
Constituent	**Amount**	
	Curies	**Grams**
Cobalt	1,103,443	
Cesium	2,337	
Strontium	1,838	
Fission Products	101,760	
Induced Activity	1,046,009	
Depleted Uranium		141,162,000
Enriched Uranium		375,099
U-233		209
Np-237		154
Pu-238		67
Pu-241		0.4
Am-241		2.8
Cm-244		28
Californium		0.06
Weapons grade Pu		975
Normal Uranium		348,000
Thorium		94,400
Tritium		219

The following table lists the radionuclide inventory at the LLRWDF (643-7E). This information is reported from *Cook, 1991*.

Inventory Of Radionuclides At The LLRWDF (643-7E)		
Radiocuclide	**Amount**	
	Curies	**Grams**
Cobalt	35,971	
Cesium	10	
Fission Products	3,765	
Induced Activity	24,736	
Other	399	
Strontium	0.4	
Depleted Uranium		7,659,000
Enriched Uranium		200,709
^{241}Am		-
^{244}Cm		0.2
Californium		0.062593
Weapons Grade Plutonium		5
^{233}U		
Normal Uranium		497,000
^{237}Np		
^{238}Pu		2.7
Tritium		20.7
Thorium		67.3

Summary/Conclusions

This review of reports/studies related to the burial grounds attempted to provide information on the following topics: waste lysimeter studies, contaminant migration/soil distribution (Kd) studies, waste inventory reports, and contaminant detection monitoring. Most of the information taken from the documents discussed above were found to be repetitive and/or related to earlier studies.

Data presented on distribution coefficient (Kd) values for various components was mainly from information contained in studies related to SRS lysimeter studies.

Data as early as 1961 on radionuclides placed in the burial grounds have been recorded in the COBRA database. However, as noted by *Hyder, 1993,* data from HP and from the COBRA database are often quite different in reported values of waste buried (e.g., tritium). Likewise, estimates of burial ground inventories are difficult to quantify simply because of the lack of content specifics and/or because curie contents of discarded buried equipment are difficult to estimate.

Documentation on estimated inventories of solvent wastes sent to the burial grounds are sparse and have not been recorded well.

Attachment Two: Source Control Technologies

Introduction

The following is a discussion of various in situ contaminant source control technologies. These technologies were selected based on their applicability, viability, and ability to reduce the leaching of contaminants (i.e., to increase the transit time) so that contaminant decay and/or natural or biological degradation can effectively reduce source term concentrations. The technologies discussed are presented as part of two main categories: (1) Solidification and Stabilization Technologies, and (2) Barrier Methods. An economic evaluation is not presented; however, based on technical feasibility, each technology is evaluated and is represented as potentially viable, limited, or is eliminated for applicability at the BGC (Table 1).

A review of viable source control techniques at the BGC are discussed below because groundwater primarily in the shallow Water Table Aquifer below the BGC is contaminated with several hazardous and radioactive materials above representative background concentrations. This groundwater is likely to remain contaminated for several decades and is in a flow path which outcrops to adjacent wetlands and/or discharges directly to surface water streams. Note that the following containment technologies do not involve remediation or immediate destruction of buried wastes, but rather utilize time as the governing mechanism for contaminant decay and/or degradation.

The ability to implement, construct, operate, and monitor the effectiveness of a source control technology so that State and community opinion supports the long-term reliability of a technology in reducing existing risk and in preventing future exposure are among several factors necessary in an evaluation of containment (source control) technologies. These are crucial points which are beyond the scope of this task and may need further evaluation.

(1) Solidification and Stabilization Technologies

Solidification is a process that produces a monolithic block of waste with a high structural integrity (Barth, 1991). The contaminants do not interact chemically with the solidification agents, but are mechanically bonded (i.e., locked within the solidified matrix). A stabilization process usually involves the addition of reagents which limit the solubility, toxicity, or mobility of the waste constituents (Chambers, 1991). Solidification would be included under stabilization due to the decrease in mobility of the contaminants. Stabilization includes use of a chemical reaction to transform the contaminants to a new, non-toxic compound or substance. Stabilization also includes pH adjustment to form metal precipitates. This effectively removes the metal ions from solution and greatly reduces the mobility of the metal contaminants. These two techniques are often used together. Due to the high cost and problems associated with the excavation of buried wastes, in situ treatment by stabilization/solidification is, in many cases, the only viable waste management technique.

Solidification/stabilization methods use a range of equipment from relatively simple, low-cost cement or silicate-based processes to more sophisticated, costly equipment used for glassification and thermoplastic techniques. Use of this waste fixation methodology should be limited to wastes which cannot be treated cost-effectively by other methods.

The waste solidification/stabilization systems that are potentially useful in remedial action activities include:

- Pozzolan-portland cement systems
- Lime-fly ash pozzolan systems
- Sorption
- Soil fixing
- Polymerization
- Thermoplastic microencapsulation
- Vitrification

Pozzolan-Portland Cement Systems

Pozzolan-portland cement systems use portland cement and pozzolan materials, such as fly ash, to produce a high strength waste/concrete composite(Chambers, 1991). The waste is contained in the concrete matrix by microencapsulation (i.e., physical entrapment).

Lime-Fly ash Pozzolan Systems

Lime-fly ash pozzolan systems combine the finely ground, non-crystalline silica in the fly ash with the calcium in lime to produce low-strength cementation. The waste is contained by microencapsulation within the pozzolan concrete matrix (Chambers, 1991).

Sorption

Sorption was originally used primarily to minimize the mobility of liquid waste. Materials such as activated carbon, clays, zeolites, anhydrous sodium silicate, diatomaceous earth, and various forms of gypsum were added to soak up any free liquids in the waste. The waste is contained only by the sorptive forces of the added materials and thus was still subject to leaching. Provisions under the Hazardous and Solid Waste Amendments (HSWA) no longer permit the use of sorbents that merely soak up liquids. Selected sorbents may still, however, be used to enhance the performance of solidification/stabilization systems. Materials, such as activated carbon or ion exchange resin beads, can also be used in permeable trenches to adsorb hydrocarbons and some heavy metals from groundwater as it passes through the wall. Eventually, the contaminated carbon or resin beads must be removed and properly disposed.

Soil Fixing

Soil fixing involves injecting chemicals into the ground which tend to make the contaminant less toxic, mobile, or soluble. Lime is often used because it raises the pH of the soil and causes many heavy metals to form insoluble hydroxides. The heavy metals may also be rendered insoluble by the addition of carbonates, silicates or sulfides. Some metals remain soluble in groundwater because they form soluble complexes with other materials called sequestering agents (Conner, 1990). By breaking these complexes, the metals can be made insoluble. In some cases, this simply requires a pH adjustment to form an insoluble hydroxide complex. In other cases, strong oxidizing agents must be used. Metals, such as chromium, may require a change of valence state before they can be rendered insoluble. Chromium in the +6 state is highly toxic and will tend to remain in solution. By reducing the chromium ion to the +3 state using a reducing agent, such as ferrous sulfate, an insoluble species can be formed.

Another method for fixing heavy metals is to add materials which will allow the metal ions to adsorb onto their surface. Materials such as ion exchange resins, molecular sieves, clays, insoluble starch xanthate, and insoluble chelating agent have been injected or tilled into soil to fix heavy metals (Czupyrna, 1989).

While all of these methods tend to reduce the mobility of the heavy metal ions, the metals still remain in the soil. No remediation has actually occurred. Any changes in soil conditions in the future could render the metal ions soluble and mobile again.

Polymerization

Polymerization can be effective in immobilizing some organic constituents, preferably those with more than one double bond. In polymerization, a catalyst is injected into a contaminant source or groundwater plume which causes linking "polymerization" of the organic monomer (e.g., vinyl chloride or urea-formaldehyde) (Jackman, 1991). The polymerization reaction causes the contaminant liquid-form monomer to transform or link into a gel-like mass. This immobilization methodology would be ideal for areas where isolated contaminant plumes exist. An in-situ polymerization procedure was successfully performed on approximately 4,200 gallons of acrylate monomer which had leaked into a glacial sand and gravel layer. Soil borings revealed that approximately 90 percent polymerization was achieved (Williams, 1982). The application of polymerization techniques to the uncontrolled release of contaminants from a hazardous waste site is, however, limited. Other major disadvantages include difficulty in defining whether the injected activator (catalyst) has made sufficient surfacial contact with the dispersed monomer and the potential formation of toxic byproducts as a result of chemical reactions.

Thermoplastic Mcroencapsulation

In thermoplastic microencapsulation, finely divided waste is blended with molten asphalt, polyethylene, polyethylene-polybutadiene, epoxy, polyesters, or urea-formaldehyde (Jackman, 1991). Here, physical entrapment in the cooled, hardened mass is the primary mechanism for containment. This method is generally used on waste streams before disposal or for excavated contaminated soil. The waste must be dried before encapsulation to prevent vapor bubbles from forming in the hot molten mass. These materials do tend to form a more water tight barrier around the waste than cement based materials do, but they are also more costly. Due to the higher material costs and the requirement for dry waste, this method has not been employed for in situ applications.

Vitrification

In situ vitrification (ISV) is the process of melting a large volume of contaminated soil by the application of an electric current using graphite electrodes. This technology is being developed at the DOE Hanford Complex for stabilization of transuranic and other hazardous wastes (Fitzpatrick, et al., 1984). In the ISV process, four electrodes are typically spaced approximately 12 to 15 feet apart and 4-5 MW of electricity are applied. The electrodes only penetrate the ground about one foot initially, but are pushed further below the surface as the melt progresses until they reach a maximum depth of about 20 feet. The melt takes 4-5 days and will produce between 400 and 900 tons of vitrified waste[14].

This system has been successfully pilot tested at DOE's Idaho National Engineering Laboratory (INEL)[14]. The cost of the process was about $16,000 per cubic meter of soil vitrified. It is estimated that the resulting glass mass produced from this trial will be about 4 to 10 times more durable than the typical borosilicate glass used to immobilize high-level nuclear waste. Although the process was initially developed to provide enhanced isolation to previously disposed radioactive wastes, the process may also destroy or immobilize many inorganic and organic hazardous chemical wastes. The vitrification process effectively contains the heavy metal and solid radioactive contaminants and prevents them from leaching into the groundwater, provided the contaminants were completely vitrified. Inhomogeneities within the mass, with partly crystalline and partly glassy areas, would create variations in the leach resistance. Testing for complete vitrification would be very difficult.

In determining the applicability of ISV, specific site characteristics must be considered. For example, soils with permeabilities greater than 10E-04 cm/sec are considered difficult to vitrify and in the presence of flowing groundwater could present economic limitations to the process.

The environmental impact in using vitrification of hazardous wastes or contaminated soils is the potential for off-gas release which needs to be addressed when considering ISV. The high heat generated during the melt will release any volatile materials present in the soil to the atmosphere. A collection system (e.g., an area hood or cover) must be installed to collect any TCE, PCE, radon, cesium, radium, and any other volatiles driven off from the soil. This stream would then be transferred to an off-gas treatment system.

The high cost of this process makes it more of a "last resort" technology. Sites, such as Hanford, with high levels of nuclear contamination may find that this process is actually about half the cost of digging up the soil and treating it. Since there is much less chance of contaminating workers, this process also has significant safety advantages for treating highly contaminated soils as well.

Application of Solidifying/Stabilization Agents

There are at least three methods for in situ application of the solidifying /stabilization agents to the subsurface. These are:

- Injection method
- Surface application
- Application of electrical energy

One type of injection method has been developed by Geo-Con, Inc (Geo-Con's sales literature, 1990 & 1991). They demonstrated this technology through the EPA's SITE program. The method uses a hollow auger which has an injection point at the bottom of the shaft. The auger is advanced into the ground to the required depth. The solidification slurry is then injected while the auger continues to operate and is withdrawn from the ground. The unique augering/mixing action of this equipment blends the soil, waste, and solidification slurry together. When solidified, the waste forms a vertical column in the ground. Additional columns are located to overlap to ensure that none of the waste material is missed. A layer of asphalt may be applied over the top of the columns to protect the solidified mass from rain and water erosion. Other injection methods include drilling holes in the soil in and around the contaminant plume followed by pumping the solidification slurry into the drill holes under pressure. This method requires porous soil for best results. It is difficult to control where the slurry ends up and usually requires the use of substantially more slurry than should theoretically be required. This method of application makes it very difficult to ensure that the entire plume has been solidified.

Surface application can only be used when the waste is sufficiently shallow and the soil is relatively permeable to allow the stabilizing agent to thoroughly penetrate. This method is often used when lime is being added to contaminated soil to raise the pH.

Application of electrical energy is the method used for in situ vitrification.

(2) Barrier methods

An alternate method for controlling the source term of groundwater contaminants is through the use of physical barriers. The methods discussed include various forms of vertical barriers and soil freezing.

Vertical Barriers

There are a number of vertical barriers which are commonly used in industry to help control the migration of contaminated groundwater. These technologies include: slurry trench cutoff walls, soil mixing, jet grouting cutoff walls, vibrating beam walls, geomembranes, steel piling, and plastic panels.

Vertical barriers are useful in preventing or impeding horizontal migration of contaminated groundwater. The barriers can be made of portland cement, pozzolanic fly ash, bitumen, clay, steel or plastic. Some barriers require excavation of the area before installation can be made. These methods are generally the most expensive to install and are limited in depth. The more economical methods usually are able to install the barriers with limited excavation needed.

Slurry Trench Cutoff Walls

In preparing a slurry trench cutoff wall, a vertically walled trench is dug to the required depth and filled with the slurry mixture. Cutoff walls are typically constructed utilizing an "intragradient" design. This means that conditions are such that an inward flow is induced through the cutoff wall and the underlying aquitard. This creates an effect where the groundwater level within the confines of the cutoff wall is lower than outside the enclosure. Hence, contaminants are less likely to leach (i.e., to migrate) beyond the cutoff wall and down into the aquifer.

Conventional subsurface cutoff walls can be constructed with polymeric materials or by compacted clay techniques. Slurry trench cutoff wall mixtures are typically made of bentonite clay and water slurry, or concrete. The bentonite clay mixture can be used in highly unstable, saturated sand.

One notable advantage in slurry-trench wall design techniques is their applicability to highly unstable (i.e., partially saturated) soils. One disadvantage of the soil-bentonite slurry cutoff walls is that it is at times more susceptible to chemical breakdown than other slurry mineralized matrices.

The soil-bentonite slurry cutoff walls are typically 2 to 3 feet in width and range in cost from $5 to $10 per vertical square foot of wall.

The compacted clay cutoff walls involve the use of moisture and density control to obtain the appropriate hydraulic conductivity. Development of these geochemical methods, however, may be quite expensive if clay materials are not locally available and/or if dewatering requirements are too demanding. Under appropriate conditions, the compacted clay wall can cost between $4 and $8 per vertical square foot. Compacted clay walls are generally much wider (i.e., typically 8 to 12 feet wide) than the slurry cutoff walls as a result of the machinery used for compaction (Ref. HAZMAT WORLD, Feb 1993).

Soil Mixing

Geo-Con Inc. of Monroeville, PA uses a soil mixing technique to form their barriers. For shallow soil mixing they use an auger that is about 12 feet in diameter. This auger can only be used to a depth of about 40 feet. The auger drills into the soil to the desired depth. The treatment chemicals are then injected into the vertical column of mixed soil while the auger is operating. The special design of the auger allows complete mixing of the soil and the treatment chemicals. The treatment chemicals will vary with the soil conditions and the contaminant, but usually consist of grout, which is a cement-bentonite mixture, and chemicals which will prevent chemical attack on the bentonite. Numerous overlapping vertical columns are made to form the barrier wall.

Deep soil mixing is performed with slightly different equipment. The augers are limited to about 3 feet in diameter while the depth of the mixing can be as much as 150 feet. The augers consist of 1 to 4 shafts which contain both auger and mixing blades. The mixing blades are arranged so that the vertical columns overlap as with the shallow soil mixing. The cement based grout is injected through the hollow stems of the mixing shafts. After the auger reaches the desired depth, the rotation of the shaft is reversed and the soil is thoroughly mixed while the augers are removed.

With both of these methods, fumes and dust are collected while the mixing is occurring to prevent air pollution. For best results, the vertical barrier should contact a continuous sub-surface layer of clay which will tend to prevent further vertical migration of the contaminated groundwater. This method of installation is generally less expensive than other methods that require excavation. Typical installation costs are $6 to $12 per vertical square foot (Ref. HAZMAT WORLD, Feb 1993).

Jet Grouting Cutoff Walls

Jet grouting is a technique where ultra-high-pressure fluids are injected into soil at 800 to 1,000 feet per second. The high speed fluid is used to cut, replace, and mix native soil with a cementing material, typically a cement-based grout.

The process begins by drilling a vertical guide hole to the required depth. The jet grouting usually begins from the bottom of the hole to the top. Panels or columns can be formed by controlling the rotation of the drill rods while lifting the jet grouting device.

This technique has been used to depths in excess of 200 feet. Costs are typically $15 to $30 per vertical square foot for a three foot wide wall (Ref. HAZMAT WORLD, Feb 1993).

Vibrating Beam

Another method which does not require excavation is the vibrated beam technique. This method is generally less expensive than excavation and is limited to depths of about 70 feet. Basically, a crane operates a vibrator with an injection beam and wear plates. The injection beam is vibrated into the soil to the desired depth. A slurry of grout is then injected through the tip of the injection beam while the beam is withdrawn from the ground. The wall that is left is a minimum of three inches thick (typically 4-6 inches) with an average permeability of 10^{-7} cm/sec. Costs are comparable to those for a slurry-trench cutoff wall (Ref. HAZMAT WORLD, Feb 1993).

Geomembranes

Geomembranes are flexible sheets of fabric filled with clay and binding materials. Geomembranes can be used alone or in conjunction with other technologies to create a low permeability cutoff wall. In one method developed by Wehran Envirotech, the geomembrane sheets are placed into an excavated trench which has been fitted with interlocking high density polyethylene (HDPE) vertical panels. The cost of geomembrane walls is estimated to be $12 to $24 per vertical square foot (Ref. HAZMAT WORLD, Feb 1993).

Steel Piling

For shallow applications, steel sheets are often driven down into the ground to form an impervious wall for groundwater flow. Each sheet is atttached to the adjacent sheets with some type of interlocking mechanism. Usually, the joints are finally filled with a clay slurry to form a low permeable seal. Since the steel is subject to corrosion, the life of these walls will vary with the amount of moisture, soil conditions, and the contaminants in contact with the wall.

Plastic Sheets

Interlocking plastic sheets are also available for making impervious barriers. These generally must be installed by excavating trenches. The type of plastic used and the thickness will vary with the application and the contaminants present.

Discussion of Vertical Barriers

All of the methods which do not require excavation cannot assure that a continuous grout wall has been created. While these methods strive to form continuous walls through overlapping and other techniques, holes or channels may be formed where they cannot be easily detected. This could result an inadequate barrier installation where contaminated groundwater can still spread beyond the walls. All of these methods require that the bottom of the wall contact a continuous aquitard to prevent vertical migration of the contaminated groundwater.

Soil Freezing

Soil freezing is a method for making an ice barrier around the contaminated groundwater plume. This technique is fairly new and is being promoted by RKK, Ltd. under their tradename Cryocell. The installation consists of boring a number of angled wells from the outside of the contaminant plume to below the middle of the plume. Liquid nitrogen is then pumped into the wells to freeze the ground all around the plume thus containing it while remediation continues. Water is injected through the wells to ensure that a barrier of ice is formed. Temperature sensors are included within the wells to control the flow of liquid nitrogen to maintain the ice barrier.

The system is self healing since a leak would cause water to flow toward it. The temperature sensors would register temperatures above freezing and call for more liquid nitrogen to be pumped. The flowing water would soon be frozen and the leak would be plugged.

RKK claims that the system is cost competitive with vertical grout barriers, but has several advantages. When remediation is over, the barrier can be easily removed by no longer pumping the liquid nitrogen. The grout barrier is there forever. The cryobarrier also does not require that there be a continuous clay sublayer to prevent vertical migration of the plume. Since the wells are dug at an angle, the plume can be enclosed in an ice barrier along both the sides and the bottom.

This barrier cannot be used in areas where there are fast moving aquifers. The large flow of water would require excessive amounts of liquid nitrogen to maintain the ice barrier which would cause the system to be uneconomical.

While there are several installations, this system is relatively unproven.

General Conclusions on Source Control Technologies

Because the soils and groundwater at the BGC are contaminated with a variety of organics, heavy metals, and radionuclides--that behave like metals, a containment technology may be a potentially viable alternative to prevent the further spread of groundwater contamination. This is in light of the fact that even though many of the chemical waste and radioisotopes buried at the BGC are relatively immobile in the soil, additional hydraulic control of this buried mixed waste would further prevent contaminants from migrating to the groundwater system. Tritium has one of the largest buried curie contents for any of the radionuclides and is extremely mobile in the groundwater. Because there is no known economical method for treating relatively low-level tritiated water, it is very important that hydraulic control of the groundwater in this area be maintained. Tritium, with a half-life of approximately 12.3 years, is eliminated through natural decay, therefore stabilization of this waste form is the best "treatment" method currently available. These source control technologies are useful, however, only for those radionuclides with short half lives, since the long-lived radionuclides will likely outlast the design life of any of these technological containment methods. The use of a containment technology would reduce, if not eliminate, the magnitude of the flux of tritium outcropping to the associated wetlands and/or directly to the adjacent surface water bodies.

Table 1 - **Technologies for Solidification\Stabilization and Barriers**

TECHNOLOGY	STATUS	COMMENTS
Solidification/Stabilization		
Pozzolan-Portland Cement Systems	E	Would contain the waste fairly well. Drums, etc. not suitable for soil mixing. Requires excavation.
Lime-Fly Ash Systems	E	Would contain the waste fairly well. Drums, etc. not suitable for soil mixing. Requires excavation.
Sorption	L	Could retain organics and heavy metals with activated carbon and ion exchange resins added to soil or permeable trench. Trench may be impractical if aquitard is too deep.
Soil Fixing	L	Will limit the migration of the heavy metals provided pH is kept high. No effect on liquids or tritium.
Polymerization	E	Not applicable.
Thermoplastic Encapsulation	E	Not for in situ application. Would work if excavated and dried.
Vitrification	PV	Would work, but very expensive. Volatiles and tritium would vaporize and would need to be recovered from offgas. Tritium is a problem.

Note:

PV = potentially viable
L = limited, only addresses some of the waste present
E = eliminated from further consideration

Table 1 - Technologies for Solidification\Stabilization and Barriers

TECHNOLOGY	STATUS	COMMENTS
Barriers		
Slurry-Trench Cutoff Walls	PV	Potentially viable if aquitard is not too deep.
Soil Mixing	PV	Potentially viable. Creates little waste.
Jet Grouting Cutoff Walls	PV	Potentially viable, but more expensive than others.
Vibrating Beam	PV	Potentially viable if aquitard is not too deep.
Geomembranes	PV	Potentially viable, but more expensive than others.
Steel Piling	PV	Potentially viable if aquitard is not too deep. Would not last well in the soil environment.
Plastic Panels	PV	Potentially viable if aquitard is not too deep. Would last better than steel in the soil environment.
Soil Freezing	PV	Need better soil characteristics before it can be recommended. Could be expensive due to liquid nitrogen usage. No need for impervious, continuous aquitard to tie into.

Note:
PV = potentially viable
L = limited, only addresses some of the waste present
E = eliminated from further consideration

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Attachment Three: Modeling Parameters

Introduction

This attachment includes basic input requirements for inclusion in a contaminant fate & transport model. At the request of the Environmental Restoration Department (ERD), Site Geotechnical Services (SGS) Department has compiled a list of recommended model inputs and field characterization data requirements necessary to develop or enhance contaminant fate & transport/risk models for the BGC.

Information and suggestions on transport modeling input parameters are presented in an outline format. Information presented also identifies data deficiencies associated with waste source terms and characterization data. Information relating to waste container life expectancy is also mentioned.

Identification of Fate/Transport Model Requirements and Data Deficiencies

The following outline identifies the basic input requirements necessary for inclusion in a comprehensive contaminant fate & transport model. In addition, the general methodology for obtaining this field data is noted for many of the parameters.

I. Flow & Transport Modeling Parameters

  A. **Flow parameters**

    (1.) Aquifer and Aquitard Thickness - obtained from well cores;

    (2.) Hydraulic Conductivity - best values obtained from aquifer pumping tests with observation wells;

    (3.) Hydraulic Head Distributions - obtained from wells or piezometers screened in the same aquifer zone. An abundance of this data already exists;

(4.) Porosity - estimated from laboratory samples or literature values;

(5.) Recharge Areas/Rates - to hydro-regime from precipitation and flux from sedimentation basins; and

(6.) Discharge Areas/Rates - to known seeplines and wetlands.

B. Parameters for Transport

(1.) Contaminant Distribution;

(2.) Dispersivity - generally difficult to measure;

(3.) Distribution Coefficient (Kd) - best values determined from field studies (e.g., lysimeter study); site-specific values should be used if available;

(4.) Molecular Diffusion - contribution is often small in magnitude in comparison to advective transport;

(5.) Physicochemical properties of soil (surface coatings, exchange capacity); and

(6.) Contaminant speciation.

C. Parameters of Fate

(1.) Biological Transformations

(2.) Chemical Transformations

II. Identification of Data Deficiencies and Information Needs

A. Data Deficiencies Associated with Source Term at the Burial Ground.

(1.) Waste/contaminant inventories for radioactive wastes are not well recorded prior to 1961.

(2.) Inventories for organic solvents buried in general are not well recorded;

(3.) Burials of discarded equipment and content specifics of buried wastes are difficult to quantify; and

(4.) Horizontal and vertical distribution for waste not well recorded.

B. Characterization Data Deficiencies

(1.) Hydraulic conductivity estimates

(2.) Vertical gradient - across aquitards for vertical flow

(3.) Groundwater divide

(4.) Contaminant distribution in groundwater and vadose zone

(5.) Transport factors

C. Information on Container Life Expectancy

(1.) Estimates for structural deterioration rates (i.e., life expectancy) for retrievable waste forms is documented for TRU Waste Drums; and

(2.) Estimates for other structural containers (non-retrievable waste forms) have not been well evaluated;

Note: This list of suggestions is not all inclusive and that other data deficiencies relating to the burial grounds exist.

Conclusion

Existing contaminant transport models tend to use the conservative approach in treating burial waste sites similar to seepage basins. This does present a worst case scenario, but may potentially distort the magnitude of predicted subsurface contamination. Therefore, the integration of container life expectancy incorporated upfront in estimating time of release should provide more realistic estimates.

The compilation of the above information integrated into an existing model should result in more representative estimations of the transport and fate of contaminants in the subsurface environment. A well-defined conceptual contaminant transport model is essential in the assessment and selection of proposed remedial alternatives.

Ref. #	Document Date	Document Number	Title	Author(s)
24	December 11, 1985	DPST-85-969	Lead and Cadmium Measurements of Groudwater Beneath the Low-Level Waste Burial Grounds	S. B. Oblath
25	Febrary 6, 1986	DPST-86-278	Technetium-99 and Iodine-129 in the Burial Ground Plume	S. B. Oblath
26	October 1986	DPST-86-314	Mercury in Shallow Savannah River Plant Soil	V. Price J. R. Cook
27	February 1987	DP-MS-86-138	Organic Compounds at the SRP Old Burial Ground for Low-Level Radioactive Waste	S. B. Oblath
28	March 1987	DPST-85-694	Environmental Infomation Document, Radioactive Waste Burial Grounds	W. J. Jaegge B. B. Looney
29	September 17, 1987	DPST-87-648	1987 Monitoring Report of Special Wasteform Lysimeters - Humid Site	P. F. McIntyre R. H. Hawkins
30	October 18, 1987	DPST-87-762	Effect of Organics on Radionuclide Mobility in the SRP Burial Ground	P. F. McIntyre E. L. Wilhite
31	October 18, 1988	DPST-88-900	Sorption Properties of Carbon-14 on Savannah River Plant Soil	P. F. McIntyre
32	March 1989	DP-1778	Integrated Report on Radionuclide Migration at the Savannah River Shallow Land Burial Site	O. A. Towler, Jr.

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34	June 27, 1991	WSRC-RP-91-709	Radionuclide Inventory of E Area	J. R. Cook
35	March 1992	WSRC-RP-90-1140	Phase II RFI/RI Work Plan for the Burial Ground Complex (U)	
36	1992	WSRC-RP-92-250	Cesium in the Savannah River Site Environment (U)	
37	1992	WSRC-RP-92-984	Assessment of Strontium in the Savannah River Site Environment (U)	
38	1993	WSRC-TR-93-217	Assessment of Technetium in the Savannah River Site Environment (U)	
39	June 1993	WSRC-TR-93-316	Tritium in the Burial Ground of the Savannah River Site (U)	M.L. Hyder
40	December 26, 1973	DRAFT	Tritium Burial Records	G. W. Earle W. J. Jacober
41	June 4, 1974		SRL Tritium Lysimeter at 643-G Memorandum	R. H. Hawkins
42	August 5, 1974		Burial of Equipment Contaminated with Transuranium Materials	E. O. Kiger B. G. Clontz

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44	November 8, 1976	DPSOX 8851	Tritium Releases from Fresh Crucible and Spent Melt	R. H. Hawkins J. G. McKibbin
45	April 19, 1978	DPST-78-317	Tritium in Groundwater at Burial Ground Well Cluster 3	J. W. Fenimore
46	1979	DP-MS-79-110	Prediction of Radionuclide Migration from Savannah River Plant's Buried Waste	D. J. Fauth E. L. Wilhite
47	April 15, 1981	DPSOX 9647	Tritium Release from Fresh Crucible and Spent Melt	R. H. Hawkins S. M. Tom
48	September 7, 1984	DPST-84-799	Radionuclide Sorption of Srp Burial Ground Soil: A Summary and Interpretation of Labortory Data	S. L. Hoeffner
49	August 18, 1983	DP-MS-83-087	Special Wasteform Lysimeter Program at the Savannah River Laboratory (U)	
50	February 15, 1985	DP-MS-84-121	Migration of Pu and Am Determined in Lysimeter Studies (U)	
51	January 12, 1989	DPSOX-11146	Lysimeter Study of Radionuclide Migration From Buried Waste (U)	
52	February 28, 1968	DPST-68-271	Migration of SRP Waste in Soil (U)	

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54	May 16, 1986	DP-MS-86-070	Migration of Elemental Mercury from Buried Sites (U)	
55	March 1,1987	DP-MS-87-025	Waste Migration in Shallow Burial Sites Under Unsaturated Flow Conditions (U)	
56	August 5, 1981	DPSOX-09381	Lysimeter Study of Radionuclide Migration From Buried Waste (U)	
57	July 1976	DP-1401	Dispersion Study of Buried Elemental Mercury	E.G. Orebaugh W.H. Hale, Jr.
58	March 15, 1982	DPSOX-09486	Migration and Leaching of Buried Solid TRU Forms	
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61	August 2, 1989	WSRC-RP-89-00721	Leaching and Migration of Low-Level Wastes Under Unsaturated Conditions (U)	

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62	September 30, 1985	DPST-85-00384	Results of the Spent Melt Lysimeter Experiment	
63	May 29, 1990	WSRC-RP-90-0495	Estimation of Burial Ground Radionuclide Inventory Due to Mixed Fission Products	J. R. Crook