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7. Abstract

This document reflects the evaluations and analyses performed in response to Tri-Party Agreement Milestone M-45-07A - "Complete Evaluation of Subsurface Barrier Feasibility" (September 1994). The feasibility study was performed to support a decision by the DOE Richland Operations Office, the Washington State Department of Ecology, and the U.S. Environmental Protection Agency regarding further development of subsurface barrier options for SSTs and whether to proceed with demonstration plans at the Hanford Site (Tri-Party Agreement Milestone M-45-07B).

Analyses of 14 integrated SST tank farm remediation alternatives were conducted in response to the three stated objectives of Tri-Party Agreement Milestone M-45-07A. The alternatives include eight with subsurface barriers and six without. Technologies used in the alternatives include three types of tank waste retrieval, seven types of subsurface barriers, a method of stabilizing the void space of emptied tanks, two types of in situ soil flushing, one type of surface barrier, and a clean-closure method. A no-action alternative and a surface-barrier-only alternative were included as nonviable alternatives for comparison. All other alternatives were designed to result in closure of SST tank farms as landfills or in clean-closure.

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Feasibility Study of Tank Leakage Mitigation Using Subsurface Barriers

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EXECUTIVE SUMMARY

The U.S. Department of Energy (DOE) has established the Tank Waste Remediation System (TWRS) to safely manage and dispose of the wastes currently stored in single-shell (SSTs) and double-shell tanks at the Hanford Site.

The TWRS program includes a work scope to develop subsurface low-permeability barriers beneath SSTs. The barriers could serve as a means to contain leakage that may result from waste retrieval operations and could also support site closure activities by facilitating cleanup. A number of studies and working meetings have taken place in an effort to identify potentially applicable subsurface barrier system(s) for SST waste retrieval applications and to determine the best approach to develop them. As a result of these activities, three types of subsurface barrier systems have emerged for further consideration: (1) chemical grout, (2) freeze wall, and (3) desiccant, represented in the feasibility study as a circulating air barrier. These barrier concepts may be installed in either close-coupled (against the tank structure) or standoff (with a soil layer between the tank and barrier) configurations.

The TWRS program has begun planning for a demonstration project to further evaluate these concepts. The plan includes an assessment of the feasibility of subsurface barrier systems to satisfy Milestones M-45-07A (September 1994) and -07B (January 1995) of the *Hanford Federal Facility Agreement and Consent Order* otherwise known as the Tri-Party Agreement.

The Tri-Party Agreement Milestone M-45-07A requires completion of a feasibility study to accomplish the following:

- Estimate the potential environmental impacts of waste storage and retrieval activities without the application of subsurface barriers

- Establish functional requirements of subsurface barriers to minimize the impacts associated with waste storage and retrieval activities

- Evaluate the application of existing subsurface barrier technologies to meet functional requirements of barriers and the potential reduction in environmental impacts from the application of barriers to SST waste storage and retrieval activities.

The feasibility study will support a decision by the DOE Richland Operations Office, the Washington State Department of Ecology, and the U.S. Environmental Protection Agency regarding further development of subsurface barrier options for SSTs and whether to proceed with demonstration plans at the Hanford Site (Tri-Party Agreement Milestone M-45-07B).

Analyses of 14 alternatives were conducted in response to the three stated objectives of Tri-Party Agreement Milestone M-45-07A. The alternatives include eight with subsurface barriers and six without. Technologies used in the alternatives include three types of tank waste retrieval, seven types of subsurface barriers, a method of stabilizing the void space of emptied tanks, two types of in situ soil flushing, one type of surface barrier, and a clean-closure method. A no-action alternative and a surface-barrier-only alternative were included as nonviable alternatives for comparison. All other alternatives were designed to result in closure of SST tank farms as landfills or in clean-closure. Technologies used in each alternative are shown in Table ES-1.

First approximations of carcinogenic risk and noncarcinogenic hazards to the maximally exposed individual for 30,000 years were estimated using the Multimedia Environmental Pollutant Assessment System (MEPAS) computer code. This code includes a one-dimensional model capable of projecting radiological and chemical risks and hazards through the groundwater and other pathways. Only the groundwater pathway was analyzed because the purpose of subsurface barriers is to prevent or limit future contamination of the groundwater. If subsurface barriers are determined feasible, then a more comprehensive analysis of environmental risks should be pursued.

Risks estimated using MEPAS were related to an incremental cancer risk range of 10^{-4} to 10^{-6}. This range spans the breadth of potential cleanup objectives usually considered acceptable for cleanup of waste sites.

Costs were estimated based on a comparative case of 99% removal of waste stored inside 12 one-million gallon tanks in a hypothetical tank farm with subsequent closure. The same hypothetical tank farm served as the basis for the risk and hazard analyses. Many assumptions were necessary to conduct these analyses; the guiding philosophy employed was

Table ES-1. Summary of Alternatives.

Alternative	Waste Retrieval Type	Assumed Tank Waste Retrieval Effectiveness	Subsurface Barrier Type	Old Leaks Flushed?	New Leaks Flushed?	Tanks Stabilized?	Surface Barrier Used?
1. No Action	None	0%	None	No	No	No	No
2. Surface Barrier Only	None	0%	None	No	No	No	Yes
3. Traditional Sluicing (Baseline)	Traditional sluicing	99%	None	No	No	Yes	Yes
4. Robotic Sluicing	Robotic sluicing	99.9%	None	No	No	Yes	Yes
5. Mechanical Retrieval	Mechanical retrieval	95%	None	No	No	Yes	Yes
6. Close-Coupled Chemical Barrier with Flushing	Traditional sluicing	99%	Close-coupled	Yes	Not Applicable	Yes	Yes
7. Close-Coupled Chemical Barrier w/o Flushing	Traditional sluicing	99%	40% None 60% Close-Coupled	No	No	Yes	Yes
8. Modified Close-Coupled Chemical Barrier w/o Flushing	Traditional sluicing	99%	Vertical Close-Coupled	No	No	Yes	Yes
9. Box-Shaped Chemical Barrier	Traditional sluicing	99%	Box-shaped chemical	Yes	Yes	Yes	Yes
10. V-Shaped Chemical Barrier	Traditional sluicing	99%	V-shaped chemical	Yes	Yes	Yes	Yes
11. V-Shaped Freeze Wall Barrier	Traditional sluicing	99%	V-shaped freeze wall	Yes	Yes	Yes	Yes
12. Circulating Air Barrier	Traditional sluicing	99%	Circulating air	Yes	Yes	Yes	Yes
13. Clean-Closure w/o Subsurface Barrier	Traditional sluicing & mining	100%	None	No	No	Not Applicable	No
14. Clean-Closure with Close-Coupled Chemical Barrier	Traditional sluicing & mining	100%	40% None 60% Close-Coupled	No	No	Not Applicable	No

each assumption should represent best judgement. Thus, the overall analyses were intended to be representative of expected performance as opposed to overly conservative or liberal projections of performance.

These analyses served as the basis for the following conclusions regarding the three objectives of Tri-Party Agreement Milestone M-45-07A as follows:

- Taking no action would result in risks approximately three orders of magnitude higher than the assumed upper limit (10^{-4}) of the target risk range.

- Taking no action other than capping the tank farm with a surface barrier capable of limiting recharge to 0.05 cm/yr (0.02 in/yr) may result in acceptable risks for some tanks, but only if collapse of the tank domes could be prevented.

- The use of either traditional sluicing (assumed capable of achieving 99% tank waste retrieval), robotic sluicing (99.9% retrieval), or mechanical retrieval (95% retrieval), in combination with stabilizing the structure of emptied tanks and using a surface barrier, appears potentially capable of attaining the target risk range for most tanks.

- The retrieval of all tank waste, including tank structures and contaminated soil to effect clean-closure, would likely result in bettering the risk range. The landfill created to contain washed, retrieved soil and debris from the tank farm would represent a new, but relatively small source of risk.

- The clean-closure alternatives would be about as cost-effective as other tank waste retrieval alternatives assuming that all recovered contaminants of environmental concern would be destroyed or treated and disposed offsite in a Federal repository, and assuming that benefit can be represented as a ratio of initial risk to achieved risk. If benefit is represented by the difference in these risks, the cost-benefit is two to eight times lower than for the other retrieval alternatives.

- Functional requirements have been established in a companion draft document, *Functions and Requirements for Single-Shell Tank Leakage Mitigation*. All functional requirements potentially can be satisfied using any of the subsurface barrier options evaluated.

- The use of any of the subsurface barrier concepts (chemical, freeze wall, and circulating air in close-coupled and standoff configurations) in general applications to tank farms would result in a relatively small incremental reduction in the risk level achievable using baseline technologies. (Baseline technologies include traditional sluicing, emptied-tank stabilization and surface barriers).

- The use of a close-coupled barrier to support clean-closure activities may be cost-effective in comparison to the clean-closure alternative without a barrier because it would limit the volume and reduce the cost of contaminated soil requiring excavation and treatment, while reducing risk.

- Except for the clean-closure application, cost-effectiveness of subsurface barrier technologies is essentially equal and relatively low. The cost-effectiveness of the subsurface barriers, calculated by the method most favorable to subsurface barriers, is about 0.0001 times that of surface barriers, and 0.01 times that of the set of baseline technologies.

- Uncertainty in the performance of subsurface barriers is high, but because the impact of subsurface barriers on risk and cost-effectiveness is very low, even best-case assumptions of subsurface barrier performance have a relatively small effect on overall risk and cost-effectiveness of SST disposal options.

- More conservative assumptions could easily lead to order of magnitude or higher projections of risk, thereby potentially rendering some alternatives without subsurface barriers incapable of achieving the target risk range. In the event a conservative analysis is required by the decision makers as a basis for establishing cleanup requirements, the use of subsurface barriers may be necessary to reduce risks sufficiently to satisfy all conditions of a closure permit.

These conclusions were based on the ability of subsurface barriers to reduce risk and improve cost-effectiveness in general-use applications to tank farms. A broader set of values beside risk and cost-effectiveness should be considered. Conclusions presented here may be modified as a result of their analysis. Investigation of the merits of selective applications of subsurface barriers should also be made, i.e., (1) to tanks that have exhibited high leakage rates during previous operations, (2) where highly conductive soils exist potentially promoting high leakage rates, and (3) to support cleanup of the most contaminated soils by enabling soil flushing without driving contaminants to the groundwater.

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APPENDIXES

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LIST OF TERMS

CAB	circulating air barrier
COC	constituent of concern
D&D	decontamination and decommissioning
DBI	DBI Gas-und Umwelttechnik Gmblt
DOE	U.S. Department of Energy
Ecology	Washington State Department of Ecology
EDTA	ethylenediaminetetraacetic acid
EPA	U.S. Environmental Protection Agency
EUAC	equivalent uniform annualized cost
HDW-EIS	Hanford Defense Waste Environmental Impact Statement
HI	hazard index
HLW	high level waste
HVAC	heating, ventilating, and air conditioning
INEL	Idaho National Engineering Laboratory
IITRI	IIT Research Institute
MEPAS	Multimedia Environmental Pollutant Assessment System
MIBRAG	Vereinigte Mitteldeutsche Braunkohlenwenke AG
O&M	operating and maintenance
RCRA	*Resource Conservation and Recovery Act of 1976*
RF	radiofrequency
SEG	Scientific Ecology Group, Inc.
SLAEMS	Single Layer Analytical Element Method-Stratified
SST	single-shell tank
TBP	tributyl phosphate
TLCC	total life cycle cost
TNPW	total net present worth
Tri-Party Agreement	Hanford Federal Facility Agreement and Consent Order
TWRS	Tank Waste Remediation System

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1.0 INTRODUCTION

In 1943, the U.S. Army Corps of Engineers selected the Hanford Site near Richland, Washington to build plutonium production reactors and processing facilities. For more than 40 years, these and other Hanford Site facilities provided nuclear weapons materials for the nation's defense. The processing of spent nuclear fuel to obtain weapons materials resulted in the accumulation of large quantities of high-level radioactive and chemical wastes in underground storage tanks. A total of 149 single-shell tanks (SSTs) and 28 double-shell tanks contain these wastes. The wastes include sludges, saltcake, and slurries that will require retrieval, treatment, and disposal.

The U.S. Department of Energy (DOE) has established the Tank Waste Remediation System (TWRS) to safely manage and dispose of the wastes currently stored in the underground storage tanks. The scope of TWRS includes: tank safety and operations; waste characterization, retrieval, and pretreatment; high-level waste immobilization; low-level waste immobilization; and associated transfer, interim and long-term storage, and disposal of wastes.

The retrieval element of TWRS includes a work scope to develop subsurface impermeable barriers beneath SSTs. The barriers could serve as a means to contain leakage that may result from waste retrieval operations and could also support site closure activities by facilitating cleanup. A number of studies and working meetings have taken place in an effort to identify potentially applicable subsurface barrier system(s) for SST waste retrieval applications and to determine the best approach to develop them (Bovay Northwest 1992; LATA 1992). As a result of these activities, three types of subsurface barrier systems have emerged for further consideration: (1) chemical grout, (2) freeze wall, and (3) desiccant, represented in this feasibility study as a circulating air barrier. These barrier concepts may be installed in either close-coupled (against the tank structure) or standoff (with a soil layer between the tank and barrier) configurations.

The TWRS program has begun planning for a demonstration project to further evaluate these concepts. The plan includes an assessment of the feasibility of subsurface barrier systems to satisfy Milestones M-45-07A (September 1994) and -07B (January 1995) of the *Hanford Federal Facility Agreement and Consent Order* (Ecology et al. 1990), otherwise known as the Tri-Party Agreement.

The Tri-Party Agreement Milestone M-45-07A requires completion of a feasibility study to accomplish the following:

- Estimate the potential environmental impacts of waste storage and retrieval activities without the application of subsurface barriers

- Establish functional requirements of subsurface barriers to minimize the impacts associated with waste storage and retrieval activities

- Evaluate the application of existing subsurface barrier technologies to meet functional requirements of barriers and the potential reduction in environmental impacts from the application of barriers to SST waste storage and retrieval activities.

The feasibility study will support a decision by the DOE Richland Operations Office, the Washington Department of Ecology (Ecology), and the U.S. Environmental Protection Agency (EPA) regarding further development of subsurface barrier options for SSTs and whether to proceed with demonstration plans at the Hanford Site (Tri-Party Agreement Milestone M-45-07B).

The feasibility study will include eight elements. These elements and their sources are identified in Table 1-1.

This report contains analyses of the costs and relative risks associated with combinations of retrieval technologies and barrier technologies that form 14 alternatives. Eight of the alternatives include the use of subsurface barriers; the remaining six nonbarrier alternatives are included in order to compare the costs, relative risks and other values of retrieval without subsurface barriers. Each alternative includes various combinations of technologies that can impact the risks associated with future contamination of the groundwater beneath the Hanford Site to varying degrees. Other potential risks associated with these alternatives, such as those related to accidents and airborne contamination resulting from retrieval and barrier emplacement operations, are not quantitatively evaluated in this report. A more comprehensive quantitative risk analysis is appropriate after consideration of the analyses in this report is made and the number of alternatives under consideration is reduced.

The contents of the remainder of this report are summarized below:

- Section 2 summarizes preliminary conclusions
- Section 3 defines the range of subsurface barrier options considered in the report
- Section 4 describes the unit technologies that make up the 14 alternatives
- Section 5 describes the 14 alternatives
- Section 6 describes the approach and results of the comparative risk assessment
- Section 7 describes the approach and results of the cost assessment
- Section 8 includes cost-benefit and sensitivity analyses, including discussion of uncertainties and the advantages and disadvantages of individual barrier options
- Section 9 includes an evaluation of the ability of the eight alternatives that include subsurface barriers to satisfy draft functions and requirements

Table 1-1. Elements of Feasibility Study.

Element	Source
1. Analysis of the mission of subsurface barriers supporting waste retrieval and tank closure operations	Mission Analysis for Single-Shell Tank Leak Mitigation, WHC-SD-WM-MAR-001, Rev. 0
2. Regulatory assessment of the Hanford Site tank application of subsurface barriers	Regulatory Assessment and Permitting Strategy for the Use of Underground Barriers at the Hanford Site Tank Farms
3. Functional requirements for the Hanford Site tank application of subsurface barriers	Functions and Requirements for Single-Shell Tank Leakage Mitigation, WHC-SD-WM-FRD-019, Rev. 0
4. Qualitative risk assessment of subsurface barriers vs. no-barriers	Qualitative Risk Assessment of Subsurface Barriers in Applications Supporting Retrieval of SST Waste, WHC-SD-WM-RA-010, Rev. 0
5. Overall conclusions regarding merits of subsurface barriers for the Hanford Site tank application	This report (Section 2)
6. Definition of subsurface barrier concepts	This report (Section 3)
7. Comparative subsurface barrier and no barrier system performance and risk analysis	This report (Sections 4 through 8)
8. Evaluation of ability of subsurface barriers to satisfy functional requirements	This report (Section 9)

- Section 10 contains references cited in the report
- Appendix A describes the comparative risk assessment model
- Appendix B provides plots of comparative risk as a function of time for each alternative evaluated
- Appendix C provides details supporting the cost assessment in Section 7.

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2.0 CONCLUSIONS

This section presents conclusions based on analyses of the costs, risks, and performance of 14 alternatives for the retrieval of waste from Hanford Site SSTs. The analyses were conducted in response to the three stated objectives of Tri-Party Agreement Milestone M-45-07A. The alternatives include eight with subsurface barriers and six without. Technologies used in the alternatives included three types of tank waste retrieval, seven types of subsurface barriers, a method for filling the void space of emptied tanks, two types of in situ soil flushing, one type of surface barrier, and a clean-closure method. A no-action alternative and a surface barrier only alternative were included as nonviable alternatives for comparison.

First approximations of carcinogenic risk and noncarcinogenic hazards were estimated using the Multimedia Environmental Pollutant Assessment System (MEPAS) computer code. This code includes a one-dimensional model capable of projecting radiological and chemical risks and hazards through the groundwater and other pathways. Only the groundwater pathway was analyzed because the purpose of subsurface barriers is to prevent or limit future contamination of the groundwater. The MEPAS code has been used for risk analyses in several environmental impact statements in the United States and is the standard risk assessment tool for the Canadian Health and Welfare Department. Although the MEPAS is less-rigorous than three-dimensional risk assessment models that have been accepted for detailed baseline risk assessments at the Hanford Site, it is well-suited to the comparative analyses conducted in this feasibility study.

First approximations of risk were estimated using MEPAS and related to an incremental cancer risk range of 10^{-4} to 10^{-6}. This range spans the breadth of potential cleanup objectives usually considered acceptable for cleanup of waste sites. A hazard index (HI) was also estimated and related to a threshold value of one. Potential carcinogenic risk objectives were determined to be somewhat more difficult to meet than potential noncarcinogenic hazard objectives.

Costs were estimated based on a comparative case of 99% removal of waste stored inside 12 one-million gallon tanks in a hypothetical tank farm. The same hypothetical tank farm served as the basis for the risk and hazard analyses. Many assumptions were necessary to conduct these analyses; the guiding philosophy employed was each assumption should represent best judgement. Thus, the overall analyses were intended to be representative of expected performance as opposed to overly conservative or liberal projections of performance.

These analyses served as the basis for conclusions drawn regarding the three objectives of Tri-Party Agreement Milestone M-45-07A as follows:

Objective 1 - Estimate the potential environmental impacts of waste storage and retrieval activities without the application of subsurface barriers.

Primary conclusions include the following:

- Taking no action would result in first-approximation risks approximately three orders of magnitude higher than the assumed upper limit (10^{-4}) of the target risk range.

- Taking no action other than capping the tank farm with a surface barrier capable of limiting recharge to 0.05 cm/yr (0.02 in/yr) may result in acceptable risks for a few tanks, but only if collapse of the tank domes could be prevented. Eventual collapse of the tanks, which would compromise barrier effectiveness and expose the surface environment to high levels of radioactivity, appears to be credible due to the deliquescent nature of the waste. This property would result in long-term drainage of contaminated salt brine from the tank and creation of voids, which eventually would lead to subsidence. The rate of creation of salt brine was not evaluated, but if it is higher than the projected rate due to recharge through the tank, it could render this option infeasible for all tanks containing deliquescent wastes, regardless if tank collapse can be prevented.

- The use of either traditional sluicing (assumed capable of achieving 99% tank waste retrieval), robotic sluicing (99.9% retrieval), or mechanical retrieval (95% retrieval), in combination with stabilizing the structure of emptied tanks and using a surface barrier, appears potentially capable of attaining the target risk range for most tanks. This conclusion was drawn despite a factor of 20 difference in projected risk between mechanical retrieval (the highest-risk option) and robotic sluicing (the lowest-risk option).

- The retrieval of all tank waste, including tank structures and contaminated soil to effect clean-closure, would likely result in bettering the risk range. The landfill created to contain washed, retrieved soil and debris from the tank farm would represent a new, but relatively small source of risk.

- The clean-closure option appears to be about as cost-effective as other tank waste retrieval options. This conclusion is based on the assumption that benefit is reflected in the proportional reduction in risk. The calculated cost-benefit of the clean-closure option is also predicated on the assumption that all recovered contaminants of environmental concern, except for residual amounts that remain after washing exhumed waste, would be destroyed or treated and disposed offsite in a Federal repository. If disposed on the Hanford Site, treated contaminants would represent a new source of risk. If benefit is represented by the difference in risk, as opposed to the proportional reduction in risk, the cost-benefit of clean closure options is two to eight times lower than for other retrieval options.

Objective 2 - Establish functional requirements of subsurface barriers to minimize the impacts associated with waste storage and retrieval activities.

Functional requirements have been established in a companion draft document, *Functions and Requirements for Single-Shell Tank Leakage Mitigation*. Other supporting documents, including; *Mission Analysis for Tank Leakage Mitigation, Regulatory Assessment and Permitting Strategy for the Use of Underground Barriers at the Hanford Site Tank Farms,* and *Qualitative Risk Assessment of Subsurface Barriers in Applications Supporting Retrieval of SST Waste*, provide bases and background for the functional requirements.

Objective 3 - Evaluate the application of existing subsurface barrier technologies to meet functional requirements of barriers and the potential reduction in environmental impacts from the application of barriers to SST waste storage and retrieval activities.

Primary conclusions include the following:

- All functional requirements potentially can be satisfied using any of the subsurface barrier options evaluated. This conclusion is tempered with the observations that (1) little hard data on the performance of subsurface barriers exist and (2) the draft functional requirements are largely and appropriately qualitative at this early state of development of this application of subsurface barriers.

- The use of any of the subsurface barrier concepts (chemical, freeze wall, and circulating air in close-coupled and standoff configurations) in general applications to tank farms would result in a relatively small incremental reduction in the risk level achievable using baseline technologies. (Baseline technologies include traditional sluicing, emptied-tank stabilization, and surface barriers).

- The use of close-coupled barriers to support clean-closure activities may be cost-effective because it would limit the volume and reduce the cost of contaminated soil requiring excavation and treatment while reducing risk. Except for the clean-closure application, cost-effectiveness of subsurface barrier technologies is essentially equal and relatively low.

- The cost-effectiveness of the subsurface barriers, calculated by the method most favorable to subsurface barriers, is about 0.0001 times that of surface barriers, and 0.01 times that of the set of baseline technologies. Uncertainty in the performance of subsurface barriers is high, but because the impact of subsurface barriers on risk and cost-effectiveness is low, even best-case assumptions of subsurface barrier performance have a relatively small effect on overall risk and cost-effectiveness of SST disposal options.

- Assumptions used in the feasibility study have not been widely reviewed by decision makers at this stage of analysis of feasibility. More conservative assumptions could easily lead to order of magnitude or higher projections of risk, thereby potentially rendering some alternatives incapable of achieving the target risk range. In the event a conservative analysis is required by the decision makers as a basis for establishing cleanup requirements, the use of subsurface barriers may reduce risks sufficiently to satisfy all conditions of a closure permit.

The conclusions presented above were based on the ability of subsurface barriers to reduce risk and improve cost-effectiveness in general-use applications to tank farms. A broader set of values beside risk and cost-effectiveness should be considered. Conclusions presented here may be modified as a result of their analysis. Investigation of the merits of selective applications of subsurface barriers should be made, i.e., (1) only to tanks that have exhibited high leakage rates during previous operations, (2) where highly conductive soils exist potentially promoting high leakage rates, and (3) to support cleanup of the most contaminated soils by enabling soil flushing without driving contaminants to the groundwater.

3.0 INTEGRATED SUBSURFACE BARRIER OPTIONS

This section identifies 13 viable integrated subsurface barrier options being considered for potential application to SSTs at the Hanford Site. The section is divided into subsections by overall method of confinement: 11 standoff concepts (i.e., options intended to be installed some distance from several tanks or a tank farm) and two close-coupled concepts (i.e., options installed in contact with individual tanks). The viable barrier options are presented in Sections 3.1 through 3.13.

Each viable subsurface barrier technology concept discussion includes a description, a graphical depiction, its current applications (if any), test and demonstration status, potential advantages and disadvantages, and other information (e.g., vendor contacts, costs, regulatory issues, material options, etc.) if available. It should be noted that much of this information is subjective (especially in the advantage/disadvantage sections) and would need to be proved or disproved during a demonstration process if subsurface barriers are to be deemed feasible for application at the Hanford Site.

Subsections of 11 "other" less viable subsurface barrier concepts are also included to demonstrate that other options were investigated but were determined not to be as viable for SST applications at this time. The rationale related to the viability issue is provided for each concept in this category. In general, these less viable concepts would generate large amounts of spoils and/or were deemed impractical for use around Hanford Site tanks or tank farms. These less viable options are presented in Sections 3.14 through 3.24.

It should be noted that a matrix of the wide variety of deployment methods against the wide variety of materials that could be used for barriers would be too complex to present. For ease of understanding, deployment methods and materials have been combined into "integrated" options. This list of options does not include all possible combinations of deployment and material options but should provide the reader a representative listing of subsurface barrier concepts.

Candidate deployment technologies for these integrated options are traditional vertical drilling, directional or slant drilling, and/or horizontal drilling. Other deployment technologies include vertically oriented 5 m (15 ft) diameter caissons installed in open areas between tanks or outside tank farms, coffered trenches constructed at the boundary of a tank farm, in situ mechanical mixing, slurry trenching, longwall mining, and other tunneling techniques. Additional information regarding subsurface barrier deployment techniques can be found in other Hanford Site documents (e.g., Jensen et al. 1992). Most of these deployment methods are unproven in Hanford Site applications.

Table 3-1 identifies the subsurface barrier materials, deployment methodologies, and their referenced subsections of the feasibility study. The following sections describe the subsurface barrier concepts in detail.

Table 3-1. Integrated Subsurface Barrier Options Considered. (Sheet 1 of 2)

Deployment Method	Material Applications	Title	Sect.
Standoff Concepts			
Directional Drilling (cone- or trough-shaped)	Cementitious Grouts	Chemical Jet Grout Encapsulation	3.1
	Ice Encapsulation	Freeze Walls	3.2
Vertical & Horizontal Drilling (box-shaped)	Cementitious Grout	Jet Grout Curtains	3.3
	Cementitious Grouts	Permeation Chemical Grouting	3.4
	Grouts with Thermoviscous Fluids	Wax Emulsion Permeation Grouting	3.5
	Colloidal Silica Sodium Silicates	Silica, Silicate Permeation Grouting	3.6
	Grouts with Polymer Grouts, Polyacrilates	Polymer Permeation Grouting	3.7
	Rubberized Cements, Clays, Grouts	Formed-In-Place Horizontal Grout Barriers	3.8
	Heated Air	Circulating Air Barriers	3.9
Directional Drilling	Electrodes	Radio Frequency Desiccating Subsurface Barriers	3.10
Piling + Horizontal	Sheet Metal w/Grout	Sheet Metal Piling Subsurface Barriers	3.11
Close-Coupled Concepts			
Directional Drilling (cone-shaped)	Low-Cost Filler + Polymer	Close-Coupled Injected Chemical Barriers	3.12
Piling & Caisson	Sheet Metal w/Polymer	Induced Liquefaction Barriers	3.13

Table 3-1. Integrated Subsurface Barrier Options Considered. (Sheet 2 of 2)

Deployment Method	Material Applications	Title	Sect.
Other Less-Viable Concepts			
Slurry Cutoff Walls	Various	Slurry Walls	3.14
Soil Auguring	Various	Deep Soil Mixing	3.15
Soil Fracturing	Cementitious Grouts	Soil Fracturing	3.16
Long Wall Mining	Various	Longwall Mining	3.17
Pug Mill Injection	Sulfur Cements	Modified Sulfur Cement	3.18
Vertical & Horizontal Drilling	Sequestering Agents	Sequestering Agents	3.19
	Reactive Agents	Reactive Barriers	3.20
	Surface Coatings	Impermeable Coatings	3.21
Microtunneling	Various	Microtunneling	3.22
Electrodes	Glass	In Situ Vitrification	3.23
Hydraulic Erosion	Grouts	Soil Saw	3.24

3.1 CHEMICAL JET GROUT ENCAPSULATION

Chemical jet grout encapsulation would isolate waste systems by using primarily high-pressure jet grouting to form columns of grouted soil via directionally-drilled wells. Standard grouts such as portland cements or bentonite clays would be used. Other, more exotic grouts, could be used for enhanced control over set times and better compatibility with Hanford Site soils. These grouts would need to be compatible with the high pressures encountered with jet grouting. Columns would be allowed to harden before adjacent columns are drilled, partially cutting into the hardened column(s). When completed, the plan view of one configuration could be similar to the spokes of a bicycle wheel in a conical shape (Figure 3-1). Alternatively, lateral barriers could be installed along two sides using vertical wells and permeation or jet grouting; slant jet grouting would then be used to connect the lateral barriers (Naudts 1989). Slant well depths of approximately 66 m (200 ft) below the bottom of the tank(s) would be required for grout encapsulation.

Slant wells and jet grouting could also be directionally drilled and grouted to form a conical barrier beneath individual tanks; however, this scenario is not as likely for SST applications since only 7.6 m (25 ft) separate many of the tanks.

3.1.1 Current Applications

Current applications of jet grouts are numerous and include foundation repairs, cofferdam barriers, groundwater control, and other specialized uses. The technology has been used in Europe for waste containment systems but has not yet been used in the United States for that purpose (Naudts 1989).

The lengths and angles of the wells required for grout encapsulation are within the capabilities of existing equipment. Since jet grouting has been used extensively for other applications, the use of this technology should be feasible in soils free of large cobbles (up to 51 cm [20 in.]) and boulders.

3.1.2 Test and Demonstration Status

Jet grout encapsulation of Hanford Site underground storage tanks has only been conceptually designed. No laboratory or field tests have been performed. The base technologies of jet grouting and directional drilling are proven technologies and should require little modification for this application.

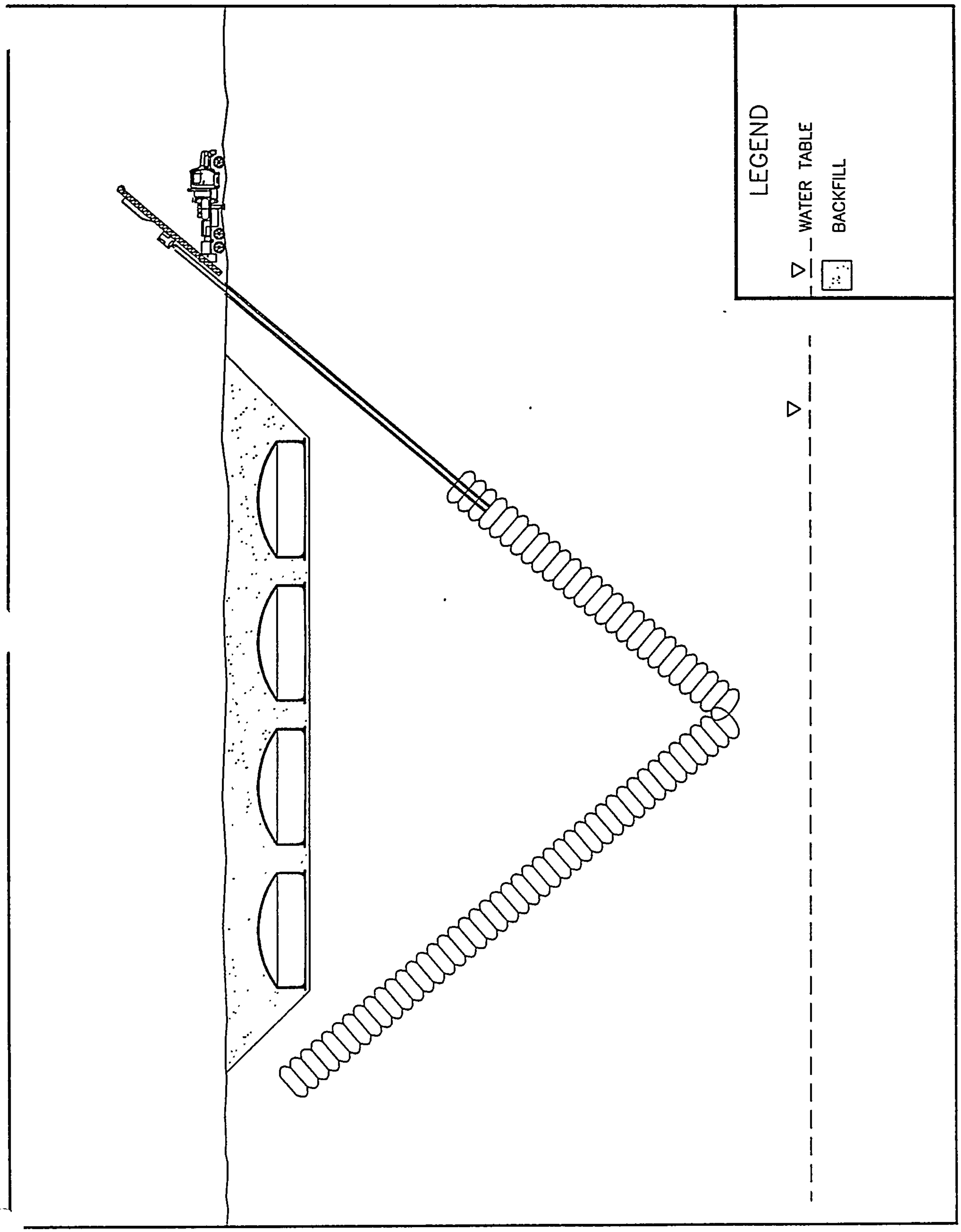

Figure 3-1. Chemical Jet Grout Encapsulation.

3.1.3 Advantages and Disadvantages

Potential Advantages

- Jet grout encapsulation uses proven drilling equipment and materials.
- Implementation of standoff grout encapsulation should result in little if any stress or heat to individual tanks.
- The passive nature of the barrier would require little or no maintenance or operational expense once installed.
- This method could be considered for application under emergency response conditions.
- Spoils brought to the surface by jet grouting would be encapsulated in the grouting material and could be easily contained.

Potential Disadvantages

- Drilling through contaminated soils may result in producing contaminated spoils. However, it is envisioned that only small quantities of spoils would be generated.
- Workers would be required to work in protective clothing when handling contaminated material. Contaminated materials brought to the surface would require appropriate management as a mixed waste.
- It could be difficult to construct a complete and uniform barrier without extensive overlapping of barrier sections.

3.1.4 Other Information

The integrity of the barriers may be verified by deploying additional slant wells above and below the underlying barrier to provide monitoring wells and a sensor array for enhanced leak detection. Other physical techniques may be feasible for locating leaks and barrier holes.

A variety of grouts with varying viscosities and set-up times are available. The grout formulation can be selected to meet rather broad design requirements, including hydraulic conductivity, strength, and capability for plastic deformation or resistance to chemical attack.

3.2 FREEZE WALLS

Underground freeze walls have been used in the United States and Europe for many decades, particularly in shaft sinking operations, tunneling, and environmental emergency response. During ground freezing, the temperature of the water within the soil is lowered below its freezing point. The formation of ice between soil particles increases soil strength and decreases soil permeability. Figure 3-2 depicts the freeze wall concept.

Two freezing methods have been used: (1) slow-rate freezing or closed-loop systems and (2) fast-freezing or open-loop systems (e.g., liquid nitrogen). For both methods directional drill holes with steel casings are placed along the desired freezing line. Standard black pipe is then inserted in the casing. In the slow-rate freezing system, a header or manifold system provides coolant, such as calcium chloride brine, ethylene glycol, or ammonia, which is circulated and returned to the refrigeration system via the inner pipe. A self-contained refrigeration system pumps coolant around the coolant loop. The fast-freezing method uses an open-loop system with an expendable coolant, such as liquid nitrogen, to achieve a much lower temperature in a shorter period.

Freeze walls created by circulating refrigerated brine are commonly accomplished by use of a calcium chloride solution. Closely spaced wells, typically 0.8 to 1.2 m (2.5 to 4 ft) apart, are cased and plugged at the bottom. The refrigerated brine is pumped down tubing to the bottom of the well and back to the surface through the annulus where it absorbs heat from the formation, forming a closed-loop system. Normally, the system would operate at a temperature of about -37 °C (-35 °F). As the soil around the pipes is cooled, a zone of frozen earth and water would advance outward from each coolant pipe. Eventually the frozen soil would overlap and form a closed barrier. After the barrier walls are established, a reduced flow of refrigerant would be used to maintain the temperature of the system.

Freeze walls created by the injection of liquid nitrogen into the ground through perforated well casings are open systems. The liquid nitrogen vaporizes and cools the ground, then diffuses through the soil and escapes to the atmosphere. An open system could be used to quickly freeze the soil and then could be coupled with a closed-loop system to maintain the freeze wall barrier.

The freezing process may be completed in as little as two months or may take up to two years depending on the method used, the type of coolant, and the application. The initial freezedown period to establish a barrier is typically about eight months. If the frozen barrier, which would be installed outside the contaminated area, is frozen slowly, it would allow the freezing process to take advantage of its purifying characteristics. Slow crystal growth excludes contaminants from the water molecules within the freeze zone (SEG and RKK 1992).

Various technologies are available to follow the progress of barrier formation during the initial freezedown, and to monitor its integrity after it is established. Monitoring could be accomplished using strategically located temperature and chemical sensors, the refrigeration

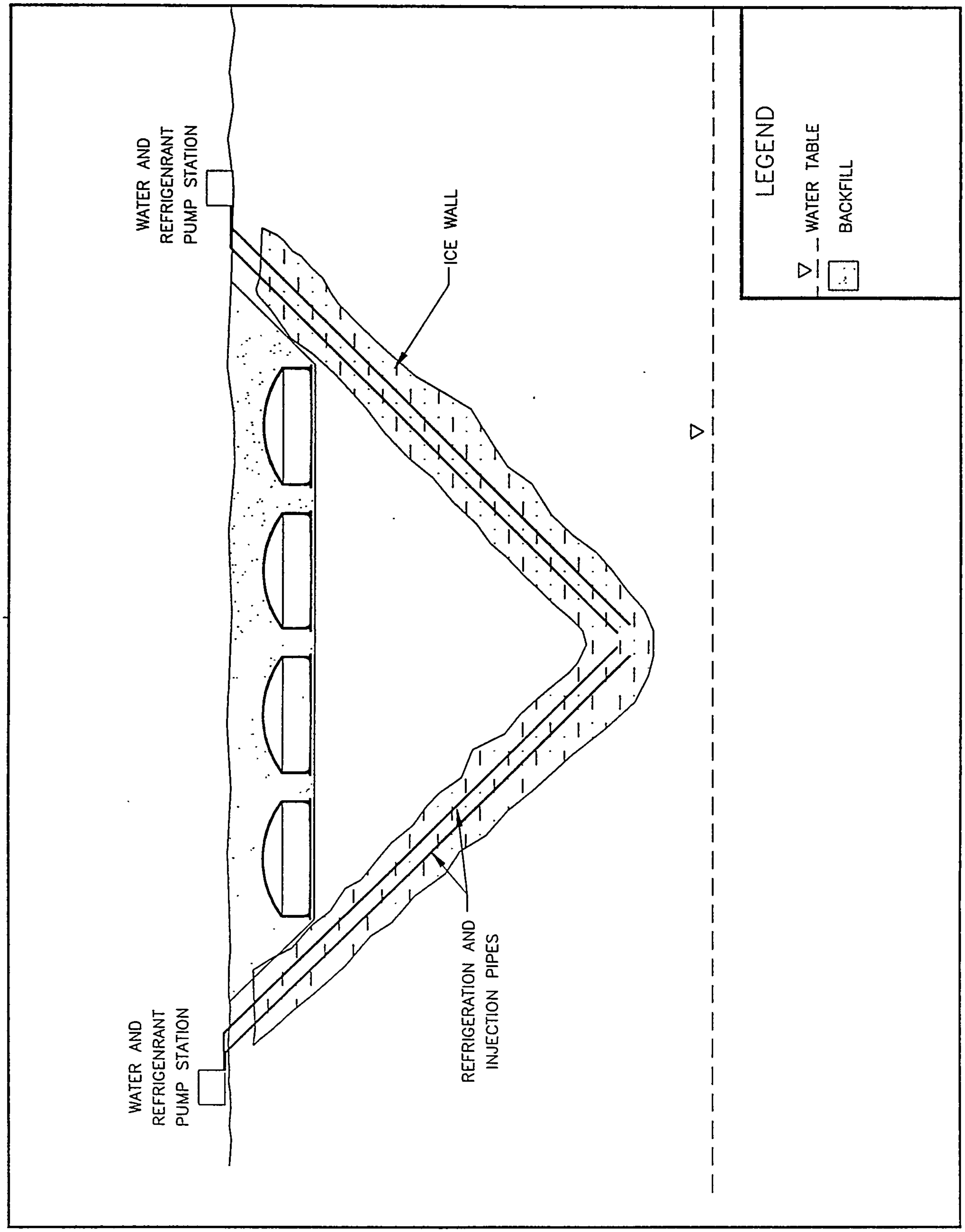

Figure 3-2. Freeze Walls.

system itself, and the injection tubes. The temperature sensors warn of barrier invasion; corrective action takes the form of preferentially increasing the amount of coolant to the affected freeze pipes. Chemical and radioactivity sensors can provide continuous monitoring against possible leakage. The refrigeration system itself could be a part of the monitoring system, since changes in cooling load would be reflected in the temperature of the return flow of refrigerant. Leakage tests can be made by pressurizing injection tubes with a nonreactive gas such as nitrogen and measuring the gas escape rate. A detected lack of integrity could be corrected by injecting hot water into the local injection pipe. The hot water would fill the breach in the barrier and freeze to seal it (Dash 1991).

Construction costs are determined by several factors, primarily soil conditions, size of the waste site, hazardous nature of working conditions, and the requirements of regulatory agencies (Dash 1991). Soil conditions and geography will determine whether the piping can be installed by pile driving, jacking, or drilling. Drilling may be more expensive and would also require special precautions in contaminated ground. The size and shape of the potential freeze wall site are important factors because the cost of containment increases with the peripheral area rather than with the contained volume.

3.2.1 Current Applications

Refrigeration in large-scale engineering projects is a well-developed technology. Artificial freezing of ground has been used for bonding wet soils to give load-bearing strength during construction; to seal tunnels, mine shafts and well holes against flooding from groundwater; and to stabilize soils during excavation. Recent applications include several large subway and highway tunnel projects and in-ground liquified natural gas storage reservoirs (Dash 1991).

Other uses of artificial freezing include effluent concentration, sludge dewatering, salt water desalination, and temporary immobilization of contaminants. Ground freezing also has potential applications for decontamination of soil, sediments, and sludges.

3.2.2 Test and Demonstration Status

Scientific Ecology Group, Inc. (SEG) and RKK Ltd. are currently demonstrating the ice barrier design in wet soils at a private site near Oak Ridge, Tennessee. They have proposed a similar demonstration at or near the Hanford Site using the native dry (semi-arid) soils. Ground freezing has been demonstrated at Idaho National Engineering Laboratory (INEL) to freeze a block of soil containing simulated wastes for subsequent one-piece removal.

3.2.3 Advantages and Disadvantages

Potential Advantages

- Ground freezing is a well-developed technology with many applications in private industry groundwater containment and mining.
- The integrity of freeze wall barriers can be monitored through refrigeration load and temperature monitors.
- Freeze walls are highly resistant to seismic activity and can be healed in the event a large earthquake causes a breach.

Potential Disadvantages

- Success would depend on uncontrollable or partially controllable factors (e.g., soil composition and water content). It is unclear if the technology would perform as planned if it were necessary to inject supplemental water into the highly transmissive soils of the Hanford Site.
- Slow migration of water could occur, leading to nonuniform deposits of ice.
- Installation could create some stresses on the SSTs due to the expansion of the soil during the freezing process.
- Freeze walls are an active subsurface barrier concept and would require a refrigeration plant to maintain the barrier indefinitely.

3.2.4 Other Information

The joint venture of RKK and SEG has proposed a proprietary freeze wall design called "CRYOCELL" for potential use in SST applications. In the RKK/SEG CRYOCELL barrier design, freeze pipes would be installed around and under the circumference of the waste site. These freeze pipes are typically steel casing, with a second casing installed inside the first. Coolant would be pumped down the annulus and returned through the inner pipe.

The two layers of freeze pipes would be installed at a slant, such that the bottoms come close together and provide closure when ice is formed under the area to be contained. Vertical pipes would be installed to enclose the two ends of the system.

Either brine, polyglycol, ammonia, or liquid nitrogen would be used as the refrigerant. The ice walls form as the interstitial water in the soil freezes. If necessary, additional water can be added to the soil through the injection system.

If the outer pipes are constructed of carbon steel casing, they are reasonably economic and strong enough to permit installation by pile driving or jacking into most soils. The use of driven or jacked carbon steel casing would reduce both the costs and possible contamination associated with well boring. A second, similar set of pipes would be installed approximately 10 m (33 ft) inside of the first set. This double set of pipes would allow the entire intervening space to be frozen, producing a solid barrier of intermixed soil and ice 13 to 15 m (40 to 50 ft) thick. Perforated pipes would be installed between the double row of freeze pipes to facilitate moisture addition. The double array design would afford greater management of the barrier, since the thickness and the temperature of the barrier are independently controlled. The double barrier design also would permit independent control of the refrigerant streams in the inner and outer arrays, so that their temperatures could be regulated separately. This would allow a degree of flexibility that could be advantageous in certain applications. For example, it could be desirable to severely limit the migration of contaminants at a site with a high hazardous/radioactive waste inventory by forming an extra thick barrier for long-term confinement. In this case the ground could be chilled by flowing liquid nitrogen in the inner array (made of special alloy steel), while refrigerating the outer set with a recirculated refrigerant at a much higher temperature (Dash 1991).

During freezedown, the outer freeze pipes would be activated first in order to form a frozen barrier totally enclosing the waste site. Then moisture would be added (if necessary) by means of the perforated moisture addition pipes, whereupon the inner freeze pipes would be activated. By freezing the outer pipes first to form an outer frozen barrier, the possibility of enhanced contaminant migration due to moisture addition would be minimized.

According to the CRYOCELL process developers, the considerable thickness of the barrier walls would make them virtually impermeable to most contaminants. Leakage via diffusion is purported to be negligible (i.e., nondetectable after 10,000 years). The ice walls would be highly resistant to chemical degradation and they would remain frozen for up to two years without refrigeration. In the event that the barrier wall is damaged in an earthquake, the developers claim that the overburden pressure would cause the ice to fuse in a short period of time, thereby reestablishing containment (SEG and RKK 1992).

A proprietary computer model would be used to predict the thermal characteristics of the frozen barrier. This three-dimensional finite element model requires characteristics such as the number and thickness of soil layers, soil types, soil thermal conductivity, moisture content, and length and spacing of refrigerant pipes, to determine the transient and steady-state response of the earth during ground freezing.

Design and construction of the freeze wall should be oriented toward minimizing maintenance costs, and the piping geometry should be designed to allow the total barrier to be formed slowly (in 4 to 12 months). This would permit use of greater spacing between the cooling pipes, extending the typical construction spacing of 0.9 m (3 ft) to as much as 3 m (10 ft) (Dash 1991).

The developer estimates that a typical CRYOCELL installation for a site with a surface area of 2 ha (5 acres) would cost \$6 to \$12 million (SEG and RKK 1992). For site areas in excess of 41 ha (100 acres), with soil conditions permitting installation by pile driving or jacking, the installation cost should range between \$1.50 to \$3.00 per cubic meter (\$2 to \$4 per cubic yard) (Dash 1991). After the barrier walls are frozen, the estimated cost to maintain a CRYOCELL system, based on a 2 ha (5 acre) site, would be less than \$100,000 per year. The 30-year total cost for the same 2 ha (5 acre) site is estimated to be \$3.00 to \$3.80 per cubic meter (\$4 to \$5 per cubic yard).

3.3 JET GROUT CURTAINS

The technology for emplacing jet-grouted curtains is similar to grout encapsulation (Section 3.1) except that both vertical or horizontal wells, rather than directionally drilled wells, would be used for injection. A high-pressure jet-grouting head would be lowered to the desired depth and air and cement would be blown through the jet at approximately 4.1×10^7 Pa (6,000 lb/in^2). Air and cement would be thoroughly mixed with the soil in a column approximately 1 to 2 m (3 to 6 ft) in diameter. A seal would be made by overlapping the cylinders in the soil/grout columns. Approximately 80 to 85% of the soil impacted by the jet would be combined with the grout to form the barrier; the remaining 15 to 20% of the soil volume would be pumped to the surface as the barrier was formed (Naudts 1989; Bovay 1992).

The horizontal barrier would be completed first. The vertical jet grout curtain would then be added and joined with the horizontal barrier.

The jet grout curtain technology as potentially applied to SSTs is depicted in Figure 3-3.

3.3.1 Current Applications

Current applications of jet grouting are numerous and include foundation repairs, cofferdam barriers, groundwater control, and other specialized uses. The technology has been used in Europe for waste containment systems but has not yet been used in the United States for that purpose (Naudts 1989).

3.3.2 Test and Demonstration Status

The use of jet-grouting for subsurface barriers for DOE and/or Hanford Site applications has only been conceptually designed. No laboratory or field tests have been performed. The technology of jet grouting is proven and should require little modification for application to SSTs.

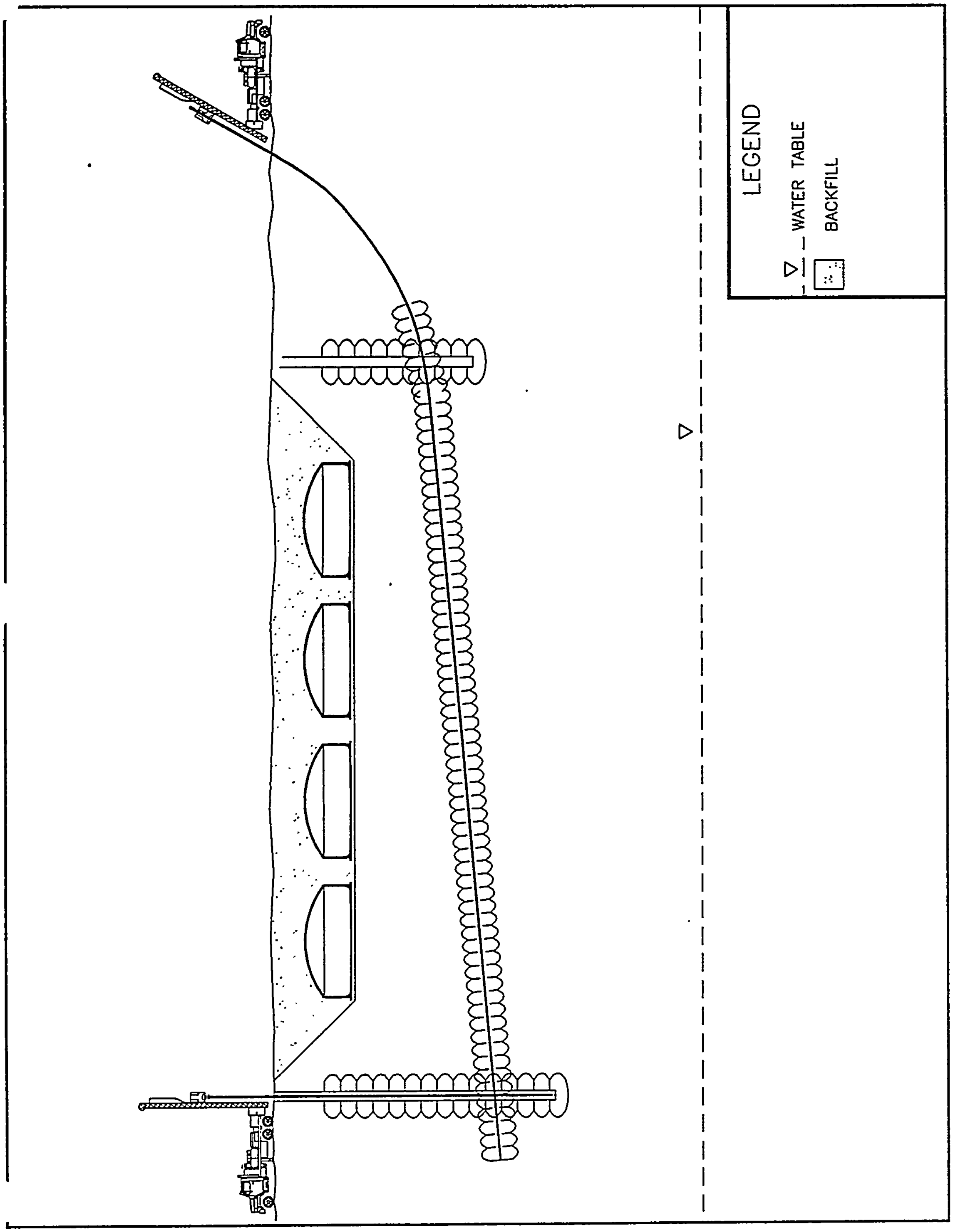

Figure 3-3. Jet Grout Curtains.

3.3.3 Advantages and Disadvantages

Potential Advantages

- Jet grout curtains are stable, flexible, and earthquake resistant.
- Jet grout curtains are resistant to chemical attack.

Potential Disadvantages

- The potential exists for exposure of personnel to contaminated soils and chemical additives used in the grouting.
- Verification of barrier integrity would be difficult.

3.3.4 Other Information

The integrity of the barriers may be verified by deploying additional horizontal wells above and beneath the underlying barrier to enable leak detection. Other physical techniques may be feasible for locating leaks and barrier holes.

A variety of grouts with varying viscosities and set-up times are available. The grout formulation can be selected to meet rather broad design requirements, including hydraulic conductivity, strength, and capability for plastic deformation or resistance to chemical attack.

3.4 PERMEATION CHEMICAL GROUTING

Permeation chemical grouts would be injected at lower pressures than would jet grouts (Section 3.1 and 3.3) and could be used to form both vertical and horizontal barriers. Injection pressures would depend upon depth, the length of the injection run, and the porosity of the soil. Other materials could be used with the permeation technique and are discussed in Sections 3.5, 3.6, and 3.7.

The application of horizontal drilling would enable placement of a horizontal permeated grout barrier beneath a tank farm. The drill holes would not have to be exactly parallel. Minor deviations within tolerances of existing equipment may provide sufficient accuracy to permit utilization of the wells for emplacement of a grout barrier. The accuracy of horizontal drilling in Hanford Site soils containing large cobbles and boulders is unknown and may not be acceptable. If the horizontal wells were installed approximately 3 m (10 ft) apart, the underlying barrier is projected to have a minimum thickness of about 2 m (6 ft), assuming installation occurs in coarse-grained, homogeneous soils. Vertical permeation barriers would be constructed by conventional techniques and have a thickness similar to that of the horizontal barrier (Naudts 1989; Bovay 1992).

The applicability of permeation grouting is highly dependent upon the properties of the grouting materials used and the properties of the soil. The barrier would be constructed by first drilling, washing, or driving a grout pipe and then pumping viscous grouting fluid into the formation as the pipe is slowly withdrawn. The grout would fill the voids in the soil and, as it sets up, would form a low-permeability barrier. Emplacement of a uniform barrier would be difficult to achieve because differences in the soil hydraulic conductivity can cause the grout thickness to be uneven.

The permeation grout technology as potentially applied to SSTs is depicted in Figure 3-4.

3.4.1 Current Applications

Permeation grouting is a proven technology commonly used in private industry for cutoff walls, sea walls, and building foundations. It has been used in Europe for both waste management and non-waste management purposes. It has been extensively used by the United States oil and gas industry.

3.4.2 Test and Demonstration Status

Permeation grouting for subsurface barriers for Hanford Site underground storage tanks has been only conceptually designed. No laboratory or field tests have been performed. The base technologies of vertical permeation grouting and horizontal drilling are proven at locations outside the Hanford Site and may require little modification for this application.

3.4.3 Advantages and Disadvantages

Potential Advantages

- The quantity of contaminated soil that may be brought to the surface in drill cutting is relatively small.
- Permeation grouting is a well-established technology used throughout the world in construction applications.
- Emplacement of the grout is not likely to cause unacceptable stress to the SSTs.
- There are minimal health and safety issues envisioned.

Potential Disadvantages

- Earthquake resistance could be relatively low; joints between successively grouted zones could part under tension.

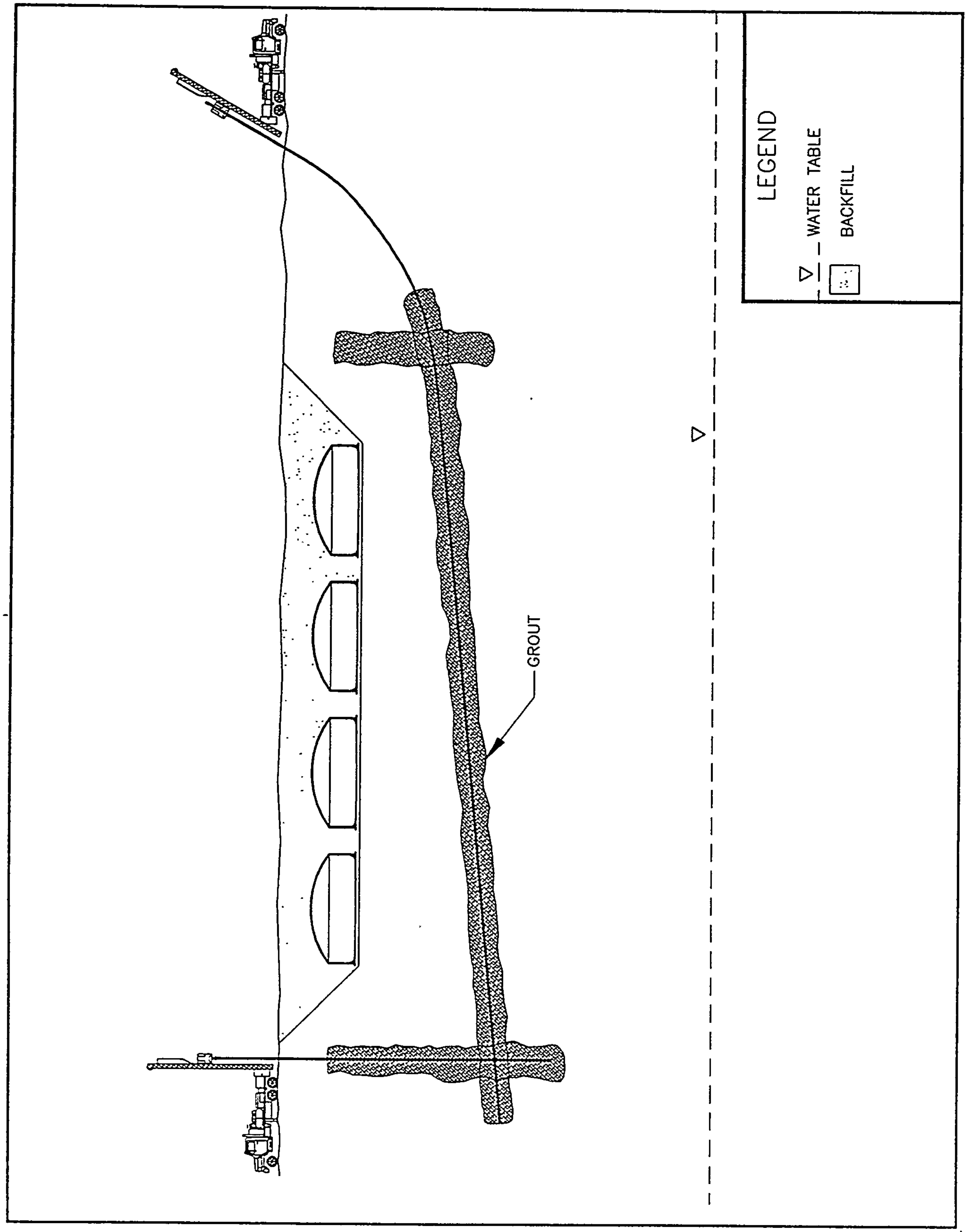

Figure 3-4. Permeation Chemical Grouting.

- It could be difficult to verify the integrity of joints because narrow gaps or cracks may not be visible using imaging techniques and other methods used in the construction industry.
- Silt lenses, clastic dikes, and other soil heterogeneities common to Hanford Site soil will prevent uniform permeation of chemicals in the ground which may result in ungrouted areas.

3.4.4 Other Information

The integrity of the barriers may be verified by deploying additional horizontal wells above and beneath the underlying barrier to enable leak detection. Other physical techniques may be feasible for locating leaks and barrier holes.

A variety of grouts with varying viscosities and set-up times are available. The grout formulation can be selected to meet rather broad design requirements. Soils with relatively low hydraulic conductivities (i.e., $< 10^{-5}$ cm/s) may not be amenable to permeation grouting due to inability of the grout-forming chemicals to permeate into the fine pores of the soil within the period defined by the set-up or gel time.

3.5 WAX EMULSION PERMEATION GROUTING

A mineral wax-bentonite emulsion called "Montan" wax has been developed for grouting applications by a German company described in Section 3.5.1. Montan wax is present in a lignite coal field in Amsdorf, Germany and has been the world's supply of the wax since the 1900s. Montan wax has properties similar to those of natural plant waxes such as those found in carnauba palms. The material features a high-melting point and is composed of C-24 to C-32 esters of long-chained acids and alcohols and includes waxes, resins, and asphaltene-like materials. Montan wax has been used in carbon inks, emulsions, polishes, and lubricants for decades (Golder 1994a).

Montan wax grout consists of a stable emulsion of Montan wax, water, and a surfactant. The emulsion is formed by injecting a stream of melted wax into water near boiling temperatures to solidify the wax into small particles. The size of the particles can be somewhat controlled by varying the temperature or using mechanical shearing. The surfactant is used to maintain the emulsion, ensuring that the wax particles are kept in suspension during the injection process. This allows the wax particles to move through the soil pores with the fluid. Once inside the soil matrix, the wax particles begin to aggregate (therefore increase in size) and move through void spaces in the soil until they bridge an opening and become fixed. Bridging these openings between pores reduces the permeability of the soil (Golder 1994a).

Figure 3-5 depicts wax emulsion permeation grouting as it might be used in SST applications.

3.5.1 Current Applications

Montan wax grout is not currently used in the United States for waste management or environmental restoration purposes; it is, however, being contemplated for containment of contaminated sites in the Halle-Leipzig-Bitterfeld area in Germany. Vereinigte Mitteldeutsche Braunkohlenwenke AG (MIBRAG), a large industrial company, has tested the feasibility of creating containment barriers with Montan wax grout emulsions in several field demonstrations containing unconsolidated soils with high permeabilities. After permeating the soils with a mixture of Montan wax, water, and bentonite, the conductivity of the soil was reduced by as much as five orders of magnitude (Golder 1994b).

3.5.2 Test and Demonstration Status

Three field-scale pilot tests have been completed to date by Golder Associates, Inc. (Golder). In addition, on a lab-scale, Golder has recently injected wax emulsion grout into soils from several DOE sites, including the Hanford Site, INEL, and Sandia. Results of these tests show that the hydraulic conductivity of unconsolidated coarse-grained Hanford Site soils can be decreased by 2 to 3 orders of magnitude to 10^{-4} to 10^{-5} cm/s [2 x 10^{-4} to 2 x 10^{-5} ft/min]) (Golder 1994b).

Additional field demonstrations by Golder are planned this summer at the city of Richland Sanitary Landfill.

3.5.3 Advantages and Disadvantages

Potential Advantages

- Montan wax has been tested in the laboratory and field, thus reducing development costs and improving understanding of the limits of the technology.
- Materials used in the Montan wax formulation are nontoxic.
- The minimum hydraulic conductivity limit for permeation grouting using Montan wax grout is low enough to permit its use in some Hanford Site soils.

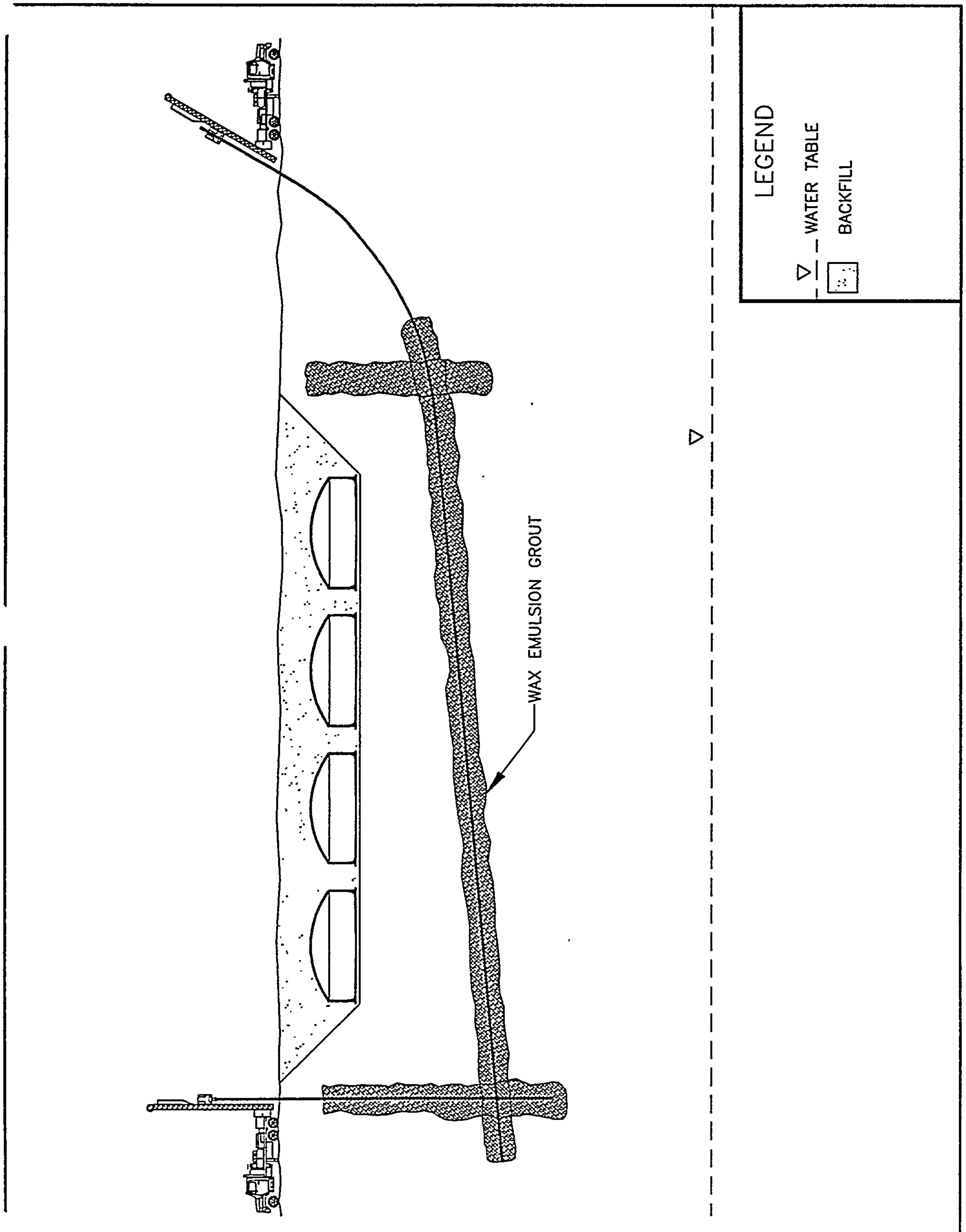

Figure 3-5. Wax Emulsion Permeation Grouting.

Potential Disadvantages

- Montan wax grout slowly softens at the surface in the presence of sodium hydroxide; the wax therefore may destabilize in the presence of SST leachates with a high pH (> 12.0).

- Verification of barrier integrity would be difficult.

- Montan wax, like any other petroleum products, may be susceptible to bacterial degradation over time.

3.5.4 Other Information

This technology was developed by MIBRAG and DBI Gas-und, Umwelttechnik GmbH (DBI). MIBRAG and DBI have invested more than $9 million in the development and testing of materials. The technology was identified by Golder Associates, Inc. when they were involved in a DOE Office of Technology Development (EM-50) funded program entitled International Technical Exchange Project in 1992 (Golder 1994b).

3.6 SILICA, SILICATE PERMEATION GROUTING

Permeation grouting using a sodium silicate-based technology was developed by the French chemical company, Societe Fancaise Hoechst, and is sold under the trade name of Klebogel. The material used is a silica-based chemical grout and has favorable characteristics that can be controlled by altering the formulation of the grout.

Sodium silicate grout consists of four components: water, an acidic liquid consisting of glyoxal and additives, an alkaline liquid consisting of silicon dioxide and sodium oxide, and an aqueous suspension of non-agglomerated silica particles in an alkaline medium. The grout is prepared by successively adding the materials together. Set time and grout viscosity can be controlled by altering the proportion of the four components (Golder 1994a).

Another siliceous material being explored for use in forming subsurface barriers at the Hanford Site is colloidal silica, a colloidal suspension with gelling properties. Colloidal silica is widely available and is used in a variety of industries, including paper, textile, and metal casting. If the pH decreases to less than 10 and the ionic strength increases by brine addition, the colloid would polymerize or gel. The gel would form as the colloidal particles aggregate to form a crosslinked network. Colloidal silica was first used as a barrier material by the petroleum industry for blocking flow in porous media.

Researchers at Lawrence Berkeley Laboratory (LBL) have devised methods to overcome the loss of gelling control (i.e., uncontrolled rapid gelling) in situ. These methods include displacement of divalent cations in the soil by preflushing with brine, displacement by using dilute colloidal silica suspensions that gel, and precipitation and complexation of divalent ions by sodium fluoride (Persoff et al. 1994).

Polysiloxanes are silicon-based polymers consisting of a mixture of two fluids and are chemically and biologically inert. They have been used historically for medical implants and as carriers for a variety of medicines injected into humans (Moridis et al. 1993).

Figure 3-6 depicts silica, silicate permeation grouting as it might be applied to SSTs.

3.6.1 Current Applications

Silica and silicate-based products have been used extensively in industrial applications in the United States. They also have been used in tunneling applications and as strengtheners in unconsolidated soils in Europe and the United States. The products have seen limited use in barrier applications similar to the ones postulated for use around SSTs.

3.6.2 Test and Demonstration Status

Sodium silicates have been extensively tested in the laboratory at the Hoechst facilities in Paris and the Technical University of Clausthal. Golder Associates Inc. injected sodium silicate grouts into soils from several DOE sites, including the Hanford Site, INEL, and Sandia in 1993. Results of these laboratory tests show that the hydraulic conductivity of coarse-grained unconsolidated Hanford Site soils can be decreased by 3 to 4 orders of magnitude to 10^{-5} to 10^{-6} cm/s [2 x 10^{-5} to 2 x 10^{-6} ft/min] (Golder 1994b).

Field tests using sodium silicate grouts are being conducted in single-borehole injection and multiple-borehole injection experiments. The single-borehole tests were performed in conjunction with cement-grout injection studies conducted at Sandia. The multiple-borehole tests to be performed at Sandia are aimed at constructing a large-scale horizontal barrier by connecting grout injected from an array of boreholes (Golder 1994a). Additional field demonstrations are planned for the summer of 1994 at the city of Richland Sanitary Landfill, near the Hanford Site.

Laboratory studies have been successfully conducted on colloidal silica and polysiloxane by Lawrence Berkley Laboratory researchers using Hanford Site soils (Moridis et al. 1993; Persoff et al. 1994).

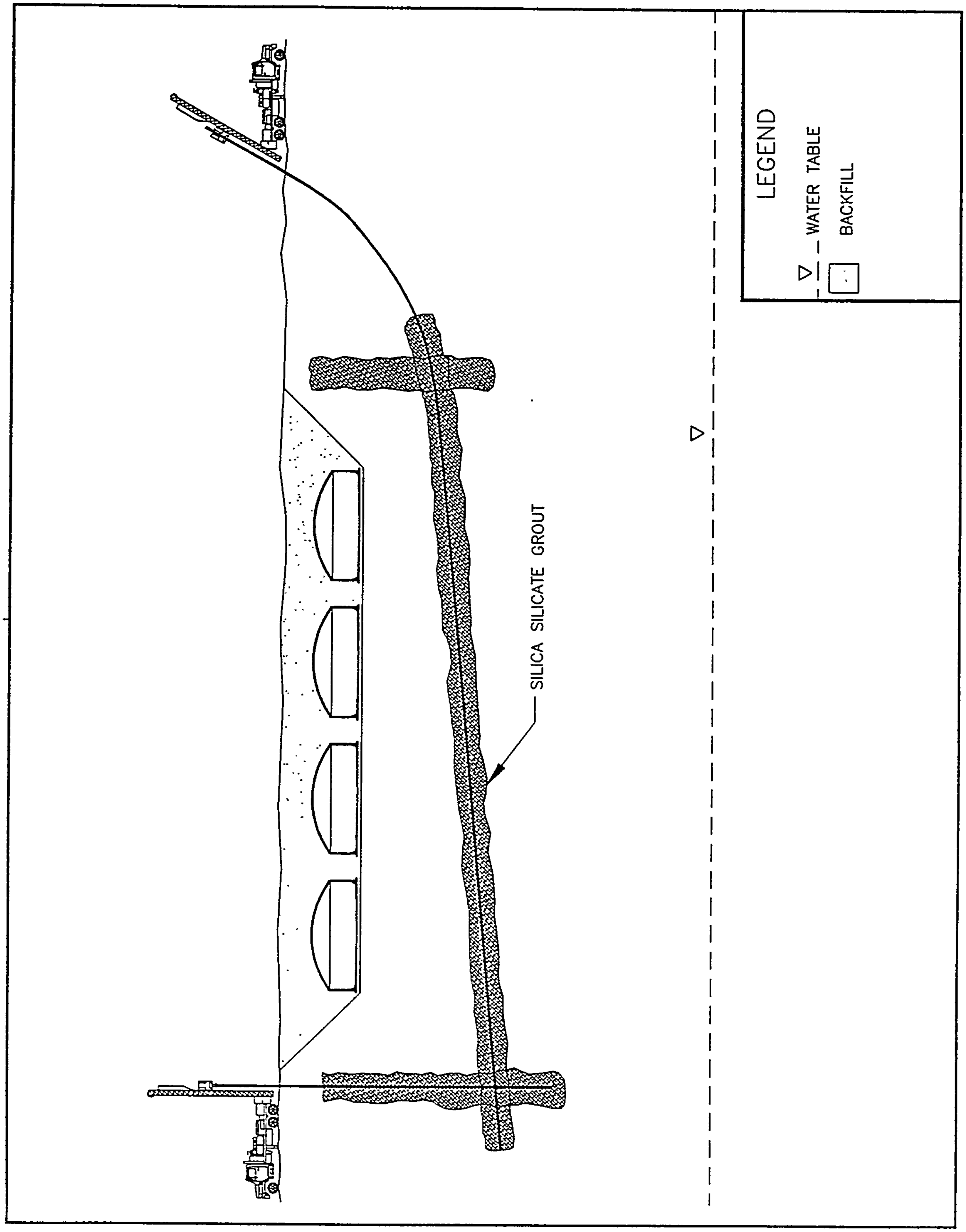

Figure 3-6. Silica, Silicate Permeation Grouting.

3.6.3 Advantages and Disadvantages

Potential Advantages

- Siliceous materials capable of forming barriers have been tested in the laboratory and field, thus reducing development costs and defining the limits of the technology.
- Siliceous materials considered for use in barriers are nontoxic.
- Pressures required for injection are lower than for Montan wax grout due to the lower viscosity of sodium silicate grouts.

Potential Disadvantages

- In the presence of sodium hydroxide, silicate grouts degrade rapidly.
- Predicting the movement of injected grout is difficult due to the anisotropy and heterogeneity of most Hanford Site soils.

3.7 POLYMER PERMEATION GROUTING

Polymer permeation grouting employs an injected liquid monomer or resin that is converted to a polymer (in place) to form a concrete-like monolithic barrier. A monomer is a molecular species capable of combining chemically to form a high-molecular-weight polymer through a process called polymerization (Fowler 1990; Bovay 1992). A discussion of the various types of monomers, resins, catalysts, promoters, and additives can be found in Section 3.7.4.

Polymer grouts are compatible with free-standing water and some soil aggregates. Water can be used in some cases for cleaning the mixing and injection equipment. The mixing equipment use for polymer permeation is similar to that used for portland cement concretes. Polymer-forming chemicals could be injected into the ground using the same methods for emplacing cement slurry walls (i.e., sleeve pipes and columns or hydrofraise) (Fowler 1990; Bovay 1992).

The polymer permeation technology as potentially applied to SSTs is depicted in Figure 3-7.

3.7.1 Current Applications

Typical uses of polymer grouts include bridge overlays, pavement repairs, dam repairs, canal locks, tunnels, rapid runway repairs, belowground utility vaults, steam distribution systems,

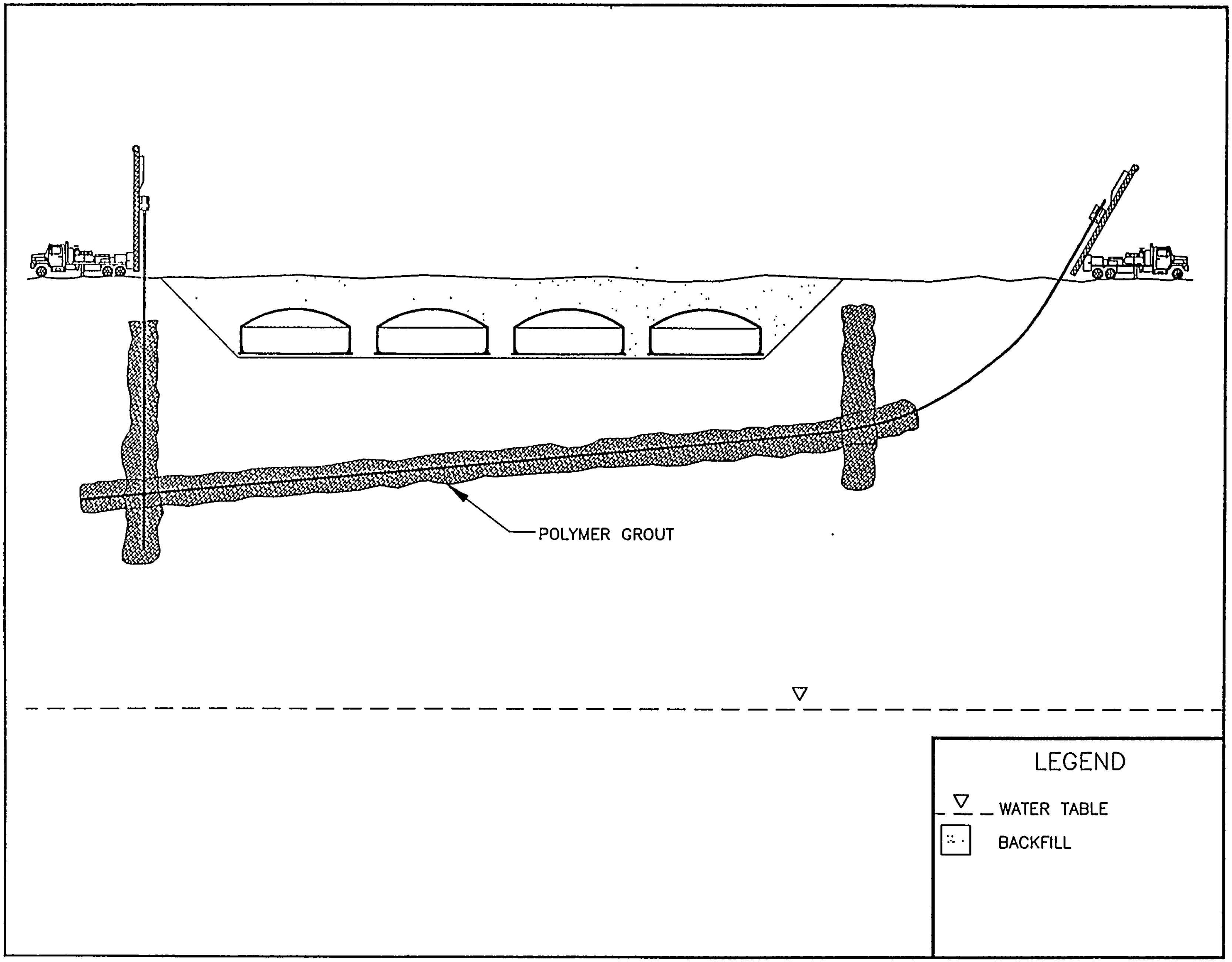

Figure 3-7. Polymer Permeation Grouting.

insulation material for liquified natural gas storage tanks, and corrosion-resistant liners for high-temperature piping. Polymer grouts have seen limited use in the United States for waste confinement purposes.

3.7.2 Test and Demonstration Status

Polymer grouts are proven technologies in a variety of construction applications. Bench-scale testing of polymer grouts with soils from different DOE sites is being conducted at Brookhaven National Laboratory.

3.7.3 Advantages and Disadvantages

Potential Advantages

- Polymer grout is extremely durable.
- Polymer grout has a much lower permeability than standard grout or cement.
- Polymer grout is more chemically, radiologically, and thermally resistant than standard grout.

Potential Disadvantages

- Polymer grout is expensive compared to standard grouts.
- Except for alcohol-based monomers, polymer grouts are insoluble in water and must be mixed with dry aggregate and/or soil.
- Some polymer grouts (e.g., furfuryl alcohol) are chemically incompatible with Hanford Site soils.
- There may be occupational hazards (fire and health) associated with the use of polymers.

3.7.4 Other Information

Monomers are mixed with different types of catalysts (initiators) and promoters to control set times and set temperatures (up to 300 °C [572 °F]). A wide variety of combinations can be used in polymer grouts for various purposes (Fowler 1990; Bovay 1992). Some of these combinations are listed below:

Monomers:	Styrene + divinyl benzene Styrene + acrylonitrile Vinylester-styrene Polyester-styrene Methyl methacrylate Furfuryl alcohol
Catalysts:	Methyl ethyl ketone peroxide Benzoyl peroxide Di-tert butyl peroxide
Promoters:	Cobalt naphthenate Dimethyl aniline Dimethyl toluidine Zinc chloride
Additives:	Latex Polymers/acrylamides/polyurethane Silica fume Fly ash

For more information on the use of polymer grouts for subsurface barrier applications, refer to the *Laboratory Evaluation of Performance and Durability of Polymer Grouts for Subsurface Hydraulic/Diffusion Barriers* prepared by Brookhaven National Laboratory (Heiser 1994).

3.8 FORMED-IN-PLACE HORIZONTAL GROUT BARRIERS

Formed-in-place horizontal grout barriers could be constructed in situ in a basin configuration without excavation. The method involves the use of a proprietary technology to generate a barrier slab of uniform thickness (0.3 m [1 ft]) between guide wires placed by horizontal drilling methods. The technology uses high pressure jets mounted on a reciprocating machine tool. The grout slurry sprayed through the jets disrupts and mixes soils to a mortar-like consistency between the guide pipes. The machine tool passes through this semi-liquid material as the hardware is pulled along the guide wires, forming a uniform barrier behind it. Adjacent panels would be emplaced at the edge of the previous panel (before it hardens totally), overlapping the previous panel to some extent to form an extended slab.

Emplacement of multiple horizontal panels could start at ground level and curve down before leveling out at the desired depth (approximately 33 to 66 m [100 to 200 ft]) and then curving back up to the surface on the other side of a waste site. The guidance wires on the edges of the site would also bring the sides of the barrier near to the surface, forming a gently sloping oval bowl. A completely horizontal grout barrier installed with this equipment could be coupled with a suitable vertical barrier such as sheet pilings with grouted joints.

Production rates for pilot-scale equipment tested to date vary considerably with soil types but are approximately 100 m^2 (1,100 ft^2) of barrier per hour. Sandy and unconsolidated soils with high void ratios would permit higher installation rates and fewer spoils. The process generates an excess of waste soil cement equal to about 30% of the barrier volume installed in sandy soils. This excess is displaced at the ground surface. Rocks and other debris larger than the thickness of the barrier would cause the tools to stop. Soft rock would be cut up by the jets. During emplacement in soft rock and other nonideal soils, the machine would produce more than 30% excess cement grout. Voids and nonuniform soils have posed no difficulty to date for this technology. Oily soils and low permeability soils are compatible with the technology because the soils are intimately mixed with the barrier material by action of the powerful jets.

Figure 3-8 depicts a formed-in-place barrier as it might be used in a SST application.

3.8.1 Current Applications

No full-scale application of this technology related specifically to waste management or environmental restoration purposes is known at this time. Applications to date have been limited to clay- and cement-based products for cold demonstrations.

3.8.2 Test and Demonstration Status

A test at Halliburton facilities in Oklahoma was conducted in late 1992 with six 3- to 3.6-m (9- to 11-ft) wide panels approximately 33 m (100 ft) long. The tests demonstrated the feasibility of constructing continuous grout barriers of high uniformity, including the joining of the panels. Guide wires in the test were spaced 3 to 3.6 m (9 to 11 ft) apart. The demonstration produced one panel in clean soil at DOE's Fernald Site. Results of in situ and ex situ tests and the final demonstration report are not yet available. A second test forming a 13 by 66 m (40 by 200 ft) panel is planned at DOE's Fernald Site near Cincinnati, Ohio in the summer of 1994.

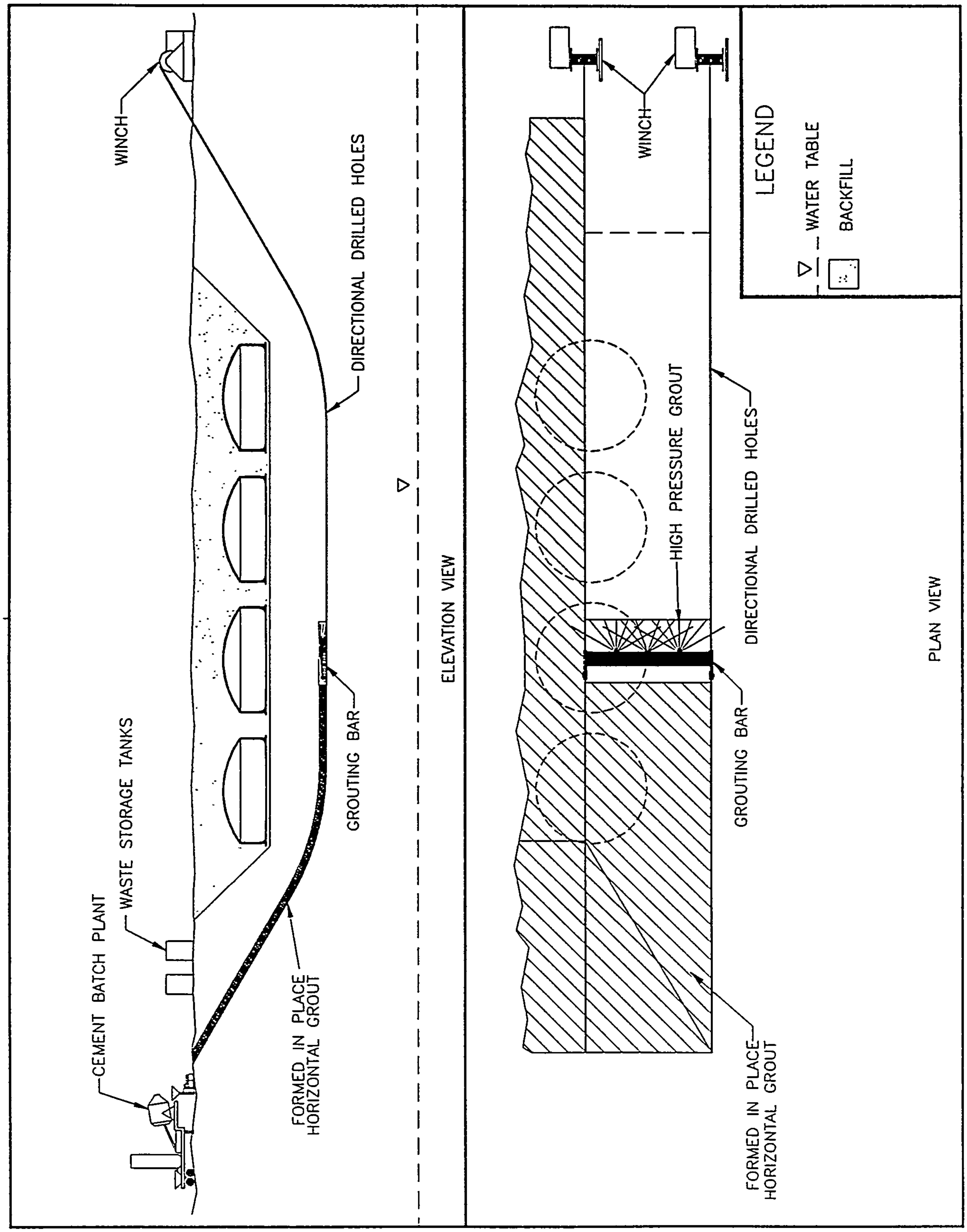

Figure 3-8. Formed In-Place Horizontal Grout Barrier.

3.8.3 Advantages and Disadvantages

Potential Advantages

- Formed-in-place horizontal grout barriers have a uniform thickness with few, if any, irregularities due to the vigorous mixing action.
- According to the vendor, spacing between the guide pipes could be increased to 33 m (100 ft) or more and tolerate a spacing error of 10% by designing a 10% overlap of individual grout panels.
- The vendor refers to the technology a "self-proving" method of placement; the tool would not pass through soil horizons until they had been liquified and grouted.
- The spoils would be in a relatively easy form to handle (i.e., wet, nondispersable grout) and could readily be disposed as solidified mixed waste.

Potential Disadvantages

- Formed-in-place horizontal grout barriers have not been proven in soils similar to those that exist at the Hanford Site.
- Unless a full-width panel (approximately 91.5 m [300 ft]) can be generated, verification that the technology prevents leakage at panel seams will be required.
- Surfacing of chemically or radiologically contaminated spoils will occur if the barrier equipment penetrates a contaminated zone.
- Relatively high volumes of spoils would be produced.
- Breakdowns may lead to hardening of panels and formation of cold joints that may be prone to leakage.

3.8.4 Other Information

This technology has been developed and tested by Halliburton NUS, a Halliburton Company subsidiary (also known as Brown & Root Environmental). Equipment required to support the grout jetting tool is standard oil field equipment and is available on short notice from Halliburton Services.

The method is capable of being used with any liquid grout material. There are plans to conduct future demonstrations with special materials including a polyacrilate being developed by Brookhaven National Laboratory and a rubberized cement developed by Halliburton Company.

3.9 CIRCULATING AIR BARRIERS

The circulating air barrier (CAB) technology would create a dry zone under the area of confinement through which no liquids could penetrate until a critical liquid saturation was exceeded. The critical saturation would be dependent upon the physical characteristics of the porous medium; however, for most sediments at the Hanford Site, the critical saturation is on the order of 5 to 25%. The water currently under the tanks is essentially immobile and, if kept at or below the critical saturation value, would remain immobile (BDM 1993).

The CAB technology injects dry air from an array of either vertical or horizontal wells. The air would be forced though porous soils to extraction wells, vaporizing water in the process. It has been calculated that with readily achievable injection flow rates, half of the entrained water in the soil would be removed in one to two years (BDM 1993).

Figures 3-9 and 3-10 depict CAB technologies as they may be applied to SSTs for horizontal applications and vertical applications, respectively.

3.9.1 Current Applications

The CAB system is based on standard oil industry practices used to extract liquids from porous media. It has not been used in the field as a subsurface barrier for waste containment.

3.9.2 Test and Demonstration Status

Although no large-scale field tests have been performed using CABs, the technology has undergone significant laboratory testing by BDM/K&M Engineering International. In addition, the injection/extraction technique has been used to recover volatile organic contaminants from groundwater and vadose zone soils.

3.9.3 Advantages and Disadvantages

<u>Advantages</u>

- The CAB utilizes several well-established technologies; thus construction and operation would be straightforward.

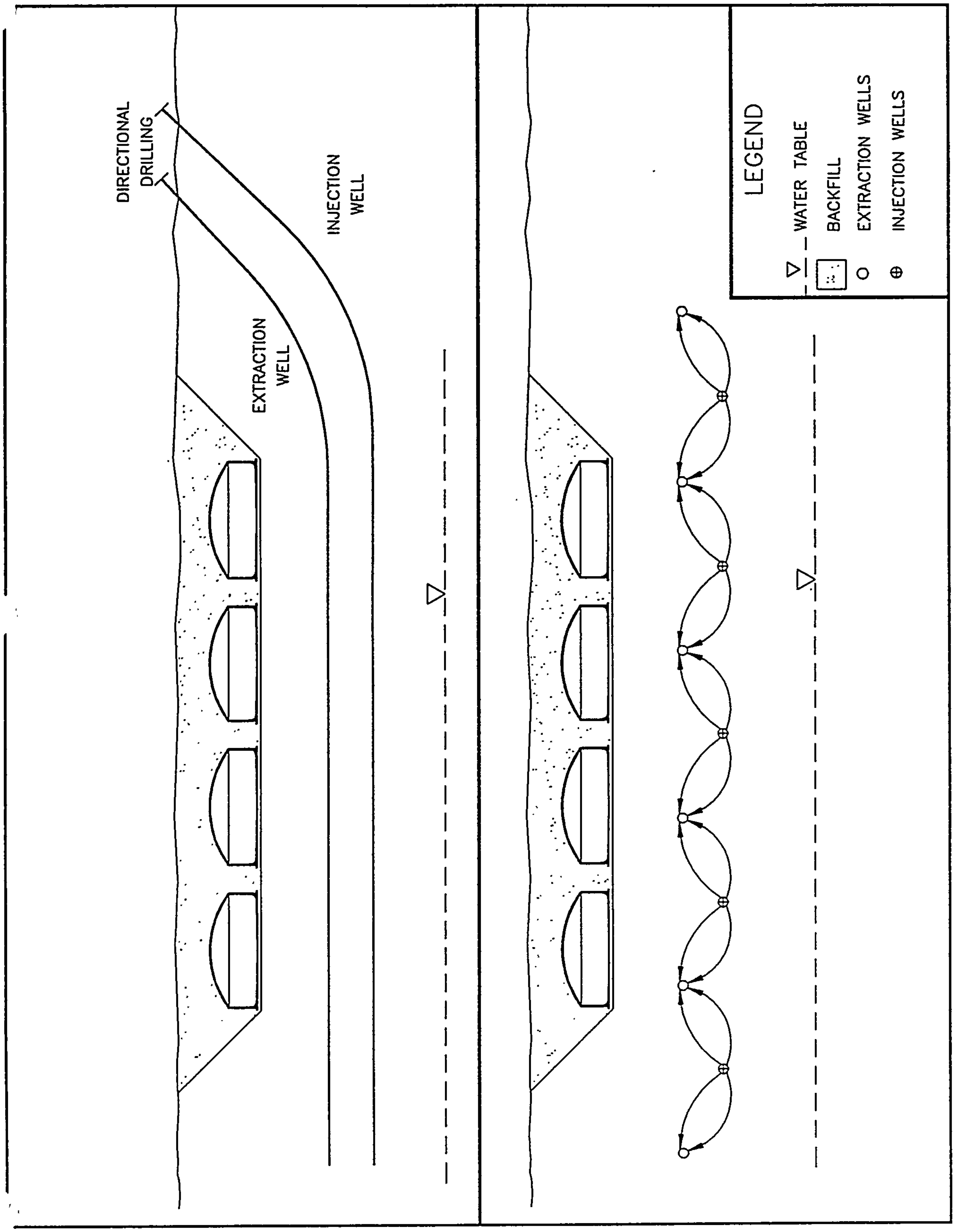

Figure 3-9. Horizontal Circulating Air Barrier.

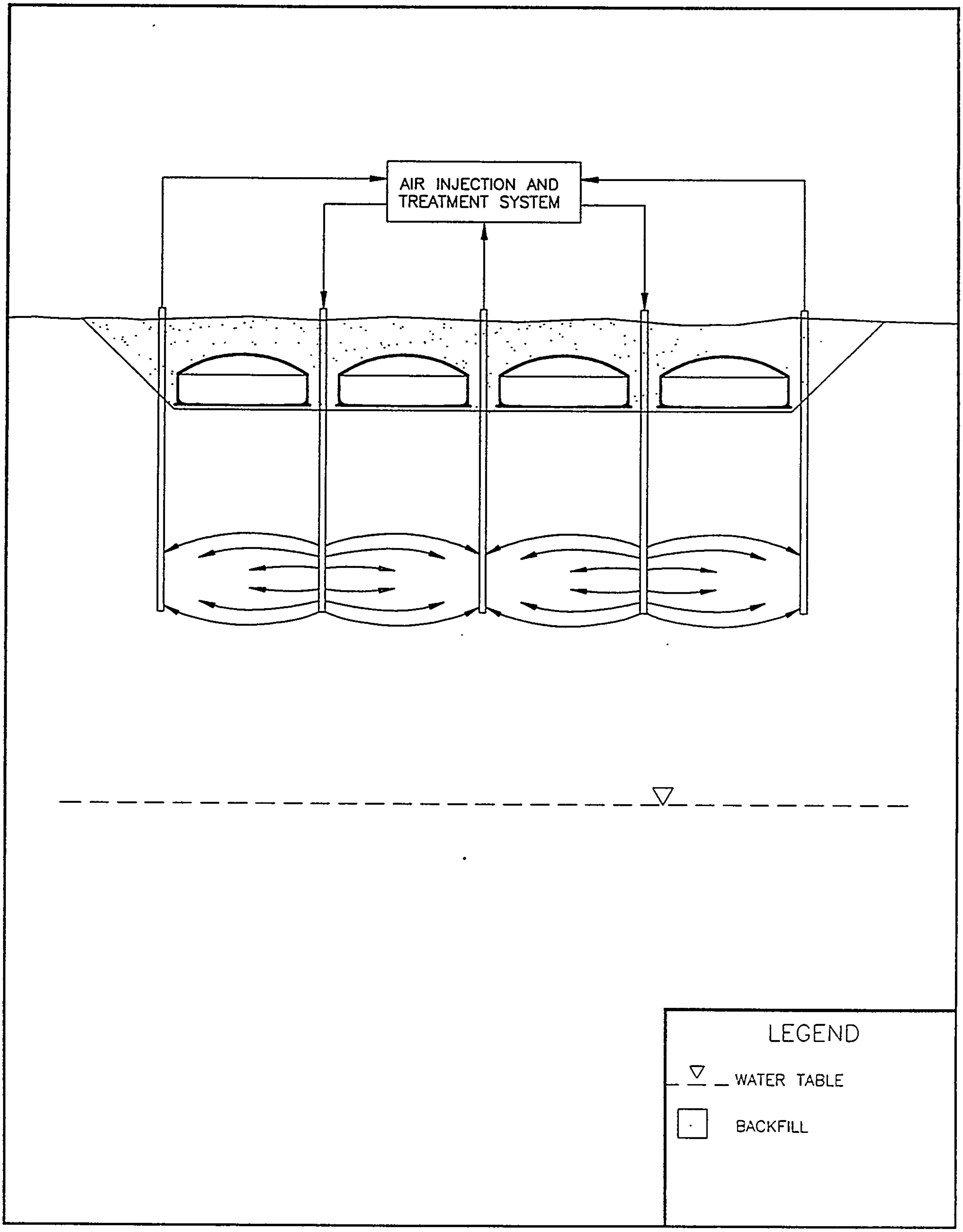

Figure 3-10. Vertical Circulating Air Barrier.

- Construction and installation of equipment would generate little, if any, contaminated spoils.
- Installation would not induce stresses around the tanks.
- The CABs would tolerate chemical environments.
- The CAB is one of the least costly of the subsurface barrier options available.
- Prolonged periods of noninjection of dry air could be tolerated without significant migration of leaks.

Disadvantages

- Containing the air in the zone of interest and in the extraction wells could present technical challenges.
- The air may flow through preferential pathways that may result in uneven drying of the soil.
- The presence of relatively impermeable zones may increase drying time considerably.
- The absence of a physical barrier would complicate recovery of leaked waste using soil flushing.

3.9.4 Other Information

According to the BDM/K&M, an example target for drying soil is below the C Tank Farm, which encompasses an area of approximately 23,300 m^2 (250,000 ft^2) and is 15 m (50 ft) thick. Air would be injected just under any pre-existing contaminant plume, about 45 m (150 ft) below the surface, and down to about 60 m (200 ft), which is about 15 m (50 ft) above the water table.

Existing vertical wells could be used as air injection or extraction wells and/or new wells could be drilled using cable tool, sonic, or air rotary drilling methods. Wells would be drilled or deepened to a depth of 60 m (200 ft). Each well would be equipped with port collars that can be mechanically opened or closed to either inject or extract air. The injection and/or extraction rates could be varied by the depth as needed to optimize drying (BDM 1993).

Horizontal wells are more efficient for injection or extraction than are vertical wells. Thus, fewer horizontal wells would be required than for vertical operations. Each horizontal well would be equipped with mechanical port collars to provide a large number of injection and extraction points and thereby improve extraction from the 15 m (50 ft) interval target for the conceptual design. Positioning of the horizontal wells would not be as accurate as that of the vertical wells; however, extreme accuracy would not be required since the air would flow in a wide-sweeping pattern (BDM 1993).

The integrity of the barrier could be verified through monitoring the air extracted. Ineffective wells can be detected from pressures, air flow rates, and geophysical well logs. The productivity and injectivity of these wells could be improved by stimulation or plugging using common oil industry technology. Humidity levels of the produced air would be monitored to indicate how well the zone around an injection well had dried (BDM 1993).

3.10 RADIOFREQUENCY DESICCATING SUBSURFACE BARRIERS

A radiofrequency (RF) heating process can be used for the formation of an active desiccating barrier underneath underground storage tanks. Electrodes would be installed in the soil between the source of the contamination and groundwater using horizontal drilling techniques. The RF energy applied to the electrodes would heat a 2 to 3 m (7 to 10 ft) thick layer of soil to temperatures above 100 °C (212 °F) to evaporate the moisture. Electrodes would be perforated and maintained under vacuum to remove the steam and volatile organics for aboveground treatment and disposal. As heat is lost from the barrier to surrounding soil, RF energy would be applied either continuously or intermittently to overcome losses (Sresty 1993).

Figure 3-11 illustrates an active desiccating subsurface barrier as applied to an SST. As shown, a horizontal row of parallel electrodes spaced about 1 to 2 m (3.3 to 6.6 ft) apart would be installed by guided horizontal drilling. After installation, pairs of electrodes would be attached to a lower shortwave band RF source. The source would excite the electrodes and cause energy to be absorbed into the soil immediately surrounding the electrodes. This in turn would heat the soil to a temperature of about 150 °C (302 °F), thereby vaporizing the water present within the soil. Waterborne contaminants would be stopped at the heated zone slab by the vaporization of the liquid carrier. Scale-model tests have demonstrated that a thin slab of earth could be heated to temperatures between 120 and 160 °C (248 and 320 °F). The energy required to maintain the heated slab at temperatures above 100 °C (212 °F) has been estimated to be between 10 and 40 W/m^2, depending on soil properties (Sresty 1993).

The RF heating process would generate high-powered RF signals by converting alternating current power to RF in a modified radio transmitter. The output of the transmitter would be applied to the soil to be heated. The power would be conveyed by coaxial cables through a matching network to the target slab. For in-place applications, an array of electrodes inserted in boreholes drilled through the target slab would be energized with RF power. Frequencies used for the heating of soil formations would be between 10 kHz and 60 MHz. The precise frequency of operation would be determined by the electrical parameters of the soil and the size of the slab to be heated (Sresty 1993).

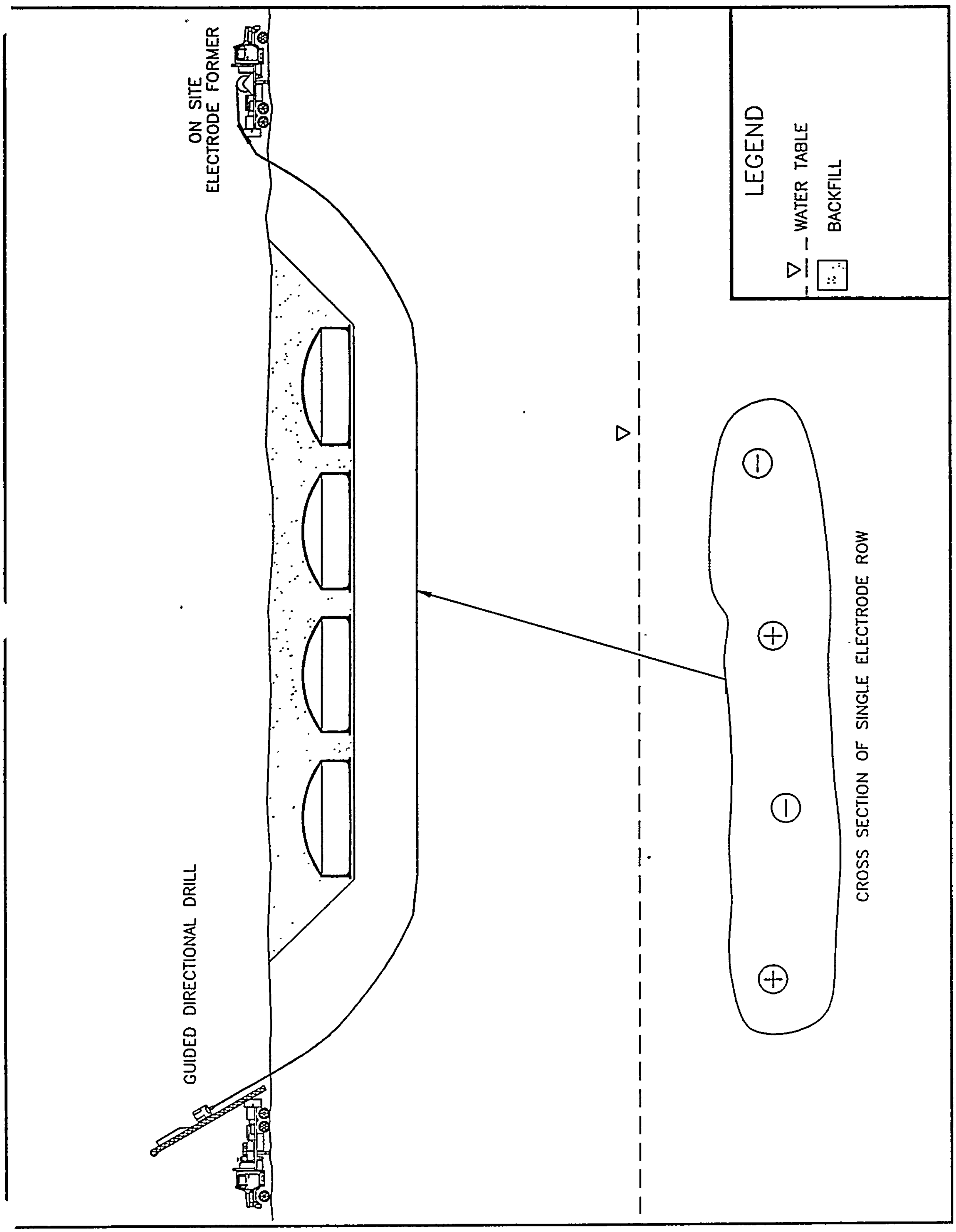

Figure 3-11. Radiofrequency Desiccating Subsurface Barrier.

As a general rule, the higher the operating frequency, the more readily soil will absorb the energy. Too rapid an absorption, however, can cause most of the energy to be absorbed within the surface layers nearest the borehole at the expense of heating the soil deeper in the slab. Lowering the operating frequency improves the depth of penetration since less power is absorbed in the surface layers (Sresty 1993).

3.10.1 Current Applications

In the late 1970s and early 1980s, the RF heating concept was applied to a fuel extraction process to uniformly heat warehouse-sized blocks of oil shale and tar sand. This technique has since been modified to heat large volumes of earth to decontaminate hazardous waste spills (Sresty 1993).

3.10.2 Test/Demonstration Status

IIT Research Institute (IITRI) is currently working with the EPA, U.S. Air Force, Electric Power Research Institute (EPRI), and other industries to develop, demonstrate, and commercialize this technology for various waste treatment applications. One of IITRI's licensees is currently using the technology for disinfection of hospital waste. A bench-scale test of radioactive resin treatment has been conducted for the Empire State Electric Energy Research Corporation (Sresty 1993).

IITRI has recently completed a project and is currently conducting a second with the EPRI in which a novel method for introducing in situ passive barriers was demonstrated in the laboratory. This technique allows for installation of horizontal desiccant barriers which, in combination with slurry walls, can contain the waste and prevent groundwater contamination. IITRI is currently developing plans for field demonstration of the concept in combination with horizontal drilling techniques in collaboration with Sandia National Laboratories (Sresty 1993).

3.10.3 Advantages and Disadvantages

Potential Advantages

- The velocity of vapor flow into electrodes should be low enough that few contaminated particulates are entrained in the air withdrawn from the extraction wells.

- The installation of the RF heating system would not induce new stresses around the tanks.

- Once a significant amount of drying has taken place, prolonged periods of nonheating can be tolerated without impairing the function of the barrier.

Potential Disadvantages

- The use of soil flushing or excavation may be required to recover leaked contamination under a tank farm. The absence of a physical barrier would complicate recovery of flush solution.

- Horizontal holes must be drilled to relatively low tolerances to achieve the required 1 to 2 m (3.3 to 6.6 ft) spacing.

3.10.4 Other Information

The moisture content of the soil dominates the electrical behavior during heating because of the polar nature of water molecules and because water behaves as an electrolyte. It is assumed that the conductivity of the soil will drop significantly as the water is evaporated. Since the heating rate of a material is directly proportional to the conductivity, the drying of soil causes it to absorb less energy. The drying of one zone of soil therefore causes progressive heating into other zones still containing water (Sresty 1993).

The integrity of the active barrier formed by the in situ heating of soil using the RF technology depends on the ability to maintain (continuously or intermittently) a temperature of 100 °C (212 °F) or more in the entire layer of soil. The dielectric properties of soil favor heating of moist regions and facilitate the formation of such a barrier. Experiments indicate that the conductivity of wet soil is 1 to 2 orders of magnitude higher than that of dried soil. Energy deposition and temperature increase calculations based on measured conductivity data show that the applied RF energy is preferentially absorbed in moist regions of soil to a distance approximately equal to the spacing of the electrodes (1 to 2 m [3.3 to 6.6 ft]). Dry soil continues to absorb energy, but at a lower rate. A layer of soil with an approximate thickness equal to the spacing between electrodes can thus be maintained at a temperature of 100 °C (212 °F) or more (Sresty 1993).

3.11 SHEET METAL PILING SUBSURFACE BARRIERS

Sheet metal piling subsurface barriers could be formed by emplacing interlocking metal sheet piling in a vertical configuration. This barrier would need to be coupled with a horizontal barrier to form a complete barrier envelope. Sheets would be sealed by injecting grout where the sheets are joined. The piling could be installed using a jetting shoe, vibratory hammer, or static emplacement methods. A continuous sheet piling wall could potentially be driven to depths of 90 m (300 ft) in unconsolidated deposits lacking boulders.

If joints are used, a wedge or plug at the bottom of each joint cavity would displace soil laterally as the sheets are driven into the ground, leaving the joints largely soil-free. Soil that does enter the joints would be relatively loose and easily removed by jetting with water. A watertight sealant would then be injected into the sealable cavities between sheet piles to create a low permeability barrier.

Leakage of water through unsealed sheet piles is acceptable for most civil engineering applications, but generally not for environmental applications. Conventional unsealed sheet piling has a bulk hydraulic conductivity in the range of 10^{-4} to 10^{-5} cm/s (2 x 10^{-4} to 2 x 10^{-5} ft/min). In comparison, bulk hydraulic conductivities of 10^{-8} to 10^{-10} cm/s (2 x 10^{-8} to 2 x 10^{-10} ft/min) are typically achieved in test cells constructed of joint-sealed sheet pile. A hydraulic conductivity at or below 10^{-7} cm/s (2 x 10^{-7} ft/min) would normally be required by regulatory agencies for vertical barriers around waste sites (Waterloo 1994).

A variety of sealant materials could be used including bentonitic grouts, vermiculitic grouts, cementitious grouts, and organic polymers. Sealants would be selected according to site conditions and project requirements.

Potential leakage paths through the barrier would be limited to the sealed joints and therefore the joints would be the focus of quality control procedures. Joints could be inspected between cleaning and sealing operations to confirm that the sheets have not separated and that the complete length of the joint would be open and could be sealed. Each joint would be sealed from bottom to top using sealant injection lines, facilitating the emplacement of sealant into the entire length of the joint. Repair procedures could be initiated if a joint separation or blockage is suspected (Waterloo 1994).

Figure 3-12 depicts sheet metal piling with grouting as applied to SSTs.

3.11.1 Current Applications

In civil engineering applications, sheet piling can be used during excavation of compressible soils in urban areas to prevent settlement due to groundwater seepage. The barrier can also be used to limit the amount of dewatering required during construction below the water table. Its use in cofferdams can be cost-effective on longer-term projects by virtually eliminating the necessity for continual pumping in order to dewater the enclosure.

At new industrial sites, sheet pile barriers can be installed to enclose the site as a preventive or security measure to control chemical releases that could occur in the future. Enclosures around new landfills can be coupled with caps or infiltration systems to manage the rate of waste degradation and leachate production (Waterloo 1994).

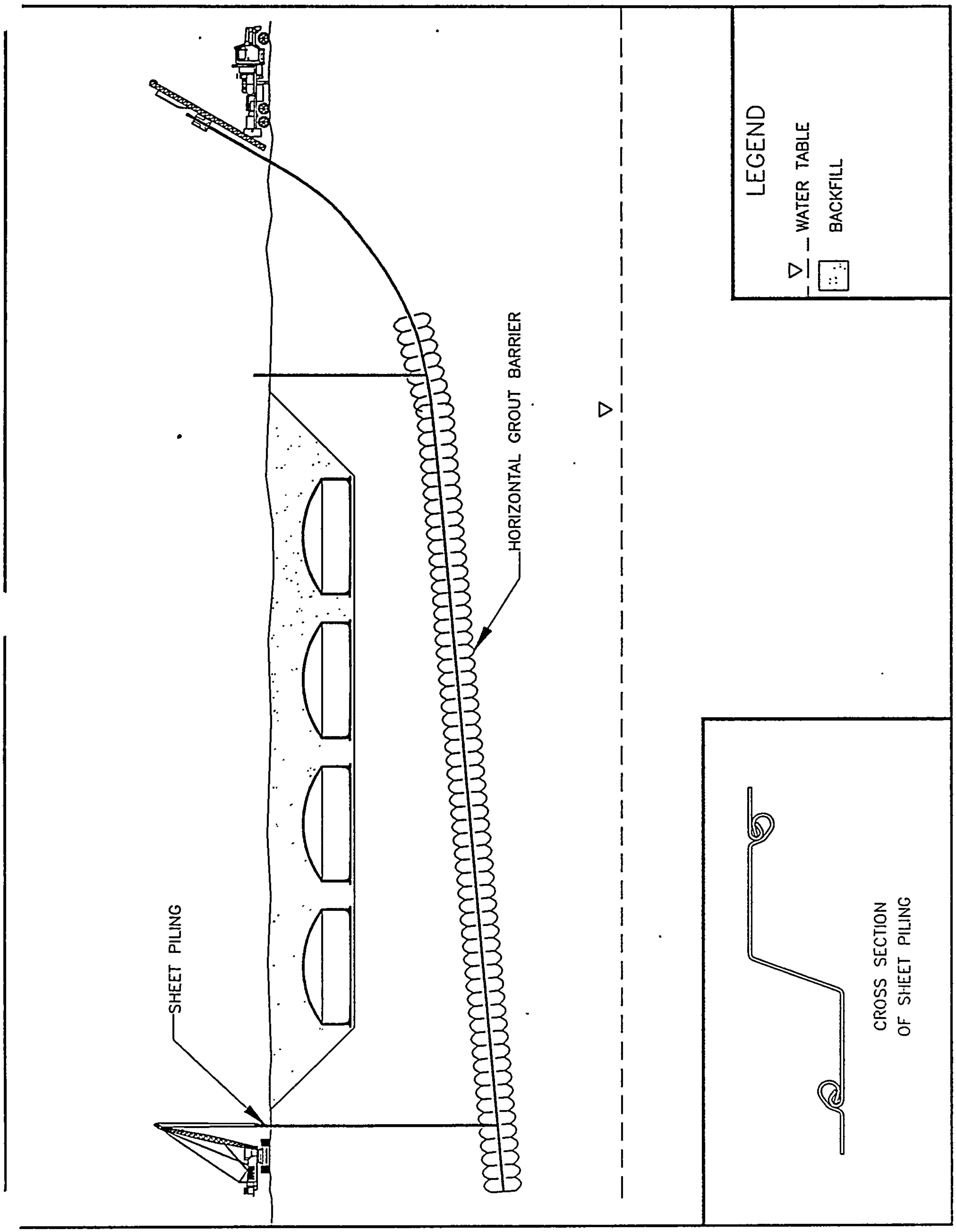

Figure 3-12. Sheet Metal Piling Subsurface Barrier.

3.11.2 Test and Demonstration Status

Sheet metal piling is a proven technology. However, field demonstration of environmental applications of sheet piling for barriers is ongoing, in particular at the University of Waterloo, Canada.

3.11.3 Advantages and Disadvantages

Potential Advantages

- Excavation of subsurface materials is not required; damage, disruption, and high costs are avoided.
- Sheet metal piling is relatively easy to install and construct given applicable soil conditions (e.g., no boulders or large cobbles).
- Topography and depth to water table have little effect on installation techniques.
- Sheet metal piling is useful for containment by itself or in combination with other in situ remediation techniques.
- Required sealant volume is small.
- Pump-and-treat costs could be reduced due to a significantly smaller volume of contaminated groundwater being processed.
- Low-strength sealants could allow the barriers to be removed.

Potential Disadvantages

- The technology is limited to vertical barrier applications only.
- The technology may not be applicable to soils containing boulders or large cobbles.
- Sheet metal pilings may be subject to corrosion unless cathodic protection is provided.
- The installation of sheet piling may induce unacceptable stresses on the tanks.

3.11.4 Other Information

A new type of containment wall composed of sealable steel sheet piling (Waterloo Barrier) has been developed at the University of Waterloo's Institute for Groundwater Research. The interlocking joints between individual sheet piles incorporate a cavity that is filled with sealant after emplacement to prevent leakage through the joints. The Waterloo barrier design is being used commercially by RCI Environmental Inc. of Kent, Washington.

At sites where a very high degree of water tightness is desired, the Waterloo Barrier could be constructed with both an internal and external cavity at each joint. Two sealable cavities would provide exceptional assurance that the joints would be fully sealed, and also provide an opportunity for using more than one sealant at each joint to accommodate different in situ conditions inside and outside the enclosure.

3.12 CLOSE-COUPLED INJECTED CHEMICAL BARRIERS

One close-coupled subsurface barrier option adapts the concepts of jet and permeation grouting in angled boreholes using directional drilling methods. Chemicals suitable for injection include portland cement, polymer formers, aggregating emulsions, and others discussed previously in this section. Unlike the concept of jet grouting to create standoff barriers discussed in Section 3.1, the chemical grout would be formed against the sides and bottom of an individual SST. In one concept, a standoff barrier would be installed around an individual tank in a conical configuration. Once the conical grout barrier hardens, vertical or shallow-slanted wells would be drilled between the tank wall and the conical grout barrier to the bottom of the cone. The area at the bottom of the cone would then be filled with cost-effective grouting materials within a few meters of the bottom of the SST. The casing would then be blocked and more effective chemical grouts would be injected from the bottom of drilled casings under pressure, allowing the material to percolate upward to encapsulate the SST. Alternately, the close-coupled barrier walls could be installed directly against the tank walls using vertical boreholes. The horizontal members of the barrier could be installed in two layers using horizontal boreholes. This latter option is the basis for evaluation of close-coupled chemical grout barriers in this feasibility study.

Figure 3-13 depicts a close-coupled chemical barrier concept as applied to a Hanford Site SST.

3.12.1 Current Applications

No full-scale application of this technology for waste management or environmental restoration purposes is known at this time.

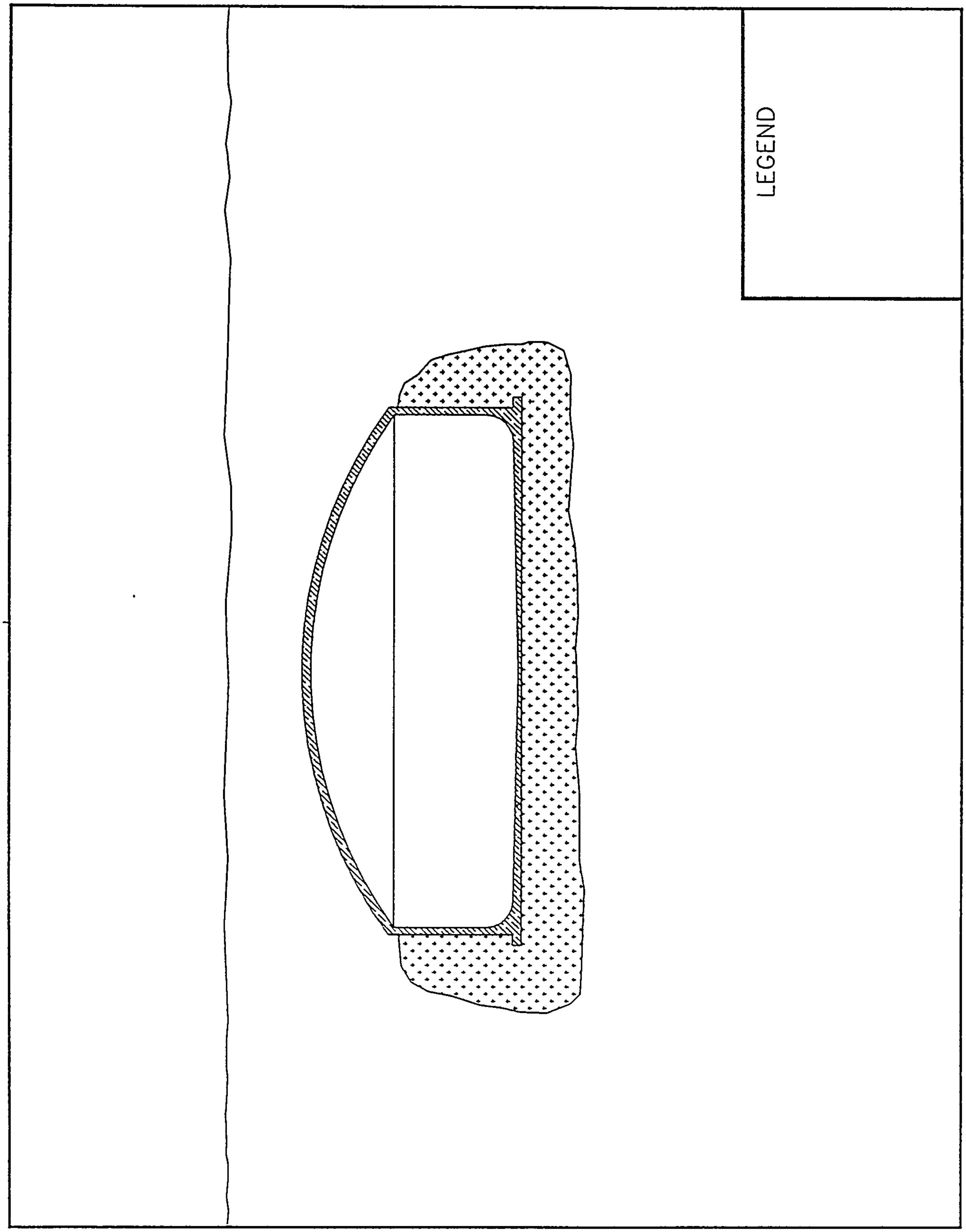

Figure 3-13. Close-Coupled Injected Chemical Barrier.

3.12.2 Test and Demonstration Status

The materials for this concept have been tested in the laboratory but have not been demonstrated in the field for this type of application.

3.12.3 Advantages and Disadvantages

Advantages

- Little or no spoils would be brought to the surface.
- Close-coupled injected chemical barriers would prevent the creation of contaminated soil by new leaks.

Disadvantages

- Close-coupled barriers may induce stresses on the tank, depending on the emplacement method used.
- Close-coupled injected chemical barriers are relatively unproven and have undergone little testing.
- It may not be possible to emplace the conical jet grout shell given the confining limitations between the Hanford Site SSTs.

3.13 INDUCED LIQUEFACTION BARRIERS

Induced liquefaction is a close-coupled subsurface barrier option that combines the concepts of sheet metal piling to create a vertical barrier with caisson-drilled horizontal jet grouting. One to three caissons would first be excavated using a 5- to 7-m (15- to 20-ft) diameter clamshell. Coffered trenches may also be used for installation of the horizontal barrier. An overlapping jet grout curtain would be installed via horizontal wells jacked in through the caisson(s) or coffered trenches to form a horizontal barrier. Sheet metal piles would then be driven or vibrated down to the horizon depth to ~30 m (~100 ft), depending upon the local strata. Joints between sheets would be grouted to ensure barrier integrity. Finally, vertical injection wells would be installed between the SST and sheet metal piling/jet grout curtain to inject grout, polymers, or other barrier-forming material from the bottom of drilled casings under pressure, allowing the material to percolate upward to encapsulate the SST.

Figure 3-14 depicts an induced liquefaction barrier as applied to Hanford Site SSTs.

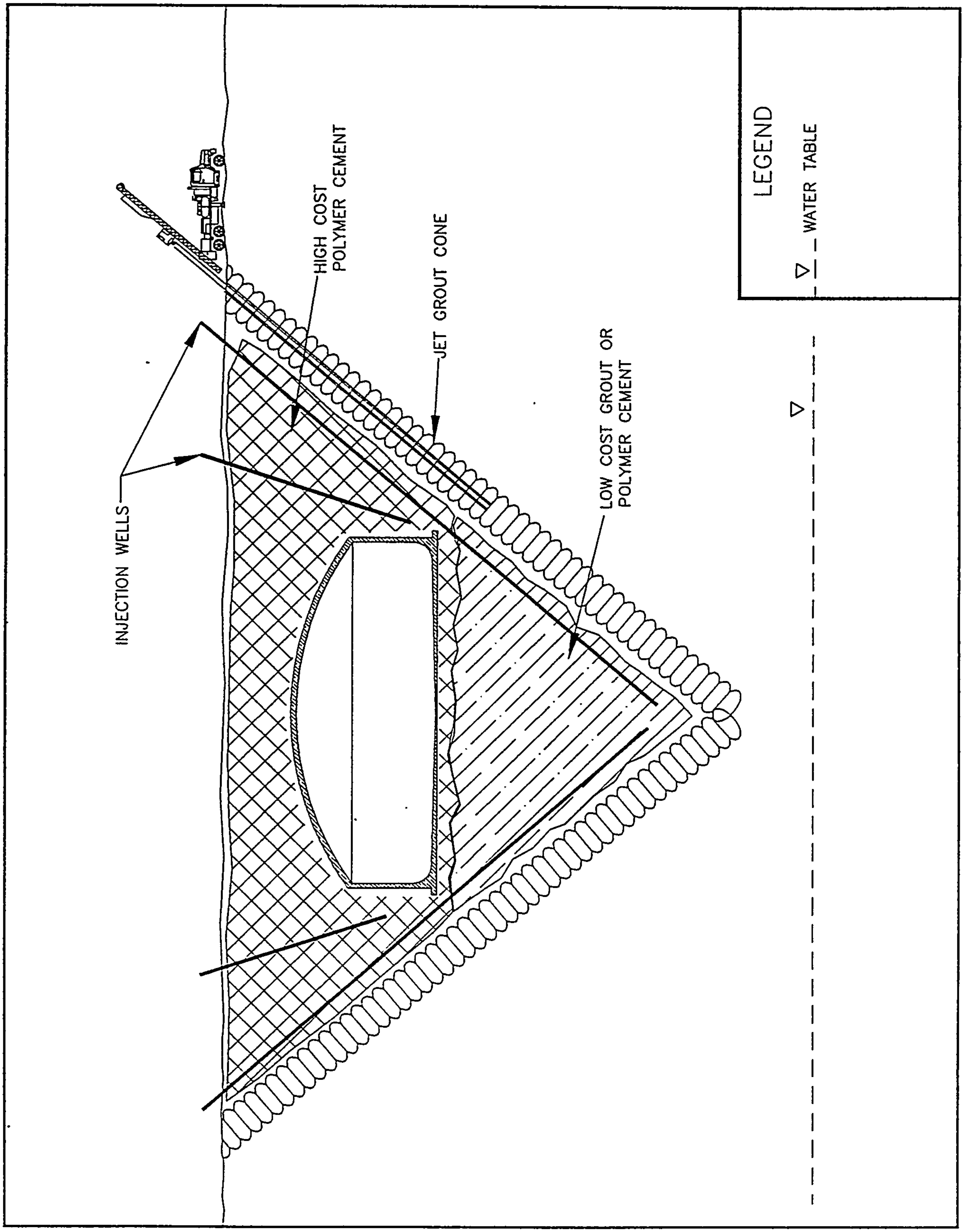

Figure 3-14. Induced Liquefaction Barrier.

3.13.1 Current Applications

No full-scale application of this technology for waste management or environmental restoration purposes is known at this time.

3.13.2 Test and Demonstration Status

Sheet metal piling has been demonstrated in several instances in the field at the Hanford Site.

3.13.3 Advantages and Disadvantages

Potential Advantages

- No spoils are brought to the surface when installing sheet piling.
- Some of the technologies included in this option, such as sheet piling, caissons, and pipe jacking, have already been demonstrated in Hanford Site soils.

Potential Disadvantages

- Sheet metal pilings may be subject to corrosion unless cathodic protection is provided.
- Boulders and large cobbles may cause the sheet metal edges to deflect, causing potential gaps.
- The horizontal component of the barrier is based on a conceptual technology with little hard evidence to support its feasibility.
- Large amounts of potentially contaminated spoils could be produced during the excavation of the caissons or trenches.

The remainder of this section includes discussion of other subsurface barrier concepts considered to be infeasible for SST applications.

3.14 SLURRY WALLS

Slurry walls (also known as curtain walls, cut-off walls, or diaphragm walls) would be dug either by traditional cut-and-fill methods or by specialized hydrophraising equipment that produces vertical panels. In all cases, the trenches would be kept open by backfilling with a bentonite slurry. Slurry would permeate into the local strata to form a filter cake, which would form a barrier. The slurry could largely be displaced, from the bottom up, with a suitable dense barrier material (cementitious grouts, polymers, plastic concrete, etc.). Displaced slurry would be pumped to a conditioning system for reuse (K&M and BDM 1993).

Hydrophraising would involve forming engineered panels in the vadose zone by specialized surface equipment that would dig a deep trench while backfilling with slurry. Once individual panels harden, overlapping of panels would be ensured by cutting new panels into adjacent panels (Bruce 1990).

When applied to SSTs, this technology may not be suitable for the following reasons: (1) the effective working depth may be too shallow for SST applications due to presence of large cobbles and boulders and (2) significant quantities of spoils must be excavated and brought to the surface, thereby creating potential safety and contamination control concerns.

3.15 DEEP SOIL MIXING

Deep soil mixing would utilize large 1 to 2 m (3.3 to 6.6 ft) diameter augers to bore into the soil. As the augers are pulled out of the hole, the cavity would be injected with grout or other suitable barrier formers. It is a relatively simple concept that would be applicable in relatively shallow (25 to 33 m [75 to 100 ft]) environments where large quantities of spoils would not be a concern.

This technology may not be feasible for SST applications at the Hanford Site for the following reasons: (1) very large quantities of soil would be brought to the surface (thereby creating a waste management concerns if contamination is encountered) and (2) the maximum working depth may not be sufficient for the depth of the tanks and existing soil contamination.

3.16 SOIL FRACTURING

Soil fracturing is used by the oil and gas industry to open cavities for the purposes of enhancing oil and gas recovery. High pressure muds are injected into normally deep formations to fracture and open soils (Bovay 1992).

Fracturing, coupled with permeation grouting, would be used in a process to create sheet-like partial barriers. It could also be used to dispose and immobilize wastes. Intermediate level liquid radioactive wastes were disposed at the Oak Ridge Site by hydrofracturing. For SST applications, vertical fracture wells would be drilled between tanks down to the required depth horizon. Grout would be used as the fracturing fluid to achieve a barrier thickness of up to 0.05 m (0.2 ft). A fracture radius of up to 50 m (150 ft) may be achievable in some geologies, but probably not at the Hanford Site. Enough fracturing wells would be drilled to provide complete overlap of individual barrier circles.

This concept may not be viable for application to SSTs for the following reasons: (1) the uncertainty associated with the direction and extent of the fractures both horizontally and vertically, (2) the difficulty in verifying it as a continuous barrier, and (3) the stress or uplift it would induce on the tanks.

3.17 LONGWALL MINING

Longwall mining would require installation of vertical shafts or coffered trenches to enable installation of horizontally mined and back-filled barriers. From the bottom of the shafts or trenches, mining machines would cut and remove soils in mass along a horizontal "long wall." As excavation occurs, the resultant cavity would be filled with a supporting barrier-forming material, such as grout. The technology has been used extensively in the mineral mining industry. It is unknown if this technology could be accomplished remotely in a potentially contaminated underground environment.

Although this technology would be one of the best for verifying the continuity of the subsurface barrier, it has a number of drawbacks. These include large amounts of spoils, potential for subsidence, and high personnel safety risks.

3.18 MODIFIED SULFUR CEMENT

Modified sulfur cement was developed by the U.S. Bureau of Mines to utilize the readily available supply of byproduct sulfur in the U.S. Modified sulfur cement is commercially available under license as "CHEMENT 2000." Modified sulfur cement is a thermoplastic material with a melting point slightly above the boiling point of water. The process for using modified sulfur cement for forming barriers would involve heating aggregate onsite in a rotary drier followed by combination with sulfur cement in a pugmill to form sulfur concrete. A production rate of about 9 metric tons per hour is achievable. Modified sulfur cement has been used in the United States for in-container solidification of radioactive wastes, incinerator ash, ion-exchange resins, sludges, and sodium nitrate. It can be used in the construction of caissons for waste storage and for sealing drill holes and shafts.

Through cut-and-fill deployment technologies, modified sulfur cement could form a continuous free-standing monolithic barrier with no residual water.

This technology may not be viable since the barrier may be prone to cracking and would be difficult to install at the required elevated temperature. It is most viable if installed in the vertical orientation.

3.19 SEQUESTERING AGENTS

The barrier materials used in this concept would be specifically selected to physically or chemically adsorb, precipitate, contain, and isolate contaminants once injected as a slurry into soils. The barrier would be porous, allowing water to pass through. The technology has been used in groundwater applications. Barrier-forming materials would be emplaced using hollow-stem augers, jets, or permeation techniques.

Zeolites (clinoptilolite and chabazite), tethered organic chelates, hydrotalcites, granulated rubber tires, and metallic iron have been studied in the laboratory to determine their applicability as porous barriers to stem the migration of strontium, chromates, carbon tetrachloride, and uranium in Hanford Site groundwater (Cantrell 1993, 1994).

The use of sequestering agents alone may not be viable for SST applications since multiple contaminants would be present, including nitrates and nitrites for which no known sequestering agent exists. In addition, in those cases where "fingers" of contamination may move rapidly through the vadose zone, the agents could become saturated and lose their effectiveness in a short period of time.

3.20 REACTIVE BARRIERS

The concept of reactive barriers in the vadose zone is new; however, it has been used previously for groundwater cleanup. The vadose zone technology would involve pumping a reactive chemical through injection wells below an existing or potential contaminated plume. The injected chemicals would be designed to chemically react via biodegradation, chemical degradation, and/or hydrolysis with contaminants as the plume moves through the reactive barrier. The reactive barrier material would be specifically tailored for the contaminants in the plume. Examples of reactive barrier materials that could be used or have been investigated for subsurface barriers include acids, bases, limestone, fly ash, ferrous salts, blast furnace slag, and phosphate salts (Riggsbee et al. 1994). Like sequestering agents discussed in the previous section, reactive barriers would allow water to pass through.

This technology is probably not viable for Hanford Site SSTs because (1) it would require significant research to identify effective reactants for all constituents of concern, and (2) suitable reactants for immobilizing nitrate and nitrite at expected leak concentrations are unlikely to be identified.

3.22 IMPERMEABLE COATINGS

This technology would apply impermeable coatings directly to the surface of buried objects following an excavation. Once the excavation has occurred, vacuum and pressure equipment would be used to coat or impregnate the exposed objects in the excavated space (Naudts 1989).

This technology is viable for precast applications only. Since it would require excavation adjacent to and beneath SSTs, it is unlikely that adequate personnel safety could be assured. In addition, a dry, clean surface is required which may not be possible for SSTs.

3.23 MICROTUNNELING

Microtunneling is a barrier deployment technology that would use vertically-oriented caissons or coffered trenches to install horizontal connecting tunnels. Laser-guided tunneling machines up to 0.7 m (2 ft) in diameter would be used to form a series of horizontal tunnels as long as 333 m (1,000 ft) using a slurry spoil removal system. An auger system could also be used, but the working length would be reduced to 83 m [250 ft] due to insufficient torque at the machine face. Once the horizontal tunnels are complete, they would be used for injecting permeation grouts or other suitable materials to form a horizontal continuous barrier.

Microtunneling was developed to install boreholes and casing in shallow soils where utilities are to be installed without disrupting the surface. It is a relatively efficient system for tunneling unconsolidated, fine-grain soils (K&M and BDM 1993).

Microtunneling is not considered a viable option for subsurface barriers for Hanford Site SSTs for the following reasons: (1) a large quantity of spoils would be generated, (2) the tunneling machine is not designed for large cobbles since it cannot be backed up a sufficient length to move around large cobbles, and (3) personnel may be required to maintain the machine at the depth horizon; this may be unacceptable from personnel safety and radiation protection perspectives.

3.24 IN SITU VITRIFICATION

In situ vitrification (ISV) barriers would employ joule heating (i.e., the application of electric current to heat the soil above its melting point) to convert soils to an obsidian-like rock. Conceptually, ISV would be performed in a progressive series of horizontal and vertical locations. Melt locations would partially overlap to ensure formation of a continuous barrier. The technology has undergone several dozen bench-to-field-scale tests and remediation of at least one hazardous waste site in North America. Although this barrier concept has been modeled thermally, it has not been tested (Garnich 1990).

The ISV technology has not been tested for barrier applications and, if installed too close to SSTs, may compromise the integrity of the tanks. Vitrification also densifies the medium it is melting, thereby causing the potential for subsidence if used beneath SSTs.

3.25 SOIL SAW

The soil saw is a relatively new method of forming deep (54 m [180 ft]) subsurface cutoff walls of relatively uniform quality. It can only be used in vertical applications. The technology employs reciprocating, high-pressure jets of cement grout or bentonite slurry to cut a continuous vertical path through the soil. Jet grouting nozzles are mounted along a rigid beam that reciprocates, thereby producing a sawing action. The combination of sawing and jet slurry grouting, results in the construction of a continuous soil/cement slurry wall.

This technology may not be viable for Hanford Site SSTs since it can only be used in the vertical plane. It has not been sufficiently tested in the field under soil conditions similar to those that exist at the Hanford Site. Once proven, it could be coupled with horizontal barrier technologies to create an integrated barrier for isolation of SSTs.

4.0 DESCRIPTION OF TECHNOLOGIES SUPPORTING SST WASTE RETRIEVAL

This section describes individual tank waste remedial technologies that, when combined into overall remedial alternatives, could result in closure of SST waste sites as landfills or in clean-closure in accordance to the requirements of the *Resource Conservation and Recovery Act of 1976* (RCRA) and the Dangerous Waste Regulations of the State of Washington (WAC 173-303 1993).

The previous section described a wide range of subsurface barrier technologies. This section identifies and further describes five types of subsurface barrier technologies deemed most applicable to SSTs. It also describes SST waste retrieval technologies, contaminated soil cleanup technologies, and closure technologies that, when linked with subsurface barrier technologies, would form complete remedial alternatives for SSTs. The following description of the technical setting for remediating the SSTs is provided to facilitate understanding of the range of technologies required to achieve closure of the SSTs.

4.1 TECHNICAL SETTING

Two major tank waste retrieval campaigns have been undertaken at the Hanford Site. From 1952 to 1957, retrieval operations were conducted in seven tank farms involving 43 SSTs as part of a process to recover uranium from tank waste. A second campaign, from 1962 to 1978, involved the retrieval of strontium-bearing sludges from 10 SSTs. The history of both campaigns is documented in *Hanford Tank Sluicing History* (Rodenhizer 1987).

These campaigns used sluicing and slurry pumping for tank waste retrieval. Freeing up tank space for storage of newly created waste was an important goal of these historic campaigns. The equipment and technologies used were based on mining industry practices and adapted for use in radioactive service. Equipment failures occurred and process limitations were experienced, but overall, the campaigns were generally successful. In most tanks, sluicing was terminated when it was no longer cost-effective to continue operations to gain a few additional inches of storage space. Leaks that occurred during sluicing in two SSTs led to the termination of waste retrieval activities in those tanks.

The use of traditional sluicing technology alone may not be effective in meeting present-day cleanup objectives. Most of the SSTs are at least 40 years old and 67 of the 149 SSTs have been declared as having leaked waste (Hanlon 1993). The use of traditional sluicing in those and other deteriorated tanks may result in higher levels of leakage than have been experienced to date (2.28×10^6 to 3.42×10^6 L [600,000 to 900,000 gal]) (Hanlon 1993). Moreover, traditional sluicing was found to be ineffective in slurrying rock-like masses of agglomerated sludge in some tanks (Boomer et al. 1993). Thus, large quantities of waste cannot be recovered with traditional technology unless augmented with other technologies.

The cleanup objectives for tanks and the associated soil have not yet been established. Schmittroth et al. (1993) concluded that more than 99% volumetric retrieval may be necessary in some tank farms to meet a 10^{-4} lifetime risk objective to an individual who uses groundwater beneath the tanks. Retrieval of greater than 99% of the waste using traditional sluicing may not be achievable (Boomer et al. 1993).

Lowe (1993) concluded that sluicing of Tank 241-C-106, an SST that is currently considered sound, may result in a leak of 152,000 L (40,000 gal) by the most likely leak mechanism. This mechanism includes a leak through the steel sidewall with penetration of leakage to the soil through the construction joint between vertical and horizontal members of the tank's concrete structure. Lowe (1993) also concluded that a leak of this magnitude would result in exceeding regulatory-based limits in the groundwater unless an impermeable cover over the tank is provided. A cover constructed of plastic sheets or other impermeable material would largely prevent the recharge of precipitation, thereby limiting the spread of contamination until soil cleanup operations are completed.

Several technical options are being considered as potentially more effective than traditional sluicing or capable of improving the effectiveness of traditional sluicing when used in combination (Boomer et al. 1993). These options include use of improved tank waste retrieval techniques, use of low-permeability subsurface barriers, use of soil flushing, and use of tank closure technologies.

Specific tank waste remediation technologies within the range of options considered by Boomer et al. (1993) were selected for evaluation in this study. The selection was based primarily on analyses of cost and effectiveness reported in Boomer et al. (1993) and other analyses contained in reports cited in Section 10.0, References. The remainder of this section describes the selected technologies that would serve as components of 14 tank waste remediation alternatives evaluated and compared in this study.

4.2 TANK WASTE RETRIEVAL

Three separate technologies for retrieving waste from SSTs are described in this section. They include: (1) traditional sluicing, (2) robotic sluicing, and (3) mechanical retrieval.

4.2.1 Traditional Sluicing

Traditional sluicing is the method historically used to retrieve wastes from SSTs (Figure 4-1). It would use a large-volume stream of liquid to disperse, dilute, and mobilize sludge. The slurry would then be pumped out of the SST to a waste processing system where the supernatant would be separated from the sludge. The supernatant would be recycled as sluicing liquid. The equipment and staff required for traditional sluicing would be minimal in comparison to arm-based retrieval methods described in the ensuing subsections.

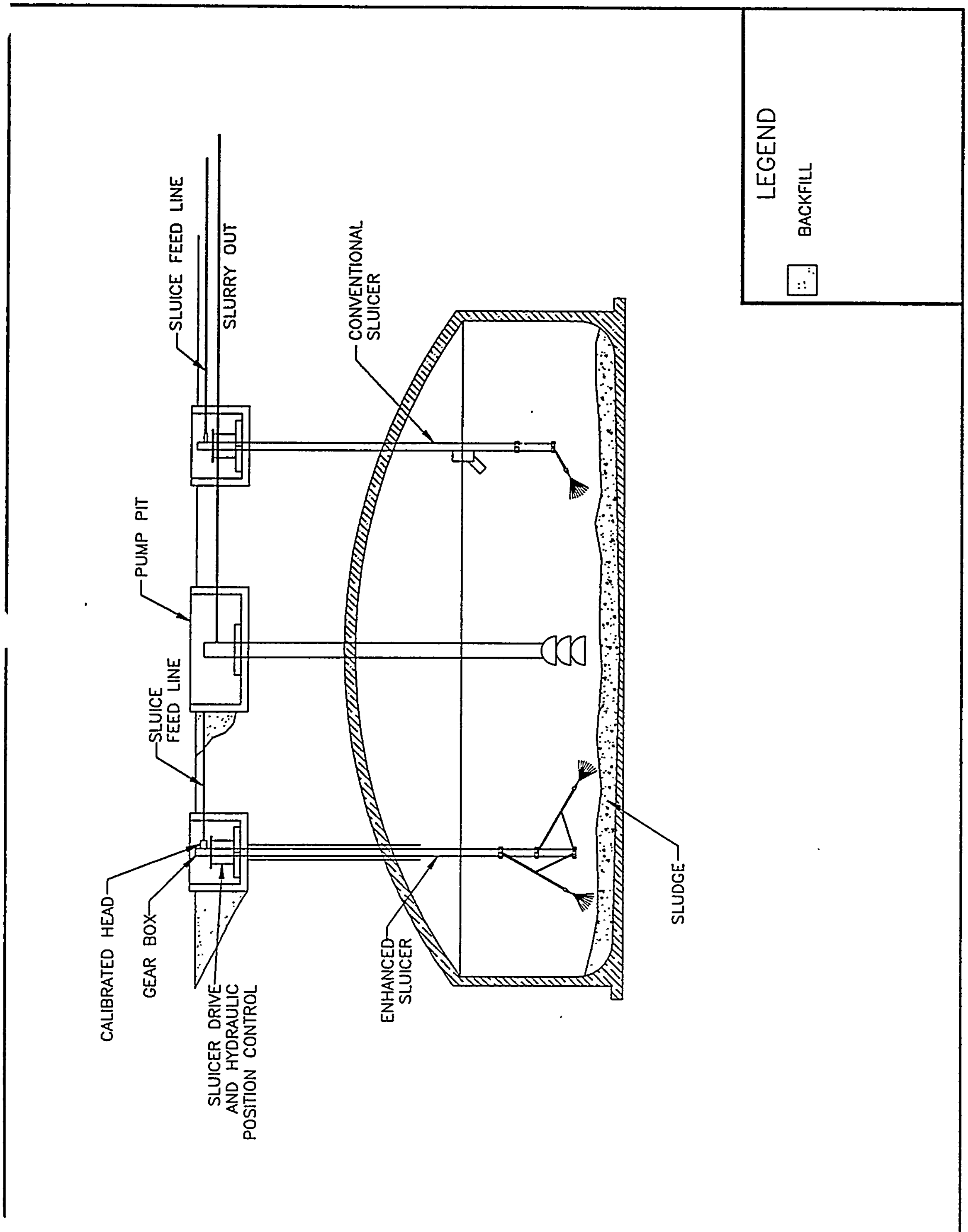

Figure 4-1. Traditional Sluicing.

Traditional sluicing would require two 1,140 L/min (300 gal/min) capacity sluicers: one in a sluice pit and the other on the opposite side of the tank in an existing slurry pump pit. Each sluicer would access the tank from the pits through existing 30.5-cm (12-in.) risers. The sluicers would be equipped with sluicing nozzles adjusted to spray in the horizontal and vertical planes. The nozzles would be used to disperse and dilute the sludge to a pumpable slurry, typically containing about 30% solids by weight (Boomer et al. 1993).

Once the desired slurry consistency is achieved, sluicing would be stopped and the slurry would be pumped from a pump heel pit located at the center of the SST via a 2,280 L/min (600 gal/min) low-head submersible pump. The pump would transfer the slurry to accumulation tanks via two, 10.2-cm (4-in.) diameter pipelines, jumpers, and a valve pit.

Each of the accumulation tanks would be equipped with a perforated distributor riser and a sluice pump. The distribution riser would distribute the slurry in the accumulation tank. The solids that settle would be pumped to a waste processing system for further treatment. The variable speed sluice pump would return the supernatant, at a minimum rate of 2,280 L/min (600 gal/min), to the sluicer nozzles at a pressure of 1,241 kPa (180 lb/in^2 [gauge]).

A heating, ventilating, and air conditioning (HVAC) system would be connected to the SST to prevent the spread of hazardous gasses and radioactive particulates to the atmosphere during sluicing operations. The HVAC system would draw approximately 98 m^3/min (3,500 ft^3/min) from the SST to remove corrosive gasses, water droplets, suspended particulates, and organic vapors using wet scrubbing, filtration, and activated carbon filtration.

4.2.2 Robotic Sluicing

Robotic sluicing (Figure 4-2) is a variation of a type of robotic armed-based retrieval systems that were first investigated at the Hanford Site in the mid-1970s. The technology is under development, but has not been tested in an actual Hanford Site SST. The system described in this report is based on the system described in Wallace (1993) and is best-suited for retrieval of hardened sludge from SSTs.

An attachment to the end of the robotic arm called an end effector would use high-pressure water jets for dislodging the waste. After the sludge is dislodged, the slurried mixture would be immediately vacuumed through a hose to an air separation system. Following separation the waste would proceed to a processing system.

The robotic arm would be suspended from a bridge-mounted confinement structure. The bridge-mounted confinement structure would be fabricated from I-beams bolted together, and stand 31.1 m (102 ft) long, 10.4 m (34 ft) wide, and 5.2 m (17 ft) high. The arm would position the high-pressure jets that dislodges the waste with a reach of 18.3 m (60 ft) deep

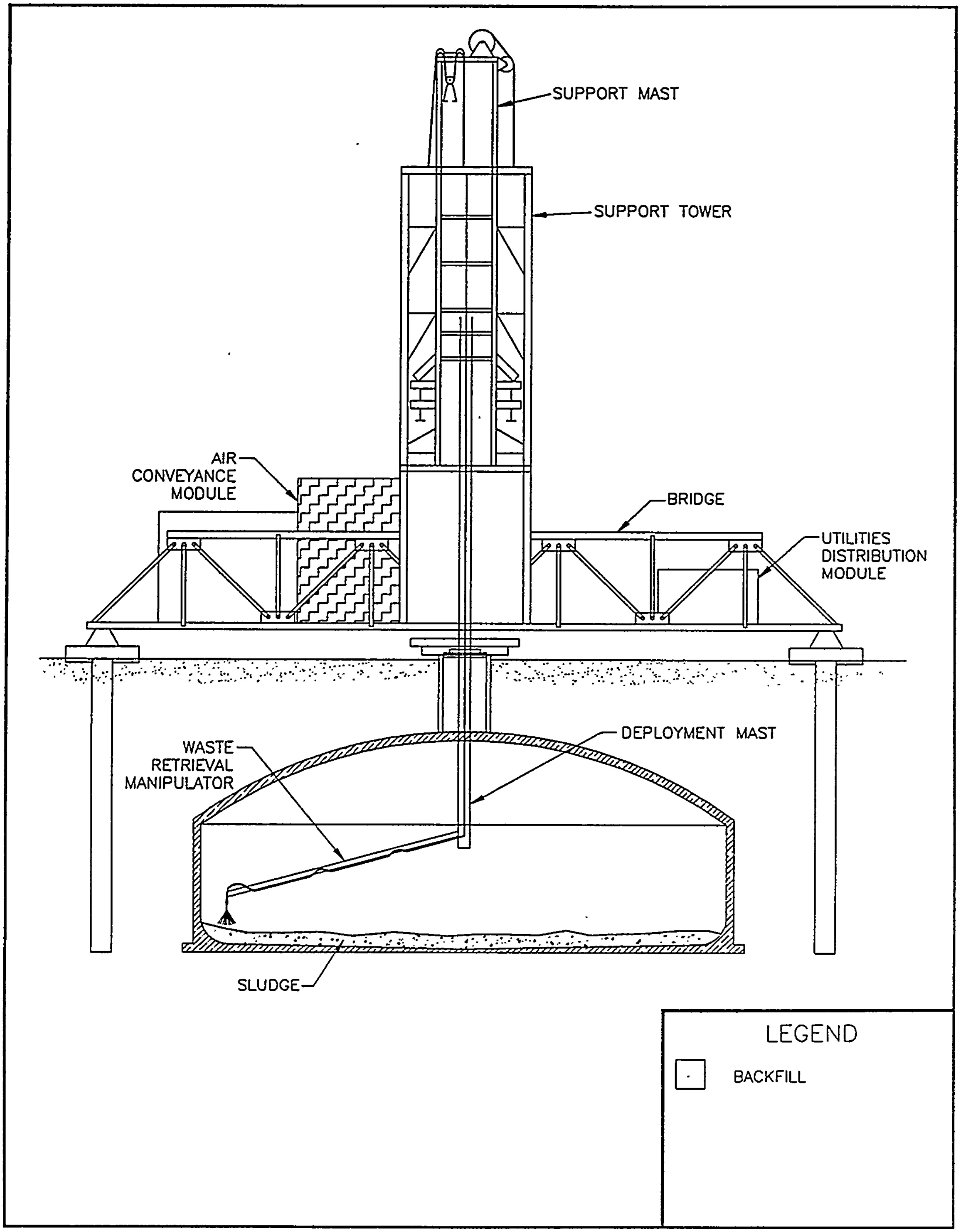

Figure 4-2. Robotic Sluicing.

and 5.2 m (17 ft) laterally. The jets would be contained within a shroud connected to an air conveyance hose. The air- and water-entrained solids vacuumed through the air conveyance hose would be sent to an air conveyance module (ACM).

The ACM would be housed within a composite concrete and steel building located on a bridge-mounted confinement structure. It would be connected to the SST via the air conveyance hose. Air, waste fluid, solid waste, and debris (of acceptable size) would flow through the hose to the ACM. The air stream would pass through a cyclone where the heavier waste particles would be separated and routed to an accumulation tank. The remaining air stream would be stripped of remaining moisture, heated, and then largely recycled through the air conveyance system. The robotic sluicing system would include other systems to support the primary retrieval components, including maintenance and decontamination capability, air filtration, and circulation.

The high pressure sluicing system should be effective in cutting through hardened sludge, but may also cut through corroded tank walls, which may cause new leaks.

4.2.3 Mechanical Retrieval

Mechanical retrieval, which is designed for removal of solid waste and debris as opposed to liquids and slurries, is one of the arm-based retrieval methods currently under consideration for use in the SSTs. It is another of several methods of retrieving waste from SSTs that have been investigated at the Hanford Site since the mid-1970s.

Mechanical retrieval would use a scoop-like end effector affixed to the end of the robotic arm for waste retrieval (Figure 4-3). The end effector would be capable of mechanically excavating the solid waste in the tank. A jack-hammer end effector may be necessary for breaking up the rock-like layer of sludge known to exist in some tanks. The excavated waste would be placed by the robotic arm into an in-tank mechanical waste conveyance system and removed from the SST for further processing.

The robotic arm would be suspended from a bridge-mounted confinement structure above the SST. It would be similar to the robotic arm used in robotic sluicing. The structure would include a deployment mast for mounting and aligning the robotic arm in the SST. The robotic arm would be deployable to a depth of 18.3 m (60 ft), its horizontal reach would be 5.2 m (17 ft), and it would have the capability of lifting 3 tons. It would be equipped with six split buckets, with two shovels each to collect the waste. The arm would deliver the waste to an in-tank transfer system that would consist of a bucket on a separate trolley that could be maneuvered independently of the robotic arm.

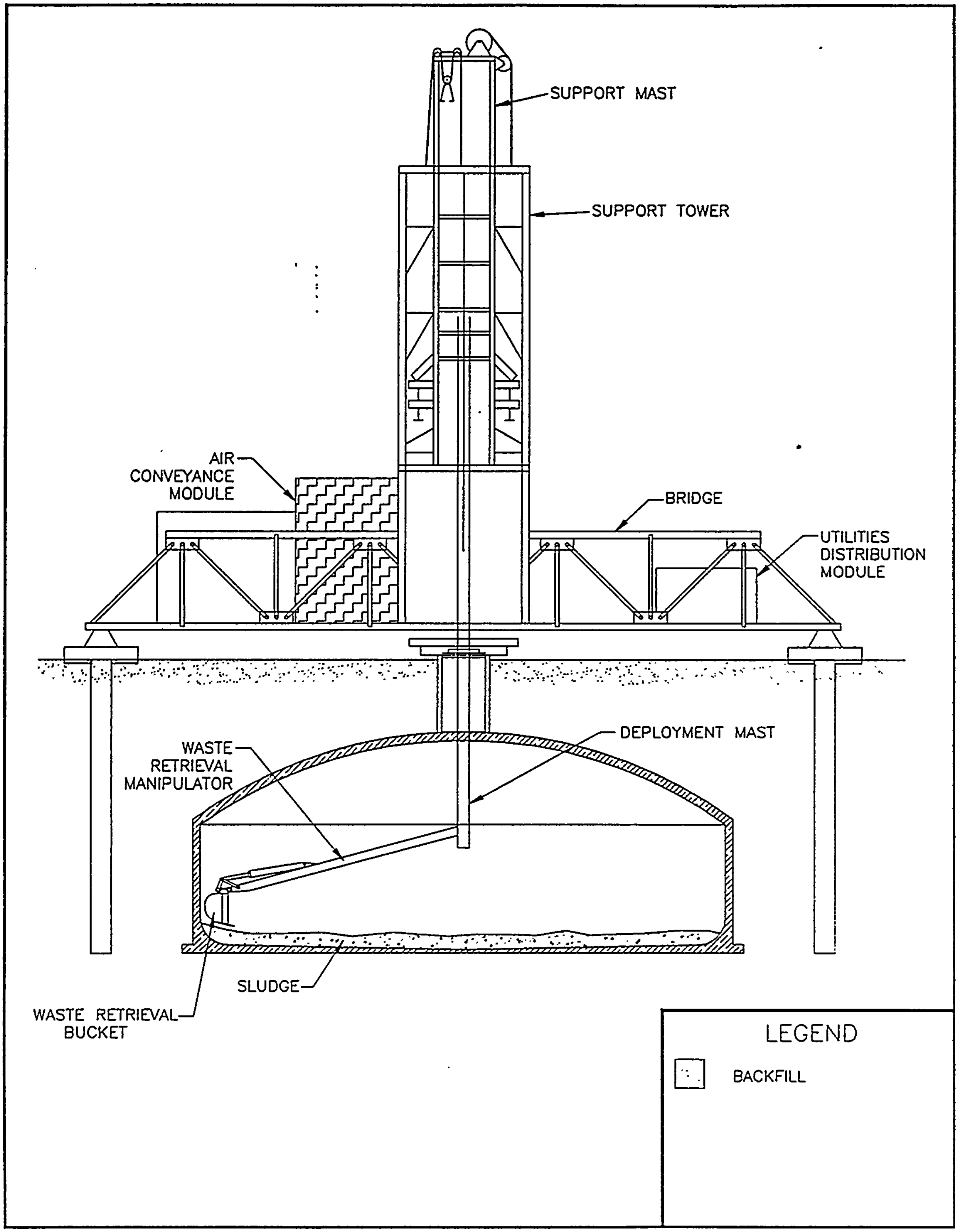

Figure 4-3. Mechanical Retrieval.

4.3 LOW-PERMEABILITY SUBSURFACE BARRIERS

A range of subsurface barrier options potentially applicable to SSTs were described in Section 3.0. Those deemed to be sufficiently well-developed and potentially feasible for the intended application can be categorized as low-permeability chemical barriers, freeze wall barriers, and circulating air barriers.

The permeation grouting option described in Section 3.4 is considered representative of chemical barriers. A wide variety of chemicals can be employed to create a low-permeability barrier as described in Section 3.0. A representative chemical for producing low-permeability barriers is not specified, although cost estimates were based on the assumption that portland cement would be used to create the barrier.

Five barrier technologies are described in this section:

- Close-coupled chemical
- Box-shaped chemical
- V-shaped chemical
- V-shaped freeze wall
- Circulating air.

The first barrier type described is a close-coupled barrier, the following three are standoff barriers, and the last creates a barrier-like effect by evaporating water in any leak that forms A close-coupled freeze wall barrier was not described because the high dissolved salt content of the liquid waste may suppress the freezing point of water to a level that prevents freezing. Forces created by frost heaving also may compromise the structural integrity of the tanks.

4.3.1 Close-Coupled Chemical Barrier

Chemicals used to create the close-coupled barrier would be injected through vertical and horizontal pipes jacked or drilled into the soil (Figure 4-4). Mudless drilling methods would be required to prevent plugging of soil pores, a condition that would interfere with subsequent chemical injections. It is assumed that the horizontal pipes would be installed from inside vertical 4.6 m (15 ft) diameter caissons, which would be installed in the open areas between tanks. The horizontal pipes could also be installed using coffered trenches. The caissons, if used, would be constructed from sections of culvert pipe that would be lowered in 3.1 m (10 ft) sections into a progressively deeper hole formed by a bucket excavator. Similar caissons have been installed in the A and SX Tank Farms (Raymond 1966). The annular space between the culvert pipe and soil would require grouting to provide structural stability for horizontal pipe jacking. The horizontal pipes could be used to convey flushing solution to the soil. (One conceptual method of removing contaminants from the soil prior to emplacement of the barrier is vacuum flushing of the soil, as described in Section 4.4.2).

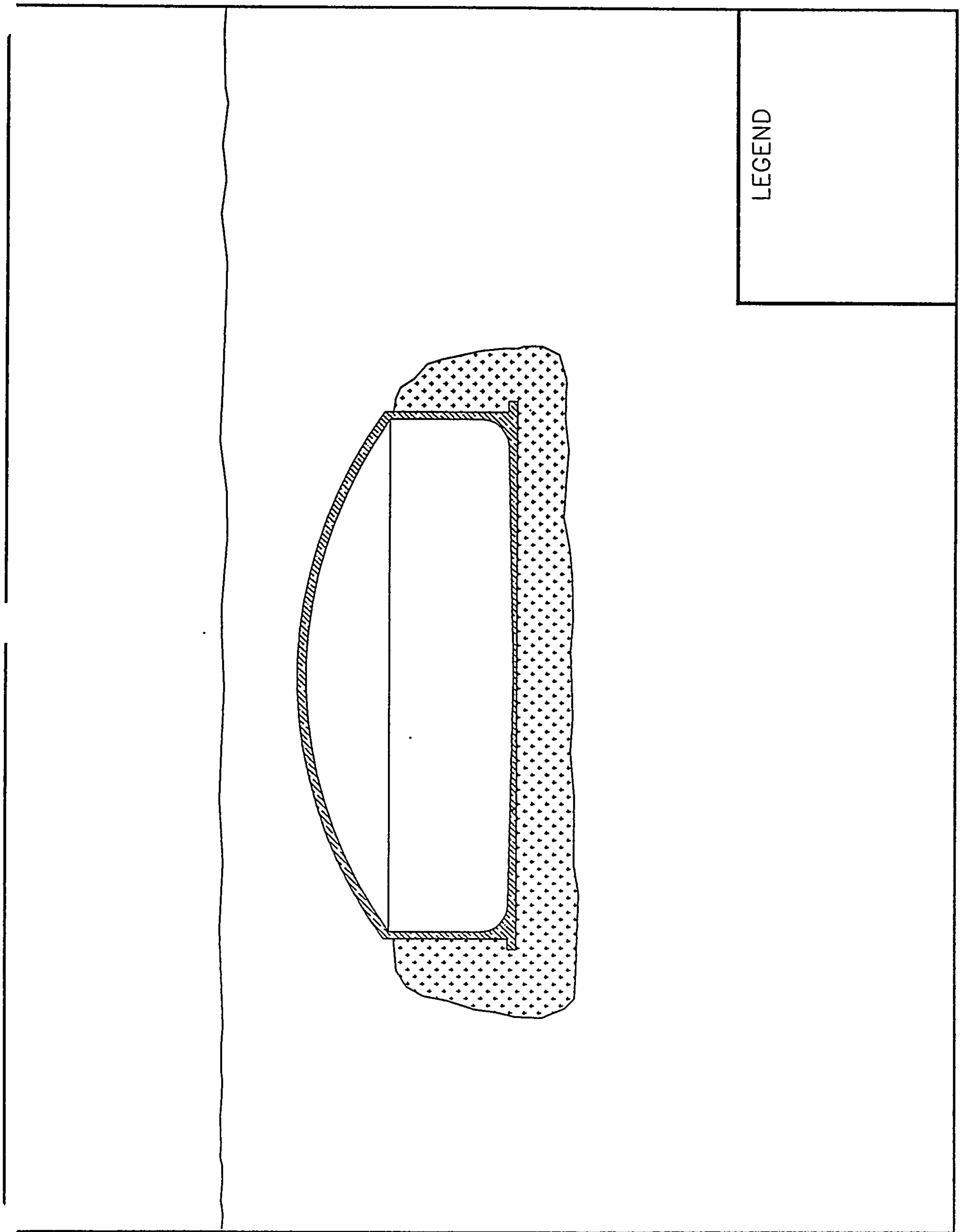

Figure 4-4. Close-Coupled Chemical Barrier.

The horizontal injection pipes would be installed in two separate planes beneath the tanks (Figure 4-5). The horizontal pipes would be perforated to allow the barrier-forming chemical to be injected into the soil. Chemicals would be injected through the lower array of pipes first. The injected chemicals would be designed to penetrate a radial distance of about 0.75 to 1.5 m (2.5 to 5.0 ft) and begin to gel in about 2 hours. The resulting barrier columns would be designed to overlap, thereby forming a barrier plane. Injection through the upper array of pipes would occur several days later, when the lower barrier plane had fully gelled. Chemicals would be injected through the upper array of pipes under slightly higher pressures than through the lower array to promote full penetration of soil in contact with the tank's structural concrete.

A similar approach would be used at the tank walls. Injection pipes would be jacked or drilled vertically from the surface to the base of the tank footings. Chemicals would be injected through the end of the pipe at this level to tie into the barrier emplaced beneath the tank. Injections would then progressively be made by working upward from the base of the tank wall until a sealed, close-coupled barrier about 10-ft thick is created around the tank.

The primary advantages of the close-coupled chemical barrier are: (1) the amount of injection piping and volume of injected chemical would be minimized because the injected chemical is designed to seal to the tank structural concrete rather than be located some distance away where the areal extent of the barrier is greater and (2) the volume of soil contaminated by new sluicing operations would be minimized because an effective close-coupled barrier would contain additional leakage from the tank, thereby preventing additional contamination of the soil. The primary disadvantages are: (1) soil contaminated from previous leaks may require flushing to remove contamination that would otherwise be incorporated into the injected barrier and (2) forces created by emplacing piping for chemical injection adjacent to the tanks may compromise their integrities.

The durability and quality of the chemical barriers are assumed to be inadequate for effective long-term containment of the highly mobile contaminants such as nitrates and ^{99}Tc. As discussed in Section 8.0, diffusion appears to be a significant mechanism in controlling transport of contaminants in the vadose zone when an effective surface barrier is used to minimize recharge. The effective diffusivity of the barrier is expected to be similar to that of soil. Thus, the barrier would have little impact in limiting the diffusive transport of mobile contaminants over the long term.

4.3.2 Box-Shaped Chemical Barrier

The function of the box-shaped chemical barrier would be to create a low-permeability basin beneath the level of existing soil contamination (Figure 4-6). The base of this standoff barrier would slope slightly to promote runoff to a low point for collection. Without the slope, liquid waste would collect in subsurface depressions on the surface of the barrier. The resulting ponds of waste could not readily be detected. The potentially high number of ponds would complicate removal of collected liquid waste.

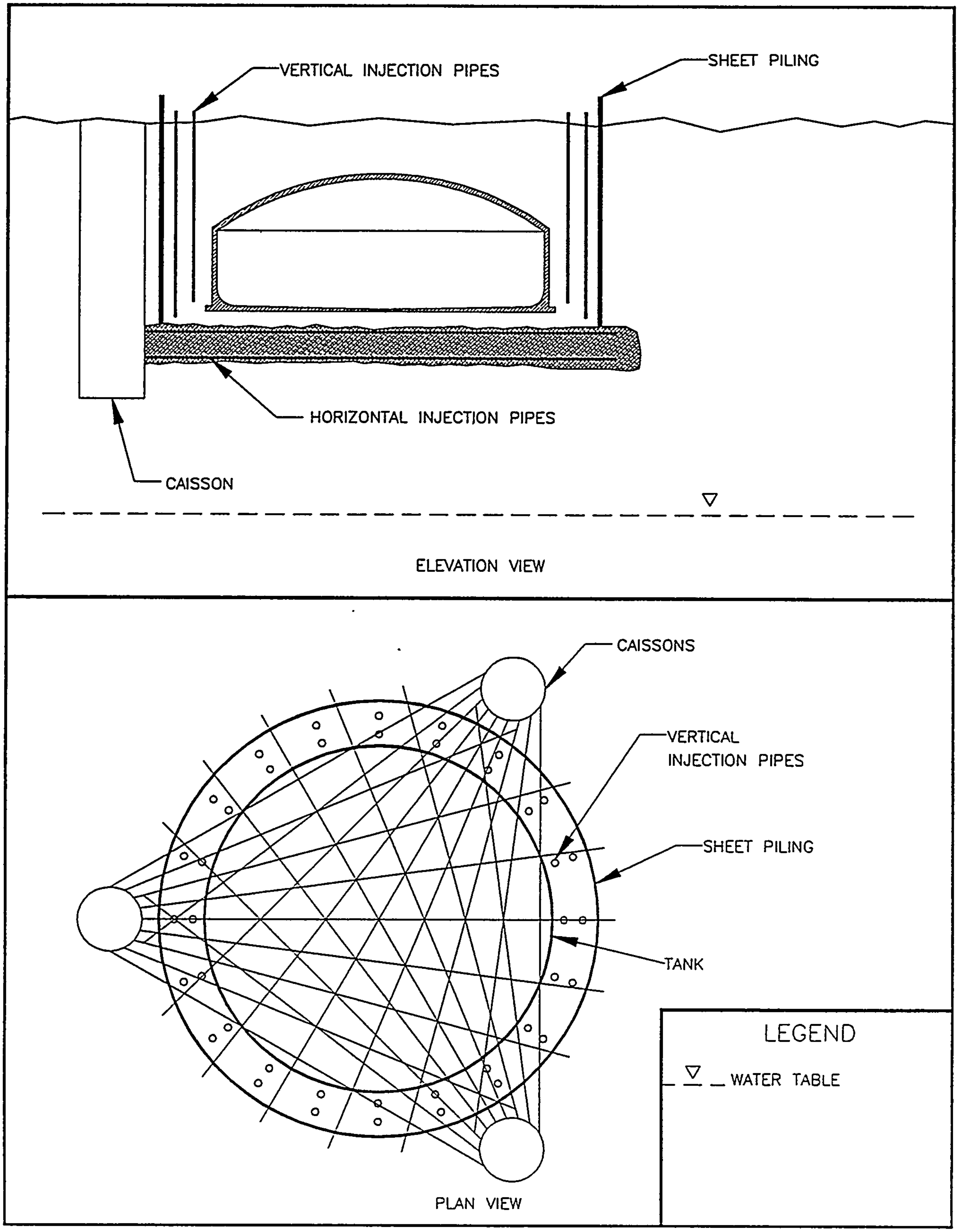

Figure 4-5. Chemical Injection Piping for Close-Coupled Barrier.

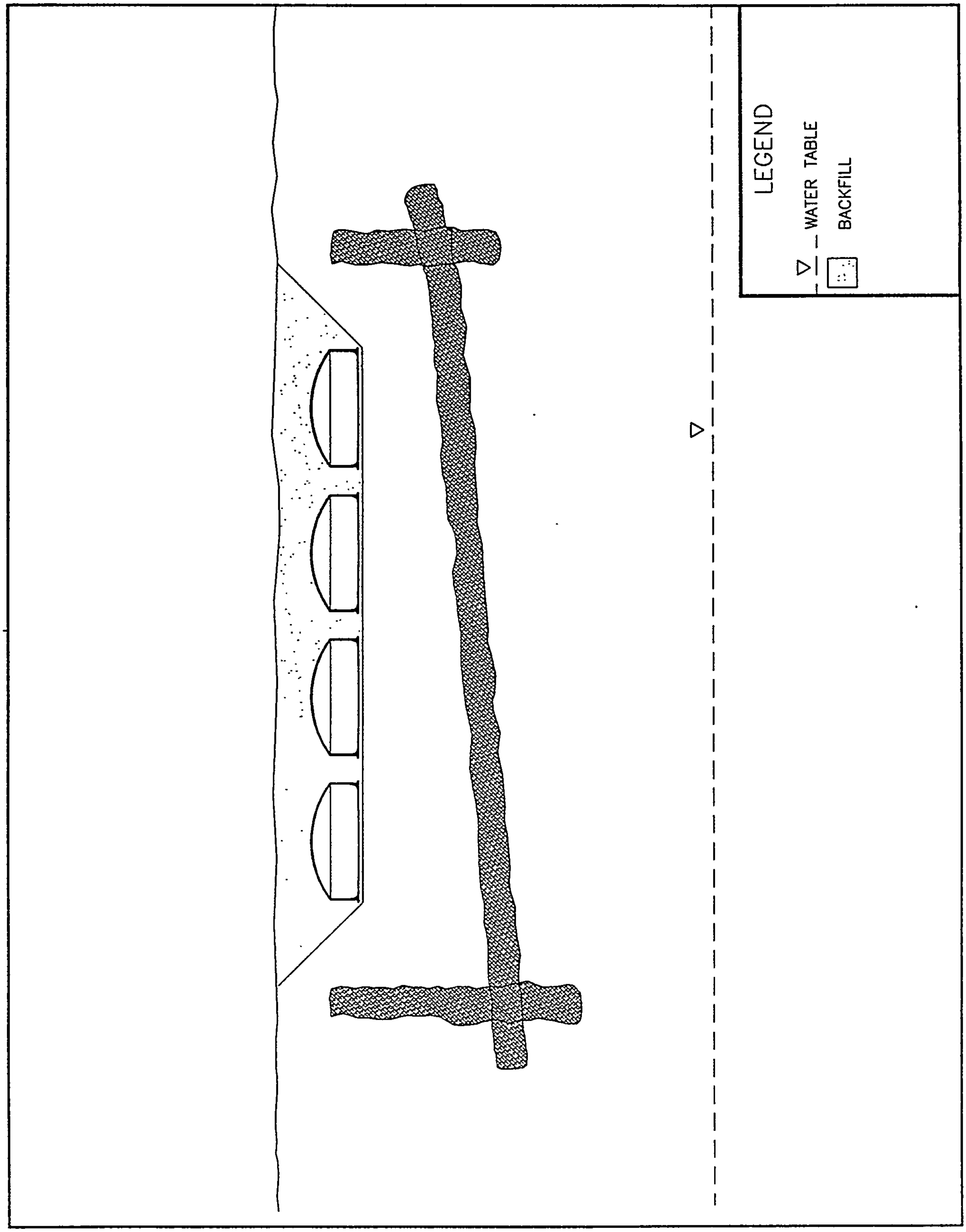

Figure 4-6. Box-Shaped Chemical Barrier.

The box-shaped chemical barrier would be created using both vertical and directional drilling techniques. The use of directional drilling avoids the need to excavate soil to a depth of 30.5 m (100 ft) or more in order to provide access for horizontal drilling beneath existing leak plumes. Directional drilling must be perfected for Hanford Site conditions if parallel horizontal boreholes are to be constructed beneath the Hanford Site tank farms (KEH 1993a). This type of drilling would begin outside the boundary of the tank farm, with the initial drill angle at 45° to 70° from vertical. As drilling progresses, the borehole would be gradually curved until the desired slope of the barrier floor is achieved. Mudless drilling methods must be used to prevent plugging of the soil pores with fine particulates. Soil pores that are plugged would prevent flow of barrier-forming chemicals into the soil.

Each borehole would be cased with an open-ended pipe. The barrier-forming chemicals would be injected through the end of the pipe as it is withdrawn from the hole. Alternatively, the chemicals could be delivered through sleeve-port piping. A cylindrical barrier section, centered around each borehole, would be created by each of these methods, assuming the barrier-forming chemicals flowed evenly into the ground. The presence of lenses, clastic dikes, and other soil heterogeneities would cause uneven flow. The boreholes would be sufficiently close to ensure that the cylinders would overlap and form a continuous barrier floor. The boreholes were assumed to be spaced 3.1 m (10 ft) apart, a distance that would result in an average barrier thickness of 3.4 m (11 ft) and a minimum thickness of 1.8 m (6 ft) under a set of hypothetical Hanford Site soil conditions (KEH 1993a). Actual Hanford Site soils are heterogeneous and closer spacing of boreholes may be required if zones of soils with low permeabilities are present as expected in some tank farms. Low permeability would limit the penetration distance of chemicals in the soil.

After the horizontal member of the barrier is formed, vertical boreholes would be drilled and cased to intersect the horizontal member. The vertical casings would be withdrawn as injection of the chemical proceeds. The resultant vertical members of the barriers are assumed to adequately seal to the horizontal member, thus creating a catchment basin for tank leaks and/or for flush water if soil flushing is used.

The primary advantages of the box-shaped chemical barrier are: (1) only one barrier system would be needed for each tank farm rather than one for each tank or leaking tank, (2) drilling to emplace the barrier-forming chemicals would not occur in contaminated soils, and (3) existing leaks would be contained and prevented from migrating to the groundwater. The primary disadvantages are: (1) long directional drill lengths would be required with little tolerance for directional deviation, and (2) the standoff barrier would not prevent or minimize new leaks.

4.3.3 V-Shaped Chemical Barrier

The V-shaped chemical barrier would be installed in a standoff configuration as shown in Figure 4-7. The relatively steep slope of the barrier would promote subsurface runoff of leaked liquid waste or flush water to the base of the barrier where it could be removed by

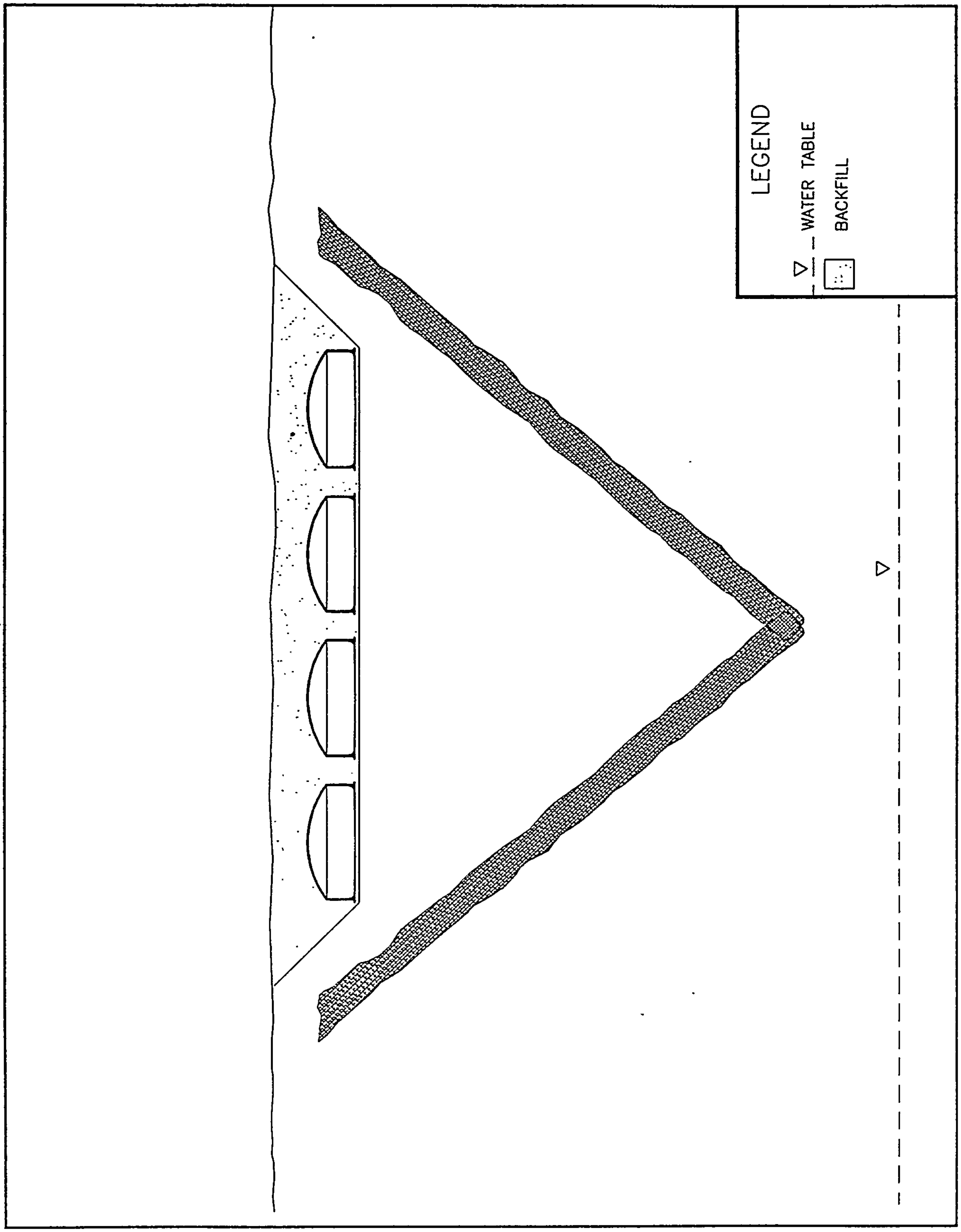

Figure 4-7. V-Shaped Barrier.

pumping. The angled boreholes required to form the "V" would be created by slant drilling, a technology that has been demonstrated at the Hanford Site. The ends of the barrier not shown in Figure 4-7 would be vertical. Vertical drilling techniques that do not require drilling muds, such as sonic drilling, are required to form the vertical boreholes for injecting the barrier-forming chemical. The barrier would be formed by injecting chemicals in each borehole at the base of the casing while the casing is being withdrawn.

The primary advantages of the V-shaped chemical barrier are: (1) only one barrier system would be needed for each tank farm rather than one for each tank or leaking tank, (2) drilling to emplace the barrier-forming chemicals would not occur in contaminated soils, and (3) leaks would be contained and prevented from migrating to the groundwater. The straight drilling techniques employed in this technology would be more likely to achieve the hole-alignment objectives needed to ensure a continuously formed barrier than would the directional drilling techniques that would be used to emplace a box-shaped chemical barrier. The primary disadvantages are: (1) long directional drill lengths would be required with little tolerance for directional deviation, and (2) the standoff barrier would not prevent or minimize new leaks.

4.3.4 V-Shaped Freeze Wall Barrier

The V-shaped freeze wall barrier would be formed from ice instead of chemicals. The barrier would be constructed to the same drilled dimensions and with the same drilling technology used to create the V-shaped chemical barrier. If needed, drilling muds would be used to help fill the voids in highly permeable soil formations. The nondraining water contained in the drilling muds would help ensure that ice fills the soil pores.

In the freeze wall barrier design, freeze pipes would be installed in a V-shaped configuration around and beneath the tanks. Each freeze pipe would include an internal pipe. Coolant would be pumped down the inside pipe and returned through the annulus. The coolant is assumed to be a salt brine cooled to -15 to -25 °C using a refrigeration system at the surface (KEH 1993a). The addition of water to the soil may be required during freezing if the natural water content of the soil is insufficient to form an effective barrier.

The primary advantage of this type of barrier is the potential ability to detect and repair leaks and other flaws in the barrier. Flaws may be detectable by monitoring temperature and pressure within the space occupied by the barrier. Additional piping would be required to enable detection and repair of flaws. The primary disadvantages are the active nature of the barrier system and its high maintenance requirements. The chemical barriers, in contrast, are passive and require little or no maintenance. Another disadvantage of the freeze wall technology is the need for additional development of methods for adding water to highly conductive Hanford Site soils.

4.3.5 Circulating Air Barrier

A circulating air barrier would rely on evaporation of water from the soil, thereby limiting the ability of a leak to migrate through the vadose zone. The circulating air barrier would use circulation of warm dry air through the soil to remove the moisture (Figure 4-8). Leaked liquids will not readily flow through dried soil until the moisture level of the soil reaches its critical liquid saturation point (KEH 1993a). The critical saturation point depends on the physical properties of the soil. This point may exceed 30% by volume water for fine-grained soils and may be less than 2% by volume water for gravels. The critical saturation point for Hanford Site soils ranges from about 5% to 25% due to the heterogenous nature of the soils. Thus, the dried soil will vary in capacity to absorb leaked waste.

The flow of dry air through the soil while a leak is occurring would also dehydrate the leaked waste by evaporation of water. As evaporation proceeds, the solubility limits of dissolved constituents would eventually be exceeded and precipitates would form in the soil pores. The precipitates may be effective in blocking additional flow.

The circulating air barrier would be created by injecting warm dry air through an array of vertical boreholes drilled between tanks. The lower end of the pipe casing in each hole would be perforated or screened. Air would flow through the perforations, into the soil, and then into perforated extraction pipes. The extracted air would be treated to remove water, volatile organics, and entrained particulates and then be reinjected.

The integrity of the circulating air barrier would be inferred by measuring the humidity of the extracted air. A sufficiently low humidity would indicate that the soil is dry enough to absorb a design-basis leak. Well pressures and injected air flow rates would provide other indications of the integrity of the barrier. Dry wells may also be installed under tanks using slant drilling as a means of obtaining pressure, temperature, and humidity data at points between the injection and extraction wells. The loss of injected air through highly permeable soil to the surface of the ground could be minimized by capping the tank farm area with an impermeable plastic membrane or layer of clay.

The primary advantages of the circulating air barrier are: (1) the technology is relatively simple and (2) it would limit the spread of leakage and possibly the volume of contaminated soil. The disadvantages are: (1) contaminated water may be recovered in the extracted air dehydration system, (2) contaminated water would require treatment and disposal, and (3) the circulating air barrier, like the three standoff barriers previously discussed, would not prevent new leakage.

4.4 SOIL FLUSHING

Soil flushing is an in situ remedial technology that may be effective for cleaning contaminated soil that has resulted from SST leaks. It also may support tank waste retrieval when a close-coupled barrier is used, by removing soil contamination prior to emplacement

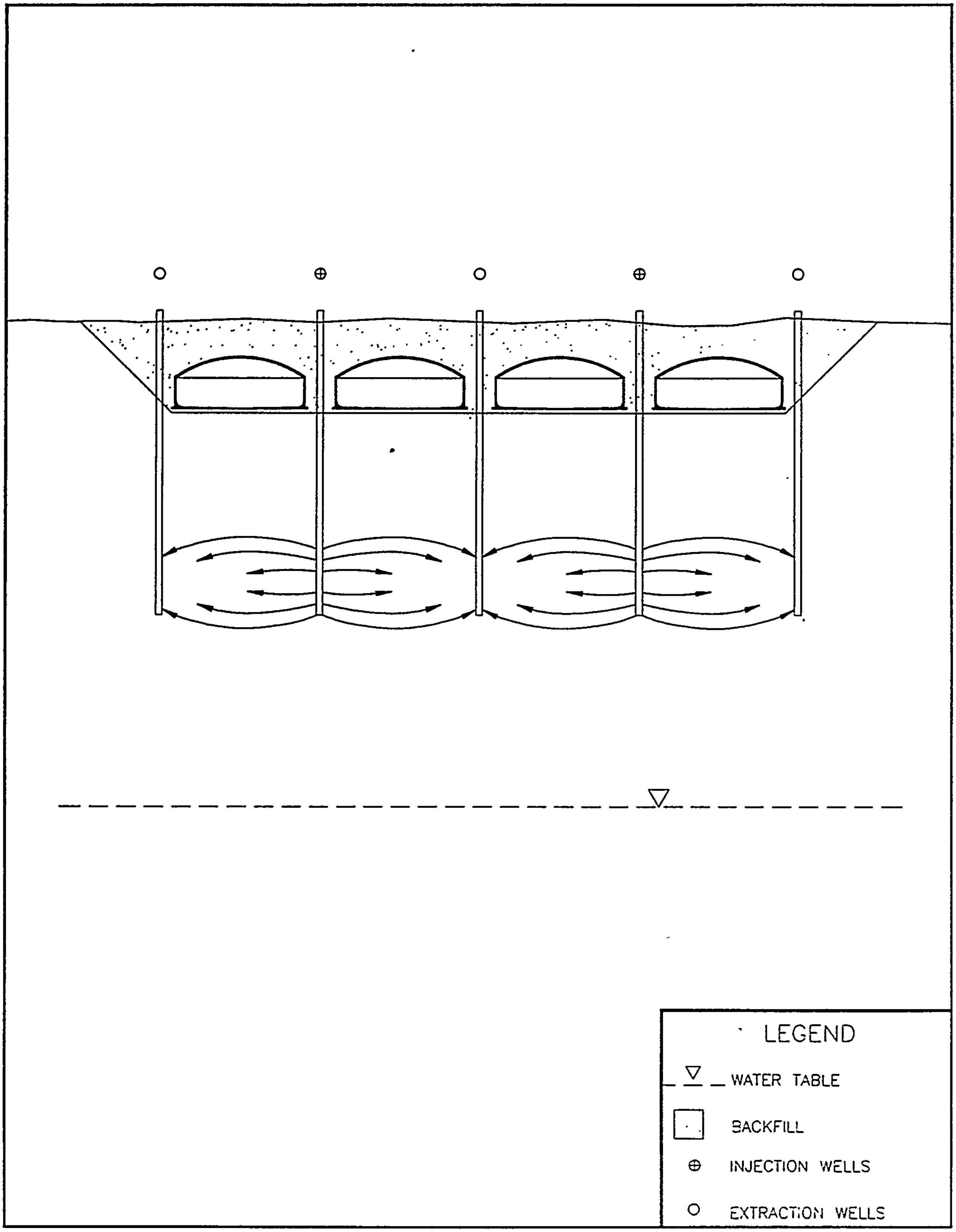

Figure 4-8. Circulating Air Barrier.

of the barrier. Soil flushing may be used to extract contaminants from soil using water or other flush solutions that solubilize and mobilize the contaminants. A related technology, soil washing, treats contaminated soil that has been excavated from a site. The primary attractiveness of soil flushing is that it eliminates the need for excavation.

Soil flushing consists of injecting a flushing solution into the soil-waste matrix and then collecting the leachate after it has passed through the matrix. The resulting leachate must be treated to remove the chemicals that have been extracted. A variety of methods that can be used for delivery and recovery of the flush solution exist. Selection of the most appropriate method is based primarily on the hydraulic conductivity of the soil.

The relatively permeable nature of the Hanford formation is conducive to soil flushing at the Hanford Site. This permeability, coupled with the high cation exchange capacity of Hanford Site soils and moderate water storage capacity of the vadose zone, led to the historic use of the soil column for disposal of large volumes of slightly contaminated wastewater to the ground via ponds, cribs, and trenches.

An important factor that determines how easily a chemical can be removed from the soil by flushing is the distribution coefficient (K_d). The K_d is a measure of the ratio of the concentration of a contaminant in the liquid phase of a liquid-solid system to the solid phase concentration at equilibrium. Contaminated soils exhibiting high K_ds are difficult to clean because very large volumes of flush solution are required to displace contaminants from the soil.

Each of the constituents of concern (COCs) in this study was assumed to feature a $K_d = 0$. These constituents include ^{99}Tc, ^{14}C, ^{129}I, ^{238}U, nitrate, nitrite, tributyl phosphate (TBP), and ethylenediaminetetraacetic acid (EDTA). The assumption, $K_d = 0$ for each of these constituents, may be somewhat nonconservative. Some species, such as uranium, may form less soluble and less mobile mineral species over time, for example. The mobility of ^{14}C may also be reduced by isotopic substitution with native carbonate salts in the soil. At $K_d = 0$, these constituents will be associated with the aqueous phase. Cleaning the Hanford Site soil by soil flushing would theoretically be a matter of displacing the residual moisture held in the soil capillaries. The theoretical amount of water required to displace the nonsorbing residual contaminated moisture is one soil pore volume under saturated conditions.

Channeling of flushing water will occur in heterogenous soils, such as those that exist at the Hanford Site, due to the presence of zones of varying hydraulic conductivities. Channeling will reduce the effectiveness of soil flushing. Moreover, some contaminants will have diffused into the pores of larger soil particles and rocks over time. This pore solution would not be displaced by advecting flushing water; affected contaminants must enter the advecting stream by the slow process of diffusion. These conditions render soil flushing less effective than predicted by theory. Thus, a minimum of several pore volume flushes are usually necessary to meet cleanup goals, even when the contaminants are not sorbed to the soil.

Two different methods of applying soil flushing were considered in this study: (1) traditional soil flushing and (2) soil flushing with vacuum recovery. A method of treating the recovered flush water is also described.

4.4.1 Traditional Soil Flushing

This method employs established pump and treat technology. Flush water would be distributed to the soil via pipes inserted into the ground near the base of tanks (Figure 4-9). Flush water could also be added to tanks to aid in flushing the leak pathways. Flushing the leak pathways may not be effective if a small crack size or plug limits flow of flush solution from the tank to the soil or if the flush solution follows different pathways to the soil than did the original leak. Contaminants would be flushed to subsurface collection basins created by the installation of standoff subsurface barriers. The collected flush solution would be pumped to the ground surface for removal of contaminants and recycled.

4.4.2 Vacuum Soil Flushing

This concept would involve the injection of flush water into the soil at the periphery and under the base of the tanks where leaks are likely to have occurred (Figure 4-9). Flush water could also be added to the tanks to flush the original leak pathways. The flush water would be removed by vacuuming it from the soil as it migrates through the contaminated zone created by the leak. Injection and vacuum removal of flush water would be accomplished through the use of perforated and porous pipes. The action of removing water from saturated and nearly saturated soil near the porous vacuum pipes would induce the flow of water into the dewatered area by wicking. The porous pipes would be segmented to avoid the preferential extraction of excess air. Each pipe segment could be isolated from the vacuum when low flush water recovery rates are indicated. Recovered flush solution would be collected in a vessel and subsequently pumped to the ground surface for treatment and recycling.

This technology would be most applicable to alternatives that employ close-coupled and circulating air barriers. Otherwise, the used flush water must be recovered by pumping after it collects in the aquifer. The concept would not be effective in highly conductive soils because of their low ability to wick water.

4.4.3 Flush Water Treatment

Flush water recovered from the application of soil flushing would require treatment to enable its reuse for flushing. It was assumed that 99% of the contaminants in the recovered flush water must be removed. This level of removal is necessary for the recycle water to be effective for meeting an assumed objective of flushing 94% of the contaminants from the soil, as discussed in Section 6. This flushing removal efficiency is based on the assumption

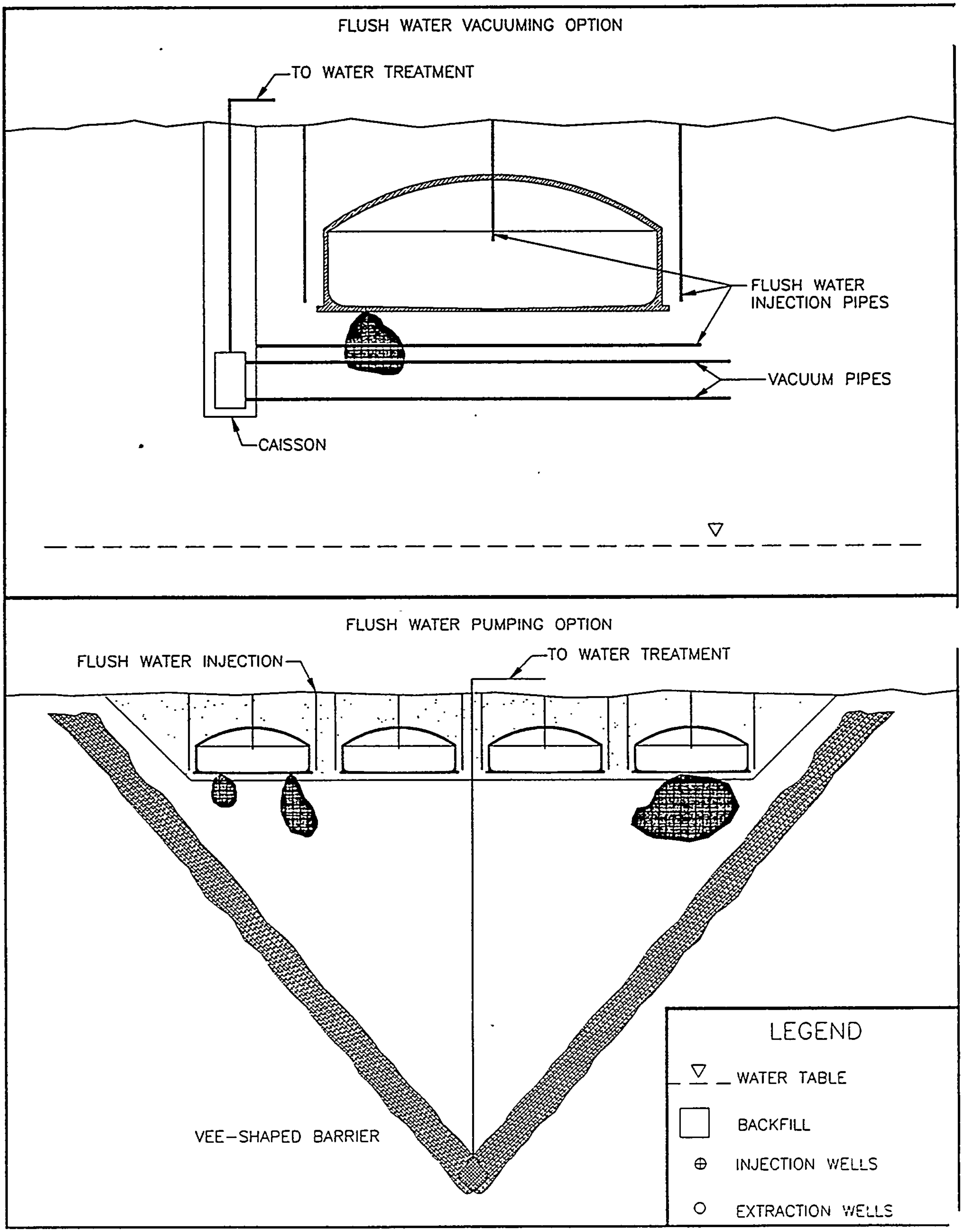

Figure 4-9. Traditional and Vacuum Soil Flushing.

that each of four pore volume flushes removes 50% of the contamination in the soil remaining after the preceding flush. Ellis and Payne (1984) reported a laboratory test in which 98% of a nonsorbing species was removed using three pore volume flushes.

The recovered contaminants would exist as organic, anionic, and particulate species. A limited quantity of cationic contaminants would be recovered due to their low mobilities in Hanford Site soil. The treatment system would be designed for removal and destruction of organic species and for solidification of the concentrated wastes for disposal.

The selection of an optimized wastewater treatment system requires evaluation of many potentially effective technologies in different process configurations. Consideration of regulatory requirements regarding the injection of treated water containing residual contaminants to the soil column is also required. A detailed evaluation of wastewater treatment options for this waste stream is beyond the scope of this study's focus on the feasibility of subsurface barriers. Thus, a low-radioactive liquid effluent treatment facility evaluated by Boomer et al. (1993) is assumed to be appropriate for treating the flush water. A more rigorous analysis of the treatment needs may indicate that a less-complex and expensive treatment facility would suffice.

The conceptual treatment facility evaluated by Boomer et al. (1993) is known as the Liquid Effluent Purification for Recycle or Discharge (LEPRD) Facility. The conceptual treatment facility would include four primary unit operations: (1) evaporation of liquid effluent, (2) organic destruction, (3) microfiltration, and (4) reverse osmosis.

Evaporation of the liquid effluent is the first step in this process. The condensed overheads would contain only 0.1% of the anions and particulate matter of concern, but most of the organics (Boomer et al. 1993). The organics in this stream would be destroyed in the second step using supercritical water oxidation. This technology would employ high pressure and temperature to ensure destruction of >99% of the organic fraction. Step three, microfiltration, would use a pneumatic hydropulse filter to remove suspended particulates. Reverse osmosis would be used as a final water cleanup step. Final retentate from this unit operation would be recycled to the evaporator.

4.5 TANK CLOSURE

It is assumed that the SSTs would be closed as landfills or clean-closed under RCRA and the Dangerous Waste Regulations of the State of Washington (WAC 173-303) following completion of all waste retrieval activities. Closure as a landfill would include adding grout to the empty tanks to physically stabilize them and then constructing a surface barrier over the stabilized tanks. The goal of this closure approach is intended to provide long-term, low-maintenance protection of residual waste from the dispersive effects of environmental processes.

Clean-closure would include removal of all residual wastes, tank structures, appurtenances, and contaminated soils to meet cleanup objectives. These objectives are assumed to conform to the cleanup regulations of the Washington State Model Toxics Control Act. Removal of tank-related wastes would be accomplished using an enclosed mining operation.

4.5.1 Grout Stabilization

The void space in SSTs following waste retrieval would be stabilized with grout. The grout-filled SSTs would serve as load-bearing structures for closure barriers installed over the tanks. Empty tanks would be subject to deterioration and eventual collapse. The collapse of the SSTs and barriers would cause residual waste in the tanks to be exposed to the environment. Structural stabilization of the SSTs by filling them with grout would ensure against their collapse, but it would not ensure that residual contaminants left in the tank would be immobilized (Figure 4-10).

The grout-fill technology that would be used for stabilizing the SSTs is based on established commercial techniques employed in the construction and mining industries. Grout-fill operations would displace vapor and radioactive dust from the empty tanks; a portable ventilation system would be installed to control air emissions.

Grout stabilization would begin with SST preparation and the installation of grout distributors on tank risers. If risers are not available or are unsuitable, new risers would be installed. With the distributors installed, the dedicated piping would be assembled and a connection made to a grout slurry plant centrally located within a tank farm group.

The grout slurry plant would receive dry materials mixed at a batch plant located conveniently to serve all of the SST farms. The batch plant would receive the dry components of the grout and mix them in correct proportions. The dry mixture would be transported to the grout slurry plant via haulers on existing roadways.

The grout slurry would be mixed and then pumped through the dedicated piping to the distributors located on tank risers. The grout would be poured in layers if needed to optimize the grout curing process. Self-leveling grout would likely be used in the SSTs.

A typical tank would be filled with grout in approximately two weeks of continuous pumping. The fill monitoring system would include the capability to visualize interior tank operations. Density and compressive strength measurements would be made as indicators of the integrity of hardened grout.

At the conclusion of the fill operations, the distributors and feed hardware would be relocated or disposed, and the tank openings would be sealed with concrete. Tank contents would be monitored as needed and the tank site would be secured pending installation of the surface barrier.

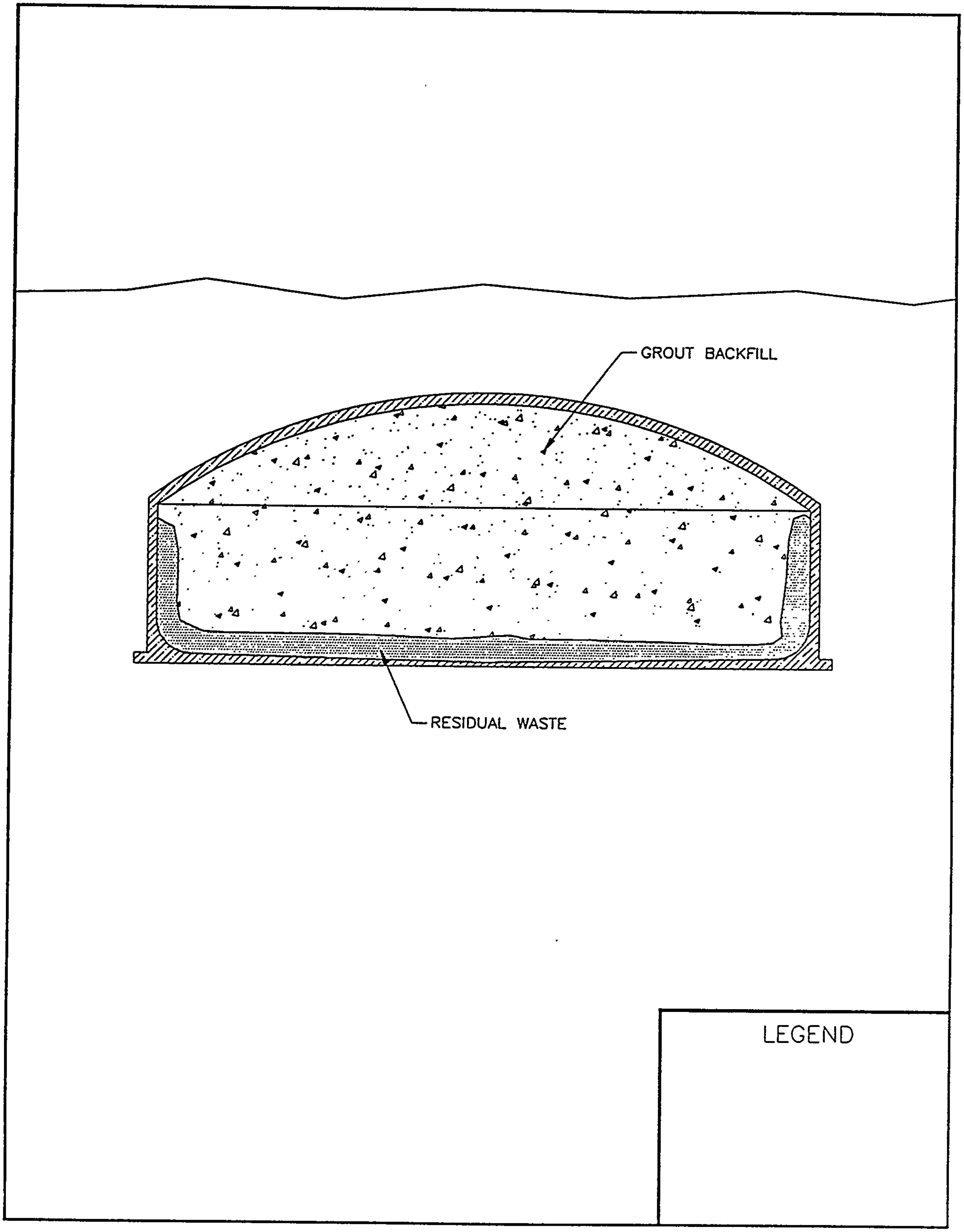

Figure 4-10. Tank Stabilized with Grout Following Waste Retrieval.

4.5.2 Permanent Isolation Surface Barrier

It is assumed that a Permanent Isolation Surface Barrier would be installed over an entire single-shell tank farm following waste retrieval and tank stabilization activities. The Operations and Engineering Contractor for the DOE's Hanford Site, Westinghouse Hanford Company, and DOE's Research and Development Contractor for the Hanford Site, Pacific Northwest Laboratory, are jointly developing and testing the Permanent Isolation Surface Barrier for Hanford Site applications. This barrier would serve to minimize water infiltration, plant and animal intrusion, wind and water erosion, human interference, and gaseous release. A more rigorous study of risks, level of compliance with regulatory requirements, and cost-benefit associated with other surface barrier options may show that others also have merit in this application.

Existing short-term barrier designs currently are available (EPA 1982, 1990). In general, the design life of these barriers is for relatively short periods such as the 30-year post-closure period specified by RCRA. The performance of barriers during this relatively short period can be monitored, and maintenance activities can be performed to correct any problems that might be encountered. However, it may be desirable to isolate residual SST wastes for much longer than the 30-year post-closure period, perhaps for a millennium or longer.

Preliminary performance objectives that have been established for the Permanent Isolation Surface Barrier include:

- Function in a semiarid-to-subhumid climate
- Limit the recharge of water through the waste to the water table to $\leq$0.05 cm/yr (0.02 in./yr)
- Be maintenance-free
- Minimize the likelihood of plant, animal, and human intrusion
- Isolate contaminants for a minimum of 1,000 years
- Minimize erosion-related problems
- Meet or exceed RCRA cover performance requirements
- Limit the exhalation of noxious gases
- Meet regulatory requirements and be publicly acceptable.

The protective surface barrier design (Figure 4-11) would consist of a fine-soil layer overlying other layers of coarser materials such as sands, gravels, and basalt riprap (Wing 1993). Each of these layers would serve a distinct purpose. The fine-soil layer would act as

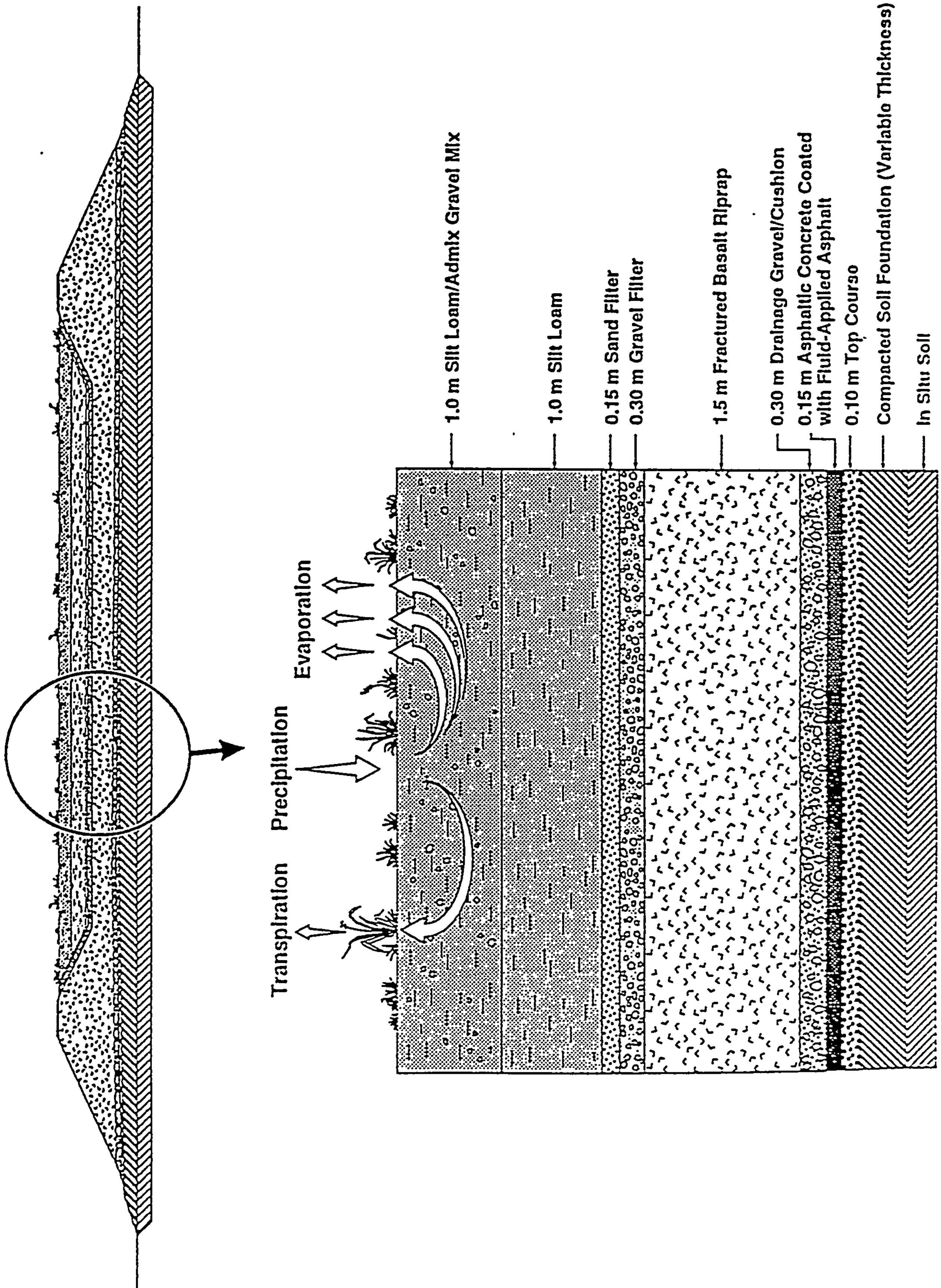

Figure 4-11. Hanford Permanent Isolation Surface Barrier.

a medium in which moisture is stored until the processes of evaporation and transpiration recycle it back to the atmosphere. The fine-soil layer would also provide the medium for establishing plants that are necessary for transpiration to take place.

The coarser materials placed directly below the fine-soil layer would create a capillary break that inhibits the downward infiltration of water through the barrier. The placement of the silt loam over the coarser materials would also create an environment that encourages plants and animals to limit their natural biological activities to the upper, fine-soil portion of the barrier, thereby reducing biointrusion into the lower layers. The coarser materials also would help to deter inadvertent human intruders from digging deeper into the barrier profile.

Low-permeability layers, placed in the barrier profile below the capillary break, would also be used in the protective barriers. The purposes of the low-permeability layers are (1) to divert away from the waste zone any infiltrating water that passes through the capillary break and (2) to limit the upward movement of noxious gases from the waste zone. The coarse materials located above the low-permeability layers would also serve as drainage media to channel any infiltrating water to the edges of the barrier.

4.5.3 Confined Demolition/Mining System

Clean-closure of the hypothetical tank farm would include removal of contaminated tank structures and soils following retrieval of wastes from the tanks. Facilities required to support this removal action would subsequently be decontaminated, decommissioned, and removed, and the site backfilled with clean soil. Few restrictions would be placed on the use of land formerly occupied by the tank farm.

Contaminated residual tank waste, waste resulting from the demolition of tanks, and contaminated soil would be washed in acid and water to remove a high fraction of the COCs. The recovered constituents would be concentrated and processed in the primary tank waste pretreatment system. The washed concrete, steel, and soil would be disposed onsite in a permitted landfill. Most of this waste would be disposed in burial boxes. Some of the boxes would require handling by remote techniques. Facilities used to provide containment of the various tank waste removal actions would be demolished and disposed in a bulk radioactive waste landfill.

Tank waste removal actions would be conducted within the confines of a truss-supported facility that would cover an entire tank farm (Figure 4-12). A movable bridge that spans the width of a tank farm would be the largest structure within the confinement facility. The bridge would support a high-capacity bridge crane with capability to access the entire area that encompasses a row of tanks (e.g., about 30.5 m [100 ft] by 91.5 m [300 ft]). The bridge crane would be equipped to use various demolition and retrieval tools, including drills, expanders, shears, cutting torches, and clam-shell buckets. Some of this equipment would be supported by the crane; others would be initially positioned by the crane and independently powered.

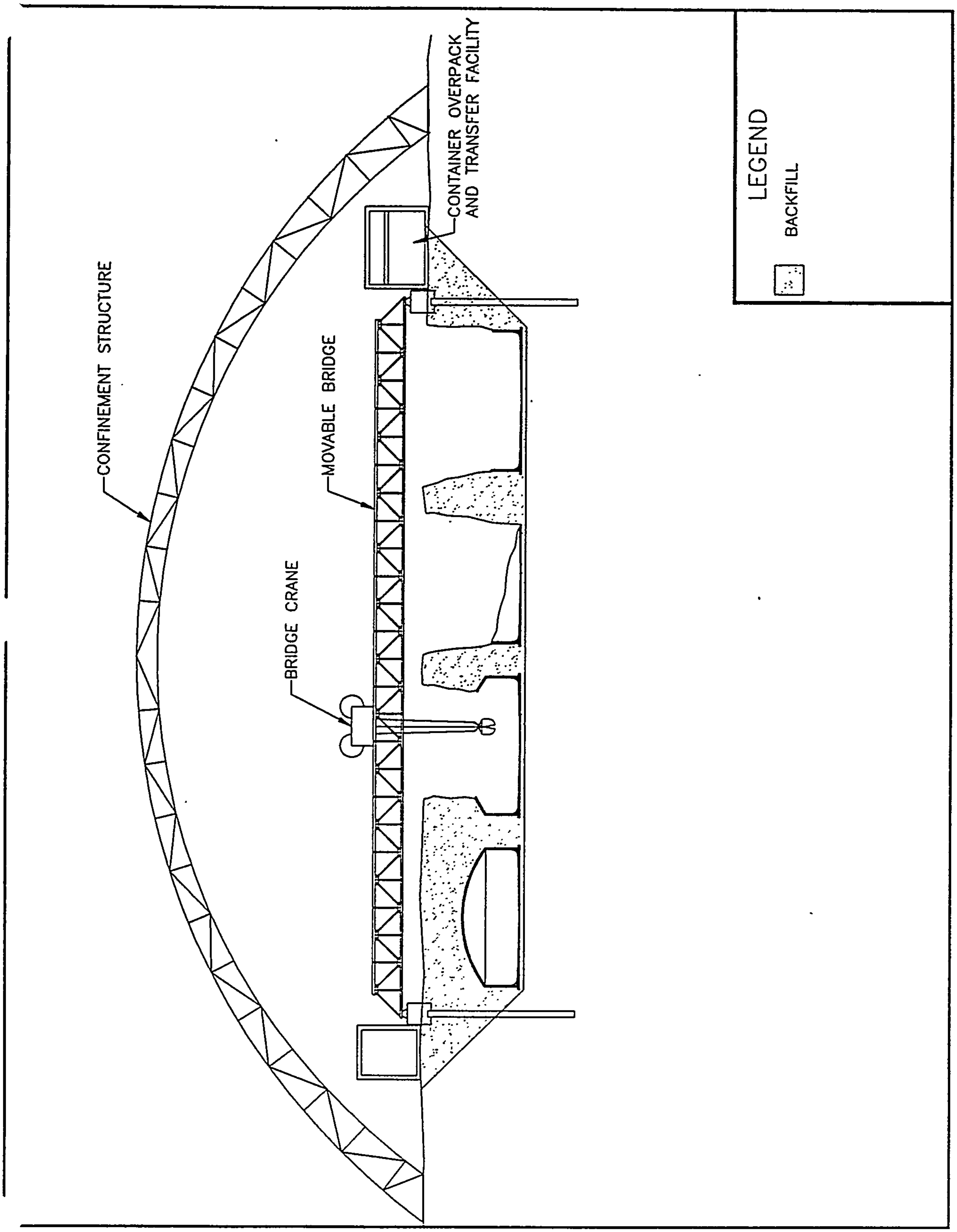

Figure 4-12. Confined Tank Demolition and Mining System.

The retrieved waste, debris, and failed equipment would be placed in 38 m^3 (50 yd^3) capacity boxes, overpacked, and hauled in shielded transporters to a decontamination and wash facility. The boxes, overpacks, and repaired equipment would be returned to the tank farm confinement facility for reuse. The confinement facility would also house a shielded facility where boxed waste would be overpacked and loaded out to the transporters. The shielded facility would also receive returned boxes and overpacks, and be capable of decontaminating overpacks. This would necessitate the use of a small, thin-film evaporator for recycling water used for decontamination.

Other important supporting equipment would include shielded crane maintenance facilities, one at each end of the bridge, and an air filtration facility including roughing filters, high efficiency particulate air (HEPA) filters, blowers, and a stack.

5.0 OVERALL SYSTEM ALTERNATIVES

This section describes alternatives that serve as bases for cost and risk analyses in subsequent sections. Unit technologies and concepts described in the previous sections were combined selectively into 14 alternatives. The alternatives were chosen to enable evaluation of a representative range of different retrieval methods, types of subsurface barriers, soil flushing methods, and use of tank stabilization and surface barriers as parts of an overall tank cleanout and closure strategy. The evaluation does not address treatment and disposal of the retrieved tank waste, except where the quantity of overall waste recovered is more or less than assumed for a baseline alternative. Cost adjustments are made in those cases.

The 14 alternatives are distinguished principally according to the absence or presence of the five types of subsurface barriers presented in the previous section. Alternatives 1 and 2 are no-action and minimal-action options presented solely as bases for comparison. Alternatives 3 through 5 include different retrieval technologies, but no subsurface barrier. Alternatives 6 through 8 include close-coupled chemical barriers. Alternatives 9 through 11 involve standoff barriers and Alternative 12 includes a circulating air barrier. Alternatives 13 and 14 are clean-closure alternatives; the latter includes a close-coupled barrier.

This section contains brief descriptions of the 14 alternatives. It also contains a summary of the key assumptions and other bases used for assessment of risk and cost. The primary features of each alternative are summarized in Table 5-1.

5.1 DESCRIPTION OF ALTERNATIVES

(1) **No-Action Alternative.** This alternative involves no action, as the name implies. It is included as a basis for comparing the benefits of other alternatives in reducing risk. The relative risks of the No-Action Alternative and other alternatives analyzed in this study include only those that would result through the groundwater pathway. Severe environmental risks would result from this alternative when tank roofs deteriorate and collapse, exposing the environment to high levels of radiation.

(2) **Surface Barrier Only Alternative.** This alternative is the same as the No-Action Alternative, but includes a Hanford Permanent Isolation Surface Barrier installed over the tanks. The surface barrier would slow and reduce the contaminant flux from the tanks, thereby increasing the time the contaminant plume from the tanks would reach the groundwater and reducing the peak concentration of contaminants in the groundwater. All alternatives except for the No-Action Alternative and the two clean-closure alternatives employ this surface barrier over the tanks.

Table 5-1. Summary of Alternatives.

Alternative	Waste Retrieval Type	Assumed Tank Waste Retrieval Effectiveness	Subsurface Barrier Type	Old Leaks Flushed?	New Leaks Flushed?	Tanks Stabilized?	Surface Barrier Used?
1. No Action	None	0%	None	No	No	No	No
2. Surface Barrier Only	None	0%	None	No	No	No	Yes
3. Traditional Sluicing (Baseline)	Traditional sluicing	99%	None	No	No	Yes	Yes
4. Robotic Sluicing	Robotic sluicing	99.9%	None	No	No	Yes	Yes
5. Mechanical Retrieval	Mechanical retrieval	95%	None	No	No	Yes	Yes
6. Close-Coupled Chemical Barrier with Flushing	Traditional sluicing	99%	Close-coupled	Yes	Not Applicable	Yes	Yes
7. Close-Coupled Chemical Barrier w/o Flushing	Traditional sluicing	99%	40% None 60% Close-Coupled	No	No	Yes	Yes
8. Modified Close-Coupled Chemical Barrier w/o Flushing	Traditional sluicing	99%	Vertical Close-Coupled	No	No	Yes	Yes
9. Box-Shaped Chemical Barrier	Traditional sluicing	99%	Box-shaped chemical	Yes	Yes	Yes	Yes
10. V-Shaped Chemical Barrier	Traditional sluicing	99%	V-shaped chemical	Yes	Yes	Yes	Yes
11. V-Shaped Freeze Wall Barrier	Traditional sluicing	99%	V-shaped freeze wall	Yes	Yes	Yes	Yes
12. Circulating Air Barrier	Traditional sluicing	99%	Circulating air	Yes	Yes	Yes	Yes
13. Clean-Closure w/o Subsurface Barrier	Traditional sluicing	100%	None	No	No	Not Applicable	No
14. Clean-Closure with Close-Coupled Chemical Barrier	Traditional sluicing	100%	40% None 60% Close-Coupled	No	No	Not Applicable	No

Like the No-Action Alternative, this alternative is included as a basis for comparison with the other alternatives. The Surface Barrier Only Alternative is not considered viable because deliquescence of the saltcake in the SSTs may create voids. This would eventually lead to collapse of the roofs of the tanks, destroying the effectiveness of the surface barrier and potentially exposing the environment to high levels of radiation. Filling of existing void space in the tanks with grout is not included to avoid the appearance that the Surface Barrier Only is a complete and viable alternative.

(3) **Traditional Sluicing (Baseline) Alternative.** This alternative would employ the use of traditional sluicing to remove an assumed 99% of the waste from the tanks (Boomer et al. 1993). Stabilization of the essentially empty tanks with grout and installation of a surface barrier over the tanks would also be included. This alternative would not include actions taken to prevent leakage from tanks nor to clean contaminated soil that resulted from old leaks and that would result from new leaks.

(4) **Robotic Sluicing Alternative.** This alternative would employ a robotic arm capable of positioning a low volumetric rate, high-pressure sluicing device at any location in the tank. The low volumetric flow rate would result in minimizing the liquid head in the tanks, thus reducing the level of leakage from the tanks. The high pressure water jets would be expected to be more effective than traditional sluicers in cutting through hardened sludge. Thus, retrieval of 99.9% of the waste in the tanks is assumed (Boomer et al. 1993). The tanks would be structurally stabilized and a surface barrier would be installed following retrieval operations.

(5) **Mechanical Retrieval Alternative.** This alternative would employ a robotic arm capable of positioning an excavating device within the tank. The wastes would be retrieved without the addition of water. The elimination of water for retrieval is assumed to eliminate the potential for new leaks. Mechanical retrieval is believed to be less effective than other retrieval options. This method is assumed to be capable of recovering 95% of the tank wastes (Boomer et al. 1993). The tanks would be stabilized and a surface barrier would be installed following retrieval operations.

(6) **Close-Coupled Chemical Barrier with Flushing Alternative.** This alternative would include soil flushing with vacuuming to remove contamination in the soil caused by old leaks. Water recovered from soil flushing operations would be treated and recycled. After flushing contaminated soil, a close-coupled chemical subsurface barrier would be installed in close contact with each tank's structural concrete. The close-coupled barrier would minimize new leakage while conducting traditional sluicing to retrieve tank wastes. The tanks would be stabilized and a surface barrier would be installed following retrieval operations.

(7) **Close-Coupled Chemical Barrier Without Flushing Alternative.** This alternative would initially employ the close-coupled barrier around only those tanks declared to have leaked waste in the past. Traditional sluicing would be used to remove wastes from all SSTs. Thirty percent of the tanks without barriers are assumed to develop leaks during new sluicing operations. Sluicing operations would cease on detection of a leak and the liquid contents of the affected tanks would be pumped to other tanks without delay. Close-coupled barriers would subsequently be emplaced around the newly leaking tanks and traditional sluicing operations would be resumed. Soil flushing would not be used in this alternative. Grout stabilization and surface barriers would be used following waste retrieval.

(8) **Modified Close-Coupled Barrier Without Flushing Alternative.** This alternative would employ only the vertical component of the close-coupled barrier around all tanks. The intent of this alternative is to seal the construction joint between the vertical and horizontal concrete members of the tank structure where more than half of the leaks are assumed to occur. It is assumed that this strategy would result in preventing 60% of the leaks that would have occurred without the use of the barriers. Soil flushing would not be employed. Traditional sluicing, grout stabilization, and surface barriers would be used in this alternative.

(9) **Box-Shaped Chemical Barrier Alternative.** This alternative would include a box-shaped subsurface chemical barrier beneath the level of old leakage from the tanks. Traditional sluicing would be employed to retrieve tank wastes. Soil contamination resulting from old and new leaks would be flushed to a low point in the subsurface barrier. The collected flush water would be pumped to the surface for treatment and then recycled. The tanks would be closed by stabilizing them with grout and installing surface barriers over them.

(10) **V-Shaped Chemical Barrier Alternative.** This alternative is similar to Alternative 9. The two alternatives differ in the barrier installation method and shape. The box-shaped barrier would be installed using directional drilling. The V-shaped barrier would employ angled drilling to create boreholes in the soil through which the barrier-forming chemicals would be injected. The shape of the V-barrier would result in the collection of contamination from leaks at a deeper level than in the case of the box-shaped barrier.

(11) **V-Shaped Freeze Wall Barrier Alternative.** This alternative would include a barrier of size and shape similar to that of the V-Shaped Chemical Barrier; however, ice would be the barrier-forming material in this alternative. An attractive feature of this alternative is the ability to melt the barrier from the upper side downward. This would enable flushing of contaminated soils

occluded in the barrier with water while maintaining the integrity of the barrier. Traditional sluicing, grout stabilization, and surface barriers would also be used in this alternative.

(12) **Circulating Air Barrier Alternative.** This alternative would include a method of drying soil beneath the SSTs using warm dry air. The dry soil and flowing air would serve to evaporate water from leaks expected to occur during sluicing. This would result in minimizing the spread of leakage from the tanks. Traditional sluicing, vacuum soil flushing, grout stabilization, and surface barriers would also be used in this alternative.

(13) **Clean-Closure Without Subsurface Barrier Alternative.** This alternative would employ traditional sluicing to recover 99% of the tank waste. All residual contamination in the tank, tank structures, and soil would then be retrieved using mechanical methods. Most of the COCs would be removed from the retrieved materials and either destroyed or disposed at a Federal high-level waste repository. The excavated site would be backfilled with clean soil after verifying that cleanup limits were achieved. Clean-closure would eliminate the need for grout stabilization and surface barrier at the tank waste site.

(14) **Clean-Closure With Close-Coupled Chemical Barrier Alternative.** This alternative is identical to Alternative 13 except that a close-coupled chemical barrier would be installed initially around only those tanks declared to have leaked in the past. Thirty percent of the tanks without barriers are assumed to develop leaks during new sluicing operations. Sluicing operations would cease on detection of a leak and the liquid contents would be pumped to other tanks without delay. Close-coupled chemical barriers subsequently would be installed around the newly leaking tanks and traditional sluicing operations would be resumed.

5.2 KEY ASSUMPTIONS

The key bases and assumptions used for the comparative risk and cost analyses in Section 6 are summarized in this section. Rationale for these data are also presented in Section 6.

(1) The relative risk and cost analyses are based on a hypothetical tank farm containing twelve, 1-Mgal SSTs (all alternatives).

(2) The eight constituents of primary concern in this study (^{14}C, ^{99}Tc, ^{129}I, ^{238}U, NO_3, NO_2, TBP, and EDTA) are soluble with nitrate (i.e., they leach congruently with nitrate) and all feature $K_d=0$ (all alternatives).

(3) The solubility of nitrate in tank waste is 360 g/L (3 lb/gal) (all alternatives).

(4) Each hypothetical tank contains masses of COCs equal to the average of their masses in all 149 SSTs (all alternatives).

(5) Recharge of meteoric water is 5 cm/yr (2 in./yr) without a surface barrier (Alternative 1) and 0.05 cm/yr (0.02 in./yr) with the presence of Hanford Permanent Isolation Barrier (Alternatives 2 through 12). Vadose zone water travel times of 190 and 19,000 years are estimated for these recharge rates.

(6) It is assumed that recharge water is not deflected by the tank dome to the sides of the tank because deterioration and cracking of the tank dome will allow the water to flow through the cracks and enter the space enclosed by the tank. Sufficient cracking will occur over the long time periods analyzed (30,000 years) to allow water to vertically penetrate into the tank space (Alternatives 1 through 12).

(7) Robotic sluicing (Alternative 4), traditional sluicing (Alternatives 3 and 6 through 14), and mechanical retrieval (Alternative 5) remove 99.9%, 99%, and 95% of the tank wastes, respectively.

(8) The time required to achieve cleanout of a tank by traditional sluicing is 123 days (Alternatives 3 and 6 through 14).

(9) A small void space (averaging 1 mm [0.04 in.] thick) exists between the tank bottom and its concrete base (all alternatives).

(10) Five of the 12 tanks in the hypothetical tank farm have leaked waste in the past. Waste at interstitial liquid concentrations fills the void space described above in these cases and the same waste has also advected into the concrete (all alternatives).

(11) Waste that has advected into the concrete has done so over the 23-m (75-ft) diametric area of the tank base at an average head of 0.46 m (1.5 ft) for 15 years (all alternatives).

(12) The hydraulic conductivity and porosity of the concrete are 3.75×10^{-10} cm/s (7.38×10^{-10} ft/min) and 0.22, respectively (all alternatives).

(13) The effective diffusivity of the concrete is 5×10^{-8} cm^2/s (8×10^{-9} in^2/s); the moisture fraction is 0.15 (all alternatives).

(14) Advection dominates diffusion as the mechanism that drives contaminants into the concrete and into any chemical barrier (all alternatives).

(15) Recharge water first dissolves residual tank waste, then quantitatively displaces waste between the tank and concrete base, and then leaches waste in the concrete. The concentration of concrete leachate is one-half the concentration in the waste in the void between the tank and concrete (Alternatives 1 through 12).

(16) Five of the 12 tanks have leaked an average of 41,600 L (11,000 gal) each to the soil (all alternatives). Leaked waste contains contaminants at one-half their concentrations in interstitial liquid (all alternatives). A total of five of 12 tanks will release new leaks to the soil during new sluicing operations (Alternatives 3, 4, and 9 through 13). These five tanks include three previously leaking tanks and two newly leaking tanks. Two previously leaking tanks are assumed to be leak-tight during new sluicing operations due to the presence of leak holes above liquid levels required for sluicing or due to pluggage of holes by waste fines.

In the case of the Close-Coupled Barrier Without Flushing Alternative and the Clean-Closure With Close-Coupled Chemical Barrier Alternative (Alternatives 7 and 14), the two newly leaking tanks will each release 41,600 L (11,000 gal) before barriers are installed. In the case of alternatives that employ traditional sluicing but no close-coupled barrier (Alternatives 3 and 9 through 13), it is assumed that the five leaking tanks release 152,000 L (40,000 gal) each. In the case of the Robotic Sluicing Alternative (Alternative 4), it is assumed that 15,200 L (4,000 gal) are released from each tank. In the case of the Modified Close-Coupled Chemical Barrier Without Flushing Alternative (Alternative 8), it is assumed that 152,000 L (40,000 gal) are released to the soil from two newly leaking tanks.

(17) The average head during traditional sluicing at the leak location is 4.6 m (15 ft) (Alternatives 3 and 6 through 14); the average head during robotic sluicing is 0.46 m (1.5 ft) (Alternative 4). These heads will cause further advection of tank waste into the tanks' concrete. The average height of liquid in the tanks during sluicing in these two cases is 3.1 m (10 ft) and 0.31 m (1 ft), respectively, because the specific gravity of the liquid is assumed to be 1.5.

(18) Leaks of 41,600 L (11,000 gal) per tank (all alternatives) and 194,000 L (51,000 gal) per tank (Alternatives 3 and 9 through 13) are estimated to have resulted in plume thicknesses of 8.5 and 15 m (28 and 49 ft), respectively.

(19) Standoff barriers are installed below the level of existing leakage plumes (Alternatives 9 through 11).

(20) Advection of waste into the close-coupled barrier occurs along the construction joint between the concrete base and concrete wall, and/or along a crack in the base. The length of the cracks through which waste can be forced into the barrier material is 10 m (33 ft) (Alternatives 6, 7, and 14).

(21) The effective hydraulic conductivity of an injected chemical barrier is 10^{-6} cm/s (2×10^{-6} ft/min) (Alternatives 6 through 10 and 14).

(22) The effective porosity of the Hanford Site soil regarding injected chemical-barrier-forming materials is 0.2 (Alternatives 6 through 10 and 14).

(23) Due to the slow migration rate of leaked waste through the soil to a standoff barrier, traditional soil flushing is necessary to effect cleanup of the leaks (Alternatives 9 through 11).

(24) Soil flushing is 94% effective in removing COCs after four pore volume flushes; soil porosity is 0.4 (Alternatives 6 and 9 through 12).

(25) The hydraulic conductivity of Hanford soil is 1.55×10^{-3} cm/s (4.4 ft/day). Soil heterogeneity and anisotropy are ignored (Alternatives 6 and 9 through 12).

(26) The time to flush four pore volumes to the standoff barrier ranges from 120 to 180 days, depending on design (Alternatives 9 through 11).

(27) The head of flush water on the standoff barrier is limited to 1.5 m (5 ft) by well-point pumping to prevent advection through the barrier (Alternatives 9 through 11).

(28) The volume of water required to effect vacuum flushing of soil in the tank farm is 14 Mgal (Alternative 6) and 20 Mgal (Alternative 12); the volume required to effect traditional flushing using standoff barriers as catchments ranges from 245 to 278 Mgal (9.3×10^8 to 10.6×10^9 L) (Alternatives 9 through 11).

(29) Relative risk is evaluated using the Multimedia Environmental Pollutant Assessment System (MEPAS), a Hanford Site-developed code with one-dimensional vadose zone modeling capability (all alternatives).

(30) Injected chemical barriers, after they have served their intended purpose to support tank cleanout and closure operations, will not significantly impact the migration of contaminants in the vadose zone (Alternatives 6 through 10).

(31) The entire vadose zone plume entering the groundwater is assumed to be captured by an operating well used to meet the domestic and irrigation needs of a 5-acre farm (i.e., an average water pumping rate of 45 m^3/day [1,589 ft^3/day]) (all alternatives).

(32) Contaminated soils and demolition wastes retrieved during clean closure operations are treated by washing to remove 99% of the constituents of concern (Alternatives 13 and 14). The washed soil and debris are disposed in a landfill that, when filled, is covered with a Hanford Permanent Isolation Barrier.

(33) The COCs recovered during soil flushing and during washing of excavated soil and debris are concentrated and treated along with waste retrieval from SSTs. It is assumed that the COCs are destroyed or disposed offsite at a federal repository such that they do not contribute to risk at the Hanford Site.

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6.0 COMPARATIVE RISK ASSESSMENT

This section describes the bases for a comparative risk assessment of alternatives presented in Section 5. It also contains a description of the methodology used to evaluate risk and a summary of risk results.

The primary objective of the comparative risk assessment is to provide a consistent evaluation of alternatives that use, and alternatives that do not use, subsurface barrier technologies to reduce relative health risks to the public from contaminant releases into the Hanford Site aquifer. This assessment was conducted to satisfy Part 1 of Tri-Party Agreement Milestone M-45-07A, "Estimate the potential environmental impacts of waste storage and retrieval activities without the application of subsurface barriers" and the latter half of Part 3, "Evaluate... the potential reduction in environmental impacts from the application of barriers to SST waste storage and retrieval activities." Other important risks, including worker safety, health risks due to atmospheric releases during installation and operation, and ecological risks, were not considered in this risk analysis. They will be considered in separate and more comprehensive analyses if the feasibility of subsurface barriers evaluated in this analysis is deemed sufficient by decision makers to warrant further study.

The purpose of subsurface barriers, used in conjunction with tank retrieval operations, is to reduce the magnitude of contamination belowground and to contain leaks until they can be flushed or excavated. This can be accomplished by the following:

- Reducing the amounts of contaminants that leak from the tanks during retrieval operations using close-coupled barriers

- Reducing the volume of newly contaminated soil underlying the tanks by intercepting liquids that leak from the tanks during retrieval operations. Extraction of those liquids would be accomplished using standoff barriers as catchments.

Subsurface chemical barriers would be in place during waste retrieval operations, which includes the period for extraction of liquids intercepted by standoff barriers and during soil flushing operations. However, it was assumed that the barriers would not remain leak-tight for an indefinite period. If they were designed for long-term leak-tightness, leachate from the residual waste would collect as in a bathtub. A major rupture of the barrier could lead to significant contamination of the groundwater and high risks to a user of well water.

For the comparative risk assessment, it was assumed that a chemical barrier would not impede the release and migration of contaminants from the tank and other sources of residual contamination after site closure. This assumption is reasonable because the likely range of hydraulic conductivities of chemical barriers would allow a hydraulic flux through the barrier equivalent to the recharge flux within a short period of time. See Section 6.1.7 for analysis of advection into chemical barriers. The relatively high ionic diffusivity expected for barriers would also facilitate migration through the barrier, especially under the low recharge rates assumed in this analysis.

It was also assumed that freeze wall and circulating air barriers would not offer permanent protection of the groundwater. Although the effectiveness of either barrier has not yet been proven for long-term containment (the freeze wall barrier appears likely to be successful with use of sufficient freeze piping and other engineered features), it seems inappropriate to assume that either of these barriers could be actively maintained for thousands of years. As discussed later in this section, the passive surface barrier alone appears capable of preventing contamination from reaching the aquifer for several thousand years, making the need for actively maintaining subsurface barriers questionable.

A first approximation of relative human health risks from exposure to contaminated groundwater was performed in a two-step analysis. The first step was definition of potential residual sources of groundwater contamination following completion of tank waste retrieval operations. This included identifying residual contaminant sources and their potential inventories of contaminants, and estimating the rates and durations of contaminant releases from these sources into the vadose zone. The assumptions and analytical methods used in defining residual contaminant source terms are presented and discussed in Section 6.1.

The second step in the assessment of relative risks involved modeling the transport of contaminants through the vadose zone and aquifer, and estimating potential human exposure and health risk. This was accomplished using the MEPAS Version 3.0g computer code (Droppo et al. 1989). The MEPAS is designed to evaluate relative human health risk from radiological and chemical contaminants released into the environment. The assumptions and analytical methods used in modeling contaminant transport and relative human health risk are presented and discussed in Section 6.2.

6.1 SOURCE TERMS, BASES, AND ASSUMPTIONS

This section defines the theoretical and parametric bases for potential sources of groundwater contamination that may result from the application of the 14 alternatives. These bases served as input to the MEPAS code to enable prediction of relative risk through the groundwater pathway.

The potential sources of groundwater contamination that were analyzed include the following:

- Residue in tank following waste retrieval
- Residue between tank steel and concrete foundation
- Residue within tank concrete
- Residue in soil due to old and new leaks
- Residue following soil flushing of old and new leaks

- Residue within close-coupled barrier
- Residue following use of standoff barrier.

General assumptions for the relative risk analysis are described in Section 6.1.1. The potential sources of groundwater contamination and bases for a separate sensitivity analysis are described in Sections 6.1.2 through 6.1.8. The sensitivity analysis was used to assess the potential impact of changes in the performance of the technologies considered. It was also used to assess the importance of parameters that impact the source term.

6.1.1 General Assumptions

A hypothetical SST tank farm comprising twelve, 3.8 x 10^6 L (1-Mgal) tanks was selected for modeling relative risk through the groundwater pathway. The tank farm was assumed to exist in a three by four array with each of the 22.9 m (75-ft) diameter tanks on 30.5 m (100-ft) centers. The base of each tank was assumed to be 15.3 m (50 ft) belowgrade. The plan dimensions of the tank farm were 83.9 by 114 m (275 by 375 ft), which yielded a surface area of 9,580 m^2 (103,000 ft^2). This area defined the assumed capture zone for precipitation, part of which was assumed to recharge through the tank-related contaminated media. The contaminants mobilized by the recharge water were assumed to be transported to the groundwater where they subsequently were drawn into a well used for drinking water, irrigation, and other uses.

One-million gallon tanks are the largest tanks used at the Hanford Site. They were selected for this analysis because they feature the largest cross-sectional area for capturing recharge water. A greater amount of recharge water corresponds to faster leaching of residual contaminated media from the tanks following sluicing. This results in a somewhat conservative analysis.

6.1.1.1 Recharge. Two recharge conditions were assumed: (1) a recharge rate of 5 cm/yr (2 in./yr), which corresponds to the approximate recharge through Hanford Site soils with minimal surface vegetation or a wetter climate (DOE 1987) and (2) a recharge rate of 0.05 cm/yr (0.02 in./yr), which corresponds to the expected maximum recharge through the Hanford Permanent Isolation Surface Barrier described in Section 4 (Gee et al. 1993). Wastes within the confines of the tanks were assumed to be mobilized by recharge through the area defined by the combined area of the 12 tanks. This area is 4,900 m^2 (53,000 ft^2). All wastes outside the tanks are assumed to be mobilized by recharge that occurs over the entire area of the tank farm.

6.1.1.2 Selection of Constituents of Concern. The full spectrum of constituents known or expected to be contained within the underground storage tanks includes more than 150 chemicals and radionuclides. To simplify the evaluation, a shorter list of COCs was developed. These include the constituents that contribute most of the risk to human health.

For the purposes of developing the list of COCs, the *Single-Shell Tank Constituent Rankings for Use in Preparing Waste Characterization Plans* report (Droppo et al. 1991) was reviewed. That report provided an analysis and ranking of tank waste constituents, based on risk to human health. Droppo et al. (1991) evaluated risks, based on leakage and transport to groundwater and human health exposure through ingestion and use of groundwater for irrigation. Table 6-1 lists the constituents that were determined in that study to result in a carcinogenic risk greater than 1 x 10^{-6} or a noncarcinogenic HI greater than 1 at recharge rates of 10 cm/yr (4 in./yr). A separate evaluation of these constituents was also performed as part of this study using the MEPAS code. The results of this second evaluation are also presented in Table 6-1. The list of COCs derived in the second evaluation is shorter, but generally consistent with the results obtained by Droppo et al. (1991).

Neither evaluation addressed organic constituents that are known or suspected to be present within the tank wastes, except for EDTA. The organic constituents in the tanks have been estimated in the Hanford Defense Waste Environmental Impact Statement (HDW-EIS) (DOE 1987). Included in the HDW-EIS evaluation are approximately 40 organic chemicals in neutralized cladding removal wastes, double-shell slurry wastes, and organic complexant wastes. The types of organic chemicals identified include solvents, volatiles, chelating/complexing agents, and acids. However, inspection of the list of chemicals revealed that many of these constituents may no longer be present in the identified form as a result of chemical interactions with each other or with the inorganic materials within the tanks. Furthermore, from the list of organic constituents above the detection limit identified in tank wastes, only EDTA and TBP have known toxicity values. Therefore, only these two organic constituents were included in the list of COCs.

From the evaluations described above, the final list of COCs to be evaluated in this study was developed and is presented in Table 6-2. The COCs selected are those that ranked in the top 90% of the cumulative risk contributors from the MEPAS evaluations. Although they did not rank in the top 90%, EDTA and TBP were also included because they are common organic contaminants in the tank wastes.

6.1.1.3 Contaminant Inventory. The original inventory of waste within the 149 SSTs was assumed to be 223,000,000 kg (491,000,000 lb) as reported by Boomer et al. (1993). This mass includes 97,000,000 kg (213,000,000 lb) of nitrate. It was assumed that the 12 tanks in the hypothetical tank farm include an average amount of nitrate, i.e., 650,000 kg (1,430,000 lb) each. Thus, the 12 tanks contain a total of 7,800,000 kg (17,200,000 lb) of nitrate. Table 6-3 shows the assumed total inventory of the eight COCs considered in this study. These inventories, which were derived from Boomer et al. (1993), reflect total masses in the hypothetical tank farm. Table 6-3 also shows the assumed concentrations of the contaminants after dissolving in recharge water and the assumed concentrations present in interstitial liquid (the aqueous phase that drains from and through the saltcake and sludge). Interstitial liquid probably exists in chemical equilibrium with the salt cake and sludge. It collects in the bottom of SSTs and is periodically removed by pumping.

Table 6-1. Comparison of Constituent Rankings.

Constituent Rankings			
Droppo et al. (1991)		This Study[a]	
Carcinogens[b]	Noncarcinogens[c]	Carcinogens	Noncarcinogens
As	Sb	^{14}C	Sb
^{238}U	EDTA[d]	^{99}Tc	NO_3
^{99}Tc	Hg	^{238}U	V
^{14}C	NO_2	^{129}I	NO_2
^{129}I	V	^{241}Am	Cr
^{235}U	Cr		F
^{242m}Am	Be		
^{240}Pu	NO_3		
^{239}Pu	Na		
^{238}Pu	F		
^{234}U	SO_4		
^{241}Am	CN		
^{242}Cm	Cu		
^{237}Np			
^{233}U			
^{241}Pu			
^{93m}Nb			

[a]Derived using MEPAS - Multimedia Environmental Pollution Assessment System.
[b]Only constituents that were determined to have a risk greater than 1×10^{-6} are included on this list.
[c]Only constituents with a hazard index of greater than 1 are included on this list.
[d]EDTA - ethylenediaminetetraacetic acid.

Table 6-2. Constituents of Concern Evaluated in the Risk Model.

Radionuclides	Chemicals
^{14}C	NO_3
^{99}Tc	NO_2
^{129}I	TBP[a]
^{238}U	EDTA[b]

[a]TBP - tributyl phosphate
[b]EDTA - ethylenediaminetetraacetic acid

Table 6-3. Assumed Contaminant Data for Hypothetical Tank Farm.

Contaminant	A Inventory	B Assumed Recharge Concentration Exiting Tanks	C Assumed Interstitial Liquid Concentration	D Assumed Solubility[a]
NO_3[b]	7,800,000 kg	360 g/L	250 g/L	360 g/L
NO_2[c]	390,000 kg	18 g/L	12 g/L	60 g/L
TBP[d]	950 kg	0.04 g/L	0.03 g/L	N/A[f]
EDTA[e]	1,400 kg	0.062 g/L	0.04 g/L	0.0028 g/L
^{14}C	240 Ci	0.011 Ci/L	0.008 Ci/L	0.000003 Ci/L
^{129}I	2 Ci	0.00009 Ci/L	0.00006 Ci/L	0.0000003 Ci/L
^{99}Tc	1,300 Ci	0.058 Ci/L	0.04 Ci/L	0.0003 Ci/L
^{238}U	37 Ci	0.002 Ci/L	0.001 Ci/L	0.0000009 Ci/L

[a]Serne and Wood (1990)
[b]NO_3^- nitrate
[c]NO_2^- - nitrite
[d]TBP - tributyl phosphate
[e]EDTA - ethylenediaminetetraacetic acid
[f]N/A - not available

The concentrations shown in Table 6-3 are based on the assumption of congruent leaching of all contaminants with nitrate. The assumed data shown for nitrate in Table 6-3 in recharge water (column B) and interstitial liquid (column C) are based on nitrate solubility information in Serne and Wood (1990) and Boomer et al. (1993), respectively. Assumed solubilities for each of the COCs reported by Serne and Wood (1990) are also shown for comparison in Table 6-3 (column D). The column D solubilities are based on the highest concentrations observed in samples of aqueous waste removed from Hanford Site tanks. The radionuclide concentrations are more than two orders of magnitude lower than corresponding concentrations estimated by assuming congruent leaching with nitrate. Thus, calculated risks associated with exposure to radionuclides are somewhat conservative. See Section 8 for a comparison of results based on the congruent leaching assumption and the column D solubilities.

If the values reported by Serne and Wood (1990) are representative of the concentrations that would be released by the SSTs over the long-term, the measures of relative carcinogenic risk computed in this analysis are conservative, but acceptable for the comparative purposes of a relative risk analysis. The estimated hazard due to exposure to noncarcinogens (NO_3, NO_2, and EDTA) using solubility data from Serne and Wood may be somewhat higher than estimated in this analysis due to a higher NO_2 solubility than assumed in the analysis. Use of the column D NO_2 solubility is probably inappropriate because it represents conditions in a single tank which would overstate risks associated with the average tank.

The residual inventories of only nitrate in the seven sources of potential groundwater contamination are analyzed in Section 6.1.2 through 6.1.8. The inventories and fluxes of nitrate are reported to facilitate the reader's comparison of the relative importance of each source. Section 6.2 provides a description of the use of MEPAS to compute relative risk. Section 6.3 provides a first approximation estimate of the groundwater risks associated with all eight COCs.

6.1.2 Residue In Tank Following Waste Retrieval

The residual waste in the tanks following waste retrieval is represented schematically in Figure 6-1. Each of the alternatives evaluated in this study included one of the following four retrieval options:

- No retrieval
- Retrieval using traditional sluicing
- Retrieval using robotic sluicing
- Retrieval using mechanical retrieval techniques.

When no retrieval occurs as in the No-Action Alternative, the residual waste inventory in the tank would be equal to the current assumed inventory. When retrieval is conducted using traditional sluicing, 1% of the inventory of each of the COCs was assumed to remain. When retrieval is conducted using robotic sluicing, 0.1% of the inventory was assumed to remain.

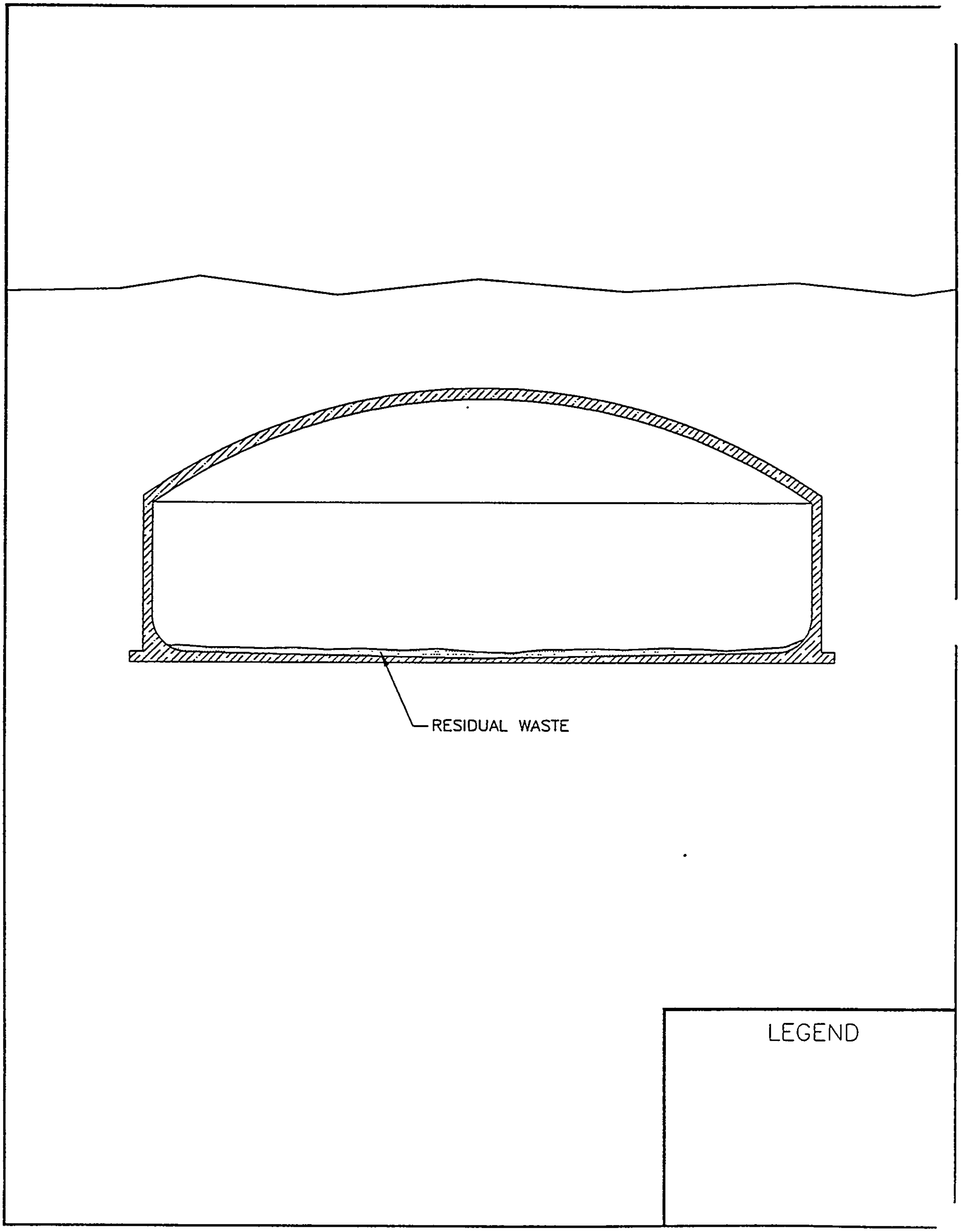

Figure 6-1. Residual Waste in Tanks Following Retrieval.

When retrieval is conducted using mechanical retrieval techniques, 5% of the inventory was assumed to remain. These removal efficiencies are based on data presented in Boomer et al. (1993). For comparison with the nitrate levels in the six other sources of potential groundwater contamination described in this section, the total residual nitrate in the 12 tanks following retrieval would be 78,000 kg (172,000 lb), 7,800 kg (17,200 lb), and 390,000 kg (860,000 lb) for traditional sluicing, robotic sluicing, and mechanical retrieval, respectively. This residual inventory was assumed to be mobilized by water advecting through the combined area of the tanks (4,900 m^2 [53,000 ft^2]). At recharge rates of 5 and 0.05 cm/yr (2 and 0.02 in./yr), this was equivalent to 0.7 and 0.007 m^3/day (24 and 0.24 ft^3/day) of total recharge water, respectively. Advection rates through individual tanks were assumed to be 0.06 and 0.0006 m^3/day (2 and 0.02 ft^3/day), for the respective recharge rates.

The solubility of nitrate in tank waste was assumed to be 360 g/L or 22.4 lb/ft^3 (Serne and Wood 1990). Thus, the assumed total dissolution rates of nitrate would be 240 and 2.4 kg/day (530 and 5.3 lb/day) for the 5 and 0.05 cm/yr (2 and 0.02 in/yr) recharge scenarios, respectively. The time (t) required to deplete the nitrate inventory by dissolution is defined by the following equation:

$$t = I/m_d \qquad \text{(Eq. 1)}$$

Where:

I = total residual nitrate inventory in the tank farm following retrieval (M = mass)

m_d = mass of nitrate dissolved per day (M/T = time)

The results of the nitrate inventory analysis are shown in Table 6-4.

Table 6-4. Tank Residual Nitrate Data.

Retrieval Method	Total Residual Inventory (kg)	Total Mass Dissolved Per Day (kg)	Time to Complete Dissolution (yr)
No-Action[a]	7,800,000	240	89
Tradition Sluicing	78,000	2.4	89
Robotic Sluicing	7,800	2.4	9
Mechanical Retrieval	390,000	2.4	445

[a]The No-Action Alternative is based on the assumption of a 5 cm/yr recharge rate. All other alternatives are based on the assumption of a 0.05 cm/yr recharge rate through a Hanford Permanent Isolation Surface Barrier installed over the structurally stabilized tank farm.

The waste inventory in the tanks was assumed to be released from an elevation 15 m (50 ft) belowgrade until the entire inventory was depleted. Species with relatively low solubilities could be released over a longer time period than nitrate. It was assumed in this analysis that all COCs leach congruently with nitrate. This assumption may be conservative in certain cases (e.g., where relatively insoluble species have been formed, such as uranium phosphate). Data presented in Serne and Wood (1990) and in Table 6-3 also support the conservatism of the congruent leaching assumption. A sensitivity analysis was conducted in Section 8 to evaluate the effects of solubility-limited releases of individual COCs.

Assumptions for Sensitivity Analysis

It may be possible to increase the effectiveness of the traditional sluicing technology if a weak acid is used during the final stages of tank cleanout. Boomer et al. (1993) reported that inhibited sulfuric acid was used in a laboratory test to dissolve hard, agglomerated sludges that resisted erosion by traditional sluicing methods. Boomer et al. (1993) also reported that the acid was believed to have been used in the cleanout of at least one tank. If the acid is successful in breaking up the sludge to increase its surface area, the sluicing water may be effective in leaching the COCs as most are soluble. Although a significant volume of insoluble waste species would remain after several in-tank leaching cycles, the insoluble species would have relatively little impact on groundwater contamination due to their low mobilities. They are relatively immobile because of low solubilities and because most would adsorb strongly to Hanford Site soil.

Consequently, for purposes of the sensitivity analysis, it was assumed that the use of weak acids would result in recovery of 99.9% of each COC. Thus, the effectiveness of traditional and robotic sluicing would be equal. In contrast, the presence of the hard, agglomerated sludges may render traditional sluicing less effective than predicted in Boomer et al. (1993). A recovery efficiency of 95% may be more appropriate if agglomerated sludges are common and weak acid is not used. Thus, the effectiveness of traditional sluicing and mechanical retrieval would be equal in this case.

6.1.3 Residue Between Tank Steel and Concrete Foundation

The residual waste between the tank steel bottom and the concrete foundation is shown schematically in Figure 6-2. Any tank that has leaked waste to the soil through its base is also likely to have at least partially filled the void space between the tank steel and concrete foundation with liquid waste. The liquid waste may also entrain solid waste particles as it flows into this void space. The small void space (assumed to average 1 mm [0.039 in.] thick) was assumed to exist because the steel bottom of the tank was constructed upon a previously formed concrete base. In certain cases (e.g., Tank 241-C-103) the steel bottom was constructed after applying a thin asphalt coating on the concrete base. The void space was assumed to exist because of roughness in the finish of the concrete and because of warpage induced by welding the sheets of steel that form the steel bottom.

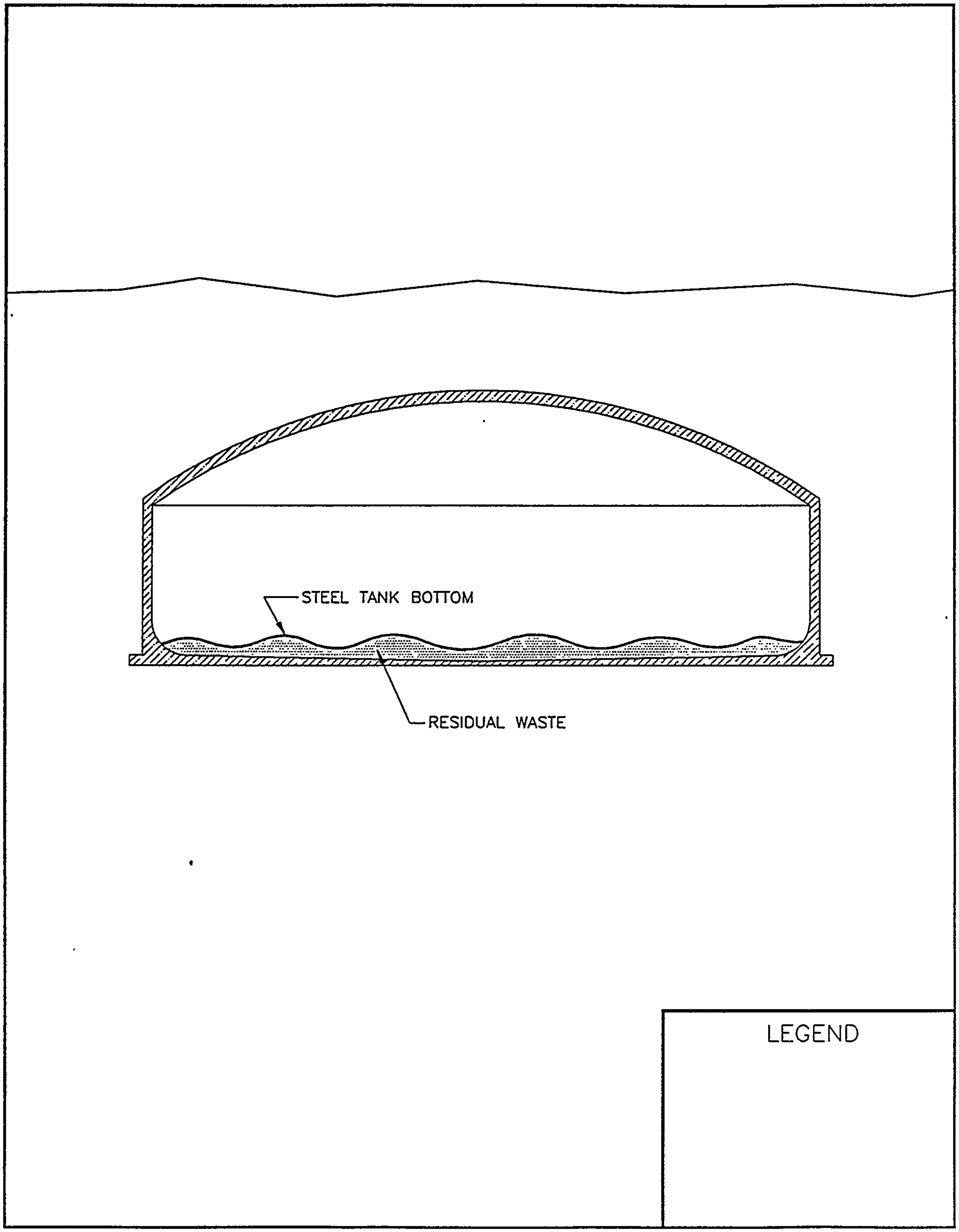

Figure 6-2. Residual Waste Trapped Between Tank Steel and Concrete Foundation.

No void space was assumed to exist between the wall of the tank and the concrete shell because this concrete was poured against the steel wall, which acted as a form. This assumption may be nonconservative. Lowe (1993), for example, reported that the most likely leak mechanism during the sluicing of Tank 241-C-106 would be formation of cracks in the steel wall, with resultant migration of the leak between the steel and concrete to the construction joint between vertical and horizontal concrete members of the tank structure.

Five of the twelve tanks in the hypothetical tank farm were assumed to contain liquid waste between the steel and concrete base. The five tanks in 12 are proportional to the 67 of 149 tanks overall that were assumed to have leaked (Hanlon 1993). An additional two tanks in the hypothetical tank farm were assumed to develop leaks through the bases of the tanks during new sluicing operations. The assumption of two additional leaking tanks was based on the assumption that the total number of leaking tanks would increase proportionately with age. Thus, alternatives that include sluicing were evaluated assuming that the hypothetical tank farm had waste between the steel and concrete in seven of its 12 tanks.

The concentration of the waste in the void space was assumed to be that of interstitial liquid shown in Table 6-3. Boomer et al. (1993) reported that 1.1×10^{10} g (2.4×10^{7} lb) of interstitial liquid in SSTs contains 1.8×10^{9} g (4.0×10^{6} lb) of nitrate. Metz (1976) reported that the density of interstitial liquid is about 1.5 g/cm^3 (94 lb/ft^3). Thus, the nitrate concentration of the interstitial liquid would be 250 g/L (15.6 lb/ft^3). All other COCs in interstitial liquid were assumed to be in concentrations proportional to the nitrate concentrations in interstitial liquid and total tank waste.

The mass of a contaminant in the void space was assumed to equal to the volume of the void times the contaminant concentration in the waste liquid. Each tank in the hypothetical tank farm was assumed to have a 23-m (75-ft) diameter base. Thus, the volume of a single tank void space would be 0.4 m^3 (14.5 ft^3) and the mass of nitrate in the steel/concrete void space in a single tank would be 100 kg (230 lb). For alternatives that do not involve sluicing, the total mass of nitrate in the void space of the five affected tanks would be 510 kg (1,100 lb). For alternatives that involve sluicing, the total nitrate mass would be 720 kg (1,600 lb) in the seven affected tanks.

It was assumed that the residual inventory of contaminants between the shell and concrete would be released through displacement by advecting recharge water. The time (t) required for the advecting water to displace the waste liquid in the void space is given by the following equation:

$$t = V_{stv}/R_{st} \qquad \text{(Eq. 2)}$$

Where:

V_{stv} = volume of waste liquid in a single tank void (0.4 m^3 [14.5 ft^3]) (L^3 = length)

R_{st} = recharge rate into single tank (0.06 m^3/d or 0.0006 m^3/d [2 ft^3/day or 0.02 ft^3/day]) (L^3/T)

The time required to displace the liquid in the voids would be 7.3 days and 730 days for recharge rates of 5 and 0.05 cm/yr (2 and 0.02 in/yr), respectively. The total flux of nitrate from this source in the five affected tanks in the No-Action Alternative would be 71 kg/day (160 lb/day). The total nitrate flux for the Mechanical Retrieval Alternative, which does not involve sluicing, would be 7.1 kg/day (1.6 lb/day). The total nitrate flux for all other alternatives would be 1 kg/day (2.2 lb/day). The waste source was assumed to release its COCs to the soil at an elevation of 15 m (50 ft) belowgrade.

<u>Assumptions for Sensitivity Analysis</u>

It was assumed that one tank in the hypothetical tank farm is similar to Tank 241-A-105. This tank has a 300,000 L (80,000 gal) bulge in the steel base. An estimated 57 to 110 m^3 (2,000 to 4,000 ft^3) of sludge were assumed to fill the void created by the bulge (Woodward-Clyde Consultants 1978). Air is assumed to fill most of the bulge space. For this study it was assumed that the tank contains 83 m^3 (3,000 ft^3) of sludge with a density of 1.8 g/cm^3 (110 lb/ft^3). Thus, the total mass of the sludge would be 150,000 kg (330,000 lb). The masses of the COCs in the sludge were assumed to be in proportion to their relative concentrations in the assumed tank waste inventory. Boomer et al. (1993) reported that the ratio of total nitrate to total sludge is 15 to 78. Thus, the inventory of nitrate in the bulge space of this hypothetical tank would be 29,000 kg (64,000 lb). This quantity greatly exceeds the mass assumed to exist in the void space of seven tanks (710 kg [1,600 lb]). For this analysis, the time for dissolution of the nitrate would be 4.0 years and 400 years for recharge rates of 5 and 0.5 cm/yr (2 and 0.02 in./yr), respectively. The associated fluxes are 20 and 0.2 kg/day (45 and 0.45 lb/day) from this tank, respectively.

6.1.4 Residue Within Tank Concrete

Contaminants assumed to have penetrated into a tank's concrete are shown schematically in Figure 6-3. Any tank that has leaked waste to the soil was assumed to have had its concrete shell exposed to contamination by advective and/or diffusive mechanisms. For purposes of defining conditions to evaluate this waste source, it was assumed that five of the 12 tanks had leaked in the past. In each case, the leak was assumed to have filled the void space between the steel and concrete base with liquid waste, as described in Section 6.1.3. The void space was assumed to have been connected hydraulically to a head of interstitial liquid contained by the tank.

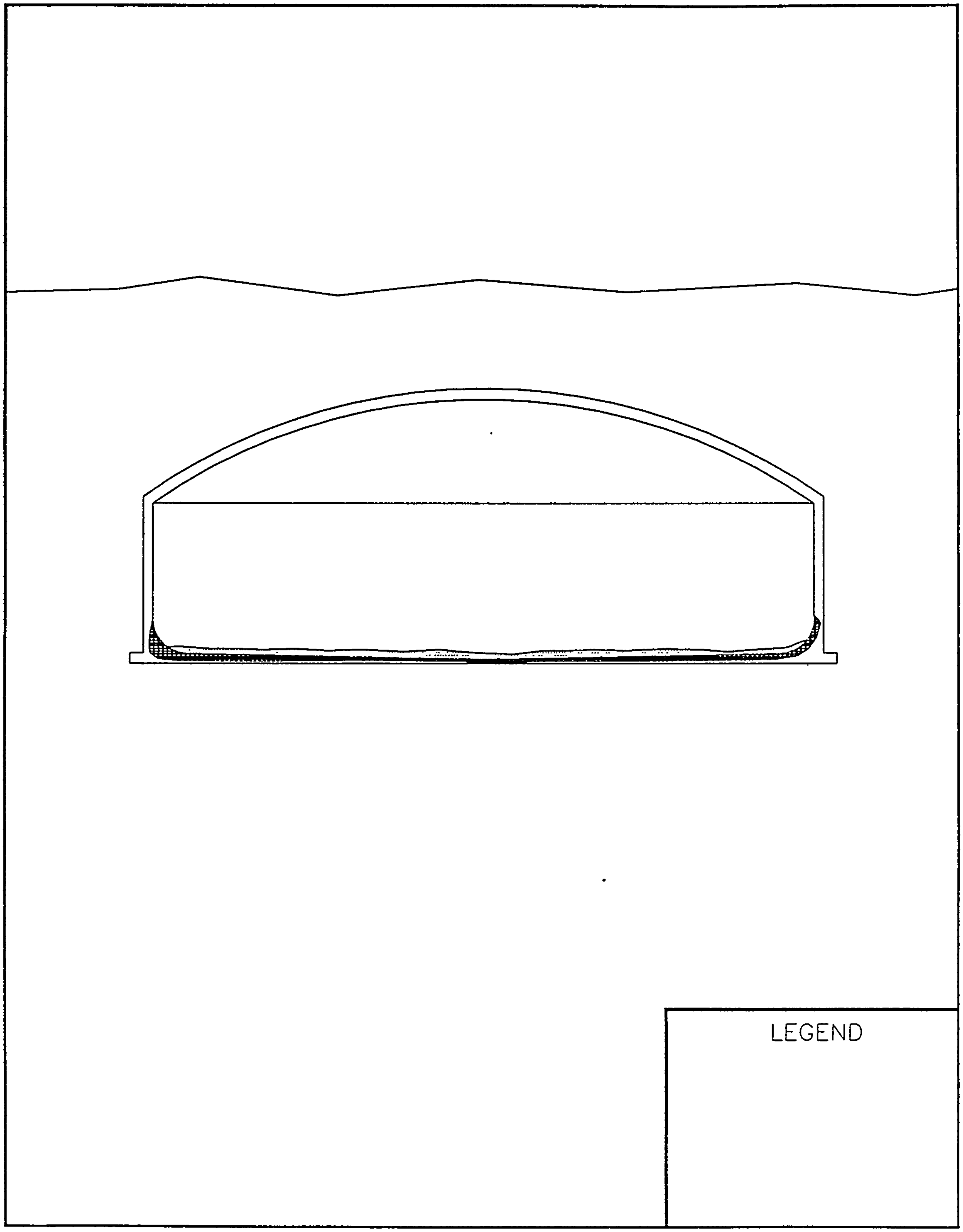

Figure 6-3. Diffusion and Advection of Waste into Concrete Foundation.

Advection

The head of liquid on the concrete was assumed to have been the driving force for advection of interstitial liquid waste into the concrete in accordance to Darcy's law:

$$Q = -KA\ dh/dx \qquad \text{(Eq. 3)}$$

Where:

- Q = rate of flow (L^3/T)
- K = hydraulic conductivity (L/T)
- A = cross-sectional area contacted at right angle by the liquid under head (L^2)
- h = liquid head (L)
- x = distance along direction of transport (L).

The flux through the concrete also depends on the effective porosity of the concrete and time;

$$Q = nA\ dx/dt \qquad \text{(Eq. 4)}$$

Where:

- n = effective porosity of the concrete (unitless)
- t = time (T).

By combining these two equations and integrating,

$$x^2 = 2(Kh/n)t \qquad \text{(Eq. 5)}$$

The mass (M) of a contaminant that has advected a distance of x into the concrete is given by:

$$M = C_o xnA \qquad \text{(Eq. 6)}$$

Where:

- C_o = initial contaminant concentration (M/L^3)

Combining Equations 5 and 6 yields:

$$M = C_o A\sqrt{2Khnt} \qquad \text{(Eq. 7)}$$

The validity of this equation is predicated on several assumptions:

- Rate of flow (Q) occurs in slug flow in one direction into the concrete, filling the entire effective porosity (n), over cross-sectional area (A) perpendicular to the flow
- The concrete provides no interference to the advancement of the slug due to the presence of air in the concrete
- The concentration (C_o) is constant throughout the advective section
- No retardation occurs
- The variation of head (h) throughout the flow zone is linear
- The gradient (-h/x) is uniform at a given time but diminishes over time as the depth of liquid penetration (x) increases
- The front of the advecting liquid (x) does not break through the concrete/soil interface.

The assumed initial concentration (C_o) of each COC is that of interstitial liquid defined in Section 6.1.1.3. It was assumed that sufficient flow of the interstitial liquid into the steel/concrete void area would occur to prevent depletion of the concentration by diffusive losses. The area (A) for the contaminant mass calculation was that defined by the 23-m (75-ft) diameter of each tank base (410 m^2 [4,400 ft^2]). The hydraulic conductivity (K) of the concrete was assumed to be 3.75×10^{-10} cm/s (1.06×10^{-6} ft/day) and the porosity was assumed to be 0.22. Both values were used to estimate the performance of concrete vaults for the disposal of Hanford Site grout (Blanchard et al. 1993).

The average height of interstitial liquid on the concrete was assumed to be 0.3 m (1 ft), or 0.5 m (1.5 ft) of water head based on the assumed density of 1.5 g/cm^3 (94 lb/ft^3) for interstitial liquid. It was assumed that this head had been applied for an average of 15 years. A period of 15 years is typical of the time elapsed since SST leaks were detected. Under these conditions, a total of 1,900 kg (4,300 lb) of nitrate were calculated to have advected into the concrete of each affected tank.

Nitrate was assumed to advect into the concrete during sluicing operations. For traditional sluicing, an average head of 4.6 m (15 ft) would be applied over a period of 123 days. The sum of the two advective terms results in 14,000 kg (31,000 lb) of nitrate advected into the concrete of the leaking tanks. Based on the assumptions associated with alternatives that employ traditional sluicing and Equation 5, the following penetrations into concrete would occur:

- 4.1 cm (1.6 in.) into two tanks (123 days at 4.6 m head)

- 8.6 cm (3.4 in.) into two tanks (15 years at 0.46 m head)
- 12.7 cm (5.0 in.) into three tanks (123 days of 4.6 m head plus 15 years at 0.46 m head).

Lower heads generated during robotic sluicing do not significantly change the total masses advected into the concrete.

It was assumed that COCs in this waste source would be leached from the concrete when the advecting recharge water passed through the associated tanks, following depletion of the entire COC inventory in the tank and void space between the tank steel and concrete. As reported in Section 6.1.2, the time to complete depletion of the tank inventory would be 89 years for the 5 cm/yr (2 in./yr) scenario and ranged from 9 years for the Robotic Sluicing Alternative to 445 years for the Mechanical Retrieval Alternative for the 0.05 cm/yr (0.02 in./yr) scenario. As reported in Section 6.1.3, the time to deplete the void space between the tank steel and concrete of COCs would be 7.3 days for the 5 cm/yr (2 in./yr) recharge scenario and 730 days for the 0.05 cm/yr (0.02 in./yr) recharge scenario.

When these inventories were depleted, the recharge water was assumed to leach the contaminants in the concrete at a rate yielding one-half the concentration of the initial waste concentration in contact with the concrete. This lower level of recovery was assumed to be appropriate because the contaminants would be diluted by water previously contained in the concrete and because the contaminants would have to diffuse to the surface of the concrete before they could be mobilized by advecting recharge water. One-half the initial concentration of nitrate in contact with the concrete would be 125 g/L (7.8 lb/ft^3). At recharge rates of 5 cm/yr (2 ft^3/day per tank) and 0.05 cm/yr (0.02 ft^3/day per tank), the time (t) for complete removal of the nitrate in the concrete would be determined by:

$$t = M_{st}/C_l R_{st} \qquad \text{(Eq. 8)}$$

Where:

M_{st} = mass of contaminant advected into concrete of a single tank (M)

C_l = resulting concentration of a contaminant in recharge water (M/L^3)

R_{st} = recharge rate through a single tank (L^3/T).

The time (t) required to deplete COCs from the concrete for the 5 and 0.05 cm/yr (2 and 0.02 in./yr) scenarios would be 0.76 years and 77 years, respectively. The associated fluxes for these cases would be 35 kg/day and 0.50 kg/day (78 lb/day and 1.1 lb/day). The elevation of this source of contamination was assumed to be 15.25 m (50 ft) belowgrade.

Assumptions for Sensitivity Analysis Involving Advection

Finely grained sludge particles may have effectively plugged the joints and cracks in the shell and concrete, thereby restricting the area and flow of waste liquid into the voids. Thus, the volume estimated to have advected into the concrete could be substantially too high (e.g., by a factor of 10). This would result in a total nitrate inventory of 1,400 kg (3,100 lb) in the seven affected tanks.

Conversely, cracks are likely to exist in the concrete and its quality may be lower since it was constructed using standards applicable 40 years ago. Degradation of the concrete over time may also have occurred. Any of these factors may have increased the effective conductivity of the concrete structure. If the average conductivity is a factor of 10 above that assumed for concrete in Blanchard et al. (1993), the mass of nitrate advected into the concrete would increase by a factor of 3.2, in accordance to Equation 7. This would result in a total nitrate mass of 45,000 kg (99,000 lb) for alternatives involving traditional sluicing. The No Action, Surface Barrier Only, Mechanical Retrieval, and Robotic Sluicing Alternatives would have a nitrate mass of 31,000 kg (68,000 lb) in this case.

Diffusion

Contaminants may also migrate into the concrete as a consequence of diffusion. The diffusive mass flow rate (J) can be determined by Fick's Law;

$$J = -\theta_m DA \, dc/dx \qquad \text{(Eq. 9)}$$

Where:

- θ_m = mass moisture content of concrete (unitless)
- D = effective ionic diffusivity in concrete (L^2/T)
- A = area across which diffusion occurs (L^2)
- c = waste concentration (M/L^3)
- x = distance for diffusive transport (L).

Several assumptions must be made to simplify diffusion calculations.

- Conceptually, diffusion proceeds one-dimensionally beyond the interface of the contaminated medium (waste solution), into the uncontaminated medium (concrete).

- The concentration gradient can be represented as approximately linear from concentration equals C_o at the interface of the liquid and concrete to concentration = O at some distance beyond the interface.

- Moisture content (θ_m) is constant at some initial moisture value (θ_{mi}) ahead of the interface. No moisture transport occurs within the diffusion zone. (Moisture transport was considered in the advection calculations earlier in this section.)

Given these assumptions Fick's law can be restated as:

$$J = \theta_{mi} D A C_o / \Delta x \qquad \text{(Eq. 10)}$$

The associated relationship for continuity is:

$$J = \theta_{mi} A C_o d(\Delta x)/dt \qquad \text{(Eq. 11)}$$

Where:

t = time (T).

By combining and integrating these equations:

$$(\Delta x)^2 = 2D\Delta t \qquad \text{(Eq. 12)}$$

$$\Delta x = \sqrt{2D\Delta t} \qquad \text{(Eq. 13)}$$

Using the simplifying assumption that the concentration profile is approximately linear, the mass (M) diffused into the concrete can be calculated as a triangle of height C_o and length Δx:

$$M = 1/2 C_o \Delta x \theta_{mt} A = C_o \theta_{mt} A \sqrt{D\Delta t/2} \qquad \text{(Eq. 14)}$$

Assumed values for contaminant concentration (C_o), area (A) and time period (Δt) are the same as those used earlier in this section. The moisture content of the concrete ahead of the advection front is estimated to be 70% of the total porosity, or 0.15. This value is based on the assumption that the fine pores in concrete will be largely filled with water under the humid conditions that exist below ground. The effective diffusivity of the concrete is assumed to be 5 x 10^{-8} cm^2/s (4.7 x 10^{-6} ft^2/day). The Hanford and Savannah River Sites used this value in performance assessments of grouted waste to be disposed at those sites (WHC 1993). For these conditions, the mass of nitrate that has diffused into the concrete in an individual tank was estimated to be 750 kg (1,600 lb).

The depth of diffusive penetration determined by this simplistic method was 6.9 cm (2.7 in.). This penetration "depth" is approximately equal to the 4.1 to 12.7 cm (1.6 to 5.0 in.) penetration depth estimated for advection. Most of the driving force for diffusion would be dissipated because advection would occur in the same space in the concrete that would be affected by diffusion. Thus, diffusion cannot be expected to control the mass of contamination in the concrete. For modeling purposes, it was assumed that the impacts of diffusion are insignificant.

Assumptions for Sensitivity Analysis Involving Diffusion

The assumed effective diffusivity value of 5×10^{-8} cm²/s (7.8×10^{-9} in.²/s) may be somewhat low since it was based on diffusion studies involving cesium and strontium. Both of these species tend to adsorb to calcic mineral phases within the concrete, thereby lowering the effective diffusivity.

Several of the contaminants of interest to this study (e.g., nitrate, nitrite, and ^{129}I) are unlikely to sorb within the concrete and will exhibit higher effective diffusivities. A 10-fold increase in the effective diffusivity would result in 3.2 times more mass and distance diffused. The resulting mass of nitrate diffused into the concrete of a single tank would be 1,700 kg (3,700 lb), an amount similar to the 2,800 kg (6,200 lb) assumed to advect into the concrete of a tank with the highest advection. Because the advective flux would encroach into the space in which diffusion is occurring, the concentration driving force from the concrete/waste solution interface would largely be eliminated. Thus, the overall effects of diffusion in this case would also be small and consequently are ignored in the sensitivity analysis.

6.1.5 Residue in Soil Due to Old and New Leaks

Soil contaminated by old and new leaks is shown schematically in Figure 6-4. It was assumed that five of the 12 tanks in the hypothetical tank farm previously leaked. Boomer et al. (1993) reported that 67 of the 149 SSTs leaked and discharged a total of about 2,850,000 L (750,000 gal). Thus, the average leakage per tank was assumed to be 42,000 L (11,000 gal). It was assumed further that each of the five hypothetical tanks leaked 42,000 L (11,000 gal) with a concentration equal to half that assumed for interstitial liquid. The reduced concentration was assumed because historic leaks occurred in many cases before the wastes were fully concentrated and after dilution of tank waste to facilitate sluicing operations. New leakage would be expected for alternatives that require sluicing except for those that include close-coupled barriers. In the cases of the Close-Coupled Barrier without Flushing Alternative and the Clean-Closure With Close-Coupled Barrier Alternative, it was assumed that two additional tanks leak 42,000 L (11,000 gal) each before barriers would be installed. In the case of the Modified Close-Coupled Barrier Without Flushing Alternative, it was assumed that two additional tanks would leak 150,000 L (40,000 gal) each due to the absence of a barrier underneath the tanks.

Lowe (1993) estimated that a leak of up to 150,000 L (40,000 gal) may occur during traditional sluicing of Tank 241-C-106 by the most likely leak mechanism. For this study it was assumed that five of the 12 tanks leak 150,000 L (40,000 gal) each during new sluicing operations at concentrations of half that of the interstitial liquid.

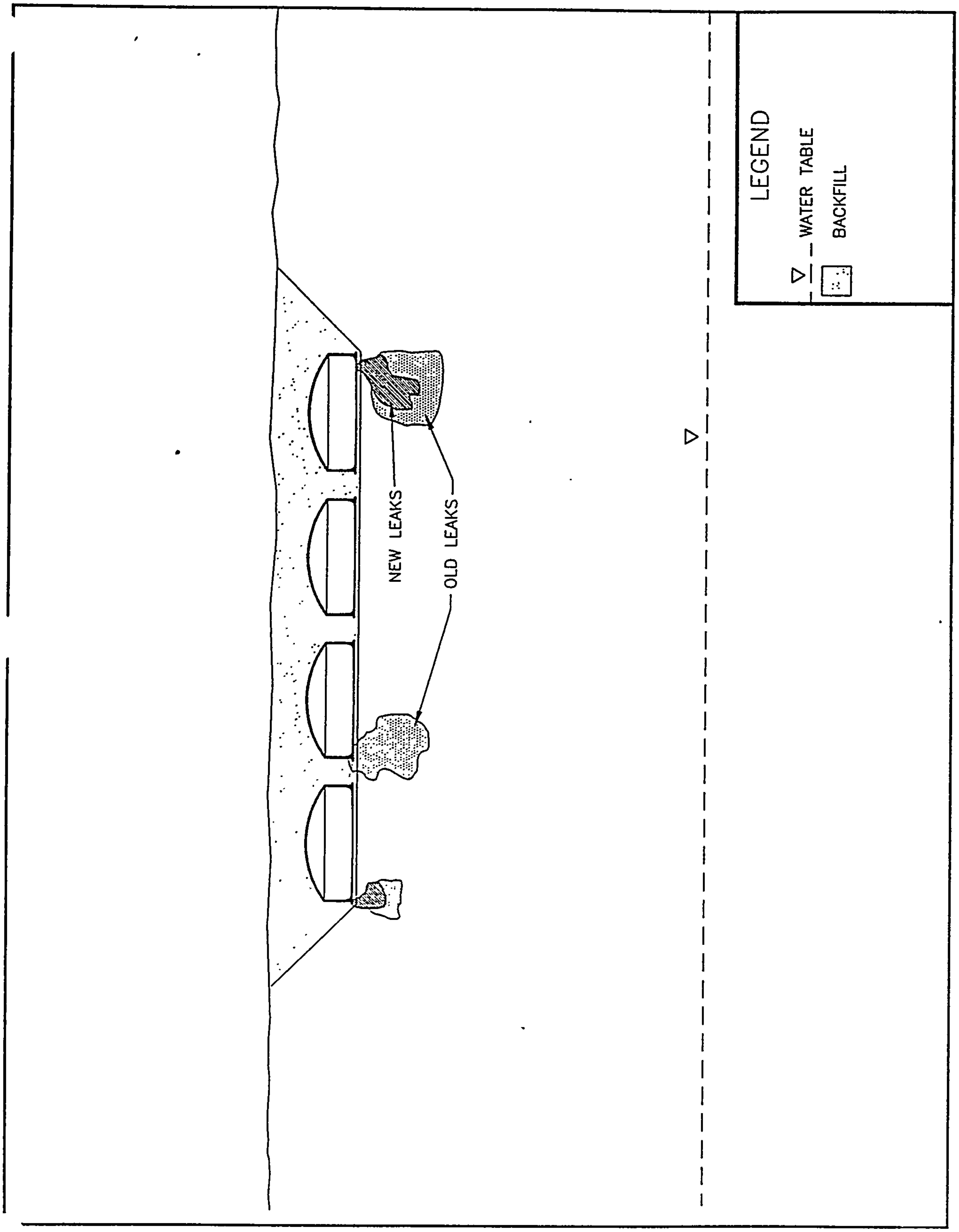

Figure 6-4. Old and New Leaks to the Soil.

It was also assumed that a total of 15,000 L (4,000 gal) leak from each of five of the 12 tanks in the case of robotic sluicing. This assumption was predicated on the lower head of liquid that will exist in tanks during robotic sluicing. This head was assumed to be 1/10 that required for traditional sluicing. The average head of liquid during traditional sluicing is expected to be about 4.6 m (15 ft) and the average head of liquid during robotic sluicing is expected to be about 0.5 m (1.5 ft). It is assumed that the lower head would be assured by pumping liquid as it slowly accumulates at existing and new salt wells in the tanks.

New leaks would likely occur in cracks or corroded areas of the tank wall where previous leaks occurred. Some locations of past leaks may have become sealed by particles or may exist at elevations above new sluicing liquid levels. New cracks may open during renewed sluicing operations. For ease of modeling, it was assumed that the five tanks that leak during renewed sluicing operations would discharge liquid waste through past leak locations.

Thus, alternatives without close-coupled barriers that involve traditional sluicing operations are modeled with five leaking tanks, each with assumed cumulative 193,000 L (51,000 gal) leaks. For comparison, the total nitrate discharged to the soil, per tank for assumed 42,000 and 193,000 L (11,000 and 51,000 gal) leaks, is 5,200 and 24,000 kg (11,000 and 53,000 lb), respectively. The total nitrate released from the five tanks was assumed to be 26,000 kg (57,000 lb) for old leaks and 120,000 kg (265,000 lb) for combined old and new leaks, respectively.

For robotic sluicing, the total old and new leakage per tank was assumed to be 57,000 L (15,000 gal), or 285,000 L (75,000 gal) for the five leaking tanks. This would be equivalent to 36,000 kg (80,000 lb) of nitrate released to the ground. For the Close-Coupled Barrier without Flushing Alternative and the Clean-Closure With Close-Coupled Barrier Alternative, a total of 293,000 L (77,000 gal) and 36,000 kg (79,000 lb) of nitrate would be released for each alternative. For the Modified Close-Coupled Barrier Alternative, a total of 26,000 kg (57,000 lb) of nitrate was assumed to have been released from old leaks. A total of 300,000 L (80,000 gal) would leak at the unprotected bases of two tanks during renewed sluicing operations. This would be equivalent to 39,000 kg (85,000 lb) of nitrate. Thus, the total nitrate that would leak to the soil in this alternative would be 63,000 kg (138,000 lb).

Boomer et al. (1993) reported data on the estimated depth of past SST leaks below the bottom of tanks, which are located 15 m (50 ft) beneath the surface. Data on the estimated depths of leaks reported by Boomer et al. (1993) are based on the assumptions that (1) plume dimensions are proportional to the well-characterized plume from Tank 241-C-106, and (2) plume volume is 57 times the leak volume. Local stratigraphy may greatly impact the size, shape, and depth of individual plumes. Using the data in Boomer et al. (1993), plume thicknesses of 8.5 and 15 m (28 and 49 ft) were estimated for leaks of 42,000 and 194,000 L (11,000 and 51,000 gal) respectively. Thus, the bases of these plumes would be located 24 and 30 m (78 and 99 ft) below the ground surface. Plumes of 57,000 L (15,000 gal) leaks resulting from robotic sluicing would be located 25 m (81 ft) below the ground surface.

The average flux (f) of contaminants from the base of a plume is modeled as:

$$f = \frac{Md_a}{t_a d_p} \qquad \text{(Eq. 15)}$$

Where:

M = total mass of contaminant in plumes (M)
t_a = time for recharge to travel from the base of the tank to the aquifer (T)
d_a = distance from the base of tank to the aquifer (L)
d_p = distance from the base of tank to the base of plume, i.e., plume thickness (L).

The time (t_a) for recharge to travel from the base of the tank to the aquifer was estimated using the MEPAS code. This code accounted for hydrogeologic definition of three strata between the surface and the aquifer (See Appendix A). Travel times of 190 years and 19,000 years were projected for recharge rates of 5 and 0.05 cm/yr (2 and 0.02 in/yr), respectively. Travel times of 19,000 years were assumed for each alternative except for the No-Action Alternative which would not include the use of the Hanford Permanent Isolation Surface Barrier. It was assumed that the distance between the tank base and the water table is 79 m (259 ft). Thus, the average pore velocity of contaminant plumes would be 0.4 m/yr (1.3 ft/yr) for the 5 cm/yr (2 in/yr) recharge scenario and 0.004 m/yr (0.013 ft/yr) for the 0.05 cm/yr (0.02 in/yr) scenario.

The duration (d) of the release is given by:

$$d = M/R \qquad \text{(Eq. 16)}$$

Where:

M = total mass of contaminant in plumes (M)
R = average contaminant release rate (M/T).

The overall release rates of nitrate, release durations, and plume depths below ground surface are summarized in Table 6-5. This table also includes nitrate release data for the Close-Coupled Barrier and Circulating Air Barrier Alternatives that use soil flushing as described in Section 6.1.6.

Assumptions for Sensitivity Analysis

New leakage may be smaller than estimated for alternatives employing traditional sluicing. For this sensitivity case, it was assumed that only 38,000 L (10,000 gal) of new leakage per tank occurs. This amount of leakage would be similar to the average of 42,000 L (11,000 gal) per tank that occurred in past leaks. The resulting 79,800 L (21,000 gal)

Table 6-5. Nitrate Release Data for Old and New Leaks.[a]

Alternative	Total Nitrate Mass in Plumes, M (kg)	Recharge Time, t_a (yr)	Tank to Aquifer Distance, d_a (m)	Plume Thickness, d_p (m)	Recharge Travel Rate, r_r (m/yr)	Overall Plume Release Rate, R (kg/day)	Release Rate Duration, d (yr)	Depth of Plume Base (m)
1. No Action	26,000	190	79	8.5	0.4	3.5	20	23.8
2. Surface Barrier Only	26,000	19,000	79	8.5	0.004	0.03	2,000	23.8
3. Traditional Sluicing	120,000	19,000	79	15	0.004	0.1	3,600	30.2
4. Robotic Sluicing	36,000	19,000	79	9.2	0.004	0.05	2,200	24.4
5. Mechanical Retrieval	26,000	19,000	79	8.5	0.004	0.03	2,000	23.8
6. Close-Coupled Barrier With Flushing[a]	1,500	19,000	79	8.5	0.004	0.002	2,000	23.8
7. Close-Coupled Barrier w/o Flushing	36,000	19,000	79	8.5	0.004	0.05	2,000	23.8
8. Modified Close-Coupled Barrier	63,000	19,000	79	15	0.004	0.05	3,600	30.3
9. Circulating Air Barrier[a]	7,200	19,000	79	8.5[b]	0.004	0.01	2,000	23.8
10. Traditional Sluicing (Low Sensitivity Case)	50,000	19,000	79	10	0.004	0.06	2,400	25.3
11. Traditional Sluicing (High Sensitivity Case)	168,000	19,000	79	16	0.004	0.12	3,800	31.3

[a]Results presented for the Close-Coupled Barrier and Circulating Air Barrier Alternatives represent conditions following soil flushing, as evaluated in Section 6.1.6.
[b]Plume thickness for the Circulating Air Barrier Alternative was assumed to be limited to the thickness of the original 41,800 L (11,000 gal) leak (8.5 m or 28 ft).

plumes (past plus new leakage) from each of the five leaking tanks would penetrate to a depth of about 10 m (34 ft) below their associated tanks, based on interpolation of data presented in Boomer et al. (1993). The total leakage from the five tanks would be 400,000 L (105,000 gal) and 49,000 kg (110,000 lb) of nitrate.

It was also assumed that a higher amount of past leakage can occur. Tank 241-T-106, for example, was estimated to have leaked a total of 437,000 L (115,000 gal) (Boomer et al. 1993). If the average past leak was assumed to be 114,000 L (30,000 gal), which is representative of a tank farm containing Tank 241-T-106 and four average leaking tanks, the cumulative old plus new leak total of 266,000 L (70,000 gal) per leaking tank would be assumed to penetrate to an average depth of 16 m (53 ft) below the tank using data in Boomer et al. (1993). The total leakage from the five tanks in this scenario would be 1,330,000 L (350,000 gal) and 165,000 kg (364,000 lb) nitrate.

Release data for the low and high sensitivity cases are summarized on Table 6-5. Total nitrate masses released due to old and new leakage are summarized in Table 6-6.

6.1.6 Residue Following Soil Flushing of Old and New Leaks

Residual contamination in the soil following soil flushing is shown schematically in Figure 6-5. It was assumed that flushing of COCs from the vadose zone using water will be effective for SST applications. Although the technology has not been developed for these applications, the low sorptive potential for the COCs and the hydraulically conductive nature of Hanford Site soils are conditions that are conducive to the successful application of the technology. A review of the literature revealed that soil flushing has resulted in removal efficiencies ranging to 98% in laboratory tests for a nonsorbing chemical following flushing with three pore volumes (Ellis and Payne 1984). Soil flushing is generally ineffective for removing strongly sorbed species.

It was assumed that retrieval of 94% of the leaked SST waste can be achieved. This removal efficiency is predicated on the assumption that 50% of the residual COCs will be removed with each succeeding pore volume flush. At this removal efficiency, the residual nitrate in the ground following 42,000 and 194,000 L (11,000 and 51,000 gal) of leakage and subsequent flushing would be 320 and 1,450 kg (690 and 3,200 lb), respectively, per affected tank. The total residual nitrate for five leaking tanks would be 1,550 and 7,220 kg (3,400 and 16,000 lb). Release data for residual nitrate following flushing for the Close-Coupled Barrier With Flushing and the Circulating Air Barrier Alternatives were provided in Table 6-5.

The estimated total volume of water required to flush five 42,000 L (11,000 gal) leaks using vacuum flushing was 5.2×10^7 L (14 Mgal). This estimate was based on the assumption that the volume requiring flushing under each tank that has leaked is defined by a cylindrical

Table 6-6. Summary of Pre-Flushing Leakage Into Soil.

	Total Leaked Nitrate (kg)[a]		
Alternative	Low Case	Best Case	High Case
1. No Action	26,000	26,000	70,000
2. Surface Barrier Only	26,000	26,000	70,000
3. Traditional Sluicing	49,000	120,000	165,000
4. Robotic Sluicing	36,000	36,000	79,000
5. Mechanical Retrieval	26,000	26,000	70,000
6. Close-Coupled Chemical w/Flushing[b]	26,000	26,000	70,000
7. Close-Coupled w/o Flushing[b]	36,000	36,000	80,000
8. Modified Close-Coupled w/o Flushing[b]	35,000	63,000	107,000
9. Box-Shaped Chemical	49,000	120,000	165,000
10. V-Shaped Chemical	49,000	120,000	165,000
11. V-Shaped Freeze Wall	49,000	120,000	165,000
12. Circulating Air Barrier	49,000	120,000	165,000
13. Clean-Closure w/o Barrier	49,000	120,000	165,000
14. Clean-Closure with Barrier[b]	36,000	36,000	80,000

[a]Total nitrate mass includes nitrate in old and new leakage.
[b]Does not include nitrate that advects into the barrier.

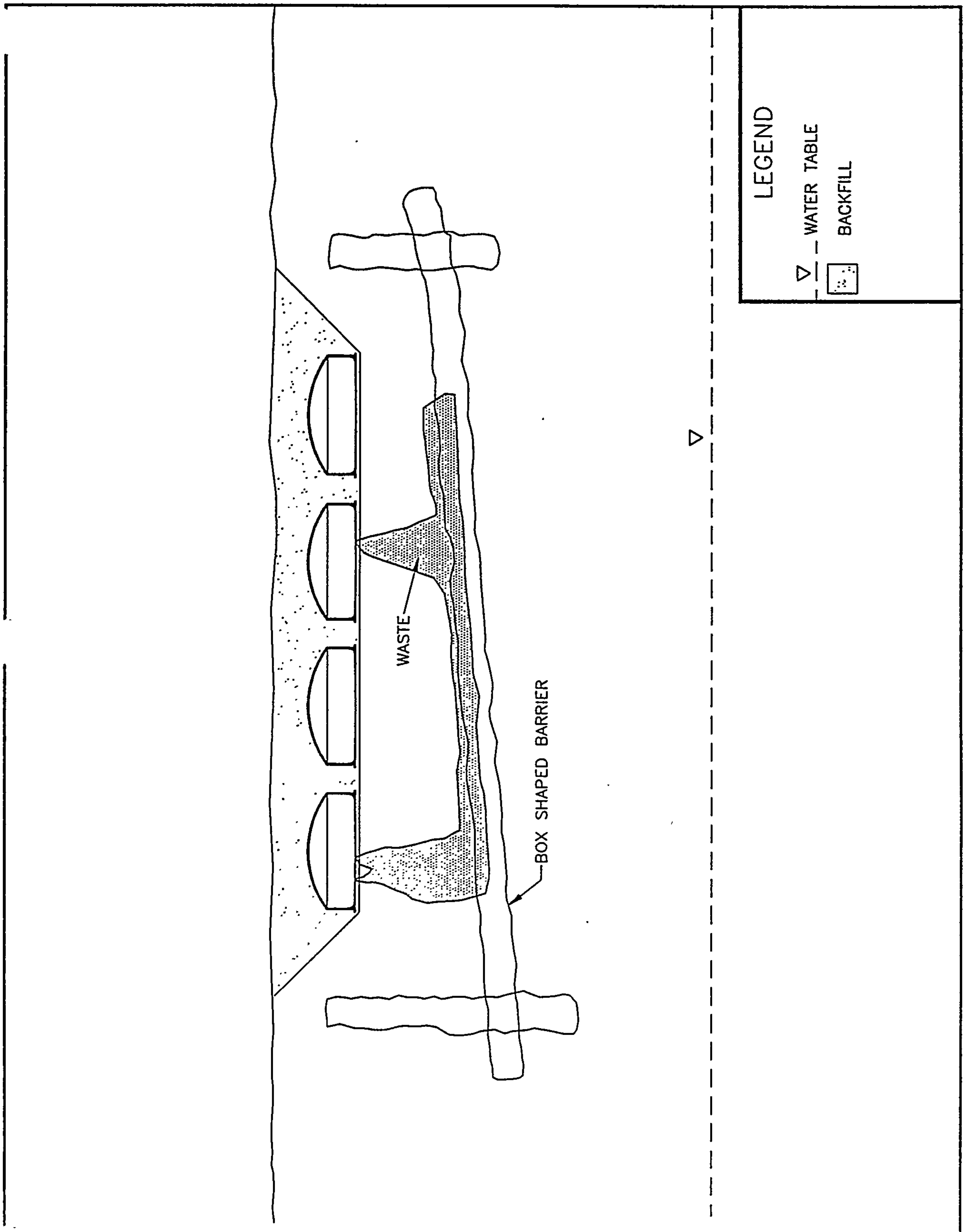

Figure 6-5. Residual Soil Contamination Following Flushing.

column of soil with a diameter of 30 m (100 ft) and a height of 9.1 m (30 ft). It was also assumed that the soil has a porosity of 0.4 and that flushing with four pore volumes is required to achieve acceptable cleanup.

Assumptions for Sensitivity Analysis

A potentially attractive flushing option is adding water to leaking SSTs to flush residual contaminants from the tanks and leak pathways. The resulting leaks would be recovered from the soil beneath the tank using vacuuming techniques. For this low case it was assumed that one-half the COCs in the residual tank waste in leaking tanks would be recovered using this approach. For options that employ traditional sluicing, the residual waste volume would be reduced to 0.5% of the inventory in the five leaking tanks. This would be equivalent to a total residual nitrate inventory of 61,700 kg (136,000 lb) in the 12 tanks.

The difficulties of emplacing flush water injection and recovery pipes under the tanks may render the technology much less-effective than expected; in this high case, a 50% recovery effectiveness was assumed. This would result in a total inventory of nitrate in the soil of 12,500 and 60,000 kg (27,500 and 132,000 lb) following 42,000 and 194,000 L (11,000 and 51,000 gal) leaks with subsequent soil flushing under all five leaking tanks.

6.1.7 Residue Within Close-Coupled Barrier

Contaminants may penetrate into the close-coupled barrier as shown schematically in Figure 6-6. It was assumed that the use of sluicing to retrieve SST wastes would impart a head and a concentration gradient on any surface of the close-coupled barrier connected hydraulically to the waste in the tank. This head and concentration gradient were assumed to result in advection and diffusion of contaminants into the barrier. The mass of contaminants assumed to be advected and diffused into the barrier is dependent on Darcy's and Fick's Laws as in the case of advection and diffusion into the tank's structural concrete. Estimation of the advected and diffused mass of contaminants is complicated by the two- or three-dimensional mass transfer that would occur along a crack or at a point source. For modeling purposes, it was assumed that waste solution with half the interstitial liquid concentration would be in contact with the barrier along a line that circumscribes the tank at the intersection of the tank's vertical and horizontal concrete structural members. This location coincides with an actual construction joint between these two members. It was also assumed that the interstitial liquid would be in contact with the barrier through a crack that passes diametrically through the concrete base (Figure 6-7). Lowe (1993) also postulated leakage at the construction joint and a crack in the concrete base. Observations of plots of past SST leaks indicate that leakage occurs at discrete points rather than evenly around the joint or in

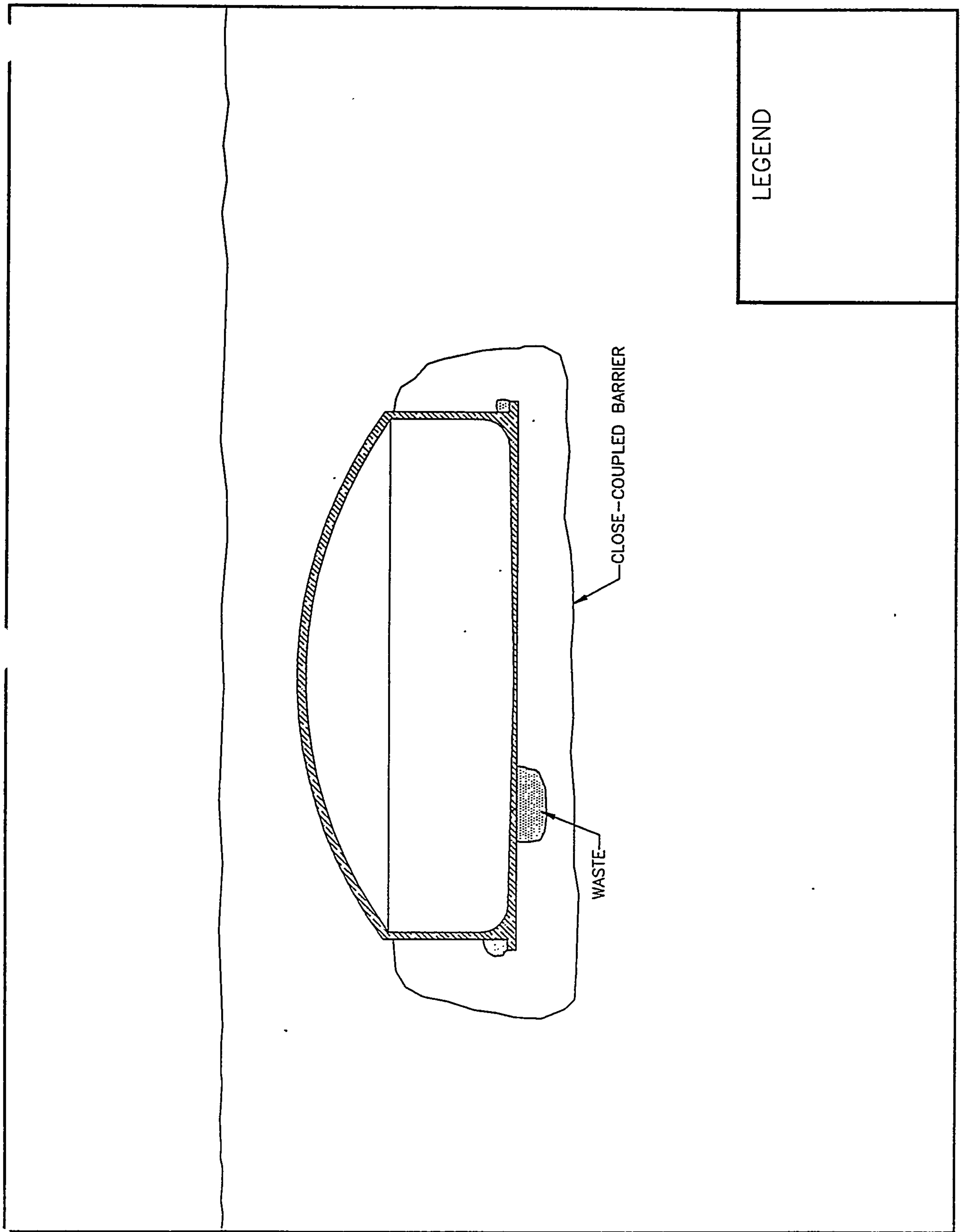

Figure 6-6. Diffusion and Advection into Close-Coupled Barrier.

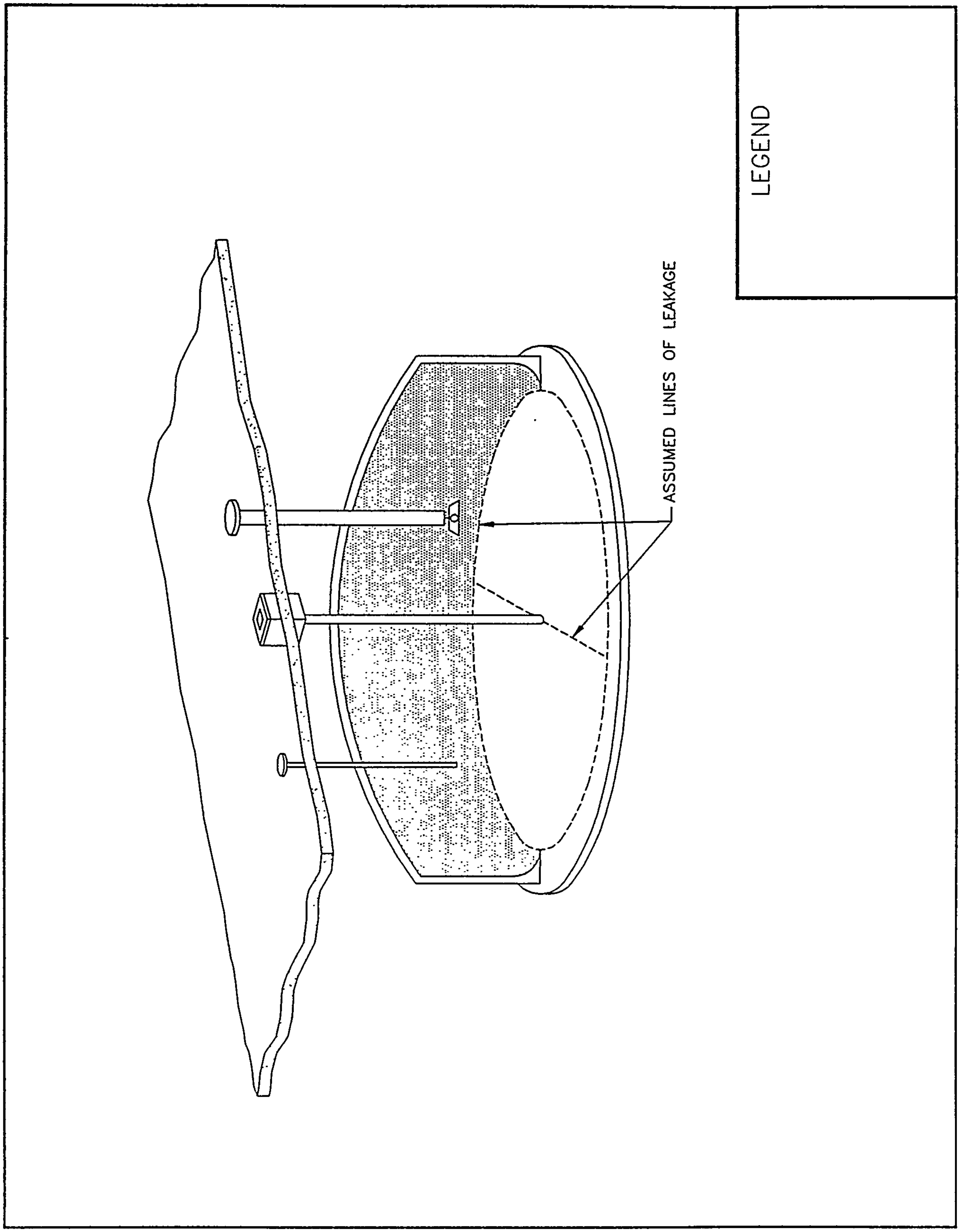

Figure 6-7. Assumed Lines of Potential Leakage from SSTs.

other cracks. Thus, it was assumed that leakage occurs along only 10% of the assumed crack line and that the remaining 90% of the crack line remains sealed. The overall length (L) of the line source is represented by the following equation:

$$L = (\pi D_o + D_o)/10 \qquad \text{(Eq. 17)}$$

For outer tank diameter, D_o = 24 m (79 ft), the line source length is 10 m (33 ft). This scenario was modeled by first calculating the advective distance for an advection period equal to the duration of the applied head. The advective distance was calculated using Equation 5, which can be restated as:

$$x = \sqrt{2Kht/n} \qquad \text{(Eq. 18)}$$

The applied average head (h) was assumed to be 4.6 m (15 ft) for traditional sluicing. The time (t) required to achieve cleanout of a tank is provided by the following expression:

$$t = \frac{V}{RE} \qquad \text{(Eq. 19)}$$

Where:

V = total volume of waste in the tank (L^3)
R = average waste retrieval rate (L^3/T)
E = total operating efficiency (unitless).

Boomer et al. (1993) reported expected average retrieval rates of 9.5 L/min (2.5 gal/min) and an estimated total operating efficiency of 56% for traditional sluicing. Boomer et al. (1993) also reported a total volume of 1.4×10^8 L (37-Mgal) of waste in 149 SSTs. Thus, the time predicted for cleanout of an average tank using traditional sluicing was 123 days.

The hydraulic conductivity of the injected grouts that may be emplaced around SSTs in a close-coupled configuration is unknown. However, Golder (1994) reported hydraulic conductivities as low as 10^{-6} cm/s (0.0028 ft/d) for laboratory samples injected with a sodium silicate grout. The requirement that chemical grouts gel within a few hours to prevent excessive loss of the grout formers by percolation through the soil makes it unlikely that the grout formers will penetrate adequately into soils with conductivities of 10^{-5} cm/s (0.028 ft/day) or lower. The head (typically less than 50 lb/in^2) and time are not sufficient to drive the barrier-forming material into the finer pores of the soil before gelation occurs. It was assumed that most of the barrier volume in an adequate barrier would exhibit conductivities lower than 10^{-6} cm/s (0.0028 ft/day). Thus, a hydraulic conductivity of 10^{-6} cm/s (0.0028 ft/day) was selected as a performance goal for injected grout barriers. Emplacement methods other than injection grouting (e.g., mechanical mixing) may be necessary to produce a barrier with an overall hydraulic conductivity of lower than 10^{-6} cm/s (0.0028 ft/day).

The expected effective porosity of the barrier is also unknown. Injection grouting typically involves the use of aqueous solutions or emulsions with high water contents to fill the soil pores. With this information and knowledge that the overall porosity of Hanford Site soils is about 0.4, a barrier effective porosity of 0.2 may be reasonable. The above assumptions and the linear advection equation (Equation 18) were used to estimate an advective penetration distance of 2.3 m (7.4 ft) for tank waste liquids. Zones with a hydraulic conductivity of 10^{-5} cm/s (0.028 ft/day) would be penetrated 7.3 m (24 ft).

The assumed penetration distance and length of the line of projected leakage can be used to estimate the volume of the contaminated barrier matrix.

The cross-section of the conceptual advection zone was assumed to be represented by a half-circle with a radius of 2.3 m (7.4 ft). The volume of the penetrated barrier region, therefore, would be 78 m^3 (2,800 ft^3). Twenty percent of this volume was assumed to contain interstitial liquid with half its initially assumed concentrations. Based on these assumptions, the total mass of nitrate that would have advected into the close-coupled barrier would be 2,000 kg (4,400 lb) for each tank. The total nitrate advected from the five leaking tanks into the barriers would be 10,000 kg (22,000 lb).

Contaminants released from the barrier are treated in a manner similar to contaminants released from concrete. The concentration of contaminants after entering the recharge water in the vadose zone were assumed to be one-quarter the interstitial water concentrations.

Assumptions for Sensitivity Analysis Involving Advection

For purposes of the sensitivity analysis, it was assumed that the effective hydraulic conductivity of the barrier matrix could be improved to 10^{-7} cm/s (3.9 x 10^{-8} in/s) through the use of innovative barrier forming materials and improved emplacement techniques. For this case, the total nitrate estimated to advect into the barrier would be 950 kg (2,100 lb) for all five leaking tanks. For a less conservative case, the linear source distance of 10 m (33 ft) for advection and diffusion into the barrier was assumed to be understated by a factor of 10. This condition would exist if the barrier former fails to seal effectively along the joint line, thereby allowing liquid waste to flow along this line and create a longer line source from which advection would occur. For this case, the total advected nitrate would be 95,000 kg (210,000 lb). This quantity is similar to 120,000 kg (265,000 lb) estimated for leakage into the ground for the No Action, which does not include a subsurface barrier. Thus, the barrier would have no beneficial effect under this assumed condition.

Diffusion

It was assumed that most of the diffusion occurs in the aqueous phase of the barrier matrix. The diffusive penetration distance (Δx) was provided earlier in Equation 13:

$$\Delta x = \sqrt{2D\Delta t}$$

The effective diffusivity (D) of subsurface barrier matrixes is unknown but may be estimated from the following equation used by Boomer et al. (1993) to estimate the diffusivity of soils:

$$D = \frac{D_m a e^{(b\theta)}}{\theta} \qquad \text{(Eq. 20)}$$

Where:

D_m = molecular diffusivity of solute materials in water (L^2/T)
θ = moisture content of barrier (unitless)
a = 0.005 (empirical constant) (unitless)
b = 10.0 (empirical constant) (unitless).

The molecular diffusivity of dissolved species in water is generally 2 x 10^{-5} cm^2/s (0.0019 ft^2/day) or lower. The moisture content of the barrier matrix was assumed to be 0.35, which represents a typical fine-grained Hanford Site soil with 88% of the pores filled with water. Applying these values to Equation 20 would yield an effective diffusivity of 1 x 10^{-5} cm^2/s (0.0009 ft^2/day).

The assumed diffusive penetration "distance," (Δx), would be 0.14 m (0.47 ft) when Δt equals 123 days. The advective penetration distance was 2.2 m (7.2 ft); thus, advective flow would clearly dominate. Diffusion-induced contamination would be insignificant.

6.1.8 Residue Following Use of Stand-off Barriers

The assumed distribution of contaminants following use of a standoff barrier is shown schematically in Figure 6-8. Sources of potential groundwater contamination would include contaminated soil and the abandoned barrier matrix. The purpose of a standoff barrier would be to provide containment of both past and new leakage to the soil and to facilitate recovery of leaked waste from the low point of the barrier.

Leaks from SSTs would be expected to migrate slowly in Hanford Site soils. The slow rate of migration of leaked SST waste is evident from plume migration data collected to track the 437,000 L (115,000 gal) leak from Tank 241-T-106. Between 1978 and 1994, the depth of leakage from this tank may have increased from 32 to 46 m (105 to 151 ft) below ground surface, based on measurements of ^{99}Tc. This migration rate, which is a function of advection and diffusion, is equivalent to about 1 m/yr (3 ft/yr). It should be noted that this migration rate may be artificially high due to factors such as cross-contamination of the soil during dry well emplacement and creation of preferential water flow paths along the well casing-soil interface. Runoff of meteoric water from the roof of the tank may also have induced water channeling along and below the circumference of the tanks. This can drive contaminants deeper in selected locations.

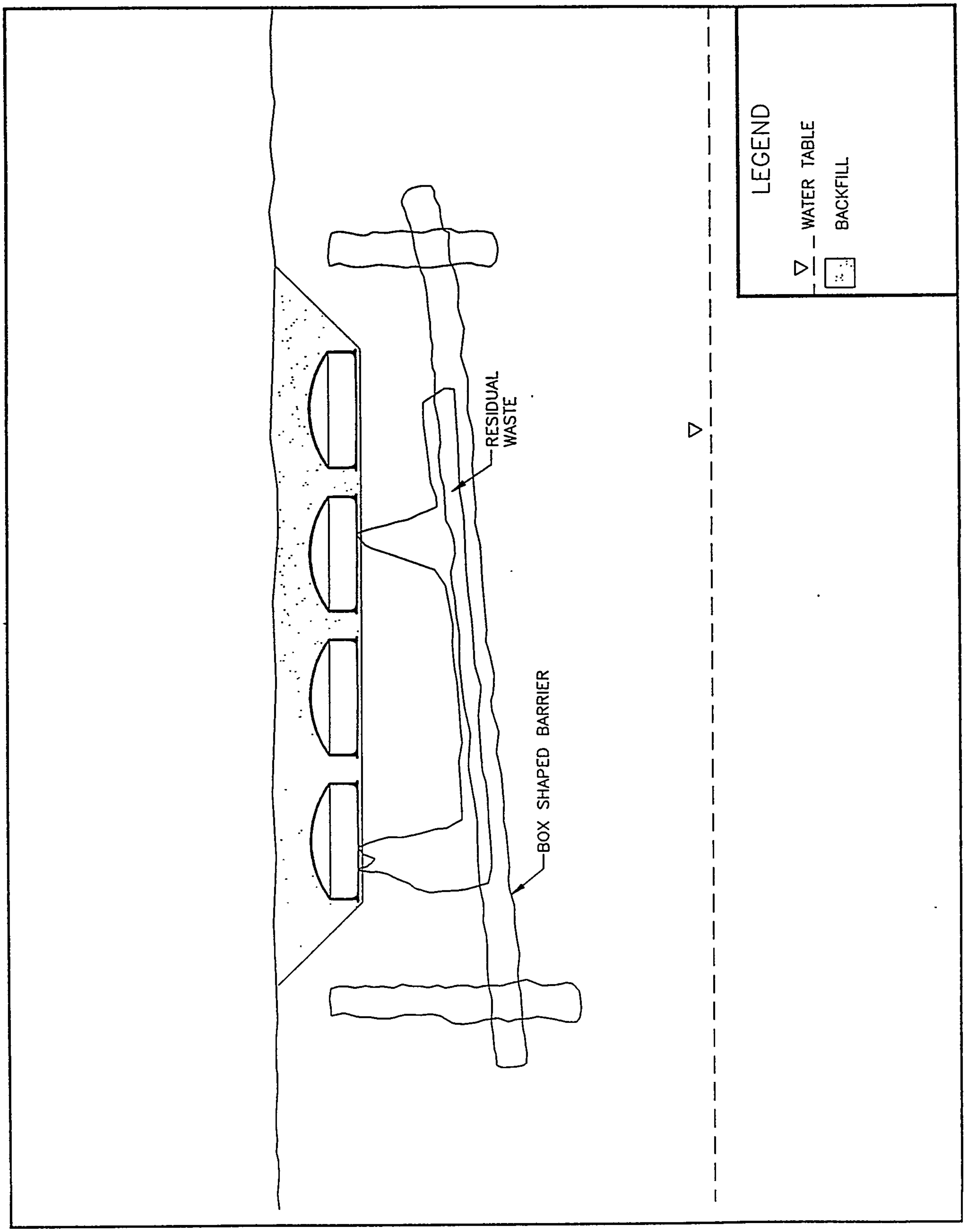

Figure 6-8. Residual Waste Following Use of Stand-off Barriers.

Smaller leaks from other SSTs may have migrated to depths of 30.5 m (100 ft), for example, due to longer migration times, higher conductivities, preferential flow paths (e.g., along clastic dikes), and/or lower field capacities in soils under those tanks. Thus, it was assumed that the standoff barrier would be installed to a depth of at least 30.5 m (100 ft) below the entire boundary of the hypothetical 12-tank, tank farm to ensure containment of past leaks. Deeper barriers, installed to depth of 46 m (150 ft) or more, would be required to confine deep leaks, such as the Tank 241-T-106 leak. Calculations based on the 46 m (150 ft) depth, the 1 m/yr (3 ft/yr) travel time and the 15-m (50-ft) depth of the base of the tanks indicate that more than 30 years would be required for the front of a small leak to migrate to a 46 m-deep (150 ft) barrier. By comparison, the 437,000 L (115,000 gal) leak from Tank 241-T-106 may have required 21 years for the plume front to apparently migrate to this depth. (The migration rate of this plume is under review; some believe the migration rate to be lower than estimated here, which would result in longer travel times to the barrier. This belief may be predicated, in part, by the past practice of disposing liquid wastes to the soil via cribs, ponds, and trenches. In designing these disposal systems, it was assumed that the wastewater would remain in the vadose zone if the volume of liquids disposed did not exceed one-third the porosity of the soil between the system and the aquifer.) After the front of the plume has reached the barrier at the 46-m depth (150-ft), it must still travel a significant vertical and/or horizontal distance to a collection point where it would be pumped to the ground surface for treatment.

The collection point at the base of the V-shaped barrier was assumed to be 76 m (250 ft) below the ground surface. Thus, under the assumed conditions of the Tank 241-T-106 plume, an additional 30 years are projected for the front of the plume to migrate to and begin to collect in the low point of the barrier. A substantial delay would also be expected in the case of the box-shaped barrier due to long horizontal travel distances to the barrier low point. A considerably longer time would be required for the tail of the plume to collect in the barrier low point.

A projected travel time of >50 years for most plumes exceeds the current schedule for the cleanup of the Hanford Site. Therefore, it was assumed that soil flushing would be used to accelerate the migration rate of leaked contaminants to the barrier collection points. The addition of flush water to the soil under slug flow conditions at a hydraulic conductivity of 1.55×10^{-3} cm/s (4.4 ft/day) and unit gradient was assumed. This conductivity was used for the sandy sequence of the Hanford formation in modeling the flow of contaminants for the Hanford Grout Performance Assessment (Blanchard et al. 1993).

It was further assumed that each of four pore volumes of injected water would be only 50% effective in flushing contaminants due to the effects of channeling and difficulty in removing contaminants diffused into larger particles. Channeling would be expected to be especially pronounced if unsaturated conditions are required to minimize the head on the barrier surface. At 50% effectiveness per flush, a total of four pore volume flushes would remove 94% of the leaked contaminants from the sediments. At the assumed hydraulic conductivity, the total time required for collection of the four pore volumes is 180 days for the V-shaped barrier and 120 days for the box-shaped barrier (Figure 6-9). These times are based on pore

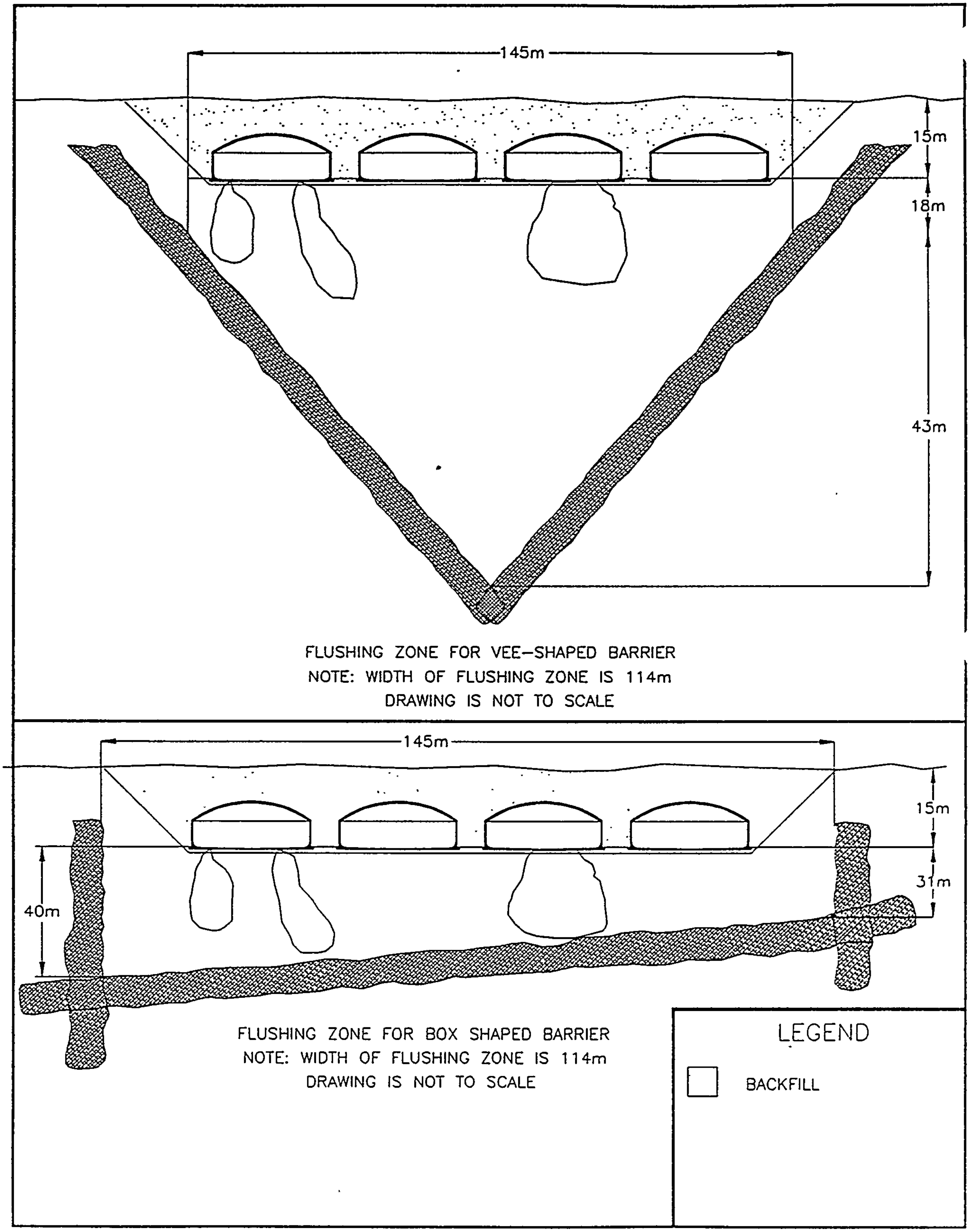

Figure 6-9. Cross-Sectional View of In Situ Flushing Zones for V-Shaped and Box-Shaped Barriers.

velocities at unit gradient, i.e., saturated conditions over the height of the soil column. The presence of caliche or other lenses of low hydraulic conductivity material under tank farms would complicate soil flushing and greatly increase the time required to complete flushing. For this case, pumping of collected flush solution from the surface of low conductivity layers or drilling through such layers to promote drainage may be required to support flushing operations.

It was assumed for modeling purposes that residual contamination in the soil after leaks had occurred is evenly distributed under the tanks between a depth of 15 and 76 m (50 and 250 ft) for V-shaped barriers and between a depth of 15 and 55 m (50 and 180 ft) for box-shaped barriers (Figure 6-9). For comparison purposes, the residual nitrate in the soil following flushing would be 6% of the total mass of old and new leaks, or 7,100 kg (15,700 lb) as described in Section 6.1.6. The nitrate fluxes for the V-shaped and box-shaped barrier alternatives would be 0.001 and 0.002 kg/day (0.003 and 0.004 lb/day), respectively. The associated durations of the fluxes would be 15,000 and 10,000 years. These time periods represent the time for advecting water to move from the base of the tank to the base of the plume, thereby flushing the contaminants into clean soil at the 76 or 55 m (250 or 180 ft) depths.

<u>Advection</u>

The head of flush water applied to the standoff barrier would likely cause contaminants to advect and diffuse into the barrier. Contaminated barrier material is another source of contamination that would eventually migrate to the groundwater, except in the case of freeze wall barriers. It was assumed that the freeze wall barrier would be constructed with heating pipes installed above and parallel to the freeze pipes to enable controlled thawing of the contaminated ice. The resulting melted ice would flow to a collection point where it would be pumped to the surface for treatment. Eventually all of the decontaminated ice would melt, leaving only soil and pore water. It was assumed that the ice decontamination strategy would be successful (i.e., the soil originally included within the ice barrier would not be contaminated to any significant degree). Thus, the soil originally within the ice barrier is not considered a source of future contamination.

Unlike freeze wall barriers, injected chemical standoff barriers likely could not be removed from the subsurface without excavating the site. Excavating the barrier would defeat one of the primary attractions of the standoff subsurface barrier (i.e., to enable use of in situ soil flushing to clean contaminants from the soil). Contaminated chemical barriers would resist cleaning using flushing because the head of liquid applied to the surface of the barrier during flushing would force contamination deeper into the barrier. The level of contamination in the injected chemical barrier would be a function of the same factors that cause contamination to be forced into the close-coupled barrier. The analysis of residual contamination in close-coupled barriers in Section 6.1.7 showed that advective transport dominated diffusive transport under the expected properties of the barrier. Thus, advective transport was modeled as the primary source of barrier contamination.

The total time the head would be applied to the barrier was assumed to be the flushing time, 180 days for the V-shaped barrier and 120 days for the box-shaped barrier. The head applied to the barrier was assumed to be limited through the use of unsaturated flushing and/or the use of multiple wells or drain pipes installed along the upper surface of the barrier. It was assumed that this strategy would limit the average head to 1.5 m (5 ft) of water. Otherwise, part of the flush water could advect through the barrier. Flushing time would be greatly increased under unsaturated flushing conditions because the soil's hydraulic conductivity decreases rapidly with only small decreases in water content below saturated conditions. Close spacing of well points or drain lines may be necessary to ensure that the head does not exceed 1.5 m (5 ft).

The contaminants in the solution that contacts the barrier were assumed to be diluted by the flush water. The average concentration (C) of the waste in contact with the barrier is given by:

$$C = 0.94\, M/(V_{nl} + V_{ol} + V_{fw}) \qquad \text{(Eq. 21)}$$

Where:

M = total mass of contaminants in old and new leaks (M)
V_{nl} = volume of new leaks (L^3)
V_{ol} = volume of old leaks (L^3)
V_{fw} = volume of flush water (L^3).

The volume of flush water (V_{fw}) is given by:

$$V_{fw} = V_s \theta N \qquad \text{(Eq. 22)}$$

Where:

V_s = volume of soil contacted by flush water (L^3)
θ = total porosity of soil (unitless)
N = number of flushes (unitless).

The volume of soil contacted by the flush water was estimated using dimensions shown for V-shaped and box-shaped barriers in Figure 6-9. These volumes would be 644,000 and 574,000 m^3 (23,200,000 and 20,500,000 ft^3), respectively. The area of the barriers contacted by the flush liquid was also estimated using Figure 6-9. These areas would be 25,000 and 19,000 m^2 (271,000 and 206,000 ft^2) for V-shaped and box-shaped barriers, respectively. The soil porosity and number of flushes were previously given as 0.4 and 4, respectively. The total calculated volumes of flush solution (1.1 x 10^9 and 9.3 x 10^8 L [278 and 245 Mgal] for V-shaped and box-shaped barriers, respectively) were added to the total volume of new and old leaks (965,000 L [255,000 gal]). The resulting average contaminant concentrations in the flush liquid were then determined. For nitrate, these concentrations were 0.11 g/L (0.0067 lb/ft^3) for V-shaped barriers and 0.12 g/L (0.0076 lb/ft^3) for box-shaped barriers.

The total mass of contaminants assumed to have advected into the barrier was determined using Equation 7. The hydraulic conductivity of the barrier (0.09 cm/day [0.0028 ft/day]) and effective porosity (0.2) used to analyze advection into close-coupled injected chemical barriers were also used in this analysis.

The estimated total nitrate advected into the V-shaped and box-shaped barriers would be 817 and 590 kg (1,800 and 1,300 lb), respectively. The penetrations of the advected fronts into the V-shaped and box-shaped barriers were calculated to be 1.5 and 1.3 m (5.0 and 4.1 ft), respectively. It was assumed for ease of modeling that this contamination would be distributed within the barriers uniformly with depth between depths of 46 and 76 m (150 and 250 ft) in the case of the V-shaped barrier and 46 and 55 m (150 and 180 ft) in the case of the box-shaped barrier. These conditions and a recharge rate of 0.05 cm/yr (0.02 in./yr), would result in a nitrate flux and duration for the V-shaped barrier of 0.0003 kg/day (0.0006 lb/day) and 2,800,000 days, respectively. The flux and duration for the box-shaped barrier would be 0.0007 kg/day (0.0015 lb/day) and 840,000 days, respectively.

A small amount of contamination would also be held up in depressions in the upper surface of the barrier. Difficulties in emplacing the barrier in the highly heterogenous sediments of the Hanford formation would likely result in undulations in the barrier surface. The low points in the undulations would collect flush solution. The masses of contaminants in these low points would be relatively small because progressively cleaner flush solution would flow through these low points. This would result in low contaminant concentrations in the low points when flushing is completed. Thus, this source of contamination was not evaluated.

<u>Assumptions for Sensitivity Analysis</u>

The contaminants for this source would be relatively low in mass and dispersed over a considerable depth (> 40 m [130 ft]). Dispersement over depth would reduce the peak impact of the waste source in terms of groundwater contamination (i.e., it would flatten the peak concentrations). Thus, the impacts to the groundwater would be relatively low. Complete penetration of the barrier by flush water due to excessive head resulting from clogging drain pipes or pump failures would be unlikely to cause a significant fraction of the contaminant inventory to collect in the vadose zone below the barrier unless no provisions were made for monitoring and maintenance. No other uncertainties were identified that would significantly increase the contribution of this source to groundwater risk. Thus, no further sensitivity analyses were deemed necessary.

6.2 CONTAMINANT TRANSPORT AND HUMAN HEALTH RISK

Following definition of residual contaminant source terms, the MEPAS code (Droppo et. al 1989) was used to model contaminant transport through the vadose zone and aquifer, and estimate the relative magnitude of human exposure to those contaminants based on assumed withdrawal and use of the groundwater. The objective of these calculations was to provide a consistent evaluation of peak groundwater contaminant concentrations and relative health risks as points for comparison of the various retrieval alternatives. The distributions of concentrations and relative health risks as a function of time after closure of the tank farm were also evaluated to provide additional information regarding the performance of different retrieval and barrier systems.

The MEPAS code was used to consistently evaluate the relative magnitude of human health impacts from radiological and chemical contaminants released to the environment under each of the retrieval alternatives. This one-dimensional model, which is still being developed, has not yet been adopted for quantitative baseline risk analyses at the Hanford Site (DOE 1993), but is suitable for the type of screening-level analysis reported in this study. Other EPA-approved models are currently deemed appropriate in these cases. The MEPAS was selected for this application over other models and codes because of its versatility and ability to be used cost-effectively in this type of application.

The MEPAS code employs a nontraditional approach of integrating all major exposure pathways into a single public health computational tool. It couples radiological and nonradiological contaminant release, migration, and fate for environmental media with exposure estimates for the major exposure routes. The MEPAS code uses empirical, analytical, and semi-analytical mathematical algorithms to model the following processes:

- Potential release of contaminants into the environment
- Transport of contaminants through and between multiple environmental media
- Exposure to surrounding human populations through the following exposure pathways: ingestion of water and food products, inhalation, dermal contact, and external radiation (Note: inhalation, dermal contact, and external radiation were not modeled in this analysis.)
- Human health effects associated with exposure to chemicals and radionuclides.

The MEPAS code Version 3.0g was used to evaluate contaminant transport and relative human health risks associated with each of the alternatives discussed in Section 5. The transport modeling and calculation of potential contaminant concentrations in groundwater are discussed in Section 6.2.1. The modeling of human exposure to these contaminants and evaluation of relative health risks are discussed in Section 6.2.2.

6.2.1 Contaminant Transport and Groundwater Concentrations

Concentrations of contaminants in groundwater were calculated based on the contaminant sources described in Section 6.1. Contaminants released from these sources were assumed to migrate through partially saturated and saturated groundwater zones. In the partially saturated zone, flow was assumed to be in the vertical direction. The MEPAS code was used for one-dimensional modeling of contaminant transport in the vadose zone. In the saturated zone, the predominant movement of the contaminants was assumed to be in the direction of the groundwater flow. The MEPAS code employs a three-dimensional advective-dispersive equation to describe the migrating plume as it disperses and attenuates through the saturated aquifer. Dispersion is considered in the longitudinal, lateral, and vertical directions. The saturated aquifer modeling function of MEPAS was not used in this analysis for reasons discussed in Section 6.3.1.

The source and geologic setting input data required for the vadose zone and groundwater transport pathway calculations are extensive and encompass the following:

- Contaminant release data
- Source characteristics
- Geologic media (partially saturated zone) characteristics
- Aquifer (saturated zone) characteristics.

The alternatives and their applicable sources are summarized in Table 6-7. Geologic media and aquifer data used in the MEPAS calculations are provided in Appendix A. Separate MEPAS calculations were performed for each source to account for source-specific characteristics, alternative-specific transport conditions, and to produce source-specific groundwater concentrations that support comparative evaluations of the alternatives. The contaminant-specific release data (timing and duration of contaminant releases) used in the MEPAS calculations are reported in Appendix A.

Figures summarizing the results of the MEPAS transport modeling and groundwater concentration calculations are presented in Appendix B. The results are also discussed and summarized in Section 6.3.

The reader is cautioned to avoid using the groundwater concentration and relative risk quantities reported in this study for other purposes unless uncertainties are properly qualified. The sensitivity analyses discussed in Section 6.1 indicated order of magnitude uncertainties for most of the sources of potential groundwater contamination that were evaluated. Large uncertainties exist in fate, transport, and toxicity determinations, regardless of the code used to assess risk. Rigorous quantitative assessments of potential risk must include a more formal definition of the uncertainties associated with the analysis. Such risk assessments will also include formal supporting analyses including toxicity assessments and risk characterizations. The uncertainties in the results of more formal and rigorous quantitative risk analyses may be little better than those associated with the use of MEPAS in this analysis, but they will be better quantified. Quantification of the myriad of uncertainties that

Table 6-7. Tank Remedial Alternatives and Applicable Sources.

No.	Alternative Name	Source							
		Tank Residual	Between Tank and Concrete	Concrete Pad	Old Leaks to Soil	Retrieval-Induced New Leaks to Soil	Close-Coupled Barrier	Standoff Barrier	Landfill
1.	No Action	X	X	X	X				
2.	Surface Barrier Only	X	X	X	X				
3.	Baseline	X	X	X	X	X			
4.	Robotic Sluicing	X	X	X	X	X			
5.	Mechanical Retrieval	X	X	X	X				
6.	Close-Coupled Chemical With Flushing	X	X	X	X		X		
7.	Close-Coupled w/o Flushing	X	X	X	X	X	X		
8.	Modified Close-Coupled Chemical w/o Flushing	X	X	X	X	X	X[a]		
9.	Box-Shaped Chemical	X	X	X	X	X		X	
10.	V-Shaped Chemical	X	X	X	X	X		X	
11.	V-Shaped Freeze Wall	X	X	X	X	X		X	
12.	Circulating Air	X	X	X	X	X			
13.	Clean-Closure w/o Barrier								X
14.	Clean-Closure with Barrier								X

[a]partial close-coupled barrier

exist in the risk analysis is beyond the scope of this study; however, it may be an important component of future analyses to support decision making on whether to implement subsurface barriers in actual SST applications.

6.2.2 Human Exposure and Health Risk

The relative magnitude of human health risks were evaluated based on assumed exposure to contaminated groundwater at the point of interest immediately downgradient of the hypothetical tank farm. Pathways by which contaminants were assumed to reach and expose a hypothetical individual at that location, based on the standards used at the Hanford Site, include:

- Drinking water ingestion
- Crop ingestion from farmland contaminated by irrigation from groundwater
- Animal product ingestion from animals fed contaminated forage and groundwater.

The exposure analyses were based on an assumed 70-year lifetime exposure to constant groundwater contaminant concentrations which are based on the average value over the 70-year period. Relative health risks were evaluated separately for exposure to carcinogenic and noncarcinogenic materials. Carcinogenic health risk was expressed as the incremental lifetime cancer risk, based on a 1×10^{-06} risk level, to an individual from exposure to radioactive contaminants and nonradioactive carcinogenic chemicals. The relative impact on an individual from exposure to noncarcinogenic toxic chemicals was evaluated by calculating the HI ratio of the calculated exposure level (dose) to a toxic threshold reference dose. An HI less than 1 is taken to indicate the probable absence of detrimental toxic effects.

Relative health risks (cancer risk and HI) were calculated for each source as the product of contaminant groundwater concentration and unit-concentration risk and HI factors derived using MEPAS. The unit risk and HI factors, and the basis of their calculations are presented in Appendix A. The results of the source-specific calculations are contaminant-specific risk and HI, as a function of time, at the point of interest immediately downgradient of the tank farm. Figures detailing the results of the relative risk and HI calculations are presented in Appendix B. The results are also discussed and summarized in Section 6.3.

6.3 SUMMARY OF RISK RESULTS

As described in the preceding sections, the MEPAS was used to estimate peak groundwater contaminant concentrations and relative health risks as points for comparison of the various retrieval alternatives. The time-distributions of concentrations and health risks were also evaluated to provide additional information regarding the relative performance of different retrieval and barrier systems. Results of the groundwater contaminant concentrations and relative health risk evaluations are discussed separately in the sections that follow.

The groundwater concentration and relative health risk values presented in these sections are screening-level results subject to ongoing review. They may be adjusted in the event that the future evaluations are performed using alternative modeling tools and input data.

6.3.1 Groundwater Concentrations

Contaminant concentrations in groundwater at the point of interest were estimated as a function of time up to 30,000 years following closure for each of the 14 alternatives. Tables of source-specific groundwater contaminant concentrations for each of the alternatives, and plots of contaminant groundwater concentrations, as a function of time, summed across all sources, are presented in Appendix B. Peak groundwater contaminant concentrations for each of the alternatives are presented in Table 6-8. The contaminant concentrations detailed in Appendix B were subsequently used as the bases for calculating potential human health risks, as discussed in Section 6.2.2.

For the clean-closure alternatives, it was assumed that the clean-closed tank farm does not release contamination into the groundwater, but the landfill at which residues from retrieval and decontamination operations are disposed does. These residues were assumed to contain 1% of the total contaminants in the tank farm following traditional sluicing. This was equivalent to 1,400 and 2,100 kg (3,100 and 4,700 lb) of nitrate for the clean closure options, with and without barriers respectively. It was further assumed that containers in which the residue would be packaged prior to emplacement in the landfill would provide no resistance to leaching after several hundred years as a result of corrosion. Thus, containment of the residues was assumed to be inconsequential for the 30,000-year modeling period. The waste residues from a single tank farm were assumed to be distributed in the landfill such that the surface area of the filled landfill would be equal to that of the original tank farm, 9,580 m^2 (103,000 ft^2). A Hanford Protective Isolation Barrier was assumed to be installed over the landfill after the landfill was filled with residual waste. Properties of the geologic setting of the landfill were assumed to be the same as those of the tank farm.

The concentrations shown in Table 6-8 are based on a modification of the MEPAS code to reflect concentrations most likely to be experienced in a well located close to the tank farm. The MEPAS code without modification can be used to calculate contaminant concentrations in the dispersive layer formed initially on the surface of the aquifer as contaminated water advects from the vadose zone in the aquifer. These initially high concentrations of contaminants in this layer would gradually decrease as contaminants disperse into the aquifer while flowing downgradient.

In the event a well is located immediately downgradient from a waste site, as is assumed in this case, the well intake (screened interval) may or may not be exposed to the contaminated water layer. If the screened interval is located substantially below the surface of the aquifer,

Table 6-8. Peak Groundwater Contaminant Concentrations[a] - All Sources.

Alternative	EDTA[b]	Nitrate	Nitrite	^{14}C	^{129}I	^{99}Tc	^{238}U	TBP[c]
1. No Action	5.8E-07	3.3E-03	1.6E-04	9.9E-11	8.2E-13	5.5E-10	1.6E-11	5.0E-07
2. Surface Barrier Only	1.8E-09	1.0E-05	5.1E-07	2.2E-14	2.5E-15	1.6E-12	4.9E-14	1.5E-09
3. Traditional Sluicing	5.0E-11	2.9E-07	1.4E-08	1.1E-15	7.1E-17	4.4E-14	1.4E-15	4.3E-11
4. Robotic Sluicing	1.2E-11	6.8E-08	3.4E-09	2.8E-16	1.7E-17	1.1E-14	3.2E-16	1.0E-11
5. Mechanical Retrieval	1.0E-10	5.8E-07	2.9E-08	2.6E-15	1.4E-16	9.0E-14	2.7E-15	8.7E-11
6. Close-Coupled Chemical	2.4E-11	1.4E-07	7.0E-09	6.4E-16	3.5E-17	2.2E-14	6.7E-16	2.1E-11
7. Close-Coupled w/o Flushing	3.3E-11	1.9E-07	9.3E-09	8.3E-16	4.7E-17	2.9E-14	9.0E-15	2.8E-11
8. Modified Close-Coupled w/o Flushing	3.8E-11	2.2E-07	1.1E-08	8.9E-16	5.4E-17	3.4E-14	1.0E-15	3.3E-11
9. Box-Shaped Chemical	2.3E-11	1.3E-07	6.5E-09	5.9E-16	3.3E-17	2.1E-14	6.3E-16	2.0E-11
10. V-Shaped Chemical	2.3E-11	1.3E-07	6.5E-09	5.9E-16	3.2E-17	2.0E-14	6.2E-16	2.0E-11
11. V-Shaped Freeze Wall	2.3E-11	1.3E-07	6.5E-09	5.8E-16	3.2E-17	2.0E-14	6.2E-16	2.0E-11
12. Circulating Air	2.4E-11	1.4E-07	6.8E-09	6.2E-16	3.4E-17	2.1E-14	6.5E-16	2.1E-11
13. Clean-Closure w/o Barrier[d]	4.9E-13	2.8E-09	1.4E-10	1.3E-17	7.0E-19	4.4E-16	1.4E-17	4.3E-13
14. Clean-Closure w/ Barrier[d]	3.0E-13	1.7E-09	8.5E-11	7.2E-18	4.2E-19	2.7E-16	8.2E-18	2.6E-13
15. Drinking Water Standards[e]	NR[f]	4.4E-05	3.3E-05	2.6E-12	2.0E-14	3.8E-12	2.0E-14	NR[f]

[a]Chemical contaminant concentrations are presented in units of g/mL. Radionuclide contaminant concentrations are presented in units of Ci/mL.
[b]EDTA - ethylenediaminetetraacetic acid
[c]TBP - tributyl phosphate
[d]Contaminant concentrations result from leaching of decontaminated residuals disposed in new landfill
[e]Source: Schmittroth 1993
[f]NR - none reported.

only uncontaminated water would be drawn into the well. If the screened interval is assumed to be located near the aquifer surface, as appropriate for a conservative analysis, contaminated water would be drawn into the operating well, but it would be diluted with uncontaminated water also drawn into the well. The unmodified MEPAS does not account for this dilution effect. Therefore, using the unmodified MEPAS to calculate groundwater contaminant concentrations immediately downgradient of the source would result in an overly conservative and unrealistically high estimate of relative risks.

A more appropriate method was used by Blanchard et al. (1993). They used the following equation to estimate well water concentrations for a scenario in which well water would be pumped at a location 100 m (328 ft) downgradient of the proposed grout disposal facility at the Hanford Site:

$$W_\mu = F_i r_v / r_p \qquad \text{(Eq. 23)}$$

Where:

- W_μ = well-intercept factor, i.e., the ratio of the concentration of a contaminant in the well water to its concentration in the vadose zone water (unitless)
- F_i = fraction of plume intercepted by the operating well (unitless)
- r_v = volumetric recharge rate through waste site (L^3/T)
- r_p = groundwater well pumping rate (L^3/T).

Blanchard et al. (1993) used the groundwater model, Single Layer Analytical Element Method-Stratified (SLAEMS), to estimate the width of interception of the contaminated water plume by a well located 100 m (328 ft) downgradient of the grout disposal site. The well pump was assumed to withdraw water at a rate of 45 m^3/day (1,600 ft^3/day) via a 4.6-m (15-ft) long screened interval positioned near the water table. This water withdrawal rate was used to simulate drinking water and irrigation needs for a 5-acre farm.

The SLAEMS model predicted a plume interception width of approximately 61 m (200 ft) based on the assumption of a fully penetrating well and aquifer properties assumed to exist near the grout disposal facility. When a partially penetrating well was assumed, the computed intercept width increased to 83.2 m (273 ft) for isotropic conditions and to 113 m (371 ft) for anisotropic conditions.

The surface dimensions of the hypothetical tank farm that served as the basis for this analysis were 84 by 114 m (275 by 375 ft). If the tank farm is assumed to be oriented longitudinally with the direction of groundwater flow and a partially penetrating well is assumed, 100% of the plume width (84 m [275 ft]) would be intercepted by the well. This conservative assumption was made for the hypothetical tank farm in this analysis.

Vadose zone contaminant concentration data are required to apply Equation 23. The vadose zone flux (f) can be expressed as:

$$f = C_v r_v$$

Where:

C_v = concentration in vadose zone (M/L^3)
r_v = volumetric recharge rate through waste site, as previously defined (L^3/T).

The well intercept factor (W_μ) in Equation 23 can also be expressed as shown below, in accordance to the definition of W_μ:

$$W_\mu = C_g/C_v \qquad \text{(Eq. 24)}$$

Where:

C_g = concentration in the groundwater (M/L^3).

Thus, the well intercept factor can be restated as:

$$W_\mu = C_g r_v/f = F_i r_v/r_p$$

Because F_i is 1.0 and r_p is 45 m^3/day (1,600 ft^3/day) as assumed previously, the groundwater concentration is given by the following intuitive equation:

$$C_g = f \div 45 \text{ m}^3\text{/day} \qquad \text{(Eq. 25)}$$

6.3.2 Health Risk

Relative health risks (cancer risk and HI) were calculated for each source as the product of contaminant groundwater concentration and unit-concentration risk and HI factors derived using the MEPAS. The unit risk and HI factors, and the basis of their calculation are presented in Appendix A. The results of the source-specific calculations are contaminant-specific relative risk and HI, as a function of time, at the point of interest. The relative cancer risks calculated for the alternatives are summarized and presented graphically in Figure 6-10. In order to present all alternatives in a single plot, a log-log scale that compressed the vertical range of risk results was used. As shown in Table 6-9, the peak relative cancer risks for the alternatives span a range of approximately seven orders of magnitude.

Figure 6-11 presents the relative cancer risks as a function of time after closure for 10 retrieval alternatives excluding the No-Action, Surface Barrier Only Alternatives and the

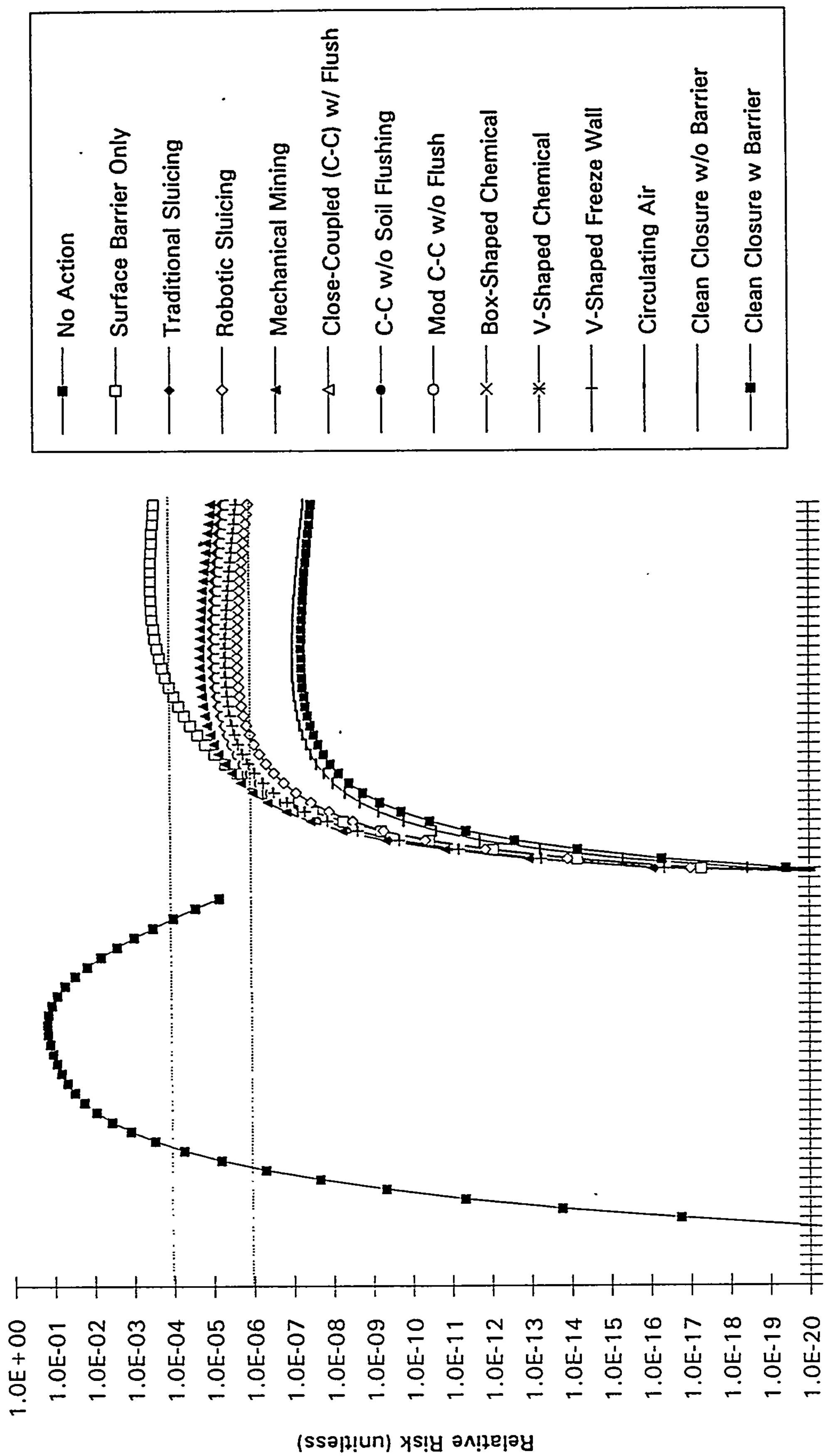

Figure 6-10. Summary of Carcinogenic Risks for All Alternatives.

Table 6-9. Peak Relative Cancer Risks and Hazard Index - Each Alternative, All Sources.

Alternative	Relative Cancer Risk	Year of Peak Relative Risk[a]	Relative HI	Year of Peak Relative HI[a]
1. No-Action	1.5E-01	276	2.8E+03	276
2. Surface Barrier Only	3.7E-04	24,750	8.6E+00	24,750
3. Traditional Sluicing	1.1E-05	19,500	2.4E-01	19,500
4. Robotic Sluicing	2.5E-06	18,750	5.7E-02	17,750
5. Mechanical Retrieval	2.1E-05	18,750	4.9E-01	18,750
6. Close-Coupled Barrier with Flushing	5.2E-06	18,000	1.2E-01	18,000
7. Close-Coupled Barrier w/o Flushing	7.0E-06	18,000	1.6E-01	18,000
8. Modified Close-Coupled Barrier w/o Flushing	8.0E-06	18,750	1.8E-01	18,750
9. Box-Shaped Chemical Barrier	4.9E-06	18,000	1.1E-01	18,750
10. V-Shaped Chemical Barrier	4.9E-06	18,000	1.1E-01	18,000
11. V-Shaped Freeze Wall Barrier	4.8E-06	18,000	1.1E-01	18,000
12. Circulating Air Barrier	5.1E-06	18,000	1.2E-01	18,000
13. Clean-Closure w/o Barrier	1.1E-07	18,750	2.4E-03	18,750
14. Clean-Closure with Barrier	6.3E-08	18,750	1.4E-03	18,750

[a]The year after closure that total relative risk or HI, summed across all sources, is at a maximum. The contributions to relative risk or HI from individual sources will peak at differing points in time.

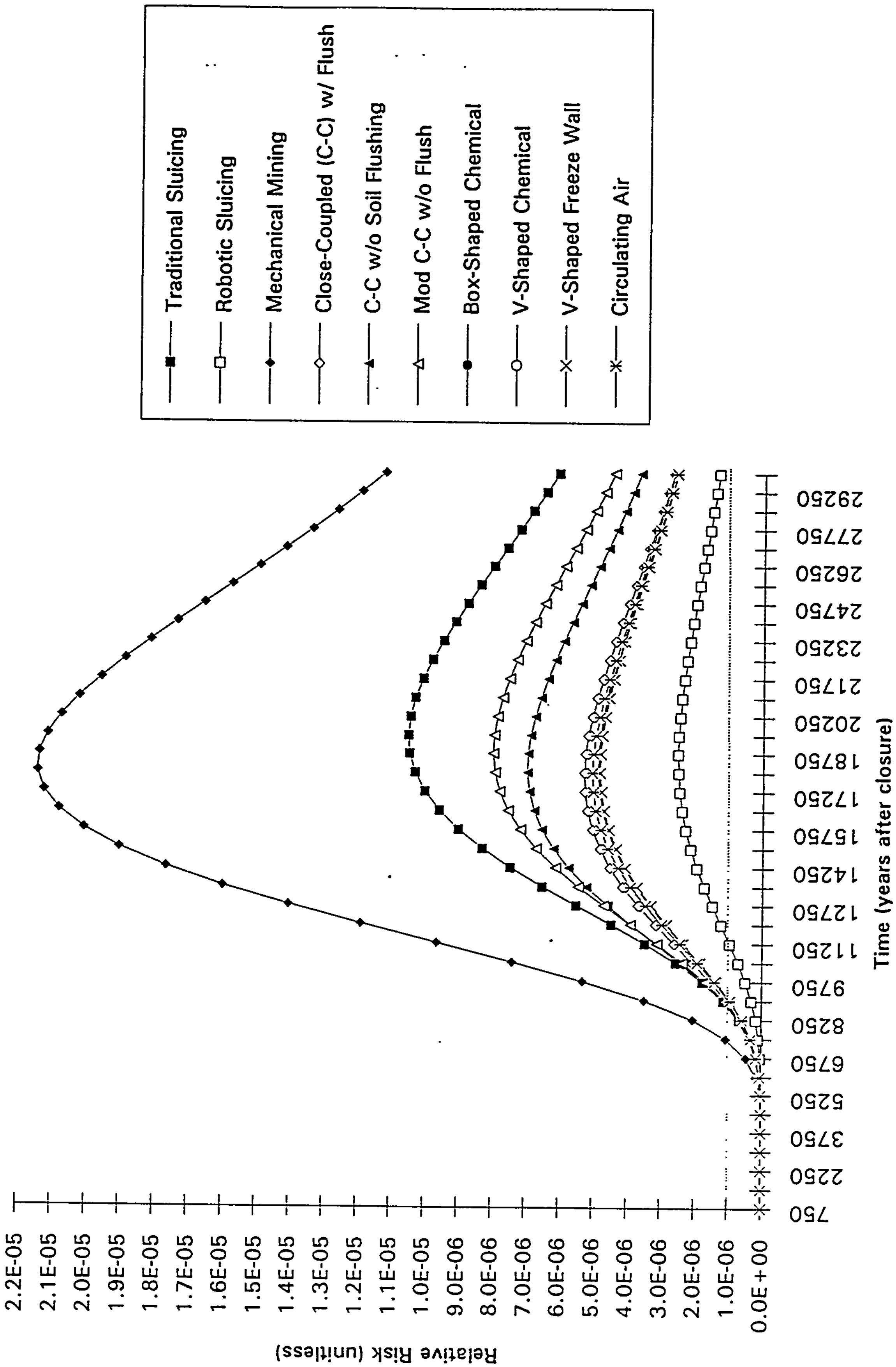

Figure 6-11. Summary of Carcinogenic Risks for All Retrieval Alternatives.

two clean closure alternatives. Because the relative risks calculated for the included alternatives span a narrower range, a linear plotting scale of relative risk was used allowing greater resolution among alternatives.

The relative HIs calculated for the alternatives are summarized and presented graphically in Figure 6-12. In order to present all cases in a single plot, a log-log scale that compressed the vertical range of HI results was used. As shown in Table 6-9, the peak relative HIs for the 14 alternatives also span a range of about seven orders of magnitude.

Figure 6-13 presents the relative HIs as a function of time for the 10 selected retrieval alternatives, excluding the No-Action, Surface Barrier Only and the two clean-closure alternatives. Because the HIs calculated for these 10 alternatives span a narrower range, a linear plotting scale of HI was used allowing greater resolution among alternatives.

In these screening-level analyses, the dominant contributor to relative cancer contributions for all cases is ^{99}Tc and the dominant contributor to HI is nitrate as shown in Table 6-10. The relative risks of the COCs are approximately constant with time because all are assumed to leach congruently with nitrate, all have a K_d of zero, and little radioactive decay occurs. The dominant contaminant source is the tank residual waste as shown in Tables 6-11 through 6-14. The nonretrieval alternatives (No-Action and Surface Barrier Only) would result in significantly higher relative carcinogenic risk and HI as shown in Figures 6-10 and 6-12. The high relative health risk of these alternatives is directly related to the inventory of waste remaining in the tanks, in the absence of any retrieval action. The relative health risks for the Surface Barrier Only Alternative are significantly less than for the No-Action Alternative as a result of the reduction in recharge rate caused by the surface barrier.

For the retrieval cases, as shown in Figures 6-11 and 6-13, the Mechanical Retrieval Alternative would result in the highest relative health risks as a direct result of the larger residual inventory remaining in the tanks (5% versus 1% for traditional sluicing). The Robotic Sluicing Alternative would result in the lowest relative health risk, aside from the clean-closure alternatives. Relative health risks for these two alternatives are the lowest of all the alternatives. Each of the alternatives involving use of barriers, excluding the Clean-Closure with Barrier Alternative, appear to result in a fairly narrow range of risks. The barrier alternatives would result in relative risks and HIs of less than a factor of three below the estimated risk and HI of the Traditional Sluicing Alternative.

Although flushing was assumed to be effective in removing the same quantity of contaminants in each of the standoff barrier (V-Shaped and Box-Shaped) and the Circulating Air Barrier alternatives, the residual contaminants would be more dispersed after flushing in the case of the standoff barriers. This dispersed contamination source resulted in a flatter concentration curve and in a somewhat lower peak relative health risk for the standoff barriers.

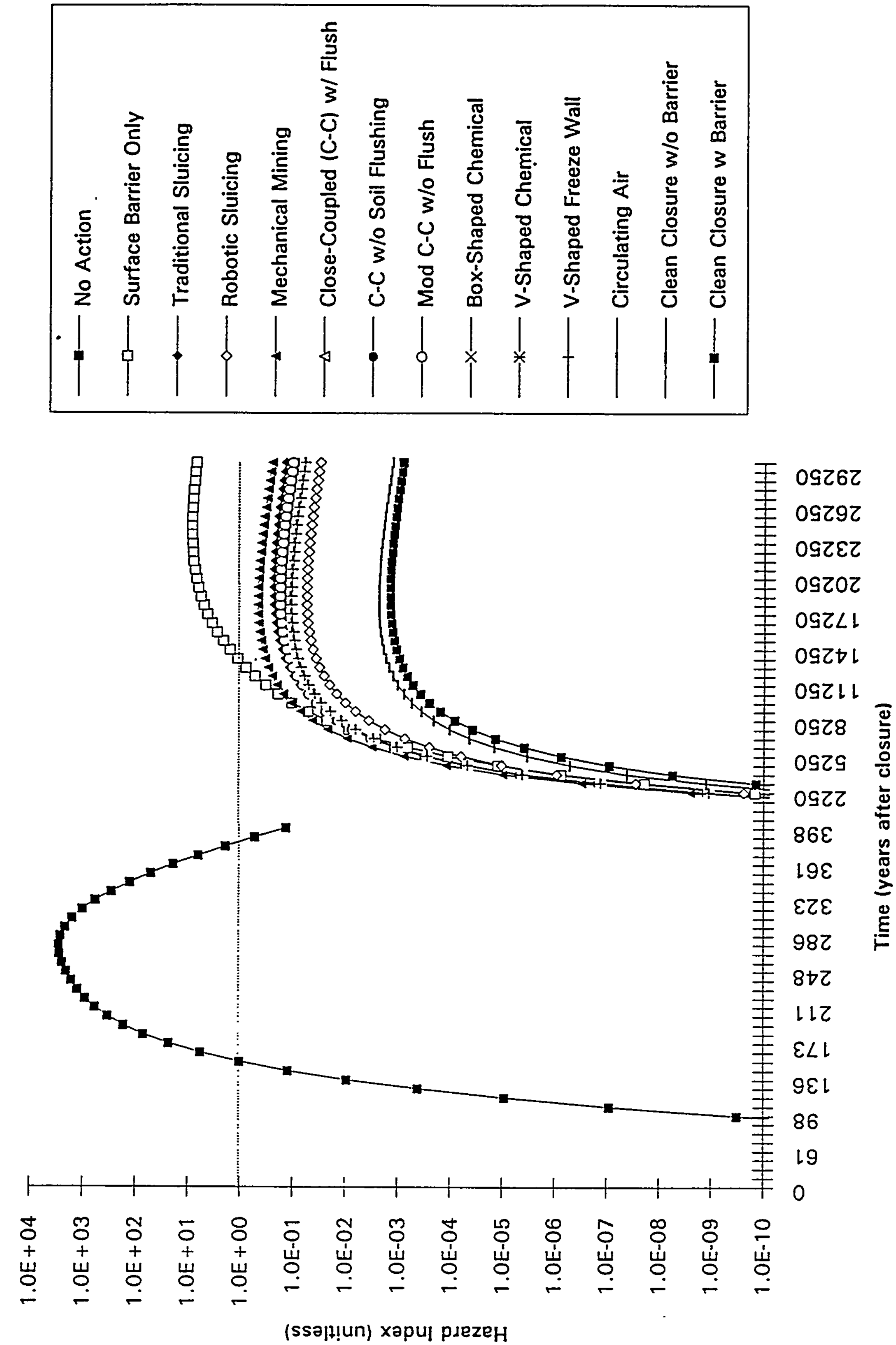

Figure 6-12. Summary of Noncarcinogenic Hazard Index for All Alternatives.

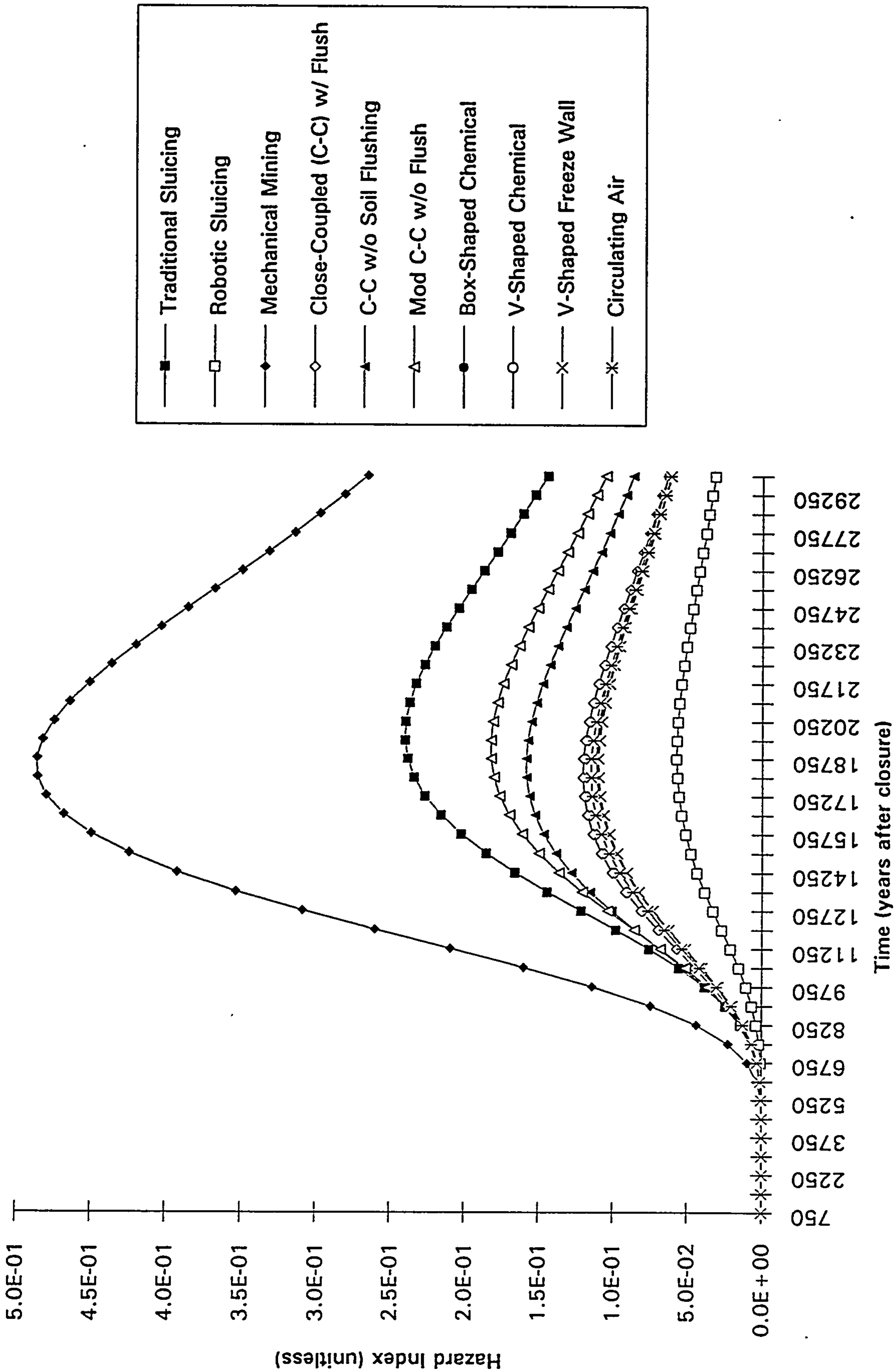

Figure 6-13. Summary of Noncarcinogenic Hazard Index for Selected Retrieval Alternatives.

Table 6-10. Relative Cancer Risks and Hazard Index for Constituents of Concern.

Carcinogens	Contribution to Relative Cancer Risk (%)	Noncarcinogens	Contribution to Relative HI (%)
^{99}Tc	63	nitrate	89
^{238}U	24	EDTA	7
^{129}I	10	nitrite	4
^{14}C	3	Total	100
TBP	0		
Total	100		

Table 6-11. Relative Source Contribution to Carcinogenic Risk. (sheet 1 of 2)

Alternative	Source	Cancer Risk Contribution at Peak	Relative Contribution (%)
1. No Action	Tank Residual	1.5E-01	100
	Between Tank and Concrete	2.4E-05	0
	In Concrete	1.6E-04	0
	Old Leaks	2.9E-05	0
		1.5E-01	100%
2. Surface Barrier Only	Tank Residual	3.7E-04	100
	Between Tank and Concrete	0.0E+00	0
	In Concrete	4.8E-07	0
	Old Leaks	1.1E-06	0
		3.7E-04	100%
3. Traditional Sluicing (Baseline)	Tank Residual	3.9E-06	37
	Between Tank and Concrete	6.5E-09	0
	In Concrete	7.0E-07	7
	Old and New Leaks	5.9E-06	56
		1.1E-05	100%
4. Robotic Sluicing	Tank Residual	2.6E-07	10
	Between Tank and Concrete	1.6E-08	1
	In Concrete	5.0E-07	20
	Old and New Leaks	1.7E-06	69
		2.5E-06	100%
5. Mechanical Retrieval	Tank Residual	2.0E-05	92
	Between Tank and Concrete	8.8E-09	0
	In Concrete	4.9E-07	2
	Old Leaks	1.3E-06	6
		2.1E-05	100%
6. Close-Coupled Chemical Barrier with Flushing	Tank Residual	4.0E-06	76
	Between Tank and Concrete	7.5E-09	0
	In Concrete	7.2E-07	14
	Flushed Old Leaks	2.5E-10	0
	In Barrier	5.1E-07	10
		5.2E-06	100%
7. Close-Coupled Chemical Barrier w/o Flushing	Tank Residual	4.0E-06	57
	Between Tank and Concrete	7.5E-09	0
	In Concrete	7.2E-07	10
	Old and New Leaks	1.8E-06	26
	In Barrier	5.1E-07	7
		7.0E-06	100%

Table 6-11. Relative Source Contribution to Carcinogenic Risk. (sheet 2 of 2)

Alternative	Source	Cancer Risk Contribution at Peak	Relative Contribution (%)
8. Modified Close-Coupled Chemical Barrier w/o Flushing	Tank Residual Between Tank and Concrete In Concrete Old and New Leaks In Barrier	4.0E-06 7.0E-09 7.1E-07 3.1E-06 3.0E-07 8.0E-06	49 0 9 38 4 100%
9. Box-Shaped Chemical Barrier	Tank Residual Between Tank and Concrete In Concrete Flushed Old and New Leaks In Barrier	4.0E-06 7.5E-09 7.2E-07 1.6E-07 2.3E-08 4.9E-08	81 0 15 3 1 100%
10. V-Shaped Chemical Barrier	Tank Residual Between Tank and Concrete In Concrete Flushed Old and New Leaks In Barrier	4.0E-06 7.5E-09 7.2E-07 1.2E-07 3.6E-08 4.9E-06	82 0 15 2 1 100%
11. V-Shaped Freeze Wall Barrier	Tank Residual Between Tank and Concrete In Concrete Flushed Old and New Leaks	4.0E-06 7.5E-09 7.2E-07 1.2E-07 4.8E-06	83 0 15 2 100%
12. Circulating Air Barrier	Tank Residual Between Tank and Concrete In Concrete Flushed Old and New Leaks	4.0E-06 7.5E-09 7.2E-07 3.5E-07 5.1E-06	79 0 14 7 100%
13. Clean-Closure w/o Close-Coupled Barrier	Landfill	1.1E-07	100%
14. Clean-Closure with Close-Coupled Barrier	Landfill	6.3E-08	100%

Table 6-12. Relative Source Contribution to Hazard Index Risk. (sheet 1 of 2)

Alternative	Source	HI Contribution at Peak	Relative Contribution (%)
1. No Action	Tank Residual	2.8E+03	100
	Between Tank and Concrete	4.0E-01	0
	In Concrete	3.0E+00	0
	Old Leaks	5.3E-01	0
		2.8E+03	100%
2. Surface Barrier Only	Tank Residual	8.6E+00	100
	Between Tank and Concrete	0.0E+00	0
	In Concrete	1.1E-02	0
	Old Leaks	2.5E-02	0
		8.6E+00	100%
3. Traditional Sluiding (Baseline)	Tank Residual	8.9E-02	37
	Between Tank and Concrete	2.3E-04	0
	In Concrete	1.6E-02	7
	Old and New Leaks	1.4E-01	56
		2.4E-01	100%
4. Robotic Sluicing	Tank Residual	6.0E-03	10
	Between Tank and Concrete	3.8E-04	1
	In Concrete	1.1E-02	20
	Old and New Leaks	3.9E-02	69
		5.7E-02	100%
5. Mechanical Retrieval	Tank Residual	4.5E-01	92
	Between Tank and Concrete	3.4E-04	0
	In Concrete	1.1E-02	2
	Old Leaks	2.9E-02	6
		4.9E-01	100%
6. Close-Coupled Chemical Barrier with Flushing	Tank Residual	9.0E-02	76
	Between Tank and Concrete	2.6E-04	0
	In Concrete	1.6E-02	14
	Flushed Old Leaks	5.0E-09	0
	In Barrier	1.2E-02	10
		1.2E-01	100%
7. Close-Coupled Chemical Barrier w/o Flushing	Tank Residual	9.0E-02	57
	Between Tank and Concrete	2.6E-04	0
	In Concrete	1.6E-02	10
	Old and New Leaks	4.0E-02	26
	In Barrier	1.2E-02	7
		1.6E-01	100%

Table 6-14. Relative Source Contribution to Hazard Index Risk. (sheet 2 of 2)

Alternative	Source	HI Risk Contribution at Peak	Relative Contribution (%)
8. Modified Close-Coupled Chemical Barrier w/o Flushing	Tank Residual	9.0E-02	49
	Between Tank and Concrete	2.5E-04	0
	In Concrete	1.6E-02	9
	Old and New Leaks	6.9E-02	38
	In Barrier	6.8E-03	4
		1.8E-01	100%
9. Box-Shaped Chemical Barrier	Tank Residual	9.0E-02	81
	Between Tank and Concrete	2.6E-04	0
	In Concrete	1.6E-02	15
	Flushed Old and New Leaks	3.6E-03	3
	In Barrier	5.2E-04	0
		1.1E-01	100%
10. V-Shaped Chemical Barrier	Tank Residual	9.0E-02	82
	Between Tank and Concrete	2.6E-04	0
	In Concrete	1.6E-02	15
	Flushed Old and New Leaks	2.7E-03	2
	In Barrier	8.1E-04	1
		1.1E-01	100%
11. V-Shaped Freeze Wall Barrier	Tank Residual	9.0E-02	83
	Between Tank and Concrete	2.6E-04	0
	In Concrete	1.6E-02	15
	Flushed Old and New Leaks	2.7E-03	2
		1.1E-01	100%
12. Circulating Air Barrier	Tank Residual	9.0E-02	79
	Between Tank and Concrete	2.6E-04	0
	In Concrete	1.6E-02	14
	Flushed Old and New Leaks	7.9E-03	7
		1.2E-01	100%
13. Clean-Closure w/o Close-Coupled Barrier	Landfill	2.4E-03	100%
14. Clean-Closure with Close-Coupled Barrier	Landfill	1.4E-03	100%

7.0 COST ANALYSIS

This section presents estimated rough-order-of-magnitude costs for the alternatives and their component technology options discussed in this report. The component options include three retrieval options, seven subsurface barrier options, soil flushing, flush water treatment, tank stabilization, a surface barrier, and clean-closure.

7.1 METHODOLOGY AND GENERAL ASSUMPTIONS

The estimated costs were developed using available published information and best engineering judgement. The cost data were mostly derived from Boomer et al., Appendixes F, J, K, M, N, and R (1993) and (KEH 1993b). The estimated costs are provided as they apply to one hypothetical tank farm with 12 single-shell underground high-level waste (HLW) storage tanks. The costs are categorized according to the options for retrieval, subsurface barriers, soil flushing, flush water treatment, stabilization, and surface barriers addressed in this report. Estimated technology readiness costs, capital costs, operating and maintenance (O&M) costs, and decontamination and decommissioning costs (D&D) are provided for each option. The total cost of each alternative and costs of individual options are expressed three ways: (1) equivalent uniform annual costs (EUAC), (2) total net present worth (TNPW), and (3) total life cycle costs (TLCC).

7.1.1 Definition of Costing Terms

Technology Readiness — Technology development costs include costs associated with technology testing and demonstration, trade-off studies, *National Environmental Policy Act* and RCRA permitting, and safety analysis.

Capital — Capital costs include costs of the following items, where applicable: design, inspection, escalation, contingency, site preparation, drilling, coffercells, buildings, mechanical equipment, piping, grout, freezing solution, surface barrier, contractor additions, and other.

O&M — The O&M costs include costs of electricity usage, labor, sampling and analysis, parts and replacement equipment, and disposal of radioactive mixed waste and HLW.

D&D — The D&D costs include costs of those components used at the surface or that are retrievable from the subsurface and are potentially radioactive.

EUAC The EUAC reflects the annual costs for all cash flows in the alternative adjusted to a base year (Ruegg 1987). EUAC is reported in units of 1994 dollars per year.

TNPW The TNPW reflects the finances currently needed to meet all requirements over the life of the alternative (Ruegg 1987). TNPW is reported as total lifetime costs (not costs per year) in 1994 dollars.

TLCC The TLCC reflects the equivalent value of the alternative's cash flow over the life span of the alternative (Ruegg 1987). TLCC is reported as total lifetime costs (not costs per year) in 1994 dollars.

7.1.2 Simplifying Assumptions

Several simplifying assumptions were made in costing the technologies. The data and assumptions used are outlined below. Bases for these and other assumptions are provided in Appendix C.

- All costs are based on one hypothetical tank farm
- The tank farm consists of twelve, 3.8 x 10^6 L (1-Mgal) SSTs in a three by four array on 30.5-m (100-ft) centers
- The tanks are in use for storage of high-level radioactive waste
- The life of all operations up to closure of the tank farm is 15 years
- The EUAC is based on a 10% discount rate per year
- The TNPW is based on a 10% discount rate per year
- The TLCC is the sum of capital costs plus D&D costs plus number of life cycle years times the O&M costs, adjusted to 1994 dollars
- All technology readiness and capital costs are incurred in the first year
- All D&D costs are incurred at the end of the life cycle
- Costs for design, inspection, escalation, and contingency of subsurface barriers are 80% of construction costs and equal to 44% of capital cost
- Costs of operating personnel are 10% per year of capital costs for active subsurface barrier options except 2% per year for chemical barrier options (which are passive)

- Costs of operating personnel are 4.2% per year of capital costs for retrieval options
- Costs of operating personnel are 15.2% per year of capital costs for flush water treatment options
- The ratio of annual O&M costs to capital costs is 0.03 for all subsurface barrier options using chemicals (passive technology, little maintenance required)
- The ratio of annual O&M costs to capital costs is 0.18 for the circulating air barrier option and the flushing water and vacuum option (active technologies)
- The ratio of annual O&M costs to capital costs is 0.16 for the freeze wall subsurface barrier option and the soil flushing and pumping option (active technologies)
- The D&D costs are zero for passive technologies such as subsurface chemical barriers and surface barriers
- The D&D costs are 10% of capital cost plus one year labor costs for active subsurface barrier technologies such as cryogenic, desiccant, soil flushing, and grout stabilization
- The D&D costs are 20% of capital cost plus two years labor cost for clean closure
- The D&D costs are 30% of capital cost plus three years labor cost for flush water treatment
- Pipe drilling and jacking costs are $500/ft
- The injected chemical volume is 15 ft^3/ft of pipe at a pipe spacing of 7 ft. Material cost is $30/$ft^3$ of injected barrier-forming chemicals
- Concentrated wastes recovered from soil flushing operations and from soil and debris washing operations are treated in the high- and low-level waste pretreatment and treatment systems
- Excess waste retrieved from tanks above 99% retrieval, as in robotic sluicing, would incur proportionally added costs for high- and low-level waste pretreatment and treatment. Reduced waste retrieval, as in mechanical retrieval, would incur proportionately reduced costs.

7.2 COSTS OF RETRIEVAL OPTIONS

Three retrieval options were considered in this report: (1) traditional sluicing, (2) robotic sluicing, and (3) mechanical retrieval. The robotic sluicing and mechanical retrieval options would be arm-based and require much of the same hardware and equipment for operation. Traditional sluicing does not use a robotic arm and requires much less equipment than either robotic sluicing or mechanical retrieval, resulting in much lower capital, O&M, and D&D costs. The estimated total costs for the retrieval options are shown in Table 7-1.

Table 7-1. Estimated Total Costs of Retrieval Options (in millions of dollars).

Retrieval Option	Tech Ready	Capital	O&M[a]	D&D	EUAC[a]	TNPW	TLCC
Traditional sluicing	2	63	4	9	13	98	136
Robotic sluicing	18	183	13	28	40	307	423
Mechanical retrieval	15	154	10	25	31	236	308

[a]Costs are presented in millions of dollars per year (not lifetime cost).

7.3 COSTS OF SUBSURFACE BARRIER OPTIONS

Seven subsurface barrier options are considered in this report: (1) close-coupled chemical with flushing, (2) box-shaped chemical, (3) V-shaped chemical, (4) V-shaped freeze wall, (5) circulating air, (6) close-coupled chemical without flushing, and (7) close-coupled chemical on tank sides only without flushing. The capital costs for all options using chemicals are estimated to be more than twice the capital costs for the circulating air barrier option (Table 7-2). The chemical options, however, would not incur D&D costs because the chemical would remain in the subsurface following waste retrieval operations, while V-shaped freeze wall and circulating air barrier options would incur D&D costs. The O&M costs for the five chemical options are projected to be comparable. The V-shaped freeze wall and V-shaped chemical options would be the most costly. The V-shaped freeze wall option would entail a high capital cost because it is assumed that three layers of pipe in a V-shaped configuration would be used to ensure barrier integrity, monitor for leak-tightness and promote interior surface melting of the barrier interior to aid in recovering contaminants that become trapped in the ice barrier. Costs for the chemical barriers reflect use of two layers of pipe for injection of chemical grout to assure barrier integrity. Additional costs would be incurred if a third pipe layer is needed to verify and monitor chemical barrier integrity.

Table 7-2. Estimated Costs of Subsurface Barrier Options (in millions of dollars).

Subsurface Barrier Option	Tech Dev.	Capital	O&M[a]	D&D	EUAC[a]	TNPW	TLCC
Close-Coupled Chemical-sides & under	13	211	6	0	36	272	318
Close-Coupled Chemical w/o Flushing	13	211	6	0	36	272	318
Modified Close-Coupled Chemical - sides only	7	123	4	0	21	158	186
Box-Shaped Chemical	13	218	7	0	37	282	331
V-Shaped Chemical	19	313	9	0	53	403	473
V-Shaped Freeze Wall	12	208	33	42	64	484	761
Circulating Air	4	71	13	14	23	177	283

[a]Costs are stated in millions of dollars per year (not lifetime cost).

7.4 COSTS OF SOIL FLUSHING OPTIONS

The two soil flushing options considered were: (1) traditional soil flushing, and (2) soil flushing with vacuum recovery. Both options would require subsequent recovery and treatment of flush water. The costs for the flushing with vacuum recovery option are more than 50% greater than the costs of the conventional flushing option (Table 7-3). Estimated costs for flush water treatment with associated transport piping are also included in this table.

Table 7-3. Estimated Costs of Soil Flushing Options (in millions of dollars).

Soil Flushing Option	Tech Dev.	Capital	O&M[a]	D&D	EUAC[a]	TNPW	TLCC
Traditional flushing	6	92	15	18	28	215	338
Vacuum soil flushing with circulating air	15	149	27	30	49	375	596
Vacuum soil flushing with close-coupled chemical	8	138	25	28	45	341	545
Flush water treatment for close-coupled barrier	0.3	8	1	7	3	22	40
Flush water treatment for box-shaped barrier	2	44	8	36	16	123	218
Flush water treatment for V-shaped barrier	2	47	9	38	17	132	232
Flush water treatment for circulating air barrier	0.6	14	3	13	6	43	77

[a]Costs are stated in millions of dollars per year (not lifetime cost).

7.5 TANK STABILIZATION AND SURFACE BARRIER

Following retrieval operations, the tanks would be stabilized by grout fill and a surface barrier would be placed over the top of the tanks. A surface barrier would also be placed over the landfill used in the clean-closure alternatives. The estimated costs for the tank stabilization and surface barrier are shown in Table 7-4.

Table 7-4. Estimated Costs of Tank Stabilization and Surface Barrier (in millions of dollars).

Closure Option	Tech Dev.	Capital	O&M[a]	D&D	EUAC[a]	TNPW	TLCC
Tank stabilization	0.1	2	0.1	0.3	0.4	3	4
Surface barrier	0.3	4	0.1	0	1	6	7

[a]Costs are stated in millions of dollars per year (not lifetime cost).

7.6 CLEAN CLOSURE

Two alternatives would employ a series of linked technologies that would result in clean closure of the hypothetical tank farm. The alternatives differ only in the use or absence of use of a close-coupled chemical barrier. The use of a barrier would result in reduced leakage during sluicing and lower quantities of contaminated soil below the tanks. The technologies assumed to be used in the alternatives and their costs are provided in Table 7-5.

7.7 SUMMARY OF ALTERNATIVES COSTS

The purpose of estimating the costs of individual options was to facilitate their comparison and to enable summing the costs in accordance with the combinations of options that define the various alternatives. Tables 7-6, 7-7, and 7-8 show the costs of options and alternatives based on EUAC, TNPW, and TLCC, respectively.

Table 7-5. Estimated Costs of Clean Closure (in millions of dollars).

	Tech Ready	Capital	O&M[a]	D&D	EAUC[b]	TNPW	TLCC
ALTERNATIVE 13, NO BARRIER							
Removal	4	141	25	71	47	356	598
Tank farm confinement	8	270	49	135	89	680	1,141
Hauling & mixed waste landfill	1	19	3	9	6	47	78
Soil & debris water wash	5	169	30	85	56	427	717
Wash water treatment	2	50	9	25	17	126	212
Washed solids to mixed waste disposal	0.0	0.06	0.01	0.03	0	0	0
Recycle piping	1.9	65	12	32	21	163	274
Backfill	0.2	5	1	3	4	30	56
HLW processing & disposal	0.3	11	2	11	5	38	70
Totals	22	730	132	370	245	1,866	3,145
ALTERNATIVE 14, WITH CLOSE-COUPLED CHEMICAL							
Close-coupled chemical barrier	4	14.5	4	72	26	199	286
Removal	3	96	17	48	32	242	406
Tank farm confinement	8	270	49	135	89	680	1,141
Hauling & mixed waste landfill	0	13	2	6	4	32	53
Soil & debris water wash	3	115	21	58	38	290	487
Wash water treatment	1	34	6	17	11	86	194
Solids to mixed waste disposal	0.0	0.04	0	0	0	0	0
Recycle piping	1.3	44	8	22	15	111	186
Backfill	0.1	4	1	2	1	9	15
HLW processing & disposal	0.2	8	2	8	4	29	54
Totals	22	729	110	368	221	1,678	2,774

[a]Costs are stated in million of dollars per year (not lifetime cost).

Table 7-6. Estimated EUAC Costs of Alternatives (in millions of dollars).

Alternative	Subsurface Barrier Option	Retrieval Option	Flushing	Flush Water Treatment	Tank Stabilized	Surface Barrier	Total Costs
1. No Action	none	none	none	none	no	none	0
2. Surface Barrier Only	none	none	none	none	no	yes 1	1
3. Traditional Sluicing (Baseline)	none	trad. sluicing 13	none	none	yes 0.4	yes 1	14
4. Robotic Sluicing	none	robotic sluicing 40	none	none	yes 0.4	yes 1	41
5. Mechanical Retrieval	none	mech. retrieval 31	none	none	yes 0.4	yes 1	32
6. Close-Coupled Chemical Barrier with Flushing	close-coupled chemical 36	trad. sluicing 13	flushing & vacuum 45	14 Mgal 3	yes 0.4	yes 1	98
7. Close-Coupled Barrier w/o Flushing	close-coupled chemical 24	trad. sluicing 13	none	none	yes 0.4	yes 1	39
8. Modified Close-Coupled Chemical	partial close-coupled chemical 21	trad. sluicing 13	none	none	yes 0.4	yes 1	35
9. Box-Shaped Chemical Barrier	box-shaped chemical 37	trad. sluicing 13	flushing & pumping 28	245 Mgal 16	yes 0.4	yes 1	96
10. V-Shaped Chemical Barrier	V-shaped chemical 53	trad. sluicing 13	flushing & pumping 28	278 Mgal 17	yes 0.4	yes 1	113
11. V-Shaped Freeze Wall Barrier	V-shaped freeze wall 64	trad. sluicing 13	flushing & pumping 28	278 Mgal 17	yes 0.4	yes 1	123
12. Circulating Air Barrier	circulating air 23	trad. sluicing 13	flushing & vacuum 49	20 Mgal 6	yes 0.4	yes 1	92
13. Clean-Closure w/o Barrier	none	trad. sluicing and mining[a] 258	none	none	not applicable	no	258
14. Clean-Closure with Barrier	close-coupled chemical 24	trad. sluicing and mining[a] 234	none	none	not applicable	no	258

[a]Includes costs for transfer, treatment, and disposal of all contaminated residues in a landfill or HLW repository.

Table 7-7. Estimated TNPW Costs of Alternatives (in millions of dollars).

Alternative	Subsurface Barrier Option	Retrieval Option	Flushing	Flush Water Treatment	Tank Stabilized	Surface Barrier	Total Costs
1. No Action	none	none	none	none	no	none	0
2. Surface Barrier Only	none	none	none	none	no	yes 6	6
3. Traditional Sluicing (Baseline)	none	trad. sluicing 98	none	none	yes 3	yes 6	107
4. Robotic Sluicing	none	robotic sluicing 307	none	none	yes 3	yes 6	316
5. Mechanical Retrieval	none	mech. retrieval 236	none	none	yes 3	yes 6	244
6. Close-Coupled Chemical Barrier with Flushing	close-coupled chemical 186	trad. sluicing 98	flushing & vacuum 341	14 Mgal 22	yes 3	yes 6	742
7. Close-Coupled Chemical Barrier w/o Flushing	none & close-coupled chemical 186	trad. sluicing 98	none	none	yes 3	yes 6	293
8. Modified Close-Coupled Chemical Barrier	partial close-coupled chemical 158	trad. sluicing 98	none	none	yes 3	yes 6	265
9. Box-Shaped Chemical Barrier	box-shaped chemical 282	trad. sluicing 98	flushing & pumping 215	245 Mgal 123	yes 3	yes 6	727
10. V-Shaped Chemical Barrier	V-shaped chemical 403	trad. sluicing 98	flushing & pumping 215	278 Mgal 132	yes 3	yes 6	857
11. V-Shaped Freeze Wall Barrier	V-shaped freeze wall 484	trad. sluicing 98	flushing & pumping 215	278 Mgal 132	yes 3	yes 6	937
12. Circulating Air Barrier	circulating air 177	trad. sluicing 98	flushing & vacuum 375	20 Mgal 43	yes 3	yes 6	702
13. Clean-Closure w/o Barrier	none	trad. sluicing and mining[a] 1965	none	none	not applicable	no	1965
14. Clean-Closure with Barrier	close-coupled chemical 186	trad. sluicing and mining[a] 1776	none	none	not applicable	no	1962

[a]includes costs for transfer, treatment, and disposal of all contaminated residues in a landfill or HLW repository.

Table 7-8. Estimated TLCC Costs of Alternatives (in millions of dollars).

Alternative	Subsurface Barrier Option	Retrieval Option	Flushing	Flush Water Treatment	Tank Stabilized	Surface Barrier	Total Costs
1. No Action	none	none	none	none	no	none	0
2. Surface Barrier Only	none	none	none	none	no	yes 7	7
3. Traditional Sluicing (Baseline)	none	trad. sluicing 136	none	none	yes 4	yes 7	146
4. Robotic Sluicing	none	robotic sluicing 423	none	none	yes 4	yes 7	431
5. Mechanical Retrieval	none	mech. retrieval 307	none	none	yes 4	yes 7	318
6. Close-Coupled Chemical Barrier with Flushing	close-coupled chemical 318	trad. sluicing 136	flushing & vacuum 545	14 Mgal 40	yes 4	yes 7	1049
7. Close-Coupled Chemical Barrier w/o Flushing	close-coupled chemical 248	trad. sluicing 136	none	none	yes 4	yes 7	364
8. Modified Close-Coupled Chemical Barrier	partial close-coupled chemical 186	trad. sluicing 136	none	none	yes 4	yes 7	332
9. Box-Shaped Chemical Barrier	box-shaped chemical 331	trad. sluicing 136	flushing & pumping 338	245 Mgal 218	yes 4	yes 7	1033
10. V-Shaped Chemical Barrier	V-shaped chemical 473	trad. sluicing 136	flushing & pumping 338	278 Mgal 232	yes 4	yes 7	1190
11. V-Shaped Freeze Wall Barrier	V-shaped freeze wall 761	trad. sluicing 136	flushing & pumping 338	278 Mgal 232	yes 4	yes 7	1478
12. Circulating Air Barrier	circulating air 283	trad. sluicing 136	flushing & vacuum 596	32 Mgal 77	yes 4	yes 7	1103
13. Clean-Closure w/o Barrier	none	trad. sluicing and mining[a] 3281	none	none	not applicable	no	3287
14. Clean-Closure with Barrier	close-coupled chemical 218	trad. sluicing and mining[a] 2910	none	none	not applicable	no	3128

[a]Includes costs for transfer, treatment, and disposal of all contaminated residues in a landfill or HLW repository.

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8.0 COST-BENEFIT AND SENSITIVITY ANALYSIS

This section contains an analysis of the relative cost-benefit of the 14 alternatives and an evaluation of the uncertainty and variability of selected factors that may impact cost and risk.

8.1 COST-BENEFIT ANALYSIS

The cost-benefit of the 14 alternatives was estimated using peak relative risk and HI measures presented in Section 6 and TNPW measures presented in Section 7. The TNPW was selected as the most appropriate measure of cost for this analysis because it reflects the discounted cost of the alternative, a true measure of overall cost.

Benefit in this analysis is defined as the ratio of relative risk or HI for an initial or baseline case to relative risk or HI after an action(s) is taken to mitigate the risk, minus one. Hence, benefit reflects the proportional reduction in risk or hazard. This approach for calculating benefit was deemed appropriate because it allows for discrimination among alternatives when there is a large difference between the riskiest alternative and several alternatives with similar risks.

Cost-benefit (C-B) in this analysis is defined as the ratio of the benefit (the "bang") to the TNPW (the "buck"), as show below:

$$C\text{-}B_{risk} = ((Risk_i/Risk_n)-1)/TNPW$$

$$C\text{-}B_{HI} = ((HI_i/HI_n)-1)/TNPW$$

For example, a reduction of relative risk from a level of 20 to 2 at a cost of 3 would equate to a cost-benefit of 3. No reduction of risk would equate to a cost-benefit of 0, regardless of cost. The cost-benefit of each alternative relative to the No-Action Alternative is shown in Table 8-1. Several conclusions can be drawn from this table, ignoring the high uncertainties in both the cost and risk analyses and other factors important in the decision making process.

- There is relatively little difference in the cost-benefit of the various subsurface barrier alternatives.

- The Robotic Sluicing and Traditional Sluicing Alternatives would be two to six times more cost-effective than would alternatives that employ subsurface barriers to support closure of tank farms as landfills. From a risk differential standpoint (i.e., benefit equals the difference in risks as opposed to the ratio of risks), cost-

Table 8-1. Cost-Benefit of Alternatives Relative to No-Action Alternative.

Alternative	Relative Risk	HI	TNPW	Risk Cost-Benefit	HI Cost-Benefit
1. No Action[a]	1.5×10^{-1}	2.8×10^{3}	0	N/A[b]	N/A[b]
2. Surface Barrier Only[a]	3.7×10^{-4}	8.6	6	67	54
3. Traditional Sluicing	1.1×10^{-5}	2.4×10^{-1}	107	127	109
4. Robotic Sluicing	2.5×10^{-6}	5.7×10^{-2}	316	190	155
5. Mechanical Retrieval	2.1×10^{-5}	4.9×10^{-1}	244	29	23
6. Close-Coupled Chemical[c]	5.2×10^{-6}	1.2×10^{-1}	742	39	31
7. Close-Coupled w/o Flushing[c]	7.0×10^{-6}	1.6×10^{-1}	293	73	60
8. Modified Close-Coupled w/o Flushing[c]	8.0×10^{-6}	1.8×10^{-1}	265	71	59
9. Box-Shaped Chemical[c]	4.9×10^{-6}	1.1×10^{-1}	727	42	35
10. V-Shaped Chemical[c]	4.9×10^{-6}	1.1×10^{-1}	857	36	30
11. V-Shaped Freeze Wall[c]	4.8×10^{-6}	1.1×10^{-1}	937	33	27
12. Circulating Air[c]	5.1×10^{-6}	1.2×10^{-1}	702	42	33
13. Clean-Closure w/o Barrier	1.1×10^{-7} [d]	2.4×10^{-3}	1,965	76[d]	600
14. Clean-Closure with Barrier[c]	6.3×10^{-8} [d]	1.4×10^{-3}	1,962	76[d]	1,000

[a]non-viable options
[b]N/A - not applicable
[c]alternatives employing a subsurface barrier
[d]risk cost-benefit based on relative risk of 10^{-6}, the assumed limit of benefit to human health (i.e., below this limit it is assumed that benefit to health is insignificant).

benefit is essentially proportional to cost. In this case, the Traditional Sluicing Alternative is two to nine times more cost-effective; the cost-effectiveness of robotic sluicing is similar to that of the other alternatives.

- Clean-closure alternatives would be similar in risk cost-effectiveness in protecting groundwater to alternatives that employ subsurface barriers. This conclusion is based on the risk-ratio method for determining benefit. For the risk-difference method, clean-closure would be two to eight times less cost-effective.

- The use of subsurface barriers to support clean-closure would improve HI cost-effectiveness, based on the HI ratio method. Using the difference method, clean closure would be two to eight times less cost-effective than alternatives that employ subsurface barriers.

The incremental cost-effectiveness of selected actions taken to reduce risk is shown in Table 8-2. This table was developed to enable comparison of the cost-benefit (based on the ratio method) of individual actions included in the alternatives. Table 8-2 includes a measure of the cost-effectiveness of an alternative not previously analyzed in this study. The alternative is the same as Alternative 3 - Traditional Sluicing Alternative (Baseline Alternative), but without a surface barrier. This alternative was analyzed in order to evaluate the incremental cost-effectiveness of the surface barrier. Costs for the individual actions are based on TNPW.

Incremental cost-benefit of an action was determined by dividing the risks of two alternatives that differ only in the specific action and subtracting 1, by the difference in the cost of the alternatives, as below:

$$Incremental\ C\text{-}B_{risk} = \frac{(Risk_n/Risk_m) - 1}{TNPW_m - TNPW_n}$$

$$Incremental\ C\text{-}B_{HI} = \frac{(HI_n/HI_m) - 1}{TNPW_m - TNPW_n}$$

Conclusions that can be drawn from this table, ignoring uncertainties and other important factors, are listed below.

- The most cost-effective individual action is adding a close-coupled subsurface barrier to support clean-closure. This result is lowering both risk and HI and the overall cost of the alternative. This apparent anomaly arises from the substantial reduction in contaminated soil and recovered contaminants requiring treatment when a subsurface barrier is used. The resulting cost savings more than offset the cost of installing the barrier.

Table 8-2. Incremental Cost-Effectiveness of Selected Actions.

Actions	Cost-Effectiveness of Action(s) (Risk-Ratio Method)				Incremental Cost-Effectiveness Compared to:
	Risk-Effectiveness		HI-Effectiveness		
	Overall[a]	Incremental	Overall[a]	Incremental	
A. Use traditional sluicing and grout tank voids-no surface barrier (new alternative)	0.3	0.3	0.3	0.3	No Action (Alt. 1)
B. Add a surface barrier to A (Alt. 3)	129	73	110	62	Traditional sluicing and void grouting (new alternative i.e., Action A)
C. Add a close-coupled chemical barrier with flushing to B (Alt. 6)	39	0.0018	31	0.0016	Traditional sluicing, void grouting, and surface barrier (Alt. 3)
D. Add a close-coupled chemical barrier w/o flushing to B (Alt. 7)	73	0.0031	60	0.0027	Traditional sluicing, void grouting, and surface barrier (Alt. 3)
E. Add a modified close-coupled chemical barrier w/o flushing to B. (Alt. 8)	71	0.0024	59	0.0021	Traditional sluicing, void grouting, and surface barrier (Alt. 3)
F. Add a box-shaped chemical barrier with flushing to B. (Alt. 9)	42	0.0020	35	0.0019	Traditional sluicing, void grouting, and surface barrier (Alt. 3)
G. Add a v-shaped chemical barrier with flushing to B. (Alt. 10)	36	0.0016	30	0.0016	Traditional sluicing, void grouting, and surface barrier (Alt. 3)
H. Add a v-shaped freeze wall barrier with flushing to B. (Alt. 11)	33	0.0015	27	0.0014	Traditional sluicing, void grouting, and surface barrier (Alt. 3)
I. Add a circulating air barrier with flushing to B. (Alt. 12)	42	0.0019	33	0.0017	Traditional sluicing, void grouting, and surface barrier (Alt. 3)
J. Add a stand-off barrier w/o flushing to B. (modified Alt. 9-12)	0	0	0	0	Traditional sluicing, void grouting, and surface barrier (Alt. 3)
K. Clean-close with close-coupled barrier (Alt. 14)	76	-0.25[b]	1,000	-0.24[b]	Clean-close w/o close-coupled barrier (Alt. 13)

[a]Relative to No-Action Alternative
[b]Results are negative because risk, HI, and overall cost are reduced. Thus, use of a barrier is cost-effective in this case.

- The next most cost-effective action is adding a surface barrier following traditional sluicing and tank void stabilization. This action is more than two orders of magnitude more cost-effective than traditional sluicing and void stabilization, and more than four orders of magnitude more cost-effective than the use of any subsurface barrier for supporting the combined actions of traditional sluicing, void stabilization, and capping with a surface barrier. The differences are much greater if the risk-difference method is used to calculate benefit.

- Incremental cost-effectiveness of the various subsurface barrier options varies by about a factor of two. The most cost-effective option among these fairly equivalent options is the use of the close-coupled chemical barrier without flushing. This alternative would use barriers only on those tanks that leaked previously and to those that develop leaks during new sluicing operations.

- Adding a standoff barrier without flushing results in a cost-effectiveness of 0 because no reduction in risk would occur.

8.2 SENSITIVITY ANALYSIS

A sensitivity analysis was conducted to evaluate the effects of uncertainty in the inventories of COCs in the seven sources of potential groundwater contamination. A separate sensitivity analysis was conducted to evaluate the effects of variability and uncertainty in the initial tank waste inventory, in the geology underlying the tanks, and in the solubilities of different COCs.

8.2.1 Uncertainty in Source Inventories and Release Rates

The following sensitivity analysis is based on a comparison of the range of estimated nitrate levels in sources of potential groundwater contamination evaluated in Section 6. Nitrate is a good indicator of both carcinogenic risk and HI as shown in Figure 8-1. This figure shows the best estimates of risk and HI analyzed in Section 6 as a function of total nitrate levels for all sources in each of the retrieval alternatives, including the two clean-closure alternatives. The strong correlation is due to (1) the assumption of congruent leaching of all COCs by recharge water (i.e., limited only by the solubility of nitrate), (2) the assumption that none of the COCs adsorb to Hanford Site soils, (3) the fact that only limited radioactive decay of COCs occurs, and (4) the existence of most of the contamination from different sources at approximately the same depth in the ground. Thus, all COCs are mobilized with nitrate and their concentrations remain in proportion to the nitrate concentration.

The total nitrate levels of each of the seven alternatives that include subsurface barriers, excluding the Clean-Closure with Close-Coupled Barrier Alternative, were compared to that of the Baseline Alternative. Each of these alternatives includes traditional sluicing as a

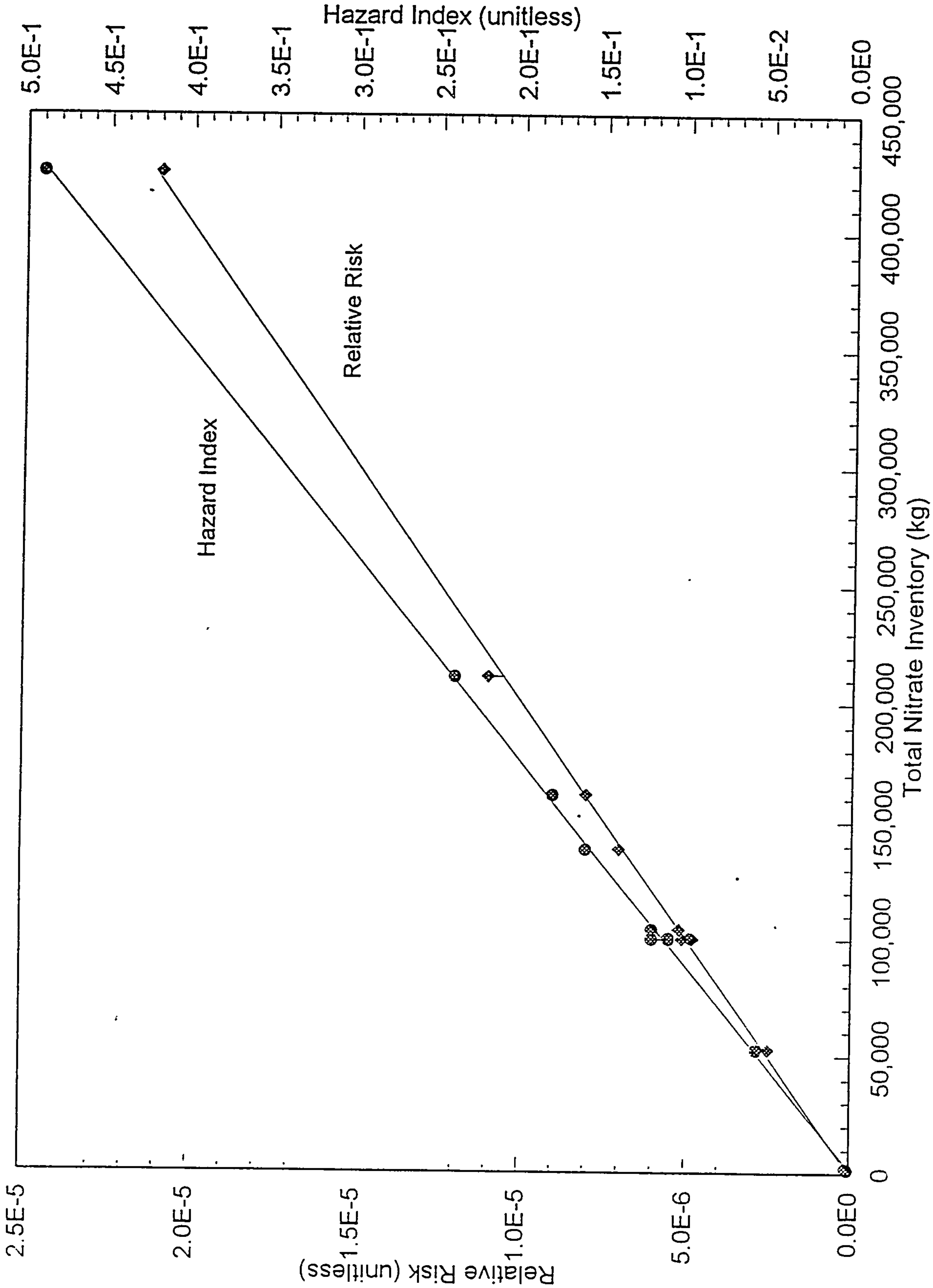

Figure 8-1. Risk and Hazard Index Versus Total Nitrate in All Sources.

common basis. Table 8-3 shows a summary of the low, best, and high estimates of nitrate levels for these alternatives and their associated waste sources. These estimates were reported and their bases described in Section 6. Table 8-3 shows that the four primary sources of nitrate (and risk) are (1) best and high cases of residual waste in the tank (all alternatives), (2) unflushed leakage to the soil (Traditional Sluicing, Close-Coupled, and Modified Close-Coupled w/o Flushing Alternatives - in soil), (3) the high cases of flushed leakage (the three standoff barrier and desiccant barrier alternatives - in soil), and (4) the high cases of advection into the close-coupled barrier (all three close-coupled barrier alternatives in barrier).

Each alternative features the same nitrate levels in the tank residuals (the first primary source of risk) because each uses traditional sluicing. Nitrate levels between the tank shell and concrete and in the concrete are also the same for each alternative. The nitrate levels in the tank residuals for the low, best, and high estimates correspond to 99.9%, 99%, and 95% retrieval effectiveness, respectively. A level of 99.9% may be achievable if enhanced technology (e.g., use of weak acids) is used to soften and dissolve agglomerated sludge. A level of 99% retrieval represents best judgement; however, enhanced technology may also be necessary to achieve this goal. A level of approximately 95% retrieval was probably exceeded in past sluicing campaigns. The level of residual nitrate in the tanks resulting from 95% retrieval would dominate all other potential sources. In this case, the use of subsurface barriers would have relatively little impact on nitrate levels and risk.

Unflushed leakage is the second primary contributor to nitrate levels and risk. The best estimate of nitrate levels in the case of unflushed leakage is based on the following key assumptions: (1) five of the 12 tanks in the hypothetical tank farm leaked an average of 42,000 L (11,000 gal) each during past operations, (2) five of the tanks would leak an average of 152,000 L (40,000 gal) each during new sluicing operations, and (3) the average nitrate concentration would be one-half that of typical interstitial liquid. The high level of nitrate estimated in the case of unflushed leakage is based on the assumption that one tank would leak the equivalent of that leaked from Tank 241-T-106 (i.e., 115,000 gal).

The low and best estimates for alternatives that include soil flushing are based on the assumption of 94% nitrate removal by flushing and vacuuming or pumping. This would result in a level of residual nitrate in the soil that is similar to that in the tanks following 99.9% waste retrieval (the low estimate). The assumption of relatively ineffective (50% removal) soil flushing as in the V-Shaped Chemical Barrier, "in soil" high estimate case (the third primary source of risk) would result in a residual nitrate level in the soil that is similar to the best estimate of tank residual nitrate (99% retrieval).

The high estimate of advection into the close-coupled barrier (the fourth primary source of risk) would result from the assumption of a factor of 10 increase in either the hydraulic conductivity of the barrier to 10^{-5} cm/s (2 x 10^{-5} in/s) or in the length of cracks through which leaks occur (to 101 m [330 ft]).

Table 8-3. Summary of Nitrate Levels in Subsurface Barrier Alternative Sources (thousand kg of nitrate).

Alternative	Estimated Nitrate Case	Sources				
		Residual in Tank	Between Tank Shell & Concrete	In Concrete	In Soil	In Barrier
3. Traditional Slucing (Baseline)	Low	7.8[a]	0.7	14	50	0
	Best	78[b]	0.7	14	120	0
	High	390[c]	30[d]	45[e]	166[f]	0
6. Close-Coupled Chemical with Flushing	Low	7.8[a]	0.7	14	1.5	1
	Best	78[b]	0.7	14	1.5	10
	High	390[c]	30[d]	45[e]	35[f]	100[g]
7. Close-Coupled Chemical w/o Flushing	Low	7.8[a]	0.7	14	36	1
	Best	78[b]	0.7	14	36	10
	High	390[c]	30[d]	45[e]	80[f]	100[g]
8. Modified Close-Coupled Chemical	Low	7.8[a]	0.7	14	35	0.6
	Best	78[b]	0.7	14	63	6
	High	390[c]	30[d]	45[e]	107[f]	60[g]
9. Box-Shaped Chemical	Low	7.8[a]	0.7	14	3	0.06
	Best	78[b]	0.7	14	7	0.6
	High	390[c]	30[d]	45[e]	81[f]	6[g]
10. V-Shaped Chemical	Low	7.8[a]	0.7	14	3	0.08
	Best	78[b]	0.7	14	7	0.8
	High	390[c]	30[d]	45[e]	81[f]	8[g]
11. V-Shaped Freeze Wall	Low	7.8[a]	0.7	14	3	0
	Best	78[b]	0.7	14	7	0
	High	390[c]	30[d]	45[e]	81[f]	0
12. Circulating Air	Low	7.8[a]	0.7	14	3	0
	Best	78[b]	0.7	14	7	0
	High	390[c]	30[d]	45[e]	81[f]	0

[a]Based on 9.9% waste retrieval
[b]Based on 99% waste retrieval
[c]Based on 95% waste retrieval
[d]Based on assumption that one tank in the 12-tank tank farm is similar to Tank 241-A-105 which has a large bulge in steel liner containing 29,000 kg nitrate.
[e]Based on a 10x increase in hydraulic conductivity of concrete due to poor quality or degradation overtime.
[f]Based on one tank leaking 115,000 gal as occurred in Tank 241-T-106 and only 50% flushing effectiveness where applicable.
[g]Based on a 10x increase in hydraulic conductivity to 10^5 cm/s.

Although Table 8-3 shows that considerable uncertainty exists in the levels of nitrate that would occur in the tank residuals, between the tank shell and concrete, and within the concrete, this uncertainty is not addressed further in this analysis since the focus of the analysis is on subsurface barriers. Risks associated with the use of subsurface barriers will primarily be affected by the residual levels of nitrate and other COCs in the soil and within the barrier. Thus, cumulative low and high nitrate estimates were made for each of the seven subsurface barrier alternatives by adding the best estimate nitrate values for residual tank waste, waste between the tank shell and concrete and within the concrete, to the low, and high estimates for the sources related to the barrier and soil. These totals are shown in Table 8-4 with the projected relative risk and HI based on Figure 8-1.

This table shows that uncertainty in the effectiveness of the various subsurface barrier systems would have little impact on the magnitude of overall risk or HI posed by the alternatives. Relative risk would range from 4.2×10^{-6} to 1.5×10^{-5} and HI would range from 1.0×10^{-1} to 3.8×10^{-1}. The small overall range in uncertainty of relative risk and HI impacted by the subsurface barrier (about a factor of 4x), when compared to the high range in risk and HI reduction that potentially would be achieved among the 10 viable landfill-closure alternatives (about a factor of 400x), attests to the relatively small impact subsurface barriers would be expected to have in reducing overall risk.

8.2.2 Other Uncertainties

Other uncertainties should be considered in the decision making process. For example, only the two clean-closure alternatives were shown as potentially achieving a 10^{-6} relative risk level in Figure 6-10. Each alternative that includes traditional sluicing, with or without a subsurface barrier, was shown as achieving at least a 10^{-4} risk level. As noted earlier, the measures of relative risk shown in this figure should be considered only as rough approximations of incremental cancer risk. If these measures prove to be reasonably accurate after applying more rigorous risk assessment methodologies and using better modeling data, then it would be possible to conclude that projected average risk for the hypothetical tank farm through the groundwater pathway would fall within the 10^{-4} to 10^{-6} range generally accepted by the EPA and Ecology for cleanup of waste sites.

Variability and uncertainties in waste inventories and local geologies could invalidate this conclusion for specific tank farms. Some tank farms will exhibit higher or lower levels of risk than estimated for the hypothetical farm which was modeled assuming average waste inventories and an assumed set of geologic conditions. The variability in the inventories of COCs in separate SST tank farm groupings was investigated by Schmittroth et al. (1993). Schmittroth reported inventories of COCs that would contribute to risk and hazard, including six COCs that served as bases for this feasibility study. The inventories are summarized in Table 8-5. Table 8-6 shows the average inventories of the same COCs within individual tank farms by grouping, and the variabilities of those inventories from those of the overall average SST tank farm.

Table 8-4. Projected Impacts of Uncertainty in the Effectiveness of Subsurface Barrier Alternatives.

Alternative	Low Case			High Case		
	Total Nitrate[a] (kg ÷ 1,000)	Projected Risk	Projected HI	Total Nitrate[a] (kg ÷ 1,000)	Projected Risk	Projected HI
6. Close-Coupled Chemical Barrier w/Flushing	95	4.2E-6	1.0E-1	228	1.0E-5	2.5E-1
7. Close-Coupled Chemical Barrier w/o Flushing	130	5.7E-6	1.4E-1	273	1.2E-5	3.0E-1
8. Modified Close-Coupled w/o Flushing	128	5.7E-6	1.4E-1	260	1.3E-5	3.3E-1
9. Box-Shaped Chemical Barrier	96	4.2E-6	1.1E-1	180	7.9E-6	2.0E-1
10. V-Shaped Chemical Barrier	96	4.2E-6	1.1E-1	182	8.0E-6 .	2.0E-1
11. V-Shaped Freeze Wall Barrier	96	4.2E-6	1.1E-1	174	7.6E-6	1.9E-1
12. Circulating Air Barrier	96	4.2E-6	1.1E-1	174	7.6E-6	1.9E-1

[a]Totals based on best case inventories shown in Table 8-3 for sources that would not be impacted by the use of subsurface barriers (i.e., residuals in tank, between shell and concrete, and in concrete), added to low or high cases for sources that would be impacted by the presence of the barrier (i.e., in soil and in barrier).

Table 8-5. Inventory of Selected Constituents of Concern by Tank Farm Grouping[a].

Radioisotope	Tank Farm Groupings						Sum
	A+AX	B+BX+BY	C	S+SX	T+TX+TY	U	
^{14}C	440 Ci	1,000 Ci	200 Ci	1,100 Ci	1,200 Ci	400 Ci	4,400 Ci
^{99}Tc	2,100 Ci	6,700 Ci	1,000 Ci	6,800 Ci	8,200 Ci	2,000 Ci	27,000 Ci
^{129}I	3.2 Ci	11 Ci	2.0 Ci	9.0 Ci	12 Ci	4.0 Ci	42 Ci
^{238}U	21 Ci	68 Ci	80 Ci	40 Ci	220 Ci	30 Ci	460 Ci
NO_3	4,400 Mg	40,000 Mg	5,600 Mg	56,000 Mg	20,000 Mg	4,300 Mg	130,000 Mg
NO_2	160 Mg	2,500 Mg	9.2 Mg	550 Mg	880 Mg	92 Mg	4,000 Mg

[a]Source: Schmittroth et al. (1993)
Mg - million grams

Table 8-6. Average Tank Farm Inventory of Selected Constituents of Concern by Tank Farm Grouping[a].

Radioisotope	Tank Farm Grouping						Overall Avg.	Variability from Overall Average
	A+AX	B+BX+BY	C	S+SX	T+TX+TY	U		
^{14}C	220 Ci	333 Ci	200 Ci	550 Ci	400 Ci	400 Ci	367 Ci	-45%,+50%
^{99}Tc	1,050 Ci	2,230 Ci	1,000 Ci	3,400 Ci	2,730 Ci	2,000 Ci	2,250 Ci	-56%,+51%
^{129}I	1.6 Ci	3.7 Ci	2.0 Ci	4.5 Ci	4.0 Ci	4.0 Ci	3.5 Ci	-54%,+29%
^{238}U	10.5 Ci	23 Ci	80 Ci	20 Ci	73 Ci	30 Ci	38 Ci	-66%,+111%
NO_3	2,200 Mg	13,000 Mg	5,600 Mg	28,000 Mg	6,700 Mg	4,300 Mg	10,800 Mg	-80%,+159%
NO_2	80 Mg	820 Mg	9.2 Mg	270 Mg	290 Mg	92 Mg	330 Mg	-97%,+148%

[a]Adapted from Schmittroth et al. (1993)
Mg - million grams

Table 8-6 shows that the variability in inventories of radioactive COCs by individual tank farm is relatively small. Risk due to variability in ^{99}Tc, the risk-controlling COC as shown in Table 6-10, would be only about 50% from average assuming all other conditions are equal and that risk is proportional to inventory as indicated in Figure 8-1. Thus the variability in the starting inventories of carcinogenic COCs in individual tank farms would appear to have a relatively minor impact on potential risk. However, the variability in nitrate and nitrite inventories is greater, which would lead to a greater impact on HI. It would also have an affect on the rate at which carcinogenic COCs would be released since it was assumed that all COCs would be released congruently with nitrate. Thus, a tank with a low nitrate inventory would release its carcinogenic COC inventory relatively quickly.

A sensitivity case was analyzed to evaluate the impacts of variability and uncertainty in inventories of COCs. The effects of uncertainties in tank farm geology and solubilities of COCs were also analyzed, following the COC inventory analysis.

High and Low COC Inventory Cases

For this sensitivity analysis, it was assumed that a high COC inventory case is based on the inventory shown for the S+SX tank farm grouping in Table 8-6. A low COC inventory case is based on the inventory shown for the A+AX tank farm grouping. Inventories for TBP and EDTA were assumed to be the same as used for previous analyses in this feasibility study. These organics are minor contributors to risk and HI as shown in Table 6-10. Overall inventories for these cases are summarized in Table 8-7.

Table 8-7. High and Low Constituent of Concern Inventory Cases for Sensitivity Analysis.

Constituent of Concern	High Case	Low Case
^{14}C	550 Ci	220 Ci
^{99}Tc	3,400 Ci	1,050 Ci
^{129}I	4.5 Ci	1.6 Ci
^{238}U	20 Ci	10.5 Ci
NO_3	28,000 Mg	2,200 Mg
NO_2	270 Mg	80 Mg
EDTA	1.4 Mg	1.4 Mg
TBP	0.95 Mg	0.95 Mg

Mg - million grams

The relative risks and HI for the high and low COC inventory cases were computed using all other assumptions made for Alternative 3 - Traditional Sluicing. Results and discussion of this analysis are presented later in this section with those of other sensitivity analyses.

Uncertainty also exists in the overall inventory of COCs in all SSTs. Differences between the overall SST inventories assumed for two recent studies are shown in Table 8-8. The differences shown in this table reflect the uses of different sources of inventory information and different levels of conservatism. Inventories used in this feasibility study were based primarily on inventories provided in Boomer et al. (1993). Except for nitrite, Boomer et al. (1993) inventories are 0 to 40% lower than used by Schmittroth et al. (1993). Thus uncertainty in initial inventory of the waste adds slightly to the overall uncertainty in projecting risk and HI.

Table 8-8. Variability in Single-Shell Tank Farm Waste Inventories.

Constituent of Concern	Study No. 1[a]		Study No. 2[b]	
	Overall	Average for 12-tank farm	Overall	Average for 12-tank farm
^{14}C	4,400 Ci	354 Ci	3,000 Ci	240 Ci
^{99}Tc	27,000 Ci	2,170 Ci	16,000 Ci	1,300 Ci
^{129}I	42 Ci	3.4 Ci	24 Ci	2 Ci
^{238}U	460 Ci	37 Ci	460 Ci	37 Ci
NO_3	130,000 Mg	10,500 Mg	96,800 Mg	7,800 Mg
NO_2	4,000 Mg	322 Mg	4,800 Mg	390 Mg
EDTA	67 Mg	5.4 Mg	NR[c]	NR[c]
TBP	NR[c]	NR[c]	NR[c]	NR[c]

[a]Schmittroth et al. (1993)
[b]Boomer et al. (1993)
[c]NR - not reported
[d]Mg - million grams

High and Low Vadose Zone Travel Rate Cases

Two sensitivity cases involving different geologies beneath the tank farm were also evaluated. One results in a projected higher vadose zone travel rate and the other in a lower rate than would occur using prior assumptions. The rate of travel affects the level of diffusion and dispersion that would occur in the vadose zone and hence, the peak concentrations of COCs and corresponding risks. The geologies evaluated are those reported for the S Tank Farm grouping and the B Tank Farm grouping in Droppo et al. (1991).

Key geologic information for the two tank farm groupings in Droppo et al. (1991) and the geologic conditions previously assumed for the hypothetical tank farm are shown in Table 8-9. The relative risks and HIs computed in this analysis were based on the same conditions used to model Alternative 3 - Traditional Sluicing, except for the changes in the geology. These previous conditions are shown in the "Feasibility Study" row in the table. Results are presented later in this section.

Table 8-9. Variability in Single-Shell Tank Farm Geologies.

Case	Description of Descending Layers Beneath Tank Farm	Thickness (cm)	Field Capacity (%)	Estimated Travel Time (yr)[a]
Feasibility Study	Sand	1,000	19	3,800
	Sand	5,000	8.5	8,500
	Sand	1,900	19	7,220
		7,900		19,520
B Tank Farm	Sand	5,000	9	9,000
	Loamy Sand	150	12	360
	Sand	2,680	9	4,824
		7,830		14,184
S Tank Farm	Loamy Sand	2,743	12	6,583
	Sandy Loam	1,524	17	5,181
	Sandy Clay Loam	762	24	3,658
	Clay Loam	305	34	2,074
	Clay	152	40	1,216
	Sand	914	9	1,645
		6,400		20,357

[a]Based on 0.05 cm/yr recharge rate.

Solubility-Limited Case

A final sensitivity case involving solubility-limited release and leaching of tank waste was conducted. Solubility limits the concentration of COCs that could penetrate between tank steel and concrete, advect into the concrete and leak from the tank. It would also impact the rate of leaching of residual tank waste by advecting recharge water. Previous analyses in this feasibility study were based on the conservative assumption that all COCs would leak and leach congruently with nitrate. Solubility data for the COCs were presented in Table 6-3. It can be inferred from these data and the assumed concentrations in recharge water and interstitial liquid also shown in this table that some COCs will dissolve at rates several orders of magnitude lower than assumed in the previous analyses. Lower solubilities would result in lower release rates of COCs and lower relative risk. There would be little affect on HI since HI results are dominated by nitrate. Nitrate was assumed to dissolve at the solubility limit reported in Table 6-3 in previous analyses. Thus, HI in the solubility-limited case is assumed to be equal to HI determined in previous analyses.

Fractional inventories of the five COCs that contribute to relative risk are provided in Table 8-10 for each of the sources previously analyzed for Alternative 3 - Traditional Sluicing. Fractional inventory is the ratio of the estimated source inventory, assuming solubility-limited releases, to the inventory estimated assuming congruent release with nitrate. To estimate solubility-limited inventories, it was assumed that all COCs were at their solubility limits when they leaked between the tank steel and concrete, advected into the concrete and leaked from the tank. It was also assumed that the solubility of TBP was the same as in the previous analyses because a separate solubility for this chemical was not provided in the original source of solubility (Serne and Wood 1990). All other conditions used for Alternative 3 - Traditional Sluicing were assumed to apply in this case.

Table 8-10. Fractional Source Inventories of Carcinogenic Constituents of Concern for Solubility-Limited Release Versus Congruent Release with Nitrate[a].

Constituent of Concern	Source			
	In Tank	Between Steel & Concrete	In Concrete	Old Leaks in Soil
^{14}C	1.0	0.0004	0.0004	0.001
^{99}Tc	1.0	0.008	0.008	0.015
^{129}I	1.0	0.005	0.005	0.01
^{234}U	1.0	0.0009	0.0009	0.002
TBP	1.0	1.0	1.0	1.0

[a]Measures determined by dividing estimated inventories for solubility-limited releases by estimated inventories assuming congruent release with nitrate.

<u>Discussion of Results</u>

Maximum relative risk and HI for the high and low COC inventory cases, high and low vadose zone travel time cases, the solubility-limited release case, and Alternative 3 - Traditional Sluicing are shown in Table 8-11. Relative risks and HI for these cases are also plotted on Figure 8-2 and 8-3 with risks and HI for selected alternatives, i.e., Alternative 4 - Robotic Sluicing, Alternative 6 - Close-Coupled Barrier with Flushing, Alternative 11 - V-Shaped Freeze Wall Barrier, and Alternative 12 - Circulating Air Barrier.

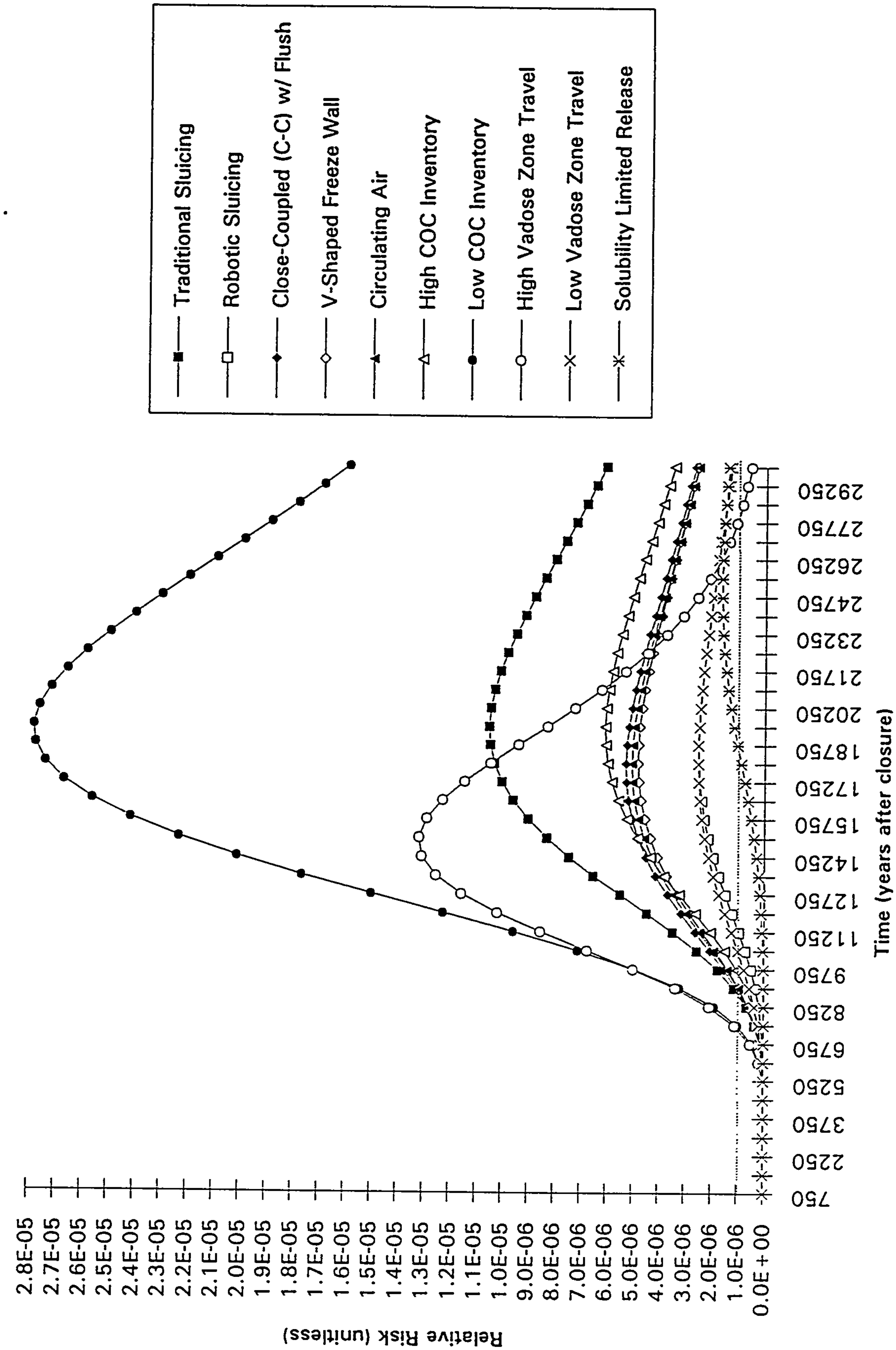

Figure 8-2. Carcinogenic Risk for Sensitivity Cases and Selected Alternatives.

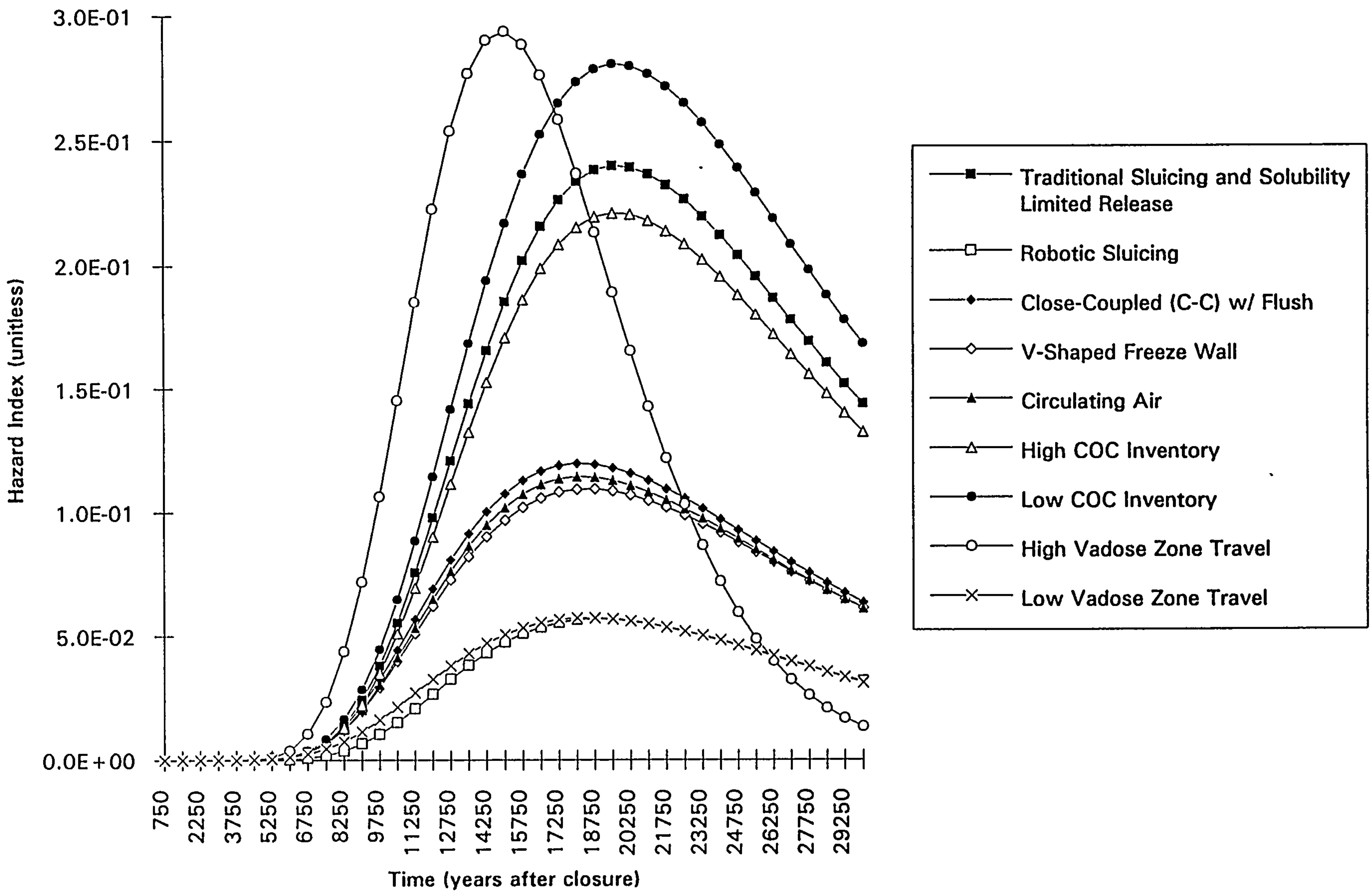

Figure 8-3. Hazard Index (HI) for Sensitivity Cases and Selected Alternatives.

Table 8-11. Summary of Relative Risks and Hazard Index for Sensitivity and Baseline Cases.

Case	Relative Risk	HI
Traditional Sluicing (Baseline)	1.0×10^{-5}	2.3×10^{-1}
High COC Inventory	6.1×10^{-6}	2.2×10^{-1}
Low COC Inventory	2.8×10^{-5}	2.8×10^{-1}
High Vadose Zone Travel Rate	1.3×10^{-5}	2.9×10^{-1}
Low Vadose Zone Travel Rate	2.5×10^{-6}	5.7×10^{-2}
Solubility-Limited Release	1.7×10^{-6}	2.3×10^{-1}

The following conclusions can be drawn from Table 8-11 and these figures:

- The impact of high versus low inventory of COCs on HI is small (about 25%); on relative risk it is higher (about 5X)
- A high vadose zone travel rate would yield relative risks and HI about 5X greater than risks and HI associated with slow vadose zone travel rates
- The use of solubility limits to model releases of COCs would reduce relative risk by about a factor of 6x from levels estimated using congruent leaching with nitrate, but would have no impact on HI
- Excluding the low carcinogenic COC inventory case, the range in estimated risks and HI between the baseline case (traditional sluicing) and the highest risk tank waste retrieval case (robotic sluicing) approximates the range of uncertainty in the sensitivity parameters evaluated earlier in this section. The relatively higher risks associated with the low carcinogenic COC inventory case is anomalous due to the assumption of congruent leaching of all COCs with the relatively small amount of nitrate in this case.

9.0 COMPLIANCE WITH FUNCTIONS AND REQUIREMENTS

The eight alternatives that include subsurface barriers were evaluated against their potential ability to satisfy functions and requirements identified in *Draft Functions and Requirements for Single-Shell Tank Leakage Mitigation* (Cruse 1994). The evaluation was made based on the following observations and assumptions.

- Little technical data exist on the performance of subsurface barriers for the intended application to support a detailed evaluation of functional requirements.

- Few requirements have been quantified at the current stage of development of *Draft Functions and Requirements for Single-Shell Tank Leakage Mitigation.* Quantitative requirements can be developed as understanding of functional needs matures based on (1) testing of the technologies, (2) completion of in-depth technical analyses, and (3) as a consequence of regulator negotiations to establish permit conditions.

The evaluation was based on the potential of an alternative to satisfy functional requirements, as currently defined, using engineering judgement. The results of the evaluation are summarized in Tables 9-1 through 9-4. Each table is based on one of four primary Level 7 functions identified in Cruse (1994):

- Prevent new leakage
- Confine past leakage
- Monitor performance/verify compliance
- Remove soil contamination.

The requirements for each function as defined in Cruse (1994) are summarized in Tables 9-1 through 9-4.

No requirement was identified that cannot be met, given sufficient time and resources. However, the ability of subsurface barriers to prevent further migration of contaminants is questionable, since there is no material known that will prevent molecular diffusion. It is assumed that the regulatory interpretation of this requirement will allow some migration. Further quantification of requirements and improved data are needed before an in-depth evaluation of ability to satisfy requirements can be made.

Table 9-1. Potential Ability of Subsurface Barriers to Prevent New Leakage.

Function:
Prevent New Leakage From SSTs

(a) 4.2.1.1.2-M1.1: During Storage
(b) 4.2.1.3.1-M.1.1: During Retrieval

	Function Requirements	**Subsurface Barrier Alternative:** 6. Close-Coupled Chemical Barrier with Flushing	7. Close-Coupled Chemical Barrier without Flushing	8. Modified Close-Coupled Chemical Barrier without Flushing	9. Box-Shaped Chemical Barrier with Flushing	10. V-Shaped Chemical Barrier with Flushing	11. C-Shaped Freeze Wall Barrier with Flushing	12. Circulating Air Barrier with Flushing	14. Clean-Closure with Close-Coupled Barrier without Flushing
a/b	Support Storage/Retrieval Activities	●	●	●	●	●	●	●	●
a/b	Take Steps to Prevent Further Leakage (DOE 5820.2A)	●	●	●	●	●	●	●	●
a/b	Minimize Waste Requiring Storage/Disposal (DOE 5820.2A)	●	●	●	●	●	●	●	●
a/b	Seal Wells After Use (WAC 173-160)	●	●	●	●	●	●	●	●
a/b	Meet ALARA Guidelines (WHC-CM-4-11)	●	●	●	●	●	●	●	●
a/b	Tank Dome Loading Limits Must Not Be Exceeded (OSD-T-151-00013, Rev. D-1)	●	●	●	●	●	●	●	●
a/b	Tank Concrete Temperature Limits Must Not Be Exceeded (OSD-T-151-00013, Rev. D-1)	●	●	●	●	●	●	●	●

● Denotes potential to satisfy requirement.

Table 9-2. Potential Ability of Subsurface Barriers to Confine Past Leaks.

Function:
Confine Past Leaks

(a) 4.2.1.1.2-M1.2: During Storage
(b) 4.2.1.3.1-M1.2: During Retrieval
(c) 4.2.3.5.2-M1.1: During Closure Preparation

	Function Requirements	Subsurface Barrier Alternative							
		6. Close-Coupled Chemical Barrier with Flushing	7. Close-Coupled Chemical Barrier without Flushing	8. Modified Close-Coupled Chemical Barrier without Flushing	9. Box-Shaped Chemical Barrier with Flushing	10. V-Shaped Chemical Barrier with Flushing	11. C-Shaped Freeze Wall Barrier with Flushing	12. Circulating Air Barrier with Flushing	14. Clean-Closure with Close-Coupled Barrier without Flushing
a	Support Storage/Retrieval Activities	•	•	•	•	•	•	•	•
a	Take Steps to Prevent Further Leakage (DOE 5820.2A)	•	•	•	•	•	•	•	•
a	Minimize Waste Requiring Storage/Disposal (DOE 5820.2A)	•	•	•	•	•	•	•	•
a	Seal Wells After Use (WAC 173-160)	•	•	•	•	•	•	•	•
a	Meet ALARA Guidelines (WHC-CM-4-11)	•	•	•	•	•	•	•	•
a	Tank Dome Loading Limits Must Not Be Exceeded (OSD-T-151-00013, Rev. D-1)	•	•	•	•	•	•	•	•
a	Tank Concrete Temperature Limits Must Not Be Exceeded (OSD-T-151-00013, Rev. D-1)	•	•	•	•	•	•	•	•
b	Prevent Further Migration (40 CFR 265)	?	?	?	?	?	?	?	•
b	Radionuclide Limits in Groundwater Must Not Be Exceeded (DOE 5400.5)	•	•	•	•	•	•	•	•
b	Avoid Uncontaminated Liquid Discharges Where Spread of Contamination Would Occur (DOE 5400.5)	•	•	•	•	•	•	•	•
c	Stand-off Barrier Must Be Box- or V-Shaped	N/A	N/A	N/A	•	•	•	N/A	N/A
c	Stand-off Barrier Must Provide Effective Confinement for 30 years	N/A	N/A	N/A	•	•	•	N/A	N/A
c	Subsurface Barrier Must Not Degrade Tank Structure	•	•	•	•	•	•	•	•

• Denotes potential to satisfy requirement.
? Migration of residual contamination will occur regardless of measures taken, except for clean-closure.
N/A Not applicable.

Table 9-3. Potential Ability of Subsurface Barrier to Support Removal of Soil Contamination.

Function:
Remove Soil Contamination

(a) 4.2.1.1.2-M1.3: During Storage
(b) 4.2.1.3.1-M1.3: During Retrieval
(c) 4.2.3.5.2-M1.2: During Closure Preparation

	Function Requirements	Subsurface Barrier Alternative: 6. Close-Coupled Chemical Barrier with Flushing	7. Close-Coupled Chemical Barrier without Flushing	8. Modified Close-Coupled Chemical Barrier without Flushing	9. Box-Shaped Chemical Barrier with Flushing	10. V-Shaped Chemical Barrier with Flushing	11. C-Shaped Freeze Wall Barrier with Flushing	12. Circulating Air Barrier with Flushing	14. Clean-Closure with Close-Coupled Barrier without Flushing
b	Install Close-Coupled Barriers with Monitoring Systems	●	●	●	N/A	N/A	N/A	N/A	●
b	Prevent Further Migration (DOE 5820.2A)	?	?	?	?	?	?	?	●
b/c	Minimize Volume of Waste (DOE 5820.2A)	●	●	●	●	●	●	●	●
b	Seal Wells After Use (WAC 173-160)	●	●	●	●	●	●	●	●
b/c	Meet ALARA Guidelines (WHC-CM-4-11)	●	●	●	●	●	●	●	●
b/c	Tank Dome Loading Limits Must Not Be Exceeded (OSD-T-151-00013, Rev. D-1)	●	●	●	●	●	●	●	●
b/c	Tank Concrete Temperature Limits Must Not Be Exceeded (OSD-T-151-00013, Rev. D-1)	●	●	●	●	●	●	●	●
c	Install Stand-off Barriers with Flushing	N/A	N/A	N/A	●	●	●	●	N/A
c	Minimize Maintenance, Protect Public Health,and Restore Land to Appearance/Use of Surroundings (WAC 173-303)	●	●	●	●	●	●	●	●
c	Support Clean-Closure or Landfill Closure of the Site (WAC 173-303)	●	●	●	●	●	●	●	●

● Denotes potential to satisfy requirement.
? Migration of residual contamination will occur regardless c ısures taken, except for clean-closure.
N/A Not applicable.

Table 9-4. Potential Ability to Monitor Performance and Verify Compliance of Subsurface Barriers.

Function:
Monitor Performance/Verify Compliance

(a) 4.2.1.1.3-M1.4: During Storage
(b) 4.2.1.3.1-M1.4: During Retrieval
(c) 4.2.3.5.2-M1.3: During Closure Preparation

	Function Requirements	Subsurface Barrier Alternative							
		6. Close-Coupled Chemical Barrier with Flushing	7. Close-Coupled Chemical Barrier without Flushing	8. Modified Close-Coupled Chemical Barrier without Flushing	9. Box-Shaped Chemical Barrier with Flushing	10. V-Shaped Chemical Barrier with Flushing	11. C-Shaped Freeze Wall Barrier with Flushing	12. Circulating Air Barrier with Flushing	14. Clean-Closure with Close-Coupled Barrier without Flushing
a/b	Incorporate Monitoring and Leak Detection Capability (DOE 5820.2A)	•	•	•	•	•	•	•	•
a/b	Monitor Tanks Continuously (Public Law 101-510)	•	•	•	•	•	•	•	•
a	Install Close-Coupled Barriers on Potential Leaking Tanks	•	•	•	N/A	N/A	N/A	N/A	•
b	Support Storage/Retrieval Activities	•	•	•	•	•	•	•	•
b	Take Steps to Prevent Further Leakage (DOE 5820.2A)	•	•	•	•	•	•	•	•
b	Minimize Waste Requiring Storage/Disposal (DOE 5820.2A)	•	•	•	•	•	•	•	•
b	Seal Wells After Use (WAC 173-160)	•	•	•	•	•	•	•	•
b/c	Meet ALARA Guidelines (WHC-CM-4-11)	•	•	•	•	•	•	•	•
b/c	Tank Dome Loading Limits Must Not Be Exceeded (OSD-T-151-00013, Rev. D-1)	•	•	•	•	•	•	•	•
b/c	Tank Concrete Temperature Limits Must Not Be Exceeded (OSD-T-151-00013, Rev. D-1)	•	•	•	•	•	•	•	•
c	Install Stand-off Barriers with Soil Flushing and Monitoring	N/A	N/A	N/A	•	•	•	•	N/A
c	Minimize Volume of Waste Requiring Storage/Disposal (DOE 5820.2A)	•	•	•	•	•	•	•	•
c	Seal Monitoring Wells After Use (WAC 173-160)	•	•	•	•	•	•	•	•
c	Support Clean-Closure or Landfill Closure (WAC 173-303)	•	•	•	•	•	•	•	•

• Denotes potential to satisfy requirement.
N/A Not applicable.

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APPENDIX A

MEPAS CODE INPUT AND OUTPUT

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A.0 MEPAS CODE INPUT AND OUTPUT

The Multimedia Environmental Pollutant Assessment System (MEPAS) is a computer-based system used to quantify relative human health impact from radiological and chemical contaminants released to the environment (Droppo et. al 1989). The MEPAS code uses empirical, analytical, and semi-analytical mathematical algorithms and a pathway analysis to estimate the following processes:

- Potential release of contaminants into the environment
- Transport of contaminants through and between multiple environmental media, including subsurface or groundwater, surface water, overland, and atmospheric
- Exposure to surrounding human populations through the following exposure pathways: inhalation, ingestion of water and food products, dermal contact, and external radiation
- Human health effects associated with exposure to chemicals and radionuclides.

For the barriers technology assessment, the MEPAS code was used to evaluate the discharge of liquid effluents to the subsurface during tank remediation, resulting in transport to groundwater and through groundwater offsite, where this water is used by the public for drinking, showering, irrigation of crops, and animal water.

MEPAS Version 3.0g was used for the public human health risk evaluation. The input parameters required by the MEPAS code are described in the following sections for the groundwater pathway.

A.1 INPUT DATA

MEPAS requires a great deal of input data to execute the transport and exposure models. The groundwater pathway requires the following types of data for execution.

- Contaminant release data
- Source characteristics
- Geologic media (partially saturated zone) characteristics
- Groundwater (saturated zone) characteristics
- Human exposure pathway selection

- Receptor location and exposure characteristics.

Table A-1 lists the input parameters required by the MEPAS code for the groundwater pathway. The values used in this evaluation for each of the input parameters are also listed in this table. In addition, Table A-2 lists the MEPAS input parameters used for the geologic media characteristics. These values were obtained directly from the data used for the Hanford Programmatic Environmental Impact Statement (Schramke 1994), based on the 200 East Area. It is assumed for the purposes of this relative risk evaluation that this data is representative of the physical characteristics associated with Hanford Site geologic stratigraphy. In addition, certain MEPAS default parameter values are used for all cases evaluated, including receptor inhalation and ingestion rates and contaminant-specific reference doses and cancer slope factors, based on a risk level of 1E-06.

For the tank waste remediation evaluation, it is assumed that liquid releases to the ground occur in the subsurface partially saturated zone, located beneath the underground storage tanks. The source of release is assumed to be represented by an area configuration equal to the average area of a tank farm. Values for the depth of release are dependent upon the source and case being evaluated. These values are listed in Table A-3. Flux values and release durations are also dependent upon the source and case under investigation and are listed in Tables A-4 through A-17 for each of the 14 alternatives and in Tables A-18 through A-23 for the five sensitivity cases. These values are computed based on the flux rates that were determined for nitrate. The fluxes of the other constituents of concern are computed as follows.

$$\text{Flux}_i = \text{Flux}_{\text{nitrate}} \times \frac{\text{Inventory}_i}{\text{Inventory}_{\text{nitrate}}}$$

Where:

Flux_i = flux rate of constituent i (g/yr)
$\text{Flux}_{\text{nitrate}}$ = flux rate of nitrate (g/yr)
Inventory_i = inventory of constituent i in all 149 tanks (g)
$\text{Inventory}_{\text{nitrate}}$ = inventory of nitrate in all 149 tanks (g)

The inventory of each of the constituents of concern in the Hanford Site 149 tanks is listed in Table A-24. These values were obtained from Boomer (1993), except for the values presented for EDTA and TBP. For these constituents, only the inventory for total organic carbon (TOC) was available from Boomer (1993). However, the Hanford Defense Waste Environmental Impact Statement (HDW-EIS; DOE 1987) provided analyses of organics in different types of tank wastes. The highest measured quantities of EDTA and TBP were used as a basis for evaluating the potential quantities by determining the percentage of EDTA and TBP comprising the TOC in the tanks to be 8.4% and 7.3%. In addition, the MEPAS toxicity values for each COC is listed in Table A-24.

A.2 OUTPUT DATA

The MEPAS code provides output data in the form of risk values for radionuclides and chemical carcinogens and RfD ratios for noncarcinogenic chemicals. These values are computed only for the 70 year lifetime period during which the maximum groundwater concentration is calculated and assumed to remain constant. Groundwater concentrations and geological strata flux rates are computed for a certain number of user-specified time intervals. For this evaluation, forty time steps were selected, resulting in a determination of time periods in increments of 13 years for cases that assumed a recharge rate of 5 cm/yr and 750 years for cases that assume a recharge rate of 0.5 cm/yr. Intermediate output, contained in *.POL files, present the computed groundwater concentrations and geological strata flux rates for all time intervals evaluated. These output values are used in combination with risk conversion factors and saturated zone dilution factors for each contaminant to compute risk or HI values for each time interval evaluated. Risk conversion factors are computed from the MEPAS output and intermediate data files as shown below.

$$RCF_i = \frac{Risk_i}{C_{gw,i}}$$

$$RCF_i = \frac{HI_i}{C_{gw,i}}$$

Where:

RCF_i = risk conversion factor for constituent i $[(g/ml)^{-1}$ or $(Ci/ml)^{-1}]$
$Risk_i$ = risk value computed by MEPAS for constituent i for the maximum groundwater concentration
HI_i = hazard index (or RfD ratio) computed by MEPAS for constituent i for the maximum groundwater concentration
$C_{gw,i}$ = maximum groundwater concentration computed by MEPAS for constituent i [(g/ml) or (Ci/ml)]

Table A-24 includes the risk conversion factors for each constituent of concern for the groundwater pathway.

Table A-1. MEPAS Code Input Parameters for the Groundwater Pathway (Sheet 1 of 4).

Parameter Type	Parameter Description	Value	Data Source or Justification
Contaminant Release Data	Contaminant-specific flux	see Schramke 1994	Dependent upon the alternative and source
	Discharge duration	see Table A-3	Dependent upon the alternative and source
	Starting date of release	04/94	Arbitrary assignment
	Starting date for risk calculations	04/94	Arbitrary assignment
	Waste liquid infiltration rate	0.00045 ft/day for alternative 1 0.0000045 ft/day for all other alternatives	Based on assumed recharge rates of 5 cm/yr and 0.05 cm/yr
Source Characteristics	Area source dimensions (length and width)	375 ft long x 275 ft wide	Average dimensions of a tank farm containing 12 tanks
	Depth of release	see Tables A-3	Dependent upon the alternative and source
Geologic Media Data	Medium types encountered moving from source to receptor (e.g., partially saturated zone to saturated zone to surface water or well)	4, see Table A-2	Schramke 1994
	Soil classification associated with the media encountered from source to receptor (e.g., sand, clay, silt, etc.)	see Table A-2	Schramke 1994

Table A-1. MEPAS Code Input Parameters for the Groundwater Pathway (Sheet 2 of 4).

Parameter Type	Parameter Description	Value	Data Source or Justification
Geologic Media Data (continued)	Percent sand, silt, and clay associated with each media classification encountered	see Table A-2	Schramke 1994
	Percent organic matter content in each media classification encountered	see Table A-2	Schramke 1994
	Percent iron and aluminum in each media classification encountered	see Table A-2	Schramke 1994
	pH of pore water in each media classification encountered	see Table A-2	Schramke 1994
	Thickness of media zone	see Table A-2	Schramke 1994
	Bulk density of media zone	see Table A-2	Schramke 1994
	Total porosity of media zone	see Table A-2	Schramke 1994
	Field capacity of media zone	see Table A-2	Schramke 1994
	Longitudinal dispersivity of media zone	see Table A-2	Schramke 1994
	Saturated hydraulic conductivity	see Table A-2	Schramke 1994
Groundwater Data	Effective porosity of the saturated zone	10 %	Schramke 1994
	Pore water velocity of the saturated zone	10.8 ft/day	Schramke 1994
	Groundwater travel distance	164 ft	Based on an assumed distance of 50 m.

Table A-1. MEPAS Code Input Parameters for the Groundwater Pathway (Sheet 3 of 4).

Parameter Type	Parameter Description	Value	Data Source or Justification
Groundwater Data (continued)	Longitudinal dispersivity of the saturated zone	16.4 ft	Droppo et. al 1989
	Transverse dispersivity of the saturated zone	3.28 ft	Droppo et. al 1989
	Vertical dispersivity of the saturated zone	0.019 ft	Droppo et. al 1989
	Percent of contaminant flux to saturated zone	100 %	Conservative assumption.
	Perpendicular distance to plume centerline	0 ft	Conservative assumption.
	Contaminant-specific subsurface adsorption coefficients (Kd) for each media zone	0	Conservative assumption
Exposure Pathway Selection	Exposure pathways considered - ingestion of groundwater - ingestion of vegetation - ingestion of meat and milk products - inhalation during showering - dermal contact during showering	None	Assumption

Table A-1. MEPAS Code Input Parameters for the Groundwater Pathway (Sheet 4 of 4).

Parameter Type	Parameter Description	Value	Data Source or Justification
Receptor Exposure Characteristics	Location of public receptor	50 m downgradient of the tank farm	Conservative assumption
	Drinking population served	1	Assumption used for the computation of risks to maximally exposed individual.
	Selection of water treatment (Y or N)	N	Conservative assumption.
	Water distribution time	0.5 days	Droppo et. al 1989
	Type of irrigation usage selection	crops and animal feed and water	Assumption
	Irrigation rate	100 L/m^2-month	Droppo et. al 1989
	Human body weight	70 kg	USEPA 1989
	Exposure duration	70 yrs	USEPA 1989

Table A-2. MEPAS Input Parameters for Geologic Media Characteristics[1].

Parameter	Partially Saturated Zone			Saturated Zone
	Layer 1	Layer 2	Layer 3	
Soil classification	Sand	Sand	Sand	Loamy sand
Percent sand (%)	90	95	90	83
Percent silt (%)	9	3	9	11
Percent clay (%)	1	2	1	6
Percent organic matter content (%)	0	0	0	0
Percent iron and aluminum (%)	2	2	2	0
pH of pore water	8.5	8.5	8.5	7.7
Thickness (ft)	33	164	62	18
Bulk density (g/cm^3)	1.76	1.6	1.76	1.64
Total porosity (%)	36	42	36	18
Field capacity (%)	19	8.5	19	NA
Longitudinal dispersivity (ft)	0.33	1.64	0.62	16.4
Saturated hydraulic conductivity (cm/s)	4.34	14.2	4.34	NA

[1]All values are taken directly from Schramke 1994.

Table A-3. Depth, Duration, and Timing of Releases from Alternative Sources. (Sheet 1 of 3)

No.	Alternative Name	Source	Depth of Release (ft)	Duration of Release (yrs)	Time Period Released
1	No Action	Tank Residual	50	89	0 - 89
		Between Tank and Concrete	50	0.02	89 - 89.1[a]
		Concrete Pad	50	0.8	89.1 - 89.9
		Old Leaks to Soil	78	20	0 - 20
2	Surface Barrier Only	Tank Residual	50	8890	0 - 8890
		Between Tank and Concrete	50	2	8890 - 8892
		Concrete Pad	50	77	8892 - 8969
		Old Leaks to Soil	78	2030	0 - 2030
3	Traditional Sluicing	Tank Residual	50	89	0 - 89
		Between Tank and Concrete	50	2	89 - 91
		Concrete Pad	50	112	91 - 203
		Old & New Leaks to Soil	99	3630	0 - 3630
4	Robotic Sluicing	Tank Residual	50	9	0 - 9
		Between Tank and Concrete	50	2	9 - 11
		Concrete Pad	50	77	11 - 88
		Old & New Leaks to Soil	81	2340	0 - 2340
5	Mechanical Retrieval	Tank Residual	50	445	0 - 445
		Between Tank and Concrete	50	2	445 - 447
		Concrete Pad	50	77	447 - 524
		Old Leaks to Soil	78	2030	0 - 2030

Table A-3. Depth, Duration, and Timing of Releases from Alternative Sources. (Sheet 2 of 3)

No.	Alternative Name	Source	Depth of Release (ft)	Duration of Release (yrs)	Time Period Released
6	Close-Coupled with Soil Flushing	Tank Residual	50	89	0 - 89
		Between Tank and Concrete	50	2	89 - 91
		Concrete Pad	50	112	91 - 203
		Old Leaks to Soil	78	1980	0 - 1980
		Close-Coupled Barrier	50	159	0 - 159
7	Close-Coupled without Soil Flushing	Tank Residual	50	89	0 - 89
		Between Tank and Concrete	50	2	89 - 91
		Concrete Pad	50	112	91 - 203
		Old Leaks to Soil	78	1970	0 - 1970
		Close-Coupled Barrier	50	159	0 - 159
8	Modified Close-Coupled without Soil Flushing	Tank Residual	50	89	0 - 89
		Between Tank and Concrete	50	2	89 - 91
		Concrete Pad	50	112	91 - 203
		Old Leaks to Soil	99	3440	0 - 3440
		Close-Coupled Barrier	50	155	0 - 155
9	Box-Shaped Chemical	Tank Residual	50	89	0 - 89
		Between Tank and Concrete	50	2	89 - 91
		Concrete Pad	50	112	91 - 203
		Flushed Old & New Leaks to Soil	180	10800	0 - 9999[b]
		Stand-Off Barrier	180	9	0 - 9

Table A-3. Depth, Duration, and Timing of Releases from Alternative Sources. (Sheet 3 of 3)

No.	Alternative Name	Source	Depth of Release (ft)	Duration of Release (yrs)	Time Period Released
10	V-Shaped Chemical	Tank Residual	50	89	0 - 89
		Between Tank and Concrete	50	2	89 - 91
		Concrete Pad	50	112	91 - 203
		Flushed Old & New Leaks to Soil	250	14300	0 - 9999[b]
		Stand-Off Barrier	250	13	0 - 13
11	V-Shaped Freeze Wall	Tank Residual	50	89	0 - 89
		Between Tank and Concrete	50	2	89 - 91
		Concrete Pad	50	112	91 - 203
		Flushed Old & New Leaks to Soil	250	14300	0 - 9999[b]
12	Circulating Air	Tank Residual	50	89	0 - 89
		Between Tank and Concrete	50	2	89 - 91
		Concrete Pad	50	112	91 - 203
		Flushed Old & New Leaks to Soil	78	2050	0 - 2050
13	Clean Closure without Barrier	Landfill	50	1280	0 - 1280
14	Clean Closure with Barrier	Landfill	50	531	0 - 531

[a]Although the release duration is less than 0.1 years, it has been set to 0.1, because this is the minimum requirement for the MEPAS code.
[b]Although the release duration is greater than 9999 years, it has been set to 9999 years, because this is the maximum value required by the MEPAS code.

Table A-4. Inventories, Flux Rates, and Release Durations for the No Action Alternative.

	Tank Residual				Btw Tank & Pad			
Contaminant	Inventory (g)	Flux Rate (g/yr)	Flux Rate (Ci/yr)	Release Duration (yr)	Inventory (g)	Flux Rate (g/yr)	Flux Rate (Ci/yr)	Release Duration (yr)
EDTA	1.4E+06	1.5E+04	NA	8.9E+01	8.6E+01	4.3E+03	NA	2.0E-02
Nitrate	7.8E+09	8.8E+07	NA	8.9E+01	5.0E+05	2.5E+07	NA	2.0E-02
Nitrite	3.9E+08	4.3E+06	NA	8.9E+01	2.5E+04	1.2E+06	NA	2.0E-02
TBP	1.2E+06	1.3E+04	NA	8.9E+01	7.5E+01	3.7E+03	NA	2.0E-02
C-14	5.4E+01	6.1E-01	2.7E+00	8.9E+01	3.5E-03	1.7E-01	7.7E-01	2.0E-02
I-129	1.2E+04	1.3E+02	2.2E-02	8.9E+01	7.6E-01	3.8E+01	6.1E-03	2.0E-02
Tc-99	7.6E+04	8.5E+02	1.4E+01	8.9E+01	4.8E+00	2.4E+02	4.1E+00	2.0E-02
U-238	1.1E+08	1.2E+06	4.2E-01	8.9E+01	7.1E+03	3.5E+05	1.2E-01	2.0E-02

	Concrete Pad				Old Leaks			
Contaminant	Inventory (g)	Flux Rate (g/yr)	Flux Rate (Ci/yr)	Release Duration (yr)	Inventory (g)	Flux Rate (g/yr)	Flux Rate (Ci/yr)	Release Duration (yr)
EDTA	1.7E+03	2.2E+03	NA	7.7E-01	4.5E+03	2.2E+02	NA	2.0E+01
Nitrate	1.0E+07	1.3E+07	NA	7.7E-01	2.6E+07	1.3E+06	NA	2.0E+01
Nitrite	4.9E+05	6.4E+05	NA	7.7E-01	1.3E+06	6.3E+04	NA	2.0E+01
TBP	1.5E+03	1.9E+03	NA	7.7E-01	3.9E+03	1.9E+02	NA	2.0E+01
C-14	6.9E-02	9.0E-02	4.0E-01	7.7E-01	1.8E-01	8.8E-03	3.9E-02	2.0E+01
I-129	1.5E+01	2.0E+01	3.2E-03	7.7E-01	3.9E+01	1.9E+00	3.2E-04	2.0E+01
Tc-99	9.7E+01	1.3E+02	2.1E+00	7.7E-01	2.5E+02	1.2E+01	2.1E-01	2.0E+01
U-238	1.4E+05	1.8E+05	6.1E-02	7.7E-01	3.7E+05	1.8E+04	6.0E-03	2.0E+01

Table A-5. Inventories, Flux Rates, and Release Durations for the Surface Barrier Only Alternative.

Contaminant	Tank Residual Inventory (g)	Tank Residual Flux Rate (g/yr)	Tank Residual Flux Rate (Ci/yr)	Tank Residual Release Duration (yr)	Btw Tank & Pad Inventory (g)	Btw Tank & Pad Flux Rate (g/yr)	Btw Tank & Pad Flux Rate (Ci/yr)	Btw Tank & Pad Release Duration (yr)
EDTA	1.4E+06	1.5E+02	NA	8.9E+03	8.6E+01	4.3E+01	NA	2.0E+00
Nitrate	7.8E+09	8.8E+05	NA	8.9E+03	5.0E+05	2.5E+05	NA	2.0E+00
Nitrite	3.9E+08	4.3E+04	NA	8.9E+03	2.5E+04	1.2E+04	NA	2.0E+00
TBP	1.2E+06	1.3E+02	NA	8.9E+03	7.5E+01	3.7E+01	NA	2.0E+00
C-14	5.4E+01	6.1E-03	2.7E-02	8.9E+03	3.5E-03	1.7E-03	7.7E-03	2.0E+00
I-129	1.2E+04	1.3E+00	2.2E-04	8.9E+03	7.6E-01	3.8E-01	6.1E-05	2.0E+00
Tc-99	7.6E+04	8.5E+00	1.4E-01	8.9E+03	4.8E+00	2.4E+00	4.1E-02	2.0E+00
U-238	1.1E+08	1.2E+04	4.2E-03	8.9E+03	7.1E+03	3.5E+03	1.2E-03	2.0E+00

Contaminant	Concrete Pad Inventory (g)	Concrete Pad Flux Rate (g/yr)	Concrete Pad Flux Rate (Ci/yr)	Concrete Pad Release Duration (yr)	Old Leaks Inventory (g)	Old Leaks Flux Rate (g/yr)	Old Leaks Flux Rate (Ci/yr)	Old Leaks Release Duration (yr)
EDTA	1.7E+03	2.2E+01	NA	7.7E+01	4.5E+03	2.2E+00	NA	2.0E+03
Nitrate	1.0E+07	1.3E+05	NA	7.7E+01	2.6E+07	1.3E+04	NA	2.0E+03
Nitrite	4.9E+05	6.4E+03	NA	7.7E+01	1.3E+06	6.3E+02	NA	2.0E+03
TBP	1.5E+03	1.9E+01	NA	7.7E+01	3.9E+03	1.9E+00	NA	2.0E+03
C-14	6.9E-02	9.0E-04	4.0E-03	7.7E+01	1.8E-01	8.8E-05	3.9E-04	2.0E+03
I-129	1.5E+01	2.0E-01	3.2E-05	7.7E+01	3.9E+01	1.9E-02	3.2E-06	2.0E+03
Tc-99	9.7E+01	1.3E+00	2.1E-02	7.7E+01	2.5E+02	1.2E-01	2.1E-03	2.0E+03
U-238	1.4E+05	1.8E+03	6.1E-04	7.7E+01	3.7E+05	1.8E+02	6.0E-05	2.0E+03

Table A-6. Inventories, Flux Rates, and Release Durations for the Traditional Sluicing Alternative.

	Tank Residual				Btw Tank & Pad			
Contaminant	Inventory (g)	Flux Rate (g/yr)	Flux Rate (Ci/yr)	Release Duration (yr)	Inventory (g)	Flux Rate (g/yr)	Flux Rate (Ci/yr)	Release Duration (yr)
EDTA	1.4E+04	1.5E+02	NA	8.9E+01	1.3E+02	6.3E+01	NA	2.0E+00
Nitrate	7.8E+07	8.8E+05	NA	8.9E+01	7.3E+05	3.6E+05	NA	2.0E+00
Nitrite	3.9E+06	4.3E+04	NA	8.9E+01	3.6E+04	1.8E+04	NA	2.0E+00
TBP	1.2E+04	1.3E+02	NA	8.9E+01	1.1E+02	5.5E+01	NA	2.0E+00
C-14	5.4E-01	6.1E-03	2.7E-02	8.9E+01	5.0E-03	2.5E-03	1.1E-02	2.0E+00
I-129	1.2E+02	1.3E+00	2.2E-04	8.9E+01	1.1E+00	5.5E-01	9.0E-05	2.0E+00
Tc-99	7.6E+02	8.5E+00	1.4E-01	8.9E+01	7.0E+00	3.5E+00	6.0E-02	2.0E+00
U-238	1.1E+06	1.2E+04	4.2E-03	8.9E+01	1.0E+04	5.2E+03	1.7E-03	2.0E+00

	Concrete Pad				Old & New Leaks			
Contaminant	Inventory (g)	Flux Rate (g/yr)	Flux Rate (Ci/yr)	Release Duration (yr)	Inventory (g)	Flux Rate (g/yr)	Flux Rate (Ci/yr)	Release Duration (yr)
EDTA	2.4E+03	2.2E+01	NA	1.1E+02	2.1E+04	5.7E+00	NA	3.6E+03
Nitrate	1.4E+07	1.3E+05	NA	1.1E+02	1.2E+08	3.3E+04	NA	3.6E+03
Nitrite	7.0E+05	6.2E+03	NA	1.1E+02	5.9E+06	1.6E+03	NA	3.6E+03
TBP	2.1E+03	1.9E+01	NA	1.1E+02	1.8E+04	5.0E+00	NA	3.6E+03
C-14	9.8E-02	8.7E-04	3.9E-03	1.1E+02	8.3E-01	2.3E-04	1.0E-03	3.6E+03
I-129	2.1E+01	1.9E-01	3.1E-05	1.1E+02	1.8E+02	5.0E-02	8.2E-06	3.6E+03
Tc-99	1.4E+02	1.2E+00	2.1E-02	1.1E+02	1.2E+03	3.2E-01	5.5E-03	3.6E+03
U-238	2.0E+05	1.8E+03	6.0E-04	1.1E+02	1.7E+06	4.7E+02	1.6E-04	3.6E+03

Table A-7. Inventories, Flux Rates, and Release Durations for the Robotic Sluicing Alternative.

Contaminant	Tank Residual Inventory (g)	Tank Residual Flux Rate (g/yr)	Tank Residual Flux Rate (Ci/yr)	Tank Residual Release Duration (yr)	Btw Tank & Pad Inventory (g)	Btw Tank & Pad Flux Rate (g/yr)	Btw Tank & Pad Flux Rate (Ci/yr)	Btw Tank & Pad Release Duration (yr)
EDTA	1.4E+03	1.5E+02	NA	8.9E+00	1.3E+02	6.3E+01	NA	2.0E+00
Nitrate	7.8E+06	8.8E+05	NA	8.9E+00	7.3E+05	3.6E+05	NA	2.0E+00
Nitrite	3.9E+05	4.3E+04	NA	8.9E+00	3.6E+04	1.8E+04	NA	2.0E+00
TBP	1.2E+03	1.3E+02	NA	8.9E+00	1.1E+02	5.5E+01	NA	2.0E+00
C-14	5.4E-02	6.1E-03	2.7E-02	8.9E+00	5.0E-03	2.5E-03	1.1E-02	2.0E+00
I-129	1.2E+01	1.3E+00	2.2E-04	8.9E+00	1.1E+00	5.5E-01	9.0E-05	2.0E+00
Tc-99	7.6E+01	8.5E+00	1.4E-01	8.9E+00	7.0E+00	3.5E+00	6.0E-02	2.0E+00
U-238	1.1E+05	1.2E+04	4.2E-03	8.9E+00	1.0E+04	5.2E+03	1.7E-03	2.0E+00

Contaminant	Concrete Pad Inventory (g)	Concrete Pad Flux Rate (g/yr)	Concrete Pad Flux Rate (Ci/yr)	Concrete Pad Release Duration (yr)	Old & New Leaks Inventory (g)	Old & New Leaks Flux Rate (g/yr)	Old & New Leaks Flux Rate (Ci/yr)	Old & New Leaks Release Duration (yr)
EDTA	1.7E+03	2.2E+01	NA	7.7E+01	6.0E+03	2.6E+00	NA	2.3E+03
Nitrate	1.0E+07	1.3E+05	NA	7.7E+01	3.5E+07	1.5E+04	NA	2.3E+03
Nitrite	4.9E+05	6.4E+03	NA	7.7E+01	1.7E+06	7.4E+02	NA	2.3E+03
TBP	1.5E+03	1.9E+01	NA	7.7E+01	5.3E+03	2.2E+00	NA	2.3E+03
C-14	6.9E-02	9.0E-04	4.0E-03	7.7E+01	2.4E-01	1.0E-04	4.6E-04	2.3E+03
I-129	1.5E+01	2.0E-01	3.2E-05	7.7E+01	5.3E+01	2.3E-02	3.7E-06	2.3E+03
Tc-99	9.7E+01	1.3E+00	2.1E-02	7.7E+01	3.4E+02	1.4E-01	2.5E-03	2.3E+03
U-238	1.4E+05	1.8E+03	6.1E-04	7.7E+01	5.0E+05	2.1E+02	7.1E-05	2.3E+03

Table A-8. Inventories, Flux Rates, and Release Durations for the Mechanical Mining Alternatives.

Contaminant	Tank Residual Inventory (g)	Tank Residual Flux Rate (g/yr)	Tank Residual Flux Rate (Ci/yr)	Tank Residual Release Duration (yr)	Btw Tank & Pad Inventory (g)	Btw Tank & Pad Flux Rate (g/yr)	Btw Tank & Pad Flux Rate (Ci/yr)	Btw Tank & Pad Release Duration (yr)
EDTA	6.8E+04	1.5E+02	NA	4.4E+02	8.6E+01	4.3E+01	NA	2.0E+00
Nitrate	3.9E+08	8.8E+05	NA	4.4E+02	5.0E+05	2.5E+05	NA	2.0E+00
Nitrite	1.9E+07	4.3E+04	NA	4.4E+02	2.5E+04	1.2E+04	NA	2.0E+00
TBP	5.9E+04	1.3E+02	NA	4.4E+02	7.5E+01	3.7E+01	NA	2.0E+00
C-14	2.7E+00	6.1E-03	2.7E-02	4.4E+02	3.5E-03	1.7E-03	7.7E-03	2.0E+00
I-129	5.9E+02	1.3E+00	2.2E-04	4.4E+02	7.6E-01	3.8E-01	6.1E-05	2.0E+00
Tc-99	3.8E+03	8.5E+00	1.4E-01	4.4E+02	4.8E+00	2.4E+00	4.1E-02	2.0E+00
U-238	5.6E+06	1.2E+04	4.2E-03	4.4E+02	7.1E+03	3.5E+03	1.2E-03	2.0E+00

Contaminant	Concrete Pad Inventory (g)	Concrete Pad Flux Rate (g/yr)	Concrete Pad Flux Rate (Ci/yr)	Concrete Pad Release Duration (yr)	Old Leaks Inventory (g)	Old Leaks Flux Rate (g/yr)	Old Leaks Flux Rate (Ci/yr)	Old Leaks Release Duration (yr)
EDTA	1.7E+03	2.2E+01	NA	7.7E+01	4.5E+03	2.2E+00	NA	2.0E+03
Nitrate	1.0E+07	1.3E+05	NA	7.7E+01	2.6E+07	1.3E+04	NA	2.0E+03
Nitrite	4.9E+05	6.4E+03	NA	7.7E+01	1.3E+06	6.3E+02	NA	2.0E+03
TBP	1.5E+03	1.9E+01	NA	7.7E+01	3.9E+03	1.9E+00	NA	2.0E+03
C-14	6.9E-02	9.0E-04	4.0E-03	7.7E+01	1.8E-01	8.8E-05	3.9E-04	2.0E+03
I-129	1.5E+01	2.0E-01	3.2E-05	7.7E+01	3.9E+01	1.9E-02	3.2E-06	2.0E+03
Tc-99	9.7E+01	1.3E+00	2.1E-02	7.7E+01	2.5E+02	1.2E-01	2.1E-03	2.0E+03
U-238	1.4E+05	1.8E+03	6.1E-04	7.7E+01	3.7E+05	1.8E+02	6.0E-05	2.0E+03

Table A-9. Inventories, Flux Rates, and Release Durations for the Close-Coupled w/Soil Flushing Alternative. (Sheet 1 of 2)

	Tank Residual				Btw Tank & Pad			
Contaminant	Inventory (g)	Flux Rate (g/yr)	Flux Rate (Ci/yr)	Release Duration (yr)	Inventory (g)	Flux Rate (g/yr)	Flux Rate (Ci/yr)	Release Duration (yr)
EDTA	1.4E+04	1.5E+02	NA	8.9E+01	1.3E+02	6.3E+01	NA	2.0E+00
Nitrate	7.8E+07	8.8E+05	NA	8.9E+01	7.3E+05	3.6E+05	NA	2.0E+00
Nitrite	3.9E+06	4.3E+04	NA	8.9E+01	3.6E+04	1.8E+04	NA	2.0E+00
TBP	1.2E+04	1.3E+02	NA	8.9E+01	1.1E+02	5.5E+01	NA	2.0E+00
C-14	5.4E-01	6.1E-03	2.7E-02	8.9E+01	5.0E-03	2.5E-03	1.1E-02	2.0E+00
I-129	1.2E+02	1.3E+00	2.2E-04	8.9E+01	1.1E+00	5.5E-01	9.0E-05	2.0E+00
Tc-99	7.6E+02	8.5E+00	1.4E-01	8.9E+01	7.0E+00	3.5E+00	6.0E-02	2.0E+00
U-238	1.1E+06	1.2E+04	4.2E-03	8.9E+01	1.0E+04	5.2E+03	1.7E-03	2.0E+00

	Concrete Pad				Flushed Old Leaks			
Contaminant	Inventory (g)	Flux Rate (g/yr)	Flux Rate (Ci/yr)	Release Duration (yr)	Inventory (g)	Flux Rate (g/yr)	Flux Rate (Ci/yr)	Release Duration (yr)
EDTA	2.4E+03	2.2E+01	NA	1.1E+02	2.7E+02	1.3E-01	NA	2.0E+03
Nitrate	1.4E+07	1.3E+05	NA	1.1E+02	1.5E+06	7.8E+02	NA	2.0E+03
Nitrite	7.0E+05	6.2E+03	NA	1.1E+02	7.6E+04	3.9E+01	NA	2.0E+03
TBP	2.1E+03	1.9E+01	NA	1.1E+02	2.3E+02	1.2E-01	NA	2.0E+03
C-14	9.8E-02	8.7E-04	3.9E-03	1.1E+02	1.1E-02	5.4E-06	2.4E-05	2.0E+03
I-129	2.1E+01	1.9E-01	3.1E-05	1.1E+02	2.3E+00	1.2E-03	1.9E-07	2.0E+03
Tc-99	1.4E+02	1.2E+00	2.1E-02	1.1E+02	1.5E+01	7.6E-03	1.3E-04	2.0E+03
U-238	2.0E+05	1.8E+03	6.0E-04	1.1E+02	2.2E+04	1.1E+01	3.7E-06	2.0E+03

Table A-9. Inventories, Flux Rates, and Release Durations for the Close-Coupled w/Soil Flushing Alternative. (Sheet 2 of 2)

	Barrier			
Contaminant	Inventory (g)	Flux Rate (g/yr)	Flux Rate (Ci/yr)	Release Duration (yr)
EDTA	1.7E+03	1.1E+01	NA	1.6E+02
Nitrate	1.0E+07	6.3E+04	NA	1.6E+02
Nitrite	4.9E+05	3.1E+03	NA	1.6E+02
TBP	1.5E+03	9.5E+00	NA	1.6E+02
C-14	6.9E-02	4.4E-04	1.9E-03	1.6E+02
I-129	1.5E+01	9.5E-02	1.6E-05	1.6E+02
Tc-99	9.7E+01	6.1E-01	1.0E-02	1.6E+02
U-238	1.4E+05	9.0E+02	3.0E-04	1.6E+02

Table A-10. Inventories, Flux Rates, and Release Durations for the Close-Coupled Alternative w/o Soil Flushing. (Sheet 1 of 2)

	Tank Residual				Btw Tank & Pad			
Contaminant	Inventory (g)	Flux Rate (g/yr)	Flux Rate (Ci/yr)	Release Duration (yr)	Inventory (g)	Flux Rate (g/yr)	Flux Rate (Ci/yr)	Release Duration (yr)
EDTA	1.4E+04	1.5E+02	NA	8.9E+01	1.3E+02	6.3E+01	NA	2.0E+00
Nitrate	7.8E+07	8.8E+05	NA	8.9E+01	7.3E+05	3.6E+05	NA	2.0E+00
Nitrite	3.9E+06	4.3E+04	NA	8.9E+01	3.6E+04	1.8E+04	NA	2.0E+00
TBP	1.2E+04	1.3E+02	NA	8.9E+01	1.1E+02	5.5E+01	NA	2.0E+00
C-14	5.4E-01	6.1E-03	2.7E-02	8.9E+01	5.0E-03	2.5E-03	1.1E-02	2.0E+00
I-129	1.2E+02	1.3E+00	2.2E-04	8.9E+01	1.1E+00	5.5E-01	9.0E-05	2.0E+00
Tc-99	7.6E+02	8.5E+00	1.4E-01	8.9E+01	7.0E+00	3.5E+00	6.0E-02	2.0E+00
U-238	1.1E+06	1.2E+04	4.2E-03	8.9E+01	1.0E+04	5.2E+03	1.7E-03	2.0E+00

	Concrete Pad				Old Leaks			
Contaminant	Inventory (g)	Flux Rate (g/yr)	Flux Rate (Ci/yr)	Release Duration (yr)	Inventory (g)	Flux Rate (g/yr)	Flux Rate (Ci/yr)	Release Duration (yr)
EDTA	2.4E+03	2.2E+01	NA	1.1E+02	6.2E+03	3.2E+00	NA	2.0E+03
Nitrate	1.4E+07	1.3E+05	NA	1.1E+02	3.6E+07	1.8E+04	NA	2.0E+03
Nitrite	7.0E+05	6.2E+03	NA	1.1E+02	1.8E+06	9.0E+02	NA	2.0E+03
TBP	2.1E+03	1.9E+01	NA	1.1E+02	5.4E+03	2.7E+00	NA	2.0E+03
C-14	9.8E-02	8.7E-04	3.9E-03	1.1E+02	2.5E-01	1.3E-04	5.6E-04	2.0E+03
I-129	2.1E+01	1.9E-01	3.1E-05	1.1E+02	5.4E+01	2.8E-02	4.5E-06	2.0E+03
Tc-99	1.4E+02	1.2E+00	2.1E-02	1.1E+02	3.5E+02	1.8E-01	3.0E-03	2.0E+03
U-238	2.0E+05	1.8E+03	6.0E-04	1.1E+02	5.1E+05	2.6E+02	8.6E-05	2.0E+03

Table A-10. Inventories, Flux Rates, and Release Durations for the Close-Coupled Alternative w/o Soil Flushing. (Sheet 2 of 2)

	Barrier			
Contaminant	Inventory (g)	Flux Rate (g/yr)	Flux Rate (Ci/yr)	Release Duration (yr)
EDTA	1.7E+03	1.1E+01	NA	1.6E+02
Nitrate	1.0E+07	6.3E+04	NA	1.6E+02
Nitrite	4.9E+05	3.1E+03	NA	1.6E+02
TBP	1.5E+03	9.5E+00	NA	1.6E+02
C-14	6.9E-02	4.4E-04	1.9E-03	1.6E+02
I-129	1.5E+01	9.5E-02	1.6E-05	1.6E+02
Tc-99	9.7E+01	6.1E-01	1.0E-02	1.6E+02
U-238	1.4E+05	9.0E+02	3.0E-04	1.6E+02

Table A-11. Inventories, Flux Rates, and Release Durations for the Modified Close-Coupled Alternative w/o Soil Flushing. (Sheet 1 of 2)

	Tank Residual				Btw. Tank & Pad			
Contaminant	Inventory (g)	Flux Rate (g/yr)	Flux Rate (Ci/yr)	Release Duration (yr)	Inventory (g)	Flux Rate (g/yr)	Flux Rate (Ci/yr)	Release Duration (yr)
EDTA	1.4E+04	1.5E+02	NA	8.9E+01	1.3E+02	6.3E+01	NA	2.0E+00
Nitrate	7.8E+07	8.8E+05	NA	8.9E+01	7.3E+05	3.6E+05	NA	2.0E+00
Nitrite	3.9E+06	4.3E+04	NA	8.9E+01	3.6E+04	1.8E+04	NA	2.0E+00
TBP	1.2E+04	1.3E+02	NA	8.9E+01	1.1E+02	5.5E+01	NA	2.0E+00
C-14	5.4E-01	6.1E-03	2.7E-02	8.9E+01	5.0E-03	2.5E-03	1.1E-02	2.0E+00
I-129	1.2E+02	1.3E+00	2.2E-04	8.9E+01	1.1E+00	5.5E-01	9.0E-05	2.0E+00
Tc-99	7.6E+02	8.5E+00	1.4E-01	8.9E+01	7.0E+00	3.5E+00	6.0E-02	2.0E+00
U-238	1.1E+06	1.2E+04	4.2E-03	8.9E+01	1.0E+04	5.2E+03	1.7E-03	2.0E+00

	Concrete Pad				Old Leaks			
Contaminant	Inventory (g)	Flux Rate (g/yr)	Flux Rate (Ci/yr)	Release Duration (yr)	Inventory (g)	Flux Rate (g/yr)	Flux Rate (Ci/yr)	Release Duration (yr)
EDTA	2.4E+03	2.2E+01	NA	1.1E+02	1.1E+04	3.2E+00	NA	3.4E+03
Nitrate	1.4E+07	1.3E+05	NA	1.1E+02	6.3E+07	1.8E+04	NA	3.4E+03
Nitrite	7.0E+05	6.2E+03	NA	1.1E+02	3.1E+06	9.0E+02	NA	3.4E+03
TBP	2.1E+03	1.9E+01	NA	1.1E+02	9.4E+03	2.7E+00	NA	3.4E+03
C-14	9.8E-02	8.7E-04	3.9E-03	1.1E+02	4.3E-01	1.3E-04	5.6E-04	3.4E+03
I-129	2.1E+01	1.9E-01	3.1E-05	1.1E+02	9.5E+01	2.8E-02	4.5E-06	3.4E+03
Tc-99	1.4E+02	1.2E+00	2.1E-02	1.1E+02	6.1E+02	1.8E-01	3.0E-03	3.4E+03
U-238	2.0E+05	1.8E+03	6.0E-04	1.1E+02	8.9E+05	2.6E+02	8.6E-05	3.4E+03

Table A-11. Inventories, Flux Rates, and Release Durations for the Modified Close-Coupled Alternative w/o Soil Flushing. (Sheet 2 of 2)

	Barrier			
Contaminant	Inventory (g)	Flux Rate (g/yr)	Flux Rate (Ci/yr)	Release Duration (yr)
EDTA	1.0E+03	6.6E+00	NA	1.5E+02
Nitrate	5.9E+06	3.8E+04	NA	1.5E+02
Nitrite	2.9E+05	1.9E+03	NA	1.5E+02
TBP	8.9E+02	5.7E+00	NA	1.5E+02
C-14	4.1E-02	2.6E-04	1.2E-03	1.5E+02
I-129	9.0E+00	5.8E-02	9.4E-06	1.5E+02
Tc-99	5.7E+01	3.7E-01	6.3E-03	1.5E+02
U-238	8.4E+04	5.4E+02	1.8E-04	1.5E+02

Table A-12. Inventories, Flux Rates, and Release Durations for the Box-Shaped Chemical Standoff Alternative. (Sheet 1 of 2)

	Tank Residual				Btw Tank & Pad			
Contaminant	Inventory (g)	Flux Rate (g/yr)	Flux Rate (Ci/yr)	Release Duration (yr)	Inventory (g)	Flux Rate (g/yr)	Flux Rate (Ci/yr)	Release Duration (yr)
EDTA	1.4E+04	1.5E+02	NA	8.9E+01	1.3E+02	6.3E+01	NA	2.0E+00
Nitrate	7.8E+07	8.8E+05	NA	8.9E+01	7.3E+05	3.6E+05	NA	2.0E+00
Nitrite	3.9E+06	4.3E+04	NA	8.9E+01	3.6E+04	1.8E+04	NA	2.0E+00
TBP	1.2E+04	1.3E+02	NA	8.9E+01	1.1E+02	5.5E+01	NA	2.0E+00
C-14	5.4E-01	6.1E-03	2.7E-02	8.9E+01	5.0E-03	2.5E-03	1.1E-02	2.0E+00
I-129	1.2E+02	1.3E+00	2.2E-04	8.9E+01	1.1E+00	5.5E-01	9.0E-05	2.0E+00
Tc-99	7.6E+02	8.5E+00	1.4E-01	8.9E+01	7.0E+00	3.5E+00	6.0E-02	2.0E+00
U-238	1.1E+06	1.2E+04	4.2E-03	8.9E+01	1.0E+04	5.2E+03	1.7E-03	2.0E+00

	Concrete Pad				Flushed Old & New Leaks			
Contaminant	Inventory (g)	Flux Rate (g/yr)	Flux Rate (Ci/yr)	Release Duration (yr)	Inventory (g)	Flux Rate (g/yr)	Flux Rate (Ci/yr)	Release Duration (yr)
EDTA	2.4E+03	2.2E+01	NA	1.1E+02	1.2E+03	1.1E-01	NA	1.1E+04
Nitrate	1.4E+07	1.3E+05	NA	1.1E+02	7.1E+06	6.6E+02	NA	1.1E+04
Nitrite	7.0E+05	6.2E+03	NA	1.1E+02	3.5E+05	3.3E+01	NA	1.1E+04
TBP	2.1E+03	1.9E+01	NA	1.1E+02	1.1E+03	1.0E-01	NA	1.1E+04
C-14	9.8E-02	8.7E-04	3.9E-03	1.1E+02	4.9E-02	4.6E-06	2.0E-05	1.1E+04
I-129	2.1E+01	1.9E-01	3.1E-05	1.1E+02	1.1E+01	1.0E-03	1.6E-07	1.1E+04
Tc-99	1.4E+02	1.2E+00	2.1E-02	1.1E+02	6.9E+01	6.4E-03	1.1E-04	1.1E+04
U-238	2.0E+05	1.8E+03	6.0E-04	1.1E+02	1.0E+05	9.4E+00	3.1E-06	1.1E+04

Table A-12. Inventories, Flux Rates, and Release Durations for the Box-Shaped Chemical Standoff Alternative. (Sheet 2 of 2)

Contaminant	Barrier			
	Inventory (g)	Flux Rate (g/yr)	Flux Rate (Ci/yr)	Release Duration (yr)
EDTA	1.0E+02	1.1E+01	NA	9.4E+00
Nitrate	5.9E+05	6.3E+04	NA	9.4E+00
Nitrite	2.9E+04	3.1E+03	NA	9.4E+00
TBP	8.9E+01	9.5E+00	NA	9.4E+00
C-14	4.1E-03	4.4E-04	1.9E-03	9.4E+00
I-129	9.0E-01	9.5E-02	1.6E-05	9.4E+00
Tc-99	5.7E+00	6.1E-01	1.0E-02	9.4E+00
U-238	8.4E+03	9.0E+02	3.0E-04	9.4E+00

Table A-13. Inventories, Flux Rates, and Release Durations for the V-Shaped Chemical Standoff Alternative. (Sheet 1 of 2)

	Tank Residual				Btw Tank & Pad			
Contaminant	Inventory (g)	Flux Rate (g/yr)	Flux Rate (Ci/yr)	Release Duration (yr)	Inventory (g)	Flux Rate (g/yr)	Flux Rate (Ci/yr)	Release Duration (yr)
EDTA	1.4E+04	1.5E+02	NA	8.9E+01	1.3E+02	6.3E+01	NA	2.0E+00
Nitrate	7.8E+07	8.8E+05	NA	8.9E+01	7.3E+05	3.6E+05	NA	2.0E+00
Nitrite	3.9E+06	4.3E+04	NA	8.9E+01	3.6E+04	1.8E+04	NA	2.0E+00
TBP	1.2E+04	1.3E+02	NA	8.9E+01	1.1E+02	5.5E+01	NA	2.0E+00
C-14	5.4E-01	6.1E-03	2.7E-02	8.9E+01	5.0E-03	2.5E-03	1.1E-02	2.0E+00
I-129	1.2E+02	1.3E+00	2.2E-04	8.9E+01	1.1E+00	5.5E-01	9.0E-05	2.0E+00
Tc-99	7.6E+02	8.5E+00	1.4E-01	8.9E+01	7.0E+00	3.5E+00	6.0E-02	2.0E+00
U-238	1.1E+06	1.2E+04	4.2E-03	8.9E+01	1.0E+04	5.2E+03	1.7E-03	2.0E+00

	Concrete Pad				Flushed Old & New Leaks			
Contaminant	Inventory (g)	Flux Rate (g/yr)	Flux Rate (Ci/yr)	Release Duration (yr)	Inventory (g)	Flux Rate (g/yr)	Flux Rate (Ci/yr)	Release Duration (yr)
EDTA	2.4E+03	2.2E+01	NA	1.1E+02	1.2E+03	8.6E-02	NA	1.4E+04
Nitrate	1.4E+07	1.3E+05	NA	1.1E+02	7.1E+06	5.0E+02	NA	1.4E+04
Nitrite	7.0E+05	6.2E+03	NA	1.1E+02	3.5E+05	2.5E+01	NA	1.4E+04
TBP	2.1E+03	1.9E+01	NA	1.1E+02	1.1E+03	7.5E-02	NA	1.4E+04
C-14	9.8E-02	8.7E-04	3.9E-03	1.1E+02	4.9E-02	3.4E-06	1.5E-05	1.4E+04
I-129	2.1E+01	1.9E-01	3.1E-05	1.1E+02	1.1E+01	7.5E-04	1.2E-07	1.4E+04
Tc-99	1.4E+02	1.2E+00	2.1E-02	1.1E+02	6.9E+01	4.8E-03	8.2E-05	1.4E+04
U-238	2.0E+05	1.8E+03	6.0E-04	1.1E+02	1.0E+05	7.1E+00	2.4E-06	1.4E+04

Table A-13. Inventories, Flux Rates, and Release Durations for the V-Shaped Chemical Standoff Alternative. (Sheet 2 of 2)

	Barrier			
Contaminant	Inventory (g)	Flux Rate (g/yr)	Flux Rate (Ci/yr)	Release Duration (yr)
EDTA	1.4E+02	1.1E+01	NA	1.3E+01
Nitrate	8.2E+05	6.3E+04	NA	1.3E+01
Nitrite	4.0E+04	3.1E+03	NA	1.3E+01
TBP	1.2E+02	9.5E+00	NA	1.3E+01
C-14	5.7E-03	4.4E-04	1.9E-03	1.3E+01
I-129	1.2E+00	9.5E-02	1.6E-05	1.3E+01
Tc-99	7.9E+00	6.1E-01	1.0E-02	1.3E+01
U-238	1.2E+04	9.0E+02	3.0E-04	1.3E+01

Table A-14. Inventories, Flux Rates, and Release Durations for the V-Shaped Freeze Wall Alternative.

Contaminant	Tank Residual Inventory (g)	Tank Residual Flux Rate (g/yr)	Tank Residual Flux Rate (Ci/yr)	Tank Residual Release Duration (yr)	Btw Tank & Pad Inventory (g)	Btw Tank & Pad Flux Rate (g/yr)	Btw Tank & Pad Flux Rate (Ci/yr)	Btw Tank & Pad Release Duration (yr)
EDTA	1.4E+04	1.5E+02	NA	8.9E+01	1.3E+02	6.3E+01	NA	2.0E+00
Nitrate	7.8E+07	8.8E+05	NA	8.9E+01	7.3E+05	3.6E+05	NA	2.0E+00
Nitrite	3.9E+06	4.3E+04	NA	8.9E+01	3.6E+04	1.8E+04	NA	2.0E+00
TBP	1.2E+04	1.3E+02	NA	8.9E+01	1.1E+02	5.5E+01	NA	2.0E+00
C-14	5.4E-01	6.1E-03	2.7E-02	8.9E+01	5.0E-03	2.5E-03	1.1E-02	2.0E+00
I-129	1.2E+02	1.3E+00	2.2E-04	8.9E+01	1.1E+00	5.5E-01	9.0E-05	2.0E+00
Tc-99	7.6E+02	8.5E+00	1.4E-01	8.9E+01	7.0E+00	3.5E+00	6.0E-02	2.0E+00
U-238	1.1E+06	1.2E+04	4.2E-03	8.9E+01	1.0E+04	5.2E+03	1.7E-03	2.0E+00

Contaminant	Concrete Pad Inventory (g)	Concrete Pad Flux Rate (g/yr)	Concrete Pad Flux Rate (Ci/yr)	Concrete Pad Release Duration (yr)	Flushed Old & New Leaks Inventory (g)	Flushed Old & New Leaks Flux Rate (g/yr)	Flushed Old & New Leaks Flux Rate (Ci/yr)	Flushed Old & New Leaks Release Duration (yr)
EDTA	2.4E+03	2.2E+01	NA	1.1E+02	1.2E+03	8.6E-02	NA	1.4E+04
Nitrate	1.4E+07	1.3E+05	NA	1.1E+02	7.1E+06	5.0E+02	NA	1.4E+04
Nitrite	7.0E+05	6.2E+03	NA	1.1E+02	3.5E+05	2.5E+01	NA	1.4E+04
TBP	2.1E+03	1.9E+01	NA	1.1E+02	1.1E+03	7.5E-02	NA	1.4E+04
C-14	9.8E-02	8.7E-04	3.9E-03	1.1E+02	4.9E-02	3.4E-06	1.5E-05	1.4E+04
I-129	2.1E+01	1.9E-01	3.1E-05	1.1E+02	1.1E+01	7.5E-04	1.2E-07	1.4E+04
Tc-99	1.4E+02	1.2E+00	2.1E-02	1.1E+02	6.9E+01	4.8E-03	8.2E-05	1.4E+04
U-238	2.0E+05	1.8E+03	6.0E-04	1.1E+02	1.0E+05	7.1E+00	2.4E-06	1.4E+04

Table A-15. Inventories, Flux Rates, and Release Durations for the Circulating Air Barrier Alternative.

	Tank Residual				Btw Tank & Pad			
Contaminant	Inventory (g)	Flux Rate (g/yr)	Flux Rate (Ci/yr)	Release Duration (yr)	Inventory (g)	Flux Rate (g/yr)	Flux Rate (Ci/yr)	Release Duration (yr)
EDTA	1.4E+04	1.5E+02	NA	8.9E+01	1.3E+02	6.3E+01	NA	2.0E+00
Nitrate	7.8E+07	8.8E+05	NA	8.9E+01	7.3E+05	3.6E+05	NA	2.0E+00
Nitrite	3.9E+06	4.3E+04	NA	8.9E+01	3.6E+04	1.8E+04	NA	2.0E+00
TBP	1.2E+04	1.3E+02	NA	8.9E+01	1.1E+02	5.5E+01	NA	2.0E+00
C-14	5.4E-01	6.1E-03	2.7E-02	8.9E+01	5.0E-03	2.5E-03	1.1E-02	2.0E+00
I-129	1.2E+02	1.3E+00	2.2E-04	8.9E+01	1.1E+00	5.5E-01	9.0E-05	2.0E+00
Tc-99	7.6E+02	8.5E+00	1.4E-01	8.9E+01	7.0E+00	3.5E+00	6.0E-02	2.0E+00
U-238	1.1E+06	1.2E+04	4.2E-03	8.9E+01	1.0E+04	5.2E+03	1.7E-03	2.0E+00

	Concrete Pad				Flushed Old & New Leaks			
Contaminant	Inventory (g)	Flux Rate (g/yr)	Flux Rate (Ci/yr)	Release Duration (yr)	Inventory (g)	Flux Rate (g/yr)	Flux Rate (Ci/yr)	Release Duration (yr)
EDTA	2.4E+03	2.2E+01	NA	1.1E+02	1.2E+03	6.0E-01	NA	2.0E+03
Nitrate	1.4E+07	1.3E+05	NA	1.1E+02	7.1E+06	3.5E+03	NA	2.0E+03
Nitrite	7.0E+05	6.2E+03	NA	1.1E+02	3.5E+05	1.7E+02	NA	2.0E+03
TBP	2.1E+03	1.9E+01	NA	1.1E+02	1.1E+03	5.2E-01	NA	2.0E+03
C-14	9.8E-02	8.7E-04	3.9E-03	1.1E+02	4.9E-02	2.4E-05	1.1E-04	2.0E+03
I-129	2.1E+01	1.9E-01	3.1E-05	1.1E+02	1.1E+01	5.3E-03	8.6E-07	2.0E+03
Tc-99	1.4E+02	1.2E+00	2.1E-02	1.1E+02	6.9E+01	3.4E-02	5.7E-04	2.0E+03
U-238	2.0E+05	1.8E+03	6.0E-04	1.1E+02	1.0E+05	5.0E+01	1.6E-05	2.0E+03

Table A-16. Inventories, Flux Rates, and Release Durations for the Clean Closure w/o Barrier Alternative.

	Disposal			
Contaminant	Inventory (g)	Flux Rate (g/yr)	Flux Rate (Ci/yr)	Release Duration (yr)
EDTA	3.7E+02	6.9E-01	NA	5.3E+02
Nitrate	2.1E+06	4.0E+03	NA	5.3E+02
Nitrite	1.0E+05	2.0E+02	NA	5.3E+02
TBP	3.2E+02	6.0E-01	NA	5.3E+02
C-14	1.5E-02	2.8E-05	1.2E-04	5.3E+02
I-129	3.2E+00	6.0E-03	9.8E-07	5.3E+02
Tc-99	2.0E+01	3.9E-02	6.6E-04	5.3E+02
U-238	3.0E+04	5.7E+01	1.9E-05	5.3E+02

Table A-17. Inventories, Flux Rates, and Release Durations for the Clean Closure w/Barrier Alternative.

	Disposal			
Contaminant	Inventory (g)	Flux Rate (g/yr)	Flux Rate (Ci/yr)	Release Duration (yr)
EDTA	2.2E+02	1.7E-01	NA	1.3E+03
Nitrate	1.3E+06	9.9E+02	NA	1.3E+03
Nitrite	6.3E+04	4.9E+01	NA	1.3E+03
TBP	1.9E+02	1.5E-01	NA	1.3E+03
C-14	8.8E-03	6.9E-06	3.1E-05	1.3E+03
I-129	1.9E+00	1.5E-03	2.5E-07	1.3E+03
Tc-99	1.2E+01	9.6E-03	1.6E-04	1.3E+03
U-238	1.8E+04	1.4E+01	4.7E-06	1.3E+03

Table A-18. Inventories, Flux Rates, and Release Durations for Sensitivity Case #1 - Traditional Sluicing w/o Surface Barrier Alternative.

Contaminant	Tank Residual Inventory (g)	Tank Residual Flux Rate (g/yr)	Tank Residual Flux Rate (Ci/yr)	Tank Residual Release Duration (yr)	Btw Tank & Pad Inventory (g)	Btw Tank & Pad Flux Rate (g/yr)	Btw Tank & Pad Flux Rate (Ci/yr)	Btw Tank & Pad Release Duration (yr)
EDTA	1.4E+04	1.5E+04	NA	8.9E-01	1.3E+02	6.3E+03	NA	2.0E-02
Nitrate	7.8E+07	8.8E+07	NA	8.9E-01	7.3E+05	3.6E+07	NA	2.0E-02
Nitrite	3.9E+06	4.3E+06	NA	8.9E-01	3.6E+04	1.8E+06	NA	2.0E-02
TBP	1.2E+04	1.3E+04	NA	8.9E-01	1.1E+02	5.5E+03	NA	2.0E-02
C-14	5.4E-01	6.1E-01	2.7E+00	8.9E-01	5.0E-03	2.5E-01	1.1E+00	2.0E-02
I-129	1.2E+02	1.3E+02	2.2E-02	8.9E-01	1.1E+00	5.5E+01	9.0E-03	2.0E-02
Tc-99	7.6E+02	8.5E+02	1.4E+01	8.9E-01	7.0E+00	3.5E+02	6.0E+00	2.0E-02
U-238	1.1E+06	1.2E+06	4.2E-01	8.9E-01	1.0E+04	5.2E+05	1.7E-01	2.0E-02

Contaminant	Concrete Pad Inventory (g)	Concrete Pad Flux Rate (g/yr)	Concrete Pad Flux Rate (Ci/yr)	Concrete Pad Release Duration (yr)	Old & New Leaks Inventory (g)	Old & New Leaks Flux Rate (g/yr)	Old & New Leaks Flux Rate (Ci/yr)	Old & New Leaks Release Duration (yr)
EDTA	2.4E+03	2.2E+03	NA	1.1E+00	2.1E+04	5.7E+02	NA	3.6E+01
Nitrate	1.4E+07	1.3E+07	NA	1.1E+00	1.2E+08	3.3E+06	NA	3.6E+01
Nitrite	7.0E+05	6.2E+05	NA	1.1E+00	5.9E+06	1.6E+05	NA	3.6E+01
TBP	2.1E+03	1.9E+03	NA	1.1E+00	1.8E+04	5.0E+02	NA	3.6E+01
C-14	9.8E-02	8.7E-02	3.9E-01	1.1E+00	8.3E-01	2.3E-02	1.0E-01	3.6E+01
I-129	2.1E+01	1.9E+01	3.1E-03	1.1E+00	1.8E+02	5.0E+00	8.2E-04	3.6E+01
Tc-99	1.4E+02	1.2E+02	2.1E+00	1.1E+00	1.2E+03	3.2E+01	5.5E-01	3.6E+01
U-238	2.0E+05	1.8E+05	6.0E-02	1.1E+00	1.7E+06	4.7E+04	1.6E-02	3.6E+01

Table A-19. Inventories, Flux Rates, and Release Durations for Sensitivity Case #2A - Traditional Sluicing with Low Nitrate Inventory Alternative.

	Tank Residual				Btw Tank & Pad			
Contaminant	Inventory (g)	Flux Rate (g/yr)	Flux Rate (Ci/yr)	Release Duration (yr)	Inventory (g)	Flux Rate (g/yr)	Flux Rate (Ci/yr)	Release Duration (yr)
EDTA	5.0E+04	5.7E+02	NA	8.9E+01	4.7E+02	2.4E+02	NA	2.0E+00
Nitrate	7.8E+07	8.8E+05	NA	8.9E+01	7.3E+05	3.6E+05	NA	2.0E+00
Nitrite	2.9E+06	3.3E+04	NA	8.9E+01	2.7E+04	1.4E+04	NA	2.0E+00
TBP	3.4E+04	3.8E+02	NA	8.9E+01	3.2E+02	1.6E+02	NA	2.0E+00
C-14	1.8E+00	2.0E-02	8.9E-02	8.9E+01	1.6E-02	8.2E-03	3.7E-02	2.0E+00
I-129	3.5E+02	4.0E+00	6.4E-04	8.9E+01	3.3E+00	1.6E+00	2.7E-04	2.0E+00
Tc-99	2.2E+03	2.5E+01	4.2E-01	8.9E+01	2.1E+01	1.0E+01	1.8E-01	2.0E+00
U-238	1.1E+06	1.3E+04	4.2E-03	8.9E+01	1.1E+04	5.3E+03	1.8E-03	2.0E+00

	Concrete Pad				Old & New Leaks			
Contaminant	Inventory (g)	Flux Rate (g/yr)	Flux Rate (Ci/yr)	Release Duration (yr)	Inventory (g)	Flux Rate (g/yr)	Flux Rate (Ci/yr)	Release Duration (yr)
EDTA	9.1E+03	8.1E+01	NA	1.1E+02	7.8E+04	2.1E+01	NA	3.6E+03
Nitrate	1.4E+07	1.3E+05	NA	1.1E+02	1.2E+08	3.3E+04	NA	3.6E+03
Nitrite	5.3E+05	4.7E+03	NA	1.1E+02	4.5E+06	1.2E+03	NA	3.6E+03
TBP	6.2E+03	5.5E+01	NA	1.1E+02	5.3E+04	1.4E+01	NA	3.6E+03
C-14	3.2E-01	2.8E-03	1.3E-02	1.1E+02	2.7E+00	7.5E-04	3.3E-03	3.6E+03
I-129	6.3E+01	5.7E-01	9.2E-05	1.1E+02	5.4E+02	1.5E-01	2.4E-05	3.6E+03
Tc-99	4.0E+02	3.6E+00	6.1E-02	1.1E+02	3.4E+03	9.4E-01	1.6E-02	3.6E+03
U-238	2.0E+05	1.8E+03	6.1E-04	1.1E+02	1.7E+06	4.8E+02	1.6E-04	3.6E+03

Table A-20. Inventories, Flux Rates, and Release Durations for Sensitivity Case #2B - Traditional Sluicing with High Nitrate Inventory Alternative.

	Tank Residual				Btw Tank & Pad			
Contaminant	Inventory (g)	Flux Rate (g/yr)	Flux Rate (Ci/yr)	Release Duration (yr)	Inventory (g)	Flux Rate (g/yr)	Flux Rate (Ci/yr)	Release Duration (yr)
EDTA	4.0E+03	4.5E+01	NA	8.9E+01	3.7E+01	1.9E+01	NA	2.0E+00
Nitrate	7.8E+07	8.8E+05	NA	8.9E+01	7.3E+05	3.6E+05	NA	2.0E+00
Nitrite	7.5E+05	8.5E+03	NA	8.9E+01	7.0E+03	3.5E+03	NA	2.0E+00
TBP	2.7E+03	3.0E+01	NA	8.9E+01	2.5E+01	1.3E+01	NA	2.0E+00
C-14	3.5E-01	3.9E-03	1.7E-02	8.9E+01	3.2E-03	1.6E-03	7.2E-03	2.0E+00
I-129	7.8E+01	8.7E-01	1.4E-04	8.9E+01	7.2E-01	3.6E-01	5.9E-05	2.0E+00
Tc-99	5.6E+02	6.3E+00	1.1E-01	8.9E+01	5.2E+00	2.6E+00	4.5E-02	2.0E+00
U-238	1.1E+05	1.2E+03	4.1E-04	8.9E+01	1.0E+03	5.1E+02	1.7E-04	2.0E+00

	Concrete Pad				Old & New Leaks			
Contaminant	Inventory (g)	Flux Rate (g/yr)	Flux Rate (Ci/yr)	Release Duration (yr)	Inventory (g)	Flux Rate (g/yr)	Flux Rate (Ci/yr)	Release Duration (yr)
EDTA	7.1E+02	6.4E+00	NA	1.1E+02	6.1E+03	1.7E+00	NA	3.6E+03
Nitrate	1.4E+07	1.3E+05	NA	1.1E+02	1.2E+08	3.3E+04	NA	3.6E+03
Nitrite	1.4E+05	1.2E+03	NA	1.1E+02	1.2E+06	3.2E+02	NA	3.6E+03
TBP	4.8E+02	4.3E+00	NA	1.1E+02	4.1E+03	1.1E+00	NA	3.6E+03
C-14	6.3E-02	5.6E-04	2.5E-03	1.1E+02	5.4E-01	1.5E-04	6.6E-04	3.6E+03
I-129	1.4E+01	1.3E-01	2.0E-05	1.1E+02	1.2E+02	3.3E-02	5.4E-06	3.6E+03
Tc-99	1.0E+02	9.1E-01	1.5E-02	1.1E+02	8.7E+02	2.4E-01	4.1E-03	3.6E+03
U-238	2.0E+04	1.8E+02	5.9E-05	1.1E+02	1.7E+05	4.7E+01	1.6E-05	3.6E+03

Table A-21. Inventories, Flux Rates, and Release Durations for Sensitivity Case #3 - Traditional Sluicing with Faster Vadose Zone Travel.

Contaminant	Tank Residual Inventory (g)	Tank Residual Flux Rate (g/yr)	Tank Residual Flux Rate (Ci/yr)	Tank Residual Release Duration (yr)	Btw Tank & Pad Inventory (g)	Btw Tank & Pad Flux Rate (g/yr)	Btw Tank & Pad Flux Rate (Ci/yr)	Btw Tank & Pad Release Duration (yr)
EDTA	1.4E+04	1.5E+02	NA	8.9E+01	1.3E+02	6.3E+01	NA	2.0E+00
Nitrate	7.8E+07	8.8E+05	NA	8.9E+01	7.3E+05	3.6E+05	NA	2.0E+00
Nitrite	3.9E+06	4.3E+04	NA	8.9E+01	3.6E+04	1.8E+04	NA	2.0E+00
TBP	1.2E+04	1.3E+02	NA	8.9E+01	1.1E+02	5.5E+01	NA	2.0E+00
C-14	5.4E-01	6.1E-03	2.7E-02	8.9E+01	5.0E-03	2.5E-03	1.1E-02	2.0E+00
I-129	1.2E+02	1.3E+00	2.2E-04	8.9E+01	1.1E+00	5.5E-01	9.0E-05	2.0E+00
Tc-99	7.6E+02	8.5E+00	1.4E-01	8.9E+01	7.0E+00	3.5E+00	6.0E-02	2.0E+00
U-238	1.1E+06	1.2E+04	4.2E-03	8.9E+01	1.0E+04	5.2E+03	1.7E-03	2.0E+00

Contaminant	Concrete Pad Inventory (g)	Concrete Pad Flux Rate (g/yr)	Concrete Pad Flux Rate (Ci/yr)	Concrete Pad Release Duration (yr)	Old & New Leaks Inventory (g)	Old & New Leaks Flux Rate (g/yr)	Old & New Leaks Flux Rate (Ci/yr)	Old & New Leaks Release Duration (yr)
EDTA	2.4E+03	2.2E+01	NA	1.1E+02	2.1E+04	5.7E+00	NA	3.6E+03
Nitrate	1.4E+07	1.3E+05	NA	1.1E+02	1.2E+08	3.3E+04	NA	3.6E+03
Nitrite	7.0E+05	6.2E+03	NA	1.1E+02	5.9E+06	1.6E+03	NA	3.6E+03
TBP	2.1E+03	1.9E+01	NA	1.1E+02	1.8E+04	5.0E+00	NA	3.6E+03
C-14	9.8E-02	8.7E-04	3.9E-03	1.1E+02	8.3E-01	2.3E-04	1.0E-03	3.6E+03
I-129	2.1E+01	1.9E-01	3.1E-05	1.1E+02	1.8E+02	5.0E-02	8.2E-06	3.6E+03
Tc-99	1.4E+02	1.2E+00	2.1E-02	1.1E+02	1.2E+03	3.2E-01	5.5E-03	3.6E+03
U-238	2.0E+05	1.8E+03	6.0E-04	1.1E+02	1.7E+06	4.7E+02	1.6E-04	3.6E+03

Table A-22. Inventories, Flux Rates, and Release Durations for Sensitivity Case #3 - Traditional Sluicing with Slower Vadose Zone Travel.

Contaminant	Tank Residual Inventory (g)	Tank Residual Flux Rate (g/yr)	Tank Residual Flux Rate (Ci/yr)	Tank Residual Release Duration (yr)	Btw Tank & Pad Inventory (g)	Btw Tank & Pad Flux Rate (g/yr)	Btw Tank & Pad Flux Rate (Ci/yr)	Btw Tank & Pad Release Duration (yr)
EDTA	1.4E+04	1.5E+02	NA	8.9E+01	1.3E+02	6.3E+01	NA	2.0E+00
Nitrate	7.8E+07	8.8E+05	NA	8.9E+01	7.3E+05	3.6E+05	NA	2.0E+00
Nitrite	3.9E+06	4.3E+04	NA	8.9E+01	3.6E+04	1.8E+04	NA	2.0E+00
TBP	1.2E+04	1.3E+02	NA	8.9E+01	1.1E+02	5.5E+01	NA	2.0E+00
C-14	5.4E-01	6.1E-03	2.7E-02	8.9E+01	5.0E-03	2.5E-03	1.1E-02	2.0E+00
I-129	1.2E+02	1.3E+00	2.2E-04	8.9E+01	1.1E+00	5.5E-01	9.0E-05	2.0E+00
Tc-99	7.6E+02	8.5E+00	1.4E-01	8.9E+01	7.0E+00	3.5E+00	6.0E-02	2.0E+00
U-238	1.1E+06	1.2E+04	4.2E-03	8.9E+01	1.0E+04	5.2E+03	1.7E-03	2.0E+00

Contaminant	Concrete Pad Inventory (g)	Concrete Pad Flux Rate (g/yr)	Concrete Pad Flux Rate (Ci/yr)	Concrete Pad Release Duration (yr)	Old & New Leaks Inventory (g)	Old & New Leaks Flux Rate (g/yr)	Old & New Leaks Flux Rate (Ci/yr)	Old & New Leaks Release Duration (yr)
EDTA	2.4E+03	2.2E+01	NA	1.1E+02	2.1E+04	5.7E+00	NA	3.6E+03
Nitrate	1.4E+07	1.3E+05	NA	1.1E+02	1.2E+08	3.3E+04	NA	3.6E+03
Nitrite	7.0E+05	6.2E+03	NA	1.1E+02	5.9E+06	1.6E+03	NA	3.6E+03
TBP	2.1E+03	1.9E+01	NA	1.1E+02	1.8E+04	5.0E+00	NA	3.6E+03
C-14	9.8E-02	8.7E-04	3.9E-03	1.1E+02	8.3E-01	2.3E-04	1.0E-03	3.6E+03
I-129	2.1E+01	1.9E-01	3.1E-05	1.1E+02	1.8E+02	5.0E-02	8.2E-06	3.6E+03
Tc-99	1.4E+02	1.2E+00	2.1E-02	1.1E+02	1.2E+03	3.2E-01	5.5E-03	3.6E+03
U-238	2.0E+05	1.8E+03	6.0E-04	1.1E+02	1.7E+06	4.7E+02	1.6E-04	3.6E+03

Table A-23. Inventories, Flux Rates, and Release Durations for Sensitivity Case #5 - Traditional Sluicing with Solubility Limited Release Alternative.

Contaminant	Tank Residual Inventory (Ci or g)	Tank Residual Flux Rate (Ci/yr or g/yr)	Tank Residual Release Duration (yr)	Btw Tank & Pad Inventory (g)	Btw Tank & Pad Flux Rate (g/yr)	Btw Tank & Pad Release Duration (yr)
TBP	1.2E+04	1.3E+02	8.9E+01	1.1E+02	5.5E+01	2.0E+00
C-14	2.4E+00	7.3E-06	3.3E+05	9.4E-06	4.7E-06	2.0E+00
I-129	2.0E-02	7.7E-07	2.6E+04	9.3E-07	4.4E-07	2.1E+00
Tc-99	1.3E+01	7.7E-04	1.7E+04	9.1E-04	4.4E-04	2.1E+00
U-238	3.7E-01	1.9E-06	2.0E+05	3.1E-06	1.5E-06	2.1E+00

Contaminant	Concrete Pad Inventory (g)	Concrete Pad Flux Rate (g/yr)	Concrete Pad Release Duration (yr)	Old & New Leaks Inventory (g)	Old & New Leaks Flux Rate (g/yr)	Old & New Leaks Release Duration (yr)
TBP	2.1E+03	1.9E+01	1.1E+02	1.8E+04	5.0E+00	3.6E+03
C-14	1.8E-04	1.6E-06	1.1E+02	3.2E-03	8.8E-07	3.7E+03
I-129	1.8E-05	1.6E-07	1.1E+02	3.1E-04	8.8E-08	3.5E+03
Tc-99	1.7E-02	1.6E-04	1.1E+02	3.0E-01	8.4E-05	3.6E+03
U-238	6.0E-05	5.5E-07	1.1E+02	1.0E-03	2.9E-07	3.5E+03

Table A-24. Inventory Distribution and Risk Conversion Factors of COCs in Tank Waste.

Constituent of Concern	Distribution of Inventory in 149 Tanks (kg or Ci)	MEPAS Slope Factor $(mg/kg\text{-}day)^{-1}$	MEPAS RfD (mg/kg-day)[c]	Risk Conversion Factor $[(g/ml)^{-1}$ or $(Ci/ml)^{-1}]$
Nitrate	9.7E+07		1.6E+00	7.5E+05
Nitrite	4.8E+06		3.4E-02	6.7E+05
EDTA[a]	1.7E+04		1.3E-03	3.2E+08
TBP[b]	1.5E+04	0.0E+00 (inh) 7.9E-03 (ing)		4.1E+02
C^{14}	3E+03	6.4E-15 (inh) 9.0E-13 (ing)		2.5E+08
I^{129}	2.4E+01	1.2E-10 (inh) 1.9E-10 (ing)		1.5E+10
Tc^{99}	1.6E+04	8.3E-12 (inh) 1.3E-12 (ing)		1.5E+08
U^{238}	4.6E+02	5.2E-08 (inh) 2.8E-11 (ing)		1.9E+09

[a]EDTA - ethylenediaminetetraacetic acid
[b]TBP - tributyl phosphate
[c]RfD values for COCs are the same for both ingestion and inhalation exposure pathways.

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APPENDIX B

GROUNDWATER CONCENTRATION AND HUMAN HEALTH RISK RESULTS

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B.0 GROUNDWATER CONCENTRATION AND HUMAN HEALTH RISK RESULTS

This appendix presents the results of groundwater contaminant concentration and human health risk calculations performed using the MEPAS computer program. For each of the 14 alternative cases and the six sensitivity cases evaluated, plots have been generated depicting groundwater concentration, relative risk, and HI as a function of time. Appendix B.1 presents the groundwater contaminant concentrations computed for each alternative or sensitivity case. These plots are presented to provide perspective to the relative contaminant concentrations for each alternative. Appendix B.2 presents the cancer risk and toxic HI results for each source within each alternative or sensitivity case.

B.1 GROUNDWATER CONTAMINANT CONCENTRATIONS

Separate MEPAS calculations were performed for each source to account for source-specific characteristics, case-specific transport conditions, and to produce source-specific groundwater concentrations that support detailed evaluations of the alternative cases. The contaminant release data used in the MEPAS calculations are detailed in Appendix A. The timing and duration of contaminant releases are summarized in Table A-3 for each source and alternative case.

The results of these source-specific calculations are contaminant concentrations in groundwater, as a function of time, at the point of exposure located near the tank farm. A 30,000 year time period was specified for the MEPAS modelling runs in order to ensure that concentration peaks for all alternatives were encompassed in the MEPAS output.

B.2 HUMAN HEALTH RISKS

Health risks (cancer risk and HI) have been calculated for each source as the product of contaminant flux rate out of the last geological strata, the dilution factor as described in Section 6.0, and unit-concentration risk and HI factors derived using the MEPAS. The unit risk and HI factors, and the basis of their calculation are presented in Appendix A. The results of the source-specific calculations are contaminant-specific risk and HI, as a function of time, at the point of interest (50 m down gradient). For each of the 14 alternative cases and six sensitivity cases evaluated, figures present the cancer risk and HI as a function of time for each applicable source.

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APPENDIX B.1

GROUNDWATER CONCENTRATION RESULTS

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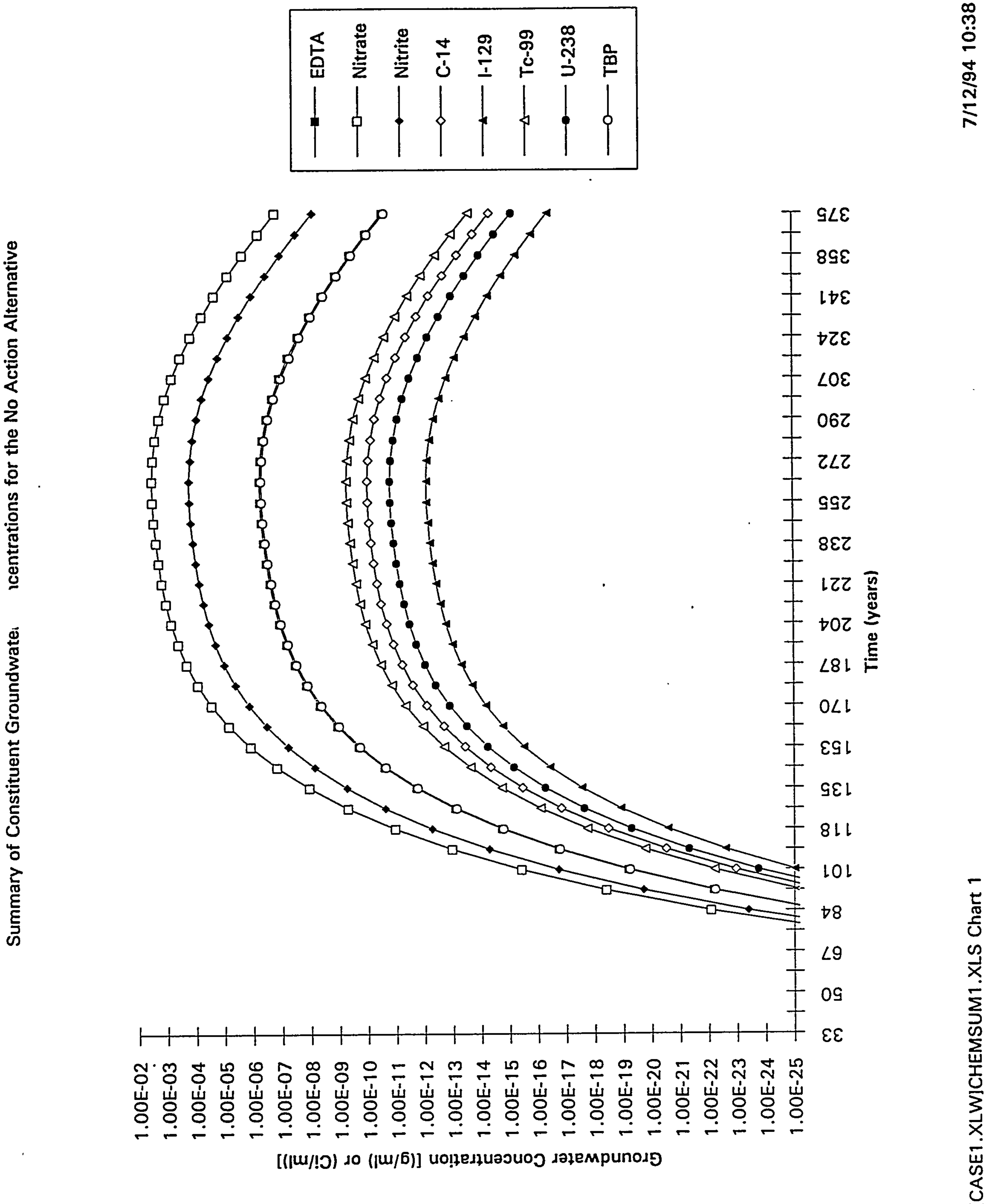
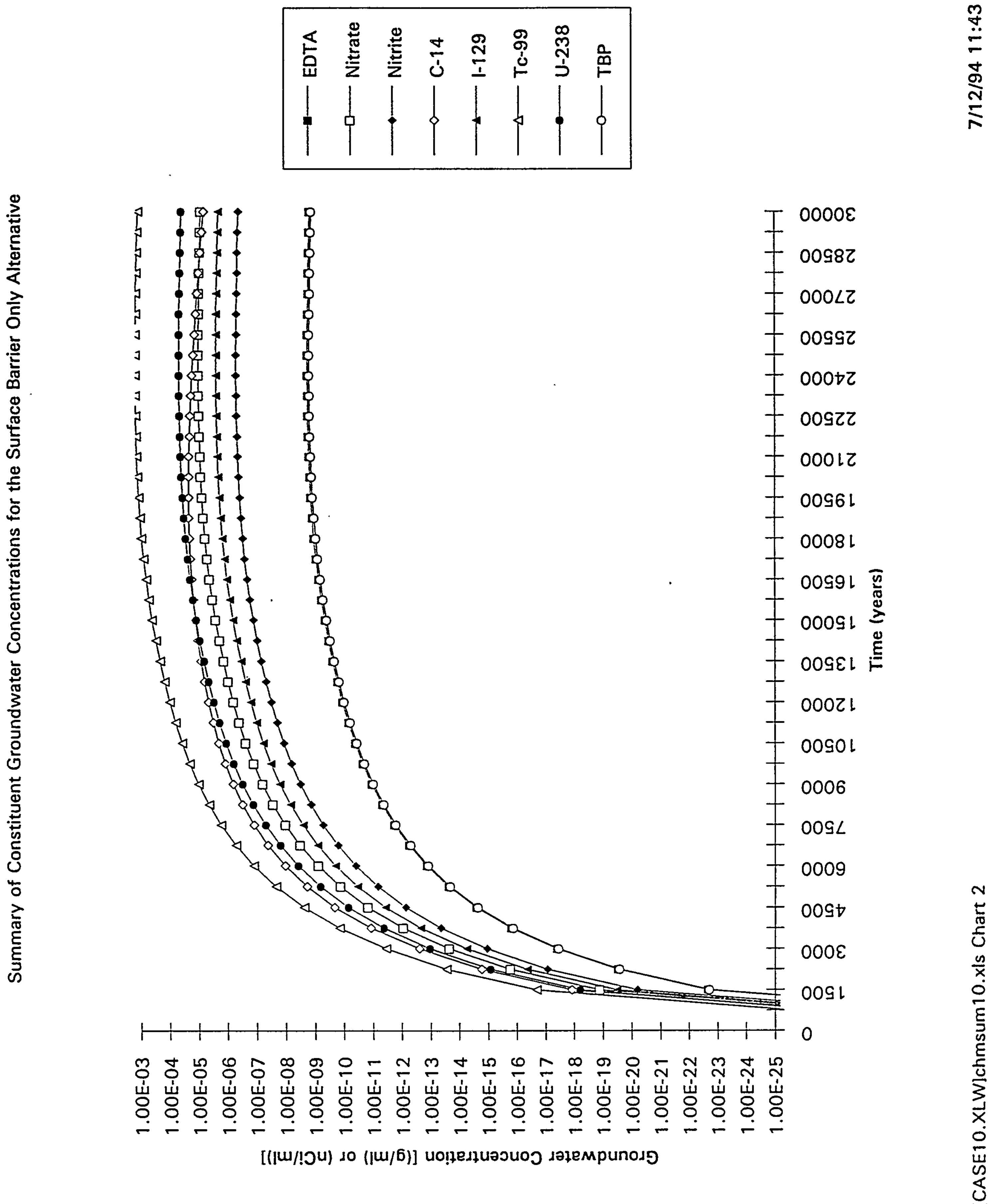
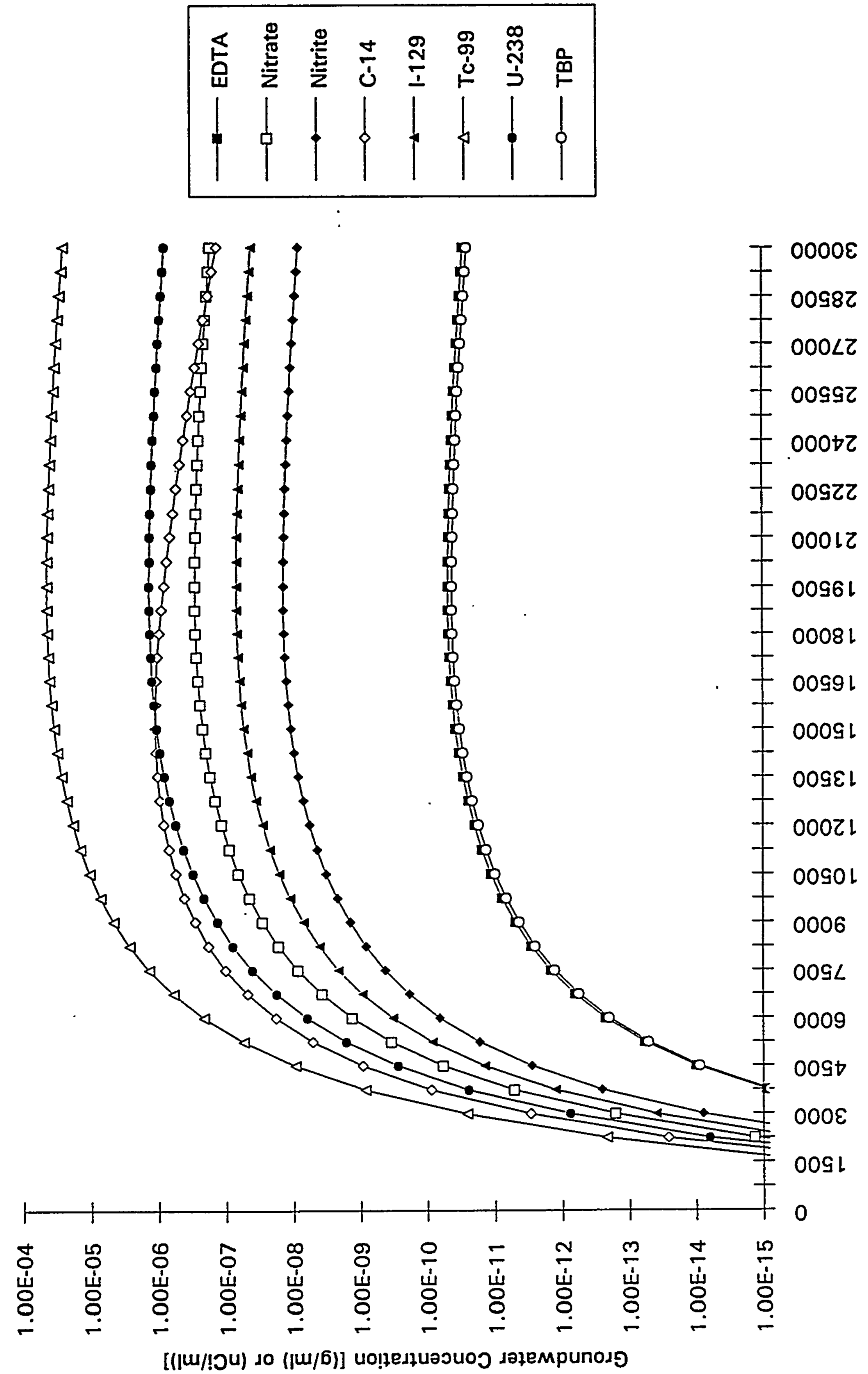

Summary of Constituent Groundwate ıcentrations for the No Action Alternative
7/12/94 10:38 AM
EDTA
Nitrate
Nitrite
C-14
I-129
Tc-99
U-238
TBP
Groundwater Concentration [(g/ml) or (Ci/ml)]
1.00E-02
1.00E-03
1.00E-04
1.00E-05
1.00E-06
1.00E-07
1.00E-08
1.00E-09
1.00E-10
1.00E-11
1.00E-12
1.00E-13
1.00E-14
1.00E-15
1.00E-16
1.00E-17
1.00E-18
1.00E-19
1.00E-20
1.00E-21
1.00E-22
1.00E-23
1.00E-24
1.00E-25
Time (years)
33
50
67
84
101
118
135
153
170
187
204
221
238
255
272
290
307
324
341
358
375
[CASE1.XLW]CHEMSUM1.XLS Chart 1


Summary of Constituent Groundwater Concentrations for the Surface Barrier Only Alternative
EDTA
Nitrate
Nitrite
C-14
I-129
Tc-99
U-238
TBP
Groundwater Concentration [(g/ml) or (nCi/ml)]
1.00E-03
1.00E-04
1.00E-05
1.00E-06
1.00E-07
1.00E-08
1.00E-09
1.00E-10
1.00E-11
1.00E-12
1.00E-13
1.00E-14
1.00E-15
1.00E-16
1.00E-17
1.00E-18
1.00E-19
1.00E-20
1.00E-21
1.00E-22
1.00E-23
1.00E-24
1.00E-25
Time (years)
0
1500
3000
4500
6000
7500
9000
10500
12000
13500
15000
16500
18000
19500
21000
22500
24000
25500
27000
28500
30000
7/12/94 11:43 AM
[CASE10.XLW]chmsum10.xls Chart 2

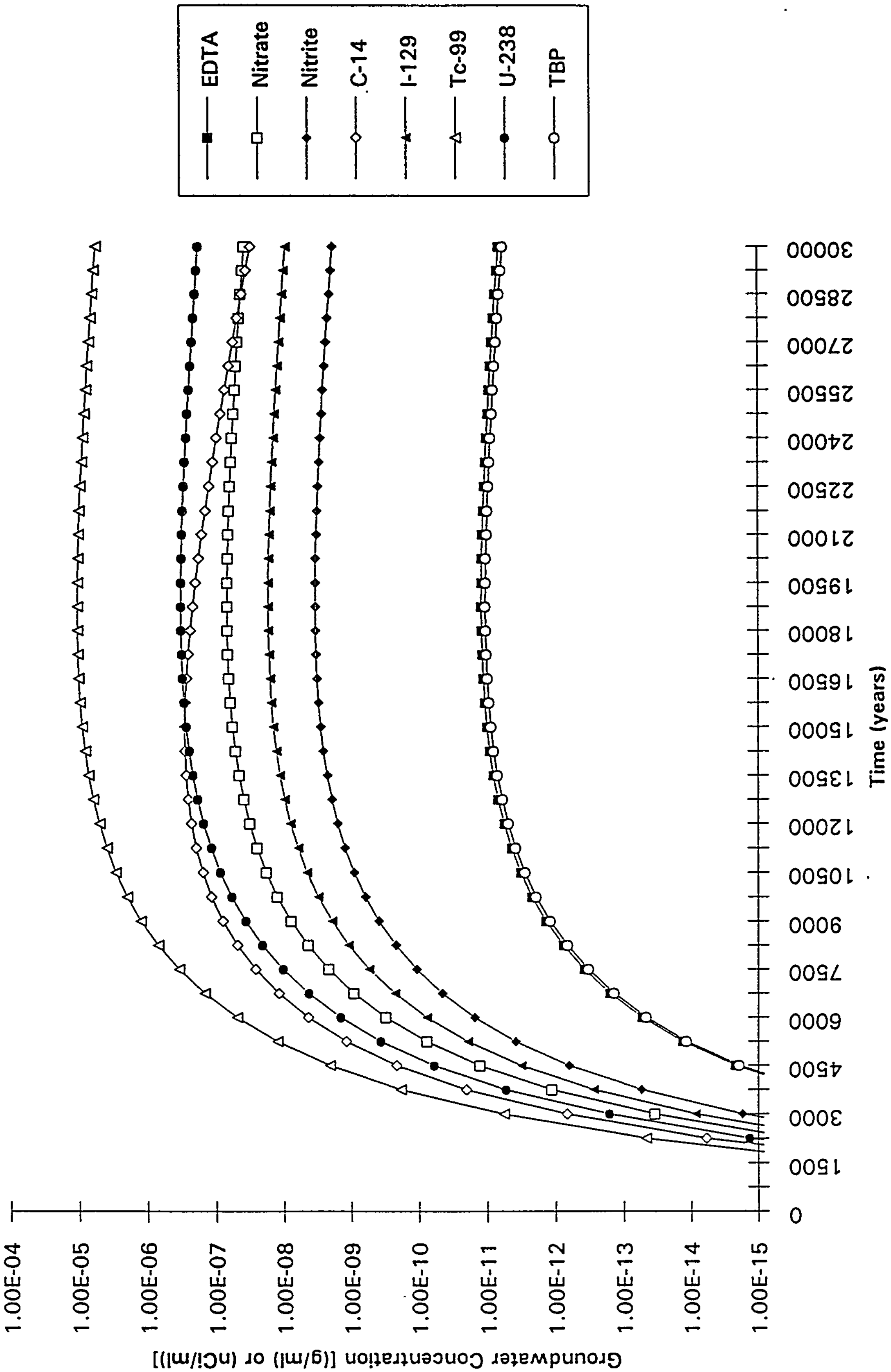
Summary of Constituent Groundwater Cc ıtrations for the Traditional Sluicing Alternative



7/8/94 10:21 AM

[CASE2.XLW]chemsum2.xls Chart 2

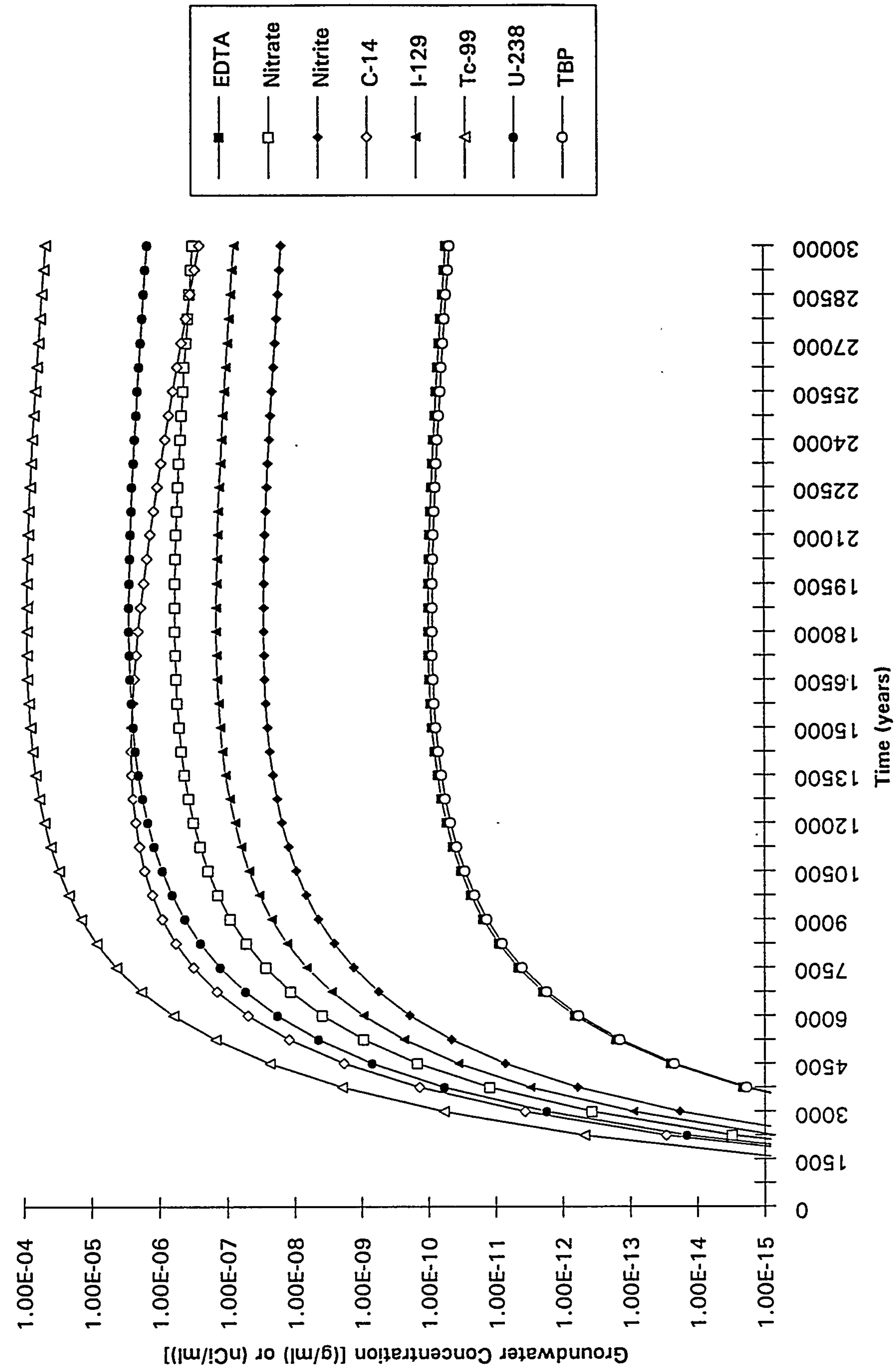
Summary of Constituent Groundwater Concentrations for the Robotic Sluicing Alternative



ICASE9.XLWIchemsum9.xls Chart 2

7/8/94 11:31 AM

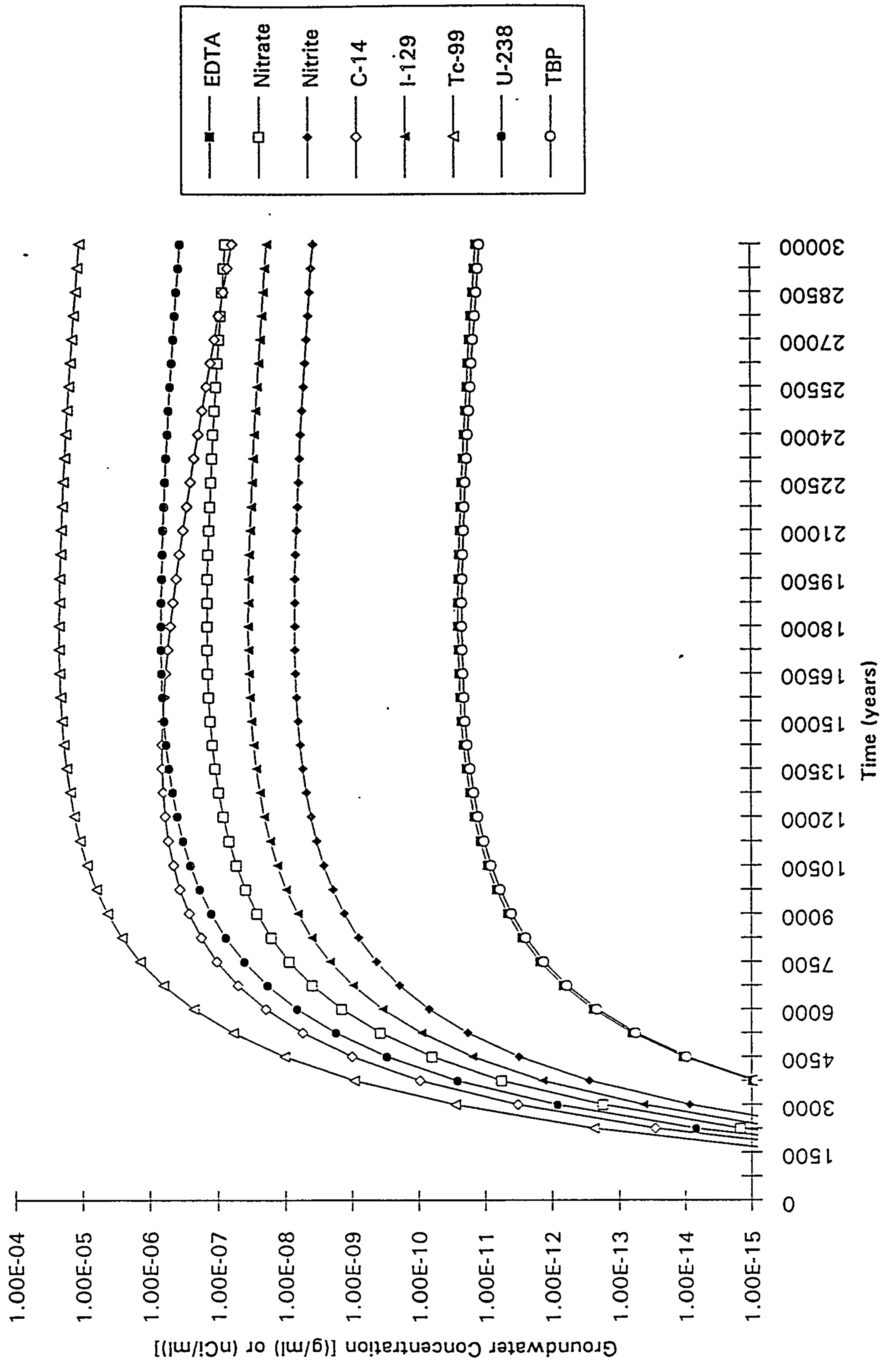
Summary of Constituent Groundwater Co[...]trations for the Mechanical Mining Alternative



7/12/94 11:41 AM

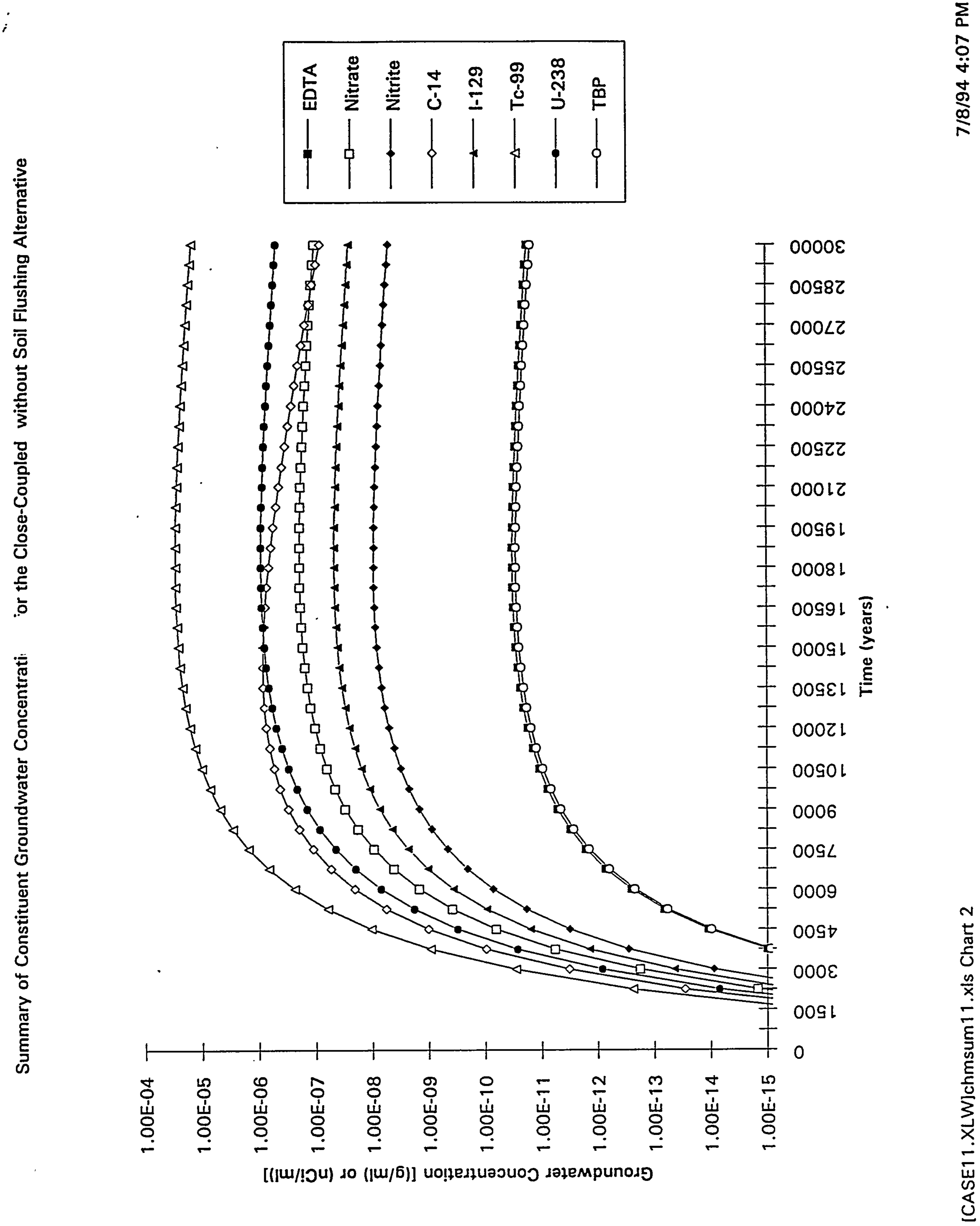
[CASE8.XLW]chemsum8.xls Chart 2

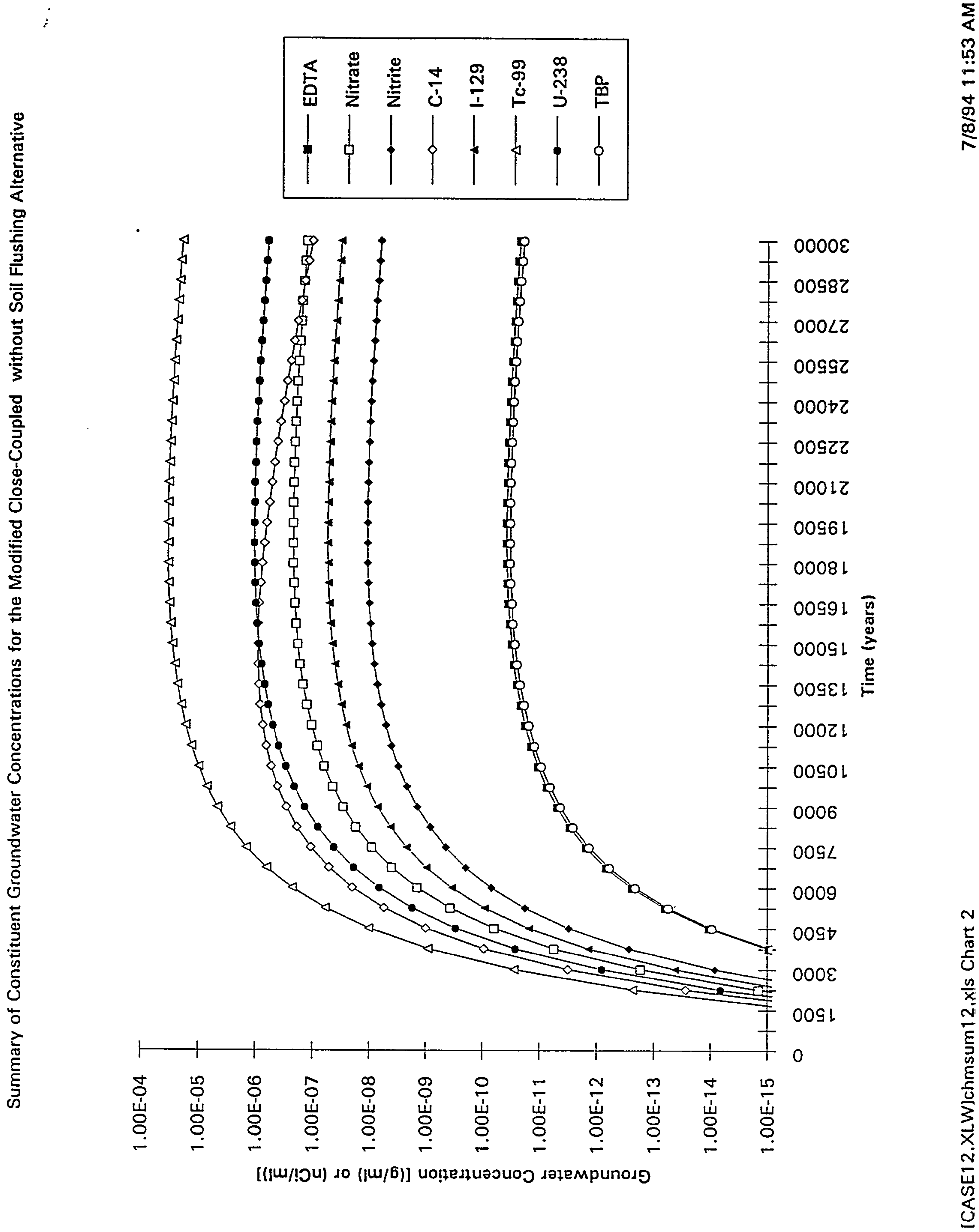
Summary of Constituent Groundwater Concentrations for the Close-Coupled with Soil Flushing Alternative

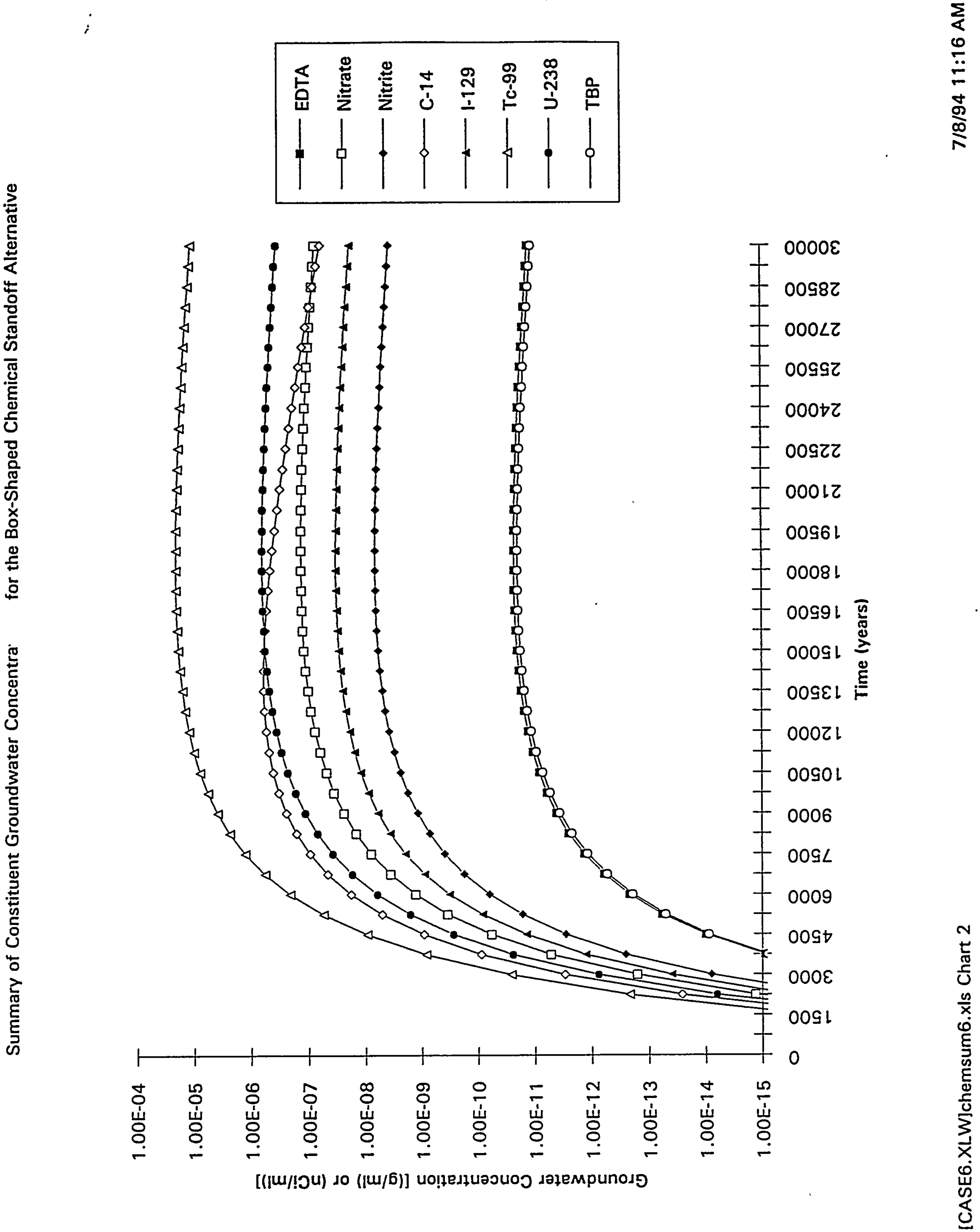


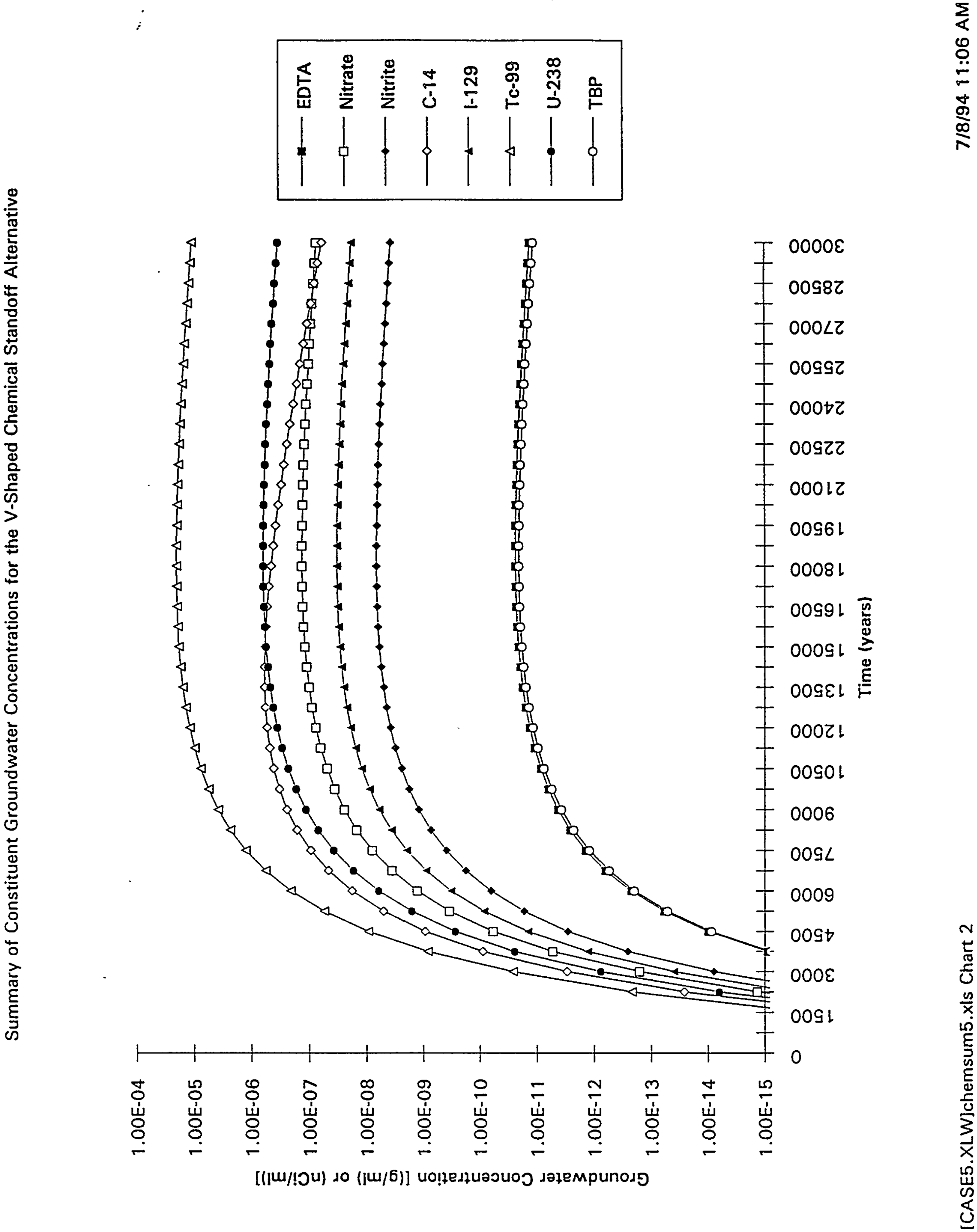
8/31/94 3:37 PM

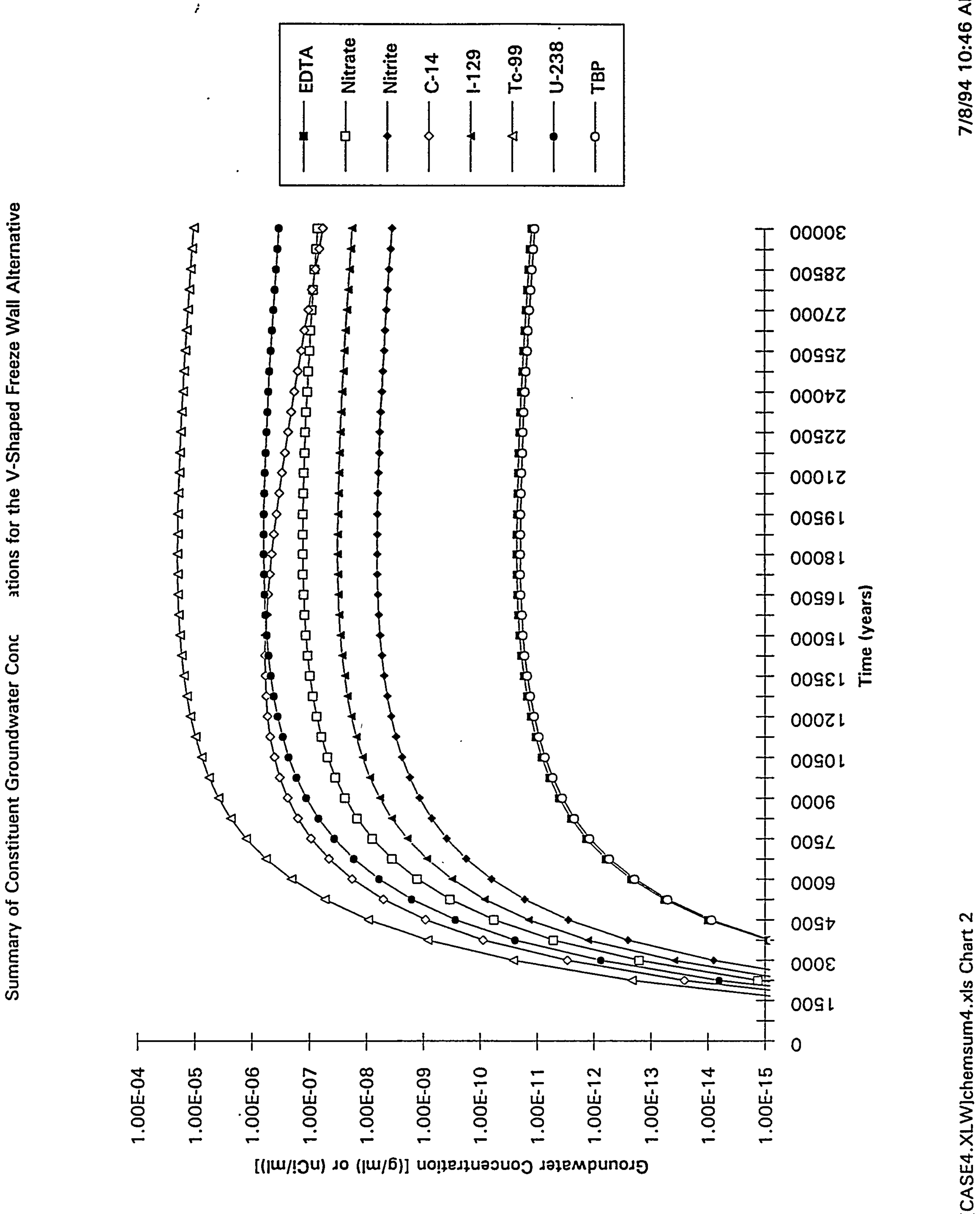
[CASE3.XLW]chemsum3.xls Chart 2

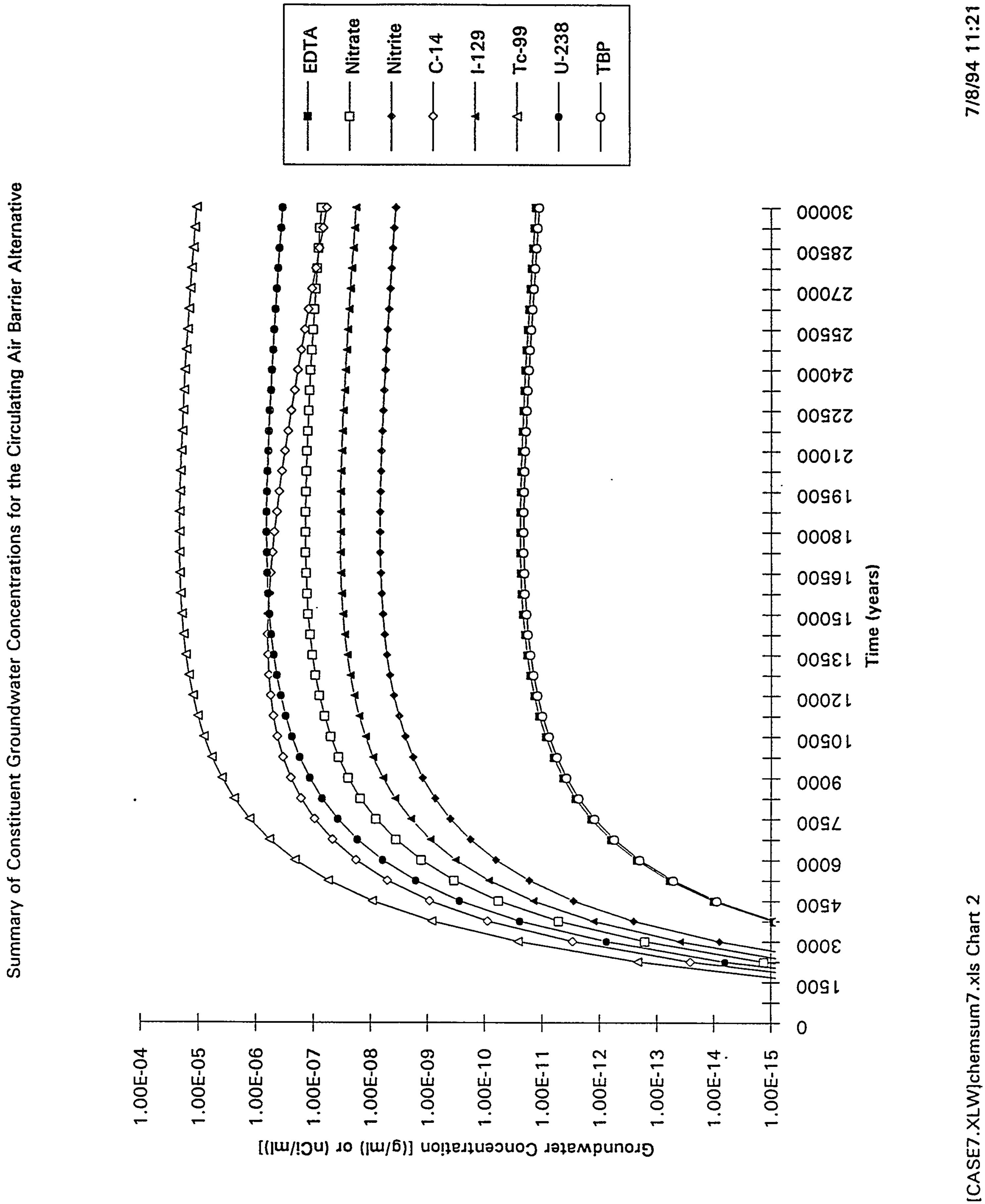

Summary of Constituent Groundwater Concentrati
'or the Close-Coupled without Soil Flushing Alternative
EDTA
Nitrate
Nitrite
C-14
I-129
Tc-99
U-238
TBP
1.00E-04
1.00E-05
1.00E-06
1.00E-07
1.00E-08
1.00E-09
1.00E-10
1.00E-11
1.00E-12
1.00E-13
1.00E-14
1.00E-15
Groundwater Concentration [(g/ml) or (nCi/ml)]
0
1500
3000
4500
6000
7500
9000
10500
12000
13500
15000
16500
18000
19500
21000
22500
24000
25500
27000
28500
30000
Time (years)
7/8/94 4:07 PM
[CASE11.XLW]chmsum11.xls Chart 2


Summary of Constituent Groundwater Concentrations for the Modified Close-Coupled without Soil Flushing Alternative
EDTA
Nitrate
Nitrite
C-14
I-129
Tc-99
U-238
TBP
Groundwater Concentration [(g/ml) or (nCi/ml)]
1.00E-04
1.00E-05
1.00E-06
1.00E-07
1.00E-08
1.00E-09
1.00E-10
1.00E-11
1.00E-12
1.00E-13
1.00E-14
1.00E-15
Time (years)
0
1500
3000
4500
6000
7500
9000
10500
12000
13500
15000
16500
18000
19500
21000
22500
24000
25500
27000
28500
30000
7/8/94 11:53 AM
[CASE12.XLW]chmsum12.xls Chart 2

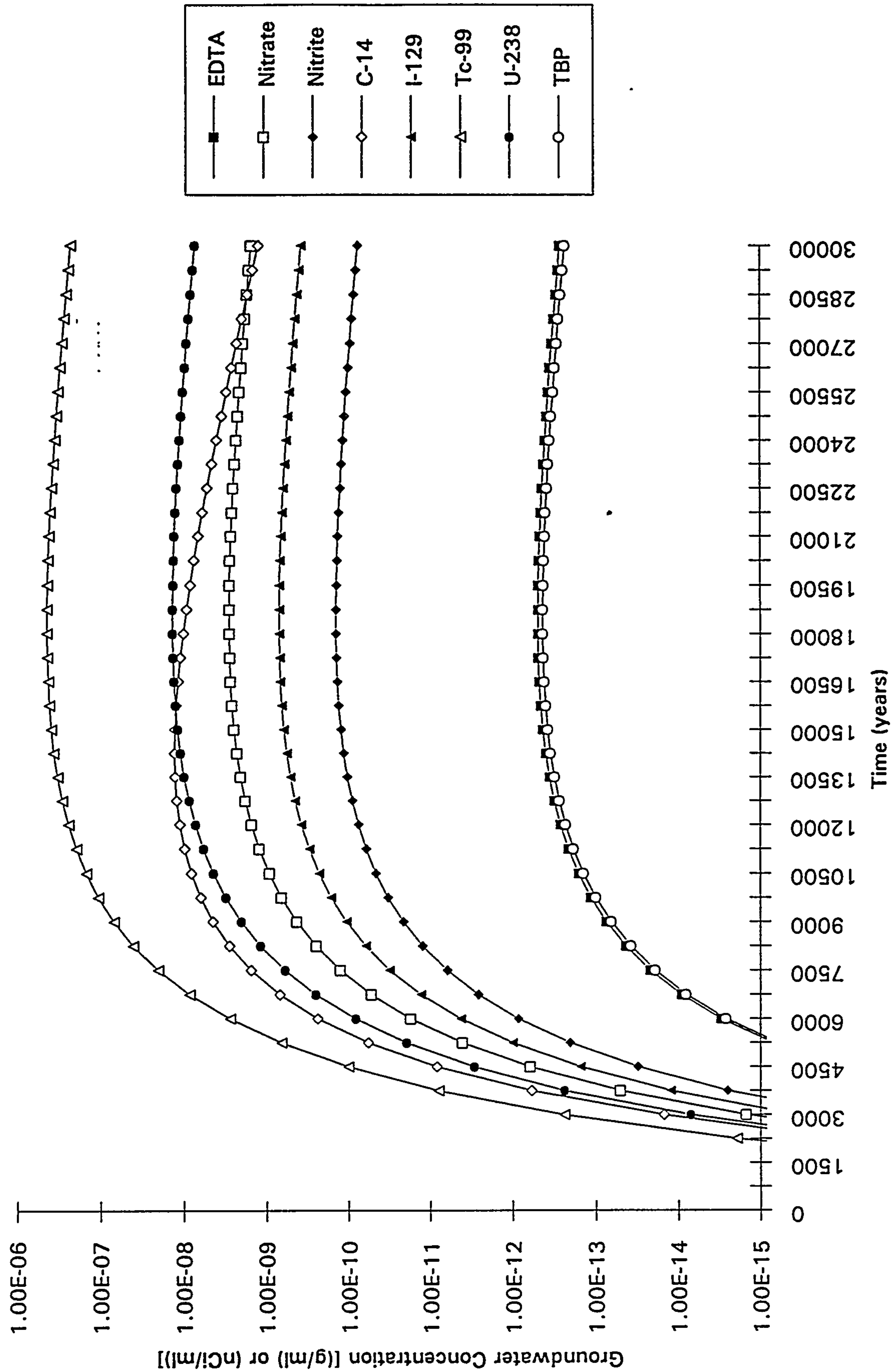

Summary of Constituent Groundwater Concentra for the Box-Shaped Chemical Standoff Alternative
7/8/94 11:16 AM
EDTA
Nitrate
Nitrite
C-14
I-129
Tc-99
U-238
TBP
Groundwater Concentration [(g/ml) or (nCi/ml)]
1.00E-04
1.00E-05
1.00E-06
1.00E-07
1.00E-08
1.00E-09
1.00E-10
1.00E-11
1.00E-12
1.00E-13
1.00E-14
1.00E-15
0
1500
3000
4500
6000
7500
9000
10500
12000
13500
15000
16500
18000
19500
21000
22500
24000
25500
27000
28500
30000
Time (years)
[CASE6.XLW]chemsum6.xls Chart 2


Summary of Constituent Groundwater Concentrations for the V-Shaped Chemical Standoff Alternative
EDTA
Nitrate
Nitrite
C-14
I-129
Tc-99
U-238
TBP
Groundwater Concentration [(g/ml) or (nCi/ml)]
1.00E-04
1.00E-05
1.00E-06
1.00E-07
1.00E-08
1.00E-09
1.00E-10
1.00E-11
1.00E-12
1.00E-13
1.00E-14
1.00E-15
0
1500
3000
4500
6000
7500
9000
10500
12000
13500
15000
16500
18000
19500
21000
22500
24000
25500
27000
28500
30000
Time (years)
7/8/94 11:06 AM
[CASE5.XLW]chemsum5.xls Chart 2


Summary of Constituent Groundwater Conc ations for the V-Shaped Freeze Wall Alternative
EDTA
Nitrate
Nitrite
C-14
I-129
Tc-99
U-238
TBP
Groundwater Concentration [(g/ml) or (nCi/ml)]
1.00E-04
1.00E-05
1.00E-06
1.00E-07
1.00E-08
1.00E-09
1.00E-10
1.00E-11
1.00E-12
1.00E-13
1.00E-14
1.00E-15
0
1500
3000
4500
6000
7500
9000
10500
12000
13500
15000
16500
18000
19500
21000
22500
24000
25500
27000
28500
30000
Time (years)
7/8/94 10:46 AM
[CASE4.XLW]chemsum4.xls Chart 2

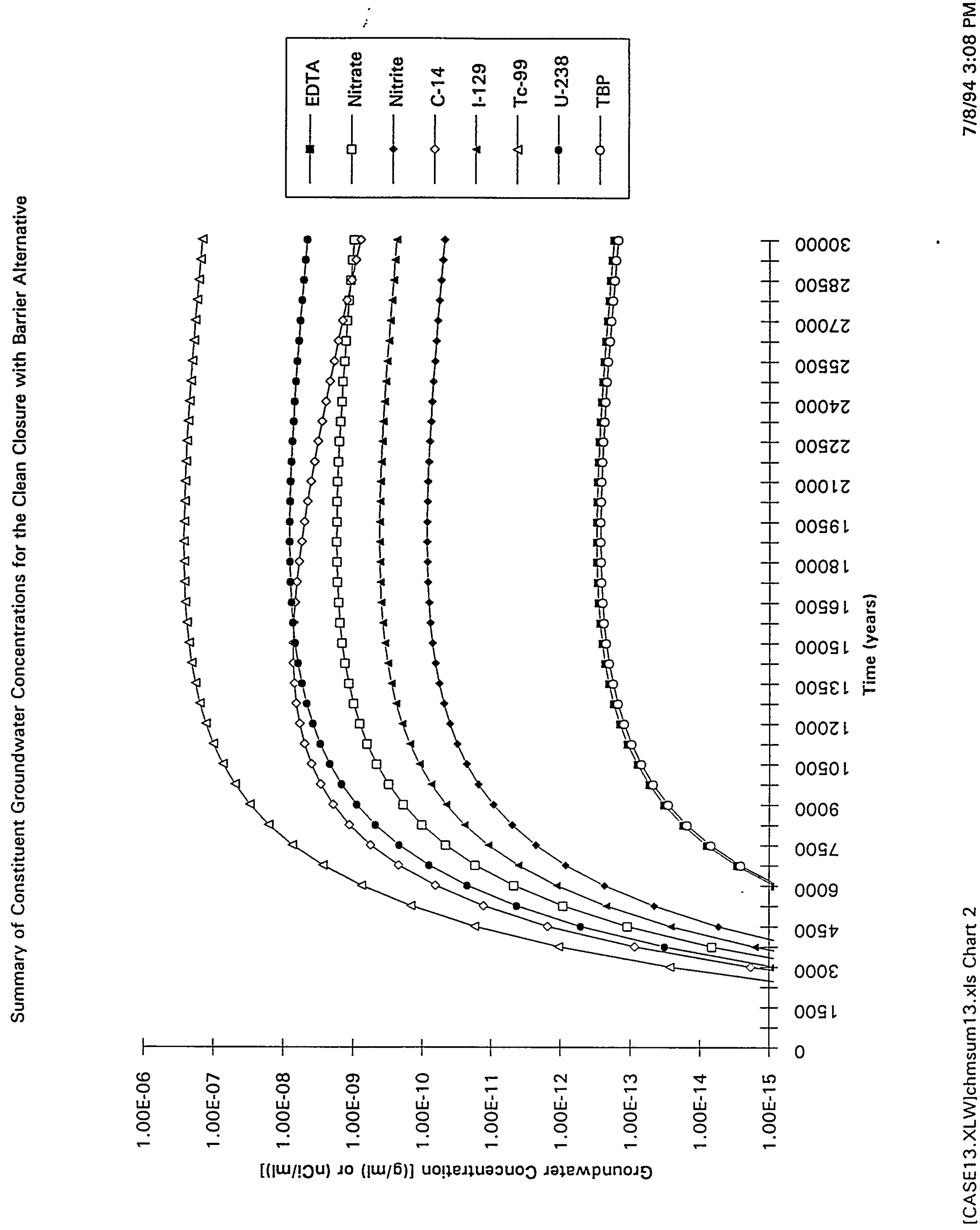

Summary of Constituent Groundwater Concentrations for the Circulating Air Barrier Alternative
EDTA
Nitrate
Nitrite
C-14
I-129
Tc-99
U-238
TBP
Groundwater Concentration [(g/ml) or (nCi/ml)]
1.00E-04
1.00E-05
1.00E-06
1.00E-07
1.00E-08
1.00E-09
1.00E-10
1.00E-11
1.00E-12
1.00E-13
1.00E-14
1.00E-15
0
1500
3000
4500
6000
7500
9000
10500
12000
13500
15000
16500
18000
19500
21000
22500
24000
25500
27000
28500
30000
Time (years)
7/8/94 11:21 AM
[CASE7.XLW]chemsum7.xls Chart 2

Summary of Constituent Groundwater Concent   ns for the Clean Closure without Barrier Alternative

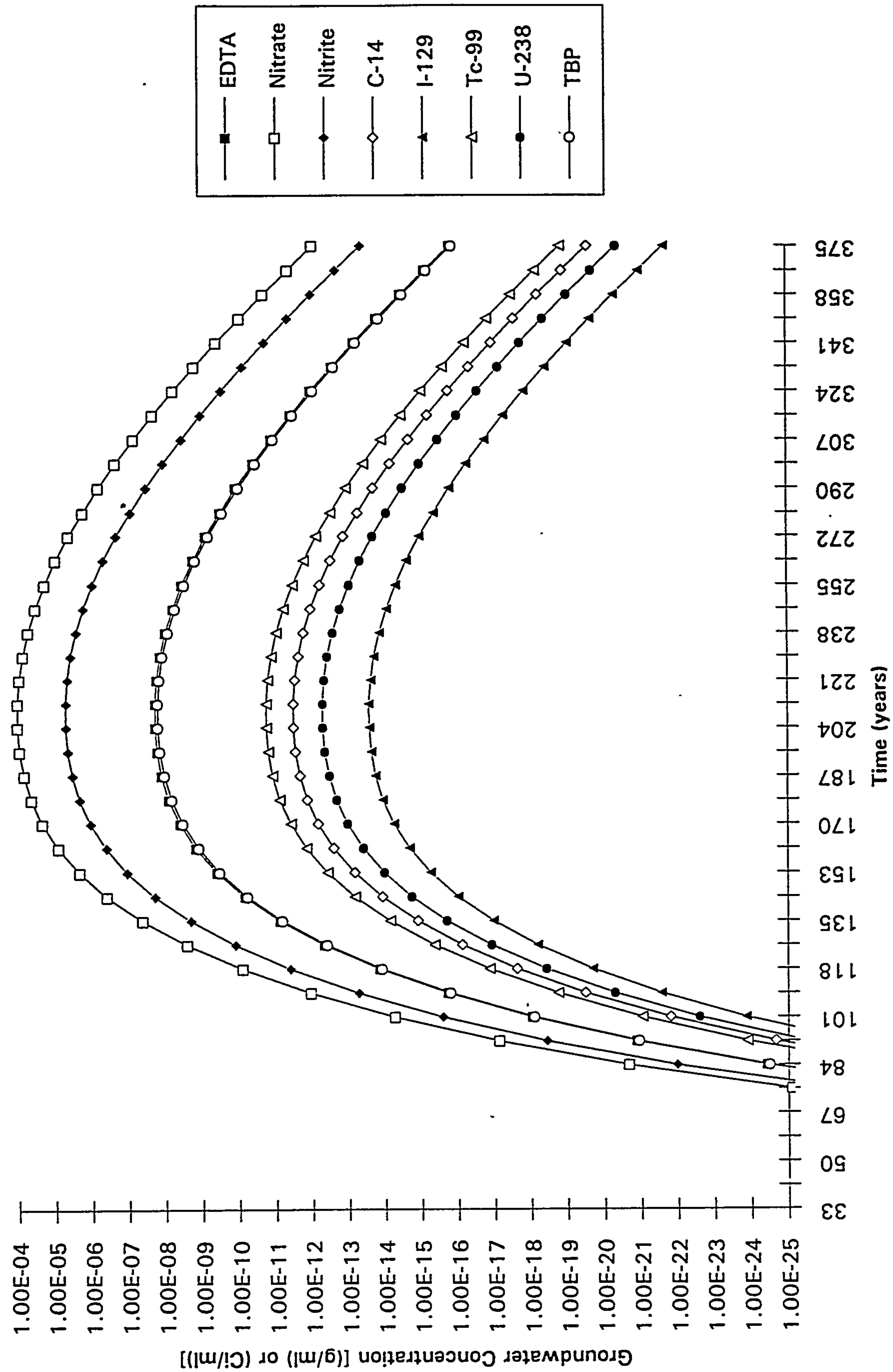


7/8/94 3:07 PM

[CASE14.XLW]chmsum14.xls Chart 2


Summary of Constituent Groundwater Concentrations for the Clean Closure with Barrier Alternative
7/8/94 3:08 PM
EDTA
Nitrate
Nitrite
C-14
I-129
Tc-99
U-238
TBP
Groundwater Concentration [(g/ml) or (nCi/ml)]
1.00E-06
1.00E-07
1.00E-08
1.00E-09
1.00E-10
1.00E-11
1.00E-12
1.00E-13
1.00E-14
1.00E-15
0
1500
3000
4500
6000
7500
9000
10500
12000
13500
15000
16500
18000
19500
21000
22500
24000
25500
27000
28500
30000
Time (years)
[CASE13.XLW]chmsum13.xls Chart 2

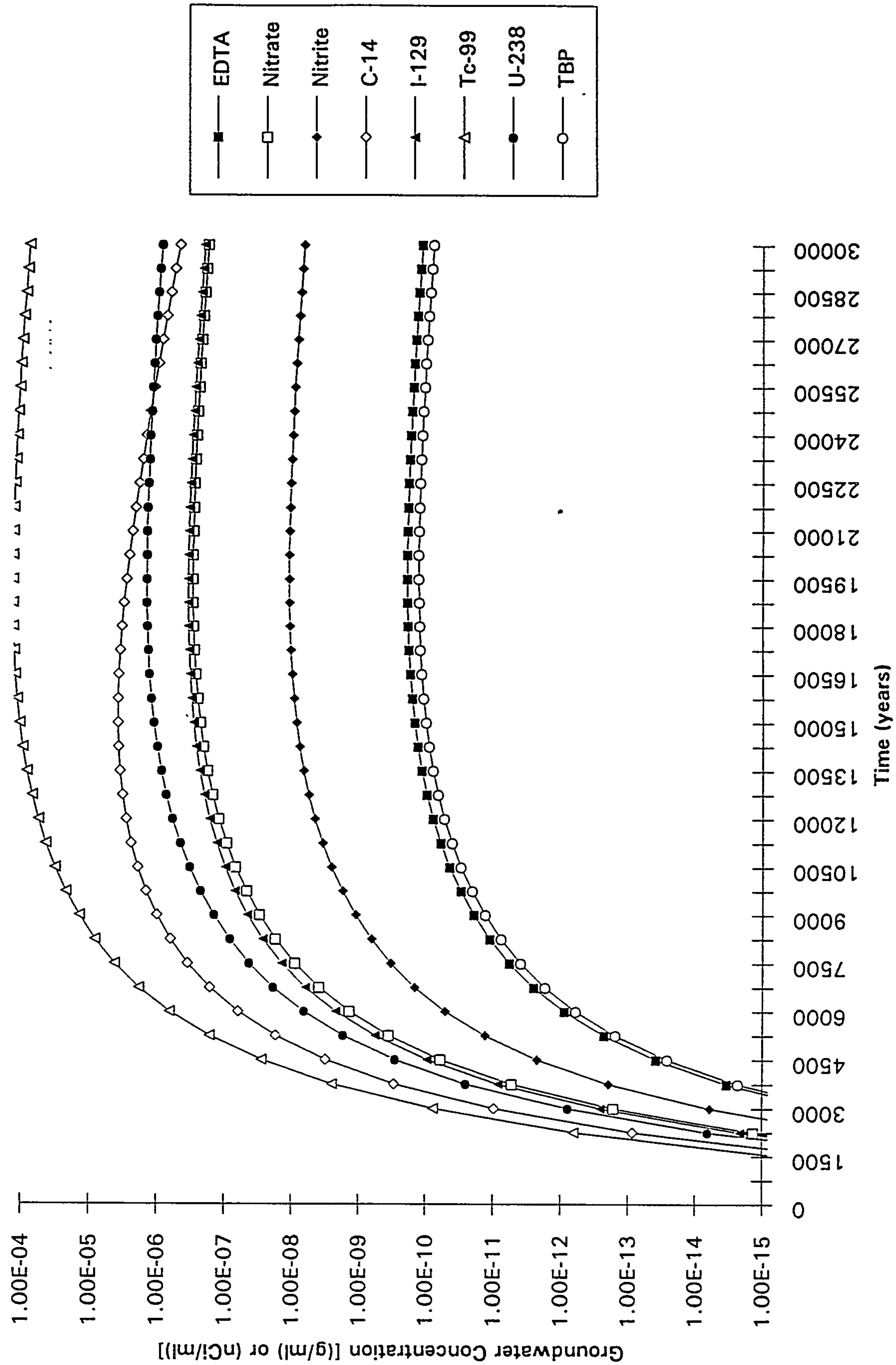
Summary of Constituent Groundwater Concentrations for itivity Case #1 - Traditional Sluicing without Surface Barrier



7/10/94 3:32 PM

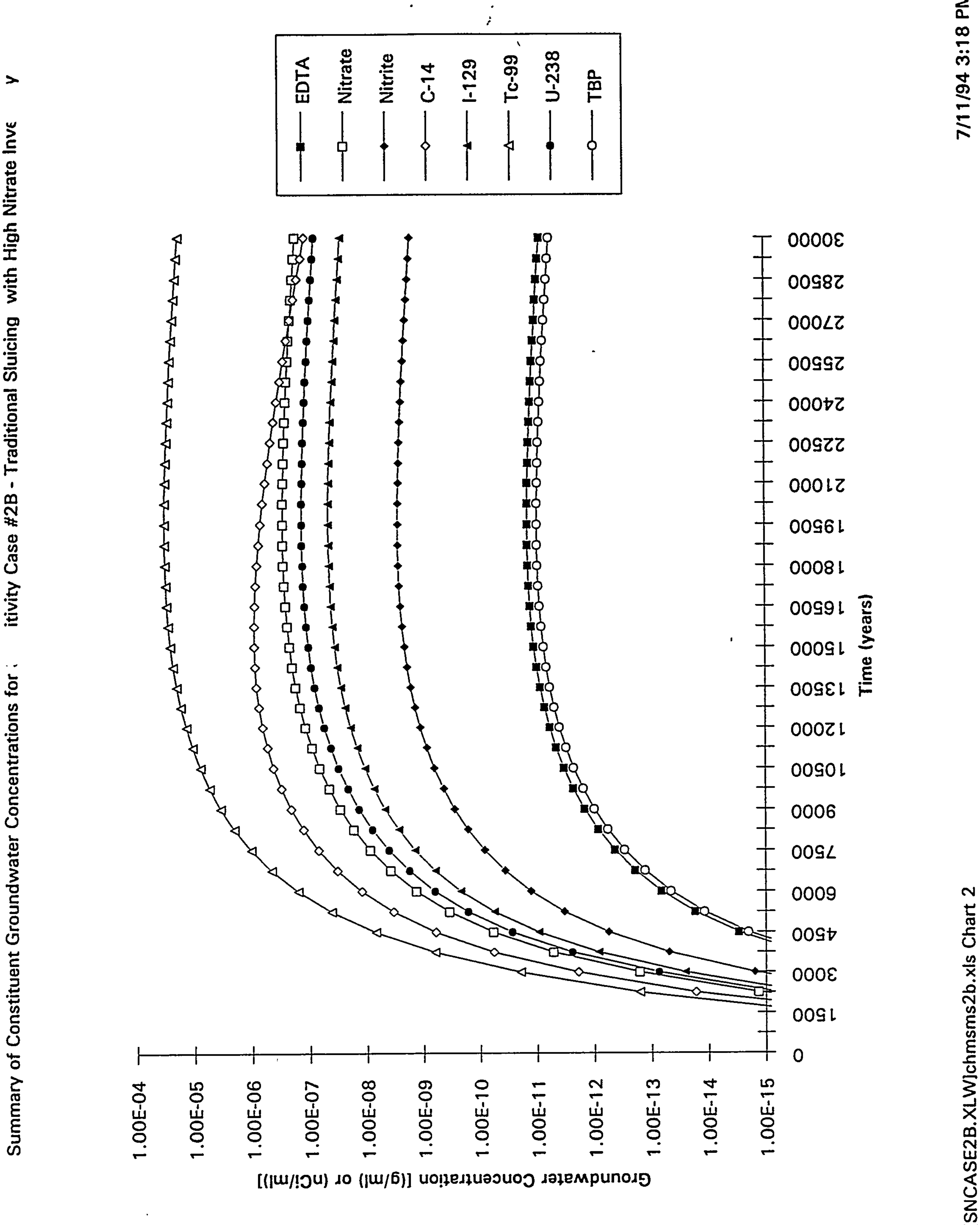
[SNSCASE1.XLW]chmsumS1.xls Chart 2

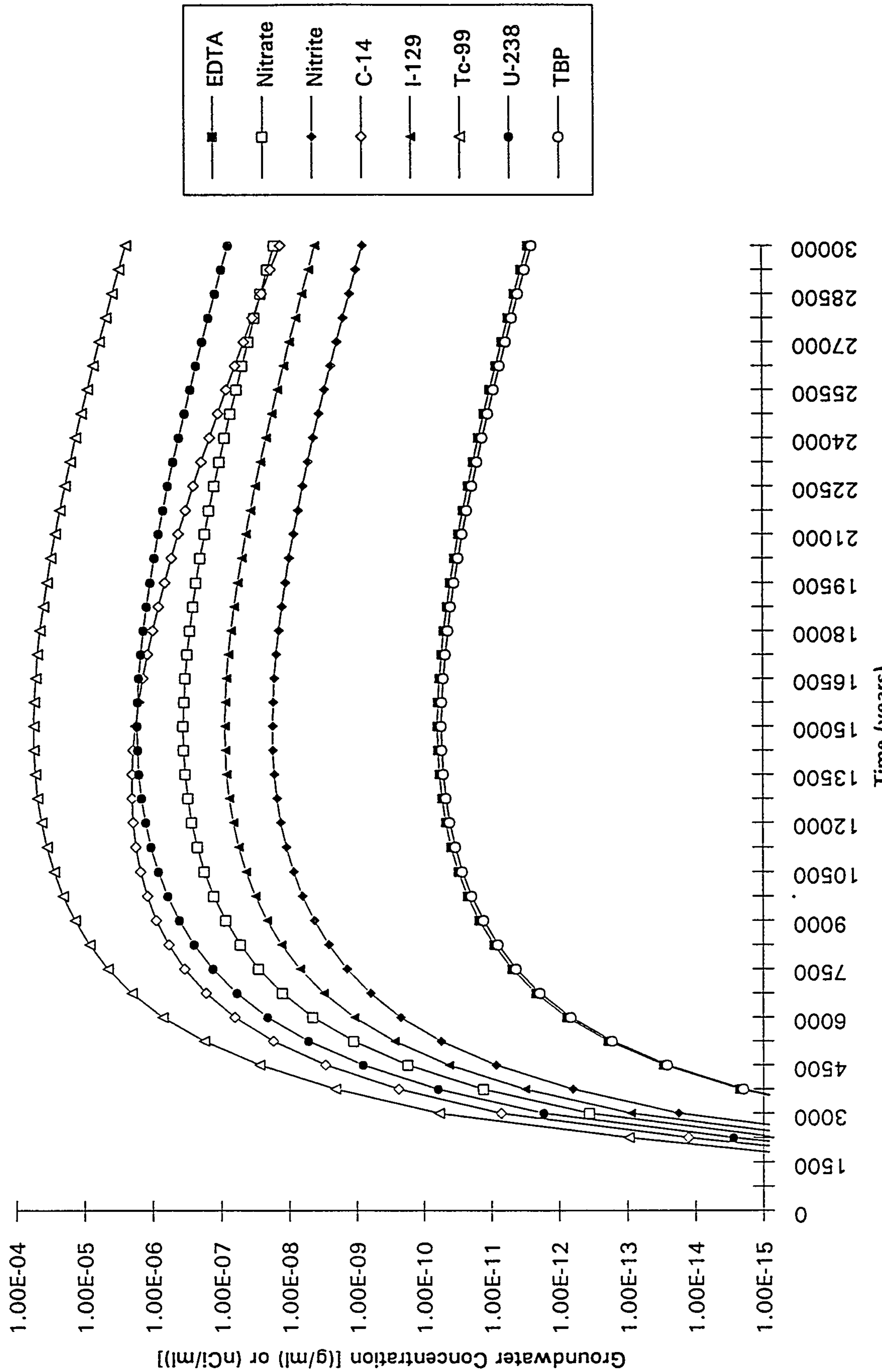
Summary of Constituent Groundwater Concentrations for Sensitivity Case #2A - Traditional Sluicing with Low Nitrate Inventory



7/11/94 3:21 PM

ISNCASF2A.XLS Wlchmsms2a.xls Chart 2

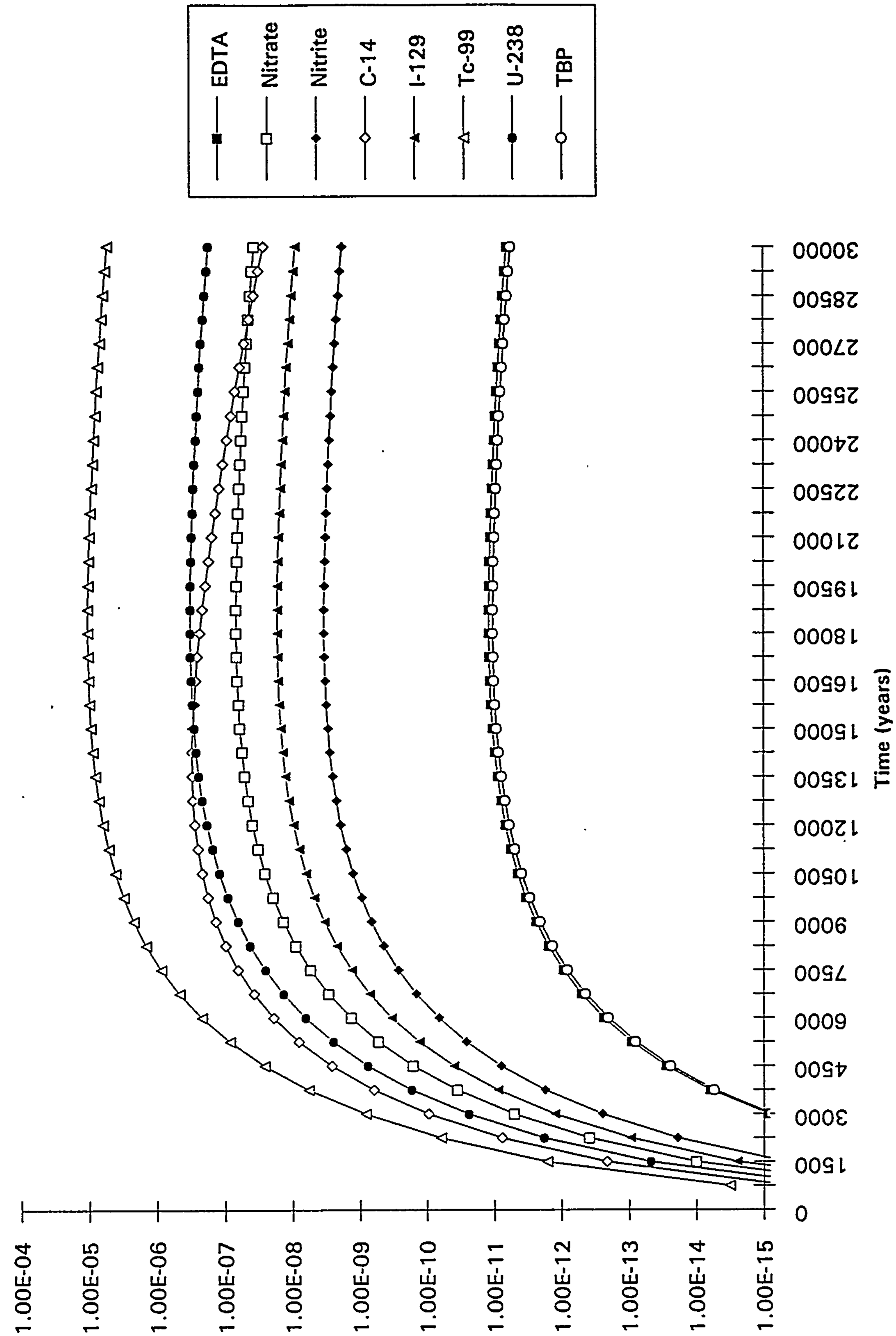

Summary of Constituent Groundwater Concentrations for ... itivity Case #2B - Traditional Sluicing with High Nitrate Inve ... y
7/11/94 3:18 PM
EDTA
Nitrate
Nitrite
C-14
I-129
Tc-99
U-238
TBP
Groundwater Concentration [(g/ml) or (nCi/ml)]
1.00E-04
1.00E-05
1.00E-06
1.00E-07
1.00E-08
1.00E-09
1.00E-10
1.00E-11
1.00E-12
1.00E-13
1.00E-14
1.00E-15
Time (years)
0
1500
3000
4500
6000
7500
9000
10500
12000
13500
15000
16500
18000
19500
21000
22500
24000
25500
27000
28500
30000
[SNCASE2B.XLW]chmsms2b.xls Chart 2



Summary of Constituent Groundwater Concentrations for Sensitivity Case #3 - Traditional Sluicing with Faster Vadose Zone Travel

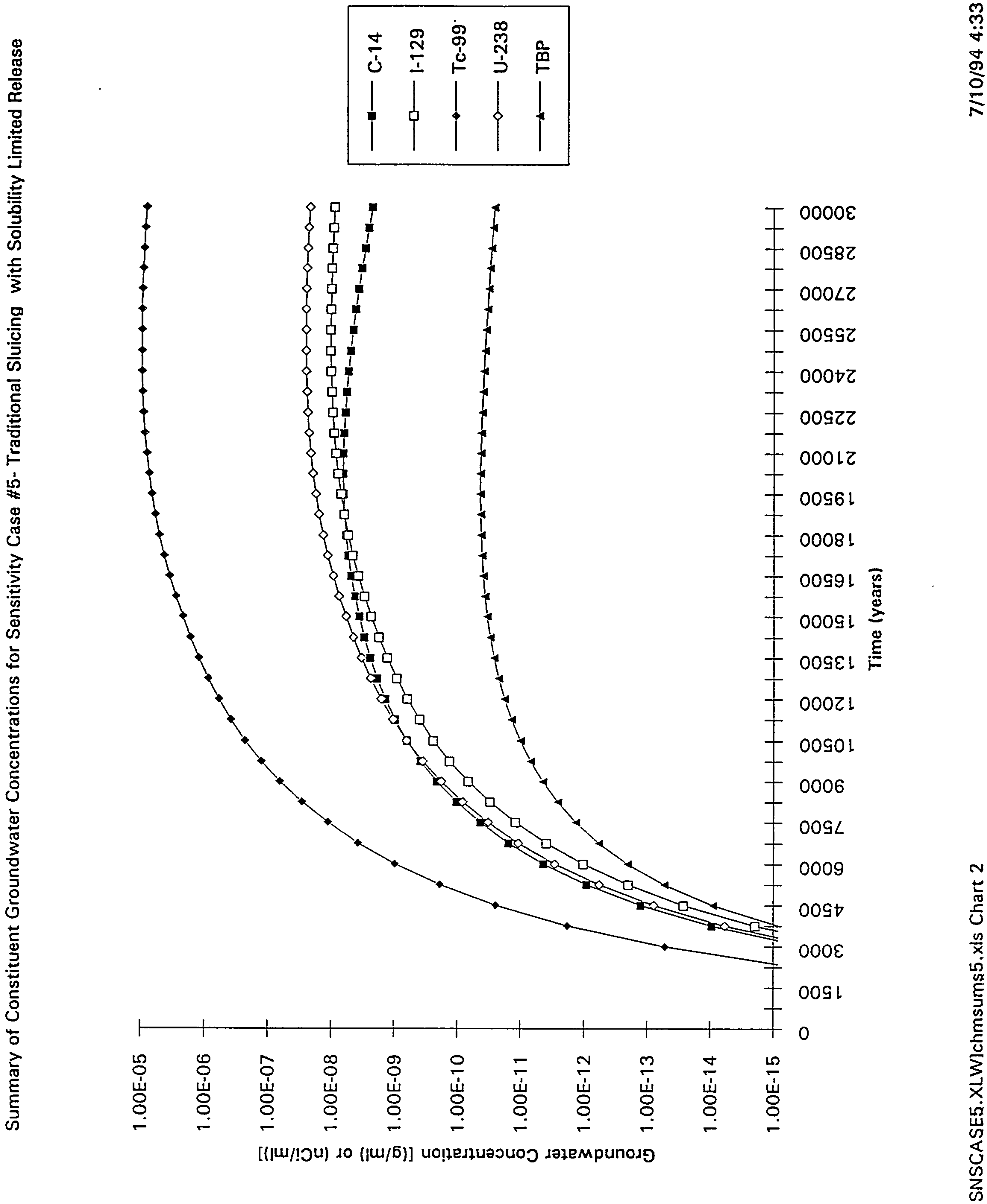
7/10/94 4:06 PM

ummary of Constituent Groundwater Concentrations for Se /ity Case #4 - Traditional Sluicing with Slower Vadose Zon vel



7/10/94 4:35 PM

[SNSCASE4.XLW]chmsums4.xls Chart 2


Summary of Constituent Groundwater Concentrations for Sensitivity Case #5- Traditional Sluicing with Solubility Limited Release
C-14
I-129
Tc-99
U-238
TBP
Groundwater Concentration [(g/ml) or (nCi/ml)]
1.00E-05
1.00E-06
1.00E-07
1.00E-08
1.00E-09
1.00E-10
1.00E-11
1.00E-12
1.00E-13
1.00E-14
1.00E-15
0
1500
3000
4500
6000
7500
9000
10500
12000
13500
15000
16500
18000
19500
21000
22500
24000
25500
27000
28500
30000
Time (years)
7/10/94 4:33 PM
[SNSCASE5.XLW]chmsums5.xls Chart 2

APPENDIX B.2

HUMAN HEALTH RISK RESULTS

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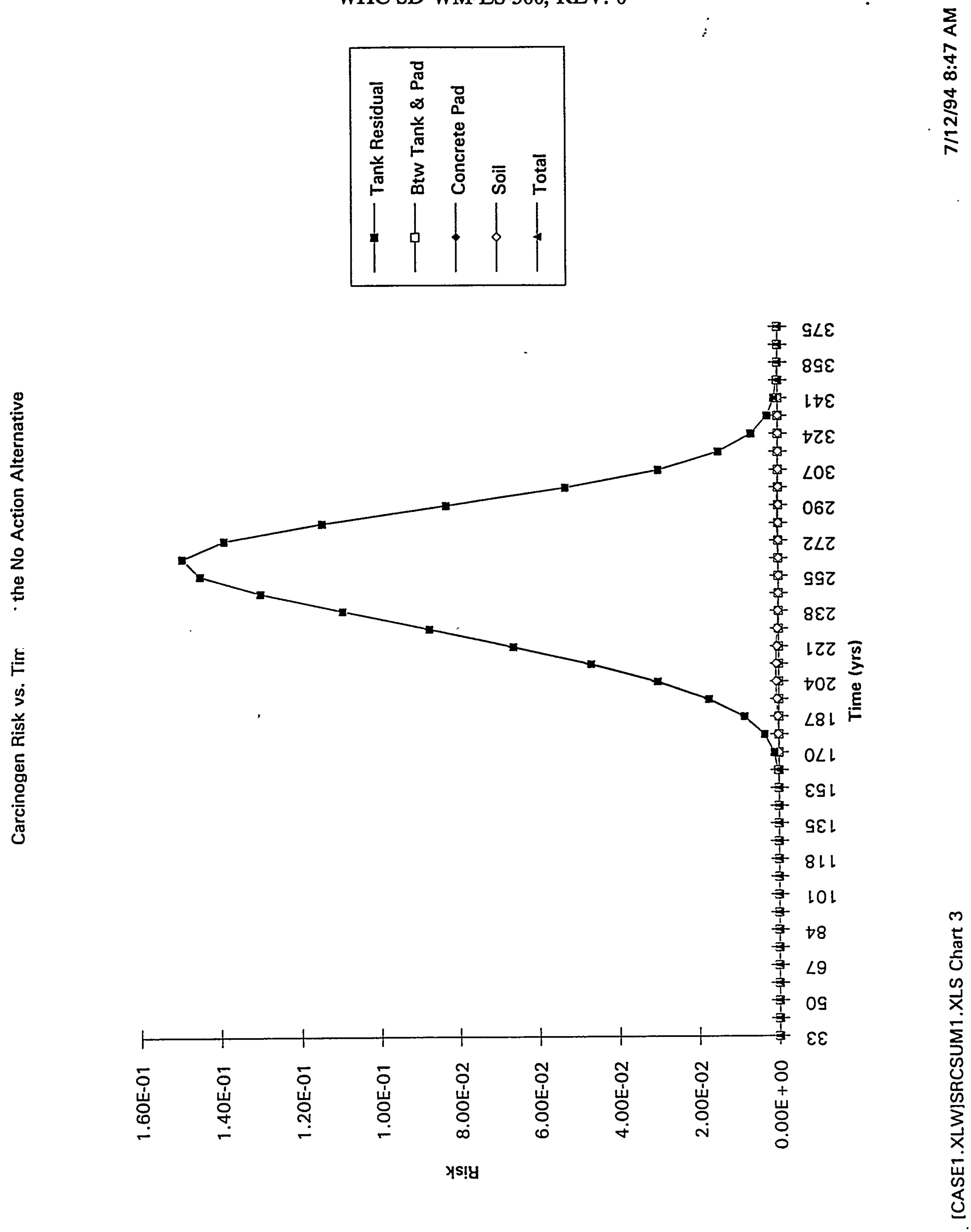
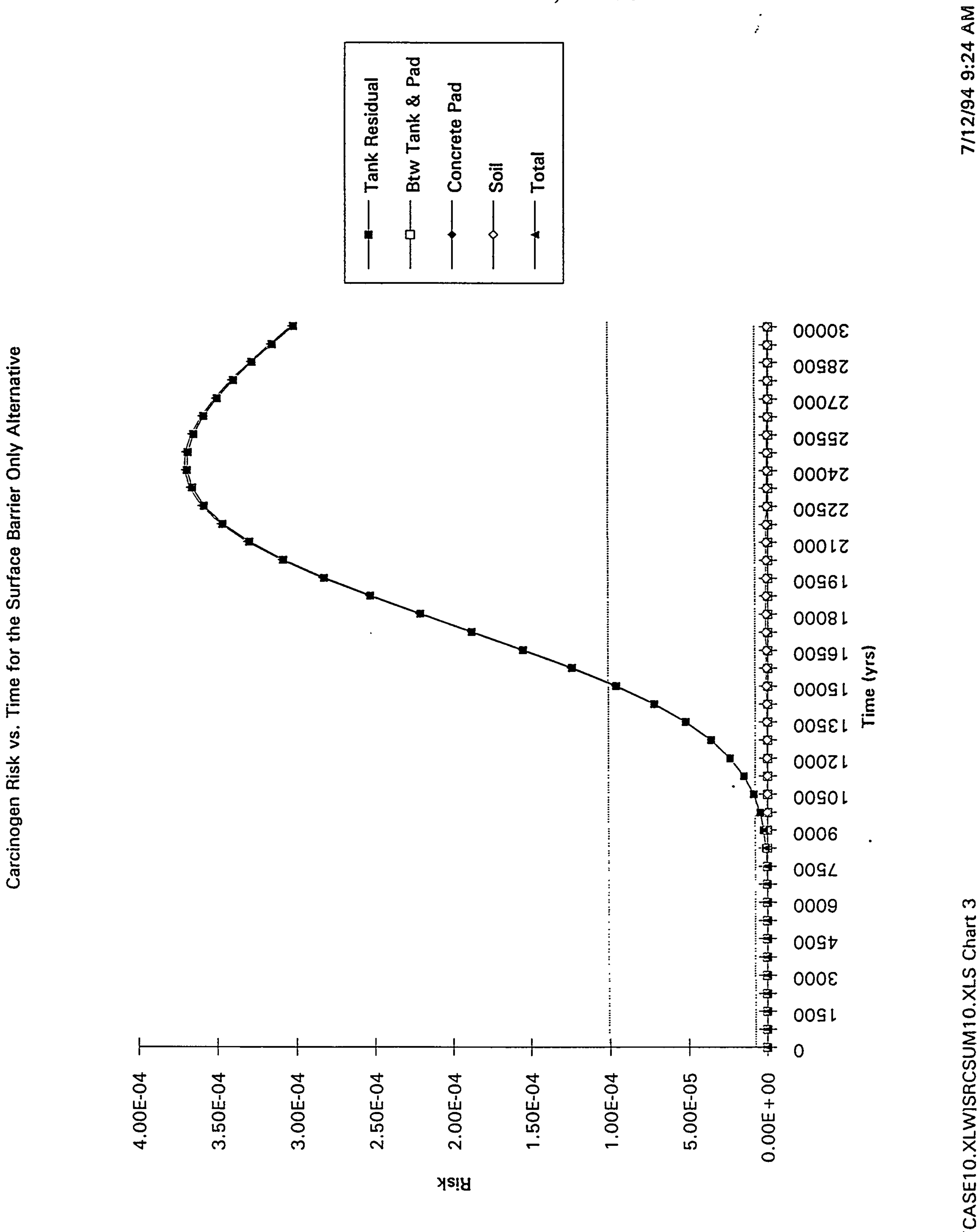
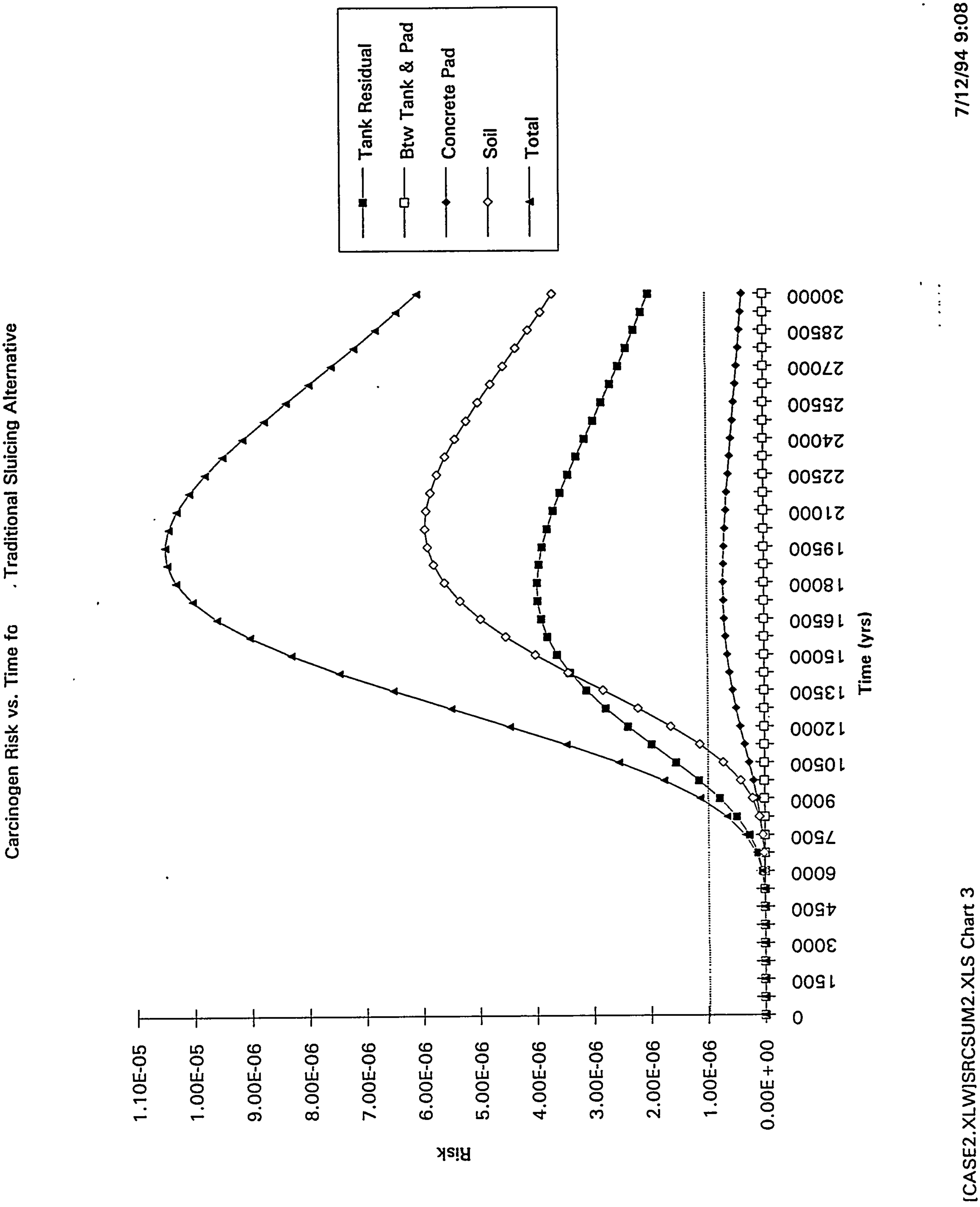
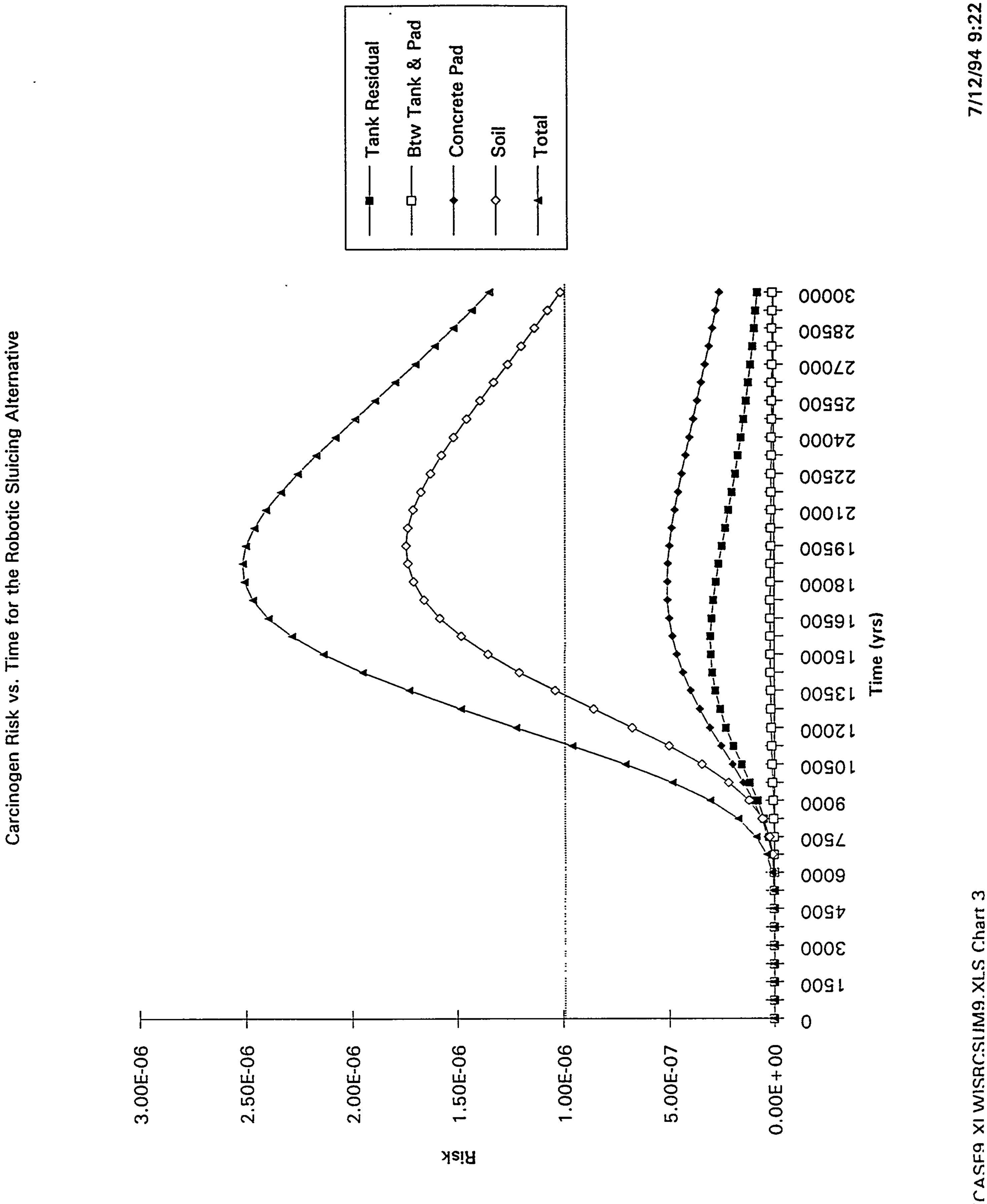
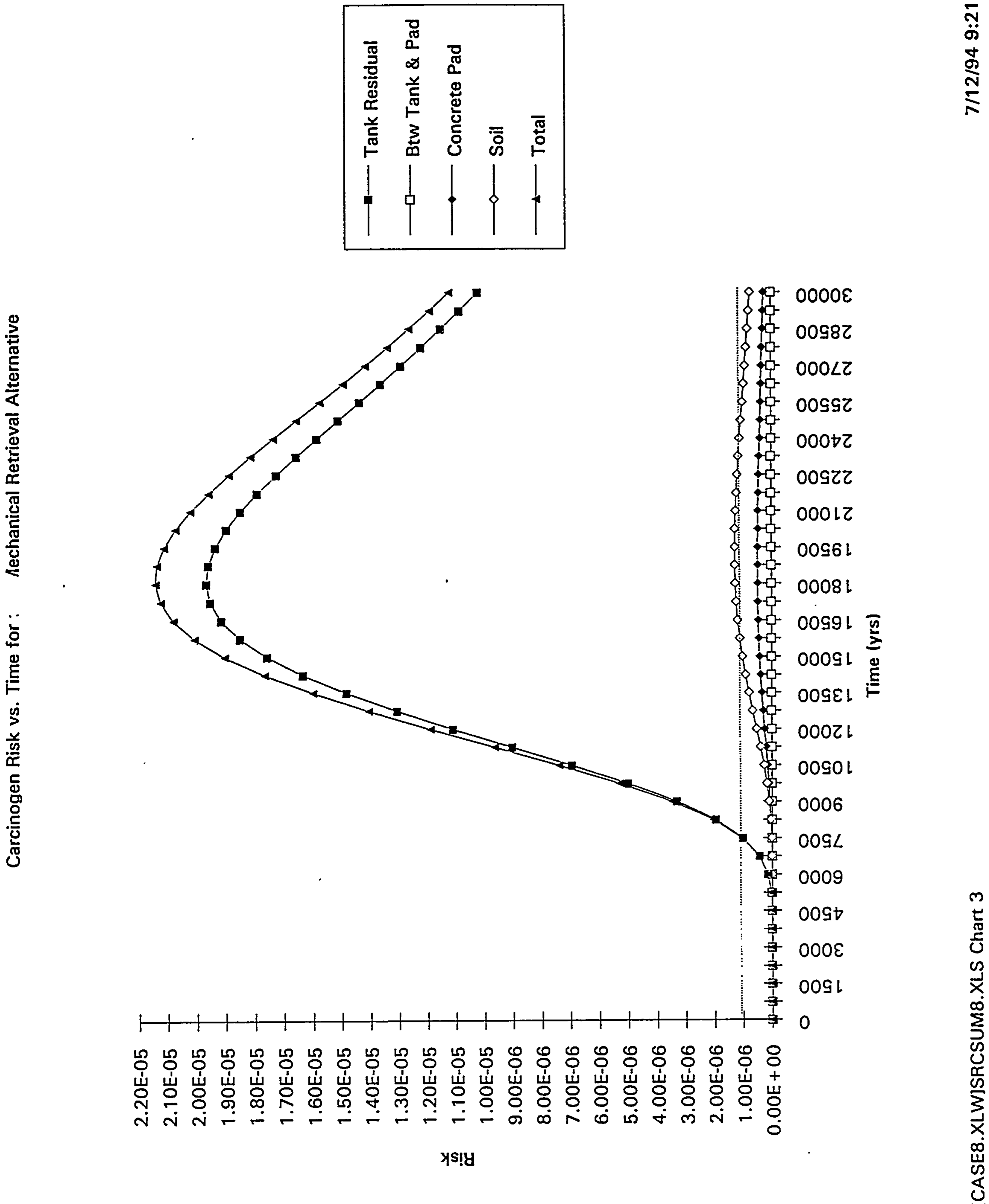

Carcinogen Risk vs. Tim · the No Action Alternative
7/12/94 8:47 AM
Tank Residual
Btw Tank & Pad
Concrete Pad
Soil
Total
Risk
1.60E-01
1.40E-01
1.20E-01
1.00E-01
8.00E-02
6.00E-02
4.00E-02
2.00E-02
0.00E+00
33
50
67
84
101
118
135
153
170
187
204
221
238
255
272
290
307
324
341
358
375
Time (yrs)
[CASE1.XLW]SRCSUM1.XLS Chart 3

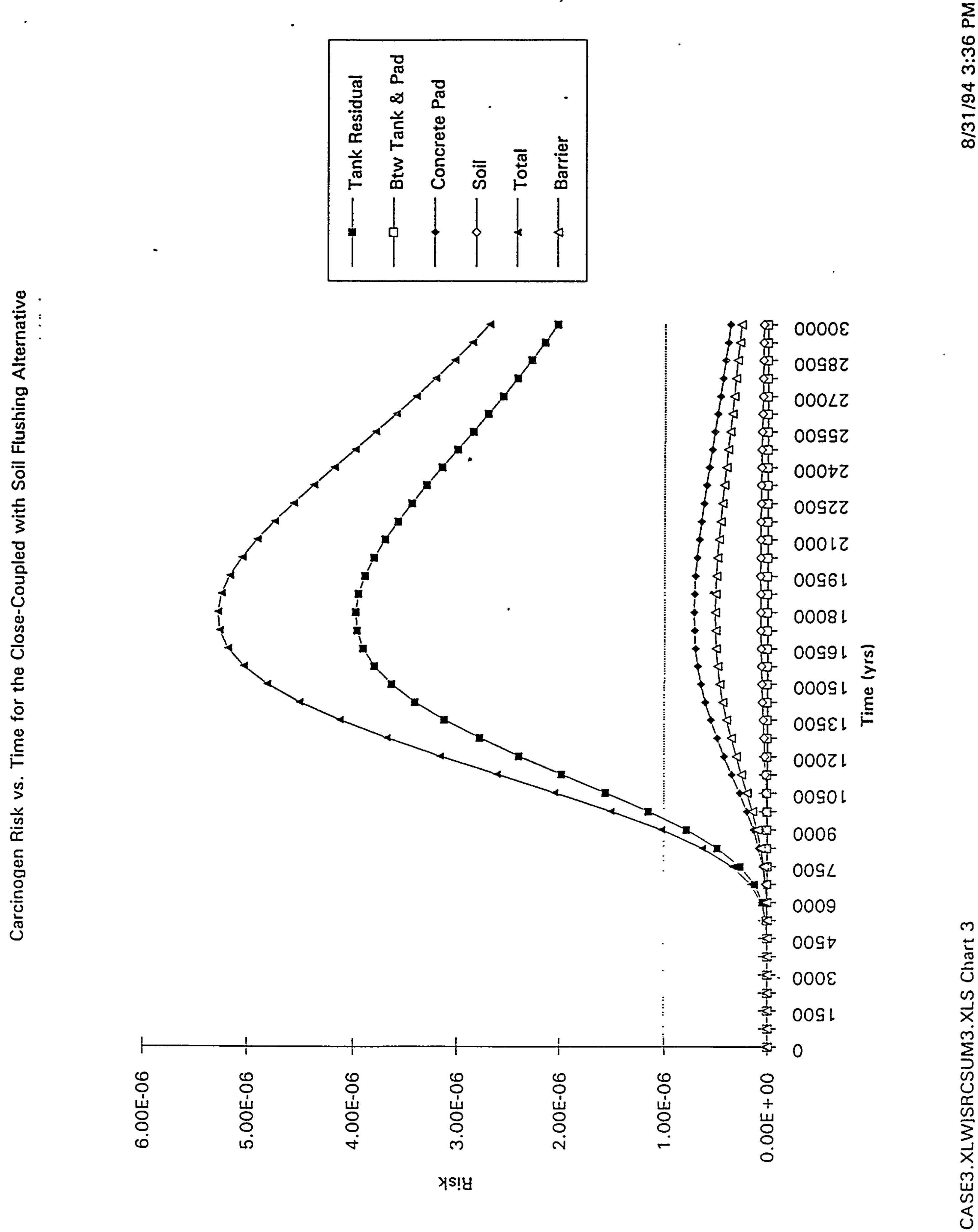

Carcinogen Risk vs. Time for the Surface Barrier Only Alternative
Tank Residual
Btw Tank & Pad
Concrete Pad
Soil
Total
Risk
4.00E-04
3.50E-04
3.00E-04
2.50E-04
2.00E-04
1.50E-04
1.00E-04
5.00E-05
0.00E+00
0
1500
3000
4500
6000
7500
9000
10500
12000
13500
15000
16500
18000
19500
21000
22500
24000
25500
27000
28500
30000
Time (yrs)
7/12/94 9:24 AM
ICASE10.XLWISRCSUM10.XLS Chart 3

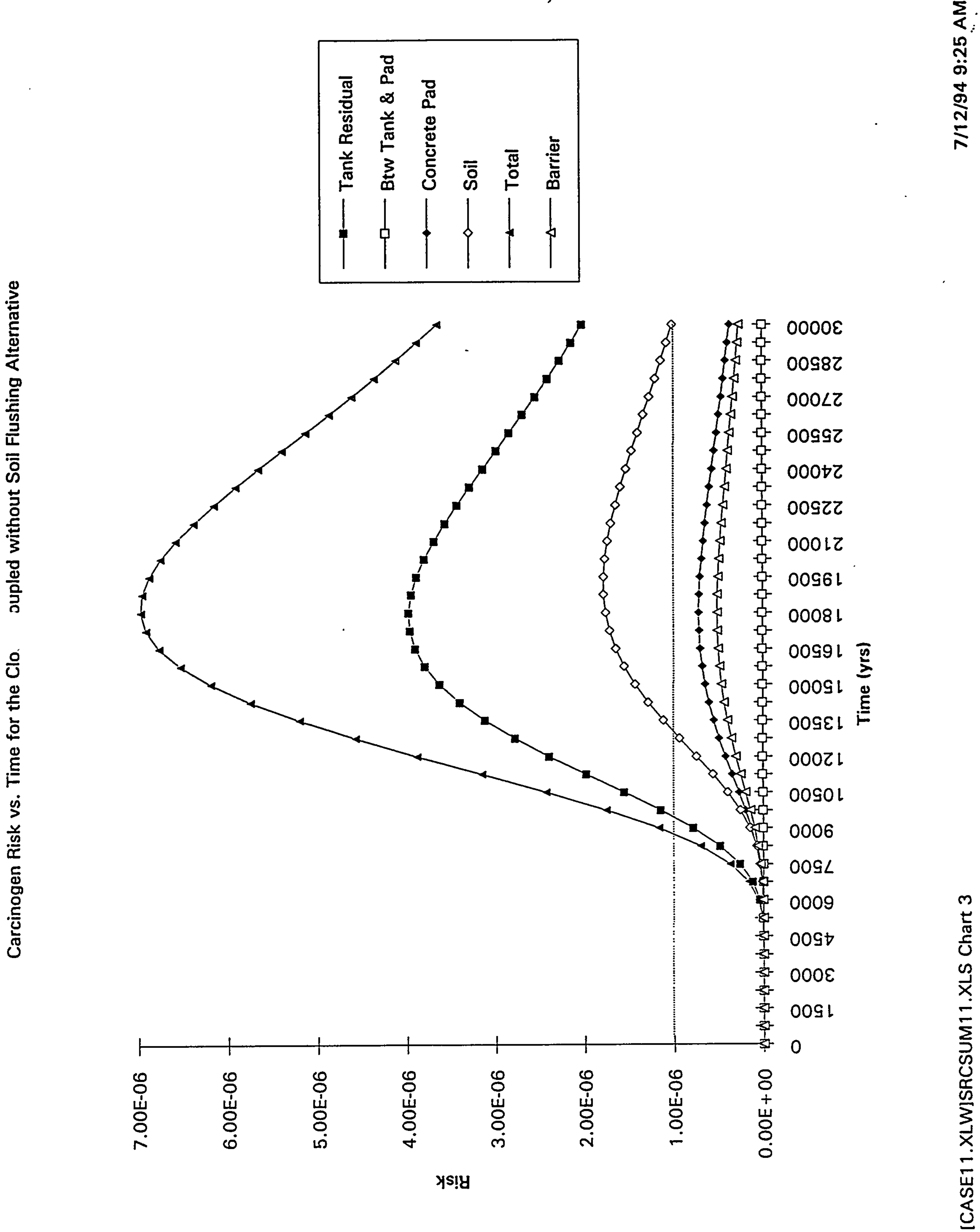

Carcinogen Risk vs. Time fo . Traditional Sluicing Alternative
Tank Residual
Btw Tank & Pad
Concrete Pad
Soil
Total
Risk
1.10E-05
1.00E-05
9.00E-06
8.00E-06
7.00E-06
6.00E-06
5.00E-06
4.00E-06
3.00E-06
2.00E-06
1.00E-06
0.00E+00
0
1500
3000
4500
6000
7500
9000
10500
12000
13500
15000
16500
18000
19500
21000
22500
24000
25500
27000
28500
30000
Time (yrs)
7/12/94 9:08 AM
[CASE2.XLW]SRCSUM2.XLS Chart 3



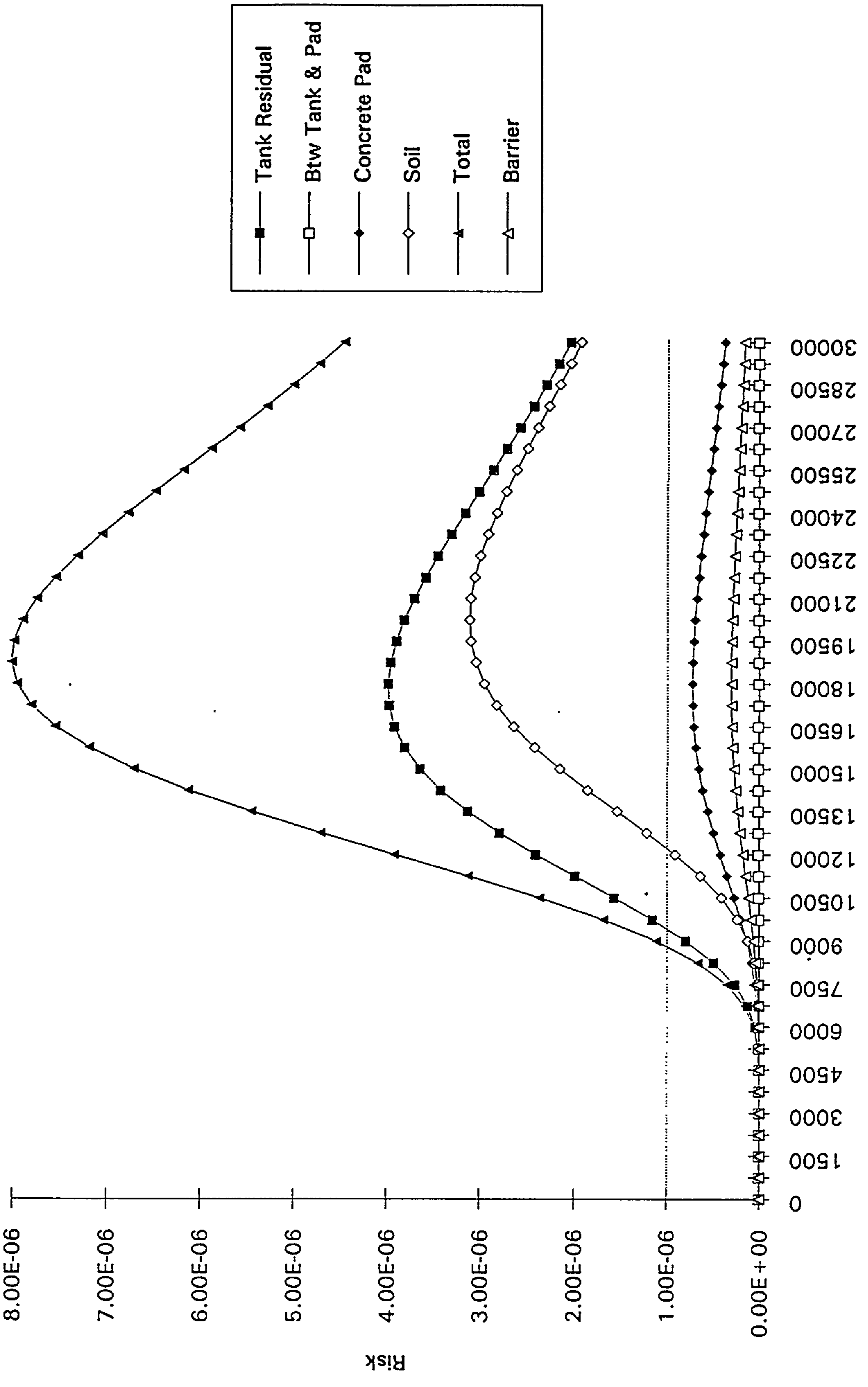
Carcinogen Risk vs. Time for the Robotic Sluicing Alternative
Tank Residual
Btw Tank & Pad
Concrete Pad
Soil
Total
Risk
3.00E-06
2.50E-06
2.00E-06
1.50E-06
1.00E-06
5.00E-07
0.00E+00
0
1500
3000
4500
6000
7500
9000
10500
12000
13500
15000
16500
18000
19500
21000
22500
24000
25500
27000
28500
30000
Time (yrs)
7/12/94 9:22 AM
XLS Chart 3


Carcinogen Risk vs. Time for :
/lechanical Retrieval Alternative
Risk
2.20E-05
2.10E-05
2.00E-05
1.90E-05
1.80E-05
1.70E-05
1.60E-05
1.50E-05
1.40E-05
1.30E-05
1.20E-05
1.10E-05
1.00E-05
9.00E-06
8.00E-06
7.00E-06
6.00E-06
5.00E-06
4.00E-06
3.00E-06
2.00E-06
1.00E-06
0.00E+00
0
1500
3000
4500
6000
7500
9000
10500
12000
13500
15000
16500
18000
19500
21000
22500
24000
25500
27000
28500
30000
Time (yrs)
Tank Residual
Btw Tank & Pad
Concrete Pad
Soil
Total
7/12/94 9:21 AM
[CASE8.XLW]SRCSUM8.XLS Chart 3


Carcinogen Risk vs. Time for the Close-Coupled with Soil Flushing Alternative
Risk
6.00E-06
5.00E-06
4.00E-06
3.00E-06
2.00E-06
1.00E-06
0.00E+00
0
1500
3000
4500
6000
7500
9000
10500
12000
13500
15000
16500
18000
19500
21000
22500
24000
25500
27000
28500
30000
Time (yrs)
Tank Residual
Btw Tank & Pad
Concrete Pad
Soil
Total
Barrier
8/31/94 3:36 PM
[CASE3.XLW]SRCSUM3.XLS Chart 3

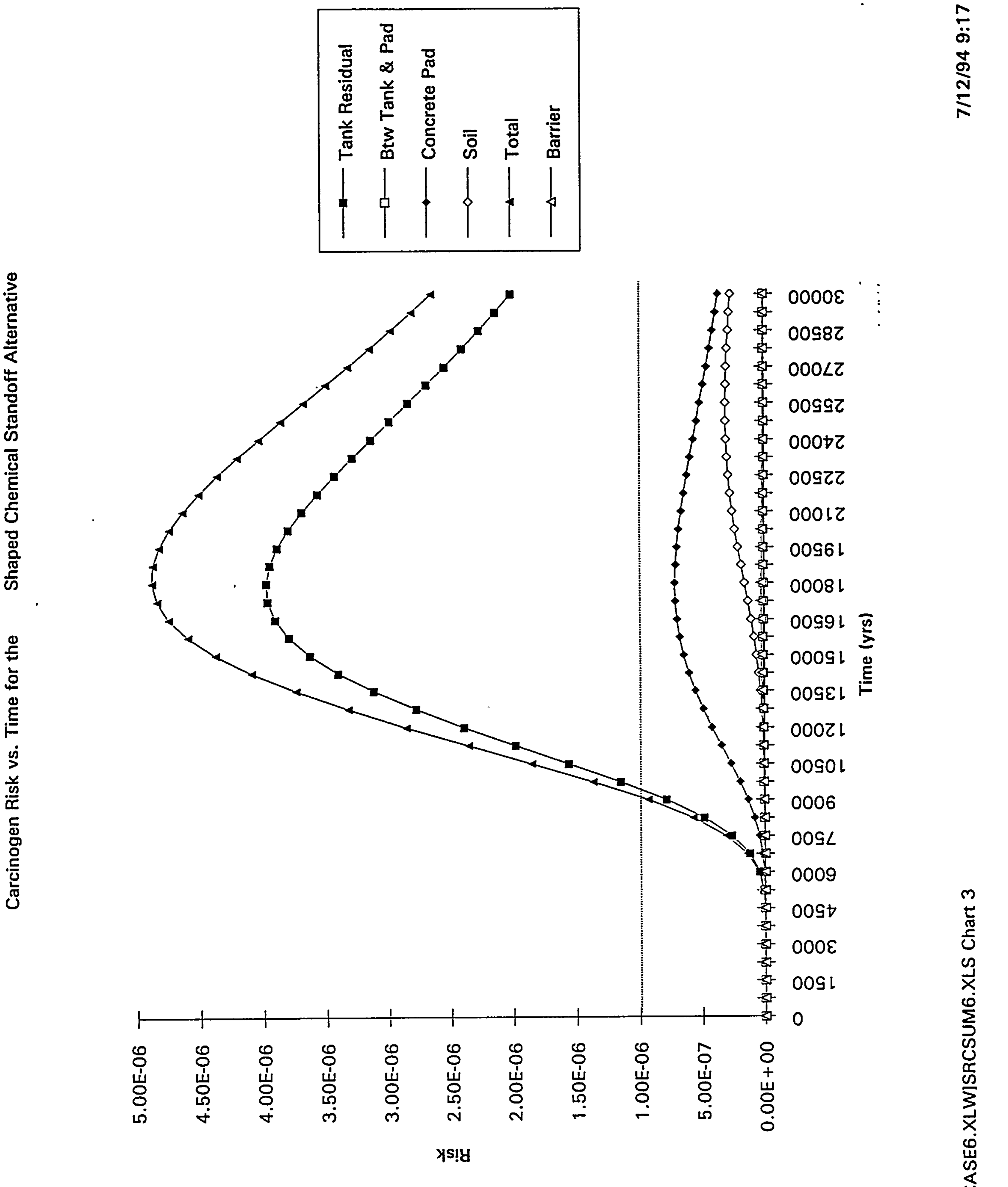

Carcinogen Risk vs. Time for the Clo oupled without Soil Flushing Alternative
Tank Residual
Btw Tank & Pad
Concrete Pad
Soil
Total
Barrier
7.00E-06
6.00E-06
5.00E-06
4.00E-06
3.00E-06
2.00E-06
1.00E-06
0.00E+00
Risk
0
1500
3000
4500
6000
7500
9000
10500
12000
13500
15000
16500
18000
19500
21000
22500
24000
25500
27000
28500
30000
Time (yrs)
7/12/94 9:25 AM
[CASE11.XLW]SRCSUM11.XLS Chart 3

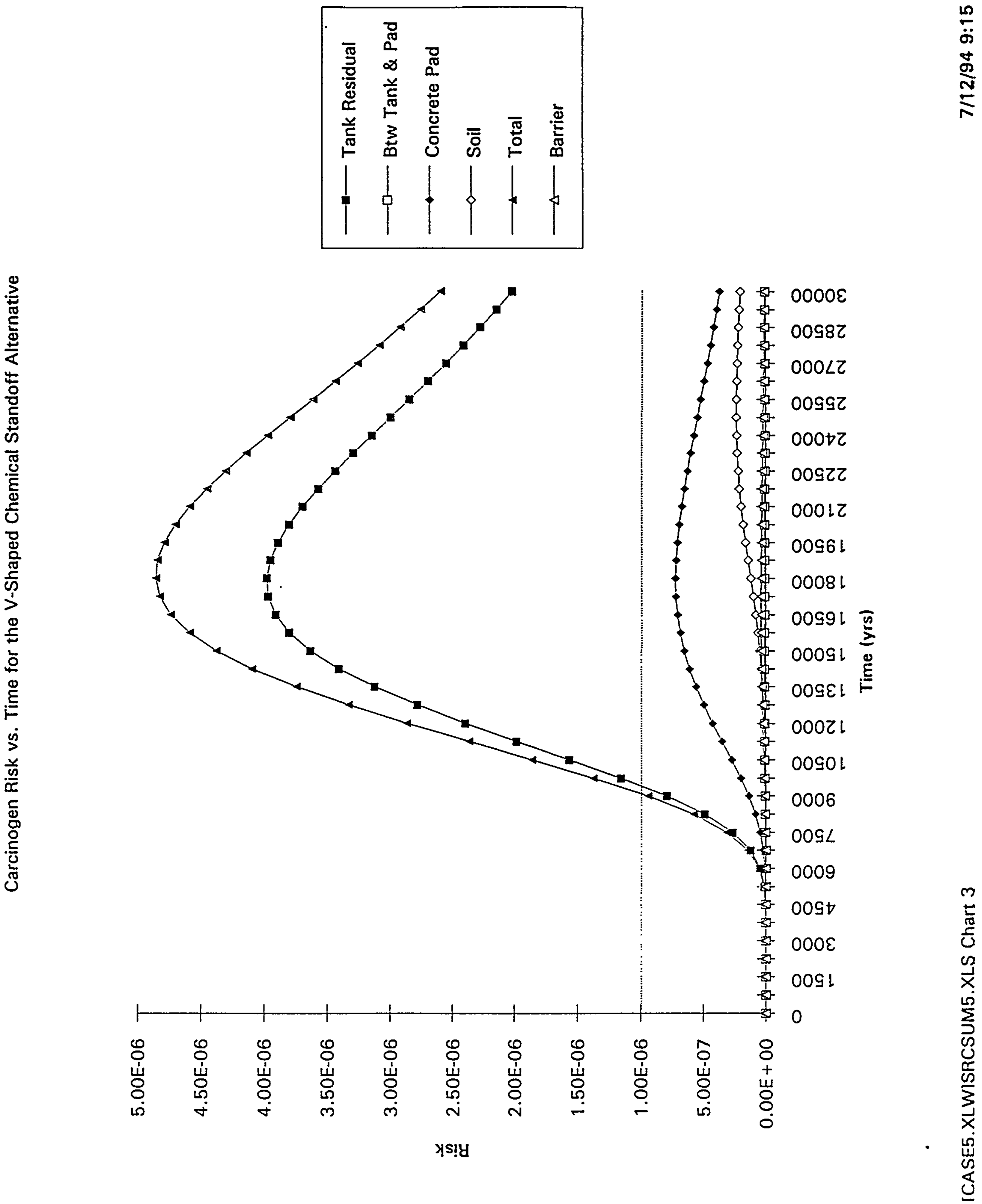
Carcinogen Risk vs. Time for the Modified Close-Coupled without Soil Flushing Alternative

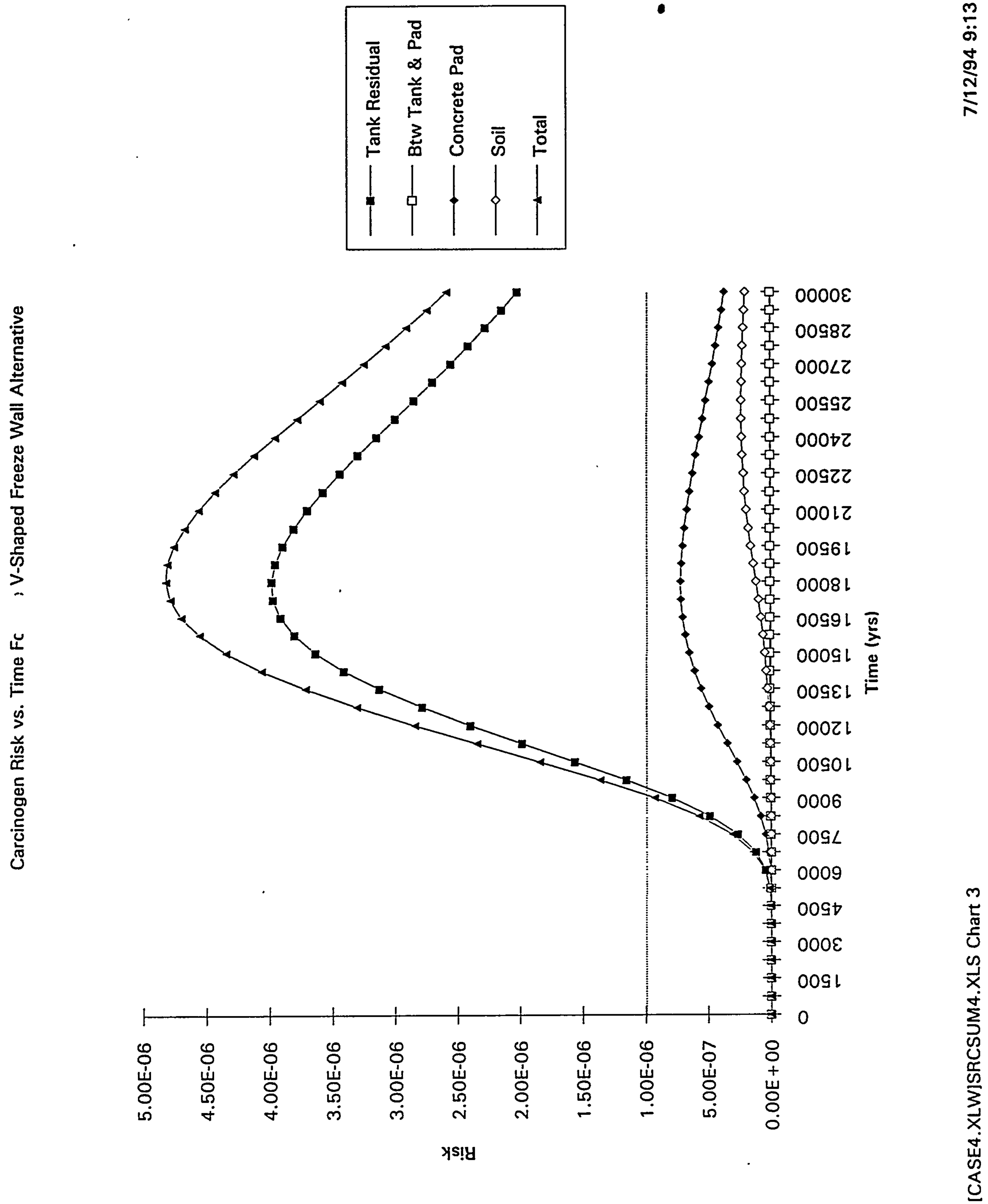


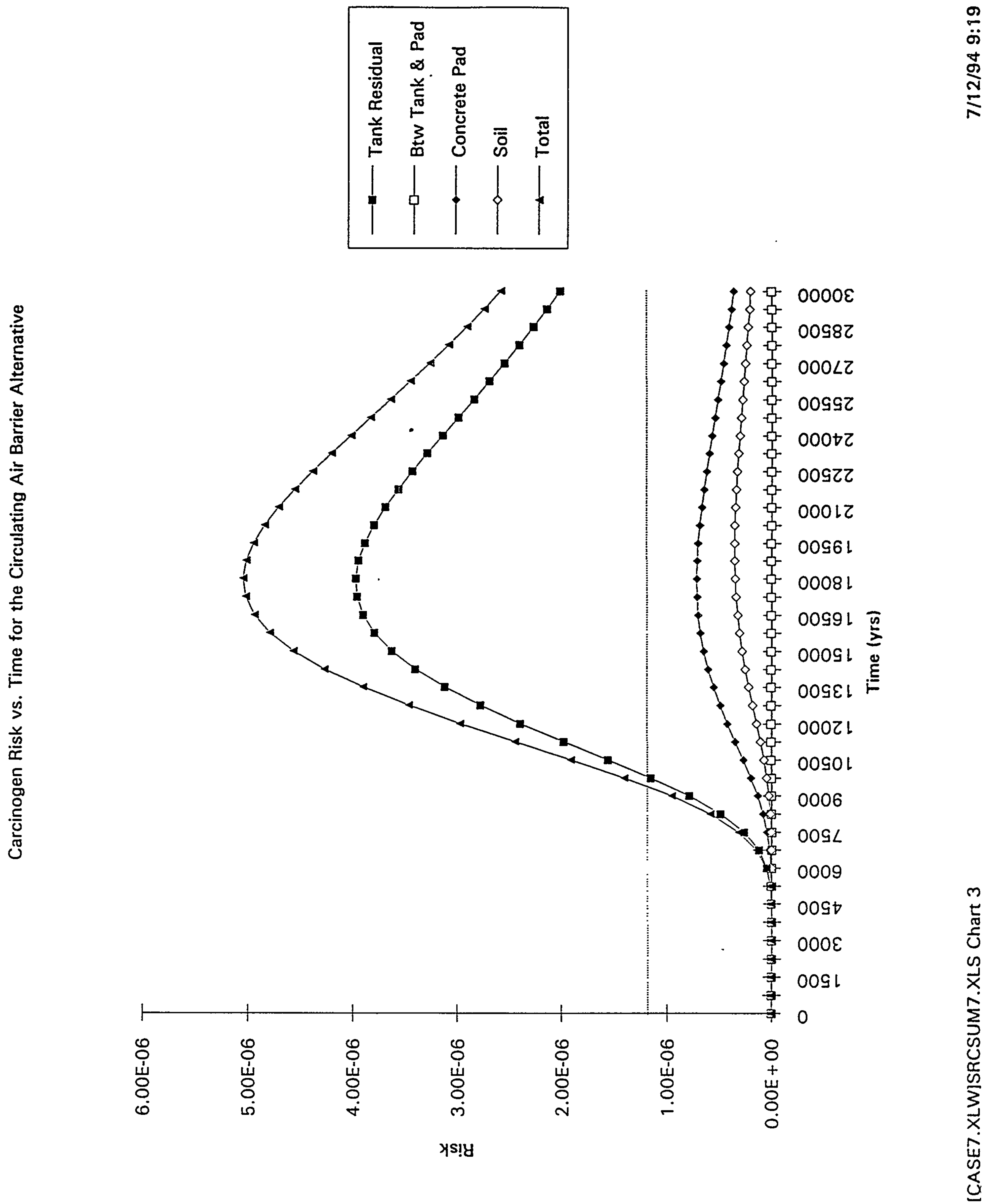
7/12/94 9:27 AM

[CASE12.XLW]SRCSUM12.XLS Chart 3

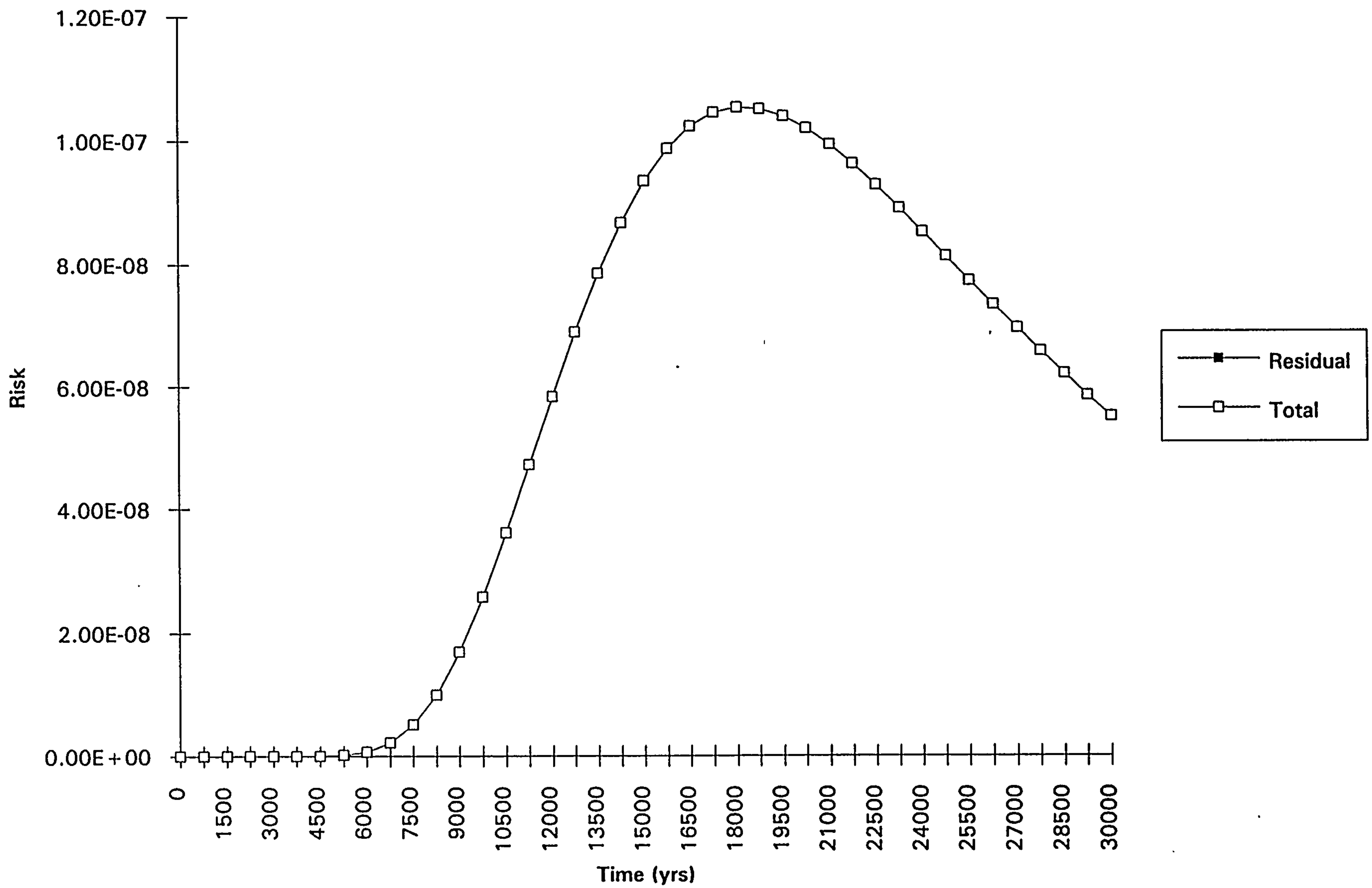

Carcinogen Risk vs. Time for the Shaped Chemical Standoff Alternative
Tank Residual
Btw Tank & Pad
Concrete Pad
Soil
Total
Barrier
Risk
5.00E-06
4.50E-06
4.00E-06
3.50E-06
3.00E-06
2.50E-06
2.00E-06
1.50E-06
1.00E-06
5.00E-07
0.00E+00
0
1500
3000
4500
6000
7500
9000
10500
12000
13500
15000
16500
18000
19500
21000
22500
24000
25500
27000
28500
30000
Time (yrs)
7/12/94 9:17 AM
[CASE6.XLW]SRCSUM6.XLS Chart 3


Carcinogen Risk vs. Time for the V-Shaped Chemical Standoff Alternative
Tank Residual
Btw Tank & Pad
Concrete Pad
Soil
Total
Barrier
Risk
5.00E-06
4.50E-06
4.00E-06
3.50E-06
3.00E-06
2.50E-06
2.00E-06
1.50E-06
1.00E-06
5.00E-07
0.00E+00
0
1500
3000
4500
6000
7500
9000
10500
12000
13500
15000
16500
18000
19500
21000
22500
24000
25500
27000
28500
30000
Time (yrs)
7/12/94 9:15 AM
ICASE5.XLWISRCSUM5.XLS Chart 3


Carcinogen Risk vs. Time Fc
V-Shaped Freeze Wall Alternative
Tank Residual
Btw Tank & Pad
Concrete Pad
Soil
Total
Risk
5.00E-06
4.50E-06
4.00E-06
3.50E-06
3.00E-06
2.50E-06
2.00E-06
1.50E-06
1.00E-06
5.00E-07
0.00E+00
0
1500
3000
4500
6000
7500
9000
10500
12000
13500
15000
16500
18000
19500
21000
22500
24000
25500
27000
28500
30000
Time (yrs)
7/12/94 9:13 AM
[CASE4.XLW]SRCSUM4.XLS Chart 3

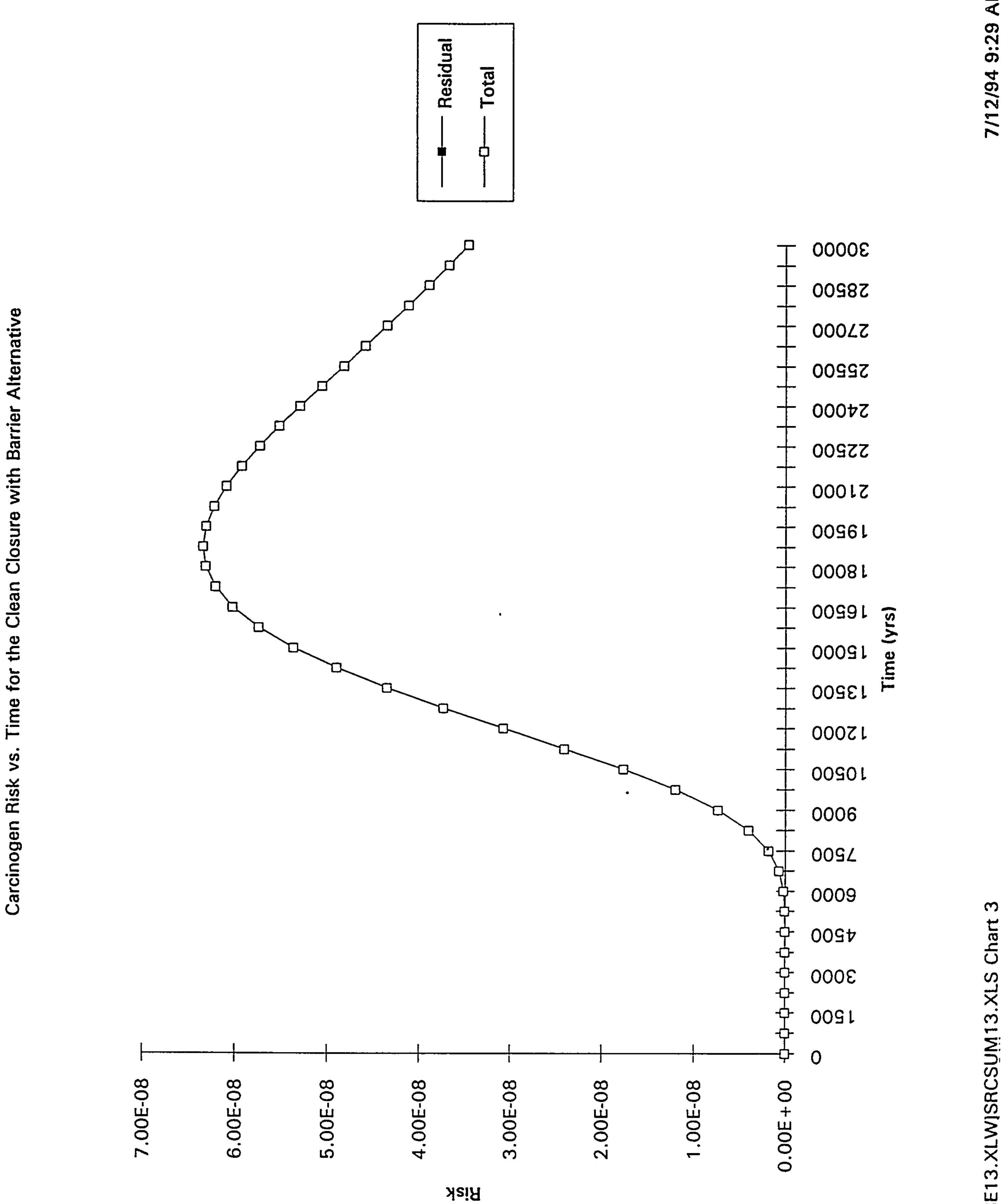

Carcinogen Risk vs. Time for the Circulating Air Barrier Alternative
Tank Residual
Btw Tank & Pad
Concrete Pad
Soil
Total
Risk
6.00E-06
5.00E-06
4.00E-06
3.00E-06
2.00E-06
1.00E-06
0.00E+00
0
1500
3000
4500
6000
7500
9000
10500
12000
13500
15000
16500
18000
19500
21000
22500
24000
25500
27000
28500
30000
Time (yrs)
7/12/94 9:19 AM
[CASE7.XLW]SRCSUM7.XLS Chart 3

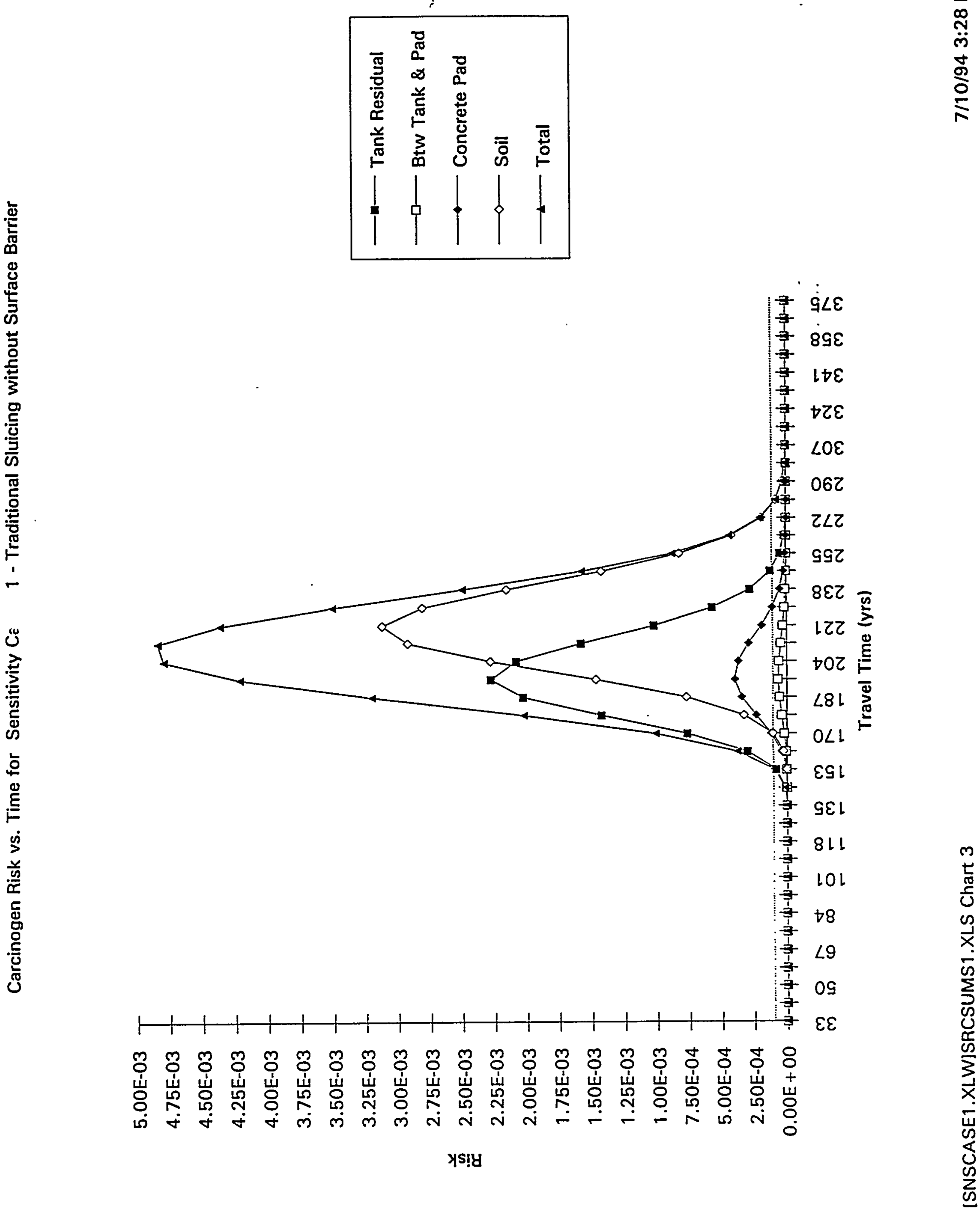
Carcinogen Risk vs. Time for the   an Closure without Barrier Alternative

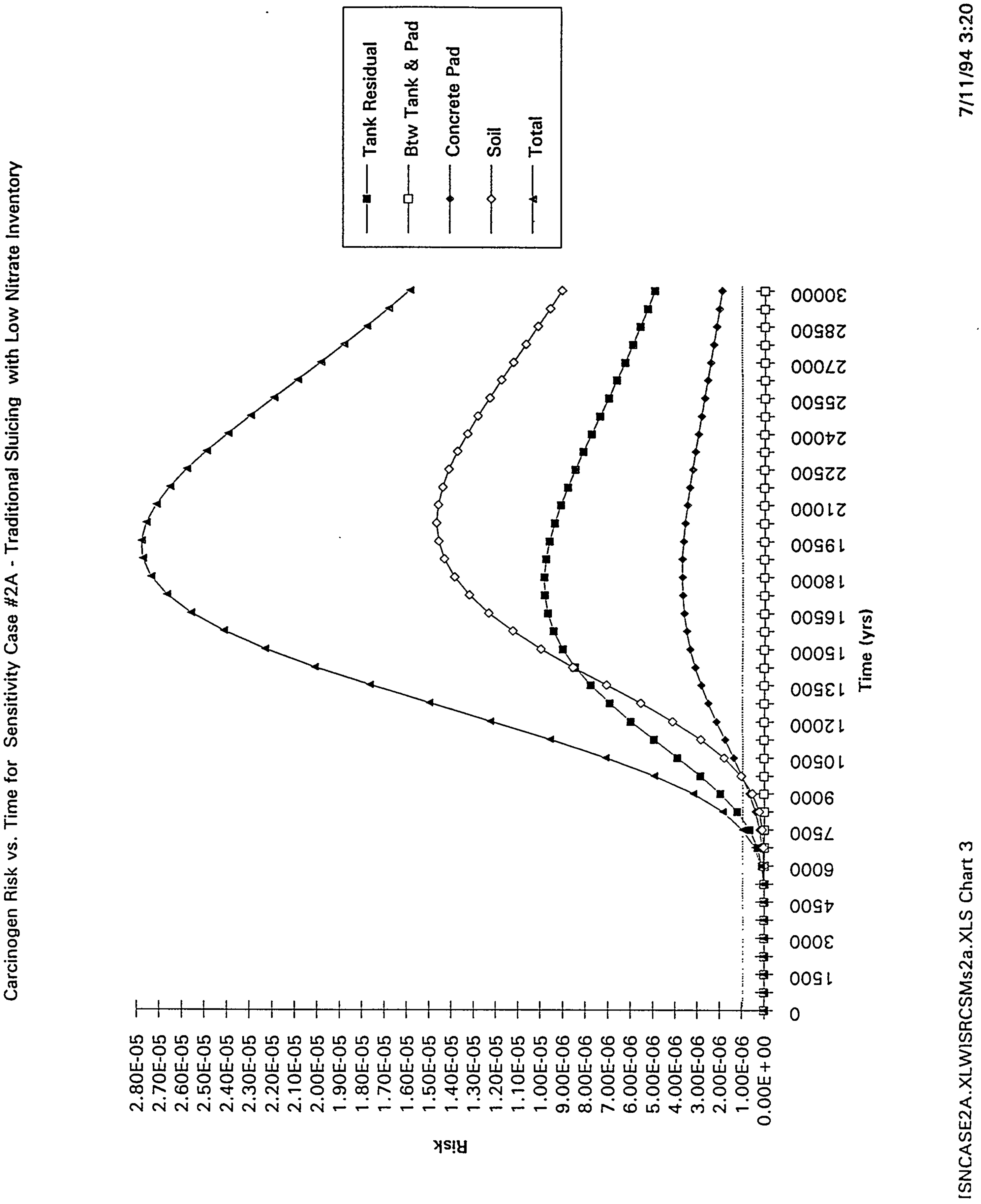


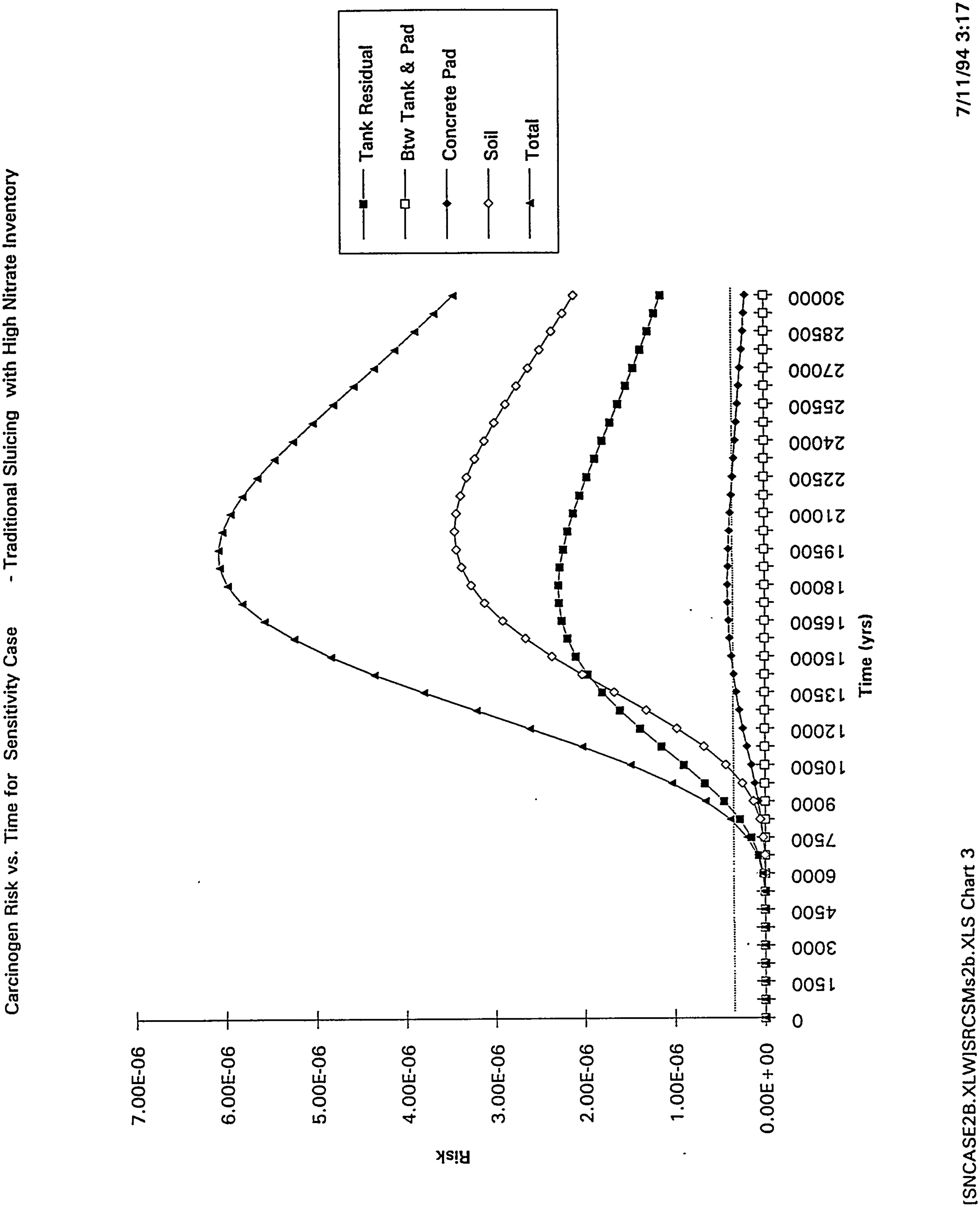
[CASE14.XLW]SRCSUM14.XLS Chart 3

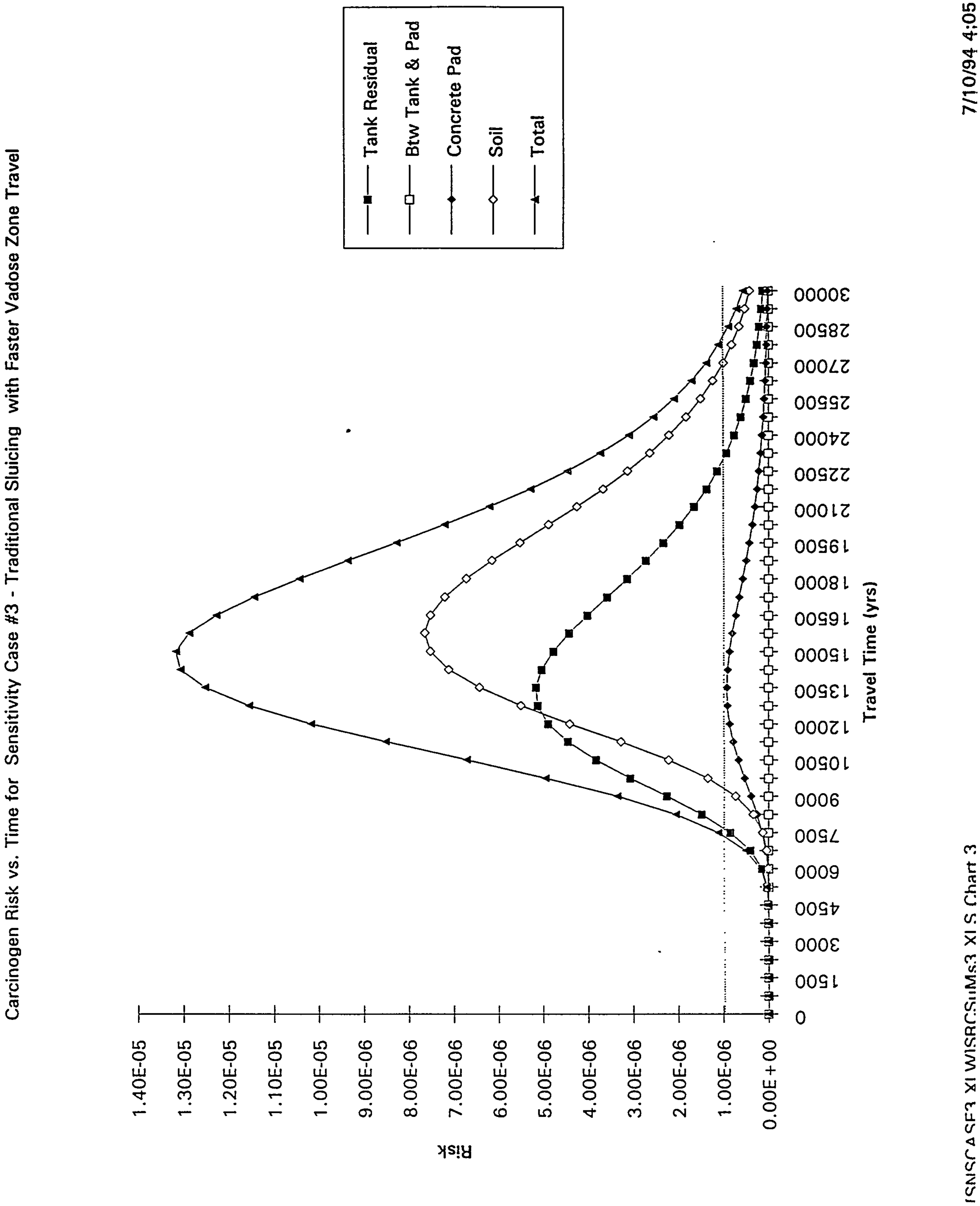
7/12/94 9:32 AM

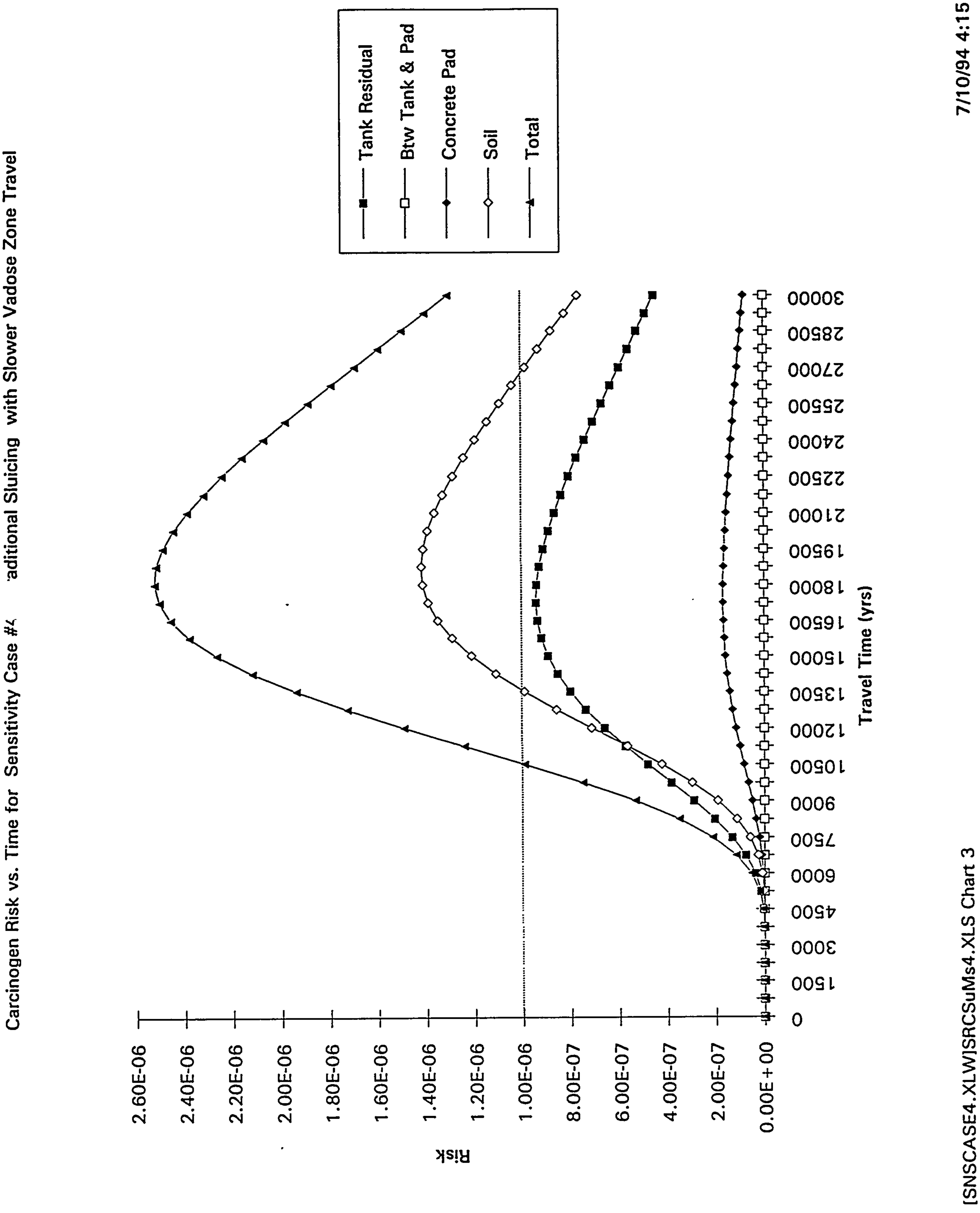

Carcinogen Risk vs. Time for the Clean Closure with Barrier Alternative
Residual
Total
Risk
7.00E-08
6.00E-08
5.00E-08
4.00E-08
3.00E-08
2.00E-08
1.00E-08
0.00E+00
0
1500
3000
4500
6000
7500
9000
10500
12000
13500
15000
16500
18000
19500
21000
22500
24000
25500
27000
28500
30000
Time (yrs)
7/12/94 9:29 AM
[CASE13.XLW]SRCSUM13.XLS Chart 3

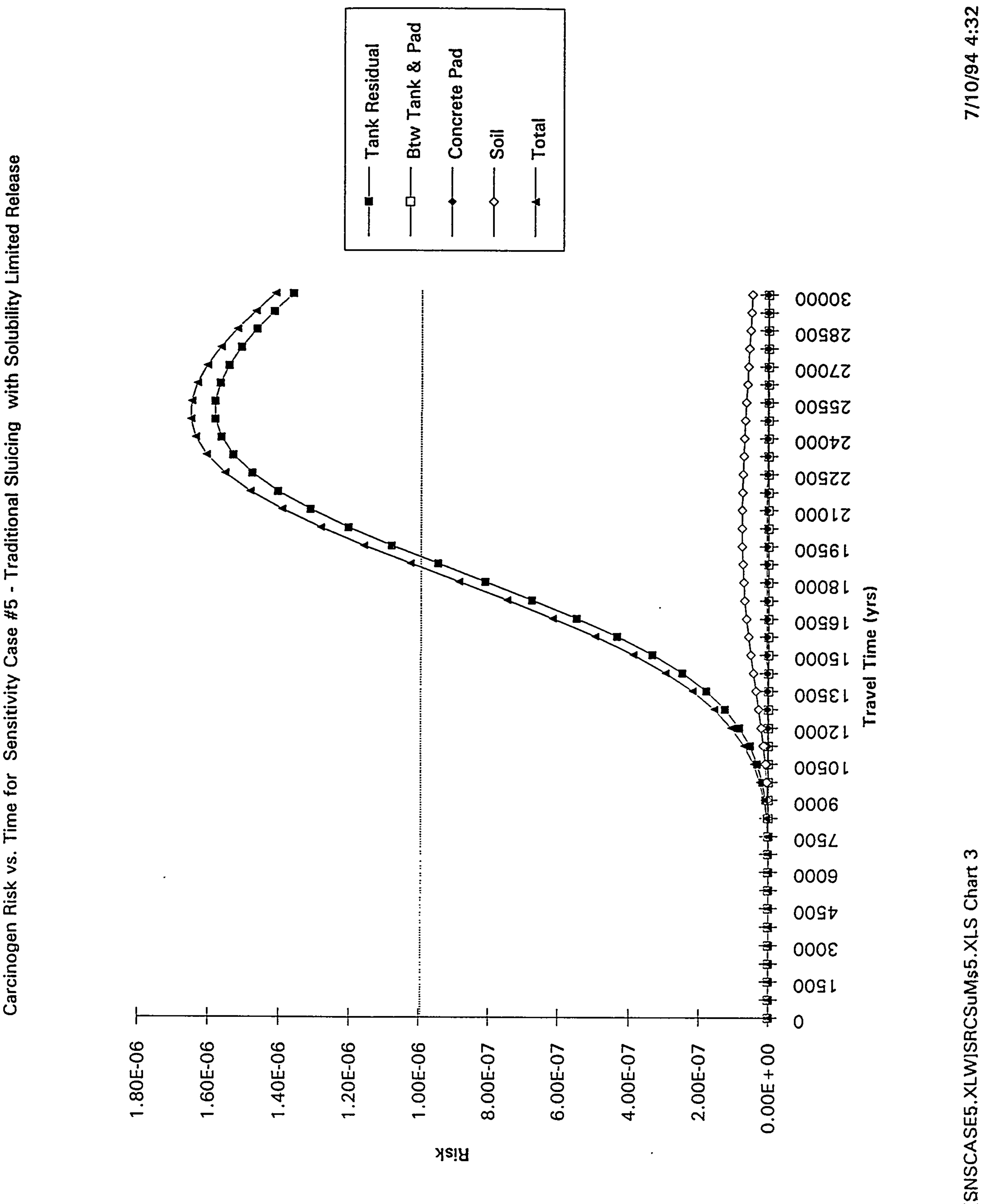

Carcinogen Risk vs. Time for Sensitivity Ca 1 - Traditional Sluicing without Surface Barrier
7/10/94 3:28 PM
Tank Residual
Btw Tank & Pad
Concrete Pad
Soil
Total
Risk
5.00E-03
4.75E-03
4.50E-03
4.25E-03
4.00E-03
3.75E-03
3.50E-03
3.25E-03
3.00E-03
2.75E-03
2.50E-03
2.25E-03
2.00E-03
1.75E-03
1.50E-03
1.25E-03
1.00E-03
7.50E-04
5.00E-04
2.50E-04
0.00E+00
33
50
67
84
101
118
135
153
170
187
204
221
238
255
272
290
307
324
341
358
375
Travel Time (yrs)
[SNSCASE1.XLW]SRCSUMS1.XLS Chart 3


Carcinogen Risk vs. Time for Sensitivity Case #2A - Traditional Sluicing with Low Nitrate Inventory
Tank Residual
Btw Tank & Pad
Concrete Pad
Soil
Total
Risk
2.80E-05
2.70E-05
2.60E-05
2.50E-05
2.40E-05
2.30E-05
2.20E-05
2.10E-05
2.00E-05
1.90E-05
1.80E-05
1.70E-05
1.60E-05
1.50E-05
1.40E-05
1.30E-05
1.20E-05
1.10E-05
1.00E-05
9.00E-06
8.00E-06
7.00E-06
6.00E-06
5.00E-06
4.00E-06
3.00E-06
2.00E-06
1.00E-06
0.00E+00
0
1500
3000
4500
6000
7500
9000
10500
12000
13500
15000
16500
18000
19500
21000
22500
24000
25500
27000
28500
30000
Time (yrs)
7/11/94 3:20 PM
ISNCASE2A.XLWISRCSMs2a.XLS Chart 3

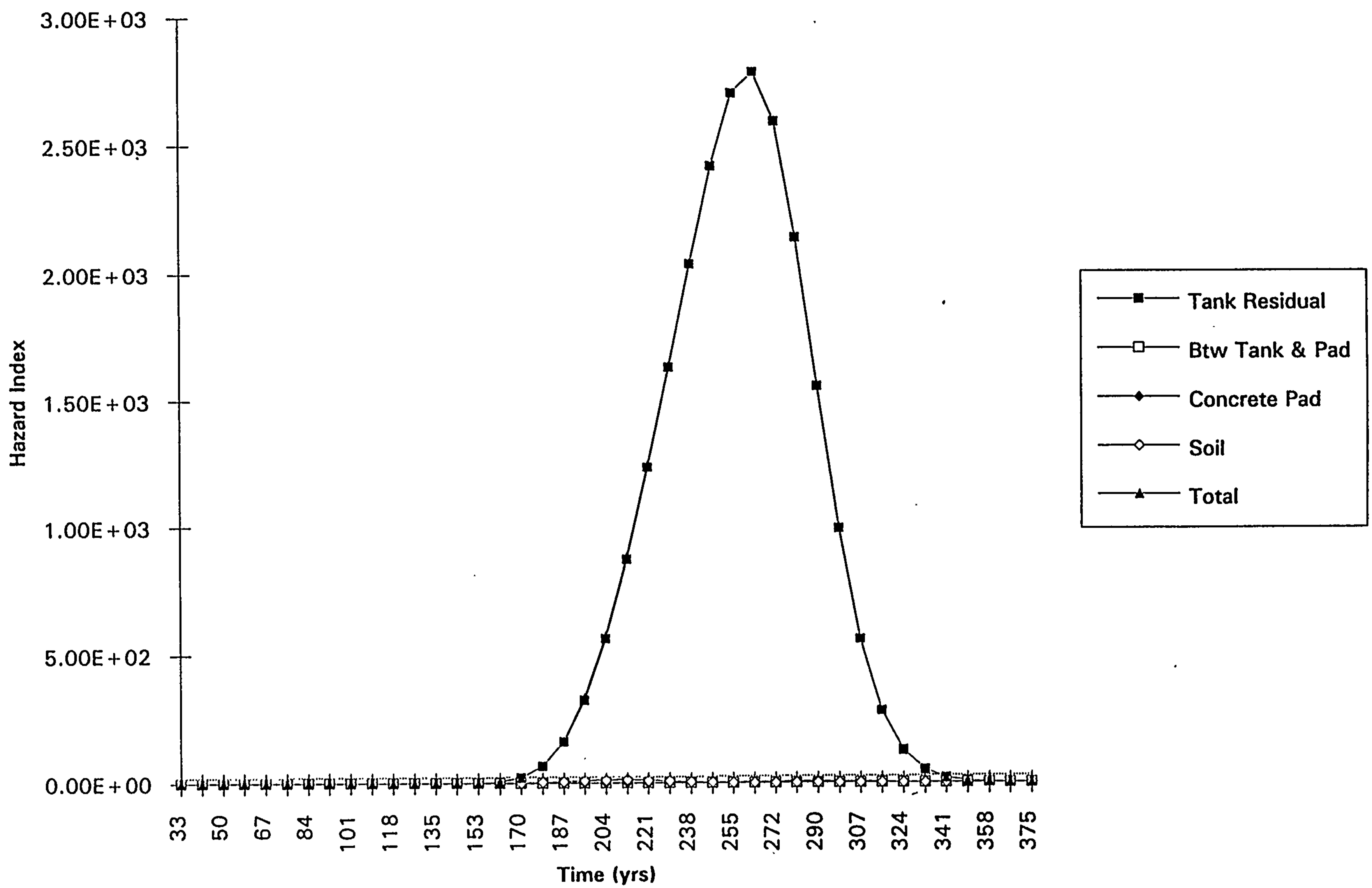

Carcinogen Risk vs. Time for Sensitivity Case - Traditional Sluicing with High Nitrate Inventory
7/11/94 3:17 PM
Tank Residual
Btw Tank & Pad
Concrete Pad
Soil
Total
Risk
7.00E-06
6.00E-06
5.00E-06
4.00E-06
3.00E-06
2.00E-06
1.00E-06
0.00E+00
0
1500
3000
4500
6000
7500
9000
10500
12000
13500
15000
16500
18000
19500
21000
22500
24000
25500
27000
28500
30000
Time (yrs)
[SNCASE2B.XLW]SRCSMs2b.XLS Chart 3


Carcinogen Risk vs. Time for Sensitivity Case #3 - Traditional Sluicing with Faster Vadose Zone Travel
Tank Residual
Btw Tank & Pad
Concrete Pad
Soil
Total
Risk
1.40E-05
1.30E-05
1.20E-05
1.10E-05
1.00E-05
9.00E-06
8.00E-06
7.00E-06
6.00E-06
5.00E-06
4.00E-06
3.00E-06
2.00E-06
1.00E-06
0.00E+00
0
1500
3000
4500
6000
7500
9000
10500
12000
13500
15000
16500
18000
19500
21000
22500
24000
25500
27000
28500
30000
Travel Time (yrs)
7/10/94 4:05 PM


Carcinogen Risk vs. Time for Sensitivity Case #4 raditional Sluicing with Slower Vadose Zone Travel
7/10/94 4:15 PM
Tank Residual
Btw Tank & Pad
Concrete Pad
Soil
Total
Risk
2.60E-06
2.40E-06
2.20E-06
2.00E-06
1.80E-06
1.60E-06
1.40E-06
1.20E-06
1.00E-06
8.00E-07
6.00E-07
4.00E-07
2.00E-07
0.00E+00
0
1500
3000
4500
6000
7500
9000
10500
12000
13500
15000
16500
18000
19500
21000
22500
24000
25500
27000
28500
30000
Travel Time (yrs)
[SNSCASE4.XLW]SRCSuMs4.XLS Chart 3

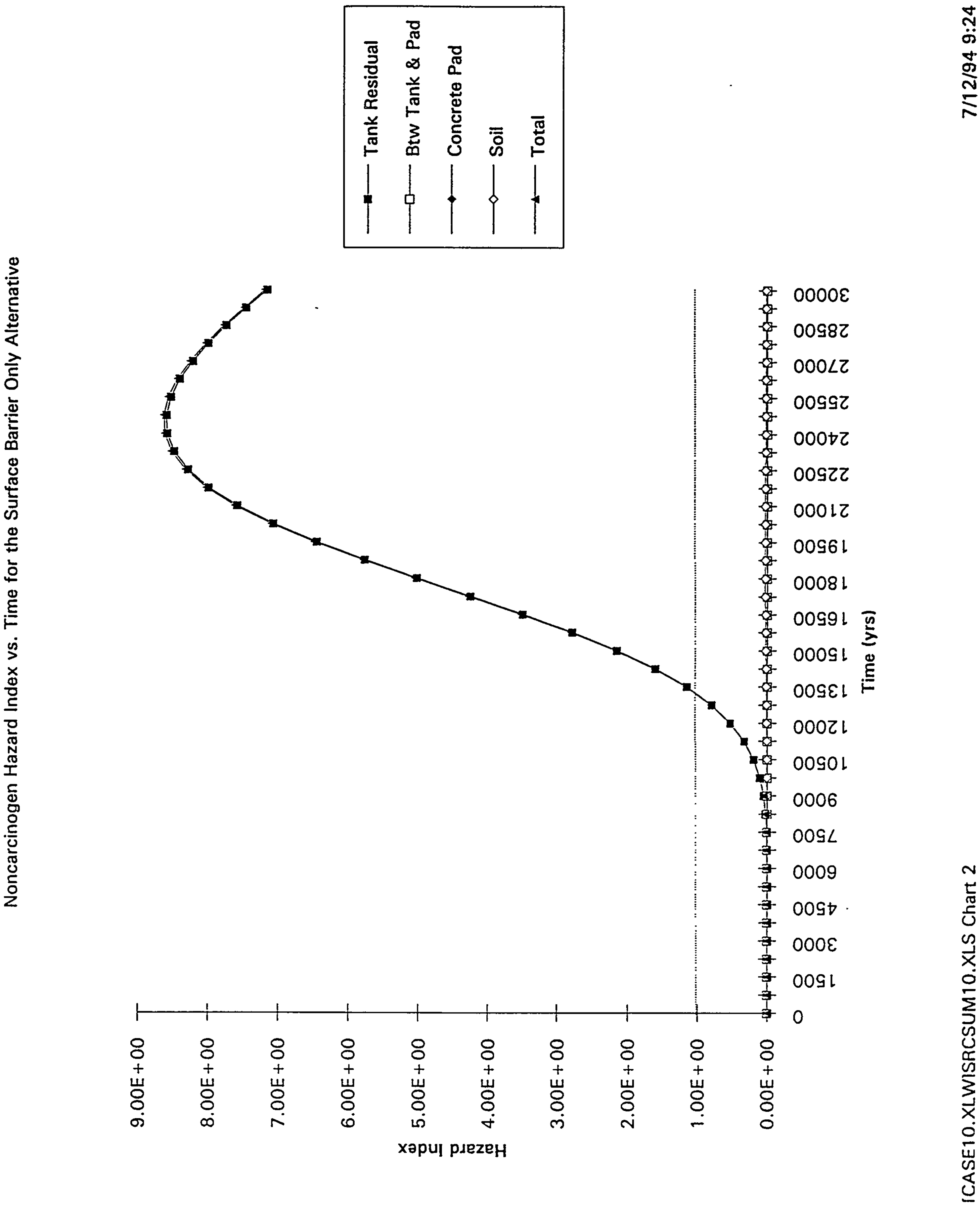

Carcinogen Risk vs. Time for Sensitivity Case #5 - Traditional Sluicing with Solubility Limited Release
Tank Residual
Btw Tank & Pad
Concrete Pad
Soil
Total
Risk
1.80E-06
1.60E-06
1.40E-06
1.20E-06
1.00E-06
8.00E-07
6.00E-07
4.00E-07
2.00E-07
0.00E+00
0
1500
3000
4500
6000
7500
9000
10500
12000
13500
15000
16500
18000
19500
21000
22500
24000
25500
27000
28500
30000
Travel Time (yrs)
[SNSCASE5.XLW]SRCSuMs5.XLS Chart 3
7/10/94 4:32 PM

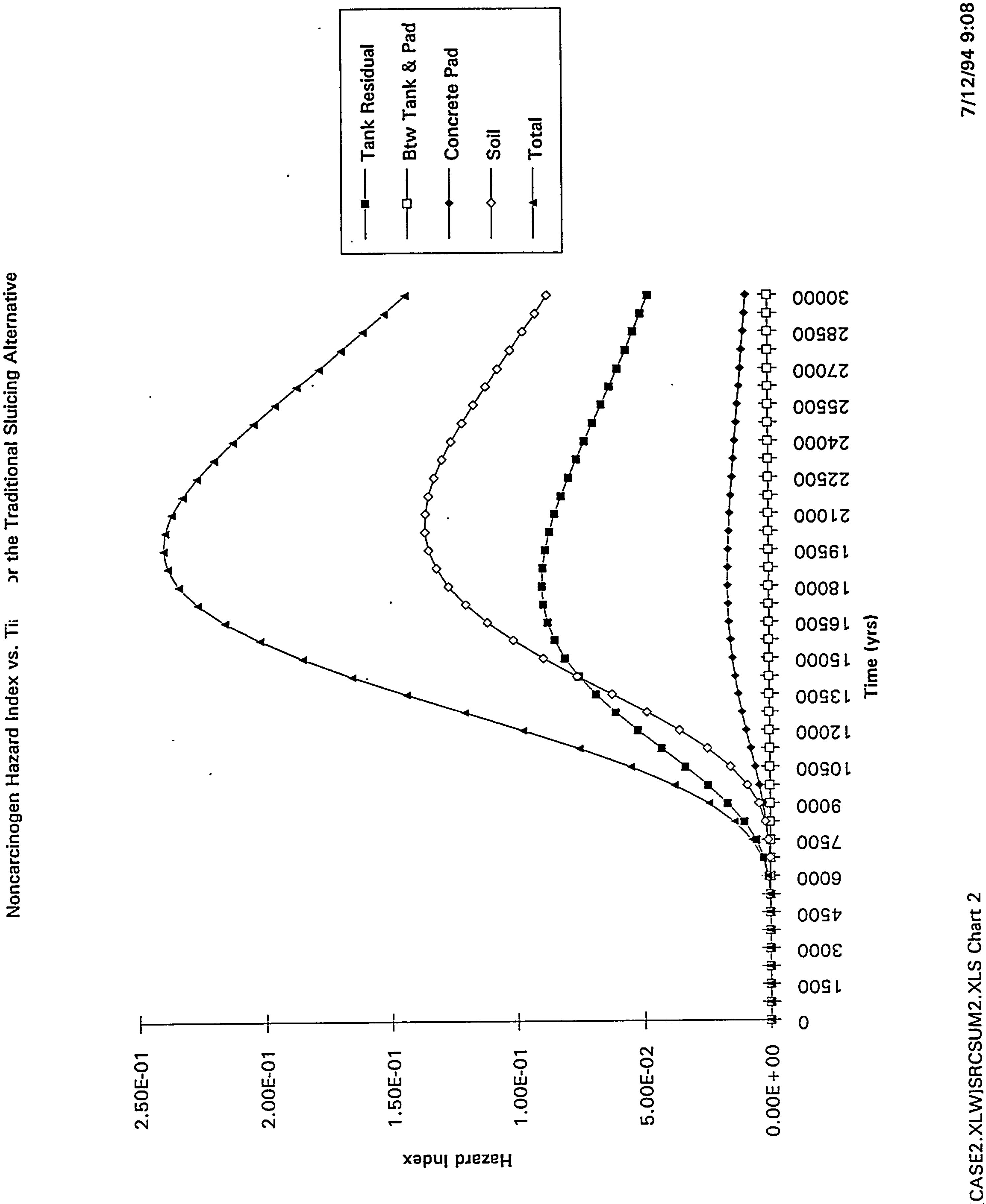
Noncarcinogen Hazard Index \ ime for the No Action Alternative

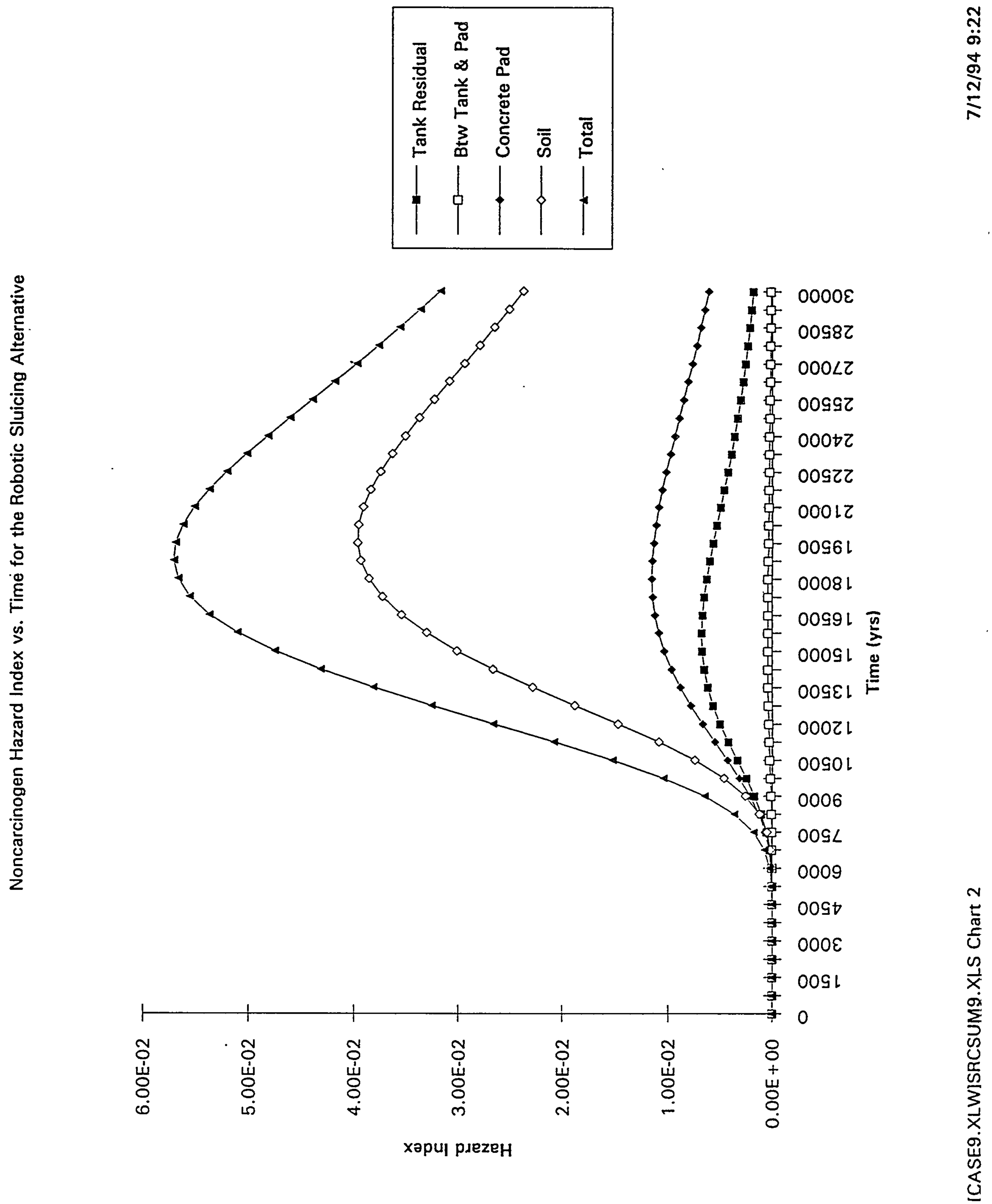


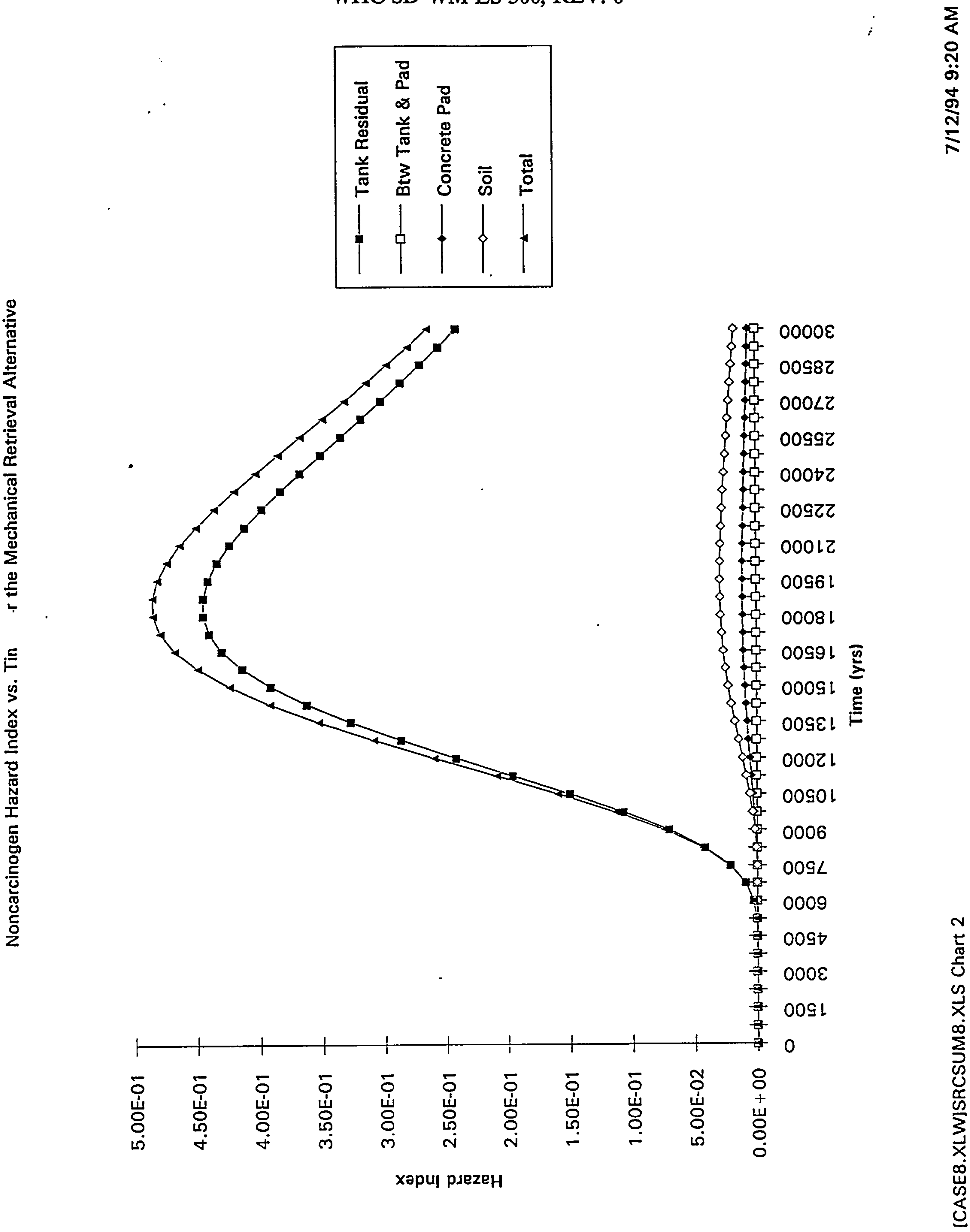
[CASE1.XLW]SRCSUM1.XLS Chart 2

7/12/94 8:46 AM

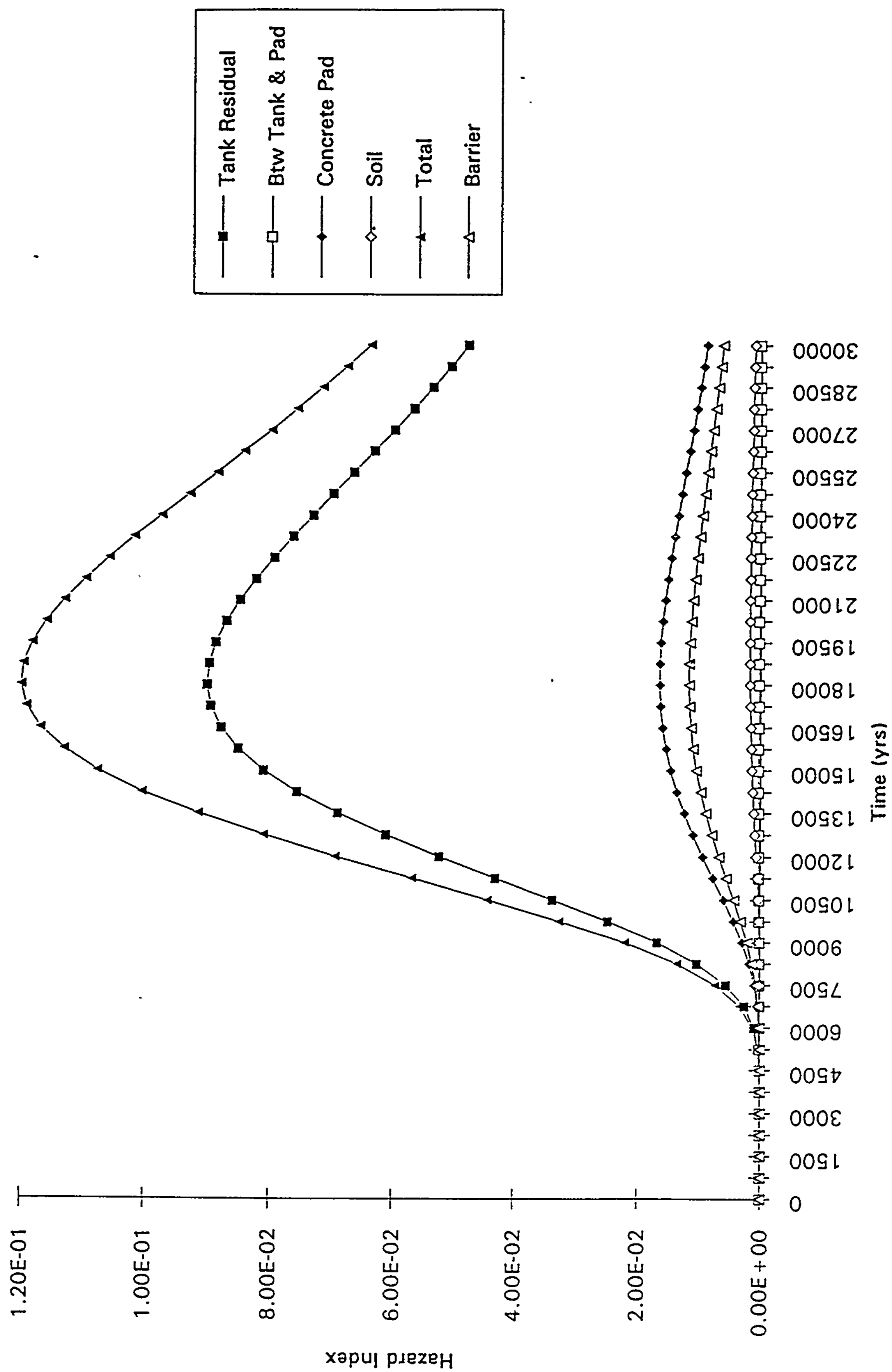

Noncarcinogen Hazard Index vs. Time for the Surface Barrier Only Alternative
Hazard Index
9.00E+00
8.00E+00
7.00E+00
6.00E+00
5.00E+00
4.00E+00
3.00E+00
2.00E+00
1.00E+00
0.00E+00
0
1500
3000
4500
6000
7500
9000
10500
12000
13500
15000
16500
18000
19500
21000
22500
24000
25500
27000
28500
30000
Time (yrs)
Tank Residual
Btw Tank & Pad
Concrete Pad
Soil
Total
7/12/94 9:24 AM
ICASE10.XLWISRCSUM10.XLS Chart 2


Noncarcinogen Hazard Index vs. Ti ɔr the Traditional Sluicing Alternative
Tank Residual
Btw Tank & Pad
Concrete Pad
Soil
Total
Hazard Index
2.50E-01
2.00E-01
1.50E-01
1.00E-01
5.00E-02
0.00E+00
0
1500
3000
4500
6000
7500
9000
10500
12000
13500
15000
16500
18000
19500
21000
22500
24000
25500
27000
28500
30000
Time (yrs)
7/12/94 9:08 AM
[CASE2.XLW]SRCSUM2.XLS Chart 2


Noncarcinogen Hazard Index vs. Time for the Robotic Sluicing Alternative
Tank Residual
Btw Tank & Pad
Concrete Pad
Soil
Total
Hazard Index
6.00E-02
5.00E-02
4.00E-02
3.00E-02
2.00E-02
1.00E-02
0.00E+00
0
1500
3000
4500
6000
7500
9000
10500
12000
13500
15000
16500
18000
19500
21000
22500
24000
25500
27000
28500
30000
Time (yrs)
ICASE9.XLWISRCSUM9.XLS Chart 2
7/12/94 9:22 AM


Noncarcinogen Hazard Index vs. Tin r the Mechanical Retrieval Alternative
Tank Residual
Btw Tank & Pad
Concrete Pad
Soil
Total
Hazard Index
5.00E-01
4.50E-01
4.00E-01
3.50E-01
3.00E-01
2.50E-01
2.00E-01
1.50E-01
1.00E-01
5.00E-02
0.00E+00
0
1500
3000
4500
6000
7500
9000
10500
12000
13500
15000
16500
18000
19500
21000
22500
24000
25500
27000
28500
30000
Time (yrs)
7/12/94 9:20 AM
[CASE8.XLW]SRCSUM8.XLS Chart 2

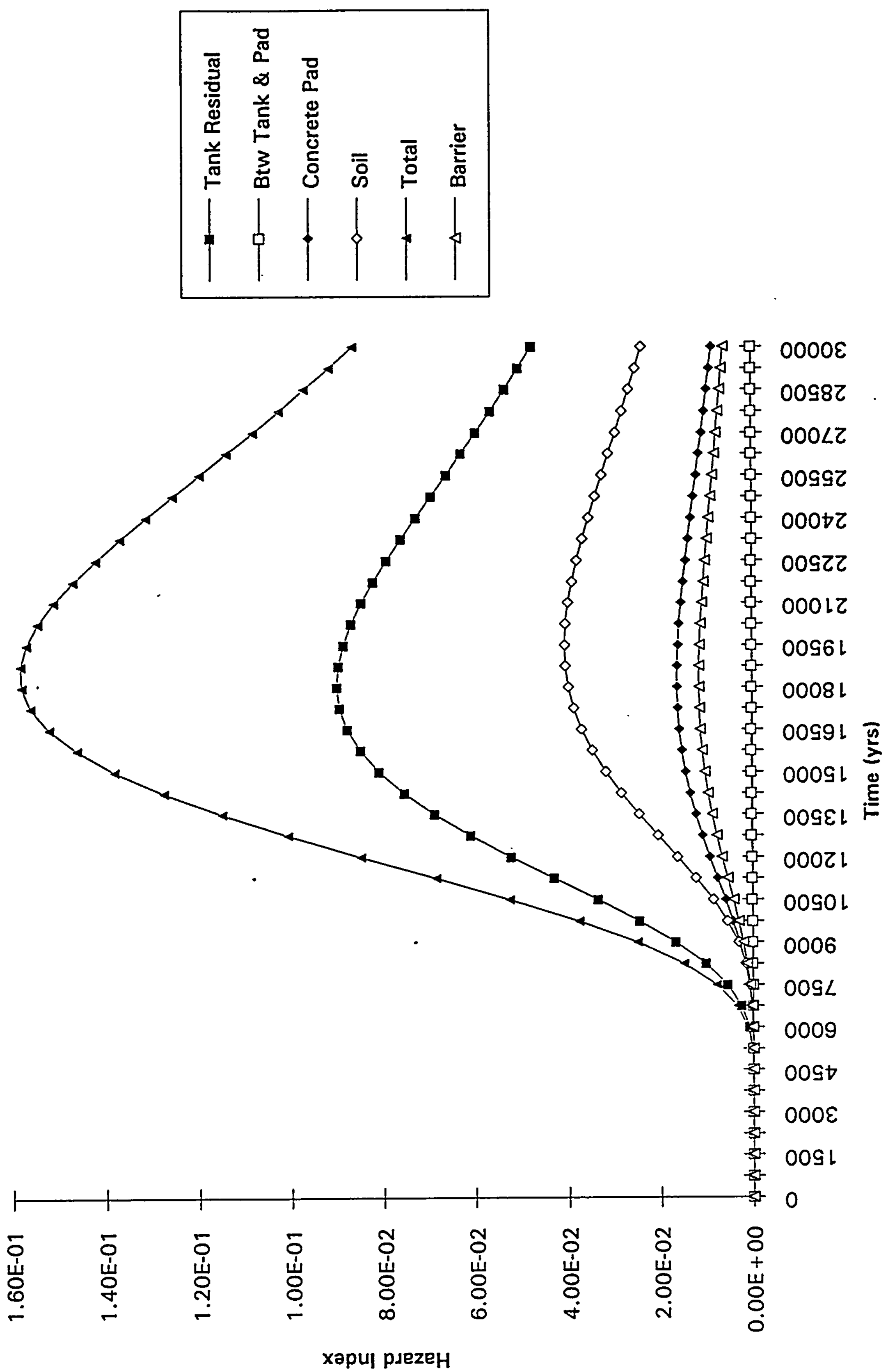
Noncarcinogen Hazard Index vs. Time for the Close-Coupled with Flushing Alternative



ICASE3.XLWISRCSUM3.XLS Chart 2

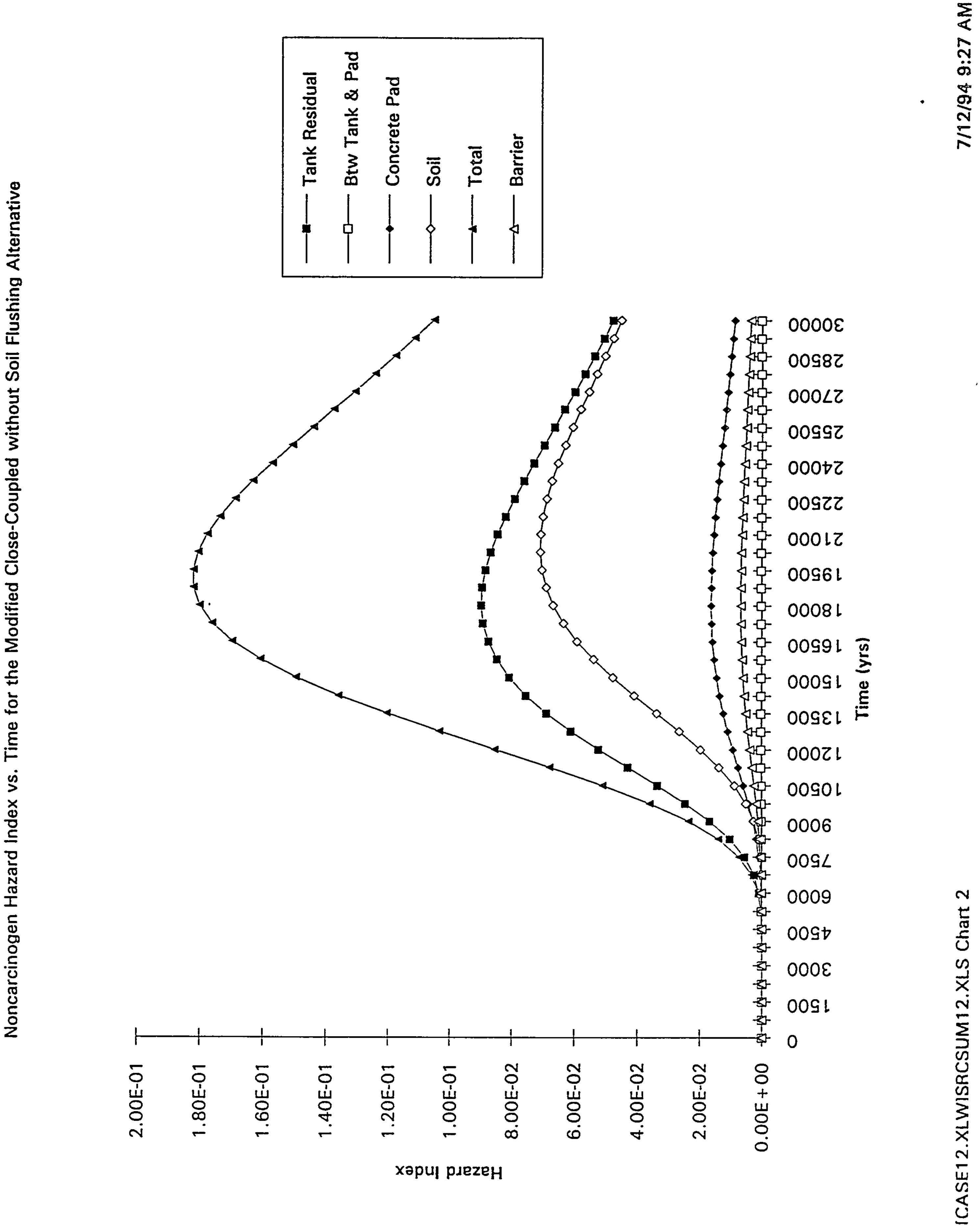
8/31/94 3:36 PM

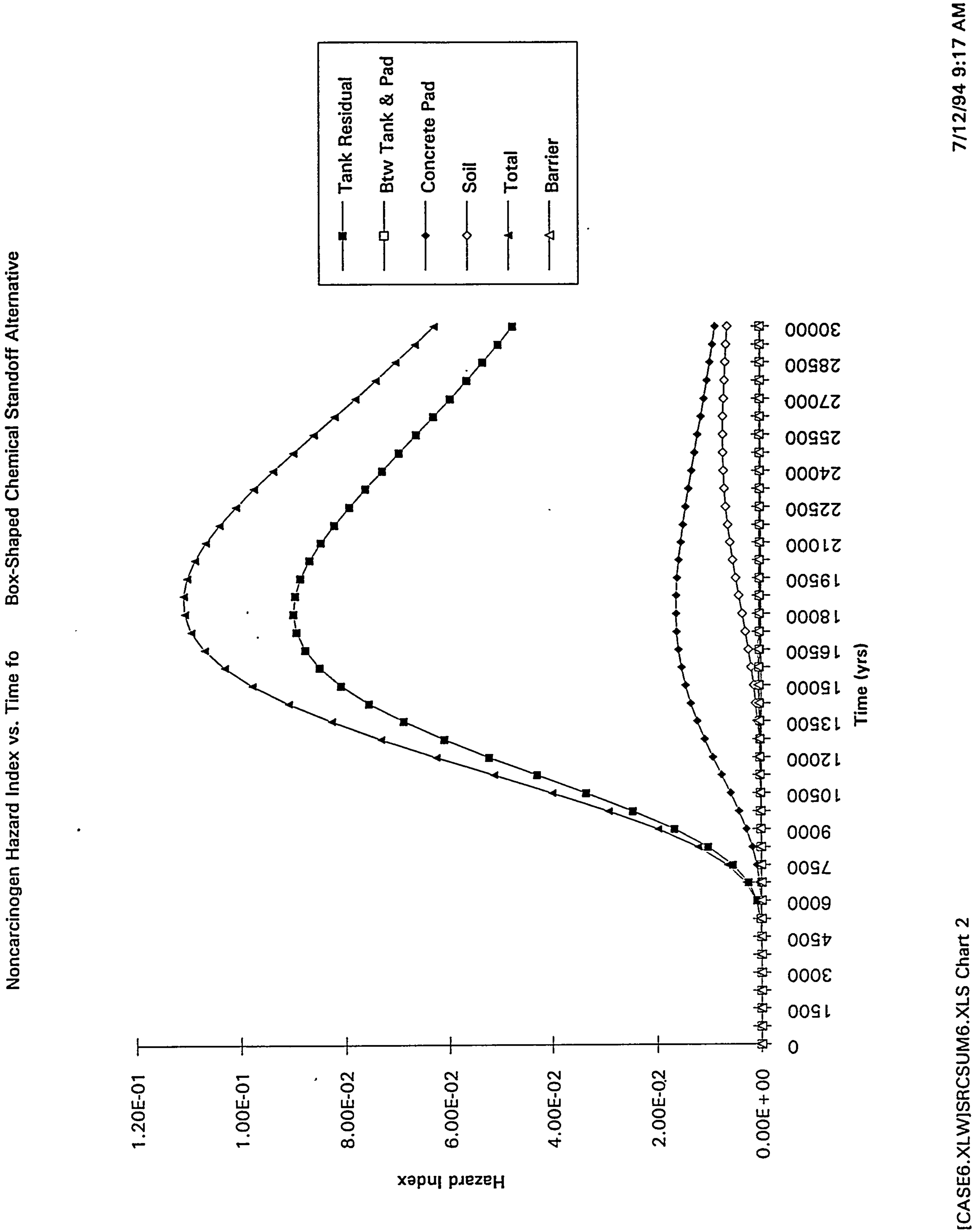
Noncarcinogen Hazard Index vs. Time for th se-Coupled without Soil Flushing Alternative

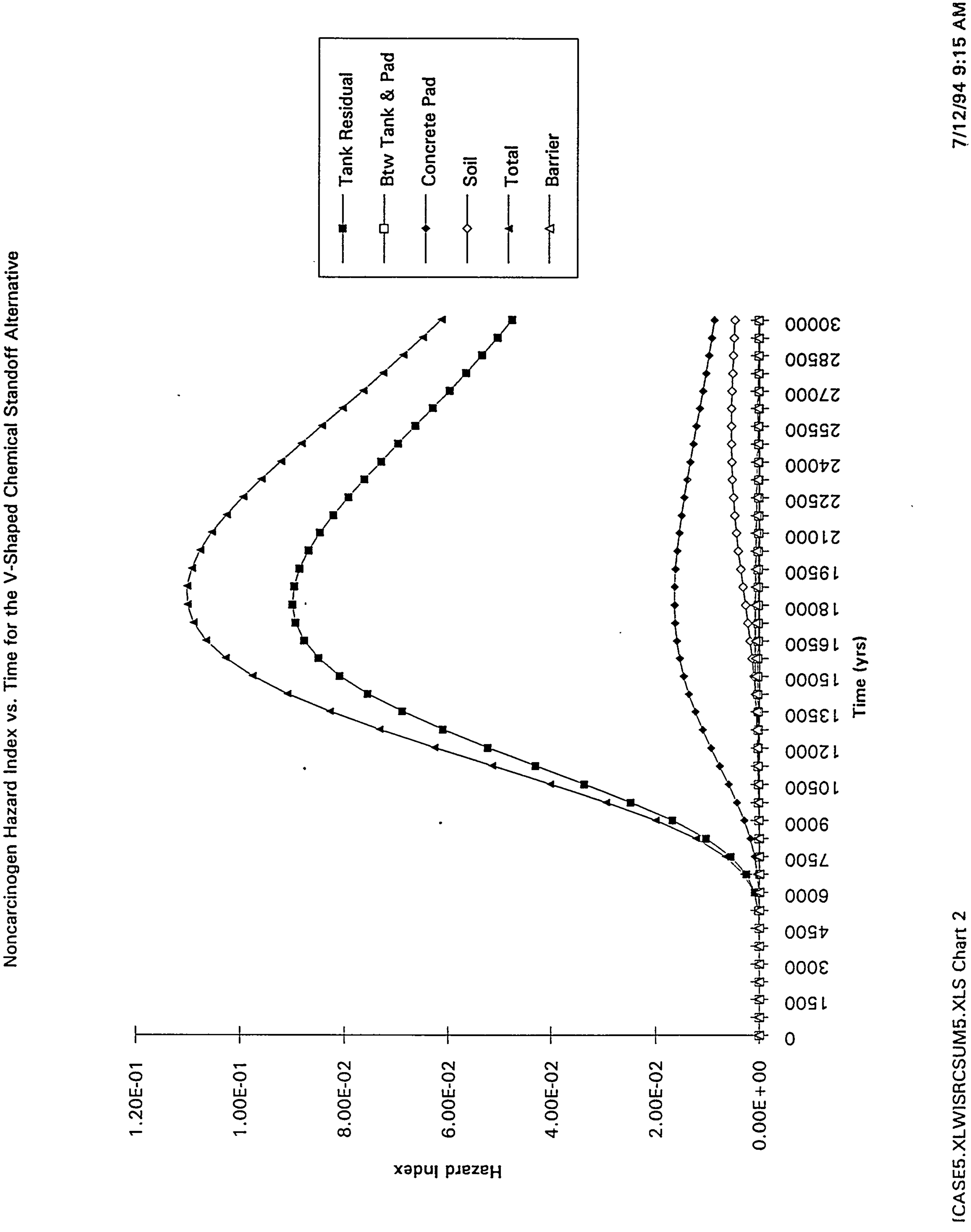


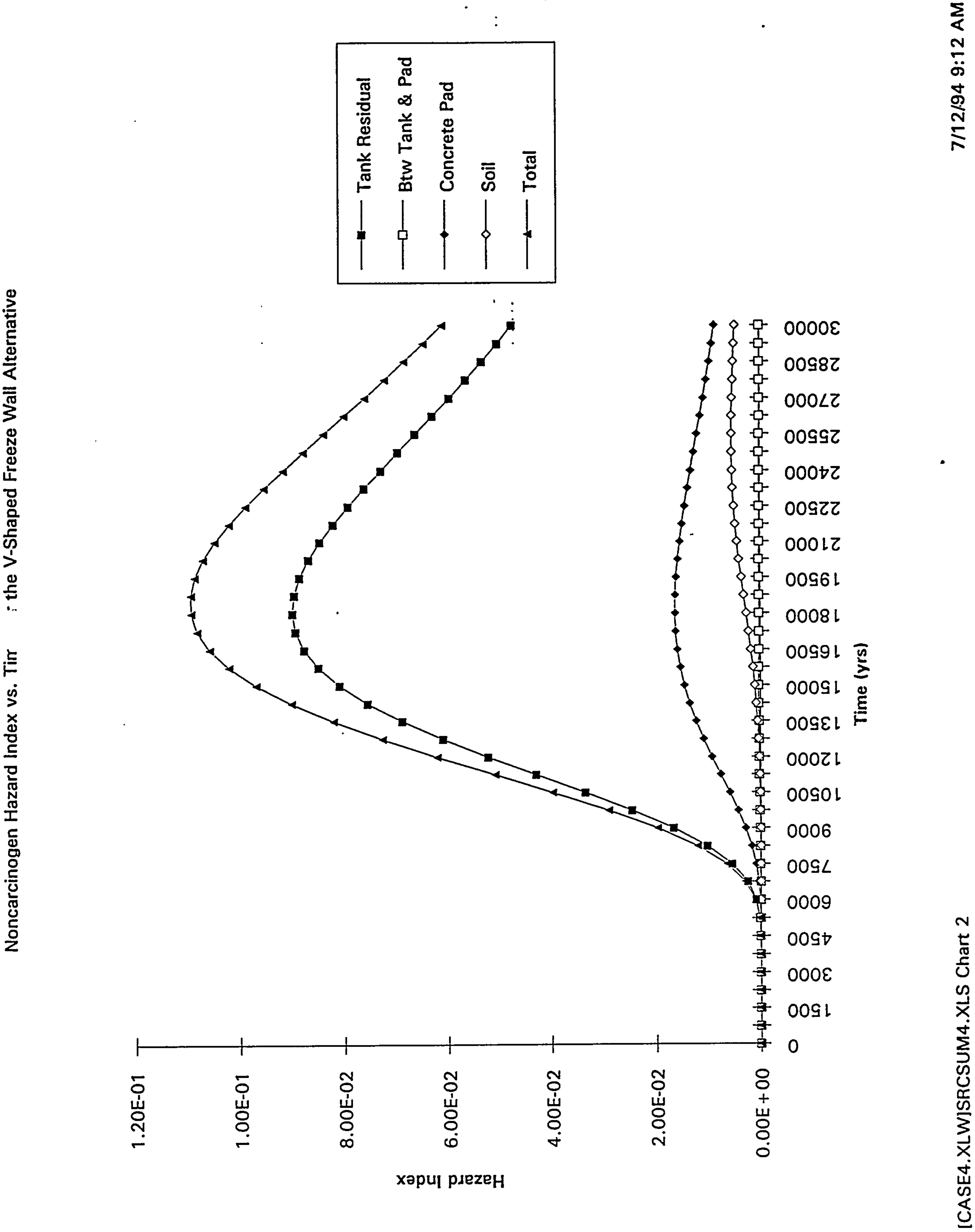
7/12/94 9:25 AM

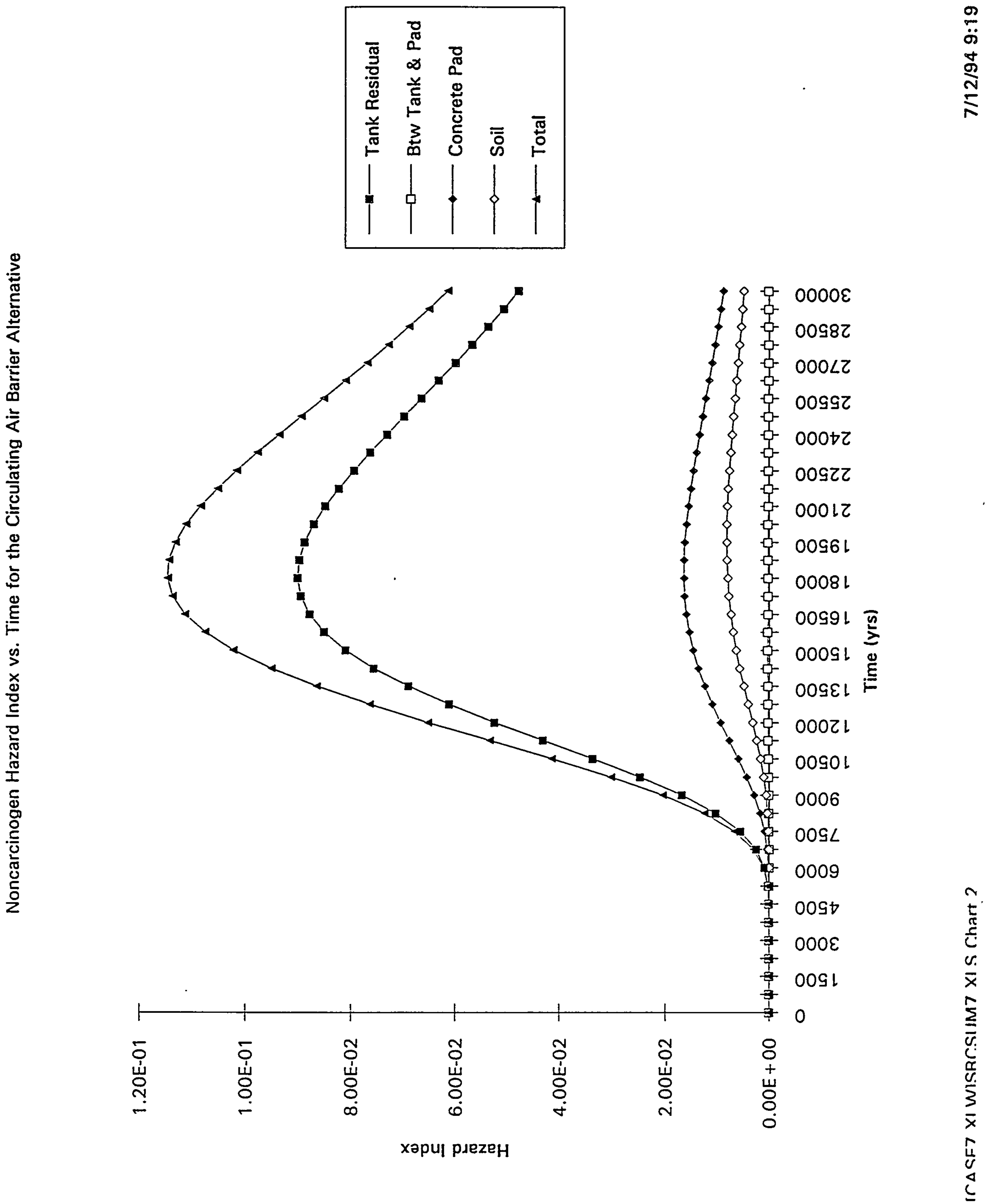
[CASE11.XLW]SRCSUM11.XLS Chart 2


Noncarcinogen Hazard Index vs. Time for the Modified Close-Coupled without Soil Flushing Alternative
Tank Residual
Btw Tank & Pad
Concrete Pad
Soil
Total
Barrier
Hazard Index
2.00E-01
1.80E-01
1.60E-01
1.40E-01
1.20E-01
1.00E-01
8.00E-02
6.00E-02
4.00E-02
2.00E-02
0.00E+00
0
1500
3000
4500
6000
7500
9000
10500
12000
13500
15000
16500
18000
19500
21000
22500
24000
25500
27000
28500
30000
Time (yrs)
7/12/94 9:27 AM
ICASE12.XLWISRCSUM12.XLS Chart 2


Noncarcinogen Hazard Index vs. Time fo Box-Shaped Chemical Standoff Alternative
7/12/94 9:17 AM
Tank Residual
Btw Tank & Pad
Concrete Pad
Soil
Total
Barrier
Hazard Index
1.20E-01
1.00E-01
8.00E-02
6.00E-02
4.00E-02
2.00E-02
0.00E+00
0
1500
3000
4500
6000
7500
9000
10500
12000
13500
15000
16500
18000
19500
21000
22500
24000
25500
27000
28500
30000
Time (yrs)
[CASE6.XLW]SRCSUM6.XLS Chart 2


Noncarcinogen Hazard Index vs. Time for the V-Shaped Chemical Standoff Alternative
Tank Residual
Btw Tank & Pad
Concrete Pad
Soil
Total
Barrier
Hazard Index
1.20E-01
1.00E-01
8.00E-02
6.00E-02
4.00E-02
2.00E-02
0.00E+00
0
1500
3000
4500
6000
7500
9000
10500
12000
13500
15000
16500
18000
19500
21000
22500
24000
25500
27000
28500
30000
Time (yrs)
7/12/94 9:15 AM
ICASE5.XLWISRCSUM5.XLS Chart 2


Noncarcinogen Hazard Index vs. Tir : the V-Shaped Freeze Wall Alternative
Tank Residual
Btw Tank & Pad
Concrete Pad
Soil
Total
Hazard Index
1.20E-01
1.00E-01
8.00E-02
6.00E-02
4.00E-02
2.00E-02
0.00E+00
0
1500
3000
4500
6000
7500
9000
10500
12000
13500
15000
16500
18000
19500
21000
22500
24000
25500
27000
28500
30000
Time (yrs)
7/12/94 9:12 AM
[CASE4.XLW]SRCSUM4.XLS Chart 2


Noncarcinogen Hazard Index vs. Time for the Circulating Air Barrier Alternative
Tank Residual
Btw Tank & Pad
Concrete Pad
Soil
Total
Hazard Index
1.20E-01
1.00E-01
8.00E-02
6.00E-02
4.00E-02
2.00E-02
0.00E+00
0
1500
3000
4500
6000
7500
9000
10500
12000
13500
15000
16500
18000
19500
21000
22500
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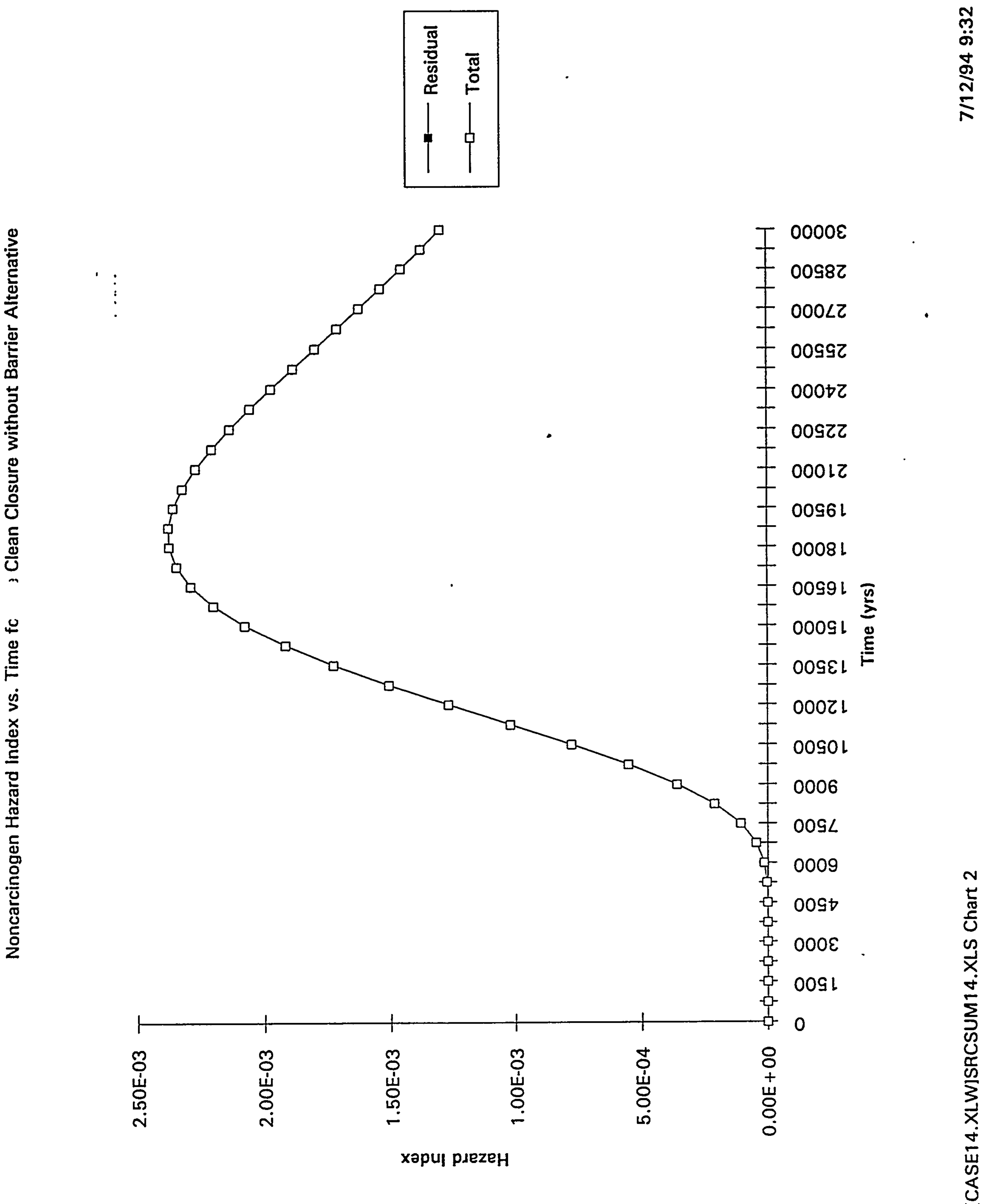
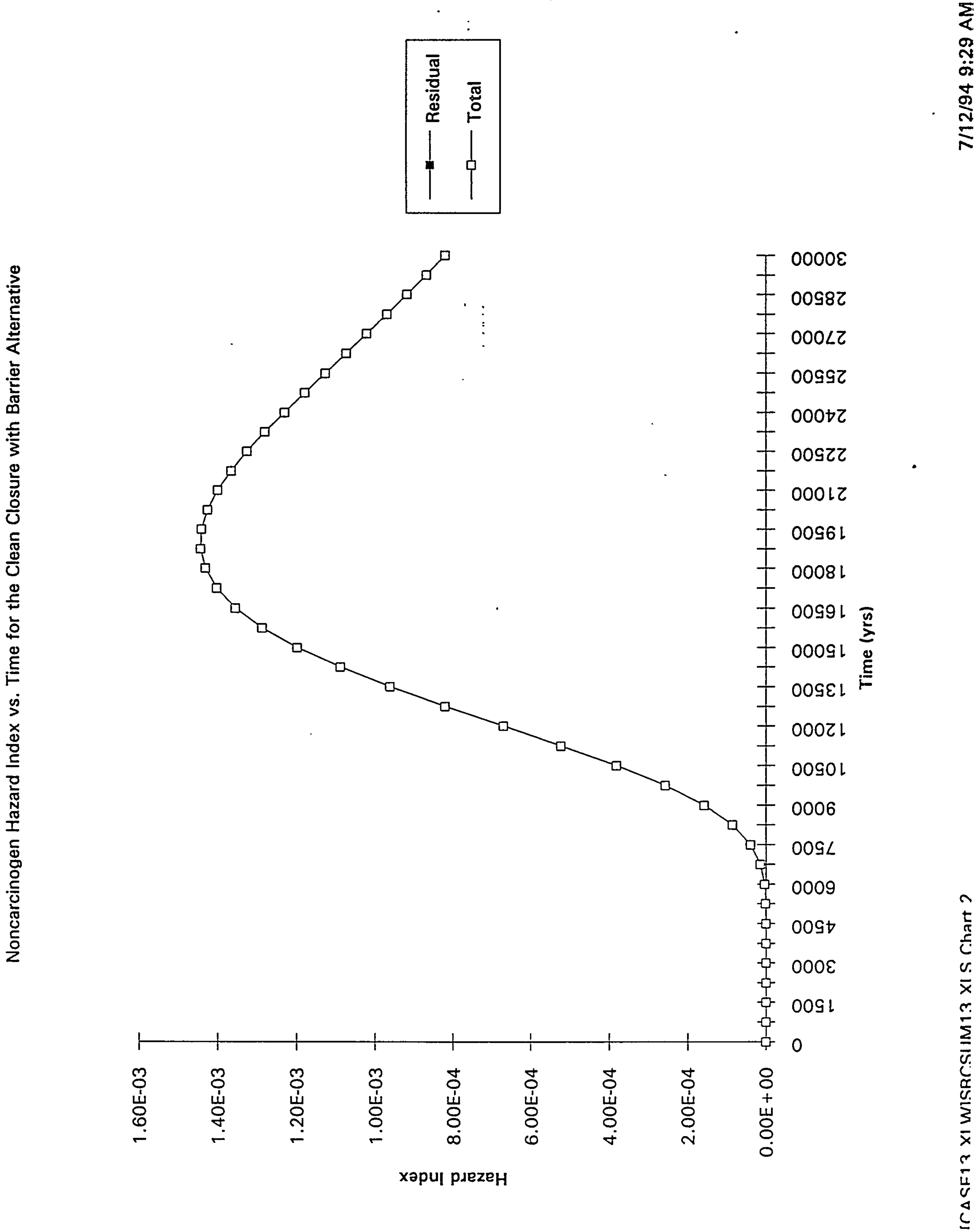
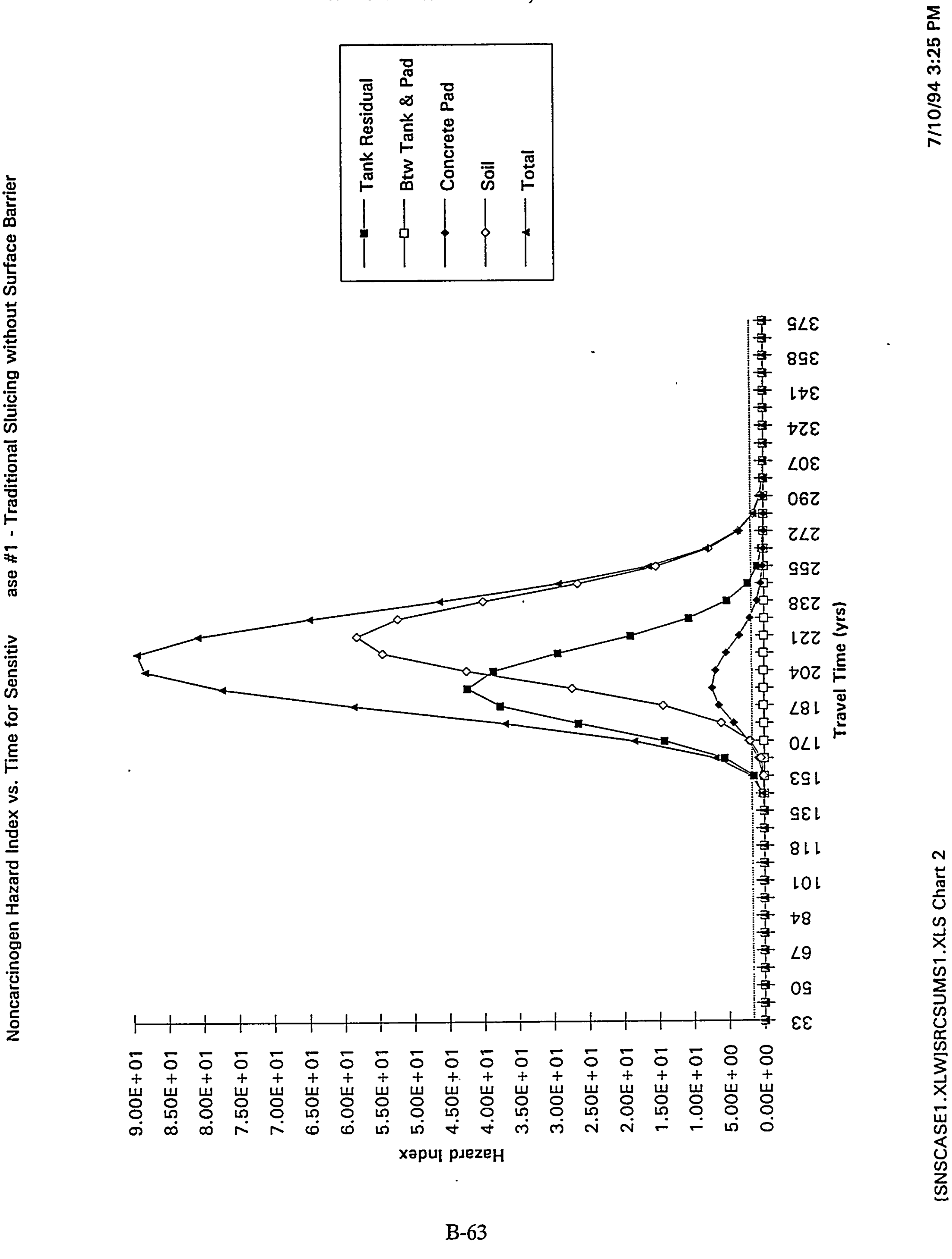
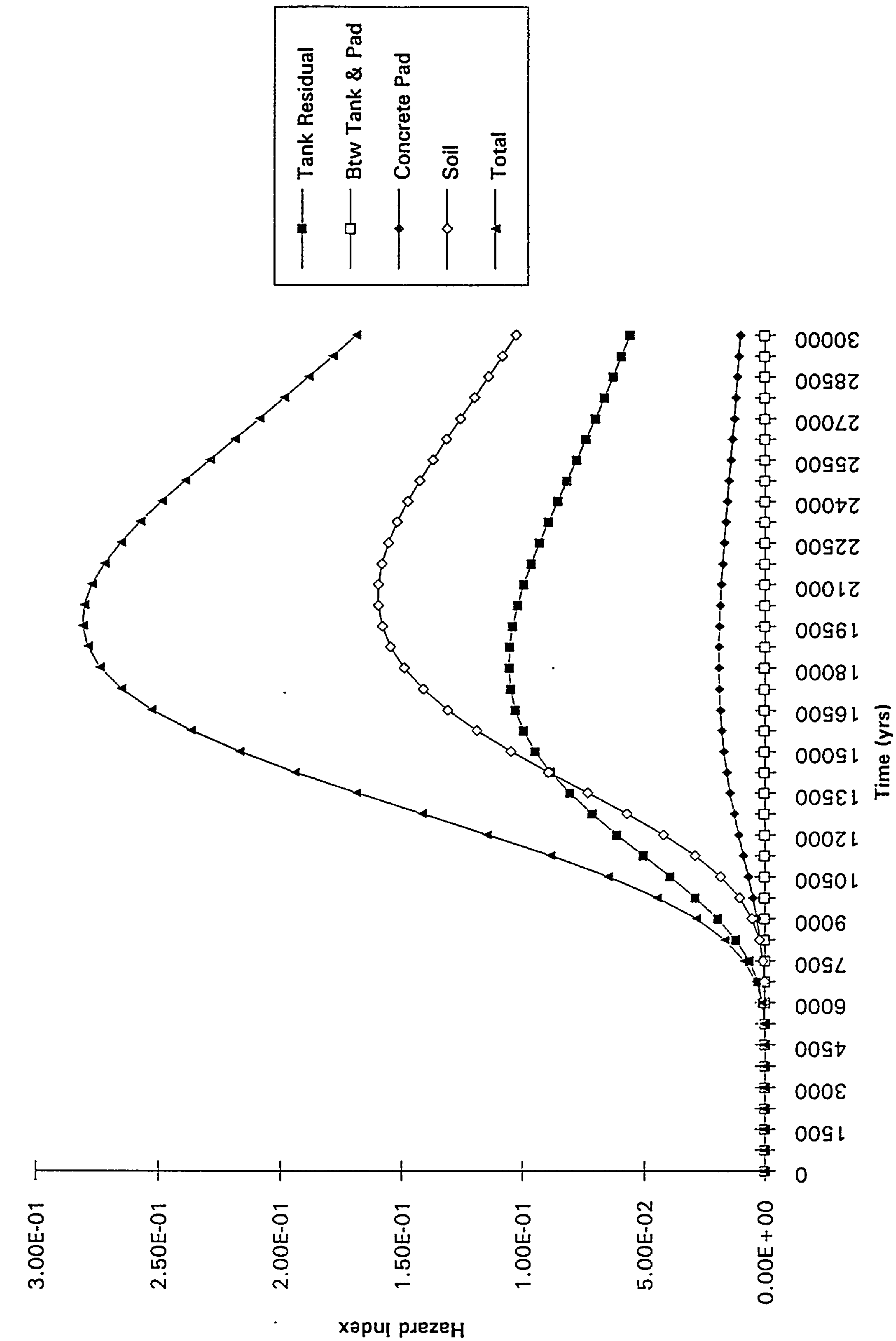
30000
Time (yrs)
7/12/94 9:19 AM


Noncarcinogen Hazard Index vs. Time fc ; Clean Closure without Barrier Alternative
Residual
Total
Hazard Index
2.50E-03
2.00E-03
1.50E-03
1.00E-03
5.00E-04
0.00E+00
0
1500
3000
4500
6000
7500
9000
10500
12000
13500
15000
16500
18000
19500
21000
22500
24000
25500
27000
28500
30000
Time (yrs)
7/12/94 9:32 AM
[CASE14.XLW]SRCSUM14.XLS Chart 2


Noncarcinogen Hazard Index vs. Time for the Clean Closure with Barrier Alternative
Residual
Total
Hazard Index
1.60E-03
1.40E-03
1.20E-03
1.00E-03
8.00E-04
6.00E-04
4.00E-04
2.00E-04
0.00E+00
0
1500
3000
4500
6000
7500
9000
10500
12000
13500
15000
16500
18000
19500
21000
22500
24000
25500
27000
28500
30000
Time (yrs)
7/12/94 9:29 AM


Noncarcinogen Hazard Index vs. Time for Sensitiv ase #1 - Traditional Sluicing without Surface Barrier
Tank Residual
Btw Tank & Pad
Concrete Pad
Soil
Total
Hazard Index
9.00E+01
8.50E+01
8.00E+01
7.50E+01
7.00E+01
6.50E+01
6.00E+01
5.50E+01
5.00E+01
4.50E+01
4.00E+01
3.50E+01
3.00E+01
2.50E+01
2.00E+01
1.50E+01
1.00E+01
5.00E+00
0.00E+00
33
50
67
84
101
118
135
153
170
187
204
221
238
255
272
290
307
324
341
358
375
Travel Time (yrs)
7/10/94 3:25 PM
[SNSCASE1.XLW]SRCSUMS1.XLS Chart 2

Noncarcinogen Hazard Index vs. Time for Sensitivity Case #2A - Traditional Sluicing with Low Nitrate Inventory

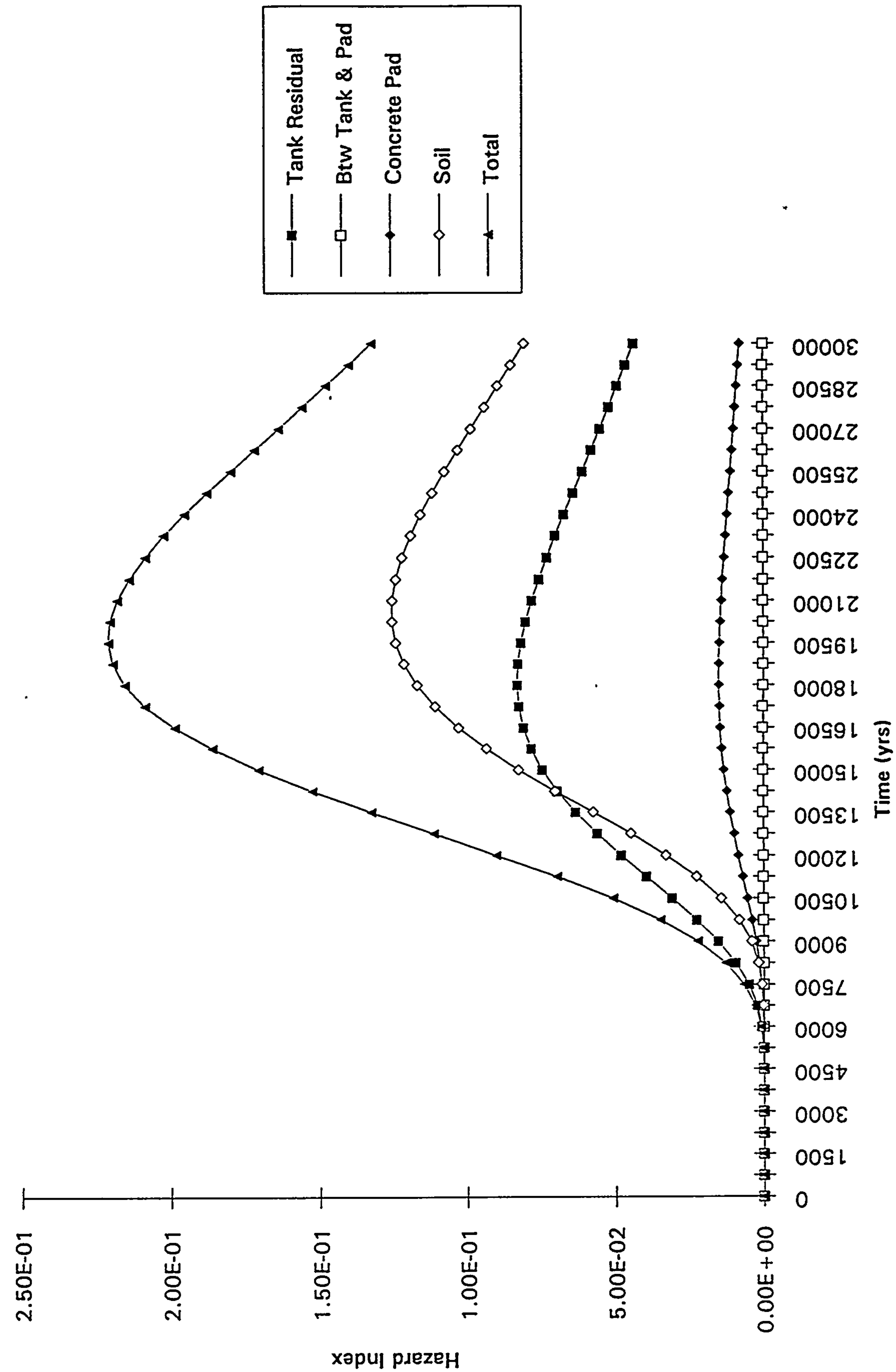


7/11/94 3:20 PM

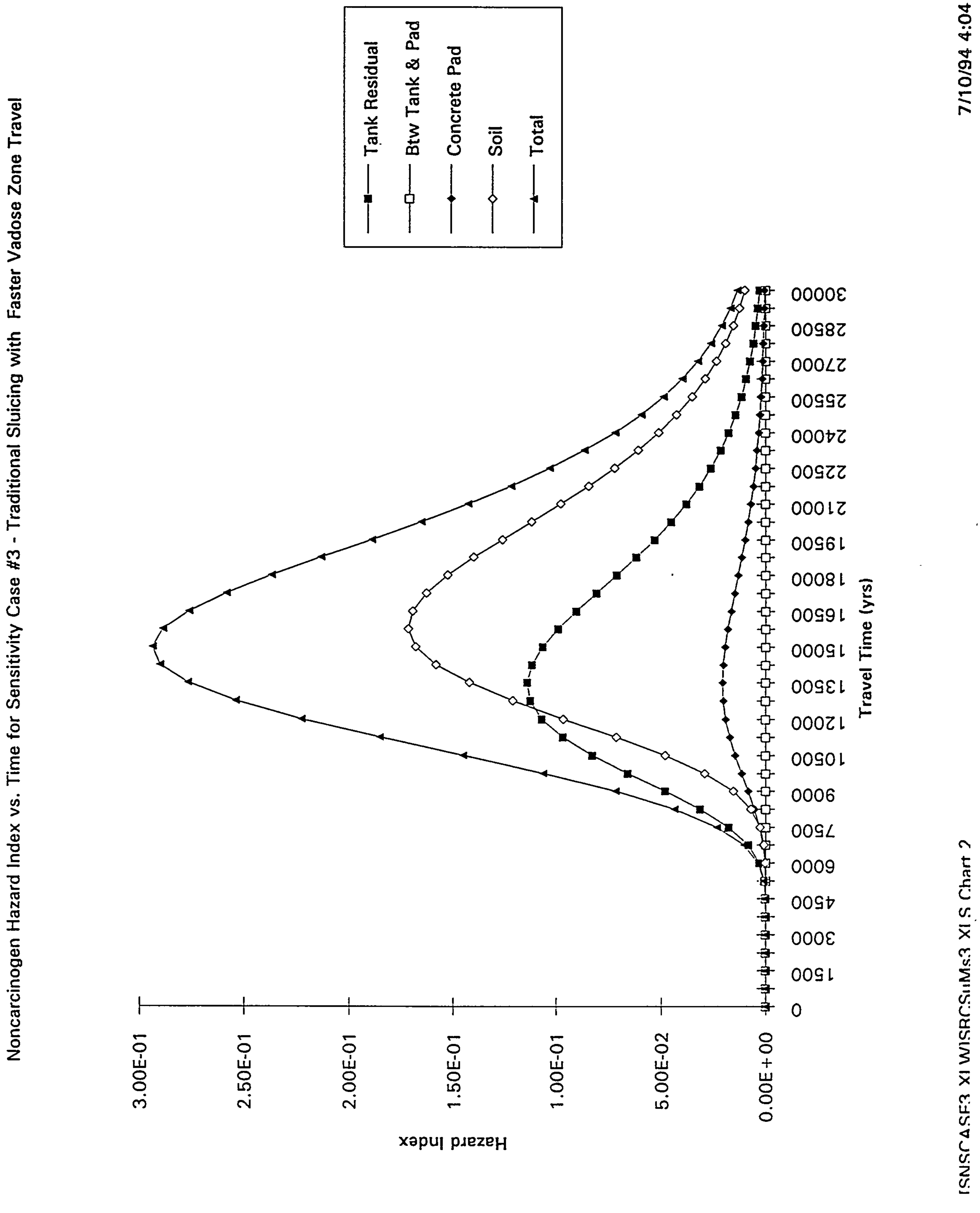
ISNCASE2A.XLWISRCSMs2a.XLS Chart 2

Noncarcinogen Hazard Index vs. Time for Sensitivity e #2B - Traditional Sluicing with High Nitrate Inventory

7/11/94 3:17 PM

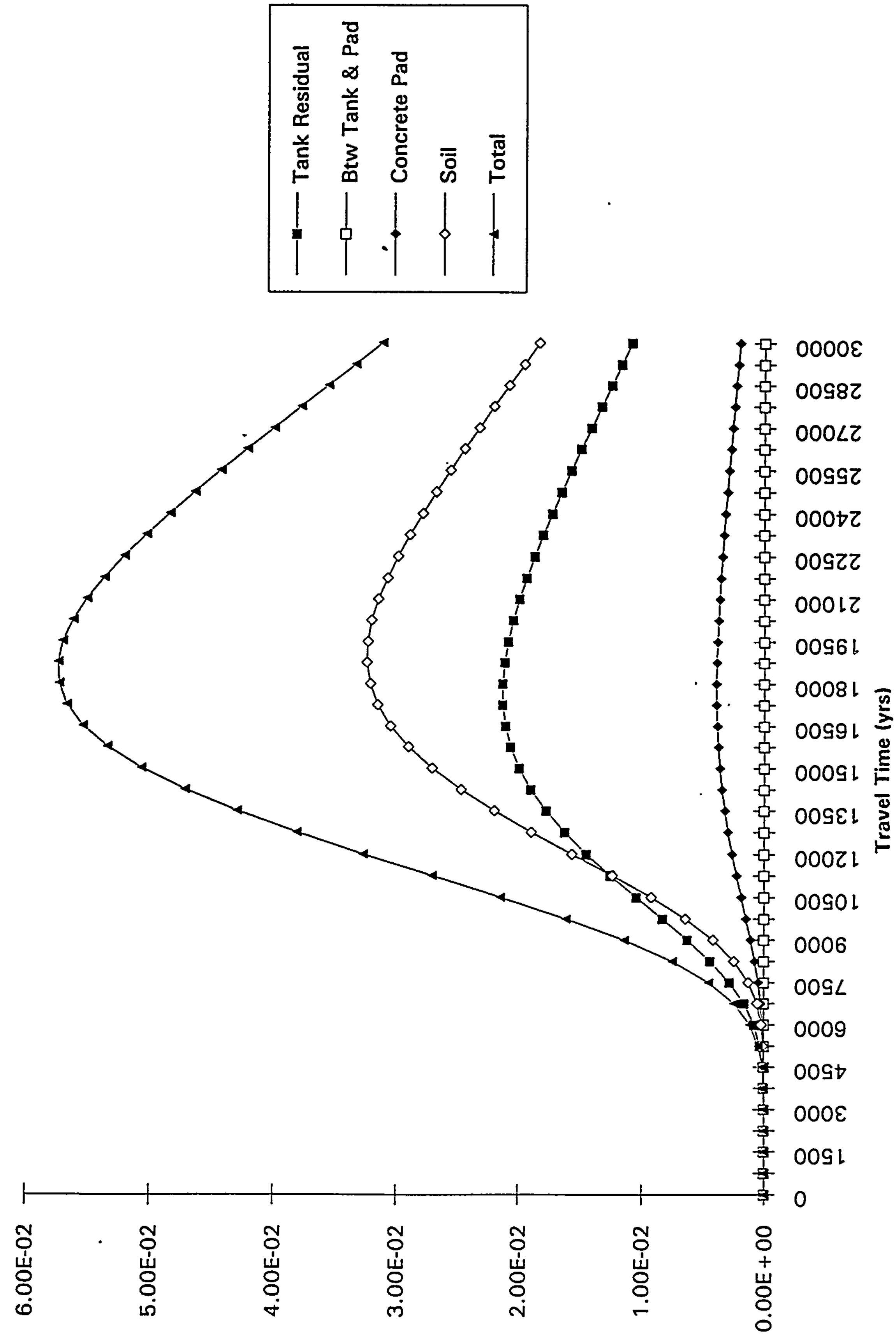


[SNCASE2B.XLW]SRCSMs2b.XLS Chart 2


Noncarcinogen Hazard Index vs. Time for Sensitivity Case #3 - Traditional Sluicing with Faster Vadose Zone Travel
Tank Residual
Btw Tank & Pad
Concrete Pad
Soil
Total
Hazard Index
3.00E-01
2.50E-01
2.00E-01
1.50E-01
1.00E-01
5.00E-02
0.00E+00
0
1500
3000
4500
6000
7500
9000
10500
12000
13500
15000
16500
18000
19500
21000
22500
24000
25500
27000
28500
30000
Travel Time (yrs)
7/10/94 4:04 PM

Noncarcinogen Hazard Index vs. Time for Sensitivity C #4 - Traditional Sluicing with Slower Vadose Zone Travel

7/10/94 4:14 PM



[SNSCASE4.XLWJSRCSuMs4.XLS Chart 2

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APPENDIX C

COST ESTIMATION

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APPENDIX C

COST ESTIMATION

This appendix provides detail regarding assumptions, sources, and analysis methods for rough order of magnitude cost estimates. Table C-1 provides estimated cost components and detail for subsurface barriers and soil flushing. Table C-2 provides detail cost factors for the nine elements of the two clean closure alternatives. Table C-3 provides estimated cost components for all 20 options including subsurface barriers and soil flushing. Table C-4 summarizes overall cost for the 20 options combined in 14 alternatives. Annual cost is estimated as equivalent uniform annual cost (EUAC). Overall cost during the life cycle is estimated as total net present worth (TNPW) and total life cycle cost (TLCC). Cost for subsurface barriers and soil flushing options are presented as footnotes designated by letters [a] through [u] with related numbered sub-footnotes as required. These notes are so extensive that they are provided as text following Tables C-1, C-2, C-3, and C-4.

Nine alternatives have high-level waste (HLW) processing and disposal requirements that differ from the common baseline of 99% retrieval. The change in HLW processing and disposal costs associated with these differences are listed below.

Option	Cost Change
Robotic sluicing	+0.009
Mechanical retrieval	-0.04
Close-coupled chemical with flushing	+0.003
Box-shaped chemical	+0.014
V-shaped chemical	+0.014
Circulating air barrier	+0.014
Clean closure with close-coupled chemical barrier	+0.021
Clean closure w/o subsurface barrier	+0.027

The baseline costs as adjusted from Boomer et al. (1993) for 149 SSTs before adjustment for 84% of the nitrate feed to the vitrification process and disposal and before adding 5% for inflation from early 1993 to mid-1994 are: capital at $5.54 billion, annual operating and maintenance (O&M) at $188 million, annual disposal to HLW repository (assumed to be on the Hanford Site since transportation cost is zero) at $499 million, and decontamination and decommissioning (D&D) at $2.71 billion. Robotic sluicing and mechanical retrieval have different retrieval fractions from baseline and thus have more or less slurry feed. Flush water treatments pass through the Liquid Effluent Purification and Recycle or Discharge (LEPRD) and produces HLW streams. Clean closure soil and debris wash water is treated i. LEPRD and resulting HLW waste streams must be processed.

Note [a] applies to all options listed in Tables C-1, C-2, C-3, and C-4. Notes [b] through [u] apply to specific options as listed on Tables C-1 and C-3. Notes [aa] through [qq] apply to clean closure options on Table C-2.

[a] General notes:

a1. A tank farm consists of 12 SSTs 75 ft in diameter. The tanks are arranged in a 3 by 4 array on 100 ft centers. Each tank has a capacity of 1,000,000 gal. Overall tank farm dimensions tangent to the tanks would be 275 by 375 ft with the bottom of the concrete tank bases at 50 ft belowgrade and the tank tops at 7 ft belowgrade.

a2. Costs are given in millions of dollars except for O&M and EUAC, where they are given in millions of dollars per year.

a3. Life cycle is 15 years per the Tri-Party Agreement of January 1994. Operating duration is planned as 10 years per Boomer et al. (1993).

a4. Capital costs for the following items are included where applicable: design, inspection, inflation, contingency, site preparation, process equipment, controls, drilling, coffercells, buildings, mechanical equipment, utilities, piping, grout, freezing solution, surface barrier, contractor additions, and other. Capital costs that are common to all systems with retrieval are excluded and include slurry transport, processing, and waste disposal.

a5. All technology readiness capital costs are incurred in the first year and have been increased for inflation by 5% from early 1993 to mid 1994.

a6. O&M = operating and maintenance includes labor, chemicals, utilities, sampling and analysis, and replacement parts and equipment.

a7. D&D = decontamination and decommissioning cost are incurred at the end of the life cycle and include a fraction of capital cost plus labor.

a8. EUAC = equivalent uniform annualized cost is based on 10%/yr and is (0.13147 * (technology readiness + capital)) + (O&M) + disposal + (0.03147 * D&D) per Ruegg (1987).

a9. TNPW = total net present worth is based on a discount factor of 10%/yr and is (technology readiness + capital) + (7.606 * (O&M + disposal) + (0.2394 * D&D) per Ruegg (1987).

Table C-1. Cost Estimates for Subsurface Barriers and Soil Flushing [a]. (sheet 1 of 2)

	Notes:	[g] V-Shaped Chemical	[f] Box-Shaped Chemical	[h] V-Shaped Freeze Wall	[c] Close-Coupled Chemical Sides & Under 12 Tanks	[i] Circulating Air Barrier	[j] Vacuum Soil Flushing w/Circulating Air [i]	[k] Traditional Flushing	[r] Chemical Close-Coupled Sides Only	[u] Vacuum Soil Flushing w/Close-Coupled Chemical [c]	[v] & [s] Close-Coupled Chemical Sides and Under 7 Tanks
1	Pipe layers	2	2	3	2	1	1/3	1/1	2	1/3	2
2	Grout cost, $/ft³[chem]	30	30		30				30		30
3	Grout volume, ft³/linear ft[chem]	15	15		15				15		14
4	Pipe space belowgrade, ft	7	7	10	7	100	10	10/20	7	10	7
5	Drill or jack, ft	148,327	103,200	155,743	81,768	3,000	53,473	43,393	44,054	53,473	47,698
6	drill or jack cost, $/ft	500	500	500	500	500	500	500	500	500	500
7	Grout vol., kft³[chem]	2,282	1,588	0	1,258	0	0	0	678	0	668
8	Coffercell linear ft, 15 ft dia.	0	0	0	1,200	0	1,200	0	1,200		1,120
9	Coffercell cost, $/ft	0	0	0	5,000	0	5,000	0	5,000		5,000
10	Air, scfm	0	0	0	0	100,000	100,000	0	0		0
11	Comp. hp	0	0	0	0	12,000	12,000	0	0		0
12	Site preparation, k$	940	670	1,100	1,120	380	790	350	650	790	1,120
13	Drill/jack & pipe, k$	74,200	51,600	77,900	40,900	1,500	26,700	21,700	22,000	26,700	23,800
14	Coffercell, k$	0	0	0	6,000	0	6,000	0	6,000	0	5,600
15	Buildings, k$	0	0	255	0	1,031	1,031	1,031	0	1,031	0
16	Mech. equipment, k$	2,512	2,512	1,380	2,512	12,951	12,951	5,000	2,512	12,951	2,512
17	Surface piping, k$	0	0	600	0	1,600	2,400	1,360	0	2,400	0
18	Chemical grout, k$	68,500	47,600	0	37,700	0	0	0	20,300	0	20,000
19	Dry or flush/vacuum, k$	0	0	0	0	12,336	12,336	12,336	0	12,336	0
20	Freeze, k$	0	0	5,388	0	0	0	0	0	0	0
21	Other, k$	6,580	4,690	7,700	7,840	2,660	5,530	2,500	4,550	5,530	7,840
22	KEH adds, k$	11,280	8,040	13,200	13,440	4,560	9,480	4,200	7,800	9,480	13,440
23	Surface cover, k$	1,880	1,340	2,200	2240	760	1,580	700	1300	1,580	2,240
24	Subtotal 1, k$	166,000	116,000	110,000	112,000	38,000	79,000	49,000	65,000	73,000	77,000

Table C-1. Cost Estimates for Subsurface Barriers and Soil Flushing [a]. (sheet 2 of 2)

	Notes:	[g] V-Shaped Chemical	[f] Box-Shaped Chemical	[h] V-Shaped Freeze Wall	[e] Close-Coupled Chemical Sides & Under 12 Tanks	[i] Circulating Air Barrier	[j] Vacuum Soil Flushing w/Circulating Air [i]	[k] Traditional Flushing	[r] Close-Coupled Chemical Sides Only	[u] Vacuum Soil Flushing w/ Close-Coupled Chemical [e]	[v] & [s] Close-coupled Chemical Sides & Under 7 Tanks
25	Design, k$					385					
26	Inspection, k$					4,110					
27	Escalation, k$					10,596					
28	Contingency, k$					15,200					
29	Subtotal 2, k$	132,324	92,467	87,684	89,279	30,291	62,973	39,059	51,814	58,191	61,379
30	Subtotal2/subtotal1	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80
31	Capital total = 1+2, k$	312,900	218,400	207,900	211,050	71,400	149,100	92,400	122,850	137,550	144,900
32	Electricity, k$/yr			415		1,806	1,806			1,806	
33	Labor, k$/yr	6,260	4,370	20,790	4,220	7,140	14,910	9,240	2,460	13,760	2,900
34	Labor/capital	0.020	0.020	0.100	0.020	0.100	0.100	0.100	0.020	0.100	0.020
35	Sample & analysis, k$/yr	300	300	300	300	300	300	300	300	300	300
36	Parts & equipment, k$/yr					3,654	9,784			8,934	
37	O&M total cost, k$/yr	9,400	6,600	33,300	6,300	12,900	26,800	14,800	3,700	24,800	4,300
38	O&M/capital	0.03	0.03	0.16	0.03	0.18	0.18	0.16	0.03	0.18	0.03
39	Parts & equipment/capital					0.051	0.066			0.065	
40	D&D, k$	0	0	41,600	0	14,300	29,800	18,500	0	27,500	0

Table C-2. Estimated Costs of Clean Closure.

Note		Option 13 Clean-Closure w/o Subsurface Barrier	Option 14 Clean-Closure with Close-Coupled Chemical Barrier
[aa]	CLEAN CLOSURE		
[bb]	Leak volume, gal	255,000	77,000
[cc]	Soil below tanks, yd^3	72,000	22,000
[dd]	Leak depth, ft	28,45,49	28
[ee]	Soil below tanks, ktons	97	30
[ff]	Tank soil and debris, ktons	45	45
[gg]	Total soil and debris, ktons	142	75
[qq]	Cost fraction for HLW processing & disposal	0.027	0.021

		Tech Ready	Capital [hh]	O&M	Disposal	D&D	EUAC	TNPW	TLCC
	Option 13, Clean-closure w/o subsurface barrier	M$	M$	M$/yr	M$/yr	M$	M$/yr	M$	M$
[ii]	Removal	4	141	25		71	47	356	598
[jj]	Tank farm confinement	8	270	49		135	89	680	1,141
[kk]	Hauling & MW land fill	1	19	3		9	6	47	78
[ll]	Soil & debris water wash	5	169	30		85	56	427	717
[mm]	LEPRD wash water treat	2	50	9		25	17	126	212
[nn]	LEPRD solids to MW disposal	0.0	0.06	0.01		0.03	0	0	0
[oo]	Recycle piping, no SALDS	1.9	65	12		32	21	163	274
[pp]	Backfill	0.2	5	1		3	4	30	56
[qq]	HLW processing & disposal	0.3	11	2	1	11	5	38	70
	Totals	22	730	131	1	371	245	1,867	3,146
	Option 14, Clean-closure with close-coupled chemical barrier	M$	M$	M$/yr	M$/yr	M$	M$/yr	M$	M$
	Close-coupled chemical barrier	4	145	4		72	26	199	286
[ii]	Removal	3	96	17		48	32	242	406
[jj]	Tank farm confinement	8	270	49		135	89	680	1,141
[kk]	Hauling & MW land fill	0	13	2		6	4	32	53
[ll]	Soil & debris water wash	3	115	21		58	38	290	487
[mm]	LEPRD wash water treat	1	34	6		17	11	86	144
[nn]	LEPRD solids to MW disposal	0.0	0.04	0		0	0	0	0
[oo]	Recycle piping, no SALDS	1.3	44	8		22	15	111	186
[pp]	Backfill	0.1	4	1		2	1	9	15
[qq]	HLW processing & disposal	0.3	8	2	1	8	4	29	54
	Totals	21	729	110	1	368	220	1,678	2,772

O&M and EUAC are stated in millions of dollars per year (not lifetime cost)

Table C-3. Estimated Capital and Operating Costs for Tank Farm Options [a].

OPTION	Tech Rdy M$	Capital M$	Cap+TR M$	O&M M$/yr	Disposal M$/yr	D&D M$	EUAC M$/yr	TNPW M$	TLCC M$	HLW Process Disposal Fraction
RETRIEVAL										
Traditional Sluicing[b]	2	63	64	4	0	9	13	98	136	
Robotic Sluicing[c]	18	183	202	13	0.4	28	40	307	423	0.009
Mechanical Retrieval[d]	15	154	170	10	(2)	15	31	236	307	(0.040)
SUBSURFACE BARRIERS										
Close-Coupled Chemical- Sides & Under 12 tanks[e]	13	211	224	6	0	0	36	272	318	
Close-Coupled Chemical-Sides Only[r]	7	123	130	4	0	0	21	158	.186	
Close-Coupled Chemical-Sides & Under 7 tanks[v]	9	145	154	4	0	0	24	186	218	
Box-Shaped Chemical[f]	13	218	232	7	0	0	37	282	331	
V-Shaped Chemical[g]	19	313	332	9	0	0	53	403	473	
V-Shaped Freeze Wall[h]	12	208	220	33	0	42	64	484	761	
Circulating Air[i]	4	71	76	13	0	14	23	177	283	
SOIL FLUSHING										
Vacuum Soil Flushing w/Circulating Air[i,j]	15	149	164	27	0	30	49	375	596	
Vacuum Soil Flushing w/Close-Coupled Chemical[e,u]	8	138	146	25	0	28	45	341	545	
Traditional Flushing[k]	6	92	98	15	0	18	28	215	338	
Flush Water Treatment for Close-Coupled Barrier[l]	0.3	8	8	1	0.1	7	3	22	40	0.003
Flush Water Treatment for Box-Shaped Barrier[m]	2	44	46	8	1	36	16	123	218	0.014
Flush Water Treatment for V-Shaped Barrier[n]	2	47	49	9	1	38	17	132	232	0.014
Flush Water Treatment for Circulating Air Barrier[o]	0.6	14	15	3	1	13	6	43	77	0.014
TANK STABILIZATION[p]	0.1	2	3	0.1	0	0.3	0.4	3	4	
SURFACE BARRIER[q]	0.3	4	5	0.1	0	0	1	6	7	
Clean Closure with Close-Coupled Chemical Barrier[s]	22	729	750	110	1	368	221	1,678	2,774	0.021
Clean Closure w/o Subsurface Barrier[t]	22	730	752	132	1	370	245	1,866	3,145	0.027

Table C-4. Estimated Total Cost of Alternatives [a].

Alternative	1 No Action	2 Surface Barrier Only	3 Traditional Sluicing (Baseline)	4 Robotic Sluicing	5 Mechanical Sluicing	6 Close-Coupled Chemical with Flushing	7 Close-Coupled Chemical w/o Flushing	8 Modified Close-Coupled Chemical w/o Flushing	9 Box-Shaped Chemical	10 V-Shaped Chemical	11 V-Shaped Freeze Wall	12 Circulating Air Barrier	13 Clean-Closure w/o Subsurface Barrier	14 Clean-Closure with Close-Coupled Chemical Barrier
EUAC:														
Retrieval	0	0	13[b]	40[c]	31[d]	13[b]	13[b]	13[b]	13[b]	13[b]	13[b]	13[b]	13[b]	13[b]
Subsurface Barrier	0	0	0	0	0	36[e]	24[e]	21[r]	37[f]	53[g]	64[h]	23[i]	0	24[e]
Tank Stabilization	0	0	0.4[p]	0.4[p]	0.4[p]	0.4[p]	0.4[p]	0.4[p]	0.4[p]	0.4[p]	0.4[p]	0.4[p]	0	0
Surface Barrier	0	1[q]	1[q]	1[q]	1[q]	1[q]	1[q]	1[q]	1[q]	1[q]	1[q]	1[q]	0	0
Flush	0	0	0	0	0	45[u]	0	0	28[k]	28[k]	28[k]	49[j]	0	0
Flush Water Treatment	0	0	0	0	0	3[l]	0	0	16[m]	17[n]	17[n]	6[o]	0	0
Clean Closure	0	0	0	0	0	0	0	0	0	0	0	0	245[t]	221[s]
Total EUAC	0	1	14	41	32	98	39	35	96	113	123	92	258	258
TNPW:														
Retrieval	0	0	98[b]	307[c]	236[d]	98[b]	98[b]	98[b]	98[b]	98[b]	98[b]	98[b]	98[b]	98[b]
Subsurface Barrier	0	0	0	0	0	272[e]	272[e]	158[r]	282[f]	403[g]	484[g]	177[i]	0	186[e]
Tank Stabilization	0	0	3[p]	3[p]	3[p]	3[p]	3[p]	3[p]	3[p]	3[p]	3[p]	3[p]	0	0
Surface Barrier	0	6[q]	6[q]	6[q]	6[q]	6[q]	6[q]	6[q]	6[q]	6[q]	6[q]	6[q]	0	0
Flush	0	0	0	0	0	341[u]	0	0	215[k]	215[k]	215[k]	375[j]	0	0
Flush Water Treatment	0	0	0	0	0	22[l]	0	0	123[m]	132[n]	132[n]	43[o]	0	0
Clean Closure	0	0	0	0	0	0	0	0	0	0	0	0	1,866[t]	1,678[s]
Total TNPW	0	6	107	316	244	742	293	265	727	857	937	702	1,965	1,962
TLCC:														
Retrieval	0	0	136[b]	423[c]	307[d]	136[b]	136[b]	136[b]	136[b]	136[b]	136[b]	136[b]	136[b]	136[b]
Subsurface Barrier	0	0	0	0	0	318[e]	218[e]	186[r]	331[f]	473[g]	761[g]	283[i]	0	218[e]
Tank Stabilization	0	0	4[p]	4[p]	4[p]	4[p]	4[p]	4[p]	4[p]	4[p]	4[p]	4[p]	0	0
Surface Barrier	0	7[q]	7[q]	7[q]	7[q]	7[q]	7[q]	7[q]	7[q]	7[q]	7[q]	7[q]	0	0
Flush	0	0	0	0	0	545[u]	0	0	338[k]	338[k]	338[k]	596[j]	0	0
Flush Water Treatment	0	0	0	0	0	40[l]	0	0	218[m]	232[n]	232[n]	77[o]	0	0
Clean Closure	0	0	0	0	0	0	0	0	0	0	0	0	3,145[t]	2,774[s]
Total TLCC	0	7	146	434	318	1,049	364	332	1,033	1,190	1,478	1,103	3,287	3,128

a10. TLCC = total life cycle cost and is the sum of technology readiness plus capital plus 15 times O&M and disposal plus D&D per Ruegg (1987).

a11. Values were adjusted from Boomer et al. (1993, Appendixes F, J, K, M, and N) and from KEH (1993).

a12. Technology development includes safety analysis at 1% of capital, permitting at 1% of capital, engineering studies from 0.5 to 4% of capital, and testing and demonstration from 0.5 to 4% of capital.

[b] Traditional Sluicing. Assumptions used to develop cost estimates for traditional sluicing are based on information from Boomer et al. (1993, Appendix F). All costs are ratioed to 12 tanks from the total 149 SSTs and 12 sluicing systems as briefly described in Section 4.2.1 of this report. The processing adjacent to tank farms, pipeline transport, and central processing into storable waste forms of the slurried waste are excluded from these cost estimates since they are estimated to be the same for all retrieval systems.

b1. Capital costs of $740 million for 149 SSTs from Boomer et al. (1993, pp. F4-99) were ratioed to 12 tanks. These costs include engineering, project management, equipment, and support facilities. A 50% contingency is included in the capital costs. No confinement facilities are required outside the tank.

b2. O&M annual cost is estimated at 6.5% of capital cost as adjusted from Boomer et al. (1993, pp. F4-19 and F4-99). O&M is the sum of personnel, electricity, and CENRTC & GPP costs. No steam or chemicals are planned for use. No disposal costs are included.

b3. Personnel annual cost is 4.2% of capital cost as adjusted from the basis of 305 total employees per Boomer et al. (1993, p. F4-99).

b4. Electricity annual cost is estimated at $0.023/kWh for 5,200,000 kWh/yr from Boomer et al. (1993, pp. N-84 and F4-99).

b5. CENRTC and GPP total annual cost is 2.25% of capital cost per Boomer et al. (1993, p. F4-99). The 2.25% factor is based on Hanford Site experience where equipment cost is typically 15% of total capital cost for chemical processes in canyon buildings and CENRTC & GPP are annually 15% of equipment cost.

b6. D&D cost is estimated at 10% of capital cost plus one year of personnel cost. This is less than the 30% of capital cost plus three years of personnel cost from Boomer et al. (1993, p. F4-99). For traditional sluicing there are no canyon buildings or other aboveground structures. The contaminated components could be left in the tanks where they would be covered by grout during tank stabilization and closure.

[c] Robotic Sluicing. Assumptions used to develop cost estimates for robotic sluicing are based on information from Boomer et al. (1993, Appendix F). All costs are ratioed to 12 tanks from the total 149 SSTs, 29 robotic systems, and 29 bridge confinements as described in Section 4.2.2 of this report. Robotic sluicing would use high pressure, low volume water to prepare the sludge for pneumatic conveying from the tank to a separation system. A bridge confinement would provide structural support for each robotic system. The processing adjacent to tank farms, transport, and central processing into storable waste forms of the slurried waste are excluded from these cost estimates since they are estimated to be the same for all retrieval systems.

c1. Capital cost for robotic sluicing is the sum of costs for in-tank robotic arms and end effectors plus the surface support structure and contamination confinement plus processing and disposal of a HLW increment. Capital costs for robotic arms and end effectors were adjusted from Boomer et al. (1993, p. F4-11) for 149 SSTs by multiplying the cost of $23.5 million for one system from Boomer et al. (1993, p. F4-85) by 29. More systems are required than for traditional sluicing since the retrieval rate is slower. A total of 29 systems are tabulated in Boomer et al. (1993, pp. F4-73 to F4-78), although a total of 36 systems is indicated in Boomer et al. (1993, p. F4-78), and 43 systems are implied by the $1.01 billion capital cost in Boomer et al. (1993, p. 4-86). Capital costs for bridge confinement were adjusted from Boomer et al. (1993, p. F7-14) by adding the $74.2 million cost of one system including nonrecurring Title I and II and project management costs to 28 times the $49 million system cost without project management. Total capital cost includes engineering, project management, equipment, structural single tank bridge confinement, and support facilities. A 50% contingency is included in the capital costs.

c2. O&M annual cost, as for traditional sluicing, is estimated at 6.5% of capital cost as adjusted from Boomer et al. (1993, pp. F4-11, F4-84, F4-86, F7-14, and F7-44) for 149 SSTs. O&M is the sum of personnel, electricity, and CENRTC & GPP costs. No steam or chemicals are planned for use. No disposal costs are included.

c3. Personnel annual cost, as for traditional sluicing, is estimated at 4.2% of capital cost as adjusted from the basis 1,452 employees listed in Boomer et al. (1993, p. F4-86) and 1,124 employees listed in Boomer et al. (1993, p. F7-44).

c4. Electricity annual cost is estimated at $0.023/kWh from Boomer et al. (1993, p. N-84) for 4,700,000 kWh/yr from Boomer et al. (1993, p. F7-44) plus 22,000,000 kWh/yr adjusted from Boomer et al. (1993, p. F4-84). The adjustment was made by assuming 182 operating years per Boomer et al. (1993, p. F4-78) divided among 29 systems for an average 6.3 systems operating at any time for 8,760 h/yr at a 400 kW power level. The power to drive a

20,000 lb/in^2, 8 gal/min pump is estimated to be 99 kW and was added to the power for the vacuum pump, air heater, and other equipment in the pneumatic system estimated at 301 kW as adjusted from Boomer et al. (1993, p. F4-84).

c5. CENRTC and GPP total annual cost is estimated at 2.25% of capital cost per Boomer et al. (1993, p. F4-86). The 2.25% factor is based on Hanford Site experience as in note [b5].

c6. D&D cost is estimated at 10% of capital cost plus one year of personnel cost. This is less than the 30% of capital cost plus three years of personnel cost from Boomer et al. (1993, pp. F4-86 and F7-44). For robotic sluicing there are no canyon buildings or other aboveground structures. The contaminated components could be left in the tanks where they would be covered by grout during tank stabilization and closure.

[d] Mechanical Retrieval. Assumptions used to develop cost estimates for mechanical retrieval are based on information from Boomer et al. (1993, Appendix F). All costs are ratioed to 12 tanks from the total 149 SSTs, 29 robotic systems, and 29 bridge confinements as briefly described in Section 4.2.3 of this report. Mechanical retrieval would use digging devices on a robotic arm to prepare the sludge for pneumatic conveying from the tank to a separation system. The processing adjacent to tank farms, transport, and central processing into storable waste forms of the slurried waste are excluded from these cost estimates since they are estimated to be the same for all retrieval systems.

Capital cost for mechanical retrieval is the sum of costs for in-tank robotic arms and end effectors plus the surface support structure and contamination confinement minus processing and disposal of a HLW increment.

d1. Capital costs for robotic equipment were adjusted from Boomer et al. (1993, p. F4-4) by multiplying the $19,500,000 cost for one system from Boomer et al. (1993, p. F4-80) by 29 as in note [c1]. Capital costs for bridge confinement were adjusted from Boomer et al. (1993, p. F7-14) by adding the $74.2 million cost of one system including nonrecurring Title I and II and project management costs to 28 times the $49 million system cost without project management. Total capital cost includes engineering, project management, equipment, structural single tank bridge confinement, and support facilities. A 50% contingency is included in the capital costs escalated to January 1993 dollars.

d2. O&M annual cost, as for traditional sluicing, is estimated at 6.5% of capital cost as adjusted from Boomer et al. (1993, pp. F4-11, F4-84, F4-86, F7-14, and F7-44). O&M is the sum of personnel, electricity, and CENRTC & GPP costs. No steam or chemicals are planned for use. No sampling analysis or disposal costs are included.

d3. Personnel annual cost is 4.2% of capital cost as adjusted from the basis 1,452 total employees listed in Boomer et al. (1993, p. F4-81) plus 1,124 employees listed in Boomer et al. (1993, p. F7-44).

d4. Electricity annual cost is estimated at $0.023/kWh from Boomer et al. (1993, p. N-84) for 4,700,000 kWh/yr from Boomer et al. (1993, p. F7-44) plus 10,600,000 kWh/yr adjusted from Boomer et al. (1993, p. F4-81).

d5. CENRTC and GPP total annual cost is 2.25% of capital cost per Boomer et al. (1993, p. F4-86). The 2.25% factor is based on Hanford Site experience as in note [b5].

d6. D&D cost is estimated at 10% of capital cost plus one year of personnel cost. This is less than the 30% of capital cost plus three years of personnel cost from Boomer et al. (1993, pp. F4-86 and F7-44). For robotic sluicing there are no canyon buildings or other aboveground structures. The contaminated components could be left in the tanks where they would be covered by grout during tank stabilization and closure.

[e] Close-Coupled Chemical Sides and Under 12 Tanks. Assumptions used to develop cost estimates for close-coupled chemical are based on information from KEH (1993b). All costs are ratioed to 12 tanks as in note [a1] and as briefly described in Section 4.3.1 of this report. On each tank there would be a ring of vertical pipes at 80 ft diameter to a depth of 46 ft and at 90 ft diameter to a depth of 50 ft. Two horizontal crossed layers of pipes under each tank at 55 ft and 63 ft belowgrade would radiate from 15 coffercells of 15 ft diameter and 100 ft depth. Three coffercells would be located within the 12 tank array and 12 would be located at the perimeter of the array.

e1. Capital costs based on KEH (1993b, p. 20) include those for engineering, project management, equipment, and support facilities. A 40% contingency is included in the capital costs. No confinement facilities are required outside the tanks. The assumed installed grout cost of $30/ft^3 for 15 ft^3/lineal ft of pipe was applied to 81,768 ft of pipe. A maximum pipe spacing of 7 ft resulted in minimum overall cost for a pipe drilling and jacking cost of $500/ft. A coffercell cost of $5,000/ft was applied to a 1,200 ft length.

e2. O&M annual cost is estimated at 3% of capital cost as adjusted from KEH (1993b, p. A-4-2) for a static underground barrier. O&M is the sum of personnel including sampling and analysis, electricity, and CENRTC & GPP costs. No steam or chemicals are planned for use. No disposal costs are included as the chemical grout is planned to stay permanently underground.

e3. Personnel annual cost, primarily for sampling and analysis, is assumed at 2% of capital cost at an average annual cost of $90,000 for each employee.

e4. Electricity annual cost was included in the O&M cost in note [e2].

e5. CENRTC and GPP annual cost was included in the O&M cost of note [e2].

e6. No D&D cost is estimated for this subsurface barrier, which will be abandoned in place.

[f] Box-Shaped Chemical. Assumptions used to develop cost estimates for box-shaped chemical are based on information from KEH (1993b). All costs are ratioed to 12 tanks as in note [a1] and as briefly described in Section 4.3.2 of this report. There would be a series of pipes at a 25 degree angle to grade and transitioning to horizontal at 130 ft belowgrade. The box would enclose 430 by 490 ft at the surface. It would have two vertical walls of 460 ft and one vertical wall of 430 ft. Pipes would be at a maximum spacing of 7 ft.

f1. Capital costs based on KEH (1993b, p. 20) include those for engineering, project management, equipment, and support facilities. A 40% contingency is included in the capital costs. No confinement facilities are required outside the tanks. The assumed installed grout cost of $\$30/ft^3$ for 15 ft^3/lineal ft of pipe was applied to 103,200 ft of pipe. A maximum pipe spacing of 7 ft resulted in minimum overall cost for a pipe drilling and jacking cost of $500/ft.

f2. O&M annual cost is estimated at 3% of capital cost as adjusted from KEH (1993b, p. A-4-2) for a static underground barrier. O&M is the sum of personnel including sampling and analysis, electricity, and CENRTC & GPP costs. No steam or chemicals are planned for use. No disposal costs are included as the chemical grout is planned to stay permanently underground.

f3. Personnel annual cost, primarily for sampling and analysis, is assumed at 2% of capital cost at an average annual cost of $90,000 for each employee.

f4. Electricity annual cost was included in the O&M cost in note [f2].

f5. CENRTC and GPP annual cost was included in the O&M cost of note [f2].

f6. No D&D cost is estimated for this subsurface barrier, which will be abandoned in place.

[g] V-Shaped Chemical. Assumptions used to develop cost estimates for V-shaped chemical are based on information from KEH (1993b). Specific adjustments to the values from KEH are listed below. All costs are ratioed to 12 tanks as in note [a1] and as briefly described in Section 4.3.3 of this report. Two staggered layers of pipes would be angled at 37 degrees to grade to a depth of 250 ft for a 96 ft minimum clearance below the tanks and from a surface width of 660 ft. The vertical end walls would have a length of 540 ft.

g1. Capital costs based on KEH (1993b, p. 20) include those for engineering, project management, equipment, and support facilities. A 40% contingency is included in the capital costs. No confinement facilities are required outside the tanks. The assumed installed grout cost of $30/ft^3 for 15 ft^3/lineal ft of pipe was applied to 148,327 ft of pipe. A maximum pipe spacing of 7 ft resulted in minimum overall cost for a pipe drilling and jacking cost of $500/ft.

g2. O&M annual cost is estimated at 3% of capital cost as adjusted from KEH (1993b, p. A-4-2) for a static underground barrier. O&M is the sum of personnel including sampling and analysis, electricity, and CENRTC & GPP costs. No steam or chemicals are planned for use. No disposal costs are included as the chemical grout is planned to stay permanently underground.

g3. Personnel annual cost, primarily for sampling and analysis, is assumed at 2% of capital cost at an average annual cost of $90,000 for each employee.

g4. Electricity annual cost was included in the O&M cost in note [g2].

g5. CENRTC and GPP annual cost was included in the O&M cost of note [g2].

g6. No D&D cost is estimated for this subsurface barrier, which will be abandoned in place.

[h] V-Shaped Freeze Wall. Assumptions used to develop cost estimates for V-shaped freeze wall are based on information from KEH (1993b). All costs are ratioed to 12 tanks as in note [a1] and as briefly described in Section 4.3.4 of this report. Three staggered layers of pipes at a 10 ft spacing will allow two layers for ice and one layer for water supply, heating, and monitoring. Pipes would be angled at 37 degrees to grade to a depth of 250 ft for a 96 ft minimum clearance below the tanks and from a surface width of 660 ft. The vertical end walls would have a length of 540 ft.

h1. Capital costs based on KEH (1993b, p. 20) include those for engineering, project management, equipment, and support facilities. A 40% contingency is included in the capital costs. No confinement facilities are required outside the tanks. The assumed installed double wall pipe cost of $500/ft was applied to 155,743 ft of pipe.

h2. O&M annual cost is estimated at 16% of capital cost as adjusted from KEH (1993b, p. A-4-2) for an active underground barrier. O&M is the sum of personnel including sampling and analysis, electricity, and CENRTC & GPP costs. No steam or chemicals are planned for use. No disposal costs are included as the ice is planned to stay permanently underground.

h3. Personnel annual cost, primarily for sampling and analysis, is assumed at 10% of capital cost at an average annual cost of $90,000 for each employee.

h4. Electricity for refrigeration compressors totaling 2,700 hp was included in the O&M cost.

h5. CENRTC and GPP annual cost of 2.25% of capital cost was included in the O&M cost of note [h2].

h6. D&D cost is estimated at 10% of capital cost plus one year of personnel cost. This is less than the 30% of capital cost plus three years of personnel cost used in Boomer et al. (1993) for canyon buildings or other major aboveground structures.

[i] Circulating Air Barrier. Assumptions used to develop cost estimates for circulating air are based on information from KEH (1993b). All costs are ratioed to 12 tanks as in note [a1] and as briefly described in Section 4.3.5 of this report. Ten supply and 10 vacuum pipes will be placed vertically to a depth of 150 ft.

i1. Capital costs based on KEH (1993b, p. 20) include those for engineering, project management, equipment, and support facilities. A 40% contingency is included in the capital costs. No confinement facilities are required outside the tanks. The assumed installed cost of $500/ft was applied to 3,000 ft of pipe.

i2. O&M annual cost is estimated at 18% of capital cost as adjusted from KEH (1993b, p. A-4-2) for an active underground barrier. O&M is the sum of personnel including sampling and analysis, electricity, and CENRTC & GPP costs. No steam or chemicals are planned for use. No disposal costs are expected.

i3. Personnel annual cost, primarily for compressor and system operation plus sampling and analysis, is assumed at 10% of capital cost at an average annual cost of $90,000 for each employee.

i4. Electricity for air compressors totaling 12,000 hp was included in the O&M cost.

i5. CENRTC and GPP annual cost of 2.25% of capital cost was included in the O&M cost of note [i2].

i6. D&D cost is estimated at 10% of capital cost plus one year of personnel cost. This is less than the 30% of capital cost plus three years of personnel cost used in Boomer et al. (1993) for canyon buildings or other major aboveground structures.

[j] Vacuum Soil Flushing with Circulating Air. Assumptions used to develop cost estimates for vacuum soil flushing are based on information from KEH (1993b). All costs are ratioed to 12 tanks as in note [a1] and as briefly described in Section 4.4.2 of this report. Around each tank there would be a ring of vertical pipes at 80 ft diameter

to a depth of 46 ft. Three horizontal crossed layers of pipes under each tank at 70 ft and 75 ft belowgrade would radiate from 15 coffercells of 15 ft diameter and 100 ft depth. Three coffercells would be located within the 12 tank array and 12 would be located at the perimeter of the array.

j1. Capital costs based on KEH (1993b, p. 20) include those for engineering, project management, equipment, and support facilities. A 40% contingency is included in the capital costs. No confinement facilities are required outside the tanks. The assumed installed cost of $500/ft was applied to 53,473 ft of pipe. A coffercell cost of $5,000/ft was applied to a 1,200 ft length.

j2. O&M annual cost is estimated at 18% of capital cost as adjusted from KEH (1993b, p. A-4-2) for an active underground barrier. O&M is the sum of personnel including sampling and analysis, electricity, and CENRTC & GPP costs. No steam or chemicals are planned for use. No disposal costs are expected.

j3. Personnel annual cost, primarily for air compressor and system operation plus sampling and analysis, is assumed at 10% of capital cost at an average annual cost of $90,000 for each employee.

j4. Electricity for air compressors totaling 12,000 hp was included in the O&M cost.

j5. CENRTC and GPP annual cost of 2.25% of capital cost was included in the O&M cost of note [j2].

j6. D&D cost is estimated at 10% of capital cost plus one year of personnel cost. This is less than the 30% of capital cost plus three years of personnel cost used in Boomer et al. (1993) for canyon buildings or other major aboveground structures.

[k] Traditional Flushing. Assumptions used to develop cost estimates for traditional flushing are based on information from KEH (1993b). All costs are ratioed to 12 tanks as in note [a1] and as briefly described in Section 4.4.1 of this report. Around each tank there would be a ring of vertical pipes at 80 ft diameter to a depth of 46 ft. An array of vertical pipes on 20 ft centers would be installed between tanks to the barrier below.

k1. Capital costs based on KEH (1993b, p. 20) include those for engineering, project management, equipment, and support facilities. A 40% contingency is included in the capital costs. No confinement facilities are required outside the tanks. The assumed installed cost of $500/ft was applied to 43,393 ft of pipe.

k2. O&M annual cost is estimated at 16% of capital cost as adjusted from KEH (1993b, p. A-4-2) for an active system of pumps. O&M is the sum of personnel including sampling and analysis, electricity, and CENRTC & GPP costs. No steam or chemicals are planned for use. No disposal costs are expected.

k3. Personnel annual cost, primarily for pump and flush system operation plus sampling and analysis, is assumed at 10% of capital cost at an average annual cost of $90,000 for each employee.

k4. Electricity annual cost was included in the O&M cost in note [k2].

k5. CENRTC and GPP annual cost of 2.25% of capital cost was included in the O&M cost of note [k2].

k6. D&D cost is estimated at 10% of capital cost plus one year of personnel cost. This is less than the 30% of capital cost plus three years of personnel cost used in Boomer et al. (1993) for canyon buildings or other major aboveground structures.

[l] Flush Water Treatment for Close-Coupled Chemical Barrier. Assumptions used to develop cost estimates for flush water treatment for close-coupled chemical are based on information from Boomer et al. (1993, Appendixes K, N, and R). All costs for 12 tanks as described in Section 4.4.3 of this report were ratioed from the total 149 SSTs and include facilities for flush water treatment as well as disposal of resulting radioactive mixed waste (MW) and HLW at the Hanford site. The cost of wastewater pipeline transport from the tank farms to the treatment facility is assumed to be in the retrieval system pipeline transport cost. The cost of a State Approved Land Disposal System (SALDS) is not included.

l1. Capital cost for flush water treatment is estimated as the sum of costs for water treatment and disposal of MW and HLW. Capital cost is based on a flow rate of 3 gal/min as calculated from 14 Mgal of wastewater treated during 15 years and 365 days/yr with a total operating efficiency of 0.6. The equivalent flow rate for 149 tanks would be 36.7 gal/min compared to the total design flow to the LEPRD of 316 gal/min as stated in Boomer et al. (1993, p. N-44). Cost for 149 tanks is based on the ratio of these flow rates to the 0.6 power multiplied by the sum of the $297 million cost for LEPRD from Boomer et al. (1993, pp. N-55 and R-397) plus the $110 million cost for MW transport and disposal from Boomer et al. (1993, p. H-178) multiplied by the 0.6 power of the flow ratio 1. Total flow is the sum of 2,860 lb/day from Boomer et al. (1993, p. N-46) and the baseline flow of 511,000 lb/day from Boomer et al. (1993, p. K-8). The MW solids disposal cost for 149 tanks includes trucks, 50 yd^3 containers, and disposal trenches with surface barrier. Total capital cost includes engineering, project management, equipment, and support facilities. A 50% contingency is included in the capital costs.

12. O&M annual cost is estimated at 18% of capital cost as adjusted from (1993, p. N-55) for an active and complex flush water treatment system. O&M is the sum of personnel including sampling and analysis, electricity, and CENRTC & GPP costs. No steam or chemicals are planned for use. Disposal costs are included.

13. Personnel annual cost, primarily for system operation plus sampling and analysis, is assumed at 15% of capital cost at an average annual cost of $90,000 for each employee.

14. Electricity annual cost was included in the O&M cost in note [12].

15. CENRTC and GPP annual cost of 2.25% of capital cost was included in the O&M cost of note [12].

16. D&D cost is estimated at 30% of capital cost plus three years of personnel cost as used in Boomer et al. (1993) for canyon buildings or other major aboveground structures.

[m] Flush Water Treatment for Box-Shaped Barrier. Assumptions used to develop cost estimates for flush water treatment for the box-shaped barrier are based on information from Boomer et al. (1993, Appendixes K, N, and R). All costs for 12 tanks as described in Section 4.4.3 of this report were ratioed from the total 149 SSTs and include facilities for flush water treatment as well as disposal of resulting MW and HLW at the Hanford Site. The cost of wastewater pipeline transport from the tank farms to the treatment facility is assumed to be in the retrieval system pipeline transport cost. The cost of a SALDS is not included.

m1. Capital cost for flush water treatment is estimated as the sum of costs for water treatment and disposal of MW and HLW. Capital cost is based on a flow rate of 51.8 gal/min as calculated from 245 Mgal of wastewater treated during 15 years and 365 days/yr with a total operating efficiency of 0.6. The equivalent flow rate for 149 tanks would be 643 gal/min compared to the total design flow to the LEPRD of 316 gal/min as stated in Boomer et al. (1993, p. N-44). Cost for 149 tanks is based on the ratio of these flow rates to the 0.6 power multiplied by the sum of the $297 million cost for LEPRD from Boomer et al. (1993, pp. N-55 and R-397) plus the $110 million cost for MW transport and disposal from Boomer et al. (1993, p. K-178) multiplied by the 0.6 power of the flow ratio 1. Total flow in the sum of 2,860 lb/day from Boomer et al. (1993, p. N-46) and the baseline flow of 511,000 lb/day from Boomer et al. (1993, p. K-8). The MW solids disposal cost for 149 tanks includes trucks, 50 yd^3 containers, and disposal trenches with surface barrier. Total capital cost includes engineering, project management, equipment, and support facilities. A 50% contingency is included in the capital costs.

m2. O&M annual cost is estimated at 18% of capital cost as adjusted from KEH (1993, p. A-4-2) for an active and complex flush water treatment system. O&M is the sum of personnel including sampling and analysis, electricity, and CENRTC & GPP costs. No steam or chemicals are planned for use. Disposal costs are included.

m3. Personnel annual cost, primarily for system operation plus sampling and analysis, is assumed at 15% of capital cost at an average annual cost of $90,000 for each employee.

m4. Electricity annual cost was included in the O&M cost in note [m2].

m5. CENRTC and GPP annual cost of 2.25% of capital cost was included in the O&M cost of note [m2].

m6. D&D cost is estimated at 30% of capital cost plus three years of personnel cost as used in Boomer et al. (1993) for canyon buildings or other major aboveground structures.

[n] Flush Water Treatment for V-Shaped Barrier. Assumptions used to develop cost estimates for flush water treatment for V-shaped barriers are based on information from Boomer et al. (1993, Appendixes K, N, and R). All costs for 12 tanks as described in Section 4.4.3 of this report were ratioed from the total 149 SSTs and include facilities for flush water treatment as well as disposal of resulting MW and HLW at the Hanford Site. The cost of wastewater pipeline transport from the tank farms to the treatment facility is assumed to be in the retrieval system pipeline transport cost. The cost of a SALDS is not included.

n1. Capital cost for flush water treatment is estimated as the sum of costs for water treatment and disposal of MW and HLW. Capital cost is based on a flow rate of 58.8 gal/min as calculated from 278 Mgal of wastewater treated during 15 years and 365 days/yr with a total operating efficiency of 0.6. The equivalent flow rate for 149 tanks would be 730 gal/min compared to the total design flow to the LEPRD of 316 gal/min as stated in Boomer et al. (1993, p. N-44). Cost for 149 tanks is based on the ratio of these flow rates to the 0.6 power multiplied by the sum of the $297 million cost for LEPRD from Boomer et al. (1993, p. N-55 and R-397) plus the $110 million cost for MW transport and disposal from Boomer et al. (1993, p. K-178) multiplied by the 0.6 power of the flow ratio 1. Total flow is the sum of 2,860 lb/day from Boomer et al. (1993, p. N-46) and the baseline flow of 511,000 lb/day from Boomer et al. (1993, p. K-8). The MW solids disposal cost for 149 tanks includes trucks, 50 yd^3 containers, and disposal trenches with surface barrier. Total capital cost includes engineering, project management, equipment, and support facilities. A 50% contingency is included in the capital costs.

n2. O&M annual cost is estimated at 18% of capital cost as adjusted from KEH (1993, p. A-4-2) for an active and complex flush water treatment system. O&M is the sum of personnel including sampling and analysis, electricity, and CENRTC & GPP costs. No steam or chemicals are planned for use. Disposal costs are included.

n3. Personnel annual cost, primarily for system operation plus sampling and analysis, is assumed at 15% of capital cost at an average annual cost of $90,000 for each employee.

n4. Electricity annual cost was included in the O&M cost in note [n2].

n5. CENRTC and GPP annual cost of 2.25% of capital cost was included in the O&M cost of note [n2].

n6. D&D cost is estimated at 30% of capital cost plus three years of personnel cost as used in Boomer et al. (1993) for canyon buildings or other major aboveground structures.

[o] Flush Water Treatment for Circulating Air Barrier. Assumptions used to develop cost estimates for flush water treatment for a circulating air barrier are based on information from Boomer et al. (1993, Appendixes K, N, and R). All costs for 12 tanks as described in Section 4.4.3 of this report were ratioed from the total 149 SSTs and include facilities for flush water treatment as well as disposal of resulting MW and HLW at the Hanford Site. The cost of wastewater pipeline transport from the tank farms to the treatment facility is assumed to be in the retrieval system pipeline transport cost. The cost of a SALDS is not included.

o1. Capital costs for flush water treatment are the sum of costs for water treatment and disposal of MW and HLW. Capital cost is based on a flow rate of 4.2 gal/min as calculated from 20 Mgal of wastewater treated during 15 years and 365 days/yr with a total operating efficiency of 0.6. The equivalent flow rate for 149 tanks would be 52.5 gal/min compared to the total design flow to the LEPRD of 316 gal/min as stated in Boomer et al. (1993, p. N-44). Cost for 149 tanks is based on the ratio of these flow rates to the 0.6 power multiplied by the sum of the $297 million cost for LEPRD from Boomer et al. (1993, pp. N-55 and R-397) plus the $110 million cost for MW transport and disposal from Boomer et al. (1993, p. K-178) multiplied by the 0.6 power of the flow ratio -1. Total flow is the sum of 2,860 lb/day from Boomer et al. (1993, p. N-46) and the baseline flow of 511,000 lb/day from Boomer et al. (1993, p. K-8). The MW solids disposal cost for 149 tanks includes trucks, 50 yd^3 containers, and disposal trenches with surface barrier. Total capital cost includes engineering, project management, equipment, and support facilities. A 50% contingency is included in the capital costs.

o2. O&M annual cost is estimated at 18% of capital cost as adjusted from KEH (1993, p. A-4-2) for an active and complex flush water treatment system. O&M is the sum of personnel including sampling and analysis, electricity, and CENRTC & GPP costs. No steam or chemicals are planned for use. Disposal costs are included.

o3. Personnel annual cost, primarily for system operation plus sampling and analysis, is assumed at 15% of capital cost at an average annual cost of $90,000 for each employee.

o4. Electricity annual cost was included in the O&M cost in note [o2].

o5. CENRTC and GPP annual cost of 2.25% of capital cost was included in the O&M cost of note [o2].

o6. D&D cost is estimated at 30% of capital cost plus three years of personnel cost as used in Boomer et al. (1993) for canyon buildings or other major aboveground structures.

[p] Tank Stabilization. Assumptions used to develop cost estimates for tank stabilization are based on information from Boomer et al. (1993, Appendix M). All costs are ratioed to 12 tanks from the total 149 SSTs. The process is briefly described in Section 4.5.1 of this report.

p1. Capital cost for stabilization by grout of 149 SSTs is estimated from the $28.6 million basis from Boomer et al. (1993, p. M135) and includes costs for engineering, project management, equipment, and support facilities. A 50% contingency is included in the capital costs. No confinement facilities are required outside the tanks.

p2. O&M annual cost is estimated at 3% of capital cost as adjusted from Boomer et al. (1993, p. M135) for a static underground barrier. O&M is the sum of personnel including sampling and analysis, electricity, and CENRTC & GPP costs. No steam or chemicals are planned for maintenance use. No disposal costs are included as the chemical grout is planned to stay permanently in the tanks.

p3. Personnel annual cost, primarily for sampling and analysis, is assumed at 2% of capital cost at an average annual cost of $90,000 for each employee.

p4. Electricity annual cost was included in the O&M cost in note [p2].

p5. CENRTC and GPP annual cost was included in the O&M cost of note [p2].

p6. D&D cost is estimated at 10% of capital cost plus one year of personnel cost. This is less than the 30% of capital cost plus three years of personnel cost used in Boomer et al. (1993) for canyon buildings or other major aboveground structures.

[q] Surface Barrier. Assumptions used to develop cost estimates for surface barriers are based on information from Boomer et al. (1993, Appendix M). All costs are ratioed to 12 tanks from the total 149 SSTs. The process is briefly described in Section 4.5.2 of this report.

q1. Capital costs of $51 million for 149 SSTs from Boomer et al. (1993, p. M138) include those for engineering, project management, equipment, and support facilities. A 50% contingency is included in the capital costs. No confinement facilities are required outside the tanks. The capital cost is based on 41.13 acres of an engineered barrier that is a nominal 15 ft thick.

q2. O&M annual cost is estimated at 3% of capital cost as adjusted from Boomer et al. (1993, p. M138) for a static barrier. O&M is the sum of personnel including sampling and analysis, electricity, and CENRTC & GPP costs. No steam or chemicals are planned for use. No disposal costs are included as the barrier is planned to stay permanently in place.

q3. Personnel annual cost, primarily for sampling and analysis, is assumed at 2% of capital cost at an average annual cost of $90,000 for each employee.

q4. Electricity annual cost was included in the O&M cost in note [q2].

q5. CENRTC and GPP annual cost was included in the O&M cost of note [q2].

q6. No D&D cost is estimated for this subsurface barrier, which will be abandoned in place.

[r] Close-Coupled Chemical Sides Only. Assumptions used to develop cost estimates for close-coupled chemical sides only are based on information from KEH (1993b). All costs are ratioed to 12 tanks as in note [a1] and as briefly described in Section 2.2.1 of this report. On each tank there would be two rings of vertical pipes, one at 80 ft diameter to a depth of 46 ft, and one at 90 ft diameter to a depth of 50 ft.

r1. Capital costs based on KEH (1993b, p. 20) include those for engineering, project management, equipment, and support facilities. A 40% contingency is included in the capital costs. No confinement facilities are required outside the tanks. The assumed installed grout cost of $30/ft^3$ for 15 ft^3/lineal ft of pipe was applied to 44,054 ft of pipe. A maximum pipe spacing of 7 ft resulted in minimum cost for a pipe drilling and jacking cost of $500/ft.

r2. O&M annual cost is estimated at 3% of capital cost as adjusted from KEH (1993b, p. A-4-2) for a static underground barrier. O&M is the sum of personnel including sampling and analysis, electricity, and CENRTC & GPP costs. No steam or chemicals are planned for use. No disposal costs are included as the chemical grout is planned to stay permanently underground.

r3. Personnel annual cost, primarily for sampling and analysis, is assumed at 2% of capital cost at an average annual cost of $90,000 for each employee.

r4. Electricity annual cost was included in the O&M cost in note [r2].

r5. CENRTC and GPP annual cost was included in the O&M cost of note [r2].

r6. No D&D cost is estimated for this subsurface barrier, which will be abandoned in place.

[s] & [t] Clean Closure with Close-Coupled Chemical Barrier and w/o Subsurface Barriers. Assumptions used to develop cost estimates for clean closure are based on information from Boomer et al. (1993). All costs for 12 tanks were ratioed from the total 149 SSTs and include facilities for flush water treatment as well as disposal of resulting MW and HLW at the Hanford Site. The cost of wastewater pipeline transport from the tank farms to the treatment facility is assumed to be in the retrieval system pipeline transport cost. The cost of a SALDS is not included.

s&t1. Capital costs for each of the process elements is listed below in notes [ii] through [qq]. The MW solids disposal cost for 149 tanks includes trucks, 50 yd^3 containers, and disposal trenches with surface barrier. Total capital cost includes engineering, project management, equipment, and support facilities as briefly described in Section 4.5.3 of this report. A 50% contingency is included in the capital costs.

s&t2. O&M annual cost is estimated at 18% of capital cost as typical for an active and complex Hanford Site systems. O&M is the sum of personnel cost including sampling and analysis, electricity, and CENRTC & GPP costs. No steam or chemicals are planned for use. Disposal costs are included.

s&t3. Personnel annual cost, primarily for system operation plus sampling and analysis, is assumed at 10% of capital cost at an average annual cost of $90,000 for each employee.

s&t4. Electricity annual cost was included in the O&M cost in note [l2].

s&t5. CENRTC and GPP annual cost of 2.25% of capital cost was included in the O&M cost of note [12].

s&t6. D&D cost is estimated as 20% of capital cost plus two years of personnel costs. These are less than 30% of capital cost plus three years of personnel cost as used in Boomer et al. (1993) for canyon buildings or other major aboveground structures.

[u] Vacuum Soil Flushing with Close-Coupled Chemical. Assumptions used to develop cost estimates for vacuum soil flushing for close-coupled chemical are based on information from KEH (1993b). All costs are ratioed to 12 tanks as in note [a1] and as briefly described in Section 4.4.2 of this report. Around each tank there would be a ring of vertical pipes at 80 ft diameter to a depth of 46 ft. Three horizontal crossed layers of pipes under each tank at 70 ft and 75 ft belowgrade would radiate from 15 coffercells of 15 ft diameter and 100 ft depth placed for construction of the close-coupled chemical barrier. Three coffercells would be located within the 12 tank array and 12 would be located at the perimeter of the array.

u1. Capital costs based on KEH (1993b, p. 20) include those for engineering, project management, equipment, and support facilities. A 40% contingency is included in the capital costs. No confinement facilities are required outside the tanks. The assumed installed cost of $500/ft was applied to 53,473 ft of pipe.

u2. O&M annual cost is estimated at 18% of capital cost as adjusted from KEH (1993b, p. A-4-2) for an active underground barrier. O&M is the sum of personnel including sampling and analysis, electricity, and CENRTC & GPP costs. No steam or chemicals are planned for use. No disposal costs are expected.

u3. Personnel annual cost, primarily for air compressor and system operation plus sampling and analysis, is assumed at 10% of capital cost at an average annual cost of $90,000 for each employee.

u4. Electricity for air compressors totaling 12,000 hp was included in the O&M cost.

u5. CENRTC and GPP annual cost of 2.25% of capital cost was included in the O&M cost of note [u2].

u6. D&D cost is estimated at 10% of capital cost plus one year of personnel cost. This is less than the 30% of capital cost plus three years of personnel cost used in Boomer et al. (1993) for canyon buildings or other major aboveground structures.

[v] Close-Coupled Chemical Sides and Under 7 Tanks. Assumptions used to develop cost estimates for close-coupled chemical are based on information from KEH (1993b). All

costs are ratioed to 7 tanks as briefly described in Section 4.3.1 of this report. On each tank there would be a ring of vertical pipes at 80 ft diameter to a depth of 46 ft and at 90 ft diameter to a depth of 50 ft. Two horizontal crossed layers of pipes under each tank at 55 ft and 63 ft belowgrade would radiate from 15 coffercells of 15 ft diameter and 100 ft depth. Three coffercells would be located within the tank array and 12 would be located at the perimeter of the array.

v1. Capital costs based on KEH (1993b, p. 20) include those for engineering, project management, equipment, and support facilities. A 40% contingency is included in the capital costs. No confinement facilities are required outside the tanks. The assumed installed grout cost of $\$30/ft^3$ for 15 ft^3/lineal ft of pipe was applied to 81,768 ft of pipe. A maximum pipe spacing of 7 ft resulted in minimum overall cost for a pipe drilling and jacking cost of $500/ft. A coffercell cost of $5,000/ft was applied to a 1,200 ft length.

v2. O&M annual cost is estimated at 3% of capital cost as adjusted from KEH (1993b, p. A-4-2) for a static underground barrier. O&M is the sum of personnel including sampling and analysis, electricity, and CENRTC & GPP costs. No steam or chemicals are planned for use. No disposal costs are included as the chemical grout is planned to stay permanently underground.

v3. Personnel annual cost, primarily for sampling and analysis, is assumed at 2% of capital cost at an average annual cost of $90,000 for each employee.

v4. Electricity annual cost was included in the O&M cost in note [v2].

v5. CENRTC and GPP annual cost was included in the O&M cost of note [v2].

v6. No D&D cost is estimated for this subsurface barrier, which will be abandoned in place.

Notes [aa] through [qq] also apply to clean closure notes [s] and [t].

[aa] For 12 of 149 SSTs with all systems scaled for a 3 by 4 tank array. Size and cost of systems was increased to stay within a 10 year operating time with the soil and debris increased by the soil from below the tanks.

[bb] Option 14 has five old leaks of 11,000 gal each. Option 13 has two old leaks of 11,000 gal each, three combined leaks of 51,000 gal each composed of three sluicing produced leaks of 40,000 gal each combined with three old leaks of 11,000 gal each, and two sluicing produced leaks of 40,000 gal each.

[cc] Per Boomer et al. (1993, p. J-8), the ratio volume contaminated soil/volume spill = 57 = 7.6 ft^3/gal.

[dd] Leak depth in addition to tank base bottom elevation of 50 ft belowgrade.

[ee] Per Boomer et al. (1993, p. K-8), soil density = 100 lb/ft^3 = 2,700 lb/yd^3 = 1.35 tons/yd^3.

[ff] Soil and debris includes soil from above and around tanks, concrete, rebar, steel tank liner plate, and for option 14, chemically grouted soil. Soil and debris were multiplied by the ratio 12/149. Per Boomer et al. (1993, p. K-8), total for 149 SSTs = 561,000 ton = 362,000 ton of concrete + 177,000 ton of soil + 22,000 ton of steel. Per Boomer et al. (1993, p. K-8), this will fill 9,900 containers of 50 yd^3 = 5,300 containers of concrete + 2,800 containers of soil + 1,800 containers of steel.

[gg] Sum of soil from below tanks plus soil, remaining tank contents, concrete and steel debris down to and including reinforced concrete tank base.

[hh] Capital costs include 50% contingency and 5% inflation from early 1993 to mid 1994.

[ii] Capital cost of removal is estimated from the basis $839 million per Boomer et al. (1993, p. J-50) proportional to the 0.6 power of the ratio of total soil to soil and debris. Cost per Boomer et al. (1993, p. J-40) = $780 million not used. Removal = demolition and excavation similar to mechanical retrieval.

[jj] Capital cost of confinement is adjusted up 5% for inflation from the basis $257 million per Boomer et al. (1993, pp. J-98 and F7-38). Confinement would be a 500 ft clear span by 150 high arch truss by 600 ft building composed of eight sections of 75 ft width moved onto pre-placed foundations. It would have an operating, crane support, and shield floor suspended 20 ft abovegrade.

[kk] Capital cost of hauling and mixed waste disposal is estimated from the basis $110 million per Boomer et al. (1993, p. K-178) proportional to the 0.6 power of the ratio of total soil to soil and debris. Hauling and mixed waste disposal includes trucks, containers, haul roads, burial boxes, onsite MW trenches, and surface barrier.

[ll] Capital cost of soil and debris water wash is estimated from the basis $1,006 million per Boomer et al. (1993, p. R-386) proportional to the 0.6 power of the ratio of total soil and debris to tank soil and debris. Soil and debris water wash would include the process facilities to reduce size, classify, and separate mixed waste from waste for backfill.

[mm] Capital cost of LEPRD wash water treatment is estimated from the basis $297 million per Boomer et al. (1993, p. R-397) proportional to the 0.6 power of the ratio of total soil to soil and debris. LEPRD wash water treatment is as described in Section 2.3.3 of this report.

[nn] Capital cost of disposing LEPRD solids as radioactive mixed waste is estimated as the incremental cost from the basis $110 million per Boomer et al. (1993, p. K-178) proportional to the 0.6 power of the solids flow ratio. Total flow is the sum of 1.43 ton/day from Boomer et al. (1993, p. N46) and the baseline flow of 256 tons/day per Boomer et al. (1993, p. K-8). This result is raised to the 0.6 power of the ratio of total soil and debris to tank soil and debris.

[oo] Capital cost of recycle piping without a SALDS is estimated from the basis $385 million per Boomer et al. (1993, p. R-348) proportional to the 0.6 power of the ratio of total soil and debris to tank soil and debris.

[pp] Capital cost of backfill is estimated from the basis $51 million for surface barriers per Boomer et al. (1993, p. R-396) proportional to the 0.6 power of the ratio of total soil and debris plus 12 Mgal to the basis surface barrier volume of 1.04 Myd^3. Surface barrier volume is estimated from 41.13 acres per Boomer et al. (1993, p. M44) by 15 ft thick per Boomer et al. (1993, p. M-125).

[qq] Capital cost of processing and disposal of HLW effluent from LEPRD is estimated as the SST nitrate fraction of 0.84 multiplied by the $5.54 billion cost for the entire 11 module system excluding retrieval. The 11 module names adapted from Boomer et al. (1993) are double-shell tank sludge wash, cesium ion exchange system, LLW glass in sulphur, LLW glass in sulfur vaults, HLW glass cullet feed lag storage, HLW glass cullet, HLW glass cullet cask storage, cullet rework and melter offgas processing, liquid effluent treatment, chemical make-up unit, and air/vapor filtration. The 0.84 factor is the ratio of 9.23×10^7 kg nitrate from the SSTs to 10.98×10^7 kg total nitrate.