

EGG-WTD-9989
May 1992



**Idaho
National
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of Energy*

**Performance-Based Technology
Selection Filter Description Report**

**INEL Buried Waste Integrated Demonstration
System Analysis Project**

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*Work performed under
DOE Contract
No. DE-AC07-76/DO1570*

Received by OSTI

JUL 23 1992

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EGG-WTD--9989

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Performance-Based Technology Selection Filter Description Report

**INEL Buried Waste Integrated Demonstration
Systems Analysis Project**

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Published May 1992

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MASTER

**Prepared for the
U.S. Department of Energy
Office of Environmental Restoration and Waste Management
Under DOE Idaho Field Office
Contract DE-AC07-76ID01570**

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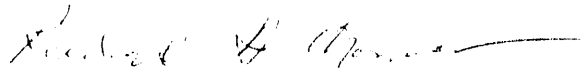
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Description Report
INEL Buried Waste Integrated Demonstration
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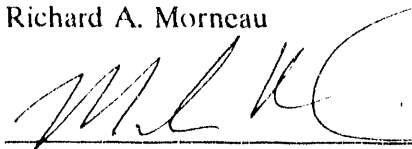
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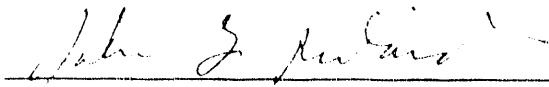
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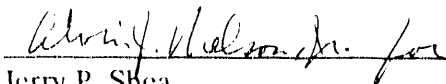
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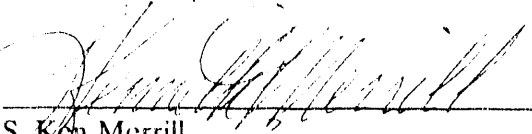
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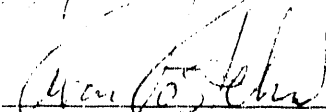
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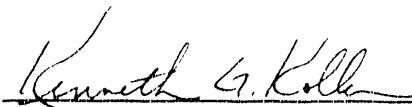
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ABSTRACT

A formal methodology has been developed for identifying technology gaps and assessing innovative or postulated technologies for inclusion in proposed Buried Waste Integrated Demonstration (BWID) remediation systems. Called the Performance-Based Technology Selection Filter, the methodology provides a formalized selection process where technologies and systems are rated and assessments made based on performance measures, and regulatory and technical requirements. The results are auditable, and can be validated with field data.

SUMMARY

The mission of the Buried Waste Integrated Demonstration (BWID) System Analysis is to identify and evaluate technology process options for the cradle-to-grave remediation of transuranic (TRU)-contaminated Waste Pits and Trenches buried at the Idaho National Engineering Laboratory (INEL). Emphasis is placed upon evaluating system configuration options and associated functional and operational requirements for retrieving and treating the buried wastes.

A Performance-Based Technology Selection Filter (PBTSF) has been developed to evaluate identified remediation systems and their enabling technologies based upon system requirements and quantitation of technical Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) balancing criteria. Functionally, the filter is a tool that represents a formal methodology for selecting and rating technology process options. The PBTSF uses two components during its application. One component screens candidate technology process options against previously defined system requirements. The second component is the execution of trade-off studies rating technology process options against performance measures, and allows direct comparison between and among various systems and their constituent technologies.

Initially, generic configuration options are developed that provide a description of a remediation system at a functional subelement, or block diagram level. Next, technology process options are generated and formally assessed to determine if they meet system requirements. Those systems that do meet requirements are then addressed by the CERCLA-based trade-off study function. The output of the trade-off study function is a score (also called a rating) that indicates how well the technology process option rates against the CERCLA-based formulas.

Technology process options that do not meet functional requirements are examined to determine where performance must be improved or, more specifically, what performance aspects of various functional subelements must be improved. Postulated innovative technologies are then inserted into the options and the options are then reevaluated against the requirements matrix. If a technology process option meets all system requirements, it is then scored via trade-off studies, and its overall performance compared to scores of other technology process options. A score lower than other existing systems indicates that the postulated innovative technology will not benefit the process, and that new and higher performance requirements must be met to fill the technology gap.

This process can iterate until a technology process option with a postulated technology generates a high system score. The assumed technology performance parameters then become requirements for technology development.

The BWID PBTSF is a systems tool whose purpose is to provide a framework and formal methodology for selection and rating of technology process options and their enabling technologies. It also provides a closed-form approach to identify technology gaps and the requirements to fill those gaps.

There are five primary attributes of the BWID PBTSF. These are:

- Technology process options and their enabling technologies are rated and selected based on performance measures
- Selection and ratings are based solely on regulatory and technical requirements, and are documentable and traceable
- Rating and selection is performed on complete technology process options
- Performance measures expressly define direct technology development
- Methodology is applicable to other remediation system analyses.

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ACRONYMS

ARAR	Applicable or relevant and appropriate requirement
BWID	Buried Waste Integrated Demonstration
BWP	Idaho National Engineering Laboratory Environmental Restoration Buried Waste Program
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act of 1980, as amended
CFR	Code of Federal Regulations
DOE	Department of Energy
EPA	Environmental Protection Agency
ER	Environmental Restoration
FFA/CO	Federal Facility Agreement and Consent Order
F&OR	Functional and Operational Requirement
FS	Feasibility Study
HWSF	Hazardous Waste Storage Facility
IAG	Interagency Agreement (among DOE, EPA, and the State of Idaho)
INEL	Idaho National Engineering Laboratory
LLW	low-level waste
LSA	Logistics, supportability, and availability
MIL-STDS	Military standards (Dept. of Defense)
MWSF	Mixed Waste Storage Facility
OU	Operable Unit (as defined in the IAG)
PBTSE	Performance-Based Technology Selection Filter
RD/RA	Remedial Design/Remedial Action
RI/FS	Remedial Investigation/Feasibility Study

ROD Record of Decision
RWMC Radioactive Waste Management Complex
SDA Subsurface Disposal Area
TAG Technical Advisory Group
TRU transuranic
TTP Technical Task Plan
WAC Waste Acceptance Criteria

Performance-Based Technology Selection Filter Description Report

INEL Buried Waste Integrated Demonstration Systems Analysis Project

1. BWID SYSTEMS ANALYSIS PROJECT OVERVIEW

The mission of the Buried Waste Integrated Demonstration (BWID) Systems Analysis is to identify and evaluate systems for the cradle-to-grave remediation of transuranic (TRU)-contaminated Waste Pits and Trenches located within the Subsurface Disposal Area (SDA) of the Idaho National Engineering Laboratory's (INEL) Radioactive Waste Management Complex (RWMC). There are three distinct objectives of the project:

- Direct U.S. Department of Energy (DOE) resources to develop technically sound and cost-effective systems for the complete remediation of DOE buried waste sites
- Guide the selection and technical justification for the development and demonstration of technologies within the BWID program
- Identify system technology gaps and define quantitative performance requirements for technologies associated with the remediation of DOE Complex buried wastes.

The BWID program will use the results of the Systems Analysis in conjunction with identified DOE Complex buried waste needs to develop a long-term strategy for improving buried waste remediation capabilities throughout the DOE system.

Initial activities within the BWID Systems Analysis project involve identifying configuration options capable of remediating the TRU-contaminated Waste Pits and Trenches at the INEL. A configuration option is defined as a top-level block diagram of a cradle-to-grave remediation system. An example of a configuration option is attached as Appendix A. An earlier report¹ identified and pre-screened a number of possible remediation configuration options per criteria set forth in DOE Order 4700.1, *Project Management Systems*. The report recommended the following three configuration options for future evaluation: Retrieve/Ex Situ Thermal Treatment, Retrieve/Chemical Oxidation and Solidification, and In Situ Vitrification/Retrieval. The current focus of the BWID Systems Analysis is to perform a rigorous evaluation of the Retrieve/Ex Situ Thermal Treatment Configuration Option. The Retrieve/Chemical Oxidation and Solidification, and the In Situ Vitrification configuration options will be studied further at a later date.

Each block within a configuration option performs a function within a system and is referred to as a "functional subelement." Functional and operational requirements (F&ORs) are defined for each functional subelement within the Retrieve/Ex Situ Thermal Treatment configuration option. The F&ORs will then direct the insertion of specific technologies into each functional subelement resulting in the formulation of technology process options (systems). A technology process option is a Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) term used

to describe a configuration option that has specific technologies or requirements defined for all functional subelements. The terms "system" and "technology process option" are used synonymously in the BWID Systems Analysis project.

The BWID Performance-Based Technology Selection Filter (PBTSE) is a tool developed within the scope of the BWID Systems Analysis that represents a formal methodology for selecting and rating candidate remediation technology process options. The PBTSE uses two components during its application. One component screens candidate systems against system requirements. The second component involves executing trade-off studies that rate technology process options against performance measures based on CERCLA selection criteria. This approach allows direct comparison between and among various systems and their constituent technologies.

This report provides a preliminary description of the various features of the PBTSE, as well as an explanation of its overall operation. A list of PBTSE-specific terms and their definitions is attached as Appendix B.

2. SYSTEM REQUIREMENTS

2.1 Definition of Requirements

System requirements are defined in the PBTFSF as a set of top-level constraints that guide the development and selection of viable remediation systems from a population of candidate remediation systems. These systems requirements are not the same as F&ORs associated with each of the functional subelements within a particular system.

2.2 Description

The selection of a remediation system is constrained by requirements such as waste/site characteristics, applicable or relevant and appropriate requirements (ARARs), and programmatic requirements defined by the U.S. Environmental Protection Agency (EPA), the U.S. Department of Energy, the State of Idaho, and the BWID program. PBTFSF system requirements are limited to those requirements that significantly affect the viability of a specific technology process option.

The system requirements, which are presented in Appendix C, have been generated from a combination of technical and regulatory sources including:

- Programmatic Requirements
 - Federal Facility Agreement and Consent Order (FFA/CO) (U.S. EPA, U.S. DOE, and State of Idaho)²
 - BWID Demonstration Plan³
- Input Requirements
 - Historical and technical characterizations of the INEL Subsurface Disposal Area^{4,a}
- Output Requirements
 - INEL RWMC Low-Level Waste Acceptance Criteria⁵
 - INEL TRU Waste Acceptance Criteria⁶
 - INEL RWMC Pad A ARARs^b

a. D. A. Arrhenholz, and J. L. Knight, *Historical Report of Transuranic Waste Pits and Trenches at the Subsurface Disposal Area of the Radioactive Waste Management Complex at the INEL*, WTD-91-027, August 1991.

b. Unpublished letter from S. G. Stiger (INEL Environmental Restoration) to W. N. Sato (DOE-ID), *Transmittal of the Revised Pad A Technical Memorandum on the Preliminary Identification of Combined Federal and State Applicable or Relevant and Appropriate Requirements (ARARs)*, SGS-15-91, December 5, 1991.

3. TRADE-OFF STUDIES

3.1 Definition

PBTSE trade-off studies are defined as a formal methodology to score technology process options using performance measures.

3.2 Derivation of Trade-Off Study Formulas

Since the INEL is designated as a Superfund site, it is appropriate to consult CERCLA to guide the evaluation of the candidate technology process options for remediating the TRU-contaminated Waste Pits and Trenches at the INEL. CERCLA provides the framework for evaluating end-to-end technology process options, or alternatives during a Feasibility Study (FS). The PBTSE methodology can be used for evaluating remedial alternatives for any Operable Unit at a CERCLA site or at a non-CERCLA site that is interested in conducting trade-off studies.

The primary objective of a CERCLA Feasibility Study is "to ensure that appropriate remedial alternatives are developed and evaluated such that relevant information concerning the remedial action options can be presented to a decision-maker and an appropriate remedy selected" (see Reference 2). A report entitled *Guidance on Feasibility Studies Under CERCLA EPA/540/G-85/003* and a revision entitled *Guidance for Conducting Remedial Investigations and Feasibility Studies Under CERCLA EPA/540/G-89/004* identify three categories of criteria that should be considered while evaluating technology process options—effectiveness, implementability, and cost. Twenty-two performance measures have been identified that reflect the text or implied meaning of the text associated with each evaluation criteria in the EPA guidance documents (see Figure 1). Excerpts of text that provide the basis for each performance measure factor are presented in Appendix D.

Formulas were developed that are used to generate numerical scores associated with each performance measure. These indicate quantitatively how well a technology process option performs relative to each performance measure. Appendix D lists these formulas. Inputs to the formulas are various system technical and institutional performance characteristics of the technology process option and are referred to as performance data (see Table 1). The following example illustrates the terminology associated with formulas and performance measures used within the PBTSE trade-off studies:

Example:

Criteria Category:	Effectiveness
Contributing Factor:	Volume Reduction
Formula:	$E1 = 1 - V_o/V_i$
Performance Measure:	E1
Performance Data:	V_o, V_i

Sources of performance data include manufacturers, proposers, lessons learned from technology demonstrations, and input requirements. When a system or technology has not been demonstrated,

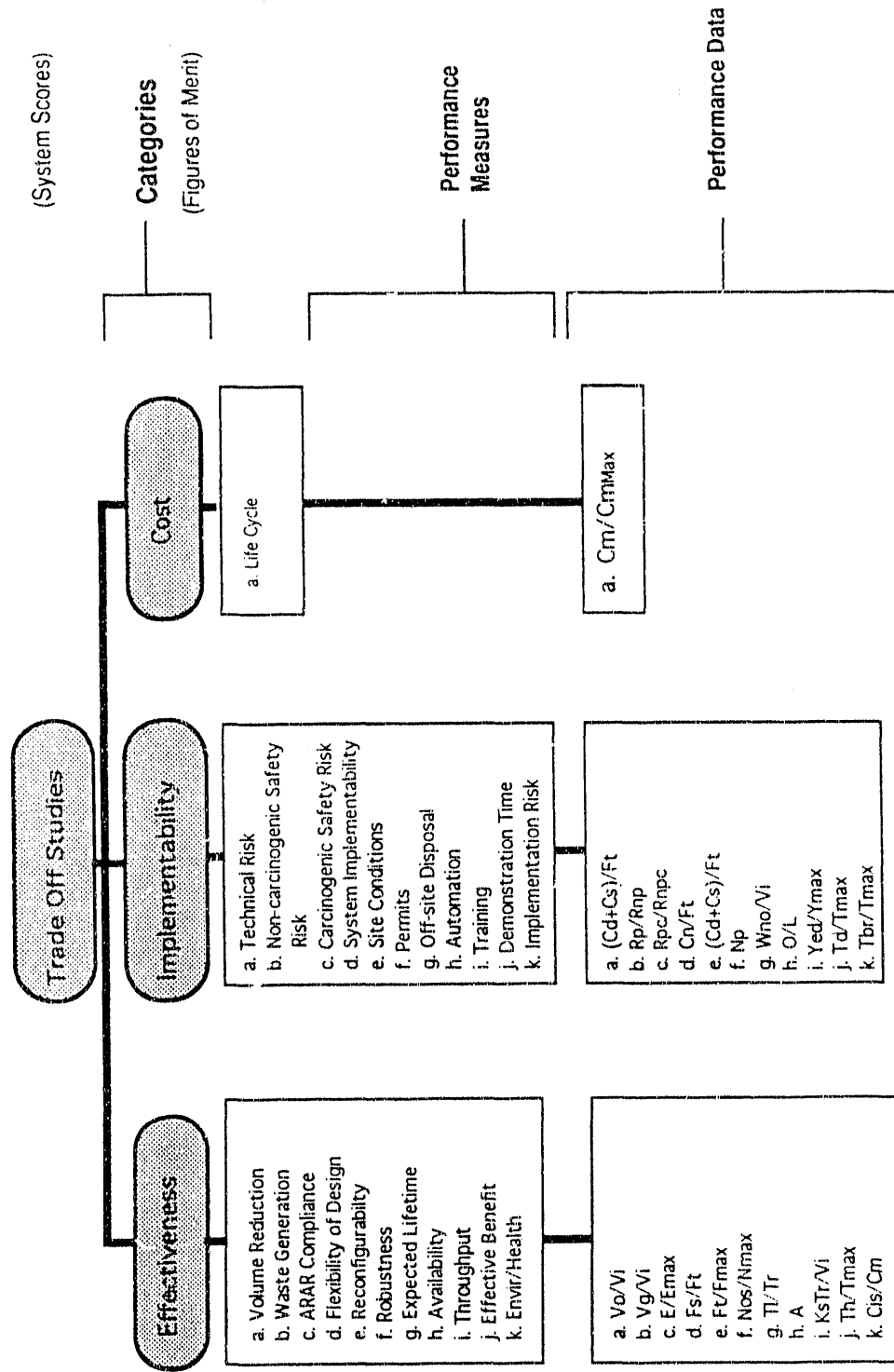


Figure 1. CERCLA derivation of performance measures.

Table 1. Performance data listing.

-
1. V_o = The volume (m^3) of output material from the process which requires monitoring and storage (includes any contaminated process material).
 2. V_i = The volume (m^3) of waste seam, matrix, overburden, and horizontal plume as defined in the input requirements.
 3. V_g = The volume (m^3) of contaminated process material produced by the system.
 4. E = Number of process-specific ARARs.
 5. F_s = COTS functional subelements.
 6. F_t = Total functional subelements.
 7. N_{OS} = Number of predefined out-of-scope inputs the system can remediate.
 8. T_l = Time until necessary line item and capital equipment replacement costs exceed 50% of acquisition cost.
 9. T_r = Time to remediate V_i .
 10. A = Availability.
 11. T_h = Time to remediate 50% of V_i .
 12. C_{is} = Important-to-safety expense
 13. C_m = Cost (life cycle).
 14. C_d = Number of subelements demonstrated under similar site and waste conditions.
 15. C_s = Number of subelements similar but not identical to a technology demonstrated under similar site and waste conditions.
 16. R_p = Hazard Index w/ process.
 17. R_{np} = Hazard Index w/o process.
 18. R_{pc} = Excess lifetime cancer risk w/ process (10^{-6})

Table 1. (continued).

-
19. R_{npc} = Excess lifetime cancer risk w/o process (10^{-6}).
20. C_n = Number of subelements not able to be demonstrated prior to full-scale implementation.
21. N_p = Number of special permits required specific to the remediation.
22. W_{no} = Volume of waste that cannot currently be moved to offsite disposal.
23. L = Operation labor hours.
24. O = Operation hours.
25. y = Mean years of specialized training (academic and facility specific).
26. T_d = Total critical path time to demonstrate.
27. T_{br} = Time to begin remediation.
-

performance data must be estimated and the uncertainty associated with the estimate identified. The Department of Defense Logistics, Supportability, and Availability (LSA) is an example of a technique that can be used to arrive at performance data estimates. Technical teams will review all performance data to ensure their validity. All input performance data, actual or estimated, will be documented for further reference.

All formulas generate performance measures whose values mostly fall between one and zero. One indicates high, or desirable performance, and zero indicates low, or undesirable performance.

3.3 Roll-Up Methodology

The performance data used to calculate performance measures may be collected at the system or the technology level. If the performance data are collected at the technology level, the data must be combined or "rolled-up" to generate system level performance data. This process is discussed in Appendix D. Techniques for rolling up data uncertainties have also been developed and are described in Appendix D.

3.4 System Scoring

Averaging all performance measures that contribute to a criteria category (Effectiveness, Implementability, or Cost) generates a number that is defined as the final value or "figure-of-merit". If desired, different weighting factors can be applied to each of the performance measures. This could be used to reflect the relative levels of importance of some measures over others.

An overall score for a technology process option is calculated by averaging the three figures of merit for Effectiveness, Implementability and Cost. Again, different weights can be applied to each of the three categories.

Note that CERCLA does not address the relative weighting of the parts that make up each category, nor does it address the relative weights of the categories to each other. The PBTSF is implemented using a computer program that will allow all the weightings to be set by Environmental Restoration, Buried Waste Program/BWID program.

4. FILTER OPERATION

Figure 2 illustrates the sequence of steps followed in the PBTSF to rate competing technology process options and generate specific technology development requirements. This section provides a detailed description of the various elements shown in Figure 2.

Initially, generic configuration options are developed that provide a description of a remediation system at a functional subelement level. Many possible technology process options may reflect the same configuration option, and differ only in performance characteristics of certain subelements. An example might be a melting and incineration configuration option analyzed with several different metal shredders. While each technology process option would have the same block diagram, their end-to-end performance characteristics will reflect each specific shredder technology. Candidate configuration options will be evaluated from a scientific/engineering standpoint to determine future consideration. Reasons for evaluating particular configuration options will be fully documented for future reference.

Specific technologies or performance requirements are defined for each functional subelement within a configuration option to develop technology process options. Technical experts will be consulted to provide and screen technology lists that are considered for each functional subelement. Again, reasons for considering technologies within a particular functional subelement will be fully documented for future reference.

Technology process options are formally assessed to determine if they meet system requirements. The results of applying the system requirements matrix will indicate explicitly which technology process options are or are not meeting system requirements and why. Those systems that do meet requirements are then addressed by the trade-off study function. The output of the trade-off study function is a score for each technology process option (also called a rating) that indicates how well the technology process options rate against the CERCLA-based formulas discussed in Section 3.

Technology process options that do not meet functional requirements are examined to determine where performance must be improved or, more specifically, what performance aspects of various functional subelements must be improved. An example might be a technical process candidate generating a waste form that cannot meet output requirements. Performance requirements are then defined at the subelement level such that system requirements can be met. Note that there may be one or more subelements that are responsible for a technology process option not meeting requirements. Thus, performance requirements may be identified for more than one subelement within a technology process option. These gaps, defined by performance requirements, may be filled by existing technologies that were not initially considered, or postulated innovative technologies. This process is called identification of technology gaps.

Postulated innovative technologies, as defined by their performance measures, are inserted into technology process options that do not meet system requirements, and the option is then reevaluated against the requirements matrix. If the technology process option meets all system requirements, it is then scored via trade-off studies, and its overall performance compared to scores of other technology process options. A score lower than other existing systems indicates that the postulated

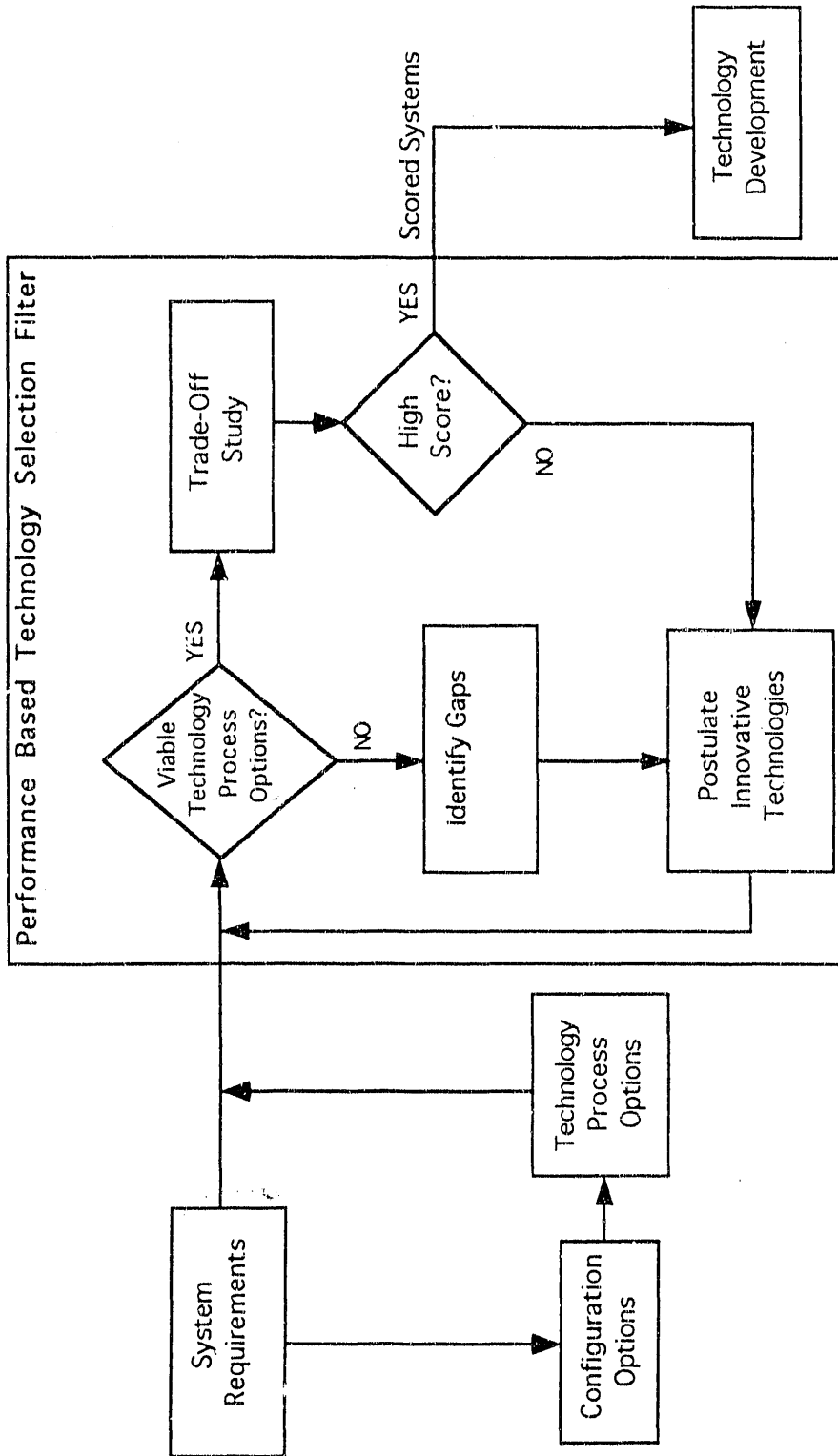


Figure 2. Performance-based technology selection filter methodology.

innovative technology will not benefit the process, and that new and higher performance requirements must be met to fill the technology gap.

This process can be iterated until a technology process option with a postulated technology generates a high system score. The assumed technology performance parameters then become requirements for technology development. Note, again, that requirements that the technology must meet are directly related to the score the technology process option must attain in order to compare favorably with existing technology process options that require little, if any further development.

5. CONCLUSION

The BWID PBTSF is a systems tool whose purpose is to provide a framework and formal methodology for selection and rating of technology process options and their enabling technologies. It also provides a closed-form approach to identify technology gaps and the requirements to fill those gaps.

There are five primary attributes of the BWID PBTSF. These are:

- Technology process options and their enabling technologies are rated and selected based on performance measures
- Selection and ratings are based solely on institutional and technical requirements, and are documentable and traceable
- Rating and selection is performed on complete systems
- Performance measures expressly define direct technology development
- Methodology is applicable to other remediation system analyses.

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3. K. M. Kostelnik, *Buried Waste Integrated Demonstration Plan*, EGG-WTD-9870, December 1991.
4. D. A. Arrenholz and J. L. Knight, *A Brief Analysis and Description of Transuranic Wastes in the Subsurface Disposal Area of the Radioactive Waste Management Complex at INEL*, EGG-WTD-9438 Rev. 1, 1991.
5. U.S. Department of Energy Idaho Field Office (DOE-ID), *INEL Low-Level Radioactive Waste Acceptance Criteria*, DOE/ID-10112 Rev. 4, October 1991.
6. U.S. Department of Energy Idaho Field Office (DOE-ID), *INEL Transuranic Waste Acceptance Criteria*, DOE/ID-100074, May 1991.

Appendix A
Configuration Option Example

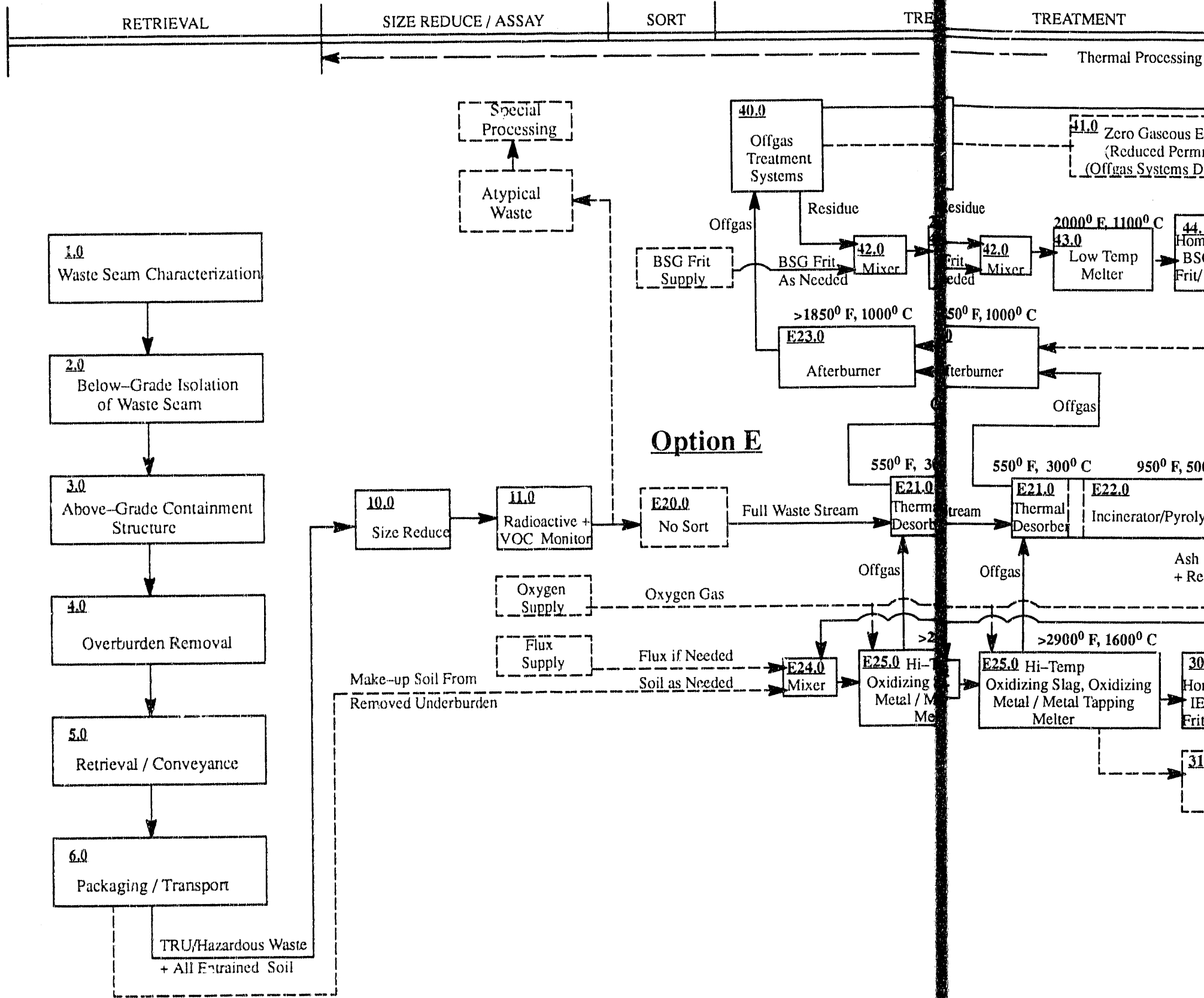
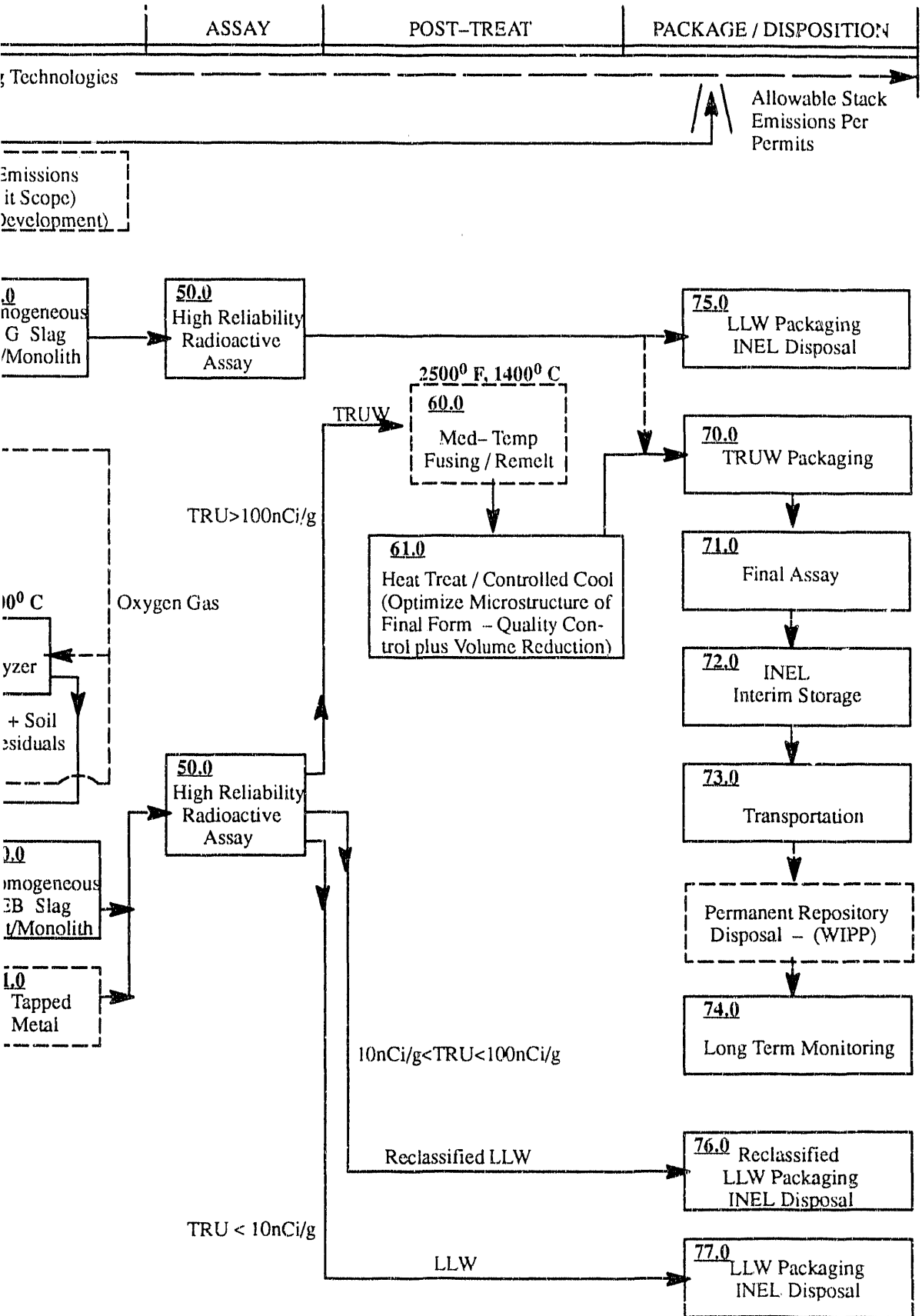


Figure A-1. BWID Retrieval/Ex Situ Thermal Treatment configuration option.



Appendix B

PBTSF Definition of Terms

Appendix B

PBTSF Definition of Terms

Configuration option	Top-level block diagram of a cradle-to-grave remediation whose overall performance is specified by system requirements.
Contributing factor	Defined indicator of one aspect of system performance derived from criteria used to evaluate technology process options.
Driver	Intuitively meaningful indicator of contributing factor performance.
Figure of merit	Numerical score or rating of a general category (effectiveness, implementability, and cost).
Functional subelement	One or more integrated components assembled to perform a function whose performance can be specified by the system requirements.
General category	One of the CERCLA development and screening criteria used in the filter to roll up scores (effectiveness, implementability, and cost).
Performance measure	System technical or institutional performance characteristic, used as input to formulas.
Similar subelement	Undemonstrated subelement that is similar to a demonstrated subelement.
Technology process option	Configuration option with specific technologies or requirements defined for all functional subelements

Appendix C

BWID Systems Analysis System Requirements

Appendix C

BWID Systems Analysis System Requirements

Programmatic Requirements

Only systems that characterize, retrieve, process, treat, package, and dispose of wastes buried in Pits 1-6, 9-15, 17, and Trenches 1-15, 19, 20, 26, 32, 34, 39, 45, 47-49, 51, and 55 of the Idaho National Engineering Laboratory (INEL) Subsurface Disposal Area (SDA) will be considered for further evaluation in this analysis. This particular group of disposal pits and trenches is called the Transuranic (TRU)-contaminated Waste Pits and Trenches and is designated by INEL Environmental Restoration as Operable Unit (OU) 7-13. Other types of remediation efforts such as in situ stabilization, containment/monitoring, and in situ treatments will not be considered in this phase of the Buried Waste Integrated Demonstration (BWID) Systems Analysis.

The U.S. EPA/State of Idaho/U.S. DOE Federal Facility Agreement and Consent Order¹ states, "The RD/RA process will be streamlined, to the extent possible, to meet the CERCLA requirement to commence substantial continuous physical on-site remedial action within 15 months of issuance of a ROD." Since a draft Record of Decision (ROD) is required for the TRU-contaminated Waste Pits and Trenches by July 1998, then a ROD will most likely be issued in 1999. Fifteen months after that date is in the year 2000. The requirement is that substantial actual remediation start in the year 2000. The implication is that remedial technologies must be sufficiently developed or developable so full-scale field implementation could begin no later than the year 1998. It might be that retrieval could begin in 1998 and separation/processing could be delayed as much as a couple of years. However, storage facilities would be required for the retrieved, unseparated waste/soil.

A draft Remedial Investigation/Feasibility Study (RI/FS) report for the TRU-contaminated Waste Pits and Trenches must be submitted to regulators for review by September 1997 per the U.S. EPA/State of Idaho/U.S. DOE Federal Facility Agreement and Consent Order. The results of any treatability study would be included in the RI/FS report. The results of the RI/FS must be sufficiently promising and rigorous to convince the reviewing regulators that the technology is viable for the response action. Therefore, technologies must be sufficiently developed or capable of development such that any required treatability studies could be successfully completed and documented by September 1997.

The 1991 DOE-HQ Environmental Restoration and Waste Management Five-Year Plan² states that remedial activities be completed by the year 2019. Therefore, technologies must be sufficiently developed or capable of development, and must have sufficient throughput, that the remediation of the TRU-contaminated Waste Pits and Trenches can be completed by the year 2019.

Input Requirements

Input Requirements Based on Physical Characteristics of Waste

A configuration option must be able to remediate the region within each pit or trench that encompasses the original excavation down to the depth of the underlying basalt. The boundary that defines the unit of waste (overburden, sideburden, underburden, and debris) to be retrieved is referred to as the "waste seam."

A configuration option must be able to characterize, retrieve, process, treat, package, and dispose of the following volumes of soil currently disposed of in the INEL TRU-contaminated Waste Pits and Trenches:^{3,4}

- 2,100,000 ft³ of underburden soil probably contaminated with radionuclides, metals, inorganic compounds, and organic compounds listed in Table C-1.
- 3,900,000 ft³ of interstitial soil probably contaminated with radionuclides, metals, inorganic compounds, and organic compounds listed in Table C-1.
- 3,650,000 ft³ of overburden soil potentially contaminated with radionuclides, metals, inorganic compounds, and organic compounds listed in Table C-1. Nonhazardous and non-TRU overburden that is removed will be placed back into the excavated pit or trench after retrieval operations are complete. Hazardous, TRU, and mixed waste soil will be packaged for treatment.

A configuration option must be able to remediate 160,500 55-gal or 120-gal steel drums assumed to be badly deteriorated.

A configuration option must be able to remediate 6,500 cardboard and plywood boxes ranging in size from 4 x 4 x 7 ft to 8 x 8 x 18 ft and weighing up to 5,000 lbs. The boxes are assumed to be badly deteriorated.

Boxes and drums are expected to contain the types of contaminated items listed in Table C-1.

A configuration must be able to retrieve, process, treat, and dispose of the following kinds of infrequently-encountered contaminated buried items that are up to 12,000 lbs and size of 4 x 4 x 8 ft.:

- Presses
- Drill presses
- Shears
- Circle shears
- Lathes
- Steel buoys
- Steel culverts
- Keller cans (steel)
- Additional items found in Table C-1.

Table C-1. Summary makeup of wastes buried in the SDA at RWMC (see References 3 and 4).

Construction and Demolition Material

Lumber, wallboard, steel plate and shapes, ducting, electrical wires, fuse boxes, roofing material, floor tile, insulation, lead sheet and bricks, asphalt paving material, soil, sand, gravel, steel stairways, ladders, and concrete blocks.

Laboratory Equipment and Materials

Hoods, laboratory benches, desks, chairs, cabinets, glassware, plastic tubing, plastic and glass bottles, solutions stabilized in concrete, plaster, or vermiculite.

Process Equipment

Tanks, heat exchangers, tube bundles, condensers, vacuum pumps, piping, cut up wide flange beams, valves, organic wastes, ion exchange resins, zirconium plate, zirconium turnings, sawdust, HEPA filters, steel buoys, and steel culverts.

Maintenance Equipment

Hand tools, metal-working machines, hoists, welders, oils and grease, metal filings, abrasive wheels and sheet, drill presses, shear, circle shear, lathes, bridge crane with rails, casting furnaces, and coating furnaces.

Decontamination Materials

Paper, rags, plastic bags and sheet, floor sweepings, brooms, and steel wool.

Miscellaneous

Sewer sludge, garbage, animal remains and excreta, jet engines, vehicles, Test Reactor Area fuel end boxes, 55-gal and 120-gal steel drums (assumed to be badly deteriorated), cardboard boxes (assumed to be badly deteriorated), reactor shield, storage tanks, and keller cans.

Note: Table C-1 is a listing for the entire SDA. For the purposes of this study, it is considered to be representative of the types of wastes believed to be buried in the INEL TRU-contaminated Waste Pits and Trenches (OU 7-13).

A system must be able to characterize and relocate the following kinds of infrequently-encountered oversize and overweight contaminated items (includes any items greater than 12,000 lbs and 4 x 4 x 8 ft):

- 14-in and 24-in wide flange beams, cut (length unknown)
- Concrete blocks 150 ft³ - 284 ft³, 13.95 tons average
- Concrete conduits, up to 3 tons each
- Aluminum heat exchangers, 26.5 ft length x 5 ft diameter, 19,960 lbs.
- Some additional oversize and overweight items are listed in Table 1 of this Appendix (e.g., bridge crane with rails)

These infrequently-encountered oversize and/or overweight and/or high activity items are considered "atypical wastes" and may be left on the floor of the excavated pit or trench and/or shielded and/or fixed to prevent aerosolization of contaminants.

Input Requirements Based on Waste Classification

A system must be able to retrieve and process waste that is within the range of physical characteristics previously described and that may be contaminated with some or all of the radionuclides and hazardous constituents listed in Table C-2 such that it is not high-level waste or spent fuel.

Output Requirements

Output Requirements Based on Waste Classification and Waste Acceptance Criteria

Output wastes of a configuration option must fall into one of the following seven categories: "clean" waste, low-level waste, hazardous waste, TRU, TRU-mixed wastes, low-level mixed waste, or atypical wastes. All packaged final "clean," low-level, TRU, hazardous, low-level mixed, and TRU-mixed waste forms must meet applicable waste acceptance criteria and Applicable or Relevant and appropriate requirements (ARARs). Waste Acceptance Criteria (WAC) requirements are outlined below.

"Clean" Waste

Without a legal, enforceable definition of "Below Regulatory Concern," all waste exhibiting characteristics of being radioactive will be considered radioactive waste. Radioactive wastes, for the purposes of this analysis, are defined as wastes containing naturally occurring radionuclides that are in concentrations greater than naturally occurring and/or any measurable amount of man-made radionuclides. Background levels of naturally occurring radionuclides have been determined in soil samples in towns surrounding the INEL.⁵ Naturally occurring radionuclides buried in OU 7-13 that must be remediated down to background levels include Thorium-232, Uranium-238, Uranium-234, and Radium-226. The background levels for these radionuclides are:

Table C-2. Waste Constituents Disposed of in TRU Waste Pits and Trenches at the SDA (see References 3 and 4).

<u>Radionuclides^a (half-life)</u>	<u>Metals</u>
Aluminum-26 (8 x 10 ⁵ y)	Aluminum
Americium-241 (458 y)	Beryllium
Californium-252 (sf 85 y)	Copper
Carbon-14 (5730 y)	Iron
Cesium-137 (30 y)	Lead
Chlorine-36 (3 x 10 ⁵ y)	Lithium
Cobalt-60 (5.23 y)	Magnesium
Curium-244 (17.6 y)	Mercury
Neptunium-237 (2.14 x 10 ⁶ y)	Molybdenum
Nickel-63 (92 y)	Platinum
Plutonium-238 (86.4 y)	Potassium (NaK)
Plutonium-239 (24,390 y)	Sodium Metal
Plutonium-240 (6580 y)	Stainless Steel
Plutonium-241 (13.2 y)	Tantalum
Plutonium-242 (3.8 x 10 ⁵ y)	Tin
Radium-226 (1602 y)	Yttrium as Y ₂ O ₃
Strontium-90 (28.1 y)	Zircaloy
Thallium-204 (3.81 y)	Zirconium
Thorium-232 (1.41 x 10 ¹⁰ y)	Zinc
Tritium (12.3 y)	
Uranium-233 (1.6 x 10 ⁵ y)	
Uranium-234 (2.47 x 10 ⁵ y)	
Uranium-235 (7.1 x 10 ⁸ y)	
Uranium-238 (4.51 x 10 ⁹ y)	
Yttrium-91 (58.8 d)	
<u>Inorganics</u>	<u>Organics</u>
Alumina Brick	Acetic Acid
Argon (gas)	Acetic Anhydride
Asbestos	Anthracene
Beryllium Oxide	Benzene
Calcium Silicate	Santo Wax
Chrome Brick	Butyl Stearate
Euxenite Ore Residue	Carbon Tetrachloride
Graphite	Cellulose
Hydrated Aluminum Oxides	Diisopropyl Fluorophosphate
Hydrated Iron Oxides	Dimethyl (1,4 bis-phenyloxazolyl benzene)
Hydrated Magnesium Oxides	Diphenyls
Hydrated Plutonium Oxides	Ether
Hydrated Silicon Oxides	Ethylene Glycol
Hydrochloric Acid	

Table C-2. (continued)

Inorganics (continued)

Hydrofluoric Acid
Iron Oxides
Lime
Lithium Hydride
Nitric Acid
Perchloric Acid
Portland Cement
Silica
Sulfuric Acid
Thallium Oxide
Uranium-Zirconium Hydride
Zirconia Brick

Salts

Barium Carbonate
Barium Fluoride
Iron Chlorides
Potassium Nitrate
Sodium Chloride
Sodium Nitrate
Thorium Fluoride
Uranium Fluoride
Radium Salts
Metal Chlorides

Miscellaneous Oils

Gearbox Oil
Hydraulic Oil
Machining Oil
Spindle Oil

Organics (continued)

Formalin and Formaldehyde
Freon
Gasoline
Methocel 400
Methyl Alcohol
3-methylcholanthrene
Nitrobenzene
Nitrocellulose
Organophosphates
Paraffin
Perchloroethylene
Polyethylene
Polychlorinated Biphenyls
Polyvinyl Chloride
Polyurethane Foam
Sodium Isobutyrate
Texaco Regal Oil
Terphenyls (ortho, meta, and para)
Toluene
1,1,1-Trichloroethane
Trichloroethylene
Varsol
VERSENE (Ethylene Diaminetetraacetic Acid)
Xylene

Unidentified Items

Acids
Alcohols
Amino Acids
Esters
Insecticides
Plastics
Proteins
Pyrimidines
Solvents

a. References 3 and 4 list mixed fission products, mixed activation products, and unidentified beta/gamma emitters as being present in the wastes. For the purposes of this study, those categories of radionuclides will include only a mixture of radionuclides found in Table C-2.

Thorium-232 - 13 ± 3 pCi/g
Uranium-238 - 14 ± 3 pCi/g
Uranium-234 - 14 ± 3 pCi/g
Radium-226 - 14 ± 3 pCi/g.

Determining whether a waste is contaminated with man-made radionuclides is dependent upon the lower threshold at which state-of-the-art radiation detection systems can measure radiation. Therefore, for the purposes of this analysis, all wastes contaminated with the remainder of radionuclides in Table C-2 at any point in time will always be considered radioactive.

Low-Level Wastes

For the purpose of this analysis, low-level waste (soil/debris) is defined as waste that contains radioactivity and is not classified as high-level waste, transuranic waste, spent fuel, or by-product material as defined in Section 11e(2) of the Atomic Energy Act.⁶ Test specimens of fissionable material irradiated for research and development only, and not for the production of power or plutonium, may be classified as low-level waste, provided the concentration of transuranic is less than 10 nCi/g. A limit of 10 nCi/g was chosen over the regulatory limit of 100 nCi/g for transuranics because all low-level waste generated in systems will be eventually disposed of at the INEL Radioactive Waste Management Complex (RWMC) that considers waste with < 10 nCi/g transuranics low-level waste.

Therefore, all low-level wastes shipped to the RWMC for disposal must meet RWMC waste acceptance criteria outlined in DOE/ID-10112 Rev. 4 entitled, "INEL Low-Level Radioactive Waste Acceptance Criteria."⁷

Hazardous Wastes

For the purpose of this analysis, hazardous waste is defined as those waste types containing constituents in Table C-2 that are considered to be hazardous by EPA regulation Title 40 Code of Federal Regulations Part 261 (40CFR261). All hazardous wastes originating from a configuration option will be packaged and shipped to the INEL Hazardous Waste Storage Facility (HWSF) for interim storage. Therefore, all hazardous wastes must meet HWSF waste acceptance criteria.⁸

Pure TRU and TRU-Mixed Wastes

For the purpose of this analysis, TRU waste is defined as waste that is contaminated with alpha-emitting transuranium radionuclides with half-lives greater than 20 years and concentrations greater than 10 nCi/g at the time of assay. Transuranic-mixed wastes will be defined in this study as those waste types containing both (a) constituents in Table C-2 considered to be hazardous by 40CFR261 and (b) radioactive constituents listed in Table C-2.

Currently, there is no repository for the disposition of exhumed TRU and TRU-mixed wastes. A limit of 10 nCi/g was chosen over the regulatory limit of 100 nCi/g for transuranics because all pure TRU and TRU-mixed wastes originating from a configuration option are assumed to be packaged and shipped to the INEL for interim storage. The INEL RWMC will not accept waste with a concentration of transuranics > 10 nCi/g for low-level waste disposal. TRU and TRU-mixed wastes

shipped to the RWMC for interim storage must meet all requirements outlined in DOE/ID-10074, a revised draft of a report entitled, "INEL Transuranic Waste Acceptance Criteria."⁹

Low-Level Mixed Waste

Low-level mixed wastes will be defined in this study as those waste types containing constituents in Table C-2 considered to be hazardous by 40CFR261 and containing radioactive constituents listed in Table C-2. Currently, there is no repository for the disposition of exhumed low-level mixed wastes. Therefore, all low-level mixed wastes originating from a system option are assumed to be packaged and shipped per the INEL Radioactive Mixed Waste Storage Facility (MWSF) waste acceptance criteria¹⁰ for interim storage.

Atypical Wastes

Wastes outside the bounds of the requirements listed in Input Requirements Based on Physical Characteristics of Waste section of this Appendix for the purposes of this study, will be considered atypical waste and the system shall characterize them and leave them in the excavated pit or trench. Retrieval, processing, treatment, or packaging of atypical wastes discovered during a configuration option will not be considered in this phase of the analysis.

ARARs

The statutory and regulatory basis for compliance with ARARs during the remediation of INEL OU 7-13 is contained in CERCLA Section 121, Cleanup Standards; NCP Subpart E - "Hazardous Substances Response"; and the INEL Federal Facility Agreement/Consent Order. CERCLA Section 121 (d) (2) requires that remedial actions comply with ARARs for any hazardous substance, pollutant or contaminant remaining onsite. Table C-3 is a preliminary list of Federal ARARs and DOE orders that will be used to define output requirements in the BWID Systems Analysis. This information was adopted from preliminary ARARs identified for the INEL Pad A in a letter from S. G. Stiger to W. N. Sato (SGS-515-91).¹¹ It should be noted that State and local ARARs are not considered in the BWID Systems Analysis. Federal ARARs are assumed at *this point in time* to adequately represent all cleanup restrictions. A final list of ARARs (Federal, State, and Local) will be refined by Environmental Restoration through the RI/FS process.

Table C-3. Preliminary list of ARARs to be used in the BWID systems analysis.

Statute

Safe Drinking Water Act

Regulation

40 CFR Part 141, National Primary Drinking Water Standards

40 CFR Part 141, Maximum Contaminant Level Goals

40 CFR Part 143, National Secondary Drinking Water Standards

Statute

Atomic Energy Act and Energy Reorganization Act

Regulation

10 CFR Part 20, US Nuclear Regulatory Commission (NRC) Standards for Protection Against Radiation

10 CFR Part 60, Technical Requirements for Land Disposal Facilities

10 CFR Part 61, Licensing Requirements for Land Disposal of Radioactive Waste

Statute

Resource Conservation and Recovery Act

Regulation

40 CFR Part 241, Guidelines for Land Disposal of Solid Waste

40 CFR Part 257, Criteria for Classification of Solid Waste Disposal Facilities and Practices

40 CFR Part 260, Hazardous Waste Management Systems

40 CFR Part 261, Identification and Listing of Hazardous Waste

40 CFR Part 262, Standards Applicable to Generators of Hazardous Waste

40 CFR Part 263, Standards Applicable to Transporters of Hazardous Wastes

40 CFR Part 264, Maximum Concentration Limits

Table C-3. (continued)

40 CFR Part 265, Requirements for Interim Status Facilities

40 CFR Part 268, Land Disposal Restrictions

Statute

Clean Air Act

Regulation

40 CFR Part 50, National Primary and Secondary Ambient Air Quality Standards

40 CFR Part 61, National Emission Standards for Hazardous Air Pollutants

40 CFR Part 61.90, National Standards for Radionuclide Emissions from DOE Facilities

Statute

Occupational Health and Safety Act

Regulation

40 CFR Part 1910, Occupational Health & Safety Standards

29 CFR Part 1926, Health and Safety Standards for Construction

The following U.S. DOE Orders, although not typically considered ARARs, will also be considered as output requirements:

DOE Orders

5480.1B Environment, Safety and Health Program for DOE Operations

5480.3 Hazardous and Radioactive Mixed Waste Management

5480.4 Environmental Protection, Safety and Health Protection Standards

5820.2A Radioactive Waste Management

5400.5 Radiation Protection of the Public and the Environment

Table C-3. (continued)

5480.11 Radiation Protection of Occupational Workers

6430.1A General Design Criteria

REFERENCES

1. *Federal Facility Agreement and Consent Order*, ADN: 1088-06-29-120, Idaho National Engineering Laboratory, May 1991.
2. U.S. Department of Energy, *Environmental Restoration and Waste Management Five-Year Plan*, Fiscal Years 1993-1997, August 1991.
3. D. A. Arrenholz and J. L. Knight, *A Brief Analysis and Description of Transuranic Wastes in the Subsurface Disposal Area of the Radioactive Waste Management Complex at INEL*, EGG-WTD-9438 Rev. 1, 1991.
4. D. A. Arrenholz and J. L. Knight, *Historical Report of Transuranic Waste Pits And Trenches at The Subsurface Disposal Area of The Radioactive Waste Management Complex at The INEL*, WTD-91-027, August 1991.
5. K. L. Martin et al., *Preliminary Assessment of Surface Soils at Active EG&G Idaho Facilities Data Document*, EGG-ESQ-9225, September 1990.
6. U.S. Department of Energy *Radioactive Waste Management*, DOE Order 5820.2A, September 26, 1988.
7. U.S. Department of Energy Idaho Field Office (DOE-ID), *INEL Low-Level Radioactive Waste Acceptance Criteria*, DOE/ID-10112 Rev. 4, October 1991.
8. U.S. Department of Energy Idaho Field Office (DOE-ID), *Hazardous Waste Storage Facility Waste Acceptance Criteria*, DOE/ID-10179, January 1992.
9. U.S. Department of Energy, Idaho Field Office (DOE-ID), *INEL Transuranic Waste Acceptance Criteria*, DOE/ID-100074, May 1991.
10. U.S. Department of Energy, Idaho Field Office, *Radioactive Mixed Waste Storage Facility Waste Acceptance Criteria*, December 1986.
11. *Transmittal of the Revised Pad A Technical Memorandum on the Preliminary Identification of Combined Federal and State Applicable or Relevant and Appropriate Requirements (ARARs)*, Letter from S. G. Stiger (INEL Environmental Restoration) to W. N. Sato (DOE-ID), SGS-515-91, December 5, 1991.

Appendix D
Filter Formula Derivation from CERCLA

Appendix D

Filter Formula Derivation from CERCLA

The following is a list of equations used within the trade-off study function of the PBTSF to obtain system performance measure values, and eventually, figures-of-merit for effectiveness, implementability, and cost. A description of performance data used in each formula is also included. The formulas were derived from text found in EPA/G-85/003 (Guidance On Feasibility Studies Under CERCLA) and EPA/G-89/004 (Guidance for Conducting Remedial Investigations and Feasibility Studies under CERCLA). All page number references in the discussion were taken from EPA 540/G-85/003.

A description of how performance data error and performance measure error are propagated is also provided. Two assumptions were made to simplify the error propagation methodology:

- Performance data are assumed to be statistically independent.
- Uncertainties (error) associated with the performance data are assumed to be quoted as standard error that is defined as sigma (standard deviation) over the square root of n (number of observations). For example, if a vendor indicates that it requires 100 person-hours +/- 10 person-hours to operate a backhoe during a particular remediation task, the performance datum would be 100 person-hours and the standard error would be 10 person-hours.

A. Effectiveness

1. Volume Reduction

Page 3-2, Sec. 3.1.1, paragraph 1: "Remedial alternatives should be evaluated in terms of their ability to perform intended functions, such as containment, diversion, removal, destruction, or treatment."

This score assesses the ability of the system to reduce waste volume. A measurable way of expressing this is net output volume divided by net input volume.

Performance Measure:

$$E_1 = 1 - V_o/V_i$$

Performance Data:

V_o = The volume (m^3) of output material from the process that requires monitoring and storage (includes any contaminated process material).

V_i = The volume (m^3) of waste matrix, overburden, and horizontal plume as defined in the input system requirements.

Performance Data Error Propagation:

Calculate the standard error for the system performance data V_o using:

$$SE_{V_o} = \sqrt{\sum_{i=1}^n SE_{V_{oi}}^2}$$

where

SE_{V_o} = The Standard Error of the system performance data V_o .

$SE_{V_{oi}}$ = The Standard Error of V_o for the i^{th} subelement in the technology process option.

n = The number of subelements in the technology process option.

V_i has been estimated from historical data; the concept of standard error does not apply.

Performance Measure Error Propagation:

Calculate the standard error for the volume reduction performance measure E_1 using:

$$SE_{E_1} = \frac{SE_{V_o}}{V_i}$$

where

SE_{E_1} = The Standard Error of the performance measure E_1 (volume reduction).

SE_{V_o} = The Standard Error of the system performance data V_o .

V_i = The volume (m^3) of waste matrix, overburden, and horizontal plume as defined in the input system requirements.

2. Waste Generation

Page 3-2, Sec. 3.1.1, paragraph 1: "Remedial alternatives should be evaluated in terms of their ability to perform intended functions, such as containment, diversion, removal, destruction, or treatment."

This score assesses the ability of the system to minimize waste generation. A measurable way of expressing this is the ratio of the volume of contaminated process material to the volume of input waste.

Performance Measure:

$$E_2 = 1 - \frac{V_g}{V_i}$$

Performance Data:

V_g = The volume (m^3) of contaminated process material produced by the system.

V_i = The volume (m^3) of waste matrix, overburden, and horizontal plume as defined in the input system requirements.

Performance Data Error Propagation:

Calculate the standard error for the system performance data V_g using:

$$SE_{V_g} = \sqrt{\sum_{i=1}^n SE_{V_{gi}}^2}$$

where

SE_{V_g} = The Standard Error of the system performance data V_g .

$SE_{V_{gi}}$ = The Standard Error of V_g for the i^{th} subelement of the technology process option.

n = The number of subelements in the technology process option.

V_i has been estimated from historical data; the concept of standard error does not apply.

Performance Measure Error Propagation

Calculate the standard error for the waste generation performance measure using:

$$SE_{E_2} = \frac{SE_{V_g}}{V_i}$$

where

SE_{E_2} = The Standard Error of the performance measure E_2 (waste generation).

SE_{V_g} = The Standard Error of the system performance data V_g .

V_i = The volume (m^3) of waste matrix, overburden, and horizontal plume as defined in the input system requirements.

3. Compliance with ARARs

Page 3-2, Sec. 3.1.1, paragraph 2: "The user should establish which environmental and public health standards are relevant or applicable at the site and evaluate proposed alternatives according to those standards."

Compliance with ARARs is measured as the degree to which process-specific ARARs are satisfied.

Performance Measure:

$$E_3 = \frac{E}{E_{\max}}$$

Performance Data:

E = The total number of process-specific ARARs satisfied by the technology process option.

E_{\max} = The total number of process-specific ARARs associated with any of the initial suite of technology process option being considered.

Performance Data Error Propagation:

The performance data for this measure are collected at the system level; the concept of a standard error does not apply.

Performance Measure Error Propagation:

The concept of a standard error does not apply in this case.

4. Flexibility of Design

Page 3-2, Sec. 3.1.1, paragraph 4: "Any special site or waste conditions that affect performance should be considered, and the design should be tailored to accommodate those conditions."

The flexibility of design performance measure assesses the flexibility of the system or subsystems after construction. The flexibility of the system is estimated by measuring the fraction of the system consisting of replaceable COTS (commercial off-the-shelf) parts or components. It assumes that systems that have a high proportion of COTS parts can be modified more easily than systems that have a high proportion of custom parts. (See definitions for COTS)

Performance Measure:

$$E_4 = \frac{F_s}{F_t}$$

Performance Data:

F_s = The number of functional subelements within a configuration option whose requirements are satisfied with commercial-off-the-shelf technologies (COTS).

F_t = The total number of functional subelements in the configuration option.

Performance Data Error Propagation:

The concept of a standard error does not apply in this context.

Performance Measure Error Propagation:

The concept of a standard error does not apply in this context.

5. Reconfigurability

Page 3-2, Sec. 3.1.1, paragraph 4: "Any special site or waste conditions that affect performance should be considered, and the design should be tailored to accommodate those conditions."

This score assesses the ability to reconfigure the system or subsystems after construction. A measurable way of estimating the reconfigurability of the system is to measure the total number of functional subelements. This assumes that systems that have many parts or operations can be modified more easily than systems that are composed of only a few parts or operations.

Performance Measure:

$$E_5 = \frac{F_t}{F_{\max}}$$

Performance Data:

F_t = The total number of functional subelements in the configuration option.

F_{\max} = The maximum number of subelements in any of the initial suite of configuration options being considered.

Performance Data Error Propagation:

The concept of a standard error does not apply in this context.

Performance Measure Error Propagation:

The concept of a standard error does not apply in this context.

6. Robustness

Page 3-2, Sec. 3.1.1, paragraph 4: "Any special site or waste conditions that affect performance should be considered, and the design should be tailored to accommodate those conditions."

This is a measure of the system's ability to accommodate unanticipated inputs without modification to the system.

Performance Measure:

$$E_6 = \frac{N_{OS}}{N_{max}}$$

Performance Data:

N_{OS} = The number of predefined out of scope inputs as defined in the input system requirements that the system can remediate.

N_{max} = The number of predefined out of scope inputs defined in the input system requirements.

Performance Data Error Propagation:

The concept of a standard error does not apply in this context.

Performance Measure Error Propagation:

The concept of a standard error does not apply in this context.

7. Expected Lifetime

Page 3-3, Sec. 3.1.2, paragraph 1: "Each alternative should be evaluated in terms of the projected service lives of its component technologies."

This performance measure is intended to measure the ability of the system to remain operational throughout the remediation process. It is measured as the ratio of the expected time until the line item and capital equipment replacement costs necessary exceed 50% of the acquisition cost to the total remediation time.

Performance Measure:

$$E_7 = \frac{T_l}{T_r}$$

Performance Data:

T_l = The time until line item and capital equipment replacement costs exceed 50% of acquisition cost. T_l is obtained by first integrating the sum of all line item and capital equipment replacement costs for each technology over time. T_l is the point in time when this integral equals half the system acquisition cost.

T_r = The time it will take to remediate V_i .

Performance Data Error Propagation:

The concept of a standard error for T_r does not apply in this context.

Performance Measure Error Propagation:

Calculate the expected lifetime performance measure standard error using:

$$SE_{E_7} = \sqrt{\frac{SE_{T_l}^2}{T_r^2} + \frac{T_l^2 \times SE_{T_r}^2}{T_r^4}}$$

where

SE_{E_7} = The Standard Error on the performance measure E_7 (expected lifetime).

SE_{T_l} = The Standard Error on the system performance data T_l .

SE_{T_r} = The Standard Error on the system performance data T_r .

T_l = The time until line item and capital equipment replacement costs exceed 50% of acquisition cost.

T_r = The time it will take to remediate V_i .

This formula has been derived from the normal law of errors,^c which states that

$$\alpha^2 = \left(\frac{\delta F}{\delta m_i}\right)^2 \alpha_1^2 + \left(\frac{\delta F}{\delta m_i}\right)^2 \alpha_2^2 + \dots + \left(\frac{\delta F}{\delta m_i}\right)^2 \alpha_n^2$$

c. J. Topping, *Errors of Observation and Their Treatment*, Chapman and Hall Limited, London, 1966.

where

- α = The standard error of the function
- F = The function being considered
- m_i = The means which comprises F
- α_i = The standard errors associated with m_i .

Note that by using the formula we have assumed T_1 and T_r are means from Gaussian distributions.

8. Availability

Page 3-3, Sec. 3.2.1, paragraph 1: "Technologies requiring frequent or complex operation and maintenance activities should be regarded as less reliable than technologies requiring little or straightforward operation and maintenance." Availability is measured as the fraction of time during the remediation process that the system is available.

Performance Measure:

$$E_g = A$$

Performance Data:

- A = The fraction of time during the remediation process that the system is available. The system performance data A is the product of all subelement availabilities. The availability of a subelement is the fraction of time during the remediation process that the subelement is available.

Performance Data Error Propagation:

Calculate the performance data error propagation for A using:

$$SE_A = \prod_{j=1}^n A_j \times \sqrt{\sum_{i=1}^n \left(\frac{SE_{A_i}}{A_i} \right)^2}$$

where

- SE_A = The Standard Error of the system performance data A (availability).
- SE_{A_i} = The Standard Error of i^{th} subelement's availability.
- A_j = The availability of j^{th} subelement.
- A_i = The availability of the i^{th} subelement.

n = The number of subelements in the technology process option.

j = The number of subelements in the technology process option.

This formula assumes subelement availabilities are from independent, Gaussian distribution (see SE_{E_7}).

Performance Measure Error Propagation:

The performance measure E_8 is identical to the system performance data A. The standard error for E_8 is SE_A in the formula above.

9. Throughput

Page 3-2, Sec. 3.1.1, paragraph 1: "Remedial alternatives should be evaluated in terms of their ability to perform intended functions."

Throughput is measured as the time per unit of waste remediated.

Performance Measure:

$$E_9 = \frac{K_s T_r}{V_i}$$

Performance Data Roll-Up:

T_r = The time (years) to remediate V_i .

V_i = The volume (m^3) of waste matrix, overburden, and horizontal plume as defined in the input system requirements.

K_s = A site specific normalizing constant ($m^3/year$) that will force the performance measure to be between 0 and 1.

Performance Data Error Propagation:

The performance data T_r is collected at the system level. No performance data error propagation occurs. V_i has been estimated from historical data; the concept of standard error does not apply.

Performance Measure Error Propagation:

Calculate the standard error for the performance measure E_9 using:

$$SE_{E_9} = \frac{V_i \times SE_{T_r}}{1000 \times T_r^2}$$

where

- SE_{E_9} = The Standard Error of the performance measure E_9 (throughput)
 SE_{T_r} = The Standard Error of the system performance data T_r .
 V_i = The volume (m^3) of waste matrix, overburden, and horizontal plume as defined in the input system requirements.
 T_r = The time (years) to remediate V_i .

10. Effective Benefit

Page 3-5, Sec. 3.3.2.2, paragraph 1: "The user should evaluate each alternative in terms of the time it takes to see beneficial results in the environment, exclusive of measures that provide temporary protection."

Effective benefit is measured as the time required to remediate 50% of the waste.

Performance Measure:

$$E_{10} = 1 - \frac{T_h}{T_{max}}$$

Performance Data:

- T_h = The time (years) to remediate 50% of V_i .
 T_{max} = The maximum time (years) allowed for the remediation process.

Performance Data Error Propagation:

The performance data for this measure are collected at the system level. The concept of standard error does not apply.

Performance Measure Error Propagation:

The standard error for the performance measure E_{10} (effective benefit) is calculated using:

$$SE_{E_{10}} = \frac{SE_{T_h}}{T_{max}}$$

where

- $SE_{E_{10}}$ = The Standard Error of the performance measure E_{10} (effective benefit).
 SE_{T_h} = The Standard Error of the system performance data T_h .
 T_{max} = The maximum time (years) allowed for the remediation process.

11. Environmental/Public Health

Page 3-5, Sec. 3.4, paragraph 1: "Each remedial alternative should be evaluated with regard to safety. This evaluation should include short-term and long-term threats to the safety of nearby communities and environments as well as those to workers during implementation. Major risks to consider are fire, explosion, and exposure to hazardous substances resulting due to both on-site and off-site activities during remedial action implementation."

This score assesses the ability of the system to maintain a safe environment. A measurable way of expressing this is the ratio of the capital costs defined as "important-to-safety" to the life-cycle cost of the system. Labor costs are not incorporated in this measure.

Performance Measure:

$$E_{11} = 1 - \frac{C_{is}}{C_m}$$

Performance Data:

C_{is} = The total capital expenses that are "important-to-safety" items.

C_m = The total life-cycle cost.

Performance Data Error Propagation:

The performance data for this measure are collected at the system level. The concept of standard error does not apply.

Performance Measure Error Propagation:

The concept of standard error is not applicable in this context.

B. Implementability

1. Technical Risk

Page 3-3, Sec 3.2.2, paragraph 1: "The user should give preference to technologies that have proven effective under waste and site conditions similar to those anticipated.

Technical Risk is assessed as the proportion of the system that has been demonstrated under similar waste and site conditions, plus the proportion of the system that is similar to technology demonstrated under similar waste and site conditions.

Performance Measure:

$$I_1 = \frac{C_d + C_s}{F_t}$$

Performance Data:

C_d = The number of subelements in a configuration option whose requirements are satisfied with technologies that have been demonstrated under similar site and waste conditions.

C_s = The number of subelements in a configuration option whose requirements are satisfied with technologies that are similar to technologies demonstrated under similar site and waste conditions.

F_t = The total number of subelements in a configuration option.

Performance Data Error Propagation:

The performance data for this measure are collected at the system level. The concept of standard error does not apply.

Performance Measure Error Propagation:

The concept of standard error is not applicable in this context.

2. Non-Carcinogenic Safety Risk

Page 3-5, Sec. 3.4, paragraph 1: "Each remedial alternative should be evaluated with regard to safety. This evaluation should include short-term and long-term threats to the safety of nearby communities and environments."

This score assesses the ability of the system to maintain a safe environment. A measurable way of expressing this is the ratio of the Hazard Index with the process to the Hazard Index without the process.

Performance Measure:

$$I_2 = 1 - \frac{R_p}{R_{np}}$$

Performance Data:

R_p = The Hazard Index with the process.

R_{np} = The Hazard Index without the process.

Performance Data Error Propagation:

The performance data for this measure are collected at the system level. The concept of standard error does not apply.

Performance Measure Error Propagation:

The concept of standard error is not applicable in this context.

3. Carcinogenic Safety Risk

Page 3-5, Sec. 3.4, paragraph 1: "Each remedial alternative should be evaluated with regard to safety. This evaluation should include short-term and long-term threats to the safety of nearby communities and environments."

This score assesses the ability of the system to maintain a safe environment. A measurable way of expressing this is the ratio of the Cancer Incidence with the process to the Cancer Incidence without the process.

Performance Measure:

$$I_3 = 1 - \frac{R_{pc}}{R_{npc}}$$

Performance Data:

R_{pc} = The Cancer Incidence with the process.

R_{npc} = The Cancer Incidence without the process.

Performance Data Error Propagation:

The performance data for this measure are collected at the system level. The concept of standard error does not apply.

Performance Measure Error Propagation:

The concept of standard error is not applicable in this context.

4. System Implementability

Page 3-4, Sec 3.3.1.1, paragraph 1: "The ability to actually build, construct, or implement the remedial technology on the site must be assessed.

The demonstrability of the system is assessed using the fraction of subelements not able to be demonstrated before full-scale implementation.

Performance Measure:

$$I_4 = 1 - \frac{C_n}{F_t}$$

Performance Data:

C_n = The number of subelements in the configuration option whose requirements are satisfied with technologies that are not able to be demonstrated prior to full-scale implementation.

F_t = The total number subelements in the configuration option. Note: $F_t = C_n + C_d + C_s$ + demonstratable, but not demonstrated subelements.

Performance Data Error Propagation:

The performance data for this measure are collected at the system level. The concept of standard error is not applicable.

Performance Measure Error Propagation:

The concept of standard error is not applicable in this context.

5. Site Conditions

Page 3-4, Sec 3.3.1.1, paragraph 1: "The ability to actually build, construct, or implement the remedial technology on the site must be assessed.

The performance measure for site conditions is based on the ratio of the number subelements previously fielded and operated in a similar environment to the number of subelements in the system.

Performance Measure:

$$I_5 = \frac{C_d + C_s}{F_t}$$

Performance Data:

C_d = The number of subelements in a configuration option whose requirements are satisfied with technologies that have been demonstrated under similar site and waste conditions.

C_s = The number of subelements in a configuration option whose requirements are satisfied with technologies that are similar to technologies demonstrated under similar site and waste conditions.

F_t = The total number of subelements in a configuration option.

Performance Data Error Propagation:

The performance data for this measure are collected at the system level. The concept of standard error does not apply.

Performance Measure Error Propagation:

The performance data used to calculate the site conditions performance measure are assumed exact, so the standard error on the performance measure is assigned a value of 0.

6. Conditions External to the Site - Permits

Page 3-4, Sec. 3.3.1.2 paragraph 2: "Certain remedial activities may require zoning clearances and local permits in addition to compliance with applicable State and Federal regulations."

The number of permits required to perform remediation activities is an indicator of regulatory complexity.

Performance Measure:

$$I_6 = \frac{1}{N_p + 1}$$

Performance Data:

N_p = Estimated gross number of permits required to perform the remediation.

Performance Data Error Propagation:

The concept of standard error does not apply in this context.

Performance Measure Error Propagation:

The concept of standard error does not apply in its context.

7. Off-Site Disposal

Page 3-4, Sec 3.3.1.2, paragraph 1: "Conditions external to the site that affect the implementability of remedial technologies include the availability and acceptability of off-site disposal sites and the equipment available for construction."

Off-Site (INEL) disposal is measured as the fraction of waste that cannot be moved to off-Site disposal.

Performance Measure:

$$I_7 = 1 - \frac{W_{no}}{V_i}$$

Performance Data:

- W_{no} = The volume of waste that cannot be moved to off site disposal.
- V_i = The volume (m^3) of waste matrix, overburden, and horizontal plume as defined in the input system requirements.

Performance Data Error Propagation:

The performance data for this measure are collected at the system level. The concept of standard error does not apply.

Performance Measure Error Propagation:

The standard error for the performance measure I_7 is calculated using:

$$SE_{I_7} = \frac{SE_{W_{no}}}{V_i}$$

where

- SE_{I_7} = The Standard Error of the performance measure I_7 (off-site disposal).
- $SE_{W_{no}}$ = The Standard Error of the system performance data W_{no} .
- V_i = The volume (m^3) of waste matrix, overburden, and horizontal plume as defined in the input system requirements.

8. Complexity of Operations - Automation

Page 3-3, Sec 3.2.1, paragraph 1: "... Also, the frequency and complexity of necessary operation and maintenance should be considered in evaluating the reliability of alternatives."

This performance measure estimates the level of automation as the ratio of operation hours per hour of labor.

Performance Measure:

$$I_8 = \frac{O}{L}$$

Performance Data:

- L = The total labor hours required to operate the remediation system.

O = The hours of operation required for the remediation.

Performance Data Error Propagation:

Calculate the standard error for the performance data L using:

$$SE_L = \sqrt{\sum_{i=1}^n SE_{L_i}^2}$$

where

SE_L = The Standard Error on the system performance data L.

SE_{L_i} = The Standard Error of L for the i^{th} subelement in the technology process option.

n = The number of subelements in the technology process option.

The performance data O is collected at the system level. The concept of standard error does not apply.

Performance Measure Error Propagation

Calculate the standard error for the performance measure I_g using:

$$SE_{I_g} = \sqrt{\frac{SE_O^2}{L^2} + \frac{O^2 \times SE_L^2}{L^4}}$$

where

SE_{I_g} = The Standard Error on the performance measure I_g (automation).

SE_O = The Standard Error on the system performance data O.

SE_L = The Standard Error on the system performance data L.

L = The total labor hours required to operate the remediation system.

O = The hours of operation required for the remediation.

This formula assumes O and L are mean of independent Gaussian distribution (see SE_{I_7}).

9. Complexity of Operations - Training

Page 3-3, Sec 3.2.1, paragraph 1: "... Also, the frequency and complexity of necessary operation and maintenance should be considered in evaluating the reliability of alternatives."

This performance measure is based on the mean years of specialized training required to operate the system.

Performance Measure:

$$I_9 = \frac{Y_{ED}}{Y_{max}}$$

Performance Data:

Y_{ED} = The mean years of specialized training (academic and facility specific) required to operate the remediation system (the sum of each operator's educational requirements).

Y_{max} = The maximum mean years of specialized training required to operate any of the initial suite of remediation systems being considered.

Performance Data Error Propagation:

The concept of standard error does not apply in this context.

Performance Measure Error Propagation:

The concept of standard error does not apply in this context.

10. Time to Demonstrate

Page 3-5, section 3.3.2.1, paragraph 1: "Implementation time includes the time it takes for special studies, design, construction, and any other technical steps that may be required for implementation. The user should evaluate alternatives in terms of the most likely construction schedules, based on experience at similar sites or on a standard engineering procedure like critical path analysis."

Temporal risk is measured as the critical path time from initiation of design to initial operation at demonstration.

Performance Measure:

$$I_{10} = 1 - \frac{T_d}{T_{max}}$$

Performance Data:

T_d = The time required until the system can be demonstrated.

T_{max} = The maximum time (years) allowed for the remediation process.

Performance Data Error Propagation:

The performance data for this measure are collected at the system level. The concept of standard error is not applicable.

Performance Measure Error Propagation:

Calculate the performance measure error propagation for I_{10} using:

$$SE_{I_{10}} = \frac{SE_{T_d}}{T_{max}}$$

where

$SE_{I_{10}}$ = The standard error of the performance measure I_{10} (time to demonstrate).

SE_{T_d} = The standard error of the system performance data T_d .

T_{max} = The maximum time (years) allowed for the remediation process.

11. Implementation Risk

Page 3-5, section 3.3.2.1, paragraph 1: "Implementation time includes the time it takes for special studies, design, construction, and any other technical steps that may be required for implementation. The user should evaluate alternatives in terms of the most likely construction schedules, based on experience at similar sites or on a standard engineering procedure like critical path analysis."

This performance measure is based upon the scheduled time from evaluation of design to beginning of operation.

$$I_{11} = 1 - \frac{T_{br}}{T_{max}}$$

Performance Data:

T_{br} = The time it takes to build and begin operation of the remediation system.

T_{max} = The maximum time (years) allowed for the remediation process.

Performance Data Error Propagation:

The performance data for this measure are collected at the system level. The concept of standard error does not apply.

Performance Measure Error Propagation:

Calculate the performance measure error propagation for I_{11} using:

$$SE_{I_{11}} = \frac{SE_{T_{br}}}{T_{max}}$$

where

$SE_{I_{11}}$ = The standard error of the performance measure I_{11} (Implementation risk).

$SE_{T_{br}}$ = The standard error of the system performance data T_{br} .

C. Cost

1. Life Cycle Cost

Page 3-3, Sec 3.2.1, paragraph 1: "Evaluations of the operation and maintenance requirements of remedial alternatives should emphasize the availability of labor and materials as well as their costs. Also, the frequency and complexity of necessary operation and maintenance should be considered in evaluating the reliability of alternatives."

This is a measure of the total cost of the remediation system.

Performance Measure:

$$C_1 = 1 - \frac{C_m}{C_{m_{max}}}$$

Performance Data:

C_m = The life cycle cost.

$C_{m_{max}}$ = The maximum lifecycle cost of all processes initially considered.

Performance Data Error Propagation:

Calculate the standard error for the system performance data C_m using:

$$SE_{C_m} = \sqrt{\sum_{i=1}^n SE_{C_{m_i}}^2}$$

where

SE_{C_m} = The Standard Error of the system performance data C_m .

$SE_{C_{m_i}}$ = The Standard Error for C_m of the i^{th} subelement in the technology process option.

n = The number of subelements in the technology process option.

Performance Measure Error Propagation:

Calculate the standard error for the performance measure C_1 using:

$$SE_{C_1} = \sqrt{\frac{SE_{C_m}}{(C_{m_{max}})^2} + \frac{(C_m SE_{C_{m_{max}}})^2}{(C_{m_{max}})^4}}$$

where

SE_{C_1} = The Standard Error of the performance measure C_1 (life cycle cost).

SE_{C_m} = The Standard Error of the system performance data C_m .

$SE_{C_{m_{max}}}$ = The standard error of the system performance data $C_{m_{max}}$.

C_m = The life cycle cost

$C_{m_{max}}$ = The maximum lifecycle cost of all processes initially considered.

END

**DATE
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9/04/92

