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OST Technology Decision Process*

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**COST SAVINGS DELIVERABLES AND CRITERIA FOR
THE OST TECHNOLOGY DECISION PROCESS**

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PURPOSE

This document has been prepared to assist focus area (FA) technical and management teams in understanding the cost savings deliverables associated with a technology system during its research and development (R&D) phases. It discusses the usefulness of cost analysis in the decision-making process, and asserts that the level of confidence and data quality of a cost analysis is proportional to the maturity of the technology system's development life cycle. Suggestions of specific investment criteria or cost savings metrics that a FA might levy on individual research projects are made but the final form of these elements should be stipulated by the FA management based on their rationale for a successful technology development project. Also, cost savings deliverables for a single FA will be more detailed than those for management of the Office of Science and Technology (OST). For example, OST management may want an analysis of the overall return on investment for each FA, while the FA program manager may want this analysis and the return on investment metrics for each technology research activity the FA supports. The table below presents the different users of the technology system cost analyses and their potential needs and requirements.

User of Cost Analyses	Needs & Requirements
Technology Developer / Principal Investigator (TD)	<ul style="list-style-type: none"> Proposed budget is well defined There is a significant return on investment (ROI) Capital costs are defined for the system Compliance dates for waste streams are factored into the completion date for the technology
Site Project Managers	<ul style="list-style-type: none"> Technology linked to a waste stream Technology scale and availability (throughput vs. compliance dates)
EM-30/40 HQ Project Managers	<ul style="list-style-type: none"> Supporting rationale/justification for technology selection at site
Focus Area Program Managers	<ul style="list-style-type: none"> Data to evaluate competing technologies Illustrate advantages over the cost of baseline technologies Proposed project cost is reasonable and appropriate There is a significant benefit associated with continued investment in the technology development
EM-50 HQ Program Managers	<ul style="list-style-type: none"> Identify technology for best use of funds Provide TDs with competitive atmosphere Life cycle costs show advantages over the cost of baseline and emerging technologies
OST Management	<ul style="list-style-type: none"> Present to Congress a direct cost saving on the overall OST program

I. STAGE / GATE PROCESS

The Technology Investment Decision Model, described in the draft entitled, "*A Framework for R&D Planning in EM*" prepared by Joe Paladino and Brian Fox [1], outlines a process for choosing and developing those Environmental Management technologies that are most likely to succeed -- that is, achieve implementation and reduce cleanup costs. Its aim is to weed out less favorable technologies at an early stage so that more investment dollars are available for developing successful technologies.

The process is broken down into several stages, each followed by a "gate" or decision point. During each stage, technical data, cost information, ES&H concerns, regulatory factors, and other pertinent information contribute to the generation of "deliverables" which address decision-making criteria at the gate. The gate is the point at which technologies are evaluated and prioritized, and those technologies that meet the gate criteria *and* are judged as the most likely to succeed advance to the next stage of development. As stated in the draft, "The gate criteria must ... enable the focus teams to adequately rank and select projects that provide the greatest value to the program ..." See Figure 1 for a description of the technology development stages, gate expectations, and deliverables.

In determining the superiority of one cleanup technology system over another, there are three factors that must be considered: cost savings, risk reduction, and system performance. The monetary value of enhanced performance and/or risk reduction is taken into account in a cost benefit analysis. For those technologies that have equal benefits, the cost effectiveness of one technology over another is a determining factor in a funding decision. In this document, cost savings deliverables are spelled out, but it is recognized that enhanced performance and risk reduction also play an important role in the technology decision process.

The cost effectiveness of a technology is therefore a critical factor in the decision-making process. Clearly, if the benefits of using technology systems are identical, an innovative technology must be more cost-effective than either the baseline technology that it is intended to replace or a competing innovative technology if it is to reach implementation. It is therefore crucial for technology developers and focus area and crosscutting program (CP) managers to know what cost information goes into the cost savings deliverables and how to present the information in a manner that demonstrates the cost effectiveness of the innovative technology system.

The technology development process begins with basic research that is directed toward discovering and understanding a process that might successfully address a DOE Environmental Management need. The progression from idea generation to product definition and how that relates to the technology stages can be envisioned in the following analogy, as seen in Figure 2. The cloud represents a nebulous collection of ideas that are

	Basic Research	Applied Research	Exploratory Development	Advanced Development	Engineering Development	Demonstration	Implementation
Technology Maturation Stages	Idea Generation No needNeed		Proof of Technology Product DefinitionWorking Model • Non-specific applications • Bench-scale• Reduction to practice • Specific applications • Bench-scale		Engineering Prototype • Scaled-up version to test design features and performance limits • Pilot-scale • Field testing	Production Prototype • End-user validation • Full-scale • "Beta" site testing	Utilization by end-user
Gate Expectations	<div><div>1</div><div>2</div><div>3</div><div>4</div><div>5</div><div>6</div></div> <div>Address Priority DOE need Knowledge of similar efforts</div> <div>Show clear advantage over available technology Demonstrate significant end-user demand</div> <div>Meet cost/benefit requirement</div> <div>Technology ready for end-user</div> <div>End-user deploys technology</div>						
Deliverables - Required for Gate Decisions		Correlation with DOE Needs Summary of Similar Work	Performance Requirements Comparison of Technological Alternatives Preliminary Market Assessment - DOE - Other Identification of Issues: - Technical - Programmatic - Market - Regulatory - Public Acceptance - Legal - Health and Safety	Product Specifications Cost/Benefit Analysis Detailed Market Assessment - DOE -Other Public/Regulator Involvement Plan Strategy for: - DOE Deployment - Commercialization - Cost-Sharing - Regulatory Compliance - Licensing Initial Performance/Cost Data Package	Demonstration Permits Partnership Agreements - Cost-Sharing - Licensing Resolution of Issues Final Performance/Cost Data Package	Signed Contract with End-User(s) Public Acceptance	

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Figure 1. Technology Investment Decision Model (from [1])

Figure 2. The progression from idea generation to product definition is compared to the formation of raindrops in a cloud. During exploratory development, several product possibilities are pursued, as represented by the several raindrops that fall from the cloud. Single product definition takes place at the end of the stage. In advanced development and beyond, a specific application is developed that addresses a specific need.

generated during the basic research stage (stage 1), where fundamental research is undertaken to build core scientific knowledge. In the applied research stage (stage 2), the application of this knowledge to achieving a practical result is initiated, but there may not be clear product definition. During exploratory development (stage 3), several product possibilities are pursued, as represented by the several raindrops that fall from the cloud. Single product definition takes place at the end of the stage. In advanced development and beyond, a specific application is developed that addresses a specific need.

In the early stages of technology development (through stage 3), the TD's focus is naturally given to the technical aspects of the project, but in the present economic climate he must consider cost savings. In the applied research stage, he should become familiar with the baseline technologies that are in use, and be formulating cost savings goals or identifying areas that require enabling technologies. By the end of the exploratory development stage, bench scale tests have led to the development of a product, and a rudimentary cost-effectiveness analysis (CEA) of the technology should be performed. The CEA is an analysis that compares the innovative or alternate technology system with a baseline system using current technology, and determines the unit cost of implementing the emerging technology system (*e.g.* in \$ per cubic meter or \$ per thousand gallons) and the unit cost savings (synonymous with cost avoidance) that would result from that implementation. In the context of EM's Ten Year Plan (TYP), the net savings that DOE might expect is calculated by applying the unit cost savings to all of the sites that would benefit from implementing the innovative technology system.

The cost-effectiveness analysis is a deliverable for gate 3 and beyond, where the analysis is revised with new information that is gathered during the stage. The accumulation of information gained as one advances through the stages can be compared to filling a bucket. Each stage contributes to the final readiness of the technology for implementation, with later stages contributing more heavily, but each stage builds on the previous and is dependent on all of the previous stages. The initial work done in early stages sets the groundwork for later stages. This is depicted pictorially in Figure 3. The same is true for the refinement of the CEA. As more information is gained, better cost and performance data is obtained and the accuracy of the cost analysis increases. In this way, the CEA is a 'living' document. It is initiated during stage 3 and reaches fruition at gate 6.

While the CEA only considers the cost of implementing the innovative technology system, return on investment (ROI) and benefit to cost ratio (B/C) calculations are made by comparing the innovative technology research and development costs to the anticipated cost savings. These cost savings products assist the program managers in determining whether it is cost-effective to continue funding specific technologies. The calculations are performed at the later stages of technology development (stages 5 & 6) when estimates of the development costs and potential cost savings are more accurate.

Figure 3. The bucket being filled with sand illustrates the accumulation of information gained as a technology passes through stages. Each stage contributes to the final implementation of the technology and as more information is gained, better cost and performance data is obtained. This leads to improvements in both the technology and the accuracy of the cost analysis.

Though beyond the scope of this paper, aggregate ROI and B/C calculations based on total accumulative costs and total projected savings for all efforts in each FA/CP should be performed. Since CEAs for most of the technologies are not presently completed, the aggregate cost savings, ROI, and B/C will be based on rough estimates of cost savings for each technology. As the CEAs of individual technology systems are performed, the aggregate savings will incorporate data from the individual CEAs and future revisions will therefore be more accurate.

Cost savings criteria are a subset of the overall criteria that will be used by FA decision makers to determine whether an innovative technology will continue in its development. Examples of cost savings criteria are given in Appendix A. If all of the criteria are satisfied, the decision makers will weigh the importance of that technology against others that have also satisfied the gate criteria, and prioritize them according to the results of the CEA, ROI, and B/C calculations while taking into account risk reduction and/or enhanced system performance. If any criterion is not satisfied, the decision makers will determine whether that criterion was critical to the decision-making process or whether it can be ignored.

II. COST SAVINGS DELIVERABLES AT GATES

A. Stage 2 – Applied Research

This is the idea generation stage, where the TD performs applied research and his goal is to develop a process or technology that meets a DOE need. A particular application of the technology may not actually be identified until just before gate 3. From the TD's perspective, technical factors are the most important and he may have no idea of ultimate process costs. As an example, a DOE need is the remediation of contaminated soils. Contaminants include radionuclides, heavy metals, hydrocarbons, inorganics, pesticides, and the like. A TD may have discovered in the basic research stage (stage 1) that a particular solvent molecule strongly absorbs ultraviolet light in a narrow band, so that research in stage 2 is directed toward determining whether the molecule photodissociates, what the photodissociation products are, and if the same process occurs in other solvents. He is addressing a DOE need in that the solvent is a major soil and water contaminant, but there is not enough data to determine whether the process will alleviate soil or water contamination.

Since a requirement at gate 2 is that the technology address a priority DOE need, the TD must be aware of the DOE needs, as well as other research that is being conducted in this field through literature searches, conference participation, and interactions with colleagues. In terms of cost, since a particular process has not been identified, there is no information that can be used to make a cost analysis. However, the TD can identify baseline technologies that are addressing the need, and determine baseline unit costs from baseline life cycle costs. This provides a target cost for the innovative technology system. It also provides a model on which to base the analysis of the technology being developed as well as cost savings goals to work toward. The baseline cost information may be provided by the FA/CP. An example of baseline life cycle costs is provided in Appendix B. In addition, major cost factors in the baseline technology will be identified, which give the TD directions in which to concentrate his research.

It is recommended that at this point the TD estimate total research and development costs (stages 2 through 6) and revise those figures as the technology development progresses. The FA/CP can provide input in the form of development costs from other technology development efforts. Ideally, a cost database will be available that will include the cost for each stage of development for every technology development effort. The TD should also become familiar with the CEA methodology which is described in detail in the next section and be able to explain how cost comparisons with the innovative technology system will be made. A peer review may be required at this gate.

The suggested deliverables and criteria for this gate are given in Table 1.

B. Stage 3 – Exploratory Development

At the beginning of the stage, one or more alternative technologies or processes are evaluated as potential solutions to a DOE problem. Bench scale experiments are performed, and a single technology or process is selected that has the potential to solve the problem in a manner that is superior (both technically and in relation to cost) to the performance of the baseline technology and other emerging technologies. To continue the example of stage 2, the TD may have found in stage 2 that photodissociation of the solvent led to the creation of harmless by-products, and the same effect was observed in many of the solvents that are major site contaminants. During stage 3, he must determine where and how to apply the technology. It may result in an ex situ treatment of excavated soils, or the use of fiber optics to irradiate small concentrations of DNAPLs in situ.

By the time the technology reaches gate 3, a specific product has been developed that targets a specific DOE application. Preliminary experiments have been performed and the TD has a rough idea of the costs for equipment and operating expenses, at least on the small scale. A comparison to similar technologies is used to provide a cost estimate on the new technology. For example, costs might be similar for technologies utilizing excavation, ion exchange or mining technologies. The exact cost of a scaled up production facility will not be known, and a cost estimate may only be accurate to a factor of 2-5. A rudimentary planning cost-effectiveness analysis of the innovative technology system using life cycle costs is then performed with the goal of demonstrating that the technology costs less than the baseline technology or competing new technologies. Having in mind the cost factors of the baseline technology, the TD should also identify definite cost and time saving goals for the project.

There are several resources available to the TD to perform the CEA for the new technology. A cost compendium of baseline EM technology costs is available from the ETCAP project at Los Alamos National Laboratory. The TD has access to cost and performance data as well as a description of cleanup sites, scales, and scenarios. The compendium can be accessed on the World Wide Web (WWW) (<http://www.lanl.gov/projects/cleanup/new>). Further examples of costs from completed environmental restoration projects are contained in the Historical Cost Analysis System (HCAS) database that is maintained by the Logistics Management Institute. The HCAS database contains data on 60 remediations that have been performed by various government agencies. It can be downloaded from the WWW (http://globe.lmi.org/lmi_hcas/). Also, the Federal Remediation Technology Roundtable (FRTR) has cost and performance reports available that can also be downloaded (<http://www.frtr.gov/costper.html>). In addition, cost estimators and analysts can assist the TDs in performing cost estimates and analyses of the new technology.

The suggested deliverables and criteria for this gate are given in Table 1.

C. Stage 4 -- Advanced Development

Now that a particular process has been identified that will solve a specific problem, bench-scale testing is performed with the goal of developing a laboratory-scale prototype. During this stage, product specifications are determined. An example of a technology at the end of this stage is a project entitled "Contaminant Removal From Solid Waste by Supercritical Carbon Dioxide". The technology makes use of the fact that supercritical CO₂ can be used to clean solvent-contaminated rags. A laboratory-scale experiment was performed that demonstrated the feasibility of the technology. As compared to stage 3, where it may have been demonstrated that supercritical CO₂ cleans solvent-contaminated rags, much additional information was generated, including the size of the equipment needed to clean a certain amount of material, the replacement rate of the CO₂, the electrical costs of operating the equipment, maintenance and replacement costs for system components, the cycle time which determines the total amount of material that can be cleaned in a year, and the reliability of the equipment. None of these costs were accurately known in the previous stage. However, the actual cost of the full-scale facility is still uncertain since there is no scale-up data.

The deliverables for this stage include a block diagram of the final system showing unit operations and a "scoping" CEA calculation accurate to +50% to -30%. The CEA at this gate should have the caliber and completeness to withstand a peer review (at the discretion of the FA/CP). The TD should also perform a more thorough review of the TYP or other baseline document and follow the steps given in Section IV to determine the maximum possible complex-wide cost savings that would result if the innovative technology system were implemented.

A cost-effectiveness analysis of the supercritical CO₂ cleaning process is given in Appendix C. The analysis has the form of the unit waste cost comparisons required of the FAs. The cleaning facility would be large enough to handle the amount of oily-rag waste produced at a typical DOE site. A block diagram is also included in the analysis (Figure 1 of the appendix).

The TD will have a better understanding of equipment costs from the laboratory-scale experiments. Estimates from vendors will help in determining the cost of scaled-up equipment. A design engineer will assist the TD in constructing a block diagram and in further estimating the scale-up costs using comparative analysis or a parametric model. Cost-savings analysts will also assist the TD in refining the CEA for the technology.

The suggested deliverables and criteria for this gate are given in Table 1.

D. Stage 5 -- Engineering Development

During this stage, laboratory-scale prototypes are refined to test design features and performance limits. This involves the construction of a pilot-scale or engineering

prototype, and field-testing is performed. The Alternative Landfill Cover Demonstration is an example of a technology which, although presently at the demonstration stage, has cost data at the level of engineering development. Alternative landfill covers are being tested against standard EPA covers at near full-scale (12,000 square feet, compared to a typical hazardous waste landfill size of 90,000 square feet) at Sandia National Laboratories for their ability to inhibit water infiltration in arid climates. This is a concern at hazardous waste disposal sites, since the seepage of water into the landfill allows hazardous waste to leach into the ground water. A CEA of this technology is given in Appendix D. Information gained during the engineering development stage included construction costs for the smaller scale project which can be scaled up to full-scale values, costs for the special materials (geomembranes and geosynthetic clay liners), and labor costs.

A conceptual design or process flow diagram is now required. This would not include dimensions or a bid package, but would give some definition to the black boxes of the block diagram of Stage 4. A revised cost analysis must be performed of "budget estimate" quality of +30% to -15%. Oftentimes costs are severely underestimated at this point due to a lack of consideration of support infrastructure. A design engineer will assist the TD in constructing the process flow diagram and a cost-savings analyst will assist in further refining the CEA.

At this time, ROI and B/C calculations are performed using the revised cost data and the total project development costs. These will be compared to hurdle rates that are set by the FA/CP for successful projects. Also, the TD should have an excellent idea of the capabilities of the innovative technology, and an in-depth analysis of the DOE cleanup baseline (the TYP or comparable document) should be made to verify the total amount of waste volume that the innovative technology can address, and hence give a defensible complex-wide cost savings.

The suggested deliverables and criteria for this gate are given in Table 1.

E. Stage 6 -- Demonstration.

At this stage, a full-scale test is typically performed at a user's site with a production prototype. In Situ Bioremediation (ISBR) is a technology that is used to remediate soils contaminated with chlorinated organic solvents. Using in situ air stripping (pumping air into the ground in one well and extracting from another well) to extract volatilized organic molecules, bioremediation is accomplished by injecting methane into the ground, providing a medium for indigenous bacteria to produce an enzyme that degrades the organics. ISBR has undergone a field demonstration (Savannah River Integrated Demonstration), and has accurate cost figures on which a detailed cost analysis has been made (see Appendix E).

After the demonstration, perhaps as much as 20% of the facility engineering has typically been performed, and the deliverables for this stage include a preliminary (but detailed) design of the final process using flowsheets, layouts, and equipment details, and a revised cost analysis of "definitive" quality that is accurate to within +15% to -5%. Reduced ROI and B/C calculations should also be made so that a range of expected values can be given. A detailed cost and performance report will be written that gives the actual costs incurred in the demonstration. An Innovative Technology Summary Report (ITSR) will be finalized that includes a summary of the cost information.

At this stage of development, a design engineer is required to provide the expertise to accurately scale-up costs from the demonstration level to the full production level.

The suggested deliverables and criteria for this gate are given in Table 1.

Following the demonstration stage, scale-up engineering derived from demonstration results is performed. A cost analysis is made from defined engineering data, such as plot and elevation plans, piping and electrical diagrams, equipment data sheets, structural and building sketches, and a complete set of specifications, and is accurate to within +15% to -5%. Full construction then follows.

Table 1. Suggested Deliverables and Criteria for All Gates

Gate	Deliverables	Criteria
2	<ul style="list-style-type: none"> • Preliminary review of TYP/Alternate technologies • Preliminary life cycle cost estimate of baseline technology • Preliminary baseline unit costs • Target cost for the new technology • Rough estimate of total project R&D costs 	<ul style="list-style-type: none"> • Has a preliminary review of the TYP been made? • Has a baseline technology (or technologies) been identified? • Has a life cycle cost estimate of each baseline technology been performed? • Has a target cost for the technology been determined? • Is the R&D project cost estimate reasonable?
3	<ul style="list-style-type: none"> • Revised baseline costs • Major cost factors of baseline • Planning (factor of 2-5) CEA of new technology • Cost goals identifying capital and O&M costs • Time savings goals • Revised estimate of project R&D costs 	<ul style="list-style-type: none"> • Is the baseline the best comparison to the innovative technology? • Have the major cost factors of the baseline been described? • Has a CEA of the new technology been performed? Is it reasonable? • Are cost and time savings goals elucidated? • Is the revised project R&D cost estimate reasonable?
4	<ul style="list-style-type: none"> • Block diagram of system • Scoping CEA calculation accurate to +50% to -30% • Thorough review of TYP • Estimate of life cycle cost savings • Estimates of Stage 5 and 6 costs 	<ul style="list-style-type: none"> • Has a block diagram of the final system been created? • Has the CEA of Gate 3 been revised? Is it accurate to a factor of +50% to -30% (or better)? Does it pass an external review (if appropriate)? • Has a review of the TYP been made to determine complex-wide savings? • Has an estimate of life cycle cost savings been made? • Are the cost estimates for stages 5 and 6 reasonable?
5	<ul style="list-style-type: none"> • Conceptual design or process flow diagram • Budget CEA with accuracy +30% to -15% • Estimate of Stage 6 cost • ROI and B/C calculations • Total complex-wide cost savings anticipated 	<ul style="list-style-type: none"> • Has a conceptual design been made? • Has the CEA of Gate 4 been revised? Is the CEA accuracy +30% to -15%? • Is the Stage 6 cost estimate reasonable? • Does the ROI meet the hurdle rate? Is the B/C acceptable? • Is the cost-savings figure credible and defensible?
6	<ul style="list-style-type: none"> • Preliminary design of final process • Definitive CEA with accuracy +15% to -5% • Refined ROI and B/C calculations • Detailed cost and performance report 	<ul style="list-style-type: none"> • Has a preliminary design of the final process been made? • Has the CEA of Gate 5 been revised? Is the CEA accuracy +15% to -5%? • Are the ROI and B/C figures acceptable? • Have the cost and performance been documented?

III. INTRODUCTION TO COST SAVINGS TERMINOLOGY

There are three cost analysis products that are used by OST in determining whether it is worthwhile to make an investment in an alternate technology system: the **cost-effectiveness analysis**, the **return on investment** and the **benefit to cost ratio**. The cost-effectiveness analysis compares technologies that give comparable benefits and determines which is more **cost-effective**. Since the comparison is between an innovative technology system and a fully developed baseline, in order to be fair the analysis does not include technology development costs. The return on investment calculation (which includes development costs), gives a measure of the pay-off of an investment over time, and the benefit to cost ratio calculates the ratio of net savings to development costs.

All three of the analyses take into account a principle called the **time value of money**. This and other economic terms (given in bold in this section) are defined in the attached Glossary of Terms. Basically, since a dollar today is worth more than a dollar tomorrow (because it can be invested and earn interest), in determining the present value of future costs or savings, future dollars are **discounted** compared to today's dollars. The result is that savings that are realized in the near future have a higher monetary value than the same amount of savings that are realized in the far future, and in order to be cost effective, greater savings must be realized in the future than development costs that are incurred in the next few years. The **discount rate** that is chosen to discount future costs and savings is determined in a number of ways (*e.g.* in business, it may be the cost of capital), but for the purposes of these analyses, it is taken from Appendix C of the OMB Circular No. A-94, "*Guidelines and Discount Rates for Benefit-Cost Analysis of Federal Programs*". This rate is tied to the interest rate given for US Treasury notes and bonds. The **present value** of savings is then the sum of the savings obtained by using the innovative technology system instead of the baseline for each year of the program's lifetime where the yearly savings have been discounted. In the same way, the present value of costs is the sum of the discounted development costs.

The cost-effectiveness analysis is to supply decision makers with a critical analysis for evaluating an innovative technology system in comparison to a baseline technology system. It is therefore one of the most important of the deliverables that will be evaluated by decision makers at the gates, because financial resources must be allocated in a cost-effective manner. The challenge in performing the cost-effectiveness analysis is to equitably compare technologies that on the surface may be quite different, avoiding a useless comparison of "apples and oranges". Since no single technology is a perfect substitute for another, there will almost always be some differences in capabilities that must be addressed in the analysis. This is accomplished by constructing performance scenarios that place the technologies on as equal a footing as possible. The analysis does not attempt to quantify the monetary value of benefits to society (hence it is not a cost-benefit analysis), nor is it simply a collection of costs of implementing the technology (a cost estimate or cost compilation).

The analysis is made by using the following methodology, which is described and developed in much more detail in a paper by Henriksen and Booth entitled "*A Practical Guide to Evaluating the Cost Effectiveness of New Environmental Technologies*" [2]. First, a baseline technology is identified which the new technology is intended to replace. Performance data on both the baseline and innovative technology are gathered, upon which performance scenarios are constructed that allow comparisons between technologies to be made on an equal basis. Cost information for both technologies is gathered, and life-cycle cost estimates are made for both technologies. From the performance scenarios and cost estimates, a cost analysis is performed. This provides decision makers with a unit cost metric, such as \$ per pound of contaminant removed from a waste stream, or \$ per cubic meter of contaminated soil that has been remediated. It is recognized that some costs will vary across the complex, such as labor or the cost of electricity. The effects of these variable costs on the analysis can be demonstrated in sensitivity analyses where a single parameter is varied and cost savings are calculated. This identifies the major cost drivers. By taking into account the applicability of the innovative technology for use at sites identified from the TYP, a complex-wide cost savings is calculated.

The type of cost estimate (and its accuracy) and the amount of time required to perform it will depend on the technology development stage. Some of the types of cost estimates are

1. Planning Estimate -- General assumptions are made regarding the system or process. Costs are based on past experience with similar projects, or best professional judgment. Accuracy: Factor of 2 to 5
2. Scoping Estimate -- An approximate estimate made without engineering data. Estimates using cost capacity curves, scale factors, and approximate ratios are examples. Accuracy: +50% to -30%
3. Budget Estimate -- Prepared with the use of flowsheets, layouts and equipment details. Accuracy: +30% to -15%
4. Definitive Estimate -- Based on defined engineering data such as plot and elevation plans, piping and electrical diagrams, equipment data sheets, structural and building sketches, and a complete set of specifications. Accuracy: +15% to -5%

These cost estimate accuracies are based on a classification given by the American Association of Cost Engineers (AACE) in *Project and Cost Engineers' Handbook* (2nd Ed., Marcel Dekker, Inc., New York, 1984), edited by K. K. Humphreys [3]. A description of the types of cost estimates that are generally required for DOE remedial design / remedial action projects is found in the "*Cost Estimating Guide*", published by the Office of Infrastructure Acquisition (FM-50) [4]. The types of cost estimates that will be due at the various gates are shown in Figure 4, along with the estimate's accuracy.

Figure 5. Trumpet diagram relating uncertainty in cost estimate (cost analysis) to degree of engineering development. The expected cost analysis uncertainty for each gate is shown, as well as the position of various designs.

at each gate will depend on the complexity of the technology.

The cost-effectiveness analysis that is a deliverable at each gate reflects the best estimate of the life cycle cost (LCC) of the technology's implementation, including design of the final process, testing, construction, start-up costs, training, operation, maintenance, decontamination and decommissioning, and any final waste disposal activities. It does not include research and development costs, since a comparison is made between the innovative technology system and a baseline, which is already developed. To be fair, a comparison which included development costs of the innovative technology system would have to include the development costs of the baseline technology.

The cost of research and development is included in the return on investment calculation. The return on investment is a measure of the pay-off of an investment over time. It is determined by varying the discount rate in present value calculations until the present value of the savings is equal to the present value of the development costs, so that the net

Figure 4. Technology Development Stages and the Corresponding Cost Estimate Types

As a technology advances through the stages of development, more accurate cost figures are available, so that at each successive gate the uncertainty in the cost analysis decreases. This is demonstrated pictorially in Figure 5, where the uncertainty in the cost analysis is seen to decrease as the level of engineering development (and hence technology maturation) increases. This so-called "trumpet" diagram gives the expected cost analysis uncertainty at each gate. A factor which will influence the level of uncertainty in the cost analysis is the sophistication of the technology. A "low tech" project may have a higher level of accuracy in the cost analysis than a "high tech" project, such as the plasma hearth, even though both might be at the same gate. For example, Landfill Covers (caps) and Plasma Arc are both at the demonstration stage of development, and the uncertainty in the cost analysis for caps is on the order of +30% to -15%, while that for Plasma Arc is likely to be +50% to -30%. In addition, a project utilizing process equipment that cannot be scaled without testing will have a higher uncertainty in the cost analysis than one using either easily scaled equipment or a mix of old equipment. Hence, the level of uncertainty

present value is zero. It is to be compared to a hurdle rate, which is a rate that the FA or CP determines beforehand that must be exceeded by the ROI before the technology will pass through the gate. If the hurdle rate is 20%, then the ROI must be greater than 20% or else the technology will not pass on to the next stage of development. Since cost savings are discounted at a higher rate than development costs (since they occur later), a high ROI rate implies large savings compared to development costs.

The benefit to cost ratio is calculated by dividing the present value of the savings by the present value of the development costs. Again, since savings are discounted at a greater rate than development costs, the benefit to cost ratio will be smaller than simply the total savings divided by the total costs. Discounting will reduce the ratio. To tie the B/C to the ROI, using the ROI as the discount rate will result in a benefit to cost ratio that is equal to 1, since that is the rate at which discounted savings equals discounted costs. The FA/CP will again have determined an acceptable benefit to cost ratio, such as 5:1.

IV. PREPARING THE COST SAVINGS DELIVERABLES

The steps for preparing the cost savings deliverables are summarized in the following chart and expanded on in the remainder of the section. An example that fully illustrates the process follows in the next section.

STEP	ACTIVITY	WHEN
1	Identify Baseline Technology (ies) from the TYP.	Gates 2-6
2	Perform Cost Comparison of Innovative with Baseline.	Gates 3-6
3	Determine Potential Life Cycle Cost Savings.	Gates 4-6
4	Estimate Return on Investment; Benefit to Cost Ratio.	Gates 5-6

STEP 1 – Identify baseline technology (ies) from the TYP. As early as stage 2, the TD should be familiar with the problem area that his technology is going to address, and hence he should be examining the TYP to see what baseline technologies can be improved upon and what alternate technologies are already being developed. This will set the stage for cost comparisons between the innovative technology system and the baseline system. The FA should provide cost data on the baseline technology (ies) so that the TD can have a target cost in mind for the innovative system. As the technology development progresses, the baseline may change, or if the technology is applicable to several cleanup scenarios, there may be several baseline technologies with which to compare the innovative technology.

STEP 2 – Perform cost comparison of innovative technology system to baseline technology system. From gates 3 and on, a cost comparison is made between the innovative and baseline technology systems. The goal is to develop unit costs for both technology systems, and then determine unit cost savings. The comparison is made following the cost-effectiveness analysis methodology, and is also known as a “unit waste” cost comparison. A breakdown of the steps required to perform the analysis is as follows:

Step 2a – Construct scenarios that give a fair comparison between technologies. The purpose of constructing scenarios is to allow an equal comparison between the innovative and the baseline technology system and to determine how the unit costs for the innovative and the baseline technology system vary depending upon the cleanup

parameters. Several scenarios should be considered, including one that puts the innovative technology in the best light. In most cases, it is unlikely that a single point unit cost will be applicable to every site in the complex. Therefore, scenarios derived from the TYP should be developed that will allow a low, medium, and high value of the unit cost to be determined for both the innovative and the baseline technology systems.

Step 2b – Characterize the performance of the baseline and innovative technology systems. Performance data are required in order to construct the comparison scenarios and to determine the cost metric. The data may be in the form of pounds of contaminant removed per year per well, or cubic meters of soil treated per day per facility. Evaluating the performance requires defining the system in which the technologies will be used and in understanding the system requirements.

Step 2c – Determine life cycle costs for technologies. Once the scenarios are set and performance characteristics of both technologies are determined, the life cycle costs are calculated for each scenario. This involves performing a cost estimate for the implementation of both the baseline and the innovative technology system based on a realistic schedule for construction and the operations required to complete the remediation. Costs are discounted by the OMB discount rate so that the present value of costs is calculated.

Step 2d – Determine unit costs for innovative and baseline technology systems and calculate unit cost savings. A unit cost is typically determined by dividing the discounted life cycle cost (present value of costs) by the total amount of soil remediated ($\$/\text{m}^3$) or contaminant removed ($\$/\text{lb}$). If the present value of costs is \$4.0M and the technology system remediated 10,000 m^3 of soil, then the unit cost would be $\$400/\text{m}^3$. A range of unit costs is calculated based on the results of the life cycle costs for the various scenarios. At this point, the cost-effectiveness analysis is nearly complete. The unit cost savings is the difference between the unit cost of the innovative technology system and the unit cost of the baseline. A rough estimate of the total costs savings can be made by applying the unit cost savings to the total volume of waste, contaminated soil or area of contaminated buildings that the technology will remediate.

STEP 3 – Determine potential life cycle cost savings. At gate 4 and beyond, the potential cost savings to DOE should be estimated, and with greater precision as the technology progresses through the development stages. The estimate should be made following these steps.

Step 3a – Identify the cost basis or market size. Determine the sites from the TYP for which the technology is applicable. Review each major project in the revised Ten Year Plan (or current baseline document) to identify sites where the innovative technology system can make substantial contributions to cost savings, risk reduction or system performance. For each site that is identified, it is important to note the site size, levels of contamination, current baseline technology system, and any other parameter that might affect the unit cost of the remediation. Finally, record the total anticipated cost of performing the remediation using the *baseline* technology (ies). This is the cost basis against which the innovative technology system will be compared and savings determined.

Step 3b – Determine the waste volume and the maximum potential cost savings. The waste volume for each site will have been recorded in the previous sub-step. The appropriate unit cost savings (low, medium, or high) will be applied to each site to determine the maximum potential cost savings. This is determined by multiplying the waste volume per site by the unit cost savings per site, summed over all of the sites. Clearly, this total savings cannot exceed the cost basis calculated in Step 3a unless income is generated in the remediation.

Step 3c – Determine the reduced potential cost savings. The applicability of the innovative technology system to each site may be reduced by any of the following factors. First, because of incomplete or incorrect characterization, the technology system may not actually be applicable at the site, or else the site may require more of a remediation than originally thought, which would increase the cost. Second, stakeholder and/or regulator acceptance may be an issue that prevents the use of the technology at the site. Finally, there may be scheduling constraints that preclude the use of the technology at that site. An engineering assessment must be made to determine the reduction factor. These reductions might be as high as 30%, and the total reduction in savings for the technology system might range from 0 to 50%. These factors should be applied to each applicable site, and ranges should be determined by the FAs or obtained from the Cost Savings Analysis Team in EM-54.

STEP 4 – Estimate return on investment and benefit to cost ratio. The ROI and B/C are calculated for gates 5 and 6 from the present value of development costs and total complex-wide cost savings. The calculations are made using life cycle costs of the innovative and baseline systems. The cost savings are computed for each year of the comparison, and the yearly savings are discounted using the OMB real discount rate. The research and development costs are also discounted. The ratio of these two quantities is the benefit to cost ratio, B/C. The ROI is determined by adjusting the discount rate until the net present value is zero (or until $B/C = 1.0$). This is best done using a spreadsheet where the effect of changing the discount factor on the discounted costs and savings can be quickly seen.

When a new product or technology system is first introduced into a market, it is not immediately accepted by the customer. There is an acceptance period or takeover time for the new technology to take its share of the market. The takeover time is defined to be the time required for the market penetration to increase from 10% to 90%. If one technology is substituted for another, as is generally the case for remediation technologies, the substitution rate resembles an S-shaped growth curve. An example of such a curve is shown in Figure 6, taken from Fisher and Pry [5]. The substitution factor increases slowly until a threshold is reached, at which point the innovative technology quickly gains a larger share of the market, and eventually the curve saturates to the final market share.

This effect is taken into account in the ROI calculation. It is assumed that it takes time for the innovative technology to be accepted so that implementation is spread out over a few years, and cost savings are initially small. Takeover times in industry range from several years to decades [5], but because of the pressures to remediate the complex quickly, it is assumed that the takeover time for remediation technologies will be 3-4 years.

Figure 6. Substitution curve describing market penetration. An S-shaped curve that predicts the substitution of a new product as a function of time. The takeover time for this example is 4 years.

Background Documents — There are several guides available to assist in the process of performing a cost estimate, determining life cycle costs, and performing the CEA, ROI and B/C. The DOE's resource for performing cost estimates is the "*Cost Estimating Guide*" [4]. The guide discusses types of estimates, direct, indirect, start-up and operating costs, escalation, contingency, and scheduling, in addition to other topics. An in-depth discussion of investment principles including an example of how to calculate ROI and B/C is contained in the paper "*Methods for Evaluating Investment Strategies for Environmental Technologies*", by Showalter, Booth and Hardie [6].

In addition, the OST program has sponsored the authorship of two documents that are useful as guides or reference materials in developing cost estimates specifically for emerging technology development activities. The first, "*EM-50 Technology Development Field Cost Estimating Guide*" [7], was developed to assist in developing cost or budget estimates for inclusion in the Technical Task Plans (TTPs), and is particularly useful in calculating research and development costs. Though the purpose of the guide was to assist in the TTP development, the principles and discussions on cost estimating methodologies are directly applicable to the cost analyses needed to support the gate decision process. A second product, "*A Practical Guide to Evaluating the Cost Effectiveness of New Environmental Technologies*" [2], was generated to specifically assist a technologist in the development and evaluation of cost analyses for emerging technology systems. It explains in detail the cost-effectiveness methodology and the steps required to perform a CEA.

In an effort to standardize cost and performance reporting across government agencies, the Federal Remediation Technologies Roundtable, consisting of representatives from the EPA, DoD, DOE, DOI, and the armed services, has prepared a document entitled "*Guide to Documenting Cost and Performance for Remediation Projects*" [8]. Cost information follows the Hazardous, Toxic and Radioactive Waste Work Breakdown Structure format which was developed by the Interagency Cost Estimating Group (ICEG) for reporting costs of remedial actions. In the interests of maintaining consistency across DOE, it is recommended that cost information in the CEA be presented in the same format.

The Office of Environmental Restoration (EM-40) has published a cost and performance guide which is similar to the FRTR document. The EM-40 guide, "*Documenting Cost and Performance for Environmental Remediation Projects*" [9], is to be followed in reporting the cost and performance results from completed, full-scale DOE waste cleanup projects as well as technology demonstrations (at gate 6). The same cost and performance information that is required for the FRTR and EM-40 documents will also be used in making the cost-effectiveness analysis and return on investment calculations. However, the cost-effectiveness analysis described in this paper has a separate purpose from the report that is generated using the EM-40 documentation guide in that its intention is to assist in the decision-making process rather than to document costs.

V. EXAMPLE

STEP 1 – Identify baseline technology (ies) from the TYP. As an example to illustrate the process, suppose that a TD has an idea for a technology system that would remediate uranium-contaminated soil. Upon examining the TYP, the TD determines that the preferred baseline technology is excavate, solidify/stabilize (if necessary), and dispose, or “muck and truck”. Alternate technologies include in-situ and ex-situ soil washing, electrokinetics, heap leach, and oxidation/reduction. The TD obtains cost figures on the baseline technologies from the FA.

STEP 2 – Perform cost comparison of innovative technology system to baseline technology system.

Step 2a – Construct scenarios that give a fair comparison between technologies. The TD has now developed the new remediation process to the point that he can identify sites from the TYP that would benefit from the application of his technology. Beginning with Los Alamos, he constructs a table which contains the site identification, site dimensions (LLLxWWWxDDD), average uranium contamination levels, baseline technologies that are being used to remediate the soil, and any other parameter that might vary from site to site, such as the number of soil characterizations that must be made. He makes similar tables for uranium-contaminated soil at Mound, Fernald, Oak Ridge, Hanford and Savannah River. The table might resemble the following:

Site Parameters

Site/Project LANL	Dimensions	Contamination	Baseline Technology	Volume
PRS105	50x100x2 m ³	500 ppm	Muck & Truck	10,000 m ³
PRS277	40x10x5 m ³	2500 ppm	Muck & Truck	2,000 m ³
PRS322	50x50x10 m ³	100 ppm	Muck & Truck	25,000 m ³
PRS370	100x25x2 m ³	250 ppm	Muck & Truck	5,000 m ³

In this example, the factors that are likely to influence the unit cost are site area, uranium contamination level, depth of contamination, disposal costs, and perhaps soil type (rocky soil would increase the unit cost). The parameter ranges would be derived from the TYP. For example, the range of uranium contamination across the complex might be from 100 ppm to 2500 ppm. Site areas might range from 500 m² to 5000 m² and depths from 1 to 10 m. Scenarios would be chosen that would result in low, medium and high remediation

costs so that a range of unit costs could be calculated. One scenario might use averaged values for all of the parameters. Here is a sample scenario list.

Scenarios

Scenario Number	Scenario For each case, cleanup level to be attained is 50 ppm
1	A field with area 500 m ² x 2 m deep, with 100 ppm U contamination
2	A field with area 1,000 m ² x 5 m deep, with 850 ppm U contamination
3	A field with area 5,000 m ² x 2 m deep with 2500 ppm U contamination

Step 2b -- Characterize the performance of the baseline and innovative technology systems. Examples of performance data that might be collected are given in Table 2. Further examples of performance data that are used in constructing the cost and performance report for EM-40 demonstrations is given in Table 3, which is taken from reference 9. Although this is performance information that would be derived from an actual demonstration, the same type of information would be required for input to a cost-effectiveness analysis.

Step 2c -- Determine life cycle costs for technologies. The essential input to the cost estimate is the cost elements. An example of general cost elements in a typical DOE construction project is given in Table 4. More detailed cost elements that are given in a checklist format are presented in Appendix F, which differentiates construction (non-recurring) from operating (recurring) costs. It should be noted that some of the items on the checklists will only be relevant to particular technologies, so that not all of the items will apply to every technology. Various cost estimating techniques such as those described in references 4 and 7 are used to determine the actual costs.

An example of life cycle costs for a baseline technology system -- a combination of Pump & Treat and Soil Vapor Extraction (P&T/SVE)-- is given in Appendix B. As seen, the costs are determined for each year that the technology system is in use, and include design, construction, mobilization, operation and maintenance, demobilization, surveillance and monitoring, decontamination and decommissioning, and waste disposal. Escalation is not included, so that the estimates are made in today's dollars. Each year's costs are summed, and a discount factor is applied to reflect the time value of money. In the example, Year 1's costs are not discounted, Year 2's costs are discounted by a factor of $(1.031)^{-1}$, Year 3's costs are discounted by a factor of $(1.031)^{-2}$ and so on until Year 10's costs are discounted by a factor of $(1.031)^{-9}$. The sum of the discounted annual costs is the present value of the costs. In the appendix, a discount rate of 3.1% was used.

Table 2. Performance Data Requirements – Examples

Site characteristics
Sensitivity/Detectability
Selectivity
Accuracy
Precision
Ruggedness
Throughput
Cycle time
Convenience/Portability
Sample turnaround time
Real-time monitoring capability
Volume of waste treated
Lowest attainable concentration
Rate of contaminant reduction
Fraction of contaminant remediated
Excavation rate
Pumping rate
Volume reduction (for contaminated soils)
Residuals generated
Data resolution
Other

Table 3: Performance-Related Information

PERFORMANCE-RELATED TOPIC	TYPE OF INFORMATION
Cleanup Goals	<ul style="list-style-type: none"> - Cleanup goals or objectives - Criteria for terminating operation
Remediation Plan	<ul style="list-style-type: none"> - Process Optimization Efforts - Sequence of Events (major phases) - Construction - Treatment, storage, disposal - Transportation
Quantity of Material Treated	<ul style="list-style-type: none"> - Quantity of material treated during the application - For in situ technologies, area, depth, thickness, volume of contaminated material treated. - For D&D projects, provide gross square footage (area) of the site. Volume or tonnage can be estimated.
Quantity of Material Stored or Disposed	<ul style="list-style-type: none"> - Quantity of material or waste stored or disposed of in-place or in a disposal cell.
Quantity of Material Transported	<ul style="list-style-type: none"> - Quantity of material or waste transported to an on-site or off-site disposal cell.
Untreated and Treated Contaminant Concentrations	<ul style="list-style-type: none"> - Measurement of initial conditions - Measurement of contaminant concentration before, during, and after treatment (matched untreated/treated pairs of data and corresponding operating condition data. - Assessment of percent removal achieved and method used to derive it.
Comparison with Cleanup Objectives	<ul style="list-style-type: none"> - Assessment of how well the technology operation achieved cleanup objectives - Assessment of whether the technology was operated to go beyond the cleanup goal
Risk Reduction	<ul style="list-style-type: none"> - Define exposure scenario(s) including populations, intake pathways, toxicity assessments - Provide risk levels before and after remediation
Residuals	<ul style="list-style-type: none"> - Types of residuals generated (e.g., off-gases, wastewaters, or sludges) - Measurement of mass or volume, and contaminant concentration, in each treatment residual

Table 4. Cost Elements and Basis of Estimates

	<u>Baseline Type Est.</u>	<u>Baseline \$</u>	<u>Innovative Type Est.</u>	<u>Innovative \$</u>
Studies and Tests (Treatability)				
Equipment				
Installation				
Labor				
Project Mgmt.				
Pre-Operations Activities				
Conceptual Design				
Permitting				
Safety				
Preparation for Ops.				
Project Mgmt.				
Facility Construction				
Design				
Construction				
Building				
Equipment				
Indirects				
Construction Mgmt.				
Inspection				
Project Mgmt.				
Operations & Maintenance (Annual)				
Labor				
Utilities				
Materials				
Maintenance				
Decontamination & Decommissioning				
Facility Decontamination				
Closure, Post Closure Monitoring				
Waste Disposal				
Treatment/Stabilization				
Transportation				
Disposal				
TOTAL				

It is recommended that costs be presented in a structure that follows the HTRW-WBS. This is the work breakdown structure that has been chosen by several government agencies to best display costs from environmental management activities. Appendix B also contains the costs for the P&T/SVE activity presented in the WBS format.

The WBS hierarchy has five levels of detail. Level 1 differentiates construction work from pre-construction activities and long term operations. Construction costs are presented in the Remedial Action WBS (RA-WBS), along with costs for operations and maintenance which take place during the construction process. Long term operations and closeout costs are given in the Operations and Maintenance WBS (O&M-WBS), while pre-construction and remedial design activities are given in the Studies and Design WBS (SD-WBS). Each WBS uses a 5 character account number, where the first 3 digits are from the Army Corps of Engineers Superfund accounting system, and the last 2 characters are user defined. The RA-WBS uses the account number 331XX, while the O&M-WBS and the SD-WBS use account numbers 342XX and 321XX, respectively.

Level 2 lists 19 major work categories generally found in a construction or O&M project. Among those are site work, solids collection and containment, biological treatment, chemical treatment, and physical treatment. Level 3 lists methods that could be used to accomplish the Level 2 elements. Soil flushing (surfactant/solvent) and aeration are examples of techniques that could be used in the physical treatment process. Levels 4 and 5 list items, products (such as "As-Built Drawings"), or specific actions that must be taken. Soil flushing, for example, may be done with a portable unit or a permanent unit; the type of unit is specified at Level 4.

The level 2 cost elements are shown in Table 5, which is taken from the EM-40 cost and performance guide [9]. The third level of cost categories is given in Appendix G. More information on the HTRW-WBS can be obtained from the WWW at the address "<http://www.mrd.usace.army.mil/mrdded-h/text/rawbs.html>", and a copy of the WBS (RA and O&M) to 4th level can be obtained at "http://globe.lmi.org/lmi_hcas/".

For some technologies, a fee will be charged to perform a cleanup activity by a vendor, so there will be no necessity for gathering construction or operating costs. It is assumed that the fee already takes into account life cycle costs. However, care must be taken to insure that it is not an unrealistic estimate but rather an accurate fee without any hidden costs. If possible, there should be a comparison to other bids. The vendor should supply a break-out of life cycle costs allowing a detailed examination of the cost estimate.

Table 5: Second Level of WBS for Collecting Cost Information

GENERAL ACTIVITY AREAS	COST ELEMENTS
Preliminary Activities	<ul style="list-style-type: none"> - Characterization - Assessment - Design
Preparatory Work	<ul style="list-style-type: none"> - Mobilization - Monitoring, Sampling, Testing, and Analysis - Site Work
Containment, Collection & Control	<ul style="list-style-type: none"> - Surface Water Collection and Control - Groundwater Collection and Control - Air Pollution/Gas Collection and Control - Solids Collection and Containment - Liquids/Sediments/Sludges Collection and Containment
Treatment	<ul style="list-style-type: none"> - Biological Treatment - Chemical Treatment - Physical Treatment - Thermal Treatment - Stabilization/Fixation/Encapsulation - Decontamination & Decommissioning (D&D)
Disposal	<ul style="list-style-type: none"> - Disposal (other than Commercial) - Disposal (Commercial)
Demobilization	<ul style="list-style-type: none"> - Site Restoration - Demobilization
Long-Term Surveillance & Maintenance	<ul style="list-style-type: none"> - Institutional Controls - Monitoring - Maintenance - Security

In this example the TD determines the discounted life cycle costs for each scenario and presents them in a table such as the following:

Life Cycle Costs

Range	Baseline	Innovative	Soil Volume
low	\$0.35 M	\$0.1 M	1,000 m ³
mid	\$4.0 M	\$2.0 M	5,000 m ³
high	\$25.0 M	\$15.0 M	10,000 m ³

Step 2d – Determine unit costs for innovative and baseline technology systems and calculate unit cost savings. Unit costs are determined by dividing the discounted life cycle costs by the total amount of soil remediated to give \$ per m³ of contaminated soil. The unit cost savings is then the difference between the unit cost of the innovative technology system and the unit cost of the baseline technology system.

Unit Costs

Range	Baseline	Innovative	Unit Cost Savings
low	\$350 /m ³	\$100 /m ³	\$250 /m ³
mid	\$800 /m ³	\$400 /m ³	\$400 /m ³
high	\$2,500 /m ³	\$1,500 /m ³	\$1,000 /m ³

STEP 3 – Determine potential life cycle cost savings.

Step 3a – Identify the cost basis or market size. The table of step 2a can now be modified to include the unit cost of the baseline to give the cost basis. For each site the TD uses engineering judgement to determine which unit cost to use -- low, medium or high.

Cost Basis

Site/Project LANL	Volume	Range	Baseline unit cost	Cost Basis
PRS105	10,000 m ³	mid	\$800 /m ³	\$8.0 M
PRS277	2,000 m ³	high	\$2,500 /m ³	\$5.0 M
PRS322	25,000 m ³	low	\$350 /m ³	\$8.75 M
PRS370	5,000 m ³	low	\$350 /m ³	\$1.75 M

Step 3b – Determine the waste volume and the maximum potential cost savings. The waste volume for each site is recorded in the previous table, and the maximum possible cost savings is calculated by multiplying the waste volume by the unit cost savings for each site. If the technology system were to be immediately accepted by the site and perform according to plan, this is the savings that would result. It does not take into account market penetration or other factors that might preclude the acceptance of the innovative technology system at the site (conservatism factor).

Maximum Potential Cost Savings

Site/Project LANL	Volume	Unit Cost Savings	Maximum Potential Cost Savings
PRS105	10,000 m ³	\$400 /m ³	\$4.0 M
PRS277	2,000 m ³	\$1,000 /m ³	\$2.0 M
PRS322	25,000 m ³	\$250 /m ³	\$6.25 M
PRS370	5,000 m ³	\$250 /m ³	\$1.25 M

Step 3c – Determine the reduced potential cost savings. The cost savings should be reduced by a conservatism factor which is determined using engineering judgement. Initially, this may be nothing more than an educated guess, but as the technology develops and implementation moves closer, the conservatism factor should decrease.

Reduced Potential Cost Savings

Site/Project LANL	Cost Basis	Maximum Cost Savings	Conservatism Factor	Reduced Cost Savings
PRS105	\$8.0 M	\$4.0 M	.8	\$3.2 M
PRS277	\$5.0 M	\$2.0 M	.7	\$1.4 M
PRS322	\$8.75 M	\$6.25 M	.7	\$4.4 M
PRS370	\$1.75 M	\$1.25 M	.9	\$1.1 M

At Los Alamos, the total reduced potential cost savings for this hypothetical example is \$10.1 M.

STEP 4 – Calculate ROI and B/C. Assume that the uranium-contaminated soil remediating technology system will have taken 5 years to develop, and the R&D costs are given in Table 6. The first year of development is Year -5, the second year is Year -4, and so on. At Year 0, implementation is initiated, and the technology takeover time is 4 years, so that at year 4 nearly all of the sites are using the technology. The remediation at each site takes about 5 years, and it is completed at all sites at year 10. The life cycle costs are presented in Table 6, and the present value of the R&D costs, $PV_{R\&D}$, and the present value of the cost savings, $PV_{Savings}$ are determined. The ratio of these two quantities is the benefit to cost ratio, B/C. The ROI is determined by adjusting the discount rate until the net present value is zero (or until $B/C = 1.0$).

In this particular example, the total R&D cost for the technology development effort is \$8.7M, but the discounted cost is \$9.0M (negative years give a discount factor greater than 1). Total savings are \$110 M which are discounted to \$94 M. The benefit to cost ratio is 10.4 and the ROI is 41%. If the first year of the technology development process were taken to be Year 0 instead of Year -5, the discounted numbers would all be different, but the ROI and B/C would be the same.

Table 6. ROI and B/C Calculation

Discount rate = 2.70%			All figures are in \$M				
year	innovative	discounted	baseline	discounted	savings		
-5	\$1.15	\$1.17	\$0	\$0	(\$1.17)	PV_{RAD} \$9.0 M	ROI 41%
-4	\$3.30	\$3.33	\$0	\$0	(\$3.33)		
-3	\$5.50	\$5.54	\$0	\$0	(\$5.54)		
-2	\$1.25	\$1.30	\$0	\$0	(\$1.30)		
-1	\$6.50	\$6.70	\$0	\$0	(\$6.70)		
0	\$2.0	\$2.0	\$0	\$0	(\$2.0)	$PV_{Savings}$ \$93.7 M	B/C 10.4
1	\$6.0	\$5.8	\$6.0	\$5.8	\$0		
2	\$12.0	\$11.4	\$14.0	\$13.3	\$1.9		
3	\$18.0	\$16.6	\$26.0	\$24.0	\$7.4		
4	\$22.0	\$19.8	\$38.0	\$34.2	\$14.4		
5	\$25.0	\$21.9	\$46.0	\$40.3	\$18.4		
6	\$23.0	\$19.6	\$46.0	\$39.2	\$19.6		
7	\$19.0	\$15.8	\$38.0	\$31.5	\$15.8		
8	\$13.0	\$10.5	\$26.0	\$21.0	\$10.5		
9	\$7.0	\$5.5	\$14.0	\$11.0	\$5.5		
10	\$3.0	\$2.3	\$6.0	\$4.6	\$2.3		

VI. SUMMARY

In summary, a gate is a decision point at which technologies are evaluated and prioritized, and those technologies which pass through the gate advance to the next stage of development. The gate decision-making criteria are satisfied by deliverables which are derived from information gained during the technology development stage. The cost-effectiveness analysis is initiated at the early stages of development and revised as development proceeds. The CEA includes only those costs associated with design, testing, construction, operations, maintenance, and decommissioning of the facility and determines the cost savings that will be realized if the technology is implemented. The return on investment and benefit to cost ratio calculations take those savings and factor in the development costs to arrive at values that are compared to pre-determined hurdles. It is then up to the FA/CP to determine whether the technology should pass through the gate, and whether cost, performance or risk reduction (or some combination thereof) is the most important factor.

Cost savings deliverables have been discussed and suggestions have been made concerning what deliverables should be expected at each gate. Cost and performance requirements have been given, and gate criteria for making the decision to pass, kill, hold or send back have been suggested. It is recognized that other considerations, such as ES&H issues, regulatory requirements, legal issues, etc. which may not have been incorporated in the cost analysis may affect the final cost, but it is beyond the scope of this paper to address those effects. A separate criterion at the gates concerning potential increased costs related to these issues may be required.

VII. REFERENCES

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VIII. GLOSSARY OF TERMS

baseline technology system: A technology system that is currently addressing a particular waste management or environmental restoration need.

benefit to cost ratio (B/C): The ratio of the present value of cost savings to the present value of development costs.

cash flow: The amount of money that is paid out (cash outflow) or taken in (cash inflow). In a comparison of an alternative project to a baseline, it is the additional costs of the alternative project (outflow) or the amount that is saved (inflow).

cost-benefit analysis: A systematic quantitative method of assessing the desirability of projects or policies when it is important to take a long view of future effects and a broad view of possible side effects.

cost effectiveness: A program is cost-effective if, on the basis of life cycle cost analysis of competing alternatives, it is determined to have the lowest costs expressed in present value terms for a given amount of benefits.

cost-effectiveness analysis (CEA): A systematic quantitative method for comparing the costs of alternative means of achieving the same stream of benefits or a given objective.

crosscutting program (CP): The development of crosscutting technologies that overlap the boundaries of the focus areas while providing simultaneous benefits.

discounted cash flow: The cash flow (including outflow and inflow) that has been discounted by multiplying by the discount factor.

discount factor: The factor that translates expected savings or costs in any given future year into present value terms. The discount factor is equal to $1/(1+i)^t$ where i is the discount rate and t is the number of years from the date of initiation for the program or policy until the given future year.

discount rate: The interest rate used in calculating the present value of expected yearly savings and costs. For the purposes of these analyses, it is taken from Appendix C of OMB Circular No. A-94, updated annually.

focus area (FA): A major remediation and waste management problem area within the DOE complex that has been targeted for action based on risk, prevalence, or the need for technology development to meet environmental requirements and regulations.

Hazardous, Toxic and Radioactive Waste Work Breakdown Structure (HTRW-WBS): A work breakdown structure that was developed by the Interagency Cost Estimating Group (ICEG) for reporting costs of remedial actions.

innovative technology system: An alternative technology system that can replace the baseline technology system.

life-cycle cost: The overall estimated cost for a particular program alternative over the time period corresponding to the life of the program.

net present value: The sum of the discounted cash flows (inflows and outflows -- costs and savings) over the life of the program.

present value: The sum of the discounted savings or costs (inflows or outflows).

return on investment (ROI): The discount rate that equates the present value of expected cash outflows with the present value of expected cash inflows (costs and savings).

time value of money: The simple principle that a dollar now is worth more than a dollar later because a dollar saved now can be converted to more dollars later.

IX. APPENDICES

- A. Example Cost Savings Criteria
- B. Life Cycle Cost Estimate for a Baseline Technology
- C. Cost-Effectiveness Analysis for "Contaminant Removal From Solid Waste by Supercritical Carbon Dioxide" -- A Stage 4 technology
- D. Cost-Effectiveness Analysis for "Alternative Landfill Cover Demonstration" -- A Stage 5 technology
- E. Cost-Effectiveness Analysis for "In Situ Bioremediation" -- A Stage 6 technology
- F. Cost Data Requirements
- G. HTRW RA-WBS 3rd Level Cost Categories

Appendix A. Example Cost Savings Criteria

An example of cost criteria for gate 5 might be:

- "Has the CEA of Gate 4 been revised?**
- Is the cost estimate accurate to a factor of +30% to -15% (or better)?**
- Does it pass an external review (if appropriate)?**
- Is the cost estimate for stage 6 reasonable?**
- Has an ROI calculation been performed? Does it meet the hurdle rate?**
- Has B/C been calculated? Does it meet the expectations of the FA/CP?"**

The examples of successful technologies should be used to establish the gate passage criteria. All technologies that reach the demonstration stage (stage 6) should have passed criteria that almost guarantee their acceptance and implementation. For example, a criterion might be "Is the return on investment greater than 25%?" This number might be based on the lowest ROI of successfully implemented technologies. In another example, "Is the benefit to cost ratio greater than 5?" or "Are the cost savings greater than \$5M?" The focus areas need to determine these "hurdles" based on their own experiences. They may be different for each of the focus areas.

Criteria "logic" may also be introduced into the stage/gate process. As an example,

- "The technology must have an ROI > 25% OR performance that will reduce the remedial action by 5 years WHILE costing < 150% of the baseline technology."**

If the focus area determines that a combination of criteria should be included together, this logic would be appropriate to implement. Of course, each FA/CP will determine the final wording of the criteria.

Appendix B. Life Cycle Cost Estimate for a Baseline Technology (Pump and Treat / Soil Vapor Extraction)

Pump and Treat/Soil Vapor Extraction Life Cycle Cost (10 years)

Pump and Treat/Soil Vapor Extraction

	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
Capital Cost										
Site Cost	\$7,500									
Equipment Cost										
Design and Engineering	\$32,000									
Mobile Equipment	\$18,000									
Well Installation	\$50,690									
Other Fixed Equipment	<u>\$168,665</u>									
Subtotal: Equipment Costs	<u>\$276,855</u>									
Mobilization Costs (150 mhrs)										
Technicians (2)	\$18,600									
Laborers (2)	\$17,400									
Oversight Engineer (1)	\$21,300									
Per Diem	<u>\$7,313</u>									
Subtotal: Mobilization Costs	<u>\$64,613</u>									
Operation and Maintenance Costs										
Monitoring /Maintenance										
Technician	\$45,260	\$45,260	\$45,260	\$45,260	\$45,260	\$45,260	\$45,260	\$45,260	\$45,260	\$45,260
Oversight Engineer	<u>\$25,915</u>	<u>\$25,915</u>	<u>\$25,915</u>	<u>\$25,915</u>	<u>\$25,915</u>	<u>\$25,915</u>	<u>\$25,915</u>	<u>\$25,915</u>	<u>\$25,915</u>	<u>\$25,915</u>
Subtotal: Monitoring/Maintenance Costs	<u>\$71,175</u>	<u>\$71,175</u>	<u>\$71,175</u>	<u>\$71,175</u>	<u>\$71,175</u>	<u>\$71,175</u>	<u>\$71,175</u>	<u>\$71,175</u>	<u>\$71,175</u>	<u>\$71,175</u>
Consumable Costs										
Catalytic Material	\$27,500	\$27,500	\$27,500	\$27,500	\$27,500	\$27,500	\$27,500	\$27,500	\$27,500	\$27,500
Electricity	\$76,650	\$76,650	\$76,650	\$76,650	\$76,650	\$76,650	\$76,650	\$76,650	\$76,650	\$76,650
Lubricants	\$1,095	\$1,095	\$1,095	\$1,095	\$1,095	\$1,095	\$1,095	\$1,095	\$1,095	\$1,095
Maintenance Supplies	<u>\$18,250</u>	<u>\$18,250</u>	<u>\$18,250</u>	<u>\$18,250</u>	<u>\$18,250</u>	<u>\$18,250</u>	<u>\$18,250</u>	<u>\$18,250</u>	<u>\$18,250</u>	<u>\$18,250</u>
Subtotal: Consumable Costs	<u>\$123,495</u>	<u>\$123,495</u>	<u>\$123,495</u>	<u>\$123,495</u>	<u>\$123,495</u>	<u>\$123,495</u>	<u>\$123,495</u>	<u>\$123,495</u>	<u>\$123,495</u>	<u>\$123,495</u>
Demobilization Costs (150 mhrs)										
Technician (2)										\$18,600
Laborers (2)										\$17,400
Oversight Engineer (1)										\$21,300
Per Diem										<u>\$7,313</u>
Subtotal: Demobilization Costs										<u>\$64,613</u>
TOTAL ANNUAL COSTS	\$536,138	\$194,670	\$194,670	\$194,670	\$194,670	\$194,670	\$194,670	\$194,670	\$194,670	\$259,283

TOTAL LIFE CYCLE PRESENT VALUE= \$2,093,906
(3.1% real discount rate)

Pump and Treat: 1 vertical well (175 ft. deep, 35 ft. screens); pumping rate -- 30 gpm

Soil Vapor Extraction: 4 vertical wells (130 ft. deep, 100 ft. screens); vapor extraction rate -- 300 scfm maximum

Contaminant extraction: The extraction rate using SVE decreases as the concentration of contaminant in the ground decreases. extraction rate -- 1st year: 11,500 lbs of VOCs

2nd year: 8600 lbs VOCs

3rd-5th years: 5800 lbs VOCs per year

6th-10th years: 2900 lbs VOCs per year

This would remediate a region of vadose zone with dimensions ~175 ft. by 150 ft. by 100 ft. deep.

HTRW RA-WBS Presentation of Costs**Pump and Treat/Soil Vapor Extraction Life Cycle
Cost (10 years)****Pump and Treat/Soil Vapor
Extraction**

	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
Construction										
33 01 01 Mobile Equipment	\$18,000									
33 01 02 Mobilization of Personnel	\$64,613									
33 02 05 Sampling	\$34,750									
33 03 03 Sitework	\$7,500									
33 03 06 Electrical Distribution	\$16,590									
33 03 08 Piping and Insulation	\$13,825									
33 06 01 Well Installation	\$53,872									
33 13 07 Air Stripping	\$63,442									
33 13 23 Soil Vapor Extraction	\$66,653									
33 14 02 Catalytic Oxidation	\$164,893									
33 21 05 Demobilization of Personnel										\$64,613
33 22 04 Design and Engineering	\$32,000									
Operation and Maintenance										
34 13 07 Air Stripping		\$55,723	\$55,723	\$55,723	\$55,723	\$55,723	\$55,723	\$55,723	\$55,723	\$55,723
34 13 23 Soil Vapor Extraction		\$55,723	\$55,723	\$55,723	\$55,723	\$55,723	\$55,723	\$55,723	\$55,723	\$55,723
34 14 02 Catalytic Oxidation		\$83,224	\$83,224	\$83,224	\$83,224	\$83,224	\$83,224	\$83,224	\$83,224	\$83,224
TOTAL ANNUAL COSTS	\$536,138	\$194,670	\$194,670	\$194,670	\$194,670	\$194,670	\$194,670	\$194,670	\$194,670	\$259,283

TOTAL LIFE CYCLE PRESENT VALUE= \$2,093,906
(3.1% real discount rate)

Appendix C. Cost-Effectiveness Analysis for "Contaminant Removal From Solid Waste by Supercritical Carbon Dioxide" – A Stage 4 technology

**CONTAMINANT REMOVAL FROM SOLID WASTE USING
SUPERCRITICAL CARBON DIOXIDE**

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- Supercritical carbon dioxide (SCCO₂) is a non-toxic, inexpensive and easily recyclable solvent that can be used for removing hazardous waste such as oils, greases, and solvents from cotton-based rags, paper wipes and protective clothing.
- Cost savings are realized by removing hazardous waste from non-hazardous debris, allowing the debris to be recycled or disposed of in a sanitary waste landfill and significantly reducing the amount of hazardous waste. Savings at a *single* production facility could amount to hundreds of thousands of dollars per year, based on hazardous waste production of 150 m³ of "oily rag" trash per year.
- Assuming a project lifetime of 15 years, the technology has a potential return on investment of 40%, a benefit-to-cost ratio of 4.25 and a payback period of 3 years. Even if the project lifetime were to be reduced by a factor of 3, which might result if regulations concerning the hazardous nature of "oily rags" were to be relaxed, the return on investment is still 30%. An even greater return would be realized if disposal costs of the hazardous waste were greater than the \$1000/m³ assumed here.
- Net discounted savings over the life of the project could be as high as \$1M per facility.
- Taking into account the additional savings that would result from not having to replace recycled rags and protective clothing would increase the benefits substantially.

Background

Large quantities of solid wastes such as rags, kimwipes, swabs, coveralls, gloves, etc., contaminated with oils, greases and hazardous solvents are generated in great quantities by industry and the government. At present, these materials must be treated as hazardous waste, and the cost of disposal of such large volumes of hazardous materials is high. If the hazardous components (oils, greases and solvents) could be segregated from the much larger bulk of non-hazardous material, then these solid materials could potentially be handled as sanitary waste, or be recycled, at a significant cost savings [1].

A supercritical fluid is a gas-like substance above its critical temperature and pressure (temperature/pressure above which a substance cannot be liquified, independent of pressure), possessing liquid-like solvating properties and gas-like diffusion and viscosity [2]. Supercritical carbon dioxide possesses many of the characteristics desired in an "environmentally acceptable" solvent system. It is non-toxic, inexpensive, and recyclable. Carbon dioxide possesses a moderate critical temperature (31°C) and pressure (1071 psi). At 37°C and pressures greater than 2000 psi, the density is greater than 0.8 g/cc -- nearly equal to that of water (1.0 g/cc). This is to be compared to the density of gaseous CO₂ at ambient conditions (0.002 g/cc). A schematic of an ideal cleaning apparatus is shown in Figure 1.

The solid waste to be cleaned is placed in the extractor and the SCCO₂ flowing through the vessel dissolves the contaminants and carries them away. When the contaminant-laden supercritical fluid expands across the pressure restrictor into the separator, the dissolved material precipitates out and is left behind in the separator. The gaseous CO₂ is cooled, reliquified, and then repressurized to be used again in the extractor. This recirculating feature allows continual exposure of the contaminated solids to clean supercritical fluid for as long as necessary without consuming large amounts of CO₂. At the end of a cleaning cycle, the clean solids are removed from the extractor to be reused or discarded as non-hazardous waste. The oils/greases/solvents, now in concentrated form, are drained from the separator and disposed of as hazardous waste [3].

Figure 1. Ideal supercritical carbon dioxide cleaning apparatus.

Tests were performed on laboratory paper wipes that were treated with 22 common solvents in a SCCO₂ cleaning system at AlliedSignal KCP [3]. During the experiment, the SCCO₂ was held at 45°C and 2600 psi -- very mild supercritical conditions. In every case, the SCCO₂ was recirculated 5 times through the extractor, taking approximately one hour. Essentially all of the solvents were fully extracted from the laboratory paper wipes. Similar results were obtained for oil-contaminated wipes. Identical results were realized for cotton based rags, while the process does not work as well for polyesters and synthetics since the CO₂ diffuses into these materials.

Assumptions [4]

- A "typical" facility produces 150 m³ of "oily rag" trash, which is disposed of as hazardous waste. This is considered to be the baseline.
- Disposal costs are roughly \$1000 per m³ for hazardous waste.
- Project lifetime is 15 years.
- SCCO₂ capital equipment cost is \$320,000 for a 200 liter SCCO₂ system.
- Operating costs are based on 1000 runs/yr, 10% CO₂ loss/run. They include maintenance, electricity consumption, CO₂ replacement, etc., but not labor.
- SCCO₂ process reduces hazardous waste volume from 150 m³ to 0.34 m³, which is comprised of the separated greases/oils/solvents.
- Operating costs are assumed to be constant over the 15 year period.
- The analysis has not considered the additional savings that would result from recycling rags and protective equipment.
- Return on investment (ROI) calculation uses a real discount rate of 4.8% to take into account the time value of money.

Analysis

The ROI calculation assumes a discount rate of 4.8% and that the equipment costs for the SCCO₂ system are incurred in the first year (-1). Thereafter, operating costs for both the SCCO₂ system and the baseline case (hazardous waste disposal of contaminated rags) are constant for 15 years. Labor costs are not included, since it is assumed that the same amount of time would be spent for each activity. The actual costs are displayed in Table 1. Return on investment is that rate at which the costs and benefits are equal, i.e. B/C = 1 [6]. It is calculated by increasing the discount rate until the total sum of the savings (14th year, last column in the table) is zero. The benefit-to-cost ratio is calculated by dividing the total net savings by the total net costs (the sum of the savings from years 0 to 14 divided by the cost from year -1 -- "savings" column). The cost-savings analysis gives a

return on investment of 40%, a benefit-to-cost-ratio (B/C) of 4.25 and a payback period of 3 years.

Table 1. Cost schedule for ROI calculation.

		discount rate = 0.048				
year	SCCO ₂	discounted	baseline	discounted	savings	sum savings
-1	\$320,000	\$335,360	\$0	\$0	(\$335,360)	(\$335,360)
0	\$16,200	\$16,200	\$145,600	\$145,600	\$129,400	(\$205,960)
1	\$16,200	\$15,458	\$145,600	\$138,931	\$123,473	(\$82,487)
2	\$16,200	\$14,750	\$145,600	\$132,568	\$117,818	\$35,331
3	\$16,200	\$14,074	\$145,600	\$126,496	\$112,422	\$147,753
4	\$16,200	\$13,430	\$145,600	\$120,702	\$107,273	\$255,026
5	\$16,200	\$12,815	\$145,600	\$115,174	\$102,359	\$357,385
6	\$16,200	\$12,228	\$145,600	\$109,899	\$97,671	\$455,056
7	\$16,200	\$11,668	\$145,600	\$104,865	\$93,198	\$548,254
8	\$16,200	\$11,133	\$145,600	\$100,062	\$88,929	\$637,183
9	\$16,200	\$10,623	\$145,600	\$95,479	\$84,856	\$722,039
10	\$16,200	\$10,137	\$145,600	\$91,106	\$80,969	\$803,009
11	\$16,200	\$9,673	\$145,600	\$86,934	\$77,261	\$880,270
12	\$16,200	\$9,230	\$145,600	\$82,952	\$73,722	\$953,992
13	\$16,200	\$8,807	\$145,600	\$79,153	\$70,346	\$1,024,338
14	\$16,200	\$8,403	\$145,600	\$75,527	\$67,124	\$1,091,462

A sensitivity analysis was performing by varying the project lifetime, which might result if regulations concerning the hazardous nature of "oily rags" were to be completely relaxed (thereby eliminating the need to separate out the solvents before disposal in a sanitary landfill, and the need for the cleaning process), or if the equipment would have to be replaced earlier than the 15 years. No salvage value for the equipment is assumed. Results from the analysis are shown in Table 2. If the project lifetime decreases, the net savings also decrease, but the effect on ROI is not large, since the savings have been discounted. Even for a project lifetime of only five years, the return on investment is still 30%, while the benefit-to-cost ratio is 1.8. The payback period does not depend on the project lifetime.

Table 2. Sensitivity analysis obtained by varying project lifetime

Lifetime (years)	ROI	B/C
15	40%	4.25
10	39%	3.15
5	30%	1.8

A sensitivity analysis was also performed by varying the hazardous waste disposal costs. This value varies across the country, and the value used in this analysis may actually be conservative. Results are given in Table 3. It can be seen that the cost analysis is strongly dependent on disposal costs. A disposal cost of only \$320/m³ is the point at which break-even occurs, and this is well below amounts which are currently charged for the disposal of hazardous waste. If the equipment is not used to its full potential, i.e., smaller amounts of waste are generated for a 200 liter system, the system is not as cost-effective, but the hazardous waste volume must drop to 40m³ before break-even occurs. Results are certainly optimized when the equipment is used to its fullest potential.

Table 3. Sensitivity analysis obtained by varying disposal costs

Disposal Cost (\$/m ³)	ROI	B/C	Payback Period (yrs.)
500	16%	1.9	7
1000	40%	4.25	3
1500	63%	6.6	2
2000	86%	9.0	1

Caveats

The disposal of hazardous solvents is regulated nationally, with additional local regulation possible. In the past, "treatment" of hazardous debris waste and separation into its hazardous and non-hazardous components was not allowed. There are now, however, federal regulations that specify performance standards for the solvent separation of certain hazardous wastes from non-hazardous debris [5]. The philosophy is as follows: "...It is not normally the debris itself that is hazardous, but rather hazardous waste that is contaminating the debris. Thus, the goal of treatment should be to destroy or remove the contamination (if possible) and if this is achieved, to dispose of the cleaned debris as a non-hazardous waste...". The regulatory requirements for liquid solvent extraction are 15 minutes contact between the debris and solvent, and the contaminant must be soluble to at least 5% by weight in the solvent. The requirements for vapor phase solvent extraction are identical except 60 minutes contact is specified. In each case it is assumed that the contaminants enter the solvent phase and are flushed away from the debris. Since a supercritical fluid is neither a liquid nor a gas, but has solvation powers and densities similar to a liquid and transport properties similar to a gas, the application of this standard to SCCO₂ would have to be ascertained.

The regulation of oils and grease disposal is addressed primarily by the states. State of Missouri regulations are currently being examined to determine if solid waste contaminated with oils and greases, and "cleaned" by SCCO₂, could be disposed of in

Missouri sanitary waste landfills. The recycle of material -- the reuse of cleaned rags -- is considerably easier than their disposal.

Applicability

This technique is applicable at all sites where step-can waste is produced and must be disposed of as hazardous waste.

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Appendix D. Cost-Effectiveness Analysis for "Alternative Landfill Cover Demonstration" – A Stage 5 technology

Alternative Landfill Cover Demonstration

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- The Alternative Landfill Cover Demonstration (ALCD) is testing full-scale alternative covers against standard EPA covers at an arid site near Albuquerque, NM.
- Standard EPA landfill cover designs work poorly in arid conditions because they dry out, shrink, and crack allowing water infiltration.
- Alternative cover designs do away with the problematical wet-compacted clay barrier, and emphasize such things as unsaturated hydraulic conductivity, capillary action, increased water storage potential to allow for eventual evaporation, and increased transpiration through engineered vegetative covers.
- Buy-in to the demonstration by the EPA and other regulatory bodies is essential to gain regulatory acceptance for the new designs.
- The most significant advantage of the alternative cover designs is that they will reduce water infiltration in arid climates, where conventional designs dry out, shrink, crack, and fail.
- The initial costs of the alternative designs will, for the most part, be less than conventional designs because they are simpler to construct with fewer steps and without the quality requirements on a wet-compacted clay layer.
- The rough estimate cost savings for various alternative cover designs are in the range of \$6-\$8/square foot, or about \$500,000 or more for a typical 2 acre hazardous waste landfill.

- Life-cycle costs for the successful alternative designs will be dramatically lower through the prevention of the need to remediate contaminated local water systems and avoidance of litigation expenses associated with the failure of conventional designs.
- The potential benefits of the new designs reach far beyond DOE because there are 250,000 disposal facilities under RCRA subtitle D in the US and those in the arid regions are still subject to regulations requiring the conventional EPA, failure-prone designs.

Engineering Background

An Environmental Protection Agency (EPA) study of 163 randomly selected landfills revealed that there is room for improvement in currently accepted landfill technologies. Minor to major problems were discovered at 146 of these sites. Problems included elevated chemical concentrations in on-site ground water, contamination of ground water at water supply well fields; surface water contamination; ecological impacts to local flora and fauna; and forced changes in the water supply for impacted communities where federal/state drinking water contamination standards were exceeded. Virtually all areas of the country have experienced some form of water contamination due to leaking leachate from landfills.

Current cover design criteria emphasizes barrier layers that block infiltration of water through the cover into the waste. Saturated hydraulic conductivity is the measurement device chosen by the EPA to define the effectiveness of the barrier layer (i.e., the lower the hydraulic conductivity, the better the layer is). This is not a realistic solution in arid and semi-arid regions because saturation of soil layers is rarely, if ever, achieved. The ALCD will focus on actual performance of covers through measurement of water infiltration under a variety of times and stress conditions.

The saturated hydraulic conductivity method can actually be detrimental to covers in arid and semi-arid regions. In order to achieve the low saturation hydraulic conductivity required by the EPA, the barrier soil must be remolded by compacting it wet which eventually leads to the later drying, shrinking, and thus cracking of the barrier layer. This defeats the original purpose of creating a barrier layer to block the infiltration of water into the waste.

The Alternative Landfill Cover Demonstration is developing technology to improve upon current landfill cover systems. The project will provide alternatives to the EPA's landfill cover designs that will work more effectively and be easier and less expensive to install in arid and semi-arid climates.

The ALCD will oversee the testing of innovative landfill covers. These covers, along with currently accepted EPA cover designs, are being installed and monitored in a side-by-side

demonstration. The location of the demonstration is in an arid region just a couple of miles to the SE of the Albuquerque international airport on the grounds of the Kirtland Air Force Base, where 10 acres have been dedicated to the demonstration plot. One side of the test plot will be evaluated under regular conditions, and the other side under "stressed" conditions controlled by a sprinkler system that will simulate light to heavy rainfall. The covers will be evaluated and compared based on construction, cost, and performance criteria. Figure 1 shows three covers that were constructed during 1995, including two standard EPA designs and one alternative design. Figure 2 shows three more alternative cover designs that will be constructed during 1996.

**Two Standard EPA Covers and One Alternative Cover
Constructed During the Summer of 1995**

Figure 1. Phase I landfill covers.

Three Alternative Covers Planned for Construction During 1996

Figure 2. Phase II landfill covers.

Some of the alternative designs will emphasize such things as unsaturated hydraulic conductivity, increased water storage potential to allow for eventual evaporation, and increased transpiration through engineered vegetative covers. The alternative covers were designed to take advantage of local materials to allow for easier construction of the covers at substantial cost savings. Extensive instrumentation at the demonstration site will produce detailed information on water infiltration, runoff, permeability, and many other performance characteristics for all of the designs.

Caveat

The key to gaining general acceptance of any new environmental technology is obtaining regulatory acceptance. The ALCD is addressing this issue by involving the EPA and environmental divisions from the western states in the project. This is aiding in gaining

acceptance of the new technologies and is encouraging interstate cooperation. The Western Governors Association and Committee to Develop On-Site Innovative Technologies (DOIT) are working with Sandia National Laboratories to promote interstate cooperation and regulatory buy-in.

Cost Saving Analysis

The ALCD costs should be less expensive than current systems because this effort will result in more efficient landfill cover designs tailored to specific site requirements. Currently, this effort is in the design and development stages. Specific cost information is currently in very rough form and will be refined as better estimates become available. The most direct form of cost information for each type of landfill cover is summarized in dollars/square foot. A typical hazardous waste landfill in the DOE complex is 2 acres in area -- or rounding off, about 90,000 square feet. This means that for every \$1.00/square foot in cost savings achieved, a typical landfill will enjoy cost savings of around \$90,000. Table 1 shows some early estimated costs for each of the cover designs currently planned for the ALCD. These costs were developed from standard engineering estimates for required materials and construction costs in NM for the designs diagrammed in Figures 1 and 2, for a 2 acre installation.

Table 1
Landfill Cover Costs **

Type of Landfill Cover	Construction Cost in \$/square foot	Approximate Cost Savings for a Typical 2 Acre Hazardous Waste Landfill
Traditional EPA Landfill Covers		
EPA Subtitle "D" (Municipal Landfill)	\$4.87	Not appropriate for hazardous waste
EPA Subtitle "C" (Hazardous Waste Landfill)	\$14.64	Current Baseline Technology
Alternative Landfill Covers		
GCL	\$8.63	\$520,000
Anisotropic	\$6.96	\$670,000
Capillary	\$8.96	\$490,000
Enhanced Evapotranspiration	\$6.75	\$690,000

** Note: These costs are considered to be rough estimates. They will be refined and updated as the ALCD develops better information.

There are about 3,000 hazardous waste landfills, of which about two-thirds (2,000) are in arid regions (New Mexico, Nevada, Idaho, Washington.) Most of these still have to go through the closure process. So a very rough estimate of the total surface area to which the new, alternative cover designs might be applied is: (2,000 landfills) * (90,000 square feet/landfill) = 180 million square feet. Each dollar of cost savings per square foot translates into about \$180 million for the entire cleanup program. With estimated cost savings in the \$6-\$8/square foot range the national savings possibilities are more than \$1 billion. (The number of hazardous waste landfills appropriate to the scope of the BEMR Report has not been verified, and perhaps the Landfill Stabilization Focus Area people can clarify this number.)

The successful demonstration and regulatory acceptance of some of the alternative designs will payoff in an important technology transfer, as well. The potential benefits of the new designs reach far beyond DOE because there are 250,000 disposal facilities under RCRA subtitle D in the United States and those in the arid regions are still subject to regulations requiring the conventional EPA, failure-prone designs.

The dollar cost of closure of hazardous waste landfills represents a direct and easily grasped potential cost savings. A more fundamental benefit of the new cover designs in arid climates is that the traditional designs do not perform the job they are supposed to accomplish. The traditional designs crack and shrink as they dry out allowing water infiltration, and therefore negating their whole purpose. Although robust data on national failure rates are not available, it is likely that cracks develop in most conventional covers within the first year, and these covers are almost never repaired or replaced. Standard practice is to close a landfill once and the cover is never expected to be replaced. If it were standard practice to make repairs, then the baseline costs would be driven up even beyond current levels. The new, alternative cover designs are intended to solve the arid land failure problem, making it possible to safely close the landfills, avoiding later groundwater contamination or the spreading of dangerous plumes below grade. Without this design solution, vastly greater costs may be incurred as a result of failed closures at many DOE sites. These costs of technical failure take on two obvious forms: (1) potential engineering and remediation costs of local water and other systems, and (2) litigation costs as contamination spreads and affected parties encounter damage. Both types of costs could rise to very high levels, but on an unpredictable or even whimsical basis. It would be unrealistic to try to quantify these costs based on guesswork about the future, but imagination can easily come up with potential remedial engineering and legal costs that would dwarf the cost of landfill covers, themselves.

Conclusions

- The most significant advantage of the alternative cover designs is that they will reduce water infiltration in arid climates, where conventional designs dry out, crack, and fail.

- The initial costs of the alternative designs will, for the most part, be less than conventional designs because they are simpler to construct with fewer steps and without the quality requirements on a wet-compacted clay layer. (For example, the GCL uses a factory manufactured sandwich of geotextiles with bentonite, which is much less costly to purchase and emplace than the conventional site-built tiers of geotextile with multiple clay lifts.)
- The rough estimate cost savings for various alternative cover designs are in the range of \$6-\$8/square foot, or about \$500,000 or more for a typical 2 acre hazardous waste landfill.
- Life-cycle costs for the alternative designs will be dramatically lower through the prevention of the need to remediate contaminated local water systems and litigation expenses associated with the failure of conventional designs. Only through ignoring contamination its subsequent remediation costs could these costs be sidestepped.
- The potential benefits of the new designs reach far beyond DOE because there are 250,000 landfills in the US and those in the arid regions are still subject to regulations requiring the conventional EPA , failure-prone designs.

References

1. Stephen F. Dwyer, "Alternative Landfill Cover Demonstration," Sandia National Laboratories report (October 1995).
2. EPA, Office of Solid Waste (1988), "Criteria for Municipal Solid Waste Landfills," (40CFR Part 258) Subtitle D of Resource Conservation and Recovery Act (RCRA). Draft - Background Document. Case Studies on Ground-Water and Surface Water Contamination from Municipal Solid Waste Landfills: EPA/530-SW-88-040, PB88-242466.
3. Stephen F. Dwyer, Interviewed November 16, 1995.

Disclaimer

This draft is issued for technical and format review. The values reported within should not be passed on for other analyses, or for decision making. Until this document has withstood a complete technical review, the contents should not be considered endorsed by the authors or their organization.

Construction Costs for Cover Portion Only -- No Details

Work Item Description	Units	Plot 1 -- Sub 'D'		Plot 2 -- GCL		Plot 3 -- Sub 'C'	
		Qty	Totals	Qty	Totals	Qty	Totals
Engineered Fill Soil -- Barrier	ton	1386	\$14,358.96		\$0.00	1848	\$19,145.28
compaction	day	3	\$4,193.25		\$0.00	12	\$16,773.00
placement	day	3	\$4,171.83		\$0.00	4	\$5,562.44
grade	day	3	\$3,792.69		\$0.00	4	\$5,056.92
Engineered Fill Soil -- Topsoil	ton	429	\$4,444.44	1848	\$19,145.28	1848	\$19,145.28
placement	day	1	\$1,390.61	3	\$4,171.83	3	\$4,171.83
grade	day	1	\$1,264.23	3	\$3,792.69	3	\$3,792.69
Sand	ton		\$0.00	864	\$9,313.92	864	\$9,313.92
placement	day		\$0.00	1	\$1,390.61	1	\$1,390.61
grade	day		\$0.00	1	\$1,264.23	1	\$1,264.23
Pea Gravel	ton		\$0.00		\$0.00		\$0.00
placement	day		\$0.00	1	\$1,390.61		\$0.00
grade	day		\$0.00	1	\$1,264.23		\$0.00
Gravel	ton		\$0.00		\$0.00		\$0.00
placement	day		\$0.00		\$0.00		\$0.00
grade	day	1	\$1,264.23		\$0.00		\$0.00
Subgrade Preparation							
cut/fill	day		\$0.00		\$0.00		\$0.00
remove rock & debris	day	1	\$226.00	1	\$226.00	1	\$226.00
grade	day	1	\$1,264.23	1	\$1,264.23	1	\$1,264.23
compact	day	1	\$1,397.75	1	\$1,397.75	1	\$1,397.75
Geomembrane, 40ml LLDPE	sf		\$0.00	13200	\$11,220.00	13200	\$11,220.00
GCL	sf		\$0.00	13200	\$16,830.00		\$0.00
Geotextile	sf		\$0.00	13200	\$3,366.00	13200	\$3,366.00
Bentonite	ton		\$0.00		\$0.00	96	\$16,320.00
mixing	day		\$0.00		\$0.00	3	\$7,585.39
QA Testing							
soil	allow	allow	\$1,000.00	allow	\$500.00	allow	\$2,500.00
geomembrane	allow	allow	\$0.00	allow	\$500.00	allow	\$500.00
Vegetation							
scarification	day	0.5	\$632.12	0.5	\$632.12	0.5	\$632.12
seed & mulch	msf	24	\$2,831.76	24	\$2,831.76	24	\$2,831.76
Survey Site	day	1	\$830.08	1	\$830.08	1	\$830.08
Foreman	day	16.5	\$5,610.00	14.5	\$4,930.00	35.5	\$12,070.00
Contingency			\$9,734.44		\$17,252.27		\$29,271.91
TOTAL			\$58,406.62		\$103,513.61		\$175,631.44
Cost per Square Foot			\$4.87		\$8.63		\$14.64

Plot 4 -- Capillary Plot 5 -- Anisotropic Plot 6 -- Enhanced ET

Work Item Description	Units	Qty	Totals	Qty	Totals	Qty	Totals
Engineered Fill Soil -- Barrier	ton	1386	\$14,358.96	1848	\$19,145.28	2310	\$23,931.60
compaction	day	3	\$4,193.25		\$0.00	5	\$6,988.75
placement	day	3	\$4,171.83	4	\$5,562.44	5	\$6,953.05
grade	day	3	\$3,792.69	4	\$5,056.92	5	\$6,321.15
Engineered Fill Soil -- Topsoil	ton	924	\$9,572.64	429	\$4,444.44	429	\$4,444.44
placement	day	2	\$2,781.22	1	\$1,390.61	1	\$1,390.61
grade	day	2	\$2,528.46	1	\$1,264.23	1	\$1,264.23
Sand	ton	1080	\$11,642.40	432	\$4,656.96		\$0.00
placement	day	2	\$2,781.22	1	\$1,390.61		\$0.00
grade	day	2	\$2,528.46	1	\$1,264.23		\$0.00
Pea Gravel	ton	819	\$12,440.61	546	\$8,293.74		\$0.00
placement	day	1	\$1,390.61	1	\$1,390.61		\$0.00
grade	day	1	\$1,264.23	1	\$1,264.23		\$0.00
Gravel	ton		\$0.00		\$0.00		\$0.00
placement	day		\$0.00		\$0.00		\$0.00
grade	day		\$0.00		\$0.00		\$0.00
Subgrade Preparation							
cut/fill	day		\$0.00		\$0.00		\$0.00
remove rock & debris	day	1	\$226.00	1	\$226.00	1	\$226.00
grade	day	1	\$1,264.23	1	\$1,264.23	1	\$1,264.23
compact	day	1	\$1,397.75	1	\$1,397.75	1	\$1,397.75
Geomembrane, 40ml LLDPE	sf		\$0.00		\$0.00		\$0.00
GCL	sf		\$0.00		\$0.00		\$0.00
Geotextile	sf		\$0.00		\$0.00		\$0.00
Bentonite	ton		\$0.00		\$0.00		\$0.00
mixing	day		\$0.00		\$0.00		\$0.00
QA Testing							
soil	allow	allow	\$1,000.00	allow	\$1,000.00	allow	\$1,000.00
geomembrane	allow	allow	\$0.00	allow	\$0.00	allow	\$0.00
Vegetation							
scarification	day	0.5	\$632.12	0.5	\$632.12	0.5	\$632.12
seed & mulch	msf	24	\$2,831.76	24	\$2,831.76	30	\$3,539.70
Survey Site	day	1	\$830.08	1	\$830.08	1	\$830.08
Foreman	day	23.5	\$7,990.00	18.5	\$6,290.00	21.5	\$7,310.00
Contingency			\$17,923.70		\$13,919.25		\$13,498.74
TOTAL			\$107,542.22		\$83,515.49		\$80,992.45
Cost per Square Foot			\$8.96		\$6.96		\$6.75

Appendix E. Cost-Effectiveness Analysis for "In Situ Bioremediation" -- A Stage 6 technology

In Situ Bioremediation: Cost Effectiveness of a Remediation Technology Field Tested at the Savannah River Integrated Demonstration Site

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The purpose of this report is to study the cost effectiveness of In Situ Bioremediation (ISBR) with horizontal wells as tested at the Savannah River Integrated Demonstration (SRID) site in Aiken, South Carolina. ISBR is an innovative new remediation technology for the removal of chlorinated solvents from contaminated soils and groundwater. The principal contaminant at the SRID is the volatile organic compound (VOC), trichloroethylene (TCE). A 384 day test run at Savannah River, sponsored by the U.S. Department of Energy, Office of Technology Development (EM-50), furnished information about the performance and applications of ISBR.

- The overall cost effectiveness of In Situ Bioremediation (ISBR) is based on the cost sensitivity of the biological component; as the biological addition increases, the cost per pound of VOCs remediated decreases.
- The short-term cost of ISBR with a biological addition of 40% above the vacuum component is \$21 per pound of VOCs remediated. The worse case scenario, ISBR + 0% addition costs \$29/lb of VOCs remediated, and is based solely on the vacuum component.
- The baseline pump and treat/soil vapor extraction system costs \$31/lb in the short-term and has no possibility of a biological addition.
- Life-cycle analysis shows that ISBR is more cost effective than the baseline pump and treat/soil vapor extraction system.
- As demonstrated, ISBR has a possible savings of \$1 million at the SRID site alone.

In Situ Bioremediation is based on two distinct processes occurring simultaneously: the physical process of in situ air stripping and the biological process of bioremediation (see

figure). Both processes have the potential to remediate some amount of contamination. A quantity of VOCs, directly measured from the extracted air stream, was removed from the test area by the physical process of air stripping. The biological process is difficult to examine. However, the results of several tests performed at the SRID and independent numerical modeling determined that the biological process remediated an additional 40% above the physical process. Given this data, the cost effectiveness of this new technology can be evaluated. In addition to calculating the cost effectiveness on the ISBR demonstration at the SRID, sensitivity analysis is conducted in order to determine how the overall cost of ISBR changes in regards to the performance of the biological component. By comparing the overall cost of this system and the price per pound of VOCs remediated against a conventional pump and treat/soil vapor extraction system, we can evaluate the overall cost effectiveness of the alternative technologies.

Schematic Diagram of the Two Processes Involved in In Situ Bioremediation

System Caveats

The In Situ Bioremediation field demonstration at the SRID site is fully described in *Test Plan for In Situ Bioremediation Demonstration of the Savannah River Integrated Demonstration Project* [Hazen 92]. The ISBR demonstration at the SRID was set up to address a "hot spot" of an overall larger VOC contaminant plume.

The pump and treat/soil vapor extraction system is engineer designed and presumed to perform optimally. Both pump and treat and soil vapor extraction systems have been tested at the SRID. The baseline system (a combination of pump and treat/soil vapor extraction apparatus) is integrated to avoid overlapping of equipment and materials, and is located in an area exactly like the ISBR demonstration in regards to all necessary site characteristics, including overall concentration of contaminants. By designing both the baseline and the innovative systems to handle equal flow and assuming equal vacuum extraction performance, a level playing field for a cost comparison is created.

Analysis

The data used in these analyses have a "field demonstration" level of confidence and are based on an actual field demonstration. The performance comparison consists of **Plan 1**, which is based on the new ISBR technology as demonstrated at the SRID, and **Plan 2**, which is based on "equivalent" conventional technologies, pump and treat/soil vapor extraction, necessary to remediate the contamination problems addressed by ISBR. Plan 2 is constructed so that it remediates the same conditions treated by ISBR at the SRID. In order to be fair to both technologies, equal physical process performance is forced from both Plan 1 and Plan 2. Plan 1 and Plan 2 are compared based on what it costs to operate them over equal periods of time. Performance data indicate that the vacuum component of ISBR destroyed 12,096 pounds of VOCs in 384 days, and an additional 40% above the vacuum component was destroyed by bioremediation. The vacuum component data is used in the pump and treat/soil vapor extraction system, assuming that the equal flow rates will remove the same quantity in an equal amount of time.

The ISBR system, as tested, uses two horizontal wells. The first well is an injection well, 300 ft long and 165 ft deep (about 35 ft below the water table). The second well is an extraction well, 175 ft long and 75 ft below the surface (in the vadose zone). A concentration of methane (between 1% and 4%) and any necessary chemical nutrients (nitrogen in the form of nitrous oxide and phosphorus in the form of triethyl phosphate) are blended into the injected air stream to create a biological element for remediation. The methane provides the necessary material substrate for the indigenous microorganism to produce the enzyme methane monooxygenase which, in turn, degrades the principal contaminant, trichloroethylene (TCE). For the conventional technologies used in Plan 2, four vertical SVE extraction wells are assumed to be equal in area influenced to the one horizontal extraction well of ISBR. One vertical pump and treat well is also used. Volatilized contaminants from both remediation systems are sent to a catalytic oxidation off-gas system where they are destroyed.

Economic comparisons for short-term costs are made by relying on actual field data and using cost sensitivity analysis; life-cycle costs are estimated in relation to possible time to achieve cleanup. The first economic comparison is a calculation of the short-term costs in relation to performance. Short term costs are those expenses incurred during the immediate field test demonstration of the technologies compared (generally about a year). The equipment capital costs are amortized yearly over the useful life of the equipment, which is assumed to be 10 years. All short-term equipment costs are amortized at 7%, which is the interest on the loan.

For ISBR there is a total cost of about \$354,000 with total 16,934 pounds of VOCs being destroyed by the vacuum component and biological component, giving a cost per pound of VOCs remediated at about \$21. The integrated pump and treat/soil vapor extraction with 4 vertical SVE wells has a total cost of about \$380,000. Assuming an equal vacuum extraction performance of 12,096 pounds of VOCs removed, the integrated system has a cost per pound of VOCs remediated at about \$31. A ratio of ISBR to the baseline shows that ISBR is 32% less expensive than the baseline.

Next, an analysis of life-cycle cost is conducted. A real discount rate of 2.3% is used to calculate the present value. ISBR, with its combination of vacuum component and bioremediation, costs \$1 million and remediates the site in only 3 years. The baseline takes 10 years to remediate the site and costs \$2 million. ISBR, therefore, saves \$1 million and 7 years of remediation. Even when we assume the baseline can perform at twice the expected time and cleans the site in only 5 years, it still costs \$1.4 million. ISBR still beats the baseline by \$400,000 and 2 years remediation time.

Where ISBR has the potential to exceed the baseline technologies is its ability to remediate a portion of the contamination *in situ*, thereby eliminating the need to physically remove the contaminant and process it. Since ISBR relies heavily on the biological component to achieve greater performance, sensitivity analysis is conducted to compare the cost per pound of VOCs remediated versus the performance of the biological component. Of particular interest is ISBR + 0% addition. This is a worse case scenario based on a 0% addition from the biological component. It assumes that all the necessary materials are added to stimulate the biological addition, but no additional remediation occurs. In this situation, ISBR still costs slightly less than the baseline, \$29 versus \$31, respectively. By adding a percent addition of pounds of VOCs destroyed by bioremediation in addition to that removed via the vacuum component, we can examine how the cost per pound changes with respect to the biological component. Six hypothetical percentages are used to account for the bioremediation levels: 0%, 20%, 40%, 50%, 70%, and 90%. The following figure shows the various hypothetical additions and the decrease in cost per pound of VOCs remediated.

The baseline technologies in Plan 2 have a constant price per pound of VOCs remediated of \$31 because there is no biological component. As the biological addition of ISBR increases, the price per pound of VOCs decreases. So, even in the worse case scenario

Comparison of Short Term Costs with Various Biological Additions

where no bioremediation occurs, ISBR breaks even with the baseline. There is, therefore, no cost risk to run ISBR over the baseline system. The savings, however, are quite substantial when the biological component is stimulated. In order for the biological component to occur, it is necessary to inject methane and nutrients into the system. Without this material, only the physical, vacuum component of ISBR is possible. Because the cost of the biological component is so inexpensive, ISBR only has to remediate an additional 1,570 lbs of VOCs over the 12,096 lbs of VOCs remediated with the vacuum component in order for the system to completely pay for the cost of the methane injection. Any additional remediation is achieved at no extra cost and increases the cost savings of ISBR over the baseline technologies.

Next, the total present value cost for operating each plan for five years, including all necessary equipment, is computed. The total equipment costs are included in the first year so that no amortization is needed. As with the short-term cost, the potential cost-savings for ISBR lie with its ability to remediate VOCs in addition to the physical process, thereby lowering the cost per pound and increasing the total amount remediated over equal time.

The same hypothetical percent additions of 0%, 20%, 40%, 50%, 70%, and 90% are used. The table below shows the decrease in price per pound as bioremediation increases. The \$38 per pound of VOCs remediated with the pump and treat/soil vapor extraction remains constant because there is no equivalent biological addition.

Life-Cycle Cost of ISBR over Five Year Operation in Comparison to Percent Addition

Hypothetical percent addition	Physical component from Life cycle costs (lbs)	Additional Pounds remediated via biological component	New Total pounds VOCs remediated	Price per pound VOC remediated
0%	37,375	0	37,375	\$38
20%	37,375	7,475	44,850	\$31
40%	37,375	14,950	52,325	\$27
50%	37,375	18,688	56,063	\$25
70%	37,375	26,162	63,537	\$22
90%	37,375	33,638	71,013	\$20

Perspectives and Cost Drivers

The two largest categories in regards to cost for both ISBR and the baseline system are the costs of consumables and labor. The labor and consumables are greater than 85% of the overall operating costs; therefore, if the overall remediation time of the project is shortened, the cost will drop. This is due to the nature of the labor and consumables which are incurred each day of operation. Since ISBR can significantly decrease operation time, ISBR lowers the overall cost of the remediation effort.

Applicability

ISBR can be very effective in settings where some interbedded thin and/or discontinuous clays are present. ISBR should prove even more successful than in situ air stripping alone because ISBR contains a biological component as well as the physical air stripping process. A potential concern with the use of ISBR is the possible lateral spread of the contaminant plume. If the geology constricts vertical flow, the injection process can push the dissolved contamination concentrically from the injection point. Thus, it may be advisable in heterogeneous formations to use ISBR in conjunction with a surrounding pump and treat system that provides hydraulic control at the site. Note that the limitations on applicable geologic settings described above also apply to soil vapor extraction and pump and treat systems.

Short-term Costs for In Situ Bioremediation

Table 2. Short term costs for In Situ Bioremediation

IN SITU BIOREMEDIATION (ISBR)

Duration (days):	384	
Lbs VOCs removed via vacuum component of ISBR	12,096	
Annual removal rate, vacuum only (Lbs VOCs)	11,498	
Total destroyed, including 40% biological addition (Lbs VOCs)	16,934	
	Costs	Cost/Lb VOC
Site Costs		
Site costs (set up and level area)	\$5,400	
Subtotal: Site Costs	\$5,400	
Site Cost/Lb VOC Removed		\$0.32
Equipment Costs		
Design and engineering {2}	\$19,200	
Mobile equipment (pickup truck)	\$18,000	
Fixed equipment—Well installation (subcontracted) {1}		
Air injection well (165 ft. deep, 300 ft. long)	\$100,500	
Air extraction well (75 ft. deep, 175 ft. long)	\$82,500	
Subtotal: Well installation	\$183,000	
Fixed Equipment—Other equipment		
Air injection compressor system (260 cfm)	\$18,700	
Air extraction system (530 cfm blower)	\$16,100	
Vapor air separator (c/s 1 @ 260 cfm)	\$1,700	
Catalytic-oxidation off-gas treatment (900° F, 260 cfm)	\$57,000	
Methane Blending system	\$37,500	
Monitoring equipment	\$18,000	
Temporary storage (metal shed)	\$1,600	
Piping and insulation (10% of fixed other equipment cost)	\$15,060	
Electrical (12% of fixed other equipment cost)	\$18,072	
Subtotal: Other equipment	\$183,732	
Total Equipment Costs	\$403,932	
Amortization fixed charge rate	0.07	
Site Equipment Costs, one year	\$57,511	
Subtotal: Site Equipment Costs during test	\$60,505	
Equipment Cost/Lb VOC Removed		\$3.57
Labor Costs {2}		
Mobilize/demobilize (based on 200 hrs set up & tear down)		
Technician — 2	\$24,800	
Laborers — 2	\$23,200	
Oversight engineer — 1	\$28,400	
Per diem	\$9,750	
Monitoring/maintenance crew		
Technician — 1 (384 days @ 2 hrs/day)	\$47,616	
Oversight engineer — 1 (384 days @ 0.5 hrs/day)	\$27,264	
Subtotal: Labor Costs	\$161,030	
Labor Cost/Lb VOC Removed		\$9.51

Consumable Costs 3		
Catalytic material	\$22,000	
Electricity – 145 kW/HR (24 hours/day)	\$66,816	
Methane [(natural gas) 1,392,774 scf used by SRS]	\$8,979	
Lubricants	\$768	
Chemical additives	\$13,440	
Maintenance supplies	<u>\$15,360</u>	
Subtotal: Consumable Costs	\$127,363	
Consumable Cost/Lb VOC Removed		\$7.52
TOTAL SITE COSTS	\$354,298	
TOTAL COST/LB VOC REMOVED (including biological addition)		\$20.92

Notes:

- {1} Original estimate for wells taken from J. Schroeder memo of 3/24/92 and updated to December 1993 dollars.
- {2} Labor rates per hour (industry averaged): Design engineer \$80; Oversight engineer, \$142; Technician, \$62. Laborer, \$58.
- {3} Consumable supplies: Catalytic material (initial charge), \$22,000; Electricity, \$0.05/kWH; Chemicals, \$35/day Methane @ \$0.64469/100scf; Lubricants, \$2/day; Maintenance supplies, \$40/day

In Situ Bioremediation Life-Cycle Costs (5 years)**IN SITU BIOREMEDIATION**

	Year 1	Year 2	Year 3	Year 4	Year 5
<u>Capital Cost</u>					
Site Cost	\$5,400				
<u>Equipment Cost</u>					
Design and Engineering	\$19,200				
Mobile Equipment	\$18,000				
Well Installation	\$183,000				
Other Fixed Equipment	<u>\$183,732</u>				
Subtotal: Equipment Costs	\$414,732				
<u>Mobilization Costs (100 mhrs)</u>					
Technicians (2)	\$12,400				
Laborers (2)	\$11,600				
Oversight Engineer (1)	\$14,200				
Per Diem	<u>\$4,875</u>				
Subtotal: Mobilization Costs	\$43,075				
<u>Operation and Maintenance Costs</u>					
<u>Monitoring /Maintenance</u>					
Technician	\$45,260	\$45,260	\$45,260	\$45,260	\$45,260
Oversight Engineer	<u>\$25,915</u>	<u>\$25,915</u>	<u>\$25,915</u>	<u>\$25,915</u>	<u>\$25,915</u>
Subtotal: Monitoring/Maintenance Costs	\$71,175	\$71,175	\$71,175	\$71,175	\$71,175
<u>Consumable Costs</u>					
Catalytic Material	\$22,000	\$22,000	\$22,000	\$22,000	\$22,000
Electricity – 145 kW/HR (\$0.05/kWH)	\$63,510	\$63,510	\$63,510	\$63,510	\$63,510
Methane (1,323,860 scfm/yr.)	\$8,600	\$8,600	\$8,600	\$8,600	\$8,600
Lubricants	\$730	\$730	\$730	\$730	\$730
Chemical Additives	\$12,775	\$12,775	\$12,775	\$12,775	\$12,775
Maintenance Supplies	<u>\$14,600</u>	<u>\$14,600</u>	<u>\$14,600</u>	<u>\$14,600</u>	<u>\$14,600</u>
Subtotal: Consumable Costs	\$122,215	\$122,215	\$122,215	\$122,215	\$122,215
<u>Demobilization Costs (100 mhrs)</u>					
Technician (2)					\$12,400
Laborers (2)					\$11,600
Oversight Engineer (1)					\$14,200
Per Diem					<u>\$4,875</u>
Subtotal: Demobilization Costs					\$43,075
TOTAL ANNUAL COSTS	\$651,197	\$193,390	\$193,390	\$193,390	\$236,465

TOTAL LIFE CYCLE PRESENT VALUE= \$1,421,574
(2.3% real discount rate)

Appendix F. Cost Data Requirements

Construction Costs	Cost
Land	
Surveys	
Fees	
Site Preparation	
Site clearing	
Site access	
Grading	
Borehole Drilling	
Permits/licenses	
Fencing	
Heat, gas, electricity, water to install system	
Structures	
Buildings	
Platforms	
Equipment structures	
Equipment shed/warehouses	
Process equipment and appurtenances	
Cost of technology parts and supplies	
Instruments	
Materials and supplies to make technology operative	
Non-process equipment	
Office and administrative equipment	
Data processing/computer equipment	
Laboratory Equipment	
Safety equipment	
Vehicles	
Utilities	
Plumbing, heating, light, security and vent equipment	
Labor	
Direct labor necessary to acquire, mobilize, and install system	
Supervisory and administrative labor to acquire, mobilize, and install system	
Design and engineering	
Other	
Rental of commercial equipment to mobilize and install system	
Start-up and testing	

Operating Costs	Cost
Direct labor	
Direct labor to operate equipment	
Direct labor supervision	
Payroll charges (FICA, vacation, worker's comp. med. insurance, pension)	
Contract labor charges	
Direct materials	
Consumable supplies	
Process materials and chemicals	
Utilities	
Fuels	
Replacement parts	
Overhead	
Plant and equipment maintenance	
Liability insurance	
Shipping charges	
Equipment rentals for operations	
Vehicle supplies and insurance	
Transportation	
General and administrative	
Administrative labor	
Marketing	
Communication	
Project management	
Travel expenses	
Interest expenses	
Decontamination and Decommissioning	
Facility decontamination	
Closure, post closure monitoring	
Waste Disposal	
Treatment/stabilization	
Transportation	
Disposal	
Other	
Maintenance contract for equipment	
Health and safety requirements	
Contract services	

Appendix G. HTRW RA-WBS 3rd Level Cost Categories

WBS Number	DESCRIPTION	UOM**	
		English	Metric
33XXX	HTRW CONSTRUCTION ACTIVITIES		
331XX	HTRW REMEDIAL ACTION (CONSTRUCTION)		
01	MOBILIZATION AND PREPARATORY WORK		
01 01	Mobilization of Construction Equipment and Facilities	EA	EA
01 02	Mobilization of Personnel	EA	EA
01 03	Submittals/Implementation Plans	EA	EA
01 04	Setup/Construct Temporary Facilities	EA	EA
01 05	Construct Temporary Utilities	EA	EA
01 06	Temporary Relocations/Roads/Structures/Utilities	EA	EA
01 07	Construction Plant Erection	EA	EA
01 08	Institutional Controls	EA	EA
01 09	Alternate Water Supply	EA	EA
01 10	Population Relocation	EA	EA
01 9X	Other (Use Numbers 90-99)		
02	MONITORING, SAMPLING, TESTING, AND ANALYSIS		
02 01	Meteorological Monitoring	EA	EA
02 02	Radiation Monitoring	EA	EA
02 03	Air Monitoring and Sampling	EA	EA
02 04	Monitoring Wells	EA	EA
02 05	Sampling Surface Water/Ground Water/Liquid Waste	EA	EA
02 06	Sampling Soil and Sediment	EA	EA
02 07	Sampling Asbestos	EA	EA
02 08	Sampling Radioactive Contaminated Media	EA	EA
02 09	Laboratory Chemical Analysis	EA	EA
02 10	Radioactive Waste Analysis	EA	EA
02 11	Geotechnical Testing	EA	EA
02 12	Geotechnical Instrumentation	EA	EA
02 13	On-Site Laboratory Facilities	EA	EA
02 14	Off-Site Laboratory Facilities	EA	EA
02 9X	Other (Use Numbers 90-99)		
03	SITework		
03 01	Demolition	SY	M2
03 02	Clearing and Grubbing	ACR	HEC
03 03	Earthwork	CY	M3
03 04	Roads/Parking/Curbs/Walks	SY	M2
03 05	Fencing	LF	M
03 06	Electrical Distribution	LF	M
03 07	Telephone/Communication Distribution	LF	M
03 08	Water/Sewer/Gas Distribution	LF	M
03 09	Steam and Condensate Distribution	LF	M
03 10	Fuel Line Distribution	LF	M
03 11	Storm Drainage/Subdrainage	LF	M
03 12	Permanent Cover Structure Over Contaminated Area	SF	M2
03 13	Development of Borrow Pit/Haul Roads	ACR	HEC
03 14	Fuel Storage Tanks (New)	EA	EA
03 9X	Other (Use Numbers 90-99)		

WBS Number		DESCRIPTION	UOM	
			English	Metric
331XX	04	ORDNANCE & EXPLOSIVE - CHEMICAL WARFARE MATERIAL (OE-CWM) REMOVAL AND DESTRUCTION		
	04 01	Ordnance Removal and Destruction	ACR	HEC
	04 9x	Other (Use Numbers 90-99)		
	05	SURFACE WATER COLLECTION AND CONTROL		
	05 01	Berms/Dikes	LF	M
	05 02	Floodwalls	SF	M2
	05 03	Levees	LF	M
	05 04	Terraces and Benches	LF	M
	05 05	Channels/Waterways (Soil/Rock)	LF	M
	05 06	Chutes or Flumes	LF	M
	05 07	Sediment Barriers	LF	M
	05 08	Storm Drainage LF	M	
	05 09	Lagoons/Basins/Tanks/Dikes/Pump System	ACR	HEC
	05 10	Pumping/Draining/Collection	MGA	KLI
	05 11	Transport to Treatment Plant	MGA	KLI
	05 12	Earthwork	CY	M3
	05 13	Erosion Control	ACR	HEC
	05 14	Development of Borrow Pit/Haul Roads	ACR	HEC
	05 9X	Other (Use Numbers 90-99)		
	06	GROUNDWATER COLLECTION AND CONTROL		
	06 01	Extraction and Injection Wells	EA	EA
	06 02	Subsurface Drainage/Collection	LF	M
	06 03	Slurry Walls	SF	M2
	06 04	Grout Curtain	SF	M2
	06 05	Sheet Piling	SF	M2
	06 06	Lagoons/Basins/Tanks/Dikes/Pump System	ACR	HEC
	06 07	Pumping/Collection	MGA	KLI
	06 08	Transport to Treatment Plant	MGA	KLI
	06 09	Development of Borrow Pit/Haul Roads	ACR	HEC
	06 9x	Other (Use Numbers 90-99)		
	07	AIR POLLUTION/GAS COLLECTION AND CONTROL		
	07 01	Gas/Vapor Collection Trench System	LF	M
	07 02	Gas/Vapor Collection Well System	EA	EA
	07 03	Gas/Vapor Collection at Lagoon Cover	SY	M2
	07 04	Fugitive Dust/Vapor/Gas Emissions Control	ACR	HEC
	07 9x	Other (Use Numbers 90-99)		
	08	SOLIDS COLLECTION AND CONTAINMENT		
	08 01	Contaminated Soil Collection	CY	M3
	08 02	Waste Containment, Portable (Furnish/Fill)	CY	M3
	08 03	Transport to Treatment Plant	CY	M3
	08 04	Radioactive Specific Waste Containment (Furnish/Fill)	CY	M3
	08 05	Capping of Contaminated Area/Waste Pile (Soil/Asphalt Cap)	ACR	HEC
	08 06	Nuclear Waste Densification (Dynamic Compaction)	CY	M3
	08 07	Development of Borrow Pit/Haul Roads	ACR	HEC
	08 9x	Other (Use Numbers 90-99)		

WBS Number		DESCRIPTION	UOM	
			English	Metric
331XX	09	LIQUIDS/SEDIMENTS/SLUDGES COLLECTION AND CONTAINMENT		
	09 01	Dredging/Excavating	CY	M3
	09 02	Industrial Vacuuming	CY	M3
	09 03	Waste Containment, Portable (Furnish/Fill)	MGA	KLI
	09 04	Transport to Treatment Plant	MGA	KLI
	09 05	Radioactive Specific Waste Containment (Furnish/Fill)	MGA	KLI
	09 06	Pumping/Draining/Collection	MGA	KLI
	09 07	Lagoons/Basins/Tanks/Dikes/Pump System	ACR	HEC
	09 08	Development of Borrow Pit/Haul Roads	ACR	HEC
	09 9x	Other (Use Numbers 90-99)		
	10	DRUMS/TANKS/STRUCTURES/MISCELLANEOUS DEMOLITION AND REMOVAL		
	10 01	Drum Removal	EA	EA
	10 02	Tank Removal	EA	EA
	10 03	Structure Removal	SF	M2
	10 04	Asbestos Abatement	SF	M2
	10 05	Piping and Pipeline Removal	LF	M
	10 06	Radioactive Specific Waste Containment (Furnish/Fill)	CY	M3
	10 07	Miscellaneous Items	ACR	HEC
	10 08	Contaminated Paint Removal	SF	M2
	10 9x	Other (Use Numbers 90-99)		
	11	BIOLOGICAL TREATMENT		
	11 01	Activated Sludge (Seq Batch Reactors)	MGA	KLI
	11 02	Rotating Biological Contractors	MGA	KLI
	11 03	Land Treatment/Farming (Solid Phase Biodegradation)	CY	M3
	11 04	In-Situ Biodegradation/Bioreclamation	CY	M3
	11 05	Trickling Filters	MGA	KLI
	11 06	Biological Lagoons	MGA	KLI
	11 07	Composting	CY	M3
	11 08	Sludge Stabilization - Aerobic	CY	M3
	11 09	Sludge Stabilization - Anaerobic	CY	M3
	11 10	Genetically Engineered Organisms (White Rot Fungus)	CY	M3
	11 11	Slurry Biodegradation	CY	M3
	11 12	Bioventing	SF	M2
	11 13	Bioslurping	SF	M2
	11 14	Biopile (Heap Pile Remediation)	CY	M3
	11 50	Construction of Permanent Plant Facility	EA	EA
	11 9x	Other (Use Numbers 90-99)		
	12	CHEMICAL TREATMENT		
	12 01	Oxidation/Reduction	MGA	KLI
	12 02	Solvent Extraction	MGA	KLI
	12 03	Chlorination	MGA	KLI
	12 04	Ozonation	MGA	KLI
	12 05	Ion Exchange	MGA	KLI
	12 06	Neutralization	MGA	KLI
	12 07	Chemical Hydrolysis	MGA	KLI
	12 08	Ultraviolet Photolysis	MGA	KLI

WBS Number			DESCRIPTION	UOM	
				English	Metric
331XX	12	09	Dehalogenation (Catalytic Dechlorination)	CY	M3
	12	10	Alkali Metal Dechlorination	CY	M3
	12	11	Alkali Metal/Polyethylene Glycol (A/PEG)	CY	M3
	12	12	Base-Catalyzed Decomposition Process	CY	M3
	12	13	Electrolysis	MGA	KLI
	12	14	Vapor Recovery/Reuse (Internal Combustion Engine)	CF	M3
	12	50	Construction of Permanent Plant Facility	EA	EA
	12	9x	Other (Use Numbers 90-99)		
13			PHYSICAL TREATMENT		
13	01		Filtration/Ultrafiltration	MGA	KLI
13	02		Sedimentation	MGA	KLI
13	03		Straining	MGA	KLI
13	04		Coagulation/Flocculation/Precipitation	MGA	KLI
13	05		Equalization	MGA	KLI
13	06		Evaporation	MGA	KLI
13	07		Air Stripping	MGA	KLI
13	08		Steam Stripping	MGA	KLI
13	09		Soil Washing (Surfactant/Solvent)	CY	M3
13	10		Soil Flushing (Surfactant/Solvent)	CY	M3
13	11		Solids Dewatering	CY	M3
13	12		Oil/Water Separation	MGA	KLI
13	13		Dissolved Air Floatation	MGA	KLI
13	14		Heavy Media Separation	CY	M3
13	15		Distillation	MGA	KLI
13	16		Chelation	MGA	KLI
13	17		Solvent Extraction	MGA	KLI
13	18		Supercritical Extraction	MGA	KLI
13	19		Carbon Adsorption - Gases	CF	M3
13	20		Carbon Adsorption - Liquids	MGA	KLI
13	21		Membrane Separation - Reverse Osmosis	MGA	KLI
13	22		Membrane Separation - Electrodialysis	MGA	KLI
13	23		Soil Vapor Extraction	CY	M3
13	24		Shredding	CY	M3
13	25		Aeration	CY	M3
13	26		Advanced Electrical Reactor	CY	M3
13	27		Low Level Waste (LLW) Compaction	CY	M3
13	28		Agglomeration	CY	M3
13	29		In-Situ Steam Extraction	MGA	KLI
13	30		Filter Presses	MGA	KLI
13	31		Lignin Adsorption/Sorptive Clays	CY	M3
13	32		Air Sparging	GAL	LIT
13	50		Construction of Permanent Plant Facility	EA	EA
13	9x		Other (Use Numbers 90-99)		
14			THERMAL TREATMENT		
14	01		Incineration	CY	M3
14	02		Low Temperature Thermal Desorption	CY	M3
14	03		Supercritical Water Oxidation	MGA	KLI
14	04		Molten Salt Destruction	CY	M3
14	05		Radio Frequency Heating	CY	M3

WBS Number	DESCRIPTION	UOM	
		English	Metric
331XX 14 06	Solar Detoxification	CY	M3
14 07	High Temperature Thermal Desorption	CY	M3
14 50	Construction of Permanent Plant Facility	EA	EA
14 9x	Other (Use Numbers 90-99)		
15	STABILIZATION/FIXATION/ENCAPSULATION		
15 01	Molten Glass	CY	M3
15 02	In-Situ Vitrification	CY	M3
15 03	In-Situ Pozzolan Process (Lime/Portland Cement)	CY	M3
15 04	Pozzolan Process (Lime/Portland Cement)	CY	M3
15 05	Asphalt-Based Encapsulation	CY	M3
15 06	Radioactive Waste Solidification (Grouting/Other)	CY	M3
15 07	Sludge Stabilization (Aggregate/Rock/Slag)	CY	M3
15 50	Construction of Permanent Plant	EA	EA
15 9x	Other (Use Numbers 90-99)		
16	RESERVED FOR FUTURE USE		
17	DECONTAMINATION AND DECOMMISSIONING (D&D)		
17 01	Pre-Decommissioning Operations	SF	M2
17 02	Facility Shutdown Activities	SF	M2
17 03	Procurement of Equipment and Material	SF	M2
17 04	Dismantling Activities	SF	M2
17 05	Research and Development (R&D)	SF	M2
17 06	Spent Fuel Handling	SF	M2
17 07	Hot Cell Cleanup	SF	M2
17 9x	Other (Use Numbers 90-99)		
18	DISPOSAL (OTHER THAN COMMERCIAL)		
18 01	Landfill/Burial Ground/Trench/Pits	CY	M3
18 02	Above-Ground Vault	CY	M3
18 03	Underground Vault	CY	M3
18 04	Underground Mine/Shaft	CY	M3
18 05	Tanks	MGA	KLI
18 06	Pads (Tumulus/Retrievable Storage/Other)	CY	M3
18 07	Storage Bldgs/Protect Cover Struct/Other Bldgs and Struct	CY	M3
18 08	Cribs	CY	M3
18 09	Deep Well Injection	MGA	KLI
18 10	Incinerator	CY	M3
18 15	Construction of Permanent Disposal Facility		
18 20	Container Handling	EA	EA
18 21	Transportation to Storage/Disposal Facility	TON	MT
18 22	Disposal Fees and Taxes	TON	MT
18 23	Mixed Waste Storage Fees and Taxes	TON	MT
18 9x	Other (Use Numbers 90-99)		
19	DISPOSAL (COMMERCIAL)		
19 20	Container Handling	EA	EA
19 21	Transportation to Storage/Disposal Facility	TON	MT
19 22	Disposal Fees and Taxes	TON	MT
19 23	Mixed Waste Storage Fees and Taxes	TON	MT
19 9x	Other (Use Numbers 90-99)		

WBS Number	DESCRIPTION	UOM	
		English	Metric
331XX	20 SITE RESTORATION		
	20 01 Earthwork	CY	M3
	20 02 Permanent Markers	EA	EA
	20 03 Permanent Features	EA	EA
	20 04 Revegetation and Planting	ACR	HEC
	20 05 Removal of Barriers	EA	EA
	20 9x Other (Use Numbers 90-99)		
	21 DEMOBILIZATION		
	21 01 Removal of Temporary Facilities	EA	EA
	21 02 Removal of Temporary Utilities	EA	EA
	21 03 Final Decontamination	EA	EA
	21 04 Demobilization of Construction Equipment and Facilities	EA	EA
	21 05 Demobilization of Personnel	EA	EA
	21 06 Submittals	EA	EA
	21 07 Construction Plant Takedown	EA	EA
	21 9x Other (Use Numbers 90-99)		
	22 GENERAL REQUIREMENTS (Optional Breakout)		
	22 01 Supervision and Management	MO	MO
	22 02 Administration Job Office	MO	MO
	22 03 Warehouse, Materials Handling, and Purchasing	MO	MO
	22 04 Engineering, Surveying, and Quality Control	MO	MO
	22 05 Equipment Maintenance and Motor Pool	MO	MO
	22 06 First Aid, Fire Protection, Traffic Control, and Security	MO	MO
	22 07 Health & Safety	MO	MO
	22 08 Temporary Construction Facilities-Ownership	MO	MO
	22 09 Temporary Construction Facilities-Operation	MO	MO
	22 10 Project Utilities	MO	MO
	22 11 Miscellaneous Project Expenses	MO	MO
	22 12 Insurance, Interest, and Fees	MO	MO
	22 9x Other (Use Numbers 90-99)		
332XX	ENGINEERING DURING CONSTRUCTION (EDC)		
333XX	SUPERVISION AND ADMINISTRATION (S&A) (CONSTRUCTION MANAGEMENT)		

****Units of Measure (UOM) Definitions**

English	Metric
EA -- Each	EA -- Each
LF -- Linear Feet	M -- Meters
SF -- Square Feet	M2 -- Square Meters
SY -- Square Yards	M2 -- Square Meters
ACR -- Acre	HEC -- Hectares
CF -- Cubic Feet	M3 -- Cubic Meters
CY -- Cubic Yards	M3 -- Cubic Meters
GAL -- Gallons	Lit -- Liters
MGA -- Thousand Gallons	KLI -- Kiloliters
LB -- Pounds	KG -- Kilograms
TON -- Tons	MT -- Metric Tons

English	Metric
HR -- Hours	HR -- Hours
MO -- Months	MO -- Months