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LIFE CYCLE COST AND RISK ESTIMATION OF ENVIRONMENTAL MANAGEMENT OPTIONS

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ABSTRACT

The Lockheed Idaho Technologies Company (LITCO) Economic and Systems Analysis program has developed a life cycle cost and risk estimation process to evaluate Environmental Management options for the United States Department of Energy. The evaluation process is demonstrated in this paper through the comparative analysis of two alternative scenarios that have been identified for the management of the alpha-contaminated mixed low-level waste that is currently stored at the Idaho National Engineering Laboratory (INEL). The two scenarios that are evaluated are a Base Case and a Delay Case. The two scenarios are realistic and based on actual data, but are not intended to exactly match actual plans currently being developed at the INEL. The paper includes a general description of each scenario, along with major assumptions that were made to support the analytical process.

Life cycle cost estimates were developed for both scenarios with the use of the System Cost Model. The resulting costs are presented and compared. Life cycle costs are shown as a function of time and also aggregated by pretreatment, treatment, storage, and disposal activities. Although there are some short-term cost savings associated with the Delay Case, the cumulative life cycle costs are shown to eventually become much higher than the costs for the Base Case over the same period of time, due mainly to the storage and repackaging necessary to accommodate the longer Delay Case schedule. Similarly, life cycle risk estimates were prepared using a relatively new risk analysis methodology that was developed for the INEL Environmental Management Integration task and has been adapted to the System Cost Model architecture for automated, systematic cost/risk applications. Relative risk summaries are presented for both scenarios as a function of time and also aggregated by pretreatment, treatment, storage, and disposal activities. The relative risk associated with the Delay Case is shown to be higher than that of the Base Case. Finally, risk and cost results are combined to show how the collective information can be used to help identify opportunities for risk or cost reduction, and highlight areas where risk reduction can be achieved most economically.

Introduction

A life cycle cost and risk estimation process has been developed to evaluate various Environmental Management options for the United States Department of Energy (DOE). The Economic and Systems Analysis program, based at the Idaho National Engineering Laboratory, has been sponsored by the Office of Waste Management, Office of Planning and Analysis (EM-35) and the Office of Science and Technology, Office of Technology Systems (EM-53).

Lockheed Idaho Technologies Company's (LITCO's) Economic and Systems Analysis (ESA) program has developed a systems engineering process for analysis of waste management problems. The process is based on the engineering analysis that LITCO has provided on the Waste Management Programmatic Environmental Impact Statement, Site Treatment Plans (STPs) as required under the Federal Facility Compliance Act, and support for the

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Baseline Environmental Management Report (BEMR). A risk methodology was also developed by the Idaho National Engineering Laboratory Environmental Management Integration Program. The combination of cost analysis and risk analysis capabilities has allowed the ESA program to address EM alternatives from new perspectives.

LITCO's Economic and Systems Analysis program has developed an extensive knowledge in waste management facility cost development, engineering model design, and risk applications. This knowledge, which was initially developed to support EM-30, has now been additionally focused on EM-50 initiatives to identify cost-effective and reduced-risk alternatives. The ESA studies will be used by EM to gain a greater understanding of the opportunities for cost reductions and provide a quantitative means for comparison of DOE policy options.

The benefits to EM-50 have included:

- Providing a baseline for comparison of Technology Development alternatives,
- Providing a method to communicate results on new technologies to EM-30,
- Providing a bridge between an "Average Site's" approach and site-specific applicability,
- Helping to identify needs for technology development,
- Providing a basis for prioritizing opportunities for risk or cost reduction.

The benefits to EM-30 have included:

- Better focused Technology Development supporting key EM-30 policy options,
- Better understanding of the costs and benefits of advanced technology options,
- Better integration of a strategic planning basis,
- Consistent methodology enabling comparative analysis of waste management alternatives,
- Better understanding of cost implications for various complex-wide configuration options.

The need for cost/risk integration has been identified by the DOE. The DOE considers risk and life cycle costs in establishing program priorities. The ESA program has developed a tool called the System Cost Model (SCM) which has facilitated the cost/risk analysis of complex EM alternatives. The SCM allows analysis of various technology processing options for mixed low-level waste (MLLW), low-level waste (LLW), and transuranic waste (TRUW)--both mixed and non-mixed. The use of the SCM has helped LITCO integrate the requirements of EM-30 and EM-50. The two models which have been developed to support cost/risk analysis are described as follows:

> **System Cost Model** (SCM) - The SCM was initially developed for EM-35 to support sensitivity analysis of waste management costs for the BEMR. The SCM produces complex-wide life cycle costs for treatment, storage, disposal, and transportation of MLLW, LLW, and TRUW. The SCM also includes a database of site-specific waste management information including: waste inventory volumes and generation rates, treatment processing schemes, existing and planned facilities, site-specific cost factors and labor rates, and schedules.
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> **System Cost Model - Risk** (SCM-R) - The SCM-R has been developed to a conceptual level for EM-35 to support cost/risk evaluations. The SCM-R is an add-on to the base SCM. The fundamental risk methodology is based on the work done by the Environmental Management Integration Program (EMIP) at the INEL. Approximately 1000 simplified risk assessments were produced for the EMIP. The SCM-R will produce simplified relative risk assessments to show baseline life cycle risk, worker and public risk, waste disposal risk, and waste transportation risk. All categories of waste, from spent fuel to low-level waste, can be accommodated, as can all types of waste (radioactive, hazardous, and mixed). The method is based on the fundamental equations of risk (e.g., as used in CERCLA risk assessments). The risk calculations are based on the product of probability and consequences. The equations are broken down into risk elements, e.g., inventory quantities, toxicities, confinement barriers. Look-up tables provide values to be used for each risk element.

Cost/Risk Study

This paper includes a specific cost/risk study demonstrating the use of the SCM and SCM-R tools. The study provides a life cycle cost/risk evaluation of the trade-offs of using long-term storage prior to treatment versus treating with existing technologies and minimizing storage. The study is based on actual INEL waste stream data and can be considered representative of the type of analysis that could be performed at any large DOE site. However, since some of the assumptions used are hypothetical, this study is not intended to accurately reflect current INEL plans. Rather, the study is meant to demonstrate a unique cost/risk analysis capability using realistic input parameters.

The purpose of the study was to compare the magnitude of the costs and risks for long-term storage versus the current planning basis. These options show the costs and risks associated with delaying treatment until new technologies are available. The study also shows how both costs and risks can be evaluated in one analysis. The remainder of this paper includes a description of the alternatives, assumptions, cost and risk results, and key study conclusions.

Alternative Descriptions

Two alternatives were defined for this cost/risk study:

1. Base Case Scenario - The Base Case Scenario is comprised of the INEL BEMR treatment, storage, and disposal configuration and the 1995 Mixed Waste Inventory Report (MWIR) waste stream data. The Base Case scenario used a treatment schedule based on the STP.

   The waste is retrieved from earthen-covered storage. Retrieval will be followed by receipt and inspection of the waste at the Stored Waste Examination Pilot Plant (SWEPP), which includes an open, dump, and sort module to determine which treatment the waste form will receive. Also included are pre-treatment handling and storage. All necessary pre-treatment facilities are assumed to be in existence at the INEL; therefore, no construction costs are included until the year 2025, when existing facilities are assumed to become obsolete and new storage is constructed.

   This case utilizes incineration followed by grouting for the particulates, sludges, and some of the debris. However, most of the debris will be treated by first shredding the waste, which is then treated by thermal desorption followed by grouting. Other solids and particulates will be treated by a polymer stabilization. Disposal is assumed to take place in an onsite engineered disposal facility.

2. Delay Case Scenario - The Base Case Scenario was revised to show the effects of long-term pre-treatment waste storage.

   Treatment and disposal for this case are identical to the Base Case with the only change being that the treatment and subsequent disposal occur fifty years later. The treatment and disposal facilities required for the Delay Case are considered to be nonexistent and will require construction. However, no post-treatment storage is required for this case since the treated waste goes directly to disposal.

   In addition to pre-treatment storage, the waste will be overpacked as it is received and inspected based on the assumption that current containers are not adequate to support another 50 years of storage. SCM does not have an "overpack" module, however, in order to provide costs to adequately reflect the overpacking, the receiving and certification module costs were artificially increased to account for the activity. After the waste is retrieved (complete in the year 2015) and overpacked (complete in the year 2039), it is stored until treatment is available in the year 2047.

General Assumptions:

- The specific waste management system defined for this study was the INEL alpha MLLW. For the sake of simplicity in modeling the INEL alpha MLLW, the initial risk analysis was limited to five waste matrix categories[2]. The total alpha MLLW inventory at the INEL is characterized by 12 waste matrix codes. However, the five waste codes chosen for this demonstration model represent 97.7% of the volume of waste to be treated at the INEL. The five waste codes chosen for this model are: S 3110, S 3120, S 5110, S 5300, and S 5400.

- The costs reflect DOE-built and operated facilities required for the alpha MLLW inventory. Since treatment facilities for this waste do not currently exist at the INEL, new facilities will be required. The alpha MLLW will be treated based on the requirements of the Resource Conservation and Recovery Act. The treatment window for the inventory is assumed to be 19 years in duration (same for both cases).

- These cases assume that the alpha MLLW inventory is disposed of onsite in an above-ground engineered disposal facility.

Scheduling Assumptions for the Base Case

- For the Base case, all construction of treatment facilities starts in 1996, with treatment to commence in 1999. The SCM was allowed to build all treatment required.

Scheduling Assumptions for the Delay Case

- Retrieval of the waste will occur over 19 years. After the waste is retrieved, it is received, inspected and assayed at the SWEPP facility over a 19-year duration that ends in 2017. As the waste is assayed it is overpacked and then placed in storage. Overpacking operations will be complete in 2039. Existing storage capacity for the retrieved and overpacked waste is not sufficient, so SCM will be allowed to construct storage facilities as required.

- Waste storage continues until 2065. SCM will construct new facilities and decontaminate and decommission (D&D) the old facilities as required during the extended storage period.

- Construction (for three years) is followed by treatment, which commences in 2047 and completes in 2065.

Cost Results

Life cycle cost estimates were calculated for the two INEL alpha MLLW cases using the SCM and based on the assumptions and case descriptions outlined above. The total life cycle cost[3] for the Base Case was estimated to be $1.25 billion (B), while the total life cycle cost for the Delay Case was estimated to be $2.79 B.

Figure 1 shows a comparison of the cumulative costs for the two cases over time. The Base Case includes higher up-front costs because all needed treatment, storage, and disposal facilities are constructed immediately. However, the cumulative costs for the Base Case level out after the last facility is decommissioned in the year 2024. Because of the much longer operational time frame, the cumulative costs for the Delay Case surpass those for the Base Case

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[2] Waste matrix categories, or codes, are defined in the DOE Waste Treatability Group Guidance (DOE/LLW-217, Rev. 0), January 1995, which was issued to support development of the MWIR.

[3] All cost estimates are in constant 1996 dollars.

in the year 2032 and are ultimately over twice as high.

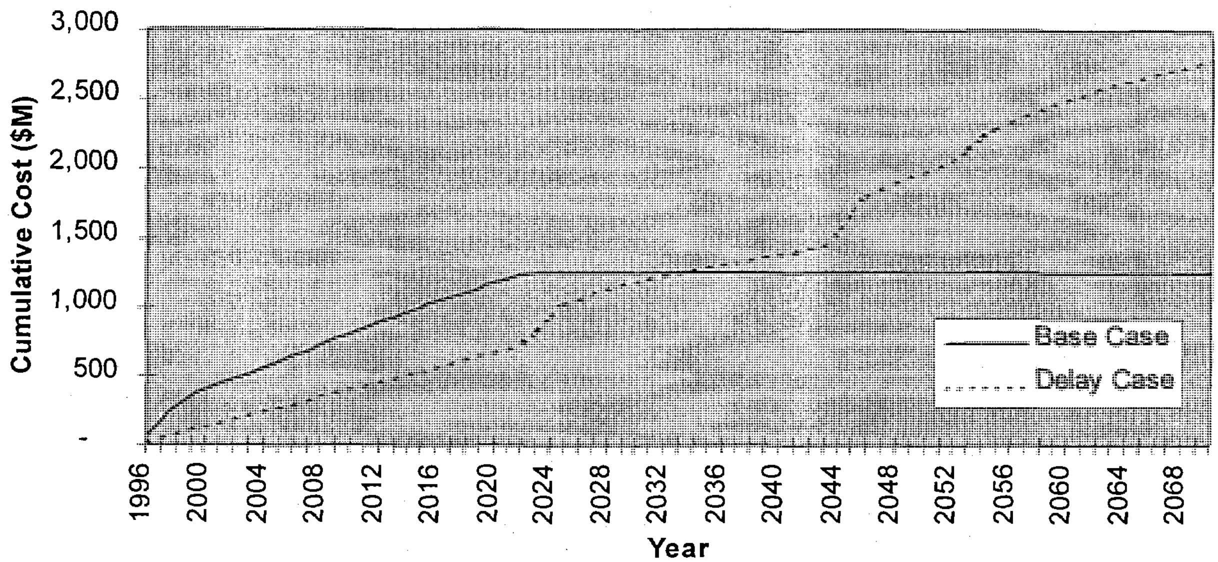

Figure 1: Cumulative Costs Over Time

Figure 2 shows a comparison of the costs for the two cases broken down by waste management function. The four waste management functions included in the SCM estimates are pre-treatment (including pre-treatment storage), treatment, post-treatment storage, and disposal. Most of the cost difference between the two cases shows up in the pre-treatment category. This is due to the increased cost of pre-treatment storage required for the Delay Case. The higher costs associated with the Delay Case are due to the construction and operations of the necessary storage facilities. The Delay Case costs also include overpacking activities and D&D of two existing storage facilities, neither of which are necessary for the Base Case.

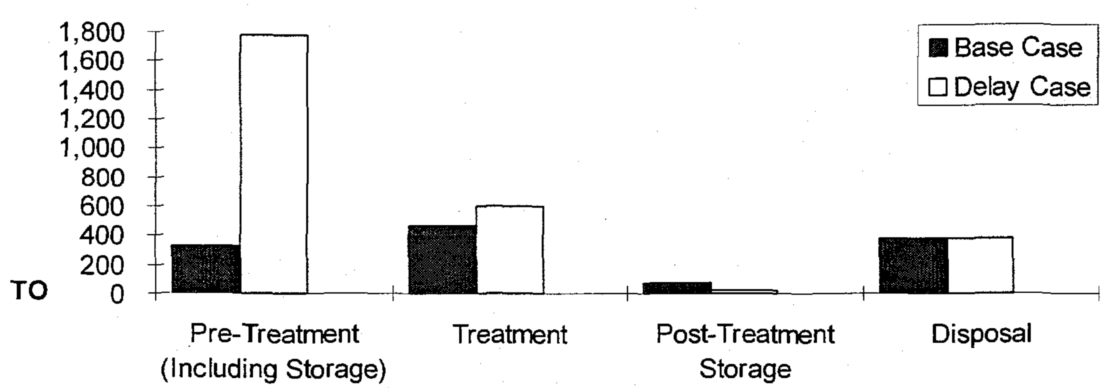

Figure 2: Costs By Waste Management Function

Risk Results

The relative risk was calculated for both the Base Case and the Delay Case. The annual relative risk for each case is presented in Figure 3. These risk profiles should be considered preliminary because the basis for the annualized risk calculations is still under development. The output depicts the annual relative risk change as the alternative is implemented. The output represents the total risk of all steps involved in managing the waste, from initial storage through retrieval, handling, treatment, and disposal. The beneficial effects of treatment on the annual risk are evident by the decreasing risk. These effects are primarily attributed to placing the waste in a less-mobile physical form.

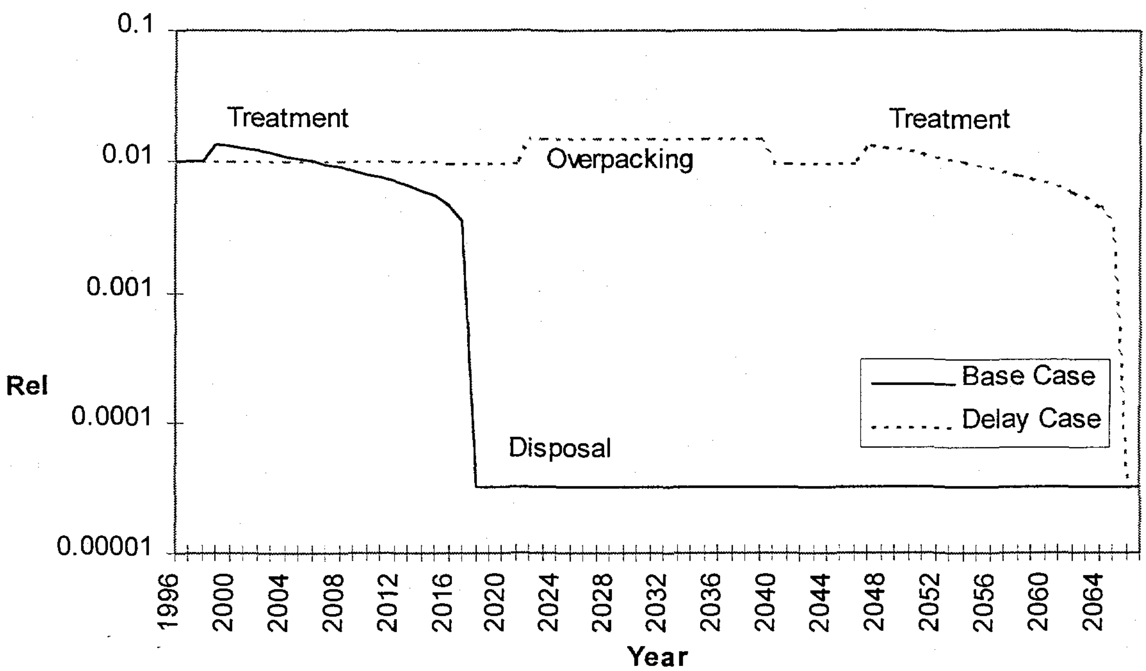

Figure 3: Relative Annual Risk Comparison

The relative risk was further defined by summary-level treatment, storage, and disposal risk states[4]. The illustration in Figure 4 indicates that the process steps contributing the most to the total time-integrated risk are pre-treatment storage and long-term disposal (>500 years).

[4]For a given material type in a given EM alternative, operational activities would proceed from the current resting place through a series of steps to a final disposition. Each of these steps is called a state. There are two types of states. A rest state is an inactive management state. Storage and disposal are rest states. A transition state is an active management state, one in which some operation is being performed on the material type. Examples of transition states are retrieval, treatment, handling, and shipping.

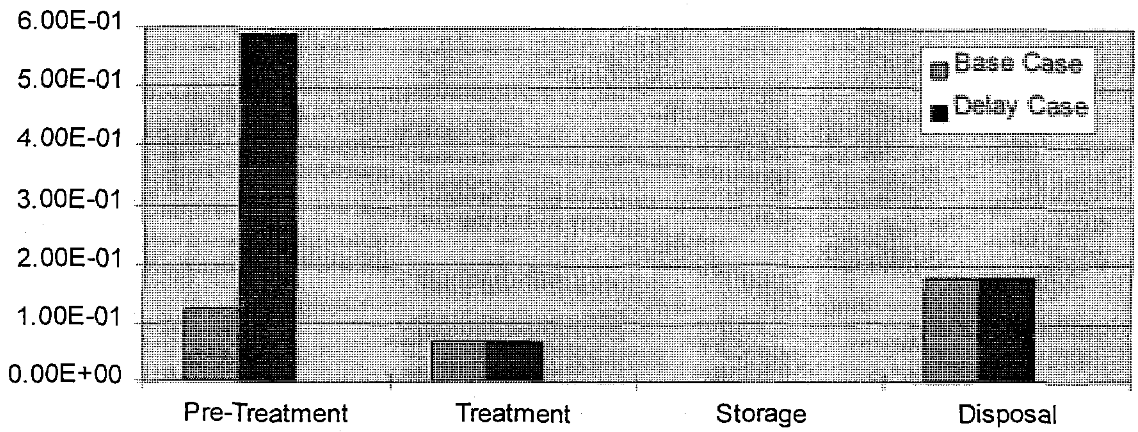

Figure 4: Relative Risk By Waste Management Function

A refinement of the output shown in the previous figure is the breakdown of the relative risk by state (equivalent to module). This output discriminates which specific processes are contributing the most risk for the alternative. For the Base Case alternative, the relative risk is greatest in the front-end module for storage. In treatment, the majority of the risk is dominated by the open, dump, and sort and the incineration module. The disposal risk is driven by the failure of the engineered barriers in the period beyond 2499 in the module.

Cost/Risk Analysis:

The individual cost and risk results provide insights to the highest cost and risk modules. This information is valuable to determine general areas of emphasis. In addition to these results, the costs and risks were integrated to provide new insights into cost-effective risk reduction opportunities. Two techniques were developed to analyze the cost/risk results:

1) **Normalized Product** technique - which can be used to guide technology development prioritization and risk mitigation activities,

2) **Marginal Alternative Comparison** technique - which discriminates risk/cost performance between alternatives to support further system optimization.

These innovative techniques were developed for the purpose of leveraging the cost and risk data to gain insights into areas of greatest cost savings and risk reduction potential. A description of the methodology for the techniques is included below. The costs and risks from the Base Case and the Delay Case scenarios were also analyzed using these techniques.

1) **Normalized Product** (NP) technique - The NP technique was used to evaluate the system components to determine the greatest opportunities for combined risk and cost reduction. The NP places cost and risk on a normalized scale so that a unit of risk is related to a unit of cost[5]. The higher values on the NP scale are indicative of the modules/states with the largest relative risks and costs as compared to the processes with

[5] The normalized risk and cost is based on the contribution of the system component (module/state) to the total system risk and cost. The normalization helps to put cost and risk on a relative scale so that the significant risk drivers can be compared against the relative costs of the module/state. For this analysis, risk and cost was normalized to the Base Case system totals.

the smallest products of cost and risk. The technique helps prioritize where funding should be directed to affect the largest potential risk reduction and cost savings. This technique was applied to the Base Case and Delay Case scenarios and the results are summarized in Figure 5.

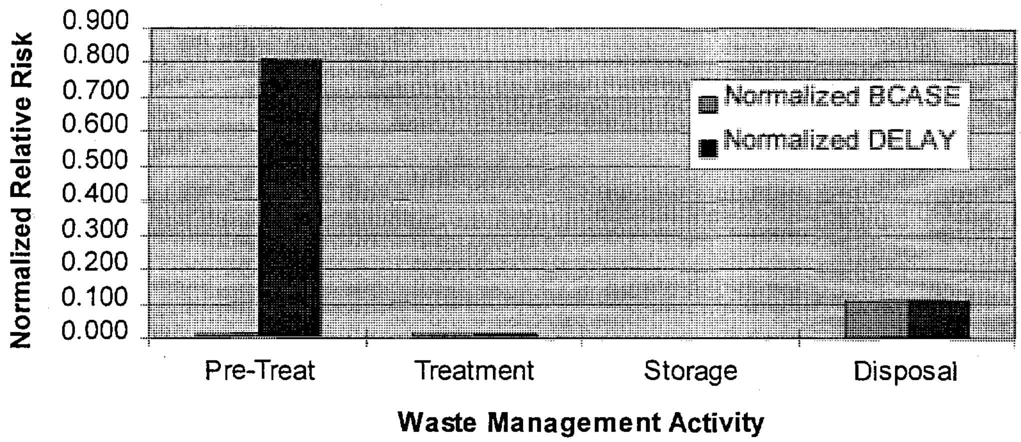

Figure 5: Normalized Relative Risk Comparison

Results using the Normalized Product technique: The results indicate that the greatest opportunities for risk and cost reduction are in the Delay Case. The marginal changes for cost and risk were highest for pre-treatment. Proportionately, the marginal cost decrement was almost five times that of the risk. This would indicate that the Delay Case has significantly higher costs and some associated increase in relative risk. The results also show an opportunity for improvement in both cases for disposal.

Risk mitigation could include (but is not limited to) reducing the number of years of pre-treatment storage, producing a less-mobile waste form, destroying organics, reducing worker exposure in characterization and packaging processes, and improved final waste form.

2) **Marginal Alternative Comparison** (MAC) technique - This technique is used to discriminate differences in risk and cost between alternatives. The MAC technique helps an analyst understand trade-offs and sensitivities between risk and costs[6] from different waste management options (technologies, scheduling, etc.). This technique can be used to help answer questions like:

> Does risk decrease proportionately with increased costs?
> How much does risk increase if costs are cut?

The technique provides a comparison of the normalized cost and risk data from the alternatives. The fractional change in normalized risk (of one alternative compared to another) is compared to the fractional change of normalized cost (between alternatives). The resulting marginal risk per unit of cost is a measure of the potential effectiveness of an improved alternative in reducing risks and costs. This technique can be used to analyze technology and operational effectiveness for pre-treatment operations, treatment, storage

[6] For example, it may be possible to achieve lower risk by developing an improved treatment technology. But the system costs for the new technology may be more or less than the current baseline technology. An optimized case would reduce system risk and cost.

and disposal. A comparison of the Delay Case to the Base Case using the MAC technique is presented in Figure 6.

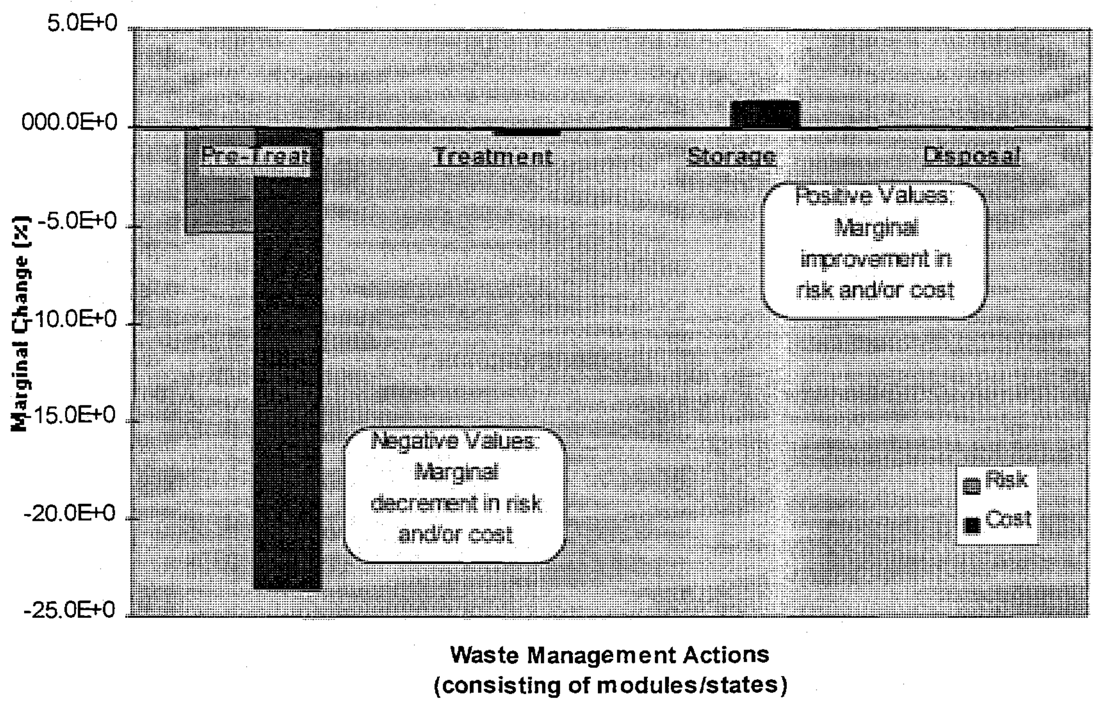

Figure 6: Marginal Risk & Cost Product Comparison (Comparing Delay Case to Base Case)

Results using the MAC technique: The results indicate that long term pre-treatment storage (including additional characterization and overpacking) causes significant cost degradation and additional risk. Post-treatment storage costs are marginally improved if treatment is delayed due to improved throughput between treatment and disposal operations. Treatment and disposal costs and risks show no significant marginal differences.

System Level impacts can also be assessed using these techniques. For example, if an improved new technology can be developed in 10 years (resulting in increased pre-treatment storage) how much better would the technology need to perform to break even with the additional costs and risk from the added storage? The system assessment could also evaluate the marginal differences of using a new treatment technology which produces an improved final waste form for disposal.

Conclusions

The cost and risks of two alternatives were analyzed using a systems-based life cycle cost and risk estimation process. Techniques were applied to integrate the results from the individual cost and risk studies. The techniques helped to provide insights into areas to maximize effectiveness while reducing risk. The techniques can be used to support many initiatives for EM:

- Define incentives for investment in R&D
- Identify and prioritize Technology Development projects
- Maximize operational effectiveness (sizing of facilities, years of operation)
- Optimize schedule
- Optimize facility siting and configuration

The ESA studies will be used by EM to gain a greater understanding of the opportunities for cost reductions and to provide a quantitative means for comparison of DOE policy options.

References

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2) Waste Management Facilities Cost Information: System Cost Model Product Description, INEL-94/0115, (draft) November 1995.

3) T. H. Smith, R. G. Peatross, I.E. Stepan, "A Simplified Method for Quantitative Assessment of the Relative Health and Safety Risk of Environmental Management Activities," December 1995 draft.