DEVELOPMENT OF A COST-EFFECTIVENESS METHODOLOGY TO PRIORITIZE ENVIRONMENTAL MITIGATION PROJECTS

THESIS

ROBERT E. THOMPSON, Captain, USAF

AFIT/GEE/ENP/93S-02

DEPARTMENT OF THE AIR FORCE
AIR UNIVERSITY
AIR FORCE INSTITUTE OF TECHNOLOGY

Wright-Patterson Air Force Base, Ohio

AFIT/GEE/ENP/93S-02

DEVELOPMENT OF A COST-EFFECTIVENESS
METHODOLOGY TO PRIORITIZE ENVIRONMENTAL
MITIGATION PROJECTS

THESIS

ROBERT E. THOMPSON, Captain, USAF

AFIT/GEE/ENP/93S-02

The views expressed in this thesis are those of the author and do not reflect the official policy or position of the Department of Defense or the U. S. Government.

AFIT/ENP/ENV/ENC/93S-02

DEVELOPMENT OF A COST-EFFECTIVENESS METHODOLOGY TO PRIORITIZE ENVIRONMENTAL MITIGATION PROJECTS

THESIS

Presented to the Faculty of the School of Engineering
of the Air Force Institute of Technology
Air University
In Partial Fulfillment of the
Requirements for the Degree of
Master of Science in
Engineering and Environmental Management

Robert E. Thompson, B.A., B.S.
Captain, USAF

September 1993

Preface

The purpose of this study was to develop a prioritization model (cost-effectiveness methodology) that would have broad applicability and rank those mitigation projects that project the most lives saved per mitigation dollar spent. The Environmental Protection Agency (EPA) identified problems in the current prioritization process in its Unfinished Business: A Comparative Assessment of Environmental Problems report. The report revealed that EPA priorities reflected the public's opinion of risk rather than actual risk.

The successful application of the cost-effectiveness methodology (CEM) to two distinctly different categories of environmentally hazardous sites demonstrates the validity of the methodology. Adoption of the CEM could save many cancer deaths as well as save millions of dollars in environmental clean-up costs.

In the development of the CEM, I had considerable help. I am indebted to my thesis advisor, Lt. Col. Richard Hartley, for his guidance on my research and his persistence on comparability of risks. I also thank my thesis readers, Lt. Col. Mike Shelley and Major Brian Woodruff for their critical contributions to my effort. Though not an official reader, I thank Dr. Vaughan for his valuable suggestions on grammar and style. In addition to these contributors, a word of thanks is owed to my thesis sponsors, Mark Mays of the Radiation Safety Office, as well as Ron Lester and his personnel of the Environmental Restoration Branch, both from Wright-Patterson Air Force Base. My sponsors provided me with valuable data on the radon problem and Landfills 8 and 10 on the base, respectively. Finally, I thank my wife, Pat, for her moral support and valuable proof reading.

Robert E. Thompson

Table of Contents

Page

List of Figures

List of Tables

Table | Page

AFIT/GEE/ENP/93S-02

Abstract

A cost-effectiveness prioritization methodology was developed using concepts from the cost-effectiveness technique. The new methodology called the Cost-Effectiveness Methodology (CEM) allows the prioritization of mitigation projects across broad categories of hazardous sites as would be ranked among the offices of the Environmental Protection Agency.

Two performance criteria were incorporated into the process--rank projects that save the most lives per dollar and enhance general applicability across different categories of risk.

A metric was developed that represents the ratio of lives saved per dollar spent on mitigation alternatives of contaminated environmental sites. This metric was incorporated into the CEM to distinguish mitigation projects that were projected to save the most lives per mitigation dollar. Steps to enhance the comparability of site risks were also incorporated into the CEM.

Once developed, the cost-effectiveness methodology was successfully applied to ranking a landfill mitigation project and a radon mitigation project--two categorically

different environmental sites characterized by posing a cancer risk to humans.

The results of the CEM demonstrated that more lives would be saved mitigating radon in 658 radon-contaminated houses to 2 pCi/L than mitigating two landfills where a comparable number of homes were exposed.

DEVELOPMENT OF A COST-EFFECTIVENESS METHODOLOGY TO PRIORITIZE ENVIRONMENTAL MITIGATION PROJECTS

I. Introduction

General Issue

Estimates to clean up years of environmental contamination by the Department of Defense (DOD) property range between 25 billion dollars to 200 billion dollars (DOD, 1992:28; Grimes, 1991:9). In addition to this large cleanup bill, our society will pay to cleanup property outside of the DOD, as well as polluted private property. No matter what the final cleanup cost, the United States is quickly facing the reality that it can't afford to clean up all environmental contamination. With shrinking federal dollars and increasing costs to clean up the environment, the government must become more efficient in reducing cancer risk. The Environmental Protection Agency in its Unfinished Business report states, "The complexity and gravity of these issues make it particularly important that EPA apply its finite resources where they will have the greatest effect" (EPA,1987c:xvii). The practice of spending vast sums of money reducing insignificant risks while leaving more significant risks unmitigated wastes government funds and gives the public a false sense of security. This misallocation of funds actually increases risks to society. According to Whipple:

> If risk reductions are limited by resource scarcity, (sic) the logical regulatory objective is to allocate the scarce resource in a way that maximizes social benefits. Opportunity costs, the value of benefits foregone from possible alternative uses of the scarce resource, become important under these circumstances. Money or regulatory attention spent on one risk is not available for another, so it is important not to waste resources on trivial risks. Here, conservatism is counterproductive, and risks are increased if resources are shifted from significant risks too small, exaggerated risks. (Whipple, 1986:50-51)

This country faces the job of cleaning up thousands of contaminated sites during a time of decreasing government and private funds. Mismanagement of mitigation funds will lead to unnecessary high cancer risks to the American people. Because the consequences of mismanagement are so serious, the EPA needs a prioritization tool to achieve the greatest risk reductions for each mitigation dollar spent. This thesis develops a methodology designed to effectively rank environmental mitigation projects to save the most lives per mitigation dollar.

<u>Problems With the Current Risk Prioritization Methods</u>

The current prioritization method is not adequate to protect the population. To demonstrate this point, one must only look as far as an EPA study.

In 1987, the EPA conducted a subjective panel study to evaluate relative risks to human health and the environment. What began as an effort to prioritize human and environmental risks became a landmark study that revealed serious flaws in this country's risk prioritization methods. The results, printed in the report titled Unfinished Business: A Comparative Assessment of Environmental Problems, are based on the expert opinions of a panel of 75 top EPA experts. Although subjective, the results are an accurate rank order of relative risks (EPA, 1987c:xviii).

In the Unfinished Business report, the panel found that EPA priorities closely aligned with public opinion, not expected risk (EPA, 1987c:xix). Of particular interest is the third finding of the report:

> RISKS AND EPA's CURRENT PROGRAM PRIORITIES DO NOT ALWAYS MATCH. In part, these differences seem to be explainable by public opinion on the seriousness of different environmental problems.
>
> - Areas of high risk/low EPA effort - radon, indoor air pollution, stratospheric ozone depletion, global warming, accidental releases of toxics, consumer and worker exposures to chemicals, non-point sources of water pollution, "other" pesticide risks.
> - Areas of medium or low risk/high EPA effort - active (RCRA) and inactive (Superfund) hazardous waste sites, releases from storage tanks and municipal non-hazardous waste. (EPA, 1987c:95)

The above finding illustrates two shortcomings of today's risk management methods:

(1) limited applicability of prioritization methods resulting in the inability to prioritize environmental hazards across EPA departmental offices and

(2) limited effectiveness to reduce the largest amount of risk per mitigation dollar resulting in erroneous perceptions of increased public safety.

To illustrate the first shortcoming, the panel found that hazardous waste sites (medium to low risk) and landfills (low risk) are earmarked for substantial superfund cleanup dollars. In comparison, the panel concluded that little effort was expended by the EPA to mitigate the two greatest causes of cancer: indoor radon exposure and worker exposure to chemicals. When looking at the risks categorically regulated between offices of the EPA, one finds those risks under the category of the superfund are receiving considerable EPA effort and funding. For example, the budget of the superfund for fiscal year 1993 is estimated at $1.75 billion. This compares with $0.279 billion for the air pollution program, $0.308 billion for the water pollution program, and .021 billion for the radiation pollution program (Executive Office of the President of the United States, 1993:868, 873). In addition to this large sum, responsible parties to contaminated sites are expected to pay for more about 65% of the cleanup bill (EPA, 1990:7). Other divisions are allocated smaller budgets to mitigate risk agents that do not alarm the public as much. Compare the $1,750 million budget of the superfund to the $20.6 million fund for radiation (includes radon). This disparity between types of risk agents emphasizes the need for a prioritization methodology with broader applicability.

The second shortcoming occurs because current risk prioritization methods do not achieve the largest number of lives saved for each mitigation dollar spent. The EPA estimates that between 7,000 and 30,000 Americans die annually of lung cancer from exposure to indoor radon (EPA, 1992:2.1), in contrast to only 40 Americans who die annually of cancer from exposure to municipal waste landfill chemicals (EPA, 1987c:31). Public opinion concentrates on chemical waste disposal more than any other environmental problem (EPA, 1987c:74). In following this consensus, the EPA's effort mirrors the public's concern for landfills and focuses most of its effort in mitigating landfills, not indoor radon (EPA, 1987c:28). This situation diverts money from truly significant risks to lower risks feared by the public. The cost is too high for the purpose of soothing public fears and still leave the public at risk.

Prioritization Model Evaluation Criteria

Because the current mitigation prioritization models are plagued by the above two primary shortcomings, these will become the evaluation criteria in this research for these models. The two evaluation criteria are the following:

(1) Capability of the model to offer wide applicability in ranking projects across wide

categories of risks.

(2) Ability of the model to favor those projects than can lower risks to society most for the money spent.

The first evaluation criteria is important to ensure "pots of money" are properly funded to reflect expected risk reduction improvements. The second evaluation criteria will help ensure the overall cancer risk to society is reduced by the quickest means available on a limited budget. As established at the beginning of this chapter, money spent on reducing trivial risks actually increases the total risk to society.

Proposed Prioritization Method for Environmental Mitigation Projects

This research proposes the implementation of the cost-effectiveness methodology (CEM) as developed in chapter III to rank environmental mitigation projects. Although components of the CEM have been applied as a regulatory risk management model known as the cost-effectiveness technique, this thesis develops a new application of the model with two unique contributions.

The first initiative overcomes limited applicability inherent in other prioritization methodologies, such as EPA's CERCLA process or DOD's Defense Priority Model (DPM), which are only applicable to hazardous waste clean-up sites. The CEM can *cross the gulf* and prioritize mitigation projects across broad categories when risks can be quantified into absolute risk (number of deaths expected). Examples of applications of CEM include ranking clean-up projects, radon mitigation projects, pollution control projects, and pollution prevention projects in the same priority list for funding. This capability will improve the prioritization of funds to between accounts of money in addition to applications within accounts of money.

The second initiative of the CEM, in this time of limited federal and private funds, incorporates the consideration of a factor not considered in other prioritization models currently used--cost. To prioritize mitigation projects, the CEM uses a decision criteria metric of lives saved per mitigation dollar spent labeled the cost-effectiveness ratio or CER. Favoring the project with the largest CER, the CEM recommends continual funding of a mitigation project until the effect of diminishing returns lowers the incremental risk reduction to the level of the second-best project (Lave, 1980:19-21). This process virtually assures that society will achieve the *biggest bang for the buck* in the risk prioritization process. If there are subjective considerations (e.g. extinction of a species or deterioration of the environment), they should be reviewed only after cost-effectiveness ratios have been calculated and the mitigation projects prioritized. Some minor modification of the prioritized list may then be warranted.

Scope of the Problem

According to the EPA, any risk assessment consists of the four processes illustrated in Figure 1. First, the hazard identification step determines if chemicals potentially exposed to humans can cause cancer. Second, the exposure assessment process estimates population exposures to hazardous substances using assumptions, models, and sampling. Third, dose-response assessment describes the relationship between exposure to a hazardous substance and the cancer development response by way of mathematical relationships. Finally, the fourth step characterizes risk through risk calculations and presentation of risk information to the risk management function for prioritization. These steps are discussed in much more detail to characterize uncertainty in the risk assessment process in Chapter II (EPA, 1992:2.2,2.12-13,2.21).

After the risk has been characterized, the results are passed to the risk management process. Figure 2 demonstrates how risk assessment interfaces with risk management. When making a decision, risk managers consider the risk and its uncertainty along with the control options and non-risk analysis.

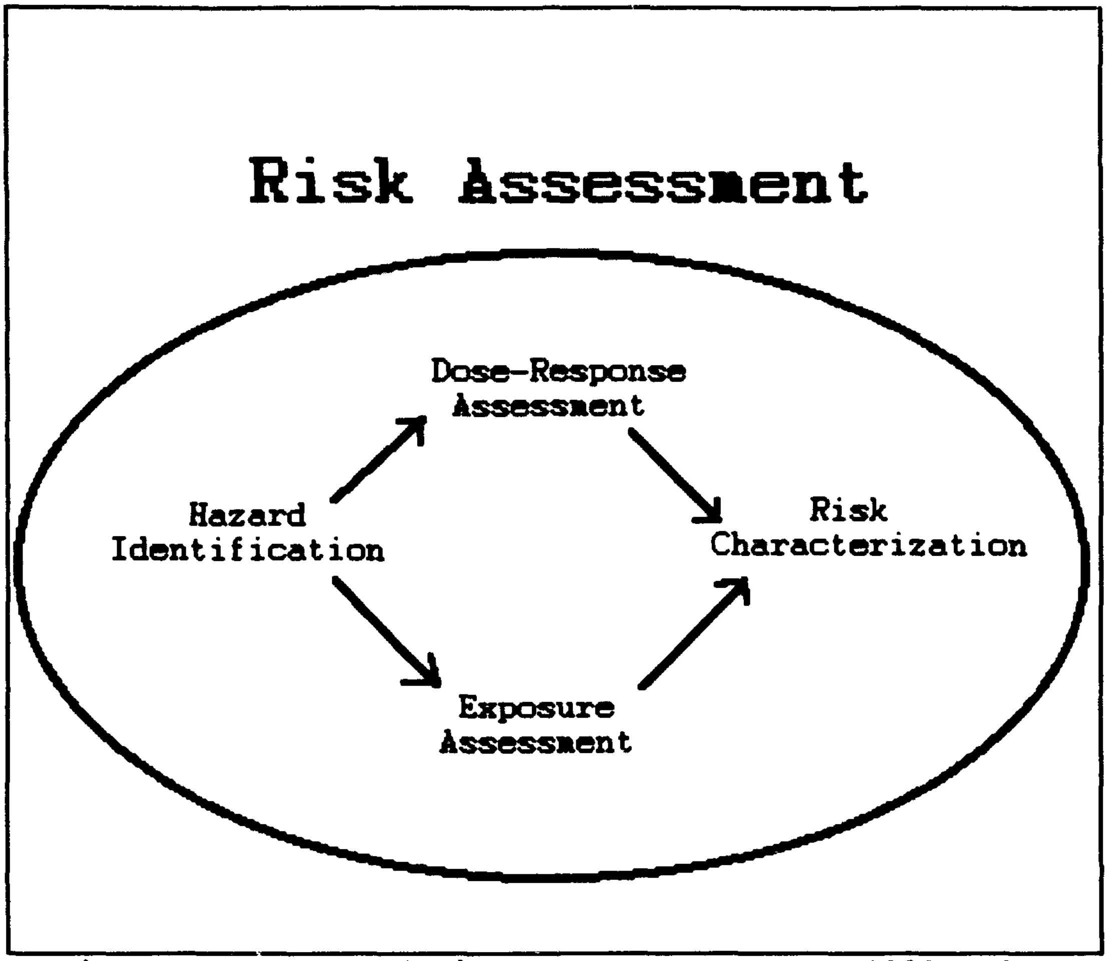

Figure 1. Steps of Risk Assessment (USAF, 1992:5.47)

To properly develop the CEM within the limitations of this research, the scope is limited analytically to the risk management process and only subjectively to the risk assessment process as shown in Figure 2. Risk assessment will be only addressed in enough detail to provide input information for the cost-effectiveness methodology and characterize the uncertainty of the risk.

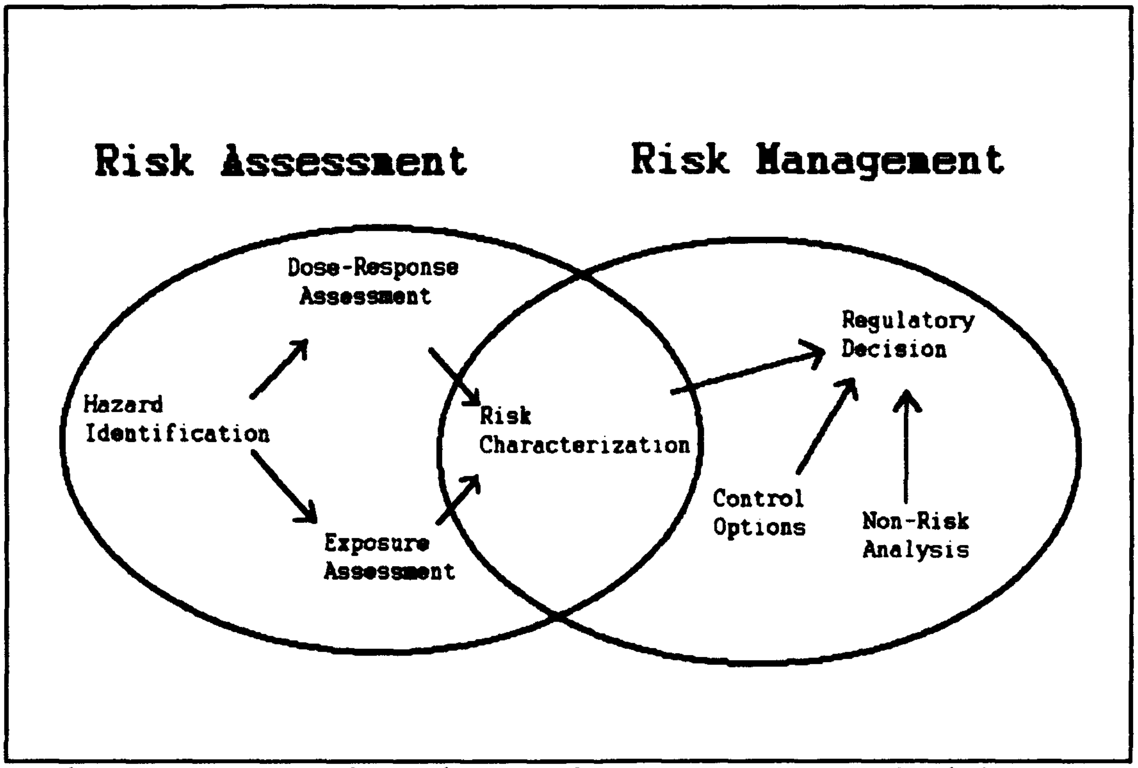

Figure 2. Relationship of Risk Assessment and Risk Management (USAF, 1992:5.48)

Since the CEM was only developed as a risk management tool, the development of the cost-effectiveness comparison methodology will help facilitate cost-effective decisions--not constrain the decision-maker with an one-and-only answer. The methodology will not consider more subjective issues such as environmental degradation and extinction of species. Once the decision maker has calculated the cost-effectiveness ratios, risk management may then consider other related subjective factors.

Specific Research

In Chapter II, the risk assessment process is subjectively analyzed to develop an understanding of the uncertainty inherit in the risk assessment process, which in turn, contributes to uncertainty in the risk management process. To focus the problem, however, this research will be limited to quantitative analysis only to the risk management procedures required to apply the CEM (see Figure 3). The CEM will use data directly from risk assessments and any feasibility studies, which are available from previous risk assessments. Data from risk assessments and feasibility studies will provide the information needed to calculate CERs and characterize the uncertainty of the risk.

Problem Statement. This research develops a methodology to apply the CEM to prioritize broad categories of hazardous sites typically ranked among the offices of the EPA. To validate the CEM, it is used to rank two types of hazardous environmental mitigation projects. To demonstrate the application versatility of CEM, two mitigation projects will be ranked using the CEM--a radon mitigation project and a landfill mitigation project (Chapter IV).

The CEM's application will be limited to that of a decision management tool. The methodology, developed in this research, will consist of a technique to evaluate subjective considerations such as environmental degradation and extinction of a species. This added procedure gives the decision maker some flexibility to account for subjective factors not considered into the CEM calculations. Once the decision makers have the cost-effectiveness ratios, decision makers may then take these related subjective factors into consideration.

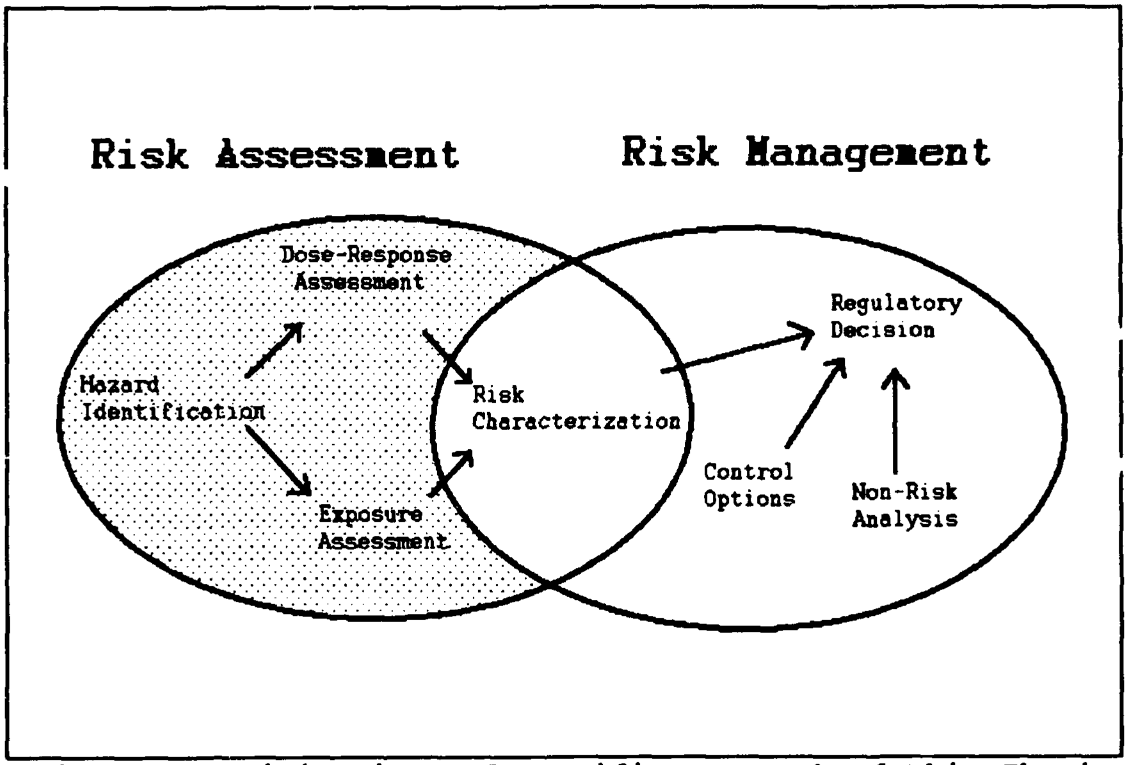

Figure 3. Limitations of Specific Research of This Thesis (USAF, 1992:5.48)

Investigative Questions

The following investigative questions parallel the evaluation criteria and are required to satisfactorily develop and apply the CEM. These questions will also guide the direction of the research.

1. What analytic procedures are required to improve the applicability of CEM across environmental problem categories?

a. What are the uncertainties associated with exposure estimates?

b. What are the uncertainties associated with the slope factors?

c. What are the uncertainties associated with residual risks after mitigation?

d. How can mitigation projects be normalized to improve comparability?

2. How can incremental risk reductions and incremental mitigation costs be determined?

a. How can CERs of feasible alternatives of a mitigation project be manipulated in a meaningful way to evaluate the alternatives?

b. What is a practical method mitigation sites may be ranked for funding using CERs?

The solutions to the above questions are necessary to develop the methodology in the CEM. The appendix contains all terms and acronyms used in this thesis.

Overview of Thesis Outline

This thesis contains five chapters detailing the development of the cost-effectiveness methodology. Chapter I establishes the need for a new risk management tool to prioritize mitigation projects. Chapter II discusses the background information required to understand and apply CEM. Chapter III develops the cost-effectiveness methodology for wide applications in mitigation project prioritization. To validate the methodology, chapter IV applies CEM to prioritize local mitigation projects at Wright-Patterson Air Force Base (WPAFB) and analyzes the information obtained with the process. Chapter V evaluates the application of CEM and discusses the conclusions, recommendations, and applicability of this thesis.

II. Background

Overview

This chapter provides information to understand, develop, and apply the cost-effectiveness methodology (CEM). First, to establish CEM's superior mitigation project ranking potential over other competing regulatory decision models from where the CEM was derived, the CEM is compared with these models using the two evaluation criteria described in Chapter I. Second, the CEM is compared with current mitigation project ranking models using the same two evaluation criteria. Third, the weaknesses of the CEM are discussed to develop an understanding of the limitations of the model. Next, the parts of the risk assessment process are analyzed for sources of uncertainty to aid in the critical task of characterizing uncertainty in the risk management process. Finally, parts of risk management process are discussed to facilitate the development of the CEM risk management process. When the CEM results are presented to the risk manager, information presented in this chapter will be useful to understand the nature of risk and the uncertainty accompanying the cost-effectiveness ratios.

Cost Effectiveness Methodology - Best Risk Prioritization Management Method

The CEM is the best available method to prioritize risk management alternatives compared to its regulatory decision-making rivals as well as current mitigation project ranking methodologies when assessed using the two evaluation criteria (See Figure 4).

Cost-Effectiveness Methodology Analysis. The CEM is based on the mathematical objective to save the most lives with the last dollar spent. Decision makers compare the CERs of each cleanup alternative and fund the most cost-effective alternative as long as the project's CER continues to exceed the largest CER of competing projects.

To illustrate this concept, consider a fuel spill one mile from a town's city water wells. The first alternative may be to place a cement cap over the area to prevent leaching. Before placing the cap, the risk analyst would consider the next more expensive mitigation alternative which might be a pump and treat alternative (pump water out of the aquifer and purify it before returning the water back to the ground). If the CER of this pump and treat alternative is larger than the CER of cleanup alternatives for other sites, the decision maker would fund the pump and treat alternative. If the CER of the pump and treat alternative was smaller than the CERs of other sites, then the decision maker would fund first the cement cap for the

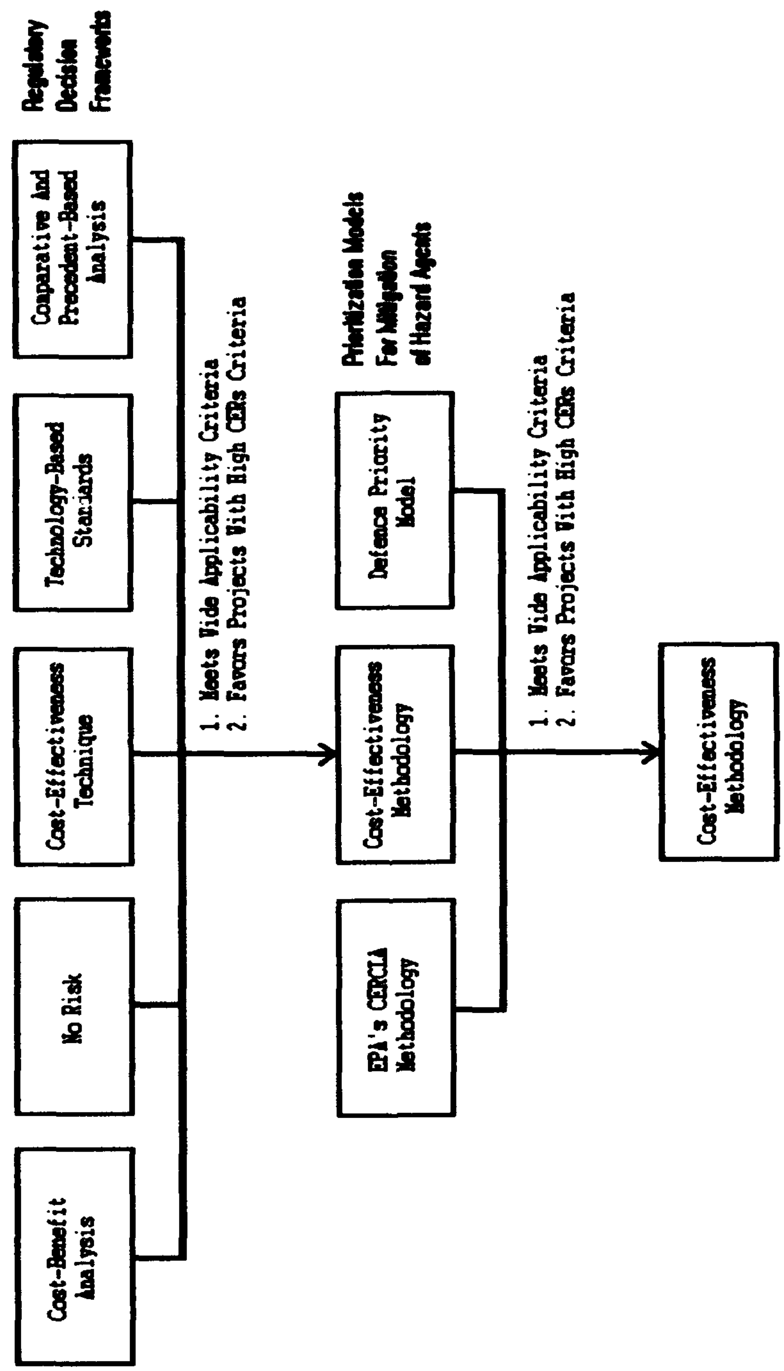

Figure 4. Comparison of Other Methodologies With the CEM

spill site and then fund the cleanup alternative of the site with the second highest CER (Lave, 1981:20).

Figure 5 illustrates this point with points along two lines. Each line represents a contaminated site competing for mitigation funds. Along these lines are points that represent cleanup alternatives that achieve estimated CERs if funded. As more expensive, but more effective cleanup alternatives are funded, the trend will usually follow a pattern of smaller CERs achieved. This pattern represents the well-known principle of diminishing returns: the first cancers prevented in site cleanup cost less than those prevented when the site is nearing safe contamination levels. The size of the risk is irrelevant; it is the size of the CERs predicting lives saved for the cost that are compared in Figure 5. The mitigation project with the largest CER in Figure 5 is funded until its CER decreases to the point that it is less than another project's CER. Once a competing project's CER is larger than the funded project, the competing project is funded.

Intuitively, the CEM assists risk-management decision makers to prioritize projects in the order of lives per dollar spent. However, risk managers and government regulators must be cautious not to introduce errors into the goal or budget. For example, when evaluating CERs in the situation of a limited funds, government decision makers should consider the cleanup costs imposed on society, not agency funds available to regulate and control the cleanup actions. Misguided goals and budgets can lead to bad decisions (Lave, 1981:20-21).

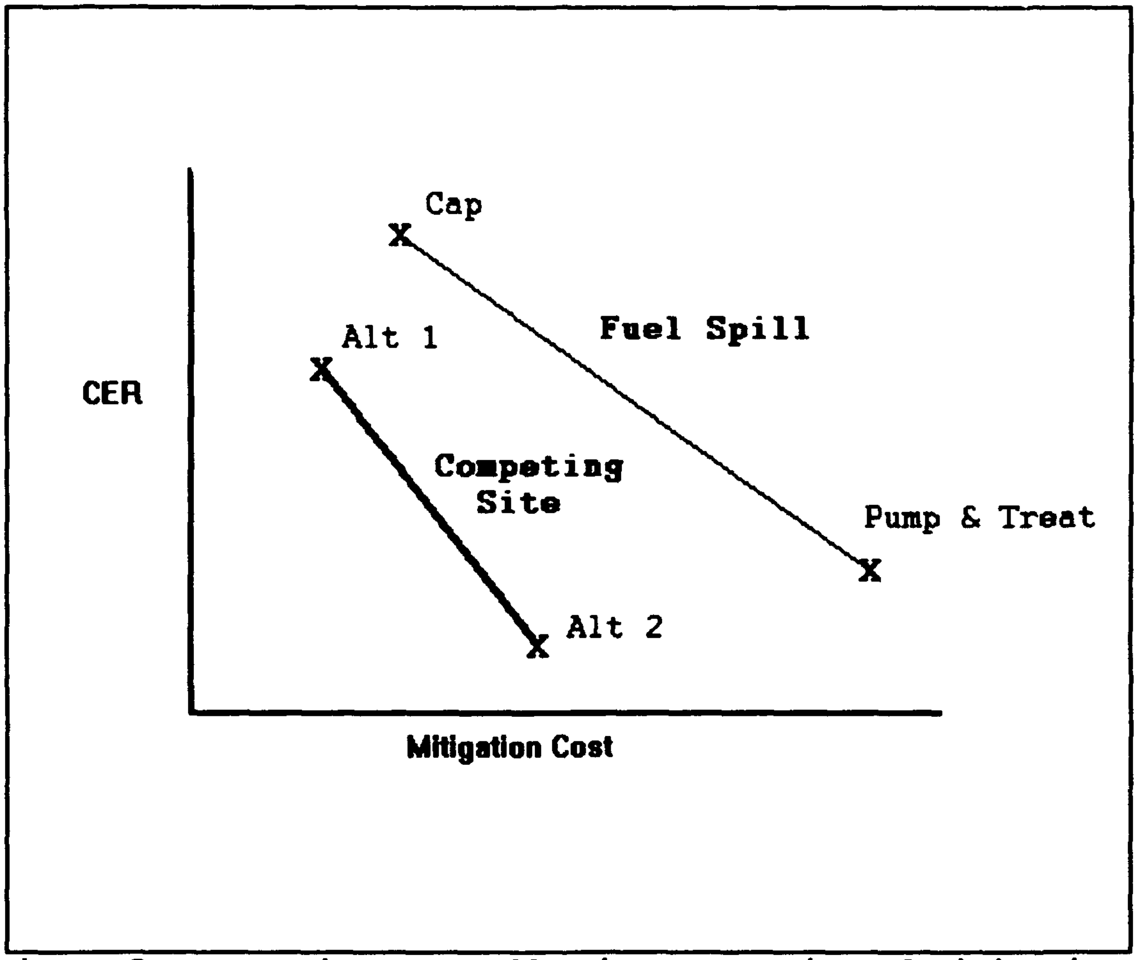

Figure 5. Comparing Cost-Effectiveness Ratios of Mitigation Projects

The CEM meets both evaluation criteria established in this research to evaluate mitigation project prioritization methodologies. First, it has wide applicability to all public risks using the metric of lives saved per dollar spent (CERs). Second, by ranking mitigation projects based on cost-effectiveness ratios, the CEM ensures projects that reduce the most risk per dollar are funded first.

The CEM, which originated as a regulatory decision-making framework, is compared with four of its competing frameworks for making regulatory decisions to show why it was selected to develop the prioritizing methodology.

CEM vs. Regulatory Decision Frameworks. When using the two-established evaluation criteria, the CEM ranks the highest of the four commonly used regulatory decision-making frameworks to rank mitigation projects. The CEM, developed in this effort, was derived and enhanced from basic concepts originating in the cost-effectiveness technique, a regulatory decision-making framework (see Figure 4). These regulatory decision-making frameworks are currently used by law-makers and governmental agencies to decide health issues and evaluate proposed health and safety regulations affecting the public. For example, regulatory decision-making frameworks were used to analyze benefits, costs, and risks resulting in the enactment of legislation such as the Toxic Substances Control Act; the Federal Insecticide, Fungicide, and Rodenticide Act; and the Consumer Product Safety Act (Lave, 1980:8-9). The four specific techniques to be compared with the CEM are: cost-benefit analysis, no-risk, technology-based standards, and comparative or precedent-based analysis.

CEM vs. Cost-Benefit Analysis. Cost-benefit analysis, the primary method of managing regulatory controlled risk, translates all benefits and costs of a project into a common metric of dollars. Dollar values are assessed to the benefits of each option and then the corresponding cost subtracted. The analyst compares the present worth of each alternative and may recommend the alternative with the most positive value (Lave, 1981:23-24). Cost-Benefit analysis evaluates alternatives using Equation 1 (Page and Ricci, 1985:56).

$$PV=\sum_{I=t}^{N}(B_t-C_t)/(1+r)^t \qquad (1)$$

Where PV = present value of the alternative

B = value of the stream of benefits

C = value of the stream of costs

t = the time period

r = social rate of discount

Cost-benefit analysis meets the first evaluation criteria of wide applicability across different types of risk; however, there is some controversy in some applications. For example, although cost-benefit analysis has been generally applied to many category applications, it falls short when the value of human life must be quantified. Because CEM's results are ratios of lives saved per dollar spent ratios, CEM does not have the difficult and controversial task of determining the value of human life required in cost-benefit analysis (Lave, 1981:20). In addition, attempting to place a value on human life raises emotional resistance. Some people think that placing monetary values on human life is treating the public as a commodity (Page and Ricci, 1985:45).

The difficulties in determining the value of human life limit the applicability of cost-benefit analysis in any ranking model addressing life and death issues. In cost-benefit analysis, analysts place a value on life ranging from $200,000 to $2,000,000--a considerable span (Page and Ricci, 1985:45). One method of placing value on human life is the human capital approach. This approach calculates the earning potential of the person killed and adds other costs such as the cost of burial. A major problem with this approach is the controversy of placing a value on elderly people--just their burial costs? Women and minorities tend to earn less; now discrimination may be an issue. Proponents of this method claim to use it only to establish a lower bound on the value of human life. To establish an upper bound, analysts consider the sacredness of life and expect society to spend whatever is feasible to save lives. This estimate could cost society several million dollars per expected life saved (Page and Ricci, 1985:46). Because current risk analysis techniques produce risk estimates with order-of-magnitude uncertainties, analysts cannot be confident of the number of lives saved for the millions of dollars spent for environmental cleanup.

There are other limitations in wide applicability of cost-benefit analysis as a basis to rank mitigation projects. The first limitation concerns cost-benefit analysis' requirement to quantify the value of extinction of a species or deterioration of the environment, in addition to placing value on human life. Placing monetary values on subjective factors such as these involves judgement on the part of the analyst. The analyst must also use judgement to decide what is important to consider in the analysis and what is insignificant and should be left out (Cohrssen and Covello, 1989:23). Entering dubious values for these subjective factors clouds the decision and could divert money away from one of the primary reasons to enact environmental legislation--to reduce cancer risk to the general population.

Cost-benefit analysis fails to meet the second evaluation criterion (achieve high CERs) even more than it fails the first. Several problems surface in cost benefit analysis that diminish its ability to discriminate which mitigation projects will save the most lives per dollar. For instance, bias can be introduced in subjective cost-benefit analysis equation variables. Monetary values placed on subjective variables such as aesthetic scenery, extinction of a species, and human life vary with the group originating the value and can introduce bias in the mitigation project prioritization process. In addition, the analysis's attempt in cost-benefit analysis to combine objective data (cost and risk values) into equations with subjective variables (personal values) clouds the meaning of the results (Lave, 1981:18, 23-24). Finally and most significant, society does not have unlimited funds to pay for all projects that return more benefits than the projects will cost. This situation is aggravated by the fact that benefit values to cost ratios do not translate to large numbers of lives-saved-to-cost ratios.

CEM vs. No-Risk. This philosophy lead to the enactment of the Delaney Clause of the Food, Drug, and Cosmetic Act. This act prohibits any amount of cancer-causing chemical in any food including residual amounts of hormones in meat or pesticides on vegetables. The no-risk methodology accepts no circumstances exposing risk to society. If the substance contains a carcinogen, then the no-risk methodology would recommend banning it (Lave, 1981:11-13).

This methodology can be ruled out because it fails both evaluation criteria. First, no-risk is not applicable to any risk situation. It is an outdated concept when strictly applied. When first adopted in the 1950s, technology could not detect trace amount of cancer-causing agents. In addition, at that time, science lacked sufficient knowledge for identifying which chemicals were carcinogens. Improved detection methods have identified traces of natural as well as man-made carcinogens in virtually every food substance. What was once applicable to risk management in food is now obsolete.

No-risk also fails the second criteria. Application of this method would bankrupt the country and in the process fail to remove all risk from food. It is impossible financially to stop adding food additives to prevent food spoilage or insect infestations. The major fallacy of the no-risk technique is that it does not differentiate between very weak toxins and potent carcinogens. If any risk were indicated at an environmental site, the technique would blindly recommend mitigation (Lave, 1981:12-13). Mitigating all sites with risk would result in very low CERs.

The CEM, on the other hand, considers more significant risks first where mitigation pays large dividends in lives saved. Threats presenting small risks in conjunction with large risk reduction costs such as natural carcinogens or food additives can not compete with the thousands of contaminated sites around the country for mitigation funds.

CEM vs. Technology-Based Standards. Technology-based standards, which base regulatory decisions primarily on installing the best available technology, require reductions of risks to the greatest technological extent possible. Air and water quality standards are based on this concept. This method requires no formal benefit or cost calculations, but only requires analysts to determine the existence of a hazard and the best technology available to reduce the risk as much as possible.

This methodology also fails both evaluation criteria. First, this methodology's applicability is limited because it is unequally applied within industry and therefore does not guarantee risk reductions. For example, economically strapped industry may not have developed a strong control technology and would be permitted to continue its polluting practices. Governmental agencies have historically eased environmental controls for economically-threatened industries in comparison to thriving industries (Lave, 1981:14-15). With regards to the second evaluation criteria, economic risk reductions may not materialize because of the principle of diminishing returns. More money can always be spent to improve the efficiency of the control technology even if the mitigation costs exceed the benefit received from the additional expense. The major question is how much money can a competing company afford to spend to buy the best-available pollution control equipment (Lave, 1981:14-15). Going for the *Cadillac* alternative in mitigation every time will surely raise costs and reduce risk-reduction efficiencies or CERs. The largest CERs will most likely be the *Chevrolet* alternative. CEM, on the other hand, considers limited cleanup budgets in its analysis and efficiently funds mitigation projects that return the largest CERs.

There is a growing movement towards a methodology that places the risk of an individual site into perspective of all other risks people are exposed to and accept as part of life. This methodology is known as the comparative and precedent-based approach and although not a regulatory decision-making framework in the pure sense, it is listed here.

CEM vs. Comparative and Precedent-Based Analysis. Some analysts, in contrast to preferring quantitative risk management methodologies, prefer a comparative and precedent-based approach to the risk prioritization problem. Here, analysts compare the risk of controversial hazards to other risks society has already accepted. When determining the acceptability of a risk, analysts may compare environmental risks to natural hazards of everyday life such as lightning strikes, tornadoes, or earthquakes. The effort is to establish minimum acceptable risk (Cohrssen and Covello, 1989:18). Risks above an established acceptable risk would be prioritized for mitigation. Cohrssen discusses on the concept of trivial or de minimis risk:

> Many federal environmental laws and regulations explicitly or implicitly recognize that estimates of very small levels of risk are not significant or worthy of attention, but the determination of how small those levels should be is often controversial. ... (The term de minimis is derived from the legal doctrine de minimis non carat lex, "the law does not concern itself with trifles.") Proponents of a de minimis risk-management principle contend that regulatory agencies should establish de minimis levels and regulate only those hazards that pose a risk greater than these levels. (Cohrssen and Covello, 1989:25)

The experience of living poses risks to everyone. The goal is to realistically reduce the risk and not significantly impose on anyone's lifestyle. Table 1 contains the type of information helpful to the risk analyst using the comparative and precedent-based approach to determine acceptable risk.

Table 1

Examples of Some Commonplace Risks in the United States

Action	Lifetime Risk
Cigarette smoking, one pack per day	0.25
All Cancers	0.22
Death in a motor vehicle accident	0.02
Radon in home with 4 pCi/L concentration	0.01-0.05
Homicide	0.01
Home accident deaths	0.01
Radon in homes, cancer deaths	*0.003
Alcohol, light drinker, cancers	0.001
Sea level background radiation, cancers	0.001
4 tablespoons peanut butter per day (aflatoxin)	0.0006
Typical EPA maximum contaminant level	0.0000001- 0.0001

(Masters, 1991:192). *Risk of radon added from (EPA, 1986:9)

The lifetime risk from exposure to radon at action cleanup-level concentrations of 4 pCi/L pose similar risks to people as car accidents and homicides. This information could be used by risk analysts to conclude that radon poses no significant risk.

On the surface, the comparative analysis approach may seem to meet the first criteria of general applicability in any situation where risks can be expressed as individual risk. Once individual risks can be determined at a variety of sites, these risks are compared with other risks acceptable to the population. The fallacy with this reasoning is that comparative analysis fails to consider why people accept some health hazards with high risks and strongly reject other health hazards with lower health risks (Cohrssen and Covello, 1989:26). The relative risk method attempts to evaluate risks by equating hazards that society rejects to risks society has already accepted, such as driving risks or living in areas where earthquakes or tornadoes occur. In the public's mind, the risks are not comparable. The risk statistics may be comparable, but the public fails to accept the analogies made.

The following list explains why the public refuses to accept comparisons of some risks with each other:

1. Voluntariness - If people perceive that they are volunteers to be exposed to a risk, it is more acceptable.
2. Risk Equity and Fairness - Hazards that expose risk to the entire community, but also benefits the same community, will be more acceptable by all who are exposed. If one sector of the community is unfairly exposed to more risk than another sector, then the risk will not be acceptable.
3. Procedural Legitimacy - If the procedures used to determine the risk are perceived to be legitimate, then the risk is more acceptable.
4. Uncertainty - The more uncertainty characterized in an established risk, the less acceptable the risk is to the community.
5. Risk Perceptions - Dread factors resulting from uncontrollable, unavoidable, involuntary, or inequitable risks are unacceptable to the public. Unknown factors such as a new risk, not observable

or unknown factors to science, or long-delayed consequences, make the risk more unacceptable. (Cox and Ricci, 1989:1017-1037)

The above five factors weaken the foundation on which the comparative and precedent-based approach depends to rank risk mitigation projects.

The comparative analysis approach fails to meet the second criteria, because this approach's goal is to mitigate only the very largest risks. Mitigating the sites with largest individual risks does not suggest the possibility of more lives saved per mitigation dollar. The largest risks may very well be the hardest to clean up. Discounting the importance to mitigate risks simply because the public has accepted a similar size risk is dangerous to society and could increase population risk. Because most environmental risks are several orders of magnitude smaller than car accidents, one would expect environmental cleanup actions to be rare and population cancer rates to increase. Cohrssen and Covello accentuate this point when they warn that introducing just one trivial risk a year and ignoring it would increase the population's risk over a period of time. Subjective comparisons with other risks is not a factor with the CEM. The CEM prioritizes mitigation projects based on objective analysis of cost-effectiveness ratios and then considers subjective considerations.

<u>CEM vs. Prioritization Models for Hazardous Sites Covered by the Comprehensive Environmental Response</u>

Compensation and Liability Act (CERCLA) (Figure 4). The CEM is the best available method to prioritize risk management alternatives when compared to two existing mitigation risk management methodologies: Defense Priority Model and the EPA's CERCLA methodology.

Any prioritization methodology is required to follow the steps defined in CERCLA. These steps are briefly defined in Table 2.

Table 2

The CERCLA Process

Discovery/Initial Notification	Discover site and notify EPA of suspect hazardous waste site.
Preliminary Assessment	Distinguish those releases that pose potential threat to public health, welfare, or environment.
Site Inspection	Satisfy data requirements for revised Hazard Ranking System (HRS) scoring; Collect data to characterize agent release.
Remedial Investigation	Determine nature & extent of contamination, threat to human health & the environment. Provide basis to determine types of actions to be considered.
Feasibility Study	Develop and evaluate potential remedies; select cost-effective mitigation action; Achieve consensus among EPA, state, and local authorities.
Remedial Design	Design the selected mitigation action
Remedial Action	Construct remedial action technology
Site Closeout	Determine all actions have been taken to protect human health and the environment.

(USAF, 1992:3.17, 5.13, 5.19, 5.23, 5.35, 5.51, 5.73, 5.90, 5.98)

At any point in the CERCLA process, a site could be determined harmless to human health and the environment thereby removing the site from further consideration.

CEM vs. EPA's CERCLA Risk Management Process. Once the Preliminary Assessment/Site Inspection is completed, the risk analyst should have the information the EPA requires to score a site with the Hazardous Ranking System (HRS). The HRS is not a mitigation prioritization model; however, the HRS is a system developed by the EPA to make binary decisions to determine which sites will be placed on the national priorities list (NPL). Mandated by Congress in CERCLA in Section 105(8) to consist of 400 sites on the NPL, the EPA compared HRS scores and determined that a score of 28.5 or higher would place the required number of sites on the NPL (Zarogoza, 1993). In September 1990, the EPA had placed approximately 32,000 sites on its automated evaluation list called Comprehensive Environmental Response, Compensation and Liability Information System (CERCLIS), and the NPL list had swelled to 1,236. The EPA estimates that NPL will grow by about 100 sites a year reaching a total of 2,100 sites by the year 2000. The average clean-up cost to mitigate an NPL site costs around $26 million (EPA, 1990:2-3, 7). The NPL represents the nation's worst contaminated sites that can compete for superfund dollars.

Once a site is placed on the NPL, the EPA (and DOD if site is DOD property) follow(s) a study process described in Table 2 called a Remedial Investigation/Feasibility Study

(RI/FS) (Arbuckle and others, 1991:478). The output of the RI/FS is a characterization of the risk and exposure pathways, as well as a description of considered feasible mitigation alternatives.

The EPA employs the results of the RI/FS process to prioritize environmental sites for mitigation. After the RI/FS has characterized the risks and mitigation alternatives at a site, the regional EPA (and DOD if the site is DOD property) in concert with state environmental authorities qualitatively prioritize the sites. Taken into consideration in the prioritization process to establish a cleanup level decision are the nine evaluation criterial located in 40 CFR 300.430(e)(9)(A-I). For convenience, these criteria are listed in the control options section later in this chapter (Zarogoza, 1993). The result of this risk management process is a decision on the remedial action, if any, called the record of decision (ROD) for NPL sites or decision document (DD) for non-NPL sites. Upon releasing the proposed ROD/DD, the Superfund Amendment and Reauthorization Act of 1986 (SARA) mandates public participation and comment (Arbuckle and others, 1991:479).

EPA's CERCLA process fails the first evaluation criteria; by CERCLA's definition, the EPA CERCLA process is limited to cleaning up hazardous substances released into the environment--not reducing risk in broad categories of hazardous sites. Contrast this limited application tool with the universal and relevant uses of the CEM to all risk management applications. The CEM can rank across a broad spectrum of hazardous sites associated with cancerous risk.

Furthermore, the EPA CERCLA process fails the second evaluation criteria for three reasons. First, according to Zarogoza, HRS is not a model designed to precisely distinguish the relative risks of environmental sites; for example, HRS can not differientiate between one site with an HRS score of 35 and another site with a score of 30 (1993). Insufficient precision to differentiate relative risks makes it very difficult to rank contaminated sites and differentiate degrees of risk reduction per dollar spent. The CEM, on the other hand, facilitates differentiation of entities associated with risk based on cost-effectiveness ratios.

The second reason why the EPA CERCLA process fails the second criteria is EPA's goal to mitigate sites characterized by the largest risks instead of mitigating sites characterized by the largest CERs. This goal impedes the desired effect of saving the most lives with limited funding. A risk management goal to eliminate the largest risks may not reduce the overall population risk effectively. The following illustration demonstrates this point. Exposure to site "A" to a population results in a cancer risk of 10^{-3}. If the population size is one million people, then 1,000 people could expect to develop cancer sometime during their lifetime. Consider exposure to a second site "B" results in a lifetime risk of 10^{-4}, or ten times less risk than site "B". Exposure to site "B" by the same population would result in an expected 100 cancers. The EPA would mitigate site "A" if state environmental authorities, local authorities, and the general public agreed. Consider some added information--a one million dollar budget can lower the risk of site "A" to 9.5×10^{-4} or lower the risk of site "B" to 1.0×10^{-6}. The expected lives saved would be 50 if site "A" is mitigated or 99 if site "B" is mitigated. This illustration clearly demonstrates that sites should be ranked for cleanup funding based upon CERs (lives saved per dollar), not the size of risk. The size of a risk from any one site is not as important as the estimated number of lives saved.

The third reason the EPA CERCLA process fails the second evaluation criteria is due to political influences on the ranking process. Over-ruling the risk characterized by a site has become public concern about the site. As was previously mentioned in the <u>Unfinished Business Report</u> published by the EPA, EPA efforts to clean up the environment mirror public opinion of the risks, not the actual relative risk (EPA, 1987c:95).

<u>CEM vs. the Defense Priority Model</u>. The Defense Priority Model (DPM) is DOD-owned automated software designed to rank Installation Restoration Program (IRP) sites based on relative risk to human health and the environment.

After the completion of the RI/FS, military risk analysts input information from this and other studies into the DPM in two general steps. First, a data input package characterizing an IRP site is assembled. The input information consists of point scores determined by answering questions about the IRP site. Second, the information from the data input package is entered for variables of the DPM software (Office of Deputy Assistant Secretary of Defense (Environment), 1992:xiii).

Once the DPM scores IRP sites after the RI/FS step, DOD allocates available funds to projects with the highest score considering also regulatory and program efficiency (Office of Deputy Assistant Secretary of Defense (Environment), 1992:5). Unfunded projects wait for end-of-year fallout money or wait for next fiscal year funding.

Although the DPM is a model that discriminates relative risks, it fails both evaluation criteria compared to the CEM. First, by the nature of the program, the DPM is strictly limited to ranking IRP sites for funding whereas, the CEM is applicable to all projects where risk can be quantified. The DPM fails the second evaluation criteria of achieving the largest CERs because its basic goal is to mitigate DOD's worst sites first (Office of Deputy Assistant Secretary of Defense (Environment), 1992:xiii). As illustrated in the previous section, the goal to mitigate sites presenting the largest risks does not necessarily result in the largest number of lives saved per dollar (large CERs). The worst sites may take significant portions of DOD's cleanup funds and at the same time reduce little risk. When funds are limited as in government today, society must reach for the "low fruit" and mitigate those sites that lower the total number of population cancers with these limited funds.

Vulnerabilities of the CEM

The CEM is not without its own vulnerabilities. First, numerical estimates of risk are required to apply the CEM. This requirement will probably require a more in-depth risk assessment than the PA/SI step if the site conditions are not well understood from this study. The risk analyst will most likely require risk estimates from RI/FS. Waiting for the RI/FS may delay cleanup actions if a provision in the CEM does not allow for removal action (remediation of a eminent or occurring threat).

The second, more significant, area of vulnerability of the CEM is uncertainty. The CEM is one of the more sensitive prioritization models to uncertainty. This sensitivity is particularly true where there are differences in the amount of uncertainty in risk estimates among sites. If all sites contained the same degree of uncertainty, then this vulnerability would be minimized.

To illustrate this second vulnerability, consider two sites (A and B) with equal calculated risks. Let site "A" contain risk agents where there is strong evidence in humans of their carcinogenicity resulting in well understood risk and slope factors characterized with little extrapolation. The exposure concentrations are well understood because these estimates are the result of direct measurements at the point of exposure. Let site "B" contain risk agents where there is only weak evidence in rats of the potential carcinogenicity of these risk agents. The slope factors of these risk agents were derived from large extrapolations of large doses to small doses expected for humans resulting in great uncertainties in the estimates of the risk agent slope factors. Exposure from site "B" could not be directly measured, so exposure concentrations were modeled to estimate human doses resulting in exposure concentration estimates of great uncertainty. Because of the great degree of uncertainty corresponding to site "B", the risk estimate will be extremely conservative (overestimated) compared to site "A". Because the risk estimates of these two hypothetical sites are calculated to be equal, the actual risk of site "B" is likely to be significantly less than the risk of site "A". The CEM is highly sensitive to differing degrees of conservatism in the risk estimate of sites whereas, other prioritization models consider the likelihood of exposure that implies a degree of risk to the potentially exposed population.

Since knowledge of the nature of uncertainty is critical in applying the CEM, the next section will discuss the origins of uncertainty more thoroughly and methods to limit the differences in the degrees of uncertainty between sites.

Sources of Uncertainty in the Risk Assessment Process

Before mitigation projects can be prioritized with any risk management methodology, analysts must conduct a risk assessment to characterize the risk and its uncertainty. There is uncertainty in all parts of the risk assessment process identified in Figure 1 in Chapter I. Analysts must attempt to quantify risks to reduce the amount of subjective characterization.

The following discussion is an analysis of the risk assessment process (hazard identification, exposure assessment, exposure-response characterization, and characterization of the risks) to develop an understanding of the sources of uncertainty and its significance in risk assessment.

Hazard Identification. Hazard identification determines if a detected substance has the potential to be cause cancer in a human population. Analysts evaluate pathways substances can enter the body and target organs susceptible to the toxicant. Carcinogens can cause mutations in cell DNA and are suspected of causing cell malfunctions eventually resulting in cancer (Masters, 1991:193-196).

The EPA executes the hazard identification step by classifying cancer-causing agents relying on the weight of carcinogenicity evidence in risk studies. The EPA has identified substances into five weight-of-evidence groups:

Group A - Carcinogen in humans (known human carcinogen). There is enough evidence in human studies to indicate the substance causes cancer in humans.

Group B - Probably carcinogenic in humans. There is either insufficient evidence in humans or sufficient evidence in animals that the substance causes cancer.

Group C - Possibly carcinogenic in humans. No evidence of carcinogenicity in humans and insufficient evidence in animals.

Group D - Not classifiable--no data.

Group E - Evidence of non-carcinogenicity in humans. (EPA, 1992:2.2-2.3)

There is uncertainty inherent in the classification of substances into these categories. Evidence of carcinogenicity decreases and uncertainty increases on the classification scale starting at group A and proceeding through groups B, C ad D. Even though a substance is classified in Group A (known carcinogen), there is still uncertainty whether the substance is a carcinogen. For example, an epidemiologic study may be biased and therefore contain uncertainty, because confounding factors such as smoking may not have been taken into consideration (Masters, 1991:199-200).

Of the hundreds of chemicals that may be detected at a site, some chemicals may fall into the Group C or D. These chemicals may contribute to increased risk of the site; however, they are not considered in risk assessment. Because the carcinogenicity of some chemicals is not known, the cancer risk may be underestimated in this situation.

For source/release assessment at a local site, the analyst estimates the amounts, frequencies, and locations of releases. Tools at the analyst's disposal to assess the release of a risk agent are monitoring, accident investigation and performance testing, statistical methods, and modeling. Because monitoring is limited to measures past and present releases, it can introduce significant uncertainty to projected future release estimates. In addition to timing, the accuracy of monitoring equipment can increase uncertainty. Accident and performance testing can introduce uncertainty, because it entails simulations and predictions of system performance such as safety equipment for a nuclear power plant. Statistical methods used to predict future occurrences introduce uncertainty, because future events are based on probabilities. Data input into models is characterized with uncertainty, resulting in output predictions also characterized with uncertainty. The uncertainty originates from errors in model assumptions as well as uncertainty in input data (Cohrssen and Covello, 1989:55-64).

Exposure Assessment. Exposure assessment consists of direct and indirect procedures to measure human exposure to risk agents.

Risk analysts use two direct exposure assessment methods--personal monitoring (eg. radiation detection badges) and ambient air monitoring (eg. toxic gas measuring devices in mines). Uncertainties can result in personal monitors when people forget to wear or tamper with the monitor. Ambient air monitoring errors occur because people characteristically will move in and out of the monitored area resulting in uncertainty in exposure levels. Other sources of error occur in poorly planned samples such as monitoring at times or locations not representative of the true situation (Cohrssen and Covello, 1989:67).

Indirect methods to estimate exposure consist of analogies and modeling. Analysts use these methods when direct measurements are not available. In using analogies, analysts compare hazardous substances with other similar chemical structures using structure-activity relationships (similar molecular structure and characteristics) to predict exposure pathways. Cohrssen and Covello characterize analogies with other risk agent predictions as introducing more uncertainty than direct measurements of environmental concentrations. Exposure models simulate the transport of hazardous risk agents to receptors. One factor influencing the accuracy of model outputs depends on the applicability of the model to the particular site. Another factor affecting accuracy is the uncertainty of the input data for the model. Uncertainty also occurs because transport models tend to over simplify complex environmental systems. Analysts typically use five types of models to simulate risk agent exposure: atmospheric models, surface-water models, groundwater/unsaturated-zone models, multimedia models, and food chain models (Cohrssen and Covello, 1989:66-73). Compared to inter-species extrapolation discussed in the next section, exposure assessment is associated with less uncertainty (Whipple, 1989:1114).

Dose-Response Characterization. In essence, this element of risk assessment establishes a linear relationship (slope factor) between the dose received by the exposed population and the carcinogenic effect. The determination of risk agent dose to a human population is a complex undertaking. There are two measures of dose. First, absorbed dose is the amount of risk agent absorbed into the body. The second measure, effective dose, is the amount of risk agent reaching the target organ experiencing the damage effect. Absorbed dose characterization applies several standard adjustment factors specific to age, sex, and other characteristics to environmental concentrations of risk agents (see Table 3). Total dose takes into consideration all factors shown in Table 4. There is variability and uncertainty originating in each factor of Table 4 (Cohrssen and Covello, 1989:75-79).

Table 3

Factors Used in Determining Dose

1.	Direct Ingestion Through Drinking -Amount of water consumed each day. -Fraction of contaminant absorbed through wall of gastrointestinal track. -Average human body weight.
2.	Inhalation of Contaminants -Air concentrations resulting from showering, bathing, or other uses of water. -Variation in air over time. -Amount of contaminated air breathed during those activities that may lead to volatilization. -Fraction of inhales contaminant absorbed through lungs. -Average human body weight.
3.	Skin Absorption from Water -Period of time spent washing and bathing. -Fraction of contaminant absorbed through the skin during washing and bathing. -Average human body weight.
4.	Ingestion of Contaminated Food -Concentrations of contaminant in edible portions of various plants and animals exposed to contaminated groundwater. -Amount of contaminated food ingestion each day. -Fraction of contaminant absorbed through wall of gastrointestinal tract. -Average human body weight.
5.	Skin Absorption for Contaminated Soil -Concentrations of contaminant in soil exposed to contaminated groundwater. -Amount of daily skin contact with soil. -Amount of soil ingested per day (by children). -Absorption rates. -Average human body weight.

(Cohrssen and Covello, 1989:77)

Analysts use extremely complex physiologically-based pharmacokinetic (PB-PK) models to simulate the transport and metabolism of risk agents to estimate effective dose. PB-PK models use vast amounts of data on body functions, such as

Table 4

Example of Data and Assumptions Necessary to Estimate Contaminant Dose to People

Item		Human Factors		
Mass of standard humans				
Man		70 kg		
Woman		60 kg		
Child		20 kg		
Skin surface area				
Totally exposed (man 180 cm tall)		1.8 m^2		
Clothed with short-sleeved shirt, pants, shoes		0.8 m^2		
Clothed with long-sleeved shirt, pants, shoes, gloves		0.1 m^2		
Respiration		Man	Woman	Child
Resting rate (l/min)		7.5	6	4.8
Light activity rate (l/min)		20	19	13
Volume of air breathed (m^3/day)		23	21	15
Food Consumption (all humans)		1,500 gm/day		
Factors Used in extrapolation				
Weight	rat	0.35 kg		
	mouse	0.03 kg		
Food consumption	rat	17.5 gm/day		
	mouse	3.9 gm/day		

(Cohrssen and Covello; 1989:78)

"partitioning of risk agents into specific tissues and fluids, rates of decay and metabolism, and biochemical interactions between risk agents and tissues" (Cohrssen and Covello, 1989:78). Much of this information originates from animal experiments. Difficulties arise in attempts to characterize human absorbed dose using extrapolations from test animals where biological differences are not well understood. Cohrssen and Covello maintain that PB-PK models overcomes much of the difficulties where, "the typical risk assessment equates effective dose with absorbed dose (or even environmental concentrations)." (Covello, 1989:79)

There are two significant problems in the dose-response characterization step that introduce much of the uncertainty in risk assessment process. One of the greatest problems with using bioassay experiments (animal tests) is their insensitivity to detect increases in cancer risk. Bioassay experiments induce extremely high doses to a minimum of 600 rodents; however, these experiments can detect cancer risks increases of only five in one hundred (Masters, 1991:199). A quotation of Environmental Magazine by Master states, "Bioassays designed to detect lower risks require many thousands of animals and, in fact, the largest experiment ever performed involved over 24,000 mice and yet it was still insufficiently sensitive to measure less than a one percent increase in tumor incidence" (Masters, 1991:199). Experimental procedures can detect cancer risk increases as small as only one in one hundred, but protection of human health has been considered warranted in the range of one in ten thousand to one in ten million (Crump, 1985:281). Whipple characterizes the application of animal bioassays to predict human risk as "a major source of uncertainty in risk assessment for toxic substances" (Whipple, 1989:1114). An illustration of the difficulty to infer carcinogenicity across species concerns 1,1,2-Trichloroethane. According to the Integrated Risk Information System (IRIS) (Jan 93), bioassays demonstrate this chemical causes carcinomas in one strain of mice, but carcinogenicity has not been shown in rats, a closely related species. However, the evidence in mice forms the basis of a "C" classification (possible human carcinogen) in a distantly related species--man (Whipple,1989:1114).

Risk analysts use extrapolation models to predict cancer risk at low doses from the high doses administered to animals in experiments as described in the previous paragraph (EPA, 1992:2.13). These extrapolation models attempt to conservatively predict (overestimate rather than under estimate) risk in this small area of interest. Figure 6 illustrates that much of the uncertainty of risk originates in the extrapolation process in the area of interest (Masters, 1991:203). In this area of interest, there are no data points, so extrapolation models try to predict the behavior of the dose-response at low doses. Extrapolation model outputs (slope factors) are useful to test the sensitivity of varying exposure scenarios.

Risk analysts choose the appropriate extrapolation based on their hypothesis of the biological mechanism in which cancer develops. Cohrssen and Covello identify three types of models based on three different theories of cancer formation: mechanistic models, threshold distribution models, and time-to-tumor models (Cohrssen and Covello, 1989:81).

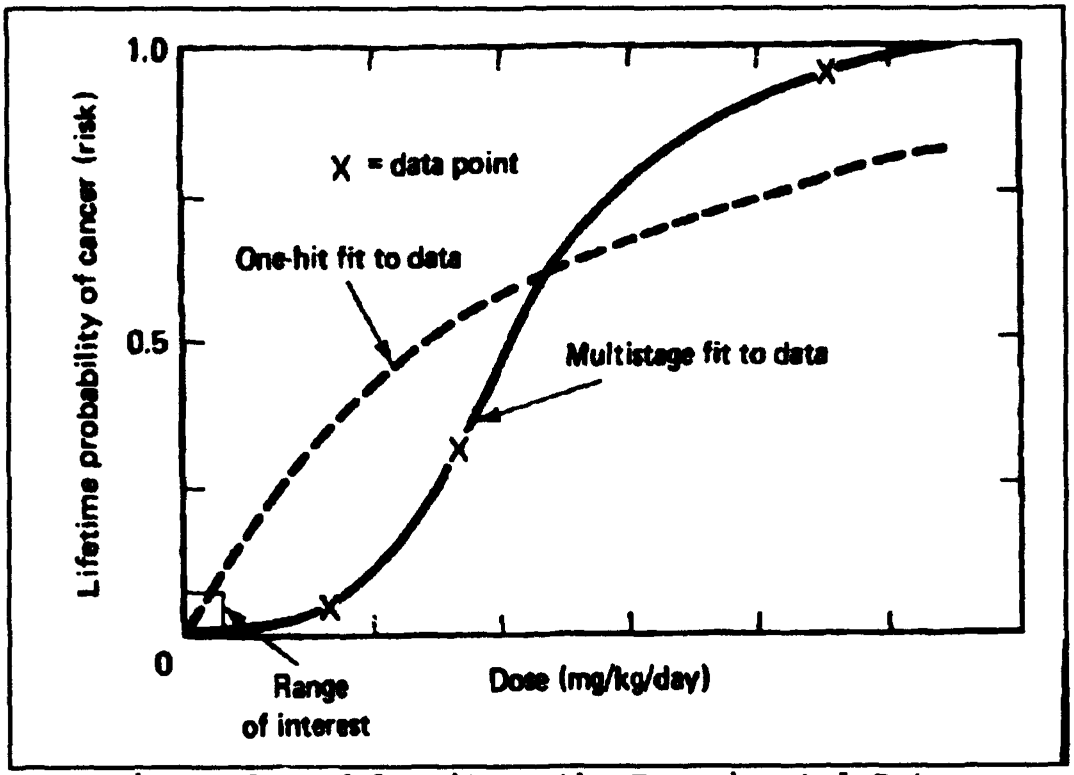

Figure 6. Models Fit to the Experimental Data (Title Added) (Masters, 1991:204)

<u>Mechanistic Models</u>. Mechanistic models are based on the theory that there are certain biological steps in the development of cancer. Two models, one-hit and multi-hit, are based on the belief that there are a certain number of *hits* (attacks from a risk agent) to a cell to transform it into a cancerous cell. The multistage model, which is the most commonly used model by the EPA, assumes a progression of steps are part of the formation of cancer tumors (Cohrssen and Covello, 1989:81).

Threshold Distribution Models. In contrast to the mechanistic models, threshold distribution models are based on the theory that people have differing resistances to risk agents. This resistance provides people with the ability to ward off cancer. These resistance characteristics are distributed in the population as a probability distribution. The models characterizing these distributions are the probit, logit and Weibull extrapolation models (Cohrssen and Covello, 1989:81).

Time-to-Tumor Models. In contrast to the previously mentioned models, these try to incorporate an added ingredient into dose-response relationship--tumor latency or time. Exposure to risk agents usually does not cause cancer immediately; Cancer development has sometimes long latency periods. Analysts try to characterize this factor with time-to tumor models (Cohrssen and Covello, 1989:81).

According to Cohrssen and Covello, there is no scientific basis to determine which dose-response model is the most accurate (1989:81). The EPA, in recent years, is now favoring the linearized multistage model, a modification of the mechanistic multistage model (Masters, 1991:203-204). This model will now be discussed more in detail.

Multistage model. The multistage model shown as Equation 2 portrays the relationship between dose (d) and lifetime risk P(d) as (Masters, 1991:203)

$$P(d)=1-\exp[-(q_0+q_1d+q_2d^2+...q_nd^n)] \qquad (2)$$

where q_i = the i^{th} positive constant with selected to best fit the dose-response data

d^i = the i^{th} polynomial exponential selected to fit the curve to data

n = exponent values of i^{th} polynomial selected to fit the data

Figure 6 demonstrates the fit of the multistage model compared to the one-hit model. The multistage model will always fit the experimental data, but the EPA prefers to err on the side of conservatism and overestimate the risk of cancer. Therefore the EPA uses a modified multistage model, called the linear multistage model, to determine its guidelines. This linear multistage model allows only a five percent statistical chance of underestimating risk (Masters, 1991:203-205).

Characterization of Risk. This final step of risk assessment ties the risk assessment steps together into a characterization of risk (Masters, 1991:215). The risk characterization step contains two parts: calculation of the risks, and a characterization of the uncertainty and assumptions originating in the risk assessment (Cohrssen and Covello, 1989:84-85; EPA, 1992:2.21).

Three risks are usually characterized: individual lifetime risk (excess cancer risk due to the risk agent), population risk (annual number of cancers resulting from one year of exposure), and relative risk (risk of exposed population compared to risk of unexposed population) (Cohrssen and Covello, 1989:85).

To characterize the effects of uncertainty on risk, risk analysts apply sensitivity analysis. During sensitivity analysis, factors that affect the risk estimate are varied to test the effect they have on risk. Varying these factors simulates the uncertainty characterized in the risk estimate (Cohrssen and Covello, 1989:91). Sensitivity analysis can also test for the model's vulnerability to uncertainty in its input variables.

The risk characterizations are used by many groups of people. At the regulatory level, decision-makers weigh risk characterizations with other costs and benefits to society in some form of cost-benefit analysis when enacting legislation. At the risk management level of mitigation project prioritization, risk managers use the risk characterizations as well as legislative requirements to prioritize mitigation projects. The public uses risk characterizations to determine the suitability of proposed risk management actions. All concerned parties need to understand the "extraordinary leaps of faith" risk analysts have to make to derive a risk estimate (Masters, 1991:215).

Propagation of the Uncertainties. As this chapter has demonstrated, there is uncertainty throughout the risk assessment process and especially significant is the uncertainty inherent in the slope factor due to the insensitivity of bioassays and dose-response extrapolation in the dose-response step. An uncertainty originating in the source/release step will carry through from later calculated exposure assessment step, and later affect the dose estimate, and finally the risk estimate. Uncertainty is cumulative in nature and rapidly raises the uncertainty of the input product for risk management--the risk estimate to the particular population (Cohrssen and Covello, 1989:94). For example, equations to calculate the chronic daily intake (CDI) and risk are equations consisting of multiplication operations. Equations for the CDI and risk may be found in step 1, task 5 of the CEM procedures outlined in Chapter III. The generic equations for the CDI and risk are:

CDI = (C x CR x EFD)/(BW x AT)

Risk = CDI x SF

Where CDI = chemical concentration (e.g. mg/liter water)

CR = contact rate; amount of contaminated medium contacter per unit time or event (e.g. liters/day)

EFD = exposure frequency and duration (days)

BW = body weight (kg)

AT = averaging time (days)

SF = slope factor e.g. units (mg/kg/day)$^{-1}$

The variance or uncertainty of the product of two independent variables is characterized by Equation (2):

$$\sigma_z^2 = (\sigma_x^2 * \sigma_y^2) + (\sigma_x^2 * \mu_y^2) + (\sigma_y^2 * \mu_x^2) \qquad (2)$$

where: z = x * y (product random variable)

x = a random independent variable

y = a random independent variable

σ^2 = variance of the subscript random variable(s)

μ = mean of the subscript random variable

Analysis of Equation (2) illustrates that the behavior of the variances in the product of two random variables grows much faster than the product of the variances. Applying Equation 2 to the equation for risk, the magnitude of uncertainty would be characterized by the following:

$$\sigma_z = \sigma_{CDI} * \sigma^2_{SF} + \sigma^2_{CDI} * \mu^2_{SF} + \sigma^2_{SF} * \mu^2_{CDI}$$

Where z = cancer risk = CDI * SF

CDI = chronic daily intake

SF = cancer slope factor

The process of adding risks characterized by uncertainty across exposure pathways factors becomes an expression characterized as a linear combination of expected risk values. For linear combinations, as independent random variables are added together, the variance of the sum will in effect increase by the sum of the random variable's variances (Devore, 1991:213-214). Therefore, as the pathway risks are added together, the uncertainty of each pathway risk will add to get the uncertainty of the total risk calculated. The end result is that uncertainty of the total risk is much greater than any one of the pathway risks.

Though uncertainties still exist, there comes a point where the studying must stop and the clean-up start. Risk managers must not lose their focus, which is to clean up the environment. Analysts cannot feasibly spend the time and money to study contaminated sites until they completely understand all there is to know about it. Compromises on data quality are sacrificed so risk management actions can proceed (USAF, 1992:5.39). These compromises, in addition to all other sources of uncertainty, create major difficulties in risk characterization to reduce the variance to the point that a risk estimate is useful to the decision maker. Reduction of variance is done by reasonably omitting sources of uncertainty from the calculations (Cohrssen and Covello, 1989:94).

Requirement of Methodological Consistency. To facilitate the comparability of risks and mitigation costs between mitigation projects, Covello et al. list eight guidelines to follow in risk assessment. The goal is to normalize the treatment of mitigation alternatives and risk to eliminate methodological bias. These are paraphrased, excluding most references to benefits, as the following:

1. Similar operating design modes (e.g., expected vs. ideal contamination movements and cleanup rates)

considered of competing alternatives should be used (Lawless and others, 1986:169).

2. Similar technology time frames should be used to normalize the costs of mitigation projects (Lawless and others, 1986:169). The exception would be those sites that are closed out early because they were rendered harmless due to the mitigation.

3. Compare alternatives through the same project life-cycle phase so all alternatives will compete on an equal basis (Lawless and others, 1986:169). Generally, alternatives should be compared through completion of mitigation of contaminants to non-harmful levels or closeout of the project. Some comparable alternative may need to be decided for mitigation project operations with near unlimited cleanup times.

4. Risks, and costs of each alternative option should be analyzed through the same impact levels--primary, secondary, tertiary (Lawless and others, 1986:169). Primary costs result directly from the mitigation project alternative. Secondary costs are "multiplier and investment effects" that dollar values can be placed upon such as increased or decreased economic growth. Tertiary costs are real costs, dollar values cannot be assessed such as public sentiment or aesthetic view (Aldrich, 1993:60).

5. Similar discount rates should be applied to future risks and costs for each option (Lawless and others, 1986:169). When working with the time value of money, equal interest and inflation rates must be used to ensure comparability of mitigation projects.

6. Multidimensional, rather than single-facet, measures should be used to compare the benefits, risks, and costs of each option; e.g., consider all health effects, not just mortality (Lawless and others, 1986:169). CEM will consider analytically mortality and cost; whereas, it will consider chronic health effects and benefits subjectively.

7. Equivalent tests of uncertainty should be applied in evaluating the estimates of alternative risks and costs (Lawless and others, 1986:169). To normalize the data for comparative risk purposes, use standardized or adjusted standardized

variables to ensure pre-mitigation and post-mitigation risks are relatively representative of the true risks. Every attempt must be made to remove methodological bias.

8. Simplifying assumptions that exclude from the analysis important differences among competing alternatives should be avoided, e.g., different citizen risk perceptions (Lawless and others, 1986:169). Over simplification of the circumstances surrounding a site could introduce bias into the risk assessment process.

Following the above guidance removes significant bias under the control of the risk analyst and moves a risk analysis closer to reaching two goals--methodological consistency and comparability of risks. If the risks are not comparable and normalized, then significant bias can be introduced into the risk assessment procedures.

Risk Management Process

The risk management process uses the information obtained in the risk assessment process in conjunction with information of a technical, social, economic, and political nature to evaluate mitigation actions, if any. Design and implementation strategies/policies also take form in this process (Cohrssen and Covello, 1989:8).

Risk Characterization. As shown in Figure 2 in Chapter I, the risk management process consists of four steps. The first, risk characterization, overlaps with risk assessment and was discussed in the previous section.

Control Options. The second step of risk management is determine the control options available for the decision maker. In the mitigation of contaminated sites, this step is called the Feasibility Study (FS). The FS evaluates the feasibility of all alternatives using the following nine criteria:

- -Overall protection of human health and environment
- -Compliance with ARARs (Applicable or Relevant and Appropriate Requirements)
- -Long-term effectiveness and permanence
- -Reduction of toxicity, mobility or volume
- -Short-term effectiveness
- -Implementability
- -Cost
- -State acceptance
- -Community acceptance

(NCP, 40 CFR 300.430(e)(9)(A-I)

Non-Risk Analysis and Regulatory Decision. Decision makers in the services do not want a rigid model which will tie their hands on a decision; "they want to retain ultimate flexibility in allocating resources". (Read, 1993) To give decision makers flexibility, a model must allow the decision maker to consider subjective factors that can not be evaluated in a model.

In the CEM, once the risks have been characterized and control options assessed concerning feasibility and cost, decision makers consider subjective factors such as public concerns and available funds to decide mitigation actions.

Conclusion

This background chapter discussed the information needed to understand the development and application of the cost-effectiveness methodology. First, this chapter supported the CEM as the methodology of choice for ranking mitigation projects in risk management and then compared CEM to other regulatory decision frameworks as well as mitigation project ranking methodologies using the two evaluation criteria. Next, this chapter characterized the uncertainty inherit in the risk assessment process to develop an understanding of the sources of uncertainty and its significance in risk assessment. Once the origins of uncertainty were addressed, this chapter discussed risk management steps and the associated considerations with each step.

III. Methodology

Overview

This chapter provides guidelines to apply the cost effectiveness methodology (CEM) for ranking mitigation projects at any administrative level of risk management. The CEM ranks mitigation projects on the basis of highest risk reduction per dollar spent. In this chapter, methodology will be provided to rank sites with both chemical and radiation carcinogens. First, this chapter outlines the procedures of the CEM. Second, guidance is provided to oversee contractor risk-assessment actions. Because most risk assessment steps are always contracted out in the PA/SI and the RI/FS, guidance will not detail contractor responsibilities. Finally, guidance is provided on the application of the CEM. The RI/FS or related document becomes a source of incremental risk data. The CEM guidance develops tasks to evaluate feasible control options. This step deviates from the current method in which the FS evaluates the alternatives, so detailed steps will be discussed. Because other factors may influence the desired mitigation alternative, guidance is provided to evaluate non-risk subjective factors specific to the site. In the final step of the CEM, all required information is provided to decision makers for the ranking of mitigation projects. The two major advantages of following this methodology are the wide applicability of the model and the prioritization of mitigation projects that saves the most lives per mitigation dollar.

Cost-Effectiveness Methodology Development

The following discussion expands each procedure of the cost-effectiveness methodology in detail and suggests possible sources of needed information.

Figure 2 diagrams the broad steps of the risk assessment and risk management process; this diagram will be followed to develop the CEM for this research. The CEM was derived after reviewing the available literature on risk analysis and risk management subjects. Generally, contractors accomplish the entire risk assessment and evaluate the control options. These areas will be touched upon to alert the risk analyst of key steps and tasks in these processes. The statement of work (SOW) describing requirements of the contractors should be modified to facilitate the CEM process. This methodology will suggest these suggested modifications in the guidance. The CEM begins after the contractors complete the risk assessment and evaluate all feasible mitigation alternatives. Because current contractor output formats do not facilitate integration of data into the CEM, some tasks will be added to transform the data. The CEM model consists of four

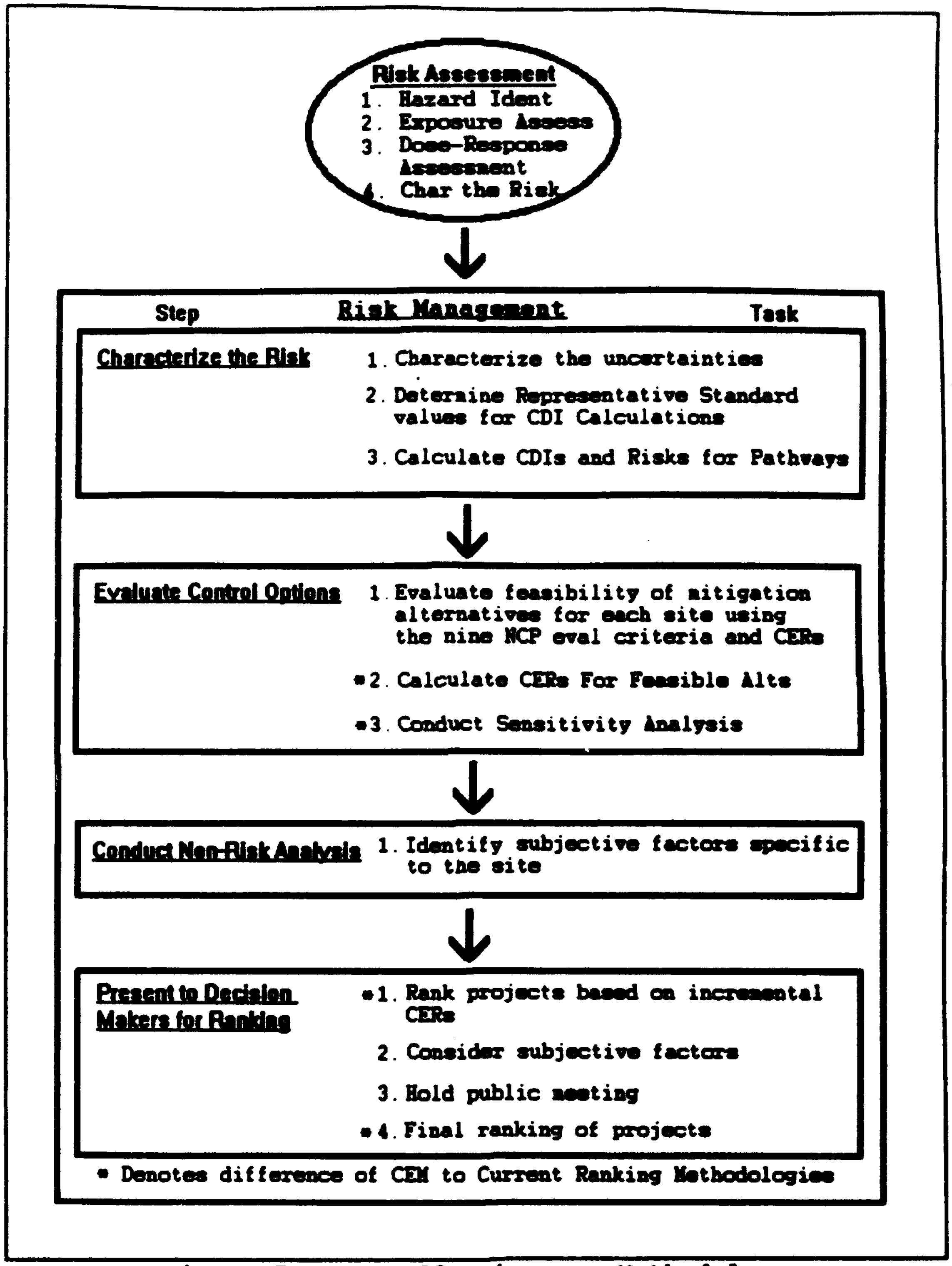

Figure 7 Cost-Effectiveness Methodology

primary steps with subcategory tasks within each step as shown in Figure 7.

Risk Assessment Process

The contractor generally has the responsibility to accomplish the majority of the risk assessment process. The remedial project manager's (RPM) responsibilities usually cover discovery of the environmental site, notification to the EPA, and supervision of the contractor's risk assessment.

From the time the contractor begins the risk assessment, the RPM must ensure the contractors follow procedures that enhance methodological consistency, comparability of risks of various types of sites, and the applicability of CEM across varied classes of environmental hazards. Without this important step, the CERs would be meaningless for prioritization purposes. All eight guidelines as suggested by Lawless et al. apply to CEM. These guidelines are listed at the end of Chapter II.

Step 1: Hazard Identification. The first step of the risk assessment, that the contractor is responsible for, is the hazard identification step.

Task 1: Identify significant Chemicals. When comparing environmental risks between hazardous sites, one must identify suspect toxic agents of concern for each site to properly determine exposure routes and exposure concentrations. Most of the time, the contractor will identify the existence of potentially hazardous chemicals or radiation sites through any of the following sources:

- Interviews with employed or retired personnel
- Historical records searches of past waste generation and site management practices
- Historical aerial photographs
- Inspection of potential sites
- Environmental Compliance Assessment and Management Program (ECAMP) audit results
- Base historian
- USDA soil surveys
- USDI Geological Survey map quadrangles
- USEPA Region Freedom of Information Officer, RCRA and CERCLIS Facilities list
- FEMA National Flood Insurance rate maps
- National Priorities List
- State leaking petroleum storage tank corrective action list
- Chemical Information Service CERCLIS database
- Interviews with adjacent private property owners
- Water well records
- Any previous sampling results
- Regulatory agency files on pervious base inspections, telephone contacts, etc.
- Community property transition and zoning records

(USAF, 1992:5.21-5.22)

Step 2: Exposure Assessment. In this step, the contractor must establish pathway exposure concentrations; this step is accomplished in conjunction with step 3 as illustrated in Figure 2 of Chapter 1. There are three primary exposure routes (ingestion, inhalation and dermal) resulting in the following potential pathways: ingestion of drinking water, ingestion of soil, ingestion of sediment, ingestion of fruits, ingestion of vegetables, inhalation of vapors while showering, inhalation of indoor air, inhalation of ambient air, dermal exposure to soil, dermal exposure to sediment, dermal exposure to water while showering, dermal exposure to surface water, and dermal exposure to leachate seep water (Engineering-Science, Inc., 1992:6.3.3-6.3.4).

Determining exposure routes is a difficult task containing a significant element of uncertainty. As discussed in Chapter II, there are two primary methods to quantify exposure durations and determine exposure dose: monitoring and modeling. Either method is acceptable; however, according to Cohrssen and Covello, monitoring provides more accurate data than modeling and often serves as a benchmark for exposure models (1989:67). Uncertainty is therefore decreased using monitoring over modeling.

Step 3: Dose-Response Assessment. Step 3 consists of the contractor actions to determine the carcinogenicity of the suspected risk agents. Once the chemicals of interest have been identified, the contractor will establish each suspect hazard agent's slope factor by reviewing either the IRIS or HEAST database. In the mitigation process, the actual dose-response assessment is accomplished as basic research to determine slope factors of risk agents that are useful to establish risk of contaminated sites. This process is discussed in detail in Chapter II.

Step 4: Risk Characterization. When overseeing the contractor in this step, it is critical that the contractor follow procedures that will enhance methodological consistency and comparability of risks, and this step consists of the following tasks described below.

__Task 1: Determine Representative Standard Values for CDI Calculations__. Table 5 contains some of the EPA recommended values for calculations of Chronic Daily Intake.

Table 5

EPA Recommended Standard Values For CDI Calculations

Parameter	**Standard Value**
Average body weight, adult	70 kg
Average body weight, child	10 kg
Amount of water ingested daily, adult	2 liters
Amount of water ingested daily, child	1 liter
Amount of air breathed daily, adult	20 m^3
Amount of air breathed daily, child	5 m^3
Amount of fish consumed daily, adult	6.5 g
If lifetime exposure, use	70 years

(Masters, 1991:206)

These standard values are used by the contractor to determine the dose received from environmental contaminant concentrations. See task 2 of the contractor's third step for Equations 3 through 10 that use these inputs. Standard exposure values are located in the __Exposure Factors Handbook__, and more detailed procedures to determine exposures are located in the __Superfund Public Health Evaluation Manual__, both published by the EPA. Although these values are standardized by the EPA, they may need to be tailored if different conditions exist to meet the circumstances of a particular site. This is one of the tasks where normalization of the methodology is critical.

For example, the average American spends 75% of his/her life in the home. If a population exposed to a contaminant located in the home spends a different amount of time in the home, the 75% figure can be adjusted. Normalizing the factors helps make the risks comparable by reducing bias.

Task 2: Calculate CDIs and Risks for Pathways. Before risks can be calculated for chemicals only, the contractor calculates the lifetime average daily dose, otherwise known as chronic daily dose (CDI), for each chemical. CDI values for chemicals are estimated using the formulae listed below (Source from RAGS, Date: 6.21, 6.35-6.48):

A generic equation for calculating chronic daily intakes

$$Intake = \frac{(C \times CR \times EFD)}{(BW \times AT)} \quad (3)$$

Residential exposure (ingestion of chemicals in drinking water)

$$Intake\ (mg/kg\text{-}day) = \frac{(CW \times IR \times EF \times ED)}{(BW \times AT)} \quad (4)$$

Residential exposure (ingestion of chemicals in surface while swimming)

$$Intake\ (mg/kg\text{-}day) = \frac{(CW \times CR \times ET \times EF \times ED)}{(BW \times AT)} \quad (5)$$

Residential exposure (dermal contact with chemicals in water)

$$Abs\ Dose\ (mg/kg\text{-}day) = \frac{(CW \times SA \times PC \times ET \times EF \times ED \times CF)}{(BW \times AT)} \quad (6)$$

Residential exposure (ingestion of chemicals in soil)

$$Intake\ (mg/kg\text{-}day) = \frac{(CS \times IR \times CF \times FI \times Ef \times ED)}{(BW \times AT)} \quad (7)$$

Residential exposure (dermal contact with chemicals in soil)

$$Abs\ Dose\ (mg/kg\text{-}day) = \frac{(CS \times CF \times SA \times AF \times ABS \times EF \times ED)}{(BW \times AT)} \quad (8)$$

Residential exposure (inhalation of airborne vapor phase chemicals)

$$Intake\ (mg/kg\text{-}day) = \frac{(CA \times IR \times ET \times EF \times ED)}{(BW \times AT)} \quad (9)$$

Residential exposure (food pathway ingestion of contaminated fish and shellfish; ingestion of contaminated fruits and vegetables; ingestion of contaminated meat, eggs and dairy products)

$$Intake\ (mg/kg\text{-}day) = \frac{(CF \times IR \times FI \times EF \times ED)}{(BW \times AT)} \quad (10)$$

(EPA, 1989:6.21,6.35-6.48)

where Intake = Absorbed Dose = CDI

C = chemical concentration; the average concentration contacted over the exposure period (e.g. mg/liter water)

CR = contact rate; the amount of contaminated medium contacted per unit time or event (e.g. liters/day)

EFD = exposure frequency and duration; describes how long and how often exposure occurs. Often calculated using two terms (EF and ED)

EF = exposure frequency (days/year for ingestion, inhalation or events/year for dermal contact or meals/year for fish or meals/year for food)

ED = exposure duration (years) (Table 5)

BW = body weight (kg) (Table 5)

AT = averaging time; period over which exposure is averaged (70 years x 365 days/year) (days) (Table 5)

CW = chemical concentration in water (mg/liter)

IR = ingestion rate (liters/day for drinking water or mg soil/day for soil or kg/meal for fish or kg/meal for food) (Table 5)

ET = exposure time (hours/event for swimming or hours/day for dermal contact or hours/day for inhalation)

SA = skin surface area available for contact (cm^2)

PC = chemical-specific dermal permeability constant (cm/hr)

CF = volumetric conversion factor for water (1 liter/1000 cm^3) for dermal contact with water or 10^{-6} mg/kg for contaminant concentration in food or 10^{-6} kg/mg for ingestion of soil or 10^{-6} kg/mg for dermal contact with soil or 10^{-6} for ingestion of fisk

CS = chemical concentration in soil (mg/kg)

FI = Fraction ingested from contaminated source (unitless)

AF = soil to skin adherence factor (mg/cm^2)

ABS = absorption factor (unitless)

CA = contaminant concentration in air (mg/m^3)

IR = inhalation rate (m^3/hour)

CF = contaminant concentration in fish or food (mg/kg)

(source = RAGS, date:6.21,6.35-6.48)

Once the chronic daily intakes for each chemical have been determined, cancer risk estimates may be calculated using the following equation (Masters, 1991:206):

$$R = CDI \times SF \qquad (11)$$

where R = Cancer risk over a 70 year lifetime period

CDI = Chronic Daily Intake (mg/kg/day for chemicals)

SF = Cancer Slope Factor $(mg/kg/day)^{-1}$

To calculate the cancer risk from exposure to radionuclide, the following equations are applied:

For inhalation of radionuclides (including radon) in air:

$$R = SF \times CA \times IR \times ET \times EF \times ED \qquad (12)$$

For ingestion of radionuclides in water:

$$R = SF \times CW \times IR \times EF \times ED \qquad (13)$$

For ingestion of radionuclides in soil:

$$R = SF \times CS \times IR \times FI \times EF \times ED \qquad (14)$$

For external exposure to radiation in the soil:

$$R = SF \times CS \times SD \times ED \times ED \quad (15)$$

(EPA, 1991:C.1-C.7)

(Note: Equations were modified to standardize with other equations in this research.)

where R = lifetime risk

SF = slope factor [risk each day per pCi/m^3 (air inhaled) or risk each day per pCi/m^3 (water ingested) or risk each day per pCi/g (soil ingested) or risk each year per pCi/m^2 (external exposure to soil)]

CA = concentration (in pCi/m^3) in air

CW = concentration (in pCi/L) in water

CS = concentration (in pCi/g) in soil

ET = exposure time (hours/day)

IR = inhalation rate (m^3/hour)

EF = exposure frequency (days/year for ingestion, inhalation or events/year for dermal contact or meals/year for fish or meals/year for food)

ED = exposure duration (years)

SD = effective surface density of the soil [depth (m) x soil density (kg/m^3) = (kg/m^2)]

The most common equation to calculate risk from exposure to indoor radon is an adjusted form of the Biological Effects of Ionizing Radiation (BEIR IV) model to estimate lung cancer risk caused by radon. This model is a relative risk model that proportions the risk from radon found in homes with the risk observed in four major cohort studies of underground miners. The practical application of the equation requires a computer program and the use of several binders of the 1980 U.S. age-specific mortality rates. Application of the BEIR IV model is too cumbersome for the scope of this research; therefore, the radionuclide cancer risk equations previously mentioned will be applied to calculate risk from radon. Estimates of cancer risk from the radionuclide cancer risk equations are well within the estimated uncertainty range of the BEIR IV model.

After the determination of pre-mitigated risks, post-mitigated risks are calculated. The best method to predict post-mitigation contaminant levels is to model the changed conditions. Many times, an RI/FS will not include estimates of post-mitigation contaminant levels. The risk analyst may have to predict these contaminant levels using effectiveness estimates of each mitigation alternative. These estimates are used to calculate the reduction of risk as a result of mitigation to determine the value of the numerator of the CER for each alternative. For very large ground or water medias, the contractor will compare the expected concentration after mitigation with the background contamination levels. If the background contamination levels are higher than the calculated reduction, the contractor will should adopt this concentration as the post-mitigation contaminant concentration. An illustration demonstrates this point. Taking salt out of sea water and releasing fresh water into the sea does not decrease the saltiness of the ocean. Unless the contamination is confined to a very small contained area (eg. a building), it is impossible to clean up the ground or water beyond the background contamination level.

Once the risk for each chemical corresponding to each pathway, the contractor adds pathway risk to determine the total risk to a population, first for the pre-mitigation risk, then for the post-mitigation risk. Martin Marietta Energy Systems, Inc., maintains that adding risks across pathways is valid if the following assumptions can be made:

- Doses are low;
- No synergistic/antagonistic interactions occur;and
- Similar endpoints are evaluated. (1992:6.5-2)

Summing the risk across the pathways results in the estimated total individual lifetime risk. After the contractor sums the pathway risks for both pre-mitigation and post-mitigation risks, the contractor subtracts the post-mitigation risk from the pre-mitigation risk to estimate the incremental individual lifetime risk reduced attributable to the hazardous environmental site remediation. To estimate the number of people in the population that may develop cancer from a site, the contractor will multiply the incremental individual risk with the population size. The result predicts the number of lives saved as a result of mitigation.

Task 3: Characterize the Uncertainties. For this task the contractor subjectively characterizes the sources of uncertainty and the relative size of the uncertainties if possible. This is no change to the current RI/FS process.

Risk Management Process

Although the risk management process of CEM contains many of the same tasks characterized by current hazardous waste prioritization methodologies, there are some key differences in the CEM. The tasks containing these differences are highlighted with asterisks in Figure 7 located near the beginning of the chapter. In addition, the following discussion will provide detail of those processes unique to the CEM and provide general guidelines to those processes similar to current risk management processes.

Step 1: Risk Characterization. This step overlaps with the risk characterization step discussed in the risk assessment process methodology. Here, the RPM should review the drafts of the risk assessment to ensure it meets the requirements listed in the contract statement of work.

Step 2: Evaluate Control Options. This step contains three tasks to evaluate the alternatives and is usually accomplished by a contractor in a study such as the feasibility study of the CERCLA process. Those tasks unique to the CEM should be added to the RI/FS statement of work (SOW).

Task 1: Evaluate Feasibility of Mitigation Alternatives for Each Site Using the Nine Evaluation Criteria listed in the National Contingency Plan. Once risks have been characterized, the contractor evaluates all possible mitigation actions for each hazardous site to determine the feasibility of the alternative to the site's location and CERs. The National Contingency Plan (NCP) establishes the following nine criteria to evaluate mitigation alternatives:

- Overall protection of human health and environment
- Compliance with ARARs (Applicable or Relevant and Appropriate Requirements)
- Long-term effectiveness and permanence
- Reduction of toxicity, mobility or volume
- Short-term effectiveness
- Implementability
- Cost
- State acceptance
- Community acceptance

(Ref to NCP, 40 CFR 300.430(e)(9)(A-I)

Many EPA publications are excellent sources to determine the effectiveness of many mitigation techniques.

Task 2: Calculate the CERs For All Feasible Mitigation Alternatives For All Environmental Sites. Once incremental risk reductions and incremental costs of mitigation have been determined, the calculation of incremental CERs is somewhat straight forward. This task should be written into the RI/FS SOW so CERs can be calculated during the feasibility analysis. Because contractors do not currently determine CERs in risk assessments, this report will include detailed CER calculations for illustrative purposes. CER calculations are eased with the use of a spreadsheet. Table 6 demonstrates a simple spreadsheet application to determine the risk of drinking water contaminated with arsenic.

If appropriate for accuracy required, the analyst may simplify calculations by identifying the hazardous agents which pose the a majority of the risk. Given the levels of magnitude inherit in most risk estimates, this simplification is a legitimate procedure and can streamline calculations when many sites are being ranked.

To begin CEM calculations, the risk analyst constructs a spreadsheet table such as the one in Table 6. Then the analyst orders all feasible mitigation alternatives from least expensive to most expensive. To determine the expected number of incremental lives saved between mitigation alternatives, the analyst takes the product of the incremental risks between site cleanup alternatives and the number of people exposed to the risk agents. The incremental cost is the difference in mitigation cost to implement the next higher-cost feasible alternative. Finally, the CER is the incremental estimated number of lives saved divided by the incremental cost to implement the next more-expensive mitigation alternative.

Table 6

Demonstration Table of Risk Calculations for

Ingestion of Arsenic in Drinking Water

Chemical	Conc of Water (mg/l)	Ingestion Rate (l/day)	Events Per Year (day/yr)	Exposure Duration (yrs)
Arsenic	.02	2	350	70
Body Wt (kg)	Averaging Time (days)	Chronic Daily Intake (mg/kg-day)	Slope Factor (1/mg/kg-day)	Cancer Risk
70 kg	25,550	5.48×10^{-4}	1.75	9.6×10^{-4}
where: CDI = CW x IR x FI x EF x ED/(BW x AT) Risk = CDI x SF				

The risk analyst plots all CERs as illustrated in Figure 8. The independent variable is the cost of the alternative, and the dependent variable is the CER. After all CERs have been plotted, it will be obvious which alternatives and mitigation projects provide the largest CER. The highest data points on the plot represent alternatives with the largest CERs. In step 4, the decision maker will use Table 7 and Figure 8 to rank the mitigation project alternatives between sites.

Table 7

Example Spreadsheet Application to Calculate CERs

Env Site	Alts	Post-Mit Risk	Incre. Est. Lives Saved*	Mitigat. Cost	Incre. Cost	CER
Landfill	Do Nothing	$1.0x10^{-3}$	0	0	0	0
"	Cap	$5.0x10^{-4}$	5	10,000	10,000	$5.0x10^{-4}$
"	Cap & Air Strip	$4.0x10^{-4}$	1	100,000	90,000	$1.1x10^{-5}$
"	Cap; Air Strip Act Char	$3.9x10^{-4}$	.1	130,000	40,000	$2.5x10^{-6}$

*Assume an exposed population of 10,000 people.

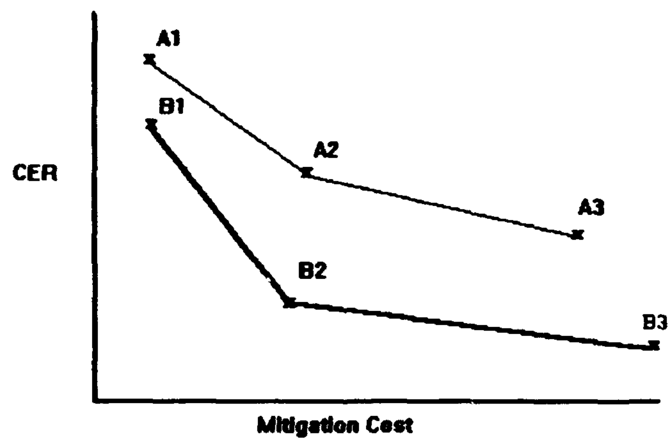

Figure 8. CERs of Cleanup Alternatives

<u>Task 3: Conduct Sensitivity Analysis</u>. To complete this task, the contractor establishes the sensitivity of the

final risk estimate to variations of the input variables. This will demonstrate where the model is most vulnerable to uncertainty.

Before the risk analyst can begin sensitivity analysis, the analyst must determine viable ranges of the input variables of the risk estimates as well as the mitigation cost estimates. If a computer spreadsheet software is used to calculate the CERs, the analyst should enter wild card dummy variables to serve to vary the input variables. The variables subject to the most uncertainty are the slope factors and exposure concentrations. The analyst can test the sensitivity of site CERs to uncertainty of the input variables. Sensitivity analysis can give insight into potential range of the CERs.

Step 3: Conduct Non-Risk Analysis. This step consists of one task.

Task 1: Evaluate subjective factors specific to the site. In this task, the risk analyst compiles all significant subjective information which might have an impact on the site or should be considered in the ranking decision. Exposed population size is not a subjective factor, because it is already inherently considered in the use of expected deaths instead of lifetime risk metric. A non-exhaustive list of some factors to consider are the following:

- Close proximity of site to sensitive human populations.

- Proactive potential to spend little money now to prevent the increased expenditure of funds later.
- Location of site near endangered or threatened species.
- Close proximity of site to water supplies.
- Future potential for risk to increase.

Step 4: Present to Decision Makers for Ranking. Information should be generalized for the decision maker who will allocate mitigation moneys to risk mitigation projects in this step.

Task 1: Rank Projects based on Incremental CERs. The decision maker will receive from the risk analyst, tables such as Table 7, and graphs such as Figure 8.

First, the decision maker will rank the mitigation projects solely on the basis of incremental CERs. To rank the projects, the risk analyst shoula follow the algorithm shown below. The project alternative funded will be the alternative increment that is larger than other site alternatives' CERs.

Algorithm to Prioritize Mitigation Projects:

1. Enter the do nothing alternative into a table such as Table 7.

2. Choor the unfunded alternative with the largest CER to fund.

3. Write in the cost and subtract the cost from the budget balance.

4. Compare the budget balance with the alternative with the next largest CER; is there enough money to fund it?
   -If yes, choose this alternative to fund and proceed to step 3.
   -If no, eliminate that site from further consideration and proceed down the list until a smaller cost alternative can be funded with the remaining balance. Proceed to step 3.

In the application of the above algorithm, the decision maker will develop a table such as Table 8. This table tracks the remaining funds for mitigation.

Table 8

Results of CER Algorithm

Alternative	Total Cost	Budget Balance
Do Nothing	0	$500,000
A1	$10,000	490,000
B1	$150,000	$340,000
A2	$90,000	$250,000
A3	$130,000	$120,000
B2	$110,000	$10,000

Once Table 8 is completed, the results are transformsed into the preliminary results illustrated in Table 9. The do-nothing alternative and mutually exclusive alternatives are left off of the table and applicable funds considered for other unfunded mitigation projects. An example of mutually exclusive alternatives at a fuel spill site are the removal of soil and capping.

Table 9

Preliminary Ranking Results for Funding

Prioritized Site	Prioritized Mitigation Alternative	Funded Amount
Landfill	A1	$10,000
Leaking Underground Storage Tank	B1	$150,000
Landfill	A2	$90,000
Landfill	A3	$130,000
Leaking Underground Storage Tank	B2	$110,000

Task 2: Consider Subjective Factors and Adjust Ranking If Necessary. The decision maker will also receive subjective information as shown in Table 10 in addition to previously illustrated tables and figures received from the risk analyst. While taking into consideration legislative mandates as well as subjective factors, decision makers may choose to modify the order of the prioritized list. It is imperative that adjustments be held to a minimum and justification statements accompany every deviation to ranking by absolute CERs. Wide-scale adjustments would result in similar problems inherit in current prioritization methodologies--encroachment of politics into the process and the spending of significant funds on insignificant risks resulting in increased risk to the public.

Table 10

Example Subjective Considerations for Landfill Cleanup Site

Alternative	Subjective Impacts
Do nothing	-Mudrun creek will remain contaminated and exceed ARARs by 200%. -Pollution could threaten 30 white tail deer. -Algae plumes will grow in Bass Lake and cover 25% of lake.
Cap landfill	Effluent will be reduced by 60% and exceed ARARs by 85%. -Mudrun creek could support deer population. Deer population would experience slight chronic effects during low water flows. -No effect on Bass Lake
Cap landfill and air strip effluent	-Effluent would meet ARARs. -Deer population would not be effected.
Cap; air strip and activated charcoal for effluent.	-Water quality of effluent would be nearly to background groundwater.

<u>Task 3: Hold Public Meeting</u>. As required in CERCLA, the decision maker holds a public meeting to inform the public of the proposed prioritized list. The decision maker solicits inputs and questions from the public.

<u>Task 4: Final Ranking of Projects</u>. In task 4, the decision maker reviews the prioritized list once more to take into consideration public inputs. The same cautions apply to widespread changes to cleanup project ranking changes as stated in step 4, task 2. The decision maker

completes the record of Decisions (RODs) and Decision Documents (DDs) as appropriate based on the final ranking of mitigation projects for funding.

Summary of CEM Application

This chapter developed the CEM to prioritize any mitigation project when the risks and mitigation costs are known. First, this chapter discussed contractor involvement in the risk assessment process and some of the RPM's responsibilities in contractor oversight. Secondly, the CEM was developed in this chapter to provide risk analysts with a model characterized with wide applications of various types of risk agents and increase the number of lives saved per mitigation dollar spent. Where CEM deviated significantly from present risk management processes, significant detail was provided to explain, as well as illustrate, the application of the CEM.

Chapter IV will validate this methodology by applying it to two mitigation projects for two different types of carcinogen threats.

IV. Application of the CEM

Overview

In this chapter the CEM, developed in Chapter III, is validated by applying it to two environmental projects at WPAFB--mitigation of high levels of radon gas in military family housing (MFH) and the mitigation of Landfills 8 and 10. The application of the CEM in this chapter will accomplish two goals. First, the application of the CEM will validate the general applicability of the CEM across classes of risks. Second, the application of the CEM will validate the CEM's ability to favor projects with the highest CERs. Other projects at WPAFB which would have been desirable to include in the application of the CEM are in their beginning stages of risk assessment, so their associated risks are not yet well understood. This chapter follows the methodology set forth in Chapter III and illustrated in Figure 7. For enhance logical flow, the risk assessment for radon in MFH will be addressed first and then the risk assessment for the landfills. When the analysis begins to compare the two sites during the risk management process, the discussions will be combined.

Because they are located near the Air Force Institute of Technology (AFIT), hazardous environmental sites at Wright-Patterson AFB (WPAFB) were selected to demonstrate the application of the CEM and validate CEM's methodology.

The Risk Assessment for Radon in MFH

The risk assessment for radon was accomplished entirely by contract. GEOMET Technologies, Inc. conducted the Radon Assessment and Mitigation Program (RAMP) detailed assessment titled Radon Assessment of the Base Housing and Other Selected Structures at Wright-Patterson Air Force Base on all residential military family housing (MFH) from the end of September 1989 to the end of September 1990 to measure the extent of radon contamination.

Hazard Identification Step for the Radon Problem. GEOMET Technologies, Inc. accomplished the hazard identification step by participating in the first two phases of a three phase RAMP process. Beginning the hazard identification, GEOMET Technologies, Inc. executed the initial screen phase that identified if WPAFB has a radon problem. In the second phase, the detailed assessment phase, the contractor identified the buildings having elevated radon concentrations. The third phase of RAMP, the post mitigation phase, will not start until base facilities are mitigated (GEOMET Technologies, Inc., 1991:v).

The primary source of indoor radon contamination is from seepage of air from the soil. Sometimes house construction materials can contribute a smaller amount of radon to indoor radon concentrations. Radon from water contributes to less than 5% of the total radon concentration (EPA, 1992:2.13).

The EPA sets the guideline for the maximum radon concentration in homes at a level below 4.0 pCi/L (EPA, undated:1.16). Being proactive, Lieutenant General Carl R. Smith, Assistant Vice Chief of Staff of the United States Air Force, directed Air Force Major Commands to implement the RAMP (Smith, 1987). The HQ USAF Implementation Plan for the RAMP describes actions, assigns responsibilities, and sets milestones for support commanders to implement the plan. There are two goals of the RAMP: (1) identify all Air Force buildings with radon levels of 4 pCi/L and (2) mitigate those buildings with elevated radon levels. The first goal of RAMP establishes the hazard identification step.

RAMP requires bases, such as Wright-Patterson Air Force Base (WPAFB), to test all buildings on base and to mitigate those with radon levels equal or exceeding 4.0 pCi/L. WPAFB has completed testing and identified 416 military family housing (MFH) units with radon levels of at least 4.0 pCi/L. WPAFB plans to reduce radon levels in all buildings with contamination levels above 3.1 pCi/L to be 95% confident that all base housing meets the Air Force requirement; the target level of 3.1 pCi/L increases the number of homes requiring mitigation to 658 (GEOMET Technologies, Inc., 1991:Appendix H).

The confirmation of high radon levels in several hundred MFH at WPAFB points to a requirement to mitigate a home. Reducing radon in homes is important because radon is a group A carcinogen, and the EPA estimates that between 7,000 and 30,000 people die from radon-caused lung cancer in the United States each year (EPA, 1992:2.1,2.3). According to the EPA, people who live in homes with radon levels of 4 pCi/L for 70 years have a 1% to 5% chance of developing lung cancer from radon present in their homes (EPA, 1986:9). This level (4 pCi/L) is the cut-off action level at which the EPA recommends homeowners mitigate their home for radon. Homes with high radon concentrations pose an obvious health risk to people, but the difficulty is how to put the risks from hazards such as radon in proper prospective with other environmental hazards competing for mitigation funds.

Exposure Assessment Step for the Radon Problem. For the radon problem at WPAFB, the contractor evaluated exposure using alpha track detectors placed in homes for an entire year to determine an average annual exposure rate in each home (GEOMET Technologies, Inc., 1991:1.4). The radon exposure results may be found in Figure 9. Base officials and GEOMET Technologies, Inc. expended considerable effort to ensure the integrity, proper placement, and retrieval of the radon detectors (GEOMET Technologies, Inc., 1991:2.4-2.16).

Other factors that determine exposure to home radon is time spent at home and equilibrium factor of radon daughters. The EPA assumes that people in the United States spend about 75% of their time in the home, based on a study by GEOMET (EPA, 1992:2.13, 2.33).

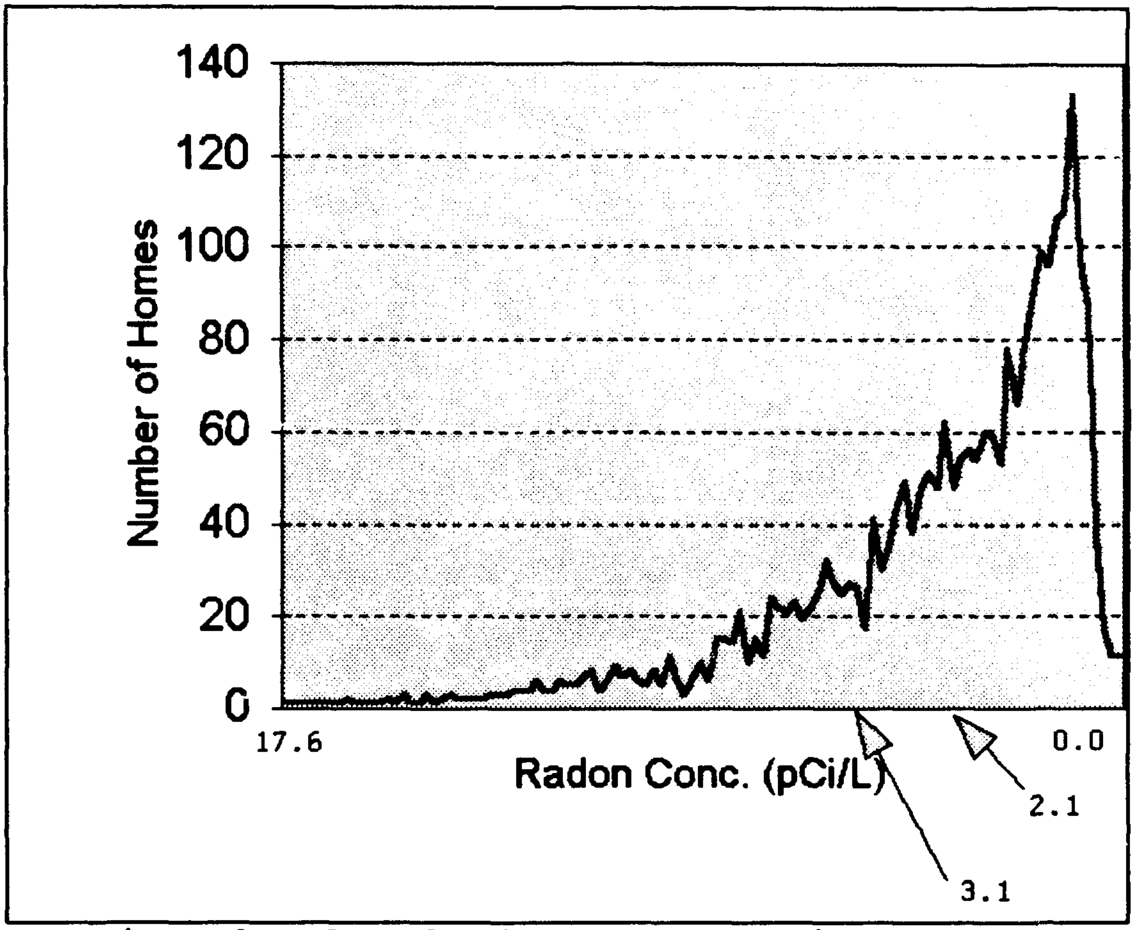

Figure 9. Plot of Radon Measurements in WPAFB MFH

Dose-Response Assessment Step for the Radon Problem. GEOMET Technologies, Inc. was not tasked to accomplish a dose-response assessment step. For radon contaminated MFH, GEOMET accomplished only the hazard identification and exposure assessment to assess the concentrations of radon found in the housing. The Air Force needed only radon concentration levels in MFH. The dose-response assessment step is assimilated here for demonstration purposes.

In the radon risk assessment, EPA estimates of lung cancer incidence are based on data obtained from underground miners. Cancer risk in miners has been detected with cumulative exposures as low as 40-70 Working Level Months (WLM). A WLM is defined as exposure to the equivalent of 100 pCi/L for 170 hours. Extrapolation models used to extrapolate extremely high doses in animals to low doses in people are not required to determine the slope factor of radon. Only small extrapolations are needed to bridge the small gap between high uranium miners exposures to residential exposures. According to the EPA, the average cumulative U.S. exposure to home radon is 18 WLM or 1.25 pCi/L concentration. Determining the cancer rate of people living in homes contaminated with 4 pCi/L concentrations of radon requires no extrapolation procedures because these residents are exposed to a 74-year lifetime exposure of 57 WLM (EPA, 1992:2.13-2.14).

Based on radon epidemiological studies of underground minors, the EPA assumes a linear exposure-response relationship for home radon concentrations. This assumption is reinforced by similar assumptions by the International Commission on Radiological Protection (ICRP) Committee and Biological Effects of Ionizing Radiation IV (BEIR IV) Committee, in addition to the EPA Science Advisory Board's recommendation to continue to assume a linear exposure-response relationship. For use with the BEIR IV model for estimating cancer risk, the EPA applies a risk factor for radon of 3.05×10^{-4} lung cancer deaths/person-WLM (EPA, 1992:2.14, 2.16).

Currently, the EPA prefers an adjusted form of the BEIR IV model to estimate lung cancer risk caused by radon. The BEIR IV Committee developed this relative risk projection model based on four major cohort studies of underground minors. The BEIR IV excess radon-caused cancer risk equation is written as the following:

$$\textit{Radon Excess Cancer Risk} = r_0(a) * \beta * \gamma(a) * (W_1 + 0.5W_2) \quad \textbf{(16)}$$

where RECR = rate of lung cancer mortality at a specific attained age (a) from elevated radon concentrations above ambient concentrations

$r_0(a)$ = 2.24 X 10^{-4} deaths/person-WLM = the age-specific baseline lung cancer mortality rate (corrected for background radon exposure). This value for radon is analogous to cancer slope factors of chemicals.

β = .0175 = the relative risk coefficient for radon-induced lung cancer and adjusted to home environment from mine environment

γ = age-specific adjustment to the relative risk coefficient for radon

γ(a) = 1.2 when (a) < 55 years

= 1.0 when (a) is 55-64 years

= 0.4 when (a) >= 65 years

W_1 = cumulative exposure occurring from 5 to 15 years before age (a)

W_2 = cumulative exposure up to age (a - 15) years

A unique characteristic of the BEIR IV model is its incorporation of epidemiologic study observation where lung cancer incidence decreased from exposures in the distant past. This adjustment for time is incorporated in the 0.5 W_2 element of Equation 16.

The understanding of radon risks has changed significantly since 1987, when the Radon Reference Manual was published. The effect has been to reduce the uncertainty in the calculations of risk. At the time of the publication of the Radon Reference Manual, the EPA advocated the Relative Risk model. Since then, the EPA adopted an average of the International Commission on Radiological Protection model that was developed in 1987 and the BEIR model developed in 1988. These events demonstrate the change in perception of cancer risk since 1987. Table 11 illustrates the change in understanding of radon over time and also demonstrates a level of uncertainty in this understanding.

Though BEIR IV is the preferred model to estimate radon risk, the model requires the development of an elaborate program and the use of several volumes of the <u>1980 U.S. Vital Statistics</u> containing death rates and lung cancer rates for a specified age person for a specified exposure

Table 11

EPA's Radon Risk Estimates

Model/Approach	Date of Estimate	Range of Estimated Annual Lung Cancer Deaths (90% Conf)
EPA Relative Risk Model	1986	5,000 - 20,000
Average of ICRP 50 and BEIR IV	1988	8,000 - 43,000
BEIR IV Model (as adjusted by EPA)	1992	7,000 - 30,000

(EPA, 1992:2.35)

concentration and exposure duration. For this reason and to enhance comparability of risks, the simple slope factor identified in the HEAST will be incorporated into the risk assessment. HEAST table slope factors are EPA-approved slope factors just as those slope factors listed in the IRIS database. The HEAST table slope factor used in Equation 12 from Chapter III will tend to overestimate the risk slightly, because radon exposures in the distant past are not reduced by 50% as in the BEIR IV model. The incremental differences of risk in CER calculations should not be affected significantly, because the pre-mitigation risk and post-mitigation risk are both inflated to the same degree.

The Risk Assessment of Landfills 8 and 10

At landfills 8 and 10, O. H. Materials Corporation conducted the PA/SI titled Preliminary Site-Specific Risk Assessment for Landfills 8 and 10, Wright-Patterson AFB, Ohio (August 13, 1991) and Engineering-Science, Inc.

conducted the RI/FS titled Off-Source Remedial Investigation Report For Landfills 8 and 10 at Wright-Patterson Air Force Base (June 1993)/Focused Feasibility Study For Landfills 8 and 10 at Wright-Patterson Air Force Base, Ohio (August 1992).

Hazard Identification Step for Landfills 8 and 10. Landfills 8 and 10 are located near each other in Area B of WPAFB. Landfill 8 consists of 13 acres and received waste from 1955 to 1962. Landfill 10 consists of 10 acres and received waste from 1965 to 1968 (O.H. Materials Corp., 1990:vi).

After closure, the area containing Landfill 8 was converted into a neighborhood park. Later, leachate (water which has seeped through the landfill debris) oozed out of the ground in the park, causing foul odors. Hazardous chemicals were detected in the leachate so the park was closed and fenced off. The closed landfills border 317 MFH where approximately 1000 people live in addition to several private homes along National Road and Zink Road (Engineering Science, 1993:1.6). Environmental health hazard warning signs are posted along the fence bordering the back yards of the MFH (O.H. Materials Corp., 1990:vi). Though these landfills are not classified as hazardous waste landfills, they do contain significant amounts of hazardous waste in addition to general refuse (O.H. Materials Corp., 1990:vi, 6.1). Tables 12 and Table 13 indicate quantity estimates of hazardous waste believed to be buried in these landfills.

The hazard potential was deemed significant enough to be placed on the NPL.

There are 16,000 open and closed landfills in the United States. In addition to polluting the environment, these landfills are also contaminating aquifers used for drinking water (EPA, 1987c:77). The EPA estimates that 40 people in the United States die annually from cancer due to exposure to cancer causing chemicals emanating from landfills (EPA, 1987c:77).

Table 12

Estimated Quantities of Hazardous Materials Landfilled During the Active Life of Landfill 8 (1955-1962)

Material Landfilled	Estimated Quantity
Nickel acetate	1,300 gal
Cadmium oxide powder, sodium cyanide, caustic soda	6,240 gal
Trichlorethylene (TCE)	Unknown
TCE degreaser sludge	2 drums
Paint remover	11,200 gal
Carbon remover, PD-680, hydraulic fluid, paint thinner	5,600 gal
Paint strippings	2,200 gal
Enamel Paints	133 drums
Solvent wastes, paint wastes, thinners	16 drums
Miscellaneous chemicals	2,400 lb
Plating solutions	400-800 gal

(O.H. Materials Corp., 1990:2-5)

Table 13

Estimated Quantities of Hazardous Materials Landfilled

During the Active Life of Landfill 10 (1965-1968)

Material Landfilled	Estimated Quantity
Nickel acetate	800 gal
Cadmium oxide powder, sodium cyanide, caustic soda	3,120 gal
Trichloroethylene (TCE)	Unknown
TCE degreaser sludge	1 drum
Paint strippers, contaminated thinners, waste paint	220 gal
Paint remover	5,600 gal
Carbon remover, PD-680, hydraulic fluid, paint thinner	2,800 gal
Paint strippings	1,100 gal
Enamel Paints	67 drums
Solvent wastes, paint wastes, thinners	8 drums
Miscellaneous chemicals	1,200 lb
Plating solutions	150-300 gal

(O. H. Materials Corp., 1990:2-7)

<u>Exposure Assessment Step for Chemicals Emanating from Landfills 8 and 10</u>. Indirect assessment of a population's exposure to chemicals such as those emanating from landfills through models introduces much more uncertainty than direct measurements of indoor radon (EPA, 1992:2.12; Cohrssen and Covello, 1989:67). Engineering-Science, Inc. determined that ingestion, inhalation, and dermal exposure were the main routes of exposure to the population near the landfills resulting in the following significant exposure pathways:

Ingestion of:	-Drinking Water -Soil -Sediment -Vegetables and Fruits
Inhalation of:	-Vapors generated during showering -Indoor air -Outdoor air
Dermal exposure to:	-Soil -Sediment -Water during showering -Surface water -Leachate water

In the RI/FS, Engineering-Science, Inc. made several assumptions concerning exposure. First, they assumed there were three potentially exposed populations: close proximity resident child, close proximity resident adult resident, and a close proximity resident adolescent trespasser. Current and future land use scenarios were used. Current close proximity residents are assumed to be Woodland Hills residents drinking from private wells, though most residents drink city water. The contractor in the RI/FS assumed that the people living around the landfills were exposed to landfill chemicals 6 years as a child and 24 years as an adult. Current trespassers are assumed to ingest on-site soil and sediment 26 days per year. Future residents are assumed to live along the boundary of the landfills drinking from private wells also located along the border of the landfills. Future trespassers are assumed to be exposed to surface water and leachate water 175 days per year (Engineering-Science, Inc, 1993:6.3.1-6.3.1).

Several models were used to estimate exposure to chemicals. The contractor modeled shower air via the Andelman model. The Industrial Source Complex Long-term Dispersion Model (air dispersion model) was used to estimate exposure to residents, assuming they all lived on the border of the landfills. To simulate ground water and solute movement through and away from the landfills, the contractor used the SUTRA model. The model accounts for the dispersion, sorption, and decay of contaminants. Another model, Groundwater Loading Effects of Agricultural Management Systems (GLEAMS) developed by the USDA Agricultural Research Service, simulated the movement of contaminants through the upper root zone for crops. This model was used to predict chemical uptake in fruits and vegetables.

Dose-Response of Landfill Chemicals. Engineering-Science, Inc. obtained its slope factors in the priority order of the IRIS first and the HEAST Tables second. If the slope factors were not available in IRIS, then the contractor used the HEAST Tables. The slope factors for the hazardous chemicals found to be emanating from Landfills 8 and 10 are located in Appendix B.

The pitfall to using these slope factors is the significant amounts of uncertainty added to the estimated risk compared to the slope factor of radon. Most slope factors originate from bioassays of rodents where experimental data were gathered from subjects in small populations exposed to high concentrations of chemicals. These data are then used in a mathematical extrapolation process to predict low dose effects in large populations.

The risk analyst's understanding the effect of uncertainty on risk will be useful during the CEM steps that evaluate subjective information. If well-understood risks lead to low CERs while poorly-understood and conservatively artificially inflate risks and CERs, the decision maker may consider re-adjusting project to compensate for this phenomena.

Risk Management Process

The risk management phase is the process where CEM deviates from current risk prioritization methodologies. In this discussion, the risk management process concerning the radon problem in WPAFB MFH and chemical contaminant problem at landfills 8 and 10 will be discussed simultaneously in this section.

Step 1: Characterize the Risk. Because the risk characterization step is the same step for the risk assessment process as well as the risk management process, this section will suffice for both processes. The risk characterization step for radon was not accomplished by GEOMET Technologies, Inc.; however, the risks from exposures to radon at WPAFB MFH will be calculated here to demonstrate the CEM.

__Task 1: Determine Representative Standard Values for CDI Calculations__. The risk equation variables for radon and the landfill chemicals will be standardized to enhance comparability of the risks. The only exception is the inhalation rate (IR); the IR for radon is an indoor value, while the IR for the landfills is an outdoor value. The standardized radon values assumed are listed in Table 14. These values were generally taken from the RI/FS for the landfills to normalize the data and enhance comparability.

Table 14

Standardized and Normalized Variables for Radon CER Calculations

Standard Description	Value
Effective Indoor Inhalation Rate (6 yrs as a child and 24 yrs as an adult)	15.16 L/day
Conversion Factor (CF)	1000 L/m^3
Exposure Frequency (EF)	360 days/yr
Exposure Duration (ED)	30 yrs
Inhalation Slope Factor for Radon	1.1 x 10-11 lung cancers/pCi

The standard values assumed for the landfills are in Appendix C. The effective intake rates and effective body weights were determined by proportional weighting (6 years as a child and 24 years as an adult). For example, the calculation for effective body rate would proceed as the following:

(6 yrs * 15 kg) + (24 yrs * 70 kg) / 30 yrs = 59 kg

Task 2: Calculate CDIs and Risks for Exposure Pathways. CDIs and cancer risk calculations of radon and landfill risk agents were strait-forward for chemicals emanating from the landfills. For example, landfill-related CDIs were calculated using Equations 4 through 10, and landfill-related cancer risks were calculated using Equation 11 located in Chapter III. Radon exposure has no CDI calculations, because radiation cancer affects are based on cumulative exposure, not average daily exposure; however, radon-caused cancer rates were calculated using Equation 12 located in Chapter III. Because there is more than one exposure pathway characterized by the landfills, the pathway risks were summed to determine a total risk from exposure to the landfills. Table 15 shows the cancer summary estimates calculated from these equations.

Table 15. Summary of Landfill Risks by Pathway Medium

Medium: Ground Water Pathways		
Pathway	Present Risk	Future Risk
Ingestion of Drink'g Water (Pri Well)	4E-04	4E-04
Inhalation of Vapors While Showering	1E-07	9E-07
Dermal Exp. to Water During Showering	1E-06	1E-04
Totals	4E-04	5E-04
Medium: Surface Water Pathways		
Pathway	Current Risk	Future Risk
Dermal Exposure to Surface Water	9E-05	4E-04
Dermal Exposure to Leachate Water	1E-06	5E-06
Totals	9E-05	4E-04
Medium: Soil Pathways		
Pathway	Current Risk	Future Risk
Ingestion of Soil	3E-07	1E-05
Ingestion of Sediment	9E-07	3E-05
Dermal Exposure to Soil	5E-06	7E-05
Dermal Exposure to Sediment	5E-06	1E-04
Ingestion of Fruits	8E-08	5E-06
Ingestion of Vegetables	6E-07	1E-05
Totals	1E-05	2E-04
Medium: Air Pathways		
Pathway	Current Risk	Future Risk
Inhalation of Indoor Air	0E+00	0E+00
Inhalation of Ambient Air	1E-04	1E-04
Totals	1E-04	1E-04
Total Site Risk	6E-04	1E-03

(Engineering Science Inc., 1993:Table 6.5.29,6.5.30)

Figure 10 summarizes the specific risks of homes with radon concentrations by increments of 1/10 of a pCi/L. The X-axis represents the continuum of alternatives ranging from the house that measured 17.6 pCi/L on the left side to 0 pCi/L on the right side of the axis. The solid line in the figure represents risk resulting from exposure to the radon concentrations. An individual's cancer risk ranges from 3.3 x 10-2 when living 30 years in a house contaminated with radon concentrations of 17.6 pCi/L to 1.9 x 10-4 when living 30 years in a house contaminated with radon concentrations of .1 pCi/L.

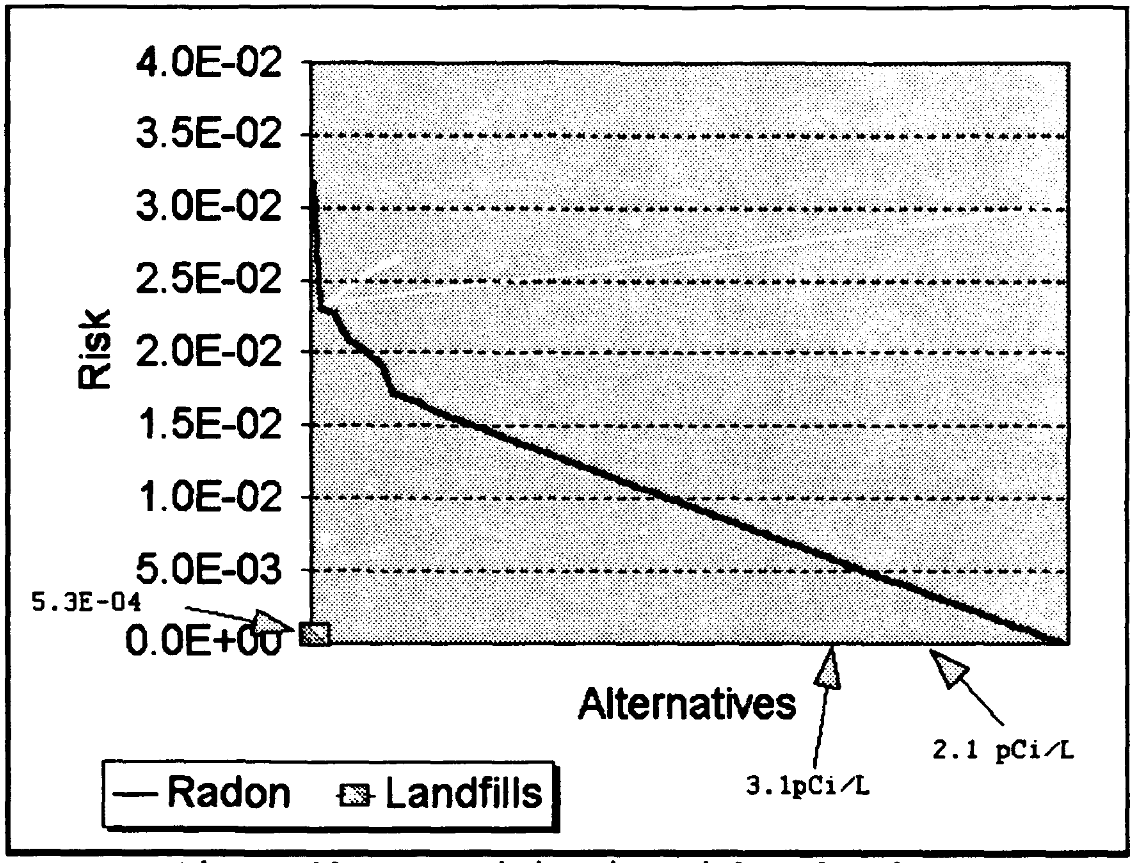

Figure 10. Pre-Mitigation Risks of Radon and Landfills 8 and 10

For landfills 8 and 10, the remedial investigation report estimates the risks to be 6×10^{-4} and 1×10^{-3} for current total pathway risk and future total pathway risk respectively. From Table 16, the analysis of landfill chemicals can be simplified to the study of three chemicals for this thesis: Arsenic, Benzo(a)pyrene, and 1,1,2,-trichloroethane. These three chemicals represent 88% of the total risk associated with the landfills. Table 17 shows the simplified landfill results of the cancer risk of each chemical and pathway. In Table 17, the total current cancer risk for this abbreviated list of chemicals totaled 5.3×10^{-4} and is compared to the risk from radon exposure in Figure 10. The risk from exposure to Landfill 8 and 10 chemicals consisted primarily of a 3.9×10^{-4} risk from drinking arsenic contaminated water drawn from private wells located near the landfill, a 7.3×10^{-5} risk from breathing air containing 1,1,2-trichloroethane in outdoor air, and a 6.6×10^{-5} risk from dermal exposure to surface water (Engineering-Science, Inc., 1993:6.5-9,6.8-2). These estimates represent the most significant of those chemicals that exceed the target risk levels of 10^{-6} to 10^{-4} set by the EPA defining significant risk (Engineering-Science, Inc., 1993:6.5.6). Exceeding the action level criteria may establish the requirement to mitigate the landfills. Figure 10 puts the risk from exposure to Landfills 8 and 10 into perspective with the risks from exposure from radon at various concentrations.

Table 16

Landfill Cancer Risk Percentages by Chemical

Chemical	Cancer Risk	% of Total Risk
Arsenic	3.9E-04	65
1,1,2-Trichloroethane	7.3E-05	12
Benzo(a)pyrene	6.8E-05	11
Benzene	1.5E-05	3
Benzo(k)fluoranthene	1.5E-05	2
Chromium VI	1.2E-05	2
Benzo(b)fluoranthene	9.5E-06	2
Beryllium	5.0E-06	<1
Trichloroethene	4.3E-06	<1
Methylene chloride	3.0E-06	<1
Aroclor-1254	2.9E-06	<1
Dibromochloromethane	1.2E-06	<1
bis(2-Ethylhexyl)phthalate	1.0E-06	<1
2378-TCDD	8.7E-07	<1
Chloroform	5.7E-07	<1
Dibenz(a,h)anthracene	5.4E-07	<1
Bromodichloromethane	5.1E-07	<1
Heptachlor	4.9E-07	<1
1234678-HPCDD	3.2E-07	<1
Aroclor-1260	3.0E-07	<1
Benzo(a)anthracene	2.5E-07	<1
Indeno(1,2,3-cd)pyrene	2.1E-07	<1
12346789-OCDD	2.0E-07	<1
Chrysene	1.3E-07	<1
Bromoform	1.0E-07	<1
Landfill Total Risk	6.1E-04	100

(Engineering Science Inc., 1993:Table 6.5.31)

Table 17

Pre-mitigation Risks of Landfills 8 and 10

Chem	Ingest. of Drink'g Water	Ingest. of Soil	Ingest. of Sedi-ment	Ingest. of Fruits	Ingest. of Veg.	Inhal. of Amb. Air	Dermal Exp. to Soil	Dermal Exp to Sedi-ment	Dermal Exp to Shower Water	Dermal Exp to Surf. Water	Dermal Exp to Leach.	Total Risk for Chem
Ars	3.9E-4	1.6E-7	7.5E-7	4.4E-8	5.6E-7	1.8E-6	1.0E-7	4.7E-7	9.4E-7	1.4E-8	2.5E-8	3.9E-4
Benzo	0.0	6.2E-9	5.9E-8	0.0	0.0	0.0	1.5E-7	1.5E-6	0.0	6.6E-5	0.0	6.8E-5
1,1,2-T	0.0	0.0	0.0	0.0	0.0	7.3E-5	0.0	0.0	0.0	0.0	0.0	7.3E-5
Tot. Pathway Risk	3.9E-4	1.7E-7	8.1E-7	1.0E-6	5.6E-7	7.4E-5	2.6E-7	1.9E-6	9.4E-7	6.6E-5	2.5E-8	5.3E-4

<u>Task 3: Characterize the Uncertainties</u>. As described in Chapter II, there are several sources of uncertainty in the risk assessments. However, the degree of uncertainty corresponding to the radon problem in MFH is much smaller than the uncertainty corresponding to hazard agents emanating from landfills 8 and 10.

<u>Uncertainties Corresponding to the Radon Problem</u>. Data reliability in the laboratory that read the radon detectors was monitored using duplicate detectors

placed side by side experimental radon detectors. Another effort to ensure data reliability was sending spiked detectors exposed to radon chambers of known concentrations to the analytical laboratory. Lab results showed that the precision of the duplicate detectors averaged +/- 10%, and accuracy and precision for spiked detectors were +/- 15% and +/- 10% or better respectively for all samples (GEOMET Technologies, Inc., 1991:3.15-3.17). Although WPAFB demonstrated great care in sampling, there is still some uncertainty in any radon testing (EPA, 1992:2.13).

The uncertainty range of the 75% individual occupancy rate is 65% to 80% (EPA, 1992:2.13, 2.33). Though this average is representative of the typical home in the United States, there is still some uncertainty introduced by using these value (EPA, 1992:2.13).

The small amount of uncertainty which exists in radon exposure results from some error in residential measurements and the occupancy factor (EPA, 1992:2.13). Compared to typical risk assessments for landfill contaminants, the average radon exposure estimates are strongly representative of the exposures. At WPAFB, the uncertainty of the average exposure concentrations was reduced because radon detectors were in place for a year, during which error may originate from seasonal fluctuations and variable weather conditions were included in the radon exposure estimates.

The EPA projects the central estimate of BEIR IV determined cancer risk from radon could be 2.6 times larger or 1.6 times lower than estimated with the BEIR IV model. The EPA central estimate for the BEIR IV slope factor (224×10^{-6}), low estimate for the BEIR IV slope factor (140×10^{-6}), and high estimate for the BEIR IV slope factor (540×10^{-6}) will be applied to EPA's HEAST Table slope factor during sensitivity analysis. The resulting uncertainty range estimate projects a slope factor that is .625 times smaller and 2.545 times larger (EPA: 1992:2.30).

Uncertainties Corresponding to the Landfill Problem. The uncertainty associated with slope factors of landfills chemicals is much greater than the uncertainty associated with the slope factor of radon, possibly orders of magnitude larger. Table 18 portrays the evidence available on each chemical and the relative degree of confidence in the value. In IRIS, the EPA noted particularly significant uncertainty concerning arsenic. Comments in IRIS stated that risk due to exposure to arsenic could be overstated and may be modified downwards by an order of magnitude relative to the risks of other carcinogens. If the risk analyst does reduce the slope factor, the EPA requires documentation stating that the slope factor was reduced (IRIS, Jan 1993). The effects of varying arsenic's slope factor, as well as other risk agents, will be studied in the sensitivity analysis.

Table 18

Evidence and Relative Degree of Confidence in the Slope Factors

Chemical	Evidence For Slope Factor	Degree of Confidence in Slope Factor
Arsenic (IRIS, Jan 1993)	1 Human study	Very Highly Uncertain
Benzo(a)pyrene (IRIS, Jan 1993)	4 Studies of 4 rodents species and several primates	Adequate Fairly Uncertain Range est = 4.5 to 11.7 per mg/kg/day
Radon (EPA, 1992:2.17, 2.30)	4 Human Cohort Studies of miners	Estimate=224 x 10^{-6} Low=140 x 10^{-6}/WLM High=570 x 10^{-6}/WLM
1,1,2-Trichloroethane (IRIS, 1993)	Modeling of 1 animal data set. Evidence in 1 strain of mice but not rats.	Highly Uncertain; Modeling was done on only one data set

The tables in Appendix D subjectively summarizes the uncertainties associated with the RI. The uncertainty associated with the mitigation cost is +50% to -30% of the estimated amount (Engineering-Science, Inc, 1992:ES.3).

Step 2: Evaluate Control Options. During this step, the contractor will require flexibility when evaluating alternatives. The varying nature of mitigation alternatives and the number of alternatives requires this need to adapt to the situation. The two sites being evaluated illustrate this point.

Task 1: Evaluate the Feasibility of Mitigation Alternatives for Each Site Using the Nine Evaluation Criteria listed in the National Contingency Plan. For mitigation of radon in existing housing without basements, sub-slab suction is the preferred mitigation technique, because it is both effective and energy efficient. The radon contamination in MFH was measured in increments of 0.1 pCi/L in a range from 0 to 17.6 pCi/L. The decision maker therefore faces a decision of what radon concentration level to mitigate to; there are 176 possible radon contamination levels to mitigate to between 0.0 pCi/L and 17.6 pCi/L. Because the EPA has recommended mitigation of homes at 4 pCi/L or higher, all authorities would agree that this would be the evaluation criterion. The nine evaluation criteria do not apply to radon contamination, because they were written for mitigation of hazardous waste. The 176 mitigation alternatives for radon contrasts to a few dozen technology alternatives to mitigate the landfills.

Evaluation of all potentially viable landfill mitigation technologies against the nine evaluation criteria resulted in a compilation of several technologies into the four alternatives listed in Table 19.

Table 20 lists the removal efficiencies expected from alternatives 2, 3, and 4. Because the contractor account for the affect of background contaminants on removal efficiencies, the removal efficiencies listed in Table 21 were assumed in this research.

Table 19

Description of Alternatives for Source Control

at Landfills 8 and 10

Alternative	Actions
Alternative 1	No Action
Alternative 2	Access restrictions; deed restrictions; air, explosive gas, and ground-water monitoring; clay caps; landfill gas extraction wells; enclosed ground flares, leachate extraction wells; public water supply, plus: Leachate treatment using equalization, biological treatment, metals removal, **chemical oxidation**; and surface water discharge.
Alternative 3	Access restrictions; deed restrictions; air, explosive gas, and ground-water monitoring; clay caps; landfill gas extraction wells; enclosed ground flares, leachate extraction wells; public water supply, plus: Leachate treatment using equalization, biological treatment, metals removal, **granular activated carbon**; and surface water discharge.
Alternative 4	Access restrictions; deed restrictions; air, explosive gas, and ground-water monitoring; clay caps; landfill gas extraction wells; enclosed ground flares, leachate extraction wells; public water supply, plus: Leachate treatment using equalization, biological treatment, metals removal, **air stripping, and activated carbon**; and surface water discharge.

Note: Differences are highlighted in bold print
(Engineering-Science, 1992:Table 4.2)

Table 20

Contractor Estimate of Removal Efficiencies

of Landfill Alternatives

Chemical	Removal Percentages*	Documentation Source
Arsenic	75% of effluent	(Engineering-Science, 1992:Tables 4.5,4.6,4.7)
Benzo(a)pyrene	90-100% of effluent	(Engineering-Science, 1992: Table 4.4)
1,1,2-Trichloroethane	89% in air	(Engineering-Science, 1992: Table 4.13)

*Alternatives 2,3, and 4 have identical removal efficiencies

Table 21

Estimate of Reduced Removal Efficiencies

of Landfill Alternatives Due to Affect of

Background Contaminants

Chemical	Removal Percentage*	Rationale
Arsenic	25% in effluent, sediment, fruits, vegetables, surface water; 0% in soil and air	Soil concentration estimate was 8 mg/kg compared to 3.1-12.3 mg/kg background concentration.
Benzo(a)pyrene	95% in effluent, sediment, soil, surface water	All organic contaminants were assumed to originate for the landfills
1,1,2-Trichloroethane	89% in air	All organic contaminants were assumed to originate for the landfills

*Alternatives 2,3, and 4 have identical removal efficiencies

Task 2: Calculate CERs for Feasible Alternatives. To calculate the CERs, the removal rates must be applied to pre-mitigation contaminant exposure concentration to estimate the post-mitigation risks. After the post-mitigation risk is estimated, incremental risks are the difference between the pre-mitigation risk and the post-mitigation risk. Figure 11 summarizes the risk reductions resulting mitigation of the radon-contaminated MFH as well as Landfills 8 and 10; It also compares the risk reductions resulting in these two mitigation projects. To better interprete risk reductions for Landfills 8 and 10, these risk reductions are specified in Table 22.

There were several assumptions made for the determination of CERs in addition to those already identified. These assumptions were normalized over both sites to enhance comparability of risks and CERs. The CER calculations included the following assumptions:

- 4 people live in each household
- Mitigation alternatives for non-organic contaminants could not lower contaminant levels below background levels.
- All organic contaminants were assumed to originate from the landfills; therefore, mitigation alternative efficiencies did not consider background levels of organic chemicals.

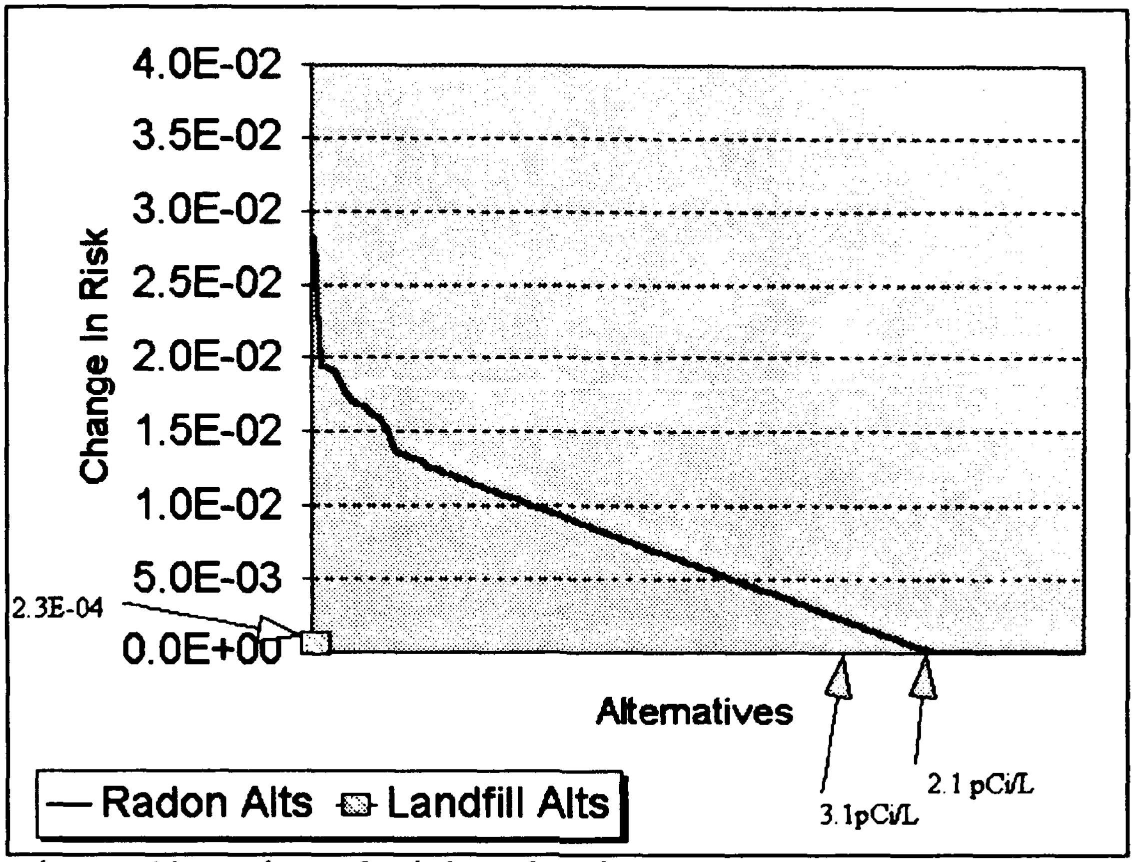

Figure 11. Size of Risk Reduction as a Result of Radon and Landfill 8 and 10 Mitigation

Tables 23 and 24 contain the results of CER calculations. Figure 12 illustrates the large difference between the size of the CERs between the two mitigation projects. In Figure 12, the line for radon alternatives represents the CER of mitigating each radon concentration listed in Table 23 to 2 pCi/L. The highest CER is for the radon concentration of 17.6 pCi/L. The location on the graph where the CERs for radon is 0 represents concentrations of 2 pCi/L or less. The four blocks near a CER of 0 represent alternatives 1, 2, 3, and 4 and correspond to CERs of 0, 1.12 x 10^{-8}, 0, and 0 respectively. The CERs for alternatives 3 and 4 are "0", because no additional risk reduction is achieved for additional cost. From these tables and Figure 12, it is concluded that mitigation of radon in the MFH at WPAFB saves many more lives per dollar than the mitigation of landfills 8 and 10; surprisingly, mitigation reductions from 2.1 pCi/L to 2.0 pCi/L produces a higher CER than all mitigation actions planned at landfills 8 and 10.

Table 22

Risk Reduction Estimates for Landfills 8 and 10 (Reducing Mitigation Efficiencies to Account for Background Contaminant Levels)

Chem.	Ingest. of Drink'g Water	Ingest. of Soil	Ingest. of Sedi-ment	Ingest. of Fruits	Ingest. of Veg.	Inhal. of Amb. Air	Dermal Exp. to Soil	Dermal Exp to Sedi-ment	Dermal Exp to Shower Water	Dermal Exp to Surf. Water	Dermal Exp to Leach.	Total Risk for Chem
Ars	9.7E-5	0.0	1.9E-7	1.1E-8	1.4E-7	0.0	0.0	1.2E-7	2.3E-7	3.5E-9	6.3E-9	9.7E-5
Benzo	0.0	5.9E-9	5.6E-8	0.0	0.0	0.0	1.5E-7	1.4E-6	0.0	6.3E-5	0.0	6.5E-5
1,1,2-T	0.0	0.0	0.0	0.0	0.0	6.5E-5	0.0	0.0	0.0	0.0	0.0	6.5E-5
Tot. Pathway Risk	9.7E-5	5.9E-9	2.4E-7	2.6E-7	1.4E-7	6.5E-5	1.5E-7	1.5E-6	2.3E-7	6.3E-5	6.3E-9	2.3E-4

Table 23. CERs of Mitigation Alternatives for Radon in WPAFB MFH Units (Mitigation to 2 pCi/L assumed)

Radon Conc.	CER	Radon Conc.	CER	Radon Conc.	CER	Radon Conc.	CER
17.6	4.3E-5	7.9	1.6E-5	5.2	8.8E-6	2.5	1.4E-6
12.8	3.0E-5	7.8	1.6E-5	5.1	8.5E-6	2.4	1.1E-6
12.7	3.0E-5	7.7	1.6E-5	5.0	8.3E-6	2.3	8.3E-7
12.6	2.9E-5	7.6	1.5E-5	4.9	8.0E-6	2.2	5.5E-7
12.0	2.8E-5	7.5	1.5E-5	4.8	7.7E-6	2.1	2.8E-7
11.6	2.7E-5	7.4	1.5E-5	4.7	7.4E-6	2.0	0.0
11.4	2.6E-5	7.3	1.5E-5	4.6	7.2E-6	1.9	0.0
11.3	2.6E-5	7.2	1.4E-5	4.5	6.9E-6	1.8	0.0
11.0	2.5E-5	7.1	1.4E-5	4.4	6.6E-6	1.7	0.0
10.8	2.4E-5	7.0	1.4E-5	4.3	6.3E-6	1.6	0.0
10.5	2.3E-5	6.9	1.4E-5	4.2	6.1E-6	1.5	0.0
9.6	2.1E-5	6.8	1.3E-5	4.1	5.8E-6	1.4	0.0
9.5	2.1E-5	6.7	1.3E-5	4.0	5.5E-6	1.3	0.0
9.4	2.0E-5	6.6	1.3E-5	3.9	5.2E-6	1.2	0.0
9.3	2.0E-5	6.5	1.2E-5	3.8	5.0E-6	1.1	0.0
9.2	2.0E-5	6.4	1.2E-5	3.7	4.7E-6	1.0	0.0
9.0	1.9E-5	6.3	1.2E-5	3.6	4.4E-6	0.9	0.0
8.9	1.9E-5	6.2	1.2E-5	3.5	4.1E-6	0.8	0.0
8.8	1.9E-5	6.1	1.1E-5	3.4	3.9E-6	0.7	0.0
8.7	1.9E-5	6.0	1.1E-5	3.3	3.6E-6	0.6	0.0
8.6	1.8E-5	5.9	1.1E-5	3.2	3.3E-6	0.5	0.0
8.5	1.8E-5	5.8	1.1E-5	3.1	3.0E-6	0.4	0.0
8.4	1.8E-5	5.7	1.0E-5	3.0	2.8E-6	0.3	0.0
8.3	1.7E-5	5.6	9.9E-6	2.9	2.5E-6	0.2	0.0
8.2	1.7E-5	5.5	9.7E-6	2.8	2.2E-6	0.1	0.0
8.1	1.7E-5	5.4	9.4E-6	2.7	1.9E-6	0.0	0.0
8.0	1.7E-5	5.3	9.1E-6	2.6	1.7E-6		

Table 24

CERs of Mitigation Alternatives for Landfills 8 and 10 at WPAFB (Most Likely Post-Mitigation Levels Considering the Influence of Background Contaminants)

Alt	Pre-Mit Risk (10^{-4})	Post-Mit Risk (10^{-4})	Incr Risk Red.	Pop # Exp	Est. Lives Saved	Mit.* Cost ($\$10^6$)	Incr* Cost of Alt.	CER
1	5.3	5.3	0	1200	0	0	0	0
2	5.3	3.1	2.3	1200	.27	24.27	24.27	1.12×10^{-8}
3	3.1	3.1	0	1200	0	25.68	1.41	0
4	3.1	3.1	0	1200	0	26.03	.35	0

* Rounded to the nearest .01

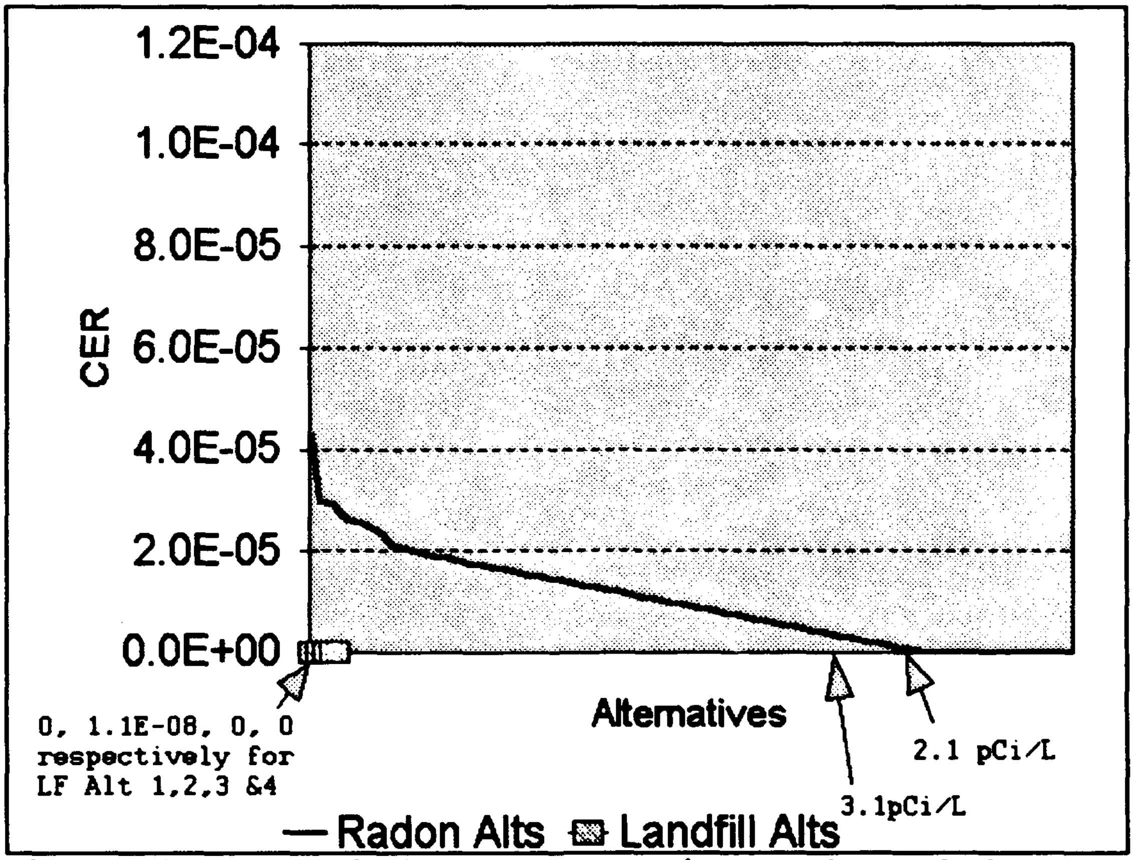

Figure 12. CERs of Cleanup Alternatives to be ranked

Task 3: Conduct Sensitivity Analysis. The sensitivity analysis concentrated on the variability of the slope factor. The sensitivity analysis on exposure concentrations will be omitted, because the linear nature of the formulae would produce similar results as varying the slope factors. Sensitivity analysis is useful to establish an understanding of how uncertainty affects the risk estimates and CERs. It is especially important if the CERs of alternatives are relatively close to each other. This information may justify readjustment of rank standings during the subjective evaluation.

For the sensitivity analysis, each slope factor was multiplied by an uncertainty factor to test the effect on the CER. Figures 13, 14, 15 and 16 illustrate the effect of varying the radon slope factor and the landfill chemical slope factors on the mitigation CER.

In reviewing Figures 13, 14, 15, and 16, two general patterns can be seen in the sensitivity analysis. First, if the exposure concentrations and the slope factors are large enough to establish a significant risk, then varying the slope factor has a substantial affect on the CER. This relationship can be seen in several circumstances. The most obvious example is variability of radon. The slope factor of radon (1.1×10^{-11} per pCi/L of cumulative lifetime exposure) and its corresponding exposure concentration are large enough to equate to a significant cancer risk. Figures 13 and 14 illustrate large fluctuations in the CERs

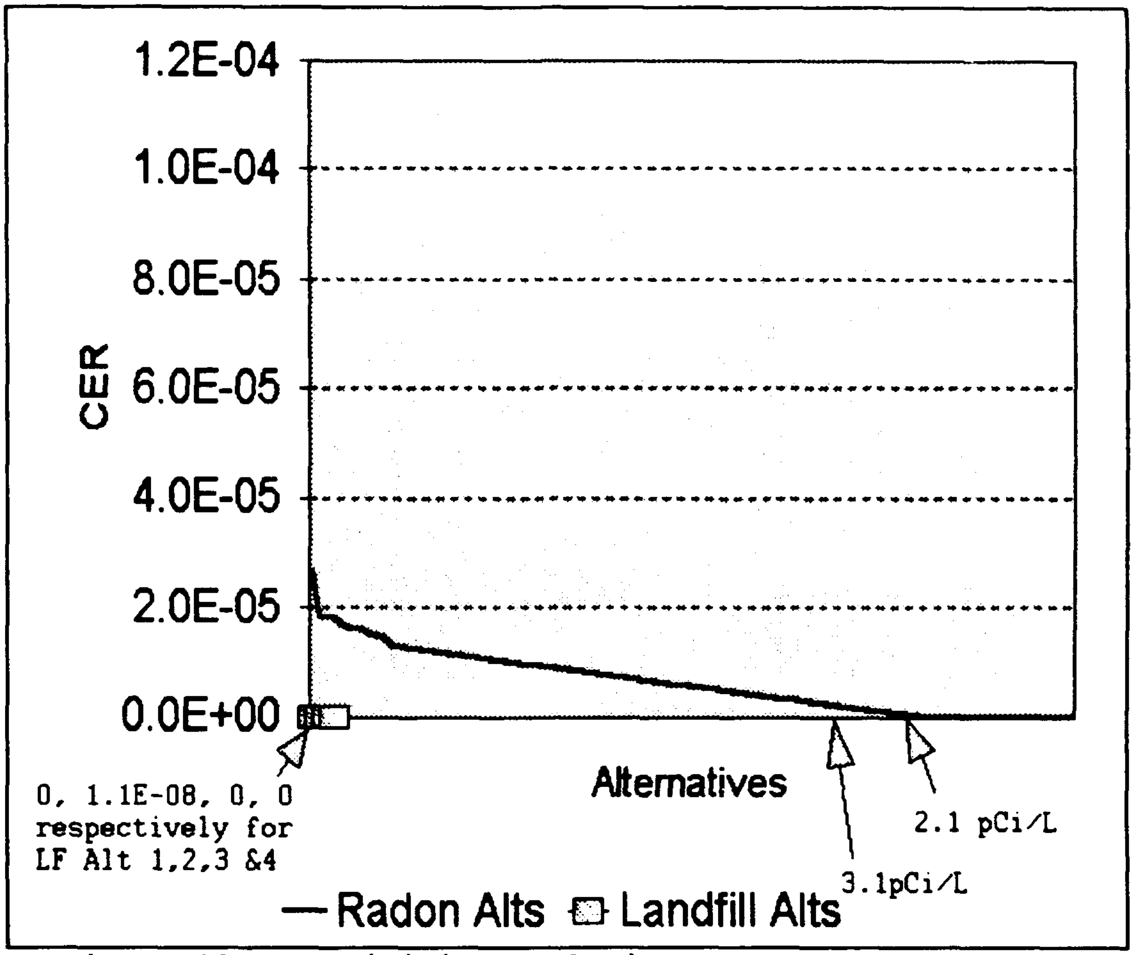

Figure 13. Sensitivity Analysis to Test the Affect of Decreasing the Radon Slope Factor by 27%

of radon mitigation as the radon slop factor is varied within a small range. This same pattern is illustrated Figure 15 and Figure 16 with the ingestion of arsenic, inhalation of 1,1,2-trichloroethane, and dermal exposure to benzo(a)pyrene. Figure 15 and Figure 16 also illustrate a second observation. Increasing the mitigation efficiencies increases the sensitivity of the CER to uncertainty in the slope factor.

Variability in the slope factors does not significantly enter into the analysis of these two sites, because of the CERs of radon mitigation are still larger than the CERs of landfill mitigations even in the sensitivity analysis. If the CERs of landfill mitigation had exceeded the CERs of radon mitigation in the sensitivity analysis, then the relationships would need closer study in the subjective analysis.

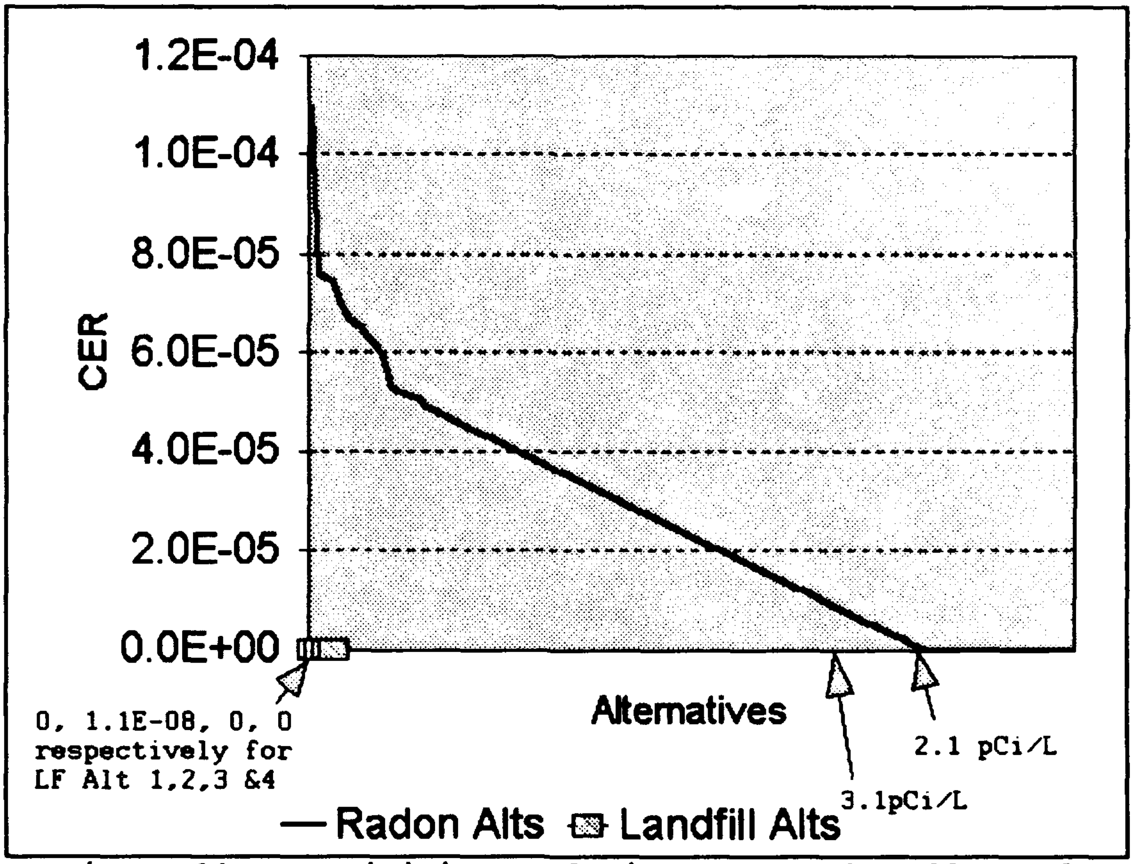

Figure 14. Sensitivity Analysis to Test the Affect of Increasing the Radon Slope Factor by 254%

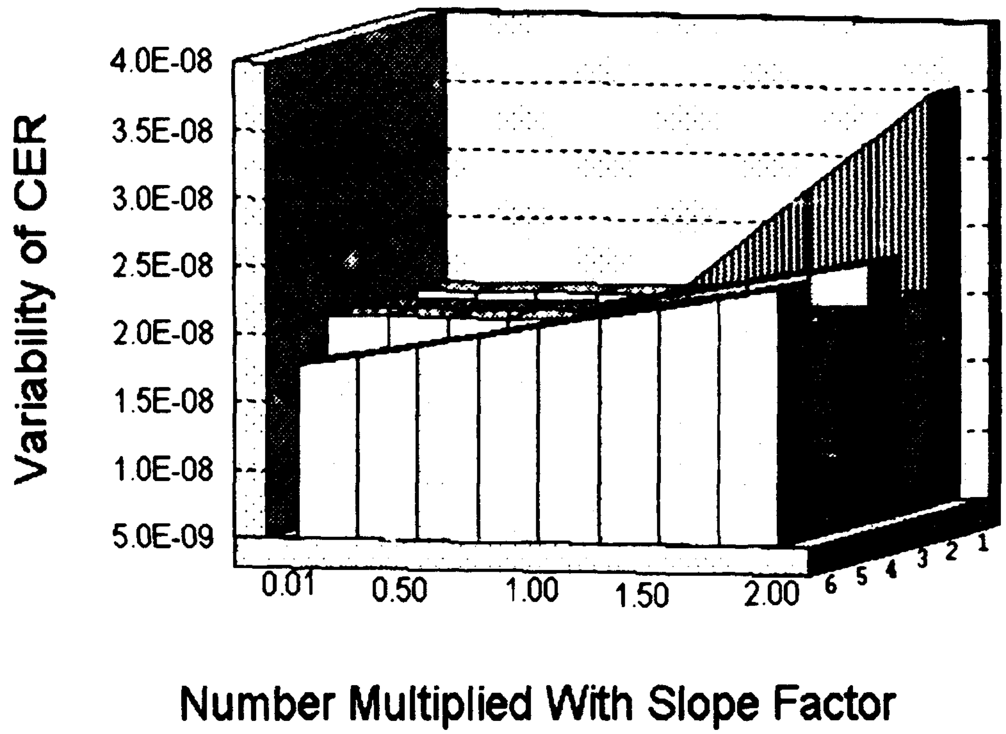

Figure 15. Sensitivity Analysis Testing the Affect of Changing Landfill Slope Factors on CERs (Ignoring Influence of Background Concentrations)

Key to Figure 15:

(1) = Ingestion route of Arsenic;

(2) = Ingestion route of Benzo(a)pyrene;

(3) = Inhalation route of 1,1,2-Trichloroethane;

(4) = Inhalation of Arsenic;

(5) = Dermal absorption of Arsenic;

(6) = Dermal Absorption of Benzo(a)pyrene.

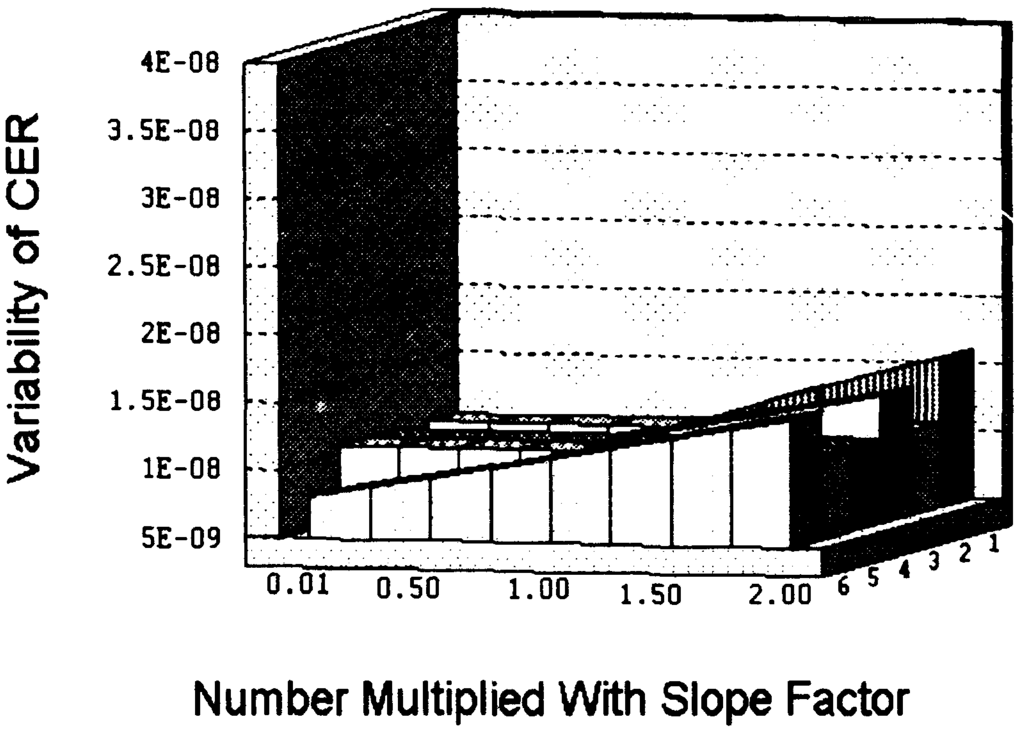

Figure 16. Sensitivity Analysis Testing the Affect of Increasing Landfill Slope Factors on CERs (Most Likely Mitigation Efficiencies)

Key to Figure 16:

(1) = Ingestion route of Arsenic;

(2) = Ingestion route of Benzo(a)pyrene;

(3) = Inhalation route of 1,1,2-Trichloroethane;

(4) = Inhalation of Arsenic;

(5) = Dermal absorption of Arsenic;

(6) = Dermal Absorption of Benzo(a)pyrene.

Step 3: Conduct Non-Risk Analysis. This step has only one task.

Task 1: Evaluate Subjective Factors Specific to the Site. For this task, the contractor will assemble all subjective factors applicable to the site. Tables 25 and 26 summarize the relevance of the subjective factors.

Table 25

Subjective Factors to Consider for Radon Mitigation Ranking

(Applies to All Radon Mitigation Alternatives)

Alternative	Subjective Factors
Do Nothing	- 15.5 additional cancers expected - Will not comply with EPA recommendations to mitigate - Will not comply with Air Force directive under RAMP to mitigate buildings over 4 pCi/L - Will not alarm public as much as man-made cancer hazards
Mitigate to 3.1 pCi/L	- Expect to save 13.6 lives - Will not alarm public as much as man-made cancer hazards - No ecological factors - Relatively little uncertainty
Mitigate to 2.0 pCi/L	- Expect to save 15.5 lives - There are no ecological factors

Table 26

Subjective Factors to Consider for Landfill 8 and 10

Mitigation Ranking

Alternative	Subjective Factors
Do Nothing (Alt 1)	- Expect .3 additional cancer - Degree of uncertainty is very large - May alarm the public - Will continue to contaminate the aquifer. - EPA may over-rule decision, because landfills 8 and 10 are on the NPL - Alternative will not meet any of the 9 NCP evaluation criteria - Alternative will not protect the health of the public
Implement Alternative 2	- Estimate to save .3 of a life - Degree of uncertainty is very large - Site will meet the 9 NCP evaluation criteria. - Small wetland on top of landfill may decrease in size - Poses additional risks to workers handling chemicals during the chemical oxidation process
Implement Alternative 3	- Same as alternative 2 except no risk to workers, because there is no chemical oxidation process
Implement Alternative 4	- Same as alternative 2 except no risk to workers, because there is no chemical oxidation process

<u>Step 4: Present to Decision-Makers for Ranking</u>. Step 4 consists of four tasks. If the SOW is properly written, all

of the CEM may be accomplished by the contractor up to this step.

Task 1: Rank Projects Based on Incremental CERs. During this task, the decision-makers rank the mitigation projects by applying the selection algorithm, as described in Chapter III, to Figure 12. In doing so, the decision-makers choose mitigation alternatives by passing a plane from the top of Figure 12. The alternative CERs which the plane passes first are ranked first. The result of this task is the creation of Table 27. For the purposes of this

Table 27

Illustrated Algorithm Output for Ranking

Site & Alternative	Incremental Cost	Budget Balance
Do Nothing	$0	$28,000,000
Mitigate Radon in MFH to 3.1 pCi/L	$1,720,012	$26,279,988
Mitigate Radon in MFH to 2.0 pCi/L	$1,184,142	$25,095,846
Implement Alt 2 to mitigate Landfills 8 & 10	$24,271,000	$824,846

thesis, a 28 million dollar budget is assumed. From Table 27, Table 28 is created. This table summarizes the ranking order resulting from the application of the ranking algorithm in Chapter III.

Table 28

Illustrated Preliminary Ranking Results for Funding

Prioritized Site	Prioritized Mitigation Alternative	Funding Amount
Radon in WPAFB MFH	Mitigate MFH Units at 3.1 pCi/L or higher	$1,720,012
Radon in WPAFB MFH	Mitigate MFH Units at 2.1 pCi/L or Higher	$1,184,142
Landfills 8 & 10	Alternative 2	$24,271,000

Task 2: Consider Subjective Factors. During this task, the decision maker weighs the subjective factors identified in step 3 and adjusts the ranking if necessary. Any adjustments must be documented and thoroughly justified for future reference.

Task 3: Hold Public Meeting. CERCLA (Section 121) requires the consideration of public comment prior to selecting the mitigation alternative.

Task 4: Final Ranking of Projects. After considering the CERs, subjective factors, and public comment, the decision maker may readjust the mitigation project ranking. Justification in writing of re-ranking is advised for future reference.

V. Conclusions and Recommendations for Further Study

Conclusion

The development of a methodology to rank mitigation projects to meet the two evaluation criteria established in Chapter 1 was achieved. The Cost Effectiveness Methodology (CEM) offers the decision maker the flexibility to rank projects across wide categories of risks (criteria 1) as well as rank mitigation projects first with the highest CERs (criteria 2).

In Chapter 2, the CEM was established as the best risk management method to prioritize mitigation projects for funding when compared to the two evaluation criteria. First, the cost-effectiveness technique, the precursor to the CEM, was compared to four other regulatory decision frameworks. The cost-effectiveness technique was the only model to meet both evaluation criteria. Furthermore, the CEM was compared with two current ranking methodologies used to rank hazardous waste sites. Again, the CEM was established as the only methodology to meet both evaluation criteria.

Next, Chapter 2 analyzed two vulnerabilities of the CEM. First, the CEM requires a thorough risk assessment to quantify site risks. This additional effort is a disadvantage over the EPA's application of the HRS after the Preliminary Risk Assessment. The Defense Priority Model shares this same disadvantage with the CEM. Second, because the CEM relies entirely on quantified risk estimates, it is vulnerable to errors when ranking mitigation projects with unequal degrees of uncertainty. Because the CEM can be applied to mitigation projects across wide categories of risks, the amount of uncertainty in risk estimates and cost-effectiveness ratios (CERs) is assured to vary.

The majority of the remainder of Chapter 2 studied sources of uncertainty in the risk assessment process to develop an understanding of the origins of uncertainty, because the CEM is vulnerable to biased uncertainty. This understanding of uncertainty is crucial if the risk analyst hopes to facilitate the comparability of risks among sites awaiting prioritization. Chapter II concluded with a brief discussion of the risk management process which serves as a road map for developing the CEM.

Once a foundation of understanding of the basic risk assessment and risk management processes was laid, as well as a development of understanding of the uncertainties inherent in the process in Chapter 2, Chapter 3 developed guidelines in applying the CEM. Designed into the CEM are measures to enhance conformance to the two evaluation criteria established in Chapter 1. These measures will help facilitate broader applicability and better comparability.

To validate the CEM, Chapter IV applied the CEM developed in Chapter III to two mitigation projects: mitigation of landfills 8 and 10 and the mitigation of high levels of radon gas in military family housing. The CEM recommended funding to mitigate radon in the military family housing to 2 pCi/L before any mitigation of Landfills 8 and 10. The risk assessment confirmed the national consensus that radon exposes more risk to people than landfills (7,000-30,000 deaths from indoor radon v.s. 40 deaths from exposure to landfill chemicals). In addition, the CEM demonstrated that mitigation of radon in the MFH at WPAFB can reduce the number of radon-caused cancers by 100 to 1000 times the number than mitigation of Landfills 8 and 10 will reduce the number of landfill-caused cancers. Comparing the size of the CERs of mitigation alternatives informs the decision makers of this observation.

The application of the CEM confirmed the external validity as well as the internal validity of the CEM. The application of the CEM to such diverse mitigation projects as mitigation of radon and mitigation of landfills adds evidence of CEM's external validity. External validity is the ability of generalize the experimental results to broader applications (Emory and Cooper, 427-428). The two sites were very much different from each other. The radon problem consisted of hundreds of individual sites contaminated from a naturally occurring radioactive element. On the other hand, the landfills were two sites emanating hazardous chemicals and considered a significant enough threat to be placed on the nation's national priority list. The application of the CEM to WPAFB does confirm that CEM prioritizes those mitigation projects that save the most lives per dollar and thereby confirms CEM's internal validity. Internal validity is achieved when conclusions drawn from a demonstrated experimental relationship imply cause (Emory and Cooper, 424-427). Inverting the CER demonstrates the intuitiveness of the CEM. Inverting the ratio changes lives saved per dollar spent to dollars spent per life saved. A methodology that will guarantee fewer dollars spent to save a life is a desirable goal.

Significance of CEM Development

The CEM, as developed in this thesis, is an excellent management tool for decision-makers who have the responsibility to choose mitigation actions for environmentally contaminated sites, prioritize contaminated sites for cleanup, and allocate funds to projects with a limited budget.

The CEM approaches the mitigation prioritization process with a new way of thinking. Where current prioritization methods rank contaminated sites exposing the most risk to a population, the CEM ranks those alternatives first that save the most lives per dollar. This new approach allocates mitigation funds in a more efficient manner; thereby, reducing the total cancer risk to a population more effectively. There are two benefits--less total cancer risk to society and more money available to spend cleaning up more sites.

Also revolutionary in the application of the CEM is the method by which the mitigation alternative for a site is selected. Contrary to the traditional CERCLA process of selecting the mitigation alternative after the RI/FS, the decision-maker, in the CEM, selects mitigation actions from a collection of unfunded competing projects. Those cleanup projects not selected will compete in future years when more funding become available. This procedure helps ensure that mitigation funding will be applied where it will have the most effect.

Recommendations for Further Study

The development of the CEM fosters many avenues for further research. Further research can be applied to four broad improvement areas: increasing the validity of the CEM, improving the efficiency of applying the CEM, strengthening inherent weaknesses of the methodology, and widening the applicability of the CEM.

The first improvement area covers the realm of improving the model validity. Although the application of the CEM demonstrated some external validity of the model, the CEM needs more and broader test applications to give it more external validity and credibility. Perhaps some applications to rank projects to mitigate sites characterized by leaking underground storage tanks, fuel spills, or asbestos in buildings may be good application tests. Incorporation of simulation models to test CEM's capability to save lives with other prioritization methodologies would best document the CEM's superior prioritization results.

The second area with potential for improvement is efficiency of model application. To facilitate the efficiency of applying the CEM, several new techniques could be incorporated into the methodology. To assist manual analysis, new tables could be developed to expedite calculating CERs. There may be a more efficient algorithm for which to rank projects given their CERs. Significant improvements in the efficiency of applying the CEM can be realized by automating the analysis with a computer program.

A third area for further research is the development of techniques to strengthen apparent weaknesses of the CEM. The first weakness was the necessity to delay the application of the CEM until the RI/FS was completed. Since preliminary assessments (PA) generally project risks, the CEM may be legitimately applied earlier in the risk analysis process. The difficulty lies in the large degree of uncertainty characterized in the PA risk estimate. As previously discussed, the CEM is sensitive to differences of uncertainty among mitigation projects. Large uncertainties of PA risk estimates and smaller uncertainties of RA risk estimates pose a challenge in applying the CEM earlier in the risk assessment process. Uncertainty also exists after the PA/SI concerning mitigation costs. Feasible mitigation actions and costs will not be known yet. The second weakness concerns the sensitivity of the CEM to differences of uncertainty among hazardous sites. Research is needed to develop more techniques to enhance methodological consistency and comparability of risks so bias can be reduced to a minimum between sites. If site risks can be rendered more comparable, then the CEM will be a more accurate and useful ranking tool.

In addition to all of these areas for further research, there is another very unique opportunity to apply the CEM--ranking pollution prevention projects. This application would follow a similar procedure as outlined in Chapter III. Estimates of risk aversion could be correlated to pollution prevention alternatives. Once a method could be established, pollution prevention cost estimates would be an elementary procedure. The ratio of risk averted to cost would establish an CER. Pollution prevention projects could then be ranked as mitigation projects were in this thesis. Eventually, mitigation projects could compete for funding using the CEM.

Appendix A: Definition of Terms

Air Staff - Headquarters, United States Air Force

Chronic Daily Intake - Average daily dose taken over an assumed 70 year lifetime (Masters, 1991:204)

Conservative - Selection of assumptions, parameter estimates, models, or procedures that are designed to ensure that resulting estimates of health risks are unlikely to be understated (Maxim, 1989:527)

Ecological Effects - Effects on natural ecosystems that result in habitat modification and environmental pollution (EPA, 1987c:6).

Ecosystem - The complex of a community and its environment functioning as an ecological unit in nature (G. & C. Merriam Company, 1975:360)

Hazardous Waste - A waste is considered hazardous if it exhibits any of the characteristics such as ignitability, reactivity, corrosivity, or EP toxicity (Wentz, 1989:89)

Health Effects Assessment Summary Tables (HEAST) - EPA reference that contains cancer slope factors

Integrated Risk Information System (*IRIS*) - EPA database of information on toxic substances (Masters, 1991:204).

MAJCOM - (Major Command) Air Force organizational structure located above the base level and under the Headquarters, United States Air Force.

Model - A representation of a system which is constructed for the purpose of studying some aspect of that system or the system as a whole (Emory and Cooper, 1991:63).

Micro-economics - Cost determination through the supply and demand relationship is the basis of micro-economics (Aldrich, 1992:6).

Mitigate - Procedure to correct or clean up an environmental hazard

Non-cancer health risks - Numerous adverse health effects in addition to cancer from toxic substances in the environment. These adverse effects can range from acute to chronic symptoms (EPA, 1987c:6).

pCi/L - Decay rate in picocuries per liter (1 pCi/L is equal to 1 radon disintegration every 27 seconds in one liter of air) (EPA, undated:G1-G12)

Radon - A colorless, naturally occurring, radioactive, inert gaseous element formed by radioactive decay of radium atoms. Chemical symbol is Rn, atomic number is 86 (EPA, 1987b:12).

Risk - Chance of cancer developing due to exposure from an environmental hazard during a specified period of time. Time period is 70 years unless otherwise specified.

Risk Agent - Chemical substance, biological organism, radioactive material, or other potentially hazardous substance or activity (Cohrssen and Covello, 1989:371).

Risk Assessment - A component of risk analysis referring to the strict technical assessment of the nature and magnitude of risk (Cohrssen and Covello, 1989:5).

Risk Analysis - A process to technically assess the nature and magnitude of risk plus methods to investigate the best use of the resulting information (Cohrssen and Covello, 1989:1).

Risk Management - The use of information from risk assessment and analysis together with information about technical resources, social, economic, and political values, and control or response options to determine means of reducing or eliminating risk (Cohrssen and Covello, 1989:2).

Slope Factor - The slope of the dose-response curve produced by a risk estimating model. Slope factors can also be interpreted as the risk produced by a lifetime average daily dose of 1 mg/kg/day (Masters, 1991:204).

Welfare Effects - Includes a variety of damages to property, goods and services or activities to which monetary value can often be assigned. Damage occurs to natural resources, recreation areas, materials, aesthetic values, and public and commercial property (EPA, 1987c:6).

Working Level (WL) - any combination of short-lived radon decay products that will result in the emission of 1.3 x 10 exponent 5 MeV of alpha energy per liter of air; the energy released by 100 pCi/L of radon in equilibrium with its decay products. (EPA, undated:G1-G12)

Working Level Month (WLM) - originally defined as the expected radiation absorbed by uranium miners during one month of work. Now defined as exposure to the equivalent of 100 pCi/L for 170 hours (EPA, undated:G1-G12).

Appendix B: Toxicity Values

TOXICITY VALUES (1)

CAS No.	Chemical	Toxicity Class 2	CAG Group 3	Ingestion RfD (mg/kg-d)	Ingestion SF (kg-d/mg)	Inhalation RfC (mg/m³)	Inhalation Unit Risk (m³/µg)
Volatile Analytes							
74-87-3	Chloromethane	C	C	UR	1.30E-02 *	UR	1.80E-06 *
75-01-4	Vinyl Chloride	C	A	NR	1.90E+00 *	NR	8.40E-05 *
75-00-3	Chloroethane	NC	NR	NR	-	1.00E+01	-
75-09-2	Methylene Chloride	C	B2	6.00E-02	7.50E-03	3.00E+00 *	4.70E-07
67-64-1	Acetone	NC	D	1.00E-01	-	NR	-
75-15-0	Carbon Disulfide	NC	NR	1.00E-01	-	1.00E-02 *	-
75-35-4	1,1-Dichloroethene	C	C	9.00E-03	6.00E-01	UR	5.00E-05
75-34-3	1,1-Dichloroethane	C	C	1.00E-01 *	NR	5.00E-01 *	NR
156-59-2	cis-1,2-Dichloroethene	NC	D	1.00E-02 *	-	NR	-
156-60-5	trans 1,2-Dichloroethene	NC	NR	2.00E-02	-	NR	-
67-66-3	Chloroform	C	B2	1.00E-02	6.10E-03	UR	2.30E-05
107-06-2	1,2-Dichloroethane	C	B2	NR	9.10E-02	NR	2.60E-05
78-93-3	2-Butanone	NC	D	5.00E-02 *	-	1.00E+00	-
71-55-6	1,1,1-Trichloroethane	NC	D	9.00E-02 *	-	1.00E+00 *	-
75-27-4	Bromodichloromethane	C	B2	2.00E-02	6.20E-02	NR	NR
78-87-5	1,2-Dichloropropane	C	B2	NR	6.80E-02 *	4.00E-03	NR
79-01-6	Trichloroethene	C	NR	UR	1.10E-02 **	UR	1.70E-06 **
124-48-1	Dibromochloromethane	C	C	2.00E-02	8.40E-02	NR	NR
79-00-5	1,1,2-Trichloroethane	C	C	4.00E-03	5.70E-02	UR	1.60E-05
71-43-2	Benzene	C	A	UR	2.90E-02	UR	8.30E-06
75-25-2	Bromoform	C	B2	2.00E-02	7.90E-03	UR	1.10E-06
108-10-1	4-Methyl-2-Pentanone	NC	NR	5.00E-02 *	-	8.00E-02 *	-
591-78-6	2-Hexanone	U	NR	NR	-	NR	-
127-18-4	Tetrachloroethene	C	NR	1.00E-02	5.20E-02 **	NR	5.80E-07 **
108-88-3	Toluene	NC	D	2.00E-01	-	4.00E-01	-
108-90-7	Chlorobenzene	NC	D	2.00E-02	-	2.00E-02 *	-

1 of 6

(Engineering-Science, Inc.,1993:Table 6.4.1)

TOXICITY VALUES (1)

CAS No.	Chemical	Toxicity Class 2	CAG Group 3	Ingestion RfD (mg/kg-d)	Ingestion SF (kg-d/mg)	Inhalation RfC (mg/m³)	Inhalation Unit Risk (m³/µg)
Volatile Analytes (Cont.)							
100-41-4	Ethylbenzene	NC	D	1.00E-01	-	1.00E+00	-
100-42-5	Styrene	NC	NR	2.00E-01	-	1.00E+00	-
1330-20-7	Xylene (Total)	NC	D	2.00E+00	-	NV *	-
108-05-4	Vinyl Acetate	NC	UR	1.00E+00 *	-	2.00E-01	-
75-18-3	Dimethyl Sulfide	U	NR	NR	-	NR	-
7783-06-4	Hydrogen Sulfide	NC	NR	3.00E-03	-	9.00E-04	-
56-23-5	Carbon Tetrachloride	C	B2	7.00E-04	1.30E-01	NR	1.50E-05
Semi-Volatile Analytes							
108-95-2	Phenol	NC	D	6.00E-01	-	NV	-
106-46-7	1,4-Dichlorobenzene	C	C	NR	2.40E-02 *	7.00E-01 *	NR
106-44-5	4-Methylphenol	C	C	5.00E-03 *#	NR	NV	NR
95-48-7	2-Methylphenol	C	C	5.00E-02	NR	NV	NR
98-95-3	Nitrobenzene	NC	D	5.00E-04	-	2.00E-03 *	-
78-59-1	Isophorone	C	C	2.00E-01	9.50E-04	NV	NR
105-67-9	2,4-Dimethylphenol	NC	NR	2.00E-02	-	NR	-
91-20-3	Naphthalene	NC	D	4.00E-02 *	-	NR	-
91-57-6	2-Methylnaphthalene	U	NR	NR	-	NR	-
59-50-7	4-Chloro-3-methylphenol	NC	NR	UR	-	UR	-
77-47-4	Hexachlorocyclopentadiene	NC	D	7.00E-03	-	7.00E-05 *	-
131-11-3	Dimethylphthalate	NC	D	1.00E+01 *	-	NV	-
208-96-8	Acenaphthylene	NC	D	UR	-	NR	-
83-32-9	Acenaphthene	NC	NR	6.00E-02	-	NR	-
132-64-9	Dibenzofuran	NC	D	NR	-	UR	-
84-66-2	Diethylphthalate	NC	D	8.00E-01	-	NR	-
86-73-7	Fluorene	NC	D	4.00E-02	-	NR	-

2 of 6

(Engineering-Science, Inc.,1993:Table 6.4.1)

Appendix B (Continued): Toxicity Values

TOXICITY VALUES (1)

CAS No.	Chemical	Toxicity Class [2]	CAG Group [3]	Ingestion RfD (mg/kg-d)	Ingestion SF (kg-d/mg)	Inhalation RfC (mg/m³)	Inhalation Unit Risk (m³/µg)
Semi-Volatile Analytes (Cont.)							
86-30-6	N-Nitrosodiphenylamine	C	B2	NR	4.90E-03	NR	NR
87-86-5	Pentachlorophenol	C	B2	3.00E-02	1.20E-01	UR	NR
85-01-8	Phenanthrene	NC	D	NR	-	NR	-
120-12-7	Anthracene	NC	D	3.00E-01	-	NR	-
86-74-8	Carbazole	C	B2	NR	2.00E-02 *	NR	NR
84-74-2	Di-n-butylphthalate	NC	D	1.00E-01	-	NV	-
206-44-0	Fluoranthene	NC	D	4.00E-02	-	NR	-
129-00-0	Pyrene	NC	D	3.00E-02	-	NR	-
85-68-7	Butylbenzylphthalate	C	C	2.00E-01	NR	NR	NR
56-55-3	Benzo(a)anthracene	C	B2	NR	1.06E+00 [4]	NR	2.47E-04 [4] *
218-01-9	Chrysene	C	B2	NR	3.21E-02 [4]	NR	7.48E-06 [4] *
117-81-7	bis(2-Ethylhexyl)phthalate	C	B2	2.00E-02	1.40E-02	NR	NR
117-84-0	Di-n-octylphthalate	NC	NR	2.00E-02 *	-	NR	-
205-99-2	Benzo(b)fluoranthene	C	B2	NR	1.02E+00 [4]	NR	2.38E-04 [4] *
207-08-9	Benzo(k)fluoranthene	C	B2	NR	4.82E-01 [4]	NR	1.12E-04 [4] *
50-32-8	Benzo(a)pyrene	C	B2	NR	7.30E+00	NR	1.70E-03 *
193-39-5	Indeno(1,2,3-cd)pyrene	C	B2	NR	1.69E+00 [4]	NR	3.94E-04 [4] *
53-70-3	Dibenz(a,h)anthracene	C	B2	NR	8.10E+00 [4]	NR	1.89E-03 [4] *
191-24-2	Benzo (g,h,i)perylene	NC	D	NR	-	NR	-
65-85-0	Benzoic Acid	NC	D	4.00E+00	-	NR	-
Metal Analytes							
7440-36-0	Antimony	NC	NR	4.00E-04	-	NR	-
7440-38-2	Arsenic	C	A	3.00E-04	1.75E+00 [5]	NR	4.30E-03
7440-39-3	Barium	NC	NR	7.00E-02	-	5.00E-04 *	-
7440-41-7	Beryllium	C	B2	5.00E-03	4.30E+00	NR	2.40E-03

3 of 6

(Engineering-Science, Inc.,1993:Table 6.4.1)

TOXICITY VALUES (1)

CAS No.	Chemical	Toxicity Class 2	CAG Group 3	Ingestion RfD (mg/kg-d)	Ingestion SF (kg-d/mg)	Inhalation RfC (mg/m³)	Inhalation Unit Risk (m³/µg)
Metal Analytes (Cont.)							
7440-43-9	Cadmium	C	B1	5.00E-04 #	NR	UR	1.80E-03
16065-83-1	Chromium (III)	NC	NR	1.00E+00	-	UR	-
7440-47-3	Chromium (VI)	C	A	5.00E-03	NR	UR	1.20E-02
7440-48-4	Cobalt	NC	NR	UR	-	NR	-
7440-50-8	Copper	NC	D	4.00E-02 6 *	-	NR	-
7439-92-1	Lead	C	B2	NR	NR	NR	NR
7439-96-5	Manganese	NC	D	5.00E-03 #	-	4.00E-04	-
7439-97-6	Mercury	NC	D	3.00E-04 *	-	3.00E-04 *	-
7440-02-0	Nickel	NC	NR	2.00E-02	-	UR	-
7782-49-2	Selenium	NC	D	5.00E-03	-	NR	-
7440-22-4	Silver	NC	D	5.00E-03	-	NR	-
7440-28-0	Thallium	U	NR	NR	-	NR	-
7440-61-1	Uranium	NC	NR	3.00E-03	-	NR	-
7440-62-2	Vanadium	NC	NR	7.00E-03 *	-	NR	-
7440-66-6	Zinc	NC	D	3.00E-01	-	NR	-
57-12-5	Cyanide	NC	D	2.00E-02	-	NR	-
Pesticide/PCB Analytes							
319-84-6	alpha-BHC	C	B2	NR	6.30E+00	NR	1.80E-03
319-86-8	delta-BHC	NC	D	NR	-	NR	-
58-89-9	gamma-BHC (Lindane)	C	B2-C	3.00E-04	1.30E+00 *	UR	NR
76-44-8	Heptachlor	C	B2	5.00E-04	4.50E+00	NR	1.30E-03
309-00-2	Aldrin	C	B2	3.00E-05	1.70E+01	NR	4.90E-03
1024-57-3	Heptachlor epoxide	C	B2	1.30E-05	9.10E+00	NR	2.60E-03
60-57-1	Dieldrin	C	B2	5.00E-05	1.60E+01	NR	4.60E-03
72-55-9	4,4'-DDE	C	B2	NR	3.40E-01	NR	NR

4 of 6

(Engineering-Science, Inc.,1993:Table 6.4.1)

Appendix B (Continued): Toxicity Values

TOXICITY VALUES (1)

CAS No.	Chemical		Toxicity Class [2]	CAG Group [3]	Ingestion RfD (mg/kg-d)	Ingestion SF (kg-d/mg)	Inhalation RfC (mg/m³)	Inhalation Unit Risk (m³/μg)
Pesticide/PCB Analytes (Cont.)								
72-20-8	Endrin		NC	D	3.00E-04	-	NR	-
33213-65-9	Endosulfan II	7	NC	NR	NR	-	NR	-
72-54-8	4,4'-DDD		C	B2	NR	2.40E-01	NR	NR
50-29-3	4,4'-DDT		C	B2	5.00E-04	3.40E-01	NR	9.70E-05
72-43-5	Methoxychlor		NC	D	5.00E-03	-	NV	-
53494-70-5	Endrin ketone		U	NR	NR	-	NR	-
5103-71-9	alpha-Chlordane	8	C	B2	6.00E-05	1.30E+00	UR	3.70E-04
5103-74-2	gamma-Chlordane	8	C	B2	6.00E-05	1.30E+00	UR	3.70E-04
11097-69-1	Aroclor-1254	9	C	B2	7.00E-05	7.70E+00	NR	NR
11096-82-5	Aroclor-1260	9	C	B2	7.00E-05	7.70E+00	NR	NR
Herbicide Analytes								
1918-00-9	Dicamba		NC	NR	3.00E-02	-	NR	-
94-75-7	2,4-D		NC	NR	1.00E-02	-	NR	-
94-74-6	MCPA		NC	NR	5.00E-04	-	NR	-
93-72-1	2,4,5-TP (Silvex)		NC	D	8.00E-03	-	NR	-
Wet Chemistry Analytes								
7664-41-7	Ammonia		NC	NR	1.00E+00 *	-	1.00E-01	-
7782-41-4	Fluoride		NC	NR	6.00E-02	-	NR	-
14797-558	Nitrate		NC	NR	1.60E+00	-	NR	-
14797-65-0	Nitrite		NC	NR	1.00E-01	-	NR	-
Dioxin Analytes								
51207-31-9	2,3,7,8-TCDF		C	NR	NR	1.50E+04 10 *	NR	3.30E+00 10 *
1746-01-6	2,3,7,8-TCDD		C	B2	NR	1.50E+05 *	NR	3.30E+01 11 *

5 of 6

(Engineering-Science, Inc.,1993:Table 6.4.1)

TOXICITY VALUES (1)

CAS No.	Chemical	Toxicity Class 2	CAG Group 3	Ingestion RfD (mg/kg-d)	Ingestion SF (kg-d/mg)	Inhalation RfC (mg/m³)	Inhalation Unit Risk (m³/µg)
Dioxin Analytes (Cont.)							
19408-74-3	1,2,3,7,8,9-HXCDD	C	B2	NR	6.20E+03	NR	1.30E+00
67562-39-4	1,2,3,4,6,7,8-HPCDF	C	NR	NR	1.50E+03 12 *	NR	3.30E-01 12 *
35822-46-9	1,2,3,4,6,7,8-HPCDD	C	NR	NR	1.50E+03 12 *	NR	3.30E-01 12 *
39001-02-0	1,2,3,4,6,7,8,9-OCDF	C	NR	NR	1.50E+02 12 *	NR	3.30E-02 12 *
3268-87-9	1,2,3,4,6,7,8,9-OCDD	C	NR	NR	1.50E+02 12 *	NR	3.30E-02 12 *

1. From IRIS (USEPA, 1993). When IRIS values were unavailable, HEAST (USEPA, 1992b) was used. An asterisk (*) indicates that values were taken from HEAST and an asterisk-pound sign (*#) indicates values taken from the July 1992 update of HEAST (USEPA, 1992c). RfD = reference dose, RfC = reference concentration, SF = slope factor, NR = not reported, UR = under review, NV = non-verifiable. A dash (-) indicates that this item is not applicable, or that there is no entry in either IRIS or HEAST. A double asterisk (**) indicates values from USEPA Superfund Technical Support (USEPA 1992d). A pound sign (#) indicates that two RfD values are available for cadmium and manganese and the most conservative value is presented.
2. NC = noncarcinogen; C = carcinogen; U = unable to assess carcinogenic potential.
3. CAG = USEPA Carcinogen Assessment Group (See text).
4. The slope factors and unit risks for the carcinogenic PAHs were derived by multiplying the slope factor and unit risk for benzo(a)pyrene by the following toxicity equivalency factors: 0.145 for benzo(a)anthracene, 0.14 for benzo(b)fluoranthene, 0.066 for benzo(k)fluoranthene, 1.11 for dibenzo(a,h) anthracene, 0.0044 for chrysene and 0.232 for indeno(1,2,3-cd)pyrene (USEPA 1988d).
5. The slope factor for arsenic is calculated from an oral unit risk of 5E-05 (L/ug).
6. The RfD for copper was calculated from a value of 1.3 mg/L, cited in HEAST.
7. The toxicity values are for endosulfan (CAS No. 115-29-7).
8. The toxicity values are for chlordane (CAS No. 57-74-9).
9. The slope factor is for PCBs (CAS No. 1336-36-3) and the RfD is for Aroclor-1016 (CAS No. 12674-11-2).
10. The slope factor and unit risk for 2,3,7,8-TCDF were derived by multiplying the unit risk for 2,3,7,8-TCDD by a toxic equivalency factor of 0.1 (USEPA, 1989b).
11. The slope factor and unit risk for 2,3,7,8-TCDD were calculated from a unit risk of 3.3E-05 (m3/pg), cited in HEAST.
12. The slope factors and unit risks for these dioxins were derived by multiplying the slope factor and unit risk for 2,3,7,8-TCDD by a toxicity equivalency factor of 0.01 for HPCDF and HPCDD and a factor of 0.001 for OCDF and OCDD (USEPA, 1989f).

(Engineering-Science, Inc.,1993:Table 6.4.1)

Appendix C: Assumed Exposure Values for Landfills 8 and 10

Exposure Pathway: Ingestion of Drinking Water (Current Land Use)		
Parameter	Off-Site Adult Resident	Off-Site Child Resident
Ingestion Rate (L/day)	2	1
Body Weight (kg)	70	15
Exposure Frequency (days/yr)	350	350
Exposure Duration (yrs)	24	6
Averaging Time (days)	25,550	25,550

(Engineering-Science, Inc.,1993:Table 6.3.19)

Exposure Pathway: Ingestion of Soil (Current Land Use)		
Parameter	Off-Site Adult Resident	Off-Site Child Resident
Ingestion Rate (mg/day)	480	N/A
Body Weight (kg)	70	N/A
Exposure Frequency (days/yr)	26	N/A
Exposure Duration (yrs)	8	N/A
Averaging Time (days)	25,550	N/A

(Engineering-Science, Inc.,1993:Table 6.3.19)

Appendix C (Continued): Assumed Exposure Values for Landfills 8 and 10

Exposure Pathway: Ingestion of Sediment (Current Land Use)		
Parameter	Off-Site Adult Resident	Off-Site Child Resident
Ingestion Rate (mg/day)	480	N/A
Body Weight (kg)	70	N/A
Exposure Frequency (days/yr)	26	N/A
Exposure Duration (yrs)	8	N/A
Averaging Time (days)	25,550	N/A

(Engineering-Science, Inc.,1993:Table 6.3.19)

Exposure Pathway: Ingestion of Fruits Contaminated by Irrigation/Soil (Current Land Use)		
Parameter	Off-Site Adult Resident	Off-Site Child Resident
Ingestion Rate (g/day)	42	9
Body Weight (kg)	70	15
Exposure Frequency (days/yr)	350	350
Exposure Duration (yrs)	24	6
Averaging Time (days)	25,550	25,550

(Engineering-Science, Inc.,1993:Table 6.3.19)

Appendix C (Continued): Assumed Exposure Values for Landfills 8 and 10

Exposure Pathway: Ingestion of Vegetables Contaminated by Irrigation/Soil (Current Land Use)		
Parameter	Off-Site Adult Resident	Off-Site Child Resident
Ingestion Rate (g/day)	80	17
Body Weight (kg)	70	15
Exposure Frequency (days/yr)	350	350
Exposure Duration (yrs)	24	6
Averaging Time (days)	25,550	25,550

(Engineering-Science, Inc., 1993:Table 6.3.19)

Exposure Pathway: Inhalation of Vapors While Showering (Current Land Use)		
Parameter	Off-Site Adult Resident	Off-Site Child Resident
Inhalation Rate (m^3/hour)	.6	N/A
Body Weight (kg)	70	N/A
Exposure Frequency (days/yr)	350	N/A
Exposure Duration (minutes)	12	N/A
Exposure Duration (yrs)	24	N/A
Averaging Time (days)	25,550	N/A

(Engineering-Science, Inc., 1993:Table 6.3.19)

Appendix C (Continued): Assumed Exposure Values for Landfills 8 and 10

Exposure Pathway: Inhalation of Indoor Air (Current Land Use)		
Parameter	Off-Site Adult Resident	Off-Site Child Resident
Inhalation Rate (m^3/day)	15.6	13.4
Body Weight (kg)	70	15
Exposure Frequency (days/yr)	350	350
Exposure Duration (yrs)	24	6
Averaging Time (days)	25,550	25,550

(Engineering-Science, Inc.,1993:Table 6.3.19)

Exposure Pathway: Inhalation of Ambient Air (Current Land Use)		
Parameter	Off-Site Adult Resident	Off-Site Child Resident
Inhalation Rate (m^3/day)	4.4	3.3
Body Weight (kg)	70	15
Exposure Frequency (days/yr)	350	350
Exposure Duration (yrs)	24	6
Averaging Time (days)	25,550	25,550

(Engineering-Science, Inc.,1993:Table 6.3.19)

Appendix C (Continued): Assumed Exposure Values for Landfills 8 and 10

Exposure Pathway: Dermal Exposure to Soil (Current Land Use)		
Parameter	Off-Site Adult Resident	Off-Site Child Resident
Contact Surface Area (cm^2/event)	5,000	N/A
Body Weight (kg)	70	N/A
Soil-Skin Adherence Factor (mg/cm^2)	1.0	N/A
Exposure Time (hrs/event)	4	N/A
Exposure Frequency (events/yr)	26	N/A
Exposure Duration (yrs)	8	N/A
Averaging Time (days)	25,550	N/A

(Engineering-Science, Inc.,1993:Table 6.3.19)

Appendix C (Continued): Assumed Exposure Values for Landfills 8 and 10

Exposure Pathway: Dermal Exposure to Sediment (Current Land Use)		
Parameter	Off-Site Adult Resident	Off-Site Child Resident
Contact Surface Area (cm^2/event)	5,000	N/A
Body Weight (kg)	70	N/A
Soil-Skin Adherence Factor (mg/cm^2)	1.0	N/A
Exposure Time (hrs/event)	4	N/A
Exposure Frequency (events/yr)	26	N/A
Exposure Duration (yrs)	8	N/A
Averaging Time (days)	25,550	N/A

(Engineering-Science, Inc.,1993:Table 6.3.19)

Appendix C (Continued): Assumed Exposure Values for Landfills 8 and 10

Exposure Pathway: Dermal Exposure to Water While Showering/Bathing (Current Land Use)		
Parameter	Off-Site Adult Resident	Off-Site Child Resident
Contact Surface Area (cm^2)	20,000	7,200
Body Weight (kg)	70	15
Exposure Frequency (events/yr)	350	350
Exposure Duration (yrs)	24	6
Averaging Time (days)	25,550	25,550

(Engineering-Science, Inc.,1993:Table 6.3.19)

Exposure Pathway: Dermal Exposure to Surface Water (Current Land Use)		
Parameter	Off-Site Adult Resident	Off-Site Child Resident
Contact Surface Area (cm^2)	5,000	N/A
Body Weight (kg)	70	N/A
Exposure Time - Splashing (hrs/event)	2.6	N/A
Exposure Frequency (days/yr)	26	N/A
Exposure Duration (yrs)	8	N/A
Averaging Time (days)	25,550	N/A

(Engineering-Science, Inc.,1993:Table 6.3.19)

Appendix C (Continued): Assumed Exposure Values for Landfills 8 and 10

Exposure Pathway: Dermal Contact to Leachate Water (Current Land Use)		
Parameter	Off-Site Adult Resident	Off-Site Child Resident
Contact Surface Area (cm^2)	5,000	N/A
Body Weight (kg)	70	N/A
Exposure Time (hrs/event)	2.6	N/A
Exposure Frequency (days/yr)	26	N/A
Exposure Duration (yrs)	8	N/A
Averaging Time (days)	25,550	N/A

(Engineering-Science, Inc.,1993:Table 6.3.19)

Effective Values (Considering 6 yrs as a child & 24 yrs as an adult)	
Effective Drinking Intake Rate (L/day)	1.8
Effective Fruit Intake Rate (kg/day)	0.0354
Effective Vegetables Intake Rate (kg/day)	0.0674
Effective Ambient Air Inhalation Rate (m^3/day)	4.18
Effective Whole Body Skin Area (cm^2)	17,440
Effective Body Weight (kg)	59

Appendix D: Subjective Summarization of Uncertainties Surrounding Study of Landfills 8 and 10

SUMMARY OF UNCERTAINTIES ASSOCIATED WITH THE BASELINE RISK ASSESSMENT
AT WPAFB LANDFILLS 8 AND 10

CATEGORY	ANALYSIS	UNCERTAINTY FACTOR	EFFECT OF UNCERTAINTY ON HAZARDS AND RISKS	COMMENT
HUMAN HEALTH CHEMICAL RISK ASSESSMENT	Target Analyte Analysis			
	Data Evaluation:	Data collection plan	May overestimate	Samples taken from areas known to be contaminated, therefore, samples not random. This results in uncertainty in the statistics used to quantitate the data.
		Reliability of data flagged during data validation	May over- or underestimate	Estimated concentrations of chemicals were used in the quantitative evaluation.
		Identification of chemicals of concern	May underestimate	Chemicals not detected during sampling may have been present at levels below the detection limit.
			May overestimate	Chemicals were included in evaluation even when only detected in one sample.
		Chemical form of metals not known	May over- or underestimate	Various forms of metals have different toxicities.
		Use of 95% UCL	May overestimate	The 95% UCL is a value well above average site concentrations.
		Retention of metals for assessment	May overestimate	All metals were evaluated, regardless of whether they may be indicative of background.

1 of 8

Rev. No. 1, 11 June 1993

(Engineering-Science, Inc.,1993:Table 6.8.1)

Appendix D (Continued): Subjective Summarization of Uncertainties Surrounding Study of Landfills 8 and 10

SUMMARY OF UNCERTAINTIES ASSOCIATED WITH THE BASELINE RISK ASSESSMENT AT WPAFB LANDFILLS 8 AND 10

CATEGORY	ANALYSIS	UNCERTAINTY FACTOR	EFFECT OF UNCERTAINTY ON HAZARDS AND RISKS	COMMENT
HUMAN HEALTH CHEMICAL RISK ASSESSMENT	Target Analyte Analysis			
	Selection of Land Use and Exposure Scenarios	Land use scenarios	May overestimate	The land use scenarios are conservative.
		Completion of exposure pathways	May overestimate	The exposure pathways may not be completed, especially ingestion of contaminated fruits and vegetables.
		Steady-state condition assumed for contaminants	May overestimate	It is assumed that the levels of contaminants detected at the site will not diminish over time.
	Exposure Point Concentrations and Chemical Intake Factors:	Estimation of exposure point concentrations	May over- or underestimate	Exposure point concentrations are estimates based on actual site data or modeled data. Some information used to determine the EPC are uncertain (i.e., Henry's Law constant, octanol-water partition coefficient).
		Parameters used to estimate chemical intake factors	May overestimate	Each exposure factor is inherently uncertain, usually reflecting the reasonable maximum, so when these values are used to derive chemical intake factors, the intake factor is uncertain.

2 of 8

(Engineering-Science, Inc.,1993:Table 6.8.1)

Appendix D (Continued): Subjective Summarization of Uncertainties Surrounding Study of Landfills 8 and 10

SUMMARY OF UNCERTAINTIES ASSOCIATED WITH THE BASELINE RISK ASSESSMENT AT WPAFB LANDFILLS 8 AND 10

CATEGORY	ANALYSIS	UNCERTAINTY FACTOR	EFFECT OF UNCERTAINTY ON HAZARDS AND RISKS	COMMENT
HUMAN HEALTH CHEMICAL RISK ASSESSMENT	**Target Analyte Analysis**			
HUMAN HEALTH CHEMICAL RISK ASSESSMENT (Cont.)	**Target Analyte Analysis (Cont.)**			
	Exposure Models:	Air modeling	May overestimate	Maximum back-calculated emission rates were used; calculated concentrations were higher than the measured maximum 24-hour concentrations; no pollutant decay or removal was assumed; one-half of the detection limit was used as a data value.
		Ground water modeling	May overestimate	Models do not account for biodegradation, a steady-state is assumed
			May underestimate	Models do not consider the formation of biodegradation products during transport.
			May over- or underestimate	Models assume steady-state of movement, but movement is actually in pulses, resulting partly from variations in the intensity and duration of precipitation at the site.
		Lead Uptake Model	May overestimate	Maximum single point value used for soil/dust.
			May over- or underestimate	Default values used in the uptake model may over- or underestimate lead exposure.

3 of 8

(Engineering-Science, Inc.,1993:Table 6.8.1)

Appendix D (Continued): Subjective Summarization of Uncertainties Surrounding Study of Landfills 8 and 10

SUMMARY OF UNCERTAINTIES ASSOCIATED WITH THE BASELINE RISK ASSESSMENT AT WPAFB LANDFILLS 8 AND 10

CATEGORY	ANALYSIS	UNCERTAINTY FACTOR	EFFECT OF UNCERTAINTY ON HAZARDS AND RISKS	COMMENT
HUMAN HEALTH CHEMICAL RISK ASSESSMENT (Cont.)	Target Analyte Analysis (Cont.)			
	Toxicity Assessment:	Toxicity values	May underestimate	Toxicity values are not available for all chemicals of concern at the site.
			May over- or underestimate	Non-cancer toxicity values are derived by adjusting data in humans or animals by an uncertainty factor. Toxicity values for cancer are the 95% UCL on lifetime risk. Additional uncertainty results from the choice of studies used to derive the toxicity values.
		Toxicity values - dermal exposure	May over- or underestimate	Dermal toxicity values are derived by adjusting the oral toxicity values by a chemical-specific oral absorption factor.
	Risk Characterization:	Additivity of calculated hazards and risks	May over- or underestimate	There is assumed to be no synergism or antagonism between chemicals. A similarity in mechanism of action and metabolism is also assumed.

4 of 8

(Engineering-Science, Inc.,1993:Table 6.8.1)

Appendix D (Continued): Subjective Summarization of Uncertainties Surrounding Study of Landfills 8 and 10

SUMMARY OF UNCERTAINTIES ASSOCIATED WITH THE BASELINE RISK ASSESSMENT
AT WPAFB LANDFILLS 8 AND 10

CATEGORY	ANALYSIS	UNCERTAINTY FACTOR	EFFECT OF UNCERTAINTY ON HAZARDS AND RISKS	COMMENT
HUMAN HEALTH CHEMICAL RISK ASSESSMENT (Cont.)	*Tentatively Identified Compound (TIC) Analysis*			
	NOTE: ALL UNCERTAINTIES ASSOCIATED WITH THE TARGET ANALYTE ANALYSIS ARE ASSOCIATED WITH TICs ADDITIONAL TIC-SPECIFIC UNCERTAINTIES ARE LISTED BELOW:			
	Data Evaluation:	TIC data	May over- or underestimate	TICs are so designated because both the identity and the reported concentration are highly uncertain.
		Use of maximum chemical concentrations	May overestimate	The TIC analysis uses the maximum detected chemical values, instead of the 95% UCL that is used in the target analyte analysis.
	Selection of Land Use and Exposure Scenarios:	Selection of pathways to be evaluated	May underestimate	Pathways involving inhalation, or the ingestion of fruits and vegetables were not evaluated.
	Toxicity Assessment:	Use of surrogate compounds to evaluate hazards and risks	Probably overestimate	Surrogate compounds used to evaluate the hazards and risks associated with TIC groups are probably more toxic than the actual TICs.
		Toxicity values for the surrogates	May underestimate	Toxicity values were not available for some surrogate compounds, therefore, they were not evaluated in the TIC a"nalysis.

5 of 8

(Engineering-Science, Inc.,1993:Table 6.8.1)

Appendix D (Continued): Subjective Summarization of Uncertainties Surrounding Study of Landfills 8 and 10

SUMMARY OF UNCERTAINTIES ASSOCIATED WITH THE BASELINE RISK ASSESSMENT AT WPAFB LANDFILLS 8 AND 10

CATEGORY	ANALYSIS	UNCERTAINTY FACTOR	EFFECT OF UNCERTAINTY ON HAZARDS AND RISKS	COMMENT
HUMAN HEALTH CHEMICAL RISK ASSESSMENT (Cont.)	"Hot-Spot" Analysis			
	NOTE: ALL UNCERTAINTIES ASSOCIATED WITH THE TARGET ANALYTE ANALYSIS ARE ASSOCIATED WITH "HOT-SPOTS" ADDITIONAL "HOT-SPOT"-SPECIFIC UNCERTAINTIES ARE LISTED BELOW:			
	Data Evaluation:	Use of detected hot-spot concentrations	May overestimate	The hot-spot analysis uses the maximum detected chemical values. These values may vary over time.
ECOLOGICAL RISK ASSESSMENT				
	Data Evaluation:	Chemical detection limits	May overestimate	For some chemicals, the cited ecological criteria are considerably lower than the method detection limit.
		Background samples	May over- or underestimate	Downstream surface water and sediment samples were not available, therefore, the extent of the contaminant plume could not be determined.
				Upgradient surface water and sediment samples may have been contaminated by extensive residential development.

OR016/16.3/O9301J01 6 of 8 Rev. No. 1, 11 June 1993

(Engineering-Science, Inc.,1993:Table 6.8.1)

Appendix D (Continued): Subjective Summarization of Uncertainties Surrounding Study of Landfills 8 and 10

SUMMARY OF UNCERTAINTIES ASSOCIATED WITH THE BASELINE RISK ASSESSMENT
AT WPAFB LANDFILLS 8 AND 10

CATEGORY	ANALYSIS	UNCERTAINTY FACTOR	EFFECT OF UNCERTAINTY ON HAZARDS AND RISKS	COMMENT
HUMAN HEALTH CHEMICAL RISK ASSESSMENT (Cont.)				
	Data Evaluation: (Cont.)	Background samples (Cont.)		Background soil samples were questionable.
		Biological tissue data	May over- or underestimate	Biological tissue chemistry was not available for potentially high-risk species and locations, therefore, information regarding the potential transfer of pesticides and heavy metals from sediments and soils to surrounding biota are not known.
	Toxicity Assessment:	Toxicity values	May underestimate	There is a scarcity of toxicological guidelines and nonhazardous dietary exposure concentrations for virtually all organic compounds.
HUMAN RADIOLOGICAL RISK ASSESSMENT	NOTE: MOST UNCERTAINTIES ASSOCIATED WITH THE CHEMICAL RISK ASSESSMENT ARE ALSO ASSOCIATED WITH THE RADIOLOGICAL RISK EVALUATION. ADDITIONAL RADIATION-SPECIFIC UNCERTAINTIES ARE LISTED BELOW:			
	Data Evaluation:	Method detection limits	May underestimate	For some radionuclides, the method detection limit is above a concentration that may be of concern.

7 of 8

(Engineering-Science, Inc.,1993:Table 6.8.1)

SUMMARY OF UNCERTAINTIES ASSOCIATED WITH THE BASELINE RISK ASSESSMENT
AT WPAFB LANDFILLS 8 AND 10

CATEGORY	ANALYSIS	UNCERTAINTY FACTOR	EFFECT OF UNCERTAINTY ON HAZARDS AND RISKS	COMMENT
HUMAN RADIOLOGICAL RISK ASSESSMENT (Cont.)				
	Data Evaluation: (Cont.)	Steady-state condition assumed for radionuclides	May over- or underestimate	Assumption does not take into account radioactive decay which will decrease the concentrations of parent compound and increase the concentrations of daughter compounds. The exposure duration may allow for total decay of some radionuclides.
		Some radionuclides lack isotopic analysis	May over- or underestimate	Isotopic distributions were assumed from national averages for groundwater and may not reflect local hydrogeology.
	Selection of Land Use and Exposure Scenarios:	Some routes of exposure were not quantified	May underestimate	Groundwater ingestion was the only pathway evaluated.

8 of 8

(Engineering-Science, Inc.,1993:Table 6.8.1)

Bibliography

Aldrich, James R. Pollution Prevention Economics. Unpublished class text for ENVR 550, Pollution Prevention Economics. School of Engineering, Air Force Institute of Technology, Wright-Patterson AFB OH, January 1993.

Arbunckle, J. Jordon and others. "Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA or Superfund)" in Environmental Law Handbook (Eleventh Edition). Rockville: Government Institutes, Inc., 1991.

Bevington, Philip R. Data Reduction and Error Analysis for the Physical Sciences. New York: McGraw-Hill Book Company, 1969.

Cohrssen, John J. and Vincet T. Covello. Risk Analysis: A Guide to Principles and Methods for Analyzing Health and Environmental Risks. Springfield VA: The National Technical Information Service, 1989.

Cox, Louis A. Jr. and Paolo F. Ricci. "Risk, Uncertainty, and Causation: Quantifying Human Health Risks," in The Risk Assessment of Environmental and Human Hazards: A Textbook of Case Studies. Ed. Dennis Paustenbach. New York NY: John Wiley & Sons, 1989.

Crump, Kenny S. "Methods for Carcinogenic Risk Assessment," in Principles of Health Risk Assessment. Ed. Paolo Ricci. Englewood Cliffs NJ: Prentice Hall, 1985.

Department of Defense. Defense Environmental Restoration Program-Annual Report to Congress for Fiscal Year 1991. February 1992.

Devore, Jay L. Probability and Statistics for Engineering and the Sciences (Third Edition). Belmont: Wadsworth, Inc., 1991.

Emory, C. William and Donald R. Cooper. Business Research Methods. Boston: Richard D. Irwin, Inc., 1991.

Environmental Protection Agency. Technical Support Document for the 1992 Citizen's Guide to Radon. Radon Division, Office of Radiation Programs, EPA 400-R-92-011. Washington: May 1992.

-----, Office of Solid Waste And Emergency Response. Superfund: Focusing on the Nation at Large. EPA/540/8-90/009. Washington: September 1990.

-----, Office of Health and Environmental Assessment. Exposure Factors Handbook. EPA 600 8-89 043. Washington: July 1989.

-----. Indoor Air Facts - EPA and Indoor Air Quality. No. 1, Washington: June 1987a.

-----. Radon Reference Manual. Office of Radiation Programs, EPA 520/1-87-20. Springfield VA: National Technical Information Service, 1987b.

-----. Unfinished Business: A Comparative Assessment of Environmental Problems--Overview Report. Report No. EPA/230/2-87/025a. Springfield: U.S. Department of Commerce National Technical Information Service, February 1987c.

-----. New York State Energy Office, and others. Reducing Radon In Structures (2nd Edition). Alexandria VA: Commercial Systems Corporation: undated.

Executive Office of the President of the United States. Budget of the United States Government--Fiscal Year 1993. Washington: U.S. Government Printing Office, 1992.

GEOMET Technologies, Inc. Radon Assessment of Base Housing and Other Selected Structures at Wright Patterson Air Force Base. Final report for the United States Air Force Occupational and Environmental Health Laboratory USAFOEHL/RZD, Brooks AFB TX, 13 August 1991.

Grimes, Vincent P. "DOD Cleans Up Its Act," National Defense. 9-11 (September 1991).

Lave, Lester B. The Strategy of Social Regulation: Decision Frameworks for Policy. Washington D.C.: The Brookings Institution, 1981.

Lawless, Edward W. and others. "Methods for Comparing the Risks of Technologies," in Risk Evaluation and Management. Ed. Vincent Covellow and others. New York: Plenum Press, 1986.

Martin Marietta Energy Systems, Inc. Installation Restoration Program Draft Off-Source Remedial Investigation Report for Landfills 8 and 10 at Wright-Patterson Air Force Base, Ohio (Volume 3). Unpublished report under contract DE--AC05-84OR21400 to Office of Environment Management, 645 Air Base Wing, Wright-Patterson Air Force Base Ohio. October 1992.

Masters, Gilbert M. Introduction to Environmental Engineering and Science. New Jersey: Printice Hall, 1991.

Maxim, Daniel L. "Problems Associated with the Use of Conservative Assumptions in Exposure and Risk Analysis" in The Risk Assessment of Environmental and Human Health Hazards: A Textbook of Case Studies. Ed. Dennis Paustenbach. New York: John Wiley & Sons, 1989.

Office of the Deputy Assistant Secretary of Defense (Environment). Defense Priority Model Users Manual - FY 93. Alexandria: The Earth Technology Corporation, May 1992.

O. H. Materials Corp. Preliminary Site-Specific Risk Assessment for Landfills 8 and 10, Wright-Patterson AFB, Ohio - Final. Unpublished report under contract No. F336011-90-CJ015 to 2750 AFB/EMR, Wright-Patterson AFB OH. 3 December 1990.

Page, Talbot and Ricci, Paolo F. "A Cost-Benefit Perspective For Risk Assessment," in Principles of Health Risk Assessment. Ed Paolo Ricci. New Jersey: Prentice-Hall, Inc.

Paustenbach, Dennis J. "A Survey of Environmental Risk Assessment," in The Risk Assessment of Environmental and Human Health Hazards: A Textbook of Case Studies. Ed. Dennis Paustenbach. New York: John Wiley & Sons, 1989.

Read, Marcia W. Office of the Secretary of Defense (Environmental), USAF, Arlington VA. Personal Correspondence. 6 May 1993.

Rudolph, Thomas E. AFMC CERCLA/IRP Legal Review Guide. Office of the Staff Judge Advocate, Air Force Materiel Command Law Center, Wright-Patterson AFB OH, 1993.

Smith, Carl R. Assistant Vice Chief of Staff, USAF, Washington DC. Personal Correspondence. 23 Oct 1987.

United States Air Force. U.S. Air Force Installation Restoration Program Remedial Project Manager's Handbook. Unpublished Handbook by HQ USAF/CE. January 1992.

Whipple, Chris. "Nonpessimistic Risk Assessment and Minimis Risk as Risk Management Tools," in The Risk Assessment of Environmental and Human Health Hazards: A Textbook of Case Studies. Ed. Dennis Paustenbach. New York: John Wiley & Sons, 1989.

-----. Hazards: Technology and Fairness. Washington, D.C.: National Academy Press, 1986.

Zarogoza, Larry. Special Assistant to Director on Hazardous Sites Evaluation Division, Washington DC. Telephone interview. 21 May 93.

Vita

Captain Robert E. Thompson was born on 18 August 1955 in Lincoln, Nebraska. He graduated from West Marshall High School in State Center, Iowa in 1974. He earned his Bachelor of Arts Degree in Biology Education from the University of Northern Iowa in 1978. Shortly after joining the Air Force, he was selected for the Airman Education and Commissioning Program (AECP), through which he earned his Bachelor of Science in Industrial Engineering at Arizona State. He began his officer career in the position as Chief of Industrial Engineering at Goodfellow AFB, Texas. While there, he studied and improved operations within the Civil Engineering Operations shops and Administrative Branch. The unit effectiveness inspection recognized his accomplishments by rating his branch "Outstanding" and referred to him as "ATC's best". Next, he served as the Chief of Industrial Engineering Branch at Anderson AFB, Guam. Hand-picked by the Wing Commander to head up improvements for the wing's self-inspection program and prepare for an Unit Effectiveness Inspection, he wrote the wing's self-inspection regulation, developed an automated self-inspection program, and implemented both into wing operations. His self-inspection program and software earned the wing two commendable findings and has been distributed to many PACAF bases. He was responsible for reorganizing his Civil Engineering Squadron until entering the School of Engineering and Environmental Management, Air Force Institute of Technology, in May 1992.

Permanent Address: ASC/EM
Wright-Patterson AFB, OH

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY (Leave blank)

2. REPORT DATE
September 1993

3. REPORT TYPE AND DATES COVERED
Master's Thesis

4. TITLE AND SUBTITLE
DEVELOPMENT OF A COST-EFFECTIVENESS METHODOLOGY TO PRIORITIZE ENVIRONMENTAL MITIGATION PROJECTS

5. FUNDING NUMBERS

6. AUTHOR(S)
Robert Eugene Thompson

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Air Force Institute of Technology,
WPAFB OH 45433-7765

8. PERFORMING ORGANIZATION REPORT NUMBER
AFIT/GEE/ENP/93S-2

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

645th ABW/EMB WPAFB OH 45433-5332	645th ABW/EMR WPAFB OH 45433-5332

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

12b. DISTRIBUTION CODE

13. ABSTRACT (Maximum 200 words)

A cost-effectiveness prioritization methodology was developed using concepts from the cost-effectiveness technique. The new methodology called the Cost-Effectiveness Methodology (CEM) allows the prioritization of mitigation projects across broad categories of hazardous sites as would be ranked among the offices of the Environmental Protection Agency.

Two performance criteria were incorporated into the process--rank projects that save the most lives per dollar and enhance general applicability across different categories of risk.

A metric was developed that represents the ratio of lives saved per dollar spent on mitigation alternatives of contaminated environmental sites. This metric was incorporated into the CEM to distinguish mitigation projects that were projected to save the most lives per mitigation dollar. Steps to enhance the comparability of site risks were also incorporated into the CEM.

Once developed, the cost-effectiveness methodology was successfully applied to ranking a landfill mitigation project and a radon mitigation project--two categorically different environmental sites characterized as a cancer risk.

The results of the CEM demonstrated that more lives would be saved mitigating radon in 658 radon-contaminated houses to 2 pCi/L than mitigating two landfills where a comparable number of homes were exposed.

14. SUBJECT TERMS
Environmental Prioritization, Cost-Effectiveness, Cost-Effectiveness Methodology, Risk, Environmental Ranking, Mitigation, Mitigation Ranking, Cleanup, Mitigation Prioritization

15. NUMBER OF PAGES
175

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	UL