

# Evaluation of the Hydrogeological Risk Involved in the Siting of Mining Operations

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## ABSTRACT

The evaluation of risk is becoming more important in the siting of mining operations in the United States as well as the rest of the world. The determination of environmental, economic, as well as health and safety risks is an important step in the planning of any mining operation. Hydrogeology plays an important role in pre-mine planning and in the determination of these risks. The mine operators must determine if ground water would inhibit mining in any way. Factors which are important to consider include mine dewatering economics, slope stability, and other adverse hydrologic impacts.

This paper presents methodologies for the characterization of hydrogeological risks for a mining operation. First of all, the term risk analysis is defined and its utility is addressed. Then, stepwise methods for performing a typical risk analysis are presented. Finally, the application of risk analysis to hydrogeology in mining is given. With slight modification, it is believed that these methodologies can be used to evaluate the hydrogeological risks for any mining operation.

## 1.0 INTRODUCTION

In recent years, there has been a growing interest in determining and reducing risks in the broad areas of engineering design, operations of facilities and mining. A reduction of risks and the consequences following systems failures or releases of contaminants is of concern to Federal and state regulatory agencies, to the industries being regulated, and to financial and insurance institutions.

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Risks are always present and inherent in most aspects of modern society. Man-made and natural catastrophes take their toll due to man's increasing population, modern technology, and use of finite resources. Risks have increased in the areas of occupational and environmental hazards, and can significantly affect economic and societal benefits. Evaluating, understanding and controlling the risks from environmental hazards has recently become a major endeavor. No longer can these risks be simply ignored, nor neglected for fear that evaluating risk can only make matters worse and unwanted draw attention. Risks must be evaluated and dealt with in a systematic manner that recognizes economic, engineering, environment and societal factors.

There is no constant formula for conducting a risk assessment. Because the risk assessment process is an analytical tool, it can be argued that it must be tailored to the needs of the program in which it is used. For example, prior to the beginning of a mining operation, risks should be evaluated in terms of economics, mine safety, and environmental protection.

The evaluation of the potential hydrological risks to a mining operation is of primary importance. Water can often make or break an operation. Too much or too little water can make a mine economically unfeasible. Water is also associated with slope stability problems and safety related risks. Water can also act as a pathway for hazardous substances (i.e. trace metals, cyanide, etc.) generated by the mining and place a population at risk.

This paper presents methodologies for the characterization of hydrogeological risks for a mining operation. First, the term risk analysis is defined and its utility is addressed. Then, stepwise methods for performing a typical risk analysis are presented. Finally, the application of risk analysis to hydrogeology in mining is given. With slight modification, it is believed that these methodologies can be used to evaluate the hydrogeological risks for any mining operation.

## 2.0 WHAT IS RISK ANALYSIS AND ITS UTILITY

The term "risk" has a variety of meanings depending on the discipline involved and how risk is to be used. Risk has been defined as the probability of an event occurring multiplied by the consequence of that event (1). This same concept of risk (2) is used in a scenario of risk assessment for uranium mill tailings in a triplet of; "what can go wrong (the event), by how likely is that to happen (probability), by what are the damages (consequences)". The concept of a risk analysis as applied to mining operations

usually involves some quantitative expression of the risks involved in siting, operating or closing a facility. This probability function is expressed as an annual frequency of an human health or environmental consequence. This definition and means of calculating risk allows the incorporation of both completeness of analysis and uncertainty of events and parameters into the risk assessment.

A risk analysis has a utility in the siting and subsequent operation of a mining facility. In the siting and operation phase of the facilities, risk analysis is used in decisions for alternative siting and design modifications. The question is asked whether the calculated level of risk is low enough to allow an operation to be built and operated. The risk evaluation can also be used to determine regulatory compliance, possible clean-up activities, and liability and insurance coverage. In the event that design or operational procedures are modified, a risk evaluation will allow a comparison of risk levels when the fault and event tree techniques are used. A comparative risk assessment can be used to set priorities among components in the system, different exposure routes, identification of populations or ecosystems at risk and a determination of mitigation efforts. A risk assessment can include calculation of cost/reduction ratios to determine the cost effectiveness of design modifications or mitigation measures.

### 3.0 THE RISK ANALYSIS PROCESS

In the completion of any risk analysis, it is important to take a stepwise approach. Such an approach is presented in Figure 1. Major categories in this approach may defined as follows.

Data Base Requirements. As defined by Dreith (3), the first step in any risk analysis is to develop an information and data base. One must obtain general information on the site and develop a description of the operation. Data includes information on the climate, geology, hydrology (surface and ground water), chemical nature of the materials to be handled, and operational aspects.

Hazard Identification. These are items which could lead to a failure mode. Sources of failure, initiating events, and failure modes must be defined. Naturally, in this process, the failure mode must be defined. This could be an environmental hazard to a nearby population, or an operational hazard which could be cause economic hardship.

Risk Analysis. This is a two step process in which the interactions of a system and the forces impinging on it are evaluated to determine the probability of a component failure or a release of contaminants and cause a

consequence. Interactions in the system components must be analyzed and the series of events determined that can lead to a system failure and subsequent harm. This is most often accomplished through the use of logic diagrams such as fault trees and event trees. An event tree starts with a top event such as a contaminant release and traces the events leading to this failure. Probabilities can be assigned to the various lower events in the logic diagram until an overall probability is calculated for the failure (Figure 2). The event tree, in contrast, starts with the initial event (such as the failure in the fault tree) and follows the sequence of events that will lead to a consequence. The secondary events make up the branches of the event tree and consists of environmental pathways, processes acting on the contaminants and other factors that influence processes or pathways (Figure 3). Finally, the systems or populations at risk must be determined, and the probabilities determined that sufficient exposure and dose to organisms has occurred to cause harm.

Risk Evaluation or Management. Risks posed by a system that have been estimated or calculated by step 3 (Figure 1) will then be used to determine if, first, the system can be considered safe and second, if mitigative measure are necessary to reduce the risks. Once the risks have been evaluated, the decision making process can answer the questions whether a proposed mitigative measure reduces the risk sufficiently and whether the measure is cost effective. Uncertainties in the risk analysis can be used to decide if more information or testing is necessary, and sensitivity analysis can pinpoint weak points in a system. The risk analysis can determine the exhaustive set of possibilities, and minimized the chances of not considering all events, alternatives and consequences. Figure 4 is a simple decision tree model which can used in financial expectations in risk management.

#### 4.0 HYDROGEOLOGIC RISKS INVOLVED IN MINING

Mine development involves a complex series of decisions where events and results cannot be exactly predicted. Substantial insight into decision making procedures can be gained by treating the problem as though there was complete information concerning the outcome of all possible decisions. Understanding the rationale for decisions under certainty conditions provides a strong foundation for the somewhat more complex analysis required for decision making under uncertainty.

The concept of risk is certainly well established in the mining industry, particularly in the economic decision making process in which assessments need to be made with respect to such factors as cost of development and market price of the extracted product. To a lesser extent, risk

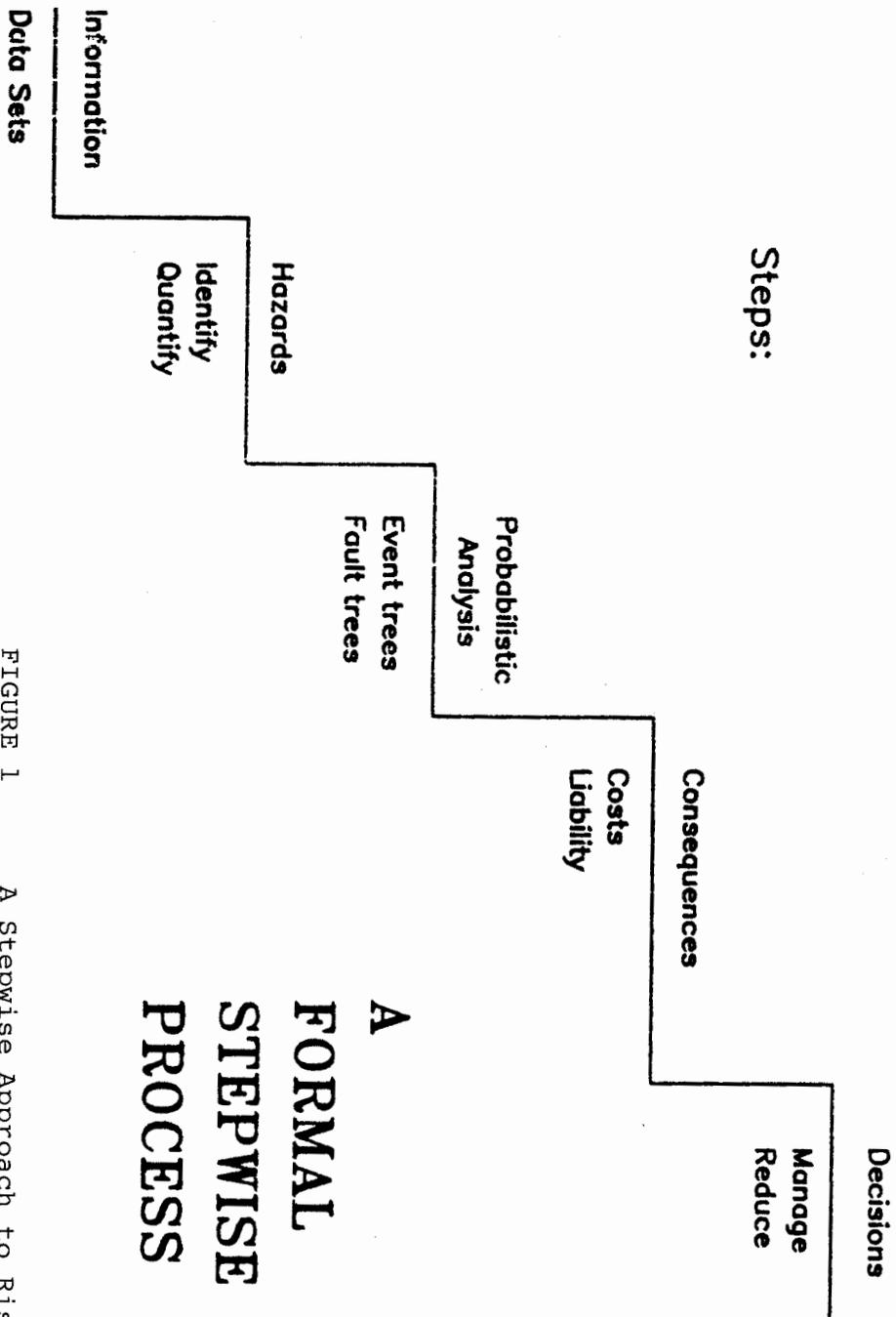
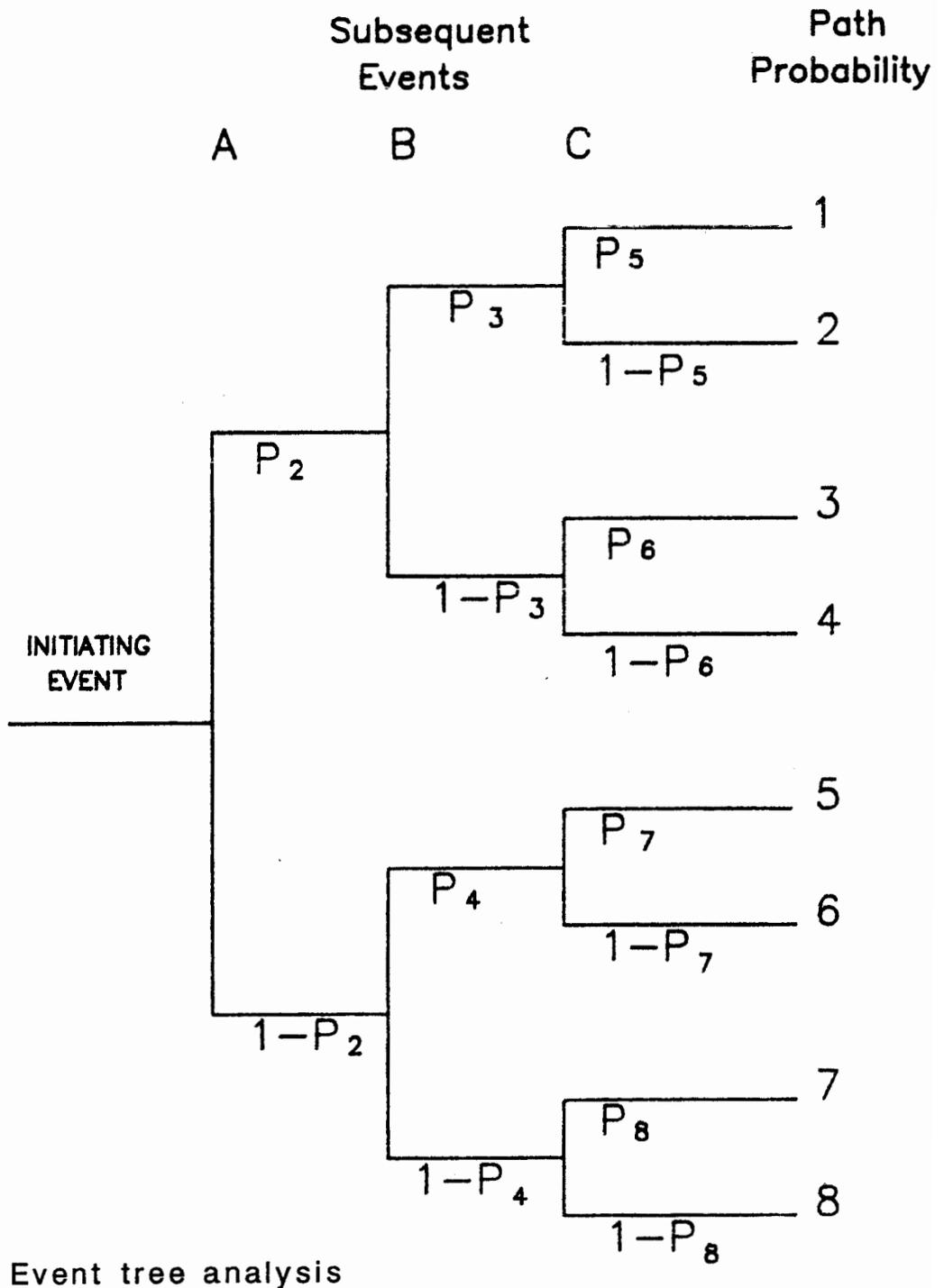


FIGURE 1 A Stepwise Approach to Risk Analysis

# Risk Evaluation



Event tree analysis

FIGURE 2 Event Tree Analysis for Risk Evaluation

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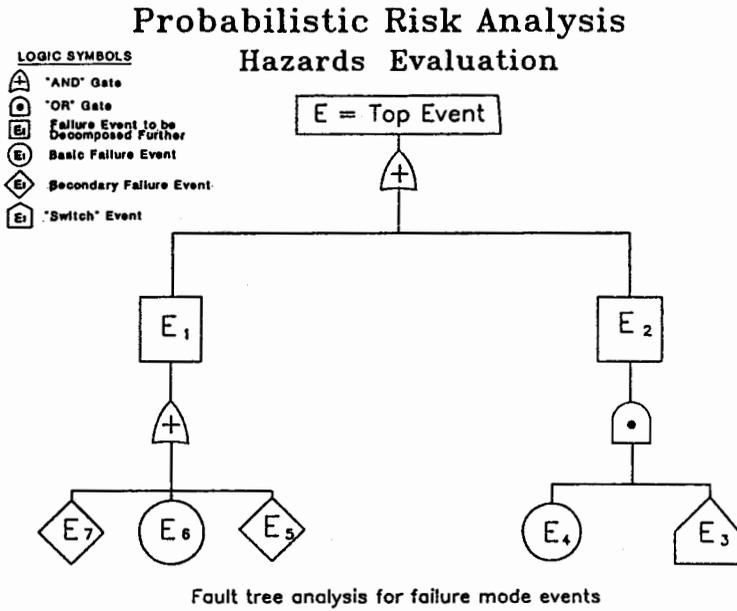


FIGURE 3 Fault tree analysis for failure mode events

### Risk Management

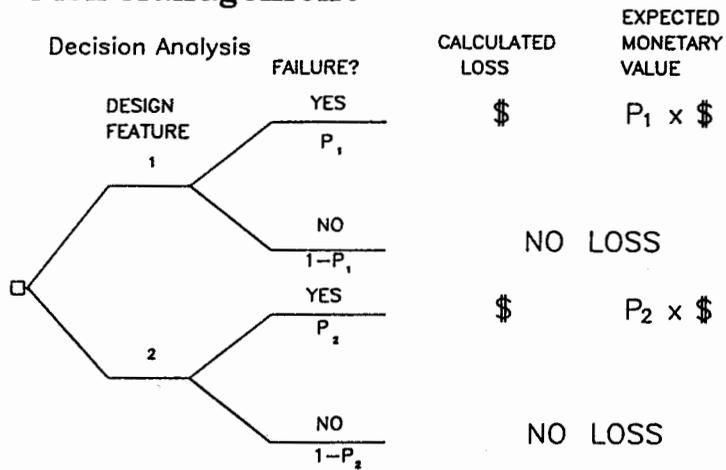


FIGURE 4 Decision Analysis for Risk Management

assessment of the engineering components has been applied. In this paper, we are dealing with only one, but we believe a significant, component of risk in mine development. That is, the risks associated with hydrogeological impacts.

Hydrogeological risk assessment in mining and mine development can cover a wide range of concerns. This may range from the presence of too much water to the absence of any water. In the case of too much water, slope stability (for an open pit mine) may be a severe restriction for mining. For an underground mine, there may be insufficient pump capacity, or the cost of pumping too prohibitive to allow mining to continue. Too little water is also a risk in mining in that minimum water quantities are required for operational needs. There are, in addition to the operational risks associated with hydrogeologic concerns, hydrogeologic risks associated with environmental concerns. These include such factors as near term and long term water supply and quality issues. Degradation of groundwater supplies via acid mine drainage, dissolution of heavy metals, and other mechanisms are of concern to mining operations throughout the world.

#### 5.0 APPLICATION TO HYDROGEOLOGY IN MINING

The application of risk analysis techniques to hydrogeology of mining as would be expected, are very site specific. One, however, must go through some patterned logic in evaluating the risks of a particular site. Such an approach can be made using the pattern laid in section 3.0 of this paper.

Data Base Requirements. As presented above, it is important that the first step in any risk analysis is to develop an information and data base. In evaluating the potential hydrologic risks involved in operating a mine, one must develop a complete hydrologic data base for the site. Data must be gathered on the climate including precipitation patterns; the hydraulic characteristics of the aquifers including their identification, transmissivity, and potentiometric surfaces; surface water for prediction of flood characteristics (soil types, vegetation cover, etc.); the geotechnical characteristics of the soils and bedrock which make up the pit walls; and the geochemistry of the material to be handled. In addition, it is also important to have a thorough understanding of the operation. This is important to understand potential failure scenarios. Obviously, the better the data base, the better and more certain is the risk assessment.

Hazard Identification. There are two principal components to assessing hydrogeologic risk: (1) operational and (2) environmental. Operational risk is associated directly with mining activities which could be impacted by adverse

hydrogeologic conditions. An example of this would be unstable high wall slopes because of saturated ground water conditions and an inability to adequately define the hydrogeologic conditions that might lead to failure. For subsurface mining, considerable economic loss could be realized if operations intercepted a high pressure water zone. Environmental risks, although they may have immediate consequences, are generally thought to represent long term concerns. In the western United States for example, degradation of ground water quality due to the altered geochemistry of mine spoils and tailing can have severe consequences that can last many tens of years after mining has ceased.

Risk Evaluation. Figure 5 depicts an event diagram which presents a sequence of operations and environmental events or occurrences that have economic implication on mining operations. The degree to which the various events and sequences can be defined and quantified will lead to determining the likely economic outcomes. Determination of the most reasonable probabilities along any path will lead to rational economic decisions, or at least identify those areas which may require additional engineering to mitigate the possible consequences. Using the same methodologies presented in Section 3.0 of this paper, risk consequence can be evaluated for all or part of the event diagram presented in Figure 5.

Risk Management. In our assessments of hydrogeologic risk, we first considered operational and environmental risks as factors to be evaluated separately. However, as we further evaluated the risks, it became increasingly apparent that in order to quantify environmental risks, economic value had to be applied. Certainly environmental considerations do cost money, and more often than not, the cost of environmental concerns can be identified and allocated to the various phases of mine development and operation. The same could be said about operational risks. All mining decisions are, or should be, based on sound economic decisions. The application of risk assessment to hydrogeological risks is an important, if not major, consideration in the evaluation of the economic viability of a mining operation.

Risk management helps define the direction the mine operator should go to reduce economic risk to the operation and is the goal of most risk analyses. Reduction of risks and subsequent overall costs can be achieved by optimization or changes in design based on the risk evaluation. Again, the basic techniques for risk management analysis via the use of decision trees as presented in Section 3.0 can be used.

## 6.0 CONCLUSIONS

A stepwise risk assessment approach is a viable method in

evaluating and reducing the hydrogeologic risks of a mining operation. Such an evaluation can be made with little information on the site or with a great deal of data. The steps taken in the process to develop a data base, identify hazards, and the performance of a probabilistic risk assessment can be used in the siting of mining operation and in the design process. Risk assessment is not new and procedures are well-established. Quantitative probabilistic hydrogeologic risk assessment of a mine site is possible.

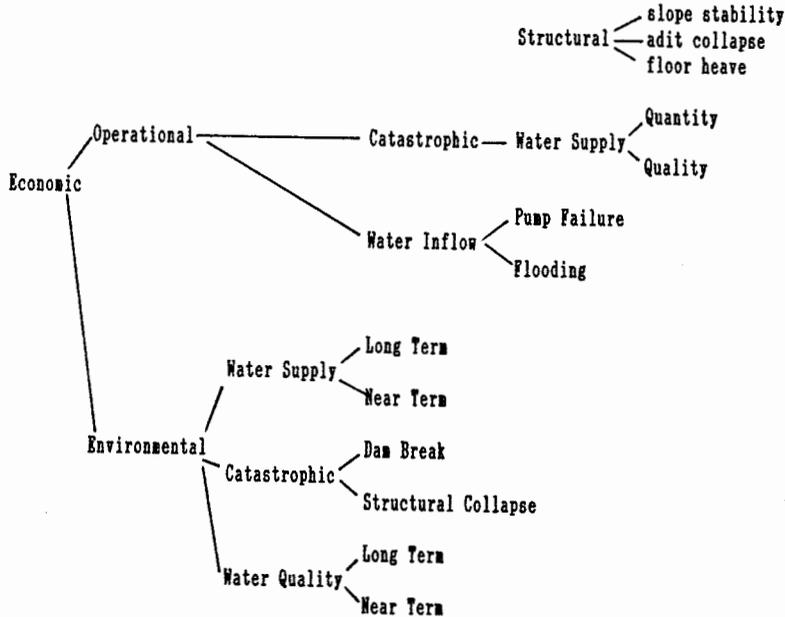


Figure 5. Hydrogeologic Risk Event Tree

7.0 REFERENCES

1. Eisenbeis, John J., Montgomery, Robert H., and Sanders Thomas G. A Risk Assessment Methodology for Hazardous Waste Landfills, in Geotechnical and Geohydrological Aspects of Waste Management, Fort Collins, Colorado, USA (1986).
2. Murray, M. L., D. B. Chambers, R. A. Knapp, and S. Kaplan, Estimation of Long Term Risk from Canadian Uranium Mill Tailings, Risk Analysis, v. 7, no. 3, pp.287-298 (1987).
3. Dreith, R.H., An Industry's Guidelines for Risk Assessment, in Risk Assessment at Hazardous Waste Sites, Ed. by F. A. Long and G. E. Schweitzer, Symp. Series 204, Am. Chem. Soc., Washington, DC, pp. 45-53 (1982).