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FACILITATING RELATIVE COMPARISONS OF HEALTH IMPACTS FROM POSTULATED ACCIDENTS IN ENVIRONMENTAL IMPACT STATEMENTS

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ABSTRACT

Current U.S. Department of Energy (DOE) guidance [1] on the performance of accident analyses supporting an environmental impact statement (EIS) stresses a graded approach that emphasizes the most important risks, calls for the evaluation of frequencies as well as consequences for severe accident scenarios, and discourages the use of "bounding analyses" that confound risk comparisons among EIS alternatives. Probabilistic risk analysis methods that have been used extensively in safety evaluations of nuclear reactors and chemical processing plants are well documented and seem to provide a logical route to achieving the goals in the DOE guidance document. Perhaps most importantly, the systematic use of these methods facilitates relative risk comparisons of the accidents associated with the various alternatives that may be investigated in an EIS. Nevertheless, the use of these methods in DOE EIS evaluations has been almost nonexistent to date.

This paper discusses methods in probabilistic risk analysis that were developed and applied in defining accidents and generating radiological source terms for the DOE *Draft Waste Management Programmatic Environmental Impact Statement* (WM PEIS); publication of the Final WM PEIS is due in late summer 1996. The strengths and shortcomings of the cited probabilistic risk analysis methods used to evaluate facility accidents are addressed, both as they relate to the WM PEIS and as they relate to more general EIS applications. Key guidance is discussed that was developed by DOE and used in shaping the techniques cited herein for application in an EIS. Related perceptions on accidents observed from the public comment process for the WM PEIS are cited. Finally, recommendations are made on the basis of needs as well as "lessons learned" in implementing the accident analysis for the WM PEIS.

INTRODUCTION AND OVERVIEW

In late May 1993, the U.S. Department of Energy (DOE) released a guidance document [1] containing recommendations for preparing an environmental impact statement (EIS) under the National Environmental Policy Act (NEPA) of 1969. This report noted that the heart of an EIS is a comparative analysis of alternatives, including the preferred action. A major theme of the guidance is to address the environmental impacts in proportion to their potential significance and to avoid addressing insignificant impacts in detail. This theme, intended to focus analysis resources to be as cost effective as possible, was sometimes referred to as a "sliding scale" approach and was especially prominent in the guidance on accident analysis.

In developing guidance on performing human health and risk impacts, three populations were identified: involved workers, noninvolved workers (those on-site but not directly involved in the preferred action), and the general public. Both routine operations and accidents were identified as sources of risk and potential human health impacts. Accidents were subdivided as involving transportation (including impacts from transport on-site as well as to and from a site) or involving construction and operation of processes or

facilities. Both radiological and chemical accidents were considered. This paper will focus on radiological risk assessment to illustrate the techniques.

To implement the sliding scale approach in accident analysis, several steps were recommended in the DOE guidance document [1]. Following is a synopsis of the steps relevant to this discussion:

1. Identify the spectrum of potential accident scenarios that are reasonably foreseeable. These scenarios could range from relatively high-frequency, low-consequence events involving human error to relatively high-consequence, low-frequency events including natural phenomena such as earthquakes.

2. Analyze events with potentially large consequences in terms of both their probabilities and their consequences. In fact, the presentation of both probability and consequence results was recommended rather than the presentation of only risk (here defined as the product of the consequence and the probability of events leading to that consequence).

3. Reference existing safety reports, including Safety Analysis Reports, if available.

4. Conduct analyses to discriminate among alternatives. In particular, do not present bounding impact estimates that could obscure differences among alternatives.

The first three recommendations were abstracted from the specific guidance on accidents, whereas the last recommendation was abstracted from specific guidance on comparing impact analyses. However, the last recommendation suggests, in support of Recommendations 1 and 2, that a more realistic look at accidents be taken as opposed to simply evaluating the end-of-spectrum bounding accidents that generally comprise so-called beyond design basis accidents. In particular, it argues against the use of overly pessimistic or conservative assumptions that can vastly overstate the consequences of accidents and in so doing obscure real differences in human health risks between competing alternatives.

The purpose of this paper is to suggest techniques developed in probabilistic risk assessment and implemented in the *Draft Waste Management Environmental Impact Statement* (WM PEIS) [2] that are cost effective in meeting the spirit of the DOE guidance [1] regarding accidents and that, if used vis-à-vis conventional techniques, should significantly improve comparative or relative risk analyses of alternative actions in an EIS. The focus here will be on illustrating the techniques used in developing the source terms associated with waste treatment facility accidents involving airborne radiological releases. However, the principles may be applied in general.

The remainder of the paper is organized as follows: a brief description of the WM PEIS is presented, with particular attention to the challenges it posed in developing an accident analysis approach. Next, the key elements of the accident approach are summarized, with particular emphasis on the techniques used that facilitate relative risk comparisons. The strengths and weaknesses of accident analysis in general and specifically with the techniques presented herein are then discussed. Based on the public response process, perceptions of both technically aware and untrained observers are noted with respect to accidents. Finally, recommendations are made on the basis of needs as well as "lessons learned" in implementing the accident analysis for the WM PEIS.

WM PEIS ACCIDENT ANALYSIS CONSIDERATIONS

Synopsis of the PEIS

The WM PEIS is a nationwide study that examines the environmental impacts of managing five types of radioactive and hazardous wastes [2,3]. The Draft WM PEIS was issued in September 1995, and the Final WM PEIS is scheduled for publication in late summer 1996. These wastes result primarily from nuclear defense activities – the development, production, and testing of nuclear weapons at a variety of DOE sites located around the United States. The five waste types are low-level mixed waste (LLMW), low-level waste (LLW), transuranic waste (TRUW), high-level waste (HLW), and hazardous waste (HW).

In the WM PEIS, an alternative is defined as a configuration of sites for treating, storing, or disposing of a specific waste type. Four categories of alternatives are considered for each waste type: a no action alternative that is generally consistent with current practice; a decentralized alternative that would, in general, result in wastes being managed where they are generated or stored currently; a regionalized alternative that would locate waste management facilities at a lesser number of sites throughout the nation; and a centralized alternative that would locate large waste management facilities at only one or two sites. For certain waste types, DOE considers more than one regionalized or centralized alternative to present a wide variety of options on the number and location of sites having major waste management facilities and the sites at which the facilities could be located. In addition, there is more than one option for treatment of some waste types. To narrow these combinations to a level permitting meaningful analysis, DOE selected 36 representative configurations to be ultimately analyzed over all the waste types considered in the WM PEIS.

Figure 1 identifies the sites where wastes are generated or stored for one or more of the types of waste evaluated in the WM PEIS. "Major" sites, as shown in the figure, are those candidate locations identified under the WM PEIS alternatives that may receive wastes generated off-site and/or host disposal facilities. These sites received detailed evaluation in the WM PEIS.

WM PEIS Analytic Framework

To evaluate the potential environmental impacts of the alternatives, DOE first identified the type, characteristics, quantity, and special requirements (e.g., handling requirements) of each waste type. To frame the analysis within reasonable bounds and to make the analytical process more manageable, specific assumptions were developed and applied. The health risks, environmental impacts, and costs of waste treatment, transport, storage, and disposal as applicable for each waste type were then determined. Figure 2 graphically depicts this framework.

The broad scope of the WM PEIS and the recent NEPA guidance result in a very large number of combinations of possible treatment, storage, and disposal options, existing or new facilities, and related possible accident scenarios to be evaluated for assessing the 36 management alternatives over the various waste types. The challenge for the accident analysis was to provide an automated methodology to allow sufficient discrimination of risk impacts among the many options and alternatives to support the WM PEIS decision-making process. Although developing all accidents in detail is not necessary, systematically applying the underlying approximate models is necessary to provide a sufficient and scrutable basis for estimating relative risk and discriminating among alternatives.

Accident Analysis Analytic Framework

The framework used to structure and implement the WM PEIS accident analysis was first described in Mueller et al.[4]. An illustration of the framework as it was implemented in the WM PEIS is shown in Figure 3 and includes the following interrelated elements: (1) selection of potentially risk-important treatment operations and related facility configurations across the DOE complex; (2) selection, development, and probabilistic evaluation of a uniform set of the most significant sequences of accidents; and (3) determination of the evolution and final compositions of source terms predicted to be released from these sequences.

These elements were integrated into a systematic, multiorganizational programmatic approach for the WM PEIS. The source terms cited above were developed by Argonne National Laboratory and subsequently used by Oak Ridge National Laboratory for assessment of the radiological and toxicological health effects to the general public and the work force. The waste management alternatives included the identification of siting options for storing and treating each waste type before disposal. The treatment throughput for each site for a given alternative was then defined by the current inventories, existing and projected waste generation rates, and disposition of the waste. The volume and radionuclide composition of each waste as it is processed to final disposal were tracked in a relational database [5]. This database was then linked to the accident database [6] to provide source term input for the health effects analyses. Thus, the relative impacts of facility accidents in treating and storing waste are calculated as a function not only of the accident sequences but also of the waste inventories at each site, the treatment technologies chosen, the facilities that will house the operation, and, of course, the site demographics.

ANALYTIC FRAMEWORK FOR RELATIVE RISK

The crux of the framework used to facilitate relative risk comparisons is to develop a structured approach for tracking the development of radioactive source terms through the progression of accidents. This is accomplished by mapping the key events during the source term onto event trees and characterizing both the conditional probabilities and the development of key source term parameters as functions of these top events.

Source Term Considerations in Relative Impact Comparisons

The relative differences in the impacts of facility accidents discussed in this paper are primarily derived from differences in the atmospheric release source terms, which are modeled according to:

$$\text{Radiological source term} = MAR \times DF \times RARF \times LPF \tag{1}$$

where *MAR* is the material at risk; *DF* is the damage fraction or fraction of *MAR* exposed to accident stresses capable of rendering the *MAR* airborne; *RARF* is the respirable airborne release fraction or fraction of material subjected to accident stresses actually rendered airborne and respirable; and *LPF* is the leak path factor or fraction of the respirable airborne inventory that escapes any containment or confinement barriers to reach the ambient atmosphere. (Note: Equation 1 is actually a vector operation where the radiological source term is a vector of the amounts of each radioisotope involved in the radiological release.)

Figure 4 illustrates the evolution of radiological source terms, the factors of which are discussed in more detail elsewhere [7]. The discussions that follow show that first-order comparisons among different accidents or among similar accidents affecting different facilities can often be readily obtained by disaggregating the potential accident source terms into the cited factors. Knowledge of the inventory amounts and compositions is generally sufficient to assess differences in the *MAR* among sites or facilities. However, to properly assess the remaining source term factors, inventory knowledge must be combined with knowledge of the waste packaging and facility containment configuration and with a physical understanding of accident progression under varying conditions.

Structured Event Trees for Accident Progression

Probabilistic risk assessment techniques were used to structure the computational framework for operational events and to track the progression of accidents for external events. Potential accident initiators were first reviewed and grouped into categories for analysis of subsequent accident progression. A generic set of accident sequences was then developed to follow the progression of accidents into various source term categories organized by release characteristics and severity levels. Generic event trees, standardized as explained below, were developed to facilitate the calculation of ultimate frequencies of accident sequences as well as to facilitate relative risk comparisons.

Figure 5 illustrates a simplified set of generic event trees used for external events (more detailed trees have also been developed). The event trees were standardized so that the top event reflected accident sequence stresses as consistent as possible with the accident stresses that were used to develop airborne release fractions (ARFs) in DOE-HDBK-3010-94 [8]. In the example shown, the dominant stresses are mechanical shock (default), overpressurization, and thermal (fire). The development of ARFs for accident assessment is not an exact science and requires considerable engineering or scientific judgment on the part of the analyst. Using standardized top events facilitates a more scrutable development of ARFs that can be tied not only to those developed in DOE-HDBK-3010-94 but to the technical bases described therein. It allows a technical reviewer to more readily follow the logic used by the original analyst as well as to review the underlying technical basis.

The event trees were also standardized so that the top events included containment barrier responses with uniquely defined leak path factors in the accident sequence. Given the conditions implied in the event tree structured sequence, the analyst can then develop leak path factors consistent with DOE-HDBK-3010-94 [8] or do explicit modeling to determine these factors. In many cases, especially those considering severe accidents, the leak path factor is conservatively assumed to be unity predicated on the containment being breached and a direct path to the atmosphere occurring. For the example trees, the facility integrity event highlights the containment response where "yes" implies integrity and functionality of high-energy-particulate-air (HEPA) filters and "no" implies uninhibited leakage.

Relative Risk Considerations

The consequences associated with different accident emissions vary directly as the radiological source terms, which are calculated per Equation 1. Thus, the consequences of two different accident sequences involving the same material at risk would vary as their damage fractions, RARFs, and LPFs. Each of these factors would be determined as functions of the events comprising the accident sequence, as illustrated by the event trees. The functionalities for the RARF and LPF factors would generally be developed using DOE-HDBK-3010-94 [8]; the functionality for the damage fraction would be primarily based on engineering judgment, which would be documented by the analyst. However, for many sequences, existing DOE Safety Analysis Reports can be used to infer damage fractions based on past work that has undergone peer review. For the WM PEIS, all the functionalities cited have been incorporated into a PC-based database called WASTE_ACC [6] to facilitate calculations.

The frequencies of the various accident sequences are calculated as the frequency of the initiating event times the conditional probabilities of the event paths. The conditional probabilities are based on the severity of the sequence and the type of containment being analyzed. The initiating event frequency is developed using existing accident data or, in the case of rare events, from frequencies in the safety literature that are generally based on the recurrence frequencies of catastrophic events.

Since the risk of an accident scenario is defined here as the frequency of that scenario times the consequence of the scenario, several types of relative risk comparisons can be readily made and the underlying reasons assessed. For example, for the same accident scenario at comparable facilities with equivalent volumes of waste but at different sites, differences in source terms can be directly traced to differences in the physical and radiological composition of the MAR. To wit, the physical composition determines in part the RARF chosen, and the radioisotope composition determines the dose conversion. Since the various source term parameters vary as functions of the composition of the material affected by the stresses, the types of stresses, the effects of various safety systems that may be triggered, and the containment response, it should be clear that a transparent methodology for highlighting differences is essential for facilitating review.

A number of categorical comments relating to the methods were received during the public comment period for the WM PEIS from both technical (e.g., DOE waste site staff) and nontechnical (general public) sources. The most salient comments express the following:

1. Concern that uncertainties have not been addressed. The WM PEIS discusses uncertainties qualitatively. However, the methods herein lend themselves to uncertainty treatment. For example, methods for calculating uncertainty of frequencies in event tree sequences are well documented.

2. General disbelief in accident analysis results (by the public). The methods herein cannot establish trust, but the scrutability of the techniques allows easy review by experts, facilitating focus on differences in key technical issues such as airborne release fractions under a set of accident stresses.

3. Concern that results do not match existing safety analyses. Existing Safety Analysis Reports relevant to the sites and

processes in the WM PEIS use a variety of assumptions. The scrutability of the methods here greatly facilitate determination of the underlying technical assumptions and their basis. Moreover, the most up-to-date accepted reference on airborne release fractions and leak path factors [8] has been directly tied into a database [6].

A key criticism often levied at probabilistic treatments like that presented herein is that little or no data are available to support the assignment of conditional probabilities. Yet it is the lack of severe-accident data that provides a major motivation for using methodologies such as event trees, which allow a rare catastrophic event to be systematically broken down into a sequence of events to which the analyst(s) can apply knowledge (and often relevant data) on an individual basis. This methodology provides a logical, scrutable, albeit often highly uncertain, path to assessing frequencies.

SUMMARY AND CONCLUSIONS

Methods from probabilistic risk analysis have been adapted to facilitate source term development in nonreactor radiological facility accidents. The techniques have been shown to greatly facilitate relative risk comparisons because of their ready incorporation into database structures. The easy identification of key parameters and clarifying assumptions is shown to facilitate technical review. The parameters used in the WM PEIS were based on the latest DOE guidance on radiological source term development.

Although specific examples were cited herein, the application of these methods is recommended for general use in both programmatic and facility-specific EISs. These methods meet both the letter and spirit of DOE's guidance on accident analysis to be performed for EISs. By providing a systematic, efficient, and readily reviewable computational framework, these methods are both technically robust and cost-effective for addressing the needs of EIS accident analysis.

ACKNOWLEDGMENT

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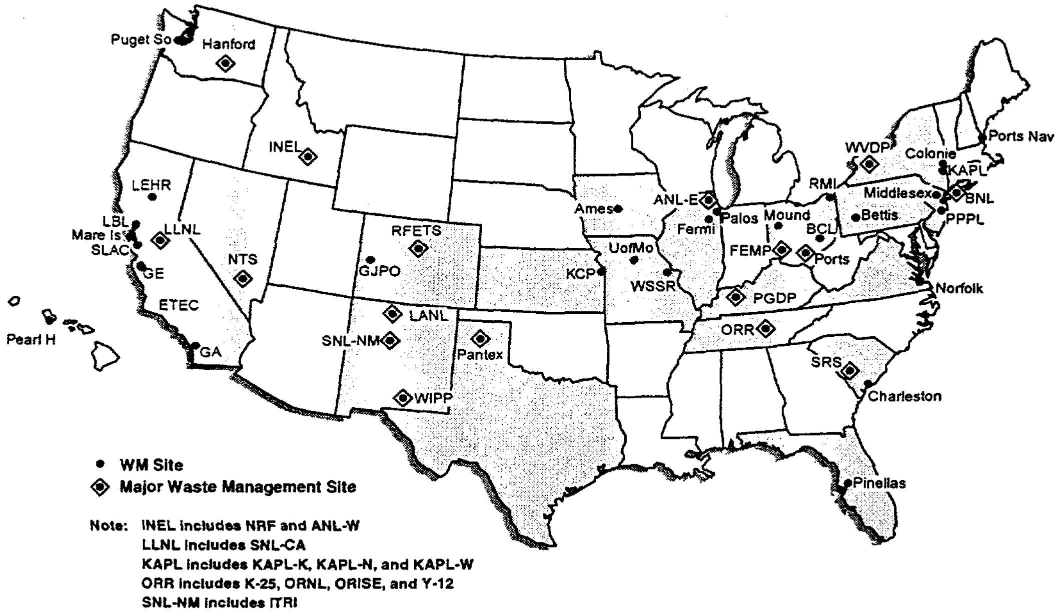


FIGURE 1 Waste Management Sites (Source: WM PEIS [2])

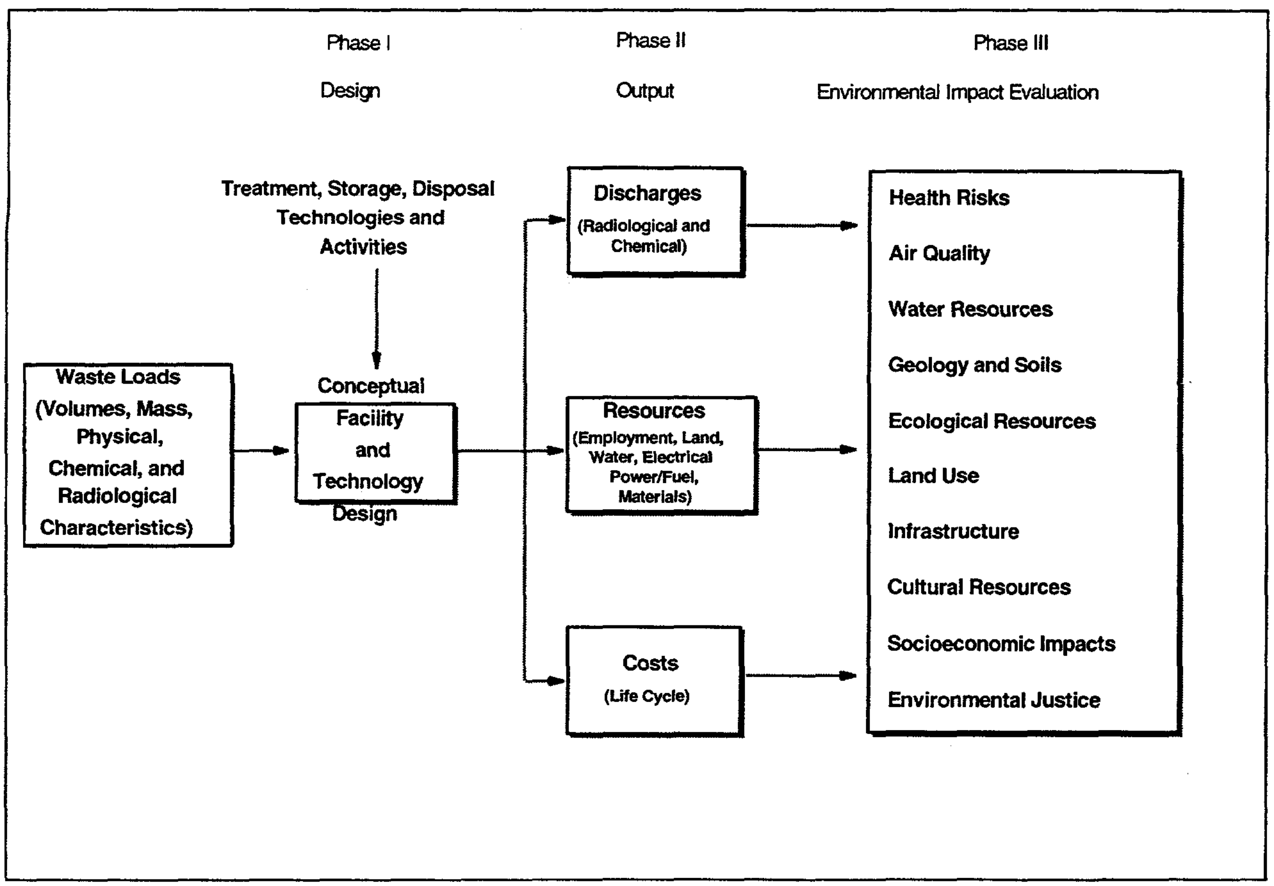


FIGURE 2 WM PEIS Analytical Process

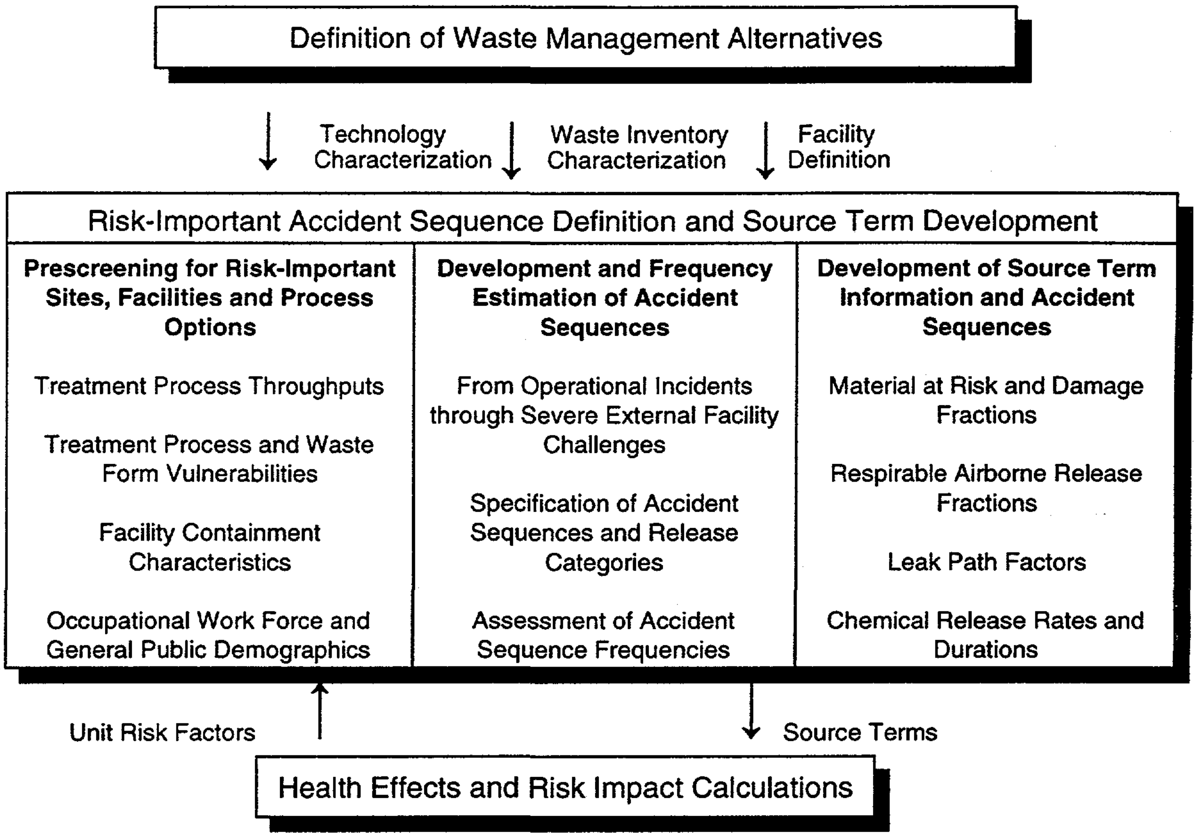


FIGURE 3 Major Components and Related Input

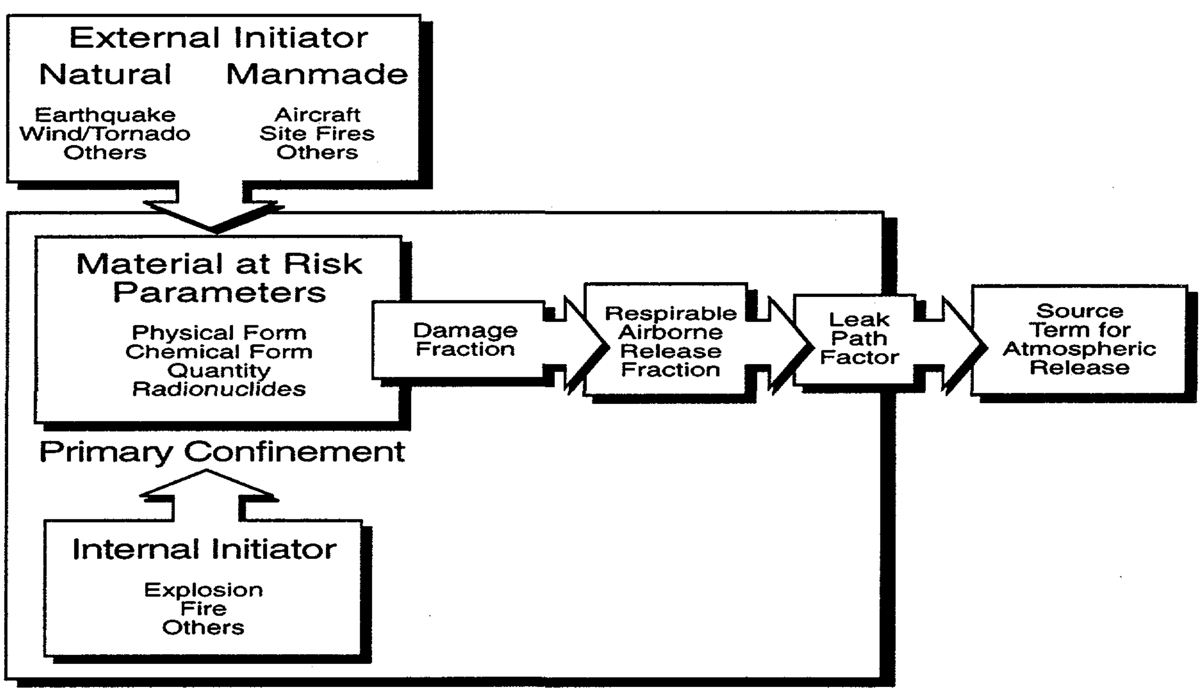
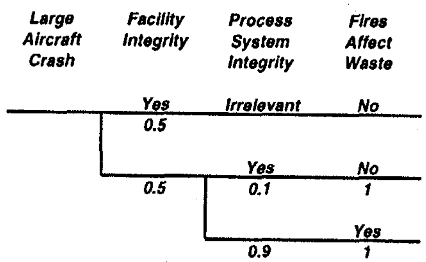
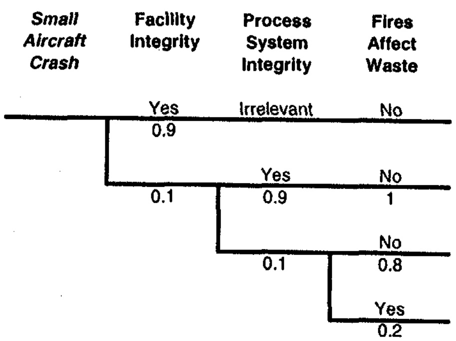


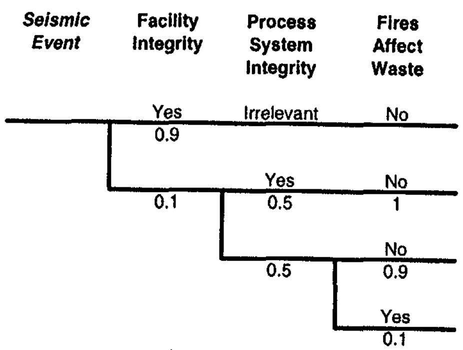
FIGURE 4 Conceptual Flow Diagram for Source Term Development



Conditional Probability of Sequence	Damage Fraction	RARF Basis	Notes
0.5	0	Irrelevant	None
0.05	3.00E-04	Vibration of enclosed HEPA filter	Release from HVAC system
0.45	Variable	50% overpressurization plus static burning of contents of ORD feed mix tank	Contents of ORD reactor assumed not to burn due to dilution with water, ORD feed mix tank contents burn due to organic contaminants



Conditional Probability of Sequence	Damage Fraction	RARF Basis	Notes
0.9	0	Irrelevant	None
0.09	3.00E-04	Vibration of enclosed HEPA filter	Release from HVAC system
0.008	Variable	50% overpressurization	Contents of ORD reactor assumed not to burn due to dilution with water
0.002	Variable	Above plus static burning	Organic content of ORD reactor assumed to burn



Conditional Probability of Sequence	Damage Fraction	RARF Basis	Notes
0.9	0	Irrelevant	None
0.05	3.00E-04	Vibration of enclosed HEPA filter	Release from HVAC system
0.045	Variable	50% overpressurization	Contents of ORD reactor assumed not to burn due to dilution with water
0.005	Variable	Above plus static burning	Organic content of ORD reactor assumed to burn

FIGURE 5 Generic Event Trees for External Initiators for Low-Level Mixed Waste Treatment Operations