CoNF-961105--19

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ANL/EA/CP--90879

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for submission to

International Congress and Exhibition on
Mechanical Engineering

November 17-22, 1996
Atlanta, Georgia

sponsored by
The American Society of Mechanical Engineers

*Work supported by the U.S. Department of Energy, Assistant Secretary for Environmental Management, under contract W-31-109-Eng-38.

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ABSTRACT

A review of accident analyses in recent U.S. Department of Energy (DOE) Environmental Impact Statements (EISs) was conducted to evaluate the consistency among approaches and to compare these approaches with existing DOE guidance. The review considered several components of an accident analysis: the overall scope, which in turn should reflect the scope of the EIS; the spectrum of accidents considered; the methods and assumptions used to determine frequencies or frequency ranges for the accident sequences; and the assumptions and technical bases for developing radiological and chemical atmospheric source terms and for calculating the consequences of airborne releases. The review also considered the range of results generated with respect to impacts on various worker and general populations. In this paper, the findings of these reviews are presented and methods recommended for improving consistency among EISs and bringing them more into line with existing DOE guidance.

INTRODUCTION AND OVERVIEW

The most recent guidance from the U.S. Department of Energy (DOE) for preparing an environmental impact statement (EIS) under the National Environmental Policy Act (NEPA) of 1969 was published in May 1993 (DOE 1993). The guidance document notes that the core of an EIS is a comparative analysis of alternatives. It also stresses addressing the environmental impacts in proportion to their potential significance and discourages the use of "bounding analyses" that confound risk comparisons among EIS alternatives. Several steps are recommended with respect to accident analysis; the following are synopses of the ones relevant to this discussion:

1. Identify the spectrum of reasonably foreseeable potential accident scenarios. These 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. Both radiological and chemical accidents should be considered.

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

3. Perform human health and risk impacts for three populations: involved workers, noninvolved workers (those on site but not directly involved in the proposed action), and the general public.

4. Conduct analysis to discriminate among alternatives; in particular, do not present bounding impact estimates that could obscure differences in alternatives. This recommendation, in turn, argues against blindly using overly pessimistic assumptions in safety analysis reports (SARs), which may vastly overstate the impacts of accidents and thus obscure real differences in human health risks among competing alternatives.

The first three recommendations were abstracted from the specific guidance on accidents; 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 accidents should be looked at more realistically, as opposed to simply evaluating bounding accidents that generally comprise so-called beyond-design-basis accidents (BDBAs).

An effort is underway to evaluate the consistency of the Waste Management Programmatic EIS (WM PEIS) (DOE 1995c), with DOE EISs in progress or those recently completed. As part of this effort, a comparative review of the associated accident analyses was conducted. The objective of the review was to evaluate the consistency of DOE EIS accident studies and to compare the various approaches with the 1993 DOE guidance. The review focused on several components of an accident analysis: its overall scope, which, in turn, should reflect the scope of the EIS; the spectrum of accidents considered; the methods and assumptions used to determine frequencies or frequency ranges for the accident sequences; and the assumptions and technical bases for developing radiological and chemical atmospheric source terms and calculating the consequences of airborne releases. The review also considered the range of results generated with respect to impacts on various worker and general populations. In the remainder of this paper, the findings of these reviews are discussed and methods recommended for improving consistency among EISs and bringing them more into line with existing DOE guidance.

EIS SCOPING CONSIDERATIONS

Six EISs (DOE 1995a-f) were reviewed in detail and served as the basis for the findings reported here. In addition, the authors' knowledge of other EISs has also been brought to bear in the conclusions drawn and the recommendations made. The EISs evaluated include both programmatic and site-specific activities and various waste types, nuclear fuels, and materials. Alternatives generally evaluated different strategies for treating, storing, and disposing of the wastes or dispositioning the spent fuel or nuclear materials. A variety of facilities were considered, ranging from those lacking a significant degree of containment (similar to normal buildings) to those structures built for highly hazardous use. These facilities house a broad variety of processes, a number of which contain chemical and radiological hazards with the potential for on-site and off-site consequences in the event of a major accident. These processes include general handling of single containers (from which a breach and subsequent release may dominate involved worker risk), current and post-treatment storage, treatment, and disposal. Treatment processes analyzed generally involved high temperature and pressure (such as incineration and evaporation) but also included nonthermal processes (such as compaction) from which process equipment failures could result in an energetic release of radioactive and/or toxic material.

The issue of a quantitative accident analysis for proposed facilities did not appear to be handled in a uniform manner; some EISs did not perform a quantitative analysis because the designs are not necessarily complete and could be changed in response to any quantitative accident analysis that would be completed later during the construction and operation phases of these facilities. In these EISs, it was generally assumed that any accidents affecting these proposed facilities would be bounded by accidents for existing facilities at the site.

SPECTRUM OF ACCIDENTS CONSIDERED

Accidents can be categorized into events that are abnormal (e.g., minor spills), events that a facility was designed to withstand, and events that a facility was not designed to withstand (but whose impacts may be offset or mitigated). In general, a complete spectrum of accidents was considered, ranging from relatively high frequency ($>10^{-2}$/yr) to somewhat beyond reasonably foreseeable ($<10^{-6}$/yr); both internal and external events were analyzed. The effects of natural phenomena as initiators of an accident are typically addressed in the various EISs. Natural events assumed to have the potential to impact operations include earthquakes, extreme winds/tornado, floods, lightning strikes, and volcanoes. Man-made events include utility malfunctions and crashes of vehicles, airplanes, and helicopters external to the various structures. Process accidents were assumed to include criticality, explosions, uncontrolled chemical reactions, fires, and various liquid releases from process line breaks and tank leaks. Beyond reasonably foreseeable events, such as a meteorite falling on a facility, were disregarded because of their low probability. Nuclear criticality was considered for situations involving both a high concentration of fissionable material and a mechanism for accumulating a critical mass. Although, in general, a criticality would not pose significant off-site impacts, a number of EISs reported criticality as the most dangerous accident scenario for the involved workforce because of potentially lethal direct radiation doses. The initiator for a multiple facility-event accident scenario typically involved a design-basis seismic event impacting multiple facilities at a site, which resulted in simultaneous releases of radioactive and/or toxic materials to the environment.

ESTIMATION OF FREQUENCIES

The EISs reviewed leaned heavily on existing SARs or related support documentation to help develop frequencies or at least assign frequency ranges or "bins" to accident initiators and/or sequences. Both generic and site-specific data were used to establish frequency data. The level of structured probabilistic analysis (e.g., event tree and/or fault tree quantification) used to establish frequencies appeared to vary considerably; the specifics were buried in the support documentation. Selected sequences for a facility in one EIS that were assigned to one frequency bin might have been assigned to a different frequency bin for a second EIS because of the variety of underlying assumptions and degree of conservatism used. In particular, events such as large aircraft crashes were considered in some EISs and ruled out as too improbable for analysis in other EISs. Because many of the actions proposed under the different alternatives for the site-specific EISs are continuations or variations of past operations, historic occurrence information was sometimes used to estimate the frequency of conditions leading to a release. For the programmatic EISs, accident frequencies were developed, as a function of the accident scenario, upon review of appropriate safety documentation, which can vary due to the type, form, amount, and process involved.

RADIOLOGICAL SOURCE TERM AND CONSEQUENCE ESTIMATION

It was generally assumed in the EISs that the primary pathway for worker exposure (except for criticality accidents) and the general public is inhalation of aerosols and vapor releases during potential accidents. A radiological atmospheric release source term may be treated as the product of four terms: the quantity of material at risk (MAR); the damage fraction (DF) or fraction of MAR exposed to accident stresses capable of rendering the MAR airborne; the respirable airborne release fraction (RARF) or fraction of material subjected to accident stresses actually rendered airborne and respirable; and the leak path factor (LPF) or fraction of the respirable airborne inventory that escapes any containment or confinement barriers and reaches the ambient atmosphere.

Assumptions used to specify the MAR and DF for EIS facility accident studies varied widely. In some cases, the MAR and DF were implicitly combined, but assumptions for each were not delineated. The degree of detail in the RARF treatment also appeared to vary widely. In some cases, it was implicitly combined with the MAR and DF, for example, by stating that 1% of the material was assumed to be released for potential inhalation. In other cases, a careful assessment of the characteristics of the material under the relevant accident stresses appeared to have been performed with the RARF being assigned using the recently published DOE-HDBK-3010-94 (DOE 1994) or its predecessors as a basis. Insufficient documentation is supplied in the various EISs to establish whether a median, bounding, or weighted average was applied in the accident analysis for the RARF. Historically, the approach most commonly followed is to choose a bounding value for conservatism. The choice of applying a median or a bounding value can result in a variation of orders of magnitude in the source term. Leak path factor modeling in severe accident scenarios generally seemed to be avoided by conservatively assuming an LPF of unity, although explicit modeling does appear in some support documentation. In general, a single release point was used to represent several release points for a facility so as to simplify estimating atmospheric dispersion. Design features and institutional and organizational controls that can prevent or mitigate potential accidents were generally discussed in the EISs considered here.

Both generic and site-tailored codes were used to calculate atmospheric transport and dose calculations. Assigned meteorology conditions ranged from 99.5% probable to 50% probable. Since this effect alone can cause differences from a factor of 10 to 100 in off-site population doses, the potential differences in the conservatism of published results are apparent. The individual receptors considered generally included the maximally exposed members of the uninvolved work force and the general public; siting differences for the former varied widely. Impacts to uninvolved workers were generally evaluated at two locations from the release point of the accident to account for workers outside the emergency planning zone for a facility and thus exposed for a greater duration. The involved worker was generally considered, but underlying assumptions in treatment varied; for example, the volume in which a given release was concentrated and the time of worker exposure differed widely. A number of EISs, however, presented potential impacts to involved workers from postulated accidents in a qualitative fashion because of potential uncertainties in the application of Gaussian plume models in calculating consequences at or near the location of an accident. Various computer codes were used in the EISs to calculate environmental transport and consequences for postulated radiological accidents. Site-tailored codes such as AXAIR89Q (WSRC 1994) and RSAC5 (Wenzel 1993) were used at Savannah River (DOE 1995d,f) and the Idaho National Engineering Laboratory (DOE 1995a), respectively, and GENII (Napier et al. 1988) for the programmatic EISs (DOE 1995b,c).

CHEMICAL SOURCE TERM AND CONSEQUENCE ESTIMATION

The considerations for MAR and DF for chemical source terms are basically the same for chemical and radiological source terms. A variety of assumptions were used to specify evaporation rates, burn rates, or aerosolization rates for chemical accidents that covered a wide variety of spills, fires, and explosions. Unlike radiological source terms, the MAR included not only the chemical components of the waste or nuclear material, but also the chemical inventories that result from a treatment process or are used to support storage activities.

The consequences of chemical accidents were modeled with several standard codes. The impacts on the receptor were presented in a variety of ways, ranging from human health risk endpoints to fractions of threshold concentrations defined in Emergency Response Planning Guidelines (ERPGs) or similar guidelines developed by the Occupational Safety and Health Administration (OSHA). On the basis of the recommendation of several federal agencies, threshold concentrations in air are sometimes used to quantify the health effects that cause short-term consequences because of the uncertainty concerning the long-term health consequences of human exposure to hazardous materials. Potential health effects are then qualitatively described. This approach, however, does not allow comparison of risks associated with accidental releases of radiological and chemical materials on an equivalent basis.

Generally, commercially available computer codes such as EPICode (Homann 1988) and ISCST3 (EPA 1995) were used for modeling accidental releases of hazardous chemicals to the environment.

RANGES OF RESULTS

The risk of latent cancer fatalities associated with facility accidents is generally small across all the EISs reviewed, because events associated with releases of large quantities of radioactive and/or toxic materials have very low estimated frequencies. The maximum reasonably foreseeable accident varies among the EISs because of the proximity of the off-site population, material type, amount, and energetics of the process involved.

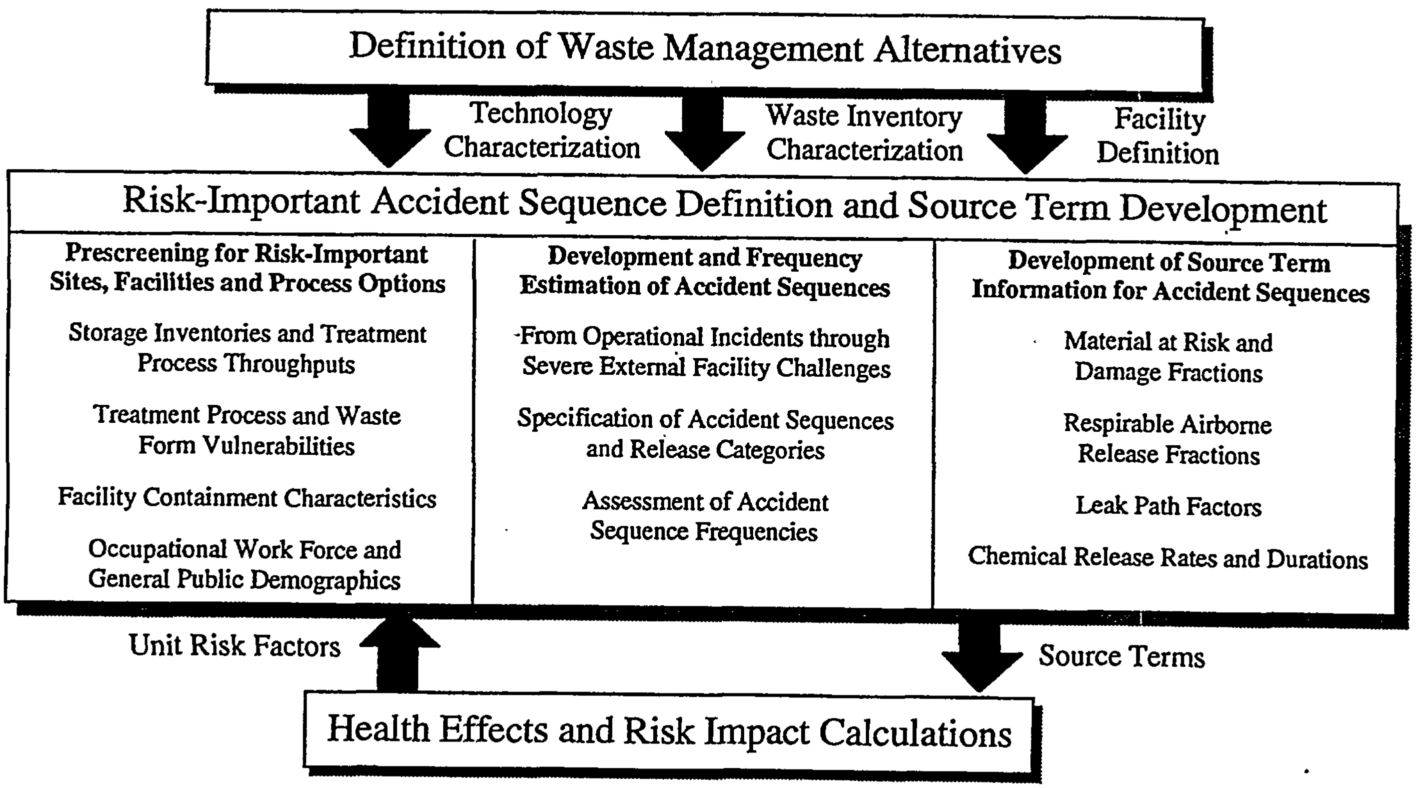
High-frequency, low-consequence accident scenarios generally focus on a breach of a single container, which involves small amounts of material, and realistically affect only the worker population. An example of a high-frequency, low-consequence accident is the breach of two low-level mixed waste containers at a disposal vault (DOE 1995c), with an accident frequency of 2×10^{-2} per year. It was estimated that a total of one additional latent cancer fatality could result in, at most, one additional latent cancer fatality.

An example of a risk-dominant accident scenario to the off-site population identified during the EIS review is the release of uranium hexafluoride (UF_6) caused by equipment failure following a seismic event (DOE 1995b). The entire contents of a UF_6 cylinder (6,800 kg) are assumed to be released to the environment, with an accident frequency on the order of 1×10^{-4} per year. In the surrounding population, this postulated accident was predicted to result in, at most, 31 additional latent cancer fatalities. The risk of developing cancer from this accident would, however, be very low because of the low frequency of occurrence. Accidents with large consequences from radioactive materials have not occurred historically and are unlikely to occur in the future.

CONCLUSIONS AND RECOMMENDATIONS

The EISs reviewed generally followed the cited DOE NEPA guidance except in the use of bounding calculations that were either explicitly calculated or used implicitly through reference to the SAR support. The variation in methods and assumptions in the various phases of an EIS accident study, as noted above, generally make intercomparisons of EIS results impossible. In principle, facility accidents for similar DOE alternatives expressed in complementary EISs should have the same or directly comparable results, depending on the specific definitions of the alternatives. Currently, this is not possible, which points to the obvious need for more standardized methods and underlying assumptions. General guidance on how to bridge the gap between SAR information and the needs of an EIS would be most useful. The challenge is to avoid reinventing the accident wheel when developing the data needed to satisfy the objectives of an EIS.

The general approach used in the WM PEIS helped to establish a more systematic look at accidents than observed in other EISs. An overview of the approach used to structure and implement the WM PEIS accident analysis was first described in Mueller et al. (1994). An illustration of the approach as it is now implemented in the Draft WM PEIS is shown in Figure 1. The use of recently published release fractions in safety analyses would help ensure consistency in safety analyses for EIS accident assessments. In addition, the probabilistic risk analysis approach taken in the Draft WM PEIS to develop functional



event trees for systematic analyses of accident sequences would help reduce uncertainties, compared with the traditional bounding analyses used in safety analyses and EIS accident analyses.

ACKNOWLEDGMENT

Work supported by the U.S. Department of Energy, Assistant Secretary for Environmental Management, under Contract W-31-109-Eng-38.

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