ANL/EA/CP-- 89877
CONF- 960804--43

A REVIEW OF THE RADIOLOGICAL TREATMENT FACILITY ACCIDENT ANALYSIS IN THE DRAFT WASTE MANAGEMENT PROGRAMMATIC ENVIRONMENTAL IMPACT STATEMENT

C. Mueller, S. Folga, B. Nabelssi, and E. Kohout
Argonne National Laboratory
9700 S. Cass Avenue
Argonne, IL 60439-4832
(708) 252-9095

DISCLAIMER

A REVIEW OF THE RADIOLOGICAL TREATMENT FACILITY ACCIDENT ANALYSES IN THE DRAFT WASTE MANAGEMENT PROGRAMMATIC ENVIRONMENTAL IMPACT STATEMENT

C. J. Mueller, S. Folga, B. Nabelssi, and E. Kohout
Argonne National Laboratory
9700 S. Cass Avenue
Argonne, Illinois 60439-4832
(708) 252-9095

INTRODUCTION AND OVERVIEW

The *Draft Waste Management Programmatic Environmental Impact Statement* (WM PEIS)[1] was released by the U.S. Department of Energy (DOE) for public comment on September 22, 1995. Prepared in accordance with the National Environmental Policy Act (NEPA), the Final WM PEIS is currently scheduled for release in late summer 1996. The Draft WM PEIS was published after about 3 years of effort to select and evaluate the best alternatives for treating, storing, and disposing of the 50-year legacy of radioactive and chemically hazardous wastes existing within the DOE complex. The evaluation examined the potential health and environmental impacts of integrated waste management alternatives for five categories of waste types at 54 DOE sites. A primary consideration as a potential source of human health impacts at all sites is that of radiological releases resulting from postulated accidents involving facilities used to treat radioactive wastes.

This paper first provides a brief, updated summary of the approach used to define and perform treatment facility accident analyses in the Draft WM PEIS. It reviews the selection of dominant sequences for the major sites most affected by the preferred waste management alternatives and highlights the salient accident analysis results. Finally, it summarizes and addresses key public and state and federal agency comments relating to accident analysis that were received in the public comment process.

SUMMARY OF APPROACH

Earlier papers[2,3] have provided an overview of the accident analysis approach and computational framework that were developed to both address the broad scope of the WM PEIS and satisfy DOE NEPA guidance.[4] The analytical details of the approach and much of the supporting data have evolved to fit the changing needs of the WM PEIS over 3 years. In summary, safety analysis reports and safety studies performed in support of recent EIS's were used as much as possible to estimate the frequencies and source term release parameters of so-called internal events, those events initiated by process or facility equipment failures or by human error. For accidents initiated by external events, which generally include catastrophic natural phenomena and aircraft crashes, a probabilistic risk analysis approach (PRA) was used with functional event trees developed to systematically analyze the accident sequences. The PRA approach facilitated relative comparisons among the frequencies and consequences of the accidents important to the various alternatives and helped to accommodate the automation of the calculations. A unique feature of the approach has been to structure the event trees so that the top events could be associated with accident stress categories that line up as closely as possible with those considered in the new DOE standard on airborne release rates and concomitant respirable fractions.[5]

Five waste types are considered in the Draft WM PEIS: low-level waste (LLW); low-level mixed waste (LLMW), which also has chemically hazardous components; transuranic waste (TRUW); high-level waste (HLW); and hazardous waste (HW), which has no radioactive components. Distinct alternatives were evaluated for each waste type and included the DOE site inventories to be stored, buried, or generated from future operations over the next 20 years. Accordingly, the facility accident analysis evaluated accident sequences and developed the concomitant radioactive or chemically hazardous source terms involving treatment of the cited waste types for each of the major DOE sites. An exception was made for the treatment of HLW, which was determined by DOE to be outside the scope of the WM PEIS. The database supporting the computational framework used to generate the radioactive source terms has been summarized in recent reports.[6-9] In the WM PEIS analytical process, these source terms were then sent to Oak Ridge National Laboratory, where the necessary calculations were performed to generate the potential human health impacts associated with the postulated accidents. In the Draft WM PEIS, human health impacts were estimated for managing each waste type at each site, and cumulative impacts were estimated for each waste type.

SELECTION OF RISK-IMPORTANT OPERATIONS

Several treatment technologies are analyzed in the Draft WM PEIS, with thermal treatment being the most effective for volume reduction and organic destruction. Analytical results for LLW, LLMW, and TRUW are discussed in the WM PEIS or in supporting technical reports for facility accidents that occur during operations involving thermal treatment processes such as incineration, wet air oxidation, and "no-flame" organic destruction.[10-13] These processes were considered to be risk-dominant because of their relatively high temperatures and pressures, the presence of a source of ignition for the first process, and a relatively highly concentrated level of either combustible or highly dispersible material-at-risk. More thorough descriptions of some of the analyses of waste-specific facility accidents have been reported earlier.[11-13] Although the methods used have remained the same, many of the analytical details, supporting data, and results for these analyses have been supplanted by more current information developed or made available since these earlier papers were published. The information presented herein represents the analyses developed for the Draft WM PEIS issued in August 1995.

SALIENT ACCIDENT RESULTS

The results of the accident analysis were obtained in the form of a detailed source term and an associated estimated annual frequency. The source term includes the amount of each radionuclide released to the atmosphere during the accident. The accidents were grouped into four categories on the basis of their estimated frequency: the categories range from anticipated events (frequency higher than 10^{-2} per year) to beyond reasonably foreseeable events (frequency less than 10^{-6} per year). Risk results are dependent on both the magnitude of the source term and the frequency of the accident.

Preliminary screening estimates for the maximally exposed individual confirmed that the risks to human health from releases related to accidental causes at LLW and LLMW management facilities would be relatively low. Generally, events associated with releases of large quantities of radioactive materials have very low estimated frequencies whereas events with a high frequency potentially result in releases of small quantities of radioactive materials. The releases associated with LLW incineration are generally low, in part a result of the small LLW throughput at the facility.

The results published in the Draft WM PEIS confirm expected trends. For localized accidents involving relatively small amounts of waste, the accidents are predicted to realistically affect only the worker population. For example, for LLW and LLMW incineration facility accidents, the risk-dominant accident is an explosion in the rotary kiln area. This accident is not expected to damage the integrity of the facility structure and filtration systems. The number of cancer fatalities for this accident for both the off-site and worker populations for all alternatives was estimated to be less than one (the modeling output allows "fractional fatalities"). For TRUW incineration facility accidents, the same risk-dominant accident would result in some fatalities for the worker population. The maximum number of fatalities was postulated to occur for the centralized alternative under which all TRUW is treated at one site. No cancer fatalities exceeding one were estimated within the off-site population under all alternatives for this accident.

In the LLMW "no-flame" treatment process, incineration and thermal desorption are replaced with sludge washing, soil washing, debris washing, and organic destruction technologies. The preliminary estimation of health effects for this option indicates relatively low impact on the on-site and off-site populations. This conclusion is supported by other comparisons of wet-air oxidation (a less hazardous form of organic destruction) with incineration.[14] The relatively low health impacts are the result of a number of factors, such as the high degree of secondary containment for the treatment facility (assumed to be a moderate-hazard facility).

The risk-dominant high-frequency accident scenario is a fire that occurs outside the organic destruction holding tank following leakage. The fire is caused by ignition of combustible solvent and is postulated to disperse radioactive particulates in the immediate area and to last for only a short period because of the limited amount of combustible material. The number of cancer fatalities for this worst-case accident was estimated to be less than one for both worker and public populations for each LLMW "no-flame" alternative.

One expected trend concerned the comparison of risks between incineration and the organic destruction technology, which replaced incineration in the LLMW "no-flame" option. The risk from organic destruction accidents would be expected to be lower than that for comparable incineration accident sequences. This conclusion is based on a number of operational differences, including less severe operating conditions, absence of a fuel source such as natural gas, and a high degree of dilution in the product stream for the organic destruction technology compared with incineration. For example, the risk-dominant chemical accident scenario for treatment by organic destruction is a facility fire involving the input feed of organic material to be treated. Such a scenario is risk-dominant because of the high frequency of internal fires (estimated to be 1.5×10^{-2} per year) relative to those initiated by external events such as natural phenomena and airplane impacts. The composition of the feed is very similar for both organic destruction and incineration technologies. However, the material-at-risk for the organic destruction facility is always less than that for the incineration facility, generally on the order of 75%. The chemical risks estimated for incineration would therefore bound those for organic destruction. The estimated number of cancer incidences from this chemical-related accident scenario was less than one for both worker and public populations for each LLMW alternative.

For end-of-spectrum accidents with very low estimated frequencies, such as those involving significant airborne releases initiated by natural phenomena or airplane crashes, more serious worker health effects and measurable public health consequences are predicted for certain alternatives at selected sites. The end-of-spectrum risk-dominant accident for treatment of LLW by incineration was determined to be a crash of a small aircraft into the facility, with a frequency falling in the beyond reasonably foreseeable range ($<10^{-6}$ per year). A fire was postulated to initiate, due either to the kiln fuel supply piping being breached and the fuel ignited or to the ignition of aviation fuel during the impact, after the aircraft engine directly impacts the major process equipment. This accident has the potential to release a portion of the radioactive contents of the kiln, the stored ash by-product of the incineration process, and the trapped contents of the filtration systems in the facility. For the centralized alternative in which all LLW is treated at a single site, several cancer fatalities within the off-site population and one cancer fatality within the worker population were predicted. Other alternatives resulted in fewer cancer fatalities for the off-site and worker populations.

For LLMW, the risk-dominant accident with high consequences and low frequency was determined to be a seismic event that severely damages the incineration facility, rendering the high-efficiency-particulate-air (HEPA) filtration system ineffective. A severe fire was assumed to be initiated in the area containing high amounts of combustible materials, the rotary kiln area, due to breaching of the fuel supply piping and subsequent ignition. The frequency of this worst-case accident was estimated to be in the extremely unlikely range. The number of cancer fatalities from this worst-case accident was determined to be less than one for both worker and off-site populations under all alternatives.

For contact-handled (CH) TRUW, the worst-case accident with high consequences and low frequency was determined to be a seismic event damaging the facility and causing a fire in the filtration systems. The frequency of this worst-case accident was estimated to be in the extremely unlikely range. The centralized alternative, under which all TRUW is treated at one site, was found to result in several cancer fatalities from the worst-case accident for the off-site and worker populations. Other alternatives were estimated to have fewer cancer fatalities in both populations than the centralized alternative. Similar analyses for remote-handled (RH) TRUW indicated that cancer fatalities would be less than one for each alternative. The risk from an accident involving RH TRUW would be lower than that from CH TRUW because of the much lower throughput volume of RH TRUW.

External challenges to the organic destruction facility include airplane impacts and natural phenomena. The risk-dominant end-of-spectrum accident scenario involves a seismic event that is postulated to rupture fittings/connections to the treatment reactor, resulting in aerosol formation. Because the majority of the reactor contents are inflammable due to extensive dilution with water and lack of ignition source, it was assumed that a small fire would not automatically occur after a seismic event. The consequences of this accident scenario were much greater than those of the high-frequency accidents, but the low frequency of occurrence limits the number of cancer fatalities for this worst-case accident to less than one for both worker and public populations for each LLMW alternative.

It is important to recognize that the limiting airborne releases discussed above are driven by sequences featuring severe disruption and dispersion of the material-at-risk from energetic fire and/or explosive effects, phenomena that could be eliminated or greatly reduced by appropriate process and facility configuration design. However, because of the generic nature of the WM PEIS and the absence of detailed facility designs, conservative treatment facility containment response and accident mitigation assumptions were made for those sequences, leading to measurable public health consequences. Also, no emergency management actions were assumed. As a result, the radioactive source terms and related consequences calculated in the Draft WM PEIS are expected to conservatively bound those that would be associated with real accident sequences.

RELATED PUBLIC COMMENT ISSUES

The public comment period officially began on September 22, 1995, and lasted approximately 150 days, ending on February 19, 1996. DOE conducted 14 public meetings at 18 locations at or near most of the major DOE sites from October 1995 through January 1996. From this process, as well as from past review exercises such as the public scoping process reported in the Implementation Plan[15] and various DOE headquarters and site reviews of earlier drafts, certain key elements emerged as representative of both technical and nontechnical perceptions of accident analysis. The more substantive technical issues involve uncertainty considerations, including completeness of accident sets and applicability of supporting data, as well as consistency comparisons with current site safety or EIS information or DOE safety or NEPA guidance.

Uncertainty Considerations

It is true that considerable uncertainties exist in various aspects of the facility accident analysis. The uncertainties range from issues pertaining to completeness of the analysis to numerical uncertainties in the parameters used in estimating the accident sequence frequency and the airborne release source terms. Uncertainties in the representativeness and completeness of the accident analysis arise from inherent limitations of the accident sequence modeling and the incomplete knowledge of the facilities and operations involved. Representativeness was addressed by reviewing existing safety analysis documentation and selecting accidents that were similar to or which bounded those found in the literature for the relevant operations, processes, and facilities. The issue of completeness was addressed by selecting surrogate accidents representative of classes of accidents and bounding the product of the frequency and severity of the surrogates so that the risk from each class of accidents was enveloped.

The numerical estimates of the frequency of the different accident sequences analyzed are also uncertain. Uncertainties exist in both the frequency of the initiating events and in the conditional probabilities of the accident progression path. The numerical estimates were generally conservatively obtained using accepted DOE or U.S. Nuclear Regulatory Commission safety guidance or site-specific safety documentation. Event trees were used to help organize the information, structure the sequences, and automate the calculations. Uncertainties in the frequencies of the sequences are expected to range from factors of 3 to 10 for anticipated accident sequences (i.e., those with annual frequencies greater than 1×10^{-2} per year) to 2 to 3 orders of magnitude for accident sequences with frequencies near or less than 1×10^{-5} per year, such as those initiated by beyond-design-basis earthquakes.

The radiological source terms were calculated as the product of four contributing factors: material-at-risk (MAR), damage fraction (DF), respirable airborne release fraction (RARF), and leak path factor (LPF), all of which have uncertainties. Uncertainties in the MAR and DF arise from lack of precise knowledge of waste stream inventory amounts, physical characteristics, radiological profiles, and operational and containment configurations under potential accident environments. The estimated radioactivity contents of the current and future inventories (i.e., reflecting both amount and composition) are probably uncertain by factors of 2 to 100, depending on the type of waste, location of generation, and current disposition. Conservative assumptions were made in an attempt to not underestimate the MAR. Damage fractions were chosen using generally conservative assumptions based on existing safety guidance and general knowledge of the physical characteristics of the MAR and the likely configurations and containment properties of the relevant storage and treatment facilities.

The RARF was conservatively adapted to the waste streams subjected to the dominant accident stresses encountered during the postulated sequences by assigning high or bounding values from the RARFs compiled in DOE-HDBK-3010-94.[5] The uncertainties caused by imprecise knowledge of accident stresses and imprecise extrapolation of experimental values, which themselves are uncertain, suggest uncertainty ranges from factors of 3 to 10 for high RARF values of greater than 1×10^{-2} to orders of magnitude for RARF values of less than 1×10^{-4}. Uncertainties in the physical compositions, particle size distribution, and containment configurations of the MAR suggest an additional order of magnitude in the RARF uncertainty. The LPF uncertainties for sequences with full or partial filtration exist because of incomplete knowledge of leak paths and filtration efficiency during accident conditions. For sequences in which the containment structure is damaged, an LPF of unity was assumed, which conservatively neglects plateout of particulates.

Recognizing that the uncertainties in the various source term factors are often interdependent, the uncertainty in source term estimates covers several orders of magnitude. Reasonable predictions of the distribution of source terms cannot be quantitatively established without a much greater level of knowledge of the waste stream inventories, the future generation of wastes within each category, and the actual characterization of the operations, processes, facility configurations, and operating and safety procedures. Developing this level of knowledge was beyond the scope of the WM PEIS. However, because of the generally conservative application of assumptions through all phases of the analysis, the likelihood of the "true" risk being greater than the predicted absolute value is relatively low.

Although the absolute values of the source term estimates are highly uncertain, the comparisons among the source terms are much less uncertain. Considerable effort was expended to ensure that the accident analysis approach and underlying assumptions were consistently applied for all waste streams and types of accidents considered and for all operations, processes, and facilities evaluated. Thus, the relative health and risk impacts, to the extent that they depend on source terms that are ultimately derived from and calculated for different facility accident sequences, are judged to provide useful, comparative information for discriminating among strategic alternatives.

Consistency Comparisons

The analyses were consistent with the most recent DOE guidance for preparation of an EIS from the Office of NEPA Oversight, which calls for consideration of the spectrum of accident scenarios that could occur in activities being evaluated.[4] This guidance also calls for a sliding scale approach emphasizing the risk-dominant scenarios, which was facilitated using the event tree techniques discussed above. Current safety analyses, environmental assessments, and EIS's were used as guidance. However, these analyses generally rely on an underlying technology base and related regulatory guidance, both of which have undergone considerable change over the past few years. Moreover, the scope and supporting levels of detail in site safety reports vary widely. Thus, directresult comparisons of consequences were difficult to make but generally showed order-of-magnitude consistency for similar scenarios.

LESSONS LEARNED

Following is a brief summary of selected insights gleaned and "lessons learned" relating to the WM PEIS accident analysis. With respect to accident results, severe accidents involving fires in the thermal treatment facilities generally dominated off-site risk. Fully developed facility fires arising from operational fires or industrial accidents tended to pose a risk comparable to that arising from natural phenomena (earthquakes). Although natural phenomena were estimated to be less frequent, they affected a greater inventory with the result that the relative risks were within an order of magnitude. Aircraft crashes were several orders of magnitude lower in risk (depending on the site). Although these events had the capability to affect large inventories for facilities in selected programmatic alternatives, the risks were offset by low frequencies.

Extreme wind and tornado loadings, though obviously capable of destroying structures and generating missiles, were estimated to have relatively low risk to human health from large-scale releases. The primary reason is that the accompanying high winds would tend to disperse respirable airborne releases much more than would be the case for scenarios with lower winds, and lower winds are more likely to be present during earthquakes and are implicit in traditional calculations of source term transport. A secondary reason is that accompanying rain or flooding, which often are part of extreme wind phenomena, would also tend to diminish the likelihood of severe fires.

Overall, LLW and LLMW accident radiological releases for all alternatives except centralization pose little threat to the public. Although TRUW scenarios pose somewhat more risk because of the plutonium and higher fission product content of TRUW, they nevertheless pose a small overall risk. Final disposition of actual treatment throughputs and storage inventories, as dictated by final decisions on the WM PEIS waste management alternatives, is required to compare the actual risks.

Methodological insights for programmatic EIS applications can be related to the obvious need to reduce uncertainties. A straightforward improvement would accrue from better or more accurate characterization of the wastes themselves. There have been considerable changes in the characterization of site waste inventories used in the analysis described herein (circa 1992) and the most current waste inventories. This relates not only to the amounts of waste but to their physical and chemical characteristics. Given the risk importance of fire scenarios, accurate assessments of the combustibility and behavior under thermal stress is obviously keyed to knowledge of the waste composition.

The "most uncertain" source term parameter was the RARF. The uncertainty in this parameter was caused not only by uncertainty in the MAR, as discussed above, but in extrapolating the conditions and materials given in DOE-HDBK-3010-94[5] to the accidents described in this paper. Improved knowledge in this area would of course greatly affect the entire safety analysis arena.

In the past few years, several safety analysis guidance documents have been issued by DOE, which should help the consistency of the safety analyses performed for EIS accident assessments. The improved underlying and appropriate implementation of the recently published release fractions[5] into safety analyses will also help. However, focus on "best estimate" or perhaps more accurately, minimally conservative accident analysis compared with the traditional bounding analyses used in safety analyses and EIS accident analyses, will force the safety community at large to more thoroughly address key accident parameters, thereby reducing their uncertainties. Increased use of structured probabilistic risk analysis techniques of the type used for the WM PEIS would greatly expedite this focus.

ACKNOWLEDGMENT

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

REFERENCES

1. U.S. Department of Energy, *Draft Waste Management Programmatic Environmental Impact Statement for Managing Treatment, Storage, and Disposal of Radioactive and Hazardous Waste*, DOE/EIS-0200-D, Office of Environmental Management, Washington, D.C. (August 1995).

2. C.J. Mueller et al., *An Overview of the Facility Accident Analysis for the Programmatic Environmental Impact Statement for U.S. Department of Energy Waste Management*, WM'94 Conference, February 27 - March 3, 1994, Tucson, Arizona (1994).

3. C.J. Mueller et al., *Methodology and Computational Framework Used for the U.S. Department of Energy Environmental Restoration and Waste Management Programmatic Environmental Impact Statement Accident Analysis*, WM'94 Conference, February 27 - March 3, 1994, Tucson, Arizona (1994).

4. U.S. Department of Energy, *Recommendations for the Preparation of Environmental Assessments and Impact Statements*, Office of NEPA Oversight, Washington, D.C. (May 1993).

5. U.S. Department of Energy, *Airborne Release Fractions/ Rates and Respirable Fractions at DOE Nonreactor Facilities,* DOE-HDBK-3010-94, Office of Scientific and Technical Information, Oak Ridge, Tennessee (December 1994).

6. E.J. Kohout et al., *The Waste Management Facility Accident Analysis Model (WASTE_ACC): A Computational Framework for Analysis of Waste Management Alternatives*, WM'96 Conference, February 25-29, 1996, Tucson, Arizona (1996).

7. B.K. Nabelssi et al., *WASTE_ACC: A Computational Model for Assessment of Radiological Releases and Health Risks from Waste Management Accidents*, 41st Health Physics Society Annual Conference, July 21-25, 1996, Seattle, Washington (1996).

8. B.K. Nabelssi et al., *WASTE_ACC: A Computer Model for Analysis of Waste Management Accidents*, ANL/EAD/TM-52 (Draft, February 1996).

9. M.M. Tompkins et al., *Computational Framework for Accident Analyses of Waste Management Alternatives in the U.S. Department of Energy Waste Management Program*, WM '95 Conference, February 26 - March 2, 1995, Tucson, Arizona (1995).

10. C.J. Mueller, "Facility Accident Considerations in the U.S. Department of Energy Waste Management Program," *Topical Symposium on Decommissioning, Decontamination, and Environmental Restoration at Contaminated Nuclear Sites (DDER-94)*, (November 13-18, 1994).

11. S. Folga et al., *Accident Analysis for the Low-Level Mixed Waste "No-Flame Option in the U.S. Department of Energy Waste Management Programmatic Environmental Impact Statement*, WM'96 Conference, February 25-29, 1996, Tucson, Arizona (1996).

12. J. Roglans-Ribas et al., *Facility Accident Analysis for Low-Level Waste Management Alternatives in the U.S. Department of Energy Waste Management Program*, WM'95 Conference, February 26 - March 2, 1995, Tucson, Arizona (1995).

13. B.K. Nabelssi et al., *Accident Analysis for Transuranic Waste Management Alternatives in the U.S. Department of Energy Waste Management Program*, WM'95 Conference, February 26 - March 2, 1995, Tucson, Arizona (1995).

14. J.C., Dehmel and G.T. Hong, "A Comparative Risk Assessment of Incineration and Supercritical Water Oxidation (SWCO) for Liquid Mixed Waste," pp. 275-283, *Proceedings of the Twenty-Seventh Mid-Year Topical Meeting of the Health Physics Society*, February 13-16, 1994, Albany, New York (1994).

15. U.S. Department of Energy, *Implementation Plan for the Environmental Restoration and Waste Management Programmatic Environmental Impact Statement, DOE/EIS-0200*, Washington, D.C. (January 1994).