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RADIOLOGICAL ACCIDENTS POTENTIALLY IMPORTANT TO HUMAN HEALTH RISK IN THE U.S. DEPARTMENT OF ENERGY WASTE MANAGEMENT PROGRAM*

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ABSTRACT

Human health risks as a consequence of potential radiological releases resulting from plausible accident scenarios constitute an important consideration in the U.S. Department of Energy (DOE) national program to manage the treatment, storage, and disposal of wastes. As part of this program, the Office of Environmental Management (EM) is currently preparing a Programmatic Environmental Impact Statement (PEIS) that evaluates the risks that could result from managing five different waste types. This paper (1) briefly reviews the overall approach used to assess process and facility accidents for the EM PEIS; (2) summarizes the key inventory, storage, and treatment characteristics of the various DOE waste types important to the selection of accidents; (3) discusses in detail the key assumptions in modeling risk-dominant accidents; and (4) relates comparative source term results and sensitivities.

OVERVIEW OF APPROACH

The objectives, scope, and various aspects of the approach to accident analysis in the U.S. Department of Energy (DOE) Environmental Management Programmatic Environmental Impact Statement (EM PEIS) have been reported earlier (1,2,3). As a consequence of evolving directions in the EM PEIS, these considerations have been somewhat refined and are briefly reviewed here. The EM PEIS currently calls for separate evaluations of the risks that could result from managing five different waste types: hazardous (HW), high-level (HLW), low-level mixed (LLMW), low-level (LLW), and transuranic (TRUW). The last four wastes present radiological risk and are addressed in this paper. Since the process details of final disposal alternatives are not being addressed in the EM PEIS, waste disposal or repository accidents are not addressed here.

The most recent guidance (4) from the Office of National Environmental Policy Act (NEPA) Oversight within DOE calls for consideration of the spectrum of accident scenarios that could

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occur in activities encompassed by the actions evaluated in the EM PEIS. This guidance also calls for a graded approach in which the risk-dominant scenarios are emphasized. Determination of risk dominance requires assessment of both the likelihood and the severity of plausible accident scenarios that could present a significant health hazard to either the workforce or the public. The spectrum of accident scenarios includes all accidents important to risk, from low-frequency events with potentially high consequences (as typified by accident sequences associated with natural phenomena such as earthquakes) to relatively high-frequency events with very low consequences (as typified by routine industrial accidents).

To address the broad scope of the EM PEIS and to comply with the recent NEPA guidance, a phased approach was developed that includes the following interrelated elements: (1) selection of potentially risk-dominant storage and treatment operations and related facility configurations across the DOE complex; (2) selection, development, and probabilistic evaluation of a uniform set of risk-dominant sequences of accidents; and (3) determination of the evolution and final compositions of source terms predicted to be released from these sequences. This paper focuses on accidents important to risk, as determined by elements 1 and 2 above, and discusses the major source term modeling assumptions used in element 3. A personal-computer-based computational framework and database (5) have been developed to automate these elements and provide source terms. The source terms were subsequently used by Oak Ridge National Laboratory in the EM PEIS to assess the radiological health effects and risks to the general public and to the workforces.

RADIOACTIVE WASTE TYPES

The inventories and salient storage and treatment characteristics of the radioactive waste types considered in the EM PEIS are summarized below. The waste management alternatives discussed in the EM PEIS include the identification of siting options for storing and treating each waste type before disposal. Storage inventories and treatment throughput for each site affected by a given alternative are then defined by the current inventories, existing and projected waste generation rates, and the disposition of the waste. The volume and radionuclide composition of each waste are tracked in a relational database (6) as the waste is processed to final disposal.

Low-Level Waste

Several million cubic meters of LLW currently exist in the DOE complex. This waste ranges from low-activity waste that can be disposed of without treatment by engineered, shallow land disposal techniques to higher activity waste requiring the use of treatment and disposal techniques that provide greater confinement. LLW includes contaminated equipment and maintenance waste from operations; dry solids and solidified sludges from processing; and miscellaneous wastes, including neutron-activated reactor vessels and surface-contaminated concrete walls from decommissioning and decontamination (D&D). The waste is generally packaged in drums or containers and stored on outdoor concrete pads or in weather-protective sheds awaiting shallow land disposal or treatment. LLW is generated at more than 30 sites; 5 sites generate more than 80%: Hanford, Idaho National Engineering Laboratory (INEL), Los Alamos National Laboratory (LANL), Oak Ridge National Laboratory (ORNL), and the Savannah River Site (SRS).

Two representative treatment philosophies are assumed in the EM PEIS: minimum treatment (stabilization of liquids and fines) and maximum volume reduction. The treatment technologies that depend on the physical characteristics of the waste and the final waste form as defined by the site-specific waste acceptance criteria (WAC) are (1) incineration, (2) solidification, (3) vitrification, (4) compaction and supercompaction, (5) size reduction (e.g., shredding, metal cutting, and shearing), (6) evaporation, (7) general aqueous treatment, and (8) various waste packaging techniques.

Low-Level Mixed Waste

About 180,000 m^3 of LLMW is currently stored at approximately 50 DOE sites. Generally, LLMW results from the same processes that generate LLW and includes aqueous liquids, organic liquids, sludge and particulates, soils, debris, special wastes, and inherently hazardous materials. LLMW is generally packaged in drums or containers and stored in Resource Conservation and Recovery Act (RCRA)-compliant weather-protective sheds before treatment. Another 250,000 m^3 of LLMW is expected to be generated over the next 20 years, excluding that derived from environmental restoration activities. More than 99% of this waste has been or will be generated at 11 sites; sites generating the largest amounts are Hanford, ORNL, Rocky Flats Environmental Technology Site (RFETS), and SRS. The EM PEIS treatment technologies are (1) organic destruction, (2) aqueous liquid (wastewater) treatment, (3) metal (wastewater metal) removal, (4) neutralization (acid or base additions to neutralize waste streams), (5) stabilization, (6) metal recovery, (7) mercury recovery, (8) decontamination, and (9) deactivation of reactives.

Transuranic Waste

At the end of 1991, there was approximately 70,000 m^3 of retrievably stored TRUW; about 96% of this waste is stored at Hanford, INEL, LANL, ORNL, and SRS. The TRUW includes solid materials, such as contaminated clothing and equipment, and liquids and sludges resulting from chemical processing. A significant fraction contains hazardous components. TRUW is generally packaged in drums or containers and stored in concrete structures, in weather-protective sheds, in earthen berms, or, in the case of remote-handled TRUW, in below-grade caissons. Most contact-handled TRUW, which dominates the total TRUW inventory, is stored in facilities with minimal containment, although DOE sites are increasingly moving toward qualified TRUW storage.

EM PEIS alternatives consider (1) minimal treatment (liquid absorption, compaction, immobilization, and repackaging) to meet the current Waste Isolation Pilot Plant (WIPP) WAC; (2) intermediate treatment (shredding, grouting, and changing containers) to reduce gas generation by waste in the repository; and (3) treatment to meet RCRA land disposal restrictions, which involves thermal destruction technologies similar to those for LLMW. For all alternatives, aqueous liquid is treated on-site before shipping. The treatment technologies are the same as those identified for LLMW.

High-Level Waste

HLW includes (1) liquid waste produced directly in reprocessing spent nuclear fuel and weapons production targets and any solid material derived from this waste that contains fission products in sufficient concentrations and (2) other material from the power reactor fuel cycle as determined by the U.S. Nuclear Regulatory Commission. HLW contains transuranic elements and fission products that are highly radioactive, heat-generating, and long-lived. DOE HLW management follows six implementation phases: current storage in underground tanks, retrieval, pretreatment, treatment (generally high-temperature vitrification to produce glass logs to be sealed in canisters), interim canister storage, and geologic repository disposal. However, the EM PEIS alternatives only address expanded interim canister storage at Hanford, SRS, and West Valley where the facilities will be sized to accommodate a production rate on the order of several hundred canisters per year.

SELECTION AND MODELING OF RISK-DOMINANT ACCIDENTS

Review of the operations and facilities discussed in the EM PEIS for the various waste types led to the establishment of three broad classes of accidents according to release characteristics and the facilities and populations affected. These classes include (1) general handling accidents involving a breach of waste packaging, (2) severe accidents at storage facilities, and (3) severe accidents involving treatment (or pretreatment) processes and facilities. Risk-dominant operations, facility configurations, dominant accident sequences, and associated frequencies within each broad class of accidents are described further below.

Radioactive atmospheric release source terms were modeled according to the following equation:

$$\text{Radiological Source Term} = MAR \times DF \times RARF \times LPF\ , \qquad \text{(Eq. 1)}$$

where

MAR = the quantity of material at risk,

DF = the damage fraction or fraction of MAR exposed to accident stresses capable of rendering the MAR airborne,

$RARF$ = the respirable airborne release fraction or fraction of material subjected to accident stresses actually rendered airborne and respirable, and

LPF = the leak path factor or fraction of the respirable airborne inventory that escapes any containment or confinement barriers to reach the ambient atmosphere.

The development of the MAR and DF parameters for the selected accidents is described below. The RARF is a function of the various accident stresses (pressurized release, fire, explosion, etc.) that affect the waste and the physical form of the MAR (liquid, sludge, solid, ash by-product, etc.), which varies by waste type, storage site, stage of treatment, and type of treatment technology. Values for the RARF were adapted from Mishima (7) to account for this functionality in the identified sequences. The LPF is a function of the response of the confinement, if any. For most risk-dominant severe accident sequences, confinement was assumed to be breached and an LPF of 1.0 was assumed.

General Handling Accidents: LLW, LLMW, and TRUW

For EM PEIS alternatives addressing these waste types, general handling accidents involving waste package breach are expected to dominate the radiological risks to workers because of the relatively high frequency of such accidents and the proximity of the workers to any release. Operations considered include handling in storage and staging areas, packaging and unpackaging, movement of waste within treatment facilities, and some treatment operations. Handling accidents include container breaches caused by package drops, by forklift or other vehicular impacts, by crane drops or crushing, and by overpressurization. The risk from exposure to radiation from operational incidents, such as puncture wounds during waste sorting, minor contamination from glove failures, and minor spreads of contamination from treatment equipment overpressurization, were judged to be enveloped by this class of accidents.

In the majority of handling accidents or hands-on processing incidents, the MAR would be limited to a single package. Although more severe sequences involving an array of several containers are plausible, the releases of greatest overall risk to the workforce were judged to involve a worker in contact with or very near to a single breached package. Thus, a MAR of 55 gal (208 L) corresponding to the contents of a standard plastic-lined, carbon-steel drum was specified for all contact-handled waste types. The physical and chemical composition of the MAR was defined by weighting the relative treatability category inventories at each site. The DF would depend on the location of the breach, the physical form of the MAR, and the severity of the accident stress. Liquids and volatiles would be free to flow out of a breached container, whereas most solid material would remain inside. Breached containers were assigned a DF of 0.25 for solid waste or a DF of 1.0 for liquid waste.

On the basis of a review of recent safety analysis reports, a probability of 1.0×10^{-4} per operation for package breaches, which is consistent with the aforementioned estimates of source term parameters, was assigned. Since most areas are simply staging areas for treatment or disposal operations, two handling operations were assumed, one for receiving and one for removal. Thus, the expected annual frequency (f_{mb}) of a container breach for waste product x caused by a handling accident is as follows:

$$f_{mb} = 0.0002 \times n_x \quad , \qquad \text{(Eq. 2)}$$

where n_x is the number of waste containers of waste product x received annually. To convert this value to a throughput number, it was conservatively assumed that the complete inventory turns over each year. Then the expected annual frequency of significant mechanical breaches would be given by the following equation:

$$f_{mb} = 0.0002 \times N \ , \qquad \text{(Eq. 3)}$$

where N is the capacity of the facility in number of drums.

General Handling Accidents: HLW

Review of available safety documentation suggests that the risk-dominant accident during interim glass canister storage is the breaching of a canister during handling operations or transfer. It was conservatively assumed that the breach was so severe that the entire contents of a canister were dispersed into the surrounding vault (MAR = 1 canister, DF = 1.0). Partially degraded facility filtration was assumed (LPF = 0.001). The frequency for a canister drop with the above release was estimated to be 1.0×10^{-5}/canister/year, with facility frequencies derived from the throughput.

Severe Storage Facility Accidents: LLW, LLMW, and TRUW

Radiation releases from severe accidents in a storage area are expected to dominate the risk of releases to on-site personnel and the general public for many DOE sites. Numerous storage facilities with large quantities of waste provide little or no formal containment or provide containment that would likely be breached in the event of severe thermal or structural challenges. This analysis focused on releases from severe operational accidents and external events involving fires in centralized storage pads and facilities judged vulnerable to large-scale releases. Other accidents were also considered but generally dismissed as being clearly enveloped in importance to risk by the fire sequences.

Accidents for storage facilities having solidified, vitrified, or otherwise highly stable wastes awaiting disposal were generally not analyzed. Landfills or other underground burial areas were also excluded from analysis. Finally, the volume of solid wastes and the number of handling operations associated with drum, box, or crate storage exceed those associated with liquids stored in tanks for all waste types except HLW. Consequently, tank storage of liquids was judged to have a low relative risk and no related source term analyses were performed.

Fires can be categorized as either being local and involving limited inventories of wastes or, at the other end of the spectrum, as major facility fires induced by events that provide a source of fuel (such as heating gas, vehicle gasoline, or aviation fuel) and that also disable or overpower any available safeguards. Design and operational safeguards are in place to prevent fire propagation from a localized source, such as a single package or drum or a rubbish pile, to a much larger inventory. Packages for combustible materials include steel drums, fire-resistant boxes, and fire-protected shipping containers and are generally required by RCRA to be segregated. Finally, most centralized facilities have fire detection and suppression capabilities, including normal operator surveillance, automatic sprinkler systems, fire barriers, and on-site fire department response (or some combination of these types of protection).

The MAR in all storage fire scenarios depends on the storage configuration. The DF is a strong function of the packaging, the physical form (and combustibility) of the MAR, and the detection of and response to the fires. Two categories of fires were considered: waste-container fires and facility fires. Because of the relative infrequency of a single-container fire and the much greater consequences of fully developed facility fires, only the latter were analyzed. The representative fire was assumed to encompass the spectrum of undetected or unsuppressed fires, and the entire facility inventory of combustible waste was assumed to constitute the MAR. A DF of 0.1 was assumed as a generic value to account for segregation and separation of waste packages in the facility and for the nature of the waste packaging as described previously. The estimated annual frequency for a fully developed facility fire with these source term parameters is 1.0×10^{-4}/yr, the product of a generic facility fire frequency of 1.0×10^{-2}/yr and a conditional fire suppression system failure probability of 1.0×10^{-2}. This value is consistent with existing documentation and is judged to be reasonable in light of the existing preventive and mitigative safeguards discussed previously. External event sequence frequencies depend on the location of the sites.

Although the inventories, physical forms, and radiological compositions of waste stored at each site are characterized in the EM PEIS and stored in the waste management database (6), compilation of analogous information for individual facilities on each site is beyond the scope of the EM PEIS. Accordingly, a unit inventory approach was used to develop radiological source terms with radiological and physical compositions derived by volume-weighing the inventories of the treatability categories within each waste type at each site. Because of the minimal containment properties of most facilities storing packaged LLW, LLMW, and contact-handled TRUW, a generic confinement configuration was assumed that did not consider containment or filtration (LPF = 1.0).

Severe Storage Facility Accidents: HLW

Because of the scope of the EM PEIS, ruptures, fires, and explosions of current storage tanks, which probably dominate the health risk of overall HLW management, were excluded. Radiological releases from severe fires, explosions, or natural phenomena-induced events were considered for interim storage facilities. However, the relevant safety reports for the various HLW interim storage facilities do not evaluate the risk of fire, in part, because there is no significant accumulation of combustibles to support fire propagation. Given this, the low frequency of severe external events, and the lack of plausible airborne release mechanisms in light of the high integrity of the HLW canisters, severe interim HLW storage facility releases were judged unimportant to risk and not analyzed further.

Severe Accidents Involving Treatment Processes and Facilities

The focus here is on possible fires or process explosions from operational or external causes. Many treatment operations were excluded from detailed investigation of large-scale releases on the basis of either the lack of a sufficiently radiologically concentrated MAR or the lack of an energy source capable of creating a risk-dominant airborne release. These operations include evaporative processes and solidification operations, such as grouting and cementation. In general, benign operations, such as packaging and nonthermal size-reduction activities, were excluded from consideration for large-scale accidents. Technologies for mercury separation were excluded because of their relatively low-energy operating characteristics. Thermal desorption of residues, sludges, and resins, or of debris wastes, involves combustible material. This process was excluded, however, because (1) it operates at lower temperatures and pressures than incineration, a competing technology, and (2) the output product is much less dispersible than the ash from incineration.

Other processes involving high temperatures or pressures were more closely reviewed in light of the potential energy source for dispersing airborne radioactive or toxic material, as well as for challenging the facility's integrity and capability for filtration. Similarly, operations involving or being performed in the presence of combustible materials or involving feed lines of natural gas or fuel were reviewed in light of the potential for ignition and subsequent fire or explosions. On the basis of these considerations, as well as consideration of the alternative-dependent volume of waste to be treated by each process, incineration, wet-air oxidation, and vitrification were identified for their potential for major airborne release. A final comparative review of the characteristics of the identified treatment processes, augmented by scoping source term calculations, led to the selection of incineration as the technology most likely to dominate risk to the staff of the facility and the site, as well as to the surrounding general populations, for LLW, LLMW, and TRUW. (Risks of HLW treatment technologies are not considered in the EM PEIS).

Detailed modeling of facilities is beyond the scope of the EM PEIS. Accordingly, a treatment facility with generic confinement characteristics was used to assess accidents to envelop the releases from accidents in the treatment process. A DOE Hazard Category of 2 and the associated performance requirements for its systems were assumed. Double high-efficiency particulate air filtration was assumed. The MAR at the time of the accident was based on the facility throughput at each site, which varies by alternative. The DF was based on the location of the MAR, which varied by accident sequence. The dominant sequences were generally unconfined operational facility fires that were assigned an annual frequency of 1.0×10^{-3} and external event driven fires, the frequencies of which are site-dependent.

COMPARATIVE RESULTS AND SENSITIVITIES

Cross comparisons of airborne source term releases from similar postulated accidents for comparably sized inventories of LLW, LLMW, and TRUW at risk at various DOE sites were made. LLW accidents would generally result in the smallest releases of radioactivity (as measured in curies) with analogous LLMW accidents producing somewhat greater releases. TRUW accidents would generally result in the largest releases of radioactivity, and, because of the higher concentration of heavy metals, would be expected to result in considerably more significant exposures than LLW or LLMW.

Primarily because of their high atmospheric dispersion potential, fire-related accident sequences initiated by either internal or external events produced the most significant radiological source terms for both storage and treatment facilities. Comparisons of internally and externally driven fires reflected tradeoffs between the lower expected frequencies of external event sequences and their higher expected DFs of material at risk. The relative importance of fire (as well as other types of source term dispersion mechanisms in accident sequences) is, of course, sensitive to the process, facility, and site characteristics identified above and to the affected waste type combustibility characteristics and initiating accident.

Because of the broad scope of the EM PEIS and the spectrum of sites, waste types, and facilities considered, generic accidents with representative source term parameters were used for analysis. The results were sensitive to two categories of uncertainty: (1) that occurring from the application of generic models to a range of real facilities, waste materials, and processes with somewhat different characteristics and (2) that from the modeling per se. One of the biggest sources of uncertainty in the results follows from the uncertainties in the physical and chemical compositions of the inventories. These uncertainties not only affect the MAR factor in the source term equation, but propagate through all the source term factors. Resulting differences in source term evolution could be reflected in threshold failure effects on accident mitigation or containment systems. Consequently, significantly different atmospheric releases would be expected.

REFERENCES

1. 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," in *Technology and Programs for Radioactive Waste Management and Environmental Restoration*, *Vol. 2*, proceedings of Waste Management '94, February 27-March 3, 1994, Tucson, Ariz., R.G. Post (editor), Laser Options, Inc., Tucson, Ariz., pp. 985-990 (1994).

2. C.J. MUELLER, "Overview of the Facility Accident Analysis for the U.S. Department of Energy Environmental Restoration and Waste Management Programmatic Environmental Impact Statement," in *Technology and Programs for Radioactive Waste Management and Environmental Restoration*, *Vol. 2*, proceedings of Waste Management '94, February 27-March 3, 1994, Tucson, Ariz., R.G. Post (editor), Laser Options, Inc., Tucson, Ariz., pp. 981-984 (1994).

3. C.J. MUELLER, et al., "Source Term Development for Facility Accidents in the U.S. Department of Energy Environmental Restoration and Waste Management Programmatic Environmental Impact Statement," in *Integrated Risk Management: Working Toward a Common Process,* proceedings of Fourth Annual Safety Analysis Workshop of the Energy Facility Contractors Operating Group, June 8-10, 1994, Albuquerque, N.M., pp. 85-86 (1994).

4. U.S. DEPARTMENT OF ENERGY, "Recommendations for the Preparation of Environmental Assessments and Environmental Impact Statements," Office of National Environmental Protection Act Oversight, Washington, D.C. (1993).

5. M.M. TOMPKINS, et al., "Computational Framework and Database for Accident Analysis of Waste Management Alternatives in the U.S. Department of Energy Waste Management Program, presented at the WM '95 Conference, February 26-March 2, 1995, Tucson, Ariz. (1995).

6. H.I. AVCI, et al., "Methodology for Integrated Evaluation of Alternative Siting and Treatment, Storage, and Disposal Strategies for U.S. Department of Energy Waste Management," in *Technology and Programs for Radioactive Waste and Environmental Restoration, Vol. 2,* proceedings of Waste Management '94, February 27 - March 3, 1994, Tucson, Ariz., R.G. Post (editor), Laser Options, Inc., Tucson, Ariz., pp. 975-980 (1994).

7. J. MISHIMA, "Recommended Values and Technical Bases for Airborne Release Fractions (ARFs), Airborne Release Rates (ARRs), and Respirable Fractions (RFs) at DOE Non-Reactor Facilities," DOE-HDBK-0013-93 (Draft), U.S. Department of Energy, Office of Engineering and Operations Support, Washington, D.C. (1993).