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INSIGHTS ON RADIOLOGICAL RISKS OF U.S. DEPARTMENT OF ENERGY RADIOACTIVE WASTE MANAGEMENT ALTERNATIVES IN THE ENVIRONMENTAL MANAGEMENT PROGRAMMATIC ENVIRONMENTAL IMPACT STATEMENT*

C. Mueller

Argonne National Laboratory
Argonne, Illinois

Safety Engineering and Risk Analysis Division

American Society of Mechanical Engineers

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ABSTRACT

A Facility Accident Analysis (1) was performed in support of the U.S. Department of Energy (DOE) Environmental Management (EM) Programmatic Environmental Impact Statement (PEIS). It used an integrated risk-based approach (2) to allow risk comparisons of EM PEIS strategies for consolidating the storage and treatment of wastes at different DOE sites throughout the country. This approach was developed in accordance with the latest National Environmental Protection Act (NEPA) compliance guidance from DOE (3), which calls for consideration of a spectrum of accident scenarios that could occur in implementing the various actions evaluated in the EM PEIS. This paper discusses our insights with respect to the likely importance of the relative radiological risks to human health of the different treatment technologies, waste management facilities and operations, and waste consolidation strategies considered in the EM PEIS.

OVERVIEW

The EM PEIS calls for separate evaluations of the risk impacts for managing five different waste types: hazardous, high-level, low-level mixed (LLMW), low-level (LLW), and transuranic (TRU). Under LLW, implications of managing certain types of greater-than-Class-C waste are also considered. For each waste type, six categorical strategies have been devised for consolidating wastes for treatment and storage: (1) "no action," where existing sites will generally store and treat their own wastes consistent with approved plans; (2) decentralization; (3) regionalization; and (4) centralization. The last three alternatives refer to the degree of consolidation and affect the number of sites that will be used to treat and store a given waste type. Each consolidation strategy has associated siting options, and each option involves both existing facilities and facilities in the design phase. Each siting option also implies unique inventories of waste to be stored and treated at each site and associated facilities. Finally, a number of treatment technologies and storage options for each waste type are to be evaluated.

The DOE alternatives for managing greater-than-Class-C wastes are currently addressing only sealed sources, which have negligible risk impacts because of their very low inventories. Although high-level waste management does raise important safety issues (4), the EM PEIS alternatives differ only in the disposition of vitrified wastes, which pose negligible risk issues. Accordingly, this paper focuses on the insights gleaned from analyses of potential accidents for the remaining radioactive waste types, namely LLW, LLMW, and TRU.

RISK-IMPORTANT OPERATIONS, FACILITIES, AND RELATED ACCIDENT TYPES

An initial screening was performed to identify those processes and facility configurations within the EM PEIS waste management alternatives with accidental radiological releases important to overall risk. To simplify this screening, waste management was first categorized as falling within three operational regimes: (1) current or pretreatment storage, which includes emplacement in and retrieval from storage and transfer to pretreatment or treatment facilities; (2) processing, which includes pretreatment (for only high-level waste) and treatment; and (3) interim storage and subsequent

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treatment. Because of the stable nature of the waste in its final form before disposal, the last operational regime was judged to pose a much smaller risk than the current storage and process operational regimes.

To further simplify the screening and subsequent analysis, facilities were categorized according to their DOE Performance Category. Storage and treatment facilities to be used in the waste management strategies considered in the EM PEIS range from outdoor storage pads or weather protection facilities to DOE Performance Category 1 — equivalent treatment facilities. The former facilities offer almost no containment capability, whereas the latter have the structural capability to withstand significant earthquakes without loss of containment and filtration functions. Facilities considered in the EM PEIS also include operating and preoperational facilities and conceptual designs. The storage inventories, treatment throughputs, and (for conceptual designs) the facility sizing are all functions of the strategic alternatives (5) being investigated by the EM PEIS.

Criteria were then developed to help identify and classify risk-dominant facilities and storage or treatment operations for each waste stream by their characteristics with respect to accidental radiological releases. These criteria included the amount and composition of the material at risk (MAR); the vulnerability of this material to airborne releases; the containment building characteristics; and the operation, facility, site, and general population demographics.

Review of the operations and facilities against these criteria led to the establishment of three broad classes of accidents as determined by their release characteristics and facilities and populations affected. These classes include (1) general handling accidents involving breach of the waste packaging, (2) storage facility accidents, and (3) treatment (or pretreatment) processes and facility accidents. Within these classes, individual operations or facilities were then reviewed to better define risk-dominant operations or facility configurations.

General Handling Accidents

General operational handling accidents are expected to dominate the radiological risks to workers because of their frequency and the proximity of the workers to the release. Such operations include storage and staging area handling, packaging and unpackaging, movement of waste within treatment facilities, and some treatment operations. These operations are prone to mechanical stresses in industrial accidents such as container drops and spills or forklift punctures, but resulting container breaches can be shown to lead to insignificant airborne releases relative to those releases involving fires or explosions. As a result, they generally constitute little hazard to the general public. Although packaged wastes involve both contact-handled and remote-handled wastes, because of the operational restrictions imposed upon remote-handled waste, the overall risk impacts of releases on occupational workers due to inadvertent breaches of containers will be less than those for contact-handled containers.

Storage Facility Accidents

Storage facilities often involve large quantities of MAR, provide little or no formal containment, and would be likely to be breached in the event of severe thermal or structural challenges. As a result, severe storage area accidents involving fires are expected to dominate the risk of releases to site personnel and the general population surrounding the site for many DOE installations. Other accidents of concern involve operations such as retrieval of liquid waste from storage tanks, which could result in releases directly to the atmosphere.

Applying the risk-importance criteria led to the low-risk categorization of storage facilities with solidified, vitrified, or otherwise highly stable predisposal wastes because of the difficulty to render such wastes into a respirable airborne state. Landfills or other underground burial areas for small, individually packaged waste containers were judged to be relatively immune from severe fires or explosions and were categorized as having low risk importance with respect to large releases. Severe storage accidents in large, robust facilities with high structural integrity and multiple filtration banks, as typified by DOE Category 1 or 2 facilities or their equivalents, would involve atmospheric source-term releases only under severe and extremely improbable accident conditions and thus were categorized as low-risk facilities. These categorizations led to the selection of facilities with large inventories of combustible waste and little confinement capability as being of the highest risk importance in severe accidents. These facilities were modeled as providing no containment for severe accidents.

Treatment Process and Facility Accidents

Unlike storage accidents for which the overriding concern relates to the total amount of MAR, treatment introduces different safety considerations such as the joint presence of high process temperatures and pressures, combustible materials, and feed lines of natural gas or fuel. Moreover, the MAR may not only involve substantial inventories but may also have physical and radiological characteristics that pose a threat to both the immediate facility work force and the populations surrounding the facility. As a result, the facilities for treatment processing are generally Performance Category 1 or 2 structures with attendant containment integrity and filtration capabilities.

The risk-importance screening for all candidate treatment processes focused on the potential energy source for propagating airborne radioactive material and for challenging the facility's integrity and filtration capability. Nonthermal treatment operations were accordingly categorized as low-risk candidates for large-scale releases, which was supported by existing safety analyses. These operations included packaging; size reduction activities such as shredding, compaction, and supercompaction; and solidification processes such as grouting and cementation.

Processes involving high temperatures or pressures and 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 and/or explosions. From these considerations, thermal or heat-accumulating pretreatment or treatment processes such as fractionation using ion-exchange columns, metal melting, incineration, wet-air oxidation, and vitrification were singled out for further review. Others, such as mercury separation technologies, were judged low risk because they are relatively low-energy operations. Some thermal processes, such as evaporation, were judged low risk because they involve noncombustible, low-radioactivity inventories. Still others were judged low risk by comparison to competing technologies. For example, thermal desorption of residues, sludges, and resins or debris wastes involves combustible material but was judged unimportant to risk because (1) it operates at lower temperatures and pressures than incineration and (2) the reactant of the material is much less dispersible than the ash product that results from incineration.

The review of the characteristics of the thermal treatment processes identified as potentially important to risk led to the selection of incineration as the technology most likely to dominate radiological risk to facility and site staff, as well as the surrounding general populations, for LLW, LLMW, and TRU. Although the fractionation and metal melting accidents may be important in assessing pretreatment or treatment operations for high-level waste, they were not considered further because they do not affect EM PEIS decisions with respect to waste management. Wet air oxidation was ranked relatively low in importance because its radioactive release hazard characteristics are clearly enveloped by those for incineration, a competing technology. Vitrification presented different source-term considerations than incineration; however, it was ranked low because consideration of dispersal of the material at risk led to prediction of very low airborne release fractions.

Incineration was thus identified as the limiting process and chosen as the bounding surrogate for treatment process risk analysis. It is a volume reduction technique for combustible solid waste, organic liquid waste, and organic sludge. The key characteristics of the incineration process with implications on the potential for airborne release include high temperature, the presence of combustible materials, the potential for vessel rupture, high concentrations of radioactivity in the ash by-product, and the high dispersibility of the ash. Because incineration results in a volume-reduction factor of roughly 100, the ash by-product has a heavy-metal radionuclide concentration roughly two orders of magnitude greater than the input feed waste. Accidents of risk-importance based on site safety documentation and corroborated by our analyses include explosions of the incinerator and fires involving the feedstock, the ash residue, or the filtration system residues.

RISK-IMPORTANT ACCIDENT SEQUENCES

The development of accident sequences was based primarily on the expected dominance to human health risk of the potential radiological releases. Populations at risk include the work force in the facility where the accident occurs, the population on-site, and the general population surrounding the site. In general, operational safeguards and equipment designs are in place to ensure that the impacts on the public health of all events are extremely limited, except in the most severe (and unlikely) accident situations. Higher-frequency operational events such as spills or drops are expected to dominate worker risks, but the limited amount of material generally ensures that they contribute little to public health risk. The less-frequent severe accidents have large inventories at risk and the potential for breaching multiple containment barriers and filtering systems and short-circuiting standard emergency procedures. As a result, their low frequency is offset by their larger consequences; typically, severe accidents are predicted to dominate overall public health risks. With different populations at risk, a spectrum of accidents covering a wide range of frequencies and expected consequences needed to be considered.

Orders, standards, and other regulatory guidance from DOE, the U.S. Nuclear Regulatory Commission, and the U.S. Environmental Protection Agency, as well as key supporting documents, were reviewed to identify a spectrum of accidents and potential releases routinely evaluated in safety analyses. Because nearly all accident scenarios capable of major airborne releases involve fires or explosions, attention was focused on these phenomena to help postulate and assess consequences and likelihoods of these sequences. The Defense Programs Safety Survey Report (6) and the Idaho National Engineering Laboratory (INEL) and Spent Fuel Environmental Impact Statement (7) were also reviewed to provide guidance for the selection and evaluation of accidents. Finally, recent safety analysis reports and other facility-specific analyses were reviewed for applicability to both explicit facilities and related generic facilities.

Probabilistic risk assessment techniques were used to structure the computational framework. Potential accident initiators were first reviewed and grouped into categories for subsequent accident progression analysis. Functional event trees were developed to project the progression of accident initiators through plausible generic accident sequences into various source term categories organized by release characteristics and severity levels. Nuclear criticality events were considered independently and judged to constitute negligible risk.

To facilitate analyses, all generic accident initiators were first categorized based on the nature of the initiator and the potential magnitude of releases. These categories included (1) operational events initiated from within the facility and (2) external challenges to the facility. The former was subdivided to account for mechanically induced breaches of waste containers, fires, and explosions resulting from human errors, equipment failures, or industrial accidents internal to the facility. The latter category was subdivided to consider accidents from generally man-made events (e.g., aircraft crashes) and potentially catastrophic natural phenomena (e.g., earthquakes, extreme winds/tornadoes, floods, and volcanoes) with likely implications on other facilities at the site. Although the frequency of an aircraft impact is obviously very low for most DOE facilities, certain facilities are located relatively close to airports or are in or near flight patterns for commercial or regional airports. For these sites, aircraft crashes with attendant fires or explosions involving aviation fuel could be important to public risk.

These accident initiator categories were then mapped into the risk-important waste management operations or facility configurations identified earlier. Surrogate accident initiators were defined for the aforementioned subcategories of internal accidents on the basis of their expected frequency, dominant accident stress mechanisms, and potential consequences. Industrial accident categories were assigned frequencies appropriate to the process and facility configuration being evaluated as reflected in the most recent site safety documentation for nuclear and hazardous waste management facilities.

Finally, the accident sequences emerging from the initiators were categorized by the following frequency classes traditionally considered in safety documentation:

Anticipated:		>	10^{-2} per yr
Unlikely:	10^{-4}	to	10^{-2} per yr
Very unlikely:	10^{-6}	to	10^{-4} per yr
Extremely unlikely:		<	10^{-6} per yr

Risk-important accident sequences from each frequency range shown above were assessed consistent with the recent NEPA guidance, in light of their potential for affecting different populations. However, accident initiators leading to sequences with nominal frequencies less than 10^{-6} were generally ignored unless (1) the predicted consequences were so high that the risk (product of frequency and consequence) was likely to be dominant or (2) the uncertainty in the estimated frequency of the sequence was so large that there was a significant chance that the true frequency was greater than 10^{-6}.

Natural phenomena considered included earthquake, flood, extreme wind or tornado, and volcanic activity. Catastrophic flooding accidents were judged unimportant with respect to subsequent airborne releases because they are both very implausible and enveloped in magnitude by airborne releases resulting from other catastrophic natural phenomena in the same frequency range. Volcanic activity was judged unimportant. It is believed to pose a credible threat to waste management facilities at only two major sites, Hanford and INEL. Eruption of the active volcanoes closest to Hanford would only result in ashfall, the potential effects of which are overwhelmed by analogous effects for earthquakes in the same frequency category. Although INEL is considered vulnerable to lava flow, the airborne releases of radiological waste would pose a negligible overall risk to on- or off-site staff relative to the risk of eruption per se.

Extreme wind and tornado loadings, though obviously capable of destroying structures and generating missiles, were judged to have relatively low-risk impact on the human health from large-scale releases. The primary reason is that the accompanying winds would tend to disperse respirable airborne releases much more than would be the case for the lower-wind scenarios more likely to be present for earthquakes and which are implicit in traditional source-term transport calculations. 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.

Severe accidents involving fires generally dominated off-site risk. Fully developed facility fires arising from operational fires or industrial accidents tended to pose a risk comparable to those arising from natural phenomena (earthquakes). Although the latter 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, the risks were offset by low frequencies.

COMPETING RISKS IN WASTE MANAGEMENT ALTERNATIVES

Although radiological releases can occur as a result of facility accidents, the total societal risk from releases in the DOE/EM waste management program will also be a function of normal waste management operations and accidents involved in the transportation of wastes to or from waste facilities. The relative risks from these three sources vary with the alternative. A DOE waste management strategy emphasizing consolidation of wastes at a small number of sites nationwide would require that waste from all over the country be transported to a selected few central or regional sites and that the risk to the public from transportation accidents be expected to rise with the level of consolidation. On the other hand, consolidation requires large facilities with associated economies of scale and efficiency that would minimize worker risk and be expected to minimize the total human health risk resulting from facility accidents and normal operational releases. However, this risk would be borne by populations at and immediately surrounding the consolidation sites.

At the present time, the risks from these three sources are calculated with different methodologies and underlying assumptions. Nevertheless, it is incumbent upon the EM PEIS to attempt evaluation of the relative risk contributions to minimize the total societal risk and to ensure that no one segment of the population bear a disproportionate risk because of a specific waste consolidation alternative.

SUMMARY AND CONCLUSIONS

The above discussion applies in general to the three waste types cited earlier. Overall, LLW and LLMW accident radiological releases pose little threat to the public. Although TRU scenarios pose somewhat more risk because of the plutonium and higher fission product content of TRU, they nevertheless pose a small overall risk. Final disposition of actual treatment throughputs and storage inventories, as dictated by final decisions on the EM PEIS waste management alternatives, is required to intercompare the actual risks.

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