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DATA COLLECTION AND ANALYSIS IN SUPPORT OF THE
U.S. DEPARTMENT OF ENERGY ENVIRONMENTAL RESTORATION
AND WASTE MANAGEMENT PROGRAMMATIC
ENVIRONMENTAL IMPACT STATEMENT
WASTE MANAGEMENT ALTERNATIVES*

R.F. Coley, H.I. Avci, and L.J. Habegger

Argonne National Laboratory
Argonne, Illinois

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Argonne National Laboratory
Argonne, Illinois

ABSTRACT

This paper is a report on work in progress in support of the U.S. Department of Energy Environmental Restoration and Waste Management (EM) Programmatic Environmental Impact Statement (PEIS). Argonne National Laboratory (ANL) has been providing technical support in the areas of waste characterization; waste treatment, storage, and disposal (TSD) facility descriptions (developed jointly with EG&G, Idaho); analysis of potential accidents at TSD facilities; and waste transportation risk assessment. Support efforts encompass the following six waste types: high-level waste; transuranic waste; low-level waste; greater-than Class-C low-level waste; low-level mixed waste; and hazardous waste. Treatment, storage, and disposal facility descriptions cover the following parameters: resource requirements, cost, staffing, capacity, by-products, and effluents. The variations in these parameters effected by the proposed alternatives are estimated. Selection of proposed initiating events, characterization of source terms, and descriptions of scenarios are covered in the accident analysis portion of the ANL work. The transportation risk assessment portion includes both off-site and on-site transportation of both radioactive and hazardous wastes for all waste management alternatives under consideration in the EM PEIS.

WASTE CHARACTERIZATION

As part of its work scope under the U.S. Department of Energy's (DOE's) Environmental Restoration and Waste Management (EM) Programmatic Environmental Impact Statement (PEIS) program, Argonne National Laboratory (ANL) collected sufficient data to characterize the waste resulting from waste management operations at all DOE facilities. The data were collected for each of the following waste types: high-level waste, transuranic waste, low-level waste, greater-than Class-C low-level waste, low-level mixed waste, and hazardous waste. The wastes were characterized with respect to the following parameters: mass or volume, chemical content, radionuclide content, and physical form. In addition to characterization of the wastes currently in storage, projections were obtained for wastes to be generated over the next 20 years. The sources used and the results of this waste characterization effort by ANL are summarized below by waste type.

High-Level Waste

At DOE facilities, high-level waste (HLW) results from the processing of irradiated fuel and uranium targets for the recovery of special nuclear materials for use in nuclear weapons and other national defense activities. This type of waste has been generated at four DOE sites — Hanford reservation near Richland, Washington; the Savannah River site (SRS) near Aiken, South Carolina; Idaho National Engineering Laboratory (INEL), near Idaho Falls, Idaho; and the West Valley Demonstration Project (WVDP), near West Valley, New York. At Hanford and SRS, these

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wastes are stored in underground tanks as alkaline liquid, sludge, salt cake, and (at Hanford) slurry. The HLW at INEL is stored as liquid in underground tanks before it is processed into solid calcine, which is stored in steel bins housed in concrete vaults. At WVDP, the HLW is stored in two underground tanks. One tank contains alkaline waste as liquid and sludge, while the other tank contains an acidic waste.

At the end of 1990, approximately 398,000 m³ of HLW was stored at the four sites. This material contains about 1×10^9 Ci of radionuclides (1). The site with the largest volume of HLW is Hanford, followed by SRS, INEL, and WVDP, in decreasing order. The radioactivity is greatest in the SRS HLW, followed by Hanford, INEL, and WVDP. Operations involving reprocessing of spent nuclear fuel at all four DOE sites have either been stopped or will be within a few years. Thus the quantity of HLW to be treated, stored, and disposed of by the DOE Office of Environmental Restoration and Waste Management consists primarily of material already in storage.

Transuranic Waste

Transuranic waste (TRUW) refers to waste materials containing radionuclides with atomic numbers greater than 92 (the atomic number for uranium). These radionuclides are generally alpha-emitting and decay slowly. Transuranic waste contains a concentration of these radionuclides that is greater than 100 nCi/g. Depending on the exposure rate at the surface of containers used for this type of waste, the wastes are also classified as contact-handled (CH) or remote-handled (RH). Contact-handled transuranic waste would have an exposure rate of less than 200 mR/h, whereas the exposure rate for RH-TRUW would be greater than 200 mR/h. Site-specific volume and activity data were obtained for both types of TRUW (2,3). The volume of mixed TRUW (MTRUW) (TRUW with hazardous chemical constituents) was obtained from the Mixed Waste Inventory Report (4). The MTRUW was assumed to have the same radiological profile as the nonmixed TRUW. The chemical profiles for the MTRUW were estimated on the basis of the latest available data and process knowledge at the Rocky Flats Plant (RFP) (5).

Thirteen sites have reported to have either current inventory or future generation of CH-TRUW. Five sites have reported the same for RH-TRUW. The sites that have the largest volumes in their current inventories are INEL (about 38,000 m³) for CH-TRUW and Hanford (2,800 m³) for RH-TRUW. In terms of activity, Los Alamos National Laboratory (LANL) has the highest curie content for CH-TRUW (1×10^6 Ci) and Hanford (about 1.7×10^6 Ci) for RH-TRUW. Savannah River is estimated to generate the largest quantity of CH-TRUW (600 m³/yr and 44,000 Ci/yr), and Hanford is estimated to generate the largest quantity of RH-TRUW (176 m³/yr or 110,000 Ci/yr).

Low-Level Waste

Low-level waste (LLW) is any radioactive waste that is not HLW, spent nuclear fuel, TRUW, or uranium mill tailings. Low-level waste can contain many different radionuclides in many different combinations with quantities ranging from trace amounts to thousands of curies. Low-level waste can also take many physical forms, ranging from dilute liquids to activated metal equipment. Because of this, it was necessary to develop representative source terms and treatability categories for LLW data used in the EM PEIS.

The LLW characterization data collected for the EM PEIS were, in large part, based on the information provided in DOE's 1992 Integrated Data Base (3) and the Waste Management Information System (WMIS) data base (6). The radiological characteristics of the waste were specified on the basis of radiological groupings identified in Ref. 3. In this grouping, the activity fractions or total curies of activity in the waste were specified for each of the six radiological categories: uranium/thorium; fission products; induced activity; tritium; alpha-emitting radionuclides; and other, a category used for mixtures or undefined radionuclides. For each radionuclide category, the fractional distribution of radioactivity by radionuclide is fixed.

The physical/chemical characteristics of the LLW were specified in terms of treatability categories. Ten treatability categories were defined: (1) combustible, (2) noncombustible and noncompactible, (3) noncombustible and compactible, (4) surface-contaminated metal, (5) bulk-contaminated metal, (6) sludge/resin, (7) a general category containing all other solid LLW, (8) aqueous, (9) organic liquid, and (10) remote-handled. The current inventory and generation rate were specified separately for each treatability category at each site. Also provided were the radiological profiles for each treatability category in terms of the radiological grouping discussed above.

On the basis of the 1991 inventory, a total of $1.1 \times 10^5 \text{ m}^3$ of LLW was estimated to reside at DOE sites. The site with the largest inventory was Oak Ridge National Laboratory (ORNL) with an estimated $4.8 \times 10^4 \text{ m}^3$ of LLW. The generation rates reported by the sites for 1991 were uniformly applied to future years for purposes of analysis in the EM PEIS.

Greater-Than-Class-C Low-Level Waste

Greater-than-Class-C low-level waste (GTCC LLW) is defined as LLW that has activity concentrations exceeding the values specified by the U.S. Nuclear Regulatory Commission (NRC) in Title 10, Part 61.55, of the *Code of Federal Regulations* (CFR) as belonging to Class C LLW. Under the Low-Level Radioactive Waste Policy Amendments Act of 1985, DOE was assigned responsibility for the disposal of GTCC LLW from commercial generators. Greater-than-Class-C low-level waste must be disposed of in an NRC-licensed disposal facility, which may be a geologic repository or an alternative facility specifically approved by the NRC that isolates the GTCC LLW.

Currently, DOE accepts limited quantities of GTCC LLW for interim storage. These are primarily small, sealed sources of radioactivity that have been used by commercial companies under a license by the NRC or an NRC Agreement State. Examples of sealed sources include the use of cesium and strontium for medical therapy research and americium used in well logging.

The current inventory of such sources at DOE sites is minimal, but a significant amount may accumulate in the future. The EM PEIS will limit the scope of alternatives for GTCC LLW to consideration of alternatives for the interim storage of the sealed sources as discussed above.

Low-Level Mixed Waste

Low-level mixed waste (LLMW) is LLW that contains hazardous chemical materials. As for LLW, it can contain many different radionuclides in varying concentrations and can take many different physical forms. In addition, it can also contain quite a large array of chemicals with varying concentrations.

The LLMW inventory and future generation rate data used in the EM PEIS were generated by the DOE Mixed Waste Treatment Project (MWTP) organized by DOE as part of the process to respond to the Federal Facility Compliance Act of 1992. The data were initially published in April 1993 as the Mixed Waste Inventory Report (MWIR) (4). Certain improvements have been made in the MWIR data that are reflected in the data used for the EM PEIS.

Similar to TRUW classification, LLMW was first classified as CH and RH. The CH component is further classified as alpha-contaminated (having a concentration of an alpha-emitting radionuclide in the 10-100 nCi/g range) and non-alpha-contaminated (less than 10 nCi/g of alpha-emitting radionuclides). Within each of the three classifications (CH-alpha, CH-non-alpha, and RH), LLMW at each site is subdivided into eight treatability groups on the basis of the waste's physical and chemical form. These treatability groups are aqueous liquids, organic liquids, sludge and particulates, soils, debris, special wastes, inherently hazardous materials, and unknowns.

The radiological and chemical concentrations in LLMW are not adequately addressed in the MWIR. Therefore for the purposes of analysis in the EM PEIS, ANL developed a method that approximates them. Although, the method provides an approximation, it is deemed adequate for a PEIS. In this method, the overall radiological profile for LLMW at a given site is assumed to resemble the radiological profile of LLW generated at the same site. Because of the longer storage times of most LLMW at most sites, the radionuclides have been allowed to decay over an average elapsed time at each site, the length of which depends on the site's process history. The radiological profile at each site is assumed to be independent of the waste streams.

The chemical profiles were estimated from information contained in the MWIR and WMIS data bases. All waste streams in the data bases were combined into one of seven kinds — aqueous liquids, organic liquids, sludge and particulates, soils, debris, special wastes, and inherently hazardous wastes. For each of the seven kinds, the five highest volume examples were selected. Chemical content information from the five highest volume examples was used to define a generic chemical profile for each of the seven waste types. These seven generic chemical profiles were assumed to be independent of the site of origin.

The available data indicate that about 250,000 m³ of LLMW is currently stored at approximately 50 DOE sites. Another approximately 1,050,000 m³ of LLMW is expected to be generated over the next 20 years. About 99.8% of this waste has been or will be generated at 13 sites; the largest generating site is Hanford (1,047,000 m³), followed by ORNL (104,000 m³), RFP (66,000 m³), and SRS (59,000 m³).

Hazardous Waste

Hazardous waste (HW) is defined in 40 CFR, Part 261, as mandated by the Resource Conservation and Recovery Act (RCRA). Hazardous wastes are considered to be either listed or characteristic. As the name implies, the listed wastes are specifically identified in one of four lists contained within 40 CFR 261. Characteristic wastes are wastes that do not appear on the lists noted above but still have certain characteristics that the U.S. Environmental Protection Agency (EPA) considers hazardous. These characteristics include ignitability, corrosivity, reactivity, and toxicity.

The primary tool used by ANL in obtaining the HW inventory and characterization information to be used in the EM PEIS was the Uniform Hazardous Waste Manifest. The hazardous waste manifest is the shipping paper that all DOE facilities must use when shipping regulated quantities of HW off-site. Argonne obtained copies of 2,024 hazardous waste manifests from 45 DOE facilities that shipped HW off-site during FY 1992. This information was incorporated into a data base developed at ANL (7). Manifest summaries extracted from the data base along with data from other available sources (for example, the Land Ban Notification and Certification forms, EPA biannual reports, and reports generated by individual states) were used to assign waste to one of the following 10 waste treatment and disposal technology groups: (1) incineration, (2) stabilization/solidification, (3) metal removal/recovery, (4) mercury recovery/removal, (5) decontamination, (6) deactivation/neutralization, (7) organic removal/recovery, (8) recycling, (9) aqueous liquid treatment, and (10) land disposal.

Because the ANL HW data base was initially designed as a transportation risk assessment data base (i.e., manifests represent off-site shipments only), it alone could not be used to get a good characterization of DOE installation HW generation rates. Contacts with site representatives and visits to targeted facilities were used to fill in data gaps and to collect necessary supplemental data not included in the data obtained from the central repository. Some sites provided details of waste generation. More importantly, the EPA biennial and state annual reports, required under RCRA (40 CFR 262.41), were acquired to obtain data on "as generated" HW (7).

An examination of the results of the inventory breakdown by technology types reveals that over 98% of the "as generated" HW is processed at on-site wastewater treatment facilities. Over 80% of the remaining HW is treated at commercial TSD facilities. In almost all cases, the treatment of HW leads to the generation of some type of process residual (i.e., fly ash from incineration, sludge or precipitate from aqueous treatment, or still bottoms from solvent distillation). At some point, most of the treatment residuals will require land disposal once the Land Disposal Restriction treatment standards have been met. The amount of residuals generated may vary greatly depending on the type of waste and the treatment process.

TREATMENT, STORAGE, AND DISPOSAL FACILITY DESCRIPTIONS

It is not the objective of the EM PEIS to decide which technologies should be used to treat, store, and/or dispose of the DOE wastes previously described. Nevertheless, the EM PEIS is expected to provide an analysis of alternative management options for the TSD of these wastes. Therefore it was necessary to define a set of generic technologies to represent the possible TSD options as part of the evaluation of the alternative management options. Table I lists the representative technologies considered for TSD of each waste type. These technologies have been selected from a list of available or soon to be available technologies. So-called developing technologies, that is, those technologies that have not been fully demonstrated and evaluated, and the probable effects of use of those technologies are discussed separately in the EM PEIS.

PLACE TABLE 1 HERE

A number of parameters were defined to characterize the selected technologies for the purposes of impact assessments in the EM PEIS. For treatment facilities, these parameters, in general, give the desired quantity as a function of throughput (i.e., the quantity of waste processed annually). For storage and disposal facilities, they give the desired quantity per unit of waste stored or disposed of. These parameters include, among others, the following:

- Resource requirements (e.g., energy, water),
- Cost,
- Staffing,
- Treated product volume or mass,
- Secondary products (liquid or solid residuals), and
- Air emissions of radionuclides and hazardous chemicals.

Some of these parameters were developed by ANL in consultation with other EM PEIS participants and the MWTP staff; others, such as the resource requirements, cost, and staffing requirements, were developed by EG&G, Idaho, and its subcontractor Morrison Knudsen Environmental Services Corporation (MK).

Flow sheets were developed to describe the flow of waste from its point of generation (or storage if generated in the past) through treatment and storage facilities and to disposal. The facility characterization parameters listed above have been used to estimate the quantities and physical/chemical/radiological characteristics of the waste at each step along the way from its origin to disposal. This process is described in the following section.

EFFECTS OF EM PEIS ALTERNATIVES

Three sets of data were required to begin analyzing the effects of the EM PEIS waste management alternatives: (1) waste inventory, generation, and characterization data; (2) TSD facility characterization data; and (3) alternative definitions that specified the technologies and the location of the technologies used to treat, store, and dispose of the wastes. The first two data types are described above. The third type, definition of alternative cases, was developed by META/Berger in consultation with DOE, ANL, and other EM PEIS team members.

The siting configurations considered generally fall under three classifications: decentralized, regionalized, and centralized. In addition, a No-Action alternative, and, for most waste types, a Current Program alternative are analyzed. Under each decentralized, regionalized, and centralized alternative, there may be several cases with different siting arrangements for each waste type. Also, there may be more than one treatment option considered for each waste type. Consequently, the number of cases (i.e., site-technology combinations) to analyze for each waste type vary from a few (HLW and GTCC) to approximately 30 (LLW and LLMW).

To evaluate critical parameters associated with the complex array of waste inventories with multiple technology and siting options for TSD accurately and efficiently, ANL developed a computational model named WASTE_MGMT. The WASTE_MGMT model is structured around the three classes of data files described above. The model is implemented on an IBM-compatible personal computer using the Microsoft® FoxPro® Version 2.5 relational data base management system. The model is described in more detail by Avci, Habegger, and Kotek (8).

The WASTE_MGMT model is used to track the wastes by waste treatability group at each site from their place of origin to disposal and to calculate the following:

- Annual quantities and characteristics of the wastes shipped among sites,
- Annual quantities and characteristics of the wastes processed by each TSD module,
- Annual air emissions of radionuclides and hazardous chemicals resulting from the operation of the TSD modules, and
- Annual generation rates and characteristics of secondary waste streams resulting from the operation of the TSD modules.

The results from the WASTE_MGMT computational model are distributed among the EM PEIS participants, as appropriate, for the calculation of

- Worker, public, and ecological risks by ORNL;
- TSD module costs, worker populations, and the resource requirements for construction of new modules and for operation of all modules by EG&G, Idaho, and MK;
- Doses and health effects to transportation workers and the public along the transportation routes by the transportation risk assessment group at ANL;
- Air emissions of radionuclides and hazardous chemicals during postulated TSD facility accidents by the facility accident analysis group at ANL; and
- Air and water quality impacts and cumulative impacts by META/Berger.

TREATMENT, STORAGE, AND DISPOSAL FACILITY ACCIDENT ANALYSIS

The above section focused on the analysis being conducted within the EM PEIS program for characterizing the parameters associated with the normal operation of waste management facilities structured under alternative overall national strategies. This section summarizes the complementary EM PEIS studies for characterizing the potential abnormal or accident scenarios associated with the alternative strategies that could influence the comparative evaluation of the strategies. [Further details on the EM PEIS accident analysis are provided in companion WM '94 paper (9-12)].

No extensive precedent exists that could be followed in defining the approach to be used for accident analysis in PEISs, in particular, as related to the programmatic waste management alternatives being considered in the EM PEIS. The DOE has provided general guidance that calls for consideration of the spectrum of accident scenarios that could occur in activities being considered (13). This guidance also calls for a graded approach that emphasizes accident scenarios with the more dominant risks. Identification of risk-dominant accident scenarios requires that both the likelihood and severity of plausible accidents be considered.

Considerable related information exists in previous safety analyses, environmental assessments, and other site-specific studies; however, this information tends to be inconsistent in approach and often cannot be used directly in cross-cut comparative analyses. It was deemed necessary to include in the EM PEIS both internally initiated industrial accidents occurring during waste management activities and externally initiated events ranging from fires in adjacent facilities to earthquakes.

These requirements and constraints led to formulation and implementation of a phased accident analysis approach. For the initial phase, a PC-based computational framework was developed at ANL to identify the facility configurations with significant waste inventories and attendant vulnerability to accidents under the various alternatives considered. This computational framework was also used to evaluate frequency of occurrence estimates for selected accident sequences and to estimate releases associated with the sequences. Site-specific unit-risk factors developed by ORNL were then utilized by ANL in conjunction with the release characteristics to establish the reference risk-dominant accidents for more rigorous evaluation. Overall accident health effects are calculated by ORNL.

Preliminary calculations indicate that the health risk to the public from radiological releases following conceivable facility accidents will be negligible for the GTCC LLW, LLW, MLLW, and TRUW management alternatives considered. Minor public health effects may be predicted for the most severe HLW storage and treatment accidents; however, the likelihood of these is projected to be low.

Perhaps as significant as the immediate usefulness of these results in the EM PEIS is the development of a risk-based computational framework and data base that can be effectively used to test further alternatives and assumptions in future DOE programmatic decision making.

WASTE TRANSPORTATION RISK ASSESSMENT

A central theme of the EM PEIS is the comparative evaluation of alternatives that involve varying levels of consolidation of the TSD waste management facilities. A consequence of this emphasis is the need to estimate health and safety risks associated with the transportation of radioactive and hazardous wastes to the waste management facilities that are identified under each of the alternatives.

A requirement for the approach used in the transportation risk assessment of alternatives is the capability of dealing with a wide range of waste types, volumes, physical and chemical forms, packaging and transport systems, and origin-destination combinations. A comprehensive assessment would include risks to both the public and transportation workers, cumulative risks to all exposed individuals and risks to maximally exposed individuals, truck and rail transport modes, and risks associated with both normal and accident conditions. For use in a National Environmental Policy Act (NEPA) document, the analytic approach should be based on methods that, to the extent possible, have been technically reviewed by the scientific community and are generally accepted by the regulators and affected public. To this end, a thorough and critical review was conducted of existing NEPA documents prepared for actions involving significant transportation components.

This section summarizes the nature and extent of the transportation risk assessment that is being conducted by ANL as part of the EM PEIS. Additional details of these assessments can be found in companion papers (14,15,16).

Radioactive Waste

The basic computational tools for the radioactive waste transportation assessment that met the overall requirements and were selected for the EM PEIS were the RADTRAN 4 computer code for cumulative population risks during normal and accident conditions (17) and the RISKIND code for maximum exposures to individuals during routine operations (18). The RISKIND code is also used to provide a more detailed assessment of the most severe transportation accidents.

Meaningful comparisons of risk among the various EM PEIS alternatives required judicious selection and uniform application of input data to the computational models. The assumptions used for packaging and shipping configurations are critical. The assumptions used (15) are consistent with federal regulations that provide general guidance on the use of container types designated as Type A, Type B, or "strong and tight" (generally for low specific-activity material) (19,20). In the absence of other generally applicable information, the analysis assumed for all shipments the limiting external dose rate value of 10 mrem/h at 2 m from the lateral surfaces of the conveyance, as specified by federal regulations.

The highway and rail route selection can affect the rate and consequences of accidents. This analysis utilized the HIGHWAY (21) and INTERLINE (22) models for highway and rail routes, respectively, that were developed and are periodically being updated by the ORNL. State-specific accident rates in urban, rural, and suburban zones along these routes are estimated from data provided by Saricks (23). The accidents that are estimated to occur are projected to have varying levels of severity with a relative frequency of occurrence based on NRC studies (24). Other parameters necessary to complete the risk assessments (i.e., package accident release characteristics, atmospheric conditions, maximum exposure scenarios, and health risk conversion factors) are selected for consistency with approaches previously used and generally accepted (15).

The analysis of thousands of rail and truck shipments under various alternatives by using the models and input data described would be prohibitively demanding within the constraints of the EM PEIS schedule. To overcome these constraints, ANL developed a unit-consequence approach to the analysis (14). In this approach, extensive preprocessing was used to develop data files of the consequences associated with unit transport for each possible set of defining parameters. These unit-consequence data files are incorporated into an easy-to-use, menu-driven interface with pop-up lists to quickly evaluate the risks of any waste transport scenario possible within the EM PEIS.

Hazardous Waste

The hazardous chemical waste methodology in the EM PEIS for estimating the likelihood of an accident resulting in a release in rural, urban, and suburban population zones during transportation is similar to that for transportation of radiological materials. However, methods for estimating the health effects due to the releases of the hazardous chemicals are not as well established, and the methods determined to be appropriate for use in the EM PEIS are discussed here and in more detail in a companion paper (16).

The focus of the evaluation of health effects from accidents during the transport of hazardous chemicals is on inhalation of the hazardous chemicals in ambient air. Information from DOE hazardous waste shipping patterns in FY 1992 was used to determine the types of containers used and the quantity typically included in a single shipment and thus potentially released in an accident. The ALOHA air dispersion model (25) is used to calculate the area surrounding the accident for which the contaminant air concentration is above levels (i.e., criteria levels) predicted to cause adverse health risks. Important human health risk endpoints with respect to accidental releases of hazardous waste that were considered include the potential for life-threatening effects, for any adverse effects, and for carcinogenic effects. All individuals within a plume area with concentrations above criteria levels for these effects were assumed to be at risk; the risk for individuals at various locations within this defined plume area was not differentiated.

The probability of life-threatening health effects is assessed for all hazardous waste components designated as poison inhalation hazards by the U.S. Department of Transportation (DOT) (49 CFR 173.115; 49 CFR 173.132-133). Approximately 100 liquids and 70 gases are on the DOT poison inhalation hazards list (26); of these, 49 were shipped by DOE in FY 1992 and are included in the baseline case assessment. The value selected for the assessment as that above which there is the potential for life-threatening effects is based on the lower of either the lowest available human LC_{LO} value divided by an uncertainty factor of 3 or the LC_{50} value for the most sensitive tested mammalian species divided by an uncertainty factor of 10. The LC_{50} is defined as that concentration of gas or vapor which, administered by continuous inhalation, causes death in half of the animals tested. The LC_{50} is obtained only from animal tests and is never available for humans. The LC_{LO} is defined as the lowest concentration of gas or vapor that causes death in any exposed individual. The LC_{LO} value may be obtained from animal tests or from accidental human exposure occurrences. For use in the EM PEIS assessment, the values were also adjusted according to exposure time (16).

Inhalation reference doses developed by the EPA have been selected for use in the EM PEIS as the most applicable toxicity values for use in deriving minimum values for which there is the potential for any adverse effects. An inhalation reference dose is defined as an estimate of continuous exposure to the human population (including sensitive subgroups) that is likely to be without appreciable risk of deleterious effects (27). In the absence of a reference dose, values used as the basis for deriving values for the potential for any adverse effect, in order of priority, were human TC_{LO} values (defined as the lowest concentration causing any adverse effect), mammalian TC_{LO} values, human LC_{LO} values, LC_{50} values, and mammalian LC_{LO} values. As appropriate, uncertainty and exposure time adjustments were also included (16).

Hazardous waste transported from DOE facilities may also be evaluated for possible increased cancer risk in exposed individuals, defined here as an increased carcinogenic risk of one in one million (10^{-6}) or higher. For the EM PEIS hazardous waste transportation assessment, an increased cancer risk concentration value has been established for each gaseous or liquid substance transported by DOE in FY 1992 and meeting the following criteria: the substance is classified as a known, probable, or possible human carcinogen in the EPA IRIS database (28) or HEAST (29); the substance has an inhalation unit-risk value available from either IRIS or HEAST; and, the substance is volatile enough that there is significant potential for exposure of the general public.

TABLE I Representative Technologies Considered for Treatment, Storage, and Disposal of U.S. Department of Energy Wastes

Waste Type	HLW	TRUW	LLW	GTCC	LLMW	HW ^a
Treatment	Vitrification Hot isostatic pressing Pretreatment: Solids-liquids separation Actinide separation Precipitation Calcination	Incineration Wet-air oxidation Evaporation Solidification Thermal desorption Shredding Pelletizing Packaging Vitrification Polymerization	Incineration Solidification Vitrification Compaction Supercompaction Size reduction Decontamination Metal melting Evaporation General aqueous treatment Packaging	None	Incineration Wet-air oxidation Evaporation Solidification Thermal desorption Shredding Pelletizing Packaging Vitrification Polymerization	Incineration Organic removal and recovery Stabilization Neutralization and deactivation Metal removal and recovery Mercury removal and recovery Aqueous treatment Recycling (batteries)
Storage	Underground tanks Near-surface calcine bins Canister storage: Near surface drywell Underground vault	In rooms On pads Containerized	In rooms On pads Containerized Uncontainerized	In rooms	In rooms On pads Containerized	In rooms On pads Containerized
Disposal	Geologic repository ^b	WIPP ^b	Shallow land burial Belowground vault Aboveground vault	None	Shallow land burial Belowground vault Aboveground vault	RCRA-permitted landfill ^b

^a Except for incineration, organic removal and recovery, and neutralization and deactivation, all treatment takes place at commercial facilities.

^b Disposal in geologic repository, Waste Isolation Pilot Plant, or at commercial facilities is not analyzed in the EM PEIS.

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