TRANSPORTATION RADIOLOGICAL RISK ASSESSMENT FOR THE PROGRAMMATIC ENVIRONMENTAL IMPACT STATEMENT: AN OVERVIEW OF METHODOLOGIES, ASSUMPTIONS, AND INPUT PARAMETERS*

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ABSTRACT

The U.S. Department of Energy is considering a broad range of alternatives for the future configuration of radioactive waste management at its network of facilities. Because the transportation of radioactive waste is an integral component of the management alternatives being considered, the estimated human health risks associated with both routine and accident transportation conditions must be assessed to allow a complete appraisal of the impacts of each alternative. This paper provides an overview of the technical approach being used to assess the radiological risks from the transportation of radioactive wastes.

The approach presented employs the RADTRAN 4 computer code to estimate the collective population risk during routine and accident transportation conditions. Supplemental analyses are conducted using the RISKIND computer code to address areas of specific concern to individuals or population subgroups. RISKIND is used for estimating routine doses to maximally exposed individuals and for assessing the consequences of the most severe credible transportation accidents. The transportation risk assessment is designed to ensure -- through uniform and judicious selection of models, data, and assumptions -- that relative comparisons of risk among the various alternatives are meaningful. This is accomplished by uniformly applying common input parameters and assumptions to each waste type for all alternatives.

The approach presented can be applied to all radioactive waste types and provides a consistent and comprehensive evaluation of transportation-related risk.

INTRODUCTION

The Environmental Restoration and Waste Management Program of the U.S. Department of Energy (DOE) is responsible for the treatment, storage, and disposal (TSD) of radioactive waste generated at DOE facilities. For purposes of the Programmatic Environmental Impact Statement (PEIS) now being prepared, DOE is considering a broad range of alternatives for the future configuration of new or expanded waste management facilities and the potential consolidation of some existing DOE facilities (1). In general, the PEIS alternatives are considered independently for each waste type and reflect decentralized, regionalized, and centralized approaches. The radioactive waste types considered are high-level, transuranic, low-level, low-level mixed, and greater-than-class-C low-level wastes. For each waste type, several options, referred to as cases, are defined for each broad alternative. Individual cases differ in the number and locations of potential TSD sites that they entail. The overall impacts of implementing the various alternatives are currently being analyzed for the PEIS to determine the safest and most economical manner in which to satisfy waste management requirements in the coming decades.

Transportation of radioactive waste is an integral component of the alternatives being considered for all waste types. For some alternatives, radioactive wastes would be shipped among DOE sites at all stages of the TSD process. The magnitude of the transportation activities varies with the approach, ranging from minimal transportation for decentralized approaches to significant transportation for some centralized approaches. The human health risks associated with transportation activities must be assessed to permit a complete appraisal of the impacts of each alternative. For example, centralized approaches to TSD operations may minimize the risks and costs associated with fixed facilities but may increase the impacts from transportation activities. Conversely, an increased fixed-facility risk and cost that may result from decentralized or regional approaches may be offset by reduced transportation requirements.

Assessing radioactive waste transportation risks for the PEIS involves some unique issues. For example, the radioactive waste stored and generated at DOE facilities includes a wide range of waste types, volumes, physical and chemical forms, and radioactivity levels. Prior to transportation, extensive characterization, treatment, and/or packaging may need to be performed for some waste types to satisfy regulatory requirements and the waste acceptance criteria specified by treatment or disposal sites. At present, information necessary to accurately estimate the extent to which these pre-transportation activities will be necessary is not available. Therefore, the scope of the transportation risk assessment described herein does not include risks associated with preparing radioactive waste for shipment.

A second unique difficulty is that the scope of the PEIS involves virtually every DOE facility, resulting in literally hundreds of possible origin-destination shipping linkages for the large number of alternatives considered. For purposes of the PEIS, a detailed consideration of every possible shipment is impractical; therefore, representative physical and radiological characteristics have been determined for each waste type to permit meaningful comparisons among alternatives.

This paper provides an overview of the technical approach that will be used in the PEIS to assess the risks from the transportation of radioactive wastes. In addition, a

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

number of the most important assumptions and input parameters are discussed for each waste type. It is important to note that the methodologies and assumptions being used in the assessment were selected in order to ensure meaningful comparisons among programmatic-level alternatives; therefore, the technical approach uses a number of simplifying assumptions and generalizations appropriate to the programmatic nature of the PEIS. Specific actions in the future involving the transportation of radioactive wastes will be supported by project-level environmental analyses and documentation.

APPROACH

The technical approach for conducting the transportation risk assessment was developed following a thorough and critical review of the literature and existing National Environmental Policy Act documentation for federal actions involving transportation of radioactive materials. Consideration was also given to recent DOE commitments arising from both litigation and public awareness. It is an approach that can be applied to all radioactive waste types, provides a consistent and comprehensive evaluation of the transportation risks associated with the alternatives being considered, and satisfies the human health risk assessment requirements of the PEIS. The approach is also currently being applied for the DOE Sitewide Environmental Impact Statement being prepared for the Idaho National Engineering Laboratory.

The technical approach is conceptualized in Fig. 1. As shown, reasonably foreseeable risks to workers and members of the public are assessed for both routine and accident transportation conditions for all alternatives. The radiological risk associated with routine transportation of radioactive materials results from potential exposure of a receptor to external penetrating radiation in the vicinity of loaded shipments. (For the majority of DOE radioactive waste shipments, external exposure rates are limited by federal regulations to a maximum value of 10 mrem/h measured 2 m from the lateral surfaces of the transport vehicle.) The radiological risk from transportation accidents lies in the potential release and dispersal of radioactive material.

Potential risks are estimated for the collective population of exposed people as well as for the maximally exposed individual. The RADTRAN 4 computer code (2) is used to estimate the collective population risk during routine and accident transportation conditions. The collective population risk is a measure of the radiological risk posed to society as a whole by the alternative being considered. As such, the collective population risk is used as the primary means of comparing different alternatives.

Supplemental analyses are conducted for the PEIS using the RISKIND computer code (3) to address areas of specific concern to individuals or population subgroups. RISKIND is used for estimating routine doses to maximally exposed individuals and for assessing the consequences of the most severe credible transportation accidents. The supplemental analyses are primarily meant to address "What if" questions, such as, "What if I live next to a site access road?" or "What if an accident happens near my town?"

RADTRAN 4

RADTRAN 4 was developed by Sandia National Laboratories to calculate the collective population risks associated with the transportation of radioactive materials by a variety of modes, including truck, rail, air, ship, and barge. The code has been extensively reviewed, updated, and verified since it was issued in the late 1970s; the latest version is available for use by DOE and its contractors through the TRANSNET computer network.

Routine Transportation. The RADTRAN 4 risk calculations for routine highway and rail transportation include models describing 1) collective doses to persons living or working

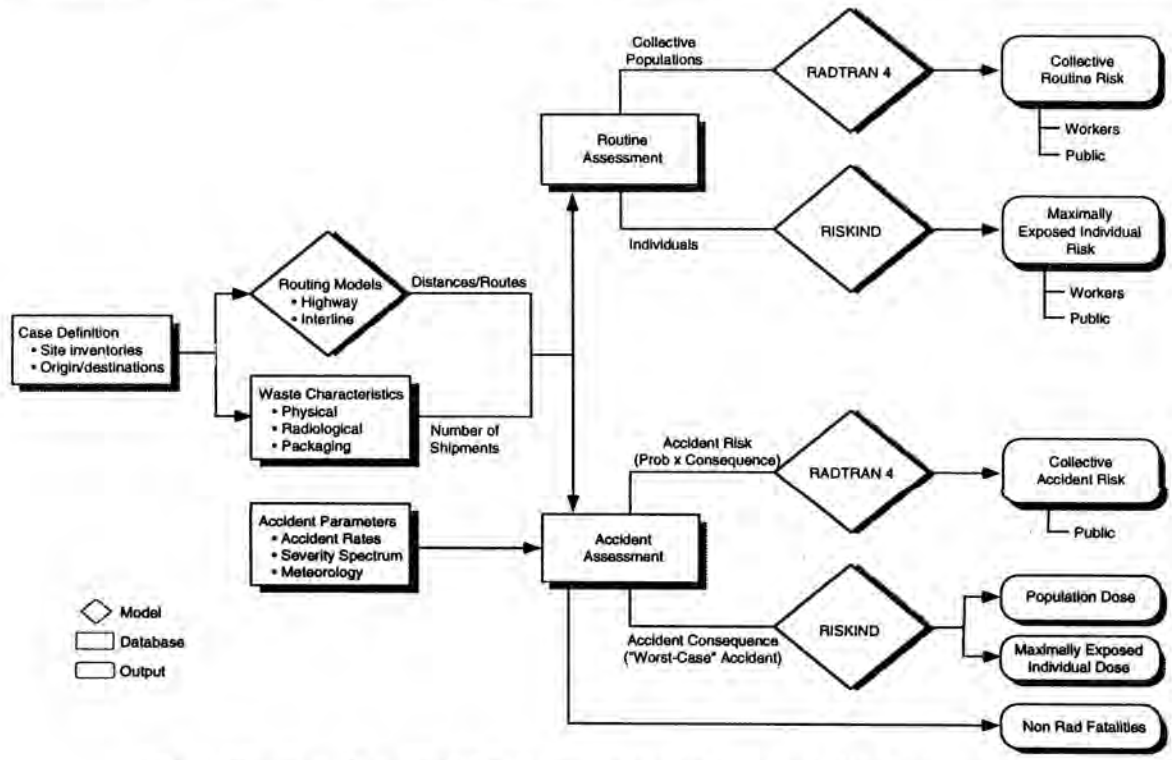

Fig. 1. Conceptual approach for the transportation radiological risk assessment.

adjacent to the transport route, 2) collective doses to persons sharing the transport route (e.g., driving on the same highway), 3) collective doses to persons at stops (e.g., refueling stops and rail classifications), and 4) collective doses to transportation crew members. The doses calculated by using the first three models are added together to yield the collective risk to the public; the dose calculated by using the fourth model represents the collective risk to workers. The RADTRAN 4 routine dose models are not intended to be used for estimating specific risks to individuals. The probability of routine risks occurring is taken to be unity in the RADTRAN 4 code.

Accident. Because accident occurrences are statistical in nature, accident risk is commonly defined as the product of the accident consequence (dose) and the probability of the accident occurring. In this respect, the RADTRAN 4 code estimates the collective accident risk to populations by considering a spectrum of credible transportation accidents. The accident spectrum is designed to encompass a range of possible accident environments, including low-probability accidents that have high consequences, and high-probability accidents that have low consequences. Accident frequencies are generally derived from historical records for the transportation mode being considered.

The calculation of collective accident risk employs models that quantify the range of potential accident severities, the response of a transport package to a particular accident environment, and the exposure of populations following the dispersion and transport of released radioactive material into the environment. Exposure pathways include external exposure to the passing radioactive cloud and to contaminated ground, and internal exposure from inhalation of airborne contaminants and ingestion of contaminated food. The collective accident risk results can be directly compared with the routine population risk results because they incorporate the probabilities of accident occurrences.

RISKIND

The RISKIND computer code was developed for the DOE Office of Civilian Radioactive Waste Management to analyze the exposures of individuals during the routine transportation of spent nuclear fuel. In addition, the RISKIND code was designed to allow a detailed assessment of the consequences to individuals and population subgroups from severe spent nuclear fuel transportation accidents under various environmental settings. Minor modifications were made to the code for PEIS applications to accommodate shipments of all radioactive waste types.

Routine Transportation. RISKIND is used to calculate the dose to maximally exposed individuals for a number of hypothetical exposure scenarios during routine conditions. Maximum estimated individual doses are generally compared with regulatory dose limits as well as with average individual doses from background radiation.

Accident. RISKIND is also used to provide a detailed assessment for each waste type of the consequences of the most severe transportation accidents. Whereas the RADTRAN accident risk assessment considers the entire range of accident severities and their related probabilities, the RISKIND accident consequence assessment assumes that an accident of the highest credible severity has occurred. These accidents represent low-probability, high-consequence events. The actual probability of an accident of this magnitude occurring for each alternative depends on the total shipment distance for the alternative; however, accidents of this severity are extremely rare in general. Detailed consequence calculations are performed using RISKIND for accidents occurring in rural, suburban, and urban population density zones. The exposure pathways considered are similar to those discussed above for RADTRAN. Accident consequences under various meteorological conditions are assessed for local populations as well as for maximally exposed individuals.

PARAMETERS AND ASSUMPTIONS

The transportation risk assessment is designed to ensure -- through uniform and judicious selection of models, data, and assumptions -- that relative comparisons of risk among the various alternatives are meaningful. This is accomplished by uniformly applying to all alternatives input parameters and assumptions common to each waste type. The major input parameters and assumptions used in the transportation risk assessment are discussed below.

Waste Inventory and Characterization. The computational model WASTE_MGMT has been developed to support PEIS risk and cost analyses (4). The model combines waste inventory and characterization information, TSD module characterization information, and the definitions of the various alternatives. One output of the model consists of the quantity, physical form, and radiological characteristics of the waste shipped between sites. For each site, radiological and physical characteristics of each waste type are determined separately. Radiological properties are provided in terms of isotope-specific activity concentrations (Ci/kg or Ci/m^3). Physical waste forms are generally classified into a small number of categories such as vitrified waste, liquid waste, metal waste, and heterogeneous solid waste.

Packaging/Shipment Configurations. All transportation activities must take place in accordance with the applicable regulations of the U.S. Department of Transportation (DOT) and U.S. Nuclear Regulatory Commission (NRC) (49 CFR 173 and 10 CFR 71). For the transportation of radioactive materials, the basic types of packaging required by the regulations are designated as Type A, Type B, or "strong and tight" (generally for low-specific-activity material). Type A packages must withstand the conditions of "normal" transportation without the loss or dispersal of the radioactive contents. "Normal" transportation refers to all conditions of transportation except those that result from accidents or sabotage. Type A packaging, typically a 55-gallon drum or standard waste box, is commonly used to transport wastes having low concentrations of radioactive material. Type B packaging, on the other hand, must provide a high degree of assurance that even in severe accidents the integrity of the package will be maintained with essentially no loss of the radioactive contents or serious impairment of the shielding capability. Type B packaging is required for the shipment of large quantities of radioactive material and must satisfy stringent testing criteria specified in 10 CFR 71. The most widely recognized Type B packages are the casks used for transporting highly radioactive spent nuclear fuel from nuclear power stations.

For the PEIS, all transportation of waste has been assumed to take place in certified containers on exclusive-use vehicles. Low-level waste and low-level mixed waste is assumed to be transported in Type A packages on heavy combination trucks or railcars. Required shipment numbers are calculated assuming truck and railcar capacities of 20 and 60 tons, respectively. These capacities roughly correspond to 80 55-gal drums per truck and 300 per railcar.

The radiological characteristics of transuranic, high-level, and most greater-than-class-C low-level waste require the use of Type *B* packaging. Shipments of transuranic waste will essentially consist of a number of Type A containers within reusable certified Type B shipping containers. The Type B containers that will be used are assumed to be the TRUPACT-II for contact-handled waste and the NuPac-72B for remote-handled waste. Shipment requirements are calculated using both volume and weight limitations. For high-level waste, vitrified canisters are assumed to be shipped in casks similar to the "defense high-level waste casks" being developed for the DOE Savannah River site. The truck cask is assumed to accept one high-level waste canister, and rail capacity is assumed to be five canisters. (A multiple-canister high-level waste truck cask will likely be developed in the future.)

Shipment Routes. Representative shipment routes have been determined for all possible pairs of DOE sites that generate or store radioactive waste. For each origin-destination pair, representative highway and rail routes are generated and analyzed by using the routing models HIGHWAY (5) and INTERLINE (6), respectively, developed by Oak Ridge National Laboratory. The routing models are updated periodically to reflect current road and track conditions and have been benchmarked against the reported shipment distances and observations of commercial truck and rail firms. The routes calculated conform to current routing practices and all applicable routing regulations and guidelines, but they do not necessarily represent the actual routes that will be used to transport waste in the future. Important route characteristics include total shipment distance between each origin-destination pair and the fractions of travel in rural, suburban, and urban population density zones.

External Exposure Rates. Given that all shipments are assumed to take place on exclusive-use vehicles, the maximum external exposure rate is limited by federal regulations to a value of 10 mrem/h measured at 2 m from the lateral surfaces of the conveyance. Because of the complex nature of the alternatives and the unavailability of site-specific estimates, the external exposure rates have been assumed to be equal to the regulatory limit for all waste types. The actual exposure rates will be a function of the composition and configuration of shielding and containment materials used in the waste packaging, the geometry of the loaded shipments, and characteristics of the waste material itself. In practice, external exposure rates will not only vary from site to site and waste type to waste type, but also from shipment to shipment at a given site, and they will generally be well below the regulatory limit assumed for this assessment.

Accident Rates. For the calculation of accident risks, truck and rail accident rates are taken from data provided in Saricks and Kvitek (1991) (7). State-specific truck accident rates are based on statistics compiled by the DOT Office of Motor Carriers for 1986–1988 specifically for heavy-combina-*tion trucks* involved in interstate commerce. Separate truck accident rates are used for rural, suburban, and urban population density zones in each state.

State-specific rail accident rates are based on statistics compiled by the Federal Railroad Administration for 1985–1988. Rail accident rates include both mainline accidents and those occurring in railyards.

Accident Severity Categories. A range of potential transportation accident severities has been described in a report prepared by NRC (8). NRC's accident classification scheme categorizes accidents as a function of the magnitudes of the mechanical forces (impact) and thermal forces (fire) to which a transport package may be subjected. In this scheme, an accident's severity is independent of the specific accident sequence. In other words, any sequence of events that results in an accident in which a transport package is subjected to forces within a certain range of values is assigned to the accident severity category associated with that range of values. A conditional probability is assigned to each category.

The RADTRAN accident risk assessment considers the entire range of accident categories as defined by NRC, including accidents with low probability but high consequences and those with high probability but low consequences. For the accident consequence assessment, on the other hand, consequences are assessed with RISKIND only for the accident category representing the most severe credible accident scenarios.

Package Accident Release Characteristics. The release fraction is defined as the fraction of the radioactive material in a transport package that could be released in a given severity of accident. Release fractions vary according to package type and the physical and chemical form of the waste. Most solid radionuclides are difficult to release in particulate form and are therefore relatively nondispersible. Gaseous radionuclides, which are sometimes produced in certain waste forms, are relatively easy to release when the container is compromised.

Where waste-type-specific release fraction data are not available, representative release fractions for Type A and Type B containers have been taken from NRC's research (8). The release fractions in this report are based on best engineering judgments and have been shown to provide conservative estimates of radioactive material releases following accidents. The estimated fractions of the material released that becomes aerosolized and respirable are developed on a waste-type-specific basis because they depend primarily upon the physical properties of the waste form.

Atmospheric Conditions. Because it is impossible to predict the specific location of a transportation accident, generic atmospheric conditions are selected for the risk and consequence assessments. For the accident risk assessment, neutral weather conditions (Pasquill stability class D) and an average wind speed of 4 m/s are assumed. Since neutral meteorological conditions comprise the most frequently occurring atmospheric stability condition in the United States, these conditions are most likely to be present during an accident. For the accident consequence assessment, doses are assessed under both neutral (class D) and stable (class F) atmospheric conditions, with respective wind speeds of 4 and 1 m/s. Results calculated for neutral conditions are meant to represent the most likely consequences, and the results for stable conditions a worst-case weather situation.

Maximally Exposed Individual Exposure Scenarios. For routine transportation conditions, the risk to maximally exposed individuals has been estimated for a number of hypothetical exposure scenarios. The receptors include transportation crew members, departure inspectors, and members of the public exposed during traffic delays, while working at a service station, or living near a DOE site. The dose to each maximally exposed individual considered is calculated for a given distance, duration, and frequency of exposure specific to that receptor. The distances, durations, and frequencies of exposure are similar to those given in previous transportation assessments (9, 10). The exposure scenarios are not meant to be exhaustive but were selected to provide a realistic range of potential exposure situations.

ASSESSMENT OF ALTERNATIVES

Based upon the technical approach and assumptions discussed above, the transportation risk assessment is conducted as follows. For each waste type, specific cases are defined by a set of origin-destination pairs representing shipping linkages between generator, treatment, and disposal sites. For each unique origin-destination pair, representative highway and rail routes are determined consistent with regulatory criteria and current routing practices. The number of shipments transported across each linkage is then calculated for both truck and rail modes using estimated site-specific waste inventories, shipment capacity information, and consideration of the applicable packaging and shipment regulations.

Potential transportation-related health risks are calculated for both all-truck and all-rail cases. For shipments between each origin-destination pair, RADTRAN is used to calculate the collective risks to workers and the public for incident-free and accident conditions based on representative radiological and physical properties of the waste type being considered. The collective risks are then summed over the set of origin-destination pairs to estimate the collective risks associated with that case. RISKIND is used to estimate the potential risks to maximally exposed individuals for various specific exposure scenarios considering the number of shipments exiting or entering each site. Finally, for the most severe credible accidents, RISKIND is used to calculate the potential consequences to populations and individuals for a representative waste shipment. Estimates of such an accident's likelihood are based on the total shipment distance for that case.

For each alternative, results are presented in terms of the total estimated dose, and numbers of expected cancer fatalities, cancer cases, and genetic effects in the exposed worker and public populations. Health effects are calculated using the health risk conversion factors recommended in ICRP 60 (11). For comparative purposes, the total number of traffic accident fatalities from collisions that would be expected based on the total estimated shipping distance is also presented for truck and rail modes.

CONCLUSIONS

The transportation radiological risk assessment being conducted for the PEIS provides a comprehensive approach that can be applied to radioactive waste shipments of all types within the DOE complex. The technical approach is consistent with previous transportation risk assessments and is responsive to public concerns and DOE commitments. The results will be an important component of the overall impacts evaluation of radioactive waste management alternatives in the PEIS.

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