THE RESOURCE HANDBOOK ON DOE TRANSPORTATION RISK ASSESSMENT

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ABSTRACT

In an attempt to bring forth increased efficiency and effectiveness in assessing transportation risks associated with radioactive materials or wastes, the U.S. Department of Energy’s (DOE’s) National Transportation Program (NTP) published a resource handbook in 2002. The handbook draws from the broad technical expertise among DOE national laboratories and industry, which reflects the extensive experience gained from DOE’s efforts in conducting assessments (i.e., environmental impact assessments) within the context of the National Environmental Policy Act (NEPA) in the past 20 years. The handbook is intended to serve as a primary source of information regarding the approach and basis for conducting transportation risk assessments under normal or accidental conditions that are associated with shipping radioactive materials or wastes. It is useful as a reference to DOE managers, NEPA assessors, technical analysts, contractors, and also stakeholders. It provides a summary of pertinent U.S. policies and regulations on the shipment of radioactive materials, existing guidance on preparing transportation risk assessments, a review of previous transportation risk assessments by DOE and others, a description of comprehensive and generally accepted transportation risk assessment methodologies, and a compilation of supporting data, parameters, and assumptions. The handbook also provides a discussion paper on an issue that has been identified as being important in the past. The discussion paper focuses on cumulative impacts, illustrating the ongoing evolution of transportation risk assessment. The discussion may be expanded in the future as emerging issues are identified. The handbook will be maintained and periodically updated to provide current and accurate information.

INTRODUCTION

The U.S. Department of Energy (DOE) complex in the past few decades has been involved in activities associated with the production and use of various types of radioactive materials (source materials, special materials, and by-product materials) that have resulted in generation of wastes (high-level radioactive waste, transuranic waste, and low-level radioactive waste). Transporting...
such materials or wastes of many different forms requires an in-depth knowledge and extreme safeguards to ensure the safety of DOE personnel and also to protect public health and safety and the environment. While such concerns had previously been factored into DOE’s operations, public input has not manifested through a formal process until enactment of the National Environmental Policy Act (NEPA) in 1970, which stipulated explicit engagement and incorporation of public input in the form of an environmental impact assessment. The NEPA process opened up a need for transparency as well as consistency and accuracy for the assessments.

Drawing on more than 20 years of experience by the staff of the DOE and its contractors, the Resource Handbook on DOE Transportation Risk Assessment (1) was prepared and issued in July 2002 under the sponsorship of the DOE Albuquerque Office, National Transportation Program (NTP). The handbook was developed by the Transportation Risk Assessment Working Group (TRAWG), which comprises transportation experts from several national laboratories and industry. The handbook takes advantage of the wealth of information developed through decades of DOE’s NEPA experience, which in the past was not streamlined or performed in a consistent manner. It contains a review of previous transportation risk assessments by DOE and others; a description of comprehensive and generally accepted transportation risk assessment methodologies (i.e., models); and a compilation of supporting data, parameters, and assumptions. The handbook is expected to serve as a primary reference for conducting transportation risk assessments for radioactive material in the NEPA context, in order to enhance consistency and to achieve savings in future NEPA endeavors.

REQUIREMENTS AND GUIDANCE FOR NEPA ASSESSMENT

DOE’s NEPA implementing procedures are documented in 10 CFR Part 1021. These procedures are intended to supplement and be used in conjunction with Council on Environmental Quality (CEQ) regulations. DOE internal requirements and responsibilities for implementing NEPA, the CEQ regulations, and the DOE NEPA implementation procedures are established in DOE Order 451.1B. Guidance concerning the preparation of risk assessments for NEPA activities is contained in Recommendations for the Preparation of Environmental Assessments and Environmental Impacts Statements, commonly known as the “Green Book” (2). In addition to revisiting many of the CEQ regulations, the Green Book emphasizes that environmental impacts be evaluated using a “sliding scale” approach. In using the sliding-scale approach, the preparer should analyze issues and impacts with an amount of detail that is commensurate with their importance. Therefore, the extent of transportation risk assessment, such as an EA or EIS, should depend on the significance of the transportation. Transportation impacts include those from transport to a site, on-site, and from a site, when such activities are reasonably construed as part of the proposed action or analyzed alternatives.

More detailed guidance on transportation assessment is provided in the Framework for Assessing the Effects of Radioactive Materials Transportation of Department of Energy Documents (3). The framework document discusses inclusion of packaging and loading/unloading activities when the primary activity addressed by the EA or EIS is transportation. It is also suggested that the focus of the radiological analysis from potential unexpected events be the largest reasonably foreseeable release of radioactive materials (the bounding case). Such a release could result
from a traffic accident or acts of terrorism or sabotage. A draft document, the *EM NEPA Technical Guidance Handbook* (4), was written to help streamline the DOE NEPA process and has been made available for comment. In this document, methodologies included in the form of computer codes were recommended. In 1999, DOE adopted a series of risk assessment principles (5); that were developed by an interagency committee led by the White House Office of Science and Technology Policy.

In addition to specific assessment requirements, other federal regulations on transportation are often referenced and utilized in NEPA assessments. These include the relevant DOT and NRC regulations on radioactive materials (such as NRC 10 CFR 71 on packaging and various DOT regulations contained in 49 CFR). Additionally, the radioactive materials highway routing regulations of the DOT are prescribed in 49 CFR 397 Subpart D. The regulation attempts to reduce potential hazards by avoiding populous areas and minimizing travel (and exposure) times. DOT, however, has no railway routing regulation specific to the transport of radioactive materials. Another area that needs to be addressed is the emergency response to accident conditions, as stipulated by the Federal Emergency Management Agency (6). The EPA has issued a set of protective action guides (PAGs) (7) to aid public officials when responding to an accident involving radioactive materials. It is to be noted that, although interdiction, evacuation, and cleanup can be introduced into the risk assessment as mitigative measures, many of the recent major EISs do not factor such actions into consideration (8-10).

**ELEMENTS AND APPROACH OF TRANSPORTATION RISK ASSESSMENT**

The transportation of radioactive materials involves a risk both to crew members and members of the public. Much of the concern about shipping radioactive materials has been focused on potential radiological exposures to crew members or the general public. These risks are usually associated with the cargo (i.e., packages containing radioactive materials or wastes). Other risks may result from the nature of transportation itself, independent of the radioactive characteristics of the cargo; such risks are usually vehicle-related.

The cargo-related impacts of primary concern to human health during transportation may be caused by exposure to low levels of ionizing radiation. Exposure to radiation may occur during routine (i.e., incident-free) transportation or in an accident. During routine operations, the external radiation field of cargo must be maintained below certain regulatory limits. In an accident, human exposure may occur following the release and dispersal of radioactive materials via multiple environmental pathways.

The vehicle-related risks during routine operations are limited to hazardous emissions from exhaust fumes. The risks from an accident are associated with injuries or deaths resulting from mechanical or other means as the direct cause. Type of vehicles (e.g., ordinary vs. combination truck) or mode of transportation (e.g., rail vs. highway) used for transporting, however, is closely related to the accident statistics compiled for risk analysis.
Risks from Routine (Incident-Free) Operations

Radiological Risks to Individuals

The receptors during routine (incident-free) operations include transportation crew members, departure inspectors, and members of the public exposed during traffic delays while working at a service station or while living near a DOE site. Potential risks to individuals are received mainly through external exposures (mostly in the form of gamma radiations) from the radioactive materials contained in the transportation packages. The dose to the maximally exposed individual (MEI) is considered for an exposure scenario that is a combination of a given distance, duration, and frequency of exposure specific to that receptor. The distances and durations of exposure for the scenarios listed here are similar to those given in previous transportation risk assessments (8-12). The MEI risks are typically assessed using the RISKIND code (13) discussed below.

Radiological Risks to Population

Risks from routine highway and rail transportation include exposures of the following population groups:

• **Persons along the Route (Off-Link Population).** Collective doses are calculated for all persons living or working on each side of a transportation route. The total number of persons within the corridor may be calculated separately for each route considered in the assessment.

• **Persons Sharing the Route (On-Link Population).** Collective doses are calculated for persons in all vehicles sharing the transportation route. This group includes persons traveling in the same or the opposite direction as the shipment, as well as persons in vehicles passing the shipment.

• **Persons at Stops.** Collective doses are calculated for people who may be exposed while a shipment is stopped en route. For truck transportation, these stops include those for refueling, food, and rest. For rail transportation, stops are assumed to occur for purposes of classification.

• **Crew Members.** Collective doses are calculated for truck transportation crew members and railyard workers.

The doses calculated for the first three population groups are added to yield the collective dose to the public; the dose calculated for the fourth group represents the collective dose to workers. The collective risks are typically calculated using the RADTRAN code (14-18) in conjunction with routing models discussed below.

Nonradiological Risks

Vehicle-related health risks resulting from routine transportation may be associated with the transporting vehicles that generate air pollutants during shipment, independent of the nature of the shipment. The health end point assessed under routine transport conditions is the excess (additional) latent mortality caused by inhalation of vehicular emissions. The nonradiological
risk is typically estimated by means of a risk factor aggregated over a unit travel distance for truck or rail. A risk factor for latent mortality from pollutant inhalation, such as the ones generated by (19) truck and rail, has been used for previous assessments. This risk factor is based on regression analyses of the effect on mortality of fugitive dust, sulfur dioxide, and particulate emissions from diesel exhaust. Excess latent mortality is assumed to be equivalent to latent fatalities. Similar risk factors are not available for rural and suburban areas.

**Accident Risks**

**Radiological Risks**

The accident risk from a specific accident is defined as the product of the accident consequence and the probability of the accident occurring. The accident risk from a given shipment is the sum of risks over the range of accidents. The collective accident risk to populations is estimated by considering a spectrum of postulated transportation-related accidents. That spectrum is designed to encompass a range of possible accidents, including low-probability accidents with high health consequences and high-probability accidents with low or no health consequences (“fender benders”). The results for collective accident risk can be directly compared with the results for routine collective risk.

Calculation of collective accident risk employs models such as RADTRAN (14-18) that quantify the range of potential accident severities and the responses of transported packages to accidents. The models take into account the transportation mode and the packaging type, the accident rates, the definition of accident severity categories, and the release fractions for such an analysis. The calculation of the collective population dose after the release and dispersal of radioactive material includes the following exposure pathways:

- External exposure to the passing radioactive cloud,
- External exposure to contaminated soil,
- Internal exposure from inhaling airborne contaminants, and
- Internal exposure from ingesting contaminated food.

For the ingestion pathway, if the user wishes to calculate state-specific ingestion doses, state-specific food transfer factors have been calculated that relate the amount of radioactive material ingested to the amount deposited on the ground, in accordance with the methods described by NRC Regulatory Guide 1.109 (20) Radiation doses from ingesting or inhaling radionuclides are calculated with standard dose conversion factors. These factors can be used as input to the RADTRAN code.

**Radiological Consequences**

During the course of DOE’s NEPA assessment history, a growing demand from the public compelled DOE to address the “what if” health consequences of some postulated accident scenarios — that is, consequences without the weigh-in by the probabilities of occurrence.
These scenarios are typically very severe but have low probabilities of occurrence. The accident consequences in the NEPA analysis are usually calculated for local populations and MEIs. The population dose includes the population within 80 km (50 mi) of the accident site. The exposure pathways considered are similar to those discussed previously for the accident risk assessment. Although remedial activities (e.g., evacuation or ground cleanup) after the accident would reduce the consequences, these activities are often not considered in the consequence assessment because the emergency response would not be uniform along a given transport route.

Because predicting the exact location of a severe transportation-related accident is impossible, separate consequences are calculated for accidents occurring in rural, suburban, and urban zones of population density. Moreover, to address the effects of the atmospheric conditions existing at the time of an accident, two different atmospheric conditions are often considered. Radiological accident consequences are typically calculated by using a code such as RISKIND (13).

**Risks Related to Vehicle Accidents**

Vehicle-related accident risk refers to the potential for transportation accidents that directly result in injuries or fatalities that are not associated with the contents in shipment’s cargo. This risk represents injuries or fatalities from accident-related mechanical or fire causes. State-specific or national transportation injury or fatality rates have been compiled for transportation modes such as truck or rail. Vehicle-related accident risks are calculated for each case by multiplying the total distance traveled in each state by the appropriate state rate for transportation-related fatalities. The vehicle-related accident risks are typically calculated by using distances for round-trip shipment that include the return trip to the origin site without the radioactive cargo.

**MODELS USED FOR RISK ASSESSMENT**

The collective routine risks are calculated for each specific alternative, as follows. Each alternative is first defined as a set of origin-and-destination pairs. For shipments between each origin-and-destination pair, the risk model (RADTRAN) (14-18) is used to calculate collective risks to workers and the public on the basis of representative radiological and physical properties of the radioactive material being transported. The number of shipments transported across each route segment is then calculated for truck and rail modes by using estimated site-specific radioactive material inventories and information on shipment capacity. The routing model (such as TRAGIS) (21) is used to determine representative highway or rail routes for each unique pair. [HIGHWAY (22) and INTERLINE (23) were the routing codes used previously for truck and rail routes, respectively. However, they have been superseded by TRAGIS.] The collective risks are then summed over the set of origin-destination pairs to estimate the collective routine risks associated with that alternative. The RISKIND code is used alone to estimate the potential risks to the maximally exposed individuals as a supplement to the total aggregated risk. Use of the computer codes for risk assessment is illustrated in Figure 1, and the codes are discussed as follows.
Figure 1. DOE Transportation Risk Assessment Approach
RADTRAN

The RADTRAN code (14) was originally developed by Sandia National Laboratories, under contract to the NRC, to serve as an analytical tool in preparing the Final Environmental Statement on the Transportation of Radioactive Material by Air and Other Modes (24). The code’s capabilities have been updated and expanded in subsequent versions of the model (15-18). RADTRAN has been used to estimate radiological risks associated with incident-free transportation of radioactive materials and with accidents that might occur during transportation. Incident-free (or normal) transportation is defined as transportation during which no accident, packaging or handling abnormality, or malevolent attack occurs. The code also may be used to estimate certain economic risks associated with transportation accidents. Documentation available for RADTRAN includes a technical manual, a user guide, and a programmer’s manual.

Seven modes of transportation are addressed in RADTRAN: two highway modes (tractor-trailer and light-duty vehicle), rail, barge, ship, cargo air, and passenger air. More than one mode may be used to transport a single package of radioactive material from its origin to its final destination. Each mode type is considered individually in assessing radiological impact. Parameters that may vary with the mode, such as velocity, shielding, and population distribution, have varying impact on population dose.

RADTRAN 4 contains seven sets of models that are used to estimate the radiological consequences and risks of radioactive material transportation. The component models use user-supplied input data and parameter values from other RADTRAN 4 calculations. The seven sets of models are as follows:

- Material model,
- Transportation model,
- Population distribution model,
- Accident-severity and package-behavior model,
- Meteorological dispersion model,
- Health effects model, and
- Economic model.

RADTRAN code has been continuously updated. The newly released version is RADTRAN 5 (18).

INTERTRAN

In 1981, Kemakta Konsult, in Sweden, adapted the second release of RADTRAN for international use. This program conversion, called INTERTRAN, was completed and documented in 1982 and is available from the International Atomic Energy Agency, in Vienna, to member countries (25). An independent peer review of INTERTRAN was completed by Pacific Northwest National Laboratory in December 1981, under a contract with the DOE (26).
Empirical validation is difficult where very low doses are involved. However, INTERTRAN (RADTRAN II) calculations have been compared to actual measurements for certain handlers and vehicle crew members in Italy (27, 28), and INTERTRAN was found to overestimate incident-free doses. The INTERTRAN/RADTRAN equations are idealized and do not directly account for vehicle shielding, for example, and neglect secondary factors such as attenuation and reflection. Thus, one would expect INTERTRAN to overestimate dose. The Italian findings show that for several classes of incident-free dose, the INTERTRAN predictions were greater than the measured doses. This work does not constitute empirical validation, but it does indicate that INTERTRAN/RADTRAN is conservative, as expected.

RISKIND

The RISKIND code (13) is used to provide a scenario-specific (i.e., “what if”) assessment of the radiological consequences of severe transportation-related accidents for each waste type. The RISKIND accident consequence assessment complements the RADTRAN code by analyzing the potential impacts of a given accident, should it occur, focusing on accidents that would result in the largest releases of radioactive material to the environment. It provides risk estimated for MEIs for both routine operations and accident conditions. The purpose of the RISKIND computer program is to aid in the analysis of the radiological consequences and health risks to individuals and the collective population from exposures associated with the transportation of spent nuclear fuel (SNF) or other radioactive materials. Its intended use is to provide scenario-specific analyses when evaluating alternatives for major federal actions involving radioactive material transport, as required by NEPA.

The major objective of RISKIND is to provide an analysis for scenarios of concern to the public for NEPA documentation, that is, the calculation of incident-free and accident impacts for a particular radioactive material shipment at specific locations along a truck or rail transport route. Reflecting local concerns, public comments on transportation risk analyses for individuals frequently include requests for information on potential impacts to receptors. The latest RISKIND model has incorporated appropriate geographic information system (GIS) features to accommodate census data. Further, it can be used to address potential consequences within the context of terrorism attacks.

Routing Models

Computerized routing models are commonly used for transportation risk assessment to select highway and rail routes between origin and destination sites. For prospective actions, routing models are often used to define “representative” routes. These representative routes are typically selected to be consistent with current routing practices and all applicable routing regulations and guidelines; however, they do not necessarily represent the actual routes that would be used to transport radioactive material. Future considerations, including road or track work, new route segments, and traffic flows, could result in alternative routes being used.

For DOE transportation assessments, two routing models developed by Oak Ridge National Laboratory (ORNL) have been extensively used: HIGHWAY (22) and INTERLINE (23). In addition, ORNL, supported by the DOE’s National Transportation Program, has developed the
Transit Information System (TRAGIS) (21), a user-friendly GIS transportation and analysis model. TRAGIS incorporates the HIGHWAY and INTERLINE models. The complete updating support of the databases for HIGHWAY and INTERLINE has been terminated, but they will remain available on TRANSNET for a transitional time period.

**TRANSNET System**

TRANSNET is the electronic gateway system of databases, analysis codes, routing algorithms, and information packages that are available to those dealing with the transportation of radioactive materials. The TRANSNET codes and databases reside on a central computer and can be accessed by authorized users to either gain information or analyze radioactive material transportation systems. Upon receipt of a password, a user can access TRANSNET with a personal computer and modem via the Internet. The TRANSNET system was first announced in 1987 and initially resided on a dedicated minicomputer, but it now resides on a UNIX-based workstation. The purpose of the TRANSNET system is to provide a means of transferring technology and data to qualified users by permitting access to the most comprehensive and up-to-date transportation risk and systems analysis codes and associated databases.

**COMPILATION OF DATA AND PARAMETERS**

The handbook contains detailed information for a variety of data categories for risk assessment: package-related parameters, such as package types, characteristics, and typical external dose rates; crew parameters; population densities and fractions of travel along routes; vehicle speed, traffic volume, and vehicle occupancy data; shielding factors; stop parameters; truck and rail accident rates; package release characteristics under accident conditions; radionuclide profiles; and vehicle-related injury and fatality rates. There are also radionuclide profiles containing typical radioactivity inventories by waste type. The isotopic data contain physical properties of radionuclides, food-transfer/soil-transfer factors, and dose conversion factors. It is anticipated that the data in the handbook will be updated as appropriate. Discussed in the following sections are key parameters that are critical for the analysis of accident risks, including traffic accident statistics and release fractions. The most credible traffic statistic data compiled are currently limited to the state level; a lot more effort is required if regional or local statistics are to be obtained.

**Accident Statistics Data**

Accident rates are used to determine the frequency of accidents that might occur during transport of radioactive materials. For each transport mode, accident rates are generically defined as the number of accident involvements in a given year per unit of travel of that mode in the same year. Therefore, the rate is a fractional value — the accident-involvement count is the numerator and vehicular activity (total traveled distance) is the denominator. Accident rates are derived from multiple-year averages that automatically account for such factors as heavy traffic and adverse weather conditions. For assessment purposes, the total numbers of expected accidents, injuries, or fatalities are calculated by multiplying the total shipping distance for a specific case by the
appropriate accident, injury, or fatality rate. Such statistical data are provided in the handbook for each of the 48 contiguous states as well as for the national aggregate.

**Highway Accidents**

A study that included heavy combination truck accident statistics was conducted to update the 1986-1988 statistics (29) with those from 1994-1996. These newer accident rate data from Saricks and Tompkins (30) are provided alongside the older data from Saricks and Kvitek (29). Part of the impetus behind the 1999 study was the completion of the interstate highway system network. Uncompleted links in the interstate network in a few states still remained as of 1988. Such discontinuities required shipments to leave multilane, access-controlled highways and traverse more hazardous two-lane roads. Another factor was the recent increase in speed limits in many states. Direct comparison of accident rates between the two studies cannot be made because of the way accidents are now being reported.

**Railway Accidents**

Rail accident rates are computed and presented similarly to truck accident rates in Saricks and Kvitek (29); however, for rail transport, the unit of haulage is the railcar. State-specific rail accident involvement, injury, and fatality rates are based on statistics compiled for 1985 to 1988 by the Federal Railway Administration (FRA). These rail accident rates include both mainline accidents and those occurring in railyards. The updated report by Saricks and Tompkins (30) compiles FRA accident data from the years 1994-1996. Accident rates and grade crossing incidents are from the latter report. Separate accident rates specific to the railroad mainline and railyards were not derived in the update. Use of the overall combined accident rate is appropriate for general freight shipments because railcars will be subject to marshalling in railyards along the route. On the other hand, dedicated rail shipments spend less time in railyards, and use of the overall rate may overestimate the accident rate. Many grade crossing incidents are not reportable accidents, but may involve injuries and fatalities.

**Accident Release Fractions**

The amount of radioactive material released as a result of a transportation accident depends on the packaging of the material and the severity of the accident. In an effort to quantify such releases for the purposes of risk assessment, release fractions for different types of packaging have been estimated for a series of accident severity categories. Release fractions have been provided in several reports over time for the various severity categories identified. These include NUREG0-170 (24) where release fractions are assigned for Type A and Type B packages. In 1987, the NRC sponsored the “Modal Study,” performed by Lawrence Livermore National Laboratory (31). The study focused on the performance of spent nuclear fuel casks under accident conditions defined by 20 severity categories for which the release fractions as well as event probabilities were estimated. More recently, a reexamination of the behavior of spent nuclear fuel casks in severe accidents was conducted by Sandia National Laboratories and published in NUREG/CR-6672 (32).

**LESSONS LEARNED AND LOOKING TO THE FUTURE**
Preparation of this resource handbook may prove very timely. A number of DOE programs expected to come to fruition in the near future will vastly increase the volume of radioactive material transported within the U.S. For example, through the year 2035, approximately 575 shipments of naval SNF are expected to be made by rail from six sites. In addition to the naval SNF, projected shipments include about 546 shipments of special-case commercial SNF from 11 non-DOE origins; 1,008 shipments of foreign research reactor SNF through 8 potential ports of entry; 519 shipments of domestic university research reactor SNF from 35 university reactors; and 1,007 intra-facility shipments of DOE-owned SNF from 8 DOE weapons complex facilities (11). Moreover, under the Nuclear Waste Policy Act, it is anticipated that SNF assemblies will eventually be transported from 72 commercial sites and 5 DOE sites throughout the U.S. to an interim storage facility or to a geologic repository. If most SNF and high level waste (HLW) can be transported by rail, about 11,000 rail shipments and 2,600 truck shipments would be needed over a 24-year period. If legal-weight truck transportation must be used, about 50,000 truck shipments and 300 rail shipments would be needed (33). An additional 10,000 rail shipments or 40,000 legal-weight truck shipments of SNF and 1,500 rail shipments or 6,700 truck shipments of HLW to an interim storage facility or repository may also be required.

Other shipments of DOE radioactive waste are also expected to increase over the next several years. Approximately 38,000 truck shipments of transuranic waste are anticipated from about 22 sites to the Waste Isolation Pilot Plant over the next 35 years. Anticipated treatment and disposal of DOE low-level waste could result in another 26,000 to 92,000 truck shipments over approximately 20 years, depending on the final regionalization strategy chosen (10).

The volume and national scope of these shipments will present some unique issues that must be addressed in the future. In particular, public concerns at times will overshadow even carefully planned transportation activities. To alleviate these concerns, continued improvement in risk assessment in an open process such as NEPA is crucial to future success. In this regard, it is anticipated that the resource handbook described herein will provide a valuable tool in evaluating the risks and informing the public.

REFERENCES


