WR-058

DOE/EM/NTP/HB-01

A RESOURCE HANDBOOK

on

DOE TRANSPORTATION RISK ASSESSMENT

Prepared for:
U.S. Department of Energy
Office of Environmental Management
National Transportation Program

July 2002

U.S. Department of Energy
National Transportation Program

A Resource Handbook on DOE Transportation Risk Assessment

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Foreword

This resource handbook was compiled for the U.S. Department of Energy's (DOE's) Transportation Risk Assessment Working Group (TRAWG). The TRAWG, established under the auspices of DOE's National Transportation Program, seeks to increase the efficiency and effectiveness of transportation risk assessments conducted for DOE environmental impact statements and environmental assessments prepared pursuant to the National Environmental Policy Act (NEPA). The TRAWG is composed primarily of members of DOE program offices and draws heavily upon the technical expertise, insights, and practical experience of program staff from across the DOE complex. The vision of the TRAWG includes reducing transportation risk assessment preparation time and cost, ensuring technical adequacy of such assessments, promoting consistency of transportation risk assessments among DOE programs, and expediting the assessment review and approval process. This document includes the first of a planned series of discussion papers on topical aspects of transportation risk problems. These discussion papers are intended to provide practical advice to program managers and technical personnel responsible for preparing NEPA documents and other transportation risk assessments.

To enhance future versions of this handbook, comments and suggestions regarding the usefulness of the material in the different sections and the discussion paper are encouraged. Contributions of additional, relevant information and ideas for new topics are also solicited. Please send any such correspondence to:

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Acronyms

AADT	annual average daily traffic
AAR	Association of American Railroads
AEC	U.S. Atomic Energy Commission
ALARA	as low as reasonably achievable
APTA	American Public Transit Association
BWR	boiling water reactor
CEDE	committed effective dose equivalent
CERCLA	Comprehensive Environmental Response, Compensation and Liability Act
CEQ	Council on Environmental Quality
CFR	Code of Federal Regulations
CH-TRUW	contact-handled transuranic waste
DDWEF	distance-dependent worker exposure factor
DOC	U.S. Department of Commerce
DOE	U.S. Department of Energy
DOT	U.S. Department of Transportation
DRF	dose reduction factor
EA	environmental assessment
EBR-II	Experimental Breeder Reactor II
EDE	effective dose equivalent
EIS	environmental impact statement
EPA	U.S. Environmental Protection Agency
EPRI	Electric Power Research Institute
ERPG	Emergency Response Planning Guidelines
FEMA	Federal Emergency Management Agency
FHWA	Federal Highway Administration
FONSI	finding of no significant impact
FRA	Federal Railroad Administration
FRERP	Federal Radiological Emergency Response Plan
FSEIS	Final Supplemental Environmental Impact Statement
GIS	geographic information system
GPUC	General Public Utilities Company
HAZMAT	hazardous materials
HLW	high-level (radioactive) waste
HPMS	Highway Performance Monitoring System
HWCQ	highway route controlled quantity
IAEA	International Atomic Energy Agency
ICRP	International Commission on Radiological Protection
IDB	integrated database (of DOE radioactive waste)
IIHS	Insurance Institute for Highway Safety
INEEL	Idaho National Engineering and Environment Laboratory (formerly Idaho National Engineering Laboratory [INEL])
INEL	Idaho National Engineering Laboratory
LCF	latent cancer fatality

LLMW	low-level mixed waste
LLNL	Lawrence Livermore National Laboratory
LLW	low-level waste
LLWMP	Low-Level Waste Management Program
LSA	low specific activity
LWT	light-weight truck
MEI	maximally exposed individual
NEPA	National Environmental Policy Act
NHTSA	National Highway and Traffic Safety Administration
NPTS	National Personal Transportation Survey
NRC	U.S. Nuclear Regulatory Commission
NRDC	Natural Resources Defense Council
NTP	National Transportation Program (DOE)
NWPA	Nuclear Waste Policy Act
OEM	Office of Environmental Management
OMC	Office of Motor Carriers
ORNL	Oak Ridge National Laboratory
PAG	protective action guide
PNL	Pacific Northwest Laboratory (now PNNL — Pacific Northwest National Laboratory)
PNNL	Pacific Northwest National Laboratory
PWR	pressurized water reactor
QA	quality assurance
RAMPOST	Radioactive Materials Post-Notification
rem	roentgen equivalent man
RCRA	Resource Conservation and Recovery Act
RH-TRUW	remote-handled transuranic waste
RMIR	Radioactive Materials Incident Reporting
ROD	Record of Decision
SECOM	Security Communications
SMAC	Shipment Mobility Accountability Collection
SNF	spent nuclear fuel
SNL	Sandia National Laboratories
SRS	Savannah River Site
SWB	standard waste box
SWIMS	Solid Waste Information Management System
TEDE	total effective dose equivalent
TI	transport index
TIGER	Topologically Integrated Geographic Encoding and Referencing System
TMI	Three Mile Island
TRAGIS	Transportation Routing Analysis Geographic Information System
TRAWG	Transportation Risk Assessment Working Group
TRIGA	training, research, and isotope reactor
TRUW	transuranic waste
U.S.	United States
U.S.C.	United States Code

WIPP	Waste Isolation Pilot Plant
WVDP	West Valley Demonstration Project

UNITS OF MEASURE

Ci	curie(s)
d	day(s)
°F	degree(s) Fahrenheit
ft	foot (feet)
g	gram(s)
gal	gallon(s)
h	hour(s)
in.	inch(es)
kg	kilogram(s)
km	kilometer(s)
km^2	square kilometer(s)
lb	pound(s)
m	meter(s)
mi	mile(s)
mi^2	square mile(s)
mph	mile(s) per hour
nCi	nanocurie(s)
s	second(s)
yr	year(s)

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Acknowledgments

This project was conducted by the Technical Subcommittee of the Transportation Risk Assessment Working Group (TRAWG) in support of the mission of the National Transportation Program (NTP), DOE's Office of Environmental Management (EM). Ashok Kapoor of the NTP, Albuquerque, NM has provided leadership for this project. Appreciation is extended to Gary Lanthrum, Director of the program and Kent Hancock, Director of Office of Transportation (EM-24). We express our special thanks to Carol Borgstom, Director, Office of National Environmental Protection Policy Act and Assistance, Environment, Safety and Health (EM-42) and her staff and the staff of General Counsel's office of Environment and Nuclear Program (GC-50) for reviewing the document and offering valued suggestions. Our many thanks are extended to Mr. Peter Siebach of DOE Chicago Operations Office for his support and insights.

Our deep appreciation goes to TRAWG members and their supporting technical staff, who represent various DOE headquarters organizations, field offices, and national laboratories, for supporting this project.

Our special recognition is extended to Mr. John Amish and his editorial staff at Argonne National Laboratory and staff at Sandia National Laboratories (SNL) in providing valuable contributions. Finally, we also express our appreciation to the secretarial staff of NTP for document production and distribution.

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1. Introduction

This resource handbook contains useful information to streamline radioactive material transportation risk assessments for National Environmental Policy Act (NEPA) documents prepared for U.S. Department of Energy (DOE) programs. Streamlining refers to instituting steps that can increase the efficiency of future assessments, reduce costs, and promote increased quality and consistency across the DOE complex. This handbook takes advantage of the wealth of information developed through decades of DOE's NEPA experience. It contains a review of historical assessments; a description of comprehensive and generally acceptable transportation risk assessment methodology (i.e., models); and a compilation of supporting data, parameters, and generally accepted assumptions. This handbook also includes a discussion paper that addresses cumulative impacts (Appendix A). The discussion paper illustrates the evolving and sometimes unresolved issues encountered in transportation risk assessment. Other topics, such as sabotage, environmental justice, and human factors, may be addressed in the future. This resource document was developed as the first primary reference book providing useful information for conducting transportation risk assessments for radioactive material in the NEPA context.

Although this resource handbook is primarily intended for NEPA assessments, the information provided here can also be used for other purposes. For example, in addition to being included in NEPA documentation, transportation risk assessments often provide the best information possible to support transportation planning, operations, evaluation, public information, program/ budget prioritization, and performance measurement. The majority of information provided in this handbook is widely applicable and not limited to NEPA applications. Consequently, this handbook provides a useful resource for those conducting transportation risk assessments in general.

The motivation behind preparing this handbook is to document and disseminate lessons learned and information accumulated from over 20 years of experience by DOE and its contractors in preparing transportation risk assessments that address the shipment of virtually all types of radioactive materials and wastes. This experience has provided considerable understanding of the risks posed by transportation and has led to a significant amount of information concerning assessment methods, input parameters, and assumptions. This document presents the majority of this information in a single source for DOE, its contractors, or others interested in conducting transportation risk assessments. This handbook will be periodically updated to provide current information.

This handbook was compiled and reviewed by the Technical Subcommittee of the DOE's Transportation Risk Assessment Working Group (TRAWG). The TRAWG, established by the DOE's National Transportation Program (NTP), seeks to increase the efficiency and effectiveness of transportation risk assessments conducted for DOE environmental impact statements (EISs) and environmental assessments (EAs). The TRAWG is composed primarily of members of DOE program offices and draws heavily upon the technical expertise, insights, and practical experience of persons from across the DOE complex. The vision of the TRAWG includes reducing transportation risk assessment preparation time and cost, ensuring technical adequacy of such assessments, promoting consistency among DOE programs, and expediting the assessment review and approval process. Discussion papers produced by the TRAWG Technical Subcommittee, the first one presented in Appendix A, provide useful insights into the underlying issues for both program managers and technical staff responsible for preparing NEPA documents or other transportation risk assessments. A record of the initial correspondence and the inaugural meeting of the TRAWG, including a listing of members and a mission statement, is provided in Appendix B at the end of this handbook.

At present, the scope of this handbook is limited to the assessment of radiological risks from shipping radioactive materials by truck and train. Chemical risks, the risks of transporting hazardous chemicals, are not addressed in this document. The vast majority of radioactive material and radioactive waste shipments in the United States (U.S.) are conducted by these modes. Although shipments of radioactive material by air and water are possible, these transport modes are generally considered secondary for waste shipments. It is anticipated that information concerning air and water shipments will be included in future updates to this handbook. In addition, the handbook is limited to those risks incurred during the actual shipment of radioactive materials; risks incurred during packaging and loading or unloading of transport vehicles are not included because such activities are generally considered in facility assessments.

This handbook contains six main sections and three appendices to address all aspects of the transportation risk assessment process. Section 2 summarizes existing guidance on preparing transportation risk assessments and pertinent federal regulations governing the shipment of radioactive materials. A brief history of NEPA transportation risk assessments is given in Section 3. Section 4 summarizes results from previous assessments and provides the current methodology used in transportation risk analysis. A brief description of the major computer programs and models most commonly used is given in Section 5. Section 6 provides a compendium of data required for most assessments. Reference documents cited in the handbook are listed in Section 7. A glossary of transportation assessment-related terms is provided in Section 8. Appendices C and D provide more detailed data on radionuclide input parameters. Appendix A is the first in a collection of papers that discuss issues often encountered when conducting transportation risk assessments. These issues include environmental justice, sabotage, uncertainty of results, human factors, hazardous chemicals, ecological impacts, and cumulative impacts. The first discussion paper summarizes previous NEPA experience and offers insight into the current state of knowledge and experience in addressing the issue of cumulative impact. It is anticipated that more of these discussion papers will be added, as appropriate, in future updates of the handbook.

2. Review of Current DOE Transportation Risk Assessments Requirements and Guidance

A brief summary of the risks posed by transporting radioactive materials is provided in Section 2.1, followed by a discussion of NEPA requirements in Section 2.2. Section 2.3 provides general guidance from DOE on the preparation of transportation risk assessments for inclusion in EAs and EISs. Although this section provides guidance, no new requirements are either suggested or imposed. Section 2.4 briefly summarizes regulations of other federal agencies pertaining to the shipment of radioactive materials that must be addressed in these types of assessments.

■ 2.1 Radioactive Material Transportation Risks

The transportation of radioactive materials involves a risk both to crew members and members of the public. Part of this risk results from the nature of transportation itself, independent of the radioactive characteristics of the cargo. For instance, increased levels of pollution from vehicular emissions (e.g., fugitive dust and engine exhaust) may affect human health. Similarly, accidents during transportation may cause injuries and fatalities. These risks can be viewed as "vehicle-related" risks. On the other hand, the transportation of radioactive materials may pose an additional risk because of the characteristics and potential hazards of the material being transported. These risks are considered "cargo-related" risks.

For radioactive materials, the cargo-related impacts of primary concern to human health during transportation may be caused by exposure to low levels of ionizing radiation. Exposures to radiation occur both during routine (i.e., incident-free) transportation and during accidents. During routine operations, the external radiation field of the cargo must be below limits specified in federal regulations. During transportation-related accidents, human exposures may occur following the release and dispersal of radioactive materials via multiple environmental pathways, such as exposure to contaminated ground, contaminated air, or ingestion of contaminated food.

The potential exposures to the general population from transporting radioactive materials, whether during routine operations or from postulated accidents, usually result in such a small dose that the primary adverse health effect is the potential induction of latent cancers (i.e., cancers that occur after a latency period of several years from the time of exposure). The correlation of radiation dose and human health effects for low doses has been traditionally based on the "linear/no-threshold hypothesis," which has been described by various international authorities on protection against radiation. This hypothesis implies, in part, that even small doses of radiation cause some risk of inducing cancer and that cancer induction is directly proportional to radiation dose, so doubling the radiation dose could double the expected numbers of cancers. The data on the health risk from radiation have been derived primarily from human epidemiological studies of past exposures, such as Japanese survivors of the atomic bomb in World War II and persons exposed during medical applications. The types of cancer induced by radiation are typically not unique and are similar to other cancers that commonly occur among the population. Radiation-induced cancers are generally expressed years after exposure.

■ 2.2 The National Environmental Policy Act

One statutory basis under which federal agencies may need to undertake risk assessment in decision-making with regard to the transportation of radioactive materials is found in NEPA, codified at 42 United States Code (U.S.C.) §4321 et seq. Section 102(2)(C) of NEPA requires that,

> *...to the fullest extent possible, all agencies of the Federal Government must include in every recommendation or report on proposals for legislation and other major federal actions significantly affecting the environment, a detailed statement by the responsible official on (1) the environmental impact of the proposed action, (2) any adverse environmental effects that cannot be avoided should the proposal be implemented, (3) alternatives to the proposed action, (4) the relationship between the local short-term uses of man's environment and the maintenance and enhancement of the long-term productivity, and (5) any irreversible and irretrievable commitments of resources that would be involved in the proposed action should it be implemented. An agency is required to prepare an EIS whenever a proposed action qualifies as a "major federal action significantly affecting the quality of the human environment." ["Major," as used above in NEPA, reinforces but does not have a meaning independent of "significantly" (see 40 CFR §1508.18).]*

NEPA also established the Council on Environmental Quality (CEQ), which promulgates regulations to promote compliance with NEPA's "action-enforcing" requirements. These regulations interpret the terms of NEPA and define the responsibilities of federal agencies with respect thereto (40 Code of Federal Regulations (CFR) Parts 1500-1508). The regulations state that an agency proposing an action may prepare an EA if it has not determined under its NEPA regulations that the action is categorically excluded from the requirement to prepare an EIS. The purpose of an EA is to provide evidence and analysis for an agency determination of whether an EIS is required (40 CFR 1508.9). If an agency determines that an EIS is required, the EA would facilitate the preparation of the EIS. If an agency determines that an EIS is not required, the agency issues a finding of no significant impact (FONSI) that explains how the agency reached its determination (40 CFR 1508.13). DOE's NEPA regulations, pursuant to instructions in the CEQ regulations (40 CFR Part 1507.3), contain detailed lists, in Appendices A, B, C, and D of Subpart D in 10 CFR Part 1021, of specific actions that are categorical exclusions (Appendices A and B), that "normally require EAs but not necessarily EISs" (Appendix C), and that "normally require EISs" (Appendix D). Transportation can be a component in a number of actions under each of these three classifications.

The CEQ regulations further require that in preparing an EIS, an agency consider three types of impacts on the environment: direct, indirect, and cumulative. Indirect impacts are defined as those "which are caused by the action and are later in time or farther removed in distance, but are still reasonably foreseeable" (40 CFR §1508.8). A cumulative impact is defined as an "impact on the environment which results from the incremental impact of the action when added to other past, present, and reasonably foreseeable future actions regardless of what agency (Federal or non-Federal) or person undertakes such other actions. Cumulative impacts can result from individually minor but collectively significant actions taking place over a period of time" (40 CFR §1508.7). Cumulative impacts can be a concern with regard to transporting spent nuclear fuel (SNF), transuranic waste (TRUW), or high-level waste (HLW). Both the physical rail system and the U.S. Department of Transportation's (DOT's) highway routing regulations for transport of these types of waste (discussed in Section 2.4.2) effectively restrict the number of available transportation routes within a geographic area. Hence, successive shipments or campaigns of radioactive materials through the same geographic area may result in cumulative radiological risks.

Both NEPA and the CEQ regulations require that agencies consider and evaluate appropriate alternatives to proposed actions that will impact the environment. Section 102(2)(E) of NEPA provides that all agencies of the Federal Government shall "study, develop, and describe appropriate alternatives to recommended courses of action in any proposal which involves unresolved conflicts concerning alternative uses of available resources." The CEQ regulations [40 CFR §1508.9(b)] require that an EA "include brief discussions . . . of alternatives as required by §102(2)(E). . . ." These requirements have been construed to be independent of any determination regarding preparation of an EIS and to be operative even if an agency makes a finding of no significant environmental impact (River Road Alliance, 1986). Moreover, DOE's NEPA procedures for applying a categorical exclusion to a proposed action require that the action must pose no unresolved conflicts considering alternate uses of available resources within the meaning of Section 102(2)(E) of NEPA [10 CFR 1021.410(b)(2)].

An agency is responsible for determining the appropriate range of alternatives to be considered through the "rule of reason." Under the rule of reason, an agency is not required to consider all possible alternatives for each aspect of a proposed action. Rather, the agency need consider "only a reasonable number of examples, covering the full spectrum of alternatives" (Natural Resources Defense Council [NRDC], 1972). The same language was also used in the qualifying remarks found in CEQ guidance ("40 Most Asked Questions," 46 *Federal Register (FR)* 18026; March 23, 1981).

What constitutes a reasonable range of alternatives depends on the nature of the proposal and the circumstances of each case. In general, the smaller the impact of the proposed action, the less extensive the search for alternatives an agency may be required to undertake. However, reviewing courts have generally insisted that an agency consider such alternatives as may partially or completely meet the proposal's goal. As a consequence, the scope of alternatives that must be considered by an agency is a function of how narrowly or broadly the objective of its proposed action is viewed (City of New York, 1984). For example, a major action involving transportation of SNF or HLW waste may require considering a full spectrum of alternatives (i.e., transportation mode and route alternatives) that would adequately protect the human environment.

The "rule of reason" governs not only which alternatives the agency must consider, but also the extent to which it must discuss them (NRDC, 1988). An agency's requisite consideration of alternatives must adequately articulate the reasons for the agency's choice and its rejection of available alternatives. While an agency is not required to select any particular alternative and the examination of alternatives need not be exhaustive, it must "be sufficient to demonstrate reasoned decision making" (Fritiofson, 1985). Therefore, an agency contemplating a major action including transportation of radioactive waste would generally perform an appropriate risk assessment for each alternative (within the full spectrum of available and appropriate transportation mode alternatives) to develop a well-reasoned decision. However, DOE frequently has no choice regarding routes, and the risk from transportation is usually small regardless of route.

An agency may find that information needed for the evaluation of environmental impacts in an EIS cannot be obtained because the overall costs of doing so are exorbitant or the means to obtain such information are not known. The CEQ regulations (40 CFR §1502.22) specify how an agency is to proceed in such circumstances. When an agency is evaluating "reasonably foreseeable" significant adverse effects on the human environment and there is incomplete or unavailable information, the agency must make clear that such information is lacking. If relevant incomplete information is essential to a reasoned choice between alternatives and the overall costs of obtaining it are not exorbitant, the agency is required to include the information in its analysis. If such information cannot be obtained because the overall costs of obtaining it are exorbitant or the means to obtain it are not known, the agency is required to include within its EIS:

> *(1) a statement that such information is incomplete or unavailable; (2) a statement of the relevance of the incomplete or unavailable information to evaluating the reasonably foreseeable significant adverse impacts on the human environment; (3) a summary of existing credible scientific evidence which is relevant to evaluating the reasonably foreseeable significant impacts on the human environment; and (4) the agency's evaluation of such impacts based upon theoretical approaches or research methods generally accepted in the scientific community*.

For the purposes of 40 CFR §1502.22, the term "reasonably foreseeable" includes impacts that have catastrophic consequences, even if their probability of occurrence is low, provided that the analysis of impacts is supported by credible scientific evidence, is not based on pure conjecture, and is consistent with the rule of reason. As discussed below, these regulations can be particularly important in developing an analysis of accident-related risks associated with the transportation of radioactive materials and consistent with NEPA requirements.

An EIS or other environmental study previously prepared by a federal agency may be used to assist in complying with the requirements of NEPA. In fact, NEPA regulations encourage the use of such reports [see 40 CFR §§1500.4(n) and 1506.4]. An agency does, however, have an obligation to independently evaluate any document (including an EIS, EA, or other environmental report) prepared by others upon which the agency intends to rely in complying with NEPA (40 CFR §1507.2). If such analyses satisfy an agency's obligation to study the potential effects of its own proposed action, the agency has no obligation to prepare its own study. However, an agency may not substitute compliance with standards or regulations administered by another agency for required NEPA analysis (Calvert Cliff's Coordination Committee, 1971). This issue is of particular significance in SNF, TRUW, and HLW transportation, since the packaging and transportation of such materials is extensively regulated by the U.S. Nuclear Regulatory Commission (NRC) and the DOT (see Section 2.4).

■ 2.3 DOE Guidance

The procedures that DOE shall use to comply with Section 102(2) of NEPA and the CEQ regulations (40 CFR Parts 1500-1508) are provided in DOE NEPA Implementing Procedures (10 CFR Part 1021). Those procedures are intended to supplement and to be used in conjunction with the CEQ regulations. DOE internal requirements and responsibilities for implementing NEPA, the CEQ regulations, and the DOE NEPA Implementing Procedures are established in DOE Order 451.1B. However, no specific federal requirements for conducting transportation risk assessments exist.

Guidance concerning the preparation of risk assessments for DOE NEPA activities is contained in *Recommendations for the Preparation of Environmental Assessments and Environmental Impact Statements,* commonly called the "Green Book." In addition to revisiting many of the CEQ regulations, the Green Book emphasizes that environmental impacts should be evaluated using a sliding scale approach. As discussed in the Green Book (DOE, 1993):

> *The term "scale" refers to the spectrum of significance of environmental impact. Generally, those proposals with greater potential for significant environmental impact require more analysis than those proposals with very small environmental impacts. …*
>
> *In other words, in using the sliding scale approach to NEPA analysis, the preparer should analyze issues and impacts with the amount of detail that is commensurate with their importance.*

Therefore, the extent of a transportation risk assessment in a document such as an EA or EIS should depend on the significance of the transportation. With respect to transportation impacts, the Green Book provides the following guidance (DOE, 1993):

> *Transportation Impacts*
>
> *When transport of waste or materials of a hazardous or radioactive nature is a necessary part of a proposed action or analyzed alternative, or, more generally, when transport is in any respect a major factor (e.g., transportation of construction materials for a proposed major dam), the environmental impacts of such transport should be analyzed, even when DOE is not responsible for 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 alternative. If not otherwise analyzed, include any necessary loading or unloading activities in the transportation impact analysis.*
>
> *As with the choice of alternatives, apply a sliding scale approach to the transportation analysis. The nature of the proposed action and analyzed*

alternatives determines whether to describe the transportation impacts qualitatively or to analyze them quantitatively, and what types of potential transportation accidents to consider (see subsection 6.4).

Recommendations

- *Analyze all transportation links that are reasonably foreseeable parts of the proposed action or analyzed alternative, such as overland transport, port transfer, and marine transport. If the action contains links that traverse the global commons (e.g., the oceans or outer space), then impacts from such transport should be included in the NEPA analysis; state that the global commons analysis is provided pursuant to Executive Order 12114.*

- *Do not rely exclusively on statements that transportation would be conducted in accordance with all applicable regulations or requirements of the U.S. Department of Transportation, the Environmental Protection Agency, the Nuclear Regulatory Commission, or State authorities.*

- *Evaluate both routine (i.e., incident-free) transport and accidents. (Accidents are discussed in subsection 6.4.) Give special emphasis to public or worker health impacts from exposure to chemicals or radiation.*

- *Be sure to use defensible estimation methods for assessing the radiological impacts of transportation (such as the most current version of RADTRAN).*

- *Estimate the annual and total impact of all DOE and non-DOE transportation associated with the use of specific routes (if known) over the term of the proposed action or analyzed alternative, including, for chemical and radiological exposure, the impact on a maximally exposed individual. The impacts of the proposed action related to transportation must be totaled over the duration of the project (e.g., 48 trips per year for 5 years). (Note: This total is not the cumulative impact of transportation impacts from the proposed action and other transportation activities over the same time period in the same area.)*

- *In determining the cumulative impact from transportation activities, use available data to estimate, for example, the number of radioactive materials packages that were shipped over a given transportation system over a given period of time.*

The primary end points for most DOE transportation risk assessments are the potential human health effects from exposure to low doses of radiation or exposure to chemicals. The principal human health effect from radiation exposure is cancer, and the principal health effect from chemical exposure may be both toxic effects and cancer. As discussed in the Green Book, "Exposure and dose are neither health effects nor environmental impacts." The difficulty lies in quantifying the potentially significant health effects (e.g., number of deaths) on the basis of potential exposure. The Green Book provides the following guidance when evaluating carcinogenic effects from radiation exposure (DOE, 1993):

> *When providing quantitative estimates of carcinogenic effects of radiation exposure, express population (or collective) effects as an estimated number of fatal cancers, and express maximum individual effects as the estimated maximum probability of the death of an individual. Evaluate effects for involved workers, noninvolved workers, and the general public under both routine operations and accident scenarios.*

Although the Green Book provides a general overview of what a DOE NEPA transportation assessment should include, recommendations are not provided regarding specific end points, scenarios, methodologies, or input parameters.

More detailed information is provided in the *Framework for Assessing the Effects of Radioactive Materials Transportation in Department of Energy Documents* (DOE, 1995a), subsequently referred to as the "Framework." The Framework discusses inclusion of packing and loading/unloading activities if the primary activity addressed by the EA or EIS is transportation. Such activities must be included if they are part of the proposed action. The analysis should consider the number of workers involved, protective equipment used, and the sequence of events followed during packing or loading/unloading (i.e., time-motion studies), including movement of the material within the facility.

As recommended in the Framework, analysis of transportation activities should cover the shipment mode (e.g., truck or rail), the number of shipments, the number of crew members per shipment, origin and destination sites (route definition), stops required along the route, and any necessary intermodal transfers. Incident-free transportation impacts to consider include the radiological dose and resultant health effects to the general public and workers (crew and others at stops). Members of the public to consider include persons alongside the route (pedestrians or persons living or working on the sides of the route), sharing the route (persons traveling on the same route), and at stops (e.g., persons at rest areas or refueling areas). In addition, impacts to a maximally exposed individual (MEI) along the route (e.g., a person living next to the transport route) should be determined.

The Framework suggests that the focus of the analysis for radiological effects from accident conditions should be the largest reasonably foreseeable release of radioactive material (the bounding case). Such a release could result from a traffic accident or acts of terrorism or sabotage. Results should be presented for the collectively exposed population and the MEI. Nonradiological effects, such as health effects resulting from vehicle emissions (e.g., fugitive dust and engine emissions) and hazards from vehicle accidents (e.g., fatalities) should also be addressed.

A draft guidance document, the *EM NEPA Technical Guidance Handbook* (DOE, 1997a), was written to help streamline the DOE NEPA process and has been made available for comment. In the section on transportation assessment, the Framework is referenced and provides the basis for the transportation analysis. For impact assessment, the computer codes HIGHWAY (Johnson et al., 1993a) and INTERLINE (Johnson et al., 1993b) are the recommended routing models.

TRAGIS (Johnson and Michelhaugh, 2000) has replaced HIGHWAY and INTERLINE, and incorporates a geographic information system (GIS). RADTRAN (Neuhauser and Kanipe, 1992; Neuhauser and Kanipe, 2000; Neuhauser et al., 2000) and RISKIND (Yuan et al., 1995) are the recommended radiological models. The implementation of these models in a comprehensive risk assessment methodology is discussed in Section 4.1, and the models themselves are described in Section 5. Emphasis is also placed on analyzing the effects on traffic and roads (e.g., increased noise, traffic volume) in the immediate vicinity of the origin and destination sites. These latter effects need only be assessed if significant changes in traffic or traffic patterns result from the proposed action, and to the degree that they impact the environment.

The DOE adopted a series of risk assessment principles that help define how risk assessments should or can be used within the DOE (DOE, 1999a). These principles were based on others developed by an interagency committee led by the White House Office of Science and Technology Policy. The principles were designed as a first cut at defining risk analysis, its purposes, and the principles to follow if it is to be done well and credibly. Included are general principles; principles for risk assessment, management, and communication; and principles for priority setting using risk analysis. The principles of risk assessment adopted by the DOE include the following (DOE, 1999a):

- Departmental programs should employ the best reasonable, obtainable information from the natural, physical, and social sciences to assess risks to health, safety, and the environment.

- Characterizations of risks and of changes in the nature or magnitude of risks should be both qualitative and quantitative — that is, both descriptive and mathematical — consistent with available data. The characterizations should be broad enough to inform the range of activities to reduce risks.

- Judgments used to develop a risk assessment, such as assumptions, defaults, and uncertainties, should be stated explicitly. The rationale for these judgments and their influence on the risk assessments should be articulated.

- Risk assessments should encompass all appropriate hazards to human health and the environment (such as acute and chronic risks, including cancer and non-cancer risks). In addition to considering the full population at risk, attention should be directed to subpopulations (including future generations) that may be particularly susceptible to such risks and/or may be more highly exposed.

- Peer review of risk assessments can ensure that the highest professional standards are maintained. Therefore, programs should develop procedures to maximize its use.

- Departmental programs should strive to adopt consistent approaches to evaluating the risks posed by hazardous agents or events.

■ 2.4 Other Federal Regulations

■ ■ 2.4.1 Packaging

Regulations that govern the transportation of radioactive materials are designed to protect the public from the potential loss or dispersal of these materials. The regulations also protect against routine doses of radiation during transit. The primary regulatory approach for ensuring safety is specifying performance standards for the proper packaging of materials.

The DOT and the NRC are the primary federal agencies responsible for regulating the transport of radioactive materials. Table 2.1 lists the most relevant DOT and NRC regulations. The DOE has signed a separate memorandum of understanding with both agencies to abide by these regulations. Implementation of these agreements by DOE is established in DOE Orders 460.1A

Table 2.1. DOT and NRC Regulations Relevant to Transportation Risk Analysis

Regulation	Topic
NRC	
10 CFR 71	Packaging and Transportation of Radioactive Material
DOT	
49 CFR 171	General Information, Regulations, and Definitions
49 CFR 172	Hazardous Material (HAZMAT) Tables Special Provisions, HAZMAT Communications Regulations, Emergency Response Information and Training Requirements
49 CFR 173	Shippers – General Requirements for Shipments and Packaging
49 CFR 174	Carriage by Rail
49 CFR 175	Carriage by Aircraft
49 CFR 176	Carriage by Vessel
49 CFR 177	Carriage by Public Highway
49 CFR 178	Packaging Specifications
49 CFR 397	Transportation of HAZMAT; Driving and Parking Rules (Subpart D – Routing of Class 7 [Radioactive] Materials)

(“Packaging and Transportation Safety”) and 460.2 (“Departmental Materials Transportation and Packaging Management”) and their respective guides (DOE G 460.1-1 and DOE G 460.2-1).

The DOT is responsible for regulating transportation of all HAZMAT; its regulations apply to shippers and carriers. The regulations most pertinent to radioactive materials are given in 49 CFR 173 (“Shippers – General Requirements for Shipments and Packaging”), Subpart I (“Radioactive Materials”). Under these regulations, DOT is specifically responsible for the design and performance specifications of packages that will carry smaller quantities of radioactive materials not exceeding Type A quantities, which are defined in 49 CFR 173.431 (“Activity Limits for Type A and Type B Packages”). The NRC regulations, in 10 CFR 71 (“Packaging and Transportation of Radioactive Material”), focus on the design and performance criteria of Type B packages (e.g., SNF casks). More detailed information on Type A and B packages relative to transportation risk assessment is provided in Section 6.1.1.

■ ■ 2.4.2 Routing

The radioactive materials highway routing regulations of the DOT are prescribed in 49 CFR 397 Subpart D (“Routing of Class 7 [Radioactive] Materials”). The objectives of the regulations are to reduce the impacts of transporting radioactive materials, to establish consistent and uniform requirements for route selection, and to identify the role of state and local governments in the routing of radioactive materials. The regulations attempt to reduce potential hazards by avoiding populous areas and minimizing travel times. Furthermore, the regulations require that the carrier of radioactive materials ensure that the vehicle is operated on routes that minimize radiological risks and that accident rates, transit times, population density and activity, time of day, and day of week are considered in determining risk.

The regulations require that a shipment of a “highway route controlled quantity (HRCQ)” (10 CFR Part 71) of radioactive materials be made over the interstate highway system except when moving from origin to interstate or from interstate to destination, when making necessary repair or rest stops, or when emergency conditions make continued use of the interstate unsafe or impossible. Carriers are required to use interstate circumferential or bypass routes, if available, to avoid populous areas. Other “preferred highways” may be designated by any state or Native American tribe to replace or supplement the interstate system. Under its authority to regulate the safety of interstate transportation, the DOT can prohibit state and local bans and restrictions as “undue restraint of interstate commerce.” State or local bans can also be preempted if inconsistent with the regulations. The DOT has published *Guidelines for Selecting Preferred Highway Routes for Highway Route Controlled Quantity Shipments of Radioactive Materials* (DOT, 1992) to aid in implementing 49 CFR 397 Subpart D.

Currently, DOT has no railroad routing regulations specific to the transportation of radioactive materials. Railroad companies in the United States are private companies that either own the right-of-way upon which they operate or have trackage rights to operate on another company’s line. Only a limited number of rail lines are owned by public agencies, and those are located primarily in large urban areas with passenger operations. Routes are generally fixed by the location of rail lines and urban areas cannot be readily bypassed.

■ ■ 2.4.3 Emergency Response

Potential radiation exposure of individuals under accident conditions at any point along a transport route can occur through many exposure pathways if an accident leads to a release of radioactive material to the environment. The Federal Radiological Emergency Response Plan (FRERP) (Federal Emergency Management Agency [FEMA], 1998) establishes a coordinated response by federal agencies when requested by state, tribal, or local government officials during a peacetime radiological emergency. The DOE has primary responsibility for providing assistance unless the radioactive source is unknown, unidentified, or from a foreign country, in which case the U.S. Environmental Protection Agency (EPA) becomes the primary coordinating federal agency.

The EPA has issued a set of protective action guides (PAGs) (EPA, 1992) to aid public officials when responding to an accident involving radioactive materials. Under emergency conditions, maximum individual dose limits for both first responders and members of the public are suggested when practicable, and are implemented by evacuation and/or interdiction. Limits are set for the early phase of an accident, lasting up to four days from the time of the initial release and for the intermediate phase of an accident, taken up to one year after the accident for purposes of dose projection.

In most cases, doses to individuals located downwind during the early phase of the accident are primarily from inhalation of the contaminated airborne plume. In the event of a transportation accident, protective actions. To mitigate dose, such as sheltering or evacuation, may not be feasible because exposure occurs in only a matter of minutes or seconds. If projected doses are expected to be near the protective action guide (PAG) values, protective actions to mitigate dose should be taken, providing the risk involved in the protective actions are not comparable to or greater than the risk posed by the accidental release itself. Protective actions include such measures as sheltering and evacuation in the early phase following an accident if the individual dose is expected to exceed 1 rem. If the release occurs over a short time (seconds), there may not be time to implement protective actions. However, if the release occurs over a longer period (minutes or hours), such as in a transportation accident involving a fire, there might be time to initiate sheltering or evacuation. It is not prudent for a risk assessment to assume effective mitigation during the early phase of an accident because exposure can occur before protective actions can be initiated and because an accident can occur along any point of a shipment route, meaning that emergency response personnel could take several minutes or longer to respond to an accident.

Intermediate-phase exposures occur through inhalation of resuspended contamination and external exposure to contaminated surfaces (groundshine) and radiation from airborne contamination (cloudshine). The PAGs suggest interdiction, evacuation, and relocation as a protective action if the first-year dose to a single individual is expected to exceed 2 rem. For doses less than 2 rem, the PAGs suggest that surface contamination be reduced to levels as low as reasonably achievable (ALARA) and recommend that initial efforts concentrate on areas where the projected doses are expected to exceed 0.5 roentgen equivalent man (rem) in the first year. Additional PAGs apply to the ingestion of contaminated foodstuffs. In commenting on draft EAs, local stakeholders have indicated that they wish to see the maximum potential consequences or risks included in the assessment. Therefore, although interdiction, evacuation, and cleanup can be introduced into the risk assessment, many of the more recent major EISs do not take credit for such actions that would reduce exposure (e.g., DOE, 1995b, 1996a, 1997b, 2002).

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3. Historical Development of DOE Transportation Analyses

During the 1970s and into the 1980s, the transportation of radioactive materials was not a major issue with the public, due in part to the excellent safety record of such transportation. Section 3.1 discusses the early development of transportation risk assessments in this time period following the passage of NEPA. Heightened public awareness after the reactor accident at Three Mile Island (TMI) in 1979 resulted in increased scrutiny and criticism of DOE's actions in complying with NEPA (Bentz et al., 1997), despite the maintenance of an excellent transportation safety record. Section 3.2 covers development of transportation risk assessments up to the present time following the repercussions from TMI. Changes brought about by public concerns and involvement in the NEPA process are discussed in Section 3.3. Section 3.4 discusses the implications of recent high-profile DOE EISs.

■ 3.1 Early Developments

The environmental impacts of transporting SNF in Type B casks by truck and rail were first analyzed by the U.S. Atomic Energy Commission (AEC) in a generic study entitled *Environmental Survey of Transportation of Radioactive Materials to and from Nuclear Power Plants* (WASH-1238 [AEC, 1972]). A subsequent AEC report, *Environmental Survey of the Uranium Fuel Cycle* (AEC, 1974), specifically applied the WASH-1238 transportation environmental impacts data to the shipment of other high-level nuclear wastes. Public hearings were held on both of these documents. As a result of these hearings, the AEC's approach to the evaluation of the accident risks associated with the transportation of radioactive waste (i.e., multiplication of the consequences of potential accidents by the probability of their occurrence), and AEC's conclusion that such risks were extremely low and well within acceptable limits, were approved by the hearing board.

In 1977, the NRC, a successor agency to the AEC, prepared its own EIS regarding the environmental impacts of the transportation of radioactive materials. The *Final Environmental Impact Statement on the Transportation of Radioactive Material by Air and Other Modes* (NUREG-0170 [NRC, 1977a]) was a generic study performed primarily with conservative engineering assumptions and national average data. The study extensively examined the potential environmental impacts of shipping radioactive materials by various modes of transportation. It has served as a benchmark EIS upon which most subsequent EAs and EISs relating to radioactive waste transportation have relied for methodology, data, and/or analysis. NUREG-0170 assessed both the incident-free radiological consequences of such transportation and the likelihood and magnitude of radiological consequences associated with potential accidents. The assessment concluded that the overall radiological risk involved in all shipments of radioactive materials was small.

Soon after publication of NUREG-0170, DOE prepared programmatic EISs for the management and storage of spent reactor fuel, other HLW, and TRUW (e.g., Final EIS on U.S. Spent Fuel Policy [DOE, 1980a], *Final EIS for Management of Commercially Generated Radioactive Waste*

[DOE, 1980b], *Final EIS for the Waste Isolation Pilot Plant* [DOE, 1980c]), relying substantially on NUREG-0170 for generic data and analysis of the environmental impacts associated with transportation.

Subsequent DOE review of specific proposed shipments of foreign and domestic SNF invariably concluded that the environmental effects of the shipment and management of SNF had been adequately addressed in previous NEPA documents (e.g., NUREG-0170 and DOE, 1980a) and that the impacts of the proposed shipments would be insignificant in comparison with impacts previously identified and evaluated in the earlier EISs. After several such reviews, in or about 1981, DOE ceased documenting reviews for similar SNF movements, on the basis of the following categorical exclusion contained in DOE's guidelines for implementing compliance with NEPA. (An EA is not required for actions that an agency determines are categorically excluded under its NEPA compliance procedures.):

> *Actions that are "substantially the same as other actions for which the environmental effects have already been assessed in a NEPA document and determined by DOE to be clearly insignificant and where such assessment is currently valid" (45 FR 20695, March 28, 1980).*

During the early and mid-1980s, DOE made several shipments of SNF from both foreign and domestic origins to DOE's Idaho National Engineering Laboratory[3] (INEL) in Idaho Falls, Idaho, and to DOE's Savannah River Site (SRS) in Aiken, South Carolina. DOE prepared no campaign-specific EAs or EISs for any of these shipments. Instead, the agency continued to rely upon NUREG-0170, certain other environmental analyses giving generic consideration to transportation environmental impacts, and the above-referenced categorical exclusion established by its NEPA compliance guidelines. During 1982, for example, about 300 nuclear fuel cycle shipments were made without incident, and with no EIS or EA (Weiner et al., 1991).

■ 3.2 Public Concerns

The March 29, 1979, accident at General Public Utilities Company's (GPUC's) Unit 2 nuclear power plant at TMI, Pennsylvania, proved to be a watershed event with regard to public and official scrutiny of the risks associated with nuclear power. Transportation of radioactive materials were scrutinized more closely because of this heightened concern (see, for example, Resnikoff, 1983). In the aftermath of the accident, the NRC prepared and published the *Final Programmatic Environmental Statement Related to Decontamination and Disposal of Radioactive Waste Resulting from March 29, 1979, Accident at Three Mile Island Nuclear Station, Unit 2* (NRC, 1981). The EIS concluded that TMI was not suitable for the long-term storage and disposal of the nuclear wastes and that TMI wastes not acceptable for storage at a commercial facility should be sent to a federal installation for storage and research until they could be repackaged in a waste form acceptable for a commercial or federal disposal facility. A four-party coordination agreement was negotiated between GPUC, DOE, NRC, and the Electric Power Research Institute (EPRI) under which DOE agreed to accept the core debris and transport it to INEL for research and storage until it could be placed in a permanent repository.

[3] Now called the Idaho National Engineering and Environmental Laboratory (INEEL).

The TMI EIS (NRC, 1981) also evaluated the environmental impacts of the cleanup and generally addressed the risks involved in transporting the core debris. Relying primarily on NUREG-0170 and NRC (1981), DOE concluded that the transportation of the core debris from TMI to INEL fell within its NEPA compliance guidelines' categorical exclusion. (DOE requested transportation consultants at Oak Ridge National Laboratory (ORNL) and ALK Associates, Inc., evaluate potential rail routing alternatives as identified by rail carriers). No serious challenge to DOE's decision not to prepare a transportation EA or EIS was initiated, although interested parties expressed concern over the absence of a campaign-specific EIS and questioned the applicability of NUREG-0170 to the TMI shipments.

NEPA requires assessing environmental impact and consideration of alternatives to a proposed action but does not mandate any particular agency decision or outcome. Therefore, judicial decisions reviewing agency compliance ensure that the agency has adequately considered and disclosed the environmental impact of its proposed actions, and that the agency's decision is not arbitrary, capricious, or an abuse of discretion. Under this standard, a court may determine whether the agency has considered all the relevant factors and has articulated a rational connection between the facts found and the choice made (Baltimore Gas & Electric, 1983).

A case with important repercussions on federal agency compliance with the requirements of NEPA in the transportation of radioactive materials is City of New York v. U.S. Dept. of Transp., 715 F.2d 732 (2nd Cir. 1983), cert. denied 465 U.S. 1055 (1984) (City of New York, 1984). This case concerned the validity of the DOT's the regulations governing the highway routing of highway-route-controlled-quantity shipments of radioactive materials. The City of New York challenged the regulations on several grounds, including the following: (1) the EA prepared by DOT did not comply with the requirements of NEPA, and (2) DOT's determination that the adoption of the regulations would not significantly affect the environment was arbitrary and capricious. The U.S. District Court for the Southern District of New York found DOT's EA to be deficient on several grounds and invalidated the regulations in part. The U.S. Circuit Court of Appeals for the Second Circuit reversed the decision of the district court and remanded the case to the district court for entry of an order upholding the regulations.

The written opinions of the Federal District Court and the Second Circuit in City of New York v. U.S. Dept. of Transportation are valuable for the depth of their examination of both risk assessment methodology and scientific and technical issues relating to compliance with NEPA in SNF and HLW transportation.

The most important challenges to DOE's policies regarding NEPA compliance in transporting radioactive waste arose from a series of lawsuits involving DOE proposals to ship research SNF from Taiwan to the United States pursuant to nonproliferation policies. The initial case (Northwest Inland Waters Coalition v. U.S. Dept. of Energy, et al. [NIWC, 1986]) involved a DOE proposal to ship 474 uranium SNF rods to a west coast port, unload the SNF rods, and transport them overland by truck to DOE's reprocessing facility at the SRS in South Carolina. Before the shipments began, the Northwest Inland Waters Coalition (the "Coalition"), an environmental organization, filed suit in Federal District Court in the State of Washington to enjoin the shipments on the ground that DOE had failed to prepare an EIS for the proposed action.

DOE contended that the shipments were categorically excluded from NEPA's environmental analysis requirements under the agency's NEPA compliance guidelines. The Coalition argued that the studies relied upon were outdated, generic, or programmatic EISs that did not fully analyze all of the risks posed by the proposed shipments. The Coalition specifically noted that the studies contained no analysis of ocean transport risks of radioactive materials and, as generic studies, did not include any route-specific information or route-selection analysis.

The district court ruled that DOE had unreasonably relied upon NUREG-0170 and the early DOE studies without conducting an analysis to determine whether the conditions under which the shipments would be implemented were accounted for and, further, ruled that the proposed shipments were a major federal action that could significantly affect the human environment, requiring preparation of an EIS.

On appeal, DOE abandoned its reliance on the categorical exclusion and generic and programmatic studies, arguing only that it should be permitted to prepare an EA to determine if an EIS was required, rather than being required to prepare an EIS. The U.S. Court of Appeals for the Ninth Circuit agreed, reversing the district court in part. However, the court specifically concurred with the district court's finding that DOE's failure to prepare an EA or EIS was unreasonable, noting that DOE had failed to conduct its own analysis specific to the conditions under which the shipments would be implemented (NIWC, 1988).

On December 11, 1986, while the appeal in the Northwest Inland Waters Coalition case was still pending, DOE published an EA (DOE, 1986) and a finding of no significant environmental impact from shipping the 474 SNF rods from Taiwan by sea to Portsmouth, Virginia, and then overland by truck to the SRS. These shipments were completed without legal challenge on July 6, 1988.

During the final stages of shipping the 474 SNF rods, DOE negotiated an agreement to accept an additional 1,100 SNF rods from Taiwan. Subsequently, DOE prepared and published a new EA (DOE, 1988c) analyzing the environmental impacts of transporting these additional SNF rods by the same route (the Phase II EA). This Phase II EA considered a no-action alternative and the alternative use of a generic west coast or gulf coast port. However, the Phase II EA did not consider the use of any other east coast ports as alternatives to Hampton Roads. DOE prepared risk assessment calculations for the Phase II EA with the RADTRAN III computer code, using conservative estimates to account for population densities and using very little site and/or route-specific information or criteria.

On December 12, 1988, the Sierra Club filed suit (Sierra Club, 1991) in the U.S. District Court for the District of Columbia to enjoin the shipments until DOE complied with the requirements of NEPA. The Sierra Club claimed that NEPA required DOE to prepare an EIS, rather than an EA, for the proposed Phase II shipments or, in the alternative, that the Phase II EA prepared by DOE was legally insufficient. The court declined to issue a preliminary injunction to halt the Phase II shipments, and transportation and delivery of the Phase II SNF rods were subsequently completed without incident.

On June 19, 1991, with litigation pending on the Phase II shipments, DOE filed a new EA (DOE, 1991) with the district court covering shipment of an additional 118 spent fuel rods from Taiwan to the SRS (the Phase III EA). The Phase III EA responded to some of the inadequacies alleged by the Sierra Club with regard to the Phase II EA. Specifically, two east coast ports, Charleston, South Carolina, and Wilmington, North Carolina, were considered as east coast alternatives to the use of the port at Hampton Roads, and the Phase III risk calculation program (RADTRAN 4) used actual population densities instead of conservative estimates for all areas located along the overland routes.

The RADTRAN 4 accident-risk calculations considered a broad range of possible accidents involving different types and degrees of stress that could be placed on a shipping cask and the consequences such accidents would have on the integrity of the cask and the amount of radiation released. However, the RADTRAN 4 accident-risk calculations did not include accidents that would generate sufficient force to create more than a one-inch-diameter breach in a cask. The Phase III EA deemed a larger breach “not credible,” effectively assuming that such an accident could not occur.

The Phase III EA mooted the Sierra Club’s claims against the Phase II EA, and the Sierra Club amended its complaint to reflect its belief that DOE had still failed to comply with the requirements of NEPA, despite the improvements made in the Phase III EA. The Sierra Club challenged the legal sufficiency of the Phase III EA on several grounds. Principally, it contended that DOE should have considered the alternative use of several additional east coast military and civilian ports with lower population densities and/or closer to the SRS; and that DOE had skewed the results of its RADTRAN 4 risk calculations by failing to include all low probability/high consequence accidents in the overall risk calculations. On December 9, 1991, the district court ruled that the Phase III EA was legally insufficient for these reasons.

The court found that DOE’s consideration of Charleston and Wilmington as alternative east coast ports to Hampton Roads did not cover the full spectrum of possible routing alternatives, and that the agency’s action was, therefore, not reasonable and constituted an abuse of discretion. The court noted that of the 11 east coast ports identified by the Sierra Club for possible routing of shipments, the EA analyzed only the second, third, and fourth most densely populated ports (selecting the port with the highest risk factor of the three), and that the EA did not consider other commercial ports with lower population densities or military ports in rural areas. Furthermore, the court observed that DOE never explained why such alternative ports were inappropriate for consideration. The court also noted that the EA provided no explanation of why the shipments would be routed through Hampton Roads.

■ 3.3 Lessons Learned

The decisions in both the Sierra Club and City of New York cases involved extensive judicial examination and discussion of several scientific, technical, and risk assessment methodology issues raised by plaintiffs regarding agency compliance with NEPA in the transportation of SNF and HLW. Some of the key rulings or pronouncements from these cases are summarized below.

Judicial Review of Scientific/Technical Issues: A reviewing court must generally defer to the expertise of an agency when assessing difficult issues of scientific and/or technical dispute, so long as the agency’s determination does not appear to be arbitrary and capricious (issues considered in the cases included transportation cask properties/reliability, dose conversion factors, and both incident-free and accident-related radiation exposure factors). When specialists express conflicting views, an agency has the discretion to rely on the reasonable opinions of its own qualified experts, even if a court might find contrary views more persuasive. Under this standard, an agency determination is merely required to have a rational basis (i.e., to be within a range of opinion generally accepted by the scientific community, or justifiable in light of current scientific thought).

Risk Assessment Methodology: The use of an overall (probabilistic) risk assessment methodology, in particular the RADTRAN 4 model and code, to calculate the risks associated with the transportation of radioactive waste, complies with the requirements of NEPA.

Cumulative Risk: While the incident-free dose from SNF or HLW transportation is usually unmeasurably small, when people along a transportation route have been exposed to this minimal dose of additional radiation repeatedly (from historic shipping campaigns), the cumulative dose must be included in risk calculations, with an explanation regarding the amount of the radiation, the number of people it might involve, and the potential health effects and risks.

Use of Bounding Values: The use of conservative estimates, or “bounding values,” for certain variables in risk assessment calculations (e.g., weather conditions, topography, and emergency response times) is generally acceptable for NEPA compliance. However, using bounding values tends to lessen or eliminate differences among alternatives, making the comparisons required by NEPA more difficult. Hence, their use should be limited to cases for which more accurate and detailed assessment is not practicable.

Low Probability/High Consequence Accidents: The potential effects of low-probability accidents with high and beyond-design-basis consequences must be considered. Accidents with a probability of occurrence of 10^{-7} (one in ten million) or more per year are considered “maximum reasonably foreseeable accidents” and accidents having a smaller probability of occurrence rarely need to be considered (DOE, 1999c). The use of the accident module in RADTRAN for the risk analysis ensures that all accidents that might occur will be considered. The RADTRAN accident severity category scheme includes the full range of mechanical and heat impact that might be involved in a transport accident, including those with probabilities less than 10^{-7}.

Human Error: Although human error in vehicle operation is included in historic accident rates, these rates do not account for some human errors that may have an effect specific to the shipping of radioactive materials (e.g., an error in sealing the casks after SNF rods have been loaded inside, or human error in the design or manufacture of the casks). To the extent that such factors can be identified, a probability of occurrence can be supported by past events, and an accidental release of radionuclides could result, these factors should be considered in a transportation risk assessment to the extent practicable.

Sabotage: To the extent that sabotage could create forces that caused a release of radionuclides, it should be considered in a transportation consequence assessment.

■ 3.4 Current Considerations and Future Outlook

Under DOE's Record of Decision (ROD) for the conduct of its Spent Fuel Management Program through the year 2035 (May 30, 1995), approximately 575 shipments of naval SNF will be made by rail to INEEL from six sites (Kesselring, Norfolk, Newport News, Pearl Harbor, Portsmouth, and Puget Sound). While insufficient data are available regarding specific transport variables to accurately assess the total number and modal mix of other DOE shipments necessary for implementation, the ROD estimates that there will be a maximum of 3,655 shipments (to INEEL and SRS combined), assuming that all shipments are by truck, with the exception of Naval SNF. In addition to the naval SNF, these 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 eight potential ports of entry; 519 shipments of domestic university research reactor SNF from 35 university reactors; and 1,007 intrafacility shipments of DOE-owned SNF from eight DOE weapons complex facilities (DOE, 1995b).

Under the Nuclear Waste Policy Act (NWPA) as amended, it is anticipated that SNF assemblies will eventually be transported from 72 commercial sites and five DOE sites throughout the United States to a geologic repository. If most SNF and HLW can be transported by rail, about 9,600 rail shipments and 1,080 truck shipments would be needed over a 24-year period. If legal-weight truck transportation must be used, about 53,000 truck shipments and 300 rail shipments (of naval SNF) would be needed (DOE 2002, Appendix J,). 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 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 to the WIPP of TRUW are anticipated from about 22 sites over the next 35 years (DOE, 1997d). Anticipated treatment and disposal of DOE low-level waste (LLW) could result in another 25,000 to 95,000 truck shipments over approximately 20 years, depending on the final regionalization strategy chosen (DOE, 1997b).

The volume and national scope of these anticipated shipments present some unique issues that must be addressed in light of legal challenges. DOE has already introduced a more comprehensive approach in its recent EISs (DOE, 1995b; 1996a; 1997b; 1999c), including (1) the introduction of specific, state-level routing and accident parameters; (2) the incorporation of consequence analysis using the RISKIND model and code, which is also used to analyze health effects to the MEI (RADTRAN continues to analyze risks to populations along routes and at stops[4]); and (3) the maintenance of consistency (including major assumptions and parameters) among its EISs. The same approach has been adopted by the Department of the Navy in its recent EIS on the container system for the management of naval SNF (U.S. Department of the Navy, 1996). This approach has enabled DOE to address concerns raised by stakeholders with regard to its previous NEPA assessments.

[4] Either RADTRAN or RISKIND can be used for all of these analyses. However, population and route analysis can be done more efficiently with RADTRAN, while consequence and MEI analysis can be done more efficiently with RISKIND.

Because a number of anticipated shipments will be made by different programs from several sites and will traverse the country, in some cases using the same transportation corridors, transportation analysis should examine the cumulative radiological exposure risks to transportation crews, cask handlers, and persons residing along the transportation routes, particularly those in the vicinity of shipping and receiving facilities.

The distances traveled through multiple states by many of these shipments has expanded the transportation alternatives considered to include different modes, intermodal transfer, and alternative routes. The spectrum of transportation alternatives considered in a NEPA analysis was increased in the Yucca Mountain EIS (DOE, 2002) to include barge transportation and intermodal transfers, as well as alternative routes. This EIS also presents alternative routes and modes, rather than choosing a particular route or transportation mode.

4. Transportation Methodology and Historical Review

Historical DOE NEPA transportation assessments were reviewed as part of this effort to streamline the process of conducting such assessments. This review documented the types of analyses and methods that have been used and accepted in the past, identified any apparent trends, and evaluated the assessment results to identify ways in which future assessments can be streamlined. This section provides a historical overview, as well as a description of an assessment approach that has been used successfully in the past and is considered well-developed and comprehensive. In addition, previous assessment results are briefly evaluated and presented to provide some perspective on expected assessment results.

Section 4.1 presents a discussion of a standardized transportation risk assessment approach identified after review of a large number of recent NEPA documents. This approach was used to support the DOE Waste Management Programmatic EIS (DOE, 1997b) and several subsequent EISs. The approach was a culmination of discussions and reviews among several organizations, including DOE offices, the Naval Reactors Program, and contractors, and was itself based on a long history of previous assessments. This assessment approach, summarized in Figure 4.1, combined the use of routing programs (HIGHWAY [Johnson et al., 1993a] and INTERLINE [Johnson et al., 1993b]) with the transportation risk assessment codes RADTRAN (Neuhauser and Kanipe, 1993; Neuhauser et al., 2000) and RISKIND (Yuan et al., 1995). (A discussion of the assessment models is provided in Section 5.) The two complementary risk assessment programs are used to satisfy the requirements and considerations of NEPA, which include not only the need to estimate impacts of alternatives, but also the need to respond to specific areas of public concern. This approach provides a uniform and comprehensive methodology for performing transportation impact assessments.

Section 4.2 summarizes the NEPA assessments reviewed to determine the assessment methodology described in Section 4.1, including a tabular summary of the methods and models used. Section 4.3 presents a brief statistical analysis of the results of previous assessments, and is intended to highlight the magnitude of expected assessment results.

■ 4.1 Transportation Risk Assessment Methodology

A commonly used approach for transportation risk assessment identified in this review is summarized in Figure 4.1 and discussed in detail in this section. For each analysis, risks are assessed for routine transportation and accidents. For the routine operations assessment, risks are calculated for the collective populations of potentially exposed individuals, as well as for the MEIs. The accident assessment consists of two components: (1) an accident risk assessment where risks are calculated for the collective population living and working along the transportation route that considers the probabilities and consequences of a range of possible transportation-related accidents, including low-probability accidents that have high consequences, and high-probability accidents that have low consequences; and (2) an accident consequence assessment that considers

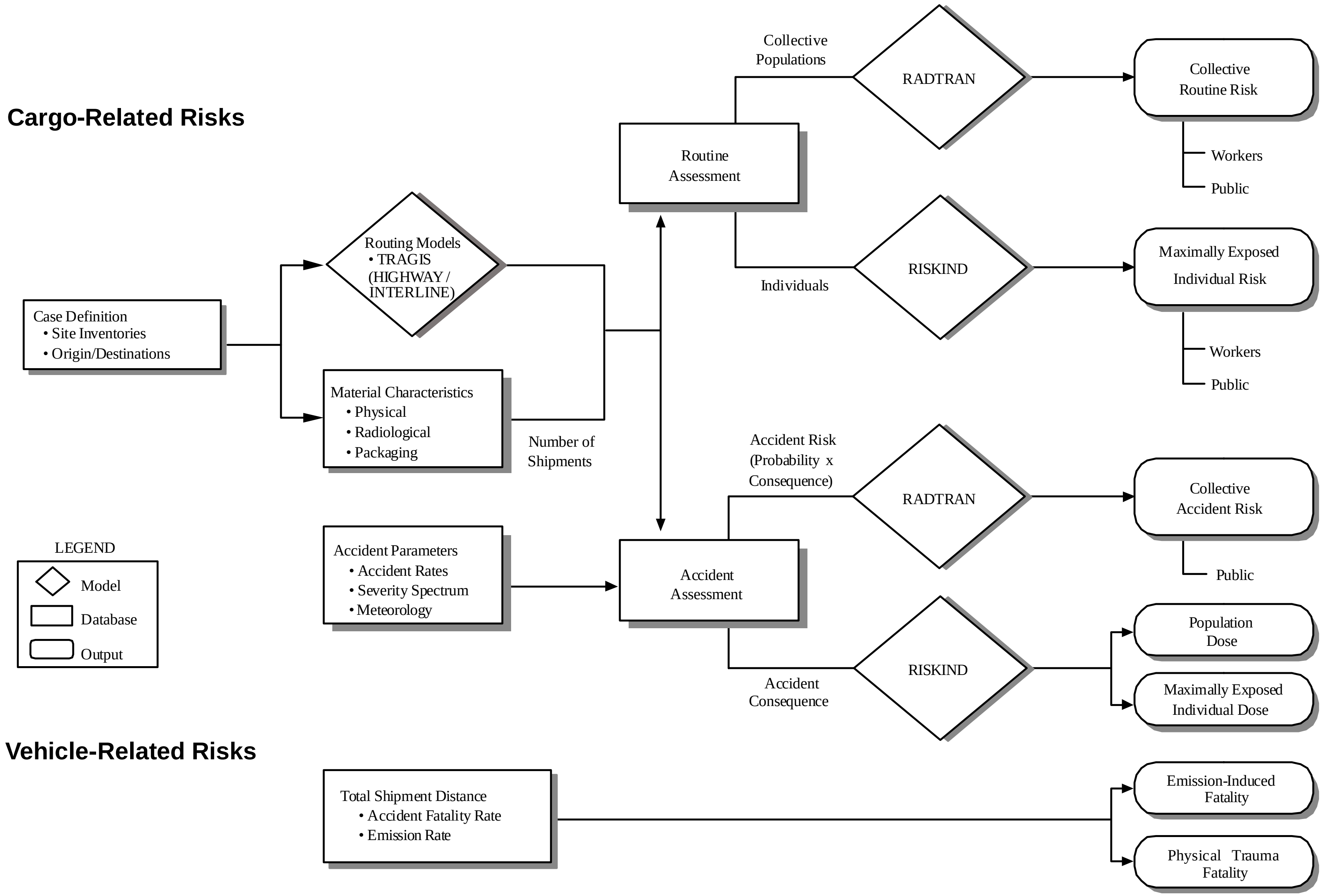

Figure 4.1. Technical Approach for Transportation Radiological Risk Assessments

only the radiological consequences to a population group and MEIs from severe transportation-related accidents postulated to result in the largest releases of radioactive material.

All radiological impacts are calculated in terms of dose and associated health effects in the exposed populations. The radiation dose calculated is the total effective dose equivalent (TEDE), as specified in 10 CFR Part 20 ("Standards for Protection against Radiation"), which is the sum of the effective dose equivalent (EDE) from exposure to external radiation and the 50-year committed effective dose equivalent (CEDE) (International Commission on Radiological Protection [ICRP], 1977) from exposure to internal radiation. Doses of radiation are typically calculated in units of rem (roentgen-equivalent man) or millirem (mrem, 1 rem = 1,000 mrem) for individuals and in units of person-rem for collective populations. In most cases, federal regulations require that individual members of the public not be exposed to more than 100 mrem/yr from licensed operations (10 CFR 20.1201). Transportation workers involved in the shipment of radioactive materials, as well as other individuals, such as state shipment inspectors, would be monitored by a dosimetry program if it were expected that they would be exposed to radiation in excess of 100 mrem/yr. In such cases, doses would be maintained ALARA at a level well below the 5 rem annual limit for radiation workers (10 CFR 20.1201).

Generally, assessment models provide estimates of the radiation dose to workers and members of the public, which are then converted to estimates of health effects for each alternative. The health effect end point typically used is radiation-induced latent cancer fatalities (LCFs), which are estimated by multiplying the dose (person-rem) by health risk conversion factors. These factors relate the radiation dose to the potential number of expected LCFs based on comprehensive studies of people historically exposed to large doses of radiation, such as the Japanese atomic bomb survivors. The factors most commonly used in recent assessments are 0.0004 LCF/person-rem of exposure for workers and 0.0005 LCF/person-rem of exposure for members of the general public (ICRP, 1991). The latter factor is slightly higher because some individuals in the public, such as infants, are more sensitive to radiation than the average worker. These factors imply that if a population of workers receives a total dose of 2,500 person-rem, on average, one additional LCF will occur among the workers. Similarly, if the general public receives a total dose of 2,000 person-rem, on average, one additional LCF will occur.

The RADTRAN computer code (Neuhauser and Kanipe, 1992; 2000; Neuhauser et al., 2000) is used for routine and accident risk assessments to estimate the radiological impacts to collective populations. The code calculates population risks associated with transporting radioactive materials by various modes, including truck, rail, air, ship, and barge. The RADTRAN calculations of population risk take into account the consequences and probabilities of potential exposures.

RADTRAN was originally developed by Sandia National Laboratories (SNL) as a tool to prepare the *Final Environmental Impact Statement on the Transportation of Radioactive Material by Air and Other Modes* (NRC, 1977a). The code has been continually updated and expanded since its inception. The latest version, RADTRAN 5 (Neuhauser et al., 2000), was released in mid-2000, but this handbook reviews assessment experience with the RADTRAN 4 code (Neuhauser and Kanipe, 1992; 1993). Unless explicitly stated, the RADTRAN models discussed in this handbook are common to both versions. RADTRAN is discussed in more detail in Section 5.3.1.

As a complement to the RADTRAN calculations, the RISKIND computer code (Yuan et al., 1995) estimates scenario-specific doses to MEIs for routine operations and accidents and estimates population impacts for the accident consequence assessment. The RISKIND computer code was originally developed by Argonne National Laboratory for the DOE Office of Civilian Radioactive Waste Management specifically to analyze radiological consequences to individuals and population subgroups associated with transporting SNF. The most recent version of the code accommodates all types of radioactive waste shipments.

The RISKIND calculations supplement the results for collective risk calculated with RADTRAN. Whereas the results for collective risk provide a measure of the overall risks of each case, the RISKIND calculations are meant to address areas of specific concern to individuals and subgroups of the population. Essentially, the RISKIND analyses address hypothetical questions, such as, "What if I live next to a site access road?" or "What if an accident happens near my town?" RISKIND is described in Section 5.3.3.

■ ■ 4.1.1 Routine (Incident-Free) Risk Assessment Method

■ ■ ■ 4.1.1.1 Collective Population Risk

The radiological risk associated with routine transportation results from the potential exposure of people to low-level external radiation from loaded shipments. For routine transportation, the RADTRAN computer code considers all major groups of potentially exposed persons. The RADTRAN calculations of risk for 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 all persons in 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 RADTRAN calculations for routine dose are based on generically expressing the dose rate as a function of distance from a point source (Neuhauser and Kanipe, 1995; Neuhauser et al., 2000). The calculation of routine doses for each exposed population group depends on parameters such as the radiation field strength, source-receptor distance, duration of exposure, vehicular speed, stopping time, traffic density; and route characteristics, such as population density. The RADTRAN manual contains derivations of the equations and descriptions of these parameters (Neuhauser and Kanipe, 1995; Neuhauser et al., 2000). The values for many of the most important parameters are presented in Section 6.

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. TRAGIS (Johnson and Michelhaugh, 2000) determines representative highway or rail routes for each unique pair. HIGHWAY (Johnson et al., 1993a) and INTERLINE (Johnson et al., 1993b) were the routing codes used previously for truck and rail routes, respectively. However, they were superseded by TRAGIS. 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. For shipments between each origin-and-destination pair, RADTRAN calculates collective risks to workers and the public based on representative radiological and physical properties of the radioactive material being transported. The collective risks are then summed over the set of origin-destination pairs to estimate the collective routine risks associated with that alternative.

■ ■ ■ 4.1.1.2 Maximally Exposed Individual Risk

The RISKIND model estimates risk to MEIs 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 while living near a DOE site.

The dose to each MEI considered is calculated with RISKIND for an exposure scenario defined by 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 (DOE, 1987; 1990; 1995b; 1996a; 1997b):

- *Crew Members*. Truck and rail crew members are assumed to be occupational radiation workers and would be monitored by a dosimetry program. Therefore, the maximum allowable dose would be 5 rem/yr. As an administrative procedure, the DOE limits doses to DOE workers to 2 rem/yr (DOE, 1994a).

- *Inspectors (Truck and Rail)*. Inspectors are assumed to be either federal or state vehicle inspectors. Inspectors are not monitored by a dosimetry program. An average exposure distance of 3 m (10 ft) and an exposure duration of 30 minutes are assumed.

- *Rail-Yard Crew Member*. A rail-yard crew member is not monitored by a dosimetry program. An average exposure distance of 10 m (33 ft) and an exposure duration of 2 hours are assumed.

- *Resident (Truck and Rail)*. A resident is assumed to live 30 m (98 ft) from a site entrance route (truck or rail). Shipments pass at an average speed of 24 km/h (15 mph), and the unshielded resident is exposed. Cumulative doses are assessed for each site based on the number of shipments entering or exiting the site, assuming that the MEI resident is present for 100% of the shipments.

- *Person in Traffic Obstruction (Truck and Rail).* A person is assumed to be stopped next to a radioactive material shipment (e.g., because of traffic slowdown). The unshielded person is assumed to be exposed at a distance of 1 m (3.3 ft) for a duration of 30 minutes.

- *Person at Truck Service Station.* A person is assumed to be exposed at an average distance of 20 m (66 ft) for a duration of 2 hours. This receptor could be a worker at a truck stop.

- *Resident near a Rail Stop.* A resident is assumed to live near a rail classification yard. The unshielded resident is assumed to be exposed at a distance of 200 m (656 ft) for a duration of 20 hours.

The scenarios are not intended to be exhaustive, but to provide a range of potential exposure situations.

The RISKIND external dose model considers direct external exposure and exposure from radiation scattered from the soil and air. The RISKIND model calculates dose (rem per hour) as a function of distance for stationary exposure and rem per event for moving shipments from a radioactive material shipment based on the shipment dimensions. The code approximates the shipment as a cylindrical volume source, and the calculated dose includes secondary radiation-scattering contributions from buildup (scattering by waste contents), cloudshine (scattering by air), and groundshine (scattering by ground). The dose rates calculated with RISKIND have been comparable with output from existing radiation transport codes, such as MCNP and Microshield (Biwer et al., 1997). The RISKIND model produces realistic, yet conservative, results.

■ ■ ■ 4.1.1.3 Vehicle-Related (Nonradiological) Routine Risk

Vehicle-related health risks resulting from routine transportation may be associated with 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. A risk factor for latent mortality from pollutant inhalation, generated by Rao et al. (1982), is 1×10^{-7}/km (1.6×10^{-7}/mi) of truck travel in an urban area (1.3×10^{-7}/railcar-km for rail). This risk factor is based on regression analyses of the effect of fugitive dust and sulfur dioxide and particulate emissions from diesel exhaust on mortality. Excess latent mortality is assumed to be equivalent to latent fatalities. Vehicle-related risks from routine transportation are calculated for each alternative by multiplying the total distance traveled in urban areas by the appropriate risk factor. Similar risk factors are not available for rural and suburban areas.

Risks are summed over the entire route and over all shipments for each alternative. This method was used in several reports to calculate risks from routine transport of radioactive wastes (DOE, 1987; 1990; 1995b; 1996a; 1997b). Lack of information for rural and suburban areas is an obvious gap in the data, although the risk factor would be lower because the number of affected persons would be lower in rural and suburban areas. As discussed in Section 6.2.2, revised and updated risk factors based on the work of Rao et al. (1982; Biwer and Butler, 1999) were recently developed to include all truck types and population zones.

■ ■ 4.1.2 Accident Assessment Method

■ ■ ■ 4.1.2.1 Radiological Accident Risk Assessment

The risk analysis for potential accidents differs fundamentally from the risk analysis for routine transportation because accident occurrences are stochastic events. The accident risk assessment is treated probabilistically in RADTRAN. The dose risk from a specific accident is defined as the product of the accident consequence (dose) and the probability of the accident occurring. The accident dose risk from a given shipment is the sum of dose risk over the range of accidents. In this respect, the RADTRAN code estimates the collective accident risk to populations by considering a spectrum of transportation-related accidents. That spectrum encompasses a range of possible accidents, including low-probability accidents with high consequences and high-probability accidents with low consequences (“fender benders”). The RADTRAN calculation of collective accident risk employs models that quantify the range of potential accident severities and the responses of transported packages to accidents. The spectrum of accident severity is divided into a number of categories. Each category of severity represents a conditional probability of occurrence — that is, the probability that an accident, if one occurs, will be of a particular severity. Release fractions, defined as the fraction of the material in a package that could be released in an accident, are assigned to each accident severity category on the basis of the physical and chemical form of the waste material. 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 are discussed further in Section 6.

For accidents involving the release of radioactive material, RADTRAN assumes that airborne material is dispersed into the environment according to standard Gaussian dispersion models. For the risk assessment, RADTRAN assumes an instantaneous ground-level release and a source cloud with an initially small diameter (Neuhauser et al., 2000). 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, state-specific food transfer factors were calculated that relate the amount of radioactive material ingested to the amount deposited on the ground (see Section 6.1.11.2 and Appendix D) in accordance with the methods described by NRC Regulatory Guide 1.109 (NRC, 1977b). These factors may be used with ground deposition calculated by RADTRAN to estimate ingestion dose. Radiation doses from ingesting or inhaling radionuclides are calculated with standard dose conversion factors (see Appendix C).

The collective accident risk for each alternative is determined in a manner similar to that described for routine collective risks. Accident risks are first calculated for each unique origin-and-destination pair and then are summed over all pairs to estimate the total risk for the alternative.

■ ■ ■ 4.1.2.2 Radiological Accident Consequence Assessment

The RISKIND code provides a scenario-specific assessment of radiological consequences of severe transportation-related accidents for each waste type. The RADTRAN accident risk assessment considers the entire range of accident severities and their related probabilities. On the other hand, the RISKIND accident consequence assessment analyzes the potential impacts of a given accident by focusing on accidents that would result in the largest releases of radioactive material to the environment. This enables estimates of accident consequences for maximum, reasonably-foreseeable accident scenarios. Maximum, reasonably-foreseeable accidents have very low probabilities of occurrence, but are not “worst case” accidents. DOE analyzes maximum, reasonably-foreseeable accidents and presents their consequences separately from their probabilities in NEPA documents.

The severe accidents considered in the consequence assessment are characterized by extreme mechanical and thermal forces. In all cases, these accidents result in a release of radioactive material to the environment. The accidents correspond to those within the highest accident severity category that may reasonably be expected to occur, as described previously. These accidents represent low-probability, high-consequence events. Therefore, accidents of this severity are expected to be extremely rare. However, the overall probability that such an accident could occur depends on the potential accident rates for this severity category and the shipping distance for each alternative.

The RISKIND model is used to assess accident consequences for two reasons. First, it can model the complex atmospheric (or site-specific) dispersion resulting from severe accidents. The atmospheric dispersion is modeled as an instantaneous release by using standard Gaussian puff methods. In addition, because severe accidents typically involve fires, modeling the potential radiological consequences takes into account physical phenomena resulting from the fire, such as buoyant plume rise. Second, RISKIND can estimate the dose to MEIs near an accident. RISKIND determines the MEI’s location on the basis of the atmospheric conditions assumed at the time of the accident and the thermal characteristics of the release.

The accident consequences are calculated for local populations and for 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 emergency responses 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 at the time of an accident, two different atmospheric conditions are often considered. The first case assumes neutral atmospheric conditions (Pasquill stability class D, 4 m/s wind speed), and the second assumes stable conditions (Pasquill stability class F, 1 m/s wind speed).

■ ■ ■ 4.1.2.3 Vehicle-Related (Nonradiological) Accident Risk Assessment

Vehicle-related accident risk refers to transportation accidents that result in fatalities unrelated to the shipment's cargo. This risk represents fatalities from mechanical causes. State-specific transportation fatality rates are discussed in Section 6.2.1. Vehicle-related accident risks are calculated 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.

■ 4.2 Summary of Recent NEPA Transportation Risk Assessments

Approximately 100 DOE NEPA documents were reviewed to identify the transportation risk assessment methodologies used and compare the results. An initial screening investigation was conducted to limit the number of NEPA documents examined in detail to those containing comprehensive radiological intersite transportation risk assessment sections. In general, the methodology review and comparison of results were conducted for the more recent NEPA documents that discussed the risk assessment methodologies and detailed results of the transportation impact assessments.

Typically, brief descriptions of the risk assessment methodology and results of the transportation impact assessments were presented in the main NEPA documents, with a more detailed description of these methodologies in separate transportation appendices and technical reports. The reviewed NEPA documents primarily involved the transportation of radioactive waste, such as LLW, TRU, SNF, and HLW. In addition, most of the reviewed assessments estimated impacts from either truck or rail modes of transport.

The NEPA documents reviewed in detail are listed in Table 4.1. The table also shows the predominant radioactive cargo being transported, the transportation modes considered, and the assessment computer codes and models. The documents listed are the only ones among the nearly 100 screened that contained significant transportation risk assessment sections.

As previously mentioned, a generally standardized assessment approach, detailed in Section 4.1, has emerged in recent years. This approach, which addresses risks to collective populations, MEIs, and the consequences of maximum severity accidents, was applied and accepted in a number of high-profile NEPA assessments. The approach combines four primary computer codes: RADTRAN and RISKIND for risk and consequence assessment, and HIGHWAY and INTERLINE for routing analysis. Note, however, that HIGHWAY and INTERLINE were superseded by TRAGIS.

Table 4.1. Reviewed DOE NEPA Documents Containing Comprehensive Transportation Risk Assessments

Document Number	NEPA Document	Predominant Cargo	Transportation Mode	Routing Models	Collective Risk Models	Incident-Free MEI Model	Accident Consequence Models
DOE/ EIS-0113	Draft EIS Disposal of Hanford Defense HLW, TRUW, and Tank Wastes	HLW, TRUW	Truck, rail	Not provided	RADTRAN II	Not evaluated	Not evaluated
DOE/ EIS-0200-F	Waste Management Programmatic EIS for Managing Treatment, Storage, and Disposal of Radioactive and Hazardous Waste	LLW, low-level mixed waste (LLMW), HLW, TRUW	Truck, rail	HIGHWAY, INTERLINE	RADTRAN 4	RISKIND	RISKIND
DOE/ EIS-0203-F	DOE Programmatic SNF Management and INEL ER and Waste Management Final EIS	SNF	Truck, rail	HIGHWAY, INTERLINE	RADTRAN 4	RISKIND	RISKIND
DOE/ EIS-0218F	Proposed Nuclear Weapons Nonproliferation Policy Concerning Foreign Research Reactor SNF	SNF	Truck, rail	HIGHWAY, INTERLINE	RADTRAN 4	RISKIND	RISKIND
DOE/ EIS-0226-D	Draft EIS for Completion of the West Valley Demonstration Project (WVDP) and Closure or Long-Term Management of Facilities at the Western New York Nuclear Service Center	LLW, TRUW, contaminated soils, low specific activity (LSA) materials	Truck, rail	HIGHWAY, INTERLINE	RADTRAN 4	RISKIND	RISKIND
DOE/ EIS-0240	Disposition of Surplus Highly Enriched Uranium Final (EIS)	Uranium compounds	Truck	INTERSTAT	RADTRAN 4	Not evaluated	Not evaluated
DOE/ EIS-0245F	Final EIS for Management of SNF from K Basins at the Hanford Site, Richland, Washington	SNF, HLW	Truck, rail	HIGHWAY, INTERLINE	RADTRAN 4	RISKIND (worker only)	GENII
DOE/ EIS-0249	Medical Isotopes Production Project: Molybdenum-99 and Related Isotopes EIS	Medical isotopes	Air, truck	HIGHWAY	RADTRAN 4	Not Provided (aircraft passenger only)	GENII
DOE/ EIS-0250D	Draft EIS for a Geologic Repository for the Disposal of SNF and High-Level Radioactive Waste at Yucca Mountain, Nye County, Nevada	SNF	Truck, rail	HIGHWAY, INTERLINE	RADTRAN 4	RISKIND	RISKIND

Table 4.1. Reviewed DOE NEPA Documents Containing Comprehensive Transportation Risk Assessments (Continued)

Document Number	NEPA Document	Predominant Cargo	Transportation Mode	Routing Models	Collective Risk Models	Incident-Free MEI Model	Accident Consequence Models
DOE/ EIS-0251	Department of the Navy Final EIS for a Container System for the Management of Naval SNF	SNF	Rail	INTERLINE	RADTRAN 4	Mathematical Formulas	RISKIND
DOE/ EIS-0269	Programmatic EIS for Alternative Strategies for the Long-Term Management and Use of Depleted Uranium Hexafluoride	Uranium compounds	Truck, rail	HIGHWAY, INTERLINE	RADTRAN 4	RISKIND	RISKIND
DOE/ EIS-0275	Final EIS S1C Prototype Reactor Plant Disposal	Reactor components	Truck, rail	HIGHWAY, INTERLINE	RADTRAN 4	Mathematical Formulas	RISKIND
DOE/ EIS-0283	Surplus Plutonium Disposition Final EIS	Plutonium and uranium compounds	Truck	HIGHWAY	RADTRAN 4	RISKIND	RISKIND
DOE/ EIS-0026-S-2	Waste Isolation Pilot Plant Disposal Phase Draft Supplemental EIS	TRUW	Truck, rail	HIGHWAY	RADTRAN 4	Not identified	RISKIND
DOE/ EA-0441	EA of Transportation, Receipt, and Storage of Fort St. Spent Fuel at the Irradiated Fuel Storage Facility at the Idaho Chemical Processing Plant	SNF	Truck	Not provided	RADTRAN 4	Not evaluated	Not evaluated
DOE/ EA-0912	EA of Urgent Relief Acceptance of Foreign Research Reactor SNF	SNF	Truck, rail	HIGHWAY	RADTRAN 4	Not identified	Not identified
DOE/ RW-0073	EA, Yucca Mountain Site, Nevada Research and Development Area, Nevada	SNF	Truck, rail	HIGHWAY, INTERLINE	RADTRAN II	Cited references (Sandquist et al., 1985)	Cited references (Sandquist et al., 1985)

■ ■ 4.2.1 Collective Population Risk

The DOE NEPA documents reviewed generally used similar methodologies to conduct the transportation risk assessments. In all cases, the cargo-related collective population risks were estimated with the RADTRAN 4 computer code coupled with the route characteristics obtained from HIGHWAY and INTERLINE. The collective population risks were estimated on the basis of “per-kilometer” unit risks, “per-shipment” unit risks, or direct output from the RADTRAN computer code. Input data for RADTRAN were obtained either from the RADTRAN user’s manual or from information collected during past shipping practices. Results from RADTRAN 5 analyses were published too recently to be included in this summary.

The RADTRAN computer code was used to estimate the “cargo-related” collective population risk for every EIS and EA reviewed. The RADTRAN computer program was originally developed by SNL to prepare the *Final Environmental Statement on the Transportation of Radioactive Material by Air and Other Modes* (NRC, 1977a). RADTRAN II (Madsen et al., 1983) and RADTRAN III (Madsen et al., 1986) were revised versions of the original code. The RADTRAN code has been continually updated and expanded since its inception and estimates the radiological risks to collective populations associated with transportation operations under both routine and accident conditions. The most current version of RADTRAN is RADTRAN 5 (Neuhauser and Kanipe, 2000). For routine cargo-related risks, RADTRAN estimates a collective radiation dose for persons living along the transportation route, sharing the transportation route, and at rest stops along the transportation route. RADTRAN also calculates the collective population dose to crew members and other workers. The potential radiation dose estimated using RADTRAN strongly depends on the external dose rate and the cargo size. RADTRAN estimates the “cargo-related” collective population risks associated with potential transportation accidents by considering both the consequences of each type of accident and the probability of an accident occurring. The exposure pathways consider inhalation, groundshine, cloudshine, and ingestion. For each NEPA document researched, the “cargo-related” risk associated with transportation accidents was a small percentage of the total risk.

■ ■ 4.2.2 Consequence Assessment

To supplement the collective risk estimates, most of the recent NEPA transportation risk assessments have included dose and the associated LCF estimates to MEIs under routine and accident transportation conditions. The radiological impacts to these individuals were estimated with such computer models as RISKIND and GENII, as well as mathematical formulas. Many of the most recent documents used the RISKIND code for both accident consequence and MEI assessments (see Table 4.1).

To address both NEPA requirements and public concerns related to transportation operations, site-specific “cargo-related” impacts are estimated for MEIs under routine and accident conditions. The RISKIND computer code (Yuan et al., 1995) was originally developed by Argonne National Laboratory in response to public comments about the need for a more complete and consistent methodology to address radiological consequence issues. Before the development of RISKIND, a variety of models estimated site-specific “cargo-related” impacts to MEIs. RISKIND was designed to address the local, scenario-specific (i.e., “what if”) concerns frequently expressed by the members of public during the NEPA scoping process. The modeled pathways incorporated into RISKIND include external radiation (routine, accident), inhalation (accident), groundshine (accident), cloudshine (accident), and ingestion (accident). Since the development of the RISKIND computer code, many of the more recent NEPA documents (see Table 4.1) have incorporated this computer tool into their assessment methodology to estimate “cargo-related” consequences to MEIs under both routine and accident conditions.

■ ■ 4.2.3 Nonradiological Risk Assessment

In addition to assessing the “cargo-related” radiological risk posed by transportation-related activities, the NEPA transportation assessments also addressed vehicle-related nonradiological risks. These risks are independent of the radioactive nature of the cargo and would be incurred for similar shipments of any commodity. Vehicle-related risks during routine transportation operations would be associated with potential exposure to increased vehicular emissions, primarily in urban environments. Most of the transportation risk assessments reviewed utilized the “per-kilometer” unit risk factors developed by Rao et al. (1982) to estimate vehicle-related impacts from routine transportation operations. Under accident conditions, vehicle-related risks refer to the potential for transportation accidents to result in death from physical trauma during the accident. Vehicle-related transportation risks were estimated in each NEPA document using “per-kilometer” unit risk factors from several sources, including Saricks and Kvitek (1994) and Rao et al. (1982).

■ 4.3 Comparison of Results from Recent NEPA Transportation Impact Assessments

The NEPA risk assessment comparison identifies common trends among the transportation risk assessments and provides the analyst a baseline for comparison with future work. Because the assessments reviewed involved varying numbers of shipments over different routes of varying distances and population densities, the transportation assessments are compared based on the average impacts estimated for each kilometer traveled (“per-kilometer” unit risks). These unit risks are intended for comparison purposes only and simply provide analysts with benchmarks against which to compare future assessment results. The unit risks in the comparisons were either obtained directly from the NEPA documents or derived from the data presented in each of the reports. The derived unit risks were calculated by dividing the total collective dose (person-rem) by the total distance traveled. For assessments of multiple cargo types, the obtained or derived unit risks for the different cargo types were aggregated into an average unit risk for this comparison. Comparisons are first presented across assessments and then across waste types.

■ ■ 4.3.1 Comparison Across Assessments

The cargo-related incident-free transportation impacts from the NEPA documents summarized above are compared in Figures 4.2 through 4.6. The comparison of NEPA transportation impact results are only for those documents that either included unit risks or provided sufficient information that appropriate unit risks could be derived from the published results. Cargo-related accident risks were not considered in the comparison because the accident risks are a small fraction of the total transportation risks.

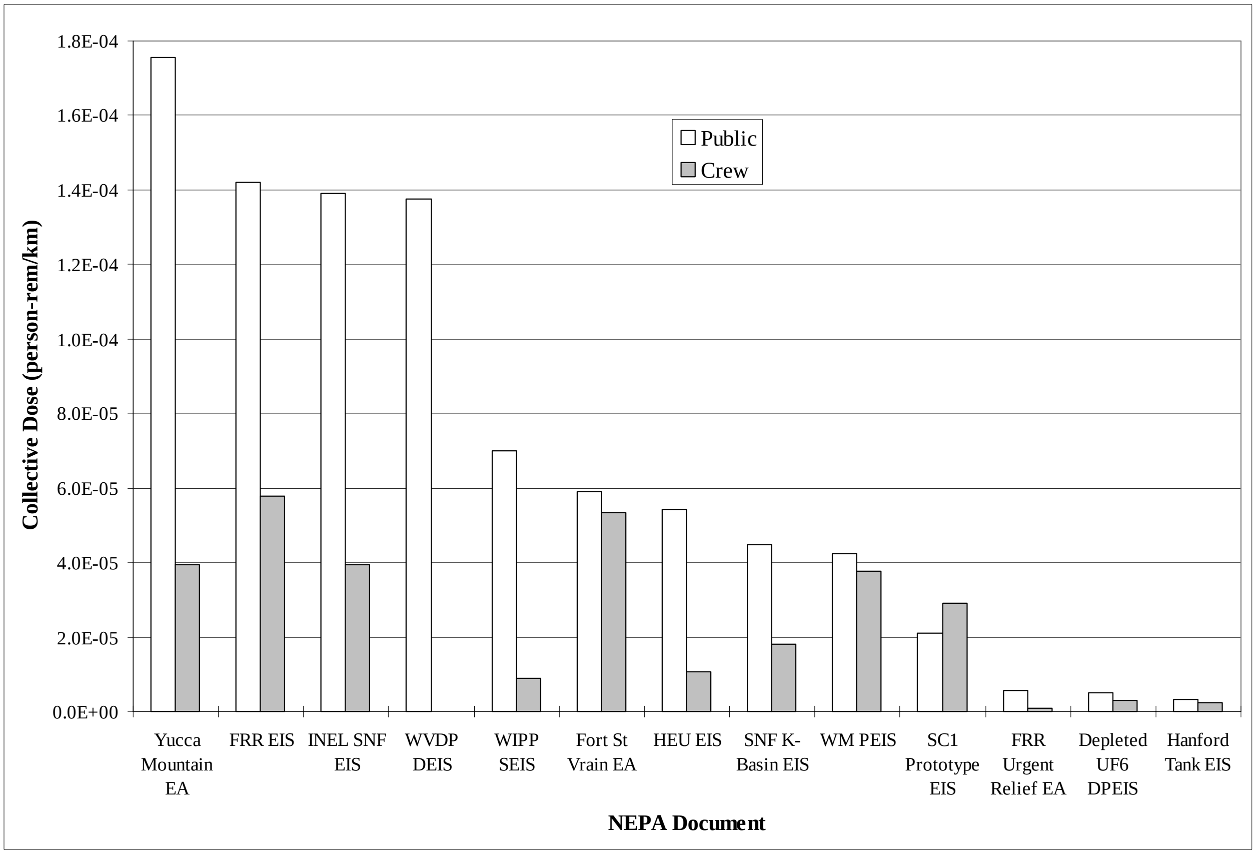

Figure 4.2. Incident-Free Cargo-Related Unit Risks for Members of the Public and Transportation Crews by Truck Transport

As shown in Figure 4.2, cargo-related unit risks for transportation workers from DOE truck shipments of radioactive material ranged from 8.5×10^{-7} to 5.8×10^{-5} person-rem/km, with an average unit risk of 2.5×10^{-5} person-rem/km and a median value of 5.7×10^{-5} person-rem/km. For members of the public, Figure 4.2 indicates that the risks ranged from 3.4×10^{-6} to 1.7×10^{-4} person-rem/km, with an average of 7.3×10^{-5} person-rem/km and a median value of 5.7×10^{-5} person-rem/km for all cargo types, ranging from depleted uranium to SNF. The majority of the public dose is accrued during stops for rest and fuel; Figure 4.3 indicates that approximately 90% of the dose to the public from truck shipments of radioactive material occurs during these routine stops. Those persons residing or working along transport routes (off-link population) receive less than 10% of the public dose during incident-free transport by truck.

The unit risks for DOE rail shipments are similar to those for truck shipments. Cargo-related unit risks for transportation crew members range from 7.1×10^{-7} to 1.8×10^{-5} person-rem/km, with an average of 1.2×10^{-5} person-rem/km and a median value of 1.5×10^{-5} person-rem/km for all cargo types (Figure 4.4). Likewise, the unit risks to members of the general public from DOE rail transport of radioactive material range from 1.4×10^{-6} to 2.3×10^{-5} person-rem/km, averaging 1.2×10^{-5} person-rem/km and a median value of 1.3×10^{-5} person-rem/km (Figure 4.4). About half of the public dose from rail shipments is accumulated during the stops, with

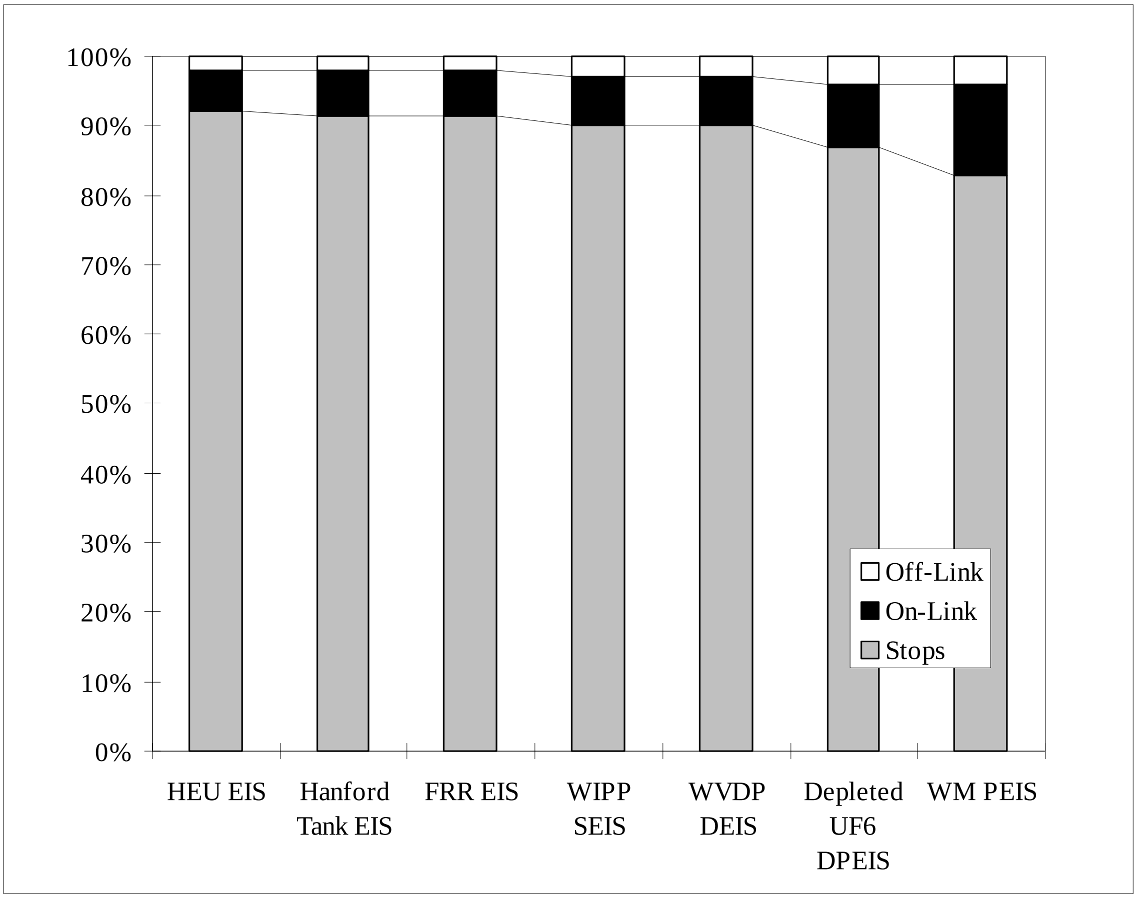

Figure 4.3. Distribution of the Total Incident-Free Dose to Members of the Public (persons at stops and off-link and on-link receptors) by Truck Transport

most of the remaining dose being delivered to persons living along the rail corridor, as shown in Figure 4.5.

The NEPA transportation documents reviewed considered a wide range of cargo types, from depleted uranium to SNF. A key parameter used in estimating routine "cargo-related" transportation impacts is the external dose rate. Several different methodologies were used to estimate the external dose rate for the NEPA documents. These methodologies included obtaining field measurements from identical or similar shipments of the same commodity, estimating an average dose rate based on multiple shipments of a similar material, and setting the external dose rate to the regulatory maximum based on the size of the package and the shipment type. When correcting for the dose rate from the various cargo types (normalized to a dose rate of 1 mrem/h at 1 m), the routine cargo-related risks for truck transport ranged from 3.4×10^{-6} to 5×10^{-5} person-rem/km, as shown in Figure 4.6, averaging 1.3×10^{-5} person-rem/km with a median value of 1.0×10^{-5} person-rem for DOE shipments of radioactive material. Similarly, the unit risks for DOE rail shipments ranged from 6.5×10^{-7} to 8.0×10^{-6} person-rem/km, averaging 2.8×10^{-6} person-rem/km and a median value of 1.7×10^{-6} person-rem/km. When accounting for the external dose rate, the "per-kilometer" unit risks are within a factor of 15 for truck shipments and less than a factor of 10 for rail shipments of radioactive material.

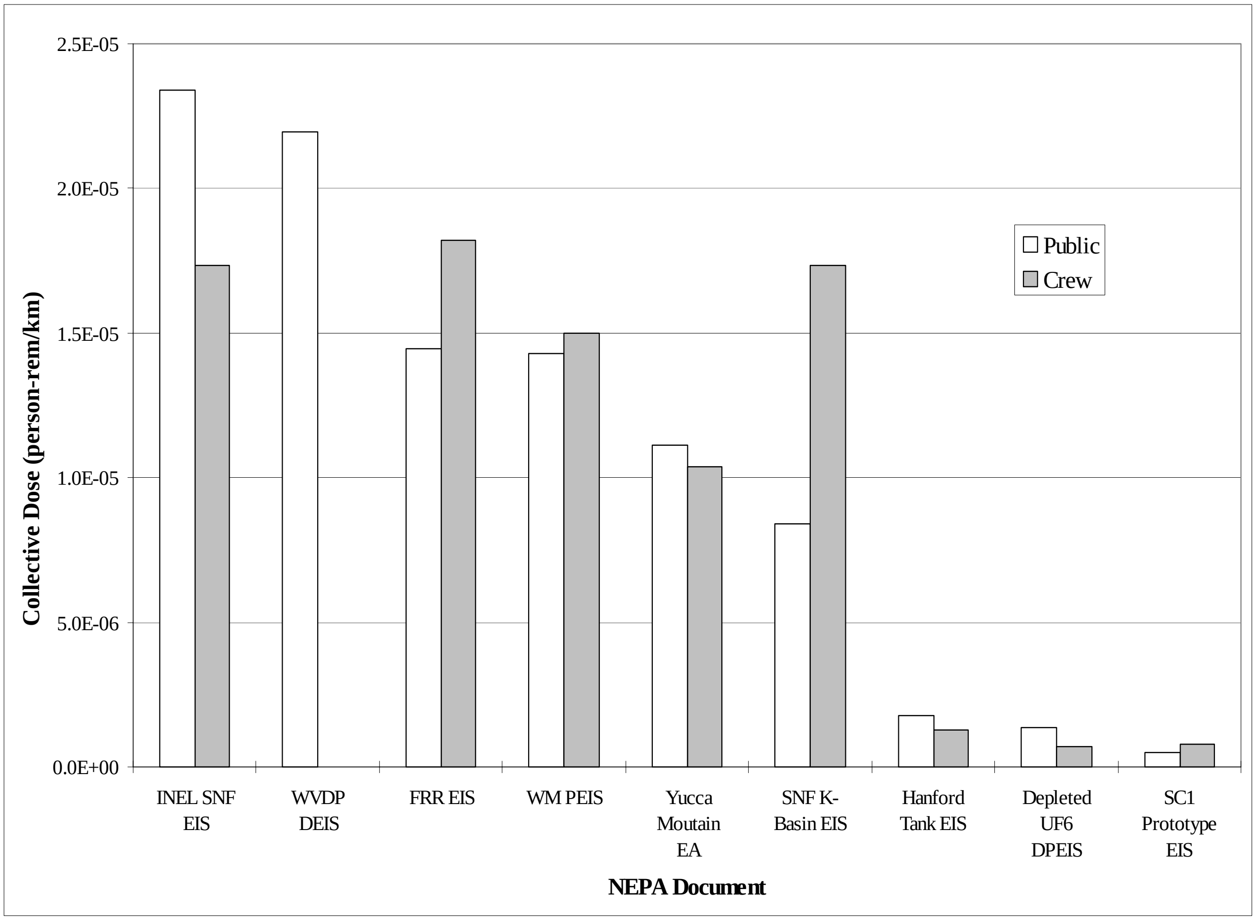

Figure 4.4. Incident-Free Cargo-Related Unit Risks for Members of the Public and Transportation Crews by Rail Transport

■ ■ 4.3.2 Dose Rate, Package Size, and Transport Route Effects

A number of different waste type transportation analyses were conducted for the *Waste Management Programmatic EIS for Managing Treatment, Storage, and Disposal of Radioactive and Hazardous Waste* (DOE, 1997b). Potential shipments of these wastes involve a variety of effective package sizes and external shipment dose rates for risk assessment. As shown in Table 4.1, the types of waste considered include HLW, TRUW, LLW, and LLMW. TRUW with a surface external dose rate of less than 200 mrem/h is defined as contact-handled (CH) TRUW (CH-TRUW). TRUW packages having an external dose-rate greater than 200 mrem/h are defined as remote-handled (RH) TRUW (RH-TRUW). More details on the different waste types are given in Sections 6.1.1.2 and 6.1.11.1.

External shipment dose rates applied in the Waste Management Programmatic Environmental Impact Statement (WM PEIS) were calculated by several methodologies. Table 4.2 lists the dose rates used. For shipments of LLW and LLMW, the dose rate was set to 1 mrem/h based on an average of about 2,500 reported external dose rates from historical shipments of LLW. For HLW shipments, the transportation index was estimated based on the external dose-rate set at the regulatory limit of 10 mrem/h at 2 m. The regulatory limit was assumed because extensive historical data for HLW shipments do not exist. For TRUW shipments, the external package dose rates were based on information provided in the Supplemental Final EIS for the WIPP (DOE, 1990).

Figure 4.7 displays the average incident-free per kilometer unit risk to members of the public during truck or rail transport of different waste types considered in the WM PEIS. The unit risks range from approximately 1×10^{-5} to 7×10^{-5} person-rem/km. When these unit risks are normalized by the dose rate to give the risk per kilometer per mrem/h, the effect of package size on the risks can be seen in Figure 4.8. The normalized risk decreases from LLW (16 m effective package size for truck) to HLW (3 m effective package size for truck) shipments.

The differences in shipment routes are reflected in the average distribution of the incident-free dose to off-link and on-link receptors and to receptors at stops, as shown in Figure 4.9 for truck shipments and in Figure 4.10 for rail shipments. About 50% or 80% of the incident-free population dose is incurred at stops during rail or truck transport, respectively. More than 10% of the exposure is received by the on-link population and the remainder by the off-link population during truck transport. For rail transport, most of the remaining dose, close to 50% on average, is received by the off-link population, with the on-link population receiving only about 1% of the incident-free dose.

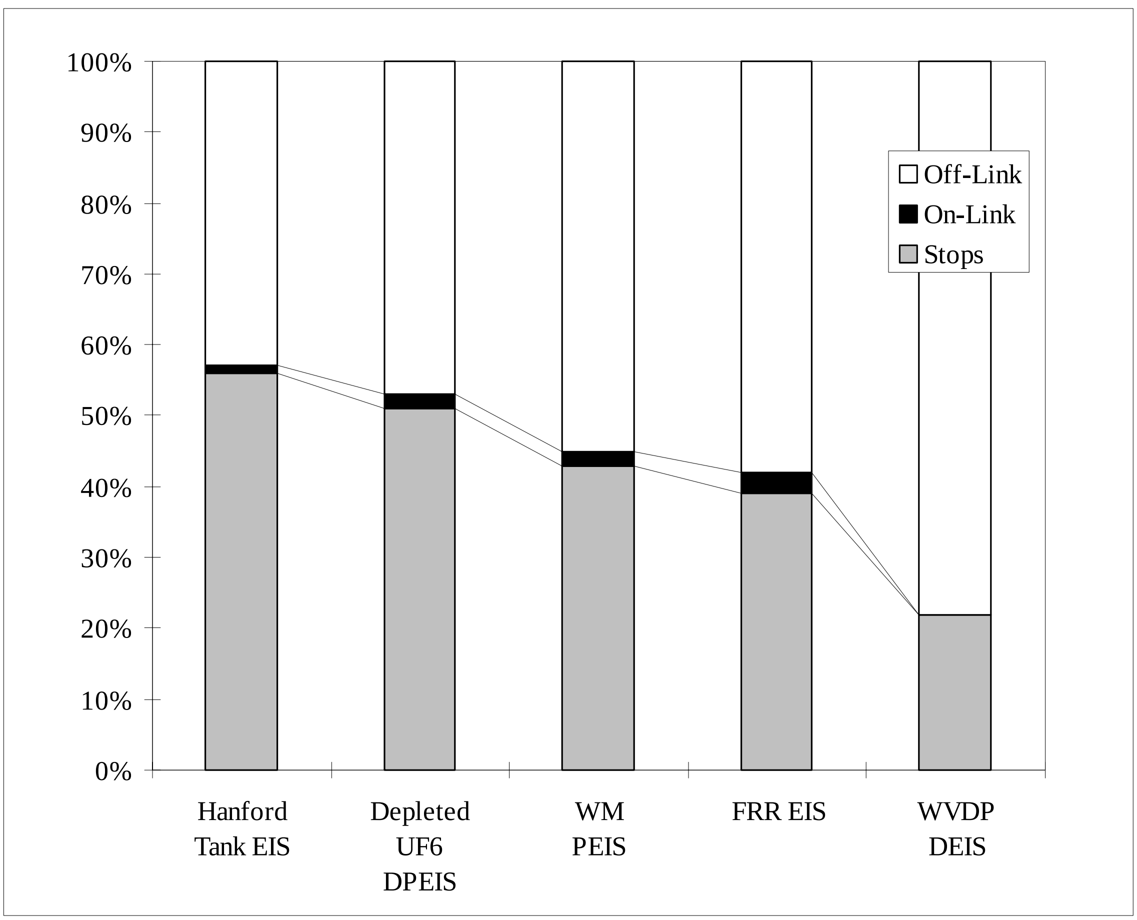

Figure 4.5. Distribution of the Total Incident-Free Dose to Members of the Public (persons at stops and off-link and on-link receptors) by Rail Transport

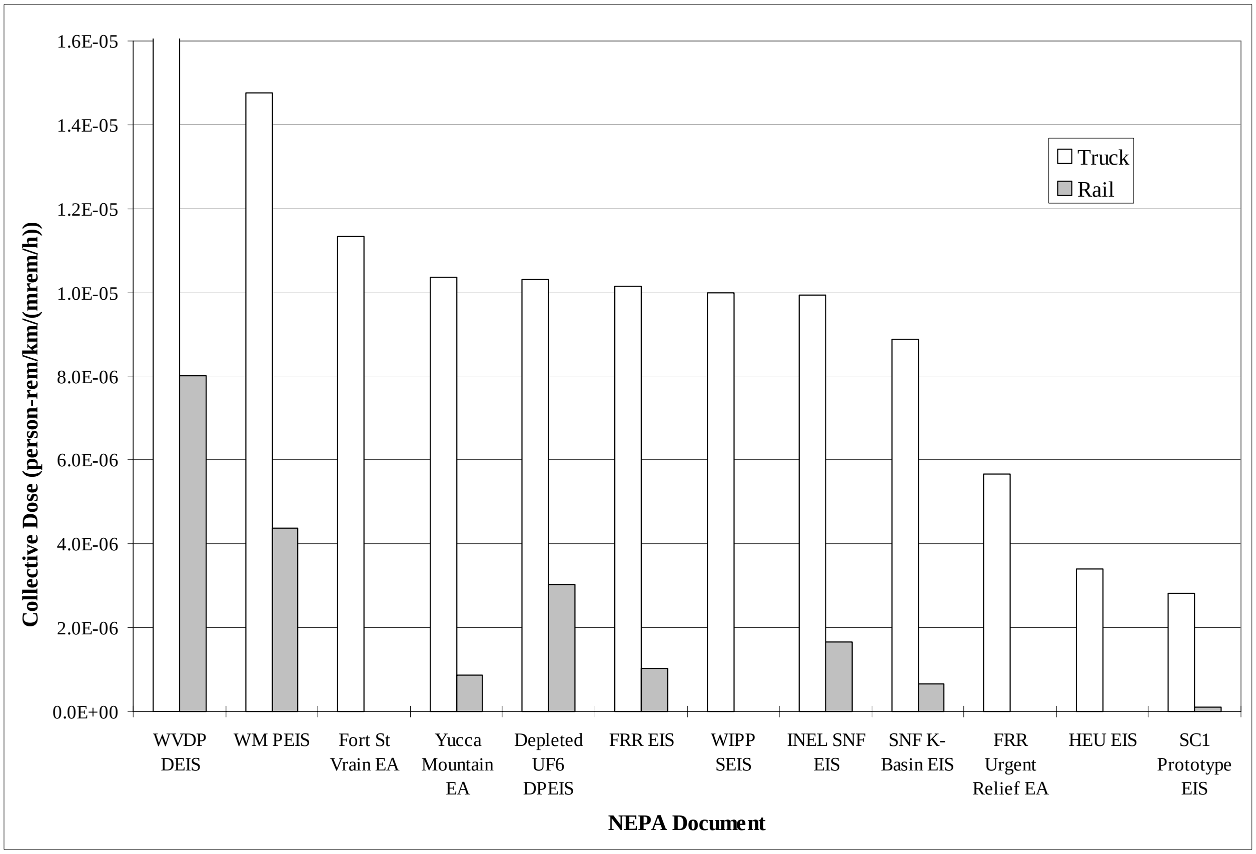

Figure 4.6. Incident-Free Cargo-Related Unit Risks Normalized by Dose Rate for Members of the Public

Table 4.2. Effective Package Sizes and Dose Rates from the WM PEIS

Waste Type	Effective Package Size (m)		Effective Dose Rate at 1 m (mrem/h)	
	Truck	Rail	Truck	Rail
LLW	12.0	16.0	1.0	1.0
LLMW	12.0	16.0	1.0	1.0
CH-TRUW	7.32	14.6	5.7	7.2
RH-TRUW	3.61	7.22	7.1	14
HLW	3.0	3.0	14	14

The differences observed in Figures 4.9 and 4.10 among all shipment types are primarily due to variations in distances traveled in different population zones (rural, suburban, and urban). The HLW, CH-TRUW, RH-TRUW, and LLW shipment information was based on data from many shipments over many different routes, giving similar average values. Activated metals was a subcategory of LLW (using the same package size and dose rate) considered in the WM PEIS. The activated metals information in Figures 4.9 and 4.10 was from a single WM PEIS alternative consisting of only five shipment routes, with some shipments traveling more than 50% in suburban and urban zones using rail transport, in contrast to the average of approximately 23% travel

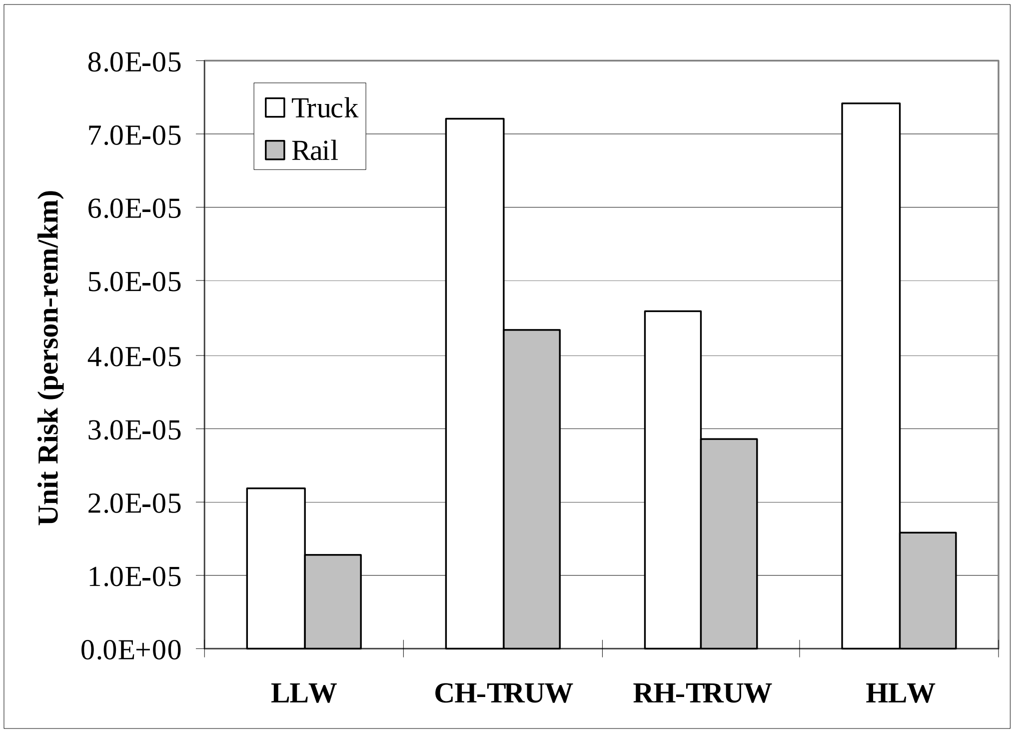

Figure 4.7. Incident-Free Cargo-Related Unit Risks for Different Cargo Types for Members of the Public, from the Waste Management Programmatic EIS (DOE, 1997b)

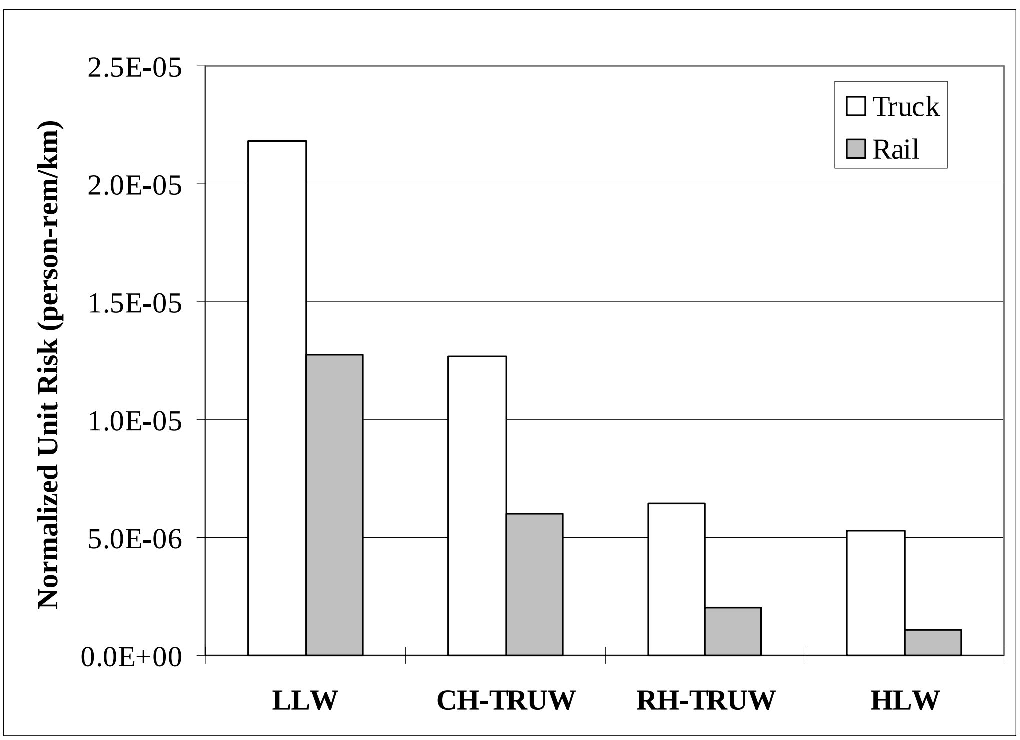

Figure 4.8. Normalized Incident-Free Cargo-Related Unit Risks for a Dose Rate of 1 mrem/h at 1 m for all Cargo Types Members of the Public, from the Waste Management Programmatic EIS (DOE, 1997b)

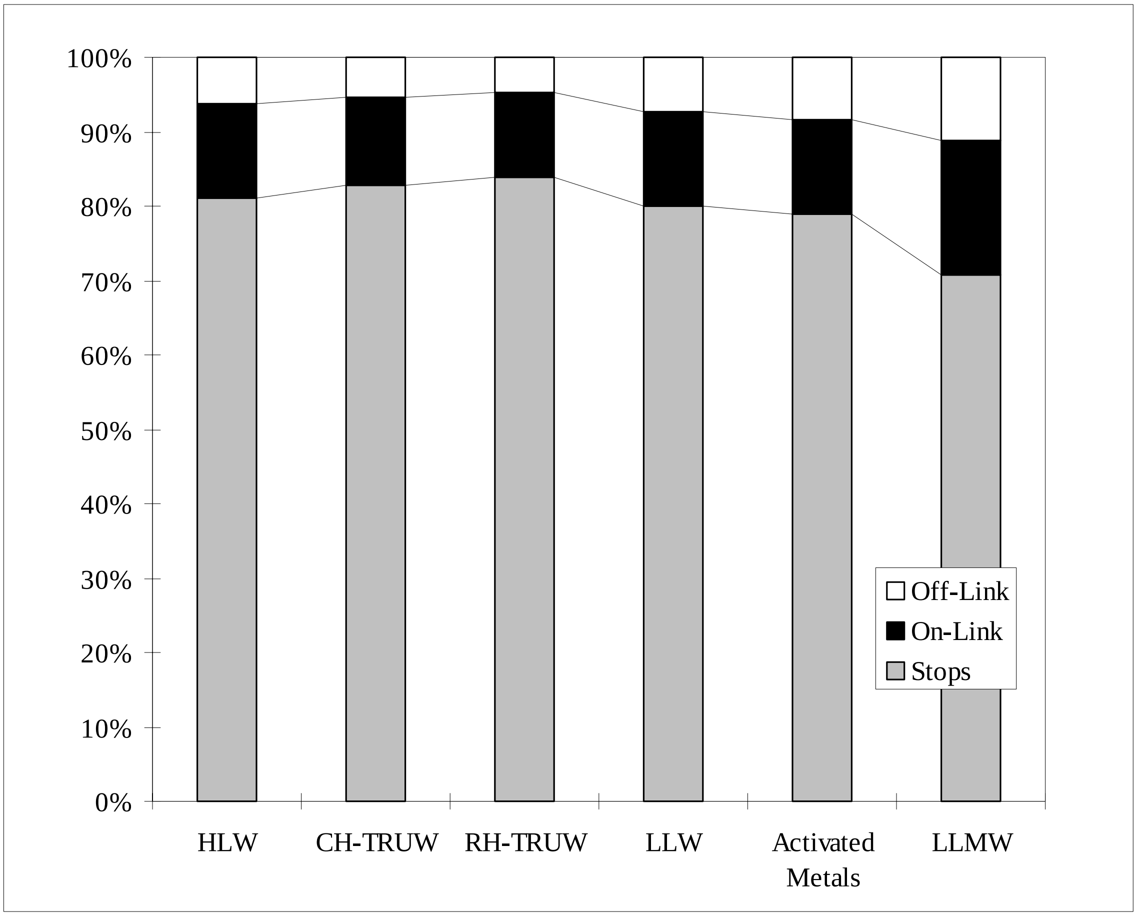

Figure 4.9. Distribution of the Total Incident-Free Dose to Members of the Public, Persons at Stops, and Off-link and On-link Receptors for all Cargo Types, from the Waste Management Programmatic EIS, Truck Transport (DOE, 1997b)

in these zones, as discussed in Section 6.1.3.2. Because the suburban and urban zones have significantly more people than rural zones, the off-link dose is proportionately larger. Likewise, the LLMW assessment used the same package size and dose rate information as the LLW assessment (see Table 4.2 and Section 6.1.1.2), and the LLMW information used in Figures 4.9 and 4.10 was taken from a single alternative with fewer LLMW shipment routes than those used in other alternatives, reflecting more travel through suburban and urban areas than on average.

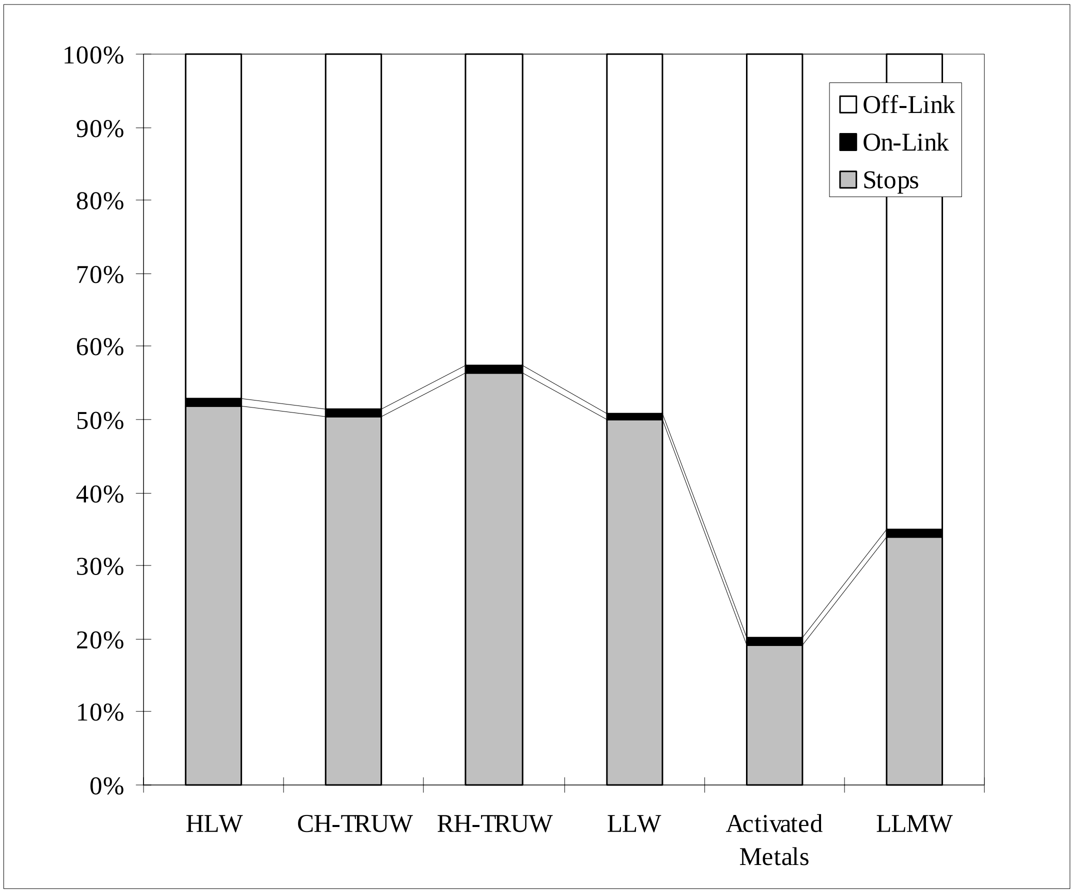

Figure 4.10. Distribution of the Total Incident-Free Dose to Members of the Public, Persons at Stops, and Off-link and On-link Receptors for all Cargo Types, from the Waste Management Programmatic EIS, Rail Transport (DOE, 1997b)

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5. Routing and Risk Assessment Models

A short description of the computer codes used for shipment routing (TRAGIS, HIGHWAY, and INTERLINE) and transportation risk assessment (RADTRAN and RISKIND) are provided in this section. As discussed in Section 4, the combined use of these programs has led to a consistent and comprehensive methodology for conducting DOE transportation risk assessments. Access to RADTRAN, HIGHWAY, and INTERLINE is provided by the TRANSNET system, which is discussed below.

■ 5.1 TRANSNET System

TRANSNET is the electronic gateway system of databases, analysis codes, routing algorithms, and information packages 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 to analyze radioactive material transportation systems. TRANSNET is accessible only through a secure shell. Information about the secure shell may be obtained by contacting one of the contact persons. Upon receipt of a password, a user can access TRANSNET with a personal computer and modem and via the Internet. The TRANSNET system was first announced in 1987 and initially resided on a dedicated minicomputer, but now resides on a UNIX-based workstation. This service is sponsored by the DOE's National Transportation Program, Office of Environmental Management (OEM).

The TRANSNET system provides 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.

■ ■ 5.1.1 Codes and Databases Accessible through TRANSNET

The models and databases listed below are currently available on the TRANSNET system.

RADTRAN: RADTRAN evaluates radiological consequences of incident-free transportation as well as risks from vehicular accidents occurring during transportation. SNL developed the original RADTRAN code in 1977 for the NRC in conjunction with the preparation of NUREG-0170, *Final Environmental Impact Statement on the Transportation of Radioactive Material by Air and Other Modes* (NRC, 1977a). The analytical capabilities of the code were expanded and refined in later versions.

HIGHWAY and INTERLINE: The HIGHWAY and INTERLINE routing models (Johnson et al., 1993a; b) were developed by ORNL to determine transportation routes. The HIGHWAY model is used to develop several different types of highway routes (commercial, quickest, shortest, or preferred routes for highway-route-controlled-quantity shipments). The INTERLINE model is used to calculate rail routes that reflect the routing practices of railroad companies. Both models provide information on population density along routes. As of January 2002, the HIGHWAY and INTERLINE routing models were superseded by a new routing model called the Transportation Routing Analysis Geographic Information System (TRAGIS) (Johnson and Michelhaugh, 2000). TRAGIS is a client-server system operating over the Internet, and is accessed independently of TRANSNET. TRAGIS includes data from the 2000 census and results of TRAGIS analysis are easily incorporated into risk assessment studies. HIGHWAY and INTERLINE will not be updated, but will be maintained as part of TRANSNET to ensure availability for review or analysis of past risk assessments.

RAMPOST: The Radioactive Materials Post-notification (RAMPOST) database is a compilation of the highway-route-controlled-quantity shipments that have been made since 1987. Data include shipment date, carrier, shipper, consignee, and highway route segments. RAMPOST has not been maintained since 1998.

RMIR: The Radioactive Materials Incident Report (RMIR) database contains information on transportation-related accidents and incidents involving radioactive materials from 1971 to 2000. RMIR was updated by SNL with new incidents and additions to the existing records of older incidents. With the advent of a new DOT database (Hazardous Materials Incident Summary Statistics and data) that reports HAZMAT/RAD incidents, the updating and maintenance of RMIR was terminated, effective 2001. However, SNL will retain historical data and respond to inquiries from customers.

TRANSNET also contains a bulletin board available to all TRANSNET users. This bulletin board is used as a public forum for information packages and other transportation systems located on the TRANSNET system.

■ ■ 5.1.2 Points of Contact

The following individuals can be contacted for more information on TRANSNET:

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Sandia National Laboratories
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■ 5.2 Routing Models

Computerized routing models are commonly used for transportation risk assessment to select highway and rail routes between origin and destination sites. These models are used to determine the population characteristics along routes, which are then used as input to risk assessment models such as RADTRAN and RISKIND. 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 transport radioactive material. Future considerations, including road or track work, new route segments, and traffic flows, could result in alternative routes being used.

■ ■ 5.2.1 TRAGIS Routing Model

TRAGIS replaced HIGHWAY and INTERLINE models, which were used to calculate routes but lacked the ability to display graphics of those routes. Additionally, many users had difficulty determining the proper node for facilities and were confused by or misinterpreted the text-based listing from the routing models. TRAGIS improved the ease of selecting locations for routing, provided the capability to graphically display the route calculated, and provided for additional geographic analysis of the route.

TRAGIS is a web-based application. It can be accessed at http://apps.ntp.doe.gov/tragis.htm. New users can link to a registration page from this home page. Another link is provided to the user's manual. TRAGIS requires a user name and password for access.

TRAGIS is designed for routes in the continental United States using the rail, truck, and waterway transportation modes. The rail network used in the initial version of the model is the database used in the INTERLINE model. This database, developed for the Federal Railroad Administration (FRA) in the mid-1970s, is not a fixed-scale database and was extensively modified by ORNL. A 1:100,000-scale rail database is under development and will be included in the TRAGIS model in the near future. The 1:100,000-scale truck database was developed from the U.S. Bureau of Census Topologically Integrated Geographic Encoding and Referencing (TIGER) system. Information for the inland waterway systems is based on the 1:2,000,000-U.S. Geodata. Deep-water routes are depicted in TRAGIS as straight-line segments.

One TRAGIS feature is a consistent user interface in the model between the transportation modes. Functions are similar when running rail, truck, or waterway routes. Some variations will occur, such as prompts requesting the name of the railroad company when sites are selected for rail routing. Overall, when the user learns to use one portion of the TRAGIS system, it will not be difficult to use other portions of the model.

TRAGIS allows the user to select the origin and destination from a series of pick lists. The user selects the state from the first list and the node from the second list. The rail portion of TRAGIS has a third list from which to select a specific railroad company. Users can view the database and determine the name of nodes. In addition to containing nodes for nearly every major city and intersection, the TRAGIS database contains hundreds of specialized nodes for locations of nuclear reactors, DOE sites, military installations, and other important facilities and sites.

After an origin and destination are selected, the model is ready to calculate a route based on criteria established by option settings. A standard set of default criteria is active for each transportation mode in the model. Upon calculating a route, TRAGIS allows the user to display that route. Users can also obtain a text listing and population density information on the route. Population density statistics are used as input for risk assessment models. The population density distribution is calculated for each transportation segment of the route and is usually reported on a state-by-state basis. The population information is based on the 2000 U.S. Census block group data.

Option settings allow various parameters in the model to be changed for route calculations. Examples include adjusting the penalty factors for the mainline classifications for rail routing; using preferred routes, as specified in 49 CFR 397 Subpart D (“Routing of Class 7 [Radioactive] Materials”) for radioactive materials for truck routes; and running alternative routes for different transportation modes in TRAGIS.

TRAGIS also provides functions to temporarily modify the routing networks. The user can select individual nodes and links to be temporarily blocked in the network. Individual states can also be selectively removed from consideration. In the rail network, the user can modify the transfer penalties between different rail systems at interchange locations.

■ ■ 5.2.2 HIGHWAY Routing Model

■ ■ ■ 5.2.2.1 Description

The HIGHWAY model provides a flexible tool to identify highway routes for transporting radioactive materials in the United States. The HIGHWAY database is essentially a computerized road atlas that currently describes over 240,000 miles of highways. Complete descriptions of the interstate highway system and all U.S. highways (except those that parallel a nearby interstate highway) are included in the database. Many of the principal state highways and a number of local and county highways are also identified. The database also includes locations of nuclear facilities and major airports.

Several types of routes may be generated, depending on a set of user-supplied constraints. Routes are generated by minimizing the total impedance between the origin and the destination. Basically, the impedance is defined as a function of distance and driving time along a particular highway segment. Several routing constraints can be imposed during the computations. One special feature of the HIGHWAY model is its ability to generate routes that maximize the use of the interstate highway system. This feature allows the user to generate routes for shipments of radioactive materials that conform to the DOT routing regulations (HM-164). Occasionally, routes are needed that bypass major population areas. All highway segments located within urbanized areas containing more than 100,000 people are identified in the HIGHWAY database. Routes generated using this information will not include roads in these urbanized areas unless no other route is available. Other features of the model include the ability to generate routes that bypass a specific state, city, town, or a highway segment.

The HIGHWAY model has been enhanced to automatically generate alternative routes. Frequently, there are a number of routes between the source and destination that vary slightly in distance and estimated driving time. With the alternative routing feature, the HIGHWAY program offers a selection of different, but nearly equal, routes. The output generated by the HIGHWAY program includes a brief summary showing the origin, destination, departure and arrival times, estimated driving time, and total distance. The mileage driven in each state is also listed, along with the mileage traveled on the various highway types. A more detailed route description is also available, along with geographic information for producing maps of routes.

The HIGHWAY model was used to generate both routes and population density statistics along routes for risk studies performed for DOE. The population density distribution is calculated for each highway segment in the route and is usually reported on a state-by-state basis. The population data utilized for this calculation are based on the 1990 U.S. Census block group data. The HIGHWAY model is currently used for route planning and scheduling of the Safe and Secure Transport fleet by the DOE Albuquerque Operations Office's Security Communications (SECOM) tracking system. Public access to the HIGHWAY model is currently provided via the TRANSNET system.

■ ■ ■ 5.2.2.2 Peer Review, Validation, and Verification

A study by Maheras and Pippen (1995) provided independent verification that the routes generated using HIGHWAY are consistent with similar, commercially-available routing programs.

■ ■ 5.2.3 INTERLINE Rail Routing Model

■ ■ ■ 5.2.3.1 Description

INTERLINE is an interactive program designed to simulate routing practices on the U.S. rail system. Because the rail industry is divided into a large number of independent, competing companies, INTERLINE breaks the U.S. rail network into 94 separate subnetworks. Routing within each subnetwork is conducted independently to replicate the routing practices of an individual company.

The database used by INTERLINE was originally obtained from the FRA and reflected the status of the U.S. railroad system in 1974. Over the past two decades, the database was extensively modified to reflect the line abandonments, corporate mergers, shortline spin-offs, and other developments. An important element of the database is the transfer locations where traffic may move from one subnetwork to another. Because transfers between railroads increase cost and delay, penalties are assigned to these movements to replicate the tendency of traffic to remain on a single railroad's line when possible. The model uses a label-setting algorithm to find minimum impedance paths within the individual subnetworks. A label-correcting routing is then used to find paths among the subnetworks. One benefit of this approach is that computer resource requirements are reduced. This feature allows INTERLINE to run as an interactive program on either a mainframe or personal computer, despite the large size of the network (approximately 16,000 links).

The user may specify a number of parameters to control the routing calculations, although defaults are provided that represent typical practices in the industry. By varying these parameters, the user can find alternative routes or examine the effect of restricting movement through specified areas, such as cities or railroad systems. Another important capability is the estimation of short-line mileage between points. Short-line mileages are distances that disregard the effects of competition among carriers and are the basis of freight rate calculations using class tariffs.

In addition to including a description of the U.S. railroad system, the INTERLINE database also includes a description of navigable inland and intracoastal waterways. Thus, the INTERLINE model is also able to generate likely barge and rail-barge intermodal routes. The output generated by the INTERLINE model includes a summary showing the origin, destination, total distance, and distances along the projected railroad lines, as well as population densities along the route. The general route listing identifies the major cities and all interchange points. A more detailed route description is also available, along with geographic information for producing maps of routes.

The INTERLINE model has been used to generate both rail routes and population density statistics for risk studies performed for DOE. The population density distribution is calculated for each rail segment in the route and is usually reported on a state-by-state basis. The population data utilized for this calculation are based on the 1990 U.S. Census block group data. Public access to the INTERLINE model is provided via the TRANSNET system.

■ ■ 5.2.4 Points of Contact

The individuals listed below can provide further information on the routing models introduced in Section 5.2.

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■ 5.3 Risk Models

■ ■ 5.3.1 RADTRAN

Various versions of the RADTRAN code have been used in historical assessments. The following sections include a detailed description of RADTRAN 5, the version of RADTRAN now in use. RADTRAN 4 was used extensively until recently, and was used in the analyses described in Chapter 4. RADTRAN 5 is primarily an improved version of RADTRAN 4. A brief discussion of the improvements incorporated in RADTRAN 5 is also included.

■ ■ ■ 5.3.1.1 Description

RADTRAN is a FORTRAN 77 computer code designed to analyze the consequences and risks of radioactive material transportation. RADTRAN I was developed by SNL 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* (NRC, 1977a). The model and code were updated and expanded in subsequent versions of the model (Taylor and Daniel, 1982; Madsen et al., 1983, 1986; Neuhauser and Kanipe, 1992; Neuhauser et al., 2000). Public access to the RADTRAN 5 model is provided via the TRANSNET system. RADTRAN 4 may be accessed through TRANSNET, but is no longer maintained. TRANSNET must be accessed via a secure shell.

RADTRAN estimates radiological risks associated with incident-free transportation of radioactive materials and with accidents that might occur during transportation. Incident-free (routine) transportation is defined as transportation during which no incident, accident, packaging or handling abnormality, or other abnormal event occurs. 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. For further descriptions of transportation processes, see Wolff (1984) and Luna et al. (1981).

In RADTRAN, the population affected by incident-free transportation may be divided into population subgroups. The subgroups of transportation workers include crew members (for truck, barge, ship, van, and aircraft), railyard workers, inspectors, and escorts. Other occupational groups include cargo handlers, warehouse personnel, passengers, flight attendants (passenger air mode only), and service station attendants. Members of the public sharing stop areas with the transporting vehicle, residents near stops, occupants of vehicles sharing the transport link with the radioactive cargo, and people along the transport link on which the vehicle is moving constitute additional population groups. The last group (people along the route) is modeled as a uniformly distributed population on both sides of the link with a variable density that may be specified by the user (except for air and ocean modes, which have no surrounding populations while in transit). The user may define population-density zones to account for different population densities. Urban, suburban, and rural zones for the entire route, or for each state along a route, may be designated and all route segments aggregated into these zones.

RADTRAN contains related sets of models to estimate the radiological consequences and risks of radioactive material transportation. The component models use (1) user-supplied input data, (2) parameter values from other RADTRAN calculations, and (3) standard values that may be read into the RADTRAN code. The sets of models are as follows:

- A package model, which includes both the model of the radiation source for incident-free transportation and the isotopic content and properties of the cargo,
- Transportation models, including the route segment and stop models,
- Population distribution models, including the resident population along the route, occupants of vehicles sharing the transportation link, people at stops, and residents near stops,
- Accident-severity and package-behavior models, including conditional severity probabilities and release, aerosol, and respirable fractions,
- Meteorological dispersion model,
- Exposure pathway models for inhalation, ingestion, resuspension, cloudshine, and groundshine exposures,

- Health effects model, and
- Non-radiological fatality model.

The incident-free module calculates values of incident-free population dose using the source terms of the material model and the population distribution and transportation models. These models may be used to calculate doses from accidents involving only immobilization of a vehicle with undamaged cargo or loss of gamma shielding. RADTRAN calculates values of population dose for accidents that result in dispersal by using material, transportation, population-distribution, accident-severity, package-release, meteorological, and exposure pathway models. Calculated doses may be converted to estimated potential stochastic health effects using the health effects model, and traffic fatalities and health effects from vehicle emissions may be calculated using the non-radiological fatality model.

■ ■ ■ 5.3.1.2 Incident-Free Transportation

The probability of incident-free transportation is considered equal to 1.0 even though it is actually equal to 1.0 minus the small probability of an accident. Thus, incident-free transportation doses (consequences) and risk are indistinguishable. The radiological consequences of incident-free transportation are the estimated collective population doses for the various population groups exposed to the package(s) being analyzed. RADTRAN calculates these population doses, which may be used, in turn, to estimate stochastic health effects.

Characteristics of radioactive material that affect incident-free transportation doses are the external vehicle dose rate, the critical dimension of the vehicle, and the fractions of gamma and neutron radiation. The external vehicle dose rate (identified as the transport index (TI) for certain package types) is defined as the highest radiation dose rate, in millirem per hour (mrem/h), from all penetrating radiation at 1 m from a vertical plane perpendicular to the outermost lateral edge of the vehicle. The TI is the external dose rate rounded up to the nearest tenth.

The package dose rate is similarly defined as the highest radiation dose rate, in millirem per hour, from all penetrating radiation at 1 m (3.3 ft) from any accessible external surface of the package. The package dose rate affects doses to handlers, warehouse personnel, and other populations that handle or are exposed to individual packages. No accommodation can be made in RADTRAN for package offset.

To analyze incident-free conditions with RADTRAN, the vehicle dose rate and vehicle critical dimension model a shipment of radioactive material as a modified point source at the center of a sphere whose diameter is the critical vehicle dimension, and, for receptor distances less than two characteristic dimensions from the vehicle, as a line source. Characteristics of the transportation system are then incorporated into mode-specific models, which use a set of input parameters to describe the population around the package and other critical mode-dependent characteristics, such as vehicle velocity, stop duration, and distances from various receptors at stops. Population-density zones and population densities for each route segment must be defined by the user, in addition to the characteristics of the various subpopulations that receive off-link, on-link, passenger, crew, stop, handling, and storage doses. The user-assigned values describing these potentially exposed subgroups may vary by mode and population-density zone. The user is given a wide latitude in adjusting parameters for analysis for a specific problem, but the accuracy of the results may be limited by the quality and quantity of the available data.

■ ■ ■ 5.3.1.3 Accident Risk

To calculate transportation accident risks, the consequences and probabilities of vehicular accidents must be calculated. The radiological consequences of an accident are the potential doses (or health effects) that might occur from (1) dispersion of a specified quantity of radioactive material beyond the immediate accident site and (2) direct exposure of persons to ionizing radiation from a vehicle that is stopped for a period of time or following damage to package shielding. The probability of an accident in which radioactive material is released, the vehicle is immobilized, or shielding is damaged is determined from the frequency of all accidents and from the conditional probabilities of accident occurrence sufficiently severe to damage shielding and/or package integrity. The frequencies of accidents by mode and route segment are usually estimated from historical data on accident rates. The spectrum of accident severity may be divided by the user into as many as 30 accident-severity categories. The user assigns each accident-severity category a conditional probability such that if an accident occurs, it will be of a specified severity. Accident severities and their conditional probabilities do not depend on the nature of the package. Corresponding package-response data (e.g., release fractions by accident-severity category) used to calculate consequences, which are package- and radionuclide inventory-dependent, also must be provided by the user.

The accident module combines user-supplied data on packaging behavior (release fractions, etc.) and accident severity to assess radiological consequences (population doses) for various severities of accidents. Separate calculations may be performed for each accident-severity category in each population-density zone. The consequence value is multiplied by an appropriate probability of occurrence derived from historical accident data to give a risk value; the sum of these individual risk calculations is the total radiological accident risk. To perform consequence calculations for release accidents, dispersal from the release point (hypothetical accident site) to downwind deposition areas is calculated with either Pasquill atmospheric-stability classes A through F or user-defined specifications. Included in the radiological consequence calculations are five exposure-pathways models – inhalation, groundshine, cloudshine, ingestion, and resuspension.

■ ■ ■ 5.3.1.4 Improvements in RADTRAN 5

RADTRAN 5 maintains the general overall objectives and much of the methodology of RADTRAN 4. In addition to greatly improved stop models and better defined roles of package and vehicle models, improvements include more user-definable input parameters, including more segment-specific parameters for a more route-specific analysis; the capability to treat individual stops separately; and the ability to treat individual handlings separately. Additional parameters for crew exposure calculations are now available as well.

Other changes for RADTRAN 5 include a maximum individual accident dose calculation, a new ingestion dose model, and calculation of nonradiological fatalities. The maximum individual accident dose calculation requires air dispersion input data similar to that required for the population accident dose calculations. The new ingestion dose model COMIDA2 (Abbot and

Rood, 1994a; b) is now used in the MACCS2 code (Chanin and Young, 1997). Nonradiological accident fatalities may now be estimated with user-supplied fatality rates.

■ ■ ■ 5.3.1.5 Peer Review, Validation, and Verification

Two independent reviews of the RADTRAN code have been performed. The first release of the RADTRAN code was reviewed in NUREG-0170, Vol. 2 (NRC, 1977a). NUREG-0170, Vol. 2, contains the responses received and corresponding changes made after a public review of the draft version (NUREG-0034), for which the first release of RADTRAN was developed (NRC, 1977a).

The Safety and Reliability Division of the United Kingdom Atomic Energy Authority reviewed the RADTRAN 4 code as part of the effort to adapt the code for international release by the International Atomic Energy Agency (IAEA) as INTERTRAN 2 (Hancox and Wilkinson, 1993). The reviewers concluded that RADTRAN 4 produced "reasonable estimates of radiation doses," but found the route-related defaults unsuitable for use in the United Kingdom and potentially in other countries outside the United States; they also recommended allowing the user to suppress the regulatory constraints (Hancox and Wilkinson, 1993).

Validating a code such as RADTRAN 4 ensures that each model embodied in the code acceptably represents the process it is intended to replicate. The validity of the RADTRAN calculations depends on the quality and accuracy of current understanding about radiological health, economic effects, and the accuracy and completeness of shipment data provided by the user. When improved information becomes available (e.g., concerning the early and latent health effects from radiation), the RADTRAN equations are modified accordingly, and calculations are updated without altering basic operations of the code. RADTRAN 4 used a health-effects model based on the "Calculation of Reactor Accident Consequences" (NRC, 1975). This model was supplanted in recent years; RADTRAN 5 uses the health model published by the National Research Council's Committee on the Biological Effects of Radiation (National Research Council, 1990).

Empirical studies, such as the *Environmental Survey of Transportation of Radioactive Materials to and from Nuclear Power Plants* (AEC, 1972), and *Radiation Dose to Population (Crew and Passengers) Resulting from the Transportation of Radioactive Material by Passenger Aircraft in the United States* (Barker et al., 1974), have contributed to the data RADTRAN uses to calculate doses.

Verification consists of demonstrating that calculations are performed correctly by the code. All calculations performed in RADTRAN 4 were verified by performing at least one hand calculation and comparing the results to those generated by the code (allowing for round-off conventions). The results of these hand calculations are archived, along with other quality records, at SNL. An independent verification of most RADTRAN 4 calculations was also performed by Maheras and Pippen (1995).

■ ■ ■ 5.3.1.6 Points of Contact

The RADTRAN computer code was developed and maintained by SNL, Risk Assessment and Transportation System Analysis Division, Albuquerque, New Mexico. Technical Manual and

User's Manual of RADTRAN 5 are also available to users. Inquiries and comments concerning the RADTRAN 4 and 5 codes may be addressed to the following persons.

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■ ■ 5.3.2 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. The current version, INTERTRAN2, is based on RADTRAN 4, and is available from the IAEA in Vienna to member countries (Ericsson and Elert, 1982). An independent peer review of INTERTRAN2 was completed by SNL in 1999 under a contract with the DOE.

INTERTRAN2 is a personal computer-based analysis tool for the assessment of the radiological consequences and risks associated with the transport of radioactive materials for shipment conditions typically encountered in land, air, and sea transport. The INTERTRAN2 package comprises a series of calculational models embodied in the code to calculate the radiological consequences and risks by combining user-supplied data with radiological information provided by the code system. INTERTRAN2 analyses are performed like RADTRAN4 analyses, except that some country-specific parameters may be controlled by the user.

The transport conditions provided for by INTERTRAN2 include both incident-free transportation and the occurrence of abnormal transport conditions, including incidents and accidents that may or may not result in radionuclide releases and the subsequent (if any) dispersal in the environment.

The INTERTRAN2 system allows the user to adjust the analysis to the specific problem being analyzed including modeling of multimodal shipments. It covers the broad range of radionuclides used in medicine, science, and technology, as well as nuclear materials and radioactive waste.

The INTERTRAN2 computer code system also provides an advanced atmospheric dispersion code, TRANSAT, which may be used by experienced users dealing with complicated weather situations.

The transport incident centerline dose calculation program Transport Incident Center Line Dose and the LHS module, a LHS sampling program, are not included in the standard version of the INTERTRAN2 package but may be downloaded separately or provided upon request.

The INTERTRAN2 code is written in Visual Objects, a 32-bit object-oriented language for Windows 95/98/2000 and NT. The INTERTRAN2 input assembles and manages input databases, constructs input files for INTERTRAN2-RT4, and executes INTERTRAN2-RT4 cases.

The INTERTRAN2-RT4 program is based on the RADTRAN4.019IOSI program, an SI-unit version of RADTRAN 4. INTERTRAN2-RT4 is a modified version of RADTRAN4.019IOS and was compiled for PC use.

All supporting documentation, including the User Guides for all related computer codes, are also available to download from the contact persons listed below.

There are some limitations in INTERTRAN2 that the user should know. The RADTRAN 4 computer code, which is the basis of the INTERTRAN2-RT4, is not intended for on-site transport risk analysis. Also, chemical hazards, such as those from uraniumhexafluoride, are not included in the risk assessment model. The health effect model INTERTRAN2 is out of date. This will be updated in due time.

INTERTRAN (RADTRAN II) calculations were compared to actual measurements for certain handlers and vehicle crew members in Italy (Permattei et al., 1985; DeMarco et al., 1983), and INTERTRAN was found to overestimate incident-free doses. The Italian findings do not constitute empirical validation, but do indicate that INTERTRAN is conservative, as expected.

■ ■ ■ 5.3.2.1 Points of Contact

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■ ■ 5.3.3 RISKIND

■ ■ ■ 5.3.3.1 Background

The RISKIND computer program aids in the analysis of radiological consequences and health risks to individuals and the collective population from exposures associated with the transportation of SNF or other radioactive materials. It provides scenario-specific analyses when evaluating alternatives for major federal actions involving radioactive material transport, as required by NEPA.

In 1977, the NRC issued a report on the transportation of radioactive materials, *Final Environmental Statement on the Transportation of Radioactive Material by Air and Other Modes* (NRC, 1977a). That report laid the groundwork for the development of the RADTRAN computer program and its successors, currently RADTRAN 5 (Neuhauser et al., 2000), to estimate the collective population risk from transporting radioactive materials under incident-free or accident conditions. However, assessing risks to individuals, in addition to the collective population, is generally needed in NEPA reviews when evaluating major federal actions involving transportation that could adversely impact the environment. Traditionally, the collective population analysis was supplemented by other models so that consequences to individuals or population subgroups could also be estimated. These models are documented in DOE EA reports (see Table 4.1). Different models were often used in the earlier reports, leading to inconsistencies and, frequently, the inappropriate use of models designed for other purposes. Incident-free impacts to individuals from routine transport were sometimes not included or were estimated from hand calculations.

Because of public comments and the need for a more complete and consistent methodology for assessing transportation risks to individuals, DOE's Office of Civilian Radioactive Waste Management funded the development of RISKIND at Argonne National Laboratory. The program picks up where the collective population risk assessment ends by analyzing incident-free and accident risks to individuals, thereby providing a comprehensive methodology for radiological transportation risk assessment and fulfilling obligations under NEPA.

■ ■ ■ 5.3.3.2 Scope

RISKIND provides 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 certain receptors:

- An individual stuck in traffic next to a radioactive materials shipment;
- An individual working near a heavily traveled transport route;
- An individual living near a heavily traveled transport route, such as a shipment origin or destination site entrance;
- An individual near a rail grade-crossing where accident rates are higher;
- Individuals in an area near a postulated SNF transportation accident location;
- An individual eating locally-grown food following an SNF transportation accident; and
- An individual drinking water that was contaminated by an accidental release of radioactive material near a drinking water supply.

The radiological consequences and health risks from these "what if" type of situations are of great interest and concern to the public. Analysis tailored to a specific situation is needed. In addition, substantial databases and technologies relevant to the transportation of SNF and other radioactive materials are available through the efforts of various research organizations. RISKIND was developed to meet the information needs of the local community and incorporates the available databases and technologies. The RISKIND code was implemented to meet four objectives:

1. Calculate site- and route-specific radiological consequences and health risks to exposed individuals and the collective local population,
2. Model the different exposure pathways for specific exposure scenarios,
3. Estimate the amount of radioactive material released in potential accident scenarios, and
4. Estimate cask accident responses specific to the transportation of SNF.

To accomplish the first objective, RISKIND calculates radiological impacts at specific receptor locations for a variety of exposure scenarios. Comprehensive mathematical models capable of handling site-specific information at the time of exposure are used; such information includes specific receptor locations, exposure conditions (including individual air and food intake rates), and meteorological conditions. The model used to assess the potential acute health effects from short-term exposures is based on a model developed by Harvard University and the NRC (Evans, 1990) and the revised model of Abrahamson et al. (1989; 1991). The dose-to-risk conversion factors to estimate latent health effects are taken from ICRP Publication 60 (ICRP, 1991).

RISKIND meets the second objective by considering all environmental pathways, including short-term exposure from the initial passing radioactive cloud, accidental exposure from loss of the cask shield, and long-term exposure from ground deposition and ingestion from the foodchain pathways. Pathway analysis can be tailored to model impacts in a wide range of locations, from large metropolitan areas to rural agricultural areas.

To meet the third objective, a radionuclide source inventory was compiled from the database developed at ORNL in which the data are specific to the type of spent fuel (pressurized water reactor [PWR] or boiling water reactor [BWR]), cooling times, and burnup rates (Notz et al., 1987; DOE, 1992). User-supplied inventories are also permitted for different types of SNF and other radioactive materials.

To meet the fourth objective, the cask accident responses and the radionuclide release fractions modeled by LLNL in a report for the NRC (Fischer et al., 1987) were incorporated into RISKIND as default values. This LLNL/NRC report is commonly referred to as the “NRC Modal Study.” Other cask responses and release fractions supplied by the user may be used in place of the default values.

■ ■ ■ 5.3.3.3 Incident-Free Transportation

Exposure during incident-free transportation results solely from the external doses received by individuals from the neutron and gamma radiation emitted from the SNF cask or other radioactive material shipping package. Incident-free exposures include those when the transport vehicle is in transit or at a stop. The receptors for the in-transit exposure may include residents adjacent to a highway and the occupants of vehicles sharing the traffic link with the transport vehicle. Exposed individuals at a stop may include the vehicle inspector, a gas station attendant, a nearby person in a traffic jam, and others.

The model used by RISKIND to predict external exposure is based on dose rates derived specifically for a spent fuel cask and takes into account the ground/air scattering of the emitted gamma or neutron radiation (Chen and Yuan, 1988). The model also allows adjusting the dose rate for changes in cask size (i.e., outer radius and length) and provides a realistic, though still somewhat conservative, estimate of the external doses to a receptor.

■ ■ ■ 5.3.3.4 Accident Conditions

Individual exposure can occur through many environmental pathways if an accident releases the radioactive contents of the cask to the environment. In RISKIND, the estimated exposure, as well as the resulting health effects, are presented individually and for each potential pathway.

Various scenarios were characterized in RISKIND according to an array of SNF cask responses, as described in the NRC's Modal Study (Fischer et al., 1987). In that study, all accidents are represented by discrete response regions (severity categories). These response regions range from likely events (with minor consequences) to highly unlikely events (with severe consequences). Twenty response regions are characterized according to two major accident parameters: impact force and thermal force (i.e., heat from a fire). Thus, accident conditions would be affected by vehicle speed, object hardness, impact angle and orientation, and fire duration and location. In the Modal Study, the bounding case release fractions were also estimated for each response region. All potential accident scenarios are thus fully represented by the 20 response regions.

To support a consistent estimate of a release, the SNF radionuclide source inventory is derived from a database developed by ORNL (Notz et al., 1987; DOE, 1992). In addition, potential release from "crud" (a mixture of reactor coolant corrosion products) spalling off the fuel rods is also incorporated. The estimate of crud release is based on a study by SNL (Sandoval et al., 1991).

The atmospheric transport module in RISKIND includes models that simulate dispersion phenomena following a short-duration release. RISKIND's transport model estimates levels of air and ground contamination based on specific meteorological conditions, geometry, and release elevation. Plume rise from the thermal buoyancy of a release involving fire and dispersion effects near the release are also considered. The uncertain effect of weather conditions on the calculated doses can be considered by constructing a cumulative probability distribution of dose values using wind-rose data for a given site. This probabilistic dose distribution then determines the median (50% weather probability) and reasonable maximum (95% weather probability) dose values at a given receptor location.

The pathway model includes exposure pathways from the cask's direct external radiation (due to loss of shielding), external exposure from the radioactive cloud and ground contamination, and internal exposure from inhalation of radionuclides in the air and ingestion of contaminated foods and water.

Health effects to individuals are estimated in terms of expected acute or latent fatalities, latent nonfatal cancer incidence, and latent adverse genetic effects from short-term exposure during initial plume passage and long-term exposure from deposited radioactive material. Acute fatalities are estimated with the latest NRC health effects model (Evans, 1990). The latent health effects are estimated by applying dose-to-risk conversion factors suggested in ICRP Publication 60 (ICRP, 1991).

The consequence model of RISKIND allows incorporating the consequence reduction benefits of indoor shielding, evacuation, interdiction of contaminated foods, and other protective actions (such as cleanup of contamination) to comply with EPA PAG levels (EPA, 1992). Consequences can be presented either deterministically (i.e., with fixed accident parameters and weather conditions) or probabilistically (i.e., analyzed over the spectrum of accident response regions and weather conditions).

■ ■ ■ 5.3.3.5 Peer Review, Validation, and Verification

RISKIND underwent two independent peer reviews. Members of the review panels were from government contractors, other national laboratories, state agencies, the NRC, and the Naval Reactor Program. The first review was conducted before the release of the original program (Yuan et al., 1993), and the second review was conducted before the release of the current version (v. 1.11) of the RISKIND program (Yuan et al., 1995).

The models employed in RISKIND are well established (i.e., validated) and are referenced in the RISKIND manual (Yuan et al., 1995). Further validation was also conducted in benchmark tests of the more important code models (Biwer et al., 1997). As new information becomes available, these models will be revised as appropriate in future versions of the program.

The development of RISKIND is controlled by a quality assurance (QA) program at Argonne National Laboratory. Computations in the code are verified against separate spreadsheet calculations kept in a project file. Independent verification of the calculations in the original release of the code was documented by Maheras and Pippen (1995). The major portions of the code's latest release (RISKIND v.1.11) were verified by Biwer et al. (1997).

■ ■ ■ 5.3.3.6 Points of Contact

The individuals listed below may provide further information on the RISKIND program discussed in this section:

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6. Compilation of Assessment Input Data and Parameters

A variety of input data are required to perform a transportation risk assessment with the risk models discussed in Section 5 according to the methodology given in Section 4.1. Section 6 provides a compendium of such data, with references for the most important parameters required by transportation risk assessment computer programs. The references cited should be consulted for more in-depth information when appropriate.

■ 6.1 Radiological Risks

■ ■ 6.1.1 Package-Related

The package size, external dose rate, and distance to crew are the most sensitive and important parameters when estimating the incident-free transportation doses. As package size increases, the near-field dose increases for a given package dose rate; likewise, the larger the dose rate, the larger the population dose for a given package size. In accident conditions, the amount of radioactive material released from a transportation accident depends on the packaging of the material. The calculated accident risks are directly proportional to the amount released, except in the case of direct external exposure to a damaged shipping package (loss of shielding).

■ ■ ■ 6.1.1.1 Packaging

The primary regulatory approach used to ensure safety in the transport of radioactive materials is specifying standards for the proper packaging. Many organizations at the federal, state, and local levels are involved in regulating the packaging and transportation of radioactive materials. As discussed in Section 2.4, primary regulatory authority is provided by the DOT under 49 CFR Part 173 (“Shippers - General Requirements for Shipments and Packaging”). For radioactive materials, additional regulations set by the NRC are provided in 10 CFR Part 71 (“Packaging and Transportation of Radioactive Material”). All DOE shipments are made in accordance with these regulations.

Packaging for radioactive materials transport must be designed, constructed, and maintained to ensure that it will contain and shield the contents during normal transportation. For very radioactive material, the packaging must contain and shield the contents in severe accidents, as well. The type of packaging is determined by the radioactive hazard associated with the packaged material. The basic types of packaging required by the applicable regulations are designated as Type A, Type B, or industrial (generally for low-specific-activity material). Some details about the characteristics and dimensions of Type A and Type B containers are provided in Table 6.1.

Table 6.1. Dimensions and Characteristics of Common Radioactive Material Packagings

Packaging	Empty Weight (kg)	Max. Gross Wt. (kg)	Capacity	Length[a] (cm)	Width/ Diameter[a] (cm)	Depth[a] (cm)
Type A						
Metal Drums						
5-gallon	3		18.9 L	34.3 (31.8)	31.1 (28.6)	
10-gallon	5.1		37.8 L	43.8 (40.0)	38.1 (35.6)	
30-gallon	15.2		114 L	74.9 (71.1)	50.8 (45.7)	
35-gallon	17.7		132 L	88.3 (85.1)	52.1 (45.7)	
55-gallon	31.75		208 L	88.9 (84.5)	61.0 (57.2)	
85-gallon	35		322 L	99.1 (96.2)	70.1 (66.6)	
Standard Waste Box (SWB)[b]	295	1,814	1.84 m^3	180 (174)	138 (132)	94 (93.2)
Type B						
TRUW						
TRUPACT-II[c]	5,436	8,732	14 55-gal drums or 2 SWB	310 (191)	239 (185)	
RH-72B[d]			3 55-gal drums	360 (310)	110 (67)	
SNF Casks			(assemblies)			
NLI-1/2 (truck)		22,340	1 PWR or 2 BWR	496 (452)	120 (34)	
TN-8L[e] (truck)	36,000	38,200	3 PWR	569 (428)	172 (23)	(23)
TN-9[f] (truck)	36,000	38,110	7 BWR	576 (452)	172 (15)	(15)
NAC-LWT (light-weight truck)	21,772	23,224	1 PWR or 2 BWR or 42 MTR	508 (460)	112 (34)	
BMI-1 (truck)	9,915	10,732	Research/ test reactor	186 (137)	85 (39)	
Model-2000 (truck)	12,746	15,218	HFIR or research reactor waste	334 (137)	183 (67)	
IF-300 (rail)	53,979	63,504	7 PWR or 17-18 BWR	533 (458)	163 (95)	
NAC-STC (rail)	95,413	113,400	26 PWR	490 (419)	221 (180)	

[a] Exterior dimension and (in parentheses) interior dimensions.
[b] Designed so that 2 SWBs can be inserted in the TRUPACT II shipping cask.
[c] For transport of CH TRUW. Source: NUREG-0383 (NRC 1997).
[d] For transport of RH TRUW. Source: NUREG-0383 (NRC 1997).
[e] Overweight truck cask; has three cubical interior cavities, each with the dimensions listed above.
[f] Overweight truck cask; has seven cubical interior cavities, each with the dimensions listed above.

Type A packaging, meeting the requirements of DOT Specification 7A (DOT-7A), as detailed in 49 CFR 178.350 ("Specification 7A; General Packaging, Type A"), must withstand normal transportation conditions without the loss or dispersal of its radioactive contents. "Normal" transportation refers to all transportation conditions except those resulting from accidents or sabotage. Approval of Type A packaging is achieved by demonstrating that the packaging can withstand specified testing conditions intended to simulate normal transportation. Type A packaging, typically consisting of a 0.21-m^3 (55-gal) drum or SWB, is commonly used to transport wastes with low radioactivity levels. Type A packaging is routinely used in waste management for storage, transportation, and disposal. Type A packaging does not usually require special handling, packaging, or transportation equipment. A comprehensive listing of approximately 300 packagings that meet DOT-7A specifications can be found in *Test and Evaluation Document for DOT Specification 7A Type A Packaging* (DOE, 1997c). Table 6.1 lists the dimensions of some commonly used Type A packagings. Not listed are specialty packagings and metal, wooden, and fiberboard boxes available in a wide variety of sizes (WHC, 1996; DOE, 1997c).

Industrial packaging may be used to transport certain LSA materials. Shipments of industrial packagings are excepted from certain packaging specifications and marking and labeling requirements, but still must comply with many administrative controls. Functionally, most industrial packagings are equivalent to Type A packaging because the contents must not leak under normal transport conditions.

In addition to meeting the standards for Type A packaging, Type B packaging must also provide a high degree of assurance that package integrity will be maintained even during severe accidents with essentially no loss of the radioactive contents or serious impairment of the shielding capability. Type B packaging is required for shipping large quantities of radioactive material and must satisfy stringent testing criteria (specified in 10 CFR 71). The testing criteria were developed to simulate conditions of severe hypothetical accidents, including impact, puncture, fire, and immersion in water. The most widely recognized Type B packagings are the massive casks used to transport highly radioactive SNF from nuclear power stations. Large-capacity cranes and mechanical lifting equipment are usually needed to handle Type B packagings. Many Type B packagings are transported on trailers specifically designed for the package. Table 6.1 includes the dimensions of some Type B packagings.

■ ■ ■ 6.1.1.2 External Dose Rates

The radiological risk associated with routine incident-free transportation results from the potential exposure of people to low levels of external radiation in the vicinity of a loaded shipment. External radiation from a shipping package must be below specified limits that minimize exposure of the handling personnel and the public. Most radioactive material shipments are handled only in accordance with directions from the shipper and the receiver, in an "exclusive-use" shipment. The shipper and carrier must ensure that any loading or unloading is conducted by properly trained personnel with the appropriate equipment. For this type of shipment (regardless of the material or package), the dose rate for external radiation during normal transportation must be maintained below the following limits (10 CFR 71.47 ["External Radiation Standards for All Packages"], and 49 CFR 173.441 ["Radiation Level Limitations"]):

- A dose of 10 mrem/h at any point 2 m (6.6 ft) from the vertical planes projected by the outer lateral surfaces of the car or vehicle, and

- A dose of 2 mrem/h in any normally occupied position in the car or vehicle. This limitation does not apply to private carriers if the exposed personnel are properly monitored as part of a radiation protection program.

Additional restrictions apply to radiation levels on the package surface; however, these restrictions do not affect the transportation-related radiological risk assessment.

The dose rate (mrem/h) at a distance of 1 m (3.3 ft) from the lateral side of the transport vehicle and the fractions of gamma and neutron radiation are input to the RADTRAN and RISKIND codes. Suggested dose rates when shipping different radioactive waste types are discussed below and listed in Table 6.2 for situations when the specific waste characteristics are not known. A significant neutron radiation component is expected only in the case of HLW or SNF shipments.

Table 6.2. Default External Dose Rates for Shipments of Different Radioactive Waste Types

Waste Type	Truck (mrem/h)	Rail[a] (mrem/h)	Fraction Gamma/ Neutron
LLW[b]	1 at 1 m	1 at 1 m	1/0
LLMW[c]	1 at 1 m	1 at 1m	1/0
TRUW[d]			
CH	4 at 1 m	5.1 at 1 m	1/0
RH	10 at 1 m	20 at 1 m	1/0
HLW	10 at 2 m[e]	10 at 2 m[e]	0.65/0.35[f]
SNF	10 at 2 m[e]	10 at 2 m[e]	0.6/0.4[g]

[a] Rail shipments are assumed to consist of a single railcar.
[b] Average value of historical DOE LLW shipments (Morris, 1993).
[c] Based on comparisons of LLMW and LLW radiological characteristics (DOE, 1997b).
[d] CH-TRUW shipments are assumed to have three and six TRUPACT-II containers per truck and rail shipment, respectively. RH-TRUW shipments are assumed to have 1 and 2 RH-72B containers per truck and rail shipment, respectively. Truck dose rate values were taken from DOE (1997a). Rail values were derived using the truck data and geometric considerations.
[e] Taken at the regulatory limit (10 CFR 71.47).
[f] Estimated for Defense Waste Processing Facility vitrified HLW in a proposed cask design (DOE, 1995c).
[g] RISKIND default (Yuan et al., 1995).

Low-Level Waste

For LLW shipments, the external dose rates from historical waste shipments (Morris, 1993) were examined for 10 years starting in fiscal year 1983 by using the Shipment Mobility Accountability Collection (SMAC) database system (Best et al., 1995). The SMAC database contains information about unclassified commercial freight shipments made by DOE and its contractors that was collected from site shipping and receiving documents. Available information for shipments of radioactive materials includes the types of material shipped, the number of packages in each shipment, shipment weights, external dose rates, and package isotopic inventories. An estimated two-thirds of all DOE unclassified shipments have been reported to the SMAC database. Of the 15,000 LLW shipments recorded in the 10-year sample, approximately 2,500 reported external dose rates, with the average dose rate approximately 1 mrem/h at 1 m (3.3 ft) from the surface of a shipment. As a result, an average dose rate of 1 mrem/h measured at 1 m (3.3 ft) from the surface of a shipment is recommended as a default value. However, shipment-specific dose rate data should be used if available.

Low-Level Mixed Waste

Because only limited data exist for historical LLMW shipments and because the radiological characteristics of LLMW are assumed to be similar to LLW, the external dose rate for LLMW shipments is assumed comparable to that for LLW shipments. As with LLW shipments, an average dose rate of 1 mrem/h measured at 1 m (3.3 ft) from the surface of a shipment is recommended unless shipment-specific dose data are available.

Transuranic Waste

External dose rates can be derived from information in the Final Supplemental Environmental Impact Statement (FSEIS) for WIPP (DOE, 1990), which presents site-specific external package dose rates for CH-TRUW and RH-TRUW packages. The average external package dose rates at 1 m (3.3 ft) were calculated to be 3 mrem/h and 7 mrem/h, respectively. Shipment-specific dose data can be used to scale the dose rates for the shipments of interest. These values should be

conservative for most calculations, except possibly at Hanford. The WIPP Disposal Phase SEIS (DOE, 1997d), which supersedes the FSEIS, used bounding values of 4 mrem/h and 10 mrem/h for CH-TRUW and RH-TRUW packages, respectively, to cover unexpected but possible shipment types at Hanford that exceeded the 3 mrem/h and 7 mrem/h values. The latter WIPP document also estimated site-specific package dose rates for CH- and RH-TRUW at those DOE sites with TRUW.

High-Level Waste

The historical external dose rate data available for HLW shipments are not extensive. The external dose rate is usually assumed to be the regulatory limit of 10 mrem/h at 2 m (6.6 ft) from the edge of the transport vehicle (DOE, 1997b). Since in practice, the dose rates may range well below the regulatory limit, this assumption provides a conservative estimate. A gamma/neutron radiation ratio of 0.65/0.35 was estimated for vitrified HLW produced at the Defense Waste Processing Facility at SRS (DOE, 1995c). Shipment-specific dose data should be used if available.

Spent Nuclear Fuel

Because of their large radionuclide inventories, shipments of SNF can have dose rates near the regulatory limit. Therefore, use of the regulatory limit is suggested. However, the gamma dose rates from many past naval SNF shipments have averaged close to 1 mrem/h at 1 m (3.3 ft) (DOE, 1995b; U.S. Department of the Navy, 1996) with a comparable neutron dose rate of approximately 1 mrem/h at 1 m (3.3 ft) (U.S. Department of the Navy, 1996), for a combined total of 2 mrem/h at 1 m (3.3 ft), well below the regulatory limit. A gamma/neutron radiation ratio of 0.6/0.4 was selected as the default in RISKIND after reviewing commercial shipment estimates for PWR and BWR SNF (Yuan et al., 1995). A gamma/neutron radiation rate of 0.5/0.5 is also frequently used for SNF (DOE, 2002).

■ ■ 6.1.2 Crew Parameters

■ ■ ■ 6.1.2.1 Truck

A truck crew typically consists of one or two drivers. Many LLW shipments have one driver (Madsen and Wilmot, 1982), while SNF shipments often have two (Hostick et al., 1992). Some shipments, such as SNF, might also require escorts in certain areas. The value suggested in RADTRAN 5 for truck crew is two. Values for several parameters are suggested in the RADTRAN 5 template files for SNF transportation. RADTRAN 5 also gives the option of using a STANDARD array of pre-assigned values for additional parameters (Neuhauser and Kanipe, 2000, pp 3-6 to 3-21). The user may substitute values for both suggested and standard values.

Dose to the crew depends primarily on distance from the cargo, except when the truck cab is shielded to maintain the crew dose below the regulated occupational limit. For smaller packagings shipped in a regular tractor-trailer combination, the distance between the crew and the package could be shorter than for a SNF cask transported on its own specially-designed trailer. The value suggested in RADTRAN is 3.1 m (10.2 ft). Table 6.3 lists the approximate distances for different shipment configurations. If the dose rate in the crew cabin is known, an effective distance can be input in conjunction with the proper dose rate to match the recorded value.

Table 6.3. Approximate Distances of Truck Crew to the Shipment Package

Shipment Configuration	Distance to Package (m)
RADTRAN suggested value[a]	3.10
Small packages in regular trailer[b]	2
CH-TRU	4.6
GA-9 SNF cask	5.8

[a] Source: Neuhauser and Kanipe (2000).
[b] Approximate distance from truck cab to leading edge of trailer (Winkler et al., 1995).

■ ■ ■ 6.1.2.2 Rail

RADTRAN does not estimate a crew dose for rail shipments because of the shielding provided by locomotives and other railcars and the longer distances between the crew and the radiation source. Instead, a crew dose is estimated for railyard workers inspecting and classifying railcars in railyards. Section 6.1.8 discusses the input for the rail crew dose estimated at these stops. Suggestions for rail inspector and railyard worker potential exposure scenarios are provided in Section 4.1.1.2 for MEI calculations using RISKIND.

■ ■ 6.1.3 Population Densities and Fractions of Travel

Estimated transport risks for both incident-free and accident transport are highly dependent on population density (the average number of people per unit area). Because population density can vary greatly over the length of a transport route, the *Final Environmental Impact Statement on the Transportation of Radioactive Material by Air and Other Modes* (NUREG-0170, NRC, 1977a) divided the population density into three zones, corresponding approximately to rural, suburban, and urban areas. Although these categorizations are not needed for RADTRAN 5 calculations, they were retained for convenience. RADTRAN 5 allows complete characterization of any route segment, and segments may be designated rural, suburban, or urban by the user. Only rural segments can have an associated fraction of land under cultivation.

Routing codes such as HIGHWAY, INTERLINE, and TRAGIS provide route-specific information on population density and fractions of travel in rural, suburban, and urban zones for transportation risk assessments. However, national average generic input data for these parameters may be required for assessments where the origin and destination sites have not yet been decided (e.g., see DOE, 1999b). Also, average population values should be used with RISKIND when conducting the accident consequence portion of the assessment because the actual location of a potential transportation accident would be unknown.

■ ■ ■ 6.1.3.1 Population Densities

National average population densities for each zone (rural, suburban, and urban) were suggested in NUREG-0170 (NRC, 1977a) based on 1970 census data for estimating the radioactive risks of a route when route-specific population densities were not available. These values are presented in Table 6.4 in the same format as Appendix E of NUREG-0170. The population zone descriptions are given below. The corresponding numbers based on 1990 census data were added for comparison. Table 6.5 provides a further breakdown of the 1990 census data.

The U.S. Bureau of the Census definition of an urbanized area has not changed significantly since NUREG-0170 was published in 1977. An urbanized area is one that has a minimum of 50,000 persons and comprises one or more central places and the adjacent densely settled area (the urban fringe) which has a density of at least 1,000 persons/mi^2 (386 persons/km^2). Urban areas are defined as comprising all territory, population, and housing units in urbanized areas and in places of 2,500 or more persons outside urbanized areas. Rural areas by default are those areas not classified as urban.

NUREG-0170 suggested using the rural density value provided by the Bureau of the Census (Department of Commerce [DOC], 1974) (6 persons/km^2). For the urban population zone, NUREG-0170 used a value of 3,861 persons/km^2 (10,000 persons/mi^2) to represent an urban housing area. This value is close to the 3,830 persons/km^2 that can be estimated for the central city in an urbanized area from 1970 census data (DOC, 1975). The value of 3,861 persons/km^2 forced NUREG-0170 to assume a population density of 719 persons/km^2 for the urban fringe in order to be consistent with the total urbanized population and land area. This value of 719 persons/km^2 was taken to be the suburban population zone density.

Table 6.4. Demographic Data for the United States

Population Zone	Fraction of Land Area		Fraction of Population		Population Density (persons/km^2)	
	NUREG-0170[a]	1990 Census[b]	NUREG-0170[a]	1990 Census[b,c]	NUREG-0170[a,c]	1990 Census [b]
A. Urbanized Area	0.0098	0.017	0.583	0.636	1,303	1,002
1. Central City/Place	0.0018	0.0067	0.315	0.317	3,861 (3,830)	1,282
2. Urban Fringe	0.008	0.011	0.268	0.319	719 (735)	823
B. Other Urban Areas	0.0053	0.0075	0.152	0.116	719 (627)	422
C. Rural Areas	0.985	0.975	0.265	0.248	6	7
Model Used						
Urban (A.1)	0.0018	0.0067	0.315	0.317	3,861 (3,830)	1,282
Suburban (A.2+B)	0.013	0.019	0.420	0.435	719 (692)	766
Rural (C)	0.985	0.975	0.265	0.248	6	7

[a] Source: NRC (1977a).
[b] Source: DOC (1993).
[c] Values in parentheses are the actual population densities determined by the Census Bureau for the given population zone. As discussed in the text, NUREG-0170 used values close to these results.

Table 6.5. U.S. Population Density Data from the 1990 Census[a]

Category	Population	Percent Population	Area (km^2)	Percent Area	Population Density (per km^2)
Total	248,709,873		9,158,960		27.2
Urban	187,053,487	75.2	226,304	2.471	826.6
Inside urbanized area	158,258,878	63.6	158,028	1.725	1001.5
Central Place	78,847,406	31.7	61,504	0.672	1282.0
Place of:					
1,000,000 or more	19,952,631	8.0	6,330	0.069	3152.3
500,000 to 999,999	10,107,184	4.1	6,891	0.075	1466.8
250,000 to 499,999	14,585,006	5.9	12,138	0.133	1201.6
100,000 to 249,999	14,602,452	5.9	13,370	0.146	1092.2
50,000 to 99,999	12,274,504	4.9	13,375	0.146	917.7
less than 50,000	7,325,629	2.9	9,400	0.103	779.3
Urban Fringe	79,411,472	31.9	96,524	1.054	822.7
Place of:					
2,500 or more	62,775,855	25.2	66,546	0.727	943.3
100,000 or more	5,100,382	2.1	3,700	0.040	1378.5
50,000 to 99,999	11,752,941	4.7	8,137	0.089	1444.5
25,000 to 49,999	15,118,958	6.1	13,675	0.149	1105.6
10,000 to 24,999	18,482,502	7.4	21,089	0.230	876.4
5,000 to 9,999	8,679,826	3.5	12,975	0.142	669.0
2,500 to 4,999	3,641,246	1.5	6,971	0.076	522.4

Table 6.5. U.S. Population Density Data from the 1990 Census (Continued)

Category	Population	Percent Population	Area (km^2)	Percent Area	Population Density (per km^2)
Place of:					
Less than 2,500	1,078,903	0.4	2,576	0.028	418.8
2,000 to 2,499	362,540	0.1	726	0.008	499.5
1,500 to 1,999	276,809	0.1	675	0.007	410.0
1,000 to 1,499	240,177	0.1	533	0.006	451.0
Less than 1,000	199,377	0.1	643	0.007	310.2
Other Urban	15,556,714	6.3	27,402	0.299	567.7
Outside Urbanized Area	28,794,609	11.6	68,276	0.745	421.7
Place of:					
25,000 or more	3,917,665	1.6	6,186	0.068	633.3
10,000 to 24,999	9,907,357	4.0	17,717	0.193	559.2
5,000 to 9,999	7,909,614	3.2	19,978	0.218	395.9
2,500 to 4,999	7,059,973	2.8	24,395	0.266	289.4
Rural	61,656,386	24.8	8,932,657	97.529	6.9
Place of:					
1,000 to 2,499	7,050,858	2.8	35,574	0.388	198.2
2,000 to 2,499	2,074,977	0.8	9,952	0.109	208.5
1,500 to 1,999	2,381,156	1.0	11,616	0.127	205.0
1,000 to 1,499	2,594,725	1.0	14,007	0.153	185.3
Place of less than 1,000	3,801,051	1.5	50,088	0.547	75.9
Other Rural	50,804,477	20.4	8,846,995	96.594	5.7

[a] Source: DOC (1993).

The primary difference in the population zone densities between the 1970 and 1990 census data, as shown in Table 6.4, is that the urban zone drops in density from 3,830 to 1,282 persons/km^2. The majority of this change is due to the increase in land area for central places by about a factor of four.

In general, population densities increase with the population of a city or town, as shown in Tables 6.5 and 6.6. However, there is a wide variation, as shown in Figure 6.1, which plots population and population density for cities with populations greater than 100,000. Table 6.7 lists those cities with populations greater than 1.5 million, and Table 6.8 lists cities with population densities greater than 5,000 persons/km^2. Even a city with a relatively small population, such as Paterson, New Jersey (population 139,000) can have a relatively high population density (6,391 persons/km^2). For cities with populations greater than 100,000 persons, the average population density is 1,864 persons/km^2, with the median being 1,219 persons/km^2. If New York City and its boroughs are not included (see Table 6.7), the average drops to 1,642 persons/km^2 and the median moves slightly to 1,216 persons/km^2.

Table 6.6. U.S. Population Density by Size of Place

Category	Population	Percent Population	Area (km^2)	Percent Area	Population Density (per km^2)
Total	248,709,873		9,158,960		27.2
Populations of:					
1,000,000 or more	19,952,631	8.0	6,330	0.069	3,152.3
500,000 to 999,999	10,107,184	4.1	6,891	0.075	1,466.8
250,000 to 499,999	14,585,006	5.9	12,138	0.133	1,201.6
100,000 to 249,999	19,702,834	7.9	17,070	0.186	1,154.2
50,000 to 99,999	24,027,445	9.7	21,511	0.235	1,117.0
25,000 to 49,999	26,362,252	10.6	29,261	0.319	900.9
10,000 to 24,999	28,389,859	11.4	38,806	0.424	731.6
5,000 to 9,999	16,589,440	6.7	32,953	0.360	503.4
2,500 to 4,999	10,701,219	4.3	31,366	0.342	341.2
2,000 to 2,499	2,437,517	1.0	10,677	0.117	228.3
1,500 to 1,999	2,657,965	1.1	12,291	0.134	216.3
1,000 to 1,499	2,834,902	1.1	14,539	0.159	195.0
Less than 1,000	4,000,428	1.6	50,731	0.554	78.9
Other Urban	15,556,714	6.3	27,402	0.299	567.7
Other Rural	50,804,477	20.4	8,846,995	96.594	5.7
Federal Highway Administration (FHWA) Classifications:					
Large Urban (> 50,000)	88,375,100	35.5	63,940	0.698	1,382.2
Small Urban (5,000-50,000)	86,898,265	34.9	128,422	1.402	676.7
Rural (< 5,000)	73,436,508	29.5	8,966,599	97.900	8.2

The population densities used for transportation risk analyses were generally obtained from the HIGHWAY (Johnson et al., 1993a) and INTERLINE (Johnson et al., 1993b) routing programs for truck and rail, respectively. These programs separated population densities into 12 ranges and reported the distance traveled in each range for a specified route. The original programs designed these ranges so that aggregating them into three larger ranges (rural, <54 persons/km^2; suburban, 54 to 1,285 persons/km^2; and urban, >1,285 persons/km^2) would correspond to the averages of 6, 719, and 3,861 persons/km^2 as originally suggested in NUREG-0170. However, these programs were updated to use 1990 census data.[5]

More than 1,250 unique truck routes (HIGHWAY) and more than 1,080 unique rail routes (INTERLINE) were generated to support the transportation analyses in four recent major EISs (DOE, 1995b; 1996a; 1997b; U.S. Department of the Navy, 1996). The average rural, suburban, and urban population densities along these routes using 1990 census data are given in Table 6.9. As shown in the table, there is fairly close agreement between the truck and rail averages,

[5] TRAGIS separates populations into 11 ranges, but maintains the aggregation scheme of HIGHWAY and INTERLINE.

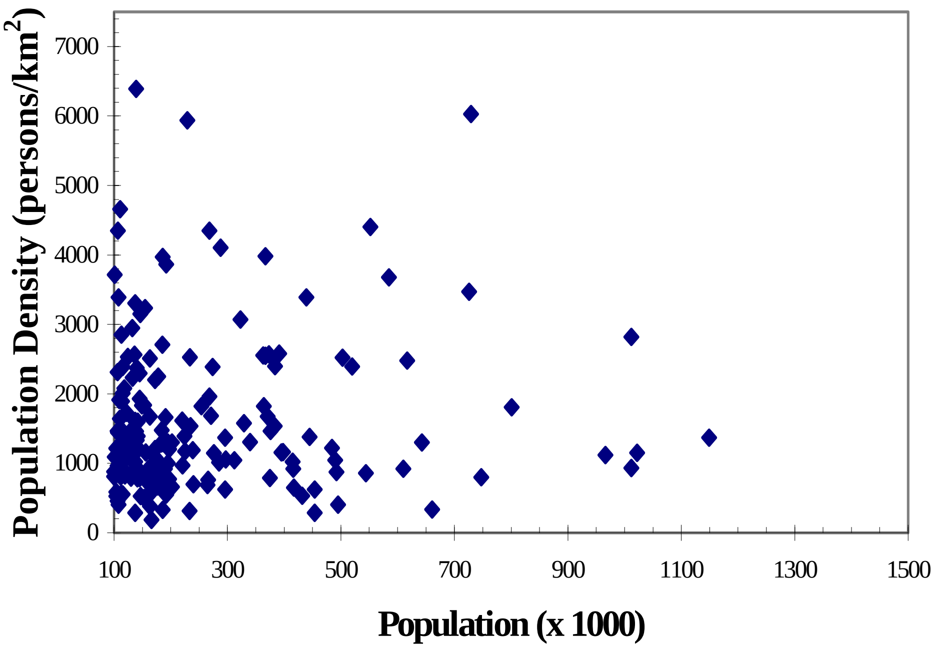

Figure 6.1. Population Densities for U.S. Cities with Populations over 100,000

Table 6.7. U.S. Cities with over 1.5 Million Persons

City	Population (1,000)	Land Area (km^2)	Population Density (persons/km^2)
Philadelphia	1,553	349.7	4,440
Houston	1,690	1397.7	1,209
Queens Borough	1,951	283.2	6,888
Brooklyn Borough	2,286	182.5	12,524
Chicago	2,768	588.1	4,705
Los Angeles	3,490	1214.9	2,872
New York	7,312	799.9	9,140

Table 6.8. U.S. Cities with Population Densities Greater than 5,000 Persons/km^2

City	Population (1,000)	Land Area (km^2)	Population Density (persons/km^2)
Jersey City	229	38.5	5,936
San Francisco	729	120.9	6,029
Paterson	139	21.7	6,391
Queens Borough	1,951	283.2	6,888
New York	7,312	799.9	9,140
Bronx Borough	1,195	108.7	10,990
Brooklyn Borough	2,286	182.5	12,524
Manhattan Borough	1,489	73.5	20,251

Table 6.9. Comparing Population Density Data (persons/km^2) by Density Zone for the U.S.

Population Zone	Route Average		NUREG-0170[c]	1990 Census[d]
	Truck[a]	Rail[b]		
Urban	2,260	2,390	3,861	1,282
Suburban	349	361	719	766
Rural	10	10	6	7

[a] Average population density from 1,258 routes generated using HIGHWAY.
[b] Average population density from 1,088 routes generated using INTERLINE.
[c] Source: NRC (1977a).
[d] Source: DOC (1993).

with a maximum difference of approximately 6% for the urban values. However, there is a wide disparity between these average numbers and those originally proposed in NUREG-0170. For perspective, Figures 6.2 and 6.3 plot the average route density as a function of the route distance for rural, suburban, and urban zones. As expected, the population densities in each zone vary widely for the shorter routes and converge as route length increases for both truck and rail.

■ ■ ■ 6.1.3.2 Fractions of Travel

The average fractions of travel in each of the three population zones for the truck and rail routes, discussed in Section 6.1.3.1, are compared in Table 6.10 with the values suggested in NUREG-0170. For perspective, Figures 6.4 and 6.4 plot the average fraction of travel as a function of the route distance for the rural, suburban, and urban zones. As with population densities, the fraction of travel in each zone varies widely for the shorter routes and converges as route length increases for both truck and rail.

Table 6.10. Comparing Fraction of Travel Data for the United States

Population Zone	Route Average		NUREG-0170[c]
	Truck[a]	Rail[b]	
Urban	0.03	0.04	0.05
Suburban	0.19	0.19	0.05
Rural	0.78	0.77	0.90

[a] Average fraction of travel from 1,258 routes generated using HIGHWAY.
[b] Average population density from 1,088 routes generated using INTERLINE.
[c] Source: NRC (1977a).

To maintain consistency when specific route data are unavailable, the average fractions of travel in different population zones was determined using HIGHWAY and INTERLINE, as shown in Table 6.10, with the average population densities in Table 6.9, also determined with HIGHWAY and INTERLINE. Similar determinations can be made using TRAGIS. Note that, while RADTRAN 4 included a utility that allowed direct use of fractions of travel, RADTRAN 5 does not have such a utility. Fractions of travel cannot be used directly in RADTRAN 5 analyses.

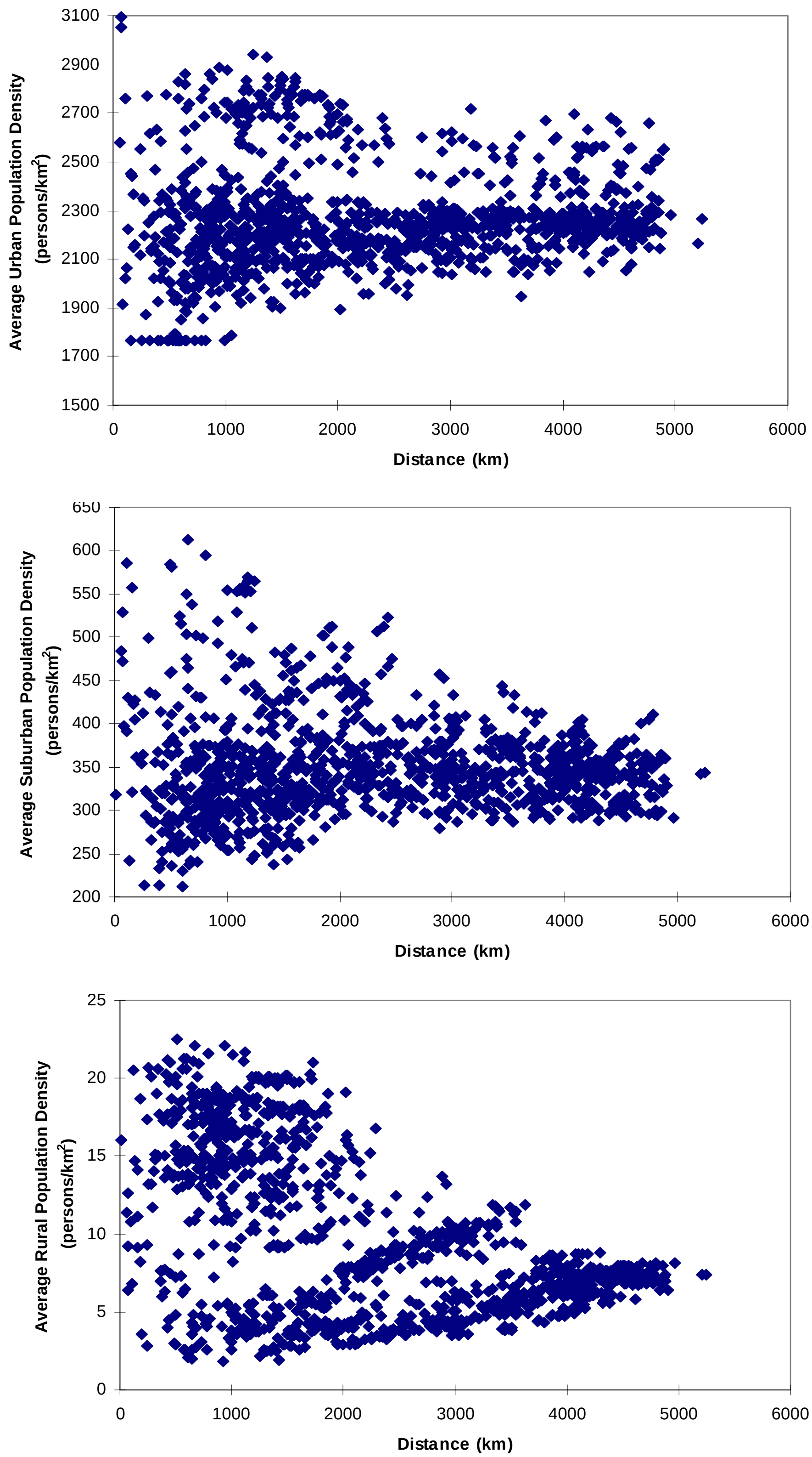

Figure 6.2. Average Population Densities Determined for Truck Travel through Rural, Suburban, and Urban Zones

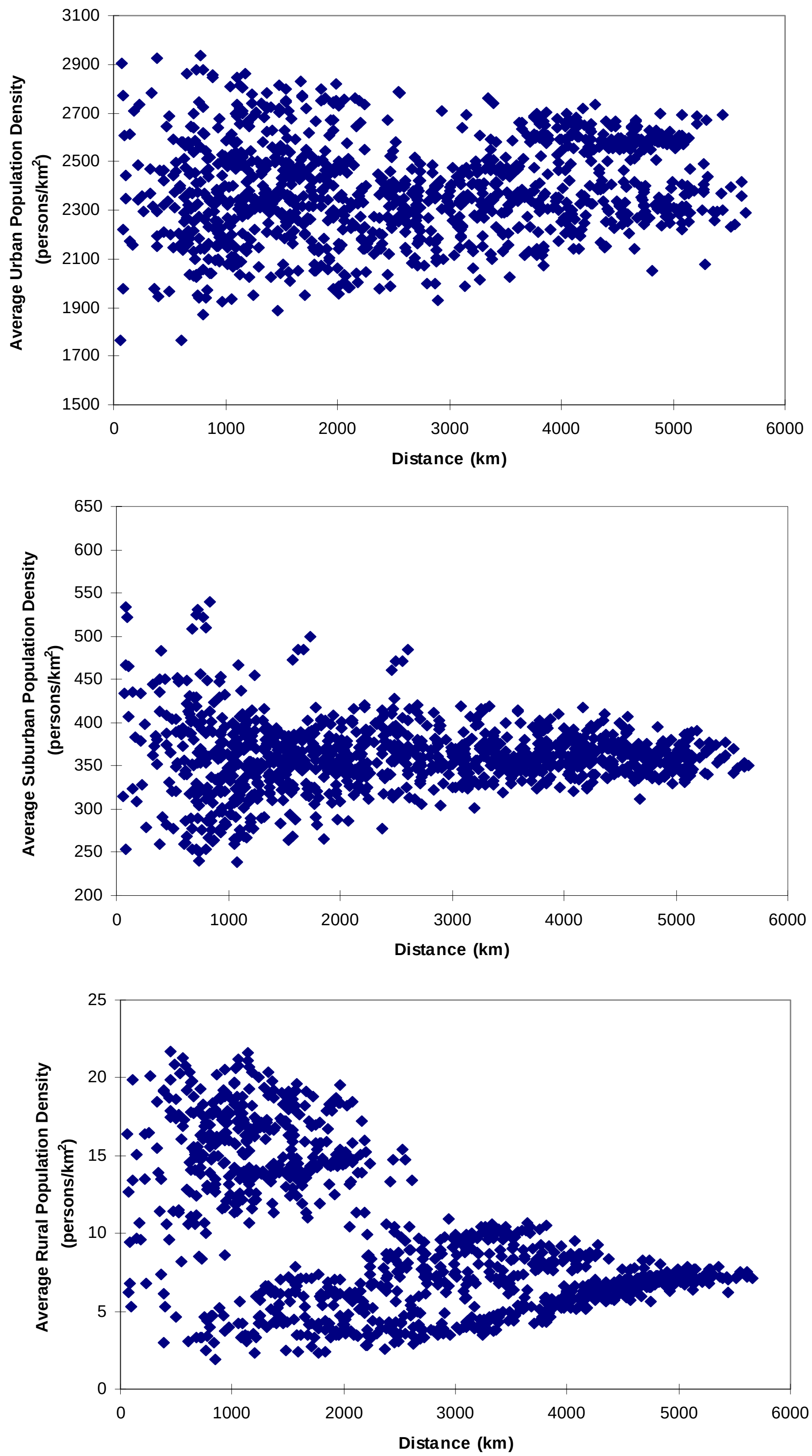

Figure 6.3. Average Population Densities Determined for Rail Travel through Rural, Suburban, and Urban Zones

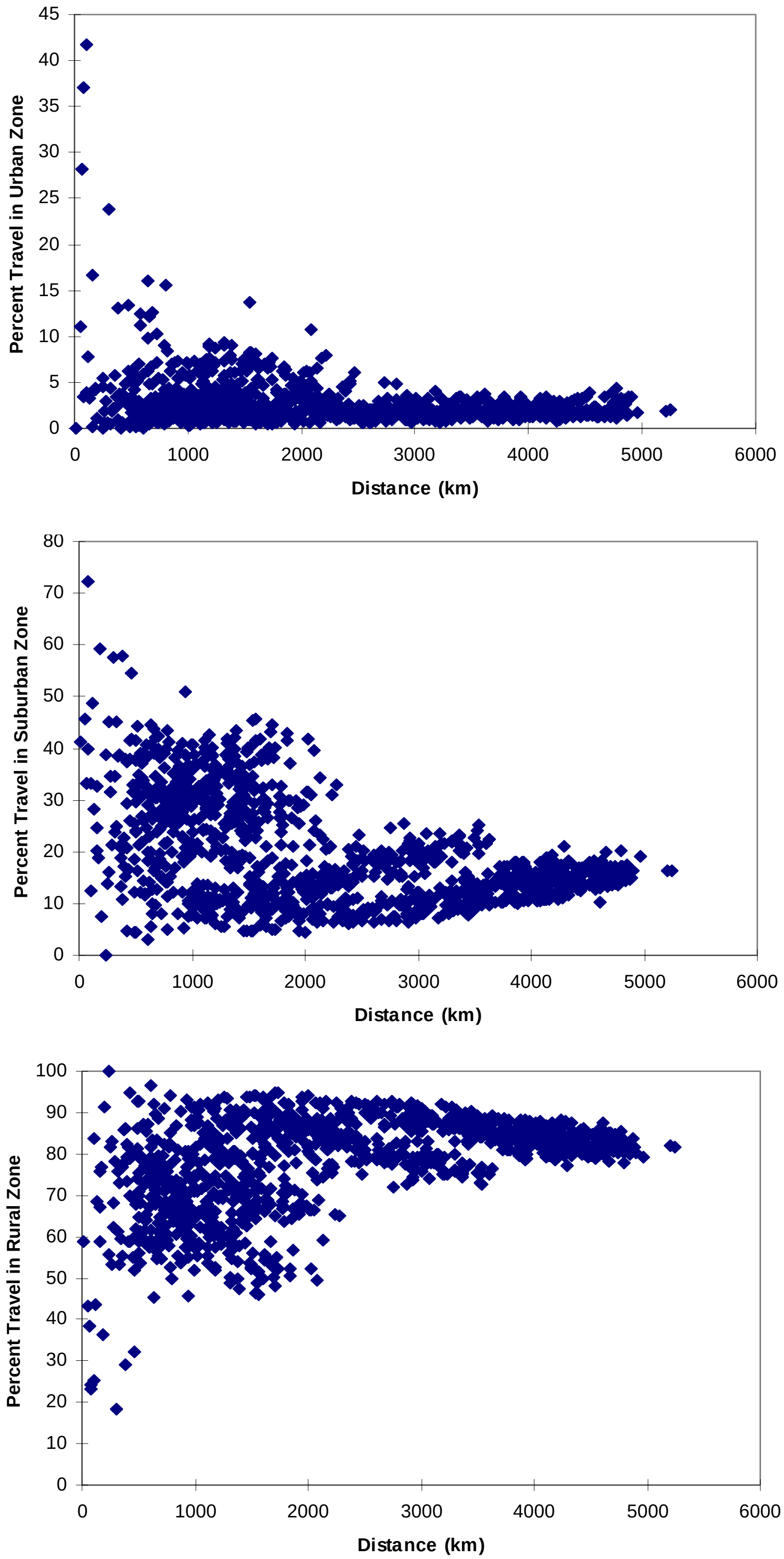

Figure 6.4. Average Fraction of Truck Travel through Rural, Suburban, and Urban Zones

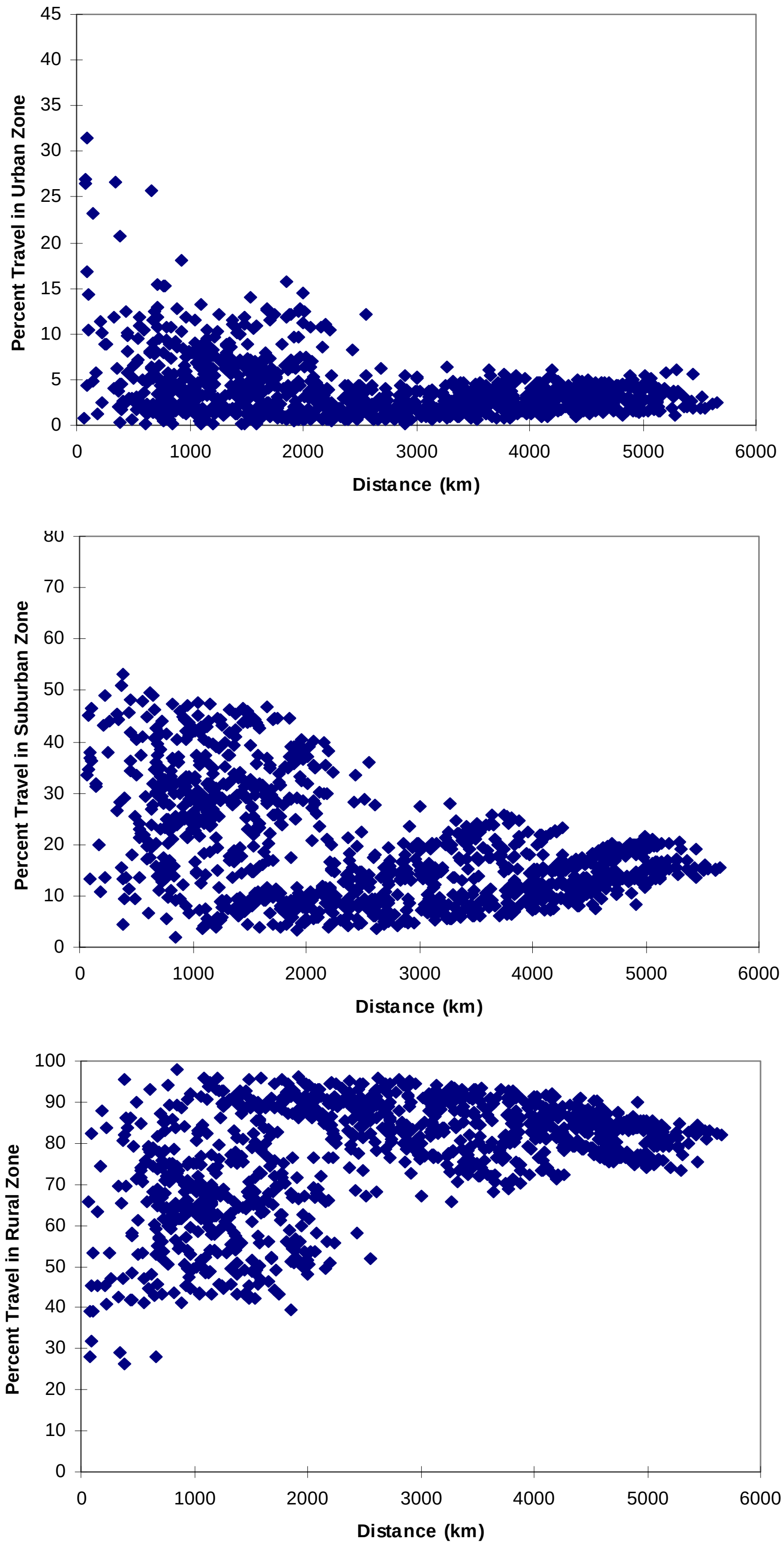

Figure 6.5. Average Fraction of Rail Travel through Rural, Suburban, and Urban Zones

6.1.4 Vehicle Speed

The vehicle speed is used in the incident-free portion of a radiological transportation risk assessment. In conjunction with the distance traveled, the vehicle speed determines the amount of time the transportation crew, the on-link population, and the off-link population (including an MEI on the side of the route) are exposed to the low levels of external radiation from the shipping package.

6.1.4.1 Truck

The truck speeds suggested in RADTRAN are listed in Table 6.11. These values are conservative, since a lower vehicle speed results in a larger estimated dose because

Table 6.11. RADTRAN Suggested Vehicle Speeds

Population Zone	Truck[a] (km/h [mph])	Rail (km/h [mph])
Rural	88.49 (55)	64.37 (40)
Suburban	40.25 (25)	40.25 (25)
Urban	24.16 (15)	24.16 (15)

[a] The 55 mph speed for rural areas also applies to suburban and urban freeways.
Source: Neuhauser and Kanipe (2000).

of the longer exposure period. Freeway speed of 27.5 mph (half of the rural freeway speed) and a corresponding fraction of the route is suggested to account for rush-hour traffic on urban and suburban freeways. The suggested freeway speed of 55 mph reflects the maximum interstate speed limit set to 55 mph in 1974 in response to the oil crisis of the time. However, speed limits have been raised significantly in recent years for the interstate highway system, on which radioactive material shipments typically spend most of their travel time. Congress allowed states to raise their rural interstate speed limits to 65 mph in 1987 and repealed the maximum speed limits imposed on the states in the National Highway System Designation Act of 1995.

The current maximum posted rural and urban interstate highway speed limits for each state are listed in Table 6.12. A number of states have truck speed limits as high as 75 mph in rural areas, a 36% increase over 55 mph, while a handful of states retained the rural 55 mph speed limit for trucks. Some states have limits as high as 70 mph in urban zones, but this does not mean that all urban areas will be posted at the maximum allowed by the state. Allowances must also be made for weather, visibility, road conditions, traffic density, and construction delays.

No federal regulations restrict the speed of HAZMAT shipments on the interstate highway system, but shippers of radioactive materials may require their carriers to maintain a maximum speed of 55 mph on the interstate highway system. A recent example is the transportation system established by DOE for transporting TRUW to the WIPP. The transportation plan calls for regulators installed on the tractor-trailers for limiting highway speeds to a maximum of 55 mph.

Table 6.12. Maximum Posted Speed Limits for Passenger Vehicles[a]

State	Limited Access Rural Interstates	Limited Access Urban Interstates	Effective Dates of Limits on Rural Interstates	State	Limited Access Rural Interstates	Limited Access Urban Interstates	Effective Dates of Limits on Rural Interstates
Alabama	70	70	5/9/96	Montana	75/*Trucks 65*	65	5/28/99
Alaska	65	55	1/15/88	Nebraska	75	65	6/1/96
Arizona	75	55	12/8/95	Nevada	75	65	12/8/95
Arkansas	70/*Trucks 65*	55	8/19/96	New Hampshire	65	65	4/16/87
California	70/*Trucks 55*	65	1/7/96	New Jersey	65	55	1/19/98
Colorado	75	65	6/24/96	New Mexico	75	55	5/15/96
Connecticut	65	55	10/1/98	New York	65	65	8/1/95
Delaware	65	55	1/17/96	North Carolina	70	65	8/5/96
D.C.	n/a	55	1974	North Dakota	70	55	6/10/96
Florida	70	65	4/8/96	Ohio	65/*Trucks 55*	65	7/15/87
Georgia	70	65	7/1/96	Oklahoma	75	70	8/29/96
Hawaii	55	50	1974	Oregon	65/*Trucks 55*	55	6/27/87
Idaho	75/*Trucks 65*	65	5/1/96	Pennsylvania	65	55	7/13/95
Illinois	65/*Trucks 55*	55	4/27/87	Rhode Island	65	55	5/12/96
Indiana	65/*Trucks 60*	55	6/1/87	South Carolina	70	70	4/30/99
Iowa	65	55	5/12/87	South Dakota	75	65	4/1/96
Kansas	70	70	3/7/96	Tennessee	70	65	3/25/98
Kentucky	65	55	6/8/87	Texas	70	70	12/8/95
Louisiana	70	55	8/15/97	Utah	75	65	5/1/96
Maine	65	55	6/12/87	Vermont	65	55	4/21/87
Maryland	65	65	7/1/95	Virginia	65	55	7/1/88
Massachusetts	65	65	1/5/92	Washington	70/*Trucks 60*	60	3/15/96
Michigan	70/*Trucks 55*	65	8/1/96	West Virginia	70	55	8/25/97
Minnesota	70	65	7/1/97	Wisconsin	65	65	6/17/87
Mississippi	70	70	2/29/96	Wyoming	75	60	12/8/95
Missouri	70	60	3/13/96				

[a] As of July 2000. Speed limits for commercial use trucks, if different, are listed in italics.
Source: Insurance Institute for Highway Safety (IIHS) (2000).

■ ■ ■ 6.1.4.2 Rail

In RADTRAN the crew dose for rail transport is only assessed at stops in classification and switch yards and rail stations, because distance and shielding from the locomotive and other railcars during transport is expected to result in negligible crew doses. Therefore, the vehicle speed is used only for assessing the incident-free doses to the on- and off-link populations during transit. Table 6.11 lists the train speeds suggested in RADTRAN for rural, suburban, and urban population zones.

In 1995, average freight train speeds were 19 mph east of the Mississippi River and 23 mph west of the Mississippi River, for a combined average of 22 mph (Association of American Railroads [AAR], 1996). These train speeds include terminal delay. Thus, the average speed for dedicated trains hauling radioactive waste is expected to be higher because they generally have fewer stops in switching yards and their shorter length allows for faster starting and stopping. On the other hand, dedicated trains may have a speed limit restriction. For example, a speed limit of 35 mph was self-imposed on all past shipments of naval SNF (U.S. Department of the Navy, 1996).

Track condition determines the maximum allowable speed on a given segment of railroad. The FRA regulates the maximum speed for freight and passenger trains on five classes of track, as shown in Table 6.13. Tracks are categorized by condition into classes 1 through 5, with tracks in the best condition as class 5 (definitions of track classes are given in 49 CFR 213 (“Track Safety Standards”). It is DOE practice to ship radioactive material over the best track class possible to minimize the chance of accidents. However, many past shipments, most notably shipments of SNF, have still been made under restricted speed conditions (Glickman and Golding, 1991). The railroads would prefer that SNF transport be conducted without speed or routing restrictions unless “there is an unacceptable risk of a cask being breached should an accident occur when the train is being moved under normal operating practices” (AAR, 1997a).

Table 6.13. Maximum Train Operating Speeds on Different Classes of Track[a]

Track Class	Maximum Allowable Speed (mph)	
	Freight Trains	Passenger Trains
Class 1	10	15
Class 2	25	30
Class 3	40	60
Class 4	60	80
Class 5	80	90

[a] Source: 49 CFR 213.9 (“Classes of Track: Operating Speed Limits”).

■ ■ 6.1.5 Traffic Volumes and Vehicle Occupancy

Traffic volumes and vehicle occupancy are used in the on-link population exposure model for routine incident-free transport. The estimated population dose is directly proportional to each of these parameters.

■ ■ ■ 6.1.5.1 Traffic Volumes

Truck

For truck transport, the U.S. interstate highway system will be used to the maximum extent when transporting radioactive materials (see Section 2.4.2). An analysis of traffic volumes on the interstate highways should, therefore, reasonably estimate average traffic flows. The most recent data available from the Highway Performance Monitoring System (HPMS) maintained by the Federal Highway Administration (FHWA) were used. These data consisted of the interstate universe records for 1993 through 1997.

Table 6.14 presents the annual average daily traffic (AADT) per lane for the four population zones used by the FHWA. The final row, urbanized areas with populations of 50,000 persons or more, is the average of the two preceding urbanized area zones in the table. Analysis of weekday travel patterns has shown that the majority of traffic (about 93% or more) in both rural and urban zones occurs between the hours of 5 a.m. and 10 p.m. (Festin, 1996). To obtain a reasonable hourly average for input into risk models, the AADT values were divided by 17 h/d, as presented in Table 6.14. Figures 6.6 and 6.7 display the percent of daily traffic for weekdays in rural and urban zones, respectively. Rush-hour vehicle density may be double the average hourly density.

Table 6.14. Average Traffic Volumes on the U.S. Interstate System

Population Zone	Average AADT[a] per Lane					Hourly Average per Lane Based on a 17-h Day[b]					
	1993	1994	1995	1996	1997	1993	1994	1995	1996	1997	Avg.
Rural Area (pop. < 5,000)	4,329	4,511	4,434	4,607	4,742	255	265	261	271	279	266
Small Urban Area (pop. 5,000 to 49,999)	6,252	6,269	6,453	6,657	6,832	368	369	380	392	402	382
Urbanized Area (pop. 50,000 to 199,999)	10,341	8,435	8,363	8,324	8,561	608	496	492	490	504	518
Urbanized Area (pop. 200,000 or more)	14,446	14,489	14,445	14,772	15,060	850	852	850	869	886	861
Urbanized Area (pop. 50,000 or more)	13,243	13,508	13,416	13,695	13,974	779	795	789	806	822	798

[a] AADT per lane for the U.S. interstate system.
[b] Approximately 93% or more of traffic on weekdays in the United States occurs between 5 a.m. and 10 p.m. (Festin, 1996).

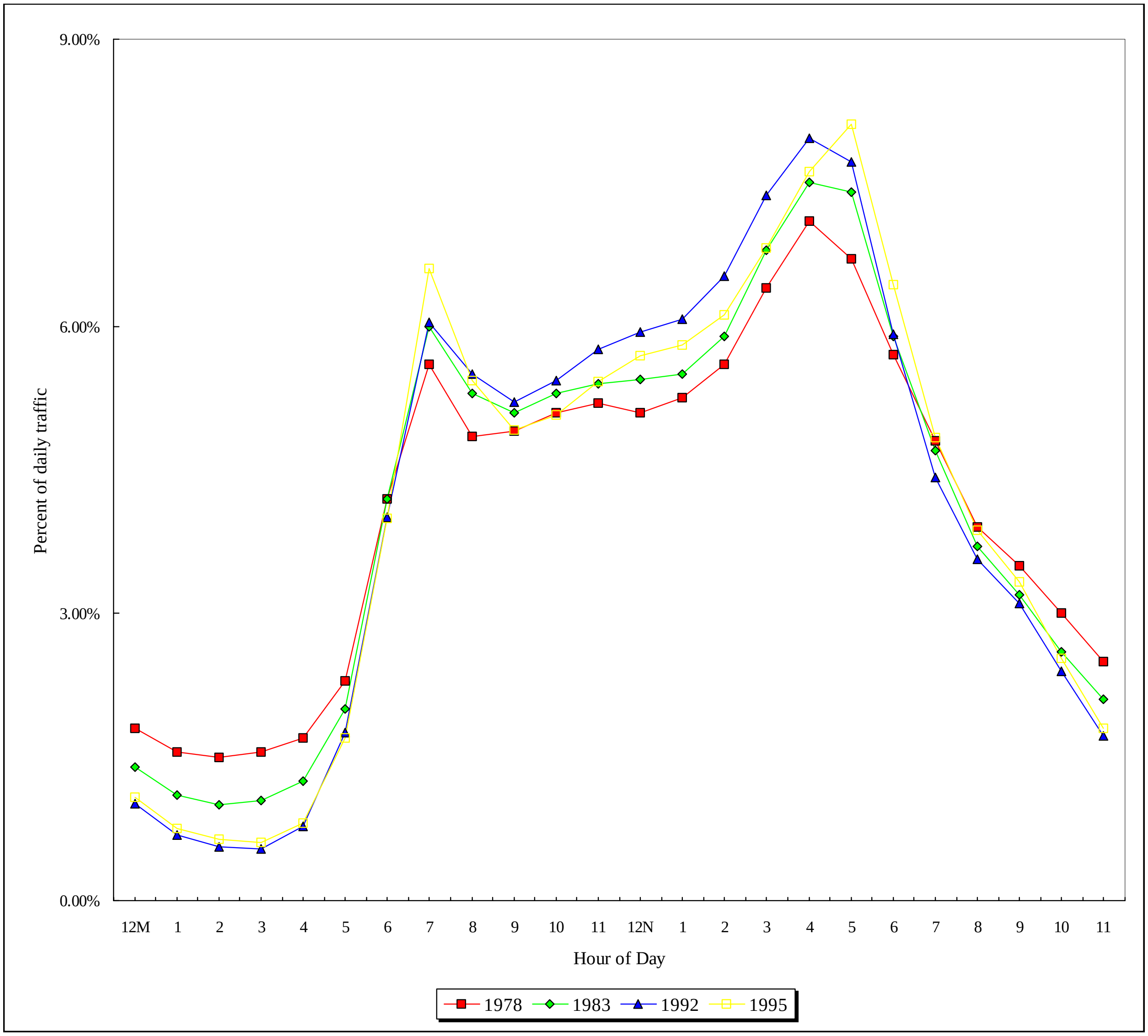

Figure 6.6. Weekday Rural Highway Traffic, 1978-1995 (Source: Festin, 1996)

More than 90% of the interstate highway system in rural zones has two lanes of traffic in each direction (DOT, 1997a). The rural average of 266 vehicles per hour per lane was multiplied by 2 to obtain the value of 530 vehicles per hour shown in Table 6.15. Similarly, the suburban value of 760 vehicles per hour was obtained from the small urban area value of 382 vehicles per hour per lane. Approximately 50% of urban interstate highways have more than two lanes of traffic in each direction (DOT, 1997a); thus the urbanized area value of 798 vehicles per hour per lane in Table 6.14 was multiplied by 3 to obtain a suggested value of 2,400 vehicles per hour for urban areas, as shown in Table 6.15. Table 6.15 also shows the default values used in NUREG-0170. Good agreement is observed; the largest difference is approximately 20% between the urban values.

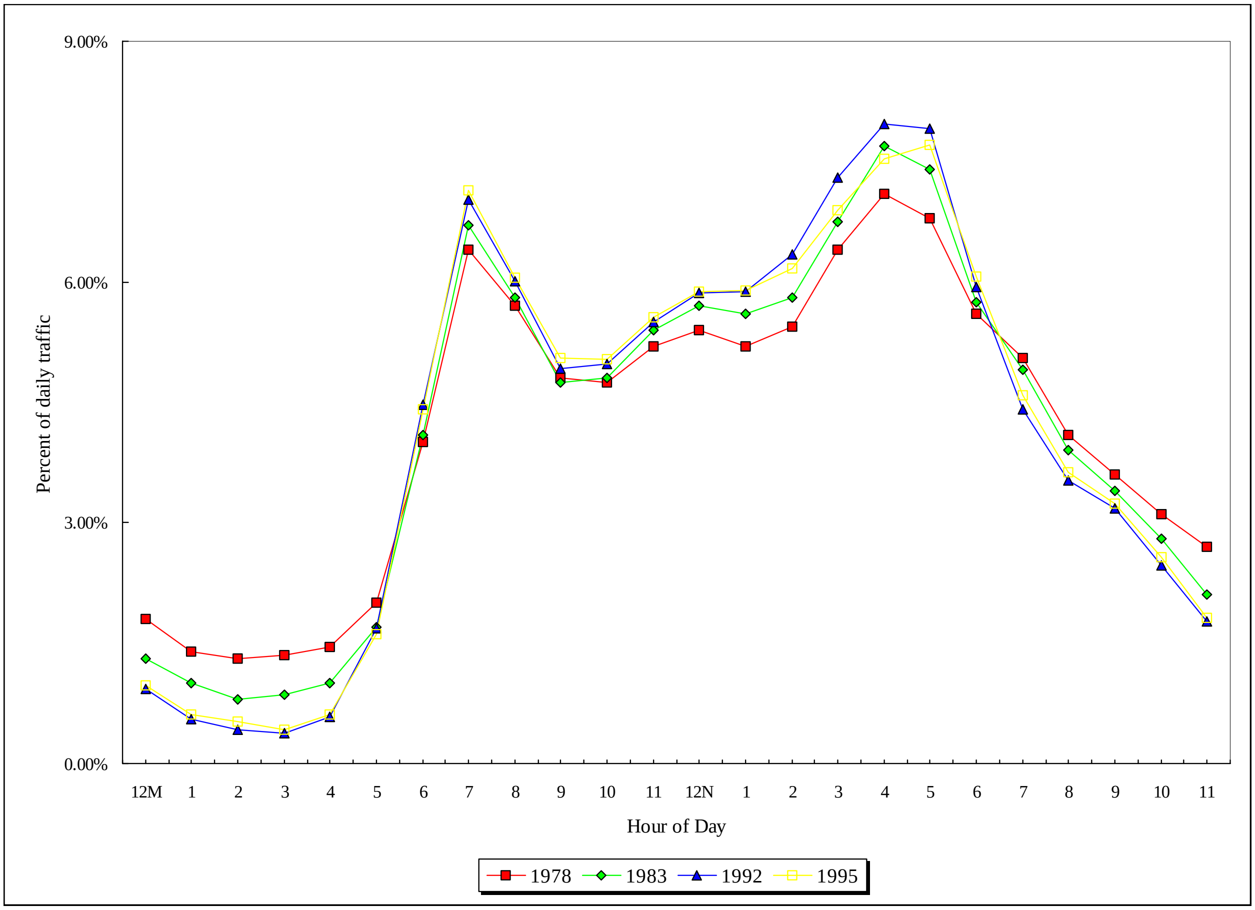

Figure 6.7. Weekday Urban Highway Traffic, 1978-1995 (Source: Festin, 1996)

Table 6.15. One-Way Traffic Volumes for Truck Transport

Population Zone	Suggested	NUREG-0170[a]
Urban	2,400[b]	2,800
Suburban	760[c]	780
Rural	530[d]	470

[a] Sources: NRC (1977a); suggested values used in RADTRAN (Neuhauser and Kanipe, 2000).
[b] Assumes three lanes in an urbanized area with a population of 50,000 or more persons.
[c] Assumes two lanes in a small urban area with a population of 5,000 to 49,999 persons.
[d] Assumes two lanes in a rural area with a population of less than 5,000 persons.

Rail

Data for Class I railroads (those with operating revenues of $259.4 million or more in 1998) are used for freight rail traffic. These railroads accounted for 71% of the mileage operated and 91% of the freight revenue generated in 1998 (AAR, 1999). As shown in Table 6.16, the U.S. annual average traffic volume per mile of railroad (whether single or parallel tracks) was 3,983 trains

Table 6.16. National Average Traffic Volumes on Class I Railroads[a]

Year	Freight Train Miles per Mile of Road Operated per Year
1994	3,599
1995	3,665
1996	3,719
1997	3,923
1998	3,983

[a] Sources: AAR (1995; 1996; 1997b; 1998; 1999).

per year in 1998 (AAR, 1999), up slightly from 3,923 trains per year in 1997 (AAR, 1998). Assuming continuous 24-hour operation, traffic flow on average is 0.45 train per hour. If 12-hour operation is assumed, the rate increases to 0.91 train per hour, which is close to the RADTRAN suggested value of one train per hour in rural areas. Intercity passenger train service by AMTRAK adds approximately 0.15 train per hour for 24-hour operation, or 0.30 train per hour for 12-hour operation (AAR, 1999). However, many of AMTRAK's routes are overnight runs between major cities. AMTRAK trains run primarily over track owned by the freight railroads, using approximately one quarter of the freight railroad network (AAR, 1999). AMTRAK owns only about 3% of the rails over which it operates (AAR, 1999).

The values for rail traffic volumes discussed above are based on national average statistics and thus are valid for rural, suburban, and urban areas. Certain suburban/urban areas have additional rail traffic volumes from commuter rail systems that operate over local portions of the freight railroad network. Table 6.17 lists the major metropolitan areas with significant commuter rail systems. For these areas, the average number of vehicles per hour, expressed as passenger cars per hour for commuter rail traffic only, is 13.3 railcars per hour for a 12-hour operational period (American Public Transit Association [APTA, 1998]). Each commuter train typically has two to four cars, suggesting that approximately three to six trains per hour pass by a given location. The RADTRAN suggested value of five trains per hour for suburban and urban areas is in reasonable agreement with the addition of the freight and commuter rail traffic values presented here for the metropolitan areas listed in Table 6.17. However, locations with heavy commuter rail operations, such as New York City, Philadelphia, and Chicago, may have significantly higher traffic volumes. Other metropolitan areas without commuter rail traffic would likely have average rail traffic volumes closer to that estimated for rural areas, approximately 1 train per hour.

The estimated traffic volumes presented here are expected to be slightly conservative national average values for radiological transportation risk assessment. Volumes will tend to be lower or higher depending on the specific rail route chosen, and not all routes consist of parallel track. In order to receive an on-link population dose estimate as calculated by RADTRAN parallel track (or a rail siding) is necessary for another train to pass or be passed by a rail shipment.

Table 6.17. Metropolitan Areas with Commuter Rail Systems

City	Transit Agency	Number of Stations
Baltimore	Mass Transit Administration, Maryland DOT	41
Boston	Massachusetts Bay Transportation Authority	102
Chicago	Regional Transportation Authority (Northeast Illinois Regional Commuter Railroad Corporation)	234
Chicago	Northern Indiana Commuter Transportation District	18
Dallas	Dallas Area Rapid Transit Authority	3
Los Angeles	Southern California Regional Rail Authority	44
Miami	Tri-County Commuter Rail Authority	17
New Haven	Connecticut DOT	8
New York	Metropolitan Transportation Authority Long Island Railroad	134
New York	Metropolitan Transportation Authority Metro-North Railroad	106
New York	New Jersey Transit Corporation	158
Philadelphia	Pennsylvania DOT	14
Philadelphia	Southeastern Pennsylvania Transportation Authority	181
San Diego	North San Diego County Transit District	8
San Francisco	Peninsula Corridor Joint Powers Board	34
Syracuse	ON TRACK	3
Washington, D.C.	Virginia Railway Express	18

Source: APTA (1998).

■ ■ ■ 6.1.5.2 Vehicle Occupancy

Truck

Recent traffic studies have shown that vehicle occupancies on the nation's roads average approximately 1.5 persons per vehicle (Grush and Gross, 1995). Two studies were reviewed — one for the 1990 National Personal Transportation Survey (NPTS) and one conducted by the National Highway and Traffic Safety Administration (NHTSA). An occupancy average of 1.50 was found in the NPTS study, and a value of 1.45 was found in the NHTSA study. Both studies considered cars, vans, and light trucks, but results were not limited to highway traffic. Including persons riding on buses is not expected to increase this number significantly because buses represented only about 0.3% of the total annual vehicle miles on rural interstate highways and less than 0.2% of the total annual vehicle miles on urban interstate highways in 1995 and 1996 (DOT, 1997a). An average value of 1.5 is 75% of the current default value of 2 for truck transport in RADTRAN (Neuhauser and Kanipe, 1992).

Rail

On freight trains, a typical train crew would consist of an engineer, a conductor (foreman), and a brakeman (helper). Three persons per train is also the RADTRAN rail default. However, some train service may require additional brakemen or other train crew, such as a fireman. On through freight trains, trains that do not drop off or pick up railcars along their route, the crew could consist of only an engineer and conductor.

The number of persons on a passenger train is, of course, much higher. For AMTRAK in 1995, 33 million train miles, 292 million railcar miles, and 5,545 million passenger miles were recorded (DOT, 1996a). Therefore, the average number of passengers per railcar was 19, with an average of 8.8 railcars per train, giving approximately 170 passengers per train plus the crew. For commuter rail traffic, the average number of passengers in a railcar was 35 in 1996 (APTA, 1998).

■ ■ 6.1.6 Urban Travel

■ ■ ■ 6.1.6.1 Fraction of Travel during Rush Hour

The fraction of travel during rush hour applies to both the suburban and urban portions of the aggregate model in RADTRAN for truck transport. It does not apply to rail transport. In the model, the shipment speeds in suburban and urban zones are halved and the traffic volumes doubled during rush hour for incident-free calculations. The user designates the rush-house fraction. Weekday urban traffic patterns for 1995 (Figure 6.7) show that about four 1-hour periods (one around 7 a.m. and three around 3 p.m. to 5 p.m.) have a percentage of traffic above the average for the working hours. These four hours account for approximately 30% of the daily traffic. The fraction of travel during rush hour depends on driving constraints for the shipment. If two drivers are used for round-the-clock driving, the fraction of travel during rush hour might be 0.17 (4/24), twice the RADTRAN default of 0.08. However, to minimize exposure and transit time, routing by the trucking company should be able to maintain a value significantly lower than 0.17.

■ ■ ■ 6.1.6.2 Fraction of Urban Travel on City Streets

Unless a radioactive materials shipment needs to follow a detour, stop for fuel or repairs, or the origin or destination sites are in urban areas, the shipment should remain on the interstate highway system (see Section 2.4.2) when passing through urban areas, and relatively little or no time should be spent on city streets. As shown in Table 6.10, the route average fraction of travel in urban zones for more than 1,250 HIGHWAY routes is 0.03, which includes both interstate and local street travel.

■ ■ ■ 6.1.6.3 Urban Pedestrian Ratio

The urban pedestrian ratio is the ratio of pedestrians per square kilometer of sidewalk to population per square kilometer of overall urban area. This ratio is used for calculations related to truck movements on urban city streets. A suggested value of 6 may be used in RADTRAN, as suggested by Finley et al. (1980), which used data from a study of the pedestrian environment in New York City (Pushkarev and Zupan, 1975).

■ ■ 6.1.7 Shielding Factors

■ ■ ■ 6.1.7.1 Inhalation

A common measure of the air filtration (sheltering) provided by an indoor environment is the indoor/outdoor air concentration ratio. As shown in Table 6.18, a wide range of possible indoor/outdoor air concentration ratios is possible. When applied to inhalation exposure, a dose reduction factor (DRF), the fraction of airborne contaminant remaining airborne after passage indoors, can be defined as the ratio of indoor to outdoor pollutant concentrations integrated from the start of contaminant cloud passage to infinity (Fogh et al., 1997). That is, the "inhalation shielding factor" in RISKIND or the "building dose factor" in RADTRAN for urban areas. Thus, DRFs will approach the indoor/outdoor concentrations for plumes of long duration. DRFs decrease with a decrease in building ventilation rates and an increase in particulate deposition velocity (Kocher, 1980).

Table 6.18. Indoor/Outdoor Air Concentration Ratios for Application as DRFs

Pollutant	Structure	Measured Indoor/Outdoor Ratio	Reference
Total suspended particulates	Homes and public buildings	0.16 to 0.51	Yocum et al., 1971
0.1–20 μm dust particulates	Old/new homes/university buildings	< 0.1 to 0.42	Alzona et al., 1979
Ca, Fe, Zn, Pb, Br	Homes and public and commercial buildings	0.043 to 0.85 (excluding Zn)	Cohen and Cohen, 1979
Particulates, iodine, noble gases	Wood or concrete construction	Calculated DRFs of 0.072 to 1	Kocher, 1980
Be-7	Danish and Finnish homes	0.23 to 0.86	Christensen and Mustonen, 1987
Various radioisotopes	Danish home	0.1 to 0.5	Roed and Cannell, 1987
Noble gGases, methyl iodide, elemental iodine, aerosols 0.1 to 2 μm	Homes, large buildings, manufacturing facilities	Calculated DRFs of 0.004 to 1	Brenk and De Witt, 1987

In RADTRAN, the building dose factor may be used in accident calculations of inhalation dose to account for the sheltering provided by building ventilation systems in urban areas. The RADTRAN suggested value is 0.0086, as suggested by Finley et al. (1980), for particulates in buildings with central air conditioning (which typically consist of filters, precipitators, and dehumidifying coils). However, noble gases have an estimated building dose factor of 1. For other continuous building intake systems, particulates have an estimated value of 0.65 (Finley et al., 1980).

The DRF depends on a number of variables, such as how much outside air can move into a building (how "leaky" or "tight" is it), whether windows are open or closed, and the rate of forced air ventilation. Most large urban cities have significant areas of closely spaced single- and multiple-family homes less likely to filter the air as efficiently than would newer urban office buildings. Even with building ventilation turned off, as might be the case with indoor sheltering following an accident releasing radioactive materials, the exchange rate between indoor and outdoor air can still be significant (Engelmann, 1992).

The DRF provided by a structure is also dependent on the particle size of the contaminant. Larger particles (such as plutonium) with higher deposition velocities are associated with lower DRFs (and, therefore, lower doses) than smaller particulates and volatile radionuclides, such as iodine and cesium, with lower deposition velocities (Fogh et al., 1997).

6.1.7.2 External Radiation

RISKIND and RADTRAN provide shielding factors to account for sheltered locations that reduce the estimated external radiation dose to persons near the transport route. Pedestrians are assumed to be unshielded. The shielding factor accounts for the reduction of gamma ray exposure afforded by occupied structures during incident-free transport, and it is also used in calculations involving accidents with loss of shielding. Many risk assessments take a conservative approach and assume no shielding in any population zone.

The two primary considerations that determine the shielding factor are the amount of time spent indoors and the amount of shielding provided by the occupied structure. On average, persons 12 years of age and older spend about 21 hours a day indoors, 1.5 hours a day outdoors, and 1.5 hours a day in a vehicle (Robinson and Thomas, 1991). Therefore, the shielding factor depends on the type of occupied structure. However, activity patterns can be quite different for rural and urban areas.

Shielding from gamma radiation must account for the type and thickness of material between the radiation source and the receptor. If shielding is considered, the RADTRAN standard value for the urban shielding factor (0.018) is based on 1-ft-thick concrete block walls, which provide a large degree of protection. The suburban standard value of 0.87 provides much less protection and is based on wood frame construction with 6-in.-thick walls. No shielding is assumed in rural areas (i.e., a shielding factor of 1). More information on the shielding characteristics of building materials can be found in Finley et al. (1980) and in Schleien (1992).

6.1.8 Stop Parameters

6.1.8.1 Truck

During truck transport, stops may be required for refueling, inspection, repair, and crew needs. Up to 20 different stops may be modeled in RADTRAN 5. Input parameters for the RADTRAN 5 stop model are the number of persons exposed to external radiation from the cargo at the stop, the area around the cargo occupied by these persons or their distance from the cargo, the exposure time, and the external dose rate. RISKIND can model MEIs at truck stops and local populations for single events by using the time spent at a given stop. Additional input for local populations is the number of persons within minimum and maximum radii from the stopped shipment.

Table 6.19 lists truck stop parameters from other sources. Hostick et al. (1992) reported on a time/motion study involving a 4,500-km overweight SNF shipment. During the 62-hour transit period, approximately 6 hours and 24 minutes were spent at weigh stations, rest areas, and truck stops, giving a distance-dependent stop time of 0.0014 h/km. A previous study of 24 shipments (seven fuel cycle, one hospital waste, and 16 LLW) suggested a distance-dependent stop time of 0.0092 h/km (Madsen and Wilmot, 1982). In the latter study, the distance-dependent stop time was less for two-driver truck crews and on shorter trips (<16 hours) for one-driver truck crews. The number and distance of persons both inside and outside of buildings exposed to radioactive material shipments at stops vary. Average recorded values are listed in Table 6.19.

Table 6.19. Truck Stop Parameters

Source	Distance Dependent Stop Time (h/km)	Number of Persons Exposed	Exposure Distance (m)
Madsen and Wilmot (1982)			
Suggested	0.0092	25	20
One driver (< 16 h trip)	0.00072 - 0.0075		
Two driver (> 16 h trip)	0.0073 - 0.019		
Two drivers	0.0014 - 0.0085		
Hostick et al. (1992)[a]	0.0014	32[b]	76.2
Griego et al. (1996)	NA[c]	7[d]	up to 16 m[d]

[a] SNF shipment with two drivers.
[b] Average from nine truck stops.
[c] Not applicable.
[d] Average of persons observed outside (11 observations) at three truck stops.

■ ■ ■ 6.1.8.2 Rail

The stop model in RISKIND is the same for both truck and rail. Specific scenarios involving MEIs and local populations can be assessed. Potential exposure scenarios for rail inspectors and railyard workers are provided in Section 4.1.1.2 for MEI calculations with RISKIND.

The occupational population dose at a single 30-hour rail classification stop, documented in Appendix B of Neuhauser et al (2000), is part of the RADTRAN 5 code. The number of classification stops per rail trip is usually two, to account for initial and final railyard classifications (Wooden, 1986), but may be defined by the user. Occupational dose at stops along the route is calculated using a user-defined distance-dependent worker exposure factor (DDWEF) as a multiplier for the classification stop dose. The RADTRAN 5 standard value for the DDWEF is 0.0018 per km (Wooden, 1986; Ostmeyer, 1986).

Similar to the truck shipments, part of the nonoccupational collective population dose at railroad stops is modeled using a distance-dependent stop time. As determined by Ostmeyer (1986), the RADTRAN suggested value is 0.033 h/km for general freight service or 0.0036 h/km for dedicated rail service. The total stop time for each route segment is determined by multiplying the segment length by the per-kilometer stop time, and a stop for each route segment is then modeled in the same way as for truck stops. The population density for the route segment is usually used, and the distance from the cargo is usually 30 to 800 m for en-route stops and 400 to 800 m for the 30-hour rail classification stop.

■ ■ 6.1.9 Accident Rates

Accident rates determine the frequency of accidents that might occur during transport of radioactive materials. Saricks and coworkers (Saricks and Kvitek, 1994; Saricks and Tompkins, 1999) performed extensive studies on accident rates for truck and rail transport. For each transport mode, accident rates were generically defined as the number of accidents in a given year per unit of that travel mode. 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.

■ ■ ■ 6.1.9.1 Truck

For truck transportation, the rates presented in Saricks and Kvitek (1994 and Sarieks and Tompkins (1999) are provided specifically for heavy combination trucks involved in interstate commerce. Heavy combination trucks are rigs consisting of a separable tractor unit containing the engine and one to three freight trailers connected to each other and the tractor. Heavy combination trucks are typically used for shipping radioactive wastes. Truck accident rates are computed for each state on the basis of statistics compiled by the DOT Office of Motor Carriers (OMC) from 1986 to 1988. Saricks and Kvitek (1994) present accident involvement counts, estimated kilometers of travel by state, and the corresponding average accident involvement rate for the three years investigated. These state-specific truck accident rates for interstate highways in rural and urban areas and also for primary and secondary highways are provided in Table 6.20. The interstate highway rates are suitable for most transportation risk assessments because the interstate system generally provides the safest and quickest route for shipments.

Saricks and Kvitek (1994) also point out that shippers and carriers of radioactive material generally have a higher-than-average awareness of transportation risk and prepare cargos and drivers for such shipments accordingly. This preparation should have the twofold effect of reducing component and equipment failure and mitigating the contribution of human error to accident causation. These effects were not considered in the compilation of data.

Saricks and Tompkins (1999) updated 1986–1988 statistics with those from 1994–1996 to include heavy combination truck accident statistics. These newer accident rate data from Saricks and Tompkins (1999) are provided alongside the older data from Saricks and Kvitek (1994) in Table 6.20. Part of the impetus behind the 1999 study was to complete the interstate highway system network. Uncompleted links in the interstate network still remained in a few states as of 1988. Such discontinuity 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 reported. The following excerpt from Saricks and Tompkins (1999) discusses the differences in the data used for the two studies:

Table 6.20. Combination Truck Accident Rates by State

State	Accidents/km								
	Saricks and Tompkins (1999)				Saricks and Kvitek (1994)				
					Interstate				
	Interstate	Primary	Other	Total	Rural	Urban	Total	Primary	Secondary
Alabama	2.82E–07	5.22E–07	2.88E–07	3.77E–07	1.26E–07	4.68E–07	1.85E–07	5.16E–07	3.96E–07
Arizona	1.32E–07	8.10E–08	4.00E–09	1.07E–07	1.60E–07	2.71E–07	1.76E–07	2.12E–07	1.45E–07
Arkansas	1.34E–07	2.33E–07	2.30E–08	1.48E–07	1.73E–07	4.82E–07	2.09E–07	4.69E–07	6.84E–07
California	1.60E–07	4.50E–08	1.79E–07	8.30E–8	1.64E–07	1.92E–07	1.76E–07	1.15E–07	2.22E–07
Colorado	4.46E–07	3.81E–07	5.46E–07	4.34E–07	2.76E–07	6.28E–07	3.60E–07	4.11E–07	4.42E–07
Connecticut	9.04E–07	3.47E–07	3.19E–06	8.82E–07	4.60E–07	2.67E–07	3.23E–07	2.56E–07	9.09E–07
Delaware	5.18E–07	8.04E–07	1.31E–06	7.25E–07	0.00E+00	2.56E–07	2.56E–07	7.35E–07	4.81E–07
Florida	6.90E–08	7.50E–08	3.75E–07	8.90E–08	1.21E–07	2.25E–07	1.50E–07	3.73E–07	6.33E–07
Georgia	*[a]	*	*	6.69E–07	1.65E–07	4.87E–07	2.28E–07	6.15E–07	4.04E–07
Idaho	2.95E–07	5.12E–07	5.19E–07	3.95E–07	2.30E–07	1.73E–07	2.22E–07	4.93E–07	2.29E–07
Illinois	2.22E–07	2.74E–07	1.38E–06	2.96E–07	1.76E–07	8.75E–07	3.53E–07	6.40E–07	1.78E–07
Indiana	2.25E–07	1.38E–07	4.30E–08	1.69E–07	1.92E–07	4.58E–07	2.43E–07	4.72E–07	2.80E–07
Iowa	1.12E–07	1.72E–07	2.47E–07	1.48E–07	1.78E–07	3.54E–07	2.02E–07	4.03E–07	1.24E–07
Kansas	2.84E–07	5.17E–07	3.14E–07	3.83E–07	2.04E–07	4.48E–07	2.56E–07	5.11E–07	1.38E–07
Kentucky	3.10E–07	1.03E–06	5.33E–07	5.18E–07	1.46E–07	5.13E–07	1.99E–07	5.74E–07	8.80E–07
Louisiana	*	*	*	2.21E–07	1.30E–07	3.54E–07	1.88E–07	3.53E–07	2.39E–07
Maine	4.39E–07	1.88E–07	7.39E–07	4.12E–07	2.44E–07	9.03E–07	2.93E–07	5.44E–07	2.28E–07
Maryland	5.40E–07	8.16E–07	2.75E–06	7.41E–07	3.95E–07	3.08E–07	3.46E–07	3.56E–07	1.24E–06
Massachusetts	8.60E–08	1.81E–07	1.29E–06	1.55E–07	6.47E–07	1.42E–07	2.68E–07	3.43E–07	4.61E–06
Michigan	2.83E–07	9.50E–08	6.17E–07	2.15E–07	1.59E–07	3.16E–07	2.12E–07	2.68E–07	8.10E–08
Minnesota	1.71E–07	1.90E–07	1.31E–07	1.76E–07	2.06E–07	2.66E–07	2.29E–07	4.19E–07	2.16E–07
Mississippi	4.80E–08	8.70E–08	3.90E–08	6.30E–08	1.19E–07	2.01E–07	1.35E–07	4.48E–07	6.50E–08
Missouri	4.64E–07	5.38E–07	9.29E–07	5.36E–07	1.78E–07	5.18E–07	2.61E–07	5.36E–07	2.49E–07
Montana	6.20E–07	6.08E–07	3.50E–07	5.81E–07	2.52E–07	1.00E–06	2.89E–07	5.38E–07	1.02E–07
Nebraska	3.19E–07	5.82E–07	4.97E–07	4.34E–07	1.77E–07	6.97E–07	2.09E–07	3.62E–07	9.90E–08
Nevada	2.25E–07	3.80E–07	2.90E–08	2.45E–07	1.57E–07	6.33E–07	1.97E–07	4.35E–07	3.17E–07
New Hampshire	2.63E–07	3.86E–07	6.79E–07	3.81E–07	1.39E–07	2.20E–08	1.18E–07	4.36E–07	3.33E–07

Table 6.20. Combination Truck Accident Rates by State (Continued)

State	Accidents/km								
	Saricks and Tompkins (1999)				Saricks and Kvitek (1994)				
					Interstate				
	Interstate	Primary	Other	Total	Rural	Urban	Total	Primary	Secondary
New Jersey	5.65E–07	2.67E–07	2.88E–06	4.93E–07	7.65E–07	2.77E–07	4.24E–07	6.80E–07	9.69E–07
New Mexico	1.13E–07	1.02E–07	1.03E–07	1.08E–07	1.92E–07	9.64E–07	2.35E–07	4.77E–07	1.22E–06
New York	*	*	*	3.45E–07	2.93E–07	5.69E–07	3.98E–07	3.16E–07	9.48E–07
North Carolina	3.46E–07	3.14E–07	3.69E–07	3.34E–07	2.28E–07	5.92E–07	2.97E–07	5.17E–07	6.37E–07
North Dakota	3.02E–07	4.87E–07	1.37E–07	3.42E–07	9.90E–08	4.40E–07	1.18E–07	1.99E–07	4.00E–08
Ohio	1.64E–07	3.80E–08	9.10E–08	1.16E–07	2.27E–07	3.16E–07	2.52E–07	4.42E–07	1.10E–06
Oklahoma	2.68E–07	3.16E–07	2.31E–07	2.76E–07	1.47E–07	3.76E–07	1.91E–07	3.61E–07	1.73E–07
Oregon	*	*	*	2.16E–07	2.20E–07	3.99E–07	2.48E–07	4.17E–07	1.63E–07
Pennsylvania	5.14E–07	7.26E–07	2.15E–06	6.79E–07	3.60E–07	3.02E–07	3.48E–07	7.21E–07	7.92E–07
Rhode Island	3.15E–07	3.66E–07	6.54E–07	3.52E–07	1.98E–07	2.27E–07	2.16E–07	1.37E–07	1.67E–06
South Carolina	*	*	*	4.69E–07	1.83E–07	3.13E–07	1.99E–07	6.27E–07	2.27E–07
South Dakota	2.33E–07	2.49E–07	1.54E–07	2.29E–07	2.09E–07	8.57E–07	2.18E–07	3.94E–07	1.49E–07
Tennessee	1.23E–07	2.81E–07	1.55E–07	1.59E–07	1.48E–07	7.97E–07	2.48E–07	5.56E–07	6.26E–07
Texas	6.00E–07	6.96E–07	7.36E–07	6.58E–07	1.56E–07	2.74E–07	2.00E–07	2.78E–07	1.09E–07
Utah	2.90E–07	3.05E–07	9.04E–07	3.40E–07	2.41E–07	2.52E–07	2.44E–07	3.70E–07	5.00E–07
Vermont	1.88E–07	5.27E–07	1.43E–07	2.98E–07	1.38E–07	0.00E+00	1.33E–07	6.30E–07	6.80E–07
Virginia	3.93E–07	1.98E–07	1.60E–08	2.65E–07	2.54E–07	2.63E–07	2.56E–07	4.67E–07	5.03E–07
Washington	2.65E–07	1.75E–07	1.23E–07	2.05E–07	2.50E–07	1.61E–07	2.10E–07	2.62E–07	7.30E–08
West Virginia	1.72E–07	3.71E–07	1.38E–07	2.15E–07	3.10E–07	2.95E–07	3.07E–07	1.17E–06	7.87E–07
Wisconsin	4.49E–07	3.96E–07	1.57E–06	5.51E–07	1.74E–07	5.29E–07	2.18E–07	2.80E–07	3.24E–07
Wyoming	6.74E–07	7.41E–07	5.56E–07	6.78E–07	3.42E–07	2.98E–07	3.40E–07	3.41E–07	3.70E–07
Mean Rate	3.15E–07	3.66E–07	6.54E–07	3.52E–07	2.03E–07	3.58E–07	2.44E–07	3.94E–07	3.98E–07
Total Rate	3.00E–07	2.78E–07	4.56E–07	3.21E–07	–[b]	–	–	–	–

Until March 4, 1993, Part 394 of Title 49 of the Code of Federal Regulations required motor carriers to submit accident reports to the Federal Highway Administration (FHWA) in the so-called "50-T" reporting format. The master file compiled from entering the data on these reports in FHWA's Office of Motor Carriers (OMC) was the basis of accident, fatality, and injury rates developed for the 1994 Argonne National Laboratory document [Saricks and Kvitek 1994]. By Final Rule of February 2, 1993 [58 ***FR*** *6726], the reporting requirement was removed; instead of submitting reports, carriers were now required to maintain a register of accidents meeting the definition of an accident (see below) for a period of one year after such an accident occurred. Carriers were to make the contents of these registers available to FHWA agents investigating specific accidents. They were also required to give "…all reasonable assistance in the investigation of any accident including providing a full, true, and correct answer to any question or inquiry," to reveal whether hazardous materials other than spilled fuel from the fuel tanks were released, and to furnish copies of all state-required accident reports [49* ***CFR*** *390.15]. The reason for this change in rule was the emergence of an automated state accident reporting system compiled from law enforcement accident reports that, pursuant to provisions of the Intermodal Surface Transportation Efficiency Act (ISTEA) of 1991 [PL 102-240, 105 STAT. 1914], was being established under the Motor Carrier Safety Assistance Program (MCSAP). Under Section 408 of Title IV of the Motor Carrier Act of 1991, a component of ISTEA, the Secretary of Transportation is authorized to make grants to states in order to help them achieve uniform implementation of the police accident reporting system for truck and bus accidents recommended by the National Governors' Association. Under this system, called SAFETYNET, accident data records generated by each state follow identical formatting and content instructions; the records are entered on approximately a weekly basis into a federally maintained database. This database is in turn compiled and managed by a DOT contractor as part of the Motor Carrier Management Information System (MCMIS).*

Motor carrier reporting rules in 49 ***CFR*** *390.5 define an accident as an occurrence involving a commercial motor vehicle operating on a public road that results in (1) a fatality and/or (2) bodily injury to a person that requires medical treatment away from the accident scene; and/or (3) one or more involved motor vehicles incurring disabling damage as a result of the accident such that the vehicle must be towed from the scene. Specifically excluded from this definition of "accident" are occurrences involving only boarding and alighting from a stationary vehicle, involving only the loading or unloading of cargo, or involving a passenger car or other multipurpose passenger vehicle owned by the carrier that is transporting neither passengers for hire nor placard-quantity hazardous materials. The latter exclusions represent a key difference between this definition and the immediate reporting requirements for hazardous materials incidents under 49* ***CFR*** *171.15, which stipulate the following criteria:*

- *Fatality*

- *Injury requiring hospitalization*
- *Total property damage in excess of $50,000 (tow-aways may not meet this threshold, but total damage could meet this criterion without a tow-away)*
- *An evacuation of the general public lasting at least one hour*
- *Closure of one or more major transportation arteries or facilities for at least one hour*
- *Alteration of an aircraft's routine flight plan (not relevant to surface modes)*
- *Fire, breakage, spillage, or suspected radioactive contamination during shipment of radioactive material*
- *Fire, breakage, spillage, or suspected contamination during shipment of etiologic agents*
- *Release of a marine pollutant in quantity exceeding 450 liters (119 gal) for liquids or 400 kg (882 lb) for solids*
- *A decision by the carrier that a reportable situation (e.g., continuing danger to life at the scene) exists.*

Thus, reportable accidents under MCSAP are far more exclusionary than for reportable hazardous materials situations, which include not only release of cargo wherever it may occur but also impacts on uninvolved parties (i.e., the general public) and also give reporting discretion to carriers not authorized under law-enforcement-based incident accounting systems.

■ ■ ■ 6.1.9.2 Rail

The FRA divides rail accidents/incidents into three major categories for reporting purposes (DOT, 1998): (1) highway-rail grade crossing incidents, (2) train accidents, and (3) other incidents. The definition of each is given in the following excerpt from Saricks and Tompkins (1999):

Under 49 ***USC*** *20901, rail carriers must file a report with the Secretary of Transportation, not later than 30 days after the end of each month in which an accident or incident occurs, that states the nature, cause, and circumstances of the reported accident or incident. The format for such reports is provided by the Federal Railroad Administration (FRA) under 49* ***CFR*** *225.11. The criteria for a reportable accident or incident currently encoded in 49* ***CFR*** *Part 225 are as follows:*

- *An impact occurs between railroad on-track equipment and (a) a motorized or non-motorized highway or farm vehicle, (b) a pedestrian, or (c) other highway user at a highway-rail crossing.*

- *A collision, derailment, fire, explosion, act of God, or other event involving the operation of standing or moving railroad on-track equipment results in aggregate damage (to on-track equipment, signals, track and/or other track structures, and/or roadbed) of more than $6,300 (as of 1998).*

- *An event arising from railroad operation that results in (a) the death of one or more persons; (b) injury to one or more persons, other than railroad employees, that requires medical treatment; (c) injury to one or more employees that requires medical treatment or results in restriction of work or motion for one or more days, one or more lost work days, transfer to another job, termination of employment, or loss of consciousness; and/or (d) any occupational illness of a railroad employee diagnosed by a physician.*

Certain types of railroad carriers are exempted from these requirements, specifically (1) those owning or operating on track entirely within a facility not part of the general freight railroad system; (2) rail urban mass transit operations not connected to the general railroad transportation system; and (3) those owning or operating an exclusively passenger-hauling railroad entirely within an installation isolated from the general freight railroad system. (The definition of isolation, or insularity, of operations in this last category excludes any situations involving one or more at-grade crossings of (active) public roads or other railroads, bridges over public roads or commercially navigated waterways, or operations conducted within 30 feet of any other (active) railroad.) Partial relief from requirements is also available for rail carriers with 15 or fewer employees covered by the hours of service law of 49 ***USC*** *21101-21107, or that own or operate track exclusively off the general system. For purposes of this analysis, the entities subject to full reporting requirements are sufficiently comprehensive.*

Carriers covered by these requirements must fulfill several bookkeeping tasks. FRA requires submittal of a monthly status report, even if there were no reportable events during the period. Accidents and incidents must be reported on the FRA standardized form, but certain types of incidents require immediate telephone notification. Logs of both reportable injuries and on-track incidents must be maintained by each railroad on which they occur, and a listing of such events must be posted and made available to employees and to the FRA, along with required records and reports, upon request for them. The consolidated data entries extracted from the FRA reporting forms are consolidated into an accident/incident database that separates reportable accidents from grade-crossing incidents. These are annually processed into event, fatality, and injury count tables as part of the Accident/Incident Bulletin.

Rail accident rates are computed and presented similarly to truck accident rates in Saricks and Kvitek (1994); 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 FRA. As provided in Table 6.21, rail accident rates include both mainline accidents and those occurring in railyards. The updated report by Saricks and Tompkins (1999) compiles FRA

Table 6.21. Rail Accident Rates by State

State	Saricks and Tompkins (1999)		Saricks and Kvitek (1994)	
	Accidents Per Car-km	Grade Crossing Incidents per Car-km	Accidents per Car-km	
			Total	Mainline Only
Alabama	2.96E–08	1.67E–07	4.80E–08	2.75E–08
Arizona	1.65E–08	1.86E–08	1.75E–08	1.30E–08
Arkansas	7.56E–08	1.62E–07	6.78E–08	3.54E–08
California	4.98E–08	5.82E–08	5.10E–08	2.51E–08
Colorado	3.67E–08	3.35E–08	1.73E–08	1.02E–08
Connecticut	3.06E–06	3.66E–07	2.83E–07	1.01E–07
Delaware	3.88E–07	3.88E–07	1.77E–07	1.11E–07
District of Columbia	2.29E–06	1.09E–07	1.17E–06	7.81E–07
Florida	4.63E–08	9.56E–08	4.02E–08	2.21E–08
Georgia	3.06E–08	1.04E–07	6.44E–08	2.84E–08
Idaho	6.41E–08	7.39E–08	7.01E–08	4.14E–08
Illinois	9.53E–08	7.43E–08	1.07E–07	2.97E–08
Indiana	4.56E–08	1.85E–07	4.64E–08	1.93E–08
Iowa	6.31E–08	1.02E–07	1.47E–07	7.16E–08
Kansas	4.41E–08	6.13E–08	3.61E–08	1.75E–08
Kentucky	2.82E–08	8.21E–08	4.48E–08	2.44E–08
Louisiana	1.25E–07	3.86E–07	1.24E–07	4.28E–08
Maine	2.62E–07	4.37E–07	3.78E–07	1.85E–07
Maryland	4.49E–08	4.10E–08	5.62E–08	2.58E–08
Massachusetts	2.39E–07	2.33E–07	1.17E–07	4.97E–08
Michigan	1.55E–07	3.78E–07	1.65E–07	7.19E–08
Minnesota	7.59E–08	1.11E–07	8.48E–08	3.16E–08
Mississippi	1.42E–07	2.47E–07	1.15E–07	8.51E–08
Missouri	3.62E–08	5.01E–08	5.28E–08	2.56E–08
Montana	3.42E–08	1.83E–08	1.73E–08	1.10E–08
Nebraska	4.60E–08	3.75E–08	4.63E–08	2.56E–08
Nevada	5.77E–09	3.71E–09	3.23E–08	2.19E–08
New Hampshire	2.61E–07	3.05E–07	2.15E–07	1.72E–07
New Jersey	1.99E–07	1.75E–07	1.24E–07	4.82E–08
New Mexico	1.14E–08	1.10E–08	9.40E–09	6.60E–09
New York	2.03E–07	5.53E–08	8.32E–08	4.30E–08
North Carolina	6.10E–08	2.88E–07	5.70E–08	2.27E–08
North Dakota	4.42E–08	3.17E–08	2.41E–08	1.80E–08
Ohio	3.46E–08	1.08E–07	4.73E–08	2.12E–08
Oklahoma	5.14E–08	1.07E–07	4.66E–08	2.72E–08
Oregon	9.73E–08	9.33E–08	1.25E–07	5.77E–08
Pennsylvania	9.38E–08	6.96E–08	4.38E–08	2.69E–08
Rhode Island	4.03E–06	4.03E–06	1.05E–06	0
South Carolina	6.92E–08	3.42E–07	5.11E–08	3.31E–08
South Dakota	1.18E–07	1.05E–07	1.02E–07	9.09E–08

Table 6.21. Rail Accident Rates by State (Continued)

State	Saricks and Tompkins (1999)		Saricks and Kvitek (1994)	
	Accidents Per Car-km	Grade Crossing Incidents per Car-km	Accidents per Car-km	
			Total	Mainline Only
Tennessee	4.43E–08	9.83E–08	5.59E–08	1.88E–08
Texas	5.05E–08	1.05E–07	7.12E–08	3.16E–08
Utah	5.87E–08	5.94E–08	5.78E–08	2.31E–08
Vermont	1.74E–07	1.07E–07	1.52E–07	1.16E–07
Virginia	4.66E–08	8.35E–08	4.35E–08	1.91E–08
Washington	8.46E–08	8.93E–08	3.49E–08	1.44E–08
West Virginia	3.17E–08	5.30E–08	9.61E–08	7.42E–08
Wisconsin	1.27E–07	2.55E–07	1.65E–07	7.66E–08
Wyoming	2.40E–08	4.90E–09	3.10E–08	1.97E–08
Mean Rate	2.74E–07	2.16E–07	5.57E–08	2.66E–08
Total	5.39E–08	8.64E–08	–[a]	–

[a] – = rate not provided.

accident data from the years 1994–1996. Accident rates and grade crossing incidents from this latter report are presented in Table 6.21. 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 the overall rate may overestimate the accident rate. Many grade crossing incidents are not reportable accidents, but may involve injuries and fatalities, as presented in Section 6.2.1.2.

■ ■ 6.1.10 Accident Release Parameters

The amount of radioactive material released from a transportation accident depends on the packaging of the material and the severity of the accident. In an effort to quantify such releases for risk assessments, release fractions for different types of packaging were estimated for a series of accident severity categories.

■ ■ ■ 6.1.10.1 Accident Severity Categories

The severity of an accident depends on such factors as impact speed and geometry, type of object impacted, crush, puncture, fire, and immersion. Clarke et al. (1976) studied accident characteristics involving shipments by airplane, truck, and train. The study focused on shipments with smaller, multiple packages. A follow-up study by Dennis et al. (1978) focused on larger package (greater than 2 tons) shipments (e.g., SNF) made by truck or train. Other studies focused primarily on accidents involving SNF shipments (Wilmot, 1981; Fischer et al., 1987; Sprung, et al., 2000). A recent study considered the severities of tractor semi-trailer accidents and their application to HAZMAT transport (Clauss et al., 1994).

NUREG-0170

A method widely used to characterize the potential severity of transportation-related accidents is described in the NRC report NUREG-0170 (NRC, 1977a). The NRC method divided the spectrum of transportation accident severities into eight categories. The NUREG-0170 accident classification scheme is shown in Figure 6.8 for truck transportation and in Figure 6.9 for rail transportation.

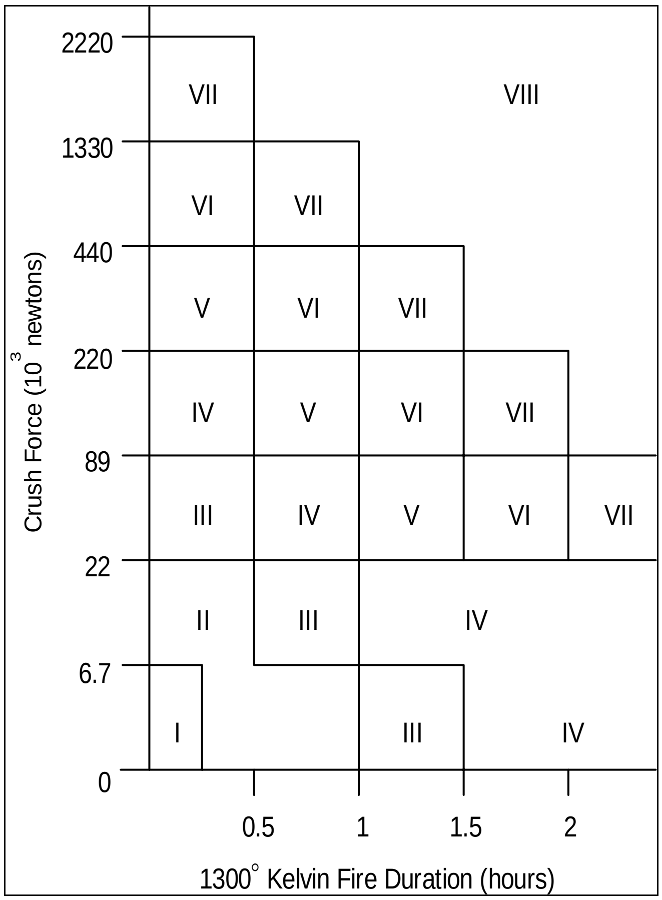

Figure 6.8. Scheme for NUREG-0170 Classification by Accident Severity Category for Truck Accidents (Source: NRC, 1977a)

Severity is described as a function of the mechanical force and thermal force (fire) magnitudes to which a package may be subjected during an accident. The mechanical criterion for truck shipments in the NUREG-0170 analysis was the crush force, using the results from Foley et al. (1974). For train shipments, puncture and impact speed were considered the primary mechanical forces, using data from Clarke et al. (1976). Because all accidents can be described in these terms, severity is independent of the specific accident sequence. In other words, any accident in which a package is subjected to forces within a certain range of values is assigned to the accident severity category associated with that range. The scheme for accident severity in NUREG-0170 takes into account all credible transportation-related accidents, including those with low probability but high consequences and those with high probability but low consequences.

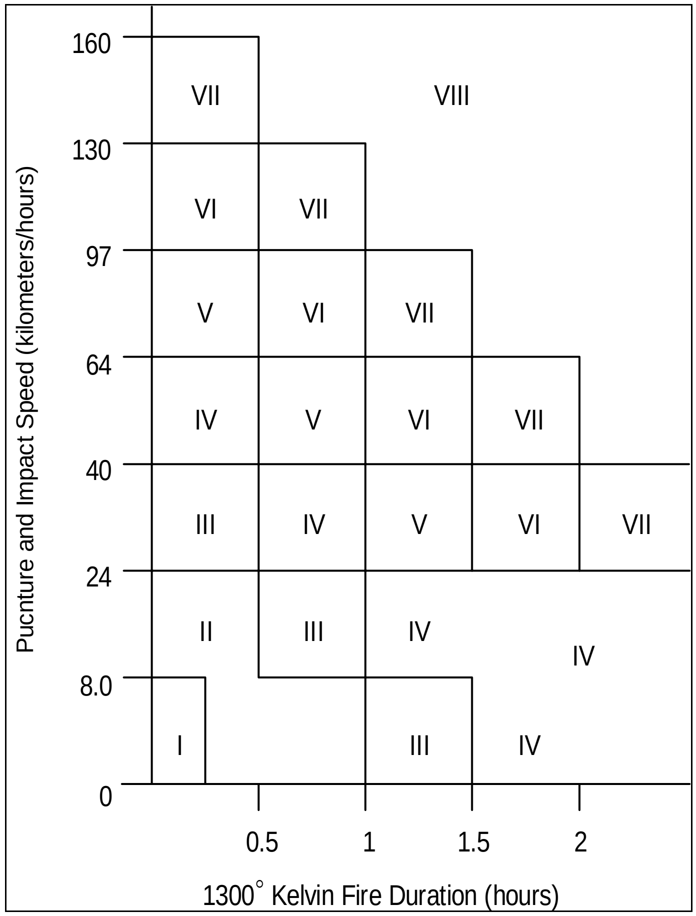

Figure 6.9. Scheme for NUREG-0170 Classification by Accident Severity Category for Rail Accidents (Source: NRC 1977a)

The fractional occurrences for accidents in the accident severity category and the population density zone used in NUREG 0170 are shown in Table 6.22.

Category I accidents are the least severe but the most frequent; Category VIII accidents are very severe, resulting in the largest releases of radioactive material, but are very infrequent. To determine the expected frequency of a given accident's severity, the conditional probability in the category is multiplied by the baseline accident rate. Each population density zone has a distinct baseline accident rate and distribution of accident severities related to differences in average vehicular velocity, traffic density, and other factors, including location (rural, suburban, or urban). Category VIII accidents are extremely rare, occurring approximately once in every 70,000 truck or 100,000 rail accidents involving a radioactive waste shipment.

Modal Study

The responses of SNF casks under a range of highway and railway accident conditions were investigated by LLNL for the NRC (Fischer et al., 1987). The results of the NRC Modal Study are often used to categorize potential SNF transportation accidents. In the NRC Modal Study all potential damage to a shipping cask during an accident is categorized according to two principal

Table 6.22. Fractional Occurrences for Accidents by Severity Category and Population Density Zone

Severity Category	Fractional Occurrence	Fractional Occurrence by Population Density Zone		
		Rural	Suburban	Urban
Truck				
I	5.5E-01	1.0E-01	1.0E-01	8.0E-01
II	3.6E-01	1.0E-01	1.0E-01	8.0E-01
III	7.0E-02	3.0E-01	4.0E-01	3.0E-01
IV	1.6E-02	3.0E-01	4.0E-01	3.0E-01
V	2.8E-03	5.0E-01	3.0E-01	2.0E-01
VI	1.1E-03	7.0E-01	2.0E-01	1.0E-01
VII	8.5E–05	8.0E-01	1.0E-01	1.0E-01
VIII	1.5E–05	9.0E-01	5.0E-02	5.0E-02
Rail				
I	5.0E-01	1.0E-01	1.0E-01	8.0E-01
II	3.0E-01	1.0E-01	1.0E-01	8.0E-01
III	1.8E-01	3.0E-01	4.0E-01	3.0E-01
IV	1.8E-02	3.0E-01	4.0E-01	3.0E-01
V	1.8E-03	5.0E-01	3.0E-01	2.0E-01
VI	1.3E–04	7.0E-01	2.0E-01	1.0E-01
VII	6.0E–05	8.0E-01	1.0E-01	1.0E-01
VIII	1.0E–05	9.0E-01	5.0E-02	5.0E-02

Source: NRC (1977a).

variables: the cask structural and thermal responses induced by cask impact and fire, respectively. Twenty cask response regions (or categories) based on varying levels of cask strain and temperature are categorized to represent the entire spectrum of transportation accidents, ranging from regions with high probability and low impacts to regions with low probability and high impacts. These cask response regions and the conditional probabilities of occurrence for combined mechanical and thermal loads, should an accident occur, are shown in Figure 6.10.

The most important accident conditions that define the mechanical loads imposed on a cask during an accident are those associated with various impacts. Because of the large weight, hardness, and rigidity of SNF casks, loads caused by crushing, projectiles, or other mechanisms are far less damaging than loads caused by impacts with hard, massive objects. As in any impact involving a motor vehicle or train, the damage sustained would depend on vehicle speed, angle of impact, hardness of the object struck, and orientation of the vehicle and object at the time of impact.

The temperature of an accident-generated fire is the most important consideration when assessing potential cask functional degradation. The cumulative heat affecting a cask depends not only on the temperature and duration of the fire, but also on the extent to which the cask is exposed. Data on fire temperatures and durations may be obtained from descriptions of severe accidents (see the RMIR available via TRANSNET); however, conservative estimates of fire temperatures and durations can be calculated based on pertinent information about the accident,

Legend:

(P_t) = Probability of occurrence assuming a truck accident occurs.
(P_r) = Probability of occurrence assuming a rail accident occurs.
The number in the upper right-hand corner of each cell represents RISKIND cask response region numbering.

Structural Response (maximum strain on inner shell, %)					
	R(4,1) 4 (P_t)1.532 × 10^{-7} (P_r)1.786 × 10^{-9}	R(4,2) 8 3.926 × 10^{-14} 3.290 × 10^{-13}	R(4,3) 12 1.495 × 10^{-14} 2.137 × 10^{-13}	R(4,4) 16 7.681 × 10^{-16} 1.644 × 10^{-13}	R(4,5) 20 <1 × 10^{-16} 3.459 × 10^{-14}
S_3 (30)					
	R(3,1) 3 (P_t)1.7984 × 10^{-3} (P_r)5.545 × 10^{-4}	R(3,2) 7 1.574 × 10^{-7} 1.021 × 10^{-7}	R(3,3) 11 2.034 × 10^{-7} 6.634 × 10^{-8}	R(3,4) 15 1.076 × 10^{-7} 5.162 × 10^{-8}	R(3,5) 19 4.873 × 10^{-8} 5.296 × 10^{-8}
S_2 (2)					
	R(2,1) 2 (P_t)3.8192 × 10^{-3} (P_r)2.7204 × 10^{-3}	R(2,2) 6 2.330 × 10^{-7} 5.011 × 10^{-7}	R(2,3) 10 3.008 × 10^{-7} 3.255 × 10^{-7}	R(2,4) 14 1.592 × 10^{-7} 2.531 × 10^{-7}	R(2,5) 18 7.201 × 10^{-8} 1.075 × 10^{-8}
S_1 (0.2)					
	R(1,1) 1 (P_t)0.994316 (P_r)0.993962	R(1,2) 5 1.687 × 10^{-5} 1.2275 × 10^{-3}	R(1,3) 9 2.362 × 10^{-5} 7.9511 × 10^{-4}	R(1,4) 13 1.525 × 10^{-5} 6.140 × 10^{-4}	R(1,5) 17 9.570 × 10^{-6} 1.249 × 10^{-4}
		T_1 (500)	T_2 (600)	T_3 (650)	T_4 (1050)

Thermal Response (lead midlayer thickness temperature, °F)

Figure 6.10. NRC Modal Study SNF Cask Response Regions and Conditional Probabilities (Source: Fischer et al., 1987).

such as the maximum fuel volume carried by a typical tank truck and the nature of the product being shipped. Another accident condition required to describe cask response is the location of a cask relative to the fire during an accident.

If the severity of a single, well-defined accident needs to be assessed, the above information can be used with the Modal Study methodology to obtain the result with hand calculations. The modal study methodology for determining SNF transportation accident severities is also incorporated in the RISKIND computer code (Yuan et al., 1995), where the user can enter the pertinent accident characteristics and the program will determine the appropriate severity category.

Reexamination of SNF Shipment Risk: NUREG/CR-6672

More recently, a reexamination of the behavior of spent fuel casks in severe accidents was conducted by Sprung et al. (2000). Accident event trees were constructed for both truck and rail transport of SNF casks. Based on the structural and thermal response characteristics of two generic cask designs, 31 truck accident scenarios leading to a potential release of radioactivity were assigned to 18 accident severity categories. Likewise, 25 train accident scenarios were assigned to 20 accident severity categories. Table 6.23 lists the conditional probabilities associated with each case.

Table 6.23. Estimated Severity Fractions (Conditional Probabilities) for SNF Shipments[a]

Case	Truck Cask			
	Steel-DU-Steel		Steel-Land-Steel	
	3 PWR Assemblies	7 BWR Assemblies	1 PWR Assembly	2 BWR Assemblies
1	1.53E–08	1.53E–08	1.53E–08	1.53E–08
2	5.88E–05	5.88E–05	6.19E–05	6.19E–05
3	1.81E–06	1.81E–06	2.81E–07	2.81E–07
4	7.49E–08	7.49E–08	6.99E–08	6.99E–08
5	4.65E–07	4.65E–07	4.89E–07	4.89E–07
6	3.31E–09	3.31E–09	9.22E–11	9.22E–11
7	0.00E+00	0.00E+00	3.30E–12	3.30E–12
8	1.13E–08	1.13E–08	1.17E–08	1.17E–08
9	8.03E–11	8.03E–11	1.90E–12	1.90E–12
10	0.00E+00	0.00E+00	0.00E+00	0.00E+00
11	1.44E–10	1.44E–10	1.49E–10	1.49E–10
12	1.02E–12	1.02E–12	2.41E–14	2.41E–14
13	0.00E+00	0.00E+00	0.00E+00	0.00E+00
14	7.49E–11	7.49E–11	6.99E–11	6.99E–11
15	0.00E+00	0.00E+00	3.30E–15	3.30E–15
16	0.00E+00	0.00E+00	0.00E+00	0.00E+00
17	0.00E+00	0.00E+00	0.00E+00	0.00E+00
18	5.86E–06	5.86E–06	5.59E–06	5.59E–06
19	0.99993	0.99993	0.99993	0.99993
	1.00000	1.00000	1.00000	1.00000

Case	Rail Cask			
	Monolithic		Steel-Land-Steel	
	24 PWR Assemblies	52 BWR Assemblies	24 PWR Assembly	52 BWR Assemblies
1	4.49E–09	4.49E–09	8.20E–06	8.20E–06
2	1.17E–07	1.17E–07	5.68E–07	5.68E–07
3	4.49E–09	4.49E–09	4.49E–09	4.49E–09
4	3.05E–05	3.05E–05	2.96E–05	2.96E–05
5	1.01E–06	1.01E–06	8.24E–07	8.24E–07
6	1.51E–08	1.51E–08	1.10E–07	1.10E–07
7	7.31E–08	7.31E–08	6.76E–08	6.76E–08
8	2.43E–09	2.43E–09	1.88E–09	1.88E–09
9	3.61E–11	3.61E–11	2.51E–10	2.51E–10
10	9.93E–10	9.93E–10	4.68E–09	4.68E–09
11	3.30E–11	3.30E–11	1.31E–10	1.31E–10
12	4.91E–13	4.91E–13	1.74E–11	1.74E–11
13	3.82E–11	3.82E–11	3.70E–11	3.70E–11
14	1.27E–12	1.27E–12	1.03E–12	1.03E–12

Table 6.23. Estimated Severity Fractions (Conditional Probabilities) for SNF Shipments[a] (Continued)

Case	Rail Cask			
	Monolithic		Steel-Land-Steel	
	24 PWR Assemblies	52 BWR Assemblies	24 PWR Assembly	52 BWR Assemblies
15	1.88E–14	1.88E–14	1.37E–13	1.37E–13
16	5.69E–11	5.69E–11	4.15E–10	4.15E–10
17	3.61E–14	3.61E–14	2.51E–13	2.51E–13
18	4.91E–16	4.91E–16	1.74E–14	1.74E–14
19	1.88E–17	1.88E–17	1.37E–16	1.37E–16
20	6.32E–06	6.32E–06	4.91E–05	4.91E–05
21	0.99996	0.99996	0.99991	0.99991
	1.00000	1.00000	1.00000	1.00000

[a] Source – Sprung et al. (2000).

6.1.10.2 Release Fractions

The human health hazard from radioactive material shipment accidents results from exposure to material released from the shipping package or when cask shielding is decreased or lost. Once released to the environment, any amount of the released fraction that is aerosolized (the airborne radioactive plume) will be dispersed by atmospheric turbulence. This plume of material is a source of external exposure (cloudshine). The respirable fraction of this aerosolized material may also contribute to inhalation exposure. Over time and distance, the aerosolized material that does not exhibit ideal gas behavior will deposit on the ground, where it (1) remains a source of external exposure (groundshine); (2) may contaminate foodstuffs, thereby contributing to exposure via ingestion; and (3) may again contribute to inhalation and cloudshine exposure via resuspension. The estimated radiological accident impacts in the different exposure pathway analyses will vary linearly with the amount of material released.

Radiological consequences are calculated by assigning package release fractions to each accident severity category. The release fraction is defined as the fraction of the radioactive material in a package that could be released during an accident of a certain severity. Release fractions take into account all mechanisms necessary to release radioactive material from a damaged package to the environment. Release fractions vary according to the package type and the physical form of the waste. Type B packagings, such as SNF casks, are designed to withstand the forces of severe accidents and, therefore, have smaller release fractions than Type A packagings, such as 55-gal drums.

The physical form of the waste also determines the aerosolized and respirable fractions. Many solid materials are difficult to release in particulate form and are, therefore, relatively nondispersible. Conversely, liquid or gaseous materials are relatively easy to release if the container is compromised in an accident. A compendium of experimental data was assembled from which airborne release fractions and respirable fractions may be derived for specific materials (DOE, 1994b).

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Package release fractions for accidents of each severity category are given in Table 6.24 for generic Type A and Type B packages, as suggested in NUREG-0170 (NRC, 1977a). These values are conservative because of the lack of data on package failure under severe conditions. Table 6.25 provides estimates for the aerosol and respirable fractions commonly used in transportation risk assessments based on data in NUREG-0170 for different types of materials.

Table 6.24. Package Release Fractions from NUREG-0170

Severity Category	Release Fraction by Package Type	
	Type A	Type B
Truck		
I	0	0
II	0.01	0
III	0.1	0.01
IV	1	0.1
V	1	1
VI	1	1
VII	1	1
VIII	1	1
Rail		
I	0	0
II	0.01	0
III	0.1	0.01
IV	1	0.1
V	1	1
VI	1	1
VII	1	1
VIII	1	1

Source: NRC (1977a).

Table 6.25. Aerosol and Respirable Fractions of Released Material

Material	Aerosol Fraction	Respirable Fraction
Immobile	1×10^{-6}	0.05
Loose Chunks	0.01	0.05
Large Powder	0.05	0.05
Small Powder/Nonvolatile Liquids	0.1	0.05
Spent Fuel Particulates	1	0.05
Volatile Solid	1	1
Other	1	1
Gas	1	1
Flammable	1	1

Source: Neuhauser and Kanipe (1992); derived from data in NUREG-0170 (NRC, 1977a).

Transuranic Waste

Considerable effort was expended by the DOE in citing and constructing an underground repository for the disposal of the nation's TRUW at the WIPP in Carlsbad, New Mexico. The site received its first shipment in March 1999. Initial shipments consisted of CH-TRUW contained in TRUPACT-II containers, a Type B packaging. Shipments of RH-TRUW will be made in RH-72B Type B casks. More information on the TRUPACT-II and the RH-72B containers is available in DOE (1990) and DOE (1997d). Table 6.26 presents the latest estimated release fractions for TRUW shipped in TRUPACT-IIs for CH-TRUW or RH-72Bs for RH-TRUW (DOE, 1997d). These fractions were derived for use in the severity category scheme developed in NUREG-0170 and incorporate the aerosolized and respirable fractions based on the general characteristics of the TRUW.

Table 6.26. Total Respirable Release Fractions for TRU Waste Type B Containers

Accident Severity Category	CH-TRU (TRUPACT-II)	RH-TRU (RH-72B)
I	0	0
II	0	0
III	8×10^{-9}	6×10^{-9}
IV	2×10^{-7}	2×10^{-7}
V	8×10^{-5}	1×10^{-4}
VI	2×10^{-4}	1×10^{-4}
VII	2×10^{-4}	2×10^{-4}
VIII	2×10^{-4}	2×10^{-4}

Source: DOE (1997d).

Spent Nuclear Fuel

Perhaps the most familiar example of a radioactive material shipment is SNF in its massive Type B shipping cask. As discussed in Section 6.1.1.1, the packaging is the primary focus of regulations designed to prevent the release of radioactive materials to the environment from a transportation accident. The Type B shipping casks licensed by the NRC for SNF shipments were engineered to prevent accidental releases in all but the most severe cases. Because NUREG-0170 was based on best engineering judgments of cask response, the NRC conducted a rigorous analysis of potential releases from SNF casks as part of its Modal Study (Fischer et al., 1987). Both the Modal Study and NUREG/CR-6672 incorporated sophisticated structural and thermal engineering analyses of cask responses to impact and thermal loads. The casks studied met only the minimum regulatory requirements.

The Modal Study considered three mechanisms necessary in the establishment of a leak path for radioactive releases. The first is the diffusion of material from cracked pellets within the fuel rod to the outer fuel rod cladding; the second is a diffusing material leak from a breach in the fuel rod cladding into the interior of the shipping cask; and the third is a leak to the outside environment of the gases, vapors, and aerosolized particles previously released to the interior of the cask.

Before radioactive material is released into the cask cavity, the fuel-rod cladding must be breached during an accident as a result of high impact or high temperature. The percentage of fuel rods breached under various impact and fire conditions in a transportation accident is estimated in the Modal Study. After a fuel rod is breached, radioactive gases, volatiles, and solids can potentially escape into the cask cavity. Only rod burst and oxidation were considered significant release mechanisms in the Modal Study. It was conservatively assumed that all the released materials in the cask cavity would be released to the environment if a leak path developed in the containment (Fischer et al., 1987). A leak path is assumed to occur for any transportation accident resulting in a maximum strain in the inner containment shell greater than 0.2%, or in a lead midlayer thickness temperature exceeding 500°F.

The estimated radionuclide fractions for five types of radionuclides and the 20 Modal Study cask response regions released and dispersed to the atmosphere under the above assumptions are presented in Table 6.27. Radionuclides are grouped by physical and chemical behavior: particulates; ruthenium, cesium, and iodine isotopes (considered to be in the form of vapors); and noble or inert gases. Table 6.27 also gives release fractions derived for aluminum and metallic SNF (DOE, 1995b). Release fractions developed for graphite fuels are given in Table 6.28.

Table 6.27. Release Fractions for Transportation Accidents by SNF Type for the NRC Modal Study Cask Response Regions

Cask Response Region[a]	Release Fraction[b]				
	Inert Gas	Vapors			Particulates
		Iodine	Cesium	Ruthenium	
Modal Study[c]					
R(1,1)	0.0	0.0	0.0	0.0	0.0
R(1,2), R(1,3)	9.9×10^{-3}	7.5×10^{-5}	6.0×10^{-6}	8.1×10^{-7}	6.0×10^{-8}
R(2,1), R(2,2), R(2,3)	3.3×10^{-2}	2.5×10^{-4}	2.0×10^{-5}	2.7×10^{-6}	2.0×10^{-7}
R(1,4), R(2,4), R(3,4)	3.9×10^{-1}	4.3×10^{-3}	2.0×10^{-4}	4.8×10^{-5}	2.0×10^{-6}
R(3,1), R(3,2), R(3,3)	3.3×10^{-1}	2.5×10^{-3}	2.0×10^{-4}	2.7×10^{-5}	2.0×10^{-6}
R(1,5), R(2,5), R(3,5),R(4,5), R(4,1), R(4,2), R(4,3), R(4,4)	6.3×10^{-1}	4.3×10^{-2}	2.0×10^{-3}	4.8×10^{-4}	2.0×10^{-5}
Aluminum and Metallic SNF[d]					
R(1,1)	0	0	0	0	0
R(1,2),R(1,3)	9.9×10^{-3}	1.1×10^{-7}	3.0×10^{-8}	4.1×10^{-9}	3.0×10^{-10}
R(2,1),R(2,2),R(2,3)	3.3×10^{-2}	3.5×10^{-7}	1.0×10^{-7}	1.4×10^{-8}	1.0×10^{-9}
R(1,4),R(2,4),R(3,4)	3.9×10^{-1}	6.0×10^{-6}	1.0×10^{-6}	2.4×10^{-7}	1.0×10^{-8}
R(3,1),R(3,2),R(3,3)	3.3×10^{-1}	3.5×10^{-6}	1.0×10^{-6}	1.4×10^{-7}	1.0×10^{-8}
R(1,5),R(2,5),R(3,5),R(4,5), R(4,1),R(4,2), R(4,3),R(4,4)	6.3×10^{-1}	6.0×10^{-5}	1.0×10^{-5}	2.4×10^{-6}	1.0×10^{-7}

[a] R(N1,N2) represents the NRC Modal Study designation of discrete severity (cask response) regions, with N1 representing the impact strain and N2 representing the temperature caused by fire.
[b] The release fraction represents the fraction of the total fuel inventory in the cask that would be released into the atmosphere.
[c] Source: Fischer et al. (1987); values used for special-case commercial, university, foreign, and non-DOE research reactor SNF (Table I-27) in DOE (1995b).
[d] Applicable to N Reactor, SRS production reactor, and DOE research/test reactor fuel, Table I-28 (DOE, 1995b). Release fractions derived from Shibata et al. (1984) and Fischer et al. (1987).

Table 6.28. Release Fractions for Transportation Accidents Involving Graphite SNF for the NRC Modal Study Cask Response Regions

Cask Response Region[a]	Release Fractions[b]					
	Inert Gas[c]	Strontium, Cerium[d]	Antimony[e]	Cesium[d]	Ruthenium, Rhodium[e]	Particulates[f]
R(1,1)	0	0	0	0	0	0
R(1,2),R(1,3),R(1,4), R(2,1),R(2,2),R(2,3), R(2,4),R(3,1),R(3,2), R(3,3),R(3,4),R(4,1), R(4,2),R(4,3),R(4,4)	5.3×10^{-3}	3.7×10^{-7}	1.0×10^{-6}	2.4×10^{-7}	7.3×10^{-8}	1.0×10^{-9}
R(1,5),R(2,5),R(3,5), R(4,5)	1.2×10^{-2}	5.0×10^{-6}	1.0×10^{-6}	9.1×10^{-6}	7.3×10^{-8}	1.0×10^{-9}

[a] Source: Table I-29 (DOE, 1995b), R(N1,N2) represents the NRC Modal Study designation of discrete severity (cask response) regions, with N1 representing the impact strain and N2 representing the temperature caused by fire.
[b] The release fraction represents the fraction of the total fuel inventory in the cask that would be released into the atmosphere.
[c] Thermally induced, from NUREG/CR-0722, Table 40, all fuel (Lorenz et al., 1980).
[d] Empirical data from the Fort St. Vrain Final Safety Analysis Report, Rev. 8, Table A.3-1 (PSC no date).
[e] Thermally induced semivolatiles from incore failed fuel; 1% fuel failure, 100% respirable; release fraction from Lorenz et al. (1980).
[f] Impact-induced nonvolatiles, 1% incore failed fuel, 5% respirable, release fraction of 2×10^{-6} (from Wilmot [1981]).

In NUREG/CR-6672 (Sprung et al., 2000), potential release fractions were also developed for PWR and BWR SNF in generic casks. Tables 6.29 and 6.30 list the estimated release fractions for PWR and BWR assemblies in truck or rail shipments, respectively. These release fractions were assumed to be the total respirable release fraction (of the amount released, the aerosolized fraction = 1, respirable fraction = 1).

■ ■ 6.1.11 Radionuclide Profiles and Data

Once radioactive material is released and dispersed in the environment, the associated radiological hazard depends on the isotopic composition of the material (radiological profile). The following subsections first discuss typical radiological profiles for the different radioactive waste types and then the relevant radiological properties of the individual isotopes.

■ ■ ■ 6.1.11.1 Profiles

In the following sections, typical radiological profiles are discussed for LLW, LLMW, TRUW, SNF, and HLW. The profiles provide a point of reference concerning typical characteristics and should not be used in calculations in lieu of site- or project-specific data.

Low-Level Waste

LLW includes all radioactive waste that is not classified as HLW, SNF, TRUW (greater than 100 nCi/g), or by-product material, as defined in Section 11e(2) of the Atomic Energy Act of 1954. LLW contains no hazardous waste constituents and is classified as either CH or RH, depending on whether the dose at the waste surface is less or greater than 200 mrem/h. Based on the types and levels of radioactive emissions, it is further categorized as alpha (combined activity of transuranic radionuclides with half-lives greater than 20 years between 10 and 100 nCi/g) or

Table 6.29. Accident Release Fractions for SNF Shipments by Truck

Case	Release Fractions for PWR Fuel Assemblies in Truck Casks					Release Fractions for BWR Fuel Assemblies in Truck Casks					
	Kr	**Cs**	**Ru**	**Particulates**	**CRUD**	**Case**	**Kr**	**Cs**	**Ru**	**Particulate**	**CRUD**
1	8.0E–01	2.4E–08	6.0E–07	6.0E–07	2.0E–03	1	8.0E–01	2.4E–08	6.0E–07	6.0E–07	2.0E–03
2	1.4E–01	4.1E–09	1.0E–07	1.0E–07	1.4E–03	2	5.4E–03	1.6E–10	4.0E–09	4.0E–09	4.5E–04
3	1.8E–01	5.4E–09	1.3E–07	1.3E–07	1.8E–03	3	1.5E–02	4.5E–10	1.1E–08	1.1E–08	1.3E–03
4	8.4E–01	3.6E–05	3.8E–06	3.8E–06	3.2E–03	4	8.4E–01	4.1E–05	4.9E–06	4.9E–06	3.1E–03
5	4.3E–01	1.3E–08	3.2E–07	3.2E–07	1.8E–03	5	9.8E–02	2.9E–09	7.3E–08	7.3E–08	1.2E–03
6	4.9E–01	1.5E–08	3.7E–07	3.7E–07	2.1E–03	6	1.4E–01	4.1E–09	1.0E–07	1.0E–07	1.7E–03
7	8.5E–01	2.7E–05	2.1E–06	2.1E–06	3.1E–03	7	8.4E–01	3.7E–05	4.0E–06	4.0E–06	3.2E–03
8	8.2E–01	2.4E–08	6.1E–07	6.1E–07	2.0E–03	8	8.2E–01	2.4E–08	6.1E–07	6.1E–07	2.0E–03
9	8.9E–01	2.7E–08	6.7E–07	6.7E–07	2.2E–03	9	8.9E–01	2.7E–08	6.7E–07	6.7E–07	2.2E–03
10	9.1E–01	5.9E–06	6.8E–07	6.8E–07	2.5E–03	10	9.1E–01	5.9E–06	6.8E–07	6.8E–07	2.5E–03
11	8.2E–01	2.4E–08	6.1E–07	6.1E–07	2.0E–03	11	8.2E–01	2.4E–08	6.1E–07	6.1E–07	2.0E–03
12	8.9E–01	2.7E–08	6.7E–07	6.7E–07	2.2E–03	12	8.9E–01	2.7E–08	6.7E–07	6.7E–07	2.2E–03
13	9.1E–01	5.9E–06	6.8E–07	6.8E–07	2.5E–03	13	9.1E–01	5.9E–06	6.8E–07	6.8E–07	2.5E–03
14	8.4E–01	9.6E–05	8.4E–05	1.8E–05	6.4E–03	14	8.4E–01	1.2E–04	1.1E–04	2.4E–05	6.5E–03
15	8.5E–01	5.5E–05	5.0E–05	9.0E–06	5.9E–03	15	8.4E–01	1.0E–04	8.9E–05	2.0E–05	6.4E–03
16	9.1E–01	5.9E–06	6.4E–06	6.8E–07	3.3E–03	16	9.1E–01	5.9E–06	6.4E–06	6.8E–07	3.3E–03
17	9.1E–01	5.9E–06	6.4E–06	6.8E–07	3.3E–03	17	9.1E–01	5.9E–06	6.4E–06	6.8E–07	3.3E–03
18	8.4E–01	1.7E–05	6.7E–08	6.7E–08	2.5E–03	18	8.4E–01	1.7E–05	6.7E–08	6.7E–08	2.5E–03
19	0.0	0.0	0.0	0.0	0.0	19	0.0	0.0	0.0	0.0	0.0

Source: Sprung et al. (2000).

Table 6.30. Accident Release Fractions for SNF Shipments by Rail

Case	Release Fractions for PWR Fuel Assemblies in Rail Casks					Release Fractions for BWR Fuel Assemblies in Rail Casks					
	Kr	Cs	Ru	Particulates	CRUD	Case	Kr	Cs	Ru	Particulate	CRUD
1	4.1E–01	1.2E–08	2.5E–07	2.5E–07	1.4E–03	1	8.9E–02	2.7E–09	5.3E–08	5.3E–08	8.9E–04
2	8.0E–01	8.6E–06	1.3E–05	1.3E–05	4.4E–02	2	8.0E–01	8.6E–06	1.3E–05	1.3E–05	4.4E–02
3	8.0E–01	1.8E–05	1.9E–05	1.9E–05	6.4E–02	3	8.0E–01	1.8E–05	1.9E–05	1.9E–05	6.4E–02
4	1.4E–01	4.1E–09	1.0E–07	1.0E–07	1.4E–03	4	5.4E–03	1.6E–10	4.0E–09	4.0E–09	4.5E–04
5	1.8E–01	5.4E–09	1.3E–07	1.3E–07	1.8E–03	5	1.5E–02	4.5E–10	1.1E–08	1.1E–08	1.3E–03
6	8.4E–01	3.6E–05	1.4E–05	1.4E–05	5.4E–03	6	8.4E–01	4.1E–05	1.8E–05	1.8E–05	5.4E–03
7	4.3E–01	1.3E–08	2.6E–07	2.6E–07	1.5E–03	7	9.8E–02	2.9E–09	5.9E–08	5.9E–08	9.8E–04
8	4.9E–01	1.5E–08	2.9E–07	2.9E–07	1.7E–03	8	1.4E–01	4.1E–09	8.3E–08	8.3E–08	1.4E–03
9	8.5E–01	2.7E–05	6.8E–06	6.8E–06	4.5E–03	9	8.4E–01	3.7E–05	1.5E–05	1.5E–05	4.9E–03
10	8.2E–01	8.8E–06	1.3E–05	1.3E–05	4.5E–02	10	8.2E–01	8.8E–06	1.3E–05	1.3E–05	4.5E–02
11	8.9E–01	9.6E–06	1.5E–05	1.5E–05	4.9E–02	11	8.9E–01	9.6E–06	1.5E–05	1.5E–05	4.9E–02
12	9.1E–01	1.4E–05	1.5E–05	1.5E–05	5.1E–02	12	9.1E–01	1.4E–05	1.5E–05	1.5E–05	5.1E–02
13	8.2E–01	1.8E–05	2.0E–05	2.0E–05	6.5E–02	13	8.2E–01	1.8E–05	2.0E–05	2.0E–05	6.5E–02
14	8.9E–01	2.0E–05	2.1E–05	2.1E–05	7.1E–02	14	8.9E–01	2.0E–05	2.1E–05	2.1E–05	7.1E–02
15	9.1E01	2.2E–05	2.2E–05	2.2E–05	7.4E–02	15	9.1E–01	2.2E–05	2.2E–05	2.2E–05	7.4E–02
16	8.4E–01	9.6E–05	8.4E–05	1.8E–05	6.4E–03	16	8.4E–01	1.2E–04	1.1E–04	2.4E–05	6.5E–03
17	8.5E–01	5.5E–05	5.0E–05	8.9E–06	5.4E–03	17	8.4E–01	1.0E–04	8.9E–05	2.0E–05	5.9E–03
18	9.1E–01	1.4E–05	1.8E–05	1.5E–05	5.1E–02	18	9.1E–01	1.4E–05	1.8E–05	1.5E–05	5.1E–02
19	9.1E–01	2.2E–05	2.3E–05	2.2E–05	7.4E–02	19	9.1E–01	2.2E–05	2.3E–05	2.2E–05	7.4E–02
20	8.4E–01	1.7E–05	2.5E–07	2.5E–07	9.4E–03	20	8.4E–01	1.7E–05	2.5E–07	2.5E–07	9.4E–03
21	0.0	0.0	0.0	0.0	0.0	21	0.0	0.0	0.0	0.0	0.0

Source: Sprung et al. (2000).

nonalpha (transuranic activity is less than 10 nCi/g) and as Class A, B, or C according to the criteria of 10 CFR Part 61.

LLW can contain many different radionuclides in activity levels ranging from trace quantities to thousands of curies. Representative DOE LLW radionuclide compositions are divided into five categories by the Integrated Database (IDB) (DOE, 1996b): (1) uranium and thorium – waste materials for which the principal hazard results from naturally-occurring uranium and thorium isotopes; (2) fission products – waste materials contaminated with beta- or gamma-ray-emitting radionuclides that originate from fission processes (primary examples are cesium-137 and strontium-90); (3) induced activity – waste materials contaminated with beta- or gamma-ray-emitting isotopes that are generated through neutron activation (of major concern is cobalt-60); (4) alpha – waste material contaminated with low levels (between 10 and 100 nCi/g) of transuranic isotopes, excluding alpha-emitting radionuclides listed under uranium and thorium; and (5) other – mixture or not defined. Standard relative concentrations of the individual radionuclides constituting each category as developed in the IDB are shown in Table 6.31.

Table 6.31. Representative DOE LLW Radionuclide Composition by Percent Activity

Uranium/Thorium		Fission Product		Induced Activity		Alpha <100 nCi/g		Other	
Isotope	Percent Activity	Isotope	Percent Activity	Isotope	Percent Activity	Isotope	Percent Activity	Isotope	Percent Activity
Tl-208	0.0017	Co-60	0.08	Cr-51	4.95	Pu-238	2.62	H-3	1.22
Pb-212	0.0045	Sr-90	7.77	Mn-54	38.1	Pu-239	0.2	C-14	0.06
Bi-212	0.0045	Y-90	7.77	Co-58	55.4	Pu-240	0.7	Mn-54	6.76
Po-212	0.0029	Zr-95	1.27	Fe-59	0.49	Pu-241	96.4	Co-58	6.24
Po-216	0.0045	Nb-95	2.83	Co-60	0.87	Am-241	0.004	Co-60	18.03
Ra-224	0.0045	Tc-99	0.02	Zn-65	0.19	Cm-242	0.056	Sr-90	8.48
Ra-228	0.0269	Sb-125	2.93			Cm-244	0.02	Y-90	8.48
Ac-228	0.0269	Te-125m	0.73	Total	100			Tc-99	0.12
Th-228	0.0045	Ru-106	6.39			Total	100	Cs-134	13.98
Th-231	0.0259	Rh-106	6.39					Cs-137	18.45
Th-232	0.273	Cs-134	0.38					Ba-137m	17.45
Th-234	33.197	Cs-137	17.31					U-238	0.73
Pa-234m	33.197	Ba-137m	16.38						
Pa-234	0.0034	Ce-144	14.67					Total	100
U-235	0.0258	Pr-144	14.67						
U-238	33.197	Pm-147	0.06						
		Sm-151	0.11						
Total	100	Eu-152	0.09						
		Eu-154	0.09						
		Eu-155	0.06						
		Total	100						

Source: DOE (1996b).

The IDB indicates that the unit activities for LLW at the various DOE sites ranges from 9 to 27 Ci/m^3. Since this range was based on information in the 1986–1988 Solid Waste Information Management System (SWIMS) and the national Low-level Waste Management Program (LLWMP) data access system, radioactive decay may have reduced much of this activity to lower levels, depending on the exact composition of the radionuclides at each site. Reviews of the IDB individual LLW physical form radioactivity and volume inventories at each site suggest a much wider range of values for the unit activities, which vary greatly depending upon the physical form and whether stored or disposed waste is considered. However, this range is subject to great uncertainties and covers materials that would not be shipped in Type A packaging because of their exceedingly high activities.

The cumulative values of radioactivity and volume of all LLW disposed through 1995 suggests that 4 Ci/m^3 is a reasonable unit activity for disposed waste. The analogous number for just the year 1995 is about twice that activity, 8 Ci/m^3. As a result of these considerations and to provide somewhat conservative estimates for calculations, a representative activity of 20 Ci/m^3 is recommended. For a standard 55-gal steel drum with a volume of about 0.2 m^3, this activity level results in a drum containing about 4 Ci. Because of the aforementioned radioactive decay, the fact that most drums have significant void fractions, and the fact that LLW with high unit activities would not be shipped in Type A packaging, the 4 Ci value should be conservative for most Type A packages of LLW. Simple scaling may be performed to extrapolate results to LLW inventories where the activities are known.

Representative radionuclide profiles for each LLW shipment may be defined to approximate the shipment radionuclide content as a linear combination of the radionuclide profiles in the six categories. These data can be combined with activity levels reported by generating sites to estimate the activities of individual radionuclides in the LLW at each site. By assuming the results of radioactive release calculations are properly weighted, isotopic concentrations account for individual shipments characteristics.

Low-Level Mixed Waste

LLMW is material that is both hazardous under the Resource Conservation and Recovery Act (RCRA) and a low-level radioactive waste. LLMW contains RCRA-regulated chemicals or special waste types in a form or concentration sufficient to render the waste hazardous under the guidelines of the *Code of Federal Regulations* (40 CFR Part 261 [“Identification and Listing of Hazardous Waste”]). Although asbestos-contaminated wastes are not hazardous under federal RCRA rules, friable asbestos waste is considered a hazardous waste in several states. The WM PEIS (DOE, 1997b) treated low-level radioactive waste contaminated with asbestos as LLMW.

LLMW is classified as either CH or RH, depending on whether the dose at the waste surface is less or greater than 200 mrem/h. The handling category determines the level of protective shielding required to safely store and process the material. LLMW is also classified as either alpha LLMW (combined activity of transuranic radionuclides with half-lives greater than 20 years between 10 and 100 nCi/g) or nonalpha LLMW (transuranic activity less than 10 nCi/g). The alpha classification of LLMW is important in determining the choice of waste treatment facilities because in some states, facilities that process alpha-containing wastes cannot be used for wastes with minimal transuranic activity.

The radiological profiles for LLMW are assumed to be similar in radionuclide content and overall activity level to the radiological profiles described above for LLW. Thus, calculations of radioactive release consequences should treat the isotopic compositions the same way as LLW.

Transuranic Waste

DOE defines TRUW as "without regard to source or form, waste that is contaminated with alpha-emitting transuranic radionuclides with half-lives greater than 20 years, and concentrations greater than 100 nCi/g at the time of assay" (DOE, 1988d). This lower limit is interpreted as being per gram of waste matrix; the limit does not include the weights of added external shielding or waste containers (including any rigid liners) (DOE, 1996c). By definition, TRUW includes isotopes of neptunium, plutonium, americium, curium, and californium. In addition, wastes containing U-233 and Ra-226 may be managed as TRUW.

Packaged TRUW is classified as either CH or RH, depending on whether the dose at the waste surface is less or greater than 200 mrem/h. CH-TRUW is typically contained in 0.21-m^3 (55-gal) drums or in SWBs, and little or no shielding is required. RH-TRUW is typically contained in drums, canisters, or concrete casks. It generally requires additional shielding during handling and transportation, and special equipment and facilities for handling, treatment, and transportation. The need for shielding and/or RH is due to the energetic gamma and neutron emissions from some of the transuranic and fission product contaminants.

TRUW has been generated since the 1940s as part of the nuclear defense research and production activities of the federal government. Several types of operations generate TRUW: (1) nuclear weapons development and manufacturing, (2) prior plutonium recovery, (3) research and development, (4) environmental restoration and decontamination and decommissioning activities, (5) waste management programs, and (6) testing and research at facilities under DOE contract.

Before 1970, all DOE-generated TRUW was disposed of on-site in shallow landfill-type configurations. In 1970, the AEC concluded that waste containing long-lived alpha-wave-emitting radionuclides should be more isolated from the environment. As a result, all TRUW generated since the early 1970s was segregated from other types of waste and placed in temporary storage pending shipment and final disposal in a permanent geologic repository (DOE, 1992). The TRUW generated since 1970 is described as retrievably stored and is the primary focus of DOE's Waste Management Program. The TRUW generated before 1970 is known as nonretrievably stored or buried TRUW and may ultimately be the focus of DOE environmental restoration activities.

The radiological profiles for TRUW vary widely from site to site. The radiological profiles presented here are taken from the WIPP Disposal Phase SEIS (DOE, 1997d). Profiles are shown in Tables 6.32 and 6.33 for stored CH- and RH-TRUW, respectively.

High-Level Waste

HLW is the highly radioactive waste generated from the chemical reprocessing of SNF and weapons production targets to recover special nuclear materials, primarily plutonium and

Table 6.32. Radionuclide Inventories (Ci) of CH-TRU Waste Stored at DOE Sites in 1995

Isotope	ANL-E	ARCO	USAMC	ETEC	Hanford	INEEL	LBL	LANL	LLNL	MOUND
Pu-238	2.11E+00	3.70E+02	–	1.11E–01	8.05E+04	5.98E+04	2.32E–04	1.15E+05	7.65E+01	4.97E+02
Pu-241	5.43E+01	–	–	6.22E+00	3.78E+04	1.50E+05	4.48E–07	1.62E+03	1.63E+03	–
Pu-239	3.28E+01	–	1.80E+01	1.79E+00	2.63E+04	4.01E+04	8.45E–06	7.91E+04	1.64E+02	6.28E+00
Am-241	5.89E+00	–	–	5.19E–01	4.73E+03	9.01E+04	9.17E–02	1.17E+04	1.44E+02	–
Pu-240	9.42E+00	–	–	6.12E–01	6.14E+03	9.84E+03	5.14E–03	1.01E+02	6.44E+01	–
Cs-137	–	–	–	–	6.83E+02	6.04E+01	–	4.81E+01	1.66E–06	–
Ba-137m	–	–	–	–	6.46E+02	5.71E+01	–	4.55E+01	1.57E–06	–
Cm-244	–	–	–	–	6.83E+01	4.93E+02	8.70E–02	1.56E+02	6.54E+01	–
Y-90	–	–	–	2.00E–01	6.92E+02	1.96E+00	–	4.44E+01	–	–
Sr-90	–	–	–	2.00E–01	6.92E+02	1.96E+00	–	4.44E+01	–	–
U-233	3.00E–02	–	–	1.20E–11	8.00E+01	8.99E+02	4.81E–03	4.46E+01	5.95E–09	–
Pu-242	1.00E–02	–	–	5.00E–05	3.80E–01	9.45E–01	1.01E–02	4.85E+02	2.02E–02	–
U-234	–	1.05E–03	–	1.93E–06	5.37E+01	6.18E+00	4.73E–09	6.06E+00	3.29E–03	2.47E–02
Pa-233	–	–	–	9.49E–07	2.72E–01	8.53E–01	6.32E–06	00>3.22E–02	4.71E–04	–
Np-237	–	–	–	9.49E–07	2.72E–01	8.53E–01	6.32E–06	3.22E–02	4.71E–04	–
Co-60	–	–	–	–	–	6.24E+01	–	7.91E–06	–	–
Eu-155	–	–	–	–	1.06E–03	3.83E–01	–	2.41E–01	–	–
Cf-252	–	–	–	–	3.52E+01	2.19E–03	–	–	–	–
Pb-212	–	–	–	–	5.18E–02	2.62E+01	–	6.16E–03	–	–
Ra-224	–	–	–	–	5.18E–02	2.62E+01	–	1.32E–03	–	–
Bi-212	–	–	–	–	5.18E–02	2.62E+01	–	1.32E–03	–	–
Po-216	–	–	–	–	5.18E–02	2.62E+01	–	1.32E–03	–	–
Rn-220	–	–	–	–	5.18E–02	2.62E+01	–	1.32E–03	–	–
Th-228	–	–	–	–	5.18E–02	2.62E+01	–	1.32E–03	–	–
U-232	–	–	–	–	–	2.53E+01	–	1.67E–03	–	–
Np-239	9.52E–02	–	–	–	9.01E–02	3.79E–01	3.85E–02	3.83E+00	2.45E–02	–

Isotope	U of MO	NTS	ORNL	PGDP	Pantex	RFETS	RFETS Residues	SRS	Total
Pu-238	–	3.15E+04	3.50E+03	–	–	3.43E+02	8.14E+03	5.53E+05	8.52E+05
Pu-241	6.32E–03	2.40E+02	4.79E+04	–	–	5.23E+04	1.02E+06	1.12E+05	1.42E+06
Pu-239	2.46E–02	2.76E+03	2.72E+03	5.57E+01	5.55E–02	9.98E+03	1.74E+05	9.35E+03	3.44E+05
Am-241	3.24E–01	2.84E+02	1.61E+03	–	–	1.10E+04	1.09E+05	2.01E+03	2.30E+05
Pu-240	–	2.66E+01	9.48E+02	–	–	7.22E+03	3.98E+04	2.31E+03	6.64E+04
Cs-137	–	3.60E–01	1.33E+00	–	–	–	–	7.51E+00	8.01E+02
Ba-137m	–	3.41E–01	1.26E+00	–	–	–	–	7.11E+00	7.57E+02
Cm-244	–	2.28E+02	1.06E+03	–	–	–	–	1.17E+03	3.24E+03
Y-90	–	3.10E–01	1.48E+03	–	–	–	–	6.98E+00	2.22E+03
Sr-90	–	3.10E–01	1.48E+03	–	–	–	–	6.98E+00	2.22E+03
U-233	1.78E–09	1.81E+00	1.77E+02	1.42E–03	–	1.29E+01	–	3.75E+00	1.22E+03
Pu-242	–	8.70E–02	2.37E–01	–	–	9.63E–05	–	3.75E–01	4.87E+02
U-234	2.98E–13	1.26E–02	1.57E+01	–	–	4.81E–03	–	2.56E+01	1.07E+02
Pa-233	2.28E–04	5.78E–03	7.32E–01	5.50E+01	–	1.70E–02	–	8.59E+00	6.55E+01
Np-237	2.28E–04	5.78E–03	7.27E–01	5.50E+01	–	1.70E–02	–	8.59E+00	6.55E+01
Co-60	–	–	1.84E–06	–	–	–	–	3.56E–01	6.28E+01
Eu-155	–	3.80E–03	–	–	–	–	–	5.28E+01	5.34E+01
Cf-252	–	1.70E–02	1.60E–01	–	–	–	–	3.62E–01	3.58E+01
Pb-212	–	1.64E–02	2.83E–01	–	–	–	–	9.20E–03	2.66E+01
Ra-224	–	1.71E–02	2.83E–01	–	–	–	–	9.20E–03	2.66E+01
Bi-212	–	1.64E–02	2.83E–01	–	–	–	–	9.20E–03	2.66E+01
Po-216	–	1.64E–02	2.83E–01	–	–	–	–	9.20E–03	2.66E+01
Rn-220	–	1.64E–02	2.83E–01	–	–	–	–	9.20E–03	2.66E+01
Th-228	–	1.64E–02	2.83E–01	–	–	–	–	9.20E–03	2.66E+01
U-232	–	1.65E–02	2.90E–01	–	–	–	–	8.94E–02	2.57E+01
Np-239	–	1.22E+00	1.49E+01	–	–	–	–	7.55E–01	2.13E+01

Source: DOE (1997d).

Table 6.33. Radionuclide Inventories (Ci) for RH-TRU Waste Stored at DOE Sites in 1995

Isotope	ETEC	Hanford	INEEL	KAPL	LANL	ORNL	WVDP	TOTAL
Y-90	2.62E+00	6.46E+03	1.70E+03	5.70E+01	1.24E+02	3.52E+04	1.96E+01	4.36E+04
Sr-90	2.62E+00	6.46E+03	1.70E+03	5.70E+01	1.24E+02	3.52E+04	1.96E+01	4.36E+04
Cs-137	2.62E+00	6.98E+03	1.90E+03	5.71E+01	1.35E+02	9.78E+03	5.35E+01	1.89E+04
Ba-137m	2.48E+00	6.61E+03	1.80E+03	5.40E+01	1.28E+02	9.25E+03	5.06E+01	1.79E+04
Pu-241	–	4.67E+03	4.81E+01	7.77E–01	–	3.97E–07	–	4.72E+03
Eu-152	–	–	1.14E–01	–	5.09E–04	3.66E+03	–	3.66E+03
Eu-154	–	–	7.90E–01	1.40E+00	3.50E–02	1.77E+03	–	1.78E+03
Cm-244	–	–	9.63E–02	–	–	9.44E+02	–	1.10E+03
Co-60	2.30E+00	3.36E+02	1.30E+01	2.75E–01	4.17E+00	6.14E+02	–	9.70E+02
Pu-239	4.00E–01	3.35E+02	2.98E+01	3.30E–03	9.28E+01	9.85E+01	–	5.59E+02
Am-241	5.85E–02	1.93E+02	4.68E+01	5.07E–02	–	2.42E+02	5.39E–01	4.83E+02
Eu-155	–	–	3.35E–01	1.81E–01	1.77E+00	3.51E+02	–	3.53E+02
Pu-240	–	1.67E+02	2.48E+01	3.10E–03	–	1.07E+00	–	1.93E+02
Th-231	4.73E–10	1.46E–01	6.42E–03	–	8.78E–03	1.86E+02	–	1.86E+02
U-235	4.73E–10	1.46E–01	5.38E–03	–	8.78E–03	1.86E+02	–	1.86E+02
Pu-238	–	4.67E+01	6.09E+01	9.27E–01	3.90E+00	2.81E+01	1.98E+01	1.69E+02
Cm-243	–	–	1.45E–02	–	–	1.48E+02	–	1.48E+02
Cs-134	–	–	5.38E+01	4.73E+00	2.42E–02	9.57E+00	–	6.81E+01
U-233	–	4.15E–01	3.91E–01	–	–	5.73E+01	–	5.81E+01
Pm-147	–	–	1.49E+01	4.34E+00	1.13E+01	–	–	3.34E+01
Rh-106	–	–	6.65E–02	4.98E–01	3.38E–01	3.21E+01	–	3.30E+01
Ru-106	–	–	6.65E–02	4.98E–01	3.38E–01	3.21E+01	–	3.30E+01
Pr-144	–	–	3.93E+00	1.54E+00	1.58E–02	1.51E+01	–	2.05E+01
Ce-144	–	–	3.98E+00	1.56E+00	1.60E–02	1.20E+01	–	1.75E+01
C-14	–	–	4.00E–02	–	–	6.11E+00	–	6.15E+00
Kr-85	–	–	5.95E+00	–	–	–	–	5.95E+00
Sb-125	–	–	9.81E–01	5.33E–01	2.79E+00	–	–	4.30E+00
Cf-252	–	–	–	–	–	3.86E+00	–	3.86E+00
Ni-63	–	–	3.50E+00	–	–	–	–	3.50E+00
U-238	–	1.03E–02	3.57E–03	–	2.00E–05	3.37E+00	–	3.38E+00
Pa-234m	–	1.03E–02	1.38E–03	–	2.00E–05	3.37E+00	–	3.38E+00
Th-234	–	1.03E–02	1.38E–03	–	2.00E–05	3.37E+00	–	3.38E+00
U-232	–	–	–	–	–	1.76E+00	–	1.76E+00
Po-216	–	1.49E–03	2.65E–05	–	–	1.68E+00	–	1.69E+00
Bi-212	–	1.49E–03	2.65E–05	–	–	1.68E+00	–	1.68E+00
Pb-212	–	1.49E–03	2.65E–05	–	–	1.68E+00	–	1.68E+00
Ra-224	–	1.49E–03	2.65E–05	–	–	1.68E+00	–	1.68E+00
Rn-220	–	1.49E–03	2.65E–05	–	–	1.68E+00	–	1.68E+00
Th-228	–	1.49E–03	2.65E–05	–	–	1.68E+00	–	1.68E+00
U-234	–	1.29E+00	1.51E–01	4.98E–06	1.11E–05	2.02E–03	4.94E–04	1.45E+00
Po-212	–	9.54E–04	1.70E–05	–	–	1.07E+00	–	1.07E+00
Te-125m	–	–	2.39E–01	1.30E–01	6.88E–01	–	–	1.06E+00

Source: DOE (1997d).

enriched uranium. HLW is liquid before it is treated and solidified, and is considered a mixed waste if it contains hazardous components regulated under RCRA. It exists at the four sites where it was generated: the Hanford Site, INEEL, SRS, and the West Valley Demonstration Project (WVDP). In 1992, DOE decided to phase out reprocessing in support of national defense activities and now stores HLW in large tanks at the four sites. However, additional HLW may be generated by waste management activities.

Because the current forms of HLW (e.g., liquid solutions or calcine) are generally not suitable for transportation, interim storage, or final disposal, current plans call for all HLW to be immobilized at the site where it was produced. The immobilized material is generally a nondispersible, robust waste that is formed in cylindrical stainless steel canisters approximately 300 cm (118 in.) high and 61 cm (24 in.) in diameter (Folga et al., 1996). Under the NWPA, as amended, the current DOE HLW program is directed at disposing of treated (i.e., immobilized) HLW in a national geologic repository. The canisters of immobilized HLW would be stored on-site following production until a national geologic repository became available. Canisters would then be transported either by truck or rail in specially designed casks to the repository for permanent disposal. Historically, no shipments of immobilized HLW have occurred in the United States.

The radiological profiles for HLW vary widely from site to site. Of interest here are the waste compositions as packaged in the canisters. The radiological profiles and activities presented are taken from the WM PEIS (DOE, 1997b) and are shown in Table 6.34. These profiles reflect the latest inventories of HLW compositions at sites projected to exist following the pretreatment and treatment operations necessary to achieve the vitrified forms to place in the HLW canisters. Many of the radionuclides now present in the untreated form would be fractionated to some extent into the high-volume, low-radioactivity LLW residuals following these operations.

Spent Nuclear Fuel

SNF is irradiated nuclear fuel discharged from a nuclear reactor. Within the DOE complex, significant differences exist in radioactive material content, fuel material design, cladding design, reactor operating history, and storage history (cooling time). These differences translate into different material release characteristics under accident conditions. To account for these variations, the following representative SNF types are considered herein: (a) SRS production reactor fuels, (b) Hanford N-Reactor fuels, (c) graphite fuels, (d) special-case commercial reactor fuels, (e) university research/test reactor fuels, (f) DOE research/test reactor fuels, (g) foreign research reactor fuels, and (h) non-DOE research reactor fuels. Naval fuels are not considered in this report.

The radiological profiles assumed in this manual were taken from the DOE *Programmatic Spent Nuclear Fuel and Idaho National Engineering Laboratory Environmental Restoration and Waste Management Final Environmental Impact Statement* (SNF/INEL PEIS) (DOE, 1995b) and are shown in Table 6.35. Conservative radiological profiles (i.e., profiles leading to releases more hazardous than the actual profiles) were developed to provide reasonable bounds for shipping accident calculations.

Table 6.34. Estimated Radionuclide Compositions (Ci/canister) for HLW Canisters at DOE Sites[a]

Radionuclide	Hanford	INEEL	SRS	WVDP
Fe-55	1.80E+01			2.76E+00
Co-60	1.50E+00		1.70E+02	3.03E+00
Ni-59	1.09E–01		2.40E–02	4.16E–01
Ni-63	1.21E+01		2.98E+00	3.02E+01
Se-79	3.15E–03		1.70E–01	1.38E–02
Rb-87			8.72E–07	
Sr-89	5.35E–13		4.27E–05	
Sr-90	2.98E+04	2.09E+03	4.68E+04	2.63E+04
Y-90	2.98E+04	2.09E+03	4.79E+04	2.63E+04
Y-91	1.38E–10		7.57E–04	
Zr-93	1.05E+00		1.12E+00	1.07E+00
Zr-95	2.92E–09		1.00E–02	
Nb-93m	6.16E–01			7.15E–01
Nb-94			9.65E–05	
Nb-95	6.73E–09		2.12E–02	
Nb-95m			1.25E–04	
Tc-99	7.51E+00		3.08E+00	4.28E–01
Ru-103	3.37E–18		1.68E–08	
Ru-106	4.18E+01	2.47E–15	2.25E+03	5.54E–02
Rh-103m	3.04E–18		1.64E–08	
Rh-106	4.18E+01	2.47E–15	2.26E+03	5.54E–02
Pd-107	3.02E–02		1.47E–02	4.33E–02
Ag-110m	2.22E–03		1.26E–01	
Cd-113m	8.53E+00			8.34E+00
Cd-115m	3.20E–18		1.21E–09	
In-113m	1.01E–07			
Sn-113	1.01E–07			
Sn-119m	6.80E–03			
Sn-121m	7.76E–02		7.90E–02	6.86E–02
Sn-123	3.65E–05		2.55E–01	
Sn-126	3.65E–01		4.42E–01	4.09E–01
Sb-124	1.15E–14		7.12E–08	
Sb-125	2.54E+02		8.50E+02	2.86E+01
Sb-126	5.10E–02		6.16E–02	5.74E–02
Sb-126m	3.65E–01		4.42E–01	4.09E–01
Te-125m	6.20E+01			7.00E+00
Te-126m			2.76E+02	
Te-127	6.55E–06		1.20E–01	
Te-127m	6.66E–06		1.23E–01	
I-129	1.29E–05			
Cs-134	9.31E+01	3.97E–06	3.37E+02	2.03E+01
Cs-135	2.02E–01		9.94E–02	6.34E–01

Table 6.34. Estimated Radionuclide Compositions (Ci/canister) for HLW Canisters at DOE Sites (Continued)

Radionuclide	Hanford	INEEL	SRS	WVDP
Cs-137	3.61E+04	2.49E+03	4.34E+04	2.83E+04
Ba-137m	3.40E+04	2.36E+03	4.16E+04	2.68E+04
Ce-142			9.61E–06	
Ce-144	8.00E+01	1.45E–18	9.87E+03	2.56E–03
Pr-144	8.00E+01	1.45E–18	9.87E+03	2.56E–03
Pr-144m	9.60E–01		1.19E+02	
Nd-144			4.86E–10	
Pm-146				4.26E–02
Pm-147	5.21E+03	1.78E–04	2.42E+04	3.45E+02
Sm-147			2.00E–06	
Sm-151	6.98E+02		2.48E+02	3.31E+02
Eu-152	1.40E+00		3.69E+00	1.43E+00
Eu-154	1.45E+02	6.61E–01	6.20E+02	3.75E+02
Eu-155	1.37E+02		4.75E+02	9.37E+01
Gd-153	1.35E–05			
Tb-160	9.49E–13		1.12E–06	
Tl-207				3.22E–02
Tl-208			1.13E–03	1.27E–02
Pb-209				8.25E–04
Pb-211				3.23E–02
Pb-212				3.53E–02
Bi-211				3.23E–02
Bi-212				3.53E–02
Bi-213				8.25E–04
Po-212				2.26E–02
Po-213				7.86E–04
Po-215				3.23E–02
Po-216				3.53E–02
At-217				8.25E–04
Rn-219				3.23E–02
Rn-220				3.53E–02
Fr-221				8.25E–04
Fr-223				4.32E–04
Ra-223				3.23E–02
Ra-224				3.53E–02
Ra-225				8.25E–04
Ra-228				5.97E–03
Ac-225				8.25E–04
Ac-227				3.23E–04
Ac-228				5.97E–03
Th-227				3.18E–02
Th-228				3.53E–02

Table 6.34. Estimated Radionuclide Compositions (Ci/canister) for HLW Canisters at DOE Sites (Continued)

Radionuclide	Hanford	INEEL	SRS	WVDP
Th-229				9.25E–04
Th-230				2.36E–04
Th-231				3.54E–04
Th-232				6.45E–03
Th-234				3.14E–03
Pa-231				5.97E–02
Pa-233				9.18E–02
Pa-234m				3.14E–03
U-232			1.34E–02	2.72E–02
U-233			1.58E–06	3.55E–02
U-234	4.57E–03		3.43E–02	1.65E–02
U-235				
U-236	4.21E–04		1.13E–03	1.10E–03
U-237				
U-238	3.51E–03		1.05E–02	3.14E–03
Np-236				3.72E–02
Np-237	1.56E–01		8.90E–03	9.18E–02
Pu-238	4.43E–01		1.48E+03	3.26E+01
Pu-239	1.17E+00		1.29E+01	6.39E+00
Pu-240	3.93E–01		8.68E+00	4.68E+00
Pu-241	1.26E+01		1.67E+03	3.17E+02
Pu-242	7.61E–05		1.22E–02	6.37E–03
Am-241	2.84E+02		1.10E+01	2.10E+02
Am-242	2.21E–01		1.44E–02	1.16E+00
Am-242m	3.79E–02		1.45E–02	1.17E+00
Am-243			5.79E–03	1.36E+00
Cm-242	1.82E–01		3.50E–02	9.63E–01
Cm-243			5.56E–03	5.27E–01
Cm-244	5.03E+00		1.08E+02	3.00E+01
Cm-245			6.72E–06	3.46E–03
Cm-246			5.34E-07	3.93E–04
Total	1.37E+05	9.03E+03	2.34E+05	1.10E+05

[a] Blanks indicate that radionuclide not present or at negligible concentration.
Source: Folga et al. (1997)

Table 6.35. Radionuclide Inventories (Ci) for Representative SNF Types[a]

Radionuclide	SRS Production Reactor[b]	Hanford N-Reactor[c]	Graphite Reactor[d]	Special-Case Commercial[e]	University Research/Test Reactor[f]	DOE Research/Test Reactor[g]	Foreign Research/Test Reactor[h]
H-3	1.21E+01	3.09E+01			3.25E+00	7.98E+00	1.31E+01
Mn-54						7.48E+02	
Fe-55						6.12E+02	
Co-58						1.25E+02	
Co-60				6.28E+02		3.55E+00	
Kr-85	2.62E+02	5.89E+02	2.35E+03	2.23E+03	8.60E+01	9.75E+01	3.63E+02
Sr-89					4.28E+01	1.45E+02	2.75E+03
Sr-90	3.21E+03	6.80E+03	1.57E+04	2.75E+04	9.30E+02	7.23E+02	3.16E+03
Y-90	3.21E+03	6.80E+03		2.73E+04	9.30E+02	7.23E+02	3.16E+03
Y-91					9.77E+01	3.67E+02	4.56E+03
Zr-95					1.48E+02	7.00E+02	6.48E+03
Nb-95					3.20E+02	1.52E+03	1.28E+04
Ru-103					7.47E+00	4.88E+01	8.44E+02
Rh-103m					6.74E+00	4.40E+01	8.44E+02
Rh-106	7.64E+00		5.94E+02			3.65E+03	
Rh-106m							2.54E+03
Ru-106	7.64E+00	5.56E+01	5.94E+02	2.52E+02	1.36E+02	3.65E+03	2.54E+03
Sn-123						2.48E+01	2.71E+01
Sb-125		1.26E+02	3.36E+02			1.21E+02	1.19E+02
Te-125m					4.11E+00	2.96E+01	2.87E+01
Te-127					2.08E+00	3.32E+01	
Te-127m					2.12E+00	3.37E+01	5.57E+01
Te-129m						1.14E+00	2.31E+01
I-129				1.48E-02			
Cs-134	1.48E+02	1.49E+02	7.45E+03	4.85E+03	1.10E+02	9.15E+01	1.16E+03
Cs-137	3.18E+03	8.39E+03	1.65E+04	3.85E+04	9.72E+02	1.04E+03	3.19E+03
Ba-137m	3.01E+03	7.94E+03		3.62E+04	9.20E+02	9.80E+02	
Ce-141					3.86E+00	1.49E+01	6.97E+02
Ce-144	1.51E+01	3.24E+01	3.77E+03	9.01E+01	1.47E+03	7.76E+03	2.55E+04
Pr-144	1.51E+01		3.77E+03		1.47E+03	7.76E+03	2.55E+04
Pr-144m						1.11E+02	
Pm-147	1.07E+02	2.24E+03	6.32E+03		8.81E+02	2.65E+03	7.02E+03
Pm-148m							4.68E+01
Sm-151			5.4E+01			2.91E+01	
Eu-154			9.48E+02				4.18E+01
Eu-155			1.38E+02			1.00E+02	2.27E+01
U-232			1.8E+01				
U-233			2.4E+01				
U-234							1.81E–04
U-235					4.00E–03	2.90E–03	7.91E–03
U-236					5.50E–03	3.34E–03	
U-238							6.51E–03
Pu-238	6.84E+01	5.06E+01	4.20E+02	1.36E+03	1.00E+00	1.48E+00	3.03E+00
Pu-239	7.69E–01	1.10E+02		1.67E+02	1.57E–01	4.05E+01	5.50E-01
Pu-240	5.23E–01	5.97E+01		2.06E+02	6.70E–02	3.61E+01	2.09E+00
Pu-241	9.52E+01	4.47E+03	3.06E+02	4.32E+04	5.88E+00	1.39E+03	2.13E+02

Table 6.35. Radionuclide Inventories (Ci) for Representative SNF Types (Continued)

Radionuclide	SRS Production Reactor[b]	Hanford N-Reactor[c]	Graphite Reactor[d]	Special-Case Commercial[e]	University Research/Test Reactor[f]	DOE Research/Test Reactor[g]	Foreign Research/Test Reactor[h]
Am-241	1.97E+00	9.33E+01		9.66E+02	4.57E–02	4.74E+00	4.07E–01
Am-242m							9.00E–03
Cm-242					1.81E–01		5.25E+00
Am-243							4.38E–04
Cm-244				6.90E+02			7.14E-03

[a] Blank indicates that radionuclide not present or at negligible concentration.
[b] Inventory based on one fuel assembly from a tritium producing charge, 10 years cooling out of reactor.
[c] Inventory based on Mark IA N-Reactor fuel, 10 years cooling out of reactor, average burnup 3,000 megawatt-days per metric ton uranium.
[d] Inventory based on six Fort St. Vrain fuel blocks, 1,600 days cooling out of reactor, average burnup of 70,000 megawatt-days per metric ton uranium.
[e] Inventory based on one PWR fuel assembly, 10 years cooling out of reactor, average burnup 33,000 megawatt-days per metric ton uranium.
[f] Inventory based on 19 TRIGA fuel rods (70% enrichment; 122 g/rod uranium-235 beginning-of-life), 1 year cooling out of reactor, 20.2% average burnup.
[g] Inventory based on EBR-II Mark-V fuel, 1 year cooling out of reactor, total burnup of 317 megawatt-days
[h] Inventory based on 40 foreign TRIGA fuel elements, 1 year cooling out of reactor, average burnup of 31 grams uranium-235 per fuel element

SRS production reactor SNF was assumed to include both the spent driver fuel used to power the production reactors and the irradiated plutonium target material currently in storage at SRS. Spent driver fuel stored at SRS includes fuel used in tritium and plutonium production. Analysis of these two fuel types showed that typical fuel used for tritium production contains a higher fission product and transuranic inventory than that used for plutonium production. Analysis of the typical irradiated plutonium target material characteristics also showed that the radionuclide inventory would be bounded by the inventory in spent tritium production driver fuel. Therefore, for analysis purposes, both spent driver fuel and irradiated plutonium target material were assumed to have the characteristics of spent tritium production driver fuel. Table 6.35 shows the radionuclide inventory developed based on published reports to represent SRS production reactor SNF (WSRC, 1990; 1991).

Characterization data for Hanford N-Reactor SNF were based on Mark IA fuel irradiated to an average burnup of 3,000 megawatt-days per metric ton of uranium and assumed a 10-year cooling time since removal from the reactor. The 10-year cooling time is conservative because the N-Reactor was last operated in 1987. Table 6.35 shows the radionuclide inventory used to represent Hanford N-Reactor SNF.

Most of the spent graphite fuel under DOE responsibility is from the Fort St. Vrain reactor owned by Public Service of Colorado. Some Fort St. Vrain SNF is already in storage at INEEL, but most is still at the reactor site awaiting transport to a DOE facility. Smaller amounts of other graphite SNF are also in storage at INEEL. Characteristics for graphite SNF are, therefore, based on Fort St. Vrain SNF. Table 6.35 shows the radionuclide inventory used to represent graphite reactor SNF based on six Fort St. Vrain fuel blocks irradiated to an average burnup of 70,000 megawatt-days per metric ton uranium and assuming a cooling time of 1,600 days (Block, 1993). The 1,600-day (about 4.3-year) cooling time is conservative because the reactor was shut down in August 1989.

SNF from various commercial reactors is currently in storage at various DOE sites, mostly at INEEL. Special-case commercial SNF at INEEL includes core debris from the damaged TMI Unit 2 reactor. Commercial SNF includes both BWR and PWR SNF, with the latter analyzed here because it is more prevalent and typically contains the highest levels of radioactivity (Fischer et al., 1987). Table 6.35 shows the radionuclide inventory used to represent commercial SNF based on one PWR fuel assembly irradiated to an average burnup of 33,000 MW-days per metric ton uranium and assuming a cooling time of 10 years (Fischer et al., 1987). The 10-year cooling time is conservative because the majority of special-case commercial SNF currently in storage at DOE sites was at least 10 years old by June 1995. RISKIND (Yuan et al., 1995) can provide a BWR or PWR SNF radionuclide inventory according to input values for fuel burnup, cooling time, and metric tons of uranium by using data from DOE (1992).

Domestic university research and test reactors represent a variety of reactor types and fuel designs. High-enriched training, research, and isotope reactor (TRIGA) SNF was chosen to represent university reactor SNF because it is one of the largest groups of university SNF and because it is a rod-type fuel expected to have the highest release of fission products under severe accident conditions. The radionuclide inventory of high-enriched TRIGA fuel was calculated with the ORIGEN2 computer code (Croff, 1980) by assuming a 17-year reactor operating cycle based on operation of the Texas A&M University TRIGA reactor. To facilitate the modeling of accident consequences, the radionuclide inventory generated by the ORIGEN2 program was truncated to eliminate minor contributors to dose. The radionuclides eliminated accounted for less than 1% of the total dose. Additional details are available in Enyeart (1995). Table 6.35 shows the radionuclide inventory representative of university research and test reactor SNF based on 19 TRIGA fuel rods irradiated to an average burnup of 20.2% and assuming a cooling time of one year.

DOE research and test reactors are also represented by a variety of reactor types and fuel designs. Experimental Breeder Reactor-II (EBR-II) Mark-V SNF was chosen to represent DOE research and test reactors because it was one of the last DOE research and test reactors operating and Mark-V fuel was the last generation of EBR-II fuel. The high plutonium content of Mark-V fuel increases the relative hazard of the radionuclide inventory compared to other DOE SNF types. The radionuclide inventory of the Mark-V fuel was calculated with the ORIGEN2 computer code by assuming a typical EBR-II operating cycle. To facilitate the modeling of accident consequences, the radionuclide inventory generated by the ORIGEN2 program was truncated to eliminate minor contributors to dose. Again, the radionuclides eliminated accounted for less than 1% of the total dose. Additional details are available in Enyeart (1995). Table 6.35 shows the radionuclide inventory representative of DOE research and test reactor SNF based on one Mark-V fuel assembly irradiated to a burnup of 7.88% and assuming a cooling time of one year.

Foreign research and test reactors use a number of different fuel designs. DOE evaluated the characteristics of foreign research reactor SNF types in the *Final Environmental Impact Statement on a Proposed Nuclear Weapons Nonproliferation Policy Concerning Foreign Research Reactor Spent Nuclear Fuel* (DOE, 1996a). On the basis of that evaluation, a shipment of 40 TRIGA-type SNF elements resulted in the highest potential release of radioactivity in the event of an accident. To provide a bounding analysis for that EIS, foreign TRIGA-type SNF was selected to represent all foreign research reactor SNF. To facilitate the modeling of accident consequences, the radionuclide inventory generated by the ORIGEN2 program was truncated to eliminate minor contributors to dose. The radionuclides eliminated accounted for less than 1% of the total dose. The radionuclide inventory of a single shipping cask, shown in Table 6.35, is based on a reactor operating period of three years, with a burnup of 31 grams of U-235 per fuel element, followed by a cooling period of one year.

Non-DOE research reactor types are generally similar to domestic university research and test reactors. Therefore, TRIGA reactor SNF was also chosen to represent non-DOE research reactor SNF.

■ ■ ■ 6.1.11.2 Isotopic Data

Appendix C lists half-lives, photon energies, and dose conversion factors for most isotopes; these characteristics are discussed in general terms below.

Physical Properties

Half-Life. The half-life is the characteristic decay period for a specific radioactive isotope after which half of the original amount remains. A compilation of half-lives for most isotopes can be found in ICRP Publication 38 (ICRP, 1983) and Firestone and Shirley (1998).

Photon Energy. The photon energy of the gamma radiation emitted by decaying radioactive isotopes is used to estimate the groundshine dose in RADTRAN. A compilation of photon energy for most isotopes can be found in ICRP Publication 38 (ICRP, 1983) and Firestone and Shirley (1998).

Food Transfer Factor/Soil Transfer Factor. The ingestion calculations in RISKIND incorporate the transfer factors suggested in Regulatory Guide 1.109 (NRC, 1977b). For ingestion calculations in RADTRAN, the food and soil transfer factors account for the activity (curies) incorporated in or deposited on food ingested per curie deposited per square meter of land cultivated. The summed factors are used in the accident ingestion calculations to provide the amount of activity in food consumed relative to the amount deposited on the ground surface. RADTRAN uses national average factors in the ingestion dose code COMIDA. The user can enter food transfer factors and parameters into COMIDA. State-specific food transfer factors have been developed for each isotope. These may be used in COMIDA, or directly with the ground deposition calculated by RADTRAN. Appendix D contains more information on food transfer factors.

Deposition Velocity of Aerosol Particles. Airborne contaminant particles from the resulting plume eventually deposit onto the ground surface following an accidental release to the atmosphere. The deposition velocity is the ratio of the deposition rate to the air concentration expressed in units of velocity. Typical deposition velocities are generally less than 0.01 m/s (Sehmel, 1980; McMahon and Denison, 1979). However, the deposition velocity depends on such variables as particle size and type, surface roughness, and atmospheric stability. Values will tend to be higher over some areas of farmland with taller crops, wooded areas, and suburban/urban areas. The frequently used deposition velocity of 0.01 m/s for particles and aerosols is the median terminal velocity for 10-μm-diameter spherical particles (Schleien and Terpilak, 1987). The RISKIND default is 0.01 m/s for all aerosols except gases.

Dose Conversion Factors

Cloudshine Dose Conversion Factor. The cloudshine dose conversion factor is used to estimate dose on the basis of external exposure from immersion in contaminated air. These dose conversion factors are provided in DOE (1988a) and more recently in Federal Guidance Report 12 (EPA, 1993a).

Groundshine Dose Conversion Factor. The groundshine dose conversion factor is used to estimate dose on the basis of external exposure from contaminated soil. These dose conversion factors are provided in DOE (1988a) and more recently in Federal Guidance Report 12 (EPA, 1993a).

CEDE for Inhalation. These factors are used to estimate dose on the basis of internal exposure from inhaling contaminated air. These dose conversion factors are provided in DOE (1988b) and in Federal Guidance Report 11 (EPA, 1988).

CEDE for Ingestion. These factors are used to estimate dose on the basis of internal exposure from ingesting contaminated food. These dose conversion factors are provided in DOE (1988b) and in Federal Guidance Report 11 (EPA, 1988).

■ ■ 6.1.12 Miscellaneous Parameters

■ ■ ■ 6.1.12.1 Breathing Rate

The breathing rate is used in RADTRAN and RISKIND to estimate inhalation exposure following an accident that released radioactive materials. Suggested values for this parameter are given in Table 6.36. These values are averages based on assumed daily activities for adults. Detailed assumptions can be found in the table references. More information on variations due to age, gender, and activity can also be found in EPA (1985), Layton (1993), Linn et al. (1992), and Shamoo et al. (1992).

■ ■ ■ 6.1.12.2 Land Under Cultivation

The “land under cultivation” parameter is the fraction of rural area devoted to food-chain land use in both RADTRAN and RISKIND. Table 6.37 lists the percentage of farmland by state (DOC, 1994), where a farm is defined as any establishment from which $1,000 or more of agricultural products were produced and sold or would normally be sold during the year.

■ 6.2 Vehicle-Related Risks

In addition to the radiological cargo-related risks posed by transportation activities, risks are also present from vehicle-related causes. These risks are independent of the radioactive nature of the cargo and would be incurred with similar shipments of any commodity. The vehicle-related risks are assessed for both incident-free conditions and accidents.

Table 6.36. Breathing Rates for Inhalation Exposures

Reference	Breathing Rate	
	m^3/s	m^3/yr
RADTRAN standard value	3.3×10^{-4}	10,000
NRC Regulatory Guide 1.109[a]	2.5×10^{-4}	8,000
Average Adult[b]	2.3×10^{-4}	7,300
Maximum Adult[b]	3.5×10^{-4}	11,000
Indoor Activity[b]		
Average	1.8×10^{-4}	5,500
Maximum	2.5×10^{-4}	7,800
Outdoor Activity[b]		
Average	3.9×10^{-4}	12,000
Maximum	8.3×10^{-4}	26,000

[a] From NRC (1977b); 22 m^3/d average based on recommendations found in ICRP (1975) of 21 m^3/d for adult females and 23 m^3/d for adult males. Default value used in RISKIND.

[b] From EPA (1989).

Table 6.37. Percentage of Farmland by State in the Contiguous United States[a]

State	Percent Farmland	State	Percent Farmland	State	Percent Farmland
Alabama	26.0	Maine	6.4	Ohio	54.4
Arizona	48.2	Maryland	35.8	Oklahoma	73.1
Arkansas	42.4	Massachusetts	10.5	Oregon	28.7
California	29.0	Michigan	27.7	Pennsylvania	25.1
Colorado	51.2	Minnesota	50.4	Rhode Island	7.4
Connecticut	11.6	Mississippi	33.9	South Carolina	23.2
Delaware	47.1	Missouri	64.8	South Dakota	92.3
Florida	31.2	Montana	64.1	Tennessee	42.3
Georgia	27.0	Nebraska	90.2	Texas	78.1
Idaho	25.4	Nevada	13.2	Utah	18.3
Illinois	76.6	New Hampshire	6.7	Vermont	21.6
Indiana	68.0	New Jersey	18.0	Virginia	33.3
Iowa	87.7	New Mexico	60.3	Washington	36.9
Kansas	89.1	New York	24.7	West Virginia	21.2
Kentucky	53.7	North Carolina	28.7	Wisconsin	44.5
Louisiana	28.1	North Dakota	89.3	Wyoming	52.9
				Contiguous U.S.	49.8

[a] Percentage of land in farms.

Source: DOC (1994)

■ ■ 6.2.1 Accident Injuries and Fatalities

The vehicle-related accident risk refers to the potential for transportation-related accidents that result in injuries or fatalities due to physical trauma unrelated to the cargo being shipped. State average rates for transportation-related injuries and fatalities are available. Vehicle-related risks are presented in terms of estimated injuries and fatalities per shipment-km for the truck and rail options.

■ ■ ■ 6.2.1.1 Truck

State-level injury and fatality rates for heavy tractor-trailer combinations involved in interstate commerce are available in reports by Saricks and coworkers (Saricks and Kvitek, 1994; Saricks and Tompkins, 1999). Tables 6.38 and 6.39 present the injury and fatality rates, respectively. As discussed in Section 6.1.9.1, these rates are not directly comparable because of accident reporting differences.

■ ■ ■ 6.2.1.2 Rail

Accident rates can be derived for an entire train or a single railcar. In either case, the number of accidents estimated for a shipping campaign would be approximately the same when using dedicated trains, or general freight trains, since most accidents are the result of railcar derailment (DOT, 1997b). However, the apportionment of injuries and fatalities on a railcar or train is not straightforward because of two considerations. First, approximately half of the injuries and fatalities are a result of accidents at rail crossings (DOT, 1997b) in which the lead locomotive is usually involved in a collision. Second, a large portion of the remaining injuries or fatalities occur in rail switching (classification) yards.

The first consideration suggests that the injury and fatality rates are independent of train length, and the rates should be based on specific trains (Cashwell et al., 1986). Therefore, if a shipment of radioactive material was considered a single railcar in a regular train with an average of 66 railcars (five-year average number of railcars in a freight train [AAR, 1997b]), the injury or fatality rate for a shipment would be 1/66th (the railcar's "contribution" to the shipment risk) that of a dedicated train shipment. Thus, the total injury and fatality risks for shipping by dedicated trains would be higher than by regular trains unless the dedicated train had as many or more railcars than a regular train.

The second consideration suggests that the injury and fatality rates are railcar dependent. A train does not exist in the classification yards until all its railcars are assembled together; thus, injuries and fatalities cannot be assigned to any one given train. The default is then to assign injury or fatality rates per railcar-km by dividing the total number of injuries or fatalities by the total number of railcar-km traveled for a given period of time. In this implementation, the total casualty risks for a shipping campaign will be the same whether regular or dedicated trains are used, since the same number of railcars are shipped and the same number of railcar-km are traveled.

The second consideration also has another aspect. Since dedicated trains spend less time in railyards undergoing classification, the injuries and fatalities associated with railyards are not as relevant to dedicated trains as they are to regular trains. From this viewpoint, the casualty risks

Table 6.38. Combination Truck Injury Rates by State

State	Injuries/km								
	Saricks and Tompkins (1999)				Saricks and Kvitek (1994)				
					Interstate				
	Interstate	Primary	Other	Total	Rural	Urban	Total	Primary	Secondary
Alabama	1.48E–07	3.17E–07	1.41E–07	2.13E–07	1.24E–07	4.66E–07	1.83E–07	5.62E–07	4.22E–07
Arizona	1.17E–07	6.30E–08	0	9.20E–08	1.65E–07	2.89E–07	1.82E–07	2.20E–07	2.77E–07
Arkansas	9.80E–08	2.08E–07	2.30E–08	1.24E–07	1.95E–07	4.09E–07	2.20E–07	4.38E–07	5.94E–07
California	1.24E–07	3.40E–08	1.44E–07	6.40E–08	1.68E–07	1.82E–07	1.74E–07	1.12E–07	2.67E–07
Colorado	3.15E–07	2.65E–07	3.72E–07	3.03E–07	2.82E–07	5.47E–07	3.45E–07	3.95E–07	3.67E–07
Connecticut	6.13E–07	2.64E–07	2.37E–06	6.16E–07	4.61E–07	1.71E–07	2.55E–07	1.89E–07	7.09E–07
Delaware	3.42E–07	5.95E–07	8.31E–07	5.11E–07	0	3.46E–07	3.46E–07	7.18E–07	3.08E–07
Florida	5.50E–08	6.00E–08	3.04E–07	7.10E–08	1.28E–07	2.36E–07	1.58E–07	4.12E–07	7.92E–07
Georgia	*[a]	*	*	4.59E–07	1.75E–07	4.37E–07	2.26E–07	6.43E–07	3.71E–07
Idaho	3.07E–07	4.74E–07	5.62E–07	3.94E–07	2.12E–07	1.18E–07	1.99E–07	3.54E–07	1.69E–07
Illinois	1.50E–07	1.30E–07	4.97E–07	1.64E–07	1.49E–07	8.23E–07	3.20E–07	6.12E–07	1.55E–07
Indiana	1.40E–07	1.11E–07	3.40E–08	1.15E–07	1.81E–07	4.36E–07	2.30E–07	4.42E–07	2.32E–07
Iowa	8.60E–08	1.34E–07	1.80E–07	1.13E–07	1.46E–07	3.78E–07	1.76E–07	3.48E–07	8.80E–08
Kansas	2.54E–07	4.81E–07	2.53E–07	3.45E–07	1.91E–07	3.66E–07	2.28E–07	4.09E–07	1.12E–07
Kentucky	2.21E–07	7.30E–07	3.17E–07	3.61E–07	1.33E–07	5.52E–07	1.94E–07	5.28E–07	8.12E–07
Louisiana	*	*	*	1.84E–07	1.32E–07	4.57E–07	2.16E–07	4.46E–07	2.85E–07
Maine	3.12E–07	1.70E–07	6.55E–07	3.33E–07	1.53E–07	4.52E–07	1.75E–07	5.00E–07	1.63E–07
Maryland	4.59E–07	6.89E–07	1.94E–06	6.06E–07	3.98E–07	3.41E–07	3.66E–07	4.32E–07	1.34E–06
Massachusetts	5.10E–08	1.27E–07	9.46E–07	1.04E–07	4.99E–07	1.13E–07	2.09E–07	3.02E–07	4.39E–06
Michigan	2.61E–07	1.03E–07	6.68E–07	2.20E–07	1.29E–07	3.04E–07	1.87E–07	2.61E–07	1.38E–07
Minnesota	8.40E–08	1.51E–07	1.13E–07	1.21E–07	1.46E–07	2.08E–07	1.69E–07	3.28E–07	1.86E–07
Mississippi	3.90E–08	8.80E–08	2.50E–08	5.70E–08	1.10E–07	1.85E–07	1.25E–07	4.55E–07	5.00E–08
Missouri	3.14E–07	3.85E–07	5.69E–07	3.65E–07	1.63E–07	5.53E–07	2.59E–07	5.06E–07	2.23E–07
Montana	2.56E–07	3.14E–07	1.17E–07	2.58E–07	1.79E–07	4.69E–07	1.93E–07	3.95E–07	2.00E–08
Nebraska	1.97E–07	3.52E–07	2.51E–07	2.59E–07	1.17E–07	6.58E–07	1.50E–07	3.54E–07	5.40E–08
Nevada	1.48E–07	2.52E–07	2.60E–08	1.62E–07	1.58E–07	5.67E–07	1.93E–07	3.72E–07	2.54E–07
New Hampshire	1.63E–07	2.40E–07	4.02E–07	2.34E–07	1.14E–07	0	9.40E–08	4.17E–07	2.22E–07

Table 6.38. Combination Truck Injury Rates by State (Continued)

State	Injuries/km								
	Saricks and Tompkins (1999)				Saricks and Kvitek (1994)				
					Interstate				
	Interstate	Primary	Other	Total	Rural	Urban	Total	Primary	Secondary
New Jersey	3.91E–07	2.37E–07	2.15E–06	3.79E–07	8.00E–07	2.69E–07	4.28E–07	6.86E–07	1.13E–06
New Mexico	1.15E–07	9.40E–08	1.10E–07	1.08E–07	1.86E–07	8.92E–07	2.25E–07	4.62E–07	1.06E–06
New York	*	*	*	1.85E–07	2.56E–07	4.49E–07	3.28E–07	2.71E–07	1.00E–06
North Carolina	3.17E–07	3.22E–07	2.99E–07	3.16E–07	2.19E–07	6.37E–07	2.99E–07	5.53E–07	6.22E–07
North Dakota	1.89E–07	3.61E–07	1.62E–07	2.53E–07	8.40E–08	4.80E–07	1.07E–07	1.63E–07	0
Ohio	1.40E–07	4.00E–08	1.17E–07	1.07E–07	2.02E–07	2.85E–07	2.25E–07	4.40E–07	1.07E–06
Oklahoma	2.89E–07	3.18E–07	2.31E–07	2.85E–07	1.36E–07	3.34E–07	1.74E–07	3.05E–07	1.59E–07
Oregon	*	*	*	1.36E–07	1.69E–07	3.82E–07	2.02E–07	2.94E–07	5.70E–08
Pennsylvania	3.83E–07	5.90E–07	1.78E–06	5.33E–07	3.28E–07	2.68E–07	3.15E–07	7.28E–07	6.42E–07
Rhode Island	2.27E–07	2.73E–07	4.69E–07	2.56E–07	2.35E–07	3.12E–07	2.84E–07	8.60E–08	2.33E–06
South Carolina	*	*	*	3.30E–07	2.20E–07	2.65E–07	2.26E–07	6.96E–07	2.27E–07
South Dakota	1.72E–07	1.63E–07	1.03E–07	*	1.38E–07	5.71E–07	1.95E–07	2.94E–07	0
Tennessee	9.20E–08	2.43E–07	1.35E–07	1.27E–07	1.44E–07	7.70E–07	2.41E–07	5.85E–07	4.67E–07
Texas	5.47E–07	5.25E–07	5.46E–07	5.37E–07	1.42E–07	2.53E–07	1.83E–07	2.53E–07	9.20E–08
Utah	2.53E–07	2.49E–07	6.77E–07	2.84E–07	2.22E–07	2.08E–07	2.18E–07	3.73E–07	4.35E–07
Vermont	1.52E–07	3.80E–07	8.00E–08	2.20E–07	1.08E–07	0	1.04E–07	6.13E–07	4.40E–07
Virginia	3.10E–07	1.73E–07	1.20E–08	2.16E–07	2.46E–07	2.49E–07	2.47E–07	5.39E–07	4.81E–07
Washington	1.80E–07	1.18E–07	9.70E–08	1.40E–07	2.14E–07	1.49E–07	1.85E–07	2.11E–07	5.10E–08
West Virginia	1.12E–07	2.59E–07	6.40E–08	1.40E–07	2.80E–07	2.78E–07	2.79E–07	9.91E–07	7.13E–07
Wisconsin	3.33E–07	3.13E–07	1.10E–06	4.10E–07	1.45E–07	4.33E–07	1.81E–07	2.51E–07	3.16E–07
Wyoming	3.23E–07	3.34E–07	2.84E–07	3.23E–07	2.84E–07	0.00E+00	2.74E–07	1.86E–07	2.35E–07
Mean Rate	2.27E–07	2.73E–07	4.69E–07	2.56E–07	1.89E–07	3.36E–07	2.28E–07	3.82E–07	3.30E–07
Total Rate	2.25E–07	2.17E–07	3.33E–07	2.39E–07	–[b]	–	–	–	–

[a] * = data not provided by state.
[b] – = rate not provided

Table 6.39. Combination Truck Fatality Rates by State

State	Fatalities/km								
	Saricks and Tompkins (1999)				Saricks and Kvitek (1994)				
					Interstate				
	Interstate	Primary	Other	Total	Rural	Urban	Total	Primary	Secondary
Alabama	8.60E–09	4.15E–08	1.17E–08	2.19E–08	1.84E–08	3.29E–08	2.09E–08	6.34E–08	7.84E–08
Arizona	9.40E–09	1.07E–08	0	9.40E–09	2.13E–08	3.56E–08	2.33E–08	4.97E–08	1.20E–08
Arkansas	6.20E–09	5.14E–08	0	2.22E–08	2.28E–08	6.61E–08	2.78E–08	8.88E–08	7.10E–08
California	7.00E–09	2.20E–09	5.90E–09	3.60E–09	2.56E–08	1.39E–08	2.06E–08	1.98E–08	3.81E–08
Colorado	1.14E–08	2.05E–08	2.83E–08	1.75E–08	2.45E–08	3.38E–08	2.67E–08	6.58E–08	5.83E–08
Connecticut	1.45E–08	1.70E–08	9.20E–08	1.91E–08	5.11E–08	1.01E–08	2.20E–08	1.17E–08	9.09E–08
Delaware	5.60E–09	3.79E–08	1.60E–08	2.35E–08	0	1.66E–08	1.66E–08	1.35E–07	7.69E–08
Florida	7.70E–09	1.06E–08	3.51E–08	1.07E–08	2.62E–08	1.74E–08	2.38E–08	5.92E–08	6.12E–08
Georgia	*[a]	*	*	1.95E–08	1.86E–08	2.37E–08	1.96E–08	8.30E–08	6.74E–08
Idaho	3.80E–09	5.52E–08	3.64E–08	2.49E–08	2.06E–08	0	1.78E–08	7.46E–08	2.54E–08
Illinois	8.30E–09	1.27E–08	4.08E–08	1.10E–08	1.39E–08	5.33E–08	2.38E–08	7.84E–08	2.30E–08
Indiana	6.70E–09	1.42E–08	3.20E–09	8.60E–09	1.22E–08	3.51E–08	1.66E–08	7.66E–08	4.02E–08
Iowa	9.40E–09	2.14E–08	8.60E–09	1.34E–08	1.05E–08	2.68E–08	1.26E–08	6.14E–08	7.30E–09
Kansas	5.20E–09	4.68E–08	1.01E–08	2.29E–08	1.88E–08	5.52E–08	2.66E–08	9.35E–08	1.72E–08
Kentucky	1.28E–08	5.30E–08	1.08E–08	2.29E–08	1.50E–08	3.22E–08	1.75E–08	6.60E–08	6.25E–08
Louisiana	*	*	*	9.20E–09	1.77E–08	4.90E–08	2.59E–08	5.73E–08	3.28E–08
Maine	9.10E–09	0	1.86E–08	7.80E–09	2.34E–08	0	2.16E–08	6.58E–08	2.17E–08
Maryland	6.50E–09	4.43E–08	6.39E–08	1.99E–08	4.03E–08	1.62E–08	2.69E–08	3.66E–08	8.99E–08
Massachusetts	8.00E–10	6.10E–09	4.19E–08	3.80E–09	6.23E–08	1.30E–08	2.53E–08	3.93E–08	5.22E–07
Michigan	1.07E–08	6.40E–09	3.14E–08	1.07E–08	1.23E–08	1.52E–08	1.33E–08	3.96E–08	1.22E–08
Minnesota	3.00E–09	2.16E–08	1.50E–09	1.20E–08	1.72E–08	2.02E–08	1.83E–08	7.69E–08	7.84E–08
Mississippi	2.50E–09	5.40E–09	6.00E–10	3.40E–09	1.81E–08	2.46E–08	1.93E–08	9.26E–08	1.62E–08
Missouri	1.24E–08	3.16E–08	1.21E–08	1.97E–08	1.23E–08	4.30E–08	1.99E–08	9.68E–08	3.25E–08
Montana	1.36E–08	2.90E–08	2.33E–08	2.03E–08	1.44E–08	3.12E–08	1.52E–08	7.97E–08	2.04E–08
Nebraska	1.37E–08	2.74E–08	1.38E–08	1.87E–08	1.10E–08	6.58E–08	1.43E–08	5.75E–08	0
Nevada	6.60E–09	1.67E–08	3.30E–09	8.90E–09	1.14E–08	8.89E–08	1.79E–08	1.05E–07	7.94E–08
New Hampshire	0	2.06E–08	8.90E–09	1.18E–08	1.49E–08	0	1.22E–08	5.77E–08	5.56E–08

Table 6.39. Combination Truck Fatality Rates by State (Continued)

State	Fatalities/km								
	Saricks and Tompkins (1999)				Saricks and Kvitek (1994)				
					Interstate				
	Interstate	Primary	Other	Total	Rural	Urban	Total	Primary	Secondary
New Jersey	1.21E–08	1.50E–09	3.91E–08	7.10E–09	6.56E–08	1.56E–08	3.06E–08	4.57E–08	1.15E–07
New Mexico	1.18E–08	1.13E–08	7.60E–09	1.10E–08	1.93E–08	9.01E–08	2.32E–08	6.99E–08	5.56E–08
New York	*	*	*	1.24E–08	1.38E–08	2.04E–08	1.63E–08	4.61E–08	1.03E–07
North Carolina	1.49E–08	1.78E–08	1.38E–08	1.62E–08	2.92E–08	5.08E–08	3.33E–08	6.71E–08	1.10E–07
North Dakota	1.02E–08	1.76E–08	0	1.11E–08	4.80E–09	4.00E–08	6.80E–09	9.80E–09	0
Ohio	3.90E–09	2.60E–09	6.90E–09	3.90E–09	1.32E–08	1.41E–08	1.35E–08	6.07E–08	9.88E–08
Oklahoma	1.33E–08	2.12E–08	7.70E–09	1.47E–08	2.06E–08	2.70E–08	2.18E–08	4.88E–08	7.10E–09
Oregon	*	*	*	2.04E–08	1.12E–08	2.47E–08	1.33E–08	5.85E–08	4.07E–08
Pennsylvania	1.35E–08	4.09E–08	5.03E–08	2.43E–08	2.97E–08	2.12E–08	2.79E–08	1.02E–07	9.29E–08
Rhode Island	8.80E–09	2.32E–08	1.96E–08	1.49E–08	3.70E–08	7.10E–09	1.80E–08	1.71E–08	6.67E–07
South Carolina	*	*	*	2.60E–08	2.57E–08	2.88E–08	2.61E–08	8.61E–08	3.95E–08
South Dakota	6.10E–09	1.53E–08	2.93E–08	1.27E–08	4.20E–09	1.43E–07	6.20E–09	5.38E–08	2.13E–08
Tennessee	1.00E–08	2.60E–08	3.90E–09	1.30E–08	1.63E–08	5.59E–08	2.24E–08	6.97E–08	1.21E–07
Texas	1.30E–08	2.86E–08	8.32E–08	2.70E–08	1.97E–08	1.93E–08	1.95E–08	4.77E–08	1.84E–08
Utah	1.19E–08	1.60E–08	2.27E–08	1.39E–08	2.21E–08	5.90E–09	1.80E–08	8.25E–08	2.17E–08
Vermont	0	2.81E–08	0	9.70E–09	4.30E–09	0	4.20E–09	3.36E–08	2.40E–07
Virginia	1.61E–08	9.90E–09	0	1.16E–08	1.76E–08	1.91E–08	1.80E–08	7.28E–08	7.73E–08
Washington	1.80E–09	7.50E–09	8.30E–09	5.30E–09	1.47E–08	8.00E–09	1.17E–08	2.54E–08	0
West Virginia	1.68E–08	6.80E–08	8.40E–09	2.78E–08	1.67E–08	1.28E–08	1.60E–08	1.78E–07	1.70E–08
Wisconsin	9.10E–09	3.21E–08	2.51E–08	2.22E–08	6.60E–09	7.70E–09	6.7E–09	3.62E–08	3.68E–08
Wyoming	1.08E–08	2.42E–08	0	1.24E–08	2.08E–08	0	2.01E–08	6.22E–08	3.70E–08
Mean Rate	8.80E–09	2.32E–08	1.96E–08	1.49E–08	1.91E–08	2.37E–08	2.03E–08	5.82E–08	4.62E–08
Total Rate	9.60E–09	1.78E–08	1.71E–08	1.42E–08	–[b]	–	–	–	–

[a] * = data not provided by state.
b– = rate not provided

are lower for dedicated trains than for regular trains. Saricks and Kvitek (1994) provide two sets of national average injury and fatality rates based on railcars. The first set, 5.37×10^{-7} injuries and 2.35×10^{-8} fatalities per railcar-km, includes all injuries and fatalities. The second set, 7.83×10^{-8} injuries and 6.50×10^{-10} fatalities per railcar-km, is consistent with the same type of truck transportation risks by excluding a large portion of casualties in railyards (primarily due to trespassers). However, there are no such equivalent risks in truck transportation. Thus, it is more appropriate to use rates that include all injuries and fatalities because they occur during a necessary portion of the rail shipment process. The updated report by Saricks and Tompkins (1999) includes all injuries and fatalities in rates at the state level, as given in Table 6.40.

At this time, there are no clear guidelines as to whether dedicated trains should be assigned higher casualties than waste shipments by regular train because casualties are independent of train length, or whether dedicated trains should be assigned lower casualties because they spend less time in rail switching yards.

■ ■ 6.2.2 Vehicle Emissions

Vehicle-related risks during incident-free transportation include incremental risks caused by potential exposure to airborne particulate matter from fugitive dust and vehicular exhaust emissions. As discussed in Section 4.1.1.3, the health end point assessed under routine transport conditions is the excess (additional) latent mortality that may be caused by inhalation of vehicular emissions. These emissions are primarily in the form of diesel exhaust and fugitive dust (resuspended particulates from the roadway). Epidemiological evidence suggests that increases in ambient PM_{10} (particulate matter with a mean aerodynamic diameter less than or equal to 10 μm) air concentrations may lead to increases in mortality (EPA, 1996a; b). Currently, it is assumed that no threshold exists and that the dose-response functions for most health effects associated with PM_{10} exposure, including premature mortality, are linear over the concentration ranges investigated (EPA, 1996a). In the short- and long-term, fatalities may result from life-shortening respiratory or cardiovascular diseases (EPA, 1996a; Ostro and Chestnut, 1998). The long-term fatalities also are assumed to include those from cancer.

A risk factor for latent mortality from pollutant inhalation, generated by Rao et al. (1982), is 1×10^{-7}/km (1.6×10^{-7}/mi) of truck travel in an urban area (1.3×10^{-7}/railcar-km for rail travel). This risk factor is based on regression analyses of fugitive dust and sulfur dioxide effects and particulate releases from diesel exhaust on mortality. Excess latent mortality is assumed equivalent to latent fatalities. Total emission fatalities for a shipment are estimated by multiplying this emission risk factor by the distance traveled in urban zones. If a major shipping campaign is involved with repeated shipments, the estimated emission impacts should be doubled to account for round-trip travel of the transport vehicle, as was done for the WM PEIS (DOE, 1997b). However, Rao's risk factors are based on an area with a population density of 3,861 persons/km^2. Such densities are only found in urban areas such as Manhattan in New York City.

Table 6.40. Rail Injury and Fatality Rates by State

State	Injuries			Fatalities		
	Non-Trespasser Injuries/ Car-km	Trespasser Injuries/ Car-km	All Injuries/ Car-km	Non-Trespasser Fatalities/ Car-km	Trespasser Fatalities/ Car-km	All Fatalities/ Car-km
Alabama	7.53E–08	4.70E–09	8.00E–08	1.48E–08	6.38E–09	2.12E–08
Arizona	5.15E–09	5.15E–09	1.03E–08	1.78E–09	8.92E–09	1.07E–08
Arkansas	6.37E–08	1.54E–09	6.52E–08	2.43E–08	3.09E–09	2.74E–08
California	1.93E–08	1.45E–08	3.38E–08	7.33E–09	2.78E–08	3.52E–08
Colorado	1.38E–08	3.77E–09	1.76E–08	6.54E–09	3.52E–09	1.01E–08
Connecticut	9.14E–08	1.25E–08	9.14E–08	4.57E–08	6.85E–07	7.31E–07
Delaware	2.26E–07	6.47E–08	2.91E–07	3.23E–08	6.47E–08	9.70E–08
District of Columbia	1.04E–07	1.25E–08	1.17E–07	1.38E–08	2.18E–07	2.18E–07
Florida	4.47E–08	2.10E–08	6.58E–08	1.64E–08	2.98E–08	4.63E–08
Georgia	3.39E–08	1.11E–08	4.50E–08	1.02E–08	7.35E–09	1.75E–08
Idaho	2.20E–08	1.83E–09	2.38E–08	1.34E–08	4.89E–09	1.83E–08
Illinois	3.40E–08	9.46E–09	4.35E–08	1.29E–08	1.28E–08	2.58E–08
Indiana	6.14E–08	1.37E–08	7.51E–08	2.02E–08	8.29E–09	2.85E–08
Iowa	4.11E–08	1.57E–09	4.27E–08	9.42E–09	2.88E–09	1.23E–08
Kansas	2.07E–08	8.71E–10	2.16E–08	7.66E–09	2.26E–09	9.92E–09
Kentucky	3.43E–08	8.28E–09	4.26E–08	6.13E–09	8.58E–09	1.47E–08
Louisiana	1.90E–07	1.71E–08	2.08E–07	4.35E–08	1.41E–08	5.76E–08
Maine	1.22E–07	5.24E–08	1.75E–07	1.38E–08	6.44E–08	7.82E–08
Maryland	2.05E–08	1.67E–08	3.72E–08	1.38E–08	3.08E–08	3.08E–08
Massachusetts	6.46E–08	7.76E–08	1.42E–07	2.59E–08	2.00E–07	2.26E–07
Michigan	1.80E–07	2.49E–08	2.05E–07	3.91E–08	2.40E–08	6.31E–08
Minnesota	3.14E–08	8.49E–09	3.99E–08	1.31E–08	3.09E–09	1.62E–08
Mississippi	1.03E–07	4.87E–09	1.08E–07	3.89E–08	1.82E–09	4.08E–08
Missouri	1.90E–08	2.00E–09	2.10E–08	7.30E–09	4.15E–09	1.15E–08
Montana	6.93E–09	2.23E–09	9.16E–09	1.98E–09	3.22E–09	5.20E–09
Nebraska	1.18E–08	6.72E–10	1.24E–08	5.88E–09	1.51E–09	7.39E–09
Nevada	1.85E–09	8.24E–10	2.68E–09	1.65E–09	1.03E–09	2.68E–09
New Hampshire	1.31E–07	1.25E–08	1.31E–07	4.36E–08	6.44E–08	4.36E–08
New Jersey	6.63E–08	5.57E–08	1.22E–07	2.39E–08	1.56E–07	1.80E–07
New Mexico	7.56E–09	3.47E–09	1.10E–08	2.45E–09	4.49E–09	6.95E–09
New York	2.07E–08	3.08E–08	5.15E–08	1.26E–08	4.78E–08	6.03E–08
North Carolina	1.05E–07	2.94E–08	1.34E–07	2.24E–08	5.25E–08	7.49E–08
North Dakota	1.41E–08	3.91E–10	1.45E–08	4.70E–09	1.96E–09	6.65E–09
Ohio	3.82E–08	2.87E–09	4.10E–08	1.47E–08	5.91E–09	2.06E–08
Oklahoma	5.78E–08	7.80E–09	6.56E–08	1.91E–08	3.55E–09	2.27E–08
Oregon	1.87E–08	1.95E–08	3.81E–08	6.49E–09	1.54E–08	2.19E–08

Table 6.40. Rail Injury and Fatality Rates by State (Continued)

State	Injuries			Fatalities		
	Non-Trespasser Injuries/ Car-km	Trespasser Injuries/ Car-km	All Injuries/ Car-km	Non-Trespasser Fatalities/ Car-km	Trespasser Fatalities/ Car-km	All Fatalities/ Car-km
Pennsylvania	1.84E–08	1.23E–08	3.06E–08	9.35E–09	1.29E–08	2.22E–08
Rhode Island	2.69E–06	1.25E–08	2.69E–06	1.38E–08	1.34E–06	1.34E–06
South Carolina	9.36E–08	1.15E–08	1.05E–07	2.56E–08	4.49E–08	7.05E–08
South Dakota	4.02E–08	1.25E–08	4.02E–08	8.53E–09	6.44E–08	8.53E–09
Tennessee	2.58E–08	6.45E–09	3.23E–08	1.11E–08	7.07E–09	1.81E–08
Texas	4.73E–08	1.17E–08	5.90E–08	1.28E–08	1.18E–08	2.47E–08
Utah	1.76E–08	5.87E–09	2.35E–08	2.02E–08	5.22E–09	2.54E–08
Vermont	1.33E–08	1.25E–08	1.33E–08	1.38E–08	1.33E–08	1.33E–08
Virginia	2.39E–08	7.45E–09	3.14E–08	6.27E–09	1.49E–08	2.12E–08
Washington	2.45E–08	1.61E–08	4.06E–08	5.08E–09	1.95E–08	2.45E–08
West Virginia	1.14E–08	1.28E–08	2.41E–08	3.31E–09	6.15E–09	9.46E–09
Wisconsin	1.07E–07	7.19E–09	1.14E–07	1.72E–08	7.19E–09	2.43E–08
Wyoming	1.35E–09	1.25E–08	1.35E–09	1.18E–09	1.18E–09	2.36E–09
Total	3.33E–08	7.75E–09	4.10E–08	1.05E–08	1.02E–08	2.08E–08
Mean Rate	1.04E–07	1.25E–08	1.17E–07	1.38E–08	6.44E–08	7.82E–08

Source: Saricks and Tompkins (1999).

More recent estimates of latent fatalities were developed by Biwer and Butler (1999) to expand the applicability of vehicle emission risk to all truck classes and to non-urban as well as urban areas. Rao et al. (1982) only considered the heavy-duty truck class in urban areas. The methods used by Rao et al. (1982) were revised in conjunction with updated epidemiological data related to the health effects of airborne particulates (PM_{10}) on human health. In addition, Biwer and Butler (1999) attempted to reconcile their results with estimates of LCFs presented in the EPA's *Motor Vehicle-Related Air Toxics Study* (EPA, 1993b). The resultant estimates were presented on a per-kilometer basis (Table 6.41) assuming a population density of 1 person/km^2 on either side of the transport route. Latent emission fatalities including, but not limited to, cancer fatalities, may be estimated by multiplying the appropriate risk factor by the distance and corresponding population density along a selected route segment.

As discussed in Biwer and Butler (1999), there are large uncertainties in the human health risk factors used to develop emission risks. In addition, because of the conservative assumptions made to reconcile results with those presented in the EPA study (EPA, 1993b), latent fatality risks estimated using the data in Table 6.41 may be near an upper bound. Use of the risk in Table 6.41 for truck class VIIIB will give estimated fatalities comparable to those from accident fatalities in some cases. This result is due in part to new, higher incremental mortality risks estimated for a given exposure to increased PM_{10} levels than was used by Rao et al. (1982) in deriving the old emission risk factors. The question as to what exactly constitutes a fatality as a direct consequence of increased PM_{10} levels from vehicle emissions is still open, but long-term fatalities have been associated with increased levels of PM_{10} (Biwer and Butler, 1999).

Table 6.41. Estimated Vehicle Emissions (10 μm) and Fatalities per Kilometer for all Truck Classes and Rail

Truck Class	Truck Weight (tons)	Tire/Brake Particulates (g/km)	Fugitive Dust (g/km)	Diesel Exhaust (g/km)	Total Emissions (g/km)	Unit Risk (fatalities/km)[a]
LDDV	2.0	0.013	0.104	0.132	0.250	2.14×10^{-11}
I	3.0	0.013	0.191	0.167	0.372	3.19×10^{-11}
IIA	4.3	0.013	0.322	0.121	0.456	3.92×10^{-11}
IIB	5.0	0.013	0.411	0.160	0.584	5.01×10^{-11}
III	9.8	0.016	1.120	0.195	1.331	1.14×10^{-10}
IV	9.8	0.016	1.120	0.267	1.403	1.20×10^{-10}
V	9.8	0.016	1.120	0.276	1.412	1.21×10^{-10}
VI	16.5	0.016	2.467	0.259	2.741	2.35×10^{-10}
VII	16.5	0.016	2.467	0.344	2.826	2.43×10^{-10}
VIIIA	16.5	0.016	2.467	0.483	2.965	2.55×10^{-10}
VIIIB	40.0	0.030	9.310	0.400	9.740	8.36×10^{-10}
Railcar	NA[b]	NA	0.931	0.48	1.41	1.2×10^{-10}

[a] Unit risk is based on a population density of 1 person/km^2.
[c] NA = not applicable.
Source: Biwer and Butler (1999).

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8. Glossary

The following glossary of transportation/packaging terms is provided for the purpose of this handbook.

A

Accident: A deviation from normal operations or activities associated with a hazard which has the potential to result in an emergency [see emergency definition].

Acute exposure: A single, brief exposure to a toxic substance.

Affected persons: Individuals who have been exposed and/or injured as a result of an accident (see accident definition) involving any type of HAZMAT (see hazardous material definition), to a degree requiring special attention (i.e., decontamination (see decontamination definition), first aid, or medical service).

Agency: Any organization that acts in the place of a government and by its authority (e.g., The FEMA) is an agency of the federal government

Alpha particle: A positively charged particle emitted by certain radioactive materials (see radioactive materials definition). It is made up of two neutrons [see neutrons definition] and two protons (see protons definition) bound together and, hence, is identical to the nucleus of a helium atom. It has low-penetrating power and short range. The most energetic alpha particle will generally fail to penetrate the skin.

Annual limit on intake: The derived limit for the amount of radioactive material taken into the body of an adult worker by inhalation or ingestion in a year. Annual limit on intake is the smaller value of intake of a given radionuclide [see radionuclide definition] in a year by the reference man (International Commission Radiological Protections Publication 23) that would result in a committed effective dose equivalent [see effective dose equivalent definition] of 5 rem (0.05 sievert) or a committed dose equivalent of 50 rems (0.5 sievert) to any individual organ or tissue. (DOE Radiological Control Manual. DOE/EH-0256T, Rev. 1. April 1994)

As low as is reasonably achievable (ALARA): Means keeping radiation exposure as low as is reasonably achievable, taking into account the state of technology, the economics of improvements in relation to the benefits to public health and safety, other societal and socioeconomic considerations, and the utilization of atomic energy in the public interest.

Assessment: See consequence assessment.

Association of American Railroads (AAR): An organization advocating the interests of railroads in the public policy arena. The AAR works to enhance the productivity of the railroad industry through research and development, and other support programs. The organization facilitates a seamless intermodal interchange by electronically exchanging information among railroads, their customers, and their suppliers. Although AAR's most visible activity is representation of its members before Congress, regulatory agencies, and the courts, most of

AAR's employees and budget are focused on operations, maintenance, safety, theoretical and applied research, economics, finance, accounting, communications, electronic data exchange, and public affairs.

B

Barge: A non-self-propelled vessel. (49CFR171.8)

Beta particle: A charged particle emitted from a nucleus during radioactive decay (see decay definition), having a single electrical charge and a mass equal to 1/1837 that of a proton (see proton definition). A negatively charged beta particle is identical to an electron (see electron definition). A positively charged beta particle is called a positron. Large amounts of beta radiation may cause skin burns, and beta emitters are harmful if they enter the body. Beta particles are easily stopped by a thin sheet of metal or plastic.

Boiling water reactor (BWR): A light-water reactor in which water, used as both coolant and moderator, is allowed to boil in the core. The resulting steam can be used directly to drive a turbine.

By-product material: Any radioactive material (except special nuclear material) yielded in or made radioactive by exposure to the radiation incident to the process of producing or utilizing special nuclear material. (10CFR50.2)

C

Canister: The metal receptacle surrounding the waste form that facilitates handling, storage, transportation, and/or disposal.

Carrier: A person engaged in the transportation of passengers or property by land or water as a common, contract, or private carrier, or by civil aircraft. (10CFR71.4)

Cask: A container for shipping or storing radioactive material of greater than A1 or A2 (see A1 and A2 definitions) quantities.

Chronic effect: Effect of exposure to a hazardous material [see hazardous material definition] that develops slowly after many exposures or that recurs often.

Civilian Radioactive Waste Management System: The composite of sites, facilities, systems, equipment, materials, information, activities, and personnel required to perform those activities necessary to manage SNF (see spent nuclear fuel definition) and high-level radioactive waste disposal.

Commercial motor vehicle: Any self-propelled or towed vehicle used on public highways in interstate commerce to transport passengers or property where the vehicle has a gross vehicle weight rating or gross combination weight rating 10,001 or more pounds; or the vehicle is designed to transport more than 15 passengers, including the driver; or the vehicle is used in the transportation of HAZMAT (see hazardous material definition) in a quantity requiring placarding under regulations issued by the Secretary (of Transportation) under the Hazardous Materials Transportation Act.

Common carrier: The most accepted characteristics: availability of service to anyone seeking a transportation movement, publication of rates, provision of the service on schedule, service to designated points or a designated area, and service of a given class of movement and commodity.

Consequence: The result (i.e., health or other environmental effect) of a release of radioactive or HAZMAT (see radioactive and hazardous material definitions) to the environment.

Consequence assessment: The evaluation and interpretation of radiological or other HAZMAT [see hazardous material definition] measurements and other information to provide a basis for decision making. (DOE Order 5500.1B)

Contact-handled (CH): Waste containers that can be handled without shielding.

Contact-handled (CH) transuranic waste (TRUW): Packaged TRUW whose external surface dose rate does not exceed 200 millirem (see millirem definition) per hour.

Containment: A protective action that prevents an adversary force from escaping from and/or removing a DOE safeguards and security interest from DOE or DOE contractor control. A protection strategy of the same name. An enclosure designed to retain fission products accidentally released from a reactor core (e.g., containment structure for a nuclear power plant or production reactor). Barriers or other physical confinements of airborne or liquid material released or which could be released into the environment.

Contamination: A hazardous substance dispersed in materials or places where it is undesirable.

Contract carrier: A carrier, whatever mode, that provides service according to contractual agreement. The contract specifies charges to be applied, the character of the service, and the time of performance. There are no specified rates under regulation, but the charges applied must be made public.

Curie (Ci): A measure of the radioactivity (see radioactivity definition) of 1.0 gram of radium, equal to 37 billion disintegrations per second.

D

Decay: The decrease in activity of any radionuclide (see radionuclide definition) over time, due to spontaneous emission of radiation from its atomic nuclei of either alpha particles (see alpha particles definition), beta particles (see beta particles definition) or gamma rays (see definition). The rate of decay for a radionuclide is related to its half-life (see half-life definition).

Decontamination: The removal of hazardous substances from employees and their equipment to the extent necessary to preclude the occurrence of foreseeable adverse health effects. (29 CFR 1910.120)

Dedicated train: Train service, as opposed to regular train service, that may include certain restrictions such as consisting of a locomotive, caboose, buffer cars, one or more cars of radioactive, and no other freight; may not travel at any time faster than 35 miles per hour; and must stop when it meets, passes, or is passed by another train. Special routing restrictions may also apply in which the railroad will attempt to avoid highly populated areas. As a separately operating train with its own crew, the special train will avoid some rail yards and sidings that are engaged in railcar switching, e.g., train make-up.

DOE Orders: Written, permanent, and temporary Departmental directives affecting more than one DOE organization which establish or change policies, organization, methods, standards, or procedures; guide, instruct, and inform employees in their work; require action or impose workload; give information essential to the administration or operation of the Department; or transmit other information to employees or contractors of the Department when use of DOE publications would not be practicable. Issuances used for permanent or long-lasting directives.

Dose: Refers to either the amount of energy absorbed by body tissue due to radiation exposure, or the amount of biological damage done by this absorbed energy. Absorbed energy is measured in gray or rad; biological damage, in sievert or rem. Various terms, such as dose equivalent (see dose equivalent definition), EDE (see effective dose equivalent definition) and collective dose, are used to evaluate the amount of biological damage a worker or member of the public sustains when exposed to ionizing radiation. These terms are used to describe the differing interactions of radiation with tissue as well as to assist in the management of personnel exposure to radiation.

Dose equivalent (H): The product of the absorbed dose (D) (in rad or gray) in tissue, a quality factor (Q), and all other rad definition modifying factors (N). Dose equivalent is expressed in units of rem (see rem definition) (or sievert) (1 rem = 0.01 sievert).

Dosimetry: The theory and application of the principles and techniques involved in measuring and recording radiation doses (see dose definition).

E

Effective dose equivalent (H_E): The summation of the products of the dose equivalent received by specified tissues of the body (H_T) and the appropriate weighting factors (W_T) — that is ($H_E = \Sigma W_T H_T$). It includes the dose (see dose definition) from radiation sources internal and/or external to the body. The EDE is expressed in units of rem (see rem definition) (or sievert).

Effective half-life: The time required for a radionuclide [see radionuclide definition] contained in a biological system, such as in humans, to reduce its activity by half, as a combined result of radioactive decay (see decay definition) and biological elimination.

Emergency: An emergency is the most serious event and consists of any unwanted operational, civil, natural-phenomenon, or security occurrence which could endanger or adversely affect people, property, or the environment. (DOE Order 5500.1B)

Emergency response: The implementation of planning and preparedness during an emergency involving the effective decisions, actions, and application of resources that must be accomplished to mitigate consequences and recover from an emergency.

Enriched uranium: Uranium (see uranium definition) containing more U-235 than the naturally occurring distribution of uranium isotopes (see isotopes definition).

Environmental Impact Statement (EIS): Detailed written statements as required by NEPA Section 102(2)(C). (40 CFR 1508.9) A document required for major federal projects or legislative proposals significantly affecting the environment.

Exclusive use: The sole use of a conveyance by a single consignor and for which all initial, intermediate, and final loading and unloading are carried out in accordance with the direction of the consignor or consignee.

F

Facility: Any equipment, structure, system, process, or activity that fulfills a specific purpose. Examples include accelerators, storage areas, fusion research devices, nuclear reactors, production or processing plants, coal conversion plants, magnetohydrodynamics experiments, windmills, radioactive waste disposal systems and burial grounds, testing laboratories, research laboratories, transportation activities, and accommodations for analytical examinations of irradiated and unirradiated components. (DOE Order 5500.1B)

Fission products: The nuclei (fission fragments) formed by the fission of heavy elements plus the nuclides (see nuclide definition) formed by the fission fragment in radioactive decay (see decay definition).

G

Gamma rays: High energy, short wavelength electromagnetic radiation emitted from the nucleus. Gamma radiation frequently accompanies alpha (see alpha definition) and beta (see beta definition) emissions and always accompanies fission. Gamma rays are very penetrating and are best stopped or shielded against by dense materials, such as lead or depleted uranium (see depleted uranium definition). Gamma rays are essentially similar to x-rays but are usually more energetic and are nuclear in origin.

H

Half-life: The time required for the activity of radionuclide (see radionuclide definition) to decrease to half of its initial value due to radioactive decay (see decay definition).

Hazard: A process, condition, or asset which has the potential to adversely impact the health and safety of personnel, the public, the environment, or national security. Hazards are divided into three classes: a) Low: hazards which present minor onsite and negligible offsite impacts to people, the environment, or national security. b) Moderate: hazards which represent considerable potential onsite impacts to the people or the environment, but at most only minor offsite impacts to people, the environment, or national security. (DOE Order 5500.1B). c) High: hazards with the potential for onsite and offsite impacts to large numbers of persons or with the potential for major impacts to the environment or national security. (DOE Order 5500.1B)

Hazardous material (HAZMAT): Any solid, liquid, or gaseous material that is toxic, flammable, radioactive, corrosive, chemically reactive, or unstable upon prolonged storage in quantities that could pose a threat to life, property, or the environment (this definition is applicable to DOE orders and is not to be confused with the term “hazardous material substance” defined in Section 101(14) of Comprehensive Environmental Response, Compensation and Liability Act of 1980 and in [40 CFR 300.6]). Also defined by 49 CFR 171.8 as a substance or material designated by the Secretary of Transportation to be capable of posing an unreasonable risk to health, safety, and property when transported in commerce and which has been so designated. See definition of hazardous substance.

Hazardous substance: As defined by Section 101(14) of the Comprehensive Environmental Response, Compensation and Liability Act, any substance designated pursuant to Section 311(b)(2) (A) of the Clean Water Act; any element, compound, mixture, solution or substance designated pursuant to Section 102 identified under or listed pursuant to Section 3001 of the Solid Waste Disposal Act (but not including any waste listed under Section 307[a] of the Clean Water Act); any hazardous air pollutant listed under Section 112 of the Clean Air Act; and any imminently hazardous chemical substance or mixture pursuant to Section 7 of the Toxic Substances Control Act. The term does not include petroleum, including crude oil or any fraction thereof, which is not otherwise specifically listed or designated as a hazardous substance in the first sentence of this paragraph, and the term does not include natural gas, natural gas liquids, liquefied natural gas, or synthetic gas usable for fuel (or mixtures of natural gas and such synthetic gas).

Hazardous waste: Those solid wastes designated by OSHA 40 CFR 261 due to the properties of ignitability, corrosivity, reactivity, or toxicity. (DOE Order 5500.2A) Any material that is subject to the Hazardous Waste Manifest requirements of the EPA specified in 40 CFR Part 262.

High-level [radioactive] waste (HLW): The highly radioactive waste material that results from the reprocessing of SNF, including liquid waste produced directly in reprocessing and any solid material derived from such liquid waste, that contains fission products in sufficient concentrations; and other highly radioactive material that is determined, consistent with existing law, to require permanent isolation (DOE M 435.1-1)

HIGHWAY: an interactive computer code that is used to calculate routes in accordance with HRCQ regulations (49 CFR 397.101) for spent-fuel shipment in the United States.

I

Incident: Any deviation from normal operations or activities which has the potential to result in an emergency (see emergency definition).

Incident-free transportation: Shipment activities without accidents or other unexpected or unusual occurrences.

Indian tribe: Any Indian tribe, band nation, or other organized group or community of Indians recognized as eligible for the services provided to Indians by the Secretary of the Interior because of their status as Indians, including any Alaska Native village, as defined in Section 3(c) of the Alaska Native Claims Settlement Act [43 U.S.C. 1602(c)].

INTERLINE: An interactive computer code used to predict rail routes for radioactive waste (see radioactive waste definition) shipments in the United States.

Intermodal transfer: The physical transfer of a package of cargo from one mode of transportation (e.g., highway, rail, or barge) to another to effect continuous movement of the shipment to destination without releasing the contents.

Ionizing radiation: Any radiation that causes displacement of electrons (see electron definition) from atoms or molecules, thereby producing ions.

Isotopes: One of two or more atoms with the same atomic number (the same chemical element) but with different atomic weights. An equivalent statement is that the nuclei of isotopes have the same number of protons but different numbers of neutrons. Isotopes usually have very nearly the same chemical properties, but somewhat different physical properties.

J

K

L

Labeling: Each person who offers for transportation or transports a HAZMAT (see hazardous material definition) in any packages or containment (see containment definition) devices listed in 49 CFR 172.400 shall label the package or containment device with labels specified for the material in the table listed in 49 CFR 172.101.

Latent cancer fatalities (LCFs): Fatal cancer that occurs a period of time after exposure to radiation. Typically used as the end point in radiological risk assessments and calculated by multiplying the collective dose to a population by health effects conversion factors.

Legal-weight truck (LWT): Refers to the total gross-weight of a motor vehicle, together with its cargo, which is within the prescribed maximum limits of the state, and not requiring overweight permits.

Limited quantity: When specified as such in a section applicable to a particular material, means the maximum amount of a HAZMAT (see hazardous material definition) for which there is a specific labeling or packaging exception.

Local government: Any county, city, village, town, district, or political subdivision of any state, Indian tribe or authorized tribal organization, or Alaska Native village or organization, including any rural community or unincorporated town or village or any other public entity.

Low-level (radioactive waste) (LLW): Radioactive material that is not high-level radioactive waste (see high-level radioactive waste definition), SNF (see SNF fuel definition), TRUW, byproduct material (as defined in Section 11e(2) of the AEA of 1954 as amended, or naturally occurring radioactive material (DOE M 435.1-1).

Low specific activity (LSA) materials: Means the following: (1) uranium (see uranium definition) or thorium ores and physical or chemical concentrates of those ores; (2) unirradiated natural or depleted uranium or unirradiated natural thorium; (3) tritium oxide in aqueous solutions provided the concentration does not exceed 5.0 millicurie per milliliter; (4) material in which the radioactivity (see radioactivity definition) is essentially uniformly distributed and in which the estimated average concentration of contents does not exceed amounts listed in 49 CFR 173.403; and (5) objects of nonradioactive material externally contaminated with radioactive material, provided that the radioactive material is not readily dispersible and the surface contamination (see contamination definition), when averaged over an area of 1 square meter, does not exceed 0.0001 millicurie per square centimeter of radionuclides (see radionuclides definition) for which the A2 quantity is not more than .05 Ci, or 0.001 millicurie per square centimeter for other radionuclides.

M

Marking: A descriptive name, identification number, instructions, cautions, weight, specification, or United Nations marks, or combinations thereof, required by this DOT on outer packaging of HAZMAT (see hazardous material definition).

Maximally exposed individual (MEI): A hypothetical individual located at a position that maximizes potential radiation exposure from incident-free transport or a potential release of radioactive material resulting from accident conditions.

Maximum reasonably foreseeable accident: A transportation accident with a probability of occurrence of more than 1×10^{-7}.

Millirem: A unit of radiation dosage equal to one-thousandth of a rem (see rem definition). According to federal standards, an individual is allowed to receive up to 500 millirem per year from nuclear fuel cycle activities.

Mixed waste: Waste containing both radioactive and hazardous components as defined by the Atomic Energy Act and the RCRA, respectively.

Monitoring: The use of sampling and detection equipment to determine the levels of radiation or other toxic materials.

Motor carrier: A motor common carrier and a motor contract carrier.

Motor common carrier: A regulated person or company engaged in carrying people or freight for a fee.

Motor contract carrier: A person, other than a motor common carrier, providing motor vehicle transportation of passengers for compensation under continuing agreement with a person or limited number of persons.

N

National Environmental Policy Act (NEPA) of 1969: The Act which established the national policy to protect the environment, requiring environmental impact statements for major federal actions that have the potential for significant impact on the environment, and established the CEQ.

Neutron: An uncharged elementary particle with a mass slightly greater than that of the proton (see proton definition); found in the nucleus of every atom heavier than hydrogen. A free neutron is unstable and decays (see decay definition) with a half-life (see half-life definition) of about 13 minutes into an electron (see electron definition), proton, and neutrino. Neutrons sustain the fission chain reaction in a nuclear reactor. Shielding for neutrons is usually large quantities of materials such as water, paraffin, or polyethylene.

Nuclear reactor: An apparatus designed or used to sustain nuclear fission in a self-supporting and controlled chain reaction.

Nuclear Regulatory Commission (NRC): The federal agency responsible for regulating commercial nuclear power plants and other commercial nuclear operations pursuant to the Atomic Energy Act of 1954, as amended, and covered by provisions under Section 170(a) of that Act. This federal agency has a broad statutory authority over transportation of radioactive material similar to that of the DOT. Under a memorandum of understanding between the two agencies, however, NRC limits its activities to performing safety evaluations of packages and issuing certificates of compliance for Type B packages and packages for fissile material (see fissile material definition). The NRC prescribes rules for monitoring of packages on receipt, for limiting the exposure of individuals to ionizing radiation, and for in-transit security of certain materials. NRC imposes DOT shipping requirements by reference and inspects against them, and enforces those requirements.

Nuclear Waste Policy Act (NWPA): An Act passed in 1982, and amended in 1987, that directs the DOE to design, site, and construct a geologic repository for the disposal of defense high-level radioactive waste (see high-level radioactive waste definition) and SNF (see spent nuclear fuel definition) from civilian (commercial) nuclear reactors. The NWPA also established the Office of Civilian Radioactive Waste Management within DOE to carry out these responsibilities.

O

Off-link population: All persons living alongside of a transportation route.

On-link population: 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.

P

Package: Protective material together with its radioactive contents as presented for transport.

Packaging: For radioactive materials, the assembly of components necessary to ensure compliance with the packaging requirements of 49 CFR 173. It may consist of one or more receptacles, absorbent materials, spacing structures, thermal insulation, radiation shielding, and devices for cooling or absorbing mechanical shocks. The conveyance, tie-down system, and auxiliary equipment may sometimes by designated as part of the packaging. (49 CFR 173.403)

Placard: Represents the hazard class(es) of the material(s) contained within the freight container, motor vehicle or rail car. A warning sign made of a durable material and placed on the exterior sides of a transport vehicle.

Plume: Airborne material spreading from a particular source. Used to denote dispersal of particles, gases, vapors, and aerosols in the atmosphere. Occasionally referred to as a cloud (for example, a “radioactive cloud”). A release of material into the atmosphere for a short duration may also be denoted as a “puff.”

Plume exposure pathway: The principal exposure sources for this pathway are: Whole body external exposure (gamma radiation) and/or contact exposure to skin or eyes (hazardous substances) from contact with materials from the plume and from deposited material. Inhalation and absorption of constituents in the passing plume.

Preferred route: A preferred route consists of either or both: (1) an interstate system highway for which an alternative route is not designated by a state routing agency (see state routing agency definition), and/or (2) a state-designated route selected by a state routing agency in accordance with the DOT Guidelines for Selecting Preferred Highway Routes for Highway Route Controlled Quantity Shipments of Radioactive Materials, or an equivalent routing analysis.

Pressurized water reactor (PWR): A nuclear reactor in which heat is transferred from the core to a heat exchanger via water kept under high pressure so that high temperatures can be maintained in the primary system without boiling the water. Steam is generated in a secondary circuit.

Private carrier: Provides a service for the movement of goods owned by the vehicle operator.

Protective action (protective response): Physical measures, such as evacuation or sheltering, taken to prevent potential health hazards resulting from a release of HAZMAT (see hazardous materials definition) to the environment from adversely affecting workers or the nearby population.

Protective Action Guide [or Guideline] (PAG): A radiation personnel exposure level or range beyond which protective action should be considered. PAG values should reflect a balance of risks and costs to onsite personnel, public health and safety, and the environment weighed against the benefits obtained from protective actions. (DOE Order 5500.1B)

R

Rad: Unit of absorbed dose (see dose definition). One rad is equal to an absorbed dose of 100 ergs per gram or 0.01 joules per kilogram (0.01 gray).

Radiation level: The radiation dose rate expressed in millirem (see millirem definition) per hour (mrem/h).

Radioactive material: With respect to transportation regulations, any material having a specific activity greater than 0.002 microcuries per gram (μCi/g).

Radioactive waste: Solid, liquid, or gaseous material that contains radionuclides (see radionuclides definition) regulated under the Atomic Energy Act of 1954, as amended, and of negligible economic value considering costs of recovery.

Radioactivity: The property possessed by some atoms of spontaneously emitting radiation in the form of rays and particles from its nucleus. Radioisotopes of elements lose particles and energy through this process and decay (see decay definition) or transform into other elements

Radionuclide: See nuclide.

RADTRAN: A computer code developed by SNL for analysis of the consequences and risks of radioactive material (see radioactive materials definition) transportation. RADTRAN is used to estimate radiological risks associated with incident-free transportation of radioactive materials and with accidents that might occur during transportation.

Railroad: Classifications based on traffic density/utilization measures which are indicative of the level of maintenance and investment applied to various rail line classes. All common carrier railway lines are subject to the Federal Railway Administration regulations intended to promote safety on the rail network.

1. <u>Mainline - Class A</u>: A traffic density measure of 20 million gross tons or more per year per route or route segment.

2. <u>Mainline - Class B</u>: A traffic density measure of at least 5 to less than 20 million gross tons per year per route or route segment.

3. <u>Branchline - Class A</u> - A traffic density measure, 5 million gross tons or more per year per route or route segment.

4. <u>Branchline - Class B</u> - A traffic density measure of at least 1 to less than 5 million gross tons per year per route or route segment. (Railroad Revitalization and Regulatory Reform Act of 1976, PL 94-210)

5. <u>Main track</u>: A track, other than an auxiliary track, extending through yards or between stations, upon which trains are operated by timetable or train order, or both, or the use of which is governed by a signal system. (49 CFR 218.5)

6. <u>Class of track</u>: The maximum allowable operating speeds for freight and passenger trains as established by the FRA. There are five such classes of track.

Release: As defined by Section 101(22) of the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA), means any spilling, leaking, pumping, pouring, emitting, emptying, discharging, injecting, escaping, leaching, dumping, or disposing into the environment (including the abandonment or discarding of barrels, containers, and other closed receptacles containing any hazardous substance or pollutant or contaminant), but excludes: any release which results in exposure to a person solely within a workplace; emissions from the engine exhaust of a motor vehicle, rolling stock, aircraft, vessel, or pipeline pumping stations engine; release of source, byproduct, or special nuclear material from a nuclear incident, as those terms are defined in the Atomic Energy Act of 1954, if such release is subject to requirements with respect to financial protections established by the NRC under Section 170 of such Act; or, for the purposes of Section 104 of CERCLA or any other response action, any release of source, byproduct, or special nuclear material (see special nuclear material definition) from any processing site designated under Section 102(a)(1) or 302(a) of the Uranium Mill Tailings Radiation Control Act of 1978; and the normal application of fertilizer. For purposes of the National Contingency Plan release also means threat of release.

Rem: Unit of dose equivalent (see dose equivalent definition). Dose equivalent in rem is numerically equal to the absorbed dose in rad (see rad definition) multiplied by the quality factor, distribution factor, and any other necessary modifying factors (1 rem = 0.01 sievert).

Remote-handled transuranic waste: Packaged TRUW (see transuranic waste definition) whose external surface dose (see dose definition) rate exceeds 200 millirem (see millirem definition) per hour. Test specimens of fissionable material irradiated for research and development purposes only and not for the production of power or plutonium may be classified as RH TRUW.

Reprocessing: The process by which SNF (see spent nuclear fuel definition) is separated into waste material for disposal and material such as uranium (see uranium definition) and plutonium for reuse.

Risk: A quantitative or qualitative expression of possible loss that considers both the probability that a hazard will cause harm and the consequences of that event.

RISKIND: Computer code developed by DOE for analyzing radiological consequences and health risks to individuals and the collective population from exposures associated with the transportation of SNF (see spent nuclear fuel definition) and other radioactive material.

S

Safety analysis: A documented process to systematically identify the hazards of a DOE operation; to describe and analyze the adequacy of the measures taken to eliminate, control, or mitigate identified hazards; and to analyze and evaluate potential accidents (see accidents definition) and their associated risks.

Sheltering: An in-place, immediate protective action which calls for people to go indoors, close all doors and windows, turn off all sources of outside air, listen to radio or television for emergency information, and remain indoors until official notification that it is safe to go out.

Shipment: Refers to the cargo entered as the load on a shipping paper, moving from one origin to one destination, and the associated regulated shipping activities.

Shipper: The person (or his or her agent) who tenders a shipment for transportation. The term includes persons who prepare packages for shipment, and offer packages to a carrier for transportation by signature on the shipping paper.

Solid waste: Any discarded material that is not excluded by 40 CFR 261.4(a) or that is not excluded by variance granted under 40 CFR 260.30 and 260.31.

Source term: The amount of material available for release.

Special form radioactive material: This is radioactive material which satisfies the following conditions: (1) it is either a single solid piece or is contained in a sealed capsule that can be opened only by destroying the capsule; (2) the piece or capsule has at least one dimension not less than 5 millimeters; (3) it satisfies the requirements of 10 CFR 71.75 (10 CFR 71.4).

Spent fuel assemblies: Nuclear fuel is fabricated into small pellets. These pellets are encased into strong cylindrical rods. An assembly is a group of these rods fastened together. Referred to as a "bundle" for some boiling water reactors [see boiling water reactors definition].

Spent nuclear fuel (SNF): Fuel that has been withdrawn from a nuclear reactor following irradiation, the constituent elements of which have not been separated by reprocessing. SNF includes (1) intact, non-defective fuel assemblies; (2) failed fuel assemblies in canisters (see canister definition); (3) fuel assemblies in canisters; (4) consolidated fuel rods in canisters; (5) nonfuel components inserted in PWR (see pressurized water reactor definition) fuel assemblies; (6) fuel channels attached to BWR (see BWR definition) fuel assemblies; and (7) nonfuel components and structural parts of assemblies in canisters.

T

Threshold limit value - time weighted average (TLV-TWA): Concentration of toxic materials for a normal 8-hour workday and a 40-hour workweek to which nearly all workers may be exposed day after day without adverse effect.

Toxic chemicals: A chemical or chemical category listed in 40CFR372.65.

Train: Except as context require, means a locomotive, or more than one locomotive coupled, with or without cars.

Train accident: A passenger, freight, or work train accident described in 49 CFR 225.19(c) (a "rail equipment accident" involving damage in excess of the current reporting threshold, $6,600 in 1998), including an accident involving a switching movement.

Train incident: An event involving the movement of railroad on-track equipment that results in a casualty but in which railroad property damage does not exceed the reporting threshold.

Transport index: The dimensionless number placed on radioactive labels to designate the degree of control to be exercised by the carrier during transportation of a radioactive material (see radioactive material definition) package.

Transuranic (TRU) radioactive waste: Waste containing more than 100 nanocuries of alpha [see alpha definition] emitting transuranic isotopes, with half-lives (see half-life definition) greater that twenty years, per gram of waste.

Transuranic (TRU) waste: TRUW is radioactive waste containing more than 100 nanocuries (3,700 becquerels) of alpha-emitting transuranic isotopes per gram of waste, with half-lives greater than 20 years, except for: (1) high-level radioactive waste; (2) waste that the Secretary of Energy has determined, with the concurrence of the Administrator of the EPA, does not need the degree of isolation required by the 40 CFR Part 191 disposal regulations; or (3) waste that the NRC has approved for disposal on a case-by-case basis in accordance with 10 CFR Part 61.

Type A package: A Type A packaging (see Type A packaging definition) along with its limited radioactive contents which are limited to A1 or A2 value.

Type A packaging: A packaging designed to retain the integrity of containment (see containment definition) and shielding required by regulation under normal conditions of transport as demonstrated by the required test.

Type B package: A Type B packaging (see Type B packaging definition) together with its radioactive contents.

Type B packaging: Packaging designed to retain the integrity of containment and shielding by regulation when subjected to the normal conditions of transport and hypothetical accident (see accidents definition) test conditions as required.

U

Uranium (U): A heavy, naturally radioactive, metallic element (atomic number 92). Its two principally occurring isotopes [see isotopes definition] are U-235 and U-238. U-235 is indispensable to the nuclear industry because it is the only isotope existing in nature to any appreciable extent that is fissionable by thermal neutrons. U-238 is also important because it absorbs neutrons (see neutrons definition) to produce a radioactive isotope that subsequently decays to Pu-239, an isotope that also is fissionable by thermal neutrons.

Uranium hexafluoride: A colorless, water insoluble corrosive chemical compound in the nuclear fuel cycle. With the application of heat, uranium hexafluoride (UF6) becomes a gas used to separate U-235 (the uranium isotope required for reactor fuel) from other uranium isotopes.

V

W

Waste form: Radioactive waste (see radioactive waste definition) material, and any encapsulating or stabilizing matrix.

Waste Isolation Pilot Plant (WIPP): Research and demonstration facility located at Carlsbad, New Mexico. WIPP is designed to dispose of TRUW left from the research and production of nuclear weapons.

WIPP corridor: The designated route for overland transport of HAZMAT (see hazardous material definition) from DOE facilities to the WIPP.

Appendix A

DISCUSSION PAPERS ON EMERGING TRANSPORTATION RISK ISSUES

This appendix presents papers from transportation risk experts that identify and provide the latest information available on issues related to transportation risk assessments. This appendix *does not* set DOE policy. The discussion papers reflect only the authors' views and opinions. Although only one paper is currently presented, others will be added (as appropriate) in future revisions of this handbook.

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Discussion Paper No. 1- Cumulative Impacts of Transportation

Abstract

This issue paper on cumulative impact arose from a need to scope out the cumulative nature, both in activity and time, of transportation risk to the community. This discussion paper summarizes previous NEPA experience from which a consistent approach can be derived. It also highlights the key elements and offers insight into the current state of knowledge and experience of cumulative impact. Application of the procedures discussed in this paper should consider future advances in knowledge and information to satisfy NEPA requirements.

1 INTRODUCTION

CEQ regulations (40 CFR 1508.25) require that the scope of environmental impact statements (EISs) include cumulative impacts. In 40 CFR 1508.7, CEQ defines cumulative impacts as:

> The impact on the environment which results from the incremental impact of the action when added to other past, present, and reasonably foreseeable future actions regardless of what agency (Federal or non-Federal) or person undertakes such other actions. Cumulative impacts can result from individually minor but collectively significant actions taking place over a period of time.

In DOE EISs and environmental assessments (EAs), incident-free and accident transportation impacts are typically estimated for people along, near, or sharing transportation routes. These impacts are often presented for the total duration of the alternatives, although annual impacts may also be presented. Often, these impacts are known as the “total transportation impacts” of a proposed action or alternative, and are not the same as the cumulative impacts of transportation, because cumulative impacts are estimated across several projects or activities.

For incident-free transportation impacts, three measures of impact are usually presented: (1) the radiological impacts to people along, near, or sharing transportation routes, (2) the nonradiological impacts from vehicle exhaust emissions to people along transportation routes, and (3) the radiological impacts for MEIs. The first two measures of impact are estimated over the entire transportation network. Therefore, it is appropriate to consider these impacts, along with transportation impacts from other projects or activities, in a cumulative impacts analysis, if there is a reasonable belief that the impacts would be coincident with impacts from the other transportation projects or activities. This is often the case for projects that would use a large portion of the interstate highway system over the same time period. Since it is unlikely that the MEI would be the same person for several projects, it is inappropriate to include these impacts in a cumulative impacts analysis.

For transportation accident impacts, three measures of impact are usually presented in DOE EIs and EAs: (1) radiological accident risks, (2) nonradiological traffic fatalities, and (3) the radiological consequences for the maximum reasonably foreseeable accident. Radiological accident risks and nonradiological traffic fatalities are estimated over the entire transportation network. However, the radiological consequences from maximum reasonably foreseeable accidents are usually estimated at specific types of locations, such as urban or rural areas. Since it is not reasonably foreseeable that two of these transportation accidents would occur in the same location, it is inappropriate to include these impacts in a cumulative impacts analysis.

2 BACKGROUND INFORMATION

2.1 Existing Requirements/Guidance

The requirements for cumulative impacts analyses are contained in the following documents:

1. "CEQ Regulations for Implementing Procedural Provisions of the National Environmental Policy Act," 40 CFR 1500-1508.

2. *Considering Cumulative Impacts Under the National Environmental Policy Act* (CEQ, 1997).

3. *Recommendations for the Preparation of Environmental Assessments and Environmental Impact Statements* (DOE, 1993). (The guidance in this document is particularly appropriate for DOE projects.)

2.2 History and Experience

A large-scale transportation cumulative impacts analysis was performed for the *Programmatic Spent Nuclear Fuel Management Environmental Impact Statement* (DOE, 1995). The analysis was divided into radiological impacts and vehicular accident impacts. Radiological impacts were further divided into the impacts from (1) historical shipments of SNF and waste, (2) shipments associated with the alternatives evaluated in the EIS, (3) shipments associated with other reasonably foreseeable actions unrelated to the alternatives evaluated in the EIS, and (4) general radioactive materials transportation unrelated to a particular action. The radiological analysis concentrated on the off-site impacts of incident-free transportation, because off-site transportation yields larger doses to members of the public than on-site transportation. The collective dose to the general population and to workers was chosen to quantify transportation cumulative impacts. These doses were usually estimated with the RADTRAN 4 computer code and expressed as cancer fatalities. Individual doses were not estimated because of the difficulty in identifying a MEI for shipments throughout the United States over an extended period of time.

Historical shipments were included in the cumulative impacts analysis because 40 CFR 1508.7 specifically includes past actions in the definition of cumulative impacts. The EM was chosen to quantify transportation cumulative impacts phases of the historical shipments was on SNF shipments that either originated or terminated at the Hanford Site, the INEL, the SRS, the Oak Ridge Reservation, or the Nevada Test Site. Because of the structure of the EIS, historical radioactive waste shipments to the INEL were also evaluated. Data were generally available back to 1971; data were extrapolated back to the start of operations at each of the five sites because a satisfactory justification could not be found to stop at any other point in time. This lack of data and the consequent need for extrapolation were disclosed in the EIS, and, to a limited extent, the extrapolation was validated. All dose assessments were made by using 1990 census data; no attempt was made to use alternative census data or to reconstruct the highway or rail system as it existed in earlier decades. Again, the potential for uncertainty in the analyses was disclosed in the EIS.

For the shipments associated with the alternatives evaluated in the EIS, a range of doses was presented. These doses were estimated with the RADTRAN 4 computer code and were also expressed as cancer fatalities.

The doses for shipments associated with other reasonably foreseeable actions were obtained from the NEPA documents for those actions. Both DOE actions and actions by other federal agencies were included, based on the definition of cumulative impacts in 40 CFR 1508.7. Most of these doses were estimated with various versions of RADTRAN. The cumulative transportation impacts analysis did not reestimate the doses from other NEPA documents, but instead included the doses that were presented in those documents. A tiered approach determined which doses from the other NEPA documents would be included in the analysis for DOE (1995). If an ROD was available for a particular action, the doses associated with the alternative chosen in the ROD were included. If an ROD was not available, the doses associated with the preferred alternative were included. If no preferred alternative was identified, a range of doses that included the alternatives with the smallest and largest transportation doses was presented. Because NEPA requires evaluating a no-action alternatives, which usually do not involve transportation, this often meant that doses ranged from zero to some maximum value. If an action had not progressed to the preparation of a NEPA document, that action was not regarded as reasonably foreseeable.

General radioactive materials transportation was included in the cumulative impacts analysis because the definition of cumulative impacts in 40 CFR 1508.7 does not differentiate between actions taken by federal or non-federal agencies and private persons; all must be included in the cumulative impacts analysis. The doses for general radioactive materials transportation were derived from those presented in NUREG-0170 (NRC, 1977) and Weiner et al. (1991a-b). NUREG-0170 derived doses for the years 1943 through 1982. The year 1943 corresponded to the start of operations at the Oak Ridge Reservation. The Weiner et al. (1991a-b) reports were used to derive doses for 1983 through 2035. The year 2035 corresponded to the end of SNF management activities evaluated in the EIS. The uncertainty created by using these extrapolations was disclosed in the EIS.

Vehicular accident impacts were chosen as the other measure of transportation cumulative impact. This measure was chosen because far more fatalities result from the trauma impacts of radioactive materials transportation traffic accidents than from the radiological impacts. In the *Programmatic Spent Nuclear Fuel Management Environmental Impact Statement* (DOE, 1995), the number of traffic fatalities estimated for shipments associated with the alternatives was compared to the baseline number of traffic fatalities in the United States. In addition, the number of historical traffic fatalities associated with radioactive materials transportation accidents was also compared to the baseline number of traffic fatalities in the United States over a similar time period. A brief description of historical transportation accidents involving SNF going back to 1949 was also presented.

The best available cumulative impact data included impacts that may have been double-counted. Where identifiable, instances of double counting were removed, but little effort was made in this area because the existing approach was conservative (i.e., overestimated impacts), and continued refinement was not viewed as cost-effective.

This approach for estimating the cumulative radiological impacts of transportation has been used in several other DOE EISs, such as the Nevada Test Site EIS (DOE, 1996a), the Container System EIS (U.S. Department of the Navy [USN], 1996), the Waste Management PEIS (DOE, 1997), the Foreign Research Reactor EIS (DOE, 1996b), the Surplus Plutonium Disposition EIS (DOE, 1999a), and the Yucca Mountain Repository DEIS (DOE, 1999b).

3 PROPOSED APPROACH

Cumulative transportation impacts could be analyzed within the framework established in the *Programmatic Spent Nuclear Fuel Management Environmental Impact Statement* (DOE, 1995).

Historical transportation impacts would be estimated to the degree practicable and extrapolated to the beginning of operations at the sites analyzed in the EIS. The transportation impacts associated with other reasonably foreseeable actions would be included in the cumulative impacts analysis by using a tiered approach based on other relevant NEPA documents (when available). The cumulative impacts analysis would include all reasonably foreseeable future actions; generally these will coincide with the timeframe evaluated in the EIS.

General transportation impacts would be estimated from the start of operations at the sites analyzed in the EIS to the conclusion of the actions analyzed in the EIS.

Accident impacts would also be evaluated in the cumulative transportation impacts analysis. The analysis would focus on vehicular accident fatalities. Radiological accident risks would also be included, but it is anticipated that these risks will be a small fraction of the number of vehicular accident fatalities. The radiological consequences of maximum reasonably foreseeable accidents would not be included in the cumulative impacts analysis, because it is not reasonably foreseeable that two such transportation accidents would occur in the same location.

To streamline the preparation of cumulative transportation impact analyses, the NTP could maintain a list of transportation impacts from EISs and EAs in the format described above. This collection would enable analysts of individual EAs and EISs to easily incorporate information, such as the transportation impacts associated with the alternatives evaluated in other EAs and EISs or the impacts of historical shipments from other DOE NEPA documents. The NTP could be responsible for gathering the data necessary to compile and maintain the list. It is anticipated that the list would be updated at each stage of the NEPA process for a project (e.g., at the draft EIS, at the final EIS, and at the ROD). Compiling and maintaining the list would be coordinated through NEPA compliance officers and NEPA document managers.

4 REFERENCES for discussion paper no. 1

Council on Environmental Quality, 1997, Considering Cumulative Impacts under the National Environmental Policy Act, Washington, D.C.

U.S. Department of Energy, 1993, Recommendations for the Preparation of Environmental Assessments and Environmental Impact Statements, Office of NEPA Oversight, Washington, D.C.

U.S. Department of Energy, 1995, Programmatic Spent Nuclear Fuel Management and Idaho National Engineering Laboratory Environmental Restoration and Waste Management Programs Final Environmental Impact Statement, DOE/EIS-0203-F, Washington, D.C.

U.S. Department of Energy, 1996a, Final Environmental impact Statement for the Nevada Test Site and Off-Site Locations in the State of Nevada, DOE/EIS-0243, Nevada Operations Office, Las Vegas, Nevada, Aug.

U.S. Department of Energy, 1996b, Final Environmental Impact Statement on a Proposed Nuclear Weapons Nonproliferation Policy Concerning Foreign Research Reactor Spent Nuclear Fuel, DOE/EIS-0218F, Assistant Secretary for Environmental Management, Washington, D.C., Feb.

U.S. Department of Energy, 1997, Final Waste Management Programmatic Environmental Impact Statement for Managing Treatment, Storage, and Disposal of Radioactive and Hazardous Waste, DOE/EIS-0200-F, Office of Environmental Management, Washington, D.C.

U.S. Department of Energy, 1999a, Surplus Plutonium Disposition Final Environmental Impact Statement, DOE/EIS-0283, Office of Fissile Material Disposition, Washington, D.C.

U.S. Department of Energy, 1999b, Draft Environmental Impact Statement for a Geologic Repository for the Disposal of Spent Nuclear Fuel and High-Level Radioactive Waste at Yucca Mountain, Nye County, Nevada, DOE/EIS-0250D, Office of Civilian Radioactive Waste Management, Las Vegas, Nevada.

U.S. Department of the Navy, 1996, Final Environmental Impact Statement for a Container System for the Management of Naval Spent Nuclear Fuel, DOE/EIS-0251, Naval Nuclear Propulsion Program, Office of the Chief of Naval Operations, Nuclear Propulsion Directorate, Code 08, Naval Sea Systems Command, Nov.

U.S. Nuclear Regulatory Commission, 1977, Final Environmental Impact Statement on the Transportation of Radioactive Material by Air and Other Modes, NUREG-0170, Washington, D.C.

Weiner, R.F., et al., 1991a, "An Approach to Assessing the Impacts of Incident-Free Transportation of Radioactive Materials: I. Air Transportation," Risk Analysis 11(4):655-660.

Weiner, R.F., et al., 1991b, "An Approach to Assessing the Impacts of Incident-Free Transportation of Radioactive Materials: II. Highway Transportation," Risk Analysis 11(4):661-666.

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Appendix B

CORRESPONDENCE AND DOCUMENTATION RELATING TO THE FORMATION AND ORGANIZATION OF THE TRANSPORTATION RISK ASSESSMENT WORKING GROUP

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DOE F 1325.8
(8-89)
EFG (07-90)

United States Government — Department of Energy

memorandum

DATE: JUN 27 1997

REPLY TO ATTN OF: EM-76 (Kapoor:3-6838)

SUBJECT: Transportation Risk Assessment Working Group Meeting

TO: Distribution

We invite you to participate in a Transportation Risk Assessment Working Group (TRAWG) meeting on July 23, 1997, at the Cloverleaf Building, 20400 Germantown Road, Germantown, MD in conference room 1062 from 9 AM to 4:30 PM.

Attached is a draft agenda for the meeting. The TRAWG is being formed to make the transportation risk analysis process more efficient and effective.

If you have any questions, please contact Ashok Kapoor at (301) 903-6838 or Michael Keane at (301) 903-7275.

Richard Brancato
Director
Office of Transportation, Emergency
Management, and Characterization Management

Attachment

ATTACHMENT

Transportation Risk Assessment Working Group Meeting
July 23, 1997
Cloverleaf Building, Germantown
Conference Room 1062
9:00 a.m. - 4:30 p.m.

1. Introduction

2. Discussion of objectives and scope

3. Membership and function of the Transportation Risk Assessment Working Group

4. Presentation of experience by DOE Offices and discussion of issues

5. Summary of recent NEPA efforts within DOE

6. Presentation of proposed approach to a streamlined risk assessment methodology

7. Discussion and comments

Distribution:

G. Ives, DP-20
M. Comar, DP-22
T. L. Leslie, DP-24
C. Borgstrom, EH-42
H. Nigam, EH-42
E. Cohen, EH-42
S. Lichman, EH-412
A. Harris, EM-341
P. Siebach, EM-36
C. Gesalman, EM-45
K. Kelkenberg, EM-47
C. Head, EM-67
A. Kapoor, EM-76
M. Keane, EM-76
M. Wangler, EM-76
M. Sullivan, GC-50
W. J. Dennison, GC-51
J. M. Sweeney, GC-51
M. Urie, GC-51
T. Long, NE-40
E. Tourigny, NE-40
E. Naples, NE-60
C. Logan, NE-60
M. Popa, RW-45
J. Booth, RW-45
K. J. Skipper, DOE/YMSCO, Las Vegas, NV
P. Dickman, AL
P. Grace, AL
T. Thomas, AL
J. Holm, AL
R. Yoshimura, SNL
G. Scott, ID
B. Lester, OR
K. Grassmeier, NV
R. McLain, SR
M. Maline, RF
K. Morgan, OH
S. Y. Chen, ANL
D. Tardiff, ORISE

DOE F 1325.8
(8-89)
EFG (07-90)

United States Government **Department of Energy**

memorandum

DATE: AUG 12 1997

REPLY TO
ATTN OF: EM-76 (Kapoor:3-6838)

SUBJECT: Record of Transportation Risk Assessment Working Group Meeting

TO: Transportation Risk Assessment Working Group Members

The Department of Energy (DOE) National Transportation Program held a Transportation Risk Assessment Working Group (TRAWG) meeting on July 23, 1997. The TRAWG comprises transportation risk specialists from DOE program offices, General Counsel, field offices, and support contractors. A total of 27 participants attended the first meeting of the TRAWG. The overall objectives of this working group are to (1) coordinate DOE offices regarding National Environmental Protection Act (NEPA) analyses of transportation, (2) identify and resolve issues leading to a streamlined approach, (3) establish consensus on standardizing the approach, (4) facilitate standardization and issuance of relevant tangible products, and (5) provide guidance and oversight.

The TRAWG discussed current transportation risk assessments under NEPA at various program offices and identified pertinent issues. The TRAWG established a sub-technical group to review these issues and asked the sub-technical group to provide its preliminary evaluation of the issues within 90 days.

Attached are the draft minutes of the meeting. TRAWG members and participants in the meeting are requested to review these draft minutes and the draft charter of the working group and forward any comments to my attention. The final charter of the group and record of this meeting will be approved by the TRAWG at the next meeting tentatively scheduled for October 8, 1997.

If you have any questions please contact me at (301) 903-6838 or Michael Keane at (301) 903-7275.

Ashok Kapoor

Ashok Kapoor
Packaging Team Leader
National Transportation Program-AL

Attachment

Transportation Risk Assessment Working Group Members

M. Comar, DP-22
S. Acharya, EH-32
S. Bhatnagar, EH-32
H. Nigam, EH-42
J. Stewart, EM-47
M. Keane, EM-76
M. Wangler, EM-76
J. Sweeney, GC-51
M. Urie, GC-51
T. Long, NE-40
W. Knoll, NE-60
K. Johnson, NE-60
M. Popa, RW-44
P. Dickman, AL
S. Chen, ANL
F. Monette, ANL
P. Sieback, CH
B. Lester, OR
R. Pope, OR
S. Ludwig, OR
R. Yoshimura, SNL
R. Luna, SNL
J. Follin, Westinghouse
S. Maheras, Yucca Mountain
C. Drew, Inst. For Evaluating Health Risks
L. Harmon, MACTEC

cc w/attachment:

T. Needels, EM-76
E. McNeil, EM-76
J. Shuler, EM-76
J. Cruickshank, EM-76
V. Gopinath, EM-76
M. Gutowski, AL
J. Holm, AL
T. Thomas, AL
M. Klimas, CH
G. Scott, ID
K. Plassus, ID
K. Grassmeier, NV
G. Callihan, OAK
D. Lee, OH
D. Claussen, RL
M. Maline, RF
K. Heavlin, RF
R. McLain, SR

ATTACHMENT

Draft Minutes of Transportation Risk Assessment Working Group Meeting on July 23, 1997

The first meeting of the Department of Energy (DOE) Transportation Risk Assessment Working Group (TRAWG) was held from 9:00 a.m. to 4:00 p.m. on July 23, 1997, in Germantown, Maryland. The meeting was chaired by Ashok Kapoor of the National Transportation Program (NTP), DOE-AL. Attendees included DOE representatives from the NTP, the DOE Center for Risk Excellence (CRE), DOE-Nevada operations Office (NV), Office of Civilian Radioactive waste management (RW), Environment, safety and Health (EH), Environmental Management (EM), Naval Reactor Program (NR), Defense Program (DP), Office of the General Counsel (GC), and office of Nuclear Energy, Science and Technology (NE); as well as support contractors from Argonne National Laboratory, Sandia National Laboratory, Oak Ridge National Laboratory, MACTEC, and Westinghouse Bettis. An attendance list is attached. These minutes present a summary of the discussions that took place at the meeting.

Handouts: The following materials were distributed at the meeting:

- Agenda
- List of attendees
- Draft TRAWG charter/mission statement
- Presentation viewgraphs: Introduction - Ashok Kapoor, NTP-AL
- Summary paper on NR approach to transportation risk assessment
- Presentation viewgraphs: Transportation Analyses for Naval SNF - Jim Follin, Westinghouse-Bettis
- Presentation viewgraphs: Center for Risk Excellence - Pete Siebach, CRE, DOE-CH
- Presentation viewgraphs: Summary of Recent DOE NEPA Transportation Risk Assessment Efforts - S.Y. Chen, ANL
- Presentation Viewgraphs (2): Review of Transportation Risk Assessment Approach; Streamlining DOE NEPA Analysis, A Risk Assessment Handbook Approach - Fred Monette, ANL

Meeting Summary

Ashok Kapoor opened the meeting by introducing the National Transportation Program (NTP) established within the Office of Deputy Assistant Secretary, Site Operations, EM-70. Two Centers of Excellence are in the process of being established, One, in the Albuquerque Operations Office, will be in charge of transportation and packaging operational issues; the other, in Idaho, will be in charge of transportation system engineering issues. Policy and packaging certification functions are to be handled at Headquarters.

Paul Dickman, Director of the NTP-Albuquerque, provided a brief overview of the NTP. Paul indicated that operations will be transferred to Albuquerque over the next several months. The goal of the program will be to gear-up to meet the challenge posed by the increase in high-risk/high-visibility transportation actions that are expected to occur in the next several years.

Ashok Kapoor briefly discussed the history, scope, and objectives of the TRAWG. The TRAWG was formed following discussions among the Senior Executive Transportation Group and the Transportation Internal Coordination Working Group. These two groups identified transportation as an important issue. Specifically, they identified the need for development of a consistent assessment approach among programs. The TRAWG was established as a direct result of these meetings and is intended to focus on transportation risk assessment issues. One goal of the TRAWG is to address the requirements in the DOE NEPA policy statement which, in part, encourage the use of team efforts and innovative approaches to improve the NEPA process. The objectives of the TRAWG meeting were identified as: (1) initiate coordination among various DOE office's NEPA analyses; (2) identify issues that may lead to process improvements; and (3) develop a charter for the TRAWG.

The issue was raised that, because transportation activities are often the most controversial aspects of an Impact Statement (IS) and have the highest visibility, current costs for preparing transportation assessments may not be excessive. Although costs may or may not be excessive, it was pointed out that there was room to improve the process and increase its efficiency.

Presentations

Jim Follin, Westinghouse-Bettis, presented a summary of the Navy approach to transportation risk assessment. The approach essentially combines the use of two computer codes, RADTRAN and RISKIND, to address the risk to both populations and individuals during incident-free and accident conditions. A short paper summarizing the approach was distributed. In the course of the discussion, environmental justice (EJ) and potential cumulative impacts were raised as important issues that need to be addressed. The issue of whether the TRAWG should address the risks from shipments of chemicals (i.e., non-radioactive) was also raised.

Pete Siebach, DOE Center for Risk Excellence (CRE), presented an overview of the purpose and function of the CRE, as well as an overview of the transportation risk approach used in the Waste Management Preliminary Environmental Impact Statement (WM PEIS). In response to the large number of sites, source terms, and alternatives, the WM PEIS used a unit-consequence approach, similar to the Navy methodology, where RADTRAN and RISKIND were used in a complementary fashion.

Hitesh Nigam, EH, briefly discussed the EH perspective for transportation risk assessments. Hitesh highlighted the need for consistency across programs and briefly gave an overview of the Green Book guidance. During the discussion,

Janine Sweeney identified terrorism/sabotage as an another area that may need additional work, probably at a policy level.

Steve Maheras, representing DOE Yucca Mountain Project, provided a brief status update of the Yucca Mountain IS. The public scoping comment response document has been completed and released. A significant number of transportation comments were received during scoping, with terrorism and routing being two of the major issues. Five different rail accesses to Yucca Mountain are being addressed. The current plan is to discuss terrorism impacts, but not as a major part of the IS accident analysis. The methodology to be used is similar to the Navy's approach.

Tim Long, NE, provided a brief overview of the Depleted Uranium Hexafluoride Management Programmatic IS. The transportation methodology used is similar to the Navy approach, except representative routes were used for distances ranging from 250 to 5,000 km. In addition, the transportation of HF and chemical impacts of UF6 were identified as important issues.

Janine Sweeney, GC, indicated that there is reason to streamline the transportation assessment process and provide program offices with guidance and choices.

S.Y. Chen, ANL, presented a summary review of the results of several recent NEPA assessments. The results indicate a general consistency in the methodology used and the incident-free assessment results among most recent assessments. Robert Luna pointed out that the accident results, which are typically of most interest to the public, are not generally as consistent as the incident-free results.

Fred Monette, ANL, presented a summary of the general risk assessment methodology used in recent NEPA assessments and described a potential approach to streamline future assessments based on the compilation of a transportation risk assessment handbook. The handbook would attempt to capitalize on the large amount of data collected to support several recent, large programmatic assessments, such as the Navy Container System IS, the INEL Programmatic SNF IS, and the WM PEIS. Such a handbook could provide a review of recent assessments, a summary of accepted assessment methodologies, a review of important input parameters, and a compilation of risk factors.

During the discussion of a streamlined approach, Sweeney pointed out the difficulty of defining anything as "representative." The value of describing the historical assessment approach and providing a summary of input parameters was voiced. The need to capitalize on the large amount of work done on recent ISs was recognized.

Summary of Key Issues

Based on the day's discussion, the following issues were identified as requiring further study by the TRAWG:

1. cumulative impacts
2. environmental justice
3. sabotage, effects on commerce following an accident
4. nonradiological risk model
5. streamlined approach
6. uncertainty in impacts
7. impact at state/town/ tribe level
8. ecological impacts
9. human factors in risk assessment

Technical Sub-Group

A technical sub-group was formed to study the issues identified above and report back to the TRAWG on possible approaches. The technical sub-group consists of the following members:

Ron Pope, ORNL
Richard Yoshimura, SNL
Bob Luna, SNL
Bettis Representative
CRE, Chicago
Steve Maheras, NV
Sushil Bhatnagar, EH-32
Chen, Monette, ANL
Christie Drew CRESP

At the end of the meeting, S.Y. Chen of Argonne National Laboratory was elected chair of the technical sub-group. He was tasked with coordinating the technical sub-group and providing feedback to the policy group, which consists of representatives solely from DOE offices.

Action Items

The technical sub-group was tasked to evaluate the 9 issues identified above and report back to the TRAWG in 90 days.

The meeting was adjourned at 4:00.

Transportation Risk Assessment Working Group (TRAWG)

Mission
The mission of the TRAWG is to improve the efficiency and effectiveness of transportation risk assessments conducted for DOE Environmental Impact Statements (EIS) and EA prepared under the NEPA of 1969.

Vision
The vision of the TRAWG includes reducing transportation risk-assessment preparation time and cost, ensuring technical adequacy of such assessments, promoting consistency among DOE programs, and expediting the assessment review and approval process.

Responsibilities
The specific responsibilities of the TRAWG include the following.

- coordinating among DOE programs
- harmonizing the transportation risk assessment approach within DOE
- providing support to ongoing NEPA projects
- performing expert peer review and approval functions

Membership
The TRAWG is composed primarily of members of DOE program offices and seeks to draw upon the technical expertise, insights, and practical experience of those across the DOE complex.

Technical Sub-Group
The technical subgroup, composed of technical experts (DOE and support contractors), charged with carrying out the specific assignments provided by the TRAWG.

Responsibilities
The responsibilities of the technical group include the following.

- providing technical input and assistance to the TRAWG
- defining assessment approaches and methodology
- collecting and evaluating data
- preparing reports and deliverables, as scheduled

The technical sub-group receives direction from and reports directly to the TRAWG.

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Appendix C

ISOTOPIC PROPERTIES

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Table C.1 contains listings of the isotopic data discussed in Section 6.1.11.2. Blank entries in the table indicate an absence of data in the given reference.

Table C.1. Isotopic Data

Nuclide	Half-Life[a]	Photon Energy[b] (MeV)	Dose Conversion Factors[c]			
			Groundshine[d] ($Sv\text{-}m^2/Bq\text{-}s$)	Cloudshine[e] ($Sv\text{-}m^3/Bq\text{-}s$)	Ingestion[f] (Sv/Bq)	Inhalation[f] (Sv/Bq)
Ac-223	2.2 m	0.0062	4.66E–18	2.07E–16		
Ac-224	2.9 h	0.2	1.89E–16	9.00E–15	8.03E–10	3.56E–08
Ac-225	10 d	0.018	1.58E–17	7.21E–16	3.00E–08	2.92E–06
Ac-226	29 h	0.13	1.24E–16	6.03E–15	1.15E–08	3.56E–07
Ac-227	21.773 y	0.0002	1.57E–19	5.82E–18	3.80E–06	1.81E–03
Ac-228	6.13 h	0.9708	9.28E–16	4.78E–14	5.85E–10	8.33E–08
Ag-102	12.9 m	3.3532	3.18E–15	1.67E–13	2.75E–11	9.11E–12
Ag-103	65.7 m	0.7651	7.41E–16	3.68E–14	4.02E–11	1.58E–11
Ag-104	69.2 m	2.6834	2.58E–15	1.32E–13	6.22E–11	1.92E–11
Ag-104m	33.5 m	1.1739	1.12E–15	5.82E–14	4.55E–11	1.69E–11
Ag-105	41 d	0.5254	5.11E–16	2.45E–14	5.52E–10	1.26E–09
Ag-106	23.96 m	0.7108	7.04E–16	3.39E–14	2.28E–11	8.92E–12
Ag-106m	8.41 d	2.8219	2.72E–15	1.38E–13	1.75E–09	1.93E–09
Ag-108	2.37 m	0.0178	1.99E–17	9.28E–16		
Ag-108m	127 y	1.6267	1.60E–15	7.80E–14	2.06E–09	7.66E–08
Ag-109m	39.6 s	0.0111	9.71E–18	1.92E–16		
Ag-110	24.6 s	0.0306	3.82E–17	1.78E–15		
Ag-110m	249.9 d	2.7505	2.65E–15	1.36E–13	2.92E–09	2.17E–08
Ag-111	7.45 d	0.0263	2.67E–17	1.29E–15	1.37E–09	1.66E–09
Ag-112	3.12 h	0.6571	6.33E–16	3.34E–14	4.41E–10	1.79E–10
Ag-115	20 m	0.7069	6.61E–16	3.61E–14	4.31E–11	1.90E–11
Al-26	7.16E+05 y	2.6756	2.49E–15	1.36E–13	3.94E–09	2.15E–08
Al-28	2.24 m	1.7788	1.62E–15	9.28E–14		
Am-237	73 m	0.3696	3.54E–16	1.70E–14	1.78E–11	6.47E–12
Am-238	98 m	0.8911	8.50E–16	4.33E–14	3.56E–11	2.32E–10
Am-239	11.9 h	0.2393	2.22E–16	1.04E–14	2.67E–10	1.24E–10
Am-240	50.8 h	1.0287	9.84E–16	5.00E–14	6.83E–10	4.96E–10
Am-241	432.2 y	0.0325	2.75E–17	8.18E–16	9.84E–07	1.20E–04
Am-242	16.02 h	0.0183	1.57E–17	6.15E–16	3.81E–10	1.58E–08
Am-242m	152 y	0.0051	3.02E–18	3.17E–17	9.50E–07	1.15E–04
Am-243	7380 y	0.056	5.35E–17	2.18E–15	9.79E–07	1.19E–04
Am-244	10.1 h	0.8071	7.79E–16	3.85E–14	5.38E–10	4.47E–09
Am-244m	26 m	0.0015	2.61E–18	6.13E–17	2.10E–11	1.90E–10
Am-245	2.05 h	0.0323	3.10E–17	1.46E–15	4.88E–11	2.18E–11
Am-246	39 m	0.6994	6.74E–16	3.28E–14	4.54E–11	1.71E–11
Am-246m	25 m	1.018	9.75E–16	5.03E–14	2.54E–11	9.02E–12
Ar-37	35.02 d	0.0002	0.00E+00	1.27E–19		

Table C.1. Isotopic Data (Continued)

Nuclide	Half-Life[a]	Photon Energy[b] (MeV)	Dose Conversion Factors[c]			
			Groundshine[d] (Sv-m^2/Bq-s)	Cloudshine[e] (Sv-m^3/Bq-s)	Ingestion[f] (Sv/Bq)	Inhalation[f] (Sv/Bq)
Ar-39	269 y	0	3.38E–19	9.10E–18		
Ar-41	1.827 h	1.2836	1.20E–15	6.50E–14		
As-69	15.2 m	1.0125	1.01E–15	4.89E–14	3.62E–11	1.32E–11
As-70	52.6 m	4.0954	3.90E–15	2.04E–13	1.13E–10	3.42E–11
As-71	64.8 h	0.5738	5.56E–16	2.74E–14	4.07E–10	3.44E–10
As-72	26 h	1.7938	1.75E–15	8.78E–14	1.64E–09	1.10E–09
As-73	80.3 d	0.016	5.95E–18	1.90E–16	1.91E–10	9.34E–10
As-74	17.76 d	0.7585	7.47E–16	3.65E–14	1.07E–09	2.15E–09
As-76	26.32 h	0.43	4.24E–16	2.13E–14	1.41E–09	1.01E–09
As-77	38.8 h	0.0087	8.95E–18	4.31E–16	3.44E–10	2.85E–10
As-78	90.7 m	1.2522	1.20E–15	6.32E–14	1.81E–10	7.22E–11
At-207	1.8 h	1.3247	1.26E–15	6.52E–14	2.36E–10	6.55E–10
At-211	7.214 h	0.0391	3.62E–17	1.59E–15	1.07E–08	2.76E–08
At-215	0.1 m	0.0001	1.91E–19	9.22E–18		
At-216	0.3 m	0.0015	1.41E–18	6.24E–17		
At-217	0.0323 s	0.0003	3.03E–19	1.48E–17		
At-218	2 s	0.0067	4.18E–18	1.19E–16		
Au-193	17.65 h	0.1595	1.53E–16	6.83E–15	1.56E–10	7.82E–11
Au-194	39.5 h	1.0671	1.00E–15	5.29E–14	5.08E–10	2.76E–10
Au-195	183 d	0.0846	7.84E–17	3.21E–15	2.87E–10	3.50E–09
Au-195m	30.5 s	0.2014	1.93E–16	9.37E–15		
Au-198	2.696 d	0.4051	4.01E–16	1.94E–14	1.14E–09	8.87E–10
Au-198m	2.3 d	0.5772	5.53E–16	2.66E–14	1.44E–09	1.31E–09
Au-199	3.139 d	0.0888	8.45E–17	4.08E–15	4.82E–10	4.05E–10
Au-200	48.4 m	0.272	2.63E–16	1.37E–14	5.46E–11	2.40E–11
Au-200m	18.7 h	2.0866	2.04E–15	1.01E–13	1.22E–09	5.93E–10
Au-201	26.4 m	0.0534	5.33E–17	2.57E–15	1.68E–11	7.23E–12
Ba-126	96.5 m	0.1631	1.62E–16	7.03E–15	2.46E–10	9.92E–11
Ba-128	2.43 d	0.0761	7.60E-17	2.86E–15	2.84E–09	8.20E–10
Ba-131	11.8 d	0.4589	4.52E–16	2.10E–14	4.98E–10	1.81E–10
Ba-131m	14.6 m	0.0766	7.46E–17	3.04E–15	3.28E–12	1.25E–12
Ba-133	10.74 y	0.4019	3.97E–16	1.78E–14	9.19E–10	2.11E–09
Ba-133m	38.9 h	0.0668	6.59E–17	2.62E–15	5.66E–10	1.68E–10
Ba-135m	28.7 h	0.0601	6.00E–17	2.32E–15	4.60E–10	1.36E–10
Ba-137m	2.552 m	0.5965	5.86E–16	2.88E–14		
Ba-139	82.7 m	0.0427	4.59E–17	2.17E–15	1.08E–10	4.64E–11
Ba-140	12.74 d	0.1827	1.80E–16	8.58E–15	2.56E–09	1.01E–09
Ba-141	18.27 m	0.8451	8.15E–16	4.16E–14	5.65E–11	2.18E–11
Ba-142	10.6 m	1.0473	1.01E–15	5.15E–14	3.01E–11	1.11E–11
Be-7	53.3 d	0.0493	4.89E–17	2.36E–15	3.45E–11	8.67E–11
Be-10	1.60E+06 y	0	4.12E–19	1.12E–17	1.26E–09	9.58E–08

Table C.1. Isotopic Data (Continued)

Nuclide	Half-Life[a]	Photon Energy[b] (MeV)	Dose Conversion Factors[c]			
			Groundshine[d] ($Sv-m^2/Bq-s$)	Cloudshine[e] ($Sv-m^3/Bq-s$)	Ingestion[f] (Sv/Bq)	Inhalation[f] (Sv/Bq)
Bi-200	36.4 m	2.3933	2.32E–15	1.16E–13	4.92E–11	1.78E–11
Bi-201	108 m	1.3388	1.29E–15	6.51E–14	1.27E–10	5.17E–11
Bi-202	1.67 h	2.713	2.61E–15	1.33E–13	9.71E–11	3.42E–11
Bi-203	11.76 h	2.384	2.23E–15	1.20E–13	5.80E–10	2.24E–10
Bi-204	11.22 h	3.0638				
Bi-205	15.31 d	1.6903	1.58E–15	8.49E–14	1.08E–09	1.17E–09
Bi-206	6.243 d	3.2781	3.14E–15	1.61E–13	2.27E–09	1.77E–09
Bi-207	38 y	1.5398	1.48E–15	7.54E–14	1.48E–09	5.41E–09
Bi-210	5.012 d	0	1.05E–18	3.29E–17	1.73E–09	5.29E–08
Bi-210m	3.00E+06 y	0.2567	2.50E–16	1.22E–14	2.59E–08	2.05E–06
Bi-211	2.14 m	0.0467	4.58E–17	2.22E–15		
Bi-212	60.55 m	0.1855	1.79E–16	9.24E–15	2.87E–10	5.83E–09
Bi-213	45.65 m	0.1331	1.32E–16	6.39E–15	1.95E–10	4.63E–09
Bi-214	19.9 m	1.5082	1.41E–15	7.65E–14	7.64E–11	1.78E–09
Bk-245	4.94 d	0.2342	2.20E–16	1.04E–14	6.52E–10	1.19E–09
Bk-246	1.83 d	0.9513	9.15E–16	4.59E–14	5.68E–10	4.63E–10
Bk-247	1380 y	0.1054	1.01E–16	4.71E–15	1.27E–06	1.55E–04
Bk-249	320 d	0	6.85E–21	8.21E–20	3.24E–09	3.75E–07
Bk-250	3.222 h	0.8866	8.51E–16	4.38E–14	1.57E–10	2.04E–09
Br-74	25.3 m	4.5488	4.04E–15	2.38E–13	5.05E–11	2.33E–11
Br-74m	41.5 m	4.0823	3.79E–15	2.08E–13	8.16E–11	4.43E–11
Br-75	98 m	1.2157	1.20E–15	5.84E–14	4.94E–11	3.54E–11
Br-76	16.2 h	2.6329	2.44E–15	1.34E–13	3.66E–10	4.32E–10
Br-77	56 h	0.3208	3.09E–16	1.51E–14	8.24E–11	7.46E–11
Br-80	17.4 m	0.0796	7.89E–17	3.85E–15	1.58E–11	7.62E–12
Br-80m	4.42 h	0.024	1.70E–17	3.11E–16	7.45E–11	1.06E–10
Br-82	35.3 h	2.6419	2.55E–15	1.30E–13	4.62E–10	4.13E–10
Br-83	2.39 h	0.0075	8.13E–18	3.82E–16	2.47E–11	2.41E–11
Br-84	31.8 m	1.7875	1.60E–15	9.41E–14	4.91E–11	2.61E–11
C-11	20.38 m	1.0195	1.01E–15	4.89E–14	3.29E–12	3.29E–12
C-14	5730 y	0	1.61E–20	2.24E–19	5.64E–10	5.64E–10
Ca-41	1.40E+05 y	0.0004	0.00E+00	0.00E+00	3.44E–10	3.64E–10
Ca-45	163 d	0	4.61E–20	8.63E–19	8.55E–10	1.79E–09
Ca-47	4.53 d	1.0627	1.00E–15	5.36E–14	1.76E–09	1.77E–09
Ca-49	8.716 m	3.1646	2.63E–15	1.73E–13		
Cd-104	57.7 m	0.2585	2.50E–16	1.14E–14	6.30E–11	2.04E–11
Cd-107	6.49 h	0.034	2.98E–17	6.02E–16	6.76E–11	2.94E–11
Cd-109	464 d	0.0263	2.25E–17	2.94E–16	3.55E–09	3.09E–08
Cd-113	9.3E+15 y	0	6.99E–20	1.45E–18	4.70E–08	4.51E–07
Cd-113m	13.6 y	0	2.63E–19	6.94E–18	4.35E–08	4.13E–07
Cd-115	53.46 h	0.2329	2.31E–16	1.12E–14	1.54E–09	1.14E–09

Table C.1. Isotopic Data (Continued)

Nuclide	Half-Life[a]	Photon Energy[b] (MeV)	Dose Conversion Factors[c] Groundshine[d] (Sv-m^2/Bq-s)	Cloudshine[e] (Sv-m^3/Bq-s)	Ingestion[f] (Sv/Bq)	Inhalation[f] (Sv/Bq)
Cd-115m	44.6 d	0.0219	2.34E–17	1.17E–15	4.37E–09	1.95E–08
Cd-117	2.49 h	1.0869	1.03E–15	5.45E–14	3.03E–10	1.22E–10
Cd-117m	3.36 h	2.0443	1.88E–15	1.05E–13	3.21E–10	1.18E–10
Ce-134	72 h	0.0262	2.79E–17	4.71E–16	2.81E–09	2.21E–09
Ce-135	17.6 h	1.7761	1.75E–15	8.54E–14	9.37E–10	4.29E–10
Ce-137	9 h	0.0355	3.65E–17	8.81E–16	2.79E–11	1.13E–11
Ce-137m	34.4 h	0.0529	5.31E–17	1.96E–15	5.94E–10	3.82E–10
Ce-139	137.66 d	0.1595	1.56E–16	6.73E–15	3.09E–10	2.45E–09
Ce-141	32.501 d	0.0762	7.38E–17	3.43E–15	7.83E–10	2.42E–09
Ce-143	33 h	0.2824	2.79E–16	1.29E–14	1.23E–09	9.16E–10
Ce-144	284.3 d	0.0207	2.03E–17	8.53E–16	5.68E–09	1.01E–07
Cf-244	19.4 m	0.0019	1.14E–18	6.91E–18	5.15E–11	2.68E–09
Cf-246	35.7 h	0.0013	7.88E–19	5.48E–18	3.86E–09	1.62E–07
Cf-248	333.5 d	0.0013	7.74E–19	4.73E–18	9.04E–08	1.37E–05
Cf-249	350.6 y	0.3351	3.28E–16	1.58E–14	1.28E–06	1.56E–04
Cf-250	13.08 y	0.0012	7.37E–19	4.50E–18	5.76E–07	7.08E–05
Cf-251	898 y	0.1317	1.22E–16	5.58E–15	1.31E–06	1.59E–04
Cf-252	2.638 y	0.0012	7.22E–19	5.06E–18	2.93E–07	4.24E–05
Cf-253	17.81 d	0	6.45E–20	1.08E–18	3.78E–09	8.43E–07
Cf-254	60.5 d	0	2.40E–21	1.47E–20	6.55E–07	7.93E–05
Cl-36	3.01E+05 y	0.0001	6.73E–19	2.23E–17	8.18E–10	5.93E–09
Cl-38	37.21 m	1.4884	1.34E–15	7.87E–14	6.36E–11	3.62E–11
Cl-39	55.6 m	1.4381	1.35E–15	7.29E–14	4.96E–11	3.06E–11
Cm-238	2.4 h	0.0771	7.10E–17	3.25E–15	9.20E–11	1.44E–09
Cm-240	27 d	0.002	1.05E–18	6.00E–18	1.69E–08	2.17E–06
Cm-241	32.8 d	0.5015	4.85E–16	2.31E–14	1.21E–09	3.97E–08
Cm-242	162.8 d	0.0018	9.56E–19	5.69E–18	3.10E–08	4.67E–06
Cm-243	28.5 y	0.1342	1.25E–16	5.88E–15	6.79E–07	8.30E–05
Cm-244	18.11 y	0.0016	8.78E–19	4.91E–18	5.45E–07	6.70E–05
Cm-245	8500 y	0.0956	8.70E–17	3.96E–15	1.01E–06	1.23E–04
Cm-246	4730 y	0.0015	7.85E–19	4.46E–18	1.00E–06	1.22E–04
Cm-247	1.56E+07 y	0.3156	3.10E–16	1.50E–14	9.24E–07	1.12E–04
Cm-248	3.39E+05 y	0.0011	6.00E–19	3.39E–18	3.68E–06	4.47E–04
Cm-249	64.15 m	0.0191	1.94E–17	9.36E–16	2.70E–11	5.22E–11
Cm-250	6900 y	0	0.00E+00	0.00E+00	2.10E–05	2.54E–03
Co-55	17.54 h	1.9942	1.93E–15	9.78E–14	1.18E–09	5.65E–10
Co-56	78.76 d	3.5801	3.29E–15	1.83E–13	3.41E–09	1.07E–08
Co-57	270.9 d	0.1252	1.15E–16	5.61E–15	3.20E–10	2.45E–09
Co-58	70.8 d	0.9756	9.50E–16	4.76E–14	9.68E–10	2.94E–09
Co-58m	9.15 h	0.002	9.32E–21	8.77E–20	2.46E–11	2.54E–11
Co-60	5.271 y	2.5043	2.35E–15	1.26E–13	7.28E–09	5.91E–08

Table C.1. Isotopic Data (Continued)

Nuclide	Half-Life[a]	Photon Energy[b] (MeV)	Dose Conversion Factors[c]			
			Groundshine[d] (Sv-m^2/Bq-s)	Cloudshine[e] (Sv-m^3/Bq-s)	Ingestion[f] (Sv/Bq)	Inhalation[f] (Sv/Bq)
Co-60m	10.47 m	0.0068	4.42E–18	2.17E–16	9.82E–13	5.74E–13
Co-61	1.65 h	0.0906	9.02E–17	3.94E–15	7.11E–11	2.86E–11
Co-62m	13.91 m	2.6978	2.52E–15	1.37E–13	3.10E–11	9.50E–12
Cr-48	22.96 h	0.4358	4.23E–16	2.06E–14	2.47E–10	2.37E–10
Cr-49	42.09 m	1.055	1.04E–15	5.03E–14	4.98E–11	1.96E–11
Cr-51	27.704 d	0.0325	3.08E–17	1.51E–15	3.98E–11	9.03E–11
Cs-125	45 m	0.6783	6.69E–16	3.22E–14	1.96E–11	1.12E–11
Cs-126	1.64 m	1.0858	1.09E–15	5.24E–14		
Cs-127	6.25 h	0.4199	4.14E–16	1.93E–14	2.12E–11	1.59E–11
Cs-128	3.9 m	0.9004	8.94E–16	4.32E–14		
Cs-129	32.06 h	0.2815	2.79E–16	1.24E–14	5.89E–11	4.29E–11
Cs-130	29.9 m	0.5167	5.12E–16	2.45E–14	1.55E–11	8.07E–12
Cs-131	9.69 d	0.0228	2.39E–17	3.28E–16	6.67E–11	4.50E–11
Cs-132	6.475 d	0.705	6.93E–16	3.34E–14	5.12E–10	3.32E–10
Cs-134	2.062 y	1.5551	1.52E–15	7.57E–14	1.98E–08	1.25E–08
Cs-134m	2.9 h	0.0267	2.59E–17	9.05E–16	1.33E–11	1.18E–11
Cs-135	2.30E+06 y	0	3.33E–20	5.65E–19	1.91E–09	1.23E–09
Cs-135m	53 m	1.5857	1.54E–15	7.76E–14	1.50E–11	6.68E–12
Cs-136	13.1 d	2.1656	2.09E–15	1.06E–13	3.04E–09	1.98E–09
Cs-137	30 y	0	2.85E–19	7.74E–18	1.35E–08	8.63E–09
Cs-138	32.2 m	2.361	2.19E–15	1.21E–13	5.25E–11	2.74E–11
Cu-57	233 m	1.0631				
Cu-60	23.2 m	3.8978	3.63E–15	1.98E–13	5.21E–11	1.87E–11
Cu-61	3.408 h	0.8285	8.15E–16	3.99E–14	1.18E–10	5.06E–11
Cu-62	9.74 m	1.0067	1.00E–15	4.86E–14		
Cu-64	12.701 h	0.1906	1.87E–16	9.10E–15	1.26E–10	7.48E–11
Cu-66	5.1 m	0.0847	8.78E–17	4.46E–15		
Cu-67	61.86 h	0.1153	1.11E–16	5.41E–15	3.55E–10	3.32E–10
Dy-155	10 h	0.5824	5.60E–16	2.77E–14	1.56E–10	6.00E–11
Dy-157	8.1 h	0.3565	3.51E–16	1.63E–14	7.60E–11	2.16E–11
Dy-159	144.4 d	0.045	4.65E–17	1.25E–15	1.20E–10	6.56E–10
Dy-165	2.334 h	0.026	2.69E–17	1.20E–15	9.81E–11	3.62E–11
Dy-166	81.6 h	0.0402	4.01E–17	1.40E–15	1.79E–09	2.02E–09
Er-161	3.24 h	0.9142	8.83E–16	4.42E–14	9.26E–11	2.45E–11
Er-165	10.36 h	0.0376	3.84E–17	1.11E–15	2.23E–11	8.08E–12
Er-167m	2.28 s	0.0968				
Er-169	9.3 d	0	8.10E–20	1.74E–18	4.06E–10	5.64E–10
Er-171	7.52 h	0.3812	3.73E–16	1.78E–14	3.91E–10	1.52E–10
Er-172	49.3 h	0.5223	5.15E–16	2.47E–14	1.14E–09	1.11E–09
Es-250	2.1 h	0.3971	3.78E–16	1.90E–14	3.20E–11	1.30E–09
Es-251	33 h	0.0984	9.09E–17	4.13E–15	2.00E–10	1.28E–09

Table C.1. Isotopic Data (Continued)

Nuclide	Half-Life[a]	Photon Energy[b] (MeV)	Dose Conversion Factors[c]			
			Groundshine[d] (Sv-m²/Bq-s)	Cloudshine[e] (Sv-m³/Bq-s)	Ingestion[f] (Sv/Bq)	Inhalation[f] (Sv/Bq)
Es-253	20.47 d	0.0011	8.18E–19	1.83E–17	9.10E–09	1.07E–06
Es-254	275.7 d	0.0191	1.27E–17	1.93E–16	8.47E–08	1.11E–05
Es-254m	39.3 h	0.4695	4.60E–16	2.25E–14	4.83E–09	1.51E–07
Eu-145	5.94 d	1.4577	1.38E–15	7.22E–14	9.12E–10	7.41E–10
Eu-146	4.61 d	2.504	2.42E–15	1.23E–13	1.54E–09	1.05E–09
Eu-147	24 d	0.4968	4.83E–16	2.32E–14	5.36E–10	9.55E–10
Eu-148	54.5 d	2.1772	2.12E–15	1.06E–13	1.55E–09	3.87E–09
Eu-149	93.1 d	0.0632	6.41E–17	2.25E–15	1.24E–10	5.10E–10
Eu-150a	12.62 h	0.0468	4.65E–17	2.21E–15	4.05E–10	1.82E–10
Eu-150b	34.2 y	1.4964	1.46E–15	7.17E–14	1.72E–09	7.25E–08
Eu-152	13.33 y	1.1545	1.10E–15	5.65E–14	1.75E–09	5.97E–08
Eu-152m	9.32 h	0.2934	2.86E–16	1.42E–14	5.40E–10	2.21E–10
Eu-154	8.8 y	1.2415	1.19E–15	6.14E–14	2.58E–09	7.73E–08
Eu-155	4.96 y	0.0605	5.90E–17	2.49E–15	4.13E–10	1.12E–08
Eu-156	15.19 d	1.3293	1.23E–15	6.75E–14	2.48E–09	3.82E–09
Eu-157	15.15 h	0.2619	2.61E–16	1.17E–14	6.59E–10	3.01E–10
Eu-158	45.9 m	1.0567	1.01E–15	5.27E–14	7.71E–11	2.54E–11
F-18	109.77 m	1.022	1.01E–15	4.90E–14	3.31E–11	2.26E–11
Fe-52	8.275 h	0.7404	7.27E–16	3.54E–14	1.51E–09	5.92E–10
Fe-55	2.7 y	0.0016	0.00E+00	0.00E+00	1.64E–10	7.26E–10
Fe-59	44.529 d	1.1888	1.12E–15	5.97E–14	1.81E–09	4.00E–09
Fe-60	1.00E+05 y	0	1.48E–20	1.95E–19	4.12E–08	2.02E–07
Fm-252	22.7 h	0.0011	7.56E–19	5.03E–18	3.10E–09	1.14E–07
Fm-253	3 d	0.0829	7.70E–17	3.53E–15	1.37E–09	1.56E–07
Fm-254	3.24 h	0.0012	8.28E–19	6.57E–18	4.69E–10	1.57E–08
Fm-255	20.07 h	0.0136	8.22E–18	1.10E–16	2.80E–09	7.21E–08
Fm-257	100.5 d	0.1108	1.03E–16	4.66E–15	4.08E–08	6.32E–06
Fr-219	21 m	0.0034	3.43E–18	1.66E–16		
Fr-220	27.4 s	0.0121	1.05E–17	4.92E–16		
Fr-221	4.8 m	0.031	2.98E–17	1.46E–15		
Fr-222	14.4 m	0	3.38E–18	1.17E–16	6.64E–10	3.32E–09
Fr-223	21.8 m	0.0594	5.65E–17	2.29E–15	2.33E–09	1.68E–09
Ga-65	15.2 m	1.1762	1.16E–15	5.65E–14	2.42E–11	9.07E–12
Ga-66	9.4 h	2.4733	2.22E–15	1.29E–13	1.30E–09	5.03E–10
Ga-67	78.26 h	0.158	1.49E–16	7.20E–15	2.12E–10	1.51E–10
Ga-68	68 m	0.9507	9.41E–16	4.58E–14	9.24E–11	3.74E–11
Ga-70	21.15 m	0.0075	9.82E–18	4.62E–16	2.03E–11	8.52E–12
Ga-72	14.1 h	2.711	2.50E–15	1.39E–13	1.25E–09	5.02E–10
Ga-73	4.91 h	0.3156	3.05E–16	1.48E–14	2.79E–10	1.03E–10
Gd-145	22.9 m	2.2574	2.08E–15	1.15E–13	3.36E–11	1.22E–11
Gd-146	48.3 d	0.2501	2.46E–16	9.95E–15	1.12E–09	1.03E–08

Table C.1. Isotopic Data (Continued)

Nuclide	Half-Life[a]	Photon Energy[b] (MeV)	Dose Conversion Factors[c]			
			Groundshine[d] (Sv-m^2/Bq-s)	Cloudshine[e] (Sv-m^3/Bq-s)	Ingestion[f] (Sv/Bq)	Inhalation[f] (Sv/Bq)
Gd-147	38.1 h	1.3372	1.30E–15	6.45E–14	7.42E–10	4.07E–10
Gd-148	93 y	0	0.00E+00	0.00E+00	5.89E–08	8.91E–05
Gd-149	9.4 d	0.4202	4.12E–16	1.92E–14	5.41E–10	6.18E–10
Gd-151	120 d	0.0638	6.38E–17	2.20E–15	2.23E–10	2.40E–09
Gd-152	1.08E+14 y	0	0.00E+00	0.00E+00	4.34E–08	6.58E–05
Gd-153	242 d	0.1055	1.06E–16	3.71E–15	3.17E–10	6.43E–09
Gd-159	18.56 h	0.0499	5.02E–17	2.21E–15	5.35E–10	2.64E–10
Ge-66	2.27 h	0.6868	6.70E–16	3.25E–14	5.68E–11	8.56E–11
Ge-67	18.7 m	1.4064	1.38E–15	6.86E–14	3.52E–11	1.64E–11
Ge-68	288 d	0.0041	2.16E–20	7.37E–20	2.89E–10	1.40E–08
Ge-69	39.05 h	0.8734	8.44E–16	4.27E–14	1.01E–10	2.27E–10
Ge-71	11.8 d	0.0041	2.18E–20	7.47E–20	2.60E–12	3.31E–11
Ge-75	82.78 m	0.0341	3.44E–17	1.68E–15	2.54E–11	1.92E–11
Ge-77	11.3 h	1.0863	1.05E–15	5.32E–14	1.55E–10	2.85E–10
Ge-78	87 m	0.278	2.71E–16	1.34E–14	7.19E–11	7.75E–11
H-3	12.35 y	0	0.00E+00	3.31E–19	1.73E–11	1.73E–11
Hf-170	16.01 h	0.5492	5.37E–16	2.52E–14	5.73E–10	3.23E–10
Hf-172	1.87 y	0.1178	1.13E–16	4.06E–15	1.21E–09	8.60E–08
Hf-173	24 h	0.4075	3.96E–16	1.85E–14	2.71E–10	1.29E–10
Hf-175	70 d	0.3691	3.63E–16	1.69E–14	4.92E–10	1.51E–09
Hf-177m	51.4 m	2.2519	2.20E–15	1.06E–13	7.43E–11	2.67E–11
Hf-178m	31 y	2.358	2.31E–15	1.12E–13	5.68E–09	6.65E–07
Hf-179m	25.1 d	0.9012	8.82E–16	4.21E–14	1.46E–09	2.73E–09
Hf-180m	5.5 h	1.0078	9.89E–16	4.74E–14	1.98E–10	6.30E–11
Hf-181	42.4 d	0.5554	5.46E–16	2.62E–14	1.27E–09	4.17E–09
Hf-182	9.00E+06 y	0.2394	2.33E–16	1.14E–14	4.29E–09	8.98E–07
Hf-182m	61.5 m	0.933	9.10E–16	4.43E–14	3.93E–11	1.68E–11
Hf-183	64 m	0.7515	7.34E–16	3.63E–14	6.87E–11	3.16E–11
Hf-184	4.12 h	0.2505	2.40E–16	1.14E–14	5.82E–10	2.31E–10
Hg-193	3.5 h	0.2027	1.92E–16	8.69E–15	9.23E–11	5.01E–11
Hg-193m	11.1 h	1.0455	9.99E–16	5.05E–14	4.65E–10	2.08E–10
Hg-194	260 y	0.0027	2.05E–19	6.92E–19	7.78E–08	4.90E–08
Hg-195	9.9 h	0.2038	1.94E–16	9.20E–15	1.09E–10	5.58E–11
Hg-195m	41.6 h	0.2139	2.02E–16	9.63E–15	6.21E–10	4.14E–10
Hg-197	64.1 h	0.07	6.42E–17	2.66E–15	2.59E–10	1.92E–10
Hg-197m	23.8 h	0.0943	8.70E–17	4.05E–15	5.14E–10	3.23E–10
Hg-199m	42.6 m	0.1861	1.77E–16	8.36E–15	2.44E–11	1.82E–11
Hg-203	46.6 d	0.2381	2.32E–16	1.13E–14	3.09E–09	1.98E–09
Hg-206	8.15 m	0.1057				
Ho-155	48 m	0.3868	3.82E–16	1.79E–14	3.50E–11	1.21E–11
Ho-157	12.6 m	0.4928	4.83E–16	2.24E–14	5.42E–12	1.41E–12

Table C.1. Isotopic Data (Continued)

Nuclide	Half-Life[a]	Photon Energy[b] (MeV)	Dose Conversion Factors[c] Groundshine[d] ($Sv-m^2/Bq-s$)	Cloudshine[e] ($Sv-m^3/Bq-s$)	Ingestion[f] (Sv/Bq)	Inhalation[f] (Sv/Bq)
Ho-159	33 m	0.3661	3.58E–16	1.60E–14	6.92E–12	1.76E–12
Ho-161	2.5 h	0.0615	6.15E–17	1.73E–15	1.35E–11	4.20E–12
Ho-162	15 m	0.1676	1.63E–16	7.35E–15	2.27E–12	6.36E–13
Ho-162m	68 m	0.5756	5.51E–16	2.74E–14	2.61E–11	6.80E–12
Ho-164	29 m	0.0296	3.03E–17	9.05E–16	6.73E–12	2.35E–12
Ho-164m	37.5 m	0.0472	4.63E–17	1.32E–15	1.44E–11	5.14E–12
Ho-166	26.8 h	0.029	3.01E–17	1.42E–15	1.51E–09	8.48E–10
Ho-166m	1200 y	1.747	1.70E–15	8.45E–14	2.18E–09	2.09E–07
Ho-167	3.1 h	0.3654	3.59E–16	1.73E–14	8.90E–11	2.94E–11
I-120	81 m	2.7294	2.56E–15	1.38E–13	2.08E–10	1.20E–10
I-120m	53 m	5.2972	5.02E–15	2.65E–13	1.34E–10	7.15E–11
I-121	2.12 h	0.4188	4.09E–16	1.94E–14	5.39E–11	3.21E–11
I-122	3.62 m	0.9458	9.40E–16	4.56E–14		
I-123	13.2 h	0.1717	1.66E–16	7.28E–15	1.43E–10	8.01E–11
I-124	4.18 d	1.0982	1.05E–15	5.38E–14	8.60E–09	5.23E–09
I-125	60.14 d	0.042	4.27E–17	5.22E–16	1.04E–08	6.53E–09
I-126	13.02 d	0.4548	4.47E–16	2.15E–14	1.92E–08	1.20E–08
I-128	24.99 m	0.085	8.77E–17	4.16E–15	2.43E–11	1.28E–11
I-129	1.57E+07 y	0.0246	2.58E–17	3.80E–16	7.46E–08	4.69E–08
I-130	12.36 h	2.1385	2.10E–15	1.04E–13	1.28E–09	7.14E–10
I-131	8.04 d	0.3815	3.76E–16	1.82E–14	1.44E–08	8.89E–09
I-132	2.3 h	2.2804	2.21E–15	1.12E–13	1.82E–10	1.03E–10
I-132m	83.6 m	0.3222	3.15E–16	1.53E–14	1.42E–10	8.10E–11
I-133	20.8 h	0.6071	5.97E–16	2.94E–14	2.80E–09	1.58E–09
I-134	52.6 m	2.6252	2.53E–15	1.30E–13	6.66E–11	3.55E–11
I-135	6.61 h	1.5762	1.47E–15	7.98E–14	6.08E–10	3.32E–10
In-109	4.2 h	0.6722	6.46E–16	3.21E–14	7.64E–11	3.21E–11
In-110a	69.1 m	1.5569	1.51E–15	7.62E–14	2.86E–10	8.32E–11
In-110b	4.9 h	3.0494	2.96E–15	1.49E–13	9.39E–11	3.66E–11
In-111	2.83 d	0.4053	3.90E–16	1.86E–14	3.59E–10	2.27E–10
In-111m	7.7 m	0.4694				
In-112	14.4 m	0.2677	2.64E–16	1.26E–14	6.46E–12	2.44E–12
In-113m	1.658 h	0.2576	2.54E–16	1.21E–14	2.83E–11	1.11E–11
In-114	71.9 s	0.0027	2.70E–18	1.39E–16		
In-114m	49.51 d	0.0944	9.15E–17	4.18E–15	4.61E–09	2.40E–08
In-115	5.1E+15 y	0	1.81E–19	4.50E–18	4.26E–08	1.01E–06
In-115m	4.486 h	0.1611	1.58E–16	7.39E–15	9.33E–11	3.59E–11
In-116m	54.15 m	2.4732	2.32E–15	1.25E–13	5.93E–11	2.06E–11
In-117	43.8 m	0.6921	6.79E–16	3.31E–14	2.59E–11	9.95E–12
In-117m	116.5 m	0.0909	8.96E–17	4.19E–15	1.15E–10	4.78E–11
In-119	2.4 m	0.7689	7.53E–16	3.74E–14		

Table C.1. Isotopic Data (Continued)

Nuclide	Half-Life[a]	Photon Energy[b] (MeV)	Dose Conversion Factors[c]			
			Groundshine[d] (Sv-m²/Bq-s)	Cloudshine[e] (Sv-m³/Bq-s)	Ingestion[f] (Sv/Bq)	Inhalation[f] (Sv/Bq)
In-119m	18 m	0.0112	1.69E–17	6.14E–16	2.88E–11	1.20E–11
Ir-182	15 m	1.3398	1.31E–15	6.50E–14	3.45E–11	1.31E–11
Ir-184	3.02 h	1.9083	1.82E–15	9.38E–14	1.88E–10	6.21E–11
Ir-185	14 h	0.6008	5.52E–16	2.94E–14	3.00E–10	1.48E–10
Ir-186a	15.8 h	1.6409	1.56E–15	8.06E–14	5.86E–10	2.46E–10
Ir-186b	1.75 h	0.9637	9.30E–16	4.65E–14		
Ir-187	10.5 h	0.3632	3.51E–16	1.68E–14	1.42E–10	5.67E–11
Ir-188	41.5 h	1.5839	1.46E–15	8.01E–14	7.73E–10	4.17E–10
Ir-189	13.3 d	0.0813	7.69E–17	3.21E–15	2.84E–10	4.46E–10
Ir-190	12.1 d	1.4427	1.41E–15	6.86E–14	1.47E–09	1.73E–09
Ir-190m	1.2 h	0.0019	3.81E–20	1.27E–19	8.54E–12	8.24E–12
Ir-190n	3.1 h	1.5546	1.53E–15	7.39E–14		
Ir-191m	4.94 s	0.0747	6.91E–17	3.02E–15		
Ir-192	74.02 d	0.8179	8.03E–16	3.91E–14	1.55E–09	7.61E–09
Ir-192m	241 y	0.161	1.55E–16	7.63E–15	4.23E–10	1.04E–07
Ir-194	19.15 h	0.0903	9.16E–17	4.54E–15	1.43E–09	7.84E–10
Ir-194m	171 d	2.3353	2.30E–15	1.12E–13	2.46E–09	1.85E–08
Ir-195	2.5 h	0.0585	5.52E–17	2.32E–15	9.25E–11	3.75E–11
Ir-195m	3.8 h	0.4319	4.07E–16	1.93E–14	1.76E–10	6.74E–11
K-38	7.636 m	3.1868	2.92E–15	1.64E–13		
K-40	1.28E+09 y	0.1563	1.46E–16	8.05E–15	5.02E–09	3.34E–09
K-42	12.36 h	0.2759	2.66E–16	1.46E–14	3.06E–10	3.67E–10
K-43	22.6 h	0.9699	9.55E–16	4.67E–14	2.08E–10	1.87E–10
K-44	22.13 m	2.2671	2.04E–15	1.19E–13	4.67E–11	2.24E–11
K-45	20 m	1.8662	1.69E–15	9.67E–14	3.01E–11	1.39E–11
Kr-74	11.5 m	1.1687	1.15E–15	5.59E–14		
Kr-76	14.8 h	0.435	4.20E–16	2.03E–14		
Kr-77	74.7 m	1.016	9.99E–16	4.86E–14		
Kr-79	35.04 h	0.2574	2.47E–16	1.21E–14		
Kr-81	2.10E+05 y	0.0117	6.15E–18	2.67E–16		
Kr-81m	13 s	0.1308	1.24E–16	6.14E–15		
Kr-83m	1.83 h	0.0026	3.80E–19	1.50E–18		
Kr-85	10.72 y	0.0022	2.64E–18	1.19E–16		
Kr-85m	4.48 h	0.1581	1.52E–16	7.48E–15		
Kr-87	76.3 m	0.793	7.32E–16	4.12E–14		
Kr-88	2.84 h	1.9545	1.74E–15	1.02E–13		
La-131	59 m	0.6709	6.61E–16	3.14E–14	3.22E–11	1.40E–11
La-132	4.8 h	2.0105	1.90E–15	1.00E–13	4.30E–10	1.48E–10
La-134	6.67 m	0.6978	6.93E–16	3.35E–14		
La-135	19.5 h	0.0357	3.71E–17	9.21E–16	3.66E–11	1.60E–11
La-137	6.00E+04 y	0.0242	2.57E–17	4.06E–16	1.23E–10	2.37E–08

Table C.1. Isotopic Data (Continued)

Nuclide	Half-Life[a]	Photon Energy[b] (MeV)	Dose Conversion Factors[c] Groundshine[d] (Sv-m²/Bq-s)	Cloudshine[e] (Sv-m³/Bq-s)	Ingestion[f] (Sv/Bq)	Inhalation[f] (Sv/Bq)
La-138	1.35E+11 y	1.2364	1.16E–15	6.20E–14	1.59E–09	3.70E–07
La-140	40.272 h	2.3149	2.16E–15	1.17E–13	2.28E–09	1.31E–09
La-141	3.93 h	0.0429	4.54E–17	2.39E–15	3.74E–10	1.57E–10
La-142	92.5 m	2.7529	2.46E–15	1.44E–13	1.79E–10	6.84E–11
La-143	14.23 m	0.0939	9.71E–17	5.18E–15	3.77E–11	1.62E–11
Lu-169	34.06 h	1.0409	9.86E–16	5.09E–14	5.49E–10	3.64E–10
Lu-170	2 d	2.4841	2.24E–15	1.28E–13	1.23E–09	6.96E–10
Lu-171	8.22 d	0.6973	6.80E–16	3.25E–14	7.85E–10	8.07E–10
Lu-172	6.7 d	1.8882	1.81E–15	9.25E–14	1.53E–09	1.35E–09
Lu-173	1.37 y	0.1296	1.28E–16	5.10E–15	2.95E–10	6.09E–09
Lu-174	3.31 y	0.1256	1.20E–16	5.46E–15	3.01E–10	1.07E–08
Lu-174m	142 d	0.0633	6.04E–17	2.18E–15	5.77E–10	6.86E–09
Lu-176	3.6E+10 y	0.4913	4.78E–16	2.32E–14	1.98E–09	1.79E–07
Lu-176m	3.68 h	0.0143	1.47E–17	5.87E–16	1.73E–10	7.21E–11
Lu-177	6.71 d	0.035	3.39E–17	1.62E–15	5.81E–10	6.63E–10
Lu-177m	160.9 d	1.0031	9.77E–16	4.67E–14	1.99E–09	1.98E–08
Lu-178	28.4 m	0.1398	1.34E–16	7.09E–15	3.32E–11	1.26E–11
Lu-178m	22.7 m	1.1086	1.09E–15	5.23E–14	2.76E–11	8.84E–12
Lu-179	4.59 h	0.0309	3.13E–17	1.52E–15	2.17E–10	9.13E–11
Md-257	5.2 h	0.1136	1.08E–16	5.03E–15	1.89E–10	1.55E–08
Md-258	55 d	0.0062	4.51E–18	5.08E–17	3.19E–08	4.47E–06
Mg-28	20.91 h	1.3705	1.30E–15	6.79E–14	2.18E–09	1.33E–09
Mn-51	46.2 m	0.9977	9.91E–16	4.80E–14	7.51E–11	3.10E–11
Mn-52	5.591 d	3.4576	3.29E–15	1.72E–13	2.05E–09	1.54E–09
Mn-52m	21.1 m	2.4088	2.30E–15	1.20E–13	4.88E–11	1.83E–11
Mn-53	3.70E+06 y	0.0013	0.00E+00	0.00E+00	2.92E–11	1.35E–10
Mn-54	312.5 d	0.836	8.12E–16	4.09E–14	7.48E–10	1.81E–09
Mn-56	2.5785 h	1.6915	1.58E–15	8.61E–14	2.64E–10	1.02E–10
Mo-90	5.67 h	0.8273	7.96E–16	3.93E–14	7.19E–10	3.34E–10
Mo-93	3500 y	0.0106	5.34E–18	2.52E–17	3.64E–10	7.68E–09
Mo-93m	6.85 h	2.2504	2.12E–15	1.13E–13	3.22E–10	1.04E–10
Mo-99	66 h	0.15	1.47E–16	7.28E–15	1.36E–09	1.07E–09
Mo-101	14.62 m	1.368	1.29E–15	6.87E–14	2.97E–11	1.12E–11
N-13	9.965 m	1.0201	1.01E–15	4.90E–14		
Na-22	2.602 y	2.1925	2.10E–15	1.08E–13	3.10E–09	2.07E–09
Na-24	15 h	4.1212	3.61E–15	2.18E–13	3.84E–10	3.27E–10
Nb-88	14.3 m	4.1264	4.01E–15	2.02E–13	2.40E–11	7.27E–12
Nb-89a	66 m	1.9253	1.90E–15	9.26E–14	1.31E–10	4.83E–11
Nb-89b	122 m	1.3909	1.32E–15	6.98E–14	2.77E–10	1.11E–10
Nb-90	14.6 h	4.2244	3.84E–15	2.17E–13	1.46E–09	6.19E–10
Nb-93m	13.6 y	0.0019	9.39E–19	4.44E–18	1.41E–10	7.90E–09

Table C.1. Isotopic Data (Continued)

Nuclide	Half-Life[a]	Photon Energy[b] (MeV)	Dose Conversion Factors[c]			
			Groundshine[d] (Sv-m^2/Bq-s)	Cloudshine[e] (Sv-m^3/Bq-s)	Ingestion[f] (Sv/Bq)	Inhalation[f] (Sv/Bq)
Nb-94	2.03E+04 y	1.5737	1.53E–15	7.70E–14	1.93E–09	1.12E–07
Nb-95	35.15 d	0.7658	7.48E–16	3.74E–14	6.95E–10	1.57E–09
Nb-95m	86.6 h	0.0683	6.26E–17	2.93E–15	6.22E–10	6.59E–10
Nb-96	23.35 h	2.4721	2.39E–15	1.21E–13	1.27E–09	6.19E–10
Nb-97	72.1 m	0.6554	6.45E–16	3.18E–14	6.30E–11	2.24E–11
Nb-97m	60 s	0.7281	7.12E–16	3.55E–14		
Nb-98	51.5 m	2.426	2.33E–15	1.21E–13	1.02E–10	3.31E–11
Nd-136	50.65 m	0.2932	2.90E–16	1.27E–14	9.62E–11	3.12E–11
Nd-138	5.04 h	0.0431	4.45E–17	1.27E–15	6.89E–10	2.78E–10
Nd-139	29.7 m	0.4055	4.00E–16	1.90E–14	1.63E–11	5.73E–12
Nd-139m	5.5 h	1.5715	1.52E–15	7.63E–14	2.94E–10	1.01E–10
Nd-141	2.49 h	0.0753	7.55E–17	2.88E–15	9.18E–12	2.78E–12
Nd-141m	62.4 s	0.7594	7.42E–16	3.70E–14		
Nd-147	10.98 d	0.1402	1.39E–16	6.19E–15	1.18E–09	1.85E–09
Nd-149	1.73 h	0.3841	3.77E–16	1.81E–14	1.26E–10	6.05E–11
Nd-151	12.44 m	0.9163	8.82E–16	4.48E–14	2.13E–11	8.43E–12
Ne-19	17.22 s	1.022	1.02E–15	4.92E–14		
Ni-56	6.1 d	1.7207	1.66E–15	8.41E–14	1.05E–09	1.12E–09
Ni-57	36.08 h	1.9219	1.80E–15	9.69E–14	1.02E–09	5.11E–10
Ni-59	7.50E+04 y	0.0024	0.00E+00	0.00E+00	5.67E–11	7.31E–10
Ni-63	96 y	0	0.00E+00	0.00E+00	1.56E–10	1.70E–09
Ni-65	2.52 h	0.5486	5.15E–16	2.79E–14	1.68E–10	9.32E–11
Ni-66	54.6 h	0	3.49E–20	6.16E–19	3.24E–09	2.25E–09
Np-232	14.7 m	1.2032	1.16E–15	5.80E–14	1.01E–11	3.39E–10
Np-233	36.2 m	0.0908	8.39E–17	3.85E–15	1.99E–12	5.87E–13
Np-234	4.4 d	1.4422	1.33E–15	7.26E–14	7.43E–10	5.49E–10
Np-235	396.1 d	0.0071	3.65E–18	5.10E–17	6.56E–11	1.12E–09
Np-236a	115000 y	0.1363	1.20E–16	5.36E–15	2.34E–07	2.81E–05
Np-236b	22.5 h	0.0507	4.67E–17	2.14E–15	3.70E–10	2.23E–08
Np-237	2.14E+06 y	0.0346	2.87E–17	1.03E–15	1.20E–06	1.46E–04
Np-238	2.117 d	0.553	5.29E–16	2.72E–14	1.08E–09	1.00E–08
Np-239	2.355 d	0.1731	1.63E–16	7.69E–15	8.82E–10	6.78E–10
Np-240	65 m	1.3134	1.27E–15	6.31E–14	6.40E–11	2.20E–11
Np-240m	7.4 m	0.3371	3.27E–16	1.62E–14		
O-14	70.599 s	3.3189				
O-15	122.24 s	1.0208	1.01E–15	4.91E–14		
O-19	26.91 s	0.957				
Os-180	22 m	0.0645	6.02E–17	2.30E–15	1.42E–11	4.71E–12
Os-181	105 m	1.2222	1.17E–15	5.94E–14	9.86E–11	3.62E–11
Os-182	22 h	0.4348	4.25E–16	2.01E–14	6.59E–10	3.73E–10
Os-185	94 d	0.7189	7.04E–16	3.43E–14	6.11E–10	2.80E–09

Table C.1. Isotopic Data (Continued)

Nuclide	Half-Life[a]	Photon Energy[b] (MeV)	Dose Conversion Factors[c]			
			Groundshine[d] (Sv-m^2/Bq-s)	Cloudshine[e] (Sv-m^3/Bq-s)	Ingestion[f] (Sv/Bq)	Inhalation[f] (Sv/Bq)
Os-189m	6 h	0.0018	3.13E–20	1.06E–19	1.81E–11	8.07E–12
Os-190m	9.9 m	1.5884	1.56E–15	7.60E–14		
Os-191	15.4 d	0.0795	7.38E–17	3.21E–15	6.23E–10	1.13E–09
Os-191m	13.03 h	0.0091	7.19E–18	2.75E–16	1.04E–10	8.20E–11
Os-193	30 h	0.0733	7.23E–17	3.40E–15	8.77E–10	5.41E–10
Os-194	6 y	0.0017	1.14E–18	2.75E–17	2.94E–09	1.81E–07
P-30	2.499 m	1.0219	1.02E–15	4.94E–14		
P-32	14.29 d	0	2.91E–18	9.90E–17	2.37E–09	4.19E–09
P-33	25.4 d	0	4.46E–20	8.23E–19	2.48E–10	6.27E–10
Pa-227	38.3 m	0.0222	1.99E–17	8.54E–16	3.55E–10	1.32E–08
Pa-228	22 h	1.1414	1.09E–15	5.54E–14	1.13E–09	1.19E–07
Pa-230	17.4 d	0.6522	6.26E–16	3.13E–14	1.68E–09	3.98E–07
Pa-231	32760 y	0.0482	4.07E–17	1.72E–15	2.86E–06	3.47E–04
Pa-232	1.31 d	0.9385	9.06E–16	4.56E–14	9.65E–10	2.47E–08
Pa-233	27 d	0.204	1.95E–16	9.35E–15	9.81E–10	2.58E–09
Pa-234	6.7 h	1.919	1.84E–15	9.34E–14	5.84E–10	2.20E–10
Pa-234m	1.17 m	0.0115	1.53E–17	7.19E–16		
Pb-195m	15.8 m	1.5986	1.55E–15	7.68E–14	2.45E–11	8.37E–12
Pb-198	2.4 h	0.4389	4.25E–16	2.04E–14	4.43E–11	2.08E–11
Pb-199	90 m	1.4761	1.39E–15	7.31E–14	6.01E–11	1.97E–11
Pb-200	21.5 h	0.2089	1.98E–16	9.20E–15	4.67E–10	2.14E–10
Pb-201	9.4 h	0.758	7.33E–16	3.63E–14	1.92E–10	7.09E–11
Pb-202	3.00E+05 y	0.0021	1.34E–19	4.52E–19	1.05E–08	2.65E–08
Pb-202m	3.62 h	2.043	1.99E–15	9.96E–14	1.53E–10	4.83E–11
Pb-203	52.05 h	0.3118	3.01E–16	1.44E–14	2.93E–10	1.43E–10
Pb-204m	67.2 m	2.1048				
Pb-205	1.43E+07 y	0.0023	1.50E–19	5.06E–19	4.41E–10	1.06E–09
Pb-209	3.253 h	0	3.01E–19	8.12E–18	5.75E–11	2.56E–11
Pb-210	22.3 y	0.0048	2.48E–18	5.64E–17	1.45E–06	3.67E–06
Pb-211	36.1 m	0.0505	5.08E–17	2.49E–15	1.42E–10	2.35E–09
Pb-212	10.64 h	0.1483	1.43E–16	6.87E–15	1.23E–08	4.56E–08
Pb-214	26.8 m	0.2497	2.44E–16	1.18E–14	1.69E–10	2.11E–09
Pd-100	3.63 d	0.1289	1.20E–16	4.65E–15	1.16E–09	1.06E–09
Pd-101	8.27 h	0.337	3.22E–16	1.53E–14	1.12E–10	5.03E–11
Pd-103	16.96 d	0.0144	1.09E–17	7.68E–17	2.13E–10	4.24E–10
Pd-107	6.50E+06 y	0	0.00E+00	0.00E+00	4.04E–11	3.45E–09
Pd-109	13.427 h	0.0117	1.12E–17	2.51E–16	5.87E–10	2.96E–10
Pm-141	20.9 m	0.744	7.28E–16	3.60E–14	2.53E–11	8.56E–12
Pm-142	40.5 s	0.8676	8.66E–16	4.22E–14		
Pm-143	265 d	0.3154	3.10E–16	1.46E–14	2.79E–10	2.94E–09
Pm-144	363 d	1.5627	1.54E–15	7.48E–14	1.17E–09	1.45E–08

Table C.1. Isotopic Data (Continued)

Nuclide	Half-Life[a]	Photon Energy[b] (MeV)	Dose Conversion Factors[c]			
			Groundshine[d] (Sv-m^2/Bq-s)	Cloudshine[e] (Sv-m^3/Bq-s)	Ingestion[f] (Sv/Bq)	Inhalation[f] (Sv/Bq)
Pm-145	17.7 y	0.031	3.26E–17	7.09E–16	1.28E–10	8.23E–09
Pm-146	2020 d	0.7532	7.41E–16	3.59E–14	9.91E–10	3.96E–08
Pm-147	2.6234 y	0	3.41E–20	6.93E–19	2.83E–10	1.06E–08
Pm-148	5.37 d	0.5745	5.48E–16	2.89E–14	2.94E–09	2.95E–09
Pm-148m	41.3 d	1.9999	1.96E–15	9.68E–14	2.07E–09	6.10E–09
Pm-149	53.08 h	0.0106	1.13E–17	5.41E–16	1.07E–09	7.93E–10
Pm-150	2.68 h	1.4313	1.36E–15	7.17E–14	2.70E–10	9.79E–11
Pm-151	28.4 h	0.3205	3.15E–16	1.51E–14	8.09E–10	4.73E–10
Po-203	36.7 m	1.6435	1.56E–15	8.12E–14	5.41E–11	2.14E–11
Po-205	1.8 h	1.5811	1.51E–15	7.80E–14	6.49E–11	3.65E–11
Po-207	350 m	1.3313	1.28E–15	6.51E–14	1.68E–10	5.45E–11
Po-209	102 y	0.0031				
Po-210	138.38 d	0	8.29E–21	4.16E–19	5.14E–07	2.54E–06
Po-211	0.516 s	0.0078	7.61E–18	3.81E–16		
Po-212	0.305 u	0	0.00E+00	0.00E+00		
Po-213	4.2 u	0	0.00E+00	0.00E+00		
Po-214	164.3 u	0	8.13E–20	4.08E–18		
Po-215 0	0.00178 s	0.0001				
Po-216	0.15 s	0	1.65E–20	8.29E–19		
Po-218	3.05 m	0	8.88E–21	4.48E–19		
Pr-136	13.1 m	2.1012	2.02E–15	1.03E–13	2.23E–11	6.68E–12
Pr-137	76.6 m	0.5005	4.93E–16	2.36E–14	3.85E–11	1.29E–11
Pr-138	1.45 m	0.8132	8.13E–16	3.92E–14		
Pr-138m	2.1 h	2.4781	2.40E–15	1.21E–13	1.39E–10	3.65E–11
Pr-139	4.51 h	0.1222	1.22E–16	5.17E–15	3.52E–11	1.56E–11
Pr-142	19.13 h	0.0584	5.78E–17	3.15E–15	1.42E–09	7.79E–10
Pr-142m	14.6 m	0	0.00E+00	0.00E+00	1.81E–11	9.98E–12
Pr-143	13.56 d	0	7.01E–19	2.10E–17	1.27E–09	2.19E–09
Pr-144	17.28 m	0.0318	3.78E–17	1.95E–15	3.15E–11	1.17E–11
Pr-144m	7.2 m	0.0126	1.30E–17	2.79E–16		
Pr-145	5.98 h	0.0131	1.56E–17	7.36E–16	4.18E–10	1.82E–10
Pr-147	13.6 m	0.863	8.39E–16	4.15E–14	2.10E–11	8.22E–12
Pt-186	2 h	0.74	7.24E–16	3.53E–14	1.10E–10	3.58E–11
Pt-188	10.2 d	0.2019	1.94E–16	8.86E–15	8.96E–10	8.48E–10
Pt-189	10.87 h	0.3251	3.14E–16	1.48E–14	1.43E–10	4.84E–11
Pt-191	2.8 d	0.3043	2.96E–16	1.34E–14	3.94E–10	1.66E–10
Pt-193	50 y	0.0021	1.19E–19	3.98E–19	3.21E–11	6.14E–11
Pt-193m	4.33 d	0.0128	1.04E–17	4.15E–16	4.90E–10	2.37E–10
Pt-195m	4.02 d	0.0764	6.87E–17	2.84E–15	6.91E–10	3.29E–10
Pt-197	18.3 h	0.025	2.27E–17	1.01E–15	4.35E–10	1.53E–10
Pt-197m	94.4 m	0.0834	7.77E–17	3.49E–15	8.46E–11	3.31E–11

Table C.1. Isotopic Data (Continued)

Nuclide	Half-Life[a]	Photon Energy[b] (MeV)	Dose Conversion Factors[c]			
			Groundshine[d] (Sv-m^2/Bq-s)	Cloudshine[e] (Sv-m^3/Bq-s)	Ingestion[f] (Sv/Bq)	Inhalation[f] (Sv/Bq)
Pt-199	30.8 m	0.2019	2.00E–16	9.73E–15	2.92E–11	1.23E–11
Pt-200	12.5 h	0.0605	5.65E–17	2.55E–15	1.30E–09	4.50E–10
Pu-234	8.8 h	0.0685	6.26E–17	2.85E–15	1.78E–10	7.40E–09
Pu-235	25.3 m	0.0947	8.65E–17	3.92E–15	1.72E–12	6.17E–13
Pu-236	2.851 y	0.002	9.81E–19	6.35E–18	3.15E–07	3.91E–05
Pu-237	45.3 d	0.0523	4.65E–17	2.02E–15	1.20E–10	5.33E–10
Pu-238	87.74 y	0.0018	8.38E–19	4.88E–18	8.65E–07	1.06E–04
Pu-239	24065 y	0.0008	3.67E–19	4.24E–18	9.56E–07	1.16E–04
Pu-240	6537 y	0.0017	8.03E–19	4.75E–18	9.56E–07	1.16E–04
Pu-241	14.4 y	0	1.93E–21	7.25E–20	1.85E–08	2.23E–06
Pu-242	376300 y	0.0014	6.67E–19	4.01E–18	9.08E–07	1.11E–04
Pu-243	4.956 h	0.0256	2.41E–17	1.03E–15	9.02E–11	4.44E–11
Pu-244	8.26E+07 y	0.0012	5.58E–19	2.97E–18	8.97E–07	1.09E–04
Pu-245	10.5 h	0.4167	4.04E–16	1.99E–14	7.34E–10	3.55E–10
Pu-246	10.85 d	0.1403	1.33E–16	6.01E–15	3.66E–09	5.92E–09
Ra-222	38 s	0.0091	9.00E–18	4.39E–16		
Ra-223	11.434 d	0.1341	1.28E–16	6.09E–15	1.78E–07	2.12E–06
Ra-224	3.66 d	0.0099	9.57E–18	4.71E–16	9.89E–08	8.53E–07
Ra-225	14.8 d	0.0136	1.33E–17	2.79E–16	1.04E–07	2.10E–06
Ra-226	1600 y	0.0067	6.44E–18	3.15E–16	3.58E–07	2.32E–06
Ra-227	42.2 m	0.1666	1.59E–16	7.41E–15	6.10E–11	7.68E–11
Ra-228	5.75 y	0	0.00E+00	0.00E+00	3.88E–07	1.29E–06
Rb-77	3.7 m	1.8311				
Rb-79	22.9 m	1.3578	1.34E–15	6.51E–14	2.79E–11	1.33E–11
Rb-80	34 s	1.246	1.25E–15	6.07E–14		
Rb-81	4.58 h	0.6233	6.07E–16	2.96E–14	3.91E–11	3.51E–11
Rb-81m	32 m	0.01	5.43E–18	1.88E–16	6.35E–12	5.43E–12
Rb-82	1.3 m	1.0933	1.09E–15	5.30E–14		
Rb-82m	6.2 h	2.9099	2.81E–15	1.43E–13	1.12E–10	7.83E–11
Rb-83	86.2 d	0.5044	4.92E–16	2.39E–14	2.08E–09	1.33E–09
Rb-84	32.77 d	0.9187	8.90E–16	4.47E–14	2.70E–09	1.76E–09
Rb-86	18.66 d	0.0945	9.31E–17	4.81E–15	2.53E–09	1.79E–09
Rb-87	4.7E+10 y	0	8.80E–20	1.82E–18	1.33E–09	8.74E–10
Rb-88	17.8 m	0.6286	5.95E–16	3.36E–14	4.71E–11	2.26E–11
Rb-89	15.2 m	2.0711	1.91E–15	1.06E–13	2.65E–11	1.16E–11
Re-177	14 m	0.6202	5.90E–16	2.96E–14	1.46E–11	6.45E–12
Re-178	13.2 m	1.2177	1.13E–15	6.09E–14	1.56E–11	6.09E–12
Re-180	2.43 m	1.1834	1.15E–15	5.72E–14		
Re-181	20 h	0.7712	7.49E–16	3.65E–14	2.81E–10	1.74E–10
Re-182a	12.7 h	1.1793	1.12E–15	5.78E–14	2.01E–10	1.09E–10
Re-182b	64 h	1.8862	1.79E–15	9.16E–14	9.18E–10	7.72E–10

Table C.1. Isotopic Data (Continued)

Nuclide	Half-Life[a]	Photon Energy[b] (MeV)	Dose Conversion Factors[c]			
			Groundshine[d] (Sv-m^2/Bq-s)	Cloudshine[e] (Sv-m^3/Bq-s)	Ingestion[f] (Sv/Bq)	Inhalation[f] (Sv/Bq)
Re-184	38 d	0.8913	8.64E–16	4.29E–14	5.91E–10	1.39E–09
Re-184m	165 d	0.3895	3.75E–16	1.82E–14	7.97E–10	3.98E–09
Re-186	90.64 h	0.0205	2.04E–17	9.19E–16	7.95E–10	8.64E–10
Re-186m	2.00E+05 y	0.0192	1.46E–17	5.00E–16	1.08E–09	9.76E–09
Re-187	5E+10 y	0	0.00E+00	0.00E+00	2.57E–12	1.47E–11
Re-188	16.98 h	0.0576	5.91E–17	2.87E–15	8.31E–10	5.44E–10
Re-188m	18.6 m	0.0802	7.56E–17	3.02E–15	1.83E–11	1.11E–11
Re-189	24.3 h	0.0693	6.74E–17	3.22E–15	4.67E–10	3.36E–10
Rh-99	16 d	0.6076	5.88E–16	2.85E–14	6.08E–10	8.36E–10
Rh-99m	4.7 h	0.6854	6.60E–16	3.29E–14	7.77E–11	2.34E–11
Rh-100	20.8 h	2.7666	2.54E–15	1.41E–13	8.56E–10	3.75E–10
Rh-101	3.2 y	0.2689	2.55E–16	1.21E–14	6.26E–10	1.07E–08
Rh-101m	4.34 d	0.3067	2.96E–16	1.41E–14	2.67E–10	2.02E–10
Rh-102	2.9 y	2.1395	2.08E–15	1.04E–13	2.82E–09	3.24E–08
Rh-102m	207 d	0.4863	4.76E–16	2.31E–14	1.27E–09	1.29E–08
Rh-103m	56.12 m	0.0017	1.25E–18	8.80E–18	3.14E–12	1.38E–12
Rh-105	35.36 h	0.0776	7.62E–17	3.72E–15	3.99E–10	2.58E–10
Rh-106	29.9 s	0.2048	2.12E–16	1.04E–14		
Rh-106m	132 m	2.915	2.80E–15	1.44E–13	1.74E–10	5.77E–11
Rh-107	21.7 m	0.3122	3.07E–16	1.50E–14	1.63E–11	6.53E–12
Rn-218	35 m	0.0007	7.45E–19	3.65E–17		
Rn-219	3.96 s	0.0561	5.49E–17	2.68E–15		
Rn-220	55.6 s	0.0003	3.81E–19	1.85E–17		
Rn-222	3.8235 d	0.0003	3.95E–19	1.91E–17		
Ru-103	39.28 d	0.4687	4.63E–16	2.25E–14	8.24E–10	2.42E–09
Ru-105	4.44 h	0.7841	7.69E–16	3.81E–14	2.87E–10	1.23E–10
Ru-106	368.2 d	0	0.00E+00	0.00E+00	7.40E–09	1.29E–07
Ru-94	51.8 m	0.5347	5.18E–16	2.54E–14	9.37E–11	3.58E–11
Ru-97	2.9 d	0.2399	2.28E–16	1.09E–14	1.88E–10	1.22E–10
S-35	87.44 d	0	1.68E–20	2.43E–19	1.98E–10	6.69E–10
Sb-115	31.8 m	0.909	8.97E–16	4.32E–14	1.96E–11	7.04E–12
Sb-116	15.8 m	2.158	2.03E–15	1.08E–13	1.90E–11	6.27E–12
Sb-116m	60.3 m	3.143	3.01E–15	1.55E–13	6.70E–11	2.07E–11
Sb-117	2.8 h	0.1847	1.77E–16	7.97E–15	2.08E–11	6.78E–12
Sb-118	3.6 m	0.8111				
Sb-118m	5 h	2.5846	2.46E–15	1.27E–13	2.56E–10	7.09E–11
Sb-119	38.1 h	0.0231	2.17E–17	2.16E–16	9.62E–11	5.69E–11
Sb-120a	15.89 m	0.452	4.47E–16	2.13E–14	9.51E–12	3.54E–12
Sb-120b	5.76 d	2.4693	2.35E–15	1.22E–13	1.54E–09	1.10E–09
Sb-122	2.7 d	0.4411	4.36E–16	2.13E–14	1.97E–09	1.39E–09
Sb-124	60.2 d	1.8171	1.71E–15	9.15E–14	2.74E–09	6.80E–09

Table C.1. Isotopic Data (Continued)

Nuclide	Half-Life[a]	Photon Energy[b] (MeV)	Dose Conversion Factors[c]			
			Groundshine[d] (Sv-m²/Bq-s)	Cloudshine[e] (Sv-m³/Bq-s)	Ingestion[f] (Sv/Bq)	Inhalation[f] (Sv/Bq)
Sb-124m	93 s	0.3518	3.47E–16	1.70E–14		
Sb-124n	20.2 m	0.0002	7.12E–20	6.75E–19	5.91E–12	2.80E–12
Sb-125	2.77 y	0.4307	4.25E–16	2.02E–14	7.59E–10	3.30E–09
Sb-126	12.4 d	2.8336	2.78E–15	1.37E–13	2.89E–09	3.17E–09
Sb-126m	19 m	1.5482	1.52E–15	7.50E–14	2.54E–11	9.17E–12
Sb-127	3.85 d	0.6884	6.76E–16	3.33E–14	1.95E–09	1.63E–09
Sb-128a	10.4 m	1.9864	1.94E–15	9.69E–14	1.59E–11	4.75E–12
Sb-128b	9.01 h	3.0931	3.02E–15	1.51E–13	1.19E–09	4.56E–10
Sb-129	4.32 h	1.4367	1.38E–15	7.14E–14	4.84E–10	1.74E–10
Sb-130	40 m	3.2636	3.16E–15	1.60E–13	7.83E–11	2.80E–11
Sb-131	23 m	1.8637	1.76E–15	9.37E–14	8.21E–11	3.88E–11
Sc-43	3.891 h	1.0962	1.08E–15	5.26E–14	2.06E–10	7.00E–11
Sc-44	3.927 h	2.1369	2.07E–15	1.05E–13	3.87E–10	1.33E–10
Sc-44m	58.6 h	0.2799	2.72E–16	1.35E–14	2.79E–09	2.05E–09
Sc-46	83.83 d	2.0094	1.93E–15	9.98E–14	1.73E–09	8.01E–09
Sc-47	3.351 d	0.1083	1.04E–16	5.14E–15	6.04E–10	4.98E–10
Sc-48	43.7 h	3.3491	3.18E–15	1.68E–13	1.96E–09	1.11E–09
Sc-49	57.4 m	0.001	4.93E–18	1.93E–16	6.80E–11	2.75E–11
Se-70	41 m	0.9988	9.81E–16	4.73E–14	1.39E–10	4.75E–11
Se-72	8.4 d	0.0343				
Se-73	7.15 h	1.0873	1.07E–15	5.16E–14	4.34E–10	1.24E–10
Se-73m	39 m	0.2439	2.40E–16	1.17E–14	4.19E–11	1.25E–11
Se-75	119.8 d	0.3942	3.77E–16	1.85E–14	2.60E–09	2.29E–09
Se-77m	17.45 s	0.0875	8.18E–17	4.03E–15		
Se-79	6.50E+04 y	0	2.07E–20	3.03E–19	2.35E–09	2.66E–09
Se-81	18.5 m	0.0092	1.13E–17	5.24E–16	1.70E–11	6.97E–12
Se-81m	57.25 m	0.0181	1.34E–17	6.18E–16	5.67E–11	2.39E–11
Se-83	22.5 m	2.4289	2.30E–15	1.21E–13	4.35E–11	1.48E–11
Si-31	157.3 m	0.0008	3.01E–18	1.17E–16	1.46E–10	6.03E–11
Si-32	450 y	0	3.10E–20	5.24E–19	5.90E–10	2.74E–07
Sm-141	10.2 m	1.405	1.36E–15	6.87E–14	2.70E–11	8.29E–12
Sm-141m	22.6 m	1.9842	1.91E–15	9.71E–14	5.33E–11	1.58E–11
Sm-142	72.49 m	0.0943	9.49E–17	3.79E–15	1.69E–10	5.82E–11
Sm-145	340 d	0.0652	6.84E–17	1.61E–15	2.46E–10	2.98E–09
Sm-146	1.03E+08 y	0	0.00E+00	0.00E+00	5.51E–08	2.23E–05
Sm-147	1.06E+11 y	0	0.00E+00	0.00E+00	5.01E–08	2.02E–05
Sm-151	90 y	0	5.03E–21	3.61E–20	1.05E–10	8.10E–09
Sm-153	46.7 h	0.0619	6.22E–17	2.28E–15	8.07E–10	5.31E–10
Sm-155	22.1 m	0.1032	1.02E–16	4.65E–15	1.93E–11	6.79E–12
Sm-156	9.4 h	0.1207	1.17E–16	5.43E–15	2.76E–10	1.89E–10
Sn-110	4 h	0.3013	2.93E–16	1.37E–14	4.13E–10	1.36E–10

Table C.1. Isotopic Data (Continued)

Nuclide	Half-Life[a]	Photon Energy[b] (MeV)	Dose Conversion Factors[c]			
			Groundshine[d] (Sv-m^2/Bq-s)	Cloudshine[e] (Sv-m^3/Bq-s)	Ingestion[f] (Sv/Bq)	Inhalation[f] (Sv/Bq)
Sn-111	35.3 m	0.5095	4.92E–16	2.45E–14	1.95E–11	7.34E–12
Sn-113	115.1 d	0.0228	2.13E–17	3.82E–16	8.33E–10	2.88E–09
Sn-117m	13.61 d	0.1579	1.51E–16	6.82E–15	7.97E–10	1.17E–09
Sn-119m	293 d	0.0114	1.04E–17	1.01E–16	3.76E–10	1.69E–09
Sn-121	27.06 h	0	1.05E–19	2.37E–18	2.44E–10	1.38E–10
Sn-121m	55 y	0.0049	4.89E–18	6.02E–17	4.19E–10	3.11E–09
Sn-123	129.2 d	0.0068	8.37E–18	4.03E–16	2.27E–09	8.79E–09
Sn-123m	40.08 m	0.1395	1.35E–16	6.55E–15	2.93E–11	1.25E–11
Sn-125	9.64 d	0.3126	3.01E–16	1.58E–14	3.33E–09	4.18E–09
Sn-126	1.00E+05 y	0.0565	5.47E–17	2.11E–15	5.27E–09	2.69E–08
Sn-127	2.1 h	1.9096	1.80E–15	9.59E–14	2.10E–10	8.75E–11
Sn-128	59.1 m	0.6657	6.57E–16	3.00E–14	1.49E–10	5.83E–11
Sr-80	100 m	0.008	1.85E–18	6.53E–18	3.38E–10	1.36E–10
Sr-81	25.5 m	1.3858	1.37E–15	6.68E–14	6.14E–11	2.28E–11
Sr-82	25 d	0.0078	1.82E–18	6.43E–18	6.61E–09	1.66E–08
Sr-83	32.4 h	0.8013	7.71E–16	3.86E–14	6.70E–10	4.11E–10
Sr-85	64.84 d	0.5118	5.00E–16	2.42E–14	5.34E–10	1.36E–09
Sr-85m	69.5 m	0.2195	2.12E–16	1.05E–14	6.46E–12	2.30E–12
Sr-87m	2.805 h	0.3203	3.15E–16	1.52E–14	3.58E–11	1.16E–11
Sr-89	50.5 d	0	2.27E–18	7.73E–17	2.50E–09	1.12E–08
Sr-90	29.12 y	0	2.84E–19	7.53E–18	3.85E–08	3.51E–07
Sr-91	9.5 h	0.6974	6.77E–16	3.45E–14	8.39E–10	4.49E–10
Sr-92	2.71 h	1.3388	1.25E–15	6.79E–14	5.43E–10	2.18E–10
Ta-172	36.8 m	1.5496	1.48E–15	7.59E–14	4.30E–11	1.53E–11
Ta-173	3.65 h	0.5848	5.68E–16	2.75E–14	2.12E–10	8.64E–11
Ta-174	1.2 h	0.6273	6.09E–16	2.97E–14	5.29E–11	1.82E–11
Ta-175	10.5 h	0.9329	8.79E–16	4.55E–14	2.45E–10	1.03E–10
Ta-176	8.08 h	2.1449	1.97E–15	1.09E–13	3.74E–10	1.26E–10
Ta-177	56.6 h	0.0671	6.57E–17	2.53E–15	1.22E–10	8.29E–11
Ta-178a	9.31 m	0.1086	1.04E–16	4.61E–15		
Ta-178b	2.2 h	1.0233	1.00E–15	4.75E–14	7.93E–11	2.24E–11
Ta-179	664.9 d	0.0324	3.16E–17	1.09E–15	7.39E–11	1.76E–09
Ta-180	1E+13 y	0.5598	5.45E–16	2.59E–14	9.82E–10	6.62E–08
Ta-180m	8.1 h	0.0485	4.76E–17	1.71E–15	5.90E–11	2.52E–11
Ta-182	115 d	1.2943	1.23E–15	6.40E–14	1.76E–09	1.21E–08
Ta-182m	15.84 m	0.2517	2.41E–16	1.11E–14	7.50E–12	3.61E–12
Ta-183	5.1 d	0.293	2.83E–16	1.31E–14	1.46E–09	1.41E–09
Ta-184	8.7 h	1.6122	1.57E–15	7.80E–14	7.60E–10	3.09E–10
Ta-185	49 m	0.1928	1.89E–16	8.73E–15	5.49E–11	2.27E–11
Ta-186	10.5 m	1.5598	1.53E–15	7.53E–14	2.08E–11	6.57E–12
Tb-147	1.65 h	1.5897	1.54E–15	7.78E–14	1.61E–10	5.63E–11

Table C.1. Isotopic Data (Continued)

Nuclide	Half-Life[a]	Photon Energy[b] (MeV)	Dose Conversion Factors[c]			
			Groundshine[d] (Sv-m²/Bq-s)	Cloudshine[e] (Sv-m³/Bq-s)	Ingestion[f] (Sv/Bq)	Inhalation[f] (Sv/Bq)
Tb-149	4.15 h	1.6139	1.53E–15	8.02E–14	2.76E–10	1.98E–09
Tb-150	3.27 h	1.6793	1.62E–15	8.26E–14	2.74E–10	8.43E–11
Tb-151	17.6 h	0.8922	8.73E–16	4.20E–14	4.03E–10	1.69E–10
Tb-153	2.34 d	0.2293	2.25E–16	9.89E–15	2.92E–10	2.04E–10
Tb-154	21.4 h	2.3516	2.13E–15	1.21E–13	7.96E–10	3.20E–10
Tb-155	5.32 d	0.1398	1.38E–16	5.56E–15	2.44E–10	2.10E–10
Tb-156	5.34 d	1.826	1.74E–15	8.94E–14	1.40E–09	1.08E–09
Tb-156m	24.4 h	0.0253	2.61E–17	7.75E–16	2.04E–10	2.06E–10
Tb-156n	5 h	0.0044	3.68E–18	1.16E–16	9.12E–11	5.86E–11
Tb-157	150 y	0.0033	2.67E–18	6.78E–17	3.35E–11	2.49E–09
Tb-158	150 y	0.7978	7.72E–16	3.84E–14	1.19E–09	6.91E–08
Tb-160	72.3 d	1.1243	1.08E–15	5.54E–14	1.82E–09	6.75E–09
Tb-161	6.91 d	0.0352	3.47E–17	1.02E–15	7.89E–10	9.20E–10
Tc-93	2.75 h	1.4587	1.35E–15	7.38E–14	4.37E–11	1.92E–11
Tc-93m	43.5 m	0.7244	6.48E–16	3.73E–14	2.00E–11	9.06E–12
Tc-94	293 m	2.6705	2.59E–15	1.30E–13	1.56E–10	7.27E–11
Tc-94m	52 m	1.8589	1.79E–15	9.18E–14	7.57E–11	3.81E–11
Tc-95	20 h	0.7964	7.72E–16	3.84E–14	1.26E–10	6.76E–11
Tc-95m	61 d	0.675	6.53E–16	3.23E–14	3.93E–10	1.05E–09
Tc-96	4.28 d	2.5057	2.43E–15	1.22E–13	7.45E–10	6.42E–10
Tc-96m	51.5 m	0.0515	4.72E–17	2.24E–15	8.61E–12	6.26E–12
Tc-97	2.60E+06 y	0.0113	6.48E–18	3.33E–17	4.63E–11	2.68E–10
Tc-97m	87 d	0.0095	6.18E–18	4.64E–17	3.36E–10	1.32E–09
Tc-98	4.20E+06 y	1.4127	1.38E–15	6.86E–14	1.32E–09	6.18E–09
Tc-99	2.13E+05 y	0	7.80E–20	1.62E–18	3.95E–10	2.25E–09
Tc-99m	6.02 h	0.1263	1.21E–16	5.89E–15	1.68E–11	8.80E–12
Tc-101	14.2 m	0.334	3.28E–16	1.61E–14	1.14E–11	4.84E–12
Tc-104	18.2 m	1.9812	1.85E–15	1.01E–13	5.11E–11	2.22E–11
Te-116	2.49 h	0.073	7.13E–17	2.29E–15	1.96E–10	7.18E–11
Te-121	17 d	0.5773	5.70E–16	2.70E–14	4.54E–10	5.15E–10
Te-121m	154 d	0.2168	2.10E–16	9.90E–15	2.08E–09	4.31E–09
Te-123	1E+13 y	0.0197	1.95E–17	2.15E–16	1.13E–09	2.85E–09
Te-123m	119.7 d	0.148	1.43E–16	6.51E–15	1.53E–09	2.86E–09
Te-125m	58 d	0.0355	3.61E–17	4.53E–16	9.92E–10	1.97E–09
Te-127	9.35 h	0.0048	5.18E–18	2.42E–16	1.87E–10	8.60E–11
Te-127m	109 d	0.0112	1.13E–17	1.47E–16	2.23E–09	5.81E–09
Te-129	69.6 m	0.0594	6.01E–17	2.75E–15	5.45E–11	2.42E–11
Te-129m	33.6 d	0.0376	3.78E–17	1.55E–15	2.89E–09	6.47E–09
Te-131	25 m	0.4204	4.10E–16	2.04E–14	2.44E–10	1.29E–10
Te-131m	30 h	1.4253	1.37E–15	7.01E–14	2.46E–09	1.73E–09
Te-132	78.2 h	0.2335	2.28E–16	1.03E–14	2.54E–09	2.55E–09

Table C.1. Isotopic Data (Continued)

Nuclide	Half-Life[a]	Photon Energy[b] (MeV)	Dose Conversion Factors[c]			
			Groundshine[d] (Sv-m²/Bq-s)	Cloudshine[e] (Sv-m³/Bq-s)	Ingestion[f] (Sv/Bq)	Inhalation[f] (Sv/Bq)
Te-133	12.45 m	0.9288	8.94E–16	4.60E–14	4.73E–11	2.49E–11
Te-133m	55.4 m	2.3128	2.22E–15	1.14E–13	2.26E–10	1.17E–10
Te-134	41.8 m	0.8856	8.67E–16	4.24E–14	6.63E–11	3.44E–11
Th-226	30.9 m	0.0087	7.75E–18	3.59E–16	2.50E–10	9.45E–09
Th-227	18.718 d	0.1101	1.04E–16	4.88E–15	1.03E–08	4.37E–06
Th-228	1.9131 y	0.0032	2.35E–18	9.20E–17	1.07E–07	9.23E–05
Th-229	7340 y	0.0958	8.54E–17	3.83E–15	9.54E–07	5.80E–04
Th-230	77000 y	0.0015	7.50E–19	1.74E–17	1.48E–07	8.80E–05
Th-231	25.52 h	0.0256	1.85E–17	5.22E–16	3.65E–10	2.37E–10
Th-232	1.405E+10 y	0.0013				
Th-234	24.1 d	0.0093	8.32E–18	3.38E–16	3.69E–09	9.47E–09
Ti-44	47.3 y	0.1347	1.32E–16	5.53E–15	6.25E–09	2.75E–07
Ti-45	3.08 h	0.8704	8.61E–16	4.18E–14	1.62E–10	5.82E–11
Tl-194	33 m	0.7793	7.62E–16	3.70E–14	6.15E–12	2.49E–12
Tl-194m	32.8 m	2.3185	2.27E–15	1.11E–13	2.65E–11	1.21E–11
Tl-195	1.16 h	1.2707	1.18E–15	6.34E–14	2.11E–11	1.25E–11
Tl-197	2.84 h	0.4087	3.91E–16	1.93E–14	1.82E–11	1.34E–11
Tl-198	5.3 h	2.0057	1.87E–15	1.01E–13	6.86E–11	4.44E–11
Tl-198m	1.87 h	1.1951	1.17E–15	5.69E–14	4.30E–11	2.89E–11
Tl-199	7.42 h	0.249	2.40E–16	1.13E–14	2.21E–11	1.88E–11
Tl-200	26.1 h	1.3106	1.25E–15	6.42E–14	1.82E–10	1.27E–10
Tl-201	3.044 d	0.0934	8.73E–17	3.78E–15	8.11E–11	6.34E–11
Tl-202	12.23 d	0.4676	4.59E–16	2.18E–14	3.98E–10	2.66E–10
Tl-204	3.779 y	0.0011	1.48E–18	5.59E–17	9.08E–10	6.50E–10
Tl-206	4.2 m	0.0001	1.99E–18	6.73E–17		
Tl-207	4.77 m	0.0022	3.76E–18	1.62E–16		
Tl-208	3.07 m	3.3745	2.98E–15	1.77E–13		
Tl-209	2.2 m	2.0317	1.90E–15	1.02E–13		
Tl-210	1.3 m	2.7357				
Tm-162	21.7 m	1.7805	1.64E–15	9.01E–14	2.18E–11	5.93E–12
Tm-166	7.7 h	1.8702	1.75E–15	9.35E–14	3.34E–10	1.02E–10
Tm-167	9.24 d	0.1456	1.43E–16	6.06E–15	6.26E–10	7.97E–10
Tm-170	128.6 d	0.0054	5.91E–18	2.23E–16	1.43E–09	7.11E–09
Tm-171	1.92 y	0.0006	6.41E–19	2.15E–17	1.16E–10	2.47E–09
Tm-172	63.6 h	0.4771	4.46E–16	2.41E–14	1.85E–09	1.32E–09
Tm-173	8.24 h	0.3882	3.84E–16	1.85E–14	3.37E–10	1.30E–10
Tm-175	15.2 m	1.0528	1.02E–15	5.13E–14	1.83E–11	6.26E–12
U-230	20.8 d	0.0029	1.80E–18	5.23E–17	2.44E–07	5.26E–06
U-231	4.2 d	0.082	7.07E–17	2.95E–15	3.20E–10	3.22E–10
U-232	72 y	0.0021	1.01E–18	1.42E–17	3.54E–07	1.78E–04
U-233	1.585E+05 y	0.0013	7.16E–19	1.63E–17	7.81E–08	3.66E–05

Table C.1. Isotopic Data (Continued)

Nuclide	Half-Life[a]	Photon Energy[b] (MeV)	Dose Conversion Factors[c]			
			Groundshine[d] (Sv-m^2/Bq-s)	Cloudshine[e] (Sv-m^3/Bq-s)	Ingestion[f] (Sv/Bq)	Inhalation[f] (Sv/Bq)
U-234	2.445E+05 y	0.0017	7.48E–19	7.63E–18	7.66E–08	3.58E–05
U-235	7.04E+08 y	0.1559	1.48E–16	7.20E–15	7.19E–08	3.32E–05
U-236	2.3415E+07 y	0.0015				
U-237	6.75 d	0.1429	1.33E–16	5.97E–15	8.57E–10	9.54E–10
U-238	4.47E+09 y	0.0013	5.51E–19	3.41E–18	6.88E–08	3.20E–05
U-239	23.54 m	0.0526	5.15E–17	2.17E–15	2.09E–11	1.01E–11
U-240	14.1 h	0.0076	4.23E–18	3.93E–17	1.20E–09	6.13E–10
V-47	32.6 m	0.9951	9.87E–16	4.79E–14	4.73E–11	1.90E–11
V-48	16.238 d	2.9141	2.78E–15	1.45E–13	2.32E–09	2.76E–09
V-49	330 d	0.0009	0.00E+00	0.00E+00	1.66E–11	9.33E–11
W-176	2.3 h	0.1773	1.71E–16	7.02E–15	1.34E–10	2.88E–11
W-177	135 m	0.9026	8.73E–16	4.26E–14	6.71E–11	1.76E–11
W-178	21.7 d	0.0144	1.30E–17	4.62E–16	2.75E–10	7.32E–11
W-179	37.5 m	0.0599	5.86E–17	1.83E–15	2.74E–12	9.47E–13
W-181	121.2 d	0.0404	3.93E–17	1.40E–15	9.31E–11	4.09E–11
W-185	75.1 d	0	1.84E–19	5.37E–18	5.38E–10	2.03E–10
W-187	23.9 h	0.4806	4.69E–16	2.28E–14	7.46E–10	1.67E–10
W-188	69.4 d	0.0019	1.92E–18	9.04E–17	2.54E–09	1.11E–09
Xe-120	40 m	0.4321	4.23E–16	1.94E–14		
Xe-121	40.1 m	1.815	1.69E–15	9.14E–14		
Xe-122	20.1 h	0.0684	6.83E–17	2.46E–15		
Xe-123	2.08 h	0.6336	6.09E–16	3.03E–14		
Xe-125	17 h	0.2713	2.65E–16	1.19E–14		
Xe-127	36.41 d	0.2802	2.73E–16	1.25E–14		
Xe-129m	8 d	0.0512	5.29E–17	1.06E–15		
Xe-131m	11.9 d	0.02	2.06E–17	3.89E–16		
Xe-133	5.245 d	0.0461	4.61E–17	1.56E–15		
Xe-133m	2.188 d	0.0407	4.07E–17	1.37E–15		
Xe-135	9.09 h	0.2485	2.42E–16	1.19E–14		
Xe-135m	15.29 m	0.429	4.24E–16	2.04E–14		
Xe-138	14.17 m	1.125	1.03E–15	5.77E–14		
Y-86	14.74 h	3.5892	3.39E–15	1.79E–13	1.14E–09	4.65E–10
Y-86m	48 m	0.2205	2.13E–16	1.06E–14	6.61E–11	2.69E–11
Y-87	80.3 h	0.4572	4.46E–16	2.15E–14	6.58E–10	4.74E–10
Y-88	106.64 d	2.6922	2.47E–15	1.37E–13	1.62E–09	7.59E–09
Y-90	64 h	0	5.32E–18	1.90E–16	2.91E–09	2.28E–09
Y-90m	3.19 h	0.629	6.16E–16	3.01E–14	1.91E–10	1.27E–10
Y-91	58.51 d	0.0036	5.74E–18	2.60E–16	2.57E–09	1.32E–08
Y-91m	49.71 m	0.5301	5.23E–16	2.55E–14	1.12E–11	9.82E–12
Y-92	3.54 h	0.2516	2.53E–16	1.30E–14	5.15E–10	2.11E–10
Y-93	10.1 h	0.0889	9.12E–17	4.80E–15	1.23E–09	5.82E–10

Table C.1. Isotopic Data (Continued)

Nuclide	Half-Life[a]	Photon Energy[b] (MeV)	Dose Conversion Factors[c]			
			Groundshine[d] (Sv-m^2/Bq-s)	Cloudshine[e] (Sv-m^3/Bq-s)	Ingestion[f] (Sv/Bq)	Inhalation[f] (Sv/Bq)
Y-94	19.1 m	1.1104	1.07E–15	5.62E–14	5.33E–11	1.89E–11
Y-95	10.7 m	0.8939	7.99E–16	4.79E–14	2.75E–11	1.02E–11
Yb-162	18.9 m	0.1366	1.33E–16	5.66E–15	2.05E–11	6.04E–12
Yb-166	56.7 h	0.0859	8.61E–17	2.86E–15	1.14E–09	8.04E–10
Yb-167	17.5 m	0.2673	2.60E–16	1.09E–14	5.01E–12	2.26E–12
Yb-169	32.01 d	0.3097	3.04E–16	1.29E–14	8.12E–10	2.18E–09
Yb-175	4.19 d	0.0396	3.91E–17	1.87E–15	4.76E–10	4.38E–10
Yb-177	1.9 h	0.1874	1.80E–16	9.23E–15	8.68E–11	3.93E–11
Yb-178	74 m	0.0349	3.47E–17	1.67E–15	1.07E–10	4.39E–11
Zn-62	9.26 h	0.4389	4.30E–16	2.07E–14	9.85E–10	5.57E–10
Zn-63	38.1 m	1.0998	1.09E–15	5.32E–14	5.92E–11	2.20E–11
Zn-65	243.9 d	0.5842	5.53E–16	2.90E–14	3.90E–09	5.51E–09
Zn-69	57 m	0	7.18E–19	2.16E–17	2.40E–11	1.06E–11
Zn-69m	13.76 h	0.4166	4.12E–16	1.99E–14	3.55E–10	2.20E–10
Zn-71m	3.92 h	1.5519	1.53E–15	7.50E–14	2.43E–10	1.05E–10
Zn-72	46.5 h	0.1519	1.41E–16	6.90E–15	1.49E–09	1.35E–09
Zr-86	16.5 h	0.2877	2.69E–16	1.28E–14	1.04E–09	5.94E–10
Zr-88	83.4 d	0.4025	3.91E–16	1.88E–14	4.03E–10	6.58E–09
Zr-89	78.43 h	1.165	1.13E–15	5.68E–14	9.25E–10	6.41E–10
Zr-93	1.53E+06 y	0	0.00E+00	0.00E+00	4.48E–10	8.67E–08
Zr-95	63.98 d	0.7388	7.23E–16	3.60E–14	1.02E–09	6.39E–09
Zr-97	16.9 h	0.1793	1.74E–16	9.02E–15	2.28E–09	1.17E–09

[a] Source: ICRP 38 (ICRP, 1983).
Listed X, γ, and γ+ radiations from column labeled "y(i)xE(i)" in ICRP 38 (ICRP, 1983).
The dose conversion factors are given as provided in the references. For changing to other commonly used units, the conversions are: 1 Sv = 100 rem and 1 Ci = 3.7 × 10^{10} Bq.
External exposure from contaminated ground surface (EPA, 1993).
External exposure from air immersion (EPA, 1993).
For internal exposure, the largest effective committed dose equivalent value for each isotope was selected (EPA, 1988).

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Appendix D

RADIONUCLIDE FOOD TRANSFER FACTORS

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Ingestion food transfer factors and the methodology used to generate them are presented in this appendix. These transfer factors are used by RADTRAN to assess population doses from ingestion of foodstuff grown on contaminated ground following an accidental release of radioactive material during a transportation accident. The transfer factors, which are expressed in terms of curie of activity available in foodstuff per curie of activity deposited on the ground, were based on state-level agricultural data.

Three types of food pathways are considered: crops, milk, and meat. It is assumed that once a radionuclide enters the foodstuff, it will eventually be consumed by humans; no crop interdiction or reduction credit (such as cleaning by washing) is assumed. The calculated transfer factors would therefore be strongly influenced by local agricultural productivity.

D.1 Methodology

The method used to calculate food ingestion transfer factors of radionuclides from an accidental release is similar to that used in NRC Regulatory Guide 1.109 (NRC, 1977) and Commentary No. 3 of the National Council on Radiation Protection and Measurements (NCRPM) (NCRPM, 1989). For accidental releases to the atmosphere, particulates are retained by vegetation in the food chain via three mechanisms. The first is direct deposition from the initial passing plume, the second is deposition onto the vegetation from contaminants resuspended from soil, and the third is retention by root uptake. Because of the particular physical and chemical behavior of radionuclides such as tritium and carbon-14 in the environment, and for the sake of completeness, transfer factors for these radionuclides are calculated separately.

D.1.1 Direct Deposition

For the direct deposition from the initial plume, the amount of radioactivity retained on the vegetation is calculated by:

$$C_{di} = \langle X_i \rangle V_d \frac{Pr}{Y_v} \exp\left[-(\lambda_{ei} t_e + \lambda_i t_h)\right] , \qquad \text{(D.1)}$$

where

C_{di} = concentration retained in vegetation (Ci/kg);

$\langle X_i \rangle$ = time-integrated air concentration of the initial passing plume (Ci-yr/m^3);

V_d = deposition velocity, assumed for particulates to be 3.16×10^5 m/yr (0.01 m/s);

r = fraction of deposited activity intercepted and retained by the edible portion of the crop (dimensionless, assumed to be 0.25);

P = probability that an accident will occur during the growing season (assumed to be 0.5);

Y_v = standing crop biomass of edible portion of vegetation at harvest, assumed to be 2 kg/m^2 for crops and 0.72 kg/m^2 for pasture grass;

λ_{ei} = effective decay constant for removal of the radionuclide deposited on vegetation (1/d), where $\lambda_e = \lambda_i + 0.693/t_w$, $t_w = 0.0383$ yr (14 d);

t_e = time period of aboveground crop exposure to contamination during the growing season, assumed to be 0.165 yr (60 d) for crops and 0.082 yr (30 d) for pasture grass;

λ_i = radioactive decay constant (yr); and

t_h = time period between harvest of vegetation and consumption, assumed to be 0.038 yr (14 d) for crops by human consumption and 0 yr for pasture grass for animals.

The deposited concentration C_{di} can derive the transfer factors based on the local agricultural foodstuff affected by the release.

D.1.2 Resuspension

Following the initial deposition, the radionuclide will eventually settle on the ground, where it can be resuspended into the air and once again become available for deposition onto the vegetation. The time-integrated concentration of radioactivity retained in vegetation is calculated by:

$$< C_{si} > \;=\; \int_0^\infty X_{Ri}(t)\;\; V_d \;\frac{r(1 - e^{-\lambda_{ei} t_e})}{Y_v\, \lambda_{ei}}\; \exp(-\lambda_i\, t_h)\, dt\,, \tag{D.2}$$

where

$<C_{si}>$ = time-integrated radioactivity concentration in vegetation due to resuspension (Ci-yr/kg), and

$X_{Ri}(t)$ = resuspended air concentration at time t (Ci/m^3).

The time-integrated concentration $<C_{si}>$, if multiplied by the annual crop yield P_c(kg/m^2-yr), represents the amount of total radioactivity transferred via crop ingestion.

The resuspended air concentration in Equation D.2 is calculated by the following (Momeni et al., 1979):

$$X_{Ri}(t) = G_i(t)\, R(t)\,, \tag{D.3}$$

where $G_i(t)$ is the deposited ground concentration at time t, and R(t) is the resuspension coefficient at time t.

$$G_i(t) \;=\; G_{io}\; \exp\,[-(\lambda_g \;+\; \lambda_i)\, t] \tag{D.4}$$

where G_{io} is the initial deposition concentration (in Ci/m^2), which is equal to $<X_i>V_d$, $\lambda_g = 0.603/t_g$,t_g, which is the ground removal half-life, assumed to be 50 yr, and

$$R(t) = \begin{cases} F_I \exp(-\lambda_w t), & 0 \le t \le t_s \\ F_E, & t_s \le t \end{cases} \tag{D.5}$$

where

F_I = initial resuspension factor (10^{-5}/m),

F_E = final resuspension factor (10^{-9}/m),

λ_w = $0.693/t_w$, t_w = 0.1368 yr (50 d), and

t_s = 1.823 yr.

The basic formulation of the above expression for the resuspension factors and the decay constant was derived from experimental measurements (Volchok, 1971; Anspaugh, 1973; Anspaugh, et al., 1974; NRC, 1974).

By using Equations D.3 through D.5, the time-integrated concentration for Equation D.2 becomes

$$< C_{Si} > \; = \; G_{io} \; < T_i > V_d \; \frac{r(1 - e^{-\lambda_{ei} t_e})}{Y_v \lambda_{ei}} \exp(-\lambda_i t_h) \; , \tag{D.6}$$

where

$$< T_i > \; = \; \frac{F_I}{(\lambda_g + \lambda_i + \lambda_w)} \left\{ 1 - \exp\left[-(\lambda_g + \lambda_i + \lambda_w) t_s \right] \right\} + \frac{F_E}{(\lambda_g + \lambda_i)} \exp\left[-(\lambda_g + \lambda_i) t_s \right] \; . \tag{D.7}$$

D.1.3 Root Uptake

The time-integrated concentration of radioactivity in vegetation via root uptake is calculated by:

$$\begin{aligned} < C_{ri} > \; &= \; \int_0^\infty G_i(t) \; \frac{B_v(i)}{\rho} \exp(-\lambda_i t_h) \; dt \\ &= \; G_{io} \; \frac{B_v(i)}{\rho(\lambda_g + \lambda_i)} \exp(-\lambda_i t_h) \end{aligned} \tag{D.8}$$

where

$<C_{ri}>$ = time-integrated radioactivity concentration in vegetation from root uptake (Ci-yr/kg);

$G_i(t)$ = ground concentration at time t, given in Equation D.4;

$B_v(i)$ = concentration ratio for the transfer of the element to the edible portion of a crop from dry soil (Ci/kg plant per Ci/kg soil) (Table D.1);[6] and

ρ = areal density for the effective root zone in dry soil, assumed to be 240 kg/m^2.

The time-integrated concentration $<C_{ri}>$, when multiplied by the annual crop yield $P_c(kg/m^2\text{-yr})$, gives the total amount of radioactivity transferred via crop ingestion.

D.1.4 Transfer Factor for Crops

The transfer factor is defined as the fraction of the radioactivity deposited on the ground that is retained in foodstuff and available for human consumption. For crops, the transfer factor is obtained by:

$$f_{ci} = \frac{< C_i^c >}{G_{io}} P_c \qquad \text{(D.9)}$$

where

f_{ci} = food transfer factor via crops $(Ci/m^2)/(Ci/m^2)$;

$<C_i^c>$ = $<C^c_{di}> + <C^c_{si}> + <C^c_{ri}>$, the total time-integrated concentration in crops (Ci-yr/kg); $<C^c_{di}>$, $<C^c_{si}>$, $<C^c_{ri}>$ = time-integrated radioactivity concentration in crops via various pathways (Ci-yr/kg);

G_{io} = initial ground deposition concentration (Ci/m^2); and

P_c = local crop yield (kg/m^2-yr).

The data for crop yield (P_c) for the 48 contiguous states are presented in Table D.2. The concentrations $<C^c_{si}>$ and $<C^c_{ri}>$ are derived according to Equations D.1 and D.2. Because the direct deposition would only affect the harvested crops during the first year of deposition, the time-integrated crop concentration $<C_{di}>$ is equal to C_{di} (Equation D.1) times 1 yr.

D.1.5 Transfer Factor for Milk

The concentration in milk can be calculated by:

$$< C_i^m > \; = \; F_{mi} < C_i^p > Q_f \; \exp(-\lambda_i t_f) \; , \qquad \text{(D.10.)}$$

where

C_i^m = time-integrated concentration of radionuclide i in milk (Ci-yr/L);

F_{mi} = transfer factor from pasture grass to milk for radionuclide i (Ci/L)/(kg/d) (see Table D.1);

[6] All tables cited in the text are at the end of the appendix.

$<C^p_i>$ = $<C^p_{di}> + <C^p_{si}> + <C^p_{ri}>$, the time-integrated concentration of radionuclide i in animal feed (Ci-yr/kg);

$<C^p_{di}>, <C^p_{si}>, <C^p_{ri}>$ = time-integrated concentrations in pasture grass as derived by Equations D.1, D.2, and D.8 (Ci-yr/kg);

Q_f = amount of feed consumed by an animal per day, assumed to be 50 kg/d; and

t_f = transport time from milk to human consumption, assumed to be 2 d.

Again, because the direct deposition would only affect the animal feed for the first year of deposition, the time-integrated crop concentration is multiplied by 1 yr. Thus, the transfer factor via the milk pathway is obtained by:

$$f_{mi} = \frac{<C_i^m>}{G_{io}} P_m , \tag{D.11}$$

where

f_{mi} = the food transfer factor via milk $(Ci/m^2)/(Ci/m^2)$, and

P_m = local milk production $(L/m^2\text{-yr})$.

The data for milk production are given in Table D.2.

D.1.6 Transfer Factor for Meat

The concentration in meat is calculated by:

$$< C_i^b > \;=\; F_{bi} < C_i^p > Q_f \;\exp(-\lambda_i t_f) \;, \tag{D.12}$$

where

$<C^b_i>$ = time-integrated concentration of radionuclide i in animal flesh (Ci-yr/kg);

F_{bi} = transfer factor from pasture grass to animal flesh for radionuclide i (Ci/kg)/(Ci/kg) (see Table D.1);

t_b = transport time from slaughter to human consumption, assumed to be 20 days; and

$<c^p_i>, Q_f$ = same as defined in Equation D.10.

Thus, the transfer factor via meat is obtained by:

$$f_{bi} \;=\; \frac{< C_i^b >}{G_{io}} \; P_b \;, \tag{D.13}$$

where

f_{bi} = food transfer factor via meat (Ci/m^2)/(Ci/m^2) and

P_b = local meat production (kg/m^2-yr).

The data for meat production are provided in Table D.2. The concentration of radionuclide i in the animal's feed, assumed to consist of fresh pasture grass and stored feeds, is calculated by:

$$< C_i^p > = f_p f_s < C_i^t > + (1 - f_p) < C_i^s > + f_p (1 - f_s) < C_i^s > \ , \tag{D.14}$$

where

f_p = fraction of the year the animals are grazing on pasture,

f_s = fraction of the daily feed that is pasture grass when the animals graze on the pasture,

$<C_i^t>$ = time-integrated concentration of radionuclide i on pasture grass (t_h = 0) (Ci-yr/kg), and

$<C_i^s>$ = time-integrated concentration of radionuclide i in stored feeds (t_h = 90 days) (Ci-yr/kg), and

If it is assumed that f_p = 0.5 and f_s = 1.0, Equation D.14 becomes:

$$< C_i^p > \ = \ 0.5 \ < C_i^t > \ + \ 0.5 \ < C_i^s > . \tag{D.15}$$

Half of the radionuclide concentration in animal feed is assumed to be derived from grazing; the other half is assumed to be stored feed.

D.1.7 Transfer Factor for Tritium

The calculation of the tritium concentration is also adapted from NRC Regulatory Guide 1.109 (NRC, 1977). For accidental releases, an equilibrium ratio is assumed for the tritium concentration; the ratio is established between the contaminated atmospheric environment and local vegetation. Thus, the time-integrated tritium concentration in vegetation is estimated by:

$$< C_T^v > = Pf \ < x_T > (0.75)\,(0.5/H) = 0.375\,Pf \, \frac{< x_T >}{H} \ , \tag{D.16}$$

where

$<C_T^v>$ = time-integrated concentration of tritium in vegetation grown at the location of interest (Ci-yr/kg),

P = probability that an accident will occur during the growing season (0.5),

f = fractional equilibrium ratio (dimensionless),

$<x_T>$ = time-integrated air concentration of tritium at the location of interest (Ci-yr/m^3),

0.75 = fraction of total plant mass that is water (dimensionless),

0.5 = ratio of tritium concentration in plant water to tritium concentration in atmospheric water (dimensionless), and

H = absolute humidity of the atmosphere at the location of interest (kg/m^3) (see Table D.2).

The fractional equilibrium ratio is assumed to be linearly proportional to the total release time and the vegetation growing season. Conservatively assuming a one-day accidental release and a 90-day growing season, f is estimated to be 0.11.

Similarly, the time-integrated tritium concentration in water is:

$$< C_T^w > \;=\; 0.5 \; Pf \; \frac{< x_T >}{H} \; . \tag{D.17}$$

Because the half-life of tritium (12.35 years) is much longer than the vegetation growing season and the period between harvest and consumption, the decay in tritium during these time periods is not considered.

By further assuming that Equation D.9 applies equally to crops, as well as pasture grass, and with the addition of the drinking water pathway for the animals, the following time-integrated concentrations are obtained:

$$\text{crops,} \qquad < C_T^c > \;=\; < C_T^v > \tag{D.18}$$

$$\text{milk,} \qquad < C_T^m > \;=\; F_{mi}\left(<C_T^v> Q_f + <C_T^w> Q_w \right) \tag{D.19}$$

$$\text{meat,} \qquad < C_T^b > \;=\; F_{bi}\left(<C_T^v> Q_f + <C_T^w> Q_w \right) \tag{D.20}$$

where

F_{mi}, F_{bi} = transfer factors from pasture grass to milk or meat for tritium, (Ci/L)/(Ci/kg) for milk and (Ci/kg)/(Ci/kg) for meat (Table D.1),

Q_f = amount of feed consumed by an animal per day (50 kg/d), and

Q_w = amount of water consumed by an animal per day (50 kg/d).

The total amount of tritium transferred to humans via food pathways is then estimated by:

$$C_T \;=\; < C_T^c > P_c \;+\; < C_T^m > P_m \;+\; < C_T^b > P_b \;, \tag{D.21}$$

where P_c, P_m, and P_b represent the local annual yield data for crops, milk, and meat. The parameter C_T is given in units of Ci/m^2.

D.1.8 Transfer Factor for Carbon-14

According to NRC Regulatory Guide 1.109 (NRC, 1977), carbon-14 is released in oxide form (CO or CO_2). The carbon-14 concentration in vegetation is calculated by assuming that its ratio to the natural carbon in vegetation is the same as that to the atmosphere surrounding the vegetation. Following NRC Regulatory Guide 1.109, the time-integrated concentration in vegetation can be derived by:

$$<C^v_{14}> = Pf<x_{14}> (0.11/0.00016) = 6.88 \times 10^2 Pf <x_{14}> , \qquad \text{(D.22)}$$

where

$<C^v_{14}>$ = time-integrated concentration of carbon-14 in vegetation grown at the location of interest,

P = probability that an accident will occur during the growing season (0.5),

f = fractional equilibrium ratio, estimated to be 0.11 (dimensionless),

0.11 = fraction of total plant mass that is natural carbon (dimensionless),

0.00016 = concentration of natural carbon in the atmosphere (kg/m^3), and

$<x_{14}>$ = time-integrated air concentration of carbon-14 (Ci-yr/m^2).

Again, the half-life of carbon-14 (5,730 yr) is much greater than the vegetation growing season so that its decay during this period need not be considered. By assuming that Equation D.14 applies equally to crops and pasture grass, the following time-integrated concentrations are obtained:

$$\text{crops, } < C^c_{14} > \; = \; < C^v_{14} > 1 \qquad \text{(D.23)}$$

$$\text{milk, } < C^m_{14} > \; = \; F_{m14} < C^v_{14} > \; Q_f \; 2 \qquad \text{(D.24)}$$

$$\text{meat } < C^b_{14} > \; = \; F_{b14} < C^v_{14} > \; Q_f \; 3 \qquad \text{(D.25)}$$

where

F_{m14}, F_{b14} = transfer factors from pasture grass to milk and meat for carbon-14, (Ci/L)/(kg/d) for milk, and (Ci/kg)/(kg/d) for meat (Table D.1), and

Q_f = same as defined in Equation D.10.

The total amount of carbon-14 transferred to humans via food pathways is estimated by:

$$C_{14} = \langle C_{14}^{v} \rangle P_c + \langle C_{14}^{m} \rangle P_m + \langle C_{14}^{b} \rangle P_b \ , \qquad \text{(D.26)}$$

where the parameters have been defined in Equation D.14, and carbon-14 is given in units of Ci/m^2.

D.2 Comparison of Transfer Factors

Intermediate results were obtained for the three food pathways studied. The ratios of the time-integrated concentrations over the initial ground concentrations were calculated and are presented in Table D.3. These ratios are $\langle C^c{}_i \rangle / G_{io}$ for crops, $\langle C^m{}_i \rangle / G_{io}$ for milk, and $\langle C^b{}_i \rangle / G_{io}$ for meat. When multiplied by the respective state yield data, these ratios represent the transfer factors; that is, the equivalent of curies in foodstuff per curies deposited on the ground. Results of the foodchain transfer factors from accidental releases are presented in Table D.4. Table D.5 contains three data samples for locations representing the states of Illinois and Nevada and the U.S. national average. Because agricultural yields in different locations vary widely, the calculated food transfer coefficients deviate accordingly. A complete set of transfer factors for selected radionuclides keyed to individual states, as well as the U.S. average, is presented in Table D.6.

Contributions from each food source (i.e., crops, milk, and meat) also vary from isotope to isotope, as well as from state to state. Examples between Illinois (crop state) and Wisconsin (dairy state) are given in Table D.5. While transfer factors are predominantly from crop ingestion for the state of Illinois, ingestion via milk products is significant for the state of Wisconsin.

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Table D.1. Transfer Coefficients Applicable to Food Chain Pathways for Various Elements

Index (i)	Element	Transfer Coefficients		
		Soil-to-Plant $B_v(i)$ (dimensionless)	**Grass-to-Meat $F_b(i)$ (d/kg)**	**Grass-to-Milk $F_m(i)$ (d/L)**
1	Hydrogen	4.8	1.2×10^{-2}	1.0×10^{-2}
2	Helium	0.0	0.0	0.0
3	Lithium	8.3×10^{-4}	1.0×10^{-2}	5.0×10^{-2}
4	Beryllium	4.2×10^{-4}	1.0×10^{-3}	1.0×10^{-4}
5	Boron	1.2×10^{-1}	8.0×10^{-4}	2.7×10^{-3}
6	Carbon	5.5	3.1×10^{-2}	1.2×10^{-2}
7	Nitrogen	7.5	7.7×10^{-2}	2.2×10^{-2}
8	Oxygen	1.6	1.6×10^{-2}	2.0×10^{-2}
9	Fluorine	6.5×10^{-4}	1.5×10^{-1}	1.4×10^{-2}
10	Neon	0.0	0.0	0.0
11	Sodium	5.2×10^{-2}	3.0×10^{-2}	4.0×10^{-2}
12	Magnesium	1.3×10^{-1}	5.0×10^{-3}	1.0×10^{-2}
13	Aluminum	1.8×10^{-4}	1.5×10^{-3}	5.0×10^{-4}
14	Silicon	1.5×10^{-4}	4.0×10^{-5}	1.0×10^{-4}
15	Phosphorous	1.1	4.6×10^{-2}	2.5×10^{-2}
16	Sulfur	5.9×10^{-1}	1.0×10^{-1}	1.8×10^{-2}
17	Chlorine	5.0	8.0×10^{-2}	5.0×10^{-2}
18	Argon	0.0	0.0	0.0
19	Potassium	3.7×10^{-1}	1.2×10^{-2}	1.0×10^{-2}
20	Calcium	3.6×10^{-2}	4.0×10^{-3}	8.0×10^{-3}
21	Scandium	1.1×10^{-3}	1.6×10^{-2}	5.0×10^{-6}
22	Titanium	5.4×10^{-5}	3.1×10^{-2}	5.0×10^{-6}
23	Vanadium	1.3×10^{-3}	2.3×10^{-3}	1.0×10^{-3}
24	Chromium	2.5×10^{-4}	2.4×10^{-3}	2.2×10^{-3}
25	Manganese	2.9×10^{-2}	8.0×10^{-4}	2.5×10^{-4}
26	Iron	6.6×10^{-4}	4.0×10^{-2}	1.2×10^{-3}
27	Cobalt	9.4×10^{-3}	1.3×10^{-2}	1.0×10^{-3}
28	Nickel	1.9×10^{-2}	5.3×10^{-3}	6.7×10^{-3}
29	Copper	1.2×10^{-1}	8.0×10^{-3}	1.4×10^{-2}
30	Zinc	4.0×10^{-1}	3.0×10^{-2}	3.9×10^{-2}
31	Gallium	2.5×10^{-4}	1.3	5.0×10^{-5}
32	Germanium	1.0×10^{-1}	2.0×10^{1}	5.0×10^{-4}
33	Arsenic	1.0×10^{-2}	2.0×10^{-3}	6.0×10^{-3}
34	Selenium	1.3	1.5×10^{-2}	4.5×10^{-3}

Table D.1. Transfer Coefficients Applicable to Food Chain Pathways for Various Elements (Continued)

Index (i)	Element	Transfer Coefficients		
		Soil-to-Plant $B_v(i)$ (dimensionless)	Grass-to-Meat $F_b(i)$ (d/kg)	Grass-to-Milk $F_m(i)$ (d/L)
35	Bromine	7.6×10^{-1}	2.6×10^{-2}	5.0×10^{-2}
36	Krypton	0.0	0.0	0.0
37	Rubidium	1.3×10^{-1}	3.1×10^{-2}	3.0×10^{-2}
38	Strontium	1.7×10^{-2}	6.0×10^{-4}	8.0×10^{-4}
39	Yttrium	2.6×10^{-3}	4.6×10^{-3}	1.0×10^{-5}
40	Zirconium	1.7×10^{-4}	3.4×10^{-2}	5.0×10^{-6}
41	Niobium	9.4×10^{-3}	2.8×10^{-1}	2.5×10^{-3}
42	Molybdenum	1.2×10^{-1}	8.0×10^{-3}	7.5×10^{-3}
43	Technetium	2.5×10^{-1}	4.0×10^{-1}	2.5×10^{-2}
44	Ruthenium	5.0×10^{-2}	4.0×10^{-1}	1.0×10^{-6}
45	Rhodium	1.3×10^{1}	1.5×10^{-3}	1.0×10^{-2}
46	Palladium	5.0	4.0×10^{-3}	1.0×10^{-2}
47	Silver	1.5×10^{-1}	1.7×10^{-2}	5.0×10^{-2}
48	Cadmium	3.0×10^{-1}	5.3×10^{-4}	1.2×10^{-4}
49	Indium	2.5×10^{-1}	8.0×10^{-3}	1.0×10^{-4}
50	Tin	2.5×10^{-3}	8.0×10^{-2}	2.5×10^{-3}
51	Antimony	1.1×10^{-2}	4.0×10^{-3}	1.5×10^{-3}
52	Tellurium	1.3	7.7×10^{-2}	1.0×10^{-3}
53	Iodine	2.0×10^{-2}	2.9×10^{-3}	6.0×10^{-3}
54	Xenon	0.0	0.0	0.0
55	Cesium	1.0×10^{-2}	4.0×10^{-3}	1.2×10^{-2}
56	Barium	5.0×10^{-3}	3.2×10^{-3}	4.0×10^{-4}
57	Lanthanum	2.5×10^{-3}	2.0×10^{-4}	5.0×10^{-6}
58	Cerium	2.5×10^{-3}	1.2×10^{-3}	6.0×10^{-4}
59	Praseodymium	2.5×10^{-3}	4.7×10^{-3}	5.0×10^{-6}
60	Neodymium	2.4×10^{-3}	3.3×10^{-3}	5.0×10^{-6}
61	Promethium	2.5×10^{-3}	4.8×10^{-3}	5.0×10^{-6}
62	Samarium	2.5×10^{-3}	5.0×10^{-3}	5.0×10^{-6}
63	Europium	2.5×10^{-3}	4.8×10^{-3}	5.0×10^{-6}
64	Gadolinium	2.6×10^{-3}	3.6×10^{-3}	5.0×10^{-6}
65	Terbium	2.6×10^{-3}	4.4×10^{-3}	5.0×10^{-6}
66	Dysprosium	2.5×10^{-3}	5.3×10^{-3}	5.0×10^{-6}
67	Holmium	2.6×10^{-3}	4.4×10^{-3}	5.0×10^{-6}
68	Erbium	2.5×10^{-3}	4.0×10^{-3}	5.0×10^{-6}

Table D.1. Transfer Coefficients Applicable to Food Chain Pathways for Various Elements (Continued)

Index (i)	Element	Transfer Coefficients		
		Soil-to-Plant $B_v(i)$ (dimensionless)	Grass-to-Meat $F_b(i)$ (d/kg)	Grass-to-Milk $F_m(i)$ (d/L)
69	Thulium	2.6×10^{-3}	4.4×10^{-3}	5.0×10^{-6}
70	Ytterbium	2.5×10^{-3}	4.0×10^{-3}	5.0×10^{-6}
71	Lutetium	2.6×10^{-3}	4.4×10^{-3}	5.0×10^{-6}
72	Hafnium	1.7×10^{-4}	4.0×10^{-1}	5.0×10^{-6}
73	Tantalum	6.3×10^{-3}	1.6	2.5×10^{-2}
74	Tungsten	1.8×10^{-2}	1.3×10^{-3}	5.0×10^{-4}
75	Rhenium	2.5×10^{-1}	8.0×10^{-3}	2.5×10^{-2}
76	Osmium	5.0×10^{-2}	4.0×10^{-1}	5.0×10^{-3}
77	Iridium	1.3×10^{1}	1.5×10^{-3}	5.0×10^{-3}
78	Platinum	5.0×10^{-1}	4.0×10^{-3}	5.0×10^{-3}
79	Gold	2.5×10^{-3}	8.0×10^{-3}	5.0×10^{-3}
80	Mercury	3.8×10^{-1}	2.6×10^{-1}	3.8×10^{-2}
81	Thallium	2.5×10^{-1}	4.0×10^{-2}	2.2×10^{-2}
82	Lead	6.8×10^{-2}	2.9×10^{-4}	6.2×10^{-4}
83	Bismuth	1.5×10^{-1}	1.3×10^{-2}	5.0×10^{-4}
84	Polonium	1.5×10^{-1}	1.2×10^{-2}	3.0×10^{-4}
85	Astatine	2.5×10^{-1}	8.0	5.0×10^{-2}
86	Radon	0.0	0.0	0.0
87	Francium	1.0×10^{-2}	2.0×10^{-2}	5.0×10^{-2}
88	Radium	3.1×10^{-4}	3.4×10^{-2}	8.0×10^{-3}
89	Actinium	2.5×10^{-3}	6.0×10^{-2}	5.0×10^{-6}
90	Thorium	4.2×10^{-3}	2.0×10^{-4}	5.0×10^{-6}
91	Protactinium	2.5×10^{-3}	8.0×10^{2}	5.0×10^{-6}
92	Uranium	2.5×10^{-3}	3.4×10^{-4}	5.0×10^{-4}
93	Neptunium	2.5×10^{-3}	2.0×10^{-4}	5.0×10^{-6}
94	Plutonium	2.5×10^{-4}	1.4×10^{-5}	2.0×10^{-6}
95	Americium	2.5×10^{-4}	2.0×10^{-4}	5.0×10^{-6}
96	Curium	2.5×10^{-3}	2.0×10^{-4}	5.0×10^{-6}
97	Berkelium	2.5×10^{-3}	2.0×10^{-4}	5.0×10^{-6}
98	Californium	2.5×10^{-3}	2.0×10^{-4}	5.0×10^{-6}
99	Einsteinium	2.5×10^{-3}	2.0×10^{-4}	5.0×10^{-6}
100	Fermium	2.5×10^{-3}	2.0×10^{-4}	5.0×10^{-6}

Source: NRC (1977).

Table D.2. Summary of State[a] Agricultural Production for Land in Farms and Absolute Humidity Data

State	Percent of Land in Farms[b]	Crops[b] (kg/km^2)	Dairy[b] (L/km^2)	Meat[b] (kg/km^2)	Mean Absolute Humidity[c] (kg/m^3)
Alabama	31.4	1.76×10^4	2.00×10^3	7.19×10^3	1.07×10^{-2}
Arizona	52.0	4.15×10^3	1.85×10^3	6.36×10^2	5.75×10^{-3}
Arkansas	44.1	3.58×10^4	2.78×10^3	9.77×10^3	9.55×10^{-3}
California	32.1	4.29×10^4	1.63×10^4	3.41×10^3	6.60×10^{-3}
Colorado	50.6	2.52×10^4	1.64×10^3	2.24×10^3	5.75×10^{-3}
Connecticut	14.2	4.36×10^3	2.32×10^4	5.97×10^3	6.60×10^{-3}
Delaware	53.0	1.45×10^5	1.24×10^4	4.98×10^4	6.60×10^{-3}
Florida	37.0	5.94×10^4	6.82×10^3	3.47×10^3	1.38×10^{-2}
Georgia	33.1	3.15×10^4	4.26×10^3	8.84×10^3	1.07×10^{-2}
Idaho	26.4	5.37×10^4	4.79×10^3	1.22×10^3	4.90×10^{-3}
Illinois	80.7	3.29×10^5	8.36×10^3	6.70×10^3	7.50×10^{-3}
Indiana	70.9	2.54×10^5	1.14×10^4	1.00×10^4	7.50×10^{-3}
Iowa	91.0	3.17×10^5	1.25×10^4	1.74×10^4	6.60×10^{-3}
Kansas	89.9	9.40×10^4	2.90×10^3	6.01×10^3	7.50×10^{-3}
Kentucky	55.8	5.05×10^4	1.04×10^4	3.14×10^3	8.40×10^{-3}
Louisiana	31.3	2.17×10^4	3.84×10	1.98×10^3	1.23×10^{-2}
Maine	7.4	1.51×10^4	4.11×10^3	1.62×10^3	7.50×10^{-3}
Maryland	40.6	8.79×10^4	2.81×10^4	1.59×10^4	7.50×10^{-3}
Massachusetts	12.2	4.55×10^3	1.35×10^4	1.57×10^3	6.60×10^{-3}
Michigan	30.0	7.84×10^4	1.62×10^4	2.24×10^3	7.50×10^{-3}
Minnesota	54.4	1.46×10^5	2.28×10^4	5.83×10^3	8.40×10^{-3}
Mississippi	41.1	2.70×10^4	3.34×10^3	4.65×10^3	1.07×10^{-2}
Missouri	66.3	6.76×10^4	7.38×10^3	5.56×10^3	4.40×10^{-3}
Montana	65.1	1.84×10^4	4.11×10^2	8.39×10^2	4.90×10^{-3}
Nebraska	91.7	1.31×10^5	3.06×10^3	7.51×10^3	5.95×10^{-3}
Nevada	14.2	1.03×10^3	3.59×10^2	1.58×10^2	4.90×10^{-3}
New Hampshire	8.2	1.04×10^3	7.11×10^3	6.63×10^2	6.60×10^{-3}
New Jersey	19.2	3.23×10^4	1.15×10^4	1.59×10^3	6.60×10^{-3}
New Mexico	60.6	2.60×10^3	1.17×10^3	6.61×10^2	5.75×10^{-3}
New York	30.3	2.72×10^4	4.10×10^4	2.07×10^3	6.60×10^{-3}
North Carolina	33.0	4.65×10^4	6.05×10^3	9.51×10^3	9.55×10^{-3}
North Dakota	90.7	9.23×10^4	2.58×10^3	1.14×10^3	4.90×10^{-3}

Table D.2. Summary of State[a] Agricultural Production for Land in Farms and Absolute Humidity Data (Continued)

State	Percent of Land in Farms[b]	Crops[b] (kg/km^2)	Dairy[b] (L/km^2)	Meat[b] (kg/km^2)	Mean Absolute Humidity[c] (kg/m^3)
Ohio	58.7	1.49×10^5	1.94×10^4	5.55×10^3	6.60×10^{-3}
Oklahoma	73.7	3.10×10^4	2.97×10^3	3.87×10^3	8.40×10^{-3}
Oregon	28.8	1.47×10^4	2.37×10^3	9.18×10^2	6.60×10^{-3}
Pennsylvania	28.9	3.62×10^4	3.61×10^4	6.13×10^3	6.60×10^{-3}
Rhode Island	9.3	1.28×10^4	7.64×10^3	2.06×10^3	6.60×10^{-3}
South Carolina	28.9	2.78×10^4	3.29×10^3	3.22×10^3	9.55×10^{-3}
South Dakota	90.1	5.04×10^4	4.06×10^3	3.20×10^3	5.75×10^{-3}
Tennessee	47.4	3.34×10^4	9.90×10^3	3.72×10^3	8.40×10^{-3}
Texas	78.3	2.19×10^4	2.53×10^3	3.26×10^3	9.87×10^{-3}
Utah	18.6	2.66×10^3	2.48×10^3	5.72×10^2	4.90×10^{-3}
Vermont	26.5	2.48×10^3	4.50×10^4	1.27×10^3	6.60×10^{-3}
Virginia	37.1	2.75×10^4	9.08×10^3	4.61×10^3	8.40×10^{-3}
Washington	38.7	5.13×10^4	8.48×10^3	1.71×10^3	5.75×10^{-3}
West Virginia	23.1	5.41×10^3	2.53×10^3	1.62×10^3	6.60×10^{-3}
Wisconsin	49.5	7.53×10^4	7.47×10^4	4.20×10^3	5.75×10^{-3}
Wyoming	54.0	5.77×10^3	2.47×10^2	6.39×10^2	4.90×10^{-3}
U.S. Average	43.6	5.58×10^4	6.71×10^3	3.07×10^3	6.00×10^{-3}

[a] For the 48 contiguous United States.

[b] Source: Saricks et al. (1989). The annual yield data for P_c, P_m, and P_b (see Equations B.1, B.11, and B.13) are obtained by multiplying the percent of land in farms (as shown in the first column) by the respective data for production of land in farms.

[c] Source: Till and Meyer (1983).

Table D.3. Ratios of Time-Integrated Concentration to Initial Ground Concentration for Crop, Milk, and Wheat Food Pathways

Isotope	Ratio of Time-Integrated Media Concentration to Ground Concentration[a]		
	Crops ($yr\text{-}m^2/kg$)	Milk ($yr\text{-}m^2/L$)	Meat ($yr\text{-}m^2/kg$)
Americium-241	7.43×10^{-3}	1.22×10^{-5}	4.89×10^{-4}
Americium-243	7.46×10^{-3}	1.23×10^{-5}	4.90×10^{-4}
Carbon-14[b]	1.20×10^{-4}	7.18×10^{-5}	1.86×10^{-4}
Cesium-134	6.77×10^{-3}	2.70×10^{-2}	8.83×10^{-3}
Cesium-137	8.38×10^{-3}	2.98×10^{-2}	9.91×10^{-3}
Cerium-144	5.88×10^{-3}	1.19×10^{-2}	2.28×10^{-3}
Cobalt-60	7.28×10^{-3}	2.37×10^{-3}	3.06×10^{-2}
Curium-244	7.41×10^{-3}	1.21×10^{-5}	4.84×10^{-4}
Europium-154	7.06×10^{-3}	1.20×10^{-5}	1.14×10^{-2}
Iodine-131	7.18×10^{-5}	4.51×10^{-4}	4.61×10^{-5}
Plutonium-238	7.36×10^{-3}	4.88×10^{-6}	3.41×10^{-5}
Plutonium-239	7.46×10^{-3}	4.90×10^{-6}	3.43×10^{-5}
Plutonium-240	7.46×10^{-3}	4.90×10^{-6}	3.43×10^{-5}
Plutonium-241	7.20×10^{-3}	4.81×10^{-6}	3.36×10^{-5}
Ruthenium-106	6.42×10^{-3}	2.09×10^{-6}	8.06×10^{-1}
Strontium-90	9.12×10^{-3}	2.01×10^{-3}	1.51×10^{-3}
Tritium[b]	8.73×10^{-5}	1.02×10^{-5}	1.22×10^{-5}

[a] The ratios are expressed by $<C^c_i>/G_{io}$ for crops, $<C^m_i>/G_{io}$ for milk, and $<C^b_i>/G_{io}$ for meat.
[b] Data provided are based on an assumed deposition velocity (V_d) of 0.01 m/s.

Table D.3. Ratios of Time-Integrated Concentration to Initial Ground Concentration for Crop, Milk, and Wheat Food Pathways

Isotope	Ratio of Time-Integrated Media Concentration to Ground Concentration[a]		
	Crops ($yr\text{-}m^2/kg$)	Milk ($yr\text{-}m^2/L$)	Meat ($yr\text{-}m^2/kg$)
Americium-241	7.43×10^{-3}	1.22×10^{-5}	4.89×10^{-4}
Americium-243	7.46×10^{-3}	1.23×10^{-5}	4.90×10^{-4}
Carbon-14[b]	1.20×10^{-4}	7.18×10^{-5}	1.86×10^{-4}
Cesium-134	6.77×10^{-3}	2.70×10^{-2}	8.83×10^{-3}
Cesium-137	8.38×10^{-3}	2.98×10^{-2}	9.91×10^{-3}
Cerium-144	5.88×10^{-3}	1.19×10^{-2}	2.28×10^{-3}
Cobalt-60	7.28×10^{-3}	2.37×10^{-3}	3.06×10^{-2}
Curium-244	7.41×10^{-3}	1.21×10^{-5}	4.84×10^{-4}
Europium-154	7.06×10^{-3}	1.20×10^{-5}	1.14×10^{-2}
Iodine-131	7.18×10^{-5}	4.51×10^{-4}	4.61×10^{-5}
Plutonium-238	7.36×10^{-3}	4.88×10^{-6}	3.41×10^{-5}
Plutonium-239	7.46×10^{-3}	4.90×10^{-6}	3.43×10^{-5}
Plutonium-240	7.46×10^{-3}	4.90×10^{-6}	3.43×10^{-5}
Plutonium-241	7.20×10^{-3}	4.81×10^{-6}	3.36×10^{-5}
Ruthenium-106	6.42×10^{-3}	2.09×10^{-6}	8.06×10^{-1}
Strontium-90	9.12×10^{-3}	2.01×10^{-3}	1.51×10^{-3}
Tritium[b]	8.73×10^{-5}	1.02×10^{-5}	1.22×10^{-5}

[a] The ratios are expressed by $<C^c_i>/G_{io}$ for crops, $<C^m_i>/G_{io}$ for milk, and $<C^b_i>/G_{io}$ for meat.
[b] Data provided are based on an assumed deposition velocity (V_d) of 0.01 m/s.

Table D.4. Comparison of Partial Transfer Factors for Crops (f_{vi}), Milk (f_{mi}), and Meat (f_{bi}) between Two Representative States

Isotope	Illinois			Wisconsin		
	Crops	Milk	Meat	Crops	Milk	Meat
	f_{vi}	f_{mi}	f_{bi}	f_{vi}	f_{mi}	f_{bi}
Americium-241	1.98×10^{-3}	8.29×10^{-9}	2.66×10^{-6}	2.80×10^{-4}	4.57×10^{-7}	1.03×10^{-6}
Americium-243	1.99×10^{-3}	8.30×10^{-8}	2.66×10^{-6}	2.81×10^{-4}	4.58×10^{-7}	1.03×10^{-6}
Carbon-14[a]	3.19×10^{-5}	4.87×10^{-7}	1.01×10^{-6}	4.51×10^{-6}	2.68×10^{-6}	3.90×10^{-7}
Cesium-134	1.80×10^{-8}	1.83×10^{-4}	4.79×10^{-5}	2.55×10^{-4}	1.01×10^{-3}	1.86×10^{-5}
Cesium-137	2.23×10^{-3}	2.01×10^{-4}	5.38×10^{-5}	3.15×10^{-4}	1.11×10^{-3}	2.08×10^{-5}
Cerium-144	1.57×10^{-3}	8.08×10^{-6}	1.24×10^{-5}	2.21×10^{-4}	4.46×10^{-5}	4.80×10^{-6}
Cobalt-60	1.94×10^{-3}	1.60×10^{-5}	1.66×10^{-4}	2.74×10^{-5}	8.85×10^{-5}	6.43×10^{-5}
Curium-244	1.97×10^{-3}	8.20×10^{-8}	2.62×10^{-6}	2.79×10^{-4}	4.52×10^{-7}	1.02×10^{-6}
Europium-154	1.93×10^{-3}	8.01×10^{-8}	6.21×10^{-5}	2.72×10^{-4}	4.47×10^{-7}	2.40×10^{-5}
Iodine-131	1.91×10^{-5}	3.05×10^{-6}	2.50×10^{-7}	2.70×10^{-6}	1.68×10^{-5}	9.68×10^{-8}
Plutonium-238	1.96×10^{-3}	3.30×10^{-8}	1.85×10^{-7}	2.77×10^{-4}	1.82×10^{-7}	7.17×10^{-8}
Plutonium-239	1.99×10^{-3}	3.32×10^{-8}	1.86×10^{-7}	2.81×10^{-4}	1.83×10^{-7}	7.20×10^{-8}
Plutonium-240	1.99×10^{-3}	3.32×10^{-8}	1.86×10^{-7}	2.81×10^{-4}	1.83×10^{-7}	7.20×10^{-8}
Plutonium-241	1.92×10^{-3}	3.26×10^{-8}	1.82×10^{-7}	2.71×10^{-4}	1.80×10^{-7}	7.20×10^{-8}
Ruthenium-106	1.71×10^{-3}	1.41×10^{-8}	4.38×10^{-3}	2.42×10^{-4}	7.79×10^{-8}	1.69×10^{-3}
Strontium-90	2.43×10^{-3}	1.36×10^{-5}	8.18×10^{-6}	3.43×10^{-4}	7.50×10^{-5}	3.17×10^{-6}
Tritium[a]	2.33×10^{-6}	6.90×10^{-8}	6.63×10^{-8}	4.29×10^{-7}	4.96×10^{-7}	3.35×10^{-8}

[a] Data provided are based on an assumed deposition velocity (V_d) of 0.01 m/s.

Table D.5. Comparison of Transfer Factors from Contaminated Land to Foodstuff for Selected Radionuclides

Isotope	Data Used in Previous Assessments[a]	Data Obtained by Current Method		
		Illinois	Nevada	United States
Americium-241	2.800×10^{-6}	1.98×10^{-3}	1.08×10^{-6}	1.83×10^{-4}
Americium-243	2.800×10^{-6}	1.99×10^{-3}	1.09×10^{-6}	1.84×10^{-4}
Carbon-14[b]	0.000	3.34×10^{-5}	2.50×10^{-8}	3.40×10^{-6}
Cesium-134	3.100×10^{-5}	2.03×10^{-3}	2.53×10^{-6}	2.58×10^{-4}
Cesium-137	3.100×10^{-5}	2.49×10^{-3}	2.92×10^{-6}	3.07×10^{-4}
Cerium-144	0.000	1.59×10^{-3}	9.58×10^{-7}	1.51×10^{-4}
Cobalt-60	6.200×10^{-5}	2.12×10^{-3}	1.85×10^{-6}	2.27×10^{-4}
Curium-244	2.800×10^{-6}	1.98×10^{-3}	1.08×10^{-6}	1.83×10^{-4}
Europium-154	0.000	1.99×10^{-3}	1.30×10^{-6}	1.93×10^{-4}
Plutonium-238	2.800×10^{-6}	1.96×10^{-3}	1.06×10^{-6}	1.81×10^{-4}
Plutonium-239	2.800×10^{-6}	1.99×10^{-3}	1.08×10^{-6}	1.83×10^{-4}
Plutonium-240	2.800×10^{-6}	1.99×10^{-3}	1.08×10^{-6}	1.83×10^{-4}
Plutonium-241	2.800×10^{-6}	1.99×10^{-3}	1.04×10^{-6}	1.77×10^{-4}
Ruthenium-106	0.000	6.09×10^{-3}	1.88×10^{-5}	1.25×10^{-3}
Strontium-90	1.500×10^{-5}	2.45×10^{-3}	1.45×10^{-6}	2.32×10^{-4}
Tritium[b]	0.000	2.46×10^{-6}	3.12×10^{-9}	2.97×10^{-7}

[a] RADTRAN data file used for EA estimation (DOE 1986a; b; c) was based on fallout data and a generic personal utilization factor (e.g., 200 kg per 33,000 m^2 for crops) as derived by Ostmeyer (1986).

[b] Data provided are based on an assumed deposition velocity (V_d) of 0.01 m/s.

Table D.6. Food Transfer Factors[a]

Nuclide	State						
	AL	AZ	AR	CA	CO	CT	DE
H-3	5.69E–08	4.26E–08	1.59E–07	2.10E-07	1.76E-07	5.53E-08	1.21E-06
BE-10	4.66E-05	1.73E-05	1.29E-04	1.07E-04	9.95E-05	7.43E-06	6.43E-04
C-14	1.11E-06	3.89E-07	2.77E-06	2.22E-06	1.81E-06	4.62E-07	1.46E-05
N-16	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
F-18	7.65E-19	1.19E-18	1.51E-18	6.43E-18	1.03E-18	4.01E-18	8.11E-18
NA-22	2.52E-04	1.28E-04	5.28E-04	6.63E-04	2.53E-04	3.64E-04	3.01E-03
NA-24	4.42E-10	6.85E-10	8.71E-10	3.72E-09	5.96E-10	2.31E-09	4.68E-09
P-32	1.71E-05	8.57E-06	3.56E-05	4.41E-05	1.67E-05	2.45E-05	2.03E-04
CA-41	1.41E-04	6.62E-05	3.67E-04	3.88E-04	2.68E-04	9.87E-05	1.87E-03
SC-46	6.03E-05	1.40E-05	1.36E-04	7.05E-05	6.82E-05	1.73E-05	7.60E-04
CR-51	9.24E-06	4.06E-06	2.42E-05	2.39E-05	1.75E-05	5.42E-06	1.23E-04
MN-54	3.70E-05	1.42E-05	1.03E-04	8.80E-05	8.05E-05	6.66E-06	5.13E-04
MN-56	2.27E-18	3.52E-18	4.48E-18	1.91E-17	3.06E-18	1.19E-17	2.41E-17
FE-55	2.40E-04	4.73E-05	4.99E-04	2.07E-04	1.93E-04	8.87E-05	2.93E-03
FE-59	7.07E-05	1.44E-05	1.48E-04	6.42E-05	5.91E-05	2.64E-05	8.63E-04
CO-57	8.73E-05	2.25E-05	1.99E-04	1.17E-04	1.04E-04	3.03E-05	1.10E-03
CO-58	4.88E-05	1.29E-05	1.12E-04	6.74E-05	5.98E-05	1.71E-05	6.19E-04
CO-60	1.09E-04	2.81E-05	2.49E-04	1.46E-04	1.31E-04	3.77E-05	1.38E-03
NI-59	1.15E-04	5.06E-05	2.91E-04	2.91E-04	2.00E-04	7.95E-05	1.51E-03
NI-63	1.03E-04	4.56E-05	2.57E-04	2.60E-04	1.74E-04	7.56E-05	1.34E-03
NI-65	4.64E-17	7.20E-17	9.15E-17	3.90E-16	6.26E-17	2.43E-16	4.92E-16
CU-64	9.35E-11	1.45E-10	1.85E-10	7.87E-10	1.26E-10	4.90E-10	9.91E-10
ZN-65	2.14E-04	1.09E-04	4.52E-04	5.66E-04	2.22E-04	3.04E-04	2.56E-03
ZN-69M	4.93E-10	7.65E-10	9.72E-10	4.15E-09	6.65E-10	2.58E-09	5.22E-09
ZN-69	1.79E-25	2.78E-25	3.54E-25	1.51E-24	2.42E-25	9.39E-25	1.90E-24
SE-79	3.52E-03	1.92E-03	8.89E-03	1.10E-02	6.32E-03	3.73E-03	4.58E-02
BR-82	1.61E-08	2.47E-08	3.20E-08	1.34E-07	2.20E-08	8.30E-08	1.72E-07
BR-83	1.11E-15	1.73E-15	2.20E-15	9.36E-15	1.50E-15	5.83E-15	1.18E-14
BR-84	2.29E-37	3.55E-37	4.52E-37	1.93E-36	3.09E-37	1.20E-36	2.43E-36
BR-85	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
KR-85	1.52E-03	6.36E-04	3.82E-03	3.64E-03	2.59E-03	9.57E-04	1.99E-02
RB-86	2.25E-05	1.34E-05	4.70E-05	7.01E-05	2.33E-05	3.96E-05	2.66E-04
RB-87	6.39E-04	2.72E-04	1.48E-03	1.48E-03	8.63E-04	5.71E-04	8.04E-03
RB-88	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
RB-89	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
SR-89	1.51E-05	6.28E-06	4.23E-05	3.89E-05	3.34E-05	4.35E-06	2.09E-04
SR-90	5.44E-05	2.21E-05	1.53E-04	1.37E-04	1.21E-04	1.34E-05	7.54E-04
SR-91	1.09E-12	1.69E-12	2.15E-12	9.18E-12	1.47E-12	5.72E-12	1.16E-11
SR-92	1.47E-17	2.28E-17	2.89E-17	1.23E-16	1.98E-17	7.69E-17	1.56E-16
Y-90	5.49E-09	2.14E-09	1.57E-08	1.35E-08	1.26E-08	7.13E-10	7.70E-08
Y-91M	1.98E-32	3.07E-32	3.91E-32	1.67E-31	2.67E-32	1.04E-31	2.10E-31

Table D.6. Food Transfer Factors (Continued)

Y-91	2.39E-05	7.36E-06	6.09E-05	4.29E-05	4.06E-05	4.96E-06	3.18E-04
Y-92	5.28E-18	8.19E-18	1.04E-17	4.44E-17	7.12E-18	2.76E-17	5.59E-17
Y-93	1.73E-14	2.69E-14	3.41E-14	1.46E-13	2.33E-14	9.07E-14	1.83E-13
ZR-93	2.26E-04	4.36E-05	4.75E-04	1.93E-04	1.91E-04	7.42E-05	2.77E-03
ZR-95	8.95E-05	1.76E-05	1.89E-04	7.90E-05	7.79E-05	2.90E-05	1.10E-03
ZR-97	1.32E-13	1.67E-13	2.89E-13	9.17E-13	2.10E-13	5.24E-13	1.51E-12
NB-93M	1.56E-03	2.47E-04	3.04E-03	8.77E-04	8.79E-04	5.91E-04	1.85E-02
NB-94	1.67E-03	2.68E-04	3.28E-03	9.64E-04	9.64E-04	6.33E-04	1.99E-02
NB-95M	1.30E-07	3.59E-08	2.74E-07	1.72E-07	1.16E-07	8.05E-08	1.59E-06
NB-95	3.14E-04	5.04E-05	6.15E-04	1.81E-04	1.79E-04	1.21E-04	3.74E-03
NB-97	1.99E-24	3.09E-24	3.93E-24	1.67E-23	2.69E-24	1.04E-23	2.11E-23
MO-93	3.29E-04	1.34E-04	8.59E-04	7.90E-04	6.16E-04	1.57E-04	4.39E-03
MO-99	1.69E-08	1.73E-08	4.00E-08	9.64E-08	2.98E-08	4.95E-08	2.05E-07
TC-99M	3.23E-12	5.01E-12	6.37E-12	2.72E-11	4.36E-12	1.69E-11	3.42E-11
TC-99	6.08E-03	1.15E-03	1.22E-02	4.65E-03	4.03E-03	2.63E-03	7.29E-02
TC-101	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
RU-103	5.26E-04	8.08E-05	1.03E-03	2.80E-04	2.90E-04	1.94E-04	6.25E-03
RU-105	6.87E-18	1.07E-17	1.36E-17	5.78E-17	9.27E-18	3.60E-17	7.28E-17
RU-106	1.83E-03	2.81E-04	3.57E-03	9.68E-04	1.00E-03	6.78E-04	2.18E-02
RH-103M	3.30E-24	5.12E-24	6.51E-24	2.78E-23	4.45E-24	1.73E-23	3.50E-23
RH-105	2.43E-08	3.44E-08	5.05E-08	1.88E-07	3.56E-08	1.13E-07	2.67E-07
RH-106	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
PD-107	9.41E-03	4.11E-03	2.61E-02	2.51E-02	2.04E-02	3.70E-03	1.29E-01
PD-109	7.27E-10	1.13E-09	1.44E-09	6.12E-09	9.81E-10	3.81E-09	7.71E-09
AG-110M	1.66E-04	1.18E-04	3.55E-04	6.33E-04	1.99E-04	3.49E-04	1.97E-03
AG-111	2.53E-06	3.00E-06	5.27E-06	1.63E-05	3.40E-06	9.70E-06	2.85E-05
CD-113M	1.55E-04	6.06E-05	4.43E-04	3.83E-04	3.57E-04	1.97E-05	2.17E-03
CD-115M	3.00E-20	4.66E-20	5.92E-20	2.53E-19	4.05E-20	1.57E-19	3.18E-19
IN-113M	1.14E-21	1.77E-21	2.26E-21	9.62E-21	1.54E-21	5.99E-21	1.21E-20
SN-113	2.70E-04	4.93E-05	5.43E-04	1.99E-04	1.84E-04	1.06E-04	3.24E-03
SN-119M	3.77E-04	6.82E-05	7.57E-04	2.74E-04	2.55E-04	1.48E-04	4.53E-03
SN-121M	4.82E-04	8.73E-05	9.71E-04	3.51E-04	3.28E-04	1.88E-04	5.80E-03
SN-123	2.86E-04	5.21E-05	5.76E-04	2.11E-04	1.95E-04	1.13E-04	3.44E-03
SN-125	6.59E-06	1.40E-06	1.33E-05	6.01E-06	4.75E-06	3.18E-06	7.93E-05
SN-126	4.91E-04	8.93E-05	9.90E-04	3.61E-04	3.37E-04	1.91E-04	5.91E-03
SB-124	2.53E-05	9.23E-06	6.46E-05	5.36E-05	4.40E-05	1.01E-05	3.35E-04
SB-125	6.04E-05	2.14E-05	1.53E-04	1.24E-04	1.03E-04	2.30E-05	7.98E-04
SB-126	2.07E-06	8.70E-07	5.22E-06	5.00E-06	3.56E-06	1.30E-06	2.71E-05
SB-126M	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
SB-127	3.73E-08	2.09E-08	1.00E-07	1.24E-07	7.82E-08	3.43E-08	5.01E-07
TE-125M	1.70E-04	3.14E-05	3.49E-04	1.31E-04	1.27E-04	6.16E-05	2.06E-03
TE-127M	2.76E-04	5.10E-05	5.66E-04	2.14E-04	2.07E-04	9.91E-05	3.35E-03
TE-127	5.53E-12	8.58E-12	1.09E-11	4.65E-11	7.46E-12	2.90E-11	5.86E-11
TE-129M	9.34E-05	1.73E-05	1.91E-04	7.25E-05	6.95E-05	3.41E-05	1.13E-03

Table D.6. Food Transfer Factors (Continued)

TE-129	2.93E-24	4.55E-24	5.78E-24	2.46E-23	3.95E-24	1.53E-23	3.11E-23
TE-131M	3.57E-10	4.43E-10	7.88E-10	2.44E-09	5.71E-10	1.38E-09	4.11E-09
TE-131	0.00E+00	0.00E+00	0.00E+00	1.40E-45	0.00E+00	1.40E-45	1.40E-45
TE-132	5.01E-08	1.91E-08	1.27E-07	1.11E-07	8.71E-08	2.33E-08	6.62E-07
TE-133M	2.36E-27	3.67E-27	4.66E-27	1.99E-26	3.19E-27	1.24E-26	2.50E-26
TE-134	5.80E-32	9.00E-32	1.14E-31	4.88E-31	7.82E-32	3.04E-31	6.15E-31
I-129	1.01E-04	4.74E-05	2.65E-04	2.79E-04	1.95E-04	6.84E-05	1.35E-03
I-130	2.52E-11	3.91E-11	4.98E-11	2.12E-10	3.40E-11	1.32E-10	2.67E-10
I-131	7.74E-07	6.04E-07	1.88E-06	3.39E-06	1.35E-06	1.55E-06	9.70E-06
I-132	8.76E-18	1.36E-17	1.73E-17	7.37E-17	1.18E-17	4.59E-17	9.29E-17
I-133	2.27E-10	3.51E-10	4.48E-10	1.91E-09	3.06E-10	1.19E-09	2.40E-09
I-134	1.04E-28	1.61E-28	2.05E-28	8.75E-28	1.40E-28	5.45E-28	1.10E-27
I-135	8.55E-13	1.33E-12	1.69E-12	7.20E-12	1.15E-12	4.48E-12	9.07E-12
CS-134M	5.69E-16	8.82E-16	1.12E-15	4.78E-15	7.67E-16	2.98E-15	6.03E-15
CS-135	9.92E-05	5.58E-05	2.46E-04	3.17E-04	1.71E-04	1.16E-04	1.28E-03
CS-136	3.67E-06	3.04E-06	8.52E-06	1.68E-05	5.81E-06	8.43E-06	4.47E-05
CS-137	8.62E-05	5.00E-05	2.11E-04	2.81E-04	1.44E-04	1.10E-04	1.10E-03
CS-138	2.33E-39	3.61E-39	4.59E-39	1.96E-38	3.14E-39	1.22E-38	2.47E-38
CS-139	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
BA-137M	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
BA-139	1.21E-23	1.87E-23	2.38E-23	1.01E-22	1.63E-23	6.31E-23	1.28E-22
BA-140	1.96E-06	7.02E-07	5.11E-06	4.15E-06	3.59E-06	6.15E-07	2.63E-05
BA-141	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
BA-142	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
LA-140	2.63E-10	1.06E-10	7.58E-10	6.70E-10	6.18E-10	3.67E-11	3.70E-09
LA-141	6.12E-18	9.50E-18	1.21E-17	5.15E-17	8.26E-18	3.21E-17	6.49E-17
LA-142	9.41E-25	1.46E-24	1.86E-24	7.91E-24	1.27E-24	4.93E-24	9.97E-24
CE-141	9.58E-06	3.78E-06	2.63E-05	2.31E-05	2.02E-05	2.61E-06	1.31E-04
CE-143	1.55E-10	1.77E-10	3.57E-10	9.78E-10	2.65E-10	5.28E-10	1.84E-09
CE-144	3.79E-05	1.46E-05	1.04E-04	8.94E-05	7.92E-05	9.37E-06	5.20E-04
PR-143	2.56E-06	7.80E-07	6.48E-06	4.54E-06	4.30E-06	5.35E-07	3.39E-05
PR-144	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
PR-144M	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
ND-147	1.30E-06	4.27E-07	3.42E-06	2.55E-06	2.40E-06	2.43E-07	1.75E-05
PM-146	6.39E-05	1.91E-05	1.60E-04	1.10E-04	1.04E-04	1.38E-05	8.44E-04
PM-147	6.14E-05	1.83E-05	1.54E-04	1.06E-04	1.00E-04	1.33E-05	8.11E-04
PM-148M	1.80E-05	5.50E-06	4.5E-05	3.20E-05	3.03E-05	3.75E-06	2.39E-04
PM-148	1.29E-07	4.54E-08	3.50E-07	2.79E-07	2.62E-07	2.08E-08	1.76E-06
PM-149	1.91E-09	7.49E-10	5.47E-09	4.74E-09	4.42E-09	2.40E-10	2.68E-08
PM-151	1.30E-11	5.72E-12	3.70E-11	3.56E-11	3.00E-11	4.12E-12	1.81E-10
SM-147	7.21E-05	2.17E-05	1.82E-04	1.25E-04	1.19E-04	1.54E-05	9.53E-04
SM-151	7.02E-05	2.10E-05	1.76E-04	1.21E-04	1.15E-04	1.51E-05	9.27E-04
SM-153	8.24E-10	3.25E-10	2.37E-09	2.06E-09	1.92E-09	1.07E-10	1.16E-08
EU-152	6.57E-05	1.96E-05	1.65E-04	1.13E-04	1.07E-04	1.42E-05	8.67E-04

Table D.6. Food Transfer Factors (Continued)

EU-154	6.50E-05	1.94E-05	1.63E-04	1.12E-04	1.06E-04	1.40E-05	8.58E-04
EU-155	6.35E-05	1.90E-05	1.59E-04	1.09E-04	1.04E-04	1.37E-05	8.39E-04
EU-156	3.33E-06	1.01E-06	8.42E-06	5.86E-06	5.55E-06	7.02E-07	4.41E-05
GD-153	4.55E-05	1.44E-05	1.17E-04	8.50E-05	8.03E-05	8.97E-06	6.09E-04
TB-160	2.85E-05	8.81E-06	7.27E-05	5.15E-05	4.87E-05	5.84E-06	3.79E-04
HO-166M	6.87E-05	2.12E-05	1.75E-04	1.24E-04	1.17E-04	1.41E-05	9.13E-04
W-181	2.93E-05	1.12E-05	8.03E-05	6.84E-05	6.11E-05	6.83E-06	4.02E-04
W-185	2.19E-05	8.37E-06	6.01E-05	5.14E-05	4.58E-05	5.15E-06	3.01E-04
W-187	3.21E-11	4.75E-11	6.51E-11	2.58E-10	4.52E-11	1.58E-10	3.47E-10
TL-207	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
TL-208	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
PB-209	1.62E-16	2.52E-16	3.21E-16	1.37E-15	2.19E-16	8.51E-16	1.72E-15
PB-210	7.65E-05	3.10E-05	2.18E-04	1.95E-04	1.76E-04	1.44E-05	1.07E-03
PB-211	3.83E-37	5.94E-37	7.55E-37	3.22E-36	5.16E-37	2.00E-36	4.06E-36
PB-212	1.58E-12	2.45E-12	3.12E-12	1.33E-11	2.13E-12	8.28E-12	1.67E-11
BI-210	1.42E-07	5.21E-08	3.65E-07	3.04E-07	2.51E-07	5.52E-08	1.89E-06
BI-211	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
BI-212	4.99E-27	7.74E-27	9.84E-27	4.19E-26	6.73E-27	2.61E-26	5.29E-26
BI-213	8.00E-32	1.24E-31	1.58E-31	6.73E-31	1.08E-31	4.19E-31	8.48E-31
PO-210	6.83E-05	1.74E-05	1.58E-04	9.19E-05	8.63-05	1.98E-05	8.70E-04
PO-212	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
PO-213	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
PO-215	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
PO-216	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
AT-217	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
FR-221	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
FR-223	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
RA-223	6.09E-06	2.31E-06	1.28E-05	1.16E-05	5.75E-06	5.99E-06	7.35E-05
RA-224	6.24E-08	5.12E-08	1.44E-07	2.82E-07	9.74E-08	1.42E-07	7.60E-07
RA-225	1.17E-05	4.01E-06	2.45E-05	1.98E-05	1.07E-05	1.00E-05	1.41E-04
RA-226	2.39E-04	6.25E-05	5.00E-04	2.96E-04	2.08E-04	1.38E-04	2.90E-03
RA-228	2.28E-04	5.98E-05	4.78E-04	2.83E-04	1.98E-04	1.33E-04	2.78E-03
AC-225	5.62E-06	1.02E-06	1.15E-05	4.24E-06	4.23E-06	1.92E-06	6.82E-05
AC-227	3.65E-04	6.42E-05	7.43E-04	2.61E-04	2.62E-04	1.26E-04	4.41E-03
AC-228	3.79E-16	5.89E-16	7.49E-16	3.19E-15	5.12E-16	1.99E-15	4.02E-15
TH-227	3.36E-06	1.31E-06	9.63E-06	8.30E-06	7.77E-06	4.03E-07	4.72E-05
TH-228	3.76E-05	1.46E-05	1.08E-04	9.26E-05	8.67E-05	4.50E-06	5.27E-04
TH-229	4.82E-05	1.88E-05	1.38E-04	1.19E-04	1.12E-04	5.73E-06	6.77E-04
TH-230	4.83E-05	1.88E-05	1.38E-04	1.19E-04	1.12E-04	5.74E-06	6.78E-04
TH-231	4.61E-12	2.25E-12	1.30E-11	1.38E-11	1.05E-11	2.44E-12	6.36E-11
TH-232	4.83E-05	1.88E-05	1.38E-04	1.19E-04	1.12E-04	5.74E-06	6.78E-04
TH-234	5.49E-06	2.14E-06	1.57E-05	1.36E-05	1.27E-05	6.56E-07	7.70E-05
PA-231	1.00E+00	6.57E-01	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00
PA-233	6.00E-01	8.91E-02	1.00E+00	2.94E-01	3.08E-01	2.25E-01	1.00E+00

Table D.6. Food Transfer Factors (Continued)

PA-234M	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
U-232	4.49E-05	1.82E-05	1.27E-04	1.14E-04	1.02E-04	9.41E-06	6.25E-04
U-233	4.70E-05	1.90E-05	1.33E-04	1.19E-04	1.07E-04	9.71E-06	6.56E-04
U-234	4.70E-05	1.90E-05	1.33E-04	1.19E-04	1.07E-04	9.71E-06	6.56E-04
U-235	4.70E-05	1.90E-05	1.33E-04	1.19E-04	1.07E-04	9.71E-06	6.56E-04
U-236	4.70E-05	1.90E-05	1.33E-04	1.19E-04	1.07E-04	9.71E-06	6.56E-04
U-237	2.42E-07	1.10E-07	6.79E-07	6.80E-07	5.45E-07	1.0E-07	3.34E-06
U-238	4.70E-05	1.90E-05	1.33E-04	1.19E-04	1.07E-04	9.71E-06	6.56E-04
NP-236	4.55E-05	1.77E-05	1.30E-04	1.12E-04	1.05E-04	5.42E-06	6.38E-04
NP-237	4.55E-05	1.77E-05	1.30E-04	1.12E-04	1.05E-04	5.42E-06	6.38E-04
NP-238	1.34E-09	5.31E-10	3.85E-09	3.37E-09	3.14E-09	1.63E-10	1.88E-08
NP-239	2.64E-09	1.05E-09	7.61E-09	6.65E-09	6.20E-09	3.14E-10	3.71E-08
PU-236	3.73E-05	1.48E-05	1.08E-04	9.38E-05	8.78E-05	4.21E-06	5.26E-04
PU-237	1.24E-05	4.88E-06	3.56E-05	3.10E-05	2.91E-05	1.39E-06	1.74E-04
PU-238	4.03E-05	1.59E-05	1.16E-04	1.01E-04	9.47E-05	4.54E-06	5.67E-04
PU-239	4.08E-05	1.61E-05	1.18E-04	1.02E-04	9.59E-05	4.60E-06	5.74E-04
PU-240	4.08E-05	1.61E-05	1.18E-04	1.02E-04	9.59E-05	4.60E-06	5.74E-04
PU-241	3.94E-05	1.56E-05	1.14E-04	9.89E-05	9.26E-05	4.44E-06	5.54E-04
PU-242	4.08E-05	1.61E-05	1.18E-04	1.02E-04	9.59E-05	4.60E-06	5.74E-04
PU-244	4.08E-05	1.61E-05	1.18E-04	1.02E-04	9.59E-05	4.60E-06	5.74E-04
AM-241	4.16E-05	1.62E-05	1.19E-04	1.03E-04	9.61E-05	4.99E-06	5.84E-04
AM-242M	4.14E-05	1.61E-05	1.19E-04	1.02E-04	9.56E-05	4.96E-06	5.81E-04
AM-243	4.18E-05	1.63E-05	1.20E-04	1.03E-04	9.64E-05	5.00E-06	5.86E-04
CM-242	2.84E-05	1.10E-05	8.12E-05	6.99E-05	6.55E-05	3.39E-06	3.98E-04
CM-243	4.21E-05	1.64E-05	1.20E-04	1.04E-04	9.71E-05	5.03E-06	5.90E-04
CM-244	4.15E-05	1.62E-05	1.19E-04	1.02E-04	9.58E-05	4.97E-06	5.82E-04
CM-245	4.55E-05	1.77E-05	1.30E-04	1.12E-04	1.05E-04	5.42E-06	6.38E-04
CM-246	4.54E-05	1.77E-05	1.30E-04	1.12E-04	1.05E-04	5.42E-06	6.38E-04
CM-247	4.55E-05	1.77E-05	1.30E-04	1.12E-04	1.05E-04	5.42E-06	6.38E-04
CM-248	4.55E-05	1.77E-05	1.30E-04	1.12E-04	1.05E-04	5.42E-06	6.38E-04
CF-252	3.83E-05	1.49E-05	1.09E-04	9.43E-05	8.83E-05	4.58E-06	5.37E-04
Nuclide	**State**						
	FL	**GA**	**ID**	**IL**	**IN**	**IA**	**KS**
H-3	1.27E-07	9.86E-08	2.12E-07	2.46E-06	1.74E-06	3.21E-06	8.31E-07
BE-10	1.69E-04	8.56E-05	1.06E-04	2.02E-03	1.37E-03	2.21E-03	6.49E-04
C-14	3.05E-06	1.89E-06	1.82E-06	3.34E-05	2.35E-05	3.83E-05	1.13E-05
N-16	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
F-18	3.11E-18	1.73E-18	1.54E-18	8.35E-18	9.98E-18	1.40E-17	3.22E-18
NA-22	4.89E-04	4.10E-04	2.43E-04	3.02E-03	2.60E-03	4.33E-03	1.25E-03
NA-24	1.80E-09	1.00E-09	8.87E-10	4.82E-09	5.77E-09	8.10E-09	1.86E-09
P-32	3.21E-05	2.76E-05	1.58E-05	1.93E-04	1.69E-04	2.82E-04	8.18E-05
CA-41	4.76E-04	2.58E-04	2.88E-04	5.08E-03	3.56E-03	5.71E-03	1.67E-03
SC-46	1.05E-04	9.10E-05	5.74E-05	1.08E-03	7.96E-04	1.35E-03	4.11E-04
CR-51	3.07E-05	1.68E-05	1.87E-05	3.35E-04	2.34E-04	3.76E-04	1.10E-04

Table D.6. Food Transfer Factors (Continued)

MN-54	1.37E-04	6.86E-05	8.62E-05	1.64E-03	1.11E-03	1.79E-03	5.25E-04
MN-56	9.24E-18	5.15E-18	4.56E-18	2.48E-17	2.97E-17	4.17E-17	9.56E-18
FE-55	2.73E-04	3.39E-04	1.27E-04	2.33E-03	1.89E-03	3.43E-03	1.07E-03
FE-59	8.48E-05	1.00E-04	4.05E-05	7.40E-04	5.93E-04	1.06E-03	3.31E-04
CO-57	1.64E-04	1.34E-04	9.15E-05	1.70E-03	1.24E-03	2.09E-03	6.30E-04
CO-58	9.48E-05	7.57E-05	5.32E-05	9.86E-04	7.17E-04	1.20E-03	3.62E-04
CO-60	2.05E-04	1.68E-04	1.14E-04	2.12E-03	1.55E-03	2.61E-03	7.88E-04
NI-59	3.53E-04	2.04E-04	2.10E-04	3.69E-03	2.61E-03	4.21E-03	1.23E-03
NI-63	3.07E-04	1.81E-04	1.82E-04	3.16E-03	2.25E-03	3.63E-03	1.06E-03
NI-65	1.89E-16	1.05E-16	9.32E-17	5.07E-16	6.06E-16	8.51E-16	1.95E-16
CU-64	3.81E-10	2.12E-10	1.88E-10	1.02E-09	1.22E-09	1.72E-09	3.94E-10
ZN-65	4.27E-04	3.49E-04	2.15E-04	2.75E-03	2.33E-03	3.85E-03	1.12E-03
ZN-69M	2.01E-09	1.12E-09	9.90E-10	5.38E-09	6.43E-09	9.04E-09	2.07E-09
ZN-69	7.29E-25	4.06E-25	3.60E-25	1.96E-24	2.34E-24	3.29E-24	7.54E-25
SE-79	1.17E-02	6.49E-03	6.89E-03	1.15E-01	8.21E-02	1.31E-01	3.80E-02
BR-82	6.55E-08	3.64E-08	3.25E-08	1.86E-07	2.15E-07	3.05E-07	7.08E-08
BR-83	4.53E-15	2.52E-15	2.24E-15	1.22E-14	1.45E-14	2.04E-14	4.69E-15
BR-84	9.32E-37	5.19E-37	4.60E-37	2.50E-36	2.99E-36	4.20E-36	9.64E-37
BR-85	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
KR-85	4.52E-03	2.66E-03	2.69E-03	4.77E-02	3.37E-02	5.45E-02	1.60E-02
RB-86	4.77E-05	3.78E-05	2.37E-05	2.69E-04	2.38E-04	3.90E-04	1.11E-04
RB-87	1.53E-03	1.07E-03	8.56E-04	1.40E-02	1.04E-02	1.71E-02	5.01E-03
RB-88	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
RB-89	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
SR-89	5.76E-05	2.84E-05	3.61E-05	6.76E-04	4.62E-04	7.39E-04	2.17E-04
SR-90	2.07E-04	1.02E-04	1.30E-04	2.45E-03	1.67E-03	2.68E-03	7.85E-04
SR-91	4.44E-12	2.47E-12	2.19E-12	1.19E-11	1.42E-11	2.00E-11	4.59E-12
SR-92	5.97E-17	3.33E-17	2.95E-17	1.60E-16	1.92E-16	2.69E-16	6.18E-17
Y-90	2.16E-08	1.04E-08	1.37E-08	2.60E-07	1.76E-07	2.82E-07	8.29E-08
Y-91M	8.06E-32	4.49E-32	3.98E-32	2.16E-31	2.58E-31	3.63E-31	8.33E-32
Y-91	6.69E-05	4.05E-05	4.06E-05	7.72E-04	5.35E-04	8.74E-04	2.59E-04
Y-92	2.15E-17	1.20E-17	1.06E-17	5.76E-17	6.89E-17	9.68E-17	2.22E-17
Y-93	7.04E-14	3.92E-14	3.48E-14	1.89E-13	2.26E-13	3.18E-13	7.29E-14
ZR-93	2.70E-04	3.20E-04	1.30E-04	2.43E-03	1.93E-03	3.46E-03	1.08E-03
ZR-95	1.12E-04	1.27E-04	5.47E-05	1.02E-03	8.04E-04	1.43E-03	4.44E-04
ZR-97	5.34E-13	2.87E-13	2.82E-13	2.66E-12	2.36E-12	3.52E-12	9.17E-13
NB-93M	1.06E-03	2.07E-03	3.30E-04	5.78E-03	6.25E-03	1.30E-02	4.34E-03
NB-94	1.17E-03	2.23E-03	3.80E-04	6.69E-03	7.04E-03	1.45E-02	4.80E-03
NB-95M	1.82E-07	1.92E-07	8.89E-08	1.46E-06	1.18E-06	2.07E-06	6.32E-07
NB-95	2.16E-04	4.18E-04	6.88E-05	1.20E-03	1.28E-03	2.66E-03	8.84E-04
NB-97	8.10E-24	4.51E-24	4.00E-24	2.17E-23	2.60E-23	3.65E-23	8.38E-24
MO-93	1.07E-03	5.89E-04	6.49E-04	1.18E-02	8.23E-03	1.33E-02	3.89E-03
MO-99	6.72E-08	3.54E-08	3.73E-08	4.57E-07	3.63E-07	5.57E-07	1.53E-07
TC-99M	1.31E-11	7.32E-12	6.49E-12	3.53E-11	4.22E-11	5.93E-11	1.36E-11

Table D.6. Food Transfer Factors (Continued)

TC-99	5.39E-03	8.31E-03	2.13E-03	3.65E-02	3.38E-02	6.49E-02	2.08E-02
TC-101	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
RU-103	3.41E-04	6.95E-04	1.01E-04	1.79E-03	2.00E-03	4.24E-03	1.42E-03
RU-105	2.80E-17	1.56E-17	1.38E-17	7.50E-17	8.97E-17	1.26E-16	2.89E-17
RU-106	1.18E-03	2.42E-03	3.45E-04	6.09E-03	6.88E-03	1.46E-02	4.90E-03
RH-103M	1.34E-23	7.48E-24	6.63E-24	3.60E-23	4.31E-23	6.05E-23	1.39E-23
RH-105	9.87E-08	5.40E-08	5.03E-08	3.72E-07	3.73E-07	5.42E-07	1.34E-07
RH-106	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
PD-107	3.56E-02	1.77E-02	2.22E-02	4.09E-01	2.81E-01	4.49E-01	1.31E-01
PD-109	2.96E-09	1.65E-09	1.46E-09	7.94E-09	9.50E-09	1.33E-08	3.06E-09
AG-110M	4.27E-04	2.96E-04	2.20E-04	2.51E-03	2.15E-03	3.43E-03	9.60E-04
AG-111	8.90E-06	5.25E-06	4.52E-06	3.63E-05	3.55E-05	5.29E-05	1.35E-05
CD-113M	6.10E-04	2.93E-04	3.86E-04	7.37E-03	4.99E-03	8.00E-03	2.35E-03
CD-115M	1.22E-19	6.81E-20	6.03E-20	3.28E-19	3.92E-19	5.51E-19	1.26E-19
IN-113M	4.66E-21	2.59E-21	2.30E-21	1.25E-20	1.49E-20	2.10E-20	4.82E-21
SN-113	2.46E-04	3.70E-04	1.01E-04	1.79E-03	1.60E-03	3.04E-03	9.73E-04
SN-119M	3.39E-04	5.15E-04	1.37E-04	2.44E-03	2.19E-03	4.18E-03	1.34E-03
SN-121M	4.36E-04	6.60E-04	1.77E-04	3.15E-03	2.83E-03	5.39E-03	1.73E-03
SN-123	2.61E-04	3.92E-04	1.06E-04	1.89E-03	1.69E-03	3.22E-03	1.03E-03
SN-125	6.72E-06	9.19E-06	2.88E-06	4.84E-05	4.26E-05	7.92E-05	2.50E-05
SN-126	4.50E-04	6.73E-04	1.84E-04	3.29E-03	2.93E-03	5.56E-03	1.78E-03
SB-124	7.47E-05	4.39E-05	4.51E-05	8.31E-04	5.80E-04	9.41E-04	2.78E-04
SB-125	1.74E-04	1.04E-04	1.05E-04	1.93E-03	1.35E-03	2.19E-03	6.48E-04
SB-126	6.22E-06	3.64E-06	3.71E-06	6.58E-05	4.65E-05	7.52E-05	2.20E-05
SB-126M	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
SB-127	1.43E-07	7.19E-08	8.72E-08	1.50E-06	1.05E-06	1.68E-06	4.85E-07
TE-125M	1.73E-04	2.36E-04	7.63E-05	1.40E-03	1.18E-03	2.18E-03	6.89E-04
TE-127M	2.83E-04	3.83E-04	1.25E-04	2.30E-03	1.93E-03	3.57E-03	1.13E-03
TE-127	2.25E-11	1.25E-11	1.11E-11	6.04E-11	7.22E-11	1.01E-10	2.33E-11
TE-129M	9.52E-05	1.30E-04	4.20E-05	7.67E-04	6.47E-04	1.20E-03	3.79E-04
TE-129	1.19E-23	6.64E-24	5.88E-24	3.20E-23	3.82E-23	5.37E-23	1.23E-23
TE-131M	1.44E-09	7.73E-10	7.61E-10	7.33E-09	6.45E-09	9.66E-09	2.53E-09
TE-131	1.40E-45	0.00E+00	0.00E+00	1.40E-45	2.80E-45	4.20E-45	1.40E-45
TE-132	1.49E-07	8.72E-08	8.98E-08	1.64E-06	1.15E-06	1.86E-06	5.47E-07
TE-133M	9.61E-27	5.36E-27	4.75E-27	2.58E-26	3.08E-26	4.33E-26	9.94E-27
TE-134	2.36E-31	1.31E-31	1.16E-31	6.33E-31	7.57E-31	1.06E-30	2.44E-31
I-129	3.46E-04	1.86E-04	2.10E-04	3.72E-03	2.61E-03	4.18E-03	1.22E-03
I-130	1.03E-10	5.72E-11	5.07E-11	2.75E-10	3.29E-10	4.63E-10	1.06E-10
I-131	2.78E-06	1.52E-06	1.58E-06	2.24E-05	1.69E-05	2.66E-05	7.50E-06
I-132	3.57E-17	1.99E-17	1.76E-17	9.57E-17	1.14E-16	1.61E-16	3.69E-17
I-133	9.23E-10	5.14E-10	4.56E-10	2.49E-09	2.97E-09	4.17E-09	9.59E-10
I-134	4.23E-28	2.36E-28	2.09E-28	1.14E-27	1.36E-27	1.91E-27	4.38E-28
I-135	3.48E-12	1.94E-12	1.72E-12	9.34E-12	1.12E-11	1.57E-11	3.60E-12
CS-134M	2.31E-15	1.29E-15	1.14E-15	6.21E-15	7.42E-15	1.04E-14	2.39E-15

Table D.6. Food Transfer Factors (Continued)

CS-134	2.28E-04	1.34E-04	1.31E-04	2.03E-03	1.50E-03	2.40E-03	6.91E-04
CS-135	3.20E-04	1.82E-04	1.87E-04	3.04E-03	2.20E-03	3.52E-03	1.02E-03
CS-136	1.24E-05	7.12E-06	6.85E-06	8.86E-05	6.97E-05	1.09E-04	3.04E-05
CS-137	2.72E-04	1.58E-04	1.57E-04	2.49E-03	1.82E-03	2.91E-03	8.40E-04
CS-138	9.48E-39	5.28E-39	4.68E-39	2.54E-38	3.04E-38	4.27E-38	9.80E-39
CS-139	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
BA-137M	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
BA-139	4.91E-23	2.73E-23	2.42E-23	1.32E-22	1.57E-22	2.21E-22	5.07E-23
BA-140	6.07E-06	3.44E-06	3.71E-06	6.92E-05	4.79E-05	7.76E-05	2.29E-05
BA-141	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
BA-142	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
LA-140	1.06E-09	5.02E-10	6.72E-10	1.28E-08	8.67E-09	1.39E-08	4.06E-09
LA-141	2.49E-17	1.39E-17	1.23E-17	6.69E-17	7.99E-17	1.12E-16	2.58E-17
LA-142	3.83E-24	2.13E-24	1.89E-24	1.03E-23	1.23E-23	1.73E-23	3.96E-24
CE-141	3.46E-05	1.76E-05	2.16E-05	4.05E-04	2.77E-04	4.45E-04	1.31E-04
CE-143	6.29E-10	3.32E-10	3.42E-10	3.80E-09	3.14E-09	4.76E-09	1.28E-09
CE-144	1.35E-04	6.95E-05	8.43E-05	1.59E-03	1.09E-03	1.75E-03	5.13E-04
PR-143	7.07E-06	4.31E-06	4.28E-06	8.14E-05	5.65E-05	9.23E-05	2.74E-05
PR-144	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
PR-144M	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
ND-147	4.00E-06	2.27E-06	2.46E-06	4.69E-05	3.23E-05	5.24E-05	1.55E-05
PM-146	1.71E-04	1.07E-04	1.03E-04	1.95E-03	1.36E-03	2.23E-03	6.62E-04
PM-147	1.64E-04	1.03E-04	9.88E-05	1.88E-03	1.31E-03	2.14E-03	6.36E-04
PM-148M	4.99E-05	3.04E-05	3.02E-05	5.75E-04	3.99E-04	6.51E-04	1.93E-04
PM-148	4.41E-07	2.32E-07	2.75E-07	5.23E-06	3.58E-06	5.77E-06	1.70E-06
PM-149	7.55E-09	3.62E-09	4.79E-09	9.13E-08	6.19E-08	9.90E-08	2.91E-08
PM-151	5.22E-11	2.49E-11	3.28E-11	6.12E-10	4.17E-10	6.67E-10	1.95E-10
SM-147	1.95E-04	1.21E-04	1.18E-04	2.24E-03	1.56E-03	2.54E-03	7.55E-04
SM-151	1.88E-04	1.17E-04	1.13E-04	2.15E-03	1.50E-03	2.45E-03	7.29E-04
SM-153	3.28E-09	1.56E-09	2.08E-09	3.96E-08	2.68E-08	4.29E-08	1.26E-08
EU-152	1.76E-04	1.10E-04	1.06E-04	2.01E-03	1.40E-03	2.30E-03	6.82E-04
EU-154	1.74E-04	1.09E-04	1.05E-04	1.99E-03	1.39E-03	2.27E-03	6.74E-04
EU-155	1.70E-04	1.06E-04	1.02E-04	1.94E-03	1.35E-03	2.21E-03	6.58E-04
EU-156	9.12E-06	5.60E-06	5.52E-06	1.05E-04	7.29E-05	1.19E-04	3.54E-05
GD-153	1.33E-04	7.80E-05	8.12E-05	1.54E-03	1.07E-03	1.74E-03	5.15E-04
TB-160	8.03E-05	4.83E-05	4.88E-05	9.28E-04	6.43E-04	1.05E-03	3.11E-04
HO-166M	1.93E-04	1.16E-04	1.17E-04	2.23E-03	1.54E-03	2.52E-03	7.47E-04
W-181	1.04E-04	5.36E-05	6.49E-05	1.23E-03	8.38E-04	1.35E-03	3.96E-04
W-185	7.81E-05	4.01E-05	4.87E-05	9.19E-04	6.29E-04	1.01E-03	2.97E-04
W-187	1.30E-10	7.20E-11	6.55E-11	4.25E-10	4.58E-10	6.56E-10	1.57E-10
TL-207	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
TL-208	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
PB-209	6.61E-16	3.68E-16	3.26E-16	1.77E-15	2.12E-15	2.98E-15	6.84E-16
PB-210	3.02E-04	1.45E-04	1.91E-04	3.62E-03	2.46E-03	3.93E-03	1.15E-03

Table D.6. Food Transfer Factors (Continued)

PB-211	1.56E-36	8.68E-37	7.69E-37	4.18E-36	4.99E-36	7.02E-36	1.61E-36
PB-212	6.43E-12	3.58E-12	3.17E-12	1.73E-11	2.06E-11	2.90E-11	6.65E-12
BI-210	4.26E-07	2.48E-07	2.58E-07	4.76E-06	3.32E-06	5.38E-06	1.59E-06
BI-211	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
BI-212	2.03E-26	1.13E-26	1.00E-26	5.45E-26	6.51E-26	9.15E-26	2.10E-26
BI-213	3.26E-31	1.81E-31	1.61E-31	8.74E-31	1.04E-30	1.47E-30	3.37E-31
PO-210	1.36E-04	1.06E-04	7.72E-05	1.45E-03	1.05E-03	1.76E-03	5.28E-04
PO-212	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
PO-213	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
PO-215	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
PO-216	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
AT-217	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
FR-221	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
FR-223	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
RA-223	1.00E-05	9.39E-06	4.94E-06	7.06E-05	5.89E-05	1.01E-04	3.00E-05
RA-224	2.08E-07	1.20E-07	1.14E-07	1.48E-06	1.16E-06	1.82E-06	5.09E-07
RA-225	1.81E-05	1.77E-05	8.86E-06	1.32E-04	1.09E-04	1.89E-04	5.67E-05
RA-226	3.21E-04	3.48E-04	1.55E-04	2.58E-03	2.10E-03	3.70E-03	1.13E-03
RA-228	3.05E-04	3.33E-04	1.47E-04	2.44E-03	1.99E-03	3.51E-03	1.08E-03
AC-225	5.77E-06	7.79E-06	2.58E-06	4.78E-05	3.99E-05	7.36E-05	2.32E-05
AC-227	3.51E-04	5.02E-04	1.50E-04	2.78E-03	2.38E-03	4.45E-03	1.42E-03
AC-228	1.54E-15	8.60E-16	7.62E-16	4.14E-15	4.95E-15	6.96E-15	1.60E-15
TH-227	1.33E-05	6.36E-06	8.41E-06	1.60E-04	1.09E-04	1.74E-04	5.11E-05
TH-228	1.48E-04	7.10E-05	9.37E-05	1.79E-03	1.21E-03	1.94E-03	5.70E-04
TH-229	1.90E-04	9.13E-05	1.21E-04	2.30E-03	1.56E-03	2.50E-03	7.33E-04
TH-230	1.91E-04	9.13E-05	1.21E-04	2.31E-03	1.56E-03	2.50E-03	7.34E-04
TH-231	1.86E-11	8.91E-12	1.16E-11	2.11E-10	1.45E-10	2.31E-10	6.72E-11
TH-232	1.91E-04	9.14E-05	1.21E-04	2.31E-03	1.56E-03	2.50E-03	7.34E-04
TH-234	2.17E-05	1.04E-05	1.37E-05	2.62E-04	1.78E-04	2.84E-04	8.34E-05
PA-231	1.00E+00	1.00E+00	6.30E-01	1.00E+00	1.00E+00	1.00E+00	1.00E+00
PA-233	3.46E-01	7.86E-01	8.55E-02	1.00E+00	1.00E+00	1.00E+00	1.00E+00
PA-234M	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
U-232	1.74E-04	8.47E-05	1.10E-04	2.08E-03	1.41E-03	2.26E-03	6.63E-04
U-233	1.83E-04	8.88E-05	1.15E-04	2.18E-03	1.48E-03	2.37E-03	6.96E-04
U-234	1.83E-04	8.88E-05	1.15E-04	2.18E-03	1.48E-03	2.37E-03	6.96E-04
U-235	1.83E-04	8.88E-05	1.15E-04	2.18E-03	1.48E-03	2.37E-03	6.96E-04
U-236	1.83E-04	8.88E-05	1.15E-04	2.18E-03	1.48E-03	2.37E-03	6.96E-04
U-237	9.55E-07	4.62E-07	5.97E-07	1.10E-05	7.54E-06	1.20E-05	3.52E-06
U-238	1.83E-04	8.88E-05	1.15E-04	2.18E-03	1.48E-03	2.37E-03	6.96E-04
NP-236	1.79E-04	8.60E-05	1.14E-04	2.17E-03	1.47E-03	2.35E-03	6.91E-04
NP-237	1.79E-04	8.60E-05	1.14E-04	2.17E-03	1.47E-03	2.35E-03	6.91E-04
NP-238	5.37E-09	2.54E-09	3.41E-09	6.51E-08	4.40E-08	7.04E-08	2.07E-08
NP-239	1.06E-08	5.02E-09	6.74E-09	1.29E-07	8.70E-08	1.39E-07	4.08E-08
PU-236	1.50E-04	7.11E-05	9.54E-05	1.82E-03	1.23E-03	1.97E-03	5.78E-04

Table D.6. Food Transfer Factors (Continued)

PU-237	4.97E-05	2.35E-05	3.16E-05	6.02E-04	4.08E-04	6.52E-04	1.91E-04
PU-238	1.62E-04	7.66E-05	1.03E-04	1.96E-03	1.33E-03	2.12E-03	6.23E-04
PU-239	1.64E-04	7.76E-05	1.04E-04	1.99E-03	1.35E-03	2.15E-03	6.31E-04
PU-240	1.64E-04	7.76E-05	1.04E-04	1.99E-03	1.34E-03	2.15E-03	6.31E-04
PU-241	1.58E-04	7.50E-05	1.01E-04	1.92E-03	1.30E-03	2.08E-03	6.09E-04
PU-242	1.64E-04	7.76E-05	1.04E-04	1.99E-03	1.35E-03	2.15E-03	6.31E-04
PU-244	1.64E-04	7.76E-05	1.04E-04	1.99E-03	1.35E-03	2.15E-03	6.31E-04
AM-241	1.64E-04	7.87E-05	1.04E-04	1.98E-03	1.34E-03	2.15E-03	6.31E-04
AM-242M	1.63E-04	7.83E-05	1.03E-04	1.97E-03	1.34E-03	2.14E-03	6.28E-04
AM-243	1.65E-04	7.90E-05	1.04E-04	1.99E-03	1.35E-03	2.16E-03	6.34E-04
CM-242	1.12E-04	5.36E-05	7.08E-05	1.35E-03	9.16E-04	1.47E-03	4.30E-04
CM-243	1.66E-04	7.95E-05	1.05E-04	2.01E-03	1.36E-03	2.18E-03	6.38E-04
CM-244	1.63E-04	7.84E-05	1.04E-04	1.98E-03	1.34E-03	2.14E-03	6.29E-04
CM-245	1.79E-04	8.60E-05	1.14E-04	2.17E-03	1.47E-03	2.35E-03	6.90E-04
CM-246	1.79E-04	8.59E-05	1.14E-04	2.17E-03	1.47E-03	2.35E-03	6.90E-04
CM-247	1.79E-04	8.60E-05	1.14E-04	2.17E-03	1.47E-03	2.35E-03	6.91E-04
CM-248	1.79E-04	8.60E-05	1.14E-04	2.17E-03	1.47E-03	2.35E-03	6.91E-04
CF-252	1.51E-04	7.23E-05	9.55E-05	1.82E-03	1.23E-03	1.98E-03	5.80E-04
Nuclide	**State**						
	KY	**LA**	**ME**	**MD**	**MA**	**MI**	**MN**
H-3	2.93E-07	4.78E-08	1.43E-08	5.12E-07	2.68E-08	2.63E-07	7.61E-07
BE-10	2.18E-04	5.23E-05	8.76E-06	2.89E-04	4.96E-06	1.79E-04	6.03E-04
C-14	4.13E-06	1.00E-06	1.78E-07	6.35E-06	2.17E-07	3.29E-06	1.09E-05
N-16	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
F-18	7.18E-18	1.47E-18	3.75E-19	1.42E-17	2.00E-18	5.99E-18	1.52E-17
NA-22	8.76E-04	2.04E-04	4.49E-05	1.79E-03	1.68E-04	6.75E-04	1.96E-03
NA-24	4.15E-09	8.48E-10	2.17E-10	8.21E-09	1.15E-09	3.46E-09	8.77E-09
P-32	5.79E-05	1.35E-05	2.99E-06	1.20E-04	1.12E-05	4.44E-05	1.29E-04
CA-41	6.75E-04	1.58E-04	2.90E-05	1.01E-03	5.09E-05	5.52E-04	1.77E-03
SC-46	1.36E-04	3.60E-05	6.30E-06	2.51E-04	5.42E-06	9.93E-05	3.49E-04
CR-51	4.28E-05	1.01E-05	1.82E-06	6.31E-05	2.80E-06	3.49E-05	1.13E-04
MN-54	1.78E-04	4.26E-05	7.15E-06	2.36E-04	4.44E-06	1.47E-04	4.92E-04
MN-56	2.13E-17	4.36E-18	1.11E-18	4.22E-17	5.93E-18	1.78E-17	4.51E-17
FE-55	3.68E-04	1.05E-04	1.93E-05	8.67E-04	2.52E-05	2.34E-04	8.56E-04
FE-59	1.14E-04	3.21E-05	5.91E-06	2.61E-04	7.78E-06	7.47E-05	2.70E-04
CO-57	2.19E-04	5.65E-05	1.00E-05	3.91E-04	1.09E-05	1.63E-04	5.60E-04
CO-58	1.26E-04	3.24E-05	5.75E-06	2.23E-04	6.31E-06	9.47E-05	3.25E-04
CO-60	2.74E-04	7.06E-05	1.25E-05	4.89E-04	1.36E-05	2.03E-04	7.00E-04
NI-59	5.02E-04	1.19E-04	2.19E-05	7.77E-04	3.95E-05	4.07E-04	1.30E-03
NI-63	4.42E-04	1.04E-04	1.95E-05	6.95E-04	3.72E-05	3.57E-04	1.14E-03
NI-65	4.36E-16	8.91E-17	2.28E-17	8.62E-16	1.21E-16	3.64E-16	9.21E-16
CU-64	8.79E-10	1.80E-10	4.59E-11	1.74E-09	2.44E-10	7.33E-10	1.86E-09
ZN-65	7.55E-04	1.76E-04	3.84E-05	1.52E-03	1.40E-04	5.85E-04	1.70E-03
ZN-69M	4.63E-09	9.46E-10	2.42E-10	9.16E-09	1.29E-09	3.86E-09	9.79E-09

Table D.6. Food Transfer Factors (Continued)

ZN-69	1.68E-24	3.44E-25	8.79E-26	3.33E-24	4.68E-25	1.40E-24	3.56E-24
SE-79	1.76E-02	4.06E-03	7.85E-04	2.79E-02	1.88E-03	1.44E-02	4.46E-02
BR-82	1.50E-07	3.07E-08	7.83E-09	2.96E-07	4.14E-08	1.25E-07	3.18E-07
BR-83	1.05E-14	2.14E-15	5.46E-16	2.07E-14	2.91E-15	8.73E-15	2.21E-14
BR-84	2.15E-36	4.40E-37	1.12E-37	4.26E-36	5.98E-37	1.80E-36	4.55E-36
BR-85	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
KR-85	6.38E-03	1.52E-03	2.78E-04	9.88E-03	4.71E-04	5.14E-03	1.66E-02
RB-86	8.94E-05	2.03E-05	4.60E-06	1.82E-04	1.86E-05	7.01E-05	1.98E-04
RB-87	2.32E-03	5.53E-04	1.08E-04	4.08E-03	2.65E-04	1.83E-03	5.72E-03
RB-88	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
RB-89	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
SR-89	7.61E-05	1.80E-05	3.09E-06	1.02E-04	2.67E-06	6.30E-05	2.08E-04
SR-90	2.72E-04	6.47E-05	1.10E-05	3.62E-04	8.52E-06	2.25E-04	7.48E-04
SR-91	1.02E-11	2.09E-12	5.35E-13	2.03E-11	2.85E-12	8.55E-12	2.17E-11
SR-92	1.38E-16	2.82E-17	7.20E-18	2.73E-16	3.83E-17	1.15E-16	2.91E-16
Y-90	2.78E-08	6.62E-09	1.10E-09	3.58E-08	5.74E-10	2.31E-08	7.73E-08
Y-91M	1.86E-31	3.80E-32	9.71E-33	3.68E-31	5.17E-32	1.55E-31	3.93E-31
Y-91	8.65E-05	2.13E-05	3.61E-06	1.27E-04	2.28E-06	6.89E-05	2.34E-04
Y-92	4.96E-17	1.01E-17	2.59E-18	9.81E-17	1.38E-17	4.14E-17	1.05E-16
Y-93	1.63E-13	3.32E-14	8.49E-15	3.22E-13	4.52E-14	1.36E-13	3.44E-13
ZR-93	3.57E-04	1.01E-04	1.83E-05	8.11E-04	1.98E-05	2.31E-04	8.48E-04
ZR-95	1.47E-04	4.13E-05	7.44E-06	3.26E-04	7.84E-06	9.66E-05	3.53E-04
ZR-97	1.10E-12	2.30E-13	5.53E-14	2.06E-12	2.63E-13	9.18E-13	2.44E-12
NB-93M	1.45E-03	4.75E-04	9.17E-05	4.77E-03	1.42E-04	6.67E-04	2.82E-03
NB-94	1.60E-03	5.21E-04	1.00E-04	5.17E-03	1.53E-04	7.58E-04	3.16E-03
NB-95M	2.71E-07	7.08E-08	1.39E-08	5.88E-07	3.10E-08	1.90E-07	6.29E-07
NB-95	2.97E-04	9.70E-05	1.87E-05	9.69E-04	2.94E-05	1.39E-04	5.83E-04
NB-97	1.87E-23	3.82E-24	9.77E-25	3.70E-23	5.20E-24	1.56E-23	3.95E-23
MO-93	1.46E-03	3.47E-04	6.16E-05	2.13E-03	8.10E-05	1.18E-03	3.88E-03
MO-99	1.25E-07	2.69E-08	6.05E-09	2.21E-07	2.50E-08	1.04E-07	2.90E-07
TC-99M	3.03E-11	6.20E-12	1.58E-12	6.00E-11	8.44E-12	2.53E-11	6.41E-11
TC-99	7.60E-03	2.26E-03	4.37E-04	2.09E-02	7.64E-04	4.36E-03	1.62E-02
TC-101	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
RU-103	4.63E-04	1.55E-04	2.99E-05	1.58E-03	4.46E-05	2.02E-04	8.86E-04
RU-105	6.45E-17	1.32E-17	3.37E-18	1.28E-16	1.80E-17	5.39E-17	1.36E-16
RU-106	1.60E-03	5.38E-04	1.04E-04	5.49E-03	1.55E-04	6.93E-04	3.04E-03
RH-103M	3.10E-23	6.33E-24	1.62E-24	6.13E-23	8.62E-24	2.59E-23	6.55E-23
RH-105	2.16E-07	4.47E-08	1.11E-08	4.17E-07	5.64E-08	1.80E-07	4.67E-07
RH-106	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
PD-107	4.78E-02	1.13E-02	1.96E-03	6.54E-02	2.14E-03	3.95E-02	1.30E-01
PD-109	6.83E-09	1.40E-09	3.57E-10	1.35E-08	1.90E-09	5.70E-09	1.44E-08
AG-110M	8.05E-04	1.79E-04	4.07E-05	1.56E-03	1.68E-04	6.46E-04	1.80E-03
AG-111	1.90E-05	3.99E-06	9.77E-07	3.70E-05	4.81E-06	1.57E-05	4.12E-05
CD-113M	7.86E-04	1.87E-04	3.12E-05	1.01E-03	1.61E-05	6.52E-04	2.19E-03

Table D.6. Food Transfer Factors (Continued)

CD-115M	2.82E-19	5.76E-20	1.47E-20	5.58E-19	7.84E-20	2.35E-19	5.96E-19
IN-113M	1.07E-20	2.20E-21	5.61E-22	2.13E-20	2.99E-21	8.97E-21	2.27E-20
SN-113	3.39E-04	1.01E-04	1.92E-05	9.14E-04	2.91E-05	1.95E-04	7.37E-04
SN-119M	4.65E-04	1.40E-04	2.65E-05	1.27E-03	4.02E-05	2.66E-04	1.01E-03
SN-121M	5.98E-04	1.79E-04	3.39E-05	1.62E-03	5.10E-05	3.42E-04	1.30E-03
SN-123	3.58E-04	1.07E-04	2.03E-05	9.68E-04	3.08E-05	2.06E-04	7.79E-04
SN-125	9.67E-06	2.75E-06	5.34E-07	2.45E-05	1.03E-06	6.01E-06	2.13E-05
SN-126	6.16E-04	1.84E-04	3.48E-05	1.66E-03	5.19E-05	3.55E-04	1.34E-03
SB-124	1.01E-04	2.43E-05	4.28E-06	1.50E-04	4.96E-06	8.10E-05	2.68E-04
SB-125	2.33E-04	5.66E-05	9.93E-06	3.50E-04	1.11E-05	1.87E-04	6.21E-04
SB-126	8.76E-06	2.08E-06	3.81E-07	1.35E-05	6.40E-07	7.07E-06	2.28E-05
SB-126M	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
SB-127	2.08E-07	4.79E-08	8.97E-09	3.08E-07	1.82E-08	1.73E-07	5.43E-07
TE-125M	2.32E-04	6.81E-05	1.26E-05	5.86E-04	1.64E-05	1.41E-04	5.27E-04
TE-127M	3.79E-04	1.11E-04	2.05E-05	9.51E-04	2.63E-05	2.30E-04	8.62E-04
TE-127	5.19E-11	1.06E-11	2.71E-12	1.03E-10	1.44E-11	4.33E-11	1.10E-10
TE-129M	1.28E-04	3.75E-05	6.96E-06	3.22E-04	9.16E-06	7.77E-05	2.90E-04
TE-129	2.75E-23	5.62E-24	1.44E-24	5.44E-23	7.65E-24	2.30E-23	5.82E-23
TE-131M	2.94E-09	6.17E-10	1.47E-10	5.48E-09	6.94E-10	2.45E-09	6.53E-09
TE-131	1.40E-45	0.00E+00	0.00E+00	4.20E-45	0.00E+00	1.40E-45	4.20E-45
TE-132	2.04E-07	4.90E-08	8.71E-09	3.07E-07	1.15E-08	1.64E-07	5.39E-07
TE-133M	2.22E-26	4.54E-27	1.16E-27	4.39E-26	6.17E-27	1.85E-26	4.69E-26
TE-134	5.45E-31	1.11E-31	2.84E-32	1.08E-30	1.51E-31	4.54E-31	1.15E-30
I-129	4.89E-04	1.15E-04	2.09E-05	7.25E-04	3.55E-05	4.01E-04	1.28E-03
I-130	2.37E-10	4.84E-11	1.24E-11	4.69E-10	6.59E-11	1.98E-10	5.01E-10
I-131	4.74E-06	1.05E-06	2.23E-07	8.09E-06	7.79E-07	3.91E-06	1.14E-05
I-132	8.23E-17	1.68E-17	4.30E-18	1.63E-16	2.29E-17	6.87E-17	1.74E-16
I-133	2.13E-09	4.35E-10	1.11E-10	4.21E-09	5.92E-10	1.78E-09	4.50E-09
I-134	9.77E-28	2.00E-28	5.10E-29	1.93E-27	2.72E-28	8.15E-28	2.07E-27
I-135	8.04E-12	1.64E-12	4.20E-13	1.59E-11	2.24E-12	6.71E-12	1.70E-11
CS-134M	5.34E-15	1.09E-15	2.79E-16	1.06E-14	1.49E-15	4.46E-15	1.13E-14
CS-134	3.64E-04	8.31E-05	1.68E-05	6.12E-04	4.90E-05	2.96E-04	8.93E-04
CS-135	4.94E-04	1.13E-04	2.23E-05	8.01E-04	5.81E-05	4.03E-04	1.24E-03
CS-136	2.24E-05	4.90E-06	1.08E-06	3.99E-05	4.20E-06	1.84E-05	5.21E-05
CS-137	4.28E-04	9.79E-05	1.96E-05	7.09E-04	5.46E-05	3.48E-04	1.06E-03
CS-138	2.19E-38	4.47E-39	1.14E-39	4.33E-38	6.08E-39	1.83E-38	4.62E-38
CS-139	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
BA-137M	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
BA-139	1.13E-22	2.31E-23	5.91E-24	2.24E-22	3.15E-23	9.45E-23	2.39E-22
BA-140	8.04E-06	1.94E-06	3.36E-07	1.16E-05	3.13E-07	6.50E-06	2.17E-05
BA-141	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
BA-142	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
LA-140	1.37E-09	3.25E-10	5.43E-11	1.75E-09	2.99E-11	1.14E-09	3.81E-09
LA-141	5.75E-17	1.18E-17	3.00E-18	1.14E-16	1.60E-17	4.80E-17	1.22E-16

Table D.6. Food Transfer Factors (Continued)

LA-142	8.84E-24	1.81E-24	4.61E-25	1.75E-23	2.46E-24	7.37E-24	1.87E-23
CE-141	4.55E-05	1.09E-05	1.85E-06	6.18E-05	1.54E-06	3.75E-05	1.24E-04
CE-143	1.22E-09	2.60E-10	6.03E-11	2.22E-09	2.66E-10	1.02E-09	2.78E-09
CE-144	1.77E-04	4.24E-05	7.21E-06	2.41E-04	5.57E-06	1.46E-04	4.85E-04
PR-143	9.14E-06	2.26E-06	3.82E-07	1.34E-05	2.43E-07	7.27E-06	2.47E-05
PR-144	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
PR-144M	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
ND-147	5.17E-06	1.26E-06	2.12E-07	7.28E-06	1.26E-07	4.17E-06	1.41E-05
PM-146	2.21E-04	5.47E-05	9.29E-06	3.30E-04	6.02E-06	1.75E-04	5.96E-04
PM-147	2.12E-04	5.26E-05	8.93E-06	3.17E-04	5.79E-06	1.68E-04	5.72E-04
PM-148M	6.45E-05	1.59E-05	2.70E-06	9.48E-05	1.70E-06	5.13E-05	1.75E-04
PM-148	5.68E-07	1.37E-07	2.30E-08	7.68E-07	1.27E-08	4.64E-07	1.57E-06
PM-149	9.73E-09	2.32E-09	3.86E-10	1.25E-08	1.98E-10	8.08E-09	2.71E-08
PM-151	6.93E-11	1.63E-11	2.80E-12	9.18E-11	2.60E-12	5.76E-11	1.90E-10
SM-147	2.52E-04	6.24E-05	1.06E-05	3.74E-04	6.80E-06	2.00E-04	6.81E-04
SM-151	2.43E-04	6.03E-05	1.02E-05	3.63E-04	6.62E-06	1.93E-04	6.56E-04
SM-153	4.22E-09	1.01E-09	1.67E-10	5.42E-09	8.77E-11	3.51E-09	1.18E-08
EU-152	2.27E-04	5.64E-05	9.57E-06	3.39E-04	6.19E-06	1.80E-04	6.14E-04
EU-154	2.25E-04	5.57E-05	9.45E-06	3.35E-04	6.12E-06	1.78E-04	6.06E-04
EU-155	2.19E-04	5.44E-05	9.24E-06	3.28E-04	5.99E-06	1.74E-04	5.92E-04
EU-156	1.18E-05	2.92E-06	4.94E-07	1.74E-05	3.16E-07	9.38E-06	3.19E-05
GD-153	1.72E-04	4.21E-05	7.12E-06	2.47E-04	4.34E-06	1.38E-04	4.67E-04
TB-160	1.04E-04	2.56E-05	4.33E-06	1.52E-04	2.71E-06	8.28E-05	2.82E-04
HO-166M	2.49E-04	6.14E-05	1.04E-05	3.64E-04	6.52E-06	1.99E-04	6.75E-04
W-181	1.36E-04	3.26E-05	5.53E-06	1.84E-04	4.08E-06	1.12E-04	3.73E-04
W-185	1.02E-04	2.45E-05	4.15E-06	1.38E-04	3.09E-06	8.40E-05	2.80E-04
W-187	2.93E-10	6.02E-11	1.52E-11	5.72E-10	7.89E-11	2.44E-10	6.26E-10
TL-207	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
TL-208	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
PB-209	1.53E-15	3.12E-16	7.97E-17	3.02E-15	4.24E-16	1.27E-15	3.23E-15
PB-210	3.93E-04	9.34E-05	1.57E-05	5.11E-04	1.03E-05	3.26E-04	1.09E-03
PB-211	3.59E-36	7.35E-37	1.88E-37	7.11E-36	1.00E-36	3.00E-36	7.60E-36
PB-212	1.48E-11	3.03E-12	7.75E-13	2.94E-11	4.13E-12	1.24E-11	3.14E-11
BI-210	5.73E-07	1.38E-07	2.43E-08	8.48E-07	2.73E-08	4.62E-07	1.53E-06
BI-211	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
BI-212	4.68E-26	9.57E-27	2.45E-27	9.27E-26	1.30E-26	3.91E-26	9.90E-26
BI-213	7.52E-31	1.54E-31	3.92E-32	1.49E-30	2.09E-31	6.27E-31	1.59E-30
PO-210	1.78E-04	4.58E-05	7.99E-06	3.06E-04	6.97E-06	1.34E-04	4.63E-04
PO-212	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
PO-213	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
PO-215	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
PO-216	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
AT-217	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
FR-221	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

Table D.6. Food Transfer Factors (Continued)

FR-223	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
RA-223	1.65E-05	4.03E-06	8.44E-07	3.45E-05	2.60E-06	1.22E-05	3.74E-05
RA-224	3.75E-07	8.22E-08	1.82E-08	6.72E-07	7.06E-08	3.08E-07	8.73E-07
RA-225	2.89E-05	7.22E-06	1.49E-06	6.14E-05	4.23E-06	2.11E-05	6.60E-05
RA-226	4.72E-04	1.25E-04	2.43E-05	1.04E-03	5.15E-05	3.27E-04	1.09E-03
RA-228	4.50E-04	1.19E-04	2.32E-05	9.93E-04	4.95E-05	3.11E-04	1.04E-03
AC-225	7.67E-06	2.25E-06	4.13E-07	1.91E-05	4.87E-07	4.64E-06	1.75E-05
AC-227	4.67E-04	1.39E-04	2.58E-05	1.22E-03	3.15E-05	2.73E-04	1.05E-03
AC-228	3.56E-15	7.29E-16	1.86E-16	7.05E-15	9.92E-16	2.97E-15	7.54E-15
TH-227	1.71E-05	4.07E-06	6.77E-07	2.19E-05	3.38E-07	1.42E-05	4.75E-05
TH-228	1.90E-04	4.54E-05	7.55E-06	2.45E-04	3.76E-06	1.58E-04	5.30E-04
TH-229	2.45E-04	5.84E-05	9.71E-06	3.15E-04	4.83E-06	2.04E-04	6.83E-04
TH-230	2.45E-04	5.85E-05	9.72E-06	3.15E-04	4.83E-06	2.04E-04	6.83E-04
TH-231	2.54E-11	5.94E-12	1.05E-12	3.49E-11	1.40E-12	2.12E-11	6.86E-11
TH-232	2.45E-04	5.85E-05	9.72E-06	3.15E-04	4.84E-06	2.04E-04	6.83E-04
TH-234	2.79E-05	6.64E-06	1.10E-06	3.58E-05	5.51E-07	2.31E-05	7.76E-05
PA-231	1.00E+00	1.00E+00	2.38E-01	1.00E+00	3.74E-01	1.00E+00	1.00E+00
PA-233	4.74E-01	1.65E-01	3.23E-02	1.00E+00	5.07E-02	1.81E-01	8.48E-01
PA-234M	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
U-232	2.28E-04	5.41E-05	9.13E-06	2.99E-04	6.38E-06	1.89E-04	6.28E-04
U-233	2.39E-04	5.67E-05	9.57E-06	3.13E-04	6.61E-06	1.98E-04	6.59E-04
U-234	2.39E-04	5.67E-05	9.57E-06	3.13E-04	6.61E-06	1.98E-04	6.59E-04
U-235	2.39E-04	5.67E-05	9.57E-06	3.13E-04	6.61E-06	1.98E-04	6.59E-04
U-236	2.39E-04	5.67E-05	9.57E-06	3.13E-04	6.61E-06	1.98E-04	6.59E-04
U-237	1.29E-06	3.02E-07	5.27E-08	1.74E-06	5.94E-08	1.07E-06	3.50E-06
U-238	2.39E-04	5.67E-05	9.57E-06	3.13E-04	6.61E-06	1.98E-04	6.59E-04
NP-236	2.31E-04	5.50E-05	9.15E-06	2.97E-04	4.56E-06	1.92E-04	6.43E-04
NP-237	2.31E-04	5.50E-05	9.15E-06	2.97E-04	4.56E-06	1.92E-04	6.43E-04
NP-238	6.93E-09	1.65E-09	2.74E-10	8.85E-09	1.40E-10	5.76E-09	1.93E-08
NP-239	1.37E-08	3.25E-09	5.41E-10	1.74E-08	2.73E-10	1.14E-08	3.81E-08
PU-236	1.93E-04	4.60E-05	7.64E-06	2.46E-04	3.74E-06	1.61E-04	5.39E-04
PU-237	6.39E-05	1.52E-05	2.53E-06	8.15E-05	1.24E-06	5.32E-05	1.78E-04
PU-238	2.08E-04	4.96E-05	8.23E-06	2.66E-04	4.03E-06	1.73E-04	5.81E-04
PU-239	2.11E-04	5.02E-05	8.34E-06	2.69E-04	4.09E-06	1.75E-04	5.88E-04
PU-240	2.11E-04	5.02E-05	8.34E-06	2.69E-04	4.09E-06	1.75E-04	5.88E-04
PU-241	2.04E-04	4.85E-05	8.05E-06	2.60E-04	3.95E-06	1.69E-04	5.68E-04
PU-242	2.11E-04	5.02E-05	8.34E-06	2.69E-04	4.09E-06	1.75E-04	5.88E-04
PU-244	2.11E-04	5.02E-05	8.34E-06	2.69E-04	4.09E-06	1.75E-04	5.88E-04
AM-241	2.11E-04	5.03E-05	8.37E-06	2.71E-04	4.17E-06	1.75E-04	5.88E-04
AM-242M	2.10E-04	5.01E-05	8.33E-06	2.70E-04	4.15E-06	1.74E-04	5.85E-04
AM-243	2.12E-04	5.05E-05	8.39E-06	2.72E-04	4.18E-06	1.76E-04	5.90E-04
CM-242	1.44E-04	3.43E-05	5.70E-06	1.85E-04	2.84E-06	1.19E-04	4.01E-04
CM-243	2.13E-04	5.09E-05	8.46E-06	2.74E-04	4.21E-06	1.77E-04	5.94E-04
CM-244	2.10E-04	5.01E-05	8.34E-06	2.70E-04	4.16E-06	1.75E-04	5.86E-04

Table D.6. Food Transfer Factors (Continued)

CM-245	2.31E-04	5.50E-05	9.15E-06	2.96E-04	4.55E-06	1.92E-04	6.43E-04
CM-246	2.31E-04	5.50E-05	9.14E-06	2.96E-04	4.55E-06	1.91E-04	6.42E-04
CM-247	2.31E-04	5.50E-05	9.15E-06	2.97E-04	4.56E-06	1.92E-04	6.43E-04
CM-248	2.31E-04	5.50E-05	9.15E-06	2.97E-04	4.56E-06	1.92E-04	6.43E-04
CF-252	1.94E-04	4.62E-05	7.69E-06	2.49E-04	3.83E-06	1.61E-04	5.40E-04
Nuclide	**State**						
	MS	**MO**	**MT**	**NE**	**NV**	**NH**	**NJ**
H-3	9.38E-08	4.32E-07	1.74E-07	1.52E-06	3.12E-09	8.35E-09	9.04E-08
BE-10	8.81E-05	3.45E-04	9.12E-05	9.23E-04	1.15E-06	9.17E-07	4.74E-05
C-14	1.78E-06	6.37E-06	1.55E-06	1.59E-05	2.50E-08	6.22E-08	9.48E-07
N-16	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
F-18	1.69E-18	6.01E-18	3.30E-19	3.47E-18	6.20E-20	7.19E-19	2.70E-18
NA-22	3.42E-04	1.04E-03	1.53E-04	1.65E-03	7.28E-06	5.85E-05	2.70E-04
NA-24	9.75E-10	3.47E-09	1.90E-10	2.01E-09	3.58E-11	4.15E-10	1.56E-09
P-32	2.28E-05	6.88E-05	9.88E-06	1.07E-04	4.86E-07	3.92E-06	1.79E-05
CA-41	2.57E-04	9.72E-04	2.31E-04	2.34E-03	4.09E-06	1.61E-05	1.68E-04
SC-46	7.53E-05	2.31E-04	5.41E-05	5.71E-04	9.33E-07	1.30E-06	2.82E-05
CR-51	1.67E-05	6.29E-05	1.52E-05	1.55E-04	2.54E-07	8.62E-07	1.03E-05
MN-54	7.11E-05	2.80E-04	7.39E-05	7.47E-04	9.39E-07	8.99E-07	3.90E-05
MN-56	5.02E-18	1.78E-17	9.79E-19	1.03E-17	1.84E-19	2.14E-18	8.00E-18
FE-55	2.52E-04	6.49E-04	1.32E-04	1.45E-03	3.12E-06	7.09E-06	7.51E-05
FE-59	7.55E-05	1.99E-04	4.10E-05	4.50E-04	9.47E-07	2.20E-06	2.37E-05
CO-57	1.14E-04	3.59E-04	8.35E-05	8.76E-04	1.48E-06	2.96E-06	4.74E-05
CO-58	6.45E-05	2.06E-04	4.82E-05	5.05E-04	8.44E-07	1.71E-06	2.75E-05
CO-60	1.42E-04	4.49E-04	1.04E-04	1.10E-03	1.85E-06	3.66E-06	5.91E-05
NI-59	1.98E-04	7.26E-04	1.69E-04	1.73E-03	3.13E-06	1.26E-05	1.25E-04
NI-63	1.74E-04	6.33E-04	1.45E-04	1.49E-03	2.80E-06	1.20E-05	1.11E-04
NI-65	1.02E-16	3.65E-16	2.00E-17	2.11E-16	3.76E-18	4.36E-17	1.64E-16
CU-64	2.07E-10	7.35E-10	4.03E-11	4.25E-10	7.58E-12	8.79E-11	3.30E-10
ZN-65	2.94E-04	9.07E-04	1.38E-04	1.48E-03	6.19E-06	4.90E-05	2.31E-04
ZN-69M	1.09E-09	3.87E-09	2.12E-10	2.24E-09	3.99E-11	4.63E-10	1.74E-09
ZN-69	3.96E-25	1.41E-24	7.72E-26	8.14E-25	1.45E-26	1.69E-25	6.32E-25
SE-79	6.39E-03	2.38E-02	5.20E-03	5.30E-02	1.14E-04	6.28E-04	4.70E-03
BR-82	3.55E-08	1.27E-07	7.40E-09	7.77E-08	1.29E-09	1.49E-08	5.61E-08
BR-83	2.46E-15	8.74E-15	4.80E-16	5.05E-15	9.02E-17	1.05E-15	3.92E-15
BR-84	5.06E-37	1.80E-36	9.87E-38	1.04E-36	1.86E-38	2.15E-37	8.07E-37
BR-85	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
KR-85	2.56E-03	9.34E-03	2.20E-03	2.24E-02	3.96E-05	1.48E-04	1.56E-03
RB-86	3.22E-05	1.00E-04	1.34E-05	1.44E-04	7.48E-07	6.55E-06	2.87E-05
RB-87	9.55E-04	3.22E-03	6.65E-04	6.91E-03	1.64E-05	8.83E-05	6.15E-04
RB-88	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
RB-89	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
SR-89	2.96E-05	1.17E-04	3.04E-05	3.08E-04	4.09E-07	6.77E-07	1.72E-05
SR-90	1.07E-04	4.22E-04	1.10E-04	1.11E-03	1.45E-06	2.03E-06	6.08E-05

Table D.6. Food Transfer Factors (Continued)

SR-91	2.41E-12	8.57E-12	4.70E-13	4.95E-12	8.84E-14	1.03E-12	3.84E-12
SR-92	3.24E-17	1.15E-16	6.32E-18	6.66E-17	1.19E-18	1.38E-17	5.17E-17
Y-90	1.10E-08	4.38E-08	1.17E-08	1.18E-07	1.43E-10	9.71E-11	6.04E-09
Y-91M	4.37E-32	1.56E-31	8.53E-33	8.99E-32	1.60E-33	1.86E-32	6.98E-32
Y-91	3.85E-05	1.40E-04	3.58E-05	3.66E-04	4.92E-07	4.55E-07	1.85E-05
Y-92	1.17E-17	4.15E-17	2.27E-18	2.40E-17	4.28E-19	4.96E-18	1.86E-17
Y-93	3.82E-14	1.36E-13	7.46E-15	7.86E-14	1.40E-15	1.63E-14	6.10E-14
ZR-93	2.41E-04	6.37E-04	1.34E-04	1.47E-03	2.91E-06	5.16E-06	7.08E-05
ZR-95	9.69E-05	2.61E-04	5.57E-05	6.07E-04	1.18E-06	2.03E-06	2.93E-05
ZR-97	2.85E-13	1.04E-12	1.13E-13	1.16E-12	8.91E-15	9.39E-14	3.86E-13
NB-93M	1.39E-03	2.86E-03	4.64E-04	5.63E-03	1.64E-05	4.10E-05	2.65E-04
NB-94	1.50E-03	3.15E-03	5.19E-04	6.25E-03	1.78E-05	4.40E-05	2.96E-04
NB-95M	1.49E-07	4.14E-07	7.83E-08	8.54E-07	2.23E-09	1.01E-08	6.68E-08
NB-95	2.81E-04	5.84E-04	9.49E-05	1.15E-03	3.35E-06	8.56E-06	5.53E-05
NB-97	4.40E-24	1.56E-23	8.58E-25	9.04E-24	1.61E-25	1.87E-24	7.02E-24
MO-93	5.82E-04	2.19E-03	5.40E-04	5.49E-03	8.52E-06	2.39E-05	3.42E-04
MO-99	3.55E-08	1.33E-07	2.00E-08	2.04E-07	9.47E-10	8.83E-09	4.09E-08
TC-99M	7.13E-12	2.54E-11	1.39E-12	1.47E-11	2.62E-13	3.04E-12	1.14E-11
TC-99	5.86E-03	1.35E-02	2.38E-03	2.75E-02	7.46E-05	2.32E-04	1.59E-03
TC-101	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
RU-103	4.63E-04	9.37E-04	1.50E-04	1.84E-03	5.40E-06	1.27E-05	8.21E-05
RU-105	1.52E-17	5.40E-17	2.96E-18	3.12E-17	5.57E-19	6.46E-18	2.42E-17
RU-106	1.61E-03	3.25E-03	5.16E-04	6.34E-03	1.88E-05	4.43E-05	2.83E-04
RH-103M	7.29E-24	2.59E-23	1.42E-24	1.50E-23	2.67E-25	3.10E-24	1.16E-23
RH-105	5.31E-08	1.92E-07	1.54E-08	1.60E-07	1.81E-09	2.02E-08	7.88E-08
RH-106	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
PD-107	1.84E-02	7.23E-02	1.84E-02	1.86E-01	2.64E-04	5.98E-04	1.11E-02
PD-109	1.61E-09	5.71E-09	3.13E-10	3.30E-09	5.90E-11	6.84E-10	2.56E-09
AG-110M	2.64E-04	8.75E-04	1.19E-04	1.25E-03	6.54E-06	5.94E-05	2.63E-04
AG-111	5.00E-06	1.75E-05	1.58E-06	1.65E-05	1.60E-07	1.72E-06	6.81E-06
CD-113M	3.10E-04	1.24E-03	3.31E-04	3.34E-03	4.04E-06	2.69E-06	1.71E-04
CD-115M	6.63E-20	2.36E-19	1.29E-20	1.36E-19	2.43E-21	2.82E-20	1.06E-19
IN-113M	2.53E-21	8.99E-21	4.93E-22	5.19E-21	9.27E-23	1.08E-21	4.03E-21
SN-113	2.62E-04	6.16E-04	1.13E-04	1.30E-03	3.24E-06	8.52E-06	6.83E-05
SN-119M	3.64E-04	8.50E-04	1.55E-04	1.78E-03	4.49E-06	1.17E-05	9.34E-05
SN-121M	4.67E-04	1.09E-03	2.00E-04	2.30E-03	5.75E-06	1.49E-05	1.20E-04
SN-123	2.78E-04	6.51E-04	1.20E-04	1.37E-03	3.43E-06	9.00E-06	7.21E-05
SN-125	6.66E-06	1.63E-05	2.94E-06	3.33E-05	8.92E-08	3.21E-07	2.16E-06
SN-126	4.77E-04	1.12E-03	2.07E-04	2.37E-03	5.88E-06	1.51E-05	1.24E-04
SB-124	4.23E-05	1.55E-04	3.83E-05	3.91E-04	5.94E-07	1.40E-06	2.31E-05
SB-125	9.92E-05	3.61E-04	8.93E-05	9.13E-04	1.38E-06	3.10E-06	5.31E-05
SB-126	3.51E-06	1.28E-05	3.03E-06	3.09E-05	5.41E-08	2.00E-07	2.14E-06
SB-126M	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
SB-127	7.42E-08	2.89E-07	6.75E-08	6.82E-07	1.27E-09	5.94E-09	5.37E-08

Table D.6. Food Transfer Factors (Continued)

TE-125M	1.71E-04	4.22E-04	8.27E-05	9.28E-04	2.08E-06	4.57E-06	4.61E-05
TE-127M	2.78E-04	6.88E-04	1.36E-04	1.52E-03	3.39E-06	7.31E-06	7.52E-05
TE-127	1.22E-11	4.34E-11	2.38E-12	2.51E-11	4.48E-13	5.20E-12	1.95E-11
TE-129M	9.41E-05	2.32E-04	4.54E-05	5.10E-04	1.15E-06	2.57E-06	2.55E-05
TE-129	6.47E-24	2.30E-23	1.26E-24	1.33E-23	2.37E-25	2.75E-24	1.03E-23
TE-131M	7.67E-10	2.81E-09	3.14E-10	3.22E-09	2.37E-11	2.48E-10	1.03E-09
TE-131	0.00E+00	1.40E-45	0.00E+00	1.40E-45	0.00E+00	0.00E+00	0.00E+00
TE-132	8.42E-08	3.09E-07	7.53E-08	7.69E-07	1.22E-09	3.39E-09	4.76E-08
TE-133M	5.22E-27	1.86E-26	1.02E-27	1.07E-26	1.91E-28	2.22E-27	8.33E-27
TE-134	1.28E-31	4.55E-31	2.50E-32	2.63E-31	4.70E-33	5.45E-32	2.04E-31
I-129	1.86E-04	7.07E-04	1.69E-04	1.72E-03	2.94E-06	1.12E-05	1.21E-04
I-130	5.57E-11	1.98E-10	1.09E-11	1.15E-10	2.04E-12	2.37E-11	8.89E-11
I-131	1.50E-06	5.57E-06	1.00E-06	1.02E-05	3.40E-08	2.72E-07	1.44E-06
I-132	1.94E-17	6.88E-17	3.78E-18	3.98E-17	7.10E-19	8.24E-18	3.09E-17
I-133	5.01E-10	1.78E-09	9.83E-11	1.04E-09	1.84E-11	2.13E-10	7.98E-10
I-134	2.30E-28	8.17E-28	4.48E-29	4.72E-28	8.43E-30	9.78E-29	3.67E-28
I-135	1.89E-12	6.72E-12	3.69E-13	3.88E-12	6.93E-14	8.04E-13	3.01E-12
CS-134M	1.26E-15	4.47E-15	2.45E-16	2.58E-15	4.61E-17	5.35E-16	2.00E-15
CS-134	1.29E-04	4.66E-04	9.30E-05	9.53E-04	2.53E-06	1.68E-05	1.03E-04
CS-135	1.77E-04	6.53E-04	1.38E-04	1.41E-03	3.29E-06	1.96E-05	1.35E-04
CS-136	6.89E-06	2.49E-05	3.98E-06	4.09E-05	1.69E-07	1.48E-06	7.10E-06
CS-137	1.52E-04	5.55E-04	1.14E-04	1.16E-03	2.92E-06	1.86E-05	1.19E-04
CS-138	5.14E-39	1.83E-38	1.00E-39	1.06E-38	1.89E-40	2.19E-39	8.21E-39
CS-139	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
BA-137M	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
BA-139	2.66E-23	9.47E-23	5.19E-24	5.47E-23	9.77E-25	1.13E-23	4.25E-23
BA-140	3.37E-06	1.26E-05	3.18E-06	3.24E-05	4.58E-08	8.12E-08	1.80E-06
BA-141	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
BA-142	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
LA-140	5.34E-10	2.15E-09	5.74E-10	5.79E-09	7.03E-12	5.42E-12	2.99E-10
LA-141	1.35E-17	4.81E-17	2.64E-18	2.78E-17	4.96E-19	5.76E-18	2.16E-17
LA-142	2.08E-24	7.39E-24	4.05E-25	4.27E-24	7.63E-26	8.85E-25	3.32E-24
CE-141	1.81E-05	7.06E-05	1.83E-05	1.85E-04	2.47E-07	3.81E-07	1.02E-05
CE-143	3.33E-10	1.24E-09	1.65E-10	1.68E-09	9.55E-12	9.46E-11	4.14E-10
CE-144	7.11E-05	2.77E-04	7.19E-05	7.28E-04	9.58E-07	1.32E-06	3.94E-05
PR-143	4.09E-06	1.48E-05	3.78E-06	3.87E-05	5.21E-08	4.87E-08	1.95E-06
PR-144	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
PR-144M	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
ND-147	2.22E-06	8.30E-06	2.15E-06	2.19E-05	2.85E-08	2.40E-08	1.11E-06
PM-146	1.00E-04	3.58E-04	9.11E-05	9.34E-04	1.27E-06	1.23E-06	4.70E-05
PM-147	9.62E-05	3.44E-04	8.76E-05	8.98E-04	1.22E-06	1.18E-06	4.52E-05
PM-148M	2.88E-05	1.04E-04	2.67E-05	2.73E-04	3.68E-07	3.41E-07	1.38E-05
PM-148	2.35E-07	9.05E-07	2.38E-07	2.41E-06	3.03E-09	2.28E-09	1.23E-07
PM-149	3.83E-09	1.54E-08	4.10E-09	4.14E-08	5.00E-11	3.30E-11	2.12E-09

Table D.6. Food Transfer Factors (Continued)

PM-151	2.64E-11	1.06E-10	2.75E-11	2.77E-10	3.71E-13	6.82E-13	1.58E-11
SM-147	1.14E-04	4.09E-04	1.04E-04	1.07E-03	1.45E-06	1.38E-06	5.37E-05
SM-151	1.10E-04	3.95E-04	1.00E-04	1.03E-03	1.40E-06	1.34E-06	5.18E-05
SM-153	1.66E-09	6.65E-09	1.78E-09	1.79E-08	2.17E-11	1.50E-11	9.19E-10
EU-152	1.03E-04	3.69E-04	9.39E-05	9.62E-04	1.31E-06	1.26E-06	4.85E-05
EU-154	1.02E-04	3.65E-04	9.27E-05	9.50E-04	1.30E-06	1.24E-06	4.78E-05
EU-155	9.95E-05	3.56E-04	9.05E-05	9.28E-04	1.27E-06	1.22E-06	4.67E-05
EU-156	5.30E-06	1.91E-05	4.88E-06	4.99E-05	6.75E-08	6.36E-08	2.52E-06
GD-153	7.52E-05	2.77E-04	7.13E-05	7.28E-04	9.62E-07	8.45E-07	3.68E-05
TB-160	4.61E-05	1.68E-04	4.30E-05	4.40E-04	5.89E-07	5.36E-07	2.22E-05
HO-166M	1.11E-04	4.03E-04	1.03E-04	1.05E-03	1.41E-06	1.29E-06	5.32E-05
W-181	5.48E-05	2.13E-04	5.55E-05	5.62E-04	7.34E-07	9.40E-07	3.01E-05
W-185	4.11E-05	1.60E-04	4.16E-05	4.22E-04	5.51E-07	7.15E-07	2.26E-05
W-187	7.05E-11	2.53E-10	1.73E-11	1.80E-10	2.49E-12	2.83E-11	1.08E-10
TL-207	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
TL-208	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
PB-209	3.59E-16	1.28E-15	7.00E-17	7.38E-16	1.32E-17	1.53E-16	5.73E-16
PB-210	1.53E-04	6.14E-04	1.62E-04	1.64E-03	2.05E-06	2.18E-06	8.68E-05
PB-211	8.45E-37	3.01E-36	1.65E-37	1.74E-36	3.10E-38	3.60E-37	1.35E-36
PB-212	3.49E-12	1.24E-11	6.81E-13	7.17E-12	1.28E-13	1.49E-12	5.57E-12
BI-210	2.40E-07	8.83E-07	2.19E-07	2.24E-06	3.36E-09	7.66E-09	1.31E-07
BI-211	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
BI-212	1.10E-26	3.92E-26	2.15E-27	2.26E-26	4.04E-28	4.69E-27	1.76E-26
BI-213	1.77E-31	6.29E-31	3.45E-32	3.63E-31	6.49E-33	7.52E-32	2.82E-31
PO-210	9.13E-05	2.95E-04	7.07E-05	7.38E-04	1.16E-06	1.70E-06	3.77E-05
PO-212	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
PO-213	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
PO-215	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
PO-216	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
AT-217	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
FR-221	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
FR-223	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
RA-223	7.55E-06	2.20E-05	3.69E-06	4.00E-05	1.36E-07	8.90E-07	4.64E-06
RA-224	1.16E-07	4.18E-07	6.65E-08	6.83E-07	2.84E-09	2.48E-08	1.19E-07
RA-225	1.40E-05	4.02E-05	6.98E-06	7.59E-05	2.39E-07	1.43E-06	7.87E-06
RA-226	2.68E-04	7.34E-04	1.40E-04	1.53E-03	3.91E-06	1.66E-05	1.14E-04
RA-228	2.56E-04	7.00E-04	1.33E-04	1.45E-03	3.73E-06	1.60E-05	1.09E-04
AC-225	5.67E-06	1.41E-05	2.81E-06	3.14E-05	6.79E-08	1.31E-07	1.49E-06
AC-227	3.60E-04	8.66E-04	1.68E-04	1.90E-03	4.29E-06	8.54E-06	8.97E-05
AC-228	8.38E-16	2.98E-15	1.64E-16	1.72E-15	3.08E-17	23.57E-16	1.34E-15
TH-227	6.73E-06	2.70E-05	7.21E-06	7.27E-05	8.76E-08	5.43E-08	3.70E-06
TH-228	7.51E-05	3.01E-04	8.04E-05	8.11E-04	9.77E-07	6.02E-07	4.13E-05
TH-229	9.66E-05	3.87E-04	1.04E-04	1.04E-03	1.26E-06	7.71E-07	5.32E-05
TH-230	9.67E-05	3.88E-04	1.04E-04	1.05E-03	1.26E-06	7.72E-07	5.32E-05

Table D.6. Food Transfer Factors (Continued)

TH-231	9.41E-12	3.75E-11	9.43E-12	9.51E-11	1.42E-13	4.18E-13	6.08E-12
TH-232	9.67E-05	3.88E-04	1.04E-04	1.05E-03	1.26E-06	7.72E-07	5.32E-05
TH-234	1.10E-05	4.40E-05	1.18E-05	1.19E-04	1.43E-07	8.83E-08	6.05E-06
PA-231	1.00E+00	1.00E+00	1.00E+00	1.00E+00	4.40E-02	1.08E-01	6.00E-01
PA-233	5.14E-01	9.88E-01	1.47E-01	1.00E+00	5.96E-03	1.46E-02	8.14E-02
PA-234M	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
U-232	8.90E-05	3.55E-04	9.34E-05	9.43E-04	1.20E-06	1.42E-06	5.05E-05
U-233	9.34E-05	3.72E-04	9.81E-05	9.90E-04	1.25E-06	1.46E-06	5.29E-05
U-234	9.34E-05	3.72E-04	9.81E-05	9.90E-04	1.25E-06	1.46E-06	5.29E-05
U-235	9.34E-05	3.72E-04	9.81E-05	9.90E-04	1.25E-06	1.46E-06	5.29E-05
U-236	9.34E-05	3.72E-04	9.81E-05	9.90E-04	1.25E-06	1.46E-06	5.29E-05
U-237	4.86E-07	1.94E-06	4.94E-07	4.99E-06	7.06E-09	1.68E-08	3.00E-07
U-238	9.34E-05	3.72E-04	9.81E-05	9.90E-04	1.25E-06	1.46E-06	5.29E-05
NP-236	9.10E-05	3.65E-04	9.76E-05	9.84E-04	1.18E-06	7.28E-07	5.01E-05
NP-237	9.10E-05	3.65E-04	9.76E-05	9.84E-04	1.18E-06	7.28E-07	5.01E-05
NP-238	2.71E-09	1.09E-08	2.92E-09	2.94E-08	3.54E-11	2.33E-11	1.51E-09
NP-239	5.35E-09	2.15E-08	5.77E-09	5.81E-08	6.98E-11	4.46E-11	2.97E-09
PU-236	7.57E-05	3.05E-04	8.17E-05	8.23E-04	9.86E-07	5.87E-07	4.19E-05
PU-237	2.50E-05	1.01E-04	2.70E-05	2.72E-04	3.26E-07	1.94E-07	1.39E-05
PU-238	8.16E-05	3.29E-04	8.81E-05	8.88E-04	1.06E-06	6.33E-07	4.52E-05
PU-239	8.26E-05	3.33E-04	8.92E-05	8.99E-04	1.08E-06	6.41E-07	4.58E-05
PU-240	8.26E-05	3.33E-04	8.92E-05	8.99E-04	1.08E-06	6.41E-07	4.58E-05
PU-241	7.98E-05	3.21E-04	8.61E-05	8.68E-04	1.04E-06	6.19E-07	4.42E-05
PU-242	8.26E-05	3.33E-04	8.92E-05	8.99E-04	1.08E-06	6.41E-07	4.58E-05
PU-244	8.26E-05	3.33E-04	8.92E-05	8.99E-04	1.08E-06	6.41E-07	4.58E-05
AM-241	8.32E-05	3.33E-04	8.92E-05	8.99E-04	1.08E-06	6.68E-07	4.58E-05
AM-242M	8.28E-05	3.32E-04	8.87E-05	8.95E-04	1.08E-06	6.64E-07	4.56E-05
AM-243	8.35E-05	3.35E-04	8.95E-05	9.02E-04	1.09E-06	6.70E-07	4.59E-05
CM-242	5.67E-05	2.27E-04	6.08E-05	6.13E-04	7.38E-07	4.54E-07	3.12E-05
CM-243	8.41E-05	3.37E-04	9.01E-05	9.09E-04	1.09E-06	6.74E-07	4.63E-05
CM-244	8.29E-05	3.32E-04	8.89E-05	8.96E-04	1.08E-06	6.65E-07	4.56E-05
CM-245	9.10E-05	3.65E-04	9.75E-05	9.83E-04	1.18E-06	7.27E-07	5.01E-05
CM-246	9.09E-05	3.64E-04	9.74E-05	9.83E-04	1.18E-06	7.27E-07	5.00E-05
CM-247	9.10E-05	3.65E-04	9.76E-05	9.84E-04	1.18E-06	7.28E-07	5.01E-05
CM-248	9.10E-05	3.65E-04	9.76E-05	9.84E-04	1.18E-06	7.28E-07	5.01E-05
CF-252	7.64E-05	3.06E-04	8.19E-05	8.26E-04	9.95E-07	6.13E-07	4.21E-05
Nuclide	**State**						
	MN	**NY**	**NC**	**ND**	**OH**	**OK**	**OR**
H-3	3.40E-08	2.32E-07	1.51E-07	1.18E-06	1.05E-06	2.30E-07	5.39E-08
BE-10	1.31E-05	6.58E-05	1.23E-04	6.34E-04	6.71E-04	1.80E-04	3.28E-05
C-14	3.16E-07	1.98E-06	2.56E-06	1.04E-05	1.20E-05	3.44E-06	6.09E-07
N-16	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
F-18	8.80E-19	1.52E-17	2.46E-18	2.90E-18	1.41E-17	2.71E-18	8.48E-19
NA-22	1.06E-04	1.25E-03	5.17E-04	9.24E-04	1.95E-03	5.74E-04	1.14E-04

Table D.6. Food Transfer Factors (Continued)

NA-24	5.08E-10	8.76E-09	1.42E-09	1.67E-09	8.15E-09	1.57E-09	4.90E-10
P-32	7.11E-06	8.32E-05	3.46E-05	5.89E-05	1.28E-04	3.81E-05	7.54E-06
CA-41	5.07E-05	4.50E-04	3.65E-04	1.60E-03	1.91E-03	5.04E-04	9.72E-05
SC-46	1.31E-05	4.15E-05	1.13E-04	3.30E-04	3.85E-04	1.37E-04	2.06E-05
CR-51	3.13E-06	2.54E-05	2.36E-05	1.05E-04	1.23E-04	3.28E-05	6.21E-06
MN-54	1.07E-05	5.69E-05	9.94E-05	5.15E-04	5.47E-04	1.45E-04	2.67E-05
MN-56	2.61E-18	4.51E-17	7.31E-18	8.60E-18	4.19E-17	8.05E-18	2.52E-18
FE-55	4.92E-05	1.46E-04	3.94E-04	6.73E-04	9.27E-04	4.21E-04	5.50E-05
FE-59	1.47E-05	4.69E-05	1.18E-04	2.16E-04	2.92E-04	1.28E-04	1.71E-05
CO-57	2.05E-05	8.68E-05	1.70E-04	5.19E-04	6.14E-04	2.08E-04	3.27E-05
CO-58	1.16E-05	5.08E-05	9.62E-05	3.02E-04	3.56E-04	1.19E-04	1.88E-05
CO-60	2.56E-05	1.08E-04	2.13E-04	6.49E-04	7.68E-04	2.60E-04	4.08E-05
NI-59	3.97E-05	3.41E-04	2.83E-04	1.16E-03	1.41E-03	3.82E-04	7.22E-05
NI-63	3.58E-05	3.16E-04	2.50E-04	9.90E-04	1.23E-03	3.34E-04	6.32E-05
NI-65	5.34E-17	9.21E-16	1.49E-16	1.76E-16	8.57E-16	1.64E-16	5.14E-17
CU-64	1.08E-10	1.86E-09	3.01E-10	3.54E-10	1.73E-09	3.32E-10	1.04E-10
ZN-65	8.97E-05	1.05E-03	4.43E-04	8.45E-04	1.71E-03	4.98E-04	9.91E-05
ZN-69M	5.67E-10	9.78E-09	1.59E-09	1.87E-09	9.10E-09	1.75E-09	5.46E-10
ZN-69	2.06E-25	3.56E-24	5.77E-25	6.79E-25	3.31E-24	6.35E-25	21.99E-25
SE-79	1.47E-03	1.56E-02	9.11E-03	3.61E-02	4.74E-02	1.22E-02	2.46E-03
BR-82	1.83E-08	3.15E-07	5.18E-08	6.40E-08	2.97E-07	5.73E-08	1.78E-08
BR-83	1.28E-15	2.21E-14	3.58E-15	4.22E-15	2.05E-14	3.95E-15	1.23E-15
BR-84	2.64E-37	4.54E-36	7.38E-37	8.67E-37	4.23E-36	8.12E-37	2.54E-37
BR-85	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
KR-85	5.02E-04	4.09E-03	3.67E-03	1.49E-02	1.80E-02	4.94E-03	9.21E-04
RB-86	1.08E-05	1.39E-04	4.84E-05	8.32E-05	1.95E-04	5.38E-05	1.15E-05
RB-87	2.23E-04	2.09E-03	1.40E-03	4.35E-03	6.04E-03	1.75E-03	3.25E-04
RB-88	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
RB-89	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
SR-89	4.69E-06	3.00E-05	4.14E-05	2.13E-04	2.31E-04	6.05E-05	1.13E-05
SR-90	1.65E-05	1.00E-04	1.49E-04	7.72E-04	8.30E-04	2.18E-04	4.07E-05
SR-91	1.26E-12	2.16E-11	3.51E-12	4.13E-12	2.01E-11	3.87E-12	1.21E-12
SR-92	1.69E-17	2.91E-16	4.72E-17	5.56E-17	2.71E-16	5.20E-17	1.63E-17
Y-90	1.59E-09	8.21E-09	1.52E-08	8.20E-08	8.61E-08	2.26E-08	4.19E-09
Y-91M	2.28E-32	3.93E-31	6.38E-32	7.50E-32	3.66E-31	7.02E-32	2.19E-32
Y-91	6.02E-06	2.55E-05	5.53E-05	2.41E-04	2.60E-04	7.56E-05	1.30E-05
Y-92	6.07E-18	1.05E-16	1.70E-17	2.00E-17	9.74E-17	1.87E-17	5.85E-18
Y-93	1.99E-14	3.43E-13	5.57E-14	6.55E-14	3.19E-13	6.13E-14	1.92E-14
ZR-93	4.54E-05	1.13E-04	3.75E-04	7.11E-04	9.26E-04	4.09E-04	5.39E-05
ZR-95	1.81E-05	4.61E-05	1.50E-04	3.01E-04	3.86E-04	1.66E-04	2.22E-05
ZR-97	1.24E-13	2.02E-12	4.11E-13	8.72E-13	2.35E-12	4.88E-13	1.35E-13
NB-93M	2.90E-04	5.59E-04	2.26E-03	1.37E-03	2.97E-03	2.13E-03	2.18E-04
NB-94	3.13E-04	6.13E-04	2.44E-03	1.62E-03	3.34E-03	2.32E-03	2.41E-04
NB-95M	3.36E-08	2.16E-07	2.30E-07	4.32E-07	6.62E-07	2.52E-07	3.85E-08

Table D.6. Food Transfer Factors (Continued)

NB-95	5.89E-05	1.20E-04	4.57E-04	2.86E-04	6.14E-04	4.33E-04	4.46E-05
NB-97	2.29E-24	3.95E-23	6.41E-24	7.54E-24	3.68E-23	7.06E-24	2.21E-24
MO-93	1.04E-04	7.60E-04	8.27E-04	3.71E-03	4.24E-03	1.15E-03	2.13E-04
MO-99	1.28E-08	1.95E-07	5.08E-08	1.47E-07	2.89E-07	6.39E-08	1.60E-08
TC-99M	3.72E-12	6.41E-11	1.04E-11	1.22E-11	5.96E-11	1.15E-11	3.58E-12
TC-99	1.24E-03	4.12E-03	9.36E-03	9.87E-03	1.72E-02	9.34E-03	1.12E-03
TC-101	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
RU-103	9.64E-05	1.60E-04	7.56E-04	4.08E-04	9.33E-04	7.08E-04	7.01E-05
RU-105	7.91E-18	1.36E-16	2.21E-17	2.60E-17	1.27E-16	2.44E-17	7.62E-18
RU-106	3.35E-04	5.53E-04	2.63E-03	1.38E-03	3.20E-03	2.46E-03	2.42E-04
RH-103M	3.80E-24	6.55E-23	1.06E-23	1.25E-23	6.09E-23	1.17E-23	3.66E-24
RH-105	2.55E-08	4.30E-07	7.70E-08	1.25E-07	4.42E-07	8.79E-08	2.60E-08
RH-106	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
PD-107	3.07E-03	2.21E-02	2.57E-02	1.29E-01	1.43E-01	3.72E-02	7.06E-03
PD-109	8.37E-10	1.44E-08	2.34E-09	2.75E-09	1.34E-08	2.58E-09	8.06E-10
AG-110M	9.28E-05	1.28E-03	3.92E-04	7.92E-04	1.78E-03	4.51E-04	1.03E-04
AG-111	2.26E-06	3.66E-05	7.30E-06	1.19E-05	3.92E-05	8.29E-06	2.31E-06
CD-113M	4.48E-05	2.31E-04	4.30E-04	2.32E-03	2.44E-03	6.39E-04	1.18E-04
CD-115M	3.46E-20	5.96E-19	9.67E-20	1.14E-19	5.54E-19	1.06E-19	3.33E-20
IN-113M	1.32E-21	2.27E-20	3.68E-21	4.33E-21	2.11E-20	4.06E-21	1.27E-21
SN-113	5.37E-05	1.50E-04	4.18E-04	4.92E-04	7.88E-04	4.22E-04	5.04E-05
SN-119M	7.47E-05	2.05E-04	5.81E-04	6.67E-04	1.08E-03	5.85E-04	6.94E-05
SN-121M	9.56E-05	2.60E-04	7.45E-04	8.63E-04	1.39E-03	7.51E-04	8.91E-05
SN-123	5.69E-05	1.59E-04	4.42E-04	5.19E-04	8.32E-04	4.47E-04	5.33E-05
SN-125	1.44E-06	6.19E-06	1.05E-05	1.36E-05	2.25E-05	1.08E-05	1.41E-06
SN-126	9.75E-05	2.66E-04	7.61E-04	9.04E-04	1.44E-03	7.69E-04	9.19E-05
SB-124	7.36E-06	4.68E-05	6.05E-05	2.60E-04	2.94E-04	8.27E-05	1.49E-05
SB-125	1.72E-05	1.05E-04	1.42E-04	6.03E-04	6.82E-04	1.94E-04	3.45E-05
SB-126	6.85E-07	5.57E-06	5.03E-06	2.06E-05	2.47E-05	6.79E-06	1.27E-06
SB-126M	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
SB-127	1.56E-08	1.59E-07	1.04E-07	4.76E-07	5.84E-07	1.47E-07	2.96E-08
TE-125M	3.38E-05	8.61E-05	2.70E-04	3.95E-04	5.69E-04	2.82E-04	3.49E-05
TE-127M	5.47E-05	1.38E-04	4.40E-04	6.52E-04	9.33E-04	4.59E-04	5.70E-05
TE-127	6.36E-12	1.10E-10	1.78E-11	2.09E-11	1.02E-10	1.96E-11	6.13E-12
TE-129M	1.86E-05	4.84E-05	1.49E-04	2.17E-04	3.14E-04	1.55E-04	1.92E-05
TE-129	3.37E-24	5.81E-23	9.43E-24	1.11E-23	5.41E-23	1.04E-23	3.25E-24
TE-131M	3.29E-10	5.34E-09	1.11E-09	2.40E-09	6.32E-09	1.32E-09	3.62E-10
TE-131	0.00E+00	4.20E-45	0.00E+00	1.40E-45	4.20E-45	0.00E+00	0.00E+00
TE-132	1.52E-08	1.05E-07	1.20E-07	5.12E-07	5.90E-07	1.64E-07	2.99E-08
TE-133M	2.72E-27	4.69E-26	7.61E-27	8.95E-27	4.36E-26	8.37E-27	2.62E-27
TE-134	6.67E-32	1.15E-30	1.87E-31	2.20E-31	1.07E-30	2.06E-31	6.43E-32
I-129	3.62E-05	3.17E-04	2.63E-04	1.17E-03	1.39E-03	3.66E-04	7.06E-05
I-130	2.90E-11	5.00E-10	8.12E-11	9.55E-11	4.66E-10	8.94E-11	2.80E-11
I-131	4.54E-07	6.16E-06	2.15E-06	7.14E-06	1.16E-05	2.77E-06	6.28E-07

Table D.6. Food Transfer Factors (Continued)

I-132	1.01E-17	1.74E-16	2.82E-17	3.32E-17	1.62E-16	3.11E-17	9.71E-18
I-133	2.61E-10	4.49E-09	7.30E-10	8.63E-10	4.18E-09	8.04E-10	2.51E-10
I-134	1.20E-28	2.06E-27	3.35E-28	3.94E-28	1.92E-27	3.69E-28	1.15E-28
I-135	9.85E-13	1.70E-11	2.75E-12	3.24E-12	1.58E-11	3.03E-12	9.48E-13
CS-134M	6.54E-16	1.13E-14	1.83E-15	2.15E-15	1.05E-14	2.02E-15	6.30E-16
CS-134	3.35E-05	3.92E-04	1.85E-04	6.41E-04	9.33E-04	2.40E-04	4.97E-05
CS-135	4.29E-05	4.75E-04	2.54E-04	9.57E-04	1.30E-03	3.37E-04	6.85E-05
CS-136	2.30E-06	3.27E-05	9.95E-06	2.83E-05	5.24E-05	1.24E-05	2.90E-06
CS-137	3.85E-05	4.40E-04	2.19E-04	7.84E-04	1.11E-03	2.86E-04	5.88E-05
CS-138	2.68E-39	4.62E-38	7.50E-39	8.82E-39	4.30E-38	8.25E-39	2.58E-39
CS-139	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
BA-137M	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
BA-139	1.39E-23	2.39E-22	3.88E-23	4.56E-23	2.23E-22	4.27E-23	1.34E-23
BA-140	5.55E-07	3.20E-06	4.79E-06	2.17E-05	2.39E-05	6.66E-06	1.20E-06
BA-141	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
BA-142	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
LA-140	7.77E-11	4.19E-10	7.40E-10	4.03E-09	4.24E-09	1.11E-09	2.06E-10
LA-141	7.05E-18	1.21E-16	1.97E-17	2.32E-17	1.13E-16	2.17E-17	6.79E-18
LA-142	1.08E-24	1.87E-23	3.03E-24	3.56E-24	1.74E-23	3.33E-24	1.04E-24
CE-141	2.86E-06	1.73E-05	2.54E-05	1.27E-04	1.38E-04	3.67E-05	6.79E-06
CE-143	1.31E-10	2.06E-09	4.77E-10	1.23E-09	2.73E-09	5.87E-10	1.54E-10
CE-144	1.11E-05	6.41E-05	9.98E-05	4.99E-04	5.38E-04	1.44E-04	2.65E-05
PR-143	6.41E-07	2.70E-06	5.87E-06	2.54E-05	2.75E-05	8.01E-06	1.38E-06
PR-144	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
PR-144M	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
ND-147	3.40E-07	1.52E-06	3.16E-06	1.47E-05	1.57E-05	4.42E-06	7.79E-07
PM-146	1.58E-05	6.51E-05	1.44E-04	6.08E-04	6.62E-04	1.95E-04	3.33E-05
PM-147	1.52E-05	6.26E-05	1.39E-04	5.85E-04	6.36E-04	1.88E-04	3.20E-05
PM-148M	4.51E-06	1.90E-05	4.14E-05	1.79E-04	1.94E-04	5.65E-05	9.72E-06
PM-148	3.50E-08	1.66E-07	3.31E-07	1.64E-06	1.74E-06	4.75E-07	8.56E-08
PM-149	5.53E-10	2.86E-09	5.32E-09	2.88E-08	3.02E-08	7.91E-09	1.47E-09
PM-151	4.21E-12	2.89E-11	3.67E-11	1.93E-10	2.10E-10	5.41E-11	1.03E-11
SM-147	1.79E-05	7.42E-05	1.64E-04	6.96E-04	7.56E-04	2.22E-04	3.80E-05
SM-151	1.74E-05	7.17E-05	1.59E-04	6.71E-04	7.29E-04	2.15E-04	3.67E-05
SM-153	2.40E-10	1.26E-09	2.30E-09	1.25E-08	1.31E-08	3.43E-09	6.36E-10
EU-152	1.63E-05	6.71E-05	1.49E-04	6.27E-04	6.82E-04	2.01E-04	3.43E-05
EU-154	1.61E-05	6.62E-05	1.47E-04	6.19E-04	6.73E-04	1.99E-04	3.39E-05
EU-155	1.57E-05	6.47E-05	1.44E-04	6.05E-04	6.57E-04	1.94E-04	3.31E-05
EU-156	8.32E-07	3.48E-06	7.62E-06	3.27E-05	3.55E-05	1.04E-05	1.78E-06
GD-153	1.16E-05	5.04E-05	1.08E-04	4.83E-04	5.19E-04	1.49E-04	2.59E-05
TB-160	7.19E-06	3.05E-05	6.61E-05	2.90E-04	3.13E-04	9.07E-05	1.57E-05
HO-166M	1.73E-05	7.33E-05	1.59E-04	6.94E-04	7.50E-04	2.18E-04	3.76E-05
W-181	8.49E-06	4.78E-05	7.70E-05	3.85E-04	4.14E-04	1.11E-04	2.04E-05
W-185	6.37E-06	3.61E-05	5.77E-05	2.89E-04	3.11E-04	8.33E-05	1.53E-05

Table D.6. Food Transfer Factors (Continued)

W-187	3.52E-11	6.00E-10	1.02E-10	1.44E-10	5.87E-10	1.15E-10	3.49E-11
TL-207	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
TL-208	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
PB-209	1.87E-16	3.22E-15	5.23E-16	6.15E-16	3.00E-15	5.76E-16	1.80E-16
PB-210	2.29E-05	1.32E-04	2.13E-04	1.14E-03	1.21E-03	3.16E-04	5.90E-05
PB-211	4.40E-37	7.59E-36	1.23E-36	1.45E-36	7.06E-36	1.36E-36	4.24E-37
PB-212	1.82E-12	3.13E-11	5.09E-12	5.98E-12	2.92E-11	5.60E-12	1.75E-12
BI-210	4.14E-08	2.61E-07	3.42E-07	1.49E-06	1.68E-06	4.70E-07	8.47E-08
BI-211	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
BI-212	5.74E-27	9.89E-26	1.61E-26	1.89E-26	9.21E-26	1.77E-26	5.53E-27
BI-213	9.21E-32	1.59E-30	2.58E-31	3.03E-31	1.48E-30	2.84E-31	8.87E-32
PO-210	1.57E-05	5.87E-05	1.36E-04	4.46E-04	5.11E-04	1.69E-04	2.68E-05
PO-212	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
PO-213	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
PO-215	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
PO-216	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
AT-217	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
FR-221	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
FR-223	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
RA-223	2.01E-06	1.90E-05	1.15E-05	2.12E-05	3.83E-05	1.27E-05	2.23E-06
RA-224	3.88E-08	5.49E-07	1.68E-07	4.70E-07	8.77E-07	2.08E-07	4.86E-08
RA-225	3.57E-06	3.06E-05	2.15E-05	3.95E-05	6.80E-05	2.37E-05	3.97E-06
RA-226	5.94E-05	3.54E-04	4.15E-04	7.60E-04	1.15E-03	4.53E-04	6.75E-05
RA-228	5.69E-05	3.40E-04	3.97E-04	7.19E-04	1.10E-03	4.32E-04	6.43E-05
AC-225	1.10E-06	2.47E-06	8.95E-06	1.36E-05	1.90E-05	9.37E-06	1.16E-06
AC-227	7.05E-05	1.51E-04	5.71E-04	7.77E-04	1.13E-03	5.88E-04	7.05E-05
AC-228	4.37E-16	7.53E-15	1.22E-15	1.44E-15	7.01E-15	1.35E-15	4.21E-16
TH-227	9.69E-07	4.95E-06	9.34E-06	5.05E-05	5.30E-05	1.39E-05	2.57E-06
TH-228	1.08E-05	5.51E-05	1.04E-04	5.64E-04	5.91E-04	1.55E-04	2.87E-05
TH-229	1.39E-05	7.09E-05	1.34E-04	7.26E-04	7.61E-04	2.00E-04	3.70E-05
TH-230	1.39E-05	7.10E-05	1.34E-04	7.27E-04	7.62E-04	2.00E-04	3.70E-05
TH-231	1.66E-12	1.38E-11	1.31E-11	6.65E-11	7.51E-11	1.91E-11	3.72E-12
TH-232	1.39E-05	7.10E-05	1.34E-04	7.27E-04	7.62E-04	2.00E-04	3.70E-05
TH-234	1.58E-06	8.08E-06	1.53E-05	8.25E-05	8.65E-05	2.27E-05	4.20E-06
PA-231	8.01E-01	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	5.29E-01
PA-233	1.09E-01	1.67E-01	8.45E-01	2.80E-01	8.82E-01	7.71E-01	7.17E-02
PA-234M	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
U-232	1.35E-05	7.88E-05	1.24E-04	6.54E-04	6.98E-04	1.83E-04	3.41E-05
U-233	1.41E-05	8.22E-05	1.30E-04	6.87E-04	7.32E-04	1.92E-04	3.58E-05
U-234	1.41E-05	8.22E-05	1.30E-04	6.87E-04	7.32E-04	1.92E-04	3.58E-05
U-235	1.41E-05	8.22E-05	1.30E-04	6.87E-04	7.32E-04	1.92E-04	3.58E-05
U-236	1.41E-05	8.22E-05	1.30E-04	6.87E-04	7.32E-04	1.92E-04	3.58E-05
U-237	8.17E-08	6.12E-07	6.78E-07	3.48E-06	3.85E-06	9.91E-07	1.90E-07
U-238	1.41E-05	8.22E-05	1.30E-04	6.87E-04	7.32E-04	1.92E-04	3.58E-05

Table D.6. Food Transfer Factors (Continued)

NP-236	1.31E-05	6.68E-05	1.26E-04	6.84E-04	7.17E-04	1.88E-04	3.48E-05
NP-237	1.31E-05	6.68E-05	1.26E-04	6.84E-04	7.17E-04	1.88E-04	3.48E-05
NP-238	3.90E-10	2.04E-09	3.75E-09	2.05E-08	2.15E-08	5.61E-09	1.04E-09
NP-239	7.69E-10	4.01E-09	7.41E-09	4.05E-08	4.24E-08	1.11E-08	2.06E-09
PU-236	1.08E-05	5.58E-05	1.05E-04	5.74E-04	6.01E-04	1.57E-04	2.91E-05
PU-237	3.59E-06	1.85E-05	3.47E-05	1.90E-04	1.99E-04	5.19E-05	9.64E-06
PU-238	1.17E-05	6.02E-05	1.13E-04	6.18E-04	6.47E-04	1.69E-04	3.14E-05
PU-239	1.18E-05	6.09E-05	1.15E-04	6.26E-04	6.56E-04	1.71E-04	3.18E-05
PU-240	1.18E-05	6.09E-05	1.15E-04	6.26E-04	6.56E-04	1.71E-04	3.18E-05
PU-241	1.14E-05	5.88E-05	1.11E-04	6.05E-04	6.33E-04	1.65E-04	3.07E-05
PU-242	1.18E-05	6.09E-05	1.15E-04	6.26E-04	6.56E-04	1.71E-04	3.18E-05
PU-244	1.18E-05	6.09E-05	1.15E-04	6.26E-04	6.56E-04	1.71E-04	3.18E-05
AM-241	1.20E-05	6.11E-05	1.16E-04	6.25E-04	6.55E-04	1.72E-04	3.18E-05
AM-242M	1.19E-05	6.08E-05	1.15E-04	6.22E-04	6.52E-04	1.71E-04	3.17E-05
AM-243	1.20E-05	6.13E-05	1.16E-04	6.27E-04	6.57E-04	1.72E-04	3.19E-05
CM-242	8.17E-06	4.16E-05	7.88E-05	4.26E-04	4.47E-04	1.17E-04	2.17E-05
CM-243	1.21E-05	6.18E-05	1.17E-04	6.32E-04	6.62E-04	1.74E-04	3.22E-05
CM-244	1.20E-05	6.09E-05	1.15E-04	6.23E-04	6.53E-04	1.71E-04	3.17E-05
CM-245	1.31E-05	6.68E-05	1.26E-04	6.83E-04	7.16E-04	1.88E-04	3.48E-05
CM-246	1.31E-05	6.68E-05	1.26E-04	6.83E-04	7.16E-04	1.88E-04	3.48E-05
CM-247	1.31E-05	6.68E-05	1.26E-04	6.84E-04	7.17E-04	1.88E-04	3.48E-05
CM-248	1.31E-05	6.68E-05	1.26E-04	6.84E-04	7.17E-04	1.88E-04	3.48E-05
CF-252	1.10E-05	5.61E-05	1.06E-04	5.74E-04	6.02E-04	1.58E-04	2.92E-05
Nuclide	**State**						
	PA	**RI**	**SC**	**SD**	**TN**	**TX**	**UT**
H-3	2.50E-07	2.27E-08	7.19E-08	6.11E-07	1.84E-07	1.52E-07	1.61E-08
BE-10	8.58E-05	9.58E-06	6.31E-05	3.49E-04	1.23E-04	1.35E-04	4.18E-06
C-14	2.34E-06	2.29E-07	1.21E-06	6.23E-06	2.54E-06	2.66E-06	1.15E-07
N-16	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
F-18	1.29E-17	8.76E-19	1.18E-18	4.51E-18	5.74E-18	2.43E-18	5.81E-19
NA-22	1.17E-03	8.82E-05	2.14E-04	8.80E-04	6.71E-04	4.87E-04	5.51E-05
NA-24	7.46E-09	5.06E-10	6.80E-10	2.60E-09	3.31E-09	1.41E-09	3.36E-10
P-32	7.85E-05	5.89E-06	1.42E-05	5.78E-05	4.46E-05	3.24E-05	3.68E-06
CA-41	4.63E-04	4.09E-05	1.81E-04	9.47E-04	4.18E-04	3.88E-04	2.18E-05
SC-46	7.09E-05	7.86E-06	4.67E-05	2.20E-04	8.96E-05	1.09E-04	3.83E-06
CR-51	2.70E-05	2.47E-06	1.17E-05	6.17E-05	2.61E-05	2.52E-05	1.28E-06
MN-54	7.20E-05	7.91E-06	5.11E-05	2.83E-04	1.01E-04	1.09E-04	3.49E-06
MN-56	3.84E-17	2.60E-18	3.50E-18	1.34E-17	1.70E-17	7.23E-18	1.73E-18
FE-55	2.61E-04	2.74E-05	1.42E-04	5.80E-04	2.78E-04	3.52E-04	1.46E-05
FE-59	8.03E-05	8.35E-06	4.31E-05	1.79E-04	8.51E-05	1.06E-04	4.43E-06
CO-57	1.25E-04	1.30E-05	7.16E-05	3.42E-04	1.43E-04	1.65E-04	6.52E-06
CO-58	7.19E-05	7.44E-06	4.09E-05	1.97E-04	8.21E-05	9.41E-05	3.73E-06
CO-60	1.56E-04	1.62E-05	8.96E-05	4.27E-04	1.79E-04	2.07E-04	8.12E-06
NI-59	3.55E-04	3.14E-05	1.37E-04	7.02E-04	3.16E-04	2.97E-04	1.68E-05

Table D.6. Food Transfer Factors (Continued)

NI-63	3.26E-04	2.84E-05	1.20E-04	6.09E-04	2.81E-04	2.60E-04	1.54E-05
NI-65	7.83E-16	5.32E-17	7.14E-17	2.73E-16	3.48E-16	1.48E-16	3.53E-17
CU-64	1.58E-09	1.07E-10	1.44E-10	5.51E-10	7.02E-10	2.98E-10	7.11E-11
ZN-65	9.89E-04	7.46E-05	1.85E-04	7.73E-04	5.73E-04	4.20E-04	4.64E-05
ZN-69M	8.32E-09	5.65E-10	7.58E-10	2.90E-09	3.70E-09	1.57E-09	3.75E-10
ZN-69	3.03E-24	2.05E-25	2.76E-25	1.06E-24	1.34E-24	5.70E-25	1.36E-25
SE-79	1.51E-02	1.24E-03	4.46E-03	2.26E-02	1.14E-02	9.59E-03	7.03E-04
BR-82	2.68E-07	1.82E-08	2.48E-08	9.56E-08	1.20E-07	5.13E-08	1.21E-08
BR-83	1.88E-14	1.28E-15	1.71E-15	6.56E-15	8.35E-15	3.54E-15	8.46E-16
BR-84	3.87E-36	2.62E-37	3.52E-37	1.35E-36	1.72E-36	7.29E-37	1.74E-37
BR-85	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
KR-85	4.34E-03	3.90E-04	1.76E-03	9.05E-03	4.00E-03	3.84E-03	2.07E-04
RB-86	1.28E-04	9.37E-06	2.04E-05	8.33E-05	6.91E-05	4.59E-05	5.93E-06
RB-87	2.11E-03	1.75E-04	6.28E-04	2.98E-03	1.58E-03	1.40E-03	1.01E-04
RB-88	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
RB-89	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
SR-89	3.50E-05	3.61E-06	2.14E-05	1.18E-04	4.37E-05	4.55E-05	1.67E-06
SR-90	1.19E-04	1.26E-05	7.68E-05	4.25E-04	1.55E-04	1.64E-04	5.72E-06
SR-91	1.84E-11	1.25E-12	1.68E-12	6.43E-12	8.19E-12	3.47E-12	8.29E-13
SR-92	2.48E-16	1.68E-17	2.26E-17	8.65E-17	1.10E-16	4.67E-17	1.12E-17
Y-90	1.05E-08	1.19E-09	7.94E-09	4.45E-08	1.55E-08	1.69E-08	5.09E-10
Y-91M	3.34E-31	2.27E-32	3.05E-32	1.17E-31	1.49E-31	6.30E-32	1.50E-32
Y-91	3.65E-05	4.10E-06	2.63E-05	1.39E-04	5.10E-05	5.79E-05	1.85E-06
Y-92	8.91E-17	6.05E-18	8.12E-18	23.11E-17	3.96E-17	1.68E-17	4.01E-18
Y-93	2.92E-13	1.98E-14	2.66E-14	1.02E-13	1.30E-13	5.51E-14	1.32E-14
ZR-93	2.26E-04	2.48E-05	1.38E-04	5.77E-04	2.62E-04	3.39E-04	1.28E-05
ZR-95	9.10E-05	9.99E-06	5.59E-05	2.38E-04	1.07E-04	1.37E-04	5.13E-06
ZR-97	1.74E-12	1.21E-13	2.00E-13	8.53E-13	8.38E-13	4.17E-13	7.85E-14
NB-93M	1.35E-03	1.43E-04	7.01E-04	2.32E-03	1.33E-03	1.87E-03	8.04E-05
NB-94	1.46E-03	1.56E-04	7.65E-04	2.57E-03	1.46E-03	2.03E-03	8.69E-05
NB-95M	2.55E-07	2.25E-08	8.78E-08	3.66E-07	2.03E-07	2.11E-07	1.29E-08
NB-95	2.78E-04	2.94E-05	1.43E-04	4.75E-04	2.73E-04	3.79E-04	1.65E-05
NB-97	3.36E-23	2.28E-24	3.06E-24	1.17E-23	1.49E-23	6.34E-24	1.51E-24
MO-93	8.41E-04	8.00E-05	4.07E-04	2.16E-03	8.79E-04	8.81E-04	4.02E-05
MO-99	1.71E-07	1.22E-08	2.52E-08	1.16E-07	9.07E-08	5.27E-08	7.73E-09
TC-99M	5.45E-11	3.70E-12	4.97E-12	1.90E-11	2.42E-11	1.03E-11	2.45E-12
TC-99	6.90E-03	6.84E-04	3.13E-03	1.15E-02	6.36E-03	8.03E-03	3.84E-04
TC-101	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
RU-103	4.32E-04	4.67E-05	2.32E-04	7.57E-04	4.36E-04	6.22E-04	2.61E-05
RU-105	1.16E-16	7.87E-18	1.06E-17	4.05E-17	5.16E-17	2.19E-17	5.22E-18
RU-106	1.50E-03	1.62E-04	8.05E-04	2.61E-03	1.51E-03	2.16E-03	9.09E-05
RH-103M	5.57E-23	3.78E-24	5.08E-24	1.94E-23	2.48E-23	1.05E-23	2.51E-24
RH-105	3.68E-07	2.52E-08	3.72E-08	1.50E-07	1.69E-07	7.71E-08	1.66E-08
RH-106	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

Table D.6. Food Transfer Factors (Continued)

PD-107	2.45E-02	2.41E-03	1.32E-02	7.22E-02	2.79E-02	2.81E-02	1.16E-03
PD-109	1.23E-08	8.34E-10	1.12E-09	4.29E-09	5.46E-09	2.32E-09	5.53E-10
AG-110M	1.15E-03	8.33E-05	1.74E-04	7.35E-04	6.11E-04	3.82E-04	5.28E-05
AG-111	3.16E-05	2.18E-06	3.43E-06	1.39E-05	1.49E-05	7.23E-06	1.43E-06
CD-113M	2.97E-04	3.35E-05	2.25E-04	1.26E-03	4.38E-04	4.77E-04	1.43E-05
CD-115M	5.07E-19	3.44E-20	4.62E-20	1.77E-19	2.25E-19	9.55E-20	2.28E-20
IN-113M	1.93E-20	1.31E-21	1.76E-21	6.74E-21	8.59E-21	3.64E-21	8.69E-22
SN-113	2.80E-04	2.89E-05	1.41E-04	5.28E-04	2.78E-04	3.60E-04	1.59E-05
SN-119M	3.86E-04	3.99E-05	1.95E-04	7.27E-04	3.84E-04	5.00E-04	2.20E-05
SN-121M	4.93E-04	5.10E-05	2.51E-04	9.35E-04	4.92E-04	6.42E-04	2.81E-05
SN-123	2.96E-04	3.05E-05	1.49E-04	5.58E-04	2.94E-04	3.81E-04	1.68E-05
SN-125	8.92E-06	8.46E-07	3.67E-06	1.40E-05	7.77E-06	9.21E-06	4.79E-07
SN-126	5.04E-04	5.22E-05	2.57E-04	9.64E-04	5.04E-04	6.57E-04	2.86E-05
SB-124	5.50E-05	5.42E-06	2.91E-05	1.52E-04	6.10E-05	6.36E-05	2.67E-06
SB-125	1.25E-04	1.25E-05	6.80E-05	3.55E-04	1.41E-04	1.49E-04	6.13E-06
SB-126	5.92E-06	5.33E-07	2.42E-06	1.25E-05	5.48E-06	5.26E-06	2.82E-07
SB-126M	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
SB-127	1.56E-07	1.32E-08	5.32E-08	2.81E-07	1.30E-07	1.13E-07	7.22E-09
TE-125M	1.70E-04	1.81E-05	9.43E-05	3.71E-04	1.82E-04	2.37E-04	9.70E-06
TE-127M	2.75E-04	2.94E-05	1.54E-04	6.06E-04	2.96E-04	3.86E-04	1.57E-05
TE-127	9.34E-11	6.34E-12	8.51E-12	3.26E-11	4.15E-11	1.76E-11	4.20E-12
TE-129M	9.44E-05	1.00E-05	5.19E-05	2.04E-04	1.00E-04	1.30E-04	5.37E-06
TE-129	4.95E-23	3.36E-24	4.51E-24	1.73E-23	2.20E-23	9.32E-24	2.23E-24
TE-131M	4.60E-09	3.21E-10	5.40E-10	2.31E-09	2.23E-09	1.12E-09	2.08E-10
TE-131	2.80E-45	0.00E+00	0.00E+00	1.40E-45	1.40E-45	0.00E+00	0.00E+00
TE-132	1.19E-07	1.14E-08	5.80E-08	3.03E-07	1.24E-07	1.27E-07	5.75E-09
TE-133M	3.99E-26	2.71E-27	3.64E-27	1.39E-26	1.77E-26	7.52E-27	1.80E-27
TE-134	9.79E-31	6.64E-32	8.92E-32	3.42E-31	4.35E-31	1.85E-31	4.41E-32
I-129	3.27E-04	2.92E-05	1.31E-04	6.91E-04	3.01E-04	2.82E-04	1.54E-05
I-130	4.26E-10	2.89E-11	3.88E-11	1.49E-10	1.89E-10	8.03E-11	1.92E-11
I-131	5.56E-06	4.15E-07	1.05E-06	5.04E-06	3.31E-06	2.23E-06	2.54E-07
I-132	1.48E-16	1.00E-17	1.35E-17	5.16E-17	6.58E-17	2.79E-17	6.66E-18
I-133	3.82E-09	2.59E-10	3.49E-10	1.34E-09	1.70E-09	7.22E-10	1.72E-10
I-134	1.76E-27	1.19E-28	1.60E-28	6.13E-28	7.81E-28	3.31E-28	7.90E-29
I-135	1.44E-11	9.80E-13	1.32E-12	5.04E-12	6.42E-12	2.72E-12	6.50E-13
CS-134M	9.60E-15	6.52E-16	8.75E-16	3.35E-15	4.27E-15	1.81E-15	4.32E-16
CS-134	3.69E-04	2.89E-05	8.85E-05	4.31E-04	2.47E-04	1.91E-04	1.71E-05
CS-135	4.54E-04	3.65E-05	1.23E-04	6.15E-04	3.26E-04	2.65E-04	2.11E-05
CS-136	2.91E-05	2.13E-06	4.77E-06	2.19E-05	1.62E-05	1.02E-05	1.33E-06
CS-137	4.17E-04	3.30E-05	1.05E-04	5.17E-04	2.87E-04	2.27E-04	1.93E-05
CS-138	3.93E-38	2.67E-39	3.58E-39	1.37E-38	21.75E-38	7.41E-39	1.77E-39
CS-139	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
BA-137M	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
BA-139	2.04E-22	1.38E-23	1.85E-23	7.10E-23	9.05E-23	3.84E-23	9.16E-24

Table D.6. Food Transfer Factors (Continued)

BA-140	3.92E-06	4.04E-07	2.34E-06	1.25E-05	4.76E-06	5.09E-06	1.92E-07
BA-141	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
BA-142	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
LA-140	5.27E-10	5.87E-11	3.89E-10	2.18E-09	7.63E-10	8.24E-10	2.53E-11
LA-141	1.03E-16	7.01E-18	9.42E-18	3.61E-17	4.59E-17	1.95E-17	4.65E-18
LA-142	1.59E-23	1.08E-24	1.45E-24	5.54E-24	7.06E-24	2.99E-24	7.15E-25
CE-141	2.07E-05	2.16E-06	1.29E-05	7.09E-05	2.62E-05	2.77E-05	9.96E-07
CE-143	1.79E-09	1.26E-10	2.35E-10	1.05E-09	9.08E-10	4.91E-10	8.09E-11
CE-144	7.83E-05	8.29E-06	5.07E-05	2.78E-04	1.02E-04	1.09E-04	3.78E-06
PR-143	3.87E-06	4.35E-07	2.79E-06	1.47E-05	5.40E-06	6.14E-06	1.96E-07
PR-144	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
PR-144M	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
ND-147	2.11E-06	2.37E-07	1.54E-06	8.30E-06	3.00E-06	3.36E-06	1.05E-07
PM-146	9.48E-05	1.06E-05	6.78E-05	3.55E-04	1.31E-04	1.50E-04	4.82E-06
PM-147	9.10E-05	1.02E-05	6.52E-05	3.41E-04	1.26E-04	1.44E-04	4.63E-06
PM-148M	2.73E-05	3.06E-06	1.97E-05	1.04E-04	3.81E-05	4.33E-05	1.38E-06
PM-148	2.23E-07	2.52E-08	1.66E-07	9.11E-07	3.23E-07	3.58E-07	1.10E-08
PM-149	3.68E-09	4.14E-10	2.78E-09	1.56E-08	5.42E-09	5.90E-09	1.77E-10
PM-151	3.27E-11	3.31E-12	1.92E-11	1.06E-10	3.97E-11	4.06E-11	1.55E-12
SM-147	1.08E-04	1.21E-05	7.72E-05	4.05E-04	1.49E-04	1.71E-04	5.47E-06
SM-151	1.04E-04	1.17E-05	7.46E-05	3.91E-04	1.45E-04	1.65E-04	5.30E-06
SM-153	1.60E-09	1.80E-10	1.20E-09	6.76E-09	2.35E-09	2.55E-09	7.72E-11
EU-152	9.75E-05	1.09E-05	6.98E-05	3.65E-04	1.35E-04	1.54E-04	4.96E-06
EU-154	9.64E-05	1.08E-05	6.90E-05	3.61E-04	1.34E-04	1.53E-04	4.90E-06
EU-155	9.42E-05	1.06E-05	6.74E-05	3.53E-04	1.30E-04	1.49E-04	4.79E-06
EU-156	5.02E-06	5.63E-07	3.60E-06	1.90E-05	6.98E-06	7.95E-06	2.54E-07
GD-153	7.12E-05	8.01E-06	5.18E-05	2.76E-04	1.00E-04	1.13E-04	3.58E-06
TB-160	4.36E-05	4.90E-06	3.15E-05	1.67E-04	6.11E-05	6.93E-05	2.20E-06
HO-166M	1.05E-04	1.18E-05	7.57E-05	4.00E-04	1.47E-04	1.67E-04	5.30E-06
W-181	5.91E-05	6.31E-06	3.91E-05	2.14E-04	7.81E-05	8.37E-05	2.86E-06
W-185	4.45E-05	4.74E-06	2.93E-05	1.61E-04	5.86E-05	6.28E-05	2.15E-06
W-187	5.12E-10	3.49E-11	4.92E-11	1.94E-10	2.32E-10	1.02E-10	2.31E-11
TL-207	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
TL-208	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
PB-209	2.74E-15	1.86E-16	2.50E-16	9.57E-16	1.22E-15	5.17E-16	1.23E-16
PB-210	1.61E-04	1.74E-05	1.11E-04	6.21E-04	2.21E-04	2.36E-04	7.71E-06
PB-211	6.46E-36	4.38E-37	5.89E-37	2.25E-36	2.87E-36	1.22E-36	2.91E-37
PB-212	2.67E-11	1.81E-12	2.43E-12	9.31E-12	1.19E-11	5.03E-12	1.20E-12
BI-210	3.08E-07	3.05E-08	1.65E-07	8.70E-07	3.45E-07	3.61E-07	1.50E-08
BI-211	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
BI-212	8.42E-26	5.71E-27	7.67E-27	2.94E-26	3.74E-26	1.59E-26	3.79E-27
BI-213	1.35E-30	9.17E-32	1.23E-31	4.71E-31	6.00E-31	2.55E-31	6.08E-32
PO-210	9.06E-05	9.85E-06	5.82E-05	2.84E-04	1.14E-04	1.34E-04	4.76E-06
PO-212	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

Table D.6. Food Transfer Factors (Continued)

PO-213	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
PO-215	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
PO-216	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
AT-217	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
FR-221	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
FR-223	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
RA-223	1.92E-05	1.53E-06	4.58E-06	1.90E-05	1.25E-05	1.07E-05	9.26E-07
RA-224	4.90E-07	3.57E-08	8.01E-08	3.66E-07	2.71E-07	1.71E-07	2.24E-08
RA-225	3.20E-05	2.62E-06	8.43E-06	3.50E-05	2.19E-05	1.99E-05	1.56E-06
RA-226	4.32E-04	3.88E-05	1.57E-04	6.50E-04	3.54E-04	3.78E-04	2.21E-05
RA-228	4.14E-04	3.71E-05	1.49E-04	6.19E-04	3.38E-04	3.61E-04	2.12E-05
AC-225	5.32E-06	5.81E-07	3.13E-06	1.24E-05	5.95E-06	7.87E-06	3.07E-07
AC-227	3.37E-04	3.67E-05	1.96E-04	7.57E-04	3.71E-04	4.97E-04	1.96E-05
AC-228	6.41E-15	4.35E-16	5.84E-16	2.24E-15	2.85E-15	1.21E-15	2.88E-16
TH-227	6.39E-06	7.24E-07	4.88E-06	2.74E-05	9.51E-06	1.04E-05	3.09E-07
TH-228	7.13E-05	8.07E-06	5.45E-05	3.05E-04	1.06E-04	1.16E-04	3.44E-06
TH-229	9.17E-05	1.04E-05	7.01E-05	3.93E-04	1.37E-04	1.49E-04	4.43E-06
TH-230	9.18E-05	1.04E-05	7.02E-05	3.94E-04	21.37E-04	1.49E-04	4.43E-06
TH-231	1.45E-11	1.35E-12	6.83E-12	3.74E-11	1.50E-11	1.44E-11	6.77E-13
TH-232	9.18E-05	1.04E-05	7.02E-05	3.94E-04	1.37E-04	1.49E-04	4.43E-06
TH-234	1.04E-05	1.18E-06	7.97E-06	4.47E-05	1.55E-05	1.69E-05	5.04E-07
PA-231	1.00E+00	3.81E-01	1.00E+00	1.00E+00	1.00E+00	1.00E+00	2.16E-01
PA-233	4.79E-01	5.16E-02	2.52E-01	7.76E-01	4.71E-01	6.85E-01	2.93E-02
PA-234M	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
U-232	9.56E-05	1.03E-05	6.44E-05	3.58E-04	1.29E-04	1.37E-04	4.58E-06
U-233	9.99E-05	1.07E-05	6.76E-05	3.76E-04	1.35E-04	1.44E-04	4.79E-06
U-234	9.99E-05	1.07E-05	6.76E-05	3.76E-04	1.35E-04	1.44E-04	4.79E-06
U-235	9.99E-05	1.07E-05	6.76E-05	3.76E-04	1.35E-04	1.44E-04	4.79E-06
U-236	9.99E-05	1.07E-05	6.76E-05	3.76E-04	1.35E-04	1.44E-04	4.79E-06
U-237	6.69E-07	6.50E-08	3.52E-07	1.94E-06	7.49E-07	7.46E-07	3.15E-08
U-238	9.99E-05	1.07E-05	6.76E-05	3.76E-04	1.35E-04	1.44E-04	4.79E-06
NP-236	8.64E-05	9.79E-06	6.61E-05	3.70E-04	1.29E-04	1.40E-04	4.17E-06
NP-237	8.64E-05	9.79E-06	6.61E-05	3.70E-04	1.29E-04	1.40E-04	4.17E-06
NP-238	2.61E-09	2.94E-10	1.97E-09	1.11E-08	3.85E-09	4.18E-09	1.25E-10
NP-239	5.12E-09	5.78E-10	3.89E-09	2.19E-08	7.60E-09	8.25E-09	2.47E-10
PU-236	7.18E-05	8.14E-06	5.51E-05	3.10E-04	1.07E-04	1.17E-04	3.46E-06
PU-237	2.38E-05	2.69E-06	1.82E-05	1.03E-04	3.55E-05	3.86E-05	1.14E-06
PU-238	7.74E-05	8.77E-06	5.94E-05	3.34E-04	1.16E-04	1.26E-04	3.73E-06
PU-239	7.84E-05	8.89E-06	6.02E-05	3.38E-04	1.17E-04	1.27E-04	3.78E-06
PU-240	7.84E-05	8.89E-06	6.01E-05	3.38E-04	1.17E-04	1.27E-04	3.77E-06
PU-241	7.57E-05	8.58E-06	5.81E-05	3.27E-04	1.13E-04	1.23E-04	3.65E-06
PU-242	7.84E-05	8.89E-06	6.02E-05	3.38E-04	1.17E-04	1.27E-04	3.78E-06
PU-244	7.84E-05	8.89E-06	6.02E-05	3.38E-04	1.17E-04	1.27E-04	3.78E-06
AM-241	7.90E-05	8.95E-06	6.04E-05	3.39E-04	1.18E-04	1.28E-04	3.82E-06

Table D.6. Food Transfer Factors (Continued)

AM-242M	7.86E-05	8.91E-06	6.01E-05	3.37E-04	1.17E-04	1.28E-04	3.80E-06
AM-243	7.93E-05	8.98E-06	6.06E-05	3.40E-04	1.18E-04	1.29E-04	3.83E-06
CM-242	5.38E-05	6.10E-06	4.12E-05	2.31E-04	8.01E-05	8.74E-05	2.60E-06
CM-243	7.99E-05	9.05E-06	6.10E-05	3.42E-04	1.19E-04	1.30E-04	3.86E-06
CM-244	7.88E-05	8.92E-06	6.02E-05	3.37E-04	1.17E-04	1.28E-04	3.80E-06
CM-245	8.64E-05	9.78E-06	6.60E-05	3.70E-04	1.29E-04	1.40E-04	4.17E-06
CM-246	8.63E-05	9.78E-06	6.60E-05	3.70E-04	1.28E-04	1.40E-04	4.17E-06
CM-247	8.64E-05	9.79E-06	6.61E-05	3.70E-04	1.29E-04	1.40E-04	4.17E-06
CM-248	8.64E-05	9.79E-06	6.61E-05	3.70E-04	1.29E-04	1.40E-04	4.17E-06
CF-252	7.26E-05	8.22E-06	5.55E-05	3.11E-04	1.08E-04	1.18E-04	3.50E-06
Nuclide	**State**						
	VT	**VA**	**WA**	**WV**	**WI**	**WY**	**US[b]**
H-3	1.52E-07	1.28E-07	2.82E-07	2.43E-08	9.58E-07	5.02E-08	2.97E-07
BE-10	8.85E-06	8.14E-05	1.53E-04	1.04E-05	2.97E-04	2.43E-05	1.88E-04
C-14	1.02E-06	1.78E-06	2.76E-06	2.60E-07	7.58E-06	4.47E-07	3.40E-06
N-16	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
F-18	1.50E-17	4.14E-18	4.08E-18	7.18E-19	4.61E-17	1.65E-19	3.64E-18
NA-22	1.16E-03	5.06E-04	5.04E-04	8.91E-05	3.90E-03	5.97E-05	5.53E-04
NA-24	8.66E-09	2.39E-09	2.36E-09	4.15E-10	2.66E-08	9.50E-11	2.10E-09
P-32	7.74E-05	3.38E-05	3.31E-05	5.98E-06	2.60E-04	3.94E-06	3.63E-05
CA-41	3.07E-04	2.86E-04	4.51E-04	4.10E-05	1.60E-03	6.40E-05	5.34E-04
SC-46	8.73E-06	6.84E-05	8.61E-05	1.13E-05	1.78E-04	1.78E-05	1.15E-04
CR-51	1.60E-05	1.78E-05	2.88E-05	2.53E-06	9.29E-05	4.22E-06	3.44E-05
MN-54	1.08E-05	6.64E-05	1.25E-04	8.46E-06	2.52E-04	1.96E-05	1.53E-04
MN-56	4.45E-17	1.23E-17	1.21E-17	2.13E-18	1.37E-16	4.89E-19	1.08E-17
FE-55	6.90E-05	2.33E-04	2.06E-04	4.38E-05	5.49E-04	5.28E-05	2.98E-04
FE-59	2.29E-05	7.04E-05	6.52E-05	1.30E-05	1.77E-04	1.60E-05	9.27E-05
CO-57	3.61E-05	1.07E-04	1.39E-04	1.75E-05	3.44E-04	2.68E-05	1.82E-04
CO-58	2.15E-05	6.12E-05	8.08E-05	9.87E-06	2.01E-04	1.53E-05	1.05E-04
CO-60	4.42E-05	1.34E-04	1.74E-04	2.18E-05	4.27E-04	3.36E-05	2.27E-04
NI-59	2.36E-04	2.19E-04	3.32E-04	3.23E-05	1.21E-03	4.82E-05	3.95E-04
NI-63	2.26E-04	1.96E-04	2.90E-04	2.93E-05	1.11E-03	4.18E-05	3.44E-04
NI-65	9.09E-16	2.51E-16	2.48E-16	4.35E-17	2.80E-15	9.98E-18	2.21E-16
CU-64	1.83E-09	5.07E-10	4.99E-10	8.78E-11	5.63E-09	2.01E-11	4.45E-10
ZN-65	9.68E-04	4.31E-04	4.38E-04	7.53E-05	3.29E-03	5.23E-05	4.82E-04
ZN-69M	9.66E-09	2.67E-09	2.63E-09	4.62E-10	2.97E-08	1.06E-10	2.35E-09
ZN-69	3.51E-24	9.71E-25	9.56E-25	1.68E-25	1.08E-23	3.86E-26	8.53E-25
SE-79	1.24E-02	7.93E-03	1.15E-02	1.19E-03	5.26E-02	1.49E-03	1.31E-02
BR-82	3.11E-07	8.64E-08	8.55E-08	1.49E-08	9.56E-07	3.56E-09	7.66E-08
BR-83	2.18E-14	6.03E-15	5.94E-15	1.04E-15	6.71E-14	2.39E-16	5.30E-15
BR-84	4.49E-36	1.24E-36	1.22E-36	2.15E-37	1.38E-35	4.93E-38	1.09E-36
BR-85	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
KR-85	2.73E-03	2.78E-03	4.22E-03	4.10E-04	1.46E-02	6.28E-04	5.06E-03
RB-86	1.31E-04	5.16E-05	5.14E-05	9.05E-06	4.32E-04	5.30E-06	5.43E-05

Table D.6. Food Transfer Factors (Continued)

RB-87	1.68E-03	1.15E-03	1.46E-03	1.85E-04	6.97E-03	2.09E-04	1.71E-03
RB-88	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
RB-89	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
SR-89	1.10E-05	2.88E-05	5.30E-05	3.72E-06	1.24E-04	8.07E-06	6.44E-05
SR-90	3.11E-05	1.02E-04	1.90E-04	1.31E-05	4.22E-04	2.92E-05	2.32E-04
SR-91	2.14E-11	5.91E-12	5.82E-12	1.02E-12	6.57E-11	2.35E-13	5.20E-12
SR-92	2.88E-16	7.95E-17	7.83E-17	1.38E-17	8.84E-16	3.16E-18	6.99E-17
Y-90	8.86E-10	1.01E-08	1.96E-08	1.25E-09	3.75E-08	3.06E-09	2.41E-08
Y-91M	3.88E-31	1.07E-31	1.06E-31	1.86E-32	1.19E-30	4.26E-33	9.43E-32
Y-91	3.33E-06	3.52E-05	5.90E-05	4.94E-06	1.15E-04	1.01E-05	7.44E-05
Y-92	1.03E-16	2.86E-17	2.81E-17	4.95E-18	3.18E-16	1.14E-18	2.51E-17
Y-93	3.39E-13	9.38E-14	9.23E-14	1.62E-14	1.04E-12	3.72E-15	8.24E-14
ZR-93	3.37E-05	2.18E-04	2.04E-04	24.03E-05	4.55E-04	5.19E-05	2.95E-04
ZR-95	1.33E-05	8.76E-05	8.53E-05	1.60E-05	1.88E-04	2.11E-05	1.22E-04
ZR-97	1.95E-12	5.98E-13	6.48E-13	1.01E-13	6.21E-12	3.98E-14	6.18E-13
NB-93M	3.11E-04	1.26E-03	6.27E-04	2.66E-04	1.94E-03	2.59E-04	1.12E-03
NB-94	3.34E-04	1.36E-03	7.09E-04	2.86E-04	2.15E-03	2.83E-04	1.25E-03
NB-95M	1.70E-07	1.61E-07	1.56E-07	2.92E-08	7.21E-07	3.03E-08	2.01E-07
NB-95	6.90E-05	2.55E-04	1.30E-04	5.39E-05	4.14E-04	5.25E-05	2.30E-04
NB-97	3.90E-23	1.08E-23	1.06E-23	1.87E-24	1.20E-22	4.28E-25	9.48E-24
MO-93	4.25E-04	6.00E-04	9.85E-04	8.43E-05	2.87E-03	1.49E-04	1.19E-03
MO-99	1.82E-07	6.40E-08	7.62E-08	1.04E-08	6.08E-07	6.21E-09	7.71E-08
TC-99M	6.33E-11	1.75E-11	1.72E-11	3.03E-12	1.95E-10	6.95E-13	1.54E-11
TC-99	2.79E-03	5.59E-03	3.82E-03	1.12E-03	1.41E-02	1.13E-03	5.84E-03
TC-101	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
RU-103	8.06E-05	4.15E-04	1.94E-04	8.86E-05	5.61E-04	8.60E-05	3.61E-04
RU-105	1.35E-16	3.72E-17	3.66E-17	6.45E-18	4.14E-16	1.48E-18	3.27E-17
RU-106	2.81E-04	1.44E-03	6.66E-04	3.08E-04	1.93E-03	2.98E-04	1.25E-03
RH-103M	6.47E-23	1.79E-23	1.76E-23	3.10E-24	1.99E-22	7.10E-25	1.57E-23
RH-105	4.21E-07	1.22E-07	1.25E-07	2.08E-08	1.31E-06	6.22E-09	1.15E-07
RH-106	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
PD-107	1.05E-02	1.85E-02	3.30E-02	2.45E-03	8.65E-02	4.92E-03	3.98E-02
PD-109	1.43E-08	3.94E-09	3.88E-09	6.83E-10	4.38E-08	1.56E-10	3.46E-09
AG-110M	1.21E-03	4.48E-04	4.71E-04	7.67E-05	3.97E-03	4.36E-05	4.87E-04
AG-111	3.57E-05	1.07E-05	1.10E-05	1.84E-06	1.12E-04	6.34E-07	1.03E-05
CD-113M	2.41E-05	2.85E-04	5.55E-04	3.53E-05	1.06E-03	8.67E-05	6.81E-04
CD-115M	5.88E-19	1.63E-19	1.60E-19	2.82E-20	1.81E-18	6.46E-21	1.43E-19
IN-113M	2.24E-20	6.20E-21	6.10E-21	1.07E-21	6.89E-20	2.46E-22	5.45E-21
SN-113	8.66E-05	2.44E-04	1.73E-04	4.84E-05	5.37E-04	5.19E-05	2.67E-04
SN-119M	1.17E-04	3.38E-04	2.37E-04	6.73E-05	7.30E-04	7.19E-05	3.67E-04
SN-121M	1.47E-04	4.33E-04	3.05E-04	8.61E-05	9.30E-04	9.24E-05	4.71E-04
SN-123	9.12E-05	2.58E-04	1.83E-04	5.12E-05	5.67E-04	5.49E-05	2.82E-04
SN-125	4.52E-06	6.61E-06	5.12E-06	1.28E-06	2.09E-05	1.31E-06	7.33E-06
SN-126	1.49E-04	4.43E-04	3.16E-04	8.78E-05	9.56E-04	9.47E-05	4.87E-04

Table D.6. Food Transfer Factors (Continued)

SB-124	2.31E-05	4.21E-05	6.79E-05	6.01E-06	1.82E-04	1.08E-05	8.34E-05
SB-125	4.97E-05	9.80E-05	1.57E-04	1.41E-05	4.10E-04	2.53E-05	1.94E-04
SB-126	3.70E-06	3.81E-06	5.81E-06	5.59E-07	2.00E-05	8.63E-07	6.96E-06
SB-126M	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
SB-127	1.17E-07	8.78E-08	1.39E-07	1.25E-08	5.53E-07	1.84E-08	1.61E-07
TE-125M	3.85E-05	1.57E-04	1.25E-04	3.03E-05	3.25E-04	3.51E-05	1.88E-04
TE-127M	6.03E-05	2.54E-04	2.05E-04	4.90E-05	5.26E-04	5.73E-05	3.07E-04
TE-127	1.08E-10	3.00E-11	2.95E-11	5.19E-12	3.33E-10	1.19E-12	2.63E-11
TE-129M	2.23E-05	8.62E-05	6.90E-05	1.67E-05	1.82E-04	1.93E-05	1.03E-04
TE-129	5.74E-23	1.59E-23	1.56E-23	2.75E-24	1.76E-22	6.30E-25	1.40E-23
TE-131M	5.15E-09	1.59E-09	1.73E-09	2.67E-10	1.64E-08	1.09E-10	1.66E-09
TE-131	4.20E-45	1.40E-45	1.40E-45	0.00E+00	1.12E-44	0.00E+00	1.40E-45
TE-132	5.87E-08	8.61E-08	1.37E-07	1.24E-08	3.97E-07	2.13E-08	1.67E-07
TE-133M	4.63E-26	1.28E-26	1.26E-26	2.22E-27	1.42E-25	5.08E-28	1.12E-26
TE-134	1.14E-30	3.14E-31	3.09E-31	5.44E-32	3.49E-30	1.25E-32	2.76E-31
I-129	2.12E-04	2.05E-04	3.28E-04	2.92E-05	1.14E-03	4.67E-05	3.88E-04
I-130	4.94E-10	1.37E-10	1.35E-10	2.37E-11	1.52E-09	5.43E-12	1.20E-10
I-131	5.54E-06	2.32E-06	2.96E-06	3.69E-07	1.96E-05	3.00E-07	3.16E-06
I-132	1.72E-16	4.75E-17	4.67E-17	8.22E-18	5.28E-16	1.89E-18	4.17E-17
I-133	4.44E-09	1.23E-09	1.21E-09	2.13E-10	1.36E-08	4.89E-11	1.08E-09
I-134	2.04E-27	5.64E-28	5.55E-28	9.76E-29	6.27E-27	2.24E-29	4.95E-28
I-135	1.68E-11	4.64E-12	4.56E-12	8.03E-13	5.15E-11	1.84E-13	4.07E-12
CS-134M	1.11E-14	3.08E-15	3.03E-15	5.34E-16	3.42E-14	1.22E-16	2.71E-15
CS-134	3.35E-04	1.75E-04	2.30E-04	2.74E-05	1.28E-03	2.77E-05	2.58E-04
CS-135	3.89E-04	2.28E-04	3.18E-04	3.49E-05	1.58E-03	4.01E-05	3.61E-04
CS-136	3.02E-05	1.15E-05	1.36E-05	1.88E-06	1.03E-04	1.26E-06	1.42E-05
CS-137	3.70E-04	2.02E-04	2.73E-04	3.14E-05	1.45E-03	3.35E-05	3.07E-04
CS-138	4.56E-38	1.26E-38	1.24E-38	2.19E-39	1.40E-37	5.01E-40	1.11E-38
CS-139	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
BA-137M	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
BA-139	2.36E-22	6.53E-23	6.43E-23	1.13E-23	7.26E-22	2.59E-24	5.74E-23
BA-140	1.22E-06	3.25E-06	5.48E-06	4.51E-07	1.30E-05	8.81E-07	6.77E-06
BA-141	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
BA-142	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
LA-140	5.98E-11	4.96E-10	9.67E-10	6.10E-11	1.89E-09	1.50E-10	1.18E-09
LA-141	1.20E-16	3.32E-17	3.27E-17	5.74E-18	3.69E-16	1.32E-18	2.91E-17
LA-142	1.84E-23	5.10E-24	5.02E-24	8.83E-25	5.67E-23	2.02E-25	4.48E-24
CE-141	5.88E-06	1.74E-05	3.16E-05	2.28E-06	7.19E-05	4.90E-06	3.86E-05
CE-143	1.96E-09	6.44E-10	7.35E-10	1.06E-10	6.39E-09	5.32E-11	7.24E-10
CE-144	1.92E-05	6.77E-05	1.23E-04	28.86E-06	2.71E-04	1.93E-05	1.51E-04
PR-143	3.56E-07	3.74E-06	6.22E-06	5.26E-07	1.21E-05	1.07E-06	7.86E-06
PR-144	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
PR-144M	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
ND-147	1.80E-07	2.03E-06	3.56E-06	2.76E-07	6.87E-06	5.94E-07	4.46E-06

Table D.6. Food Transfer Factors (Continued)

PM-146	8.77E-06	9.16E-05	1.50E-04	1.30E-05	2.92E-04	2.60E-05	1.90E-04
PM-147	8.42E-06	8.80E-05	1.44E-04	1.25E-05	2.80E-04	2.50E-05	1.82E-04
PM-148M	2.46E-06	2.64E-05	4.39E-05	3.71E-06	8.53E-05	7.55E-06	5.55E-05
PM-148	1.79E-08	2.16E-07	3.96E-07	2.81E-08	7.57E-07	6.41E-08	4.91E-07
PM-149	2.96E-10	3.53E-09	6.87E-09	4.35E-10	1.31E-08	1.07E-09	8.44E-09
PM-151	1.17E-11	2.60E-11	4.83E-11	3.33E-12	1.17E-10	7.21E-12	5.84E-11
SM-147	9.86E-06	1.04E-04	1.71E-04	1.48E-05	3.33E-04	2.96E-05	2.17E-04
SM-151	9.61E-06	1.01E-04	1.65E-04	1.43E-05	3.21E-04	2.87E-05	2.09E-04
SM-153	1.44E-10	1.53E-09	2.98E-09	1.89E-10	5.73E-09	4.65E-10	3.66E-09
EU-152	9.01E-06	9.42E-05	1.54E-04	1.34E-05	3.00E-04	2.68E-05	1.95E-04
EU-154	8.91E-06	9.31E-05	1.52E-04	1.33E-05	2.97E-04	2.65E-05	1.93E-04
EU-155	8.71E-06	9.10E-05	1.49E-04	1.30E-05	2.90E-04	2.59E-05	1.89E-04
EU-156	4.63E-07	4.84E-06	8.03E-06	6.84E-07	1.56E-05	1.38E-06	1.01E-05
GD-153	6.16E-06	6.89E-05	1.18E-04	9.50E-06	2.27E-04	1.99E-05	1.48E-04
TB-160	3.88E-06	4.22E-05	7.09E-05	5.89E-06	1.37E-04	1.21E-05	8.93E-05
HO-166M	9.34E-06	1.01E-04	1.70E-04	1.42E-05	3.29E-04	2.91E-05	2.14E-04
W-181	1.31E-05	5.19E-05	9.46E-05	6.78E-06	2.04E-04	1.49E-05	1.16E-04
W-185	1.01E-05	3.90E-05	7.11E-05	5.09E-06	1.54E-04	1.12E-05	8.72E-05
W-187	5.90E-10	1.67E-10	1.68E-10	2.87E-11	1.83E-09	7.60E-12	1.52E-10
TL-207	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
TL-208	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
PB-209	3.18E-15	8.80E-16	8.67E-16	1.52E-16	9.79E-15	3.49E-17	7.74E-16
PB-210	2.99E-05	1.44E-04	2.76E-04	1.81E-05	5.73E-04	4.26E-05	3.38E-04
PB-211	7.50E-36	2.07E-36	2.04E-36	3.59E-37	2.30E-35	8.23E-38	1.82E-36
PB-212	3.10E-11	8.56E-12	8.43E-12	1.48E-12	9.52E-11	3.40E-13	7.52E-12
BI-210	1.25E-07	2.38E-07	3.87E-07	3.37E-08	1.02E-06	6.15E-08	4.76E-07
BI-211	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
BI-212	9.77E-26	2.70E-26	2.66E-26	4.68E-27	3.00E-25	1.07E-27	2.37E-26
BI-213	1.57E-30	4.34E-31	4.27E-31	7.51E-32	4.82E-30	1.72E-32	3.81E-31
PO-210	1.56E-05	8.41E-05	1.15E-04	1.33E-05	2.47E-04	2.21E-05	1.50E-04
PO-212	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
PO-213	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
PO-215	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
PO-216	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
AT-217	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
FR-221	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
FR-223	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
RA-223	1.68E-05	9.63E-06	9.49E-06	1.71E-06	6.06E-05	1.43E-06	1.12E-05
RA-224	5.08E-07	1.93E-07	2.28E-07	3.17E-08	1.72E-06	2.11E-08	2.37E-07
RA-225	2.65E-05	1.70E-05	1.66E-05	3.05E-06	9.83E-05	2.71E-06	2.01E-05
RA-226	2.72E-04	2.84E-04	2.70E-04	5.17E-05	1.19E-03	5.46E-05	3.54E-04
RA-228	2.62E-04	2.72E-04	2.57E-04	4.95E-05	1.14E-03	5.21E-05	3.37E-04
AC-225	8.49E-07	5.11E-06	4.16E-06	9.84E-07	9.70E-06	1.18E-06	6.27E-06
AC-227	5.50E-05	3.24E-04	2.46E-04	6.35E-05	5.87E-04	7.34E-05	3.80E-04

Table D.6. Food Transfer Factors (Continued)

AC-228	7.44E-15	2.06E-15	2.02E-15	3.56E-16	2.29E-14	8.16E-17	1.81E-15
TH-227	4.36E-07	6.18E-06	1.21E-05	7.63E-07	2.28E-05	1.89E-06	1.48E-05
TH-228	4.78E-06	6.90E-05	1.34E-04	8.51E-06	2.54E-04	2.10E-05	1.65E-04
TH-229	6.11E-06	8.88E-05	1.73E-04	1.09E-05	3.27E-04	2.71E-05	2.13E-04
TH-230	6.11E-06	8.89E-05	1.73E-04	1.10E-05	3.27E-04	2.71E-05	2.13E-04
TH-231	7.86E-12	9.92E-12	1.75E-11	1.32E-12	5.18E-11	2.50E-12	2.08E-11
TH-232	6.11E-06	8.89E-05	1.73E-04	1.10E-05	3.27E-04	2.71E-05	2.13E-04
TH-234	7.07E-07	1.01E-05	1.97E-05	1.24E-06	3.72E-05	3.08E-06	2.42E-05
PA-231	6.81E-01	1.00E+00	1.00E+00	7.40E-01	1.00E+00	6.86E-01	1.00E+00
PA-233	9.24E-02	4.59E-01	1.80E-01	1.00E-01	5.66E-01	9.29E-02	3.64E-01
PA-234M	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
U-232	2.04E-05	8.44E-05	1.60E-04	1.07E-05	3.39E-04	2.46E-05	1.95E-04
U-233	2.08E-05	8.84E-05	1.67E-04	1.12E-05	3.54E-04	2.58E-05	2.05E-04
U-234	2.08E-05	8.84E-05	1.67E-04	1.12E-05	3.54E-04	2.58E-05	2.05E-04
U-235	2.08E-05	8.84E-05	1.67E-04	1.12E-05	3.54E-04	2.58E-05	2.05E-04
U-236	2.08E-05	8.84E-05	1.67E-04	1.12E-05	3.54E-04	2.58E-05	2.05E-04
U-237	3.03E-07	4.94E-07	8.91E-07	6.47E-08	2.38E-06	1.31E-07	1.07E-06
U-238	2.08E-05	8.84E-05	1.67E-04	1.12E-05	3.54E-04	2.58E-05	2.05E-04
NP-236	5.77E-06	8.37E-05	1.63E-04	1.03E-05	3.08E-04	2.55E-05	2.00E-04
NP-237	5.77E-06	8.37E-05	1.63E-04	1.03E-05	3.08E-04	2.55E-05	2.00E-04
NP-238	2.16E-10	2.50E-09	4.90E-09	3.06E-10	9.35E-09	7.61E-10	6.00E-09
NP-239	3.94E-10	4.93E-09	9.66E-09	6.04E-10	1.84E-08	1.50E-09	1.19E-08
PU-236	4.64E-06	6.96E-05	1.37E-04	8.51E-06	2.57E-04	2.13E-05	1.68E-04
PU-237	1.54E-06	2.30E-05	4.52E-05	2.82E-06	8.52E-05	7.04E-06	5.55E-05
PU-238	5.00E-06	7.50E-05	1.47E-04	9.18E-06	2.77E-04	2.30E-05	1.81E-04
PU-239	5.07E-06	7.60E-05	1.49E-04	9.30E-06	2.81E-04	2.32E-05	1.83E-04
PU-240	5.06E-06	7.59E-05	1.49E-04	9.29E-06	2.81E-04	2.32E-05	1.83E-04
PU-241	4.89E-06	7.33E-05	1.44E-04	8.98E-06	2.71E-04	2.24E-05	1.77E-04
PU-242	5.07E-06	7.60E-05	1.49E-04	9.30E-06	2.81E-04	2.33E-05	1.83E-04
PU-244	5.07E-06	7.60E-05	1.49E-04	9.30E-06	2.81E-04	2.33E-05	1.83E-04
AM-241	5.29E-06	7.65E-05	1.49E-04	9.44E-06	2.81E-04	2.33E-05	1.83E-04
AM-242M	5.27E-06	7.61E-05	1.48E-04	9.39E-06	2.80E-04	2.32E-05	1.82E-04
AM-243	5.31E-06	7.67E-05	1.50E-04	9.47E-06	2.82E-04	2.34E-05	1.84E-04
CM-242	3.61E-06	5.21E-05	1.02E-04	6.43E-06	1.92E-04	1.59E-05	1.25E-04
CM-243	5.35E-06	7.73E-05	1.51E-04	9.54E-06	2.84E-04	2.36E-05	1.85E-04
CM-244	5.27E-06	7.62E-05	1.49E-04	9.40E-06	2.80E-04	2.32E-05	1.83E-04
CM-245	5.76E-06	8.36E-05	1.63E-04	1.03E-05	3.08E-04	2.55E-05	2.00E-04
CM-246	5.76E-06	8.36E-05	1.63E-04	1.03E-05	3.07E-04	2.55E-05	2.00E-04
CM-247	5.77E-06	8.37E-05	1.63E-04	1.03E-05	3.08E-04	2.55E-05	2.00E-04
CM-248	5.77E-06	8.37E-05	1.63E-04	1.03E-05	3.08E-04	2.55E-05	2.00E-04
CF-252	4.86E-06	7.03E-05	1.37E-04	8.67E-06	2.58E-04	2.14E-05	1.68E-04

[a] Values are interpreted as 1 µCi/m^2 available through ingestion pathways per 1 µCi/m^2 of radionuclide deposited on the ground.
[b] U.S. average.