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Chapter 5

Sections 5.11 and 5.12

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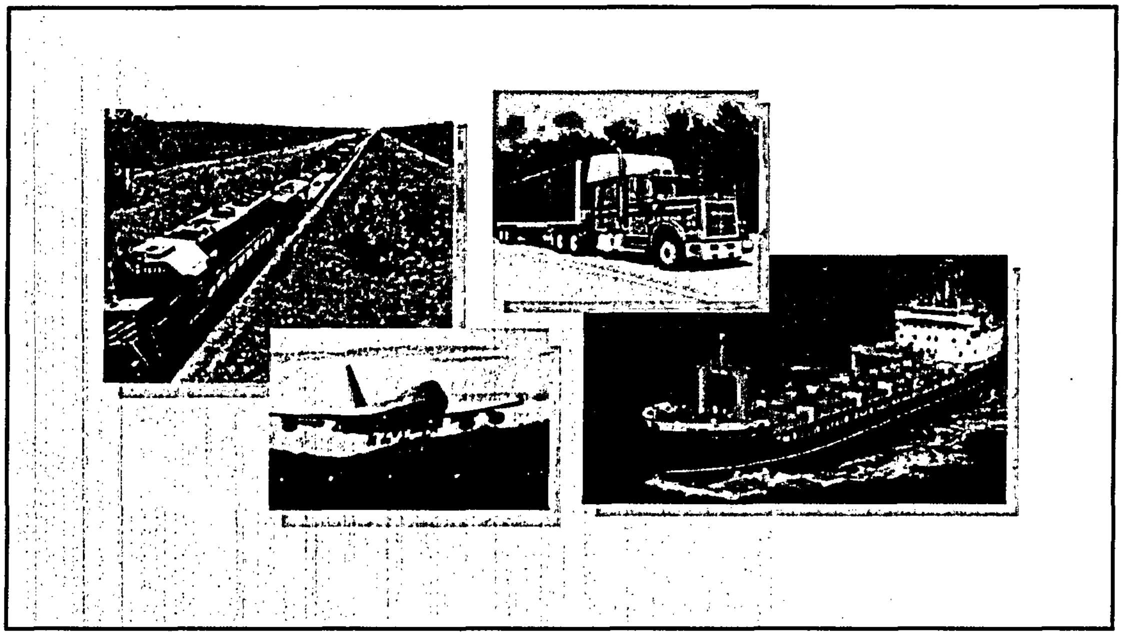
A RESOURCE HANDBOOK

on

DOE TRANSPORTATION RISK ASSESSMENT



Prepared for:
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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

Prepared by: DOE Transportation Risk Assessment Working Group Technical Subcommittee

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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

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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

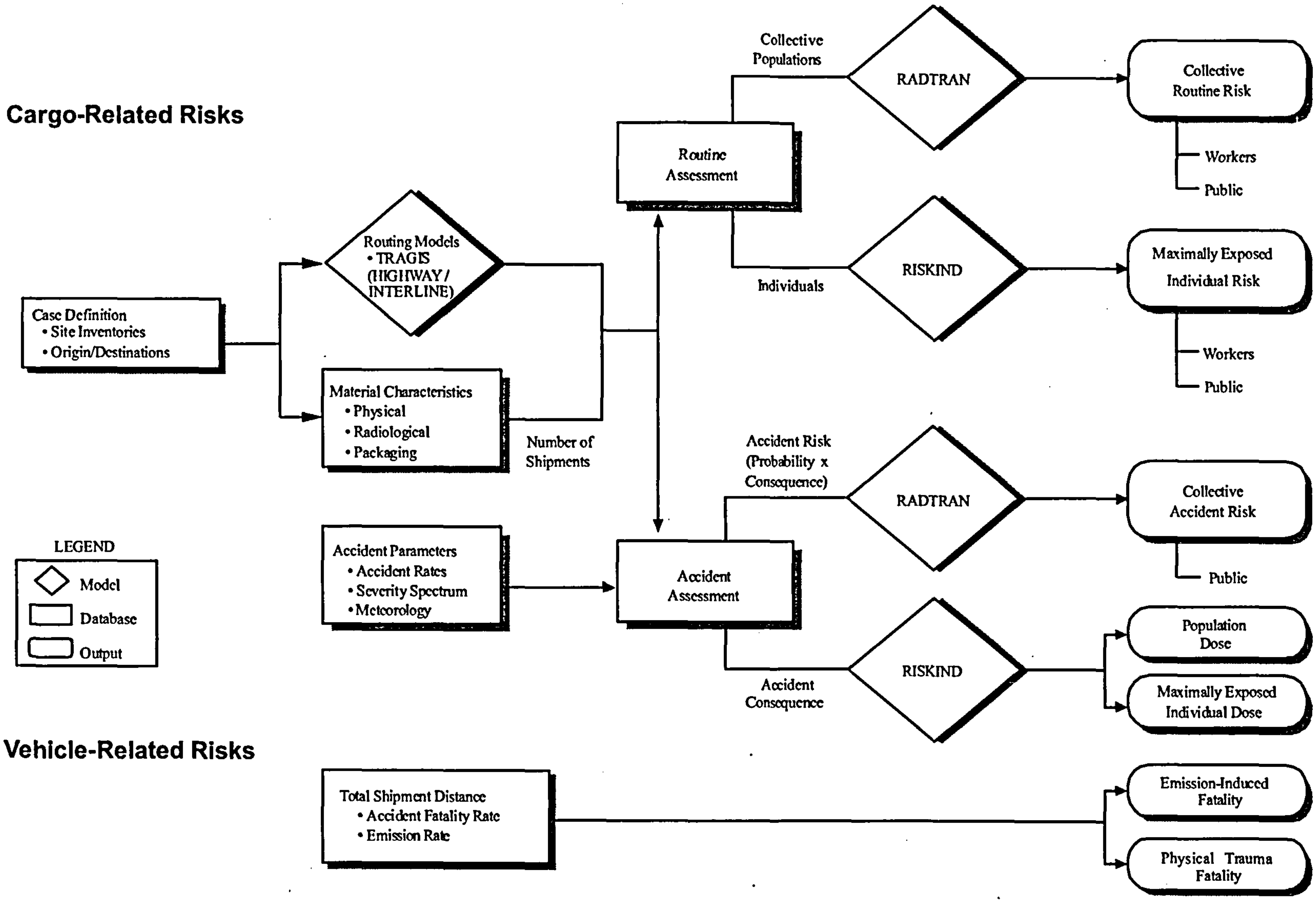

Figure 4.1. Technical Approach for Transportation Radiological Risk Assessments

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.

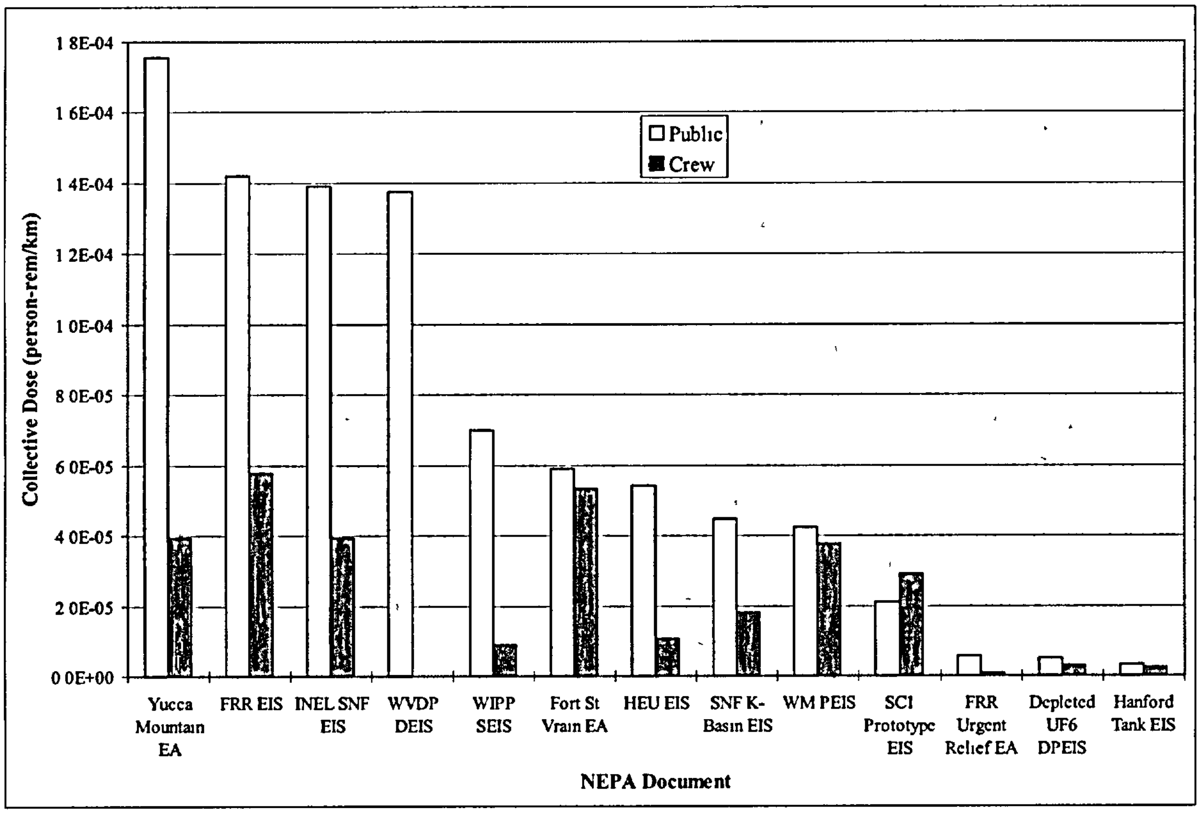

Figure 4.2. Incident-Free Cargo-Related Unit Risks for Members of the Public and Transportation Crews by Truck Transport

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

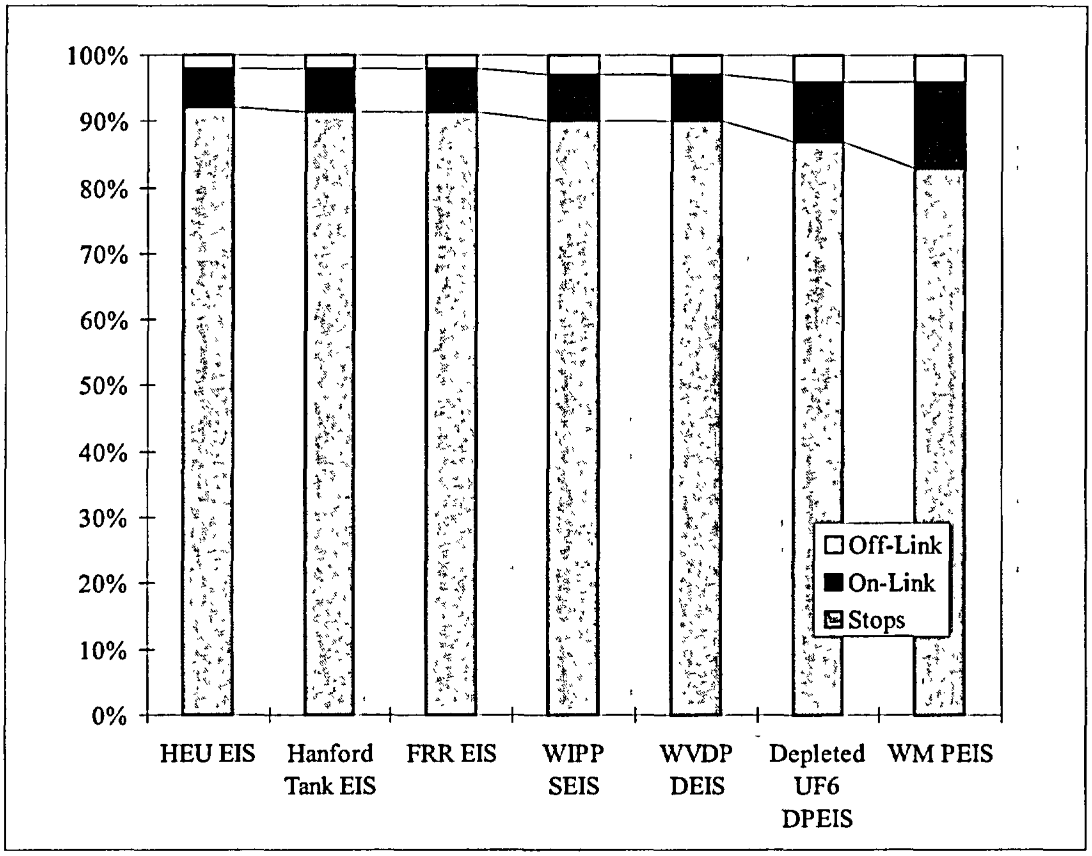

Figure 4.3. Distribution of the Total Incident-Free Dose to Members of the Public (persons at stops and off-link and on-link receptors) by Truck Transport

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.

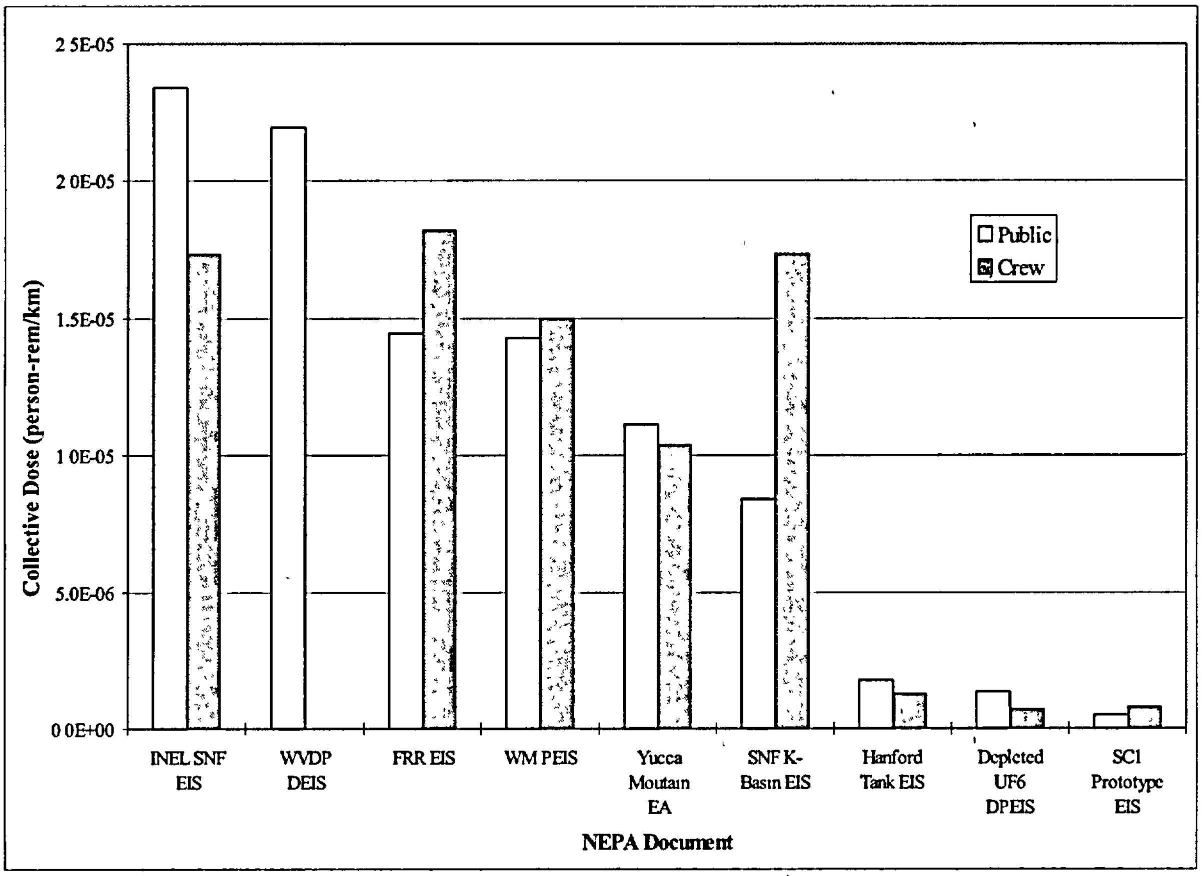

Figure 4.4. Incident-Free Cargo-Related Unit Risks for Members of the Public and Transportation Crews by Rail Transport

■ ■ 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.

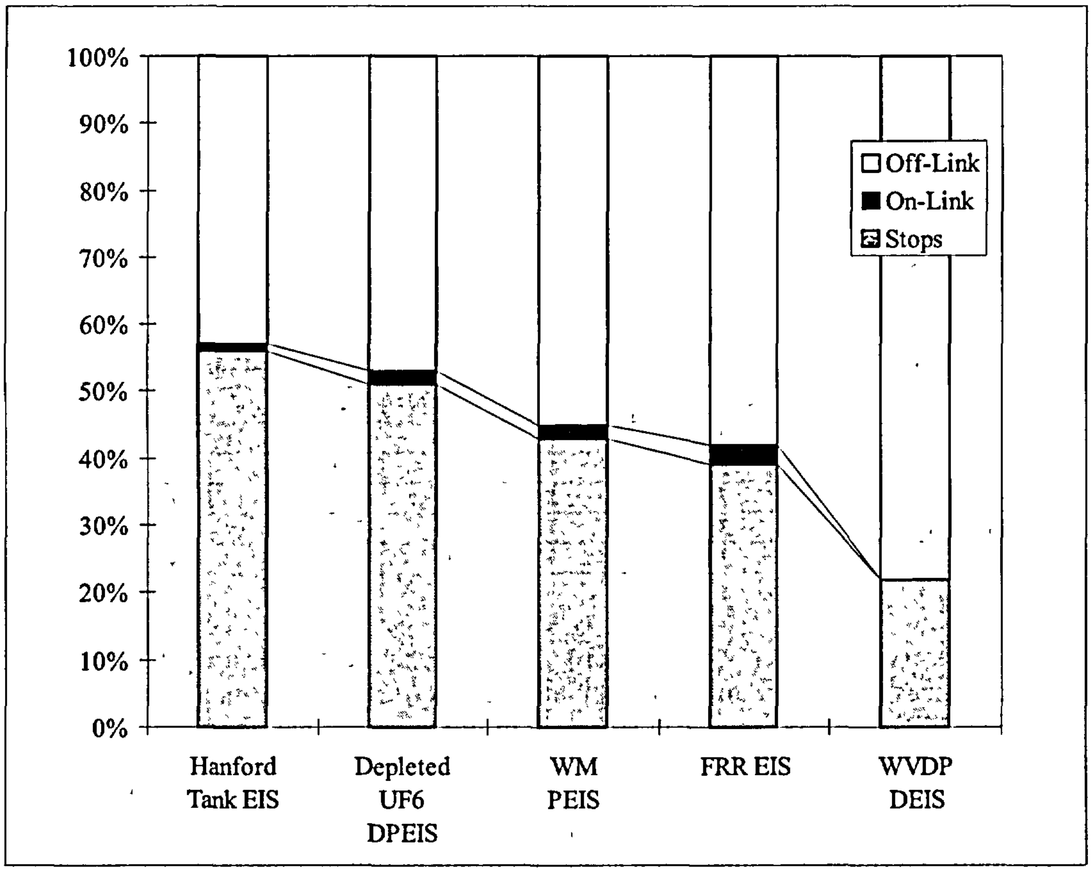

Figure 4.5. Distribution of the Total Incident-Free Dose to Members of the Public (persons at stops and off-link and on-link receptors) by Rail Transport

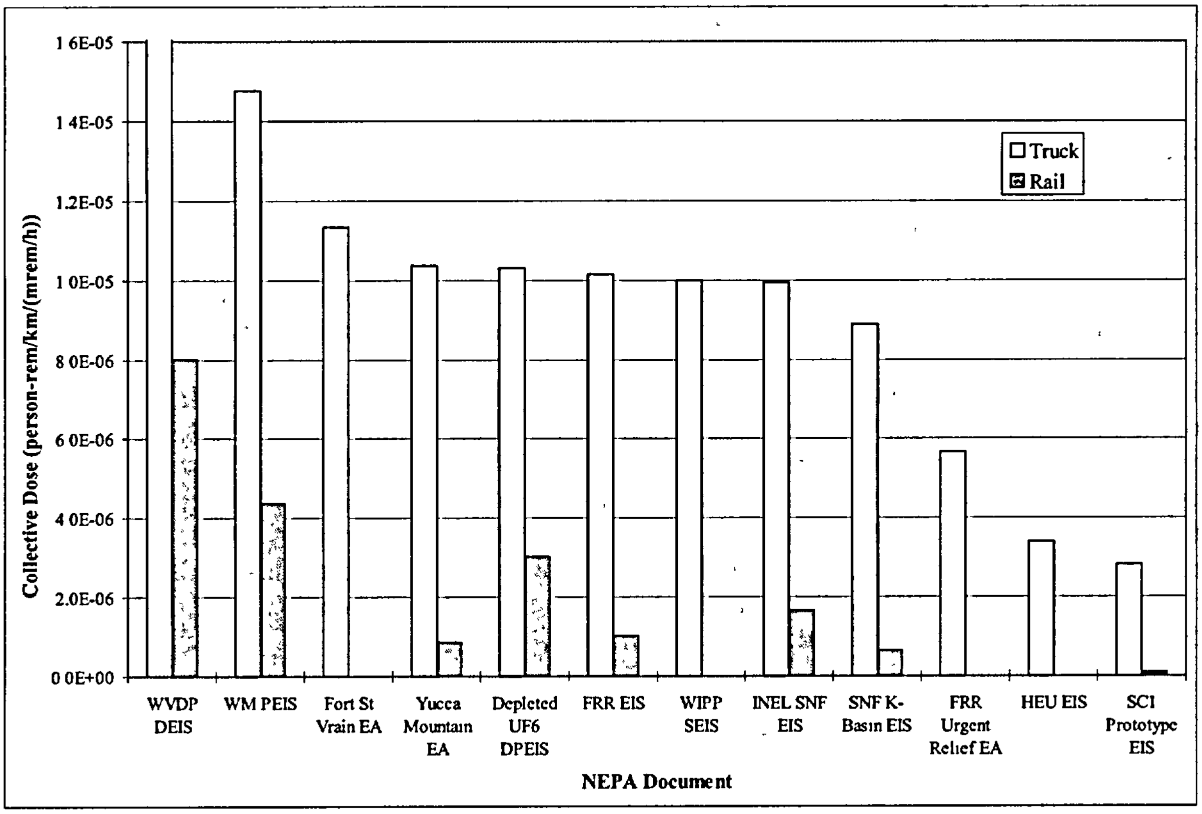

Figure 4.6. Incident-Free Cargo-Related Unit Risks Normalized by Dose Rate for Members of the Public

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

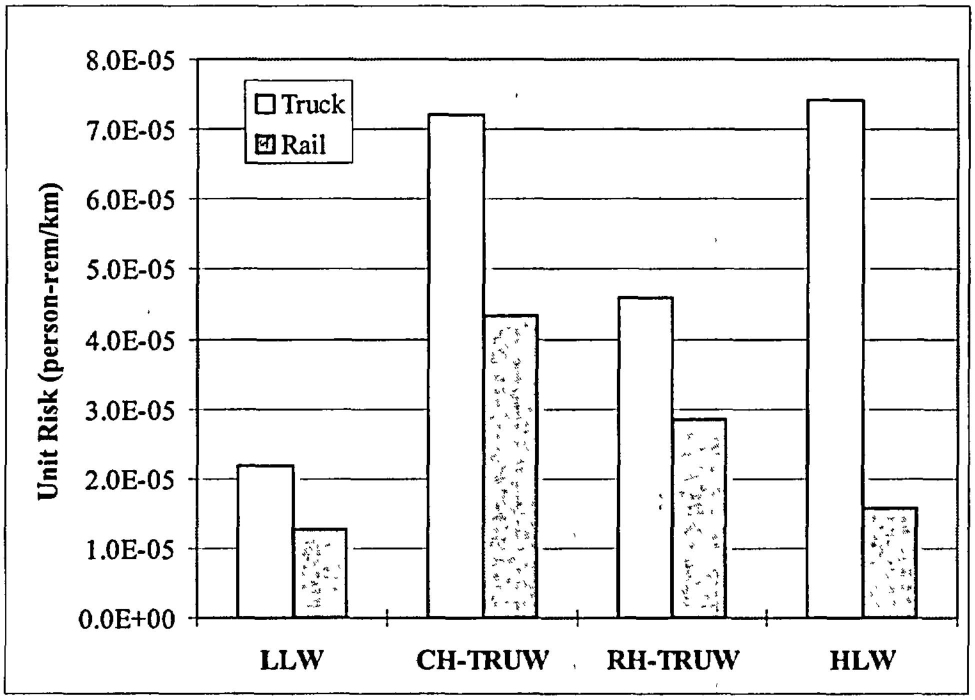

Figure 4.7. Incident-Free Cargo-Related Unit Risks for Different Cargo Types for Members of the Public, from the Waste Management Programmatic EIS (DOE, 1997b)

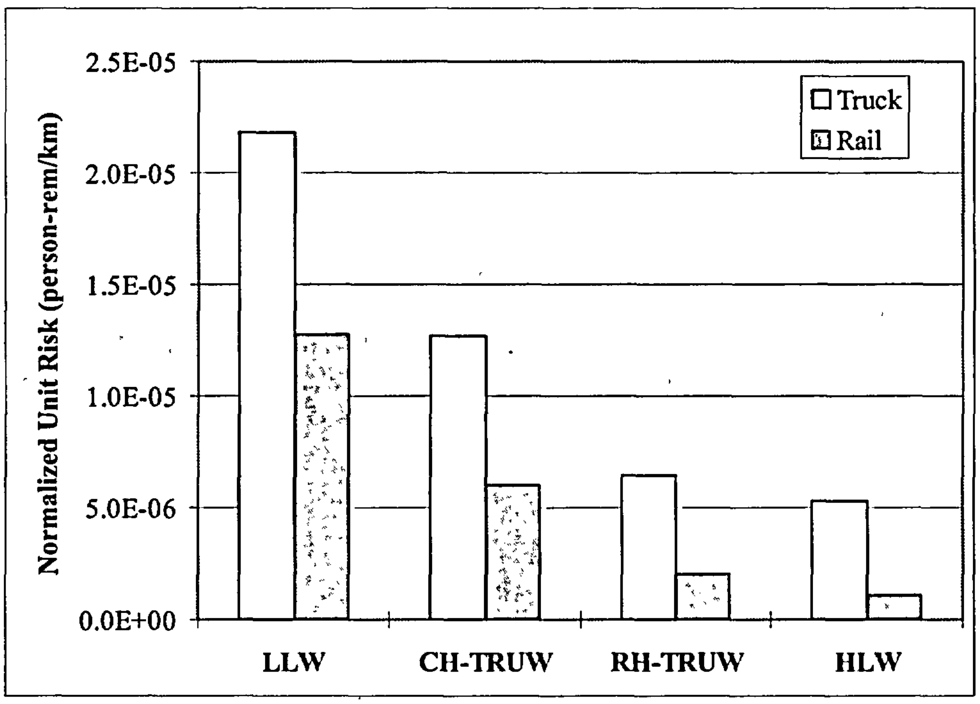

Figure 4.8. Normalized Incident-Free Cargo-Related Unit Risks for a Dose Rate of 1 mrem/h at 1 m for all Cargo Types Members of the Public, from the Waste Management Programmatic EIS (DOE, 1997b)

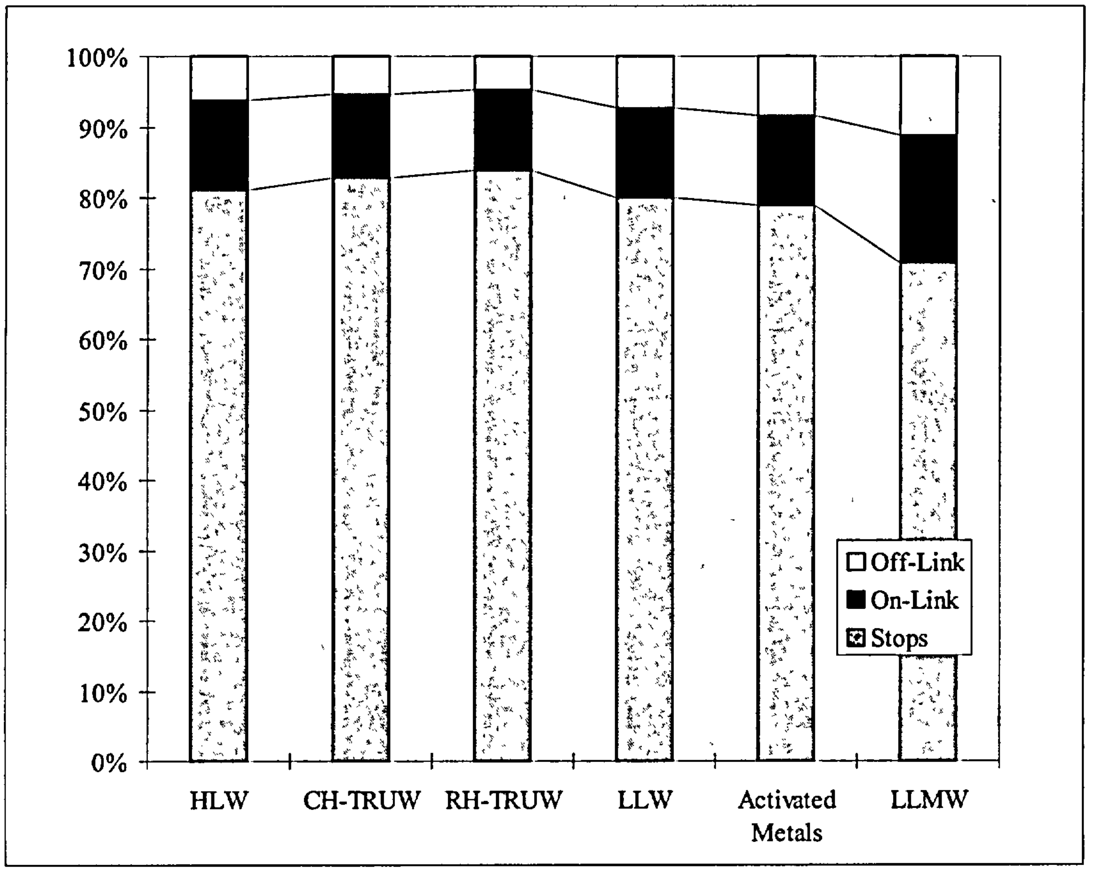

Figure 4.9. Distribution of the Total Incident-Free Dose to Members of the Public, Persons at Stops, and Off-link and On-link Receptors for all Cargo Types, from the Waste Management Programmatic EIS, Truck Transport (DOE, 1997b)

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.

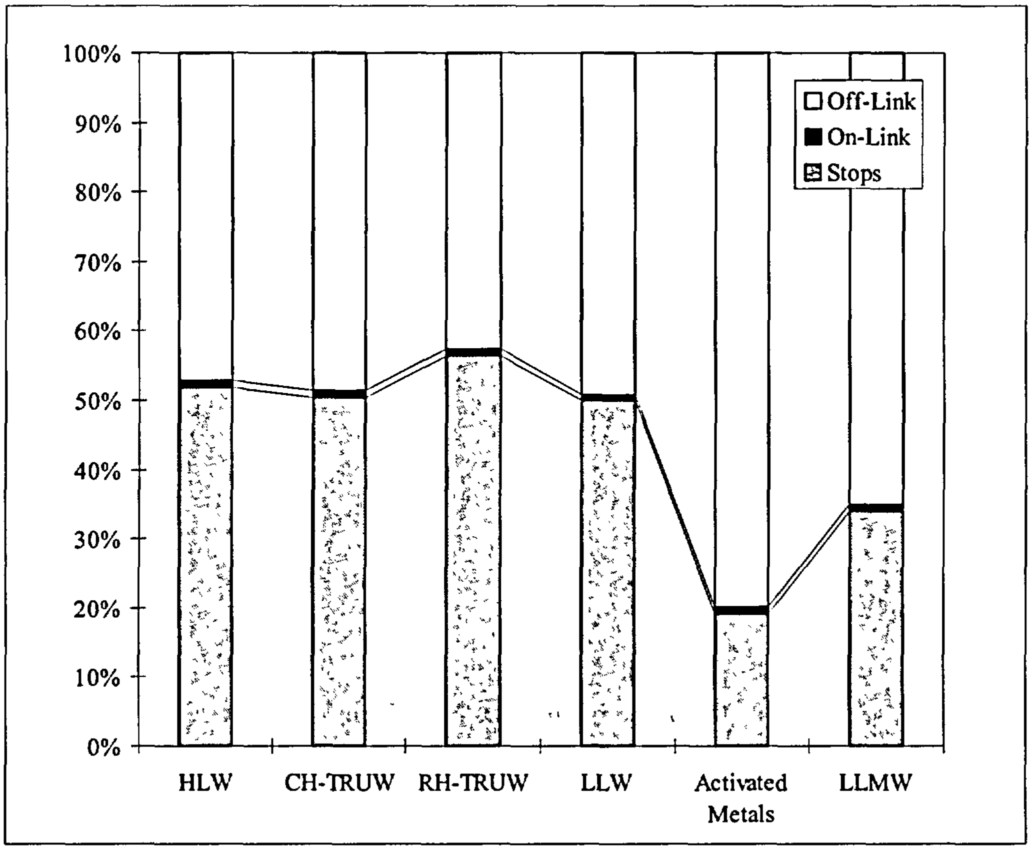

Figure 4.10. Distribution of the Total Incident-Free Dose to Members of the Public, Persons at Stops, and Off-link and On-link Receptors for all Cargo Types, from the Waste Management Programmatic EIS, Rail Transport (DOE, 1997b)

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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/km²)	
	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 (km²)	Percent Area	Population Density (per km²)
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.

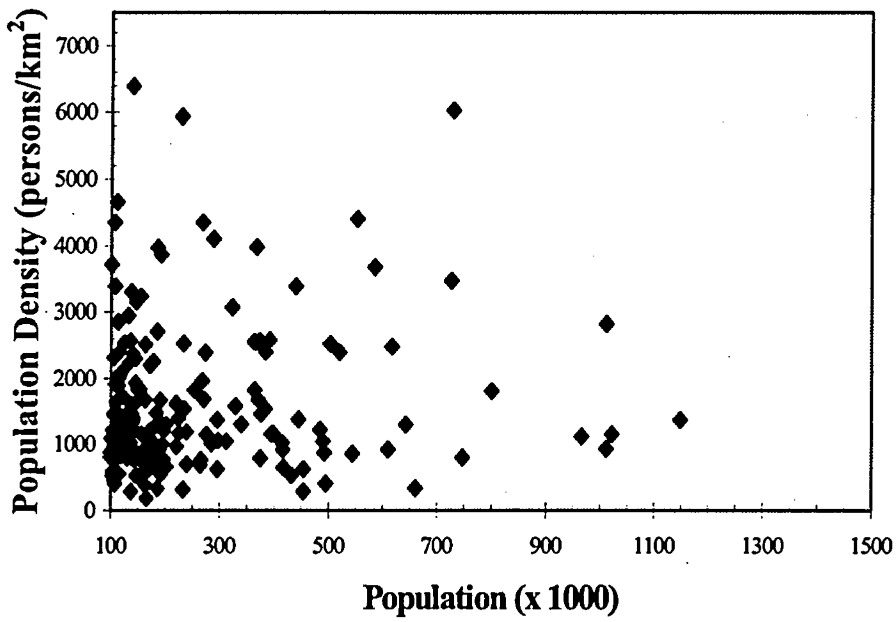

Figure 6.1. Population Densities for U.S. Cities with Populations over 100,000

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.

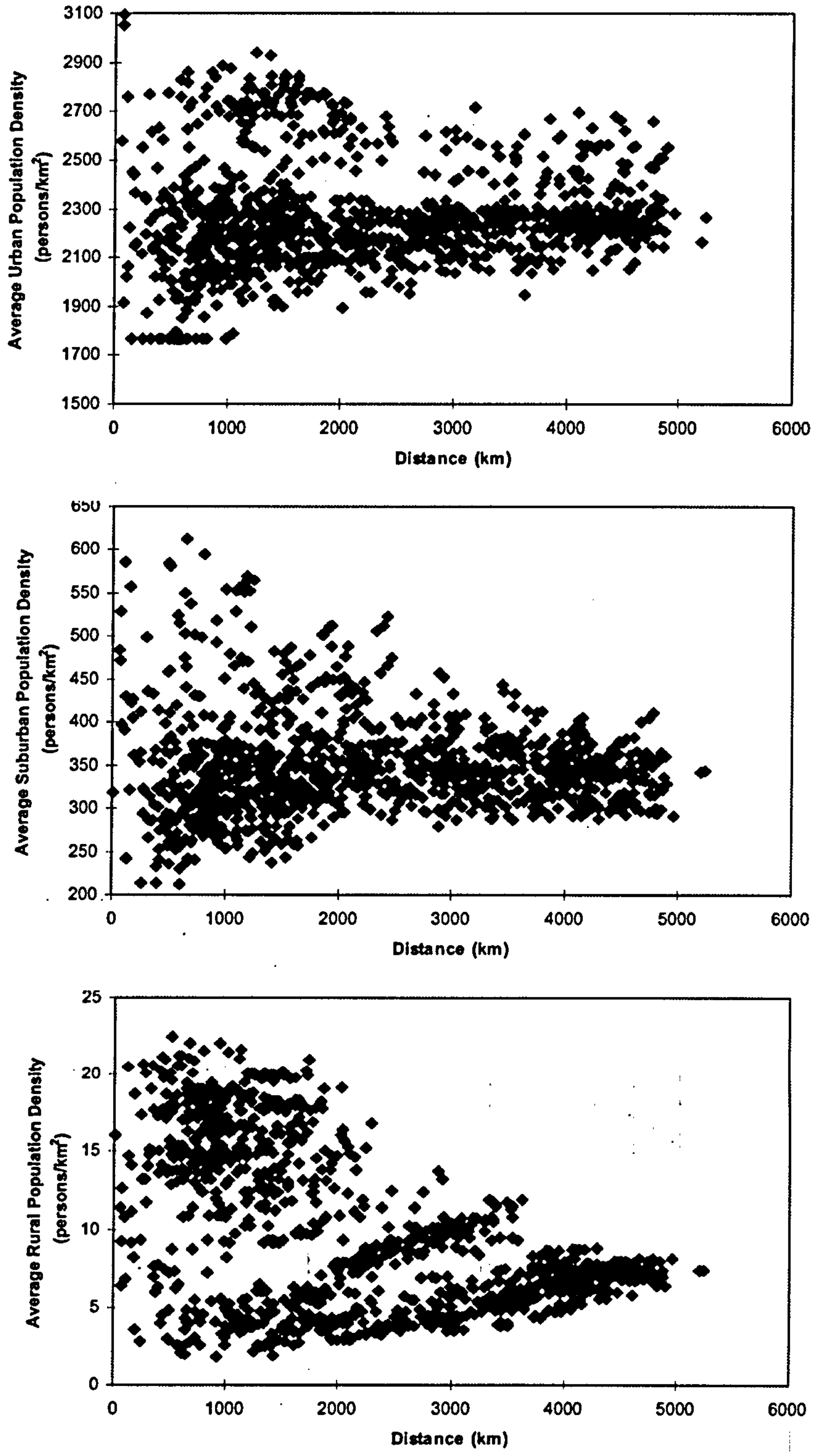

Figure 6.2. Average Population Densities Determined for Truck Travel through Rural, Suburban, and Urban Zones

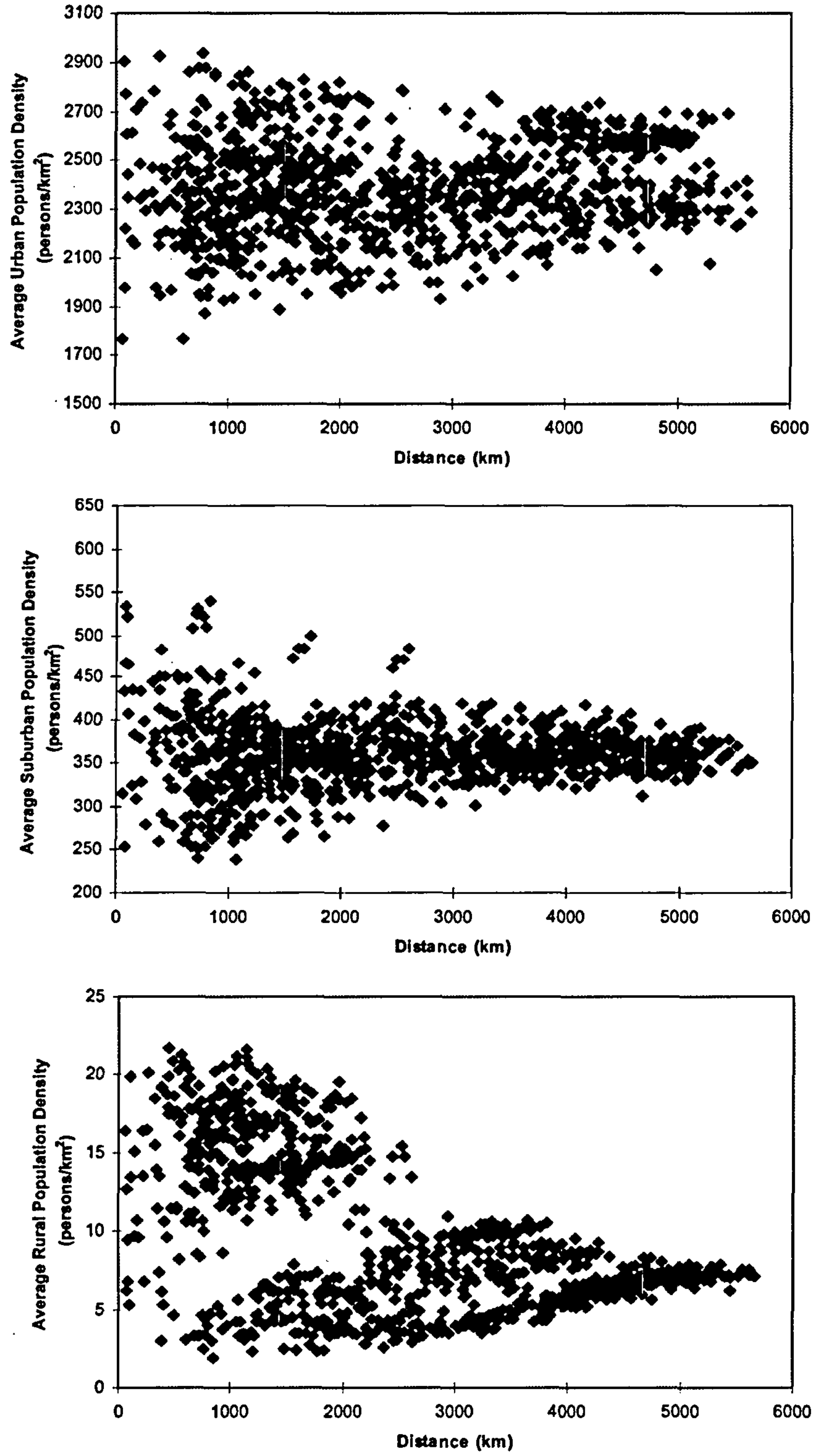

Figure 6.3. Average Population Densities Determined for Rail Travel through Rural, Suburban, and Urban Zones

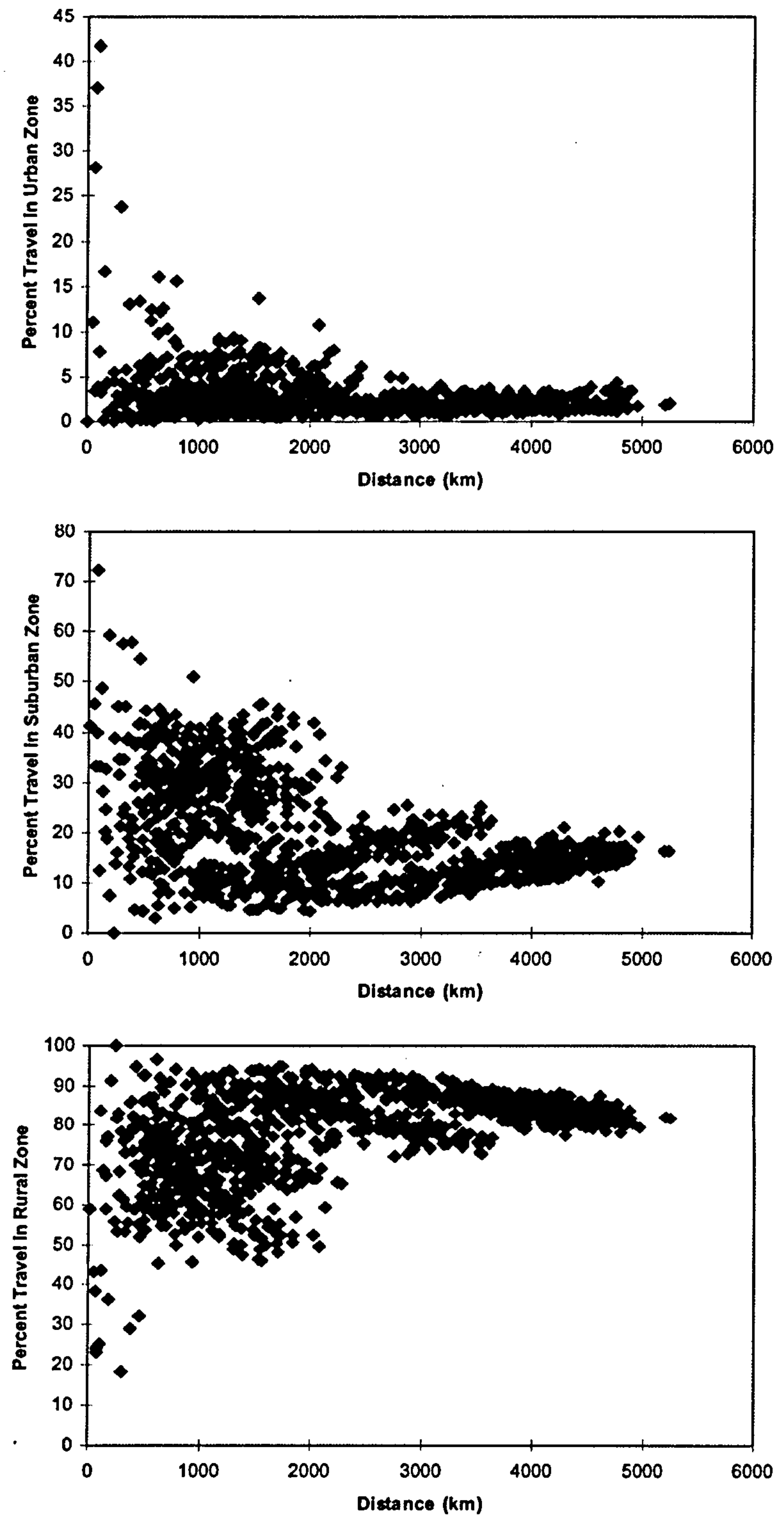

Figure 6.4. Average Fraction of Truck Travel through Rural, Suburban, and Urban Zones

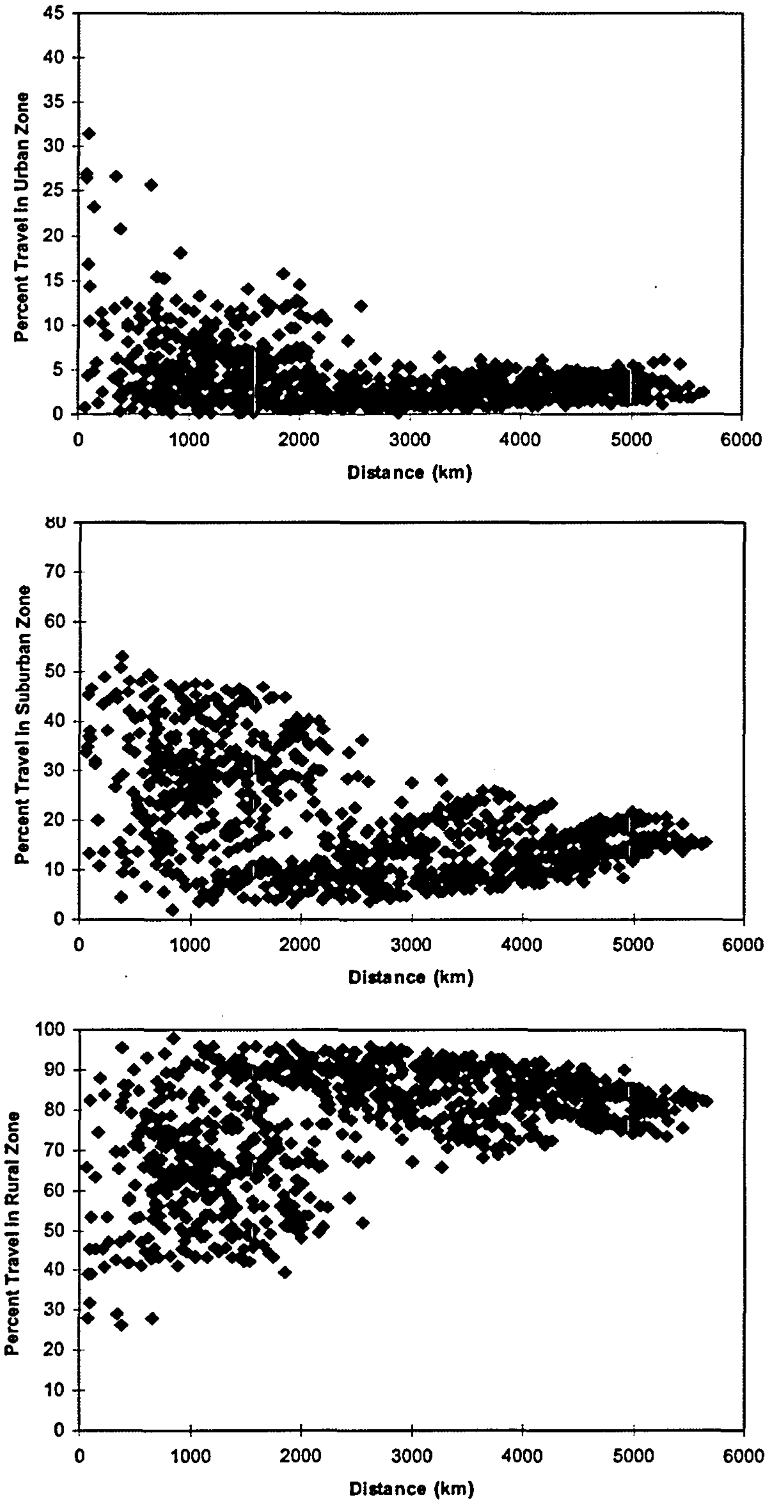

Figure 6.5. Average Fraction of Rail Travel through Rural, Suburban, and Urban Zones

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).

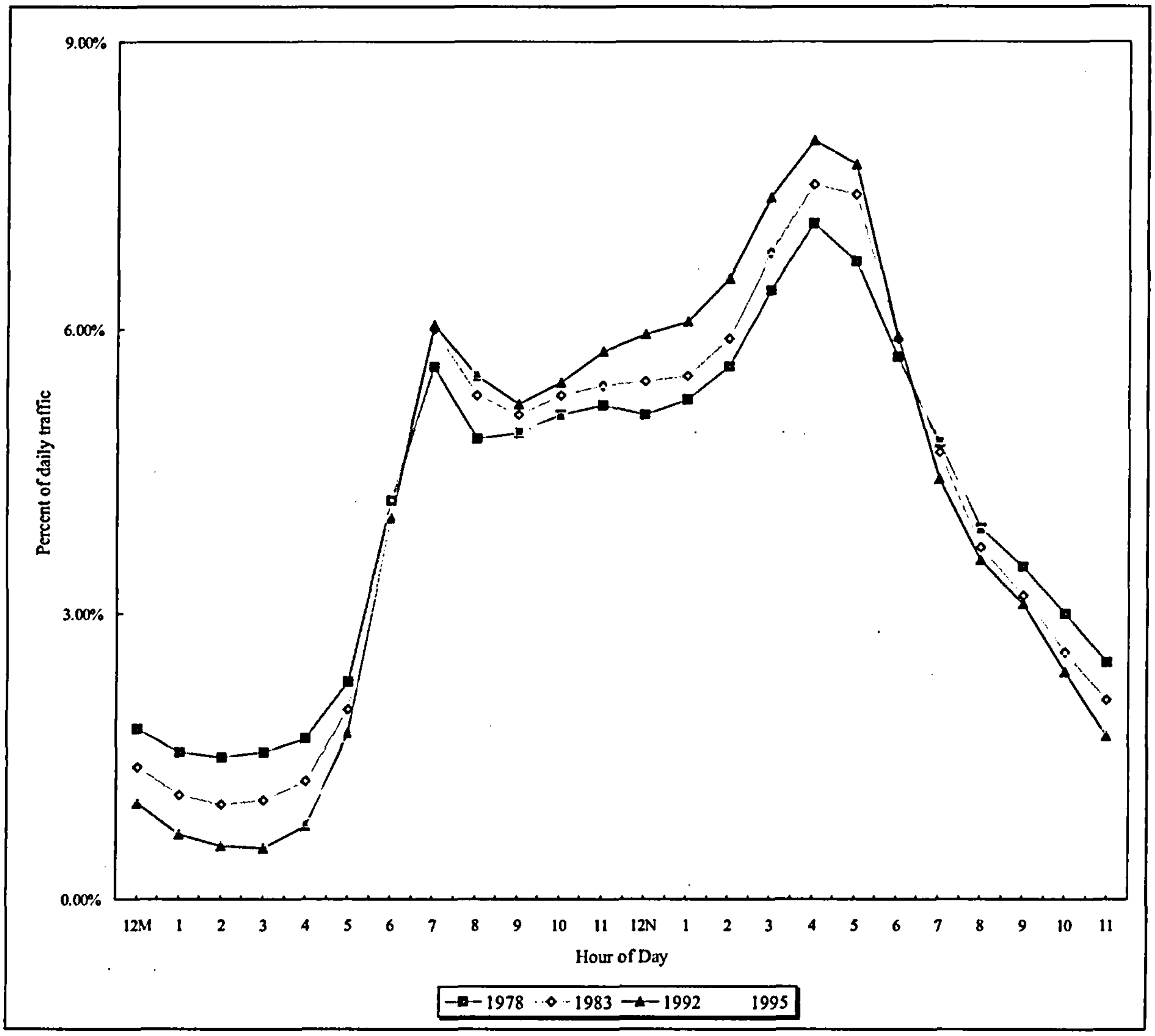

Figure 6.6. Weekday Rural Highway Traffic, 1978-1995 (Source: Festin, 1996)

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.

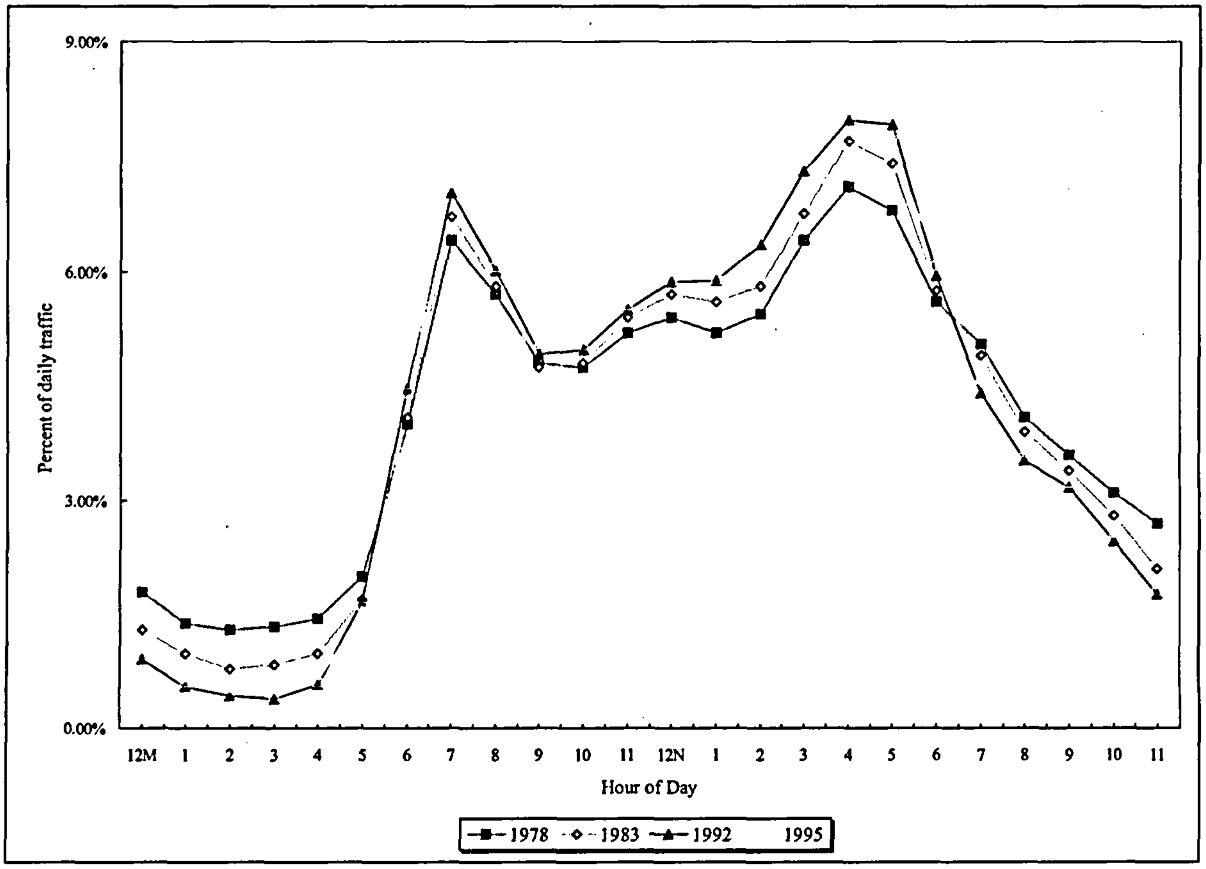

Figure 6.7. Weekday Urban Highway Traffic, 1978-1995 (Source: Festin, 1996)

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.

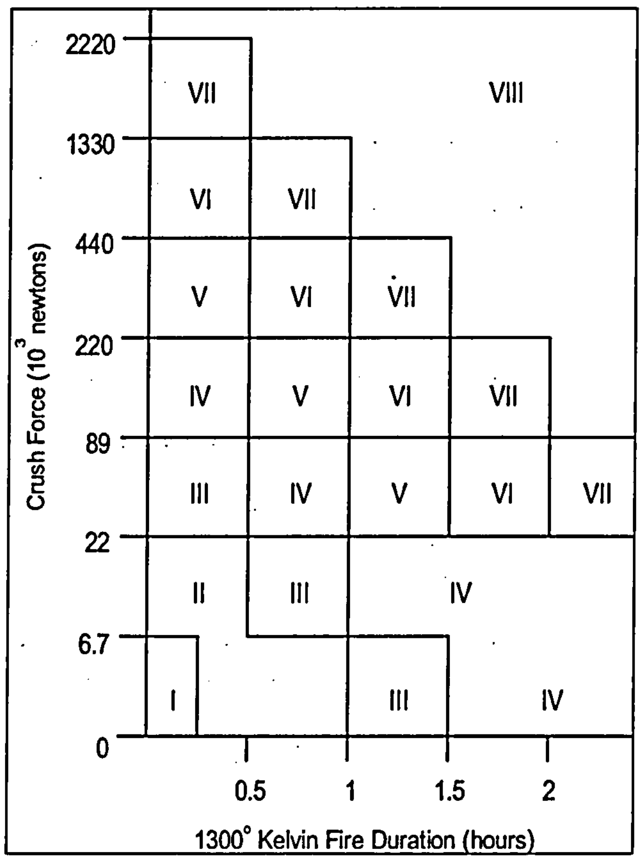

Figure 6.8. Scheme for NUREG-0170 Classification by Accident Severity Category for Truck Accidents (Source: NRC, 1977a)

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.

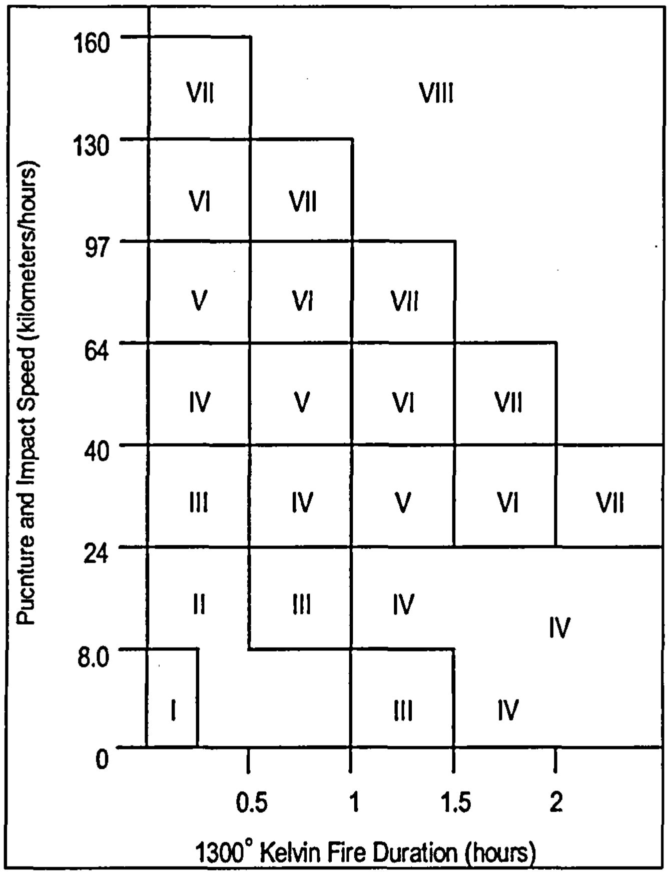

Figure 6.9. Scheme for NUREG-0170 Classification by Accident Severity Category for Rail Accidents (Source: NRC 1977a)

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, %)					
	4 R(4,1) (P_t)1.532×10^{-7} (P_r)1.786×10^{-9}	8 R(4,2) 3.926×10^{-14} 3.290×10^{-13}	12 R(4,3) 1.495×10^{-14} 2.137×10^{-13}	16 R(4,4) 7.681×10^{-16} 1.644×10^{-13}	20 R(4,5) $<1 \times 10^{-16}$ 3.459×10^{-14}
S_3 (30)					
	3 R(3,1) (P_t)1.7984×10^{-3} (P_r)5.545×10^{-4}	7 R(3,2) 1.574×10^{-7} 1.021×10^{-7}	11 R(3,3) 2.034×10^{-7} 6.634×10^{-8}	15 R(3,4) 1.076×10^{-7} 5.162×10^{-8}	19 R(3,5) 4.873×10^{-8} 5.296×10^{-8}
S_2 (2)					
	2 R(2,1) (P_t)3.8192×10^{-3} (P_r)2.7204×10^{-3}	6 R(2,2) 2.830×10^{-7} 5.011×10^{-7}	10 R(2,3) 3.008×10^{-7} 3.255×10^{-7}	14 R(2,4) 1.592×10^{-7} 2.531×10^{-7}	18 R(2,5) 7.201×10^{-8} 1.075×10^{-8}
S_1 (0.2)					
	1 R(1,1) (P_t)0.994316 (P_r)0.993962	5 R(1,2) 1.687×10^{-5} 1.2275×10^{-3}	9 R(1,3) 2.362×10^{-5} 7.9511×10^{-4}	13 R(1,4) 1.525×10^{-5} 6.140×10^{-4}	17 R(1,5) 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.
[b] 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. Komar, 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-m^2/Bq-s)	Cloudshine[e] (Sv-m^3/Bq-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] ($Sv\text{-}m^2/Bq\text{-}s$)	Cloudshine[e] ($Sv\text{-}m^3/Bq\text{-}s$)	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-m²/Bq-s)	Cloudshine[e] (Sv-m³/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-m²/Bq-s)	Cloudshine[e] (Sv-m³/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] ($Sv\text{-}m^2/Bq\text{-}s$)	Cloudshine[e] ($Sv\text{-}m^3/Bq\text{-}s$)	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-m²/Bq-s)	Cloudshine[e] (Sv-m³/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-m²/Bq-s)	Cloudshine[e] (Sv-m³/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-m²/Bq-s)	Cloudshine[e] (Sv-m³/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-m²/Bq-s)	Cloudshine[e] (Sv-m³/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-m²/Bq-s)	Cloudshine[e] (Sv-m³/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-m²/Bq-s)	Cloudshine[e] (Sv-m³/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-m^2/Bq-s)	Cloudshine[e] (Sv-m^3/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] ($Sv\text{-}m^2/Bq\text{-}s$)	Cloudshine[e] ($Sv\text{-}m^3/Bq\text{-}s$)	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_{ci} = effective decay constant for removal of the radionuclide deposited on vegetation (1/d), where $\lambda_c = \lambda_i + 0.693/t_w$, $t_w = 0.0383$ yr (14 d);

t_c = 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:

$$< C_{si} > \;=\; \int_0^{\infty} X_{Ri}(t)\; V_d\; \frac{r(1 - e^{-\lambda_{ei} t_e})}{Y_v \lambda_{ei}}\; \exp(-\lambda_i t_h)\, dt\,, \qquad \text{(D.2)}$$

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):

$$X_{Ri}(t) = G_i(t)\, R(t)\,, \qquad \text{(D.3)}$$

where $G_i(t)$ is the deposited ground concentration at time t, and R(t) is the resuspension coefficient at time t.

$$G_i(t) \;=\; G_{io} \exp\left[-(\lambda_g + \lambda_i)t\right] \qquad \text{(D.4)}$$

where G_{io} is the initial deposition concentration (in Ci/m^2), which is equal to $<X_i>V_d$, λ_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 $(kg/m^2\text{-yr})$.

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-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:

$$<C_i^p> = f_p f_s <C_i^t> + (1-f_p) <C_i^s> + f_p (1-f_s) <C_i^s> , \quad \text{(D.14)}$$

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:

$$<C_i^p> \; = \; 0.5 \; <C_i^t> \; + \; 0.5 \; <C_i^s> . \quad \text{(D.15)}$$

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:

$$<C_T^v> = Pf <x_T> (0.75)(0.5/H) = 0.375 \, Pf \frac{<x_T>}{H} , \quad \text{(D.16)}$$

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),

$<\chi_T>$ = 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:

$$< C_T^w > \; = \; 0.5 \; Pf \, \frac{< \chi_T >}{H} \; . \qquad \text{(D.17)}$$

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:

$$\text{crops,} \quad < C_T^c > \; = \; < C_T^v > \qquad \text{(D.18)}$$

$$\text{milk,} \quad < C_T^m > \; = \; F_{mi}\left(< C_T^v > Q_f + < C_T^w > Q_w \right) \qquad \text{(D.19)}$$

$$\text{meat,} \quad < C_T^b > \; = \; F_{bi}\left(< C_T^v > Q_f + < C_T^w > Q_w \right) \qquad \text{(D.20)}$$

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:

$$C_T \; = \; < C_T^c > P_c \; + \; < C_T^m > P_m \; + \; < C_T^b > P_b \; , \qquad \text{(D.21)}$$

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:

$$<C^v_{14}> = Pf<x_{14}>(0.11/0.00016) = 6.88 \times 10^2 Pf<x_{14}>, \tag{D.22}$$

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 ($Ci\text{-}yr/m^2$).

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:

$$\text{crops, } <C^c_{14}> = <C^v_{14}> 1 \tag{D.23}$$

$$\text{milk, } <C^m_{14}> = F_{m14} <C^v_{14}> Q_f 2 \tag{D.24}$$

$$\text{meat } <C^b_{14}> = F_{b14} <C^v_{14}> Q_f 3 \tag{D.25}$$

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:

$$C_{14} = \langle C^{v}_{14} \rangle P_c + \langle C^{m}_{14} \rangle P_m + \langle C^{b}_{14} \rangle P_b \ , \qquad \text{(D.26)}$$

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 $\langle C^c_i \rangle / G_{io}$ for crops, $\langle C^m_i \rangle / G_{io}$ for milk, and $\langle C^b_i \rangle / G_{io}$ for meat.
[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-m²/kg)	Milk (yr-m²/L)	Meat (yr-m²/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 $\mu Ci/m^2$ available through ingestion pathways per 1 $\mu Ci/m^2$ of radionuclide deposited on the ground.
[b] U.S. average.

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Appendix J

Transportation

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APPENDIX J. TRANSPORTATION

This appendix provides additional information for readers who wish to gain a better understanding of the methods and analyses the U.S. Department of Energy (DOE or the Department) used to determine the human health impacts of transportation for the Proposed Action and Inventory Modules 1 and 2 discussed in this environmental impact statement (EIS). The materials included in Module 1 are the 70,000 metric tons of heavy metal (MTHM) for the Proposed Action and additional quantities of spent nuclear fuel and high-level radioactive waste that DOE could dispose of in the repository as part of a reasonably foreseeable future action. The materials included in Module 2 include the materials in Module 1 and other highly radioactive materials. Appendix A describes materials included in Modules 1 and 2. This appendix also provides the information DOE used to estimate traffic fatalities that would be associated with the long-term maintenance of storage facilities at 72 commercial sites and 5 DOE sites.

The appendix describes the key data and assumptions DOE used in the analyses and the analysis tools and methods the Department used to estimate impacts of loading operations at 72 commercial and 5 DOE sites; incident-free transportation by highway, rail and barge; intermodal transfer; and transportation accidents. The references listed at the end of this appendix contain additional information.

This appendix presents information on analyses of the impacts of national transportation and on analyses of the impacts that could occur in Nevada. Section J.1 presents information on the analysis of occupational and public health and safety impacts for the transportation of spent nuclear fuel and high-level radioactive waste from the 77 sites to the repository. Section J.2 presents information on the analysis of rail and intermodal transportation alternatives. Section J.3 presents information on the analysis of transportation in Nevada. Section J.4 presents state-specific transportation impacts and maps of analyzed state-specific transportation routes.

J.1 Methods Used To Estimate Potential Impacts of Transportation

This section provides information on the methods and data DOE used to estimate impacts from shipping spent nuclear fuel and high-level radioactive waste from 72 commercial sites and 5 DOE sites throughout the United States to the Yucca Mountain Repository.

MOSTLY LEGAL-WEIGHT TRUCK AND MOSTLY RAIL SCENARIOS

The Department would prefer most shipments to a Yucca Mountain repository be made using rail transportation. It also expects that the mostly rail scenario described in this EIS best represents the mix of rail and truck transportation that would be used. However, it cannot be certain of the actual mix of rail and truck transportation that would occur over the 24 years of the Proposed Action. Consequently, DOE used the mostly legal-weight truck and mostly rail scenarios as a basis for the analysis of potential impacts to ensure the analysis addressed the range of possible transportation impacts. The estimated number of shipments for the mostly legal-weight truck and mostly rail scenarios represents the two extremes in the possible mix of transportation modes, thereby covering the range of potential impacts to human health and safety and to the environment for the transportation modes DOE could use for the Proposed Action.

J.1.1 ANALYSIS APPROACH AND METHODS

Three types of impacts could occur to the public and workers from transportation activities associated with the Proposed Action. These would be a result of the transportation of spent nuclear fuel and high-level radioactive waste and of the personnel, equipment, materials, and supplies needed to construct, operate and monitor, and close the proposed Yucca Mountain Repository. The first type, radiological impacts, would be measured by radiological dose to populations and individuals and the resulting estimated number of latent cancer fatalities that would be caused by radiation from shipments of spent nuclear fuel and high-level radioactive waste from the 77 sites under normal and accident transport conditions. The second and third types would be nonradiological impacts—potential fatalities resulting from vehicle emissions and caused by vehicle accidents. The analysis also estimated impacts due to the characteristics of hazardous cargoes from accidents during the transportation of nonradioactive hazardous materials to support repository construction, operation and monitoring, and closure. For perspective, about 11 fatalities resulting from hazardous material occur each year during the transportation of more than 300 million shipments of hazardous materials in the United States (DIRS 156755-BLS 2001, Table A-8). Therefore, DOE expects that the risks from exposure to hazardous materials that could be released during shipments to and from the repository sites would be very small (see Section J.1.4.2.4). The analysis evaluated the impacts of traffic accidents and vehicle emissions arising from these shipments.

The analysis used a step-wise process to estimate impacts to the public and workers. The process used the best available information from various sources and computer programs and associated data to accomplish the steps. Figures J-1 and J-2 show the steps followed in using data and computer programs. DOE has determined that the computer programs identified in the figure are suitable, and provide results in the appropriate measures, for the analysis of impacts performed for this EIS.

The CALVIN computer program (DIRS 155644-CRWMS M&O 1999, all) was used to estimate the numbers of shipments of spent nuclear fuel from commercial sites. This program used information on spent nuclear fuel stored at each site and an assumed scenario for picking up the spent fuel from each site. The program also used information on the capacity of shipping casks that could be used.

The HIGHWAY computer program (DIRS 104780-Johnson et al. 1993, all) is a routing tool used to select existing highway routes that would satisfy U.S. Department of Transportation route selection regulations and that DOE could use to ship spent nuclear fuel and high-level radioactive waste from the 77 sites to the repository.

The INTERLINE computer program (DIRS 104781-Johnson et al. 1993, all) is a routing tool used to select existing rail routes that railroads would be likely to use to ship spent nuclear fuel and high-level radioactive waste from the 77 sites to the repository.

The RADTRAN 5 computer program (DIRS 150898-Neuhauser and Kanipe 2000, all; DIRS 155430-Neuhauser, Kanipe, and Weiner 2000, all) was used in estimating the radiological doses and dose risks to populations and transportation workers resulting from incident-free transportation and to the general population from accident scenarios. For the analysis of incident-free transportation risks, the code used scenarios for persons who would share transportation routes with shipments—called *onlink populations*, persons who live along the route of travel—*offlink populations*, and persons exposed at stops. For accident risks, the code evaluated the range of possible accident scenarios from high probability and low consequence to low probability and high consequence.

The RISKIND computer program (DIRS 101483-Yuan et al. 1995, all) was used to estimate radiological doses to maximally exposed individuals for incident-free transportation and to populations and maximally exposed individuals for accident scenarios. To estimate incident-free doses to maximally exposed individuals, RISKIND used geometry to calculate the dose rate at specified locations that would arise from a source of radiation. RISKIND was also used to calculate the radiation dose to a population and hypothetical maximally exposed individuals from releases of radioactive materials postulated to occur in maximum reasonably foreseeable accident scenarios.

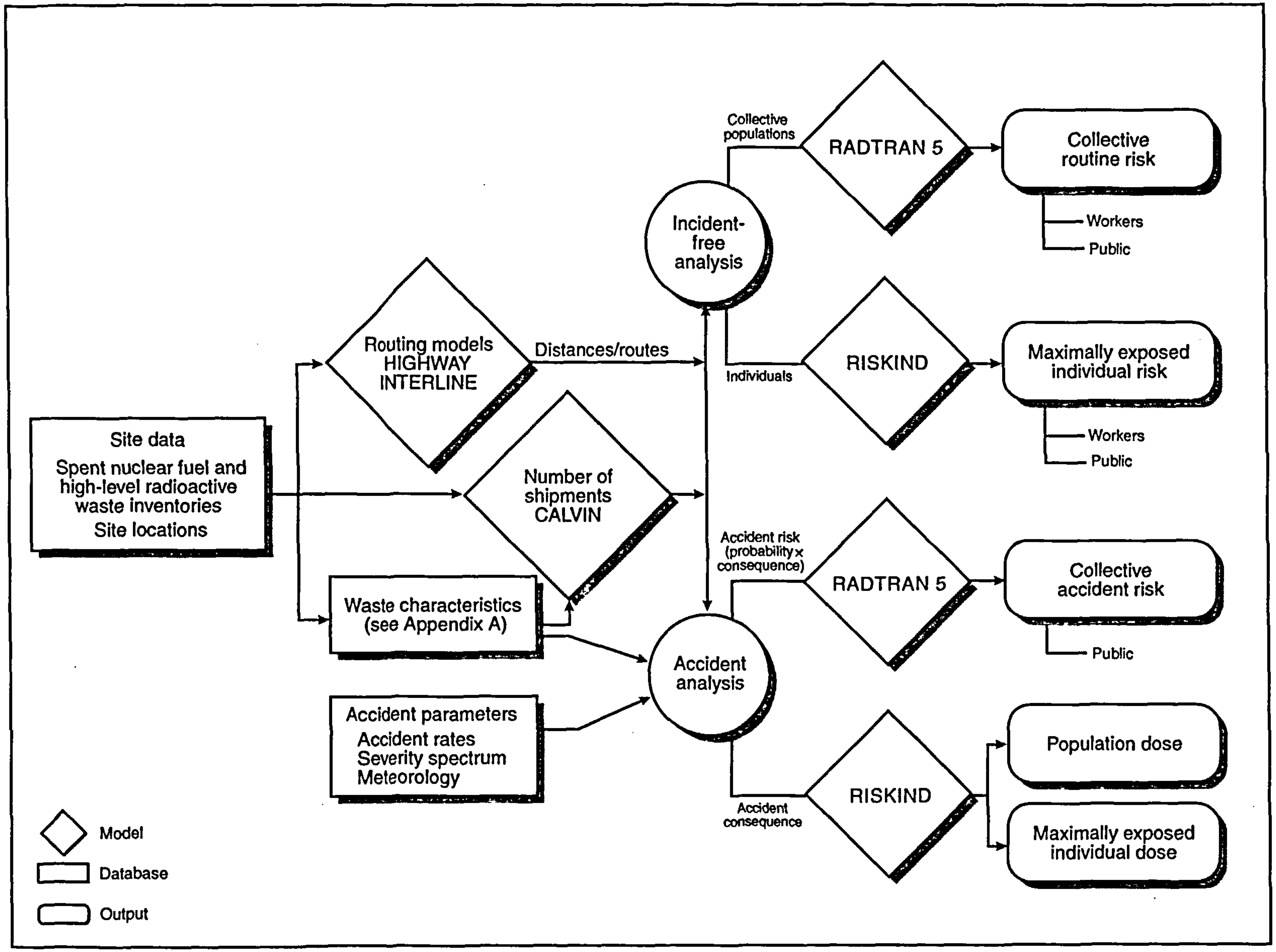


Figure J-1. Methods and approach for analyzing transportation radiological health risk.

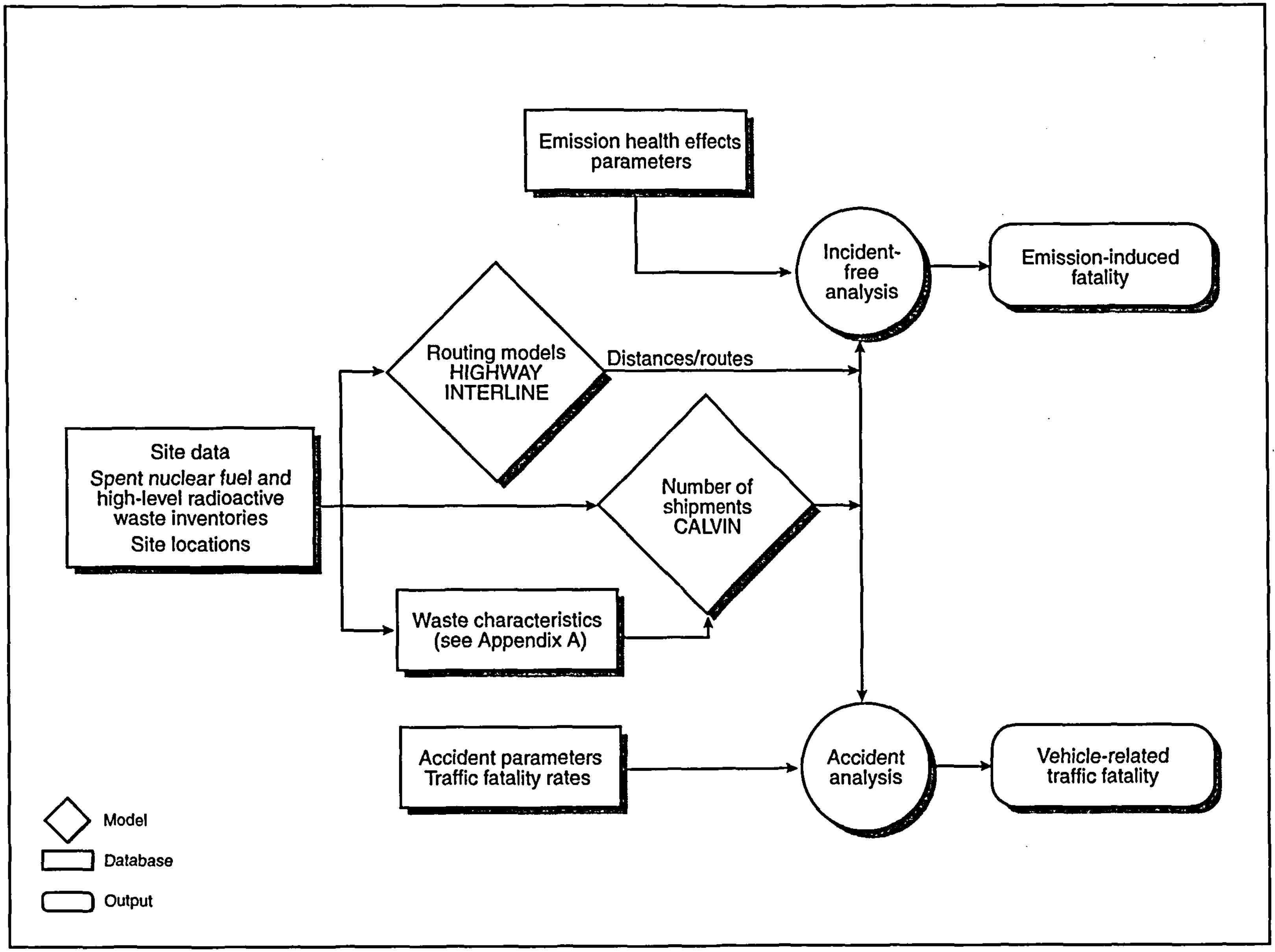


Figure J-2. Methods and approach for analyzing transportation nonradiological health risk.

DOSE RISK

Dose risk is a measure of radiological impacts to populations – public or workers – from the potential for exposure to radioactive materials. Thus, a potential of 1 chance in 1,000 of a population receiving a collective dose of 1 rem (1 person-rem) from an accident would result in a dose risk of 0.001 person-rem (0.001 is the product of 1 person-rem and the quotient of 1 over 1,000). The risk of latent cancer fatalities (a commonly used measure of radiological impact to populations) is obtained by multiplying the dose risk (in person-rem) by a conversion factor of 0.0005 fatal cancer per person-rem for the public. For workers, the conversion factor is 0.0004 fatal cancer per person-rem.

The use of dose risk to measure radiological impacts allows a comparison of alternatives with differing characteristics in terms of radiological consequences that could result and the likelihood that the consequences would actually occur.

The following sections describe these programs in detail.

J.1.1.1 CALVIN

The Civilian Radioactive Waste Management System Analysis and Logistics Visually Interactive (CALVIN) model (DIRS 155644-CRWMS M&O 1999, all) was developed to be a planning tool to estimate the logistic and cost impacts of various operational assumptions for accepting radioactive wastes. CALVIN was used in transportation modeling to determine the number of shipments of commercial spent nuclear fuel from each reactor site. The parameters that the CALVIN model used to determine commercial spent nuclear fuel movement include the shipping cask specifications including heat limits, $k_{infinity}$ (measure of criticality) limits for the contents of the casks, capacity (assemblies or canisters/cask), burnup/enrichment curves, and cooling time for the fuel being shipped.

The source data used by CALVIN for commercial spent nuclear fuel projections include the RW-859 historic data collected by the Energy Information Administration, and the corresponding projection produced based on current industry trends for commercial fuel (see Appendix A). This EIS used CALVIN to estimate commercial spent nuclear fuel shipment numbers based on the cask capacity (see Section J.1.2) and the shipping cask handling capabilities at each site. For the mostly rail national transportation scenario, CALVIN assumed that shipments would use the largest cask a site would be capable of handling. In some cases the analysis, using CALVIN, estimated that the characteristics of the spent nuclear fuel that would be picked up at a site (principally the estimated heat generation rate) would limit the number of fuel assemblies that could be transported to fewer than the full capacity of the cask. In such cases, to provide a realistic estimate of the number of shipments that would be made, CALVIN assumed the cask would contain the smaller number of assemblies. The reduction in capacity was sufficient to accommodate the characteristics of the spent nuclear fuel the program estimated for pickup at the site. In addition, the analysis assumed that sites without sufficient crane capacity to handle a rail cask while operational would be upgraded after reactor shutdown such that the sites could handle rail casks.

J.1.1.2 HIGHWAY

The HIGHWAY computer program (DIRS 104780-Johnson et al. 1993, all) was used to select highway routes for the analysis of impacts presented in this EIS. Using data for actual highways and rules that apply to carriers of Highway Route-Controlled Quantities of Radioactive Materials (49 CFR 397.101), HIGHWAY selected highway routes for legal-weight truck shipments from each commercial and DOE site to the Yucca Mountain site. In addition, DOE used this program to estimate the populations within 800 meters (0.5 mile) of the routes it selected. These population densities were used in calculating incident-free radiological risks to the public along the routes.

One of the features of the HIGHWAY model is its ability to estimate routes for the transport of Highway Route-Controlled Quantities of Radioactive Materials. The U.S. Department of Transportation has established a set of routing regulations for the transport of these materials (49 CFR 397.101). Routes following these regulations are frequently called HM-164 routes. The regulations require the transportation of these shipments on preferred highways, which include:

- Interstate highways
- An Interstate System bypass or beltway around a city
- State-designated preferred routes

State routing agencies can designate preferred routes as an alternative to, or in addition to, one or more Interstate highways. In making this determination, the state must consider the safety of the alternative preferred route in relation to the Interstate route it is replacing, and must register all such designated preferred routes with the U.S. Department of Transportation.

Frequently, the origins and destinations of Highway Route-Controlled Quantities of Radioactive Materials are not near Interstate highways. In general, the U.S. Department of Transportation routing regulations require the use of the shortest route between the pickup location to the nearest preferred route entry location and the shortest route to the destination from the nearest preferred route exit location. In general, HM-164 routes tend to be somewhat longer than other routes; however, the increased safety associated with Interstate highway travel is the primary purpose of the routing regulations.

Because many factors can influence the time in transit over a preferred route, a carrier of Highway Route-Controlled Quantities of Radioactive Materials must select a route for each shipment. Seasonal weather conditions, highway repair or construction, highways that are closed because of natural events (for example, a landslide in North Carolina closed Interstate 40 near the border with Tennessee from June until November 1997), and other events (for example, the 1996 Olympic Games in Atlanta, Georgia) are all factors that must be considered in selecting preferred route segments to reduce time in transit. For this analysis, the highway routes were selected by the HIGHWAY program using an assumption of normal travel and without consideration for factors such as seasons of the year or road construction delays. Although these shipments could use other routes, DOE considers the impacts determined in the analyses to be representative of other possible routings that would also comply with U.S. Department of Transportation regulations. Specific route mileages for truck transportation are presented in Section J.1.2.2.1.

In selecting existing routes for use in the analysis, the HIGHWAY program determined the length of travel in each type of population zone—rural, suburban, and urban. The program characterized rural, suburban, and urban population areas according to the following breakdown: rural population densities range from 0 to 54 persons per square kilometer (0 to 140 persons per square mile); the suburban range is 55 to 1,300 persons per square kilometer (140 to 3,300 persons per square mile); and urban is all population densities greater than 1,300 persons per square kilometer (3,300 persons per square mile). The population densities along a route used by the HIGHWAY program are derived from 1990 data from the Bureau of the Census. In addition, the analysis used results of the 2000 Census for state populations as well as population forecasts published by the Bureau of the Census in estimating radiological impacts to populations that would live along transportation routes (see Sections J.1.3.2.1 and J.1.4.2.1).

J.1.1.3 INTERLINE

Shipments of radioactive materials by rail are not subject to route restrictions imposed by regulations. For general freight rail service, DOE anticipates that railroads would route shipments of spent nuclear fuel and high-level radioactive waste to provide expeditious travel and the minimum practical number of interchanges between railroads. The selection of a route determines the potentially exposed population along the route as well as the expected frequency of transportation-related accidents. The analysis used the INTERLINE computer program (DIRS 104781-Johnson et al. 1993, all) to project the railroad routes that DOE would use to ship spent nuclear fuel and high-level radioactive waste from the sites to the Yucca Mountain site. Specific routes were projected for each originating generator with the exception of six that do not have capability to handle or load a rail transportation cask (see Section J.1.2.1.1). INTERLINE computes rail routes based on rules that simulate historic routing practices of U.S. railroads. The INTERLINE database consists of 94 separate subnetworks and represents various competing rail companies in the United States. The database, which was originally based on data from the Federal Railroad Administration and reflected the U.S. railroad system in 1974, has been expanded and modified extensively over the past two decades. The program is updated periodically to reflect current track conditions and has been benchmarked against reported mileages and observations of commercial rail firms. The program also provides an estimate of the population within 800 meters (0.5 mile) of the routes it selected. This population estimate was used to calculate incident-free radiological risk to the public along the routes selected for analysis.

In general, rail routes are calculated by minimizing the value of a factor called *impedance* between the origin and the destination. The impedance is determined by considering trip distance along a route, the mainline classification of the rail lines that would be used, and the number of interchanges that would occur between different railroad companies involved. In general, impedance determined by the INTERLINE program:

- Decreases as the distance traveled decreases
- Is reduced by use of mainline track that has the highest traffic volume (see below)
- Is reduced for shipments that involve the fewest number of railroad companies

Thus, routes that are the most direct, that use high-traffic volume mainline track, and that involve only one railroad company would have the lowest impedance. The most important of these characteristics from a routing standpoint is the *mainline classification,* which is the measure of traffic volume on a particular link. The mainline classifications used in the INTERLINE routing model are as follows:

- A – mainline – more than 20 million gross ton miles per year
- B – mainline – between 5 and 20 million gross ton miles per year
- A – branch line – between 1 and 5 million gross ton miles per year
- B – branch line – less than 1 million gross ton miles per year

The INTERLINE routing algorithm is designed to route a shipment preferentially on the rail lines having the highest traffic volume. Frequently traveled routes are preferred because they are generally well maintained because the railroad depends on these lines for a major portion of its revenue. In addition, routing along the high-traffic lines usually replicates railroad operational practices.

The population densities along a route were derived from 1990 data from the Bureau of the Census, as described above for the HIGHWAY computer program. In addition, the analysis used the results of the 2000 Census for state populations as well as population forecasts published by the Bureau of the Census to estimate radiological impacts to populations that would live along transportation routes (see Sections J.1.3.2.1 and J.1.4.2.1).

DOE anticipates that routing of rail shipments in dedicated (special) train service, if used, would be similar to routing of general freight shipments for the same origin and destination pairs. However, because cask cars would not be switched between trains at classification yards, dedicated train service would be likely to result in less time in transit.

J.1.1.4 RADTRAN 5

DOE used the RADTRAN 5 computer program (DIRS 150898-Neuhauser and Kanipe 2000, all; DIRS 155430-Neuhauser, Kanipe, and Weiner 2000, all) in conjunction with a Microsoft Access database for the routine and accident cargo-related risk assessment to estimate radiological impacts to collective populations. The Department used RADTRAN 5 to generate risk factors such as transportation impacts per kilometer of travel. The database was used to manage the large amount of data and results for the analysis. Sandia National Laboratories developed RADTRAN 5 to calculate population risks associated with the transportation of radioactive materials by a variety of modes, including truck, rail, air, ship, and barge. The RADTRAN codes, which have been reviewed and updated periodically, have been used extensively by DOE for transportation risk assessment since the late 1970s. In 1995, DIRS 101845-Maheras and Pippen (1995, p. iii) conducted an analysis "to validate the estimates made by" selection of computer codes used to estimate radiation doses from the transportation of radioactive materials. The RADTRAN 4 computer code was included in the analysis. The analysis demonstrated that the RADTRAN 4 code, an earlier version of RADTRAN 5 yielded acceptable results. In the context of this analysis, "acceptable results" means that the differences between the estimates generated by the RADTRAN 4 code and hand calculations were small [that is, less than 5 percent (DIRS 101845-Maheras and Pippen 1995, p. 3-1)]. DIRS 153967-Steinman and Kearfott (2000, all) compared RADTRAN 5 results to measured radiation doses from moving sources, and found that RADTRAN 5 overpredicts the measured radiation dose to the receptor.

The RADTRAN 5/database calculations for routine (or incident-free) dose are based on expressing the dose rate as a function of distance from a point source. Associated with the calculation of routine doses for each exposed population group are parameters such as the radiation field strength, the source-receptor distance, the duration of the exposure, vehicle speed, stopping time, traffic density, and route characteristics such as population density and route segment length. The radiation dose to the exposed population decreases as the source-receptor distance and the vehicle speed increase. The radiation dose to the exposed population increases as the other parameters mentioned above increase. In calculating population doses from incident-free transportation, RADTRAN 5 and the database used population density data provided by the HIGHWAY and INTERLINE computer programs. These data are based on the 1990 Census. The results of the RADTRAN 5/database analyses were escalated to account for population growth to 2035.

In addition to routine doses, the RADTRAN 5/database combination was used to estimate dose risk from a spectrum of accident scenarios. This spectrum encompasses the range of possible accidents, including low-probability accident scenarios that have high consequences, and high-probability accident scenarios that have low consequences (fender benders). The RADTRAN 5/database calculation of collective accident risks for populations along routes employed models that quantified the range of potential accident severities and the responses of the shipping casks to those scenarios. The spectrum of accident severity was divided into categories. Each category of severity has a conditional probability of occurrence; that is, the probability that an accident will be of a particular severity if it occurs. A release fraction, which is the fraction of the material in a shipping cask that could be released in an accident, is assigned to each accident scenario severity category on the basis of the physical and chemical form of the material being transported. The analysis also considered accidents that would lose lead radiation shielding but with no release of radioactive material. The model also considers the mode of transportation, the state-specific accident rates, and population densities for rural, suburban, and urban population zones through which shipments would pass to estimate accident risks for this analysis. The

RADTRAN 5/database calculation used actual population densities within 800 meters (0.5 mile) of the transportation routes based on 1990 Census data to estimate populations within 80 kilometers (50 miles).

For accident scenarios involving releases of radioactive material, RADTRAN 5 assumes that the material is dispersed in the environment (as described by a Gaussian dispersion model). The dispersion analysis assumed that meteorological conditions are national averages for wind speed and atmospheric stability. For the risk assessment, the analysis used these meteorological conditions and assumed an instantaneous ground-level release and a small-diameter source cloud (DIRS 155430-Neuhauser, Kanipe, and Weiner 2000, Section 4.1.1). The calculation of the collective population dose following the release and the dispersal of radioactive material includes the following exposure pathways:

- External exposure to the passing radioactive cloud
- External exposure to contaminated ground
- Internal exposure from inhalation of airborne contaminants
- Internal exposure from ingestion of contaminated food

For the ingestion pathway, the analysis used the ground deposition calculated using RADTRAN 5 and state-specific food transfer factors, which relate the amount of radioactive material ingested to the amount deposited on the ground, as input to the database. Radiation doses from the ingestion or inhalation of radionuclides were calculated by using standard dose conversion factors from Federal Guidance Reports No. 11 and 12 (DIRS 104800-CRWMS M&O 1999, p. 36).

POTENTIAL HUMAN HEALTH IMPACTS OF TRANSPORTATION ACCIDENTS THAT COULD CONTAMINATE SURFACE-WATER AND GROUNDWATER RESOURCES

The EIS does not specifically analyze a transportation accident involving contamination of surface water or groundwater. Analyses performed in previous EISs (see Chapter 1, Section 1.5.3 and Table 1-1) have consistently shown that the airborne pathway has the greatest potential for exposing large numbers of people to radioactive material in the event of a release of such material during a severe transportation accident. A paper by R.M. Ostmeyer analyzed the potential importance of water pathway contamination for spent nuclear fuel transportation accident risk using a worst-case water contamination scenario. The analysis showed that the impacts of the water contamination scenario were about 1/50th of the impacts of a comparable accident in an urban area (DIRS 104784-Ostmeyer 1986, all).

J.1.1.5 RISKIND

The RISKIND computer program (DIRS 101483-Yuan et al. 1995, all) was used as a complement to the RADTRAN 5 calculations to estimate scenario-specific doses to maximally exposed individuals for both routine operations and accident conditions and to estimate population impacts for the assessment of accident scenario consequences. The RISKIND code was originally developed for the DOE Office of Civilian Radioactive Waste Management specifically to analyze radiological consequences to individuals and population subgroups from the transportation of spent nuclear fuel and is used now to analyze the transport of other radioactive materials, as well as spent nuclear fuel.

The RISKIND external dose model considers direct external exposure and exposure from radiation scattered from the ground and air. RISKIND was used to calculate the dose as a function of distance from a shipment on the basis of the dimensions of the shipment (millirem per hour for stationary exposures and millirem per event for moving shipments). The code approximates the shipment as a cylindrical volume source, and the calculated dose includes contributions from secondary radiation scatter from buildup (scattering by material contents), cloudshine (scattering by air), and groundshine (scattering by the ground). Credit for potential shielding between the shipment and the receptor was not considered.

The RISKIND code was also used to provide a scenario-specific assessment of radiological consequences of severe transportation-related accidents. Whereas the RADTRAN 5 risk assessment considers the entire range of accident severities and their related probabilities, the RISKIND consequence assessment focuses on accident scenarios that result in the largest releases of radioactive material to the environment that are reasonably foreseeable. The consequence assessment was intended to provide an estimate of the potential impacts posed by a severe, but highly unlikely, transportation-related accident scenario.

The dose to each maximally exposed individual considered was 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 were similar to those given in previous transportation risk assessments. The scenarios were not meant to be exhaustive but were selected to provide a range of potential exposure situations.

J.1.2 NUMBER AND ROUTING OF SHIPMENTS

This section discusses the number of shipments and routing information used to analyze potential impacts that would result from preparation for and conduct of transportation operations to ship spent nuclear fuel and high-level radioactive waste to the Yucca Mountain site. Table J-1 summarizes the estimated numbers of shipments for the various inventory and national shipment scenario combinations.

J.1.2.1 Number of Shipments

DOE used two analysis scenarios—mostly legal-weight truck and mostly train (rail)—as bases for estimating the number of shipments of spent nuclear fuel and high-level radioactive waste from 72 commercial and 5 DOE sites. The number of shipments for the scenarios was used in analyzing transportation impacts for the Proposed Action and Inventory Modules 1 and 2. DOE selected the scenarios because, more than 10 years before the projected start of operations at the repository, it cannot accurately predict the actual mix of rail and legal-weight truck transportation that would occur from the 77 sites to the repository. Therefore, the selected scenarios enable the analysis to bound (or bracket) the ranges of legal-weight truck and rail shipments that could occur.

The analysis estimated the number of shipments from commercial sites where spent nuclear fuel would be loaded and shipped and from DOE sites where spent nuclear fuel, naval spent nuclear fuel, and high-level radioactive waste would be loaded and shipped.

For the mostly legal-weight truck scenario, with one exception, shipments were assumed to use legal-weight trucks. Overweight, overdimensional trucks weighing between about 36,300 and 52,200 kilograms (80,000 and 115,000 pounds) but otherwise similar to legal-weight trucks could be used for some spent nuclear fuel and high-level radioactive waste (for example, spent nuclear fuel from the South Texas reactors). The exception that gives the scenario its name—mostly legal-weight truck—was for shipments of naval spent nuclear fuel. Under this scenario, naval spent nuclear fuel would be shipped by rail, as decided in the *Record of Decision for a Dry Storage Container System for the Management of Naval Spent Nuclear Fuel* (62 *FR* 1095; January 8, 1997).

For the mostly rail scenario, the analysis assumed that all sites would ship by rail, with the exception of those with physical limitations that would make rail shipment impractical. The exception would be for shipments by legal-weight trucks from six commercial sites that do not have the capability to load rail casks. However, the analysis also assumed that these six sites would be upgraded to handle a rail cask after the reactors were shut down and would ship either by direct rail or by heavy-haul truck or barge to

Table J-1. Summary of estimated number of shipments for the various inventory and national transportation analysis scenario combinations.

	Mostly truck		Mostly rail	
	Truck	Rail	Truck	Rail
Proposed Action				
Commercial spent nuclear fuel	41,001	0	1,079	7,218
High-level radioactive waste	8,315	0	0	1,663
DOE spent nuclear fuel	3,470	300	0	765
Greater-Than-Class-C waste	0	0	0	0
Special-Performance-Assessment-Required waste	0	0	0	0
Proposed Action totals	*52,786*	*300*	*1,079*	*9,646*
Module 1[a]				
Commercial spent nuclear fuel	79,684	0	3,122	12,989
High-level radioactive waste	22,280	0	0	4,458
DOE spent nuclear fuel	3,721	300	0	796
Greater-Than-Class-C waste	0	0	0	0
Special-Performance-Assessment-Required waste	0	0	0	0
Module 1 totals	*105,685*	*300*	*3,122*	*18,243*
Module 2[a]				
Commercial spent nuclear fuel	79,684	0	3,122	12,989
High-level radioactive waste	22,280	0	0	4,458
DOE spent nuclear fuel	3,721	300	0	796
Greater-Than-Class-C waste	1,096	0	0	282
Special-Performance-Assessment-Required waste	1,763	55	0	410
Module 2 totals	*108,544*	*355*	*3,122*	*18,935*

a. The number of shipments for Module 1 includes all shipments of spent nuclear fuel and high-level radioactive waste included in the Proposed Action and shipments of additional spent nuclear fuel and high-level radioactive waste as described in Appendix A. The number of shipments for Module 2 includes all the shipments in Module 1 and additional shipments of highly radioactive materials described in Appendix A.

nearby railheads. Of these six sites, two are direct rail sites and four are indirect rail sites. Of the four indirect rail sites, three are adjacent to navigable waterways and could ship by barge. In addition, under this scenario, the analysis assumed that 24 commercial sites that do not have direct rail service but that could handle large casks would ship by barge or heavy-haul truck to nearby railheads with intermodal capability.

For commercial spent nuclear fuel, the CALVIN code was used to compute the number of shipments. The number of shipments of DOE spent nuclear fuel and high-level radioactive waste was estimated based on the data in Appendix A and information provided by the DOE sites. The numbers of shipments were estimated based on the characteristics of the materials shipped, mode interface capability (for example, the lift capacity of the cask-handling crane) of each shipping facility, and the modal-mix case analyzed. Table J-2 summarizes the basis for the national and Nevada transportation impact analysis.

Detailed descriptions of spent nuclear fuel and high-level radioactive waste that would be shipped to the Yucca Mountain site are presented in Appendix A.

J.1.2.1.1 *Commercial Spent Nuclear Fuel*

For the analysis, the CALVIN model used 31 shipping cask configurations: 9 for legal-weight truck casks (Figure J-3) and 22 for rail casks (Figure J-4). Table J-3 lists the legal-weight truck and rail cask configurations used in the analysis and their capacities. The analysis assumed that all shipments would use one of the 31 configurations. If the characteristics of the spent nuclear fuel projected for shipment

Table J-2. Analysis basis—national and Nevada transportation scenarios.[a,b]

Material	Mostly legal-weight truck scenario national and Nevada	National mostly rail scenario: Nevada rail scenario	National mostly rail scenario: Nevada heavy-haul truck scenario
Casks			
Commercial SNF	Truck casks – about 1.8 MTHM per cask	Rail casks – 6 to 12 MTHM per cask for shipments from 66 sites	Rail casks – 6 to 12 MTHM per cask for shipments from 66 sites
		Truck casks – about 1.8 MTHM per cask for shipments from 6 sites[c]	Truck casks – about 1.8 MTHM per cask for shipments from 6 sites
DOE HLW and DOE SNF, except naval SNF	Truck casks – 1 SNF or HLW canister per cask	Rail casks – four to nine SNF or HLW canisters per cask	Rail casks – four to nine SNF or HLW canisters per cask
Naval SNF	Disposal canisters in large rail casks for shipment from INEEL	Disposable canisters in large rail casks for shipments from INEEL	Disposable canisters in large rail casks for shipments from INEEL
Transportation modes			
Commercial SNF	Legal-weight trucks	Direct rail from 49 sites served by railroads to repository	Rail from 49 sites served by railroads to intermodal transfer station in Nevada, then heavy-haul trucks to repository
		Heavy-haul trucks from 7 sites to railhead, then rail to repository	Heavy-haul trucks from 7 sites to railheads, then rail to intermodal transfer station in Nevada, then heavy-haul trucks to repository
		Heavy-haul trucks or barges[d] from 17 sites to railhead, then rail to repository	Heavy-haul trucks or barges[d] from 17 sites to railheads, then rail to intermodal transfer station in Nevada, then heavy-haul trucks to repository
		Legal-weight trucks from 6 sites to repository[c]	Legal-weight trucks from 6 sites to repository[c]
DOE HLW and DOE SNF, except naval SNF	Legal-weight trucks	Rail from DOE sites[e] to repository	Rail from DOE sites[e] to intermodal transfer station in Nevada, then heavy-haul trucks to repository
Naval SNF	Rail from INEEL to intermodal transfer station in Nevada, then heavy-haul trucks to repository	Rail from INEEL to repository	Rail from INEEL to intermodal transfer station in Nevada, then heavy-haul trucks to repository

a. Abbreviations: SNF = spent nuclear fuel; MTHM = metric tons of heavy metal; HLW = high-level radioactive waste; INEEL = Idaho National Engineering and Environmental Laboratory.
b. G. E. Morris facility is included with the Dresden reactor facilities in the 72 commercial sites.
c. The analysis assumed that the six legal-weight truck sites would upgrade their crane capacity upon reactor shutdown and would ship all remaining spent nuclear fuel by rail. Of those six sites, four are heavy-haul sites and two are direct rail sites. Three of the heavy-haul sites have barge capability (Pilgrim, St. Lucie 1, and Indian Point).
d. Seventeen of 24 commercial sites not served by a railroad are on or near a navigable waterway. Some of these 17 sites could ship by barge rather than by heavy-haul truck to a nearby railhead. Salem/Hope Creek treated as two sites for heavy-haul or barge analysis.
e. Hanford Site, Savannah River Site, Idaho National Engineering and Environmental Laboratory, West Valley Demonstration Project, and Ft. St. Vrain.

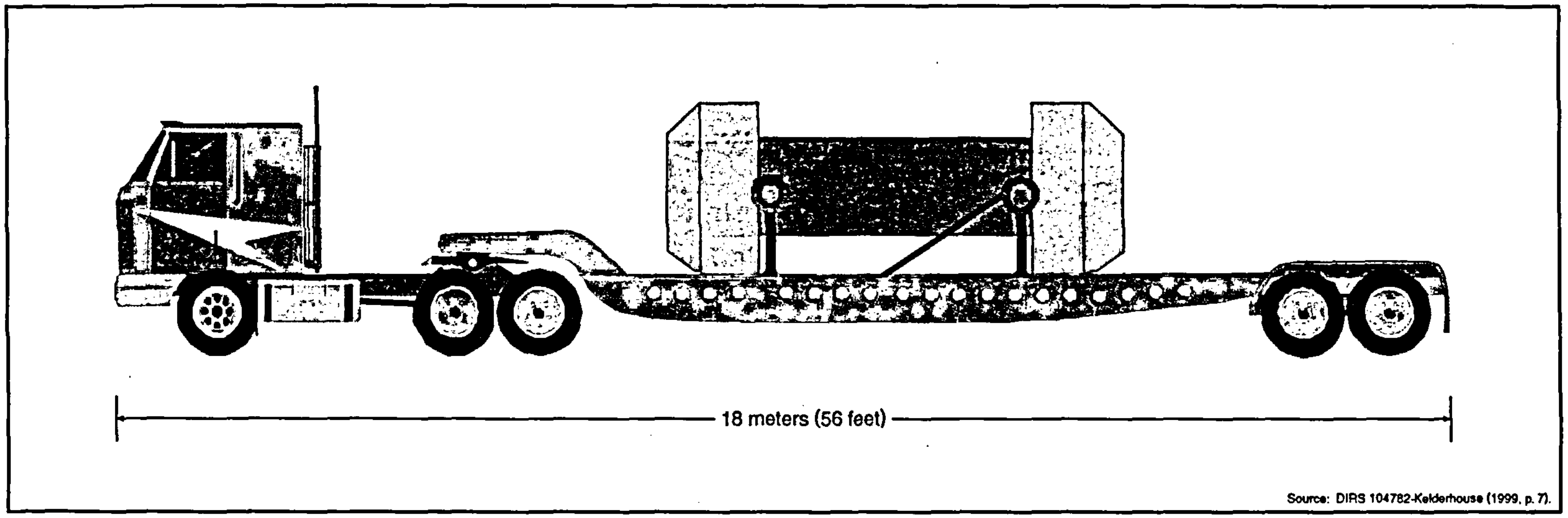


Figure J-3. Artist's conception of a truck cask on a legal-weight tractor-trailer truck.

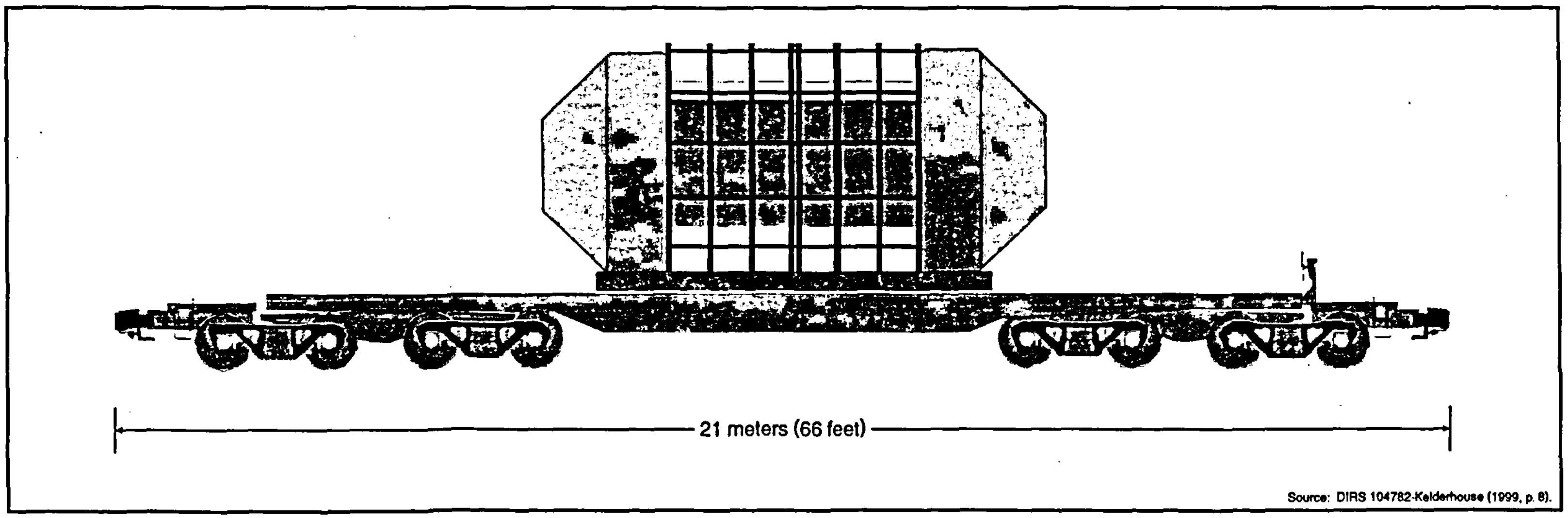


Figure J-4. Artist's conception of a large rail cask on a railcar.

Table J-3. Shipping cask configurations.

Shipping cask	Capacity (number of spent nuclear fuel assemblies)	Description[a,b]
Rail		
B-R-32-SP	32	BWR single-purpose shipping container
B-R-32-SP-HH	32	BWR single-purpose high-heat-capacity shipping container
B-R-44-SP	44	Medium BWR single-purpose shipping container
B-R-68-OV	68	Large BWR overpack shipping container
B-R-68-SP	68	Large BWR single-purpose shipping container
B-R-BP64-OV	64	Plant-unique overpack shipping container
B-R-HI68-OV	68	BWR HISTAR overpack shipping container
B-R-NAC56-OV	56	BWR NAC UMS overpack shipping container
P-R-12-SP	12	Small PWR single-purpose shipping container
P-R-12-SP-HH	12	Small PWR single-purpose high-heat-capacity shipping container
P-R-21-SP	21	Medium PWR single-purpose shipping container
P-R-24-OV	24	Large PWR overpack shipping container
P-R-24-SP	24	Large PWR single-purpose shipping container
P-R-7-SP-HH	7	PWR high heat shipping container
P-R-9-OV-MOX	9	PWR mixed-oxide overpack shipping container
P-R-9-SP-MOX	9	PWR mixed-oxide single-purpose shipping container
P-R-MP24-OV	24	PWR MP-187 (large) overpack shipping container
P-R-NAC26-OV	26	PWR NAC UMS overpack shipping container
P-R-ST17-SP	17	PWR plant-unique single-purpose shipping container
P-R-VSC24-OV	24	PWR Transtor ventilated storage cask overpack shipping container
P-R-WES21-OV	21	PWR WESFLEX overpack shipping container
P-R-YR36-OV	36	PWR plant-unique overpack shipping container
Truck		
B-T-9/9-SP	9	BWR single-purpose shipping container
B-T-9/7-SP	7	Derated BWR single-purpose shipping container
P-T-4/4-SP	4	Primary PWR single-purpose shipping container
P-T-4/3-SP	3	Derated PWR single-purpose shipping container
P-T-4/2-SP	2	Derated PWR single-purpose shipping container
P-T-4/4-SP-ST	4	PWR plant-unique single-purpose shipping container
P-T-4/3-SP-ST	3	PWR Derated plant-unique single-purpose shipping container
P-T-4/4-SP-MOX	4	PWR Mixed-oxide single-purpose shipping container
P-T-4/4-SP-BP	1	PWR plant-unique single-purpose shipping container

a. Source: DIRS 157206-CRWMS M&O (2000, all).
b. BWR = boiling-water reactor; PWR = pressurized-water reactor; SNF = spent nuclear fuel.

exceeded the capabilities of one of the casks, the model reduced the cask's capacity for the affected shipments. The reduction, which is sometimes referred to as cask derating, was needed to satisfy nuclear criticality, shielding, and thermal constraints. For shipments that DOE would make using specific casks, derating would be accomplished by partially filling the assigned casks in compliance with provisions of applicable Nuclear Regulatory Commission certificates of compliance. An example of derating is discussed in Section 5 of the GA-4 legal-weight truck shipping cask design report (DIRS 101831-General Atomics 1993, p. 5.5-1). The analysis addresses transport of two high-burnup or short cooling time pressurized-water reactor assemblies rather than four design basis assemblies.

RAIL SHIPMENTS

This appendix assumes that rail shipments of spent nuclear fuel would use large rail shipping casks, one per railcar. DOE anticipates that as many as five railcars with casks containing spent nuclear fuel or high-level radioactive waste would move together in individual trains with buffer cars and escort cars. For general freight service, a train would include other railcars with other materials. In dedicated (or special) service, trains would move only railcars containing spent nuclear fuel or high-level radioactive waste and the buffer and escort cars.

For the mostly rail scenario, six sites without sufficient crane capacity to lift a rail cask or without other factors such as sufficient floor loading capacity or ceiling height were assumed to ship by legal-weight truck. However, the analysis assumed that these sites would be upgraded to handle rail casks once the reactors were shut down, and all remaining spent nuclear fuel would ship by rail. Of these six sites, two are direct rail and four are indirect rail sites. Of the four with indirect rail access, three have access to a navigable waterway. The 24 sites with sufficient crane capacity but without direct rail access were assumed to ship by heavy-haul truck to the nearest railhead. Of these 24 sites, 17 with access to navigable waterways were analyzed for shipping by barge to a railhead (see Section J.2.4). The number of rail shipments (direct or indirect) was estimated based on each site using the largest cask size feasible based on the load capacity of its cask handling crane. In calculating the number of shipments from the sites, the model used the *Acceptance, Priority Ranking & Annual Capacity Report* (DIRS 104382-DOE 1995, all). Using CALVIN, the number of shipments of legal-weight truck casks (Figure J-3) of commercial spent nuclear fuel estimated for the Proposed Action (63,000 MTHM of commercial spent nuclear fuel) for the mostly legal-weight truck scenario, would be about 15,000 containing boiling-water reactor assemblies and 26,000 containing pressurized-water reactor assemblies. Under Inventory Modules 1 and 2, for which approximately 105,000 MTHM of commercial spent nuclear fuel would be shipped to the repository (see Appendix A), the estimated number of shipments for the mostly legal-weight truck scenario would be 29,000 for boiling-water reactor spent nuclear fuel and 51,000 for pressurized-water reactor spent nuclear fuel. Table J-4 lists the number of shipments of commercial spent nuclear fuel for the mostly legal-weight truck scenario. Specifically, it lists the site, plant, and state where shipments would originate, the total number of shipments from each site, and the type of spent nuclear fuel that would be shipped. A total of 72 commercial sites with 104 plants (or facilities) are listed in the table.

The number of shipments of truck and rail casks (Figure J-4) of commercial spent nuclear fuel estimated for the Proposed Action for the mostly rail scenario would be approximately 2,700 for boiling-water reactor spent nuclear fuel and 5,600 for pressurized-water reactor spent nuclear fuel. Under Modules 1 and 2, the estimated number of shipments for the mostly rail scenario would be approximately 5,400 containing boiling-water reactor spent nuclear fuel and 10,700 containing pressurized-water reactor spent nuclear fuel. Table J-5 lists the number of shipments for the mostly rail scenario. It also lists the site and state where shipments would originate, the total number of shipments from each site, the size of rail cask assumed for each site, and the type of spent nuclear fuel that would be shipped. In addition, it lists the 24 sites not served by a railroad that would ship rail casks by barge or heavy-haul trucks to a nearby railhead and the 6 commercial sites without capability to load a rail cask.

J.1.2.1.2 *DOE Spent Nuclear Fuel and High-Level Radioactive Waste*

To estimate the number of DOE spent nuclear fuel and high-level radioactive waste shipments, the analysis used the number of handling units or number of canisters and the number of canisters per shipment reported by the DOE sites in 1998 (see Appendix A, p. A-34; DIRS 104778-Jensen 1998, all). To determine the number of shipments of DOE spent nuclear fuel and high-level radioactive waste, the analysis assumed one canister would be shipped in a legal-weight truck cask. For rail shipments, the analysis assumed that five 61-centimeter (24-inch)-diameter high-level radioactive waste canisters would be shipped in a rail cask. For rail shipments of DOE spent nuclear fuel, the analysis assumed that rail casks would contain nine approximately 46-centimeter (18-inch) canisters or four approximately 61-centimeter canisters. The number of DOE spent nuclear fuel canisters of each size is presented in Appendix A.

Under the mostly legal-weight truck scenario for the Proposed Action, DOE would transport a total of 11,785 truck shipments of DOE spent nuclear fuel and high-level radioactive waste (one high-level waste canister per shipment) to the repository. In addition, DOE would transport 300 shipments of naval spent nuclear fuel by rail from the Idaho National Engineering and Environmental Laboratory to the repository

Table J-4. Shipments of commercial spent nuclear fuel, mostly legal-weight truck scenario[a] (page 1 of 2).

Site	Reactor	State	Fuel type	Proposed Action (2010-2033)	Modules 1 and 2 (2010-2048)
Browns Ferry	Browns Ferry 1	AL	B[b]	738	1,550
	Browns Ferry 3	AL	B	324	807
Joseph M. Farley	Joseph M. Farley 1	AL	P[c]	363	779
	Joseph M. Farley 2	AL	P	330	843
Arkansas Nuclear One	Arkansas Nuclear One, Unit 1	AR	P	362	645
	Arkansas Nuclear One, Unit 2	AR	P	432	905
Palo Verde	Palo Verde 1	AZ	P	383	694
	Palo Verde 2	AZ	P	375	691
	Palo Verde 3	AZ	P	360	716
Diablo Canyon	Diablo Canyon 1	CA	P	359	971
	Diablo Canyon 2	CA	P	370	1,130
Humboldt Bay	Humboldt Bay	CA	B	44	44
Rancho Seco	Rancho Seco 1	CA	P	124	124
San Onofre	San Onofre 1	CA	P	52	52
	San Onofre 2	CA	P	408	817
	San Onofre 3	CA	P	393	829
Haddam Neck	Haddam Neck	CT	P	255	255
Millstone	Millstone 1	CT	B	321	321
	Millstone 2	CT	P	361	694
	Millstone 3	CT	P	310	1,008
Crystal River	Crystal River 3	FL	P	277	621
St. Lucie	St. Lucie 1	FL	P	426	849
	St. Lucie 2	FL	P	380	987
Turkey Point	Turkey Point 3	FL	P	291	574
	Turkey Point 4	FL	P	292	570
Edwin I. Hatch	Edwin I. Hatch 1	GA	B	939	1,820
Vogtle	Vogtle 1	GA	P	725	1,379
Duane Arnold	Duane Arnold	IA	B	324	576
Braidwood	Braidwood 1	IL	P	565	1,142
Byron	Byron 1	IL	P	617	1,136
Clinton	Clinton 1	IL	B	363	636
Dresden/Morris	Dresden 1	IL	B	76	76
	Dresden 2	IL	B	459	726
	Dresden 3	IL	B	514	760
	Morris[d]	IL	B	319	319
	Morris[d]	IL	P	88	88
LaSalle	LaSalle 1	IL	B	769	2,080
Quad Cities	Quad Cities 1	IL	B	979	1,567
Zion	Zion 1	IL	P	557	557
Wolf Creek	Wolf Creek 1	KS	P	396	678
River Bend	River Bend 1	LA	B	353	636
Waterford	Waterford 3	LA	P	374	607
Pilgrim	Pilgrim 1	MA	B	322	575
Yankee-Rowe	Yankee-Rowe 1	MA	P	134	134
Calvert Cliffs	Calvert Cliffs 1	MD	P	867	1,612
Maine Yankee	Maine Yankee	ME	P	356	356
Big Rock Point	Big Rock Point	MI	B	110	111
D. C. Cook	D. C. Cook 1	MI	P	832	1,759
Fermi	Fermi 2	MI	B	377	662
Palisades	Palisades	MI	P	409	660
Monticello	Monticello	MN	B	257	435
Prairie Island	Prairie Island 1	MN	P	665	1,109
Callaway	Callaway 1	MO	P	435	701
Grand Gulf	Grand Gulf 1	MS	B	592	1,383
Brunswick	Brunswick 1	NC	P	40	40
	Brunswick 2	NC	P	36	36
	Brunswick 1	NC	B	281	702
	Brunswick 2	NC	B	282	657

Table J-4. Shipments of commercial spent nuclear fuel, mostly legal-weight truck scenario[a] (page 2 of 2).

Site	Reactor	State	Fuel type	Proposed Action (2010-2033)	Modules 1 and 2 (2010-2048)
Shearon Harris	Shearon Harris 1	NC	P	289	549
	Shearon Harris	NC	B	152	152
McGuire	McGuire 1	NC	P	372	932
	McGuire 2	NC	P	419	1,069
Cooper Station	Cooper Station	NE	B	272	621
Fort Calhoun	Fort Calhoun	NE	P	260	457
Seabrook	Seabrook 1	NH	P	277	590
Oyster Creek	Oyster Creek 1	NJ	B	451	658
Salem/Hope Creek	Salem 1	NJ	P	329	725
	Salem 2	NJ	P	304	826
	Hope Creek	NJ	B	444	796
James A. FitzPatrick/ Nine Mile Point	James A. FitzPatrick	NY	B	413	732
	Nine Mile Point 1	NY	B	426	628
	Nine Mile Point 2	NY	B	387	722
Ginna	Ginna	NY	P	320	472
Indian Point	Indian Point 1	NY	P	40	40
	Indian Point 2	NY	P	400	805
	Indian Point 3	NY	P	285	694
Davis-Besse	Davis-Besse 1	OH	P	343	786
Perry	Perry 1	OH	B	293	528
Trojan	Trojan	OR	P	195	195
Beaver Valley	Beaver Valley 1	PA	P	309	649
	Beaver Valley 2	PA	P	248	472
Limerick	Limerick 1	PA	B	740	1,354
Peach Bottom	Peach Bottom 2	PA	B	567	1,023
	Peach Bottom 3	PA	B	575	1,035
Susquehanna	Susquehanna 1	PA	B	1,044	2,482
Three Mile Island	Three Mile Island 1	PA	P	320	654
Catawba	Catawba 1	SC	P	327	555
	Catawba 2	SC	P	310	574
Oconee	Oconee 1	SC	P	970	1,668
	Oconee 3	SC	P	324	666
H. B. Robinson	H. B. Robinson 2	SC	P	249	470
Summer	Summer 1	SC	P	281	713
Sequoyah	Sequoyah	TN	P	644	1,768
Watts Bar	Watts Bar 1	TN	P	158	552
Comanche Peak	Comanche Peak 1	TX	P	665	1,409
South Texas	South Texas 1	TX	P	271	614
	South Texas 2	TX	P	257	590
North Anna	North Anna 1	VA	P	675	1,588
Surry	Surry 1	VA	P	863	1,457
Vermont Yankee	Vermont Yankee 1	VT	B	380	613
Columbia Generating Station	Columbia Generating Station	WA	B	415	1,006
Kewaunee	Kewaunee	WI	P	306	516
LaCrosse	LaCrosse	WI	B	37	37
Point Beach	Point Beach	WI	P	653	1,051
Total BWR[b]				15,229	28,719
Total PWR[c]				25,772	50,965

a. Source: DIRS 157206-CRWMS M&O (2000, all).
b. B = boiling-water reactor (BWR).
c. P = pressurized-water reactor (PWR).
d. Morris is a storage facility located close to the three Dresden reactors.

Table J-5. Shipments of commercial spent nuclear fuel, mostly rail scenario[a] (page 1 of 2).

Site	Reactor	State	Fuel type	Cask	Proposed Action 2010 - 2033	Modules 1 and 2 2010 - 2048
Browns Ferry	Browns Ferry 1	AL	B[b]	Rail	122	247
	Browns Ferry 3	AL	B	Rail	51	120
Joseph M. Farley	Joseph M. Farley 1	AL	P[c]	Rail	57	132
	Joseph M. Farley 2	AL	P	Rail	53	131
Arkansas Nuclear One	Arkansas Nuclear One, Unit 1	AR	P	Rail	57	108
	Arkansas Nuclear One, Unit 2	AR	P	Rail	64	149
Palo Verde	Palo Verde 1	AZ	P	Rail	65	97
	Palo Verde 2	AZ	P	Rail	62	94
	Palo Verde 3	AZ	P	Rail	66	102
Diablo Canyon	Diablo Canyon 1	CA	P	Rail	60	148
	Diablo Canyon 2	CA	P	Rail	61	160
Humboldt Bay	Humboldt Bay	CA	B	Rail	6	6
Rancho Seco	Rancho Seco 1	CA	P	Rail	21	21
San Onofre	San Onofre 1	CA	P	Rail	9	9
	San Onofre 2	CA	P	Rail	65	131
	San Onofre 3	CA	P	Rail	64	137
Haddam Neck	Haddam Neck	CT	P	Rail	40	40
Millstone	Millstone 1	CT	B	Rail	91	91
	Millstone 2	CT	P	Rail	115	199
	Millstone 3	CT	P	Rail	49	138
Crystal River	Crystal River 3	FL	P	Rail	25	17
Crystal River	Crystal River 3	FL	P	Truck	133	437
St Lucie	St. Lucie 1	FL	P	Rail	12	13
St. Lucie	St. Lucie 1	FL	P	Truck	358	751
	St. Lucie 2	FL	P	Rail	61	147
Turkey Point	Turkey Point 3	FL	P	Rail	52	85
	Turkey Point 4	FL	P	Rail	52	86
Edwin I. Hatch	Edwin I. Hatch 1	GA	B	Rail	116	288
Vogtle	Vogtle 1	GA	P	Rail	205	283
Duane Arnold	Duane Arnold	IA	B	Rail	57	129
Braidwood	Braidwood 1	IL	P	Rail	94	162
Byron	Byron 1	IL	P	Rail	101	159
Clinton	Clinton 1	IL	B	Rail	59	87
Dresden/Morris	Dresden 1	IL	B	Rail	11	11
	Dresden 2	IL	B	Rail	83	158
	Dresden 3	IL	B	Rail	89	160
	Morris[d]	IL	B	Rail	43	43
	Morris[d]	IL	P	Rail	15	15
LaSalle	LaSalle 1	IL	B	Rail	101	305
Quad Cities	Quad Cities 1	IL	B	Rail	172	329
Zion	Zion 1	IL	P	Rail	93	93
Wolf Creek	Wolf Creek 1	KS	P	Rail	63	97
River Bend	River Bend 1	LA	B	Rail	57	87
Waterford	Waterford 3	LA	P	Rail	66	93
Pilgrim	Pilgrim 1	MA	B	Rail	24	18
Pilgrim	Pilgrim 1	MA	B	Truck	154	394
Yankee-Rowe	Yankee-Rowe 1	MA	P	Rail	15	15
Calvert Cliffs	Calvert Cliffs 1	MD	P	Rail	169	320
Maine Yankee	Maine Yankee	ME	P	Rail	55	55
Big Rock Point	Big Rock Point	MI	B	Rail	7	7
D. C. Cook	D. C. Cook 1	MI	P	Rail	149	268
Fermi	Fermi 2	MI	B	Rail	61	91
Palisades	Palisades	MI	P	Rail	70	122
Monticello	Monticello	MN	B	Rail	32	19
Monticello	Monticello	MN	B	Truck	8	250
Prairie Island	Prairie Island 1	MN	P	Rail	103	205
Callaway	Callaway 1	MO	P	Rail	71	101
Grand Gulf	Grand Gulf 1	MS	B	Rail	80	215

Table J-5. Shipments of commercial spent nuclear fuel, mostly rail scenario[a] (page 2 of 2).

Site	Reactor	State	Fuel type	Cask	Proposed Action 2010 - 2033	Modules 1 and 2 2010 - 2048
Brunswick	Brunswick 1	NC	P[c]	Rail	14	14
	Brunswick 2	NC	P	Rail	12	12
	Brunswick 1	NC	B[b]	Rail	78	142
	Brunswick 2	NC	B	Rail	78	140
Shearon Harris	Shearon Harris 1	NC	P	Rail	89	146
	Shearon Harris	NC	B	Rail	43	43
McGuire	McGuire 1	NC	P	Rail	83	164
	McGuire 2	NC	P	Rail	89	173
Cooper Station	Cooper Station	NE	B	Rail	42	124
Fort Calhoun	Fort Calhoun	NE	P	Rail	61	120
Seabrook	Seabrook 1	NH	P	Rail	49	80
Oyster Creek	Oyster Creek 1	NJ	B	Rail	64	110
Salem/Hope Creek	Salem 1	NJ	P	Rail	59	101
	Salem 2	NJ	P	Rail	54	108
	Hope Creek	NJ	B	Rail	67	105
James A. FitzPatrick/ Nine Mile Point	FitzPatrick	NY	B	Rail	60	121
	Nine Mile Point 1	NY	B	Rail	72	99
	Nine Mile Point 2	NY	B	Rail	65	105
Ginna	Ginna	NY	P	Rail	36	22
Ginna	Ginna	NY	P	Truck	91	297
Indian Point	Indian Point 1	NY	P	Truck	40	40
	Indian Point 2	NY	P	Rail	35	34
	Indian Point 2	NY	P	Truck	150	471
	Indian Point 3	NY	P	Rail	22	19
	Indian Point 3	NY	P	Truck	145	482
Davis-Besse	Davis-Besse 1	OH	P	Rail	64	140
Perry	Perry 1	OH	B	Rail	42	67
Trojan	Trojan	OR	P	Rail	33	33
Beaver Valley	Beaver Valley 1	PA	P	Rail	52	94
	Beaver Valley 2	PA	P	Rail	41	76
Limerick	Limerick 1	PA	B	Rail	148	216
Peach Bottom	Peach Bottom 2	PA	B	Rail	82	157
	Peach Bottom 3	PA	B	Rail	80	157
Susquehanna	Susquehanna 1	PA	B	Rail	201	460
Three Mile Island	Three Mile Island 1	PA	P	Rail	57	97
Catawba	Catawba 1	SC	P	Rail	70	109
	Catawba 2	SC	P	Rail	69	107
Oconee	Oconee 1	SC	P	Rail	208	353
	Oconee 3	SC	P	Rail	64	129
H. B. Robinson	H. B. Robinson 2	SC	P	Rail	82	128
Summer	Summer 1	SC	P	Rail	46	113
Sequoyah	Sequoyah	TN	P	Rail	95	275
Watts Bar	Watts Bar 1	TN	P	Rail	26	74
Comanche Peak	Comanche Peak 1	TX	P	Rail	154	250
South Texas	South Texas 1	TX	P	Rail	58	104
	South Texas 2	TX	P	Rail	57	105
North Anna	North Anna 1	VA	P	Rail	143	289
Surry	Surry 1	VA	P	Rail	197	330
Vermont Yankee	Vermont Yankee 1	VT	B	Rail	73	137
Columbia Generating Station	Columbia Generating Station	WA	B	Rail	77	159
Kewaunee	Kewaunee	WI	P	Rail	51	87
La Crosse	La Crosse	WI	B	Rail	5	5
Point Beach	Point Beach	WI	P	Rail	130	213
Total BWR[b]					2,701	5,402
Total PWR[c]					5,596	10,709

a. Source: DIRS 157206-CRWMS M&O (2000, all).
b. B = boiling-water reactor (BWR).
c. P = pressurized-water reactor (PWR).
d. Morris is a storage facility located close to the three Dresden reactors.

(one naval spent nuclear fuel canister per rail cask). For Modules 1 and 2 under the mostly legal-weight truck scenario, the analysis estimated 26,001 DOE spent nuclear fuel and high-level radioactive waste truck shipments, as well as the 300 naval spent nuclear fuel shipments by rail.

Under the mostly rail scenario for the Proposed Action, the analysis estimated that DOE would transport 2,128 railcar shipments of DOE spent nuclear fuel and high-level radioactive waste (five high-level waste canisters per shipment), as well as the 300 shipments of naval spent nuclear fuel. For Modules 1 and 2 under this scenario, DOE would transport 4,954 railcar shipments of DOE spent nuclear fuel and high-level radioactive waste, as well as the 300 shipments of naval spent nuclear fuel. Table J-6 lists the estimated number of shipments of DOE and naval spent nuclear fuel from each of the sites for both the Proposed Action and Modules 1 and 2. Table J-7 lists the number of shipments of high-level radioactive waste for the Proposed Action and for Modules 1 and 2.

Table J-6. DOE and naval spent nuclear fuel shipments by site.

	Proposed Action		Module 1 or 2	
Site	Mostly truck	Mostly rail	Mostly truck	Mostly rail
INEEL[a]	1,388[b]	433	1,467[c]	442
Savannah River Site	1,316	149	1,411	159
Hanford	754	147	809	157
Fort St. Vrain	312	36	334	38
Totals	*3,770*	*765*	*4,021*	*796*

a. INEEL = Idaho National Engineering and Environmental Laboratory.
b. Includes 1,088 truck shipments of DOE spent nuclear fuel and 300 railcar shipments of naval spent nuclear fuel.
c. Includes 1,167 truck shipments of DOE spent nuclear fuel and 300 railcar shipments of naval spent nuclear fuel.

Table J-7. High-level radioactive waste shipments by site.[a]

	Proposed Action		Module 1 or 2	
Site	Mostly truck[b]	Mostly rail[c]	Mostly truck[b]	Mostly rail[c]
INEEL[d]	0	0	1,292	260[e]
Hanford	1,960	392	14,500	2,900
Savannah River Site	6,055	1,211	6,188	1,238
West Valley[f]	300	60	300	60
Totals	*8,315*	*1,663*	*22,280*	*4,458*

a. The total U.S. inventory of high-level radioactive waste at the time of shipment would be 22,280 canisters. Under the Proposed Action, DOE would only ship 8,315 canisters. Under Inventory Module 1 or 2, DOE would ship the entire inventory.
b. One canister per shipment.
c. Five canisters per shipment.
d. INEEL = Idaho National Engineering and Environmental Laboratory.
e. 238 shipments of Idaho Nuclear Technology and Engineering Center glass form waste, 20 shipments of Argonne National Laboratory-West ceramic form waste, and 2 shipments of Argonne National Laboratory-West metallic form waste (see Appendix A, Section A.2.3.5.1).
f. High-level radioactive waste at West Valley is commercial rather than DOE waste.

J.1.2.1.3 *Greater-Than-Class-C and Special-Performance-Assessment-Required Waste Shipments*

Reasonably foreseeable future actions could include shipment of Greater-Than-Class-C and Special-Performance-Assessment-Required waste to the Yucca Mountain Repository (Appendix A describes Greater-Than-Class-C and Special-Performance-Assessment-Required wastes). Commercial nuclear powerplants, research reactors, radioisotope manufacturers, and other manufacturing and research institutions generate low-level radioactive waste that exceeds the Nuclear Regulatory Commission Class C shallow-land-burial disposal limits. In addition to DOE-held material, there are three other sources or categories of Greater-Than-Class-C low-level radioactive waste:

- Nuclear utilities
- Sealed sources
- Other generators

The activities of nuclear electric utilities and other radioactive waste generators to date have produced relatively small quantities of Greater-Than-Class-C low-level radioactive waste. As the utilities take their reactors out of service and decommission them, they could generate more waste of this type.

DOE Special-Performance-Assessment-Required low-level radioactive waste could include the following materials:

- Production reactor operating wastes
- Production and research reactor decommissioning wastes
- Non-fuel-bearing components of naval reactors
- Sealed radioisotope sources that exceed Class C limits for waste classification
- DOE isotope production-related wastes
- Research reactor fuel assembly hardware

The analysis estimated the number of shipments of Greater-Than-Class-C and Special-Performance-Assessment-Required waste by assuming that 10 cubic meters (about 350 cubic feet) would be shipped in a rail cask and 2 cubic meters (about 71 cubic feet) would be shipped in a truck cask. Table J-8 lists the resulting number of commercial Greater-Than-Class-C shipments in Inventory Module 2 for both truck and rail shipments. The shipments of Greater-Than-Class-C waste from commercial utilities would originate among the commercial reactor sites. Typically, boiling-water reactors would ship a total of about 9 cubic meters (about 318 cubic feet) of Greater-Than-Class-C waste per site, while pressurized-water reactors would ship about 20 cubic meters (about 710 cubic feet) per site (see Appendix A). The impacts of transporting this waste were examined for each reactor site. The analysis assumed that sealed sources and Greater-Than-Class-C waste identified as "other" would be shipped from the DOE Savannah River Site (see Table J-8).

Table J-8. Commercial Greater-Than-Class-C waste shipments.[a]

Category	Truck	Rail
Commercial utilities	742	210
Sealed sources	121	25
Other	233	47
Totals	*1,096*	*282*

a. Source: Appendix A.

The analysis assumed DOE Special-Performance-Assessment-Required waste would be shipped from four DOE sites listed in Table J-9. Naval reactor and Argonne East Special-Performance-Assessment-Required waste is assumed to be shipped from the Idaho National Engineering and Environmental Laboratory.

Table J-9. DOE Special-Performance-Assessment-Required waste shipments.[a]

Site[b]	Rail	Truck
Hanford	2	10
INEEL[c]	58	66
SRS (ORNL)	294	1,466
West Valley	56	276
Totals	*410*	*1,763*

a. Source: Appendix A; rounded.
b. Abbreviations: INEEL = Idaho National Engineering and Environmental Laboratory; SRS = Savannah River Site; ORNL = Oak Ridge National Laboratory.
c. Includes 55 rail shipments of naval Special-Performance-Assessment-Required waste. These shipments would travel by rail regardless of scenario.

J.1.2.1.4 *Sensitivity of Transportation Impacts to Number of Shipments*

As discussed in Section J.1.2.1, the number of shipments from commercial and DOE sites to the repository would depend on the mix of legal-weight truck and rail shipments. At this time, many years before shipments could begin, it is impossible to predict the mix with a reasonable degree of accuracy. Therefore, the analysis used two scenarios to provide results that bound the range of anticipated impacts. Thus, for a mix of legal-weight truck and rail shipments within the range of the mostly legal-weight truck and mostly rail scenarios, the impacts would be likely to lie within the bounds of the impacts predicted by the analysis. For example, a mix that is different from the scenarios analyzed could consist of 10,000 legal-weight truck shipments and 8,000 rail shipments over 24 years (compared to approximately 1,100 and 9,600, respectively, for the mostly rail scenario). In this example, the number of traffic fatalities would be between 3.1 (estimated for the Proposed Action under the mostly rail scenario) and 4.5 (estimated for the mostly legal-weight truck scenario). Other examples that have different mixes within the ranges bounded by the scenarios would lead to results that would be within the range of the evaluated impacts.

In addition to mixes within the brackets, the number of shipments could fall outside the ranges used for the mostly legal-weight truck and rail transportation scenarios. If, for example, the mostly rail scenario used smaller rail casks than the analysis assumed, the number of shipments would be greater. If spent nuclear fuel was placed in the canisters before they were shipped, the added weight and size of the canisters would reduce the number of fuel assemblies that a given cask could accommodate; this would increase the number of shipments. However, for the mostly rail scenario, even if the capacity of the casks was half that used in the analysis, the impacts would remain below those forecast for the mostly legal-weight truck scenario. Although impacts would be related to the number of shipments, because the number of rail shipments would be very small in comparison to the total railcar traffic on the Nation's railroads, increases or decreases would be small for impacts to biological resources, air quality, hydrology, noise, and other environmental resource areas. Thus, the impacts of using smaller rail casks would be covered by the values estimated in this EIS.

For legal-weight truck shipments, the use of casks carrying smaller payloads than those used in the analysis (assuming the shipment of the same spent nuclear fuel) would lead to larger impacts for incident-free transportation and traffic fatalities and about the same level of radiological accident risk. The relationship is approximately linear; if the payloads of truck shipping casks in the mostly legal-weight truck scenario were less by one-half, the incident-free impacts would increase by approximately a factor of 2. Conversely, because the amount of radioactive material in a cask would be less (assuming shipment of the same spent nuclear fuel), the radiological consequences of maximum reasonably foreseeable accident scenarios would be less with the use of smaller casks. If smaller casks were used to accommodate shipments of spent nuclear fuel with shorter cooling time and higher burnup, the radiological consequences of maximum reasonably foreseeable accident scenarios would be about the same.

J.1.2.2 Transportation Routes

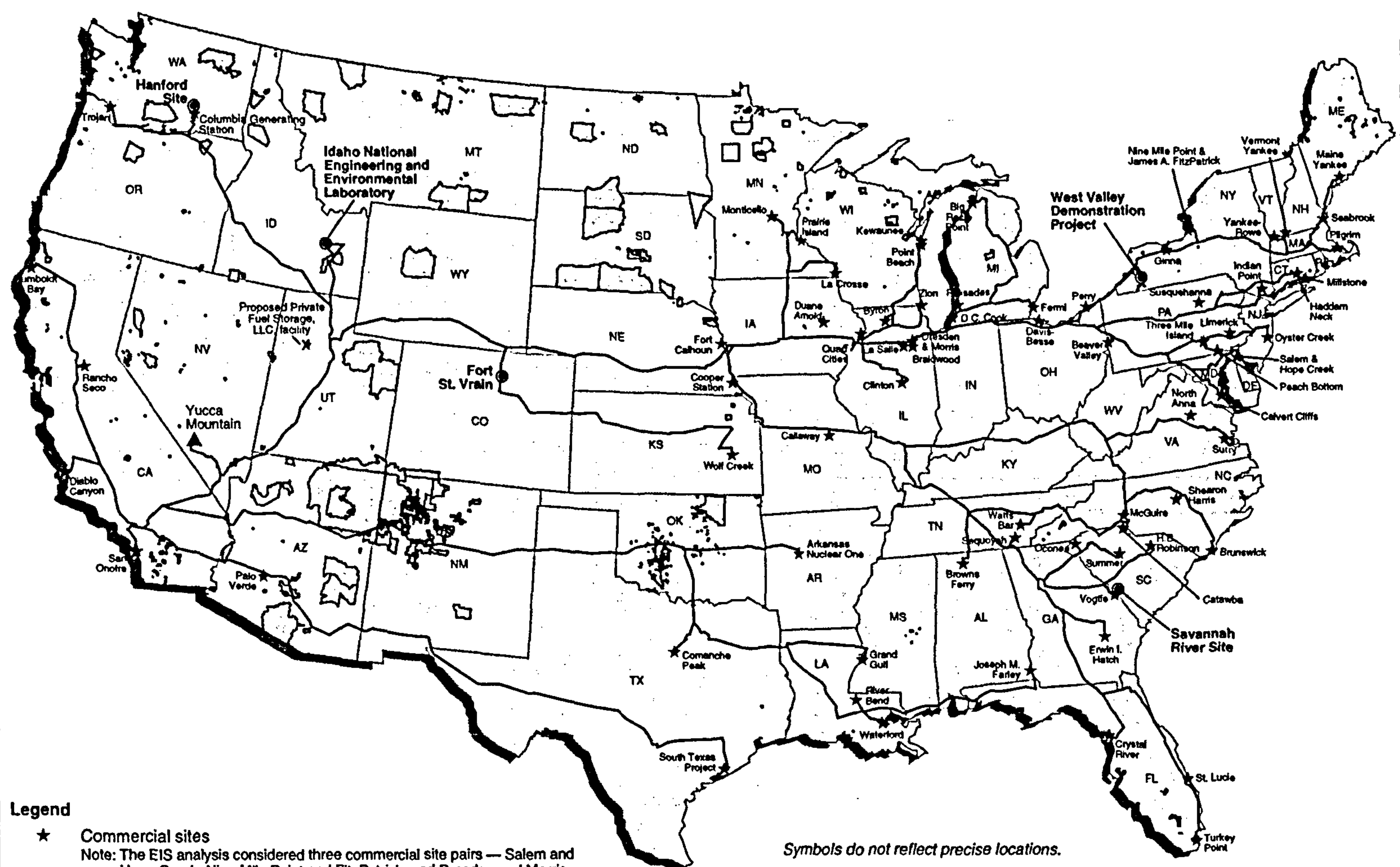
At this time, about 10 years before shipments could begin, DOE has not determined the specific routes it would use to ship spent nuclear fuel and high-level radioactive waste to the proposed repository. Nonetheless, this analysis used current regulations governing highway shipments and historic rail industry practices to select existing highway and rail routes to estimate potential environmental impacts of national transportation. Routing for shipments of spent nuclear fuel and high-level radioactive waste to the proposed repository would comply with applicable regulations of the U.S. Department of Transportation and the Nuclear Regulatory Commission in effect at the time the shipments occurred, as stated in the proposed DOE revised policy and procedures (DIRS 104741-DOE 1998, all) for implementing Section 180(c) of the Nuclear Waste Policy Act, as amended (NWPA).

Approximately 4 years before shipments to the proposed repository began, the Office of Civilian Radioactive Waste Management plans to identify the preliminary routes that DOE anticipates using in state and tribal jurisdictions so it can notify governors and tribal leaders of their eligibility for assistance under the provisions of Section 180(c) of the NWPA. DOE has published a revised proposed policy statement that sets forth its revised plan for implementing a program of technical and financial assistance to states and Native American tribes for training public safety officials of appropriate units of local government and tribes through whose jurisdictions the Department plans to transport spent nuclear fuel or high-level radioactive waste (63 *FR* 23756, January 2, 1998) (see Appendix M, Section M.8).

The analysis of impacts of the Proposed Action and Modules 1 and 2 used characteristics of routes that shipments of spent nuclear fuel and high-level radioactive waste could travel from the originating sites listed in Tables J-4 through J-7. Existing routes that could be used were identified for the mostly legal-weight truck and mostly rail transportation scenarios and included the 10 rail and heavy-haul truck implementing alternatives evaluated in the EIS for transportation in Nevada. The route characteristics used were the transportation mode (highway, railroad, or navigable waterway) and, for each of the modes, the total distance between an originating site and the repository. In addition, the analysis estimated the fraction of travel that would occur in rural, suburban, and urban areas for each route. The fraction of travel in each population zone was determined using 1990 Census data (see Section J.1.1.2 and J.1.1.3) to identify population-zone impacts for route segments. The highway routes were selected for the analysis using the HIGHWAY computer program and routing requirements of the U.S. Department of Transportation for shipments of Highway Route-Controlled Quantities of Radioactive Materials (49 CFR 397.101). Shipments of spent nuclear fuel and high-level radioactive waste would contain Highway Route-Controlled Quantities of Radioactive Materials.

J.1.2.2.1 *Routes Used in the Analysis*

Routes used in the analysis of transportation impacts of the Proposed Action and Inventory Modules 1 and 2 are highways and rail lines that DOE anticipates it could use for legal-weight truck or rail shipments from each origin to Nevada. For rail shipments that would originate at sites not served by railroads, routes used for analysis include highway routes for heavy-haul trucks or barge routes from the sites to railheads. Figures J-5 and J-6 show the truck and rail routes, respectively, analyzed for the Proposed Action and Inventory Modules 1 and 2. Tables J-10 and J-11 list the lengths of trips and the distances of the highway and rail routes, respectively, in rural, suburban, and urban population zones. Sites that would be capable of loading rail casks, but that do not have direct rail access, are listed in Table J-11. The analysis used six ending rail nodes in Nevada (Beowawe, Caliente, Dry Lake, Eccles,



Legend

★ Commercial sites

Note: The EIS analysis considered three commercial site pairs — Salem and Hope Creek, Nine Mile Point and FitzPatrick, and Dresden and Morris — to be single sites due to their proximity to each other.

◉ DOE sites

Note: The EIS analysis included the high-level radioactive waste at West Valley. The State of New York owns the high-level radioactive waste and the site. Under the West Valley Demonstration Project Act, DOE is responsible for solidifying and transporting the high-level radioactive waste to a repository.

—— National highways analyzed

▭ Federally recognized Native American lands

These routes represent the routes analyzed in Chapter 6 and might not be the routes actually used for shipments to the proposed repository at Yucca Mountain. Truck routes comply with U.S. Department of Transportation routing regulations. States or tribes can designate alternative preferred routes (40 CFR 397.103).

Source: Modified from DIRS 101779-DOE (1998, Overview, p. 5).

Figure J-5. Representative truck routes from commercial and DOE sites to Yucca Mountain analyzed for the Proposed Action and Inventory Modules 1 and 2.

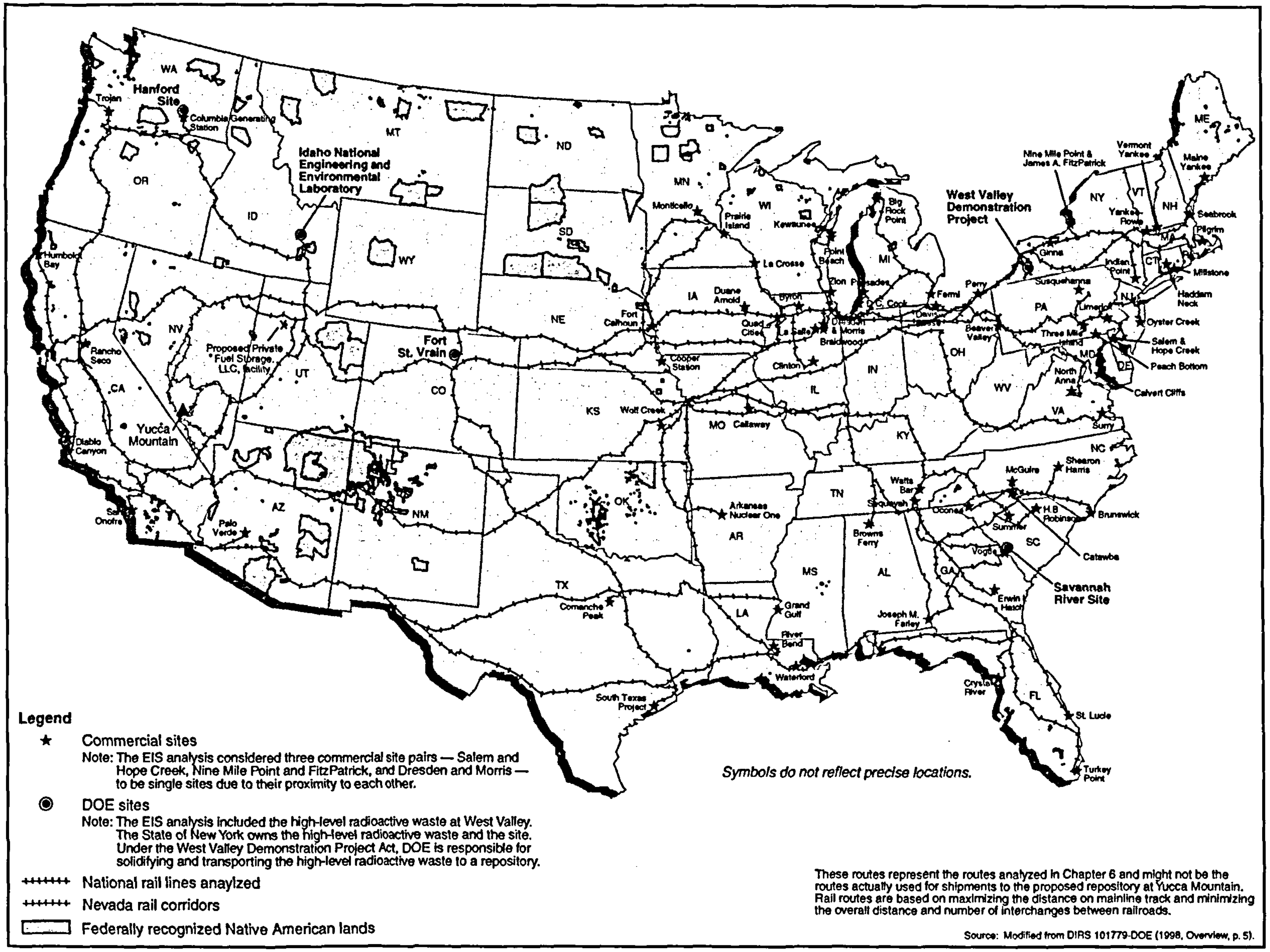


Figure J-6. Representative rail routes from commercial and DOE sites to Yucca Mountain analyzed for the Proposed Action and Inventory Modules 1 and 2.

Table J-10. Highway distances for legal-weight truck shipments from commercial and DOE sites to Yucca Mountain, mostly legal-weight truck transportation (kilometers)[a,b] (page 1 of 2).

Origin	State	Total[c]	Rural	Suburban	Urban
Browns Ferry	AL	3,798	3,344	393	61
Joseph M. Farley	AL	4,149	3,617	463	69
Arkansas Nuclear One	AR	2,810	2,588	191	30
Palo Verde	AZ	1,007	886	100	21
Diablo Canyon	CA	1,015	828	119	68
Humboldt Bay	CA	1,749	1,465	192	92
Rancho Seco	CA	1,228	1,028	124	76
San Onofre	CA	694	517	89	87
Haddam Neck	CT	4,519	3,708	736	75
Millstone	CT	4,527	3,673	746	109
Crystal River	FL	4,675	3,928	672	75
St. Lucie	FL	4,944	4,115	748	80
Turkey Point	FL	5,198	4,210	840	148
Edwin I. Hatch	GA	4,342	3,695	572	74
Vogtle	GA	4,294	3,623	592	79
Duane Arnold	IA	2,773	2,544	189	40
Braidwood	IL	3,063	2,796	231	36
Byron	IL	3,032	2,773	223	36
Clinton	IL	3,104	2,814	252	38
Dresden/Morris	IL	3,059	2,798	225	36
La Salle	IL	3,017	2,766	215	36
Quad Cities	IL	2,877	2,631	211	36
Zion	IL	3,167	2,834	284	50
Wolf Creek	KS	2,686	2,474	173	38
River Bend	LA	3,479	3,097	322	60
Waterford	LA	3,565	3,159	346	59
Pilgrim	MA	4,722	3,697	930	94
Yankee-Rowe	MA	4,615	3,692	831	92
Calvert Cliffs	MD	4,278	3,511	684	82
Maine Yankee	ME	4,894	3,733	1,052	108
Big Rock Point	MI	3,866	3,266	547	52
D. C. Cook	MI	3,196	2,827	318	51
Fermi	MI	3,524	3,014	449	61
Palisades	MI	3,244	2,855	338	51
Monticello	MN	3,003	2,702	261	41
Prairie Island	MN	2,993	2,720	232	41
Callaway	MO	2,988	2,721	225	43
Grand Gulf	MS	3,354	2,989	311	54
Brunswick	NC	4,773	3,994	696	82
Shearon Harris	NC	4,543	3,815	649	79
McGuire	NC	4,347	3,737	535	74
Cooper Station	NE	2,523	2,328	160	36
Fort Calhoun	NE	2,348	2,165	148	35
Seabrook	NH	4,725	3,675	942	107
Oyster Creek	NJ	4,424	3,530	825	69
Salem/Hope Creek	NJ	4,350	3,531	739	79
Ginna	NY	4,089	3,356	642	91
Indian Point	NY	4,382	3,695	620	67
James A. FitzPatrick/ Nine Mile Point	NY	4,234	3,461	688	85

Table J-10. Highway distances for legal-weight truck shipments from commercial and DOE sites to Yucca Mountain, mostly legal-weight truck transportation (kilometers)[a,b] (page 2 of 2).

Origin	State	Total[c]	Rural	Suburban	Urban
Davis-Besse	OH	3,520	3,106	358	55
Perry	OH	3,693	3,157	464	73
Trojan	OR	2,137	1,865	236	36
Beaver Valley	PA	3,779	3,214	500	64
Limerick	PA	4,287	3,484	741	62
Peach Bottom	PA	4,205	3,479	662	63
Susquehanna	PA	4,126	3,539	528	59
Three Mile Island	PA	4,147	3,443	643	60
Catawba	SC	4,350	3,686	594	70
Oconee	SC	4,208	3,586	551	71
H. B. Robinson	SC	4,467	3,739	647	81
Summer	SC	4,352	3,704	576	71
Sequoyah	TN	3,856	3,361	433	61
Watts Bar	TN	3,933	3,460	413	61
Comanche Peak	TX	2,794	2,547	213	34
South Texas	TX	3,011	2,652	295	64
North Anna	VA	4,437	3,825	533	79
Surry	VA	4,611	3,898	629	83
Vermont Yankee	VT	4,615	3,675	846	94
Colombia Generating Station	WA	1,880	1,669	178	32
Kewaunee	WI	3,347	2,978	314	55
La Crosse	WI	3,014	2,773	198	43
Point Beach	WI	3,341	2,972	314	55
Ft. St. Vrain[d]	CO	1,637	1,501	108	28
INEEL[e]	ID	1,201	1,044	129	27
West Valley[f]	NY	3,959	3,322	562	75
Savannah River[e]	SC	4,294	3,622	593	79
Hanford[e]	WA	1,881	1,671	178	32

a. To convert kilometers to miles, multiply by 0.62137.
b. Distances determined for purposes of analysis using HIGHWAY computer program.
c. Totals might differ from sums due to method of calculation and rounding.
d. DOE spent nuclear fuel site.
e. DOE spent nuclear fuel and high-level radioactive waste site.
f. High-level radioactive waste site.

Jean, and Apex) to select rail routes from the 77 sites. These rail nodes would be starting points for the rail and heavy-haul truck implementing alternatives analyzed for transportation in Nevada.

Selection of Highway Routes. The analysis of national transportation impacts used route characteristics of existing highways, such as distances, population densities, and state-level accident statistics. The analysis of highway shipments of spent nuclear fuel and high-level radioactive waste used the HIGHWAY computer model (DIRS 104780-Johnson et al. 1993, all) to determine highway routes using regulations of the U.S. Department of Transportation (49 CFR 397.101) that specify how routes are selected. The selection of "preferred routes" is required for shipment of these materials. DOE has determined that the HIGHWAY program is appropriate for calculating highway routes and related information (DIRS 101845-Maheras and Pippen 1995, pp. 2 to 5). HIGHWAY is a routing tool that DOE has used in previous EISs [for example, the programmatic EIS on spent nuclear fuel (DIRS 101802-DOE 1995, Volume 1, p. I-6) and the Waste Isolation Pilot Plant Supplement II EIS (DIRS 101814-DOE 1997, pp. 5 to 13)] to determine highway routes for impact analysis.

Table J-11. Rail transportation distances from commercial and DOE sites to Nevada ending rail nodes[a] (kilometers)[b,c] (page 1 of 3).

Site	Total[d]	Rural	Suburban	Urban
Commercial sites with direct rail access				
Arkansas Nuclear One	2,593 - 2,930	2,427 - 2,720	149 - 181	17 - 29
Beaver Valley	3,242 - 3,579	2,675 - 2,968	452 - 484	115 - 127
Braidwood	2,586 - 2,923	2,260 - 2,553	253 - 286	73 - 85
Brunswick	4,145 - 4,482	3,363 - 3,656	721 - 753	60 - 72
Byron	2,403 - 2,740	2,207 - 2,500	172 - 204	24 - 35
Catawba	3,819 - 4,156	3,265 - 3,559	495 - 527	59 - 70
Clinton	2,595 - 2,932	2,358 - 2,651	196 - 228	41 - 53
Columbia Generating Station	1,369 - 1,706	1,274 - 1,567	84 - 116	11 - 22
Comanche Peak	2,492 - 2,678	2,218 - 2,401	213 - 236	37 - 43
Crystal River	4,175 - 4,653	3,481 - 3,960	587 - 672	55 - 106
D. C. Cook	2,632 - 2,969	2,261 - 2,555	277 - 309	94 - 105
Davis Besse	2,917 - 3,254	2,452 - 2,745	356 - 389	109 - 121
Dresden/Morris	2,510 - 2,847	2,253 - 2,546	222 - 255	35 - 46
Duane Arnold	2,168 - 2,505	2,014 - 2,307	135 - 167	20 - 31
Edwin I. Hatch	3,929 - 4,266	3,396 - 3,689	480 - 513	53 - 64
Fermi	3,072 - 3,409	2,513 - 2,806	437 - 469	123 - 135
H. B. Robinson	3,889 - 4,226	3,137 - 3,430	685 - 717	68 - 79
Humboldt Bay	724 - 1,412	550 - 1,093	137 - 239	36 - 80
James A. FitzPatrick/Nine Mile Point	3,632 - 3,969	2,848 - 3,141	631 - 663	154 - 165
Joseph M. Farley	4,021 - 4,358	3,438 - 3,731	529 - 561	54 - 66
La Crosse	2,851 - 3,579	2,578 - 3,361	196 - 234	22 - 39
La Salle	2,653 - 3,381	2,396 - 3,179	181 - 220	20 - 37
Limerick	3,934 - 4,271	3,148 - 3,441	664 - 696	123 - 135
Maine Yankee	4,435 - 4,771	3,245 - 3,538	1,008 - 1,040	182 - 193
McGuire	3,916 - 4,253	3,170 - 3,463	679 - 712	66 - 78
Millstone	4,139 - 4,476	3,078 - 3,371	893 - 925	168 - 179
Monticello	2,655 - 2,822	2,347 - 2,543	241 - 265	38 - 44
North Anna	3,944 - 4,281	3,132 - 3,425	639 - 672	172 - 184
Palo Verde	872 - 1,466	778 - 1,113	77 - 252	18 - 101
Perry	3,222 - 3,558	2,836 - 3,129	317 - 349	69 - 80
Prairie Island	2,344 - 2,681	2,100 - 2,393	223 - 255	22 - 33
Quad Cities	2,595 - 3,323	2,324 - 3,108	194 - 233	21 - 38
Rancho Seco	263 - 882	178 - 694	61 - 139	24 - 48
River Bend	3,266 - 3,405	2,966 - 3,027	268 - 358	28 - 68
San Onofre	472 - 1,133	322 - 756	93 - 264	58 - 112
Seabrook	4,282 - 4,619	3,183 - 3,477	920 - 952	179 - 190
Sequoyah	3,366 - 3,703	3,044 - 3,337	277 - 309	46 - 57
Shearon Harris	4,046 - 4,383	3,301 - 3,595	686 - 718	59 - 70
South Texas	2,815 - 3,277	2,539 - 2,770	234 - 434	42 - 73
Summer	3,755 - 4,092	3,291 - 3,584	414 - 446	50 - 62
Susquehanna	3,827 - 4,164	2,883 - 3,176	771 - 803	173 - 185
Three Mile Island	3,828 - 4,165	3,129 - 3,422	588 - 620	111 - 123
Trojan	1,326 - 2,048	1,040 - 1,836	172 - 346	40 - 108
Vermont Yankee	4,078 - 4,415	3,135 - 3,429	778 - 811	164 - 176
Vogtle	3,985 - 4,322	3,443 - 3,736	489 - 522	53 - 64
Waterford	3,408 - 3,540	2,878 - 3,086	293 - 453	63 - 76
Watts Bar	3,310 - 3,647	3,011 - 3,304	254 - 286	46 - 57
Wolf Creek	2,108 - 2,445	1,995 - 2,288	98 - 130	15 - 27
Zion	2,542 - 2,879	2,231 - 2,525	247 - 279	64 - 75

Table J-11. Rail transportation distances from commercial and DOE sites to Nevada ending rail nodes[a] (kilometers)[b,c] (page 2 of 3).

Site	Total[d]	Rural	Suburban	Urban
Commercial sites with indirect rail access				
Big Rock Point				
HH[e]-20.0 kilometers	3,258 - 3,595	2,766 - 3,059	399 - 431	93 - 105
Browns Ferry				
HH-55.4 kilometers	3,118 - 3,455	2,723 - 3,016	353 - 386	42 - 53
Callaway				
HH-18.5 kilometers	2,230 - 2,567	2,103 - 2,396	108 - 140	20 - 32
Calvert Cliffs				
HH-41.9 kilometers	3,829 - 4,166	3,024 - 3,317	631 - 663	174 - 185
Cooper Station				
HH-53.8 kilometers	1,852 - 2,189	1,719 - 2,012	109 - 141	25 - 36
Diablo Canyon				
HH-43.5 kilometers	715 - 789	461 - 522	162 - 181	73 - 105
Fort Calhoun				
HH-6.0 kilometers	1,736 - 2,073	1,656 - 1,949	70 - 102	10 - 21
Ginna				
HH-35.1 kilometers	3,532 - 3,869	2,792 - 3,086	604 - 636	136 - 147
Grand Gulf				
HH-47.8 kilometers	3,108 - 3,445	2,817 - 3,115	259 - 373	28 - 67
Haddam Neck				
HH-16.6 kilometers	4,105 - 4,442	3,070 - 3,363	868 - 901	167 - 178
Hope Creek				
HH-51.0 kilometers	3,978 - 4,315	2,842 - 3,135	912 - 944	225 - 236
Indian Point				
HH-14.2 kilometers	3,981 - 4,318	3,034 - 3,327	781 - 813	166 - 177
Kewanee				
HH-9.7 kilometers	2,867 - 3,204	2,421 - 2,714	363 - 395	84 - 95
Oconee				
HH-17.5 kilometers	3,738 - 4,075	3,221 - 3,514	464 - 496	54 - 65
Oyster Creek				
HH-28.5 kilometers	4,061 - 4,398	2,862 - 3,155	957 - 989	242 - 254
Palisades				
HH-41.9 kilometers	2,680 - 3,017	2,279 - 2,572	306 - 338	96 - 107
Peach Bottom				
HH-58.9 kilometers	3,849 - 4,186	3,134 - 3,427	604 - 637	111 - 122
Pilgrim				
HH-8.7 kilometers	4,263 - 4,600	3,103 - 3,396	986 - 1,018	174 - 185
Point Beach				
HH-36.4 kilometers	2,820 - 3,157	2,405 - 2,698	338 - 370	78 - 89
Salem				
HH-51.0 kilometers	3,950 - 4,287	2,868 - 3,161	864 - 896	219 - 230
St. Lucie				
HH-23.5 kilometers	4,315 - 4,840	3,464 - 3,984	732 - 809	74 - 125
Surry				
HH-75.2 kilometers	4,065 - 4,402	3,468 - 3,761	523 - 555	74 - 85
Turkey Point				
HH-17.4 kilometers	4,662 - 5,140	3,696 - 4,175	785 - 870	127 - 179
Yankee-Rowe				
HH-10.1 kilometers	3,998 - 4,335	3,083 - 3,376	752 - 784	164 - 175

Table J-11. Rail transportation distances from commercial and DOE sites to Nevada ending rail nodes[a] (kilometers)[b,c] (page 3 of 3).

Site	Total[d]	Rural	Suburban	Urban
DOE spent nuclear fuel and high-level radioactive waste				
Ft. St. Vrain[f]	1,039 - 1,321	1,011 - 1,214	24 - 93	3 - 13
Hanford Site[g]	1,356 - 1,693	1,262 - 1,555	84 - 116	11 - 22
INEEL[g]	482 - 819	445 - 738	34 - 66	4 - 15
Savannah River Site[g]	3,751 - 4,088	3,081 - 3,374	605 - 638	65 - 76
West Valley[h]	3,447 - 3,784	2,774 - 3,067	538 - 570	135 - 146

a. The ending rail nodes (INTERLINE computer program designations) are Apex-14763; Caliente-14770; Beowawe-14791; and Jean-16328.
b. To convert kilometers to miles, multiply by 0.62137.
c. This analysis used the INTERLINE computer program to estimate distances.
d. Totals might differ from sums due to method of calculation and rounding.
e. HH = heavy-haul truck distance.
f. DOE spent nuclear fuel.
g. DOE spent nuclear fuel and high-level radioactive waste.
h. High-level radioactive waste.

Because the regulations require that the preferred routes result in reduced time in transit, changing conditions, weather, and other factors could result in the use of more than one route at different times for shipments between the same origin and destination. However, for this analysis the program selected only one route for travel from each site to the Yucca Mountain site. Section J.4 describes the highway routes used in the analysis along with estimated impacts of legal-weight truck shipments for each state.

Although shipments could use more than one preferred route in national highway transportation to comply with U.S. Department of Transportation regulations (49 CFR 397.101), under current U.S. Department of Transportation regulations all preferred routes would ultimately enter Nevada on Interstate 15 and travel to the repository on U.S. Highway 95. States or tribes can designate alternative or additional preferred routes for highway shipments (49 CFR 397.103). At this time the State of Nevada has not identified any alternative or additional preferred routes that DOE could use for shipments to the repository.

STATE-DESIGNATED PREFERRED ROUTES

U.S. Department of Transportation regulations specify that states and tribes can designate preferred routes that are alternatives, or in addition to, Interstate System highways including bypasses or beltways for the transportation of Highway Route-Controlled Quantities of Radioactive Materials. Highway Route-Controlled of Radioactive Materials include spent nuclear fuel and high-level radioactive waste in quantities that would be shipped on a truck or railcar to the repository. If a state or tribe designated such a route, highway shipments of spent nuclear fuel and high-level radioactive waste would use the preferred route if (1) it was an alternative preferred route, (2) it would result in reduced time in transit, or (3) it would replace pickup or delivery routes. Fourteen states have designated alternative or additional preferred routes (65 *FR* 75771; December 4, 2000). Although Nevada has designated a State routing agency to the Department of Transportation (Nevada Revised Statutes, Chapter 408.141), the State has not yet designated alternative or preferred routes for Highway Route-Controlled Quantities of Radioactive Materials. State route designations in the future could require changes in highway routes that would be used for shipments of spent nuclear fuel and high-level radioactive waste from 77 sites to Yucca Mountain. As an example of recent changes, two states notified the U.S. Department of Transportation of state-designated preferred routes (65 *FR* 75771; December 4, 2000) near or following publication of the Draft EIS.

Selection of Rail Routes. Rail transportation routing of spent nuclear fuel and high-level radioactive waste shipments is not regulated by the U.S. Department of Transportation. As a consequence, the routing rules used by the INTERLINE computer program (DIRS 104781-Johnson et al. 1993, all) assumed that railroads would select routes using historic practices. DOE has determined that the INTERLINE program is appropriate for calculating routes and related information for use in transportation analyses (DIRS 101845-Maheras and Pippen 1995, pp. 2 to 5). Because the routing of rail shipments would be subject to future, possibly different practices of the involved railroads, DOE could use other rail routes. Section J.4 contains maps of the rail routes used in the analysis along with estimated impacts of rail shipments for each state.

For the 24 commercial sites that have the capability to handle and load rail casks but do not have direct rail service, DOE used the HIGHWAY computer program to identify routes for heavy-haul transportation to nearby railheads. For such routes, routing agencies in affected states would need to approve the transport and routing of overweight and overdimensional shipments.

J.1.2.2.2 *Routes for Shipping Rail Casks from Sites Not Served by a Railroad*

In addition to routes for legal-weight trucks and rail shipments, 24 commercial sites that are not served by a railroad, but that have the capability to load rail casks, could ship spent nuclear fuel to nearby railheads using heavy-haul trucks (see Table J-11). In addition, six of the sites that initially are legal-weight truck sites would be indirect rail sites after plant shutdown.

J.1.2.2.3 *Sensitivity of Analysis Results to Routing Assumptions*

Routing for shipments of spent nuclear fuel and high-level radioactive waste to the proposed repository would comply with regulations of the U.S. Department of Transportation and the Nuclear Regulatory Commission in effect at the time shipments would occur. Unless the State of Nevada designates alternative or additional preferred routes, to comply with U.S. Department of Transportation regulations all preferred routes would ultimately enter Nevada on Interstate 15 and travel to the repository on U.S. Highway 95. States can designate alternative or additional preferred routes for highway shipments. At this time the State of Nevada has not identified any alternative or additional preferred routes DOE could use for shipments to the repository. Section J.3.1.3 examines the sensitivity of transportation impacts both nationally and regionally (within Nevada) to changes in routing assumptions within Nevada.

J.1.3 ANALYSIS OF IMPACTS FROM INCIDENT-FREE TRANSPORTATION

DOE analyzed the impacts of incident-free transportation for shipments of commercial and DOE spent nuclear fuel and DOE high-level radioactive waste that would be shipped under the Proposed Action and Inventory Modules 1 and 2 from 77 sites to the repository. The analysis estimated impacts to the public and workers and included impacts of loading shipping casks at commercial and DOE sites and other preparations for shipment as well as intermodal transfers of casks from heavy-haul trucks or barges to rail cars.

J.1.3.1 Methods and Approach for Analysis of Impacts for Loading Operations

The analysis used methods and assessments developed for spent nuclear fuel loading operations at commercial sites to estimate radiological impacts to involved workers at commercial and DOE sites. Previously developed conceptual radiation shield designs for shipping casks (DIRS 101747-Schneider et al. 1987, Sections 4 and 5), rail and truck shipping cask dimensions, and estimated radiation dose rates at locations where workers would load and prepare casks (DIRS 104791-DOE 1992, p. 4.2) for shipment were the analysis bases for loading operations. In addition, tasks and time-motion evaluations from these studies were used to describe spent nuclear fuel handling and loading. These earlier evaluations were based on normal, incident-free operations that would be conducted according to Nuclear Regulatory Commission regulations that establish radiation protection criteria for workers.

The analysis assumed that noninvolved workers would not have tasks that would result in radiation exposure. In a similar manner, the analysis projected that the dose to the public from loading operations would be extremely small, resulting in no or small impacts. A separate evaluation of the potential radiation dose to members of the public from loading operations at commercial nuclear reactor facilities showed that the dose would be very low, less than 0.001 person-rem per metric ton uranium of spent nuclear fuel loaded (DIRS 104731-DOE 1986, p. 2.42, Figure 2.9). Public doses from activities at commercial and DOE sites generally come from exposure to airborne emissions and, in some cases, waterborne effluents containing low levels of radionuclides. However, direct radiation at publicly accessible locations near these sites typically is not measurable and contributes negligibly to public dose and radiological impacts. Though DOE expects no releases from loading operations, this analysis estimated that the dose to the public would be 0.001 person-rem per metric ton uranium, and metric ton equivalents, for DOE spent nuclear fuel and high-level radioactive waste. Noninvolved workers could also be exposed to low levels of radioactive materials and radioactivity from loadout operations. However, because these workers would not work in radiation areas they would receive a very small fraction of the dose received by involved workers. DOE anticipates that noninvolved workers would receive individual doses similar to those received by members of the public. Because the population of noninvolved workers would be small compared to the population of the general public near the 77 sites, the dose to these workers would be a small fraction of the public dose.

The analysis used several basic assumptions to evaluate impacts from loading operations at DOE sites:

- Operations to load spent nuclear fuel and high-level radioactive waste at DOE facilities would be similar to loading operations at commercial facilities.
- Commercial spent nuclear fuel would be in storage pools or in dry storage at the reactors and DOE spent nuclear fuel would be in dry storage, ready to be loaded directly in Nuclear Regulatory Commission-certified shipping casks and then on transportation vehicles. In addition, DOE high-level radioactive waste could be loaded directly in casks. All preparatory activities, including packaging, repackaging, and validating the acceptability of spent nuclear fuel for acceptance at the repository would be complete prior to loading operations.
- Commercial spent nuclear fuel to be placed in the shipping casks would be uncanistered or canistered fuel assemblies, with at least one assembly in a canister. DOE spent nuclear fuel and high-level radioactive waste would be in disposable canisters. Typically, uncanistered assemblies would be loaded into shipping casks under water in storage pools (wet storage). Canistered spent nuclear fuel could be loaded in casks directly from dry storage facilities or storage pools.

In addition, because handling and loading operations for DOE spent nuclear fuel and high-level radioactive waste and commercial spent nuclear fuel would be similar, the analysis assumed that impacts to workers during the loading of commercial spent nuclear fuel could represent those for the DOE materials, even though the radionuclide inventory of commercial fuel and the resultant external dose rate would be higher than those of the DOE materials. This conservative assumption of selecting impacts from commercial handling and loading operations overestimated the impacts of DOE loading operations, but it enabled the use of detailed real information developed for commercial loading operations to assess impacts for DOE operations. Equivalent information was not available for operations at DOE facilities. To gauge the conservatism of the assumption DOE compared the radioactivity of contents of shipments of commercial and DOE spent nuclear fuel and high-level radioactive waste. Table J-12 compares typical inventories of important contributors to the assessment of worker and public health impacts. These are cesium-137 and actinide isotopes (including plutonium) for rail shipments of commercial spent nuclear

Table J-12. Average cesium-137, actinide isotope, and total radioactive material content (curies) in a rail shipping cask.[a]

Material	Cesium-137	Actinides	Total (all isotopes)
Commercial spent nuclear fuel (PWR)[b]	816,000	694,000	2,130,000
High-level radioactive waste	27,000	53,000[c]	180,000
DOE spent nuclear fuel (except naval spent nuclear fuel)	119,000	40,000	265,000
Naval spent nuclear fuel	450,000	28,000	1,100,000

a. Source: Appendix A. Source estimated based on 24 typical pressurized-water reactor fuel assemblies for commercial spent nuclear fuel; one dual-purpose shipping canister for naval spent fuel; nine canisters of DOE spent nuclear fuel; and five canisters of high-level radioactive waste.
b. PWR = pressurized-water reactor.
c. Includes immobilized plutonium with high-level radioactive waste.

fuel, DOE spent nuclear fuel, and DOE high-level radioactive waste. Although other factors are also important (for example, material form and composition), these indicators provide an index of the relative hazard potential of the materials. Appendix A contains additional information on the radionuclide inventory and characteristics of spent nuclear fuel and high-level radioactive waste.

J.1.3.1.1 *Radiological Impacts of Loading Operations at Commercial Sites*

In 1987, DOE published a study of the estimated radiation doses to the public and workers resulting from the transport of spent nuclear fuel from commercial nuclear power reactors to a hypothetical deep geologic repository (DIRS 101747-Schneider et al. 1987, all). This study was based on a single set of spent nuclear fuel characteristics and a single split [30 percent/70 percent by weight; 900 metric tons uranium/2,100 metric tons uranium per year] between truck and rail conveyances. DOE published its findings on additional radiological impacts on monitored retrievable storage workers in an addendum to the 1987 report (DIRS 104791-DOE 1992, all). The technical approaches and impacts summarized in these DOE reports were used to project involved worker impacts that would result from commercial at-reactor spent nuclear fuel loading operations. DOE did not provide a separate analysis of noninvolved worker impacts in these reports. For the analysis in this EIS, DOE assumed that noninvolved workers would not receive radiation exposures from loading operations. This assumption is appropriate because noninvolved workers would be personnel with managerial or administrative support functions directly related to the loading tasks but at locations, typically in offices, away from areas where loading activities took place.

In the DOE study, worker impacts from loading operations were estimated for a light-water reactor with pool storage of spent nuclear fuel. The radiological characteristics of the spent nuclear fuel in the analysis was 10-year-old, pressurized-water reactor fuel with an exposure history (burnup) of 35,000 megawatt-days per metric ton. In addition, the reference pressurized-water reactor and boiling-water reactor fuel assemblies were assumed to contain 0.46 and 0.19 MTU, respectively, prior to reactor irradiation. The term MTU (metric ton of uranium) is from the DOE study. An MTU is approximately the same quantity of spent nuclear fuel as a metric ton of heavy metal, or MTHM, as described in this EIS. In this section, the terms are used interchangeably to allow the information reported in prior DOE studies to be used without modification. These parameters for spent nuclear fuel are similar to those presented in Appendix A of this EIS. The use of the parameters for spent nuclear fuel presented in Appendix A would be likely to lead to similar results.

In the 1987 study, radiation shielding analyses were done to provide information on (1) the conceptual configuration of postulated reference rail and truck transportation casks, and (2) the direct radiation levels at accessible locations near loaded transportation casks. The study also presented the results of a detailed time-motion analysis of work tasks that used a loading concept of operations. This task analysis was coupled with cask and at-reactor direct radiation exposure rates to estimate radiation doses to involved workers (that is, those who would participate directly in the handling and loading of the transportation casks and conveyances). Impacts to members of the public from loading operations had been shown to be small [fraction of a person-millirem population dose; (DIRS 101747-Schneider et al. 1987, p. 2.9)] and were eliminated from further analysis in the 1987 report. The at-reactor-loading concept of operations included the following activities:

1. Receiving the empty transportation cask at the site fence
2. Preparing and moving the cask into the facility loading area
3. Removing the cask from the site prime mover trailer
4. Preparing the cask for loading and placing it in the water-filled loading pit
5. Transferring spent nuclear fuel from its pool storage location to the cask
6. Removing the cask from the pool and preparing it for shipment
7. Placing the cask on the site prime mover trailer
8. Moving the loaded cask to the site fence where the trailer is connected to the transportation carrier's prime mover for offsite shipment

The results for loading operations are listed in Table J-13.

Table J-13. Principal logistics bases and results for the reference at-reactor loading operations.[a]

	Conveyance		
Parameter	Rail[b]	Truck[c]	Total
Annual loading rate (MTU/year)[d]	2,100	900	3,000
Transportation cask capacity, PWR - BWR (MTU/cask)	6.5 - 6.7	0.92 - 0.93	NA[e]
Annual shipment rate (shipments/year)	320	970	1,290
Average loading duration,[f] PWR - BWR (days)	2.3 - 2.5	1.3 - 1.4	NA
Involved worker specific CD,[g] PWR - BWR (person-rem/MTU)	0.06 - 0.077	0.29 - 0.31	NA

a. Source: DIRS 101747-Schneider et al. (1987, pp. 2.5 and 2.7).
b. 14 pressurized-water reactor and boiling-water reactor spent nuclear fuel assemblies per rail transportation cask.
c. 2 pressurized-water reactor and boiling-water reactor spent nuclear fuel assemblies per truck transportation cask.
d. MTU = metric tons of uranium. One MTU is approximately equal to 1 MTHM.
e. NA = not applicable.
f. Based on single shift operations; carrier drop-off and pick-up delays were not included.
g. Collective dose expressed as the sum of the doses accumulated by all loading (involved) workers, regardless of the total number of workers assigned to loading tasks.

The loading activities that the study determined would produce the highest collective unit impacts are listed in Table J-14. As listed in this table, the involved worker collective radiation doses would be dominated by tasks in which the workers would be near the transportation cask when it contained spent nuclear fuel, particularly when they were working around the cask lid area. These activities would deliver at least 40 percent of the total collective worker doses. Worker impacts from the next largest dose-producing tasks (working to secure the transportation cask on the trailer) would account for 12 to 19 percent of the total impact. The impacts are based on using crews of 13 workers [the number of workers

Table J-14. At-reactor reference loading operations—collective impacts to involved workers.[a]

Task description	Rail: CD per MTU[b,c] (PWR - BWR)[d]	Rail: Percent of total impact	Truck: CD per MTU (PWR - BWR)	Truck: Percent of total impact
Install cask lids; flush cask interior; drain, dry and seal cask	0.025 - 0.024	40 - 31	0.126 - 0.126	43 - 40
Install cask binders, impact limiters, personnel barriers	0.010 - 0.009	15 - 12	0.056 - 0.055	19 - 18
Load SNF into cask	0.011 - 0.027	17 - 35	0.011 - 0.027	4 - 9
On-vehicle cask radiological decontamination and survey	0.003 - 0.003	5 - 4	0.018 - 0.018	6 - 6
Final inspection and radiation surveys	0.002 - 0.002	4 - 3	0.016 - 0.015	5 - 5
All other (19) activities	0.011 - 0.012	19 - 16	0.066 - 0.073	23 - 23
Task totals	*0.062 - 0.077*	*100 - 100*	*0.29 - 0.31*	*100 - 100*

a. Source: DIRS 101747-Schneider et al. (1987, p. 2.9).
b. CD/MTU = Collective dose (person-rem effective dose equivalent) per metric ton uranium. One MTU is approximately equal to 1 MTHM.
c. The at-reactor loading crew size is assumed to be 13 involved workers.
d. PWR = pressurized-water reactor; BWR = boiling-water reactor.

assumed in the DIRS 101747-Schneider et al. (1987, Section 2) study] dedicated solely to performing cask-handling work. The involved worker collective dose was calculated using the following formula:

$$\text{Collective dose (person-rem)} = A \times B \times C \times D \times E$$

where: A = number of pressurized-water or boiling-water reactor spent nuclear fuel shipments being analyzed under each transportation scenario (from Tables J-4 and J-5)

B = number of transportation casks included in a shipment (set at 1 for both transportation scenarios)

C = number of pressurized-water or boiling-water reactor spent nuclear fuel assemblies in a transportation cask (from Table J-3)

D = amount of uranium in the spent nuclear fuel assembly prior to reactor irradiation, expressed as metric tons uranium per assembly (from Table J-13)

E = involved worker-specific collective dose in person-rem/metric ton uranium for each fuel type (from Table J-13)

Because worker doses are linked directly to the number of loading operations performed, the highest average individual doses under each transportation scenario would occur at the reactor sites having the most number of shipments. Accordingly, the average individual dose impacts were calculated for the limiting site using the equation:

$$\text{Average individual dose (rem per involved worker)} = (A \times B \times C \times D \times E) \div F$$

where: A = largest value for the number of shipments from a site under each transportation scenario (from Tables J-4 and J-5)

B = number of transportation casks included in a shipment (set at 1 for both transportation scenarios)

C = number of spent nuclear fuel assemblies in a transportation cask (from Table J-3)

D = amount of uranium in the spent nuclear fuel assembly prior to reactor irradiation in metric tons uranium per assembly (from Table J-13)

E = involved worker-specific collective dose in person-rem per metric ton uranium for each fuel type (from Table J-13)

F = involved worker crew size (set at 13 persons for both transportation scenarios; from Table J-14)

J.1.3.1.2 *Radiological Impacts of DOE Spent Nuclear Fuel and High-Level Radioactive Waste Loading Operations*

The methodology used to estimate impacts to workers during loading operations for commercial spent nuclear fuel was also used to estimate impacts of loading operations for DOE spent nuclear fuel and high-level radioactive waste. The exposure factor (person-rem per MTU) for loading boiling-water reactor spent nuclear fuel in truck casks at commercial facilities was used (see Table J-14). The exposure factor for truck shipments of boiling-water reactor spent nuclear fuel was based on a cask capacity of five boiling-water reactor spent nuclear fuel assemblies (about 0.9 MTU or 0.9 MTHM). The analysis used this factor because it would result in the largest estimates for dose per operation.

J.1.3.2 Methods and Approach for Analysis of Impacts from Incident-Free Transportation

The potential exists for human health impacts to workers and members of the public from incident-free transportation of spent nuclear fuel and high level radioactive waste. *Incident-free* transportation means normal accident-free shipment operations during which traffic accidents and accidents in which radioactive materials could be released do not occur (Section J.1.4. discusses accidents). Incident-free impacts could occur from exposure to (1) external radiation in the vicinity of the transportation casks, or (2) transportation vehicle emissions, both during normal transportation.

J.1.3.2.1 *Incident-Free Radiation Dose to Populations*

The analysis used the RADTRAN 5 computer model and program (DIRS 150898-Neuhauser and Kanipe 2000, all; DIRS 155430-Neuhauser, Kanipe, and Weiner 2000, all) to evaluate incident-free impacts for populations. The RADTRAN 5 input parameters used to estimate incident-free impacts are listed in Table J-15. Through extensive review (DIRS 101845-Maheras and Pippen 1995, Section 3 and 4), DOE has determined that this program provides reasonable, but conservative, estimates of population doses for use in the evaluation of risks of transporting radioactive materials, including spent nuclear fuel and high-level radioactive waste. DOE used the previous version, RADTRAN 4, to analyze transportation impacts for other environmental impact statements (for example, DIRS 101802-DOE 1995, Volume 1, Appendix E; DIRS 101816-DOE 1997, Appendixes F and G). RADTRAN 4 was subjected to extensive review (DIRS 101845-Maheras and Pippen 1995, Sections 3 and 4). RADTRAN 5 is an upgrade to RADTRAN 4, and has been validated by comparison with dose measurements (DIRS 153967-Steinman and Kearfott 2000, all). RADTRAN 5 consistently overestimates doses from transported radioactive materials when the results are compared to measured doses. The program and associated database, using population densities from 1990 Census data escalated to 2035, calculated the collective dose to populations that live along transportation routes [within 800 meters (0.5 mile) of either side of the route]. Table J-16 lists the estimated number of people who live within 800 meters of national routes.

Table J-15. Input parameters and parameter values used for the incident-free national truck and rail transportation analysis, except stops.

Parameter	Legal-weight truck transportation	Rail transportation	Legal-weight truck and rail
Package type			Type B shipping cask
Package dimension	5.2 meters[a] long 1.0 meters diameter	5.06 meters long 2.0 meters diameter	
Dose rate			10 millirem per hour, 2 meters from side of vehicle[f]
Number of crewmen	2	5	
Distance from source to crew	3.1 meters[a]	152 meters[b]	
Speed			
Rural	88 km[c,d] per hour	64 km per hour	
Suburban	88 km/hr non-rush hour 44 km/hr rush hour	40 km per hour	
Urban	88 km/hr non-rush hour 44 km/hr rush hour	24 km per hour	
Input for stop doses: see Table J-17			
Number of people per vehicle sharing route	2	3	
Minimum and maximum distances to exposed population			30 meters to 800 meters
Population densities (persons per km^2)[d]			
Rural			(e)
Suburban			(e)
Urban			(e)
One-way traffic count (vehicles per hour)			
Rural	470	1	
Suburban	780	5	
Urban	2,800	5	

a. To convert meters to feet, multiply by 3.2808.
b. Rail crew in transit would be too far and too well shielded from the external cask radiation to receive any dose. This number is not used in the calculation and is provided for information only.
c. To convert kilometers to miles, multiply by 0.62137.
d. Assumes general freight rather than dedicated service.
e. Population densities along transportation routes were estimated using the HIGHWAY and INTERLINE computer programs, then were extrapolated to 2035.
f. The actual (equivalent) input to RADTRAN 5 is 14 millirem per hour at 1 meter (3.3 feet) from the side of the vehicle.

Table J-16. Population within 800 meters (0.5 mile) of routes for incident-free transportation using 2035 population.

Transportation scenario	2035 population
Mostly legal-weight truck	10,400,000
Mostly rail	16,400,000

RADTRAN 5 uses the following information to estimate collective incident-free doses to the public:

- The external radiation dose rate around shipping casks
- The resident population density (number of people per square kilometer) in the census block groups that contain the route (from HIGHWAY or INTERLINE)
- In urban areas, a factor for nonresident population density
- The speed of the vehicle (truck or train)
- The number of shipments that would be transported over each route
- The density of vehicles (number of vehicles per kilometer) sharing the route with the shipment and the average number of people in each vehicle
- Conditions at vehicle stops, which are described in greater detail below.

Most of these parameters were developed using the data listed in Tables J-15 and J-17. The number of shipments that would use a transportation route was developed with the use of the CALVIN computer program discussed in Section J.1.1.1, the DOE Throughput Study (DIRS 100265-CRWMS M&O 1997, Section 6.1.1), data on DOE spent nuclear fuel and high-level radioactive waste inventories in Appendix A, and data from DOE sites (DIRS 104778-Jensen 1998, all). The analysis used CALVIN to estimate the number of shipments from each commercial site. The Throughput Study provided the estimated number of shipments of high-level radioactive waste from the four DOE sites. Information provided by the DOE National Spent Nuclear Fuel Program (DIRS 104778-Jensen 1998, all) and in Appendix A was used to estimate shipments of DOE spent nuclear fuel.

The analysis used a value of 10 millirem per hour at a distance of 2 meters (6.6 feet) from the side of a transport vehicle for the external dose rate around shipping casks. This value is the maximum allowed by regulations of the U.S. Department of Transportation for shipments of radioactive materials [49 CFR 173.441(b)]. Dose rates at distances greater than 2 meters from the side of a vehicle would be less. The dose rate at 30 meters (98 feet) from the vehicle would be less than 0.2 millirem per hour; at a distance of 800 meters (2,600 feet) the dose rate would be less than 0.0002 millirem per hour.

In addition, the analysis used RADTRAN 5 to estimate doses to people closer to the cask than the resident population along the route, and to people who would be exposed for longer periods of time. These populations would include the truck or rail crew, others working near the cask, people in vehicles that share the route with the shipment, members of the public at truck stops, and residents of the area near the truck and rail stops.

The analysis also uses the potential number of people close enough to shipments to be exposed to radiation from the casks. The analysis determined the estimated offlink number of people [those within the 1.6-kilometer (1-mile) region of influence] by multiplying the population densities (persons per square kilometer) in population zones through which a route would pass by the 1.6-kilometer width of the region of influence and by the length of the route through the population zones. Onlink populations (those sharing the route and people at stops along the route) were estimated using assumptions from other EISs that have evaluated transportation impacts (DIRS 101802-DOE 1995, Volume 1, Appendix I; DIRS 101812-DOE 1996, Appendix E; DIRS 101816-DOE 1997, Appendixes F and G). The travel distance in each population zone was determined for legal-weight truck shipments by using the HIGHWAY computer program (DIRS 104780-Johnson et al. 1993, all) and for rail shipments by using the INTERLINE

Table J-17. Input parameter values for stop doses for routine incident-free transportation.

Stop type	Population exposed	Minimum distance (meters)[a]	Maximum distance (meters)[a]	Stop time	Other
		Doses to the public			
People at truck stops	6.9[b]	1[b]	15.8[b]	20 min[b]	845 km[c] between stops
Residents near truck stops	Rural, suburban, or urban[d]	30	800	20 min[b]	845 km between stops
Residents near truck walkaround inspections[e]	Rural, suburban, or urban	30	800	10 min	161 km between stops
Residents near rail classification stops	Rural, suburban, or urban	30	800	30 hr[a]	One stop at each end of trip
Residents near rail crew change stops	Rural, suburban, or urban	30	800	0.033 hr/km[b]	
		Occupational stop doses			
Truck crew dose at rest/refuel stops	2	1	15.8	20 min	845 km between stops
Truck crew dose at walkaround inspectons	1	1	1	10 min	161 km between stops
	1	Dose rate = 2 mrem/hr by regulation			
Rail crew dose at classification stops	5	(e)		30 hr	One stop at each end of trip
Rail crew dose at crew change stops	5	Calculated by multiplying the classification stop dose by 0.0018/km: a distance-dependent worker exposure factor[f]			

a. To convert meters to feet, multiply by 3.2808.
b. Derived from DIRS 152084-Griego, Smith, and Neuhauser (1996, all).
c. km = kilometer; to convert kilometers to miles, multiply by 0.62137.
d. Values used in DIRS 152476-Sprung et al. (2000, pp. 3-5 to 3-9, Table 3.3).
e. DIRS 155430-Neuhauser, Kanipe, and Weiner (2000, Appendix B) explains this calculation, which has been incorporated into RADTRAN 5.
f. DIRS 150898-Neuhauser and Kanipe (2000, pp. 51 to 52).

program (DIRS 104781-Johnson et al. 1993, all). These programs used 1990 census block group data to identify where highways and railroads enter and exit each type of population zone, which the analysis used to determine the total lengths of the highways and railroads in each population zone.

The third kind of information—the distances individuals live from the route used in the analysis—is the estimated the number of people who live within 800 meters (about 2,600 feet) of the route. The analysis assumed that population density is uniform in population zones.

The analysis used RADTRAN 5 to calculate exposures for the following groups:

- *Public along the route (Offlink Exposure):* Collective doses for persons living or working within 0.8 kilometer (0.5 mile) on each side of the transportation route.

- *Public sharing the route (Onlink Exposure):* Collective doses for persons in vehicles sharing the transportation route; this includes persons traveling in the same or opposite direction and those in vehicles passing the shipment.

- *Public during stops (Stops):* Collective doses for people who could be exposed while a shipment was stopped en route. For truck transportation, these would include stops for refueling, food, and rest and for brief inspections at regular intervals. For rail transportation, stops would occur in railyards at the beginning and end of each trip, and along the route to switch railcars from inbound trains to outbound trains traveling toward the Yucca Mountain site, and to change train crews and equipment (locomotives).

- *Worker exposure (Occupational Exposure):* Collective doses for truck and rail transportation crew members.
- *Security escort exposure (Occupational Exposure):* Collective doses for security escorts. In calculating doses to workers the analysis conservatively assumed that the maximum number of escorts required by regulations (10 CFR 73.37) would be present for urban, suburban, and rural population zones.

The sum of the doses for the first three categories is the total nonoccupational (public) dose.

The sensitivity analysis in Section J.1.3.2.2.3 evaluates impacts of requiring additional escorts such as escorts in separate vehicles for all parts of every shipment of loaded legal-weight truck casks and two escorts in all areas for rail shipments.

Table J-17 lists input parameter values for doses to public and workers at stops. RADTRAN 5 models stops separately, and does not use the "hours per kilometer of travel" of the RADTRAN 4 model. Documentation for a stop model for dose to the public at truck rest and refueling stops is in DIRS 152084-Griego, Smith, and Neuhauser (1996, all). Models for calculating doses to members of the public who reside near stops, as well as occupational doses, for truck and rail, are in DIRS 152476-Sprung et al. (2000, pp. 8-14 to 8-18). For each model, the analysis includes a population or population density component, a total stop-time component, and the calculation, using RADTRAN 5, of an "hour per kilometer" equivalent for consistency with the unit risk factors listed in Table J-18. The external dose rate from the cask for all stops is 10 millirem per hour at 2 meters (6.6 feet) from the cask.

Unit dose factors were used to calculate incident-free collective doses. The offlink unit risk factors listed in Table J-18 represent the dose that would be received by a population density of one person per square kilometer for one shipment of radioactive material moving a distance of 1 kilometer (0.62 mile) in the indicated population density zone, and reflect the assumption that the dose rate external to shipments of spent nuclear fuel and high-level radioactive waste would be the maximum value allowed by U.S. Department of Transportation regulations—10 millirem per hour at 2 meters (6.6 feet) from the side of the transport vehicle (49 CFR 173.441). The onlink unit risk factors represent the doses that would be received by occupants of vehicles sharing the transportation route with the cargo. There are two kinds of stop dose unit risk factors: one for the resident population near stops, based on a population density of one person per square kilometer, and another for the public at rest and refueling stops, which is independent of population density. The incident-free dose from transporting a single shipment was determined by multiplying the appropriate unit dose factors by corresponding distances in each of the population zones through which the shipment route would pass and by the population density of the zone. The collective dose from all shipments from a site was determined by multiplying the dose from a single shipment by the number of shipments that would be required to transport the site's spent nuclear fuel or high-level radioactive waste to the repository. Collective dose was converted to the estimated number of latent cancer fatalities using conversion factors recommended by the International Commission on Radiological Protection (DIRS 101836-ICRP 1991, p. 22). These values are 0.0004 latent cancer fatality per person-rem for radiation workers and 0.0005 latent cancer fatality per person-rem for the general population.

J.1.3.2.2 *Methods Used To Evaluate Incident-Free Impacts to Maximally Exposed Individuals*

To estimate impacts to maximally exposed individuals, the same kinds of information as those used for population doses (except for population size) were needed. The analysis of doses to maximally exposed individuals used projected exposure times, the distance a hypothetical individual would be from a shipment, the number of times an exposure event could occur, and the assumed external radiation dose

Table J-18. Incident-free dose factors.

Factor		Barge	Heavy-haul truck	Rail	Legal-weight truck
Public					
Off-link[a] [rem per (persons per square kilometer) per kilometer]	Rural	1.72×10^{-7}	6.24×10^{-8}	3.90×10^{-8}	2.98×10^{-8}
	Suburban	1.72×10^{-7}	6.24×10^{-8}	6.24×10^{-8}	3.18×10^{-8}
	Urban	1.72×10^{-7}	6.24×10^{-8}	1.04×10^{-7}	3.18×10^{-8}
On-link[b] (person-rem per kilometer)	Rural		1.01×10^{-4}	1.21×10^{-7}	9.53×10^{-6}[c]
	Suburban		7.94×10^{-5}	1.55×10^{-6}	2.75×10^{-5}
	Urban		2.85×10^{-4}	4.29×10^{-6}	9.88×10^{-5}
Residents near rest/refueling stops (rem per person per kilometer)[d]	Rural		3.96×10^{-9}	1.24×10^{-7}	5.50×10^{-9}
	Suburban		3.96×10^{-9}	1.24×10^{-7}	5.50×10^{-9}
	Urban		3.96×10^{-9}	1.24×10^{-7}	5.50×10^{-9}
Residents near classification stops (rem per person per square kilometer)	Suburban			1.59×10^{-5}	
Public including workers at rest/ refueling stops (person-rem per kilometer)					7.86×10^{-6}
Workers					
Classification stops (person-rem)				8.07×10^{-3}	
In-transit rail stops (person-rem per kilometer)				1.45×10^{-5}	
In moving vehicle (person-rem per kilometer)	Rural	2.11×10^{-6}	5.54×10^{-6}		4.52×10^{-5}
	Suburban	2.11×10^{-6}	5.54×10^{-6}		4.76×10^{-5}
	Urban	2.11×10^{-6}	5.54×10^{-6}		4.76×10^{-5}
Walkaround inspection (person-rem per kilometer)			6.27×10^{-7}		1.93×10^{-5}

a. Offlink general population includes persons in the census block groups on the route; the population density in each census block group is assumed to be the population density in the half-mile on either side of the route.
b. Onlink general population included persons sharing the road or railway.
c. Onlink dose factors are larger than offlink because the onlink population (vehicles and persons per vehicle) is included in the dose factor, and because the vehicles are much closer to the radioactive cargo.
d. The methodology, equations, and data used to develop the unit dose factors are discussed in DIRS 152084-Griego, Smith, and Neuhauser (1996, all); DIRS 155430-Neuhauser, Kanipe, and Weiner (2000, Chapter 3); and DIRS 152476-Sprung et al. (2000, Chapter 3).

rate 2 meters (6.6 feet) from a shipment (10 millirem per hour). These analyses used the RISKIND computer program (DIRS 101483-Yuan et al. 1995, all). DOE has used RISKIND for analyses of transportation impacts in other environmental impact statements (DIRS 104382-DOE 1995, Appendix J; DIRS 101812-DOE 1996, Appendix E; DIRS 101816-DOE 1997, Appendix E). RISKIND provides appropriate results for analyses of incident-free transportation and transportation accidents involving radioactive materials (DIRS 101845-Maheras and Pippen 1995, Sections 5.2 and 6.2; DIRS 102060-Biwer et al. 1997, all).

The maximally exposed individual is a hypothetical person who would receive the highest dose. Because different maximally exposed individuals can be postulated for different exposure scenarios, the analysis evaluated the following exposure scenarios.

- *Crew Members.* In general, truck crew members, would receive the highest doses during incident-free transportation (see discussions below). The analysis assumed that the crews would be limited to a total job-related exposure of 2 rem per year (DIRS 156764-DOE 1999, Article 211).

- *Inspectors (Truck and Rail).* Inspectors would be Federal or state vehicle inspectors. On the basis of information provided by the Commercial Vehicle Safety Alliance (DIRS 104597-Battelle 1998, all;

DIRS 156422-CVSA 2001, all), the analysis assumed an average exposure distance of 1 meter (3 feet) and an exposure duration of 1 hour (see discussion in J.1.3.2.2.2).

- *Railyard Crew Member.* For a railyard crew member working in a rail classification yard assembling trains, the analysis assumed an average exposure distance of 10 meters (33 feet) and an exposure duration of 2 hours (DIRS 101816-DOE 1997, p. E-50).

- *Resident.* The analysis assumed this maximally exposed individual is a resident who lives 30 meters (100 feet) from a point where shipments would pass. The resident would be exposed to all shipments along a particular route (DIRS 101802-DOE 1995, Volume 1, Appendix I, p. I-52).

- *Individual Stuck in Traffic (Truck or Rail).* The analysis assumed that a member of the public could be 1.2 meter (4 feet) from the transport vehicle carrying a shipping cask for 1 hour. Because these circumstances would be random and unlikely to occur more than once for the same individual, the analysis assumed the individual to be exposed only once.

- *Resident Near a Rail Stop.* The analysis assumed a resident who lives within 200 meters (660 feet) of a switchyard and an exposure time of 20 hours for each occurrence. The analysis of exposure for this maximally exposed individual assumes that the same resident would be exposed to all rail shipments to the repository (DIRS 101802-DOE 1995, Volume 1, Appendix I, p. I-52).

- *Person at a Truck Service Station.* The analysis assumed that a member of the public (a service station attendant) would be exposed to shipments for 49 minutes for each occurrence at a distance of 16 meters (52 feet) (DIRS 152084-Griego, Smith, and Neuhauser 1996, all). The analysis also assumed this individual would work at a location where all truck shipments would stop.

As discussed above for exposed populations, the analysis converted radiation doses to estimates of radiological impacts using dose-to-risk conversion factors of the International Commission on Radiological Protection.

J.1.3.2.2.1 Estimation of Incident-Free Maximally Exposed Individuals in Nevada. This section presents the assumptions used to estimate incident-free exposures to maximally exposed individuals in Nevada.

Transporting spent nuclear fuel to the Yucca Mountain site by legal-weight or heavy-haul trucks would require transport through Nevada on existing roads and highways. The proximity of existing structures that could house a maximally exposed individual have been determined and the maximally exposed individual identified and potential dose calculated as discussed in Section J.1.3.2.2. DOE considered a number of different sources of information concerning the proximity of the maximally exposed individual to a passing truck carrying spent nuclear fuel or high-level radioactive waste.

- An analysis prepared for the City of North Las Vegas (DIRS 155112-Berger 2000, p. 104) locates the maximally exposed individual 15 meters (50 feet) from an intersection. This individual would be exposed for 1 minute per shipment and an additional 30 minutes per year due to traffic delays. DOE believes the conditions listed greatly exceed actual conditions that would be encountered. Nevertheless, the estimated dose to this maximally exposed individual would be 530 millirem over 24 years.

- DOE performed a survey to determine the location of and proximity to the proposed routes that identified potential maximally exposed individual locations as follows:

  - Residences approximately 5 meters (15 feet) from Highway 93 in Alamo, Nevada (DIRS 155825-Poston 2001, p. 10). The analysis estimated the dose to a maximally exposed individual at this location based on 10,000 heavy-haul truck shipments over 24 years. This estimated dose would be 25 millirem.

- The courthouse and fire station in Goldfield, Nevada, are 5.5 and 4.9 meters (18 and 15 feet), respectively (DIRS 155825-Poston 2001, p. 12) from the road. The analysis estimated the dose to maximally exposed individuals at this location assuming potential exposure to 10,000 heavy-haul truck shipments over 24 years. The estimated dose would be 56 millirem.

- The width of the cleared area for a branch rail line would be 60 meters (200 feet); therefore, the closest resident would be at least 30 meters (98 feet) from a branch rail line. A maximally exposed individual who would be a minimum distance of 30 meters from a branch rail line, assuming 10,000 shipments over 24 years, would receive an estimated dose of 2 millirem.

- The *Intermodal and Highway Transportation of Low-Level Radioactive Waste to the Nevada Test Site* (DIRS 155779-DOE 1999, VI pc-23, Table C-11) identifies the maximally exposed individual as residing between Barstow, California, and the Nevada Test Site approximately 10.7 meters (35 feet) from a highway over 24 years of shipments; this individual would receive an estimated 20 millirem.

As identified above, the maximally exposed individual dose over 24 years for transportation in Nevada would range from 2 to 530 millirem.

J.1.3.2.2.2 Incident-Free Radiation Doses to Inspectors. DOE estimated radiation doses to the state inspectors who would inspect shipments of spent nuclear fuel and high-level radioactive waste originating in, passing through, or entering a state. For legal-weight truck and railcar shipments, the analysis assumed that:

- Each inspection would involve one individual working for 1 hour at a distance of 1 meter (3.3 feet) from a shipping cask.
- The radiation field surrounding the cask would be the maximum permitted by regulations of the U.S. Department of Transportation (49 CFR 173.441).
- There would be no shielding between an inspector and a cask.

For rail shipments, the analysis assumed that:

- There would be a minimum of two inspections per trip—one at origin and one at destination—with additional inspections en route occurring at intermediate stops.
- Rail crews would conduct the remaining along-the-route inspections.

For legal-weight truck shipments, the analysis assumed that:

- On average, state officials would conduct two inspections during each trip – one at the origin and one at the destination.
- The inspectors would use the Enhanced North American Uniform Inspection Procedures and Out-of-Service Criteria for Commercial Highway Vehicles Transporting Transuranics, Spent Nuclear Fuel, and High-Level Radioactive Waste (DIRS 156422-CVSA 2001, all).

- The shipments would receive a Commercial Vehicle Safety Alliance inspection sticker on passing inspection and before departing from the 77 sites.
- Display of such a sticker would provide sufficient evidence to state authorities along a route that a shipment complied with U.S. Department of Transportation regulations (unless there was contradictory evidence), and there would be no need for additional inspections.

The analysis used the RISKIND computer program (DIRS 101483-Yuan et al. 1995, all) to determine doses to state inspectors. The data used by the program to calculate dose includes the estimated value for dose rate at 1 meter (3.3 feet) from a cask surface, the length and diameter of the cask, the distance between the location of the individual and the cask surface, and the estimated time of exposure. For rail shipments, using the assumptions outlined above, the estimated value for whole-body dose to an individual inspector for one inspection would be 17 millirem. Under the mostly rail scenario in which approximately 400 rail shipments would arrive in Nevada annually, a Nevada inspector working 1,800 hours per year could inspect as many as 82 shipments in a year. This inspector would receive a dose of 1.4 rem. If this same inspector inspected 82 shipments per year over the 24 years of the Proposed Action, he or she would be exposed to 34 rem.

The use of the dose-to-risk conversion factors published by the International Commission on Radiation Protection projects this exposure to increase the likelihood of the inspector incurring a fatal cancer. The projection would add 2 percent to the likelihood for fatal cancers from all other causes, increasing the likelihood from approximately 23 percent (DIRS 153066-Murphy 2000, p. 5) to 25 percent.

For shipments by legal-weight truck, the analysis used the RISKIND computer program to estimate doses to inspectors (DIRS 101483-Yuan et al. 1995, all). The data used by the program to calculate dose includes the estimated value for dose rate at 1 meter (3.3 feet) from a cask surface, the length and diameter of the cask, the distance between the location of the individual and the cask surface, and the estimated time of exposure. For this calculation, the analysis assumed that an inspector following Commercial Vehicle Safety Alliance procedures (DIRS 156422-CVSA 2001, all) would work for 1 hour at an average distance of 1 meter (3.3 feet) from the cask. The analysis assumed that a typical legal-weight truck cask would be about 1 meter in diameter and about 5 meters (16 feet) long and that the dose rate 1 meter from the cask surface would be 14 millirem per hour. A dose rate of 14 millirem per hour 1 meter from the surface of a truck cask is approximately equivalent to the maximum dose rate allowed by U.S. Department of Transportation regulations for exclusive-use shipments of radioactive materials (49 CFR 173.441).

Using these data, the RISKIND computer program calculated an expected dose of 18 millirem for an individual inspector. Under the mostly legal-weight truck scenario in which approximately 2,200 legal-weight truck shipments would arrive in Nevada annually, a Nevada inspector working 1,800 hours per year could inspect as many as 450 shipments in a year. This inspector would receive a dose of 8.1 rem. If this same inspector inspected all shipments over the 24 years of the Proposed Action, he or she would be exposed to approximately 200 rem. However, DOE would control worker exposure through administrative procedures (see DIRS 156764-DOE 1999, Article 211). Actual worker exposure would likely be 2 rem per year, or a maximum of 48 rem over 24 years. The use of the dose-to-risk conversion factors published by the International Commission on Radiation Protection projects this exposure to increase the likelihood of this individual contracting a fatal cancer. The projection would add about 2 percent to the likelihood for fatal cancers from all other causes, increasing the likelihood from approximately 23 percent (DIRS 153066-Murphy 2000, p. 5) to 25 percent. As discussed below, however, doses to inspectors likely would be much smaller.

DOE implements radiation protection programs at its facilities where there is the potential for worker exposure to cumulative doses from ionizing radiation. The Department anticipates that the potential for individual whole-body doses such as those reported above would lead an involved state to implement such a radiation protection program. If similar to those for DOE facilities, the administrative control limit on individual dose would not exceed 2 rem per year (DIRS 156764-DOE 1999, Article 211), and the expected maximum exposure for inspectors would be less than 500 millirem per year.

Under the mostly legal-weight truck scenario, the annual dose to inspectors in a state that inspected all incoming legal-weight truck shipments containing spent nuclear fuel or high-level radioactive waste would be as much as 40 person-rem. Over 24 years, the population dose for these inspectors would be about 950 person-rem. This would result in about 0.38 latent cancer fatality (this is equivalent to a 47-percent likelihood that there would be 1 additional latent cancer fatality among the exposed group).

The EIS analysis assumed that shipments would be inspected in the state of origin and in the destination state. If each state required an inspection on entry, the total occupational dose over 24 years of operation for the mostly legal-weight truck scenario would increase from approximately 14,000 person-rem to approximately 21,000 person-rem, resulting in an additional 3 latent cancer fatalities to the occupationally exposed population.

J.1.3.2.2.3 Incident-Free Radiation Doses to Escorts. This section has been moved to Volume IV of this EIS.

J.1.3.2.3 *Vehicle Emission Impacts*

Human health impacts from exposures to vehicle exhaust depend principally on the distance traveled and on the impact factors for fugitive dust and exhaust particulates from truck (including escort vehicles) or rail emissions (DIRS 151198-Biwer and Butler 1999, all; DIRS 155786-EPA 1997, all; DIRS 155780-EPA 1993, all).

The analysis estimated incident-free impacts using unit risk factors that account for fatalities associated with emissions of pollution in urban, suburban, and rural areas by transportation vehicles, including escort vehicles. Because the impacts would occur equally for trucks and railcars transporting loaded or unloaded shipping casks, the analysis used round-trip distances. Escort vehicle impacts were included only for loaded truck shipment miles, but were included for round trips for rail escort cars.

The analysis used risk factors to estimate impacts. The factors considered the effects of population density near highways and railroads. For urban areas, the value used for truck transportation was about 5 latent fatalities per 100 million kilometers traveled (8 latent fatalities per 100 million miles) by trucks and 2 latent fatalities per 10 million kilometers traveled by railcars (3 latent fatalities per 10 million miles). For trucks traveling in suburban and rural areas, the respective risk factors used are about 3 latent fatalities in 100 million kilometers (5 in 100 million miles) and 3 in 10 billion kilometers (5 in 10 billion miles). For railcars traveling in suburban and rural areas, the respective risk factors used are about 9 latent fatalities in 100 million kilometers (1.5 in 10 million miles) and about 8 in 10 billion kilometers (1.5 in 1 billion miles).

Although the analysis estimated human health and safety impacts of transporting spent nuclear fuel and high-level radioactive waste, exhaust and other pollutants emitted by transport vehicles into the air would not measurably affect national air quality. National transportation of spent nuclear fuel and high-level radioactive waste, which would use existing highways and railroads, would average 14.2 million truck kilometers per year for the mostly truck case and 3.5 million railcar kilometers per year from the mostly rail case. The national yearly average for total highway and railroad traffic is 186 billion truck kilometers and 49 billion railcar kilometers (DIRS 148081-BTS 1999, Table 3-22). Spent nuclear fuel and high-level radioactive waste transportation would represent a very small fraction of the total national highway and railroad traffic (0.008 percent of truck kilometers and 0.007 percent of rail car kilometers). In addition, the contributions to vehicle emissions in the Las Vegas air basin, where all truck shipments (an average of five per day) would travel under the mostly legal-weight truck scenario, would be small in comparison to those from other vehicle traffic in the area. The annual average daily traffic on I-15 0.3 kilometer (0.2 mile) north of the Sahara Avenue interchange is almost 200,000 vehicles (DIRS 103405-NDOT 1997, p. 7), about 20 percent of which are trucks (DIRS 104727-Cerocke 1998, all). For these reasons, national transportation of spent nuclear fuel and high-level radioactive waste by truck and rail would not constitute a meaningful source of air pollution along the nation's highways and railroads.

J.1.3.2.4 *Sensitivity of Dose Rate to Characteristics of Spent Nuclear Fuel*

For this analysis, DOE assumed that the dose rate external to all shipments of spent nuclear fuel and high-level radioactive waste would be the maximum value allowed by regulations (49 CFR 173.441). However, the dose rate for actual shipments would not be the maximum value of 10 millirem per hour at 2 meters (6.6 feet) from the sides of vehicles. Administrative margins of safety that are established to compensate for limits of accuracy in instruments and methods used to measure dose rates at the time shipments are made would result in lower dose rates. In addition, the characteristics of spent nuclear fuel and high-level radioactive waste that would be loaded into casks would always be within the limit values allowed by the cask's design and its Nuclear Regulatory Commission certificate of compliance.

For example, DOE used data provided in the *GA-4 Legal-Weight Truck Cask Design Report* (DIRS 101831-General Atomics 1993, pp. 5.5-18 and 5.5-19) to estimate dose rates 2 meters (6.6 feet) from transport vehicles for various characteristics of spent nuclear fuel payloads. Figure J-7 shows ranges of burnup and cooling times for spent nuclear fuel payloads for the GA-4 cask. The figure indicates the characteristics of a typical pressurized-water reactor spent nuclear fuel assembly (see Appendix A). Based on the design data for the GA-4 cask, a shipment of typical pressurized-water reactor spent nuclear fuel would result in a dose rate of about 6 millirem per hour at 2 meters from the side of the transport vehicle, or about 60 percent of the limit established by U.S. Department of Transportation regulations (49 CFR 173.441). Therefore, DOE estimates that, on average, dose rates at locations 2 meters (6.6 feet) from the sides of transport vehicles would be about 50 to 70 percent of the regulatory limits. As a result, DOE expects radiological risks to workers and the public from incident-free transportation to be no more than 50 to 70 percent of the values presented in this EIS.

J.1.4 METHODS AND APPROACH TO ANALYSIS OF ACCIDENT SCENARIOS

J.1.4.1 Accidents in Loading Operations

J.1.4.1.1 *Radiological Impacts of Loading Accidents*

The analysis used information in existing reports to consider the potential for radiological impacts from accidents during spent nuclear fuel loading operations at the commercial and DOE sites. These included a report that evaluated health and safety impacts of multipurpose canister systems (DIRS 104794-CRWMS M&O 1994, all) and two safety analysis reports for onsite dry storage of commercial spent nuclear fuel at independent spent fuel storage installations (DIRS 103449-PGE 1996, all; DIRS 103177-CP&L 1989, all). The latter reports address the handling and loading of spent nuclear fuel assemblies in large casks similar to large transportation casks. In addition, DOE environmental impact statements on the management of spent nuclear fuel and high-level radioactive waste (DIRS 101802-DOE 1995, all; DIRS 101816-DOE 1997, all) provided information on radiological impacts from loading accidents.

DIRS 104794-CRWMS M&O (1994, Sections 3.2 and 4.2) discusses potential accident scenario impacts of four cask management systems at electric utility and other spent nuclear fuel storage sites. This report concentrated on unplanned contact (bumping) during lift-handling of casks, canisters, or fuel assemblies. The two safety analysis reports for independent spent fuel storage installations for commercial spent

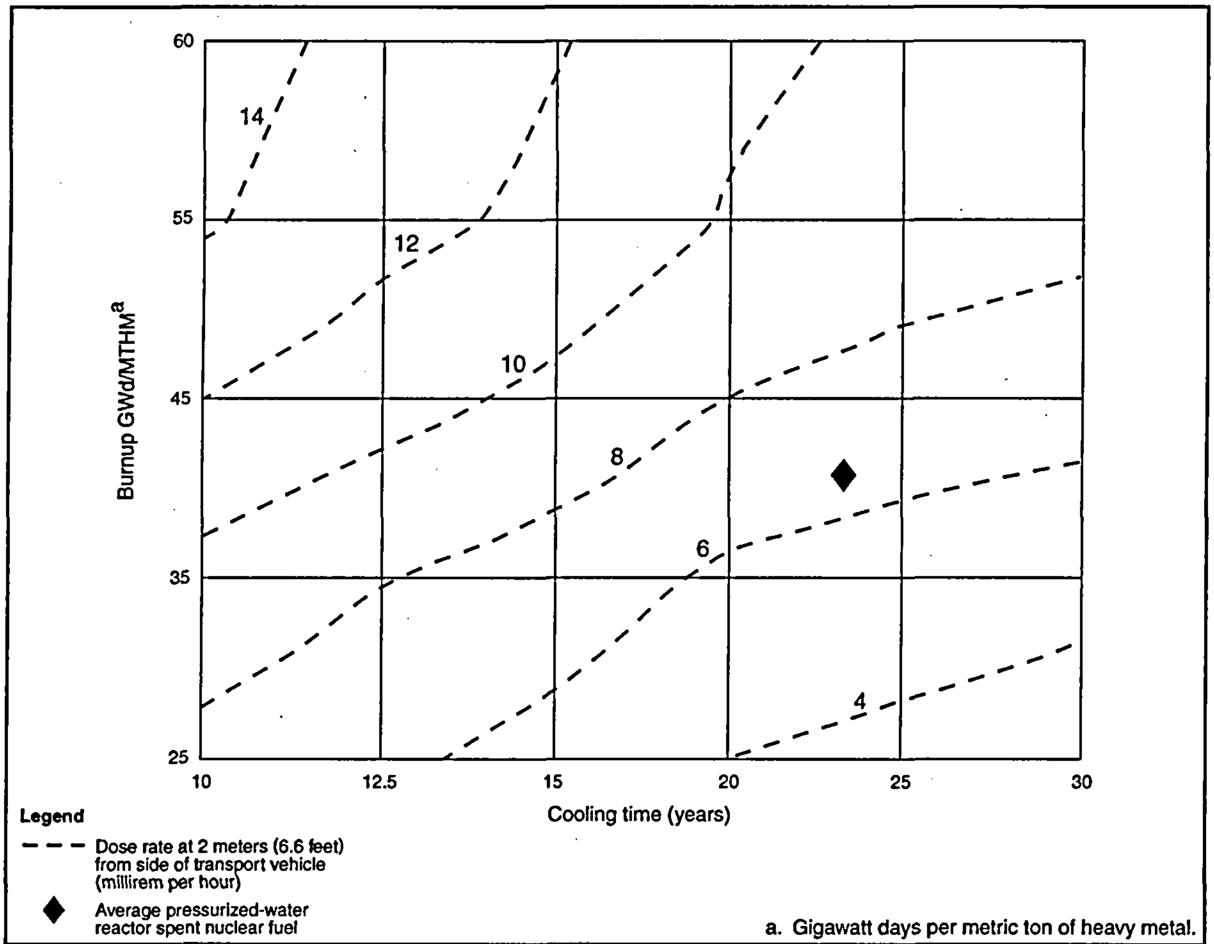


Figure J-7. Comparison of GA-4 cask dose rate and spent nuclear fuel burnup and cooling time.

nuclear fuel (DIRS 103449-PGE 1996, all; DIRS 103177-CP&L 1989, all) evaluated a comprehensive spectrum of accident-initiating events. These events included fires, chemical explosions, seismic events, nuclear criticality, tornado strikes and tornado-generated missile impacts, lightning strikes, volcanism, canister and basket drop, loaded shipping cask drop, and interference (bumping, binding) between the transfer cask and storage module. The DOE environmental impact statements for the interim management of spent nuclear fuel and high-level radioactive waste (DIRS 101802-DOE 1995, Volume 1, Appendix E; DIRS 101816-DOE 1997, Appendixes F and G) included radiological impacts from potential accident scenarios associated with preparing, storing, and shipping these materials. These EISs do not discuss quantitative radiological impacts for accident scenarios associated with material loading, but do contain estimates of radiological impacts from accident scenarios for the spent nuclear fuel and high-level radioactive waste management activities considered. As discussed for routine loading operations, this analysis converted radiation doses to estimates of radiological impacts using dose-to-risk conversion factors of the International Commission on Radiological Protection.

The DIRS 104794-CRWMS M&O (1994, all) study concluded that radiological impacts from handling incidents would be small. The population dose (person-rem) for accidents in handling the four cask systems considered in the study would vary from 0.1 rem to 0.04 rem. This dose would be the total for all persons who would be exposed, onsite workers as well as the public. The highest estimated dose (0.1 person-rem) could result in 0.00005 latent cancer fatality in the exposed population.

J.1.4.1.2 *Industrial Safety Impacts of Loading Operations at Commercial Facilities*

The principal industrial safety impact parameters of importance to commercial industry and the Federal Government are (1) total recordable (injury and illness) cases, (2) lost workday cases associated with workplace injuries and illnesses, and (3) workplace fatalities. The frequency of these impacts under the Proposed Action and the inventory modules (Modules 1 and 2) was projected using the involved worker level of effort, expressed as the number of full-time equivalent worker multiples, that would be needed to conduct shipment tasks. The workplace loss incidence rate for each impact parameter [as shown in a Bureau of Labor Statistics summary (DIRS 148091-BLS 1998, all)] was used as a multiplier to convert the level of effort to expected industrial safety losses.

DOE did not explicitly analyze impacts to noninvolved workers in its earlier reports (DIRS 101747-Schneider et al. 1987, all; DIRS 104791-DOE 1992, all). However, for purposes of analysis in this EIS, DOE estimated that impacts to noninvolved workers would be 25 percent of the impacts to the involved workforce. This assumption is based on (1) the DOE estimate that about one of five workers assigned to a specific task would perform administrative or managerial duties, and (2) the fact that noninvolved worker loss incidence rates are generally less than those for involved workers (see Appendix F, Section F.2.2.2).

The estimated involved worker full-time equivalent multiples for each shipment scenario were estimated using the following formula:

$$\text{Involved worker full-time equivalent multiples} = (A \times B \times C \times D) \div E$$

where: A = number of shipments (from Tables J-5 and J-6)

B = average loading duration for each shipment by fuel type and conveyance mode (workdays; from Table J-13)

C = workday conversion factor = 8 hours per workday

D = involved worker crew size (13 workers; from Table J-14)

E = full-time equivalent conversion factor = 2,000 worker hours per full-time equivalent

The representative Bureau of Labor Statistics loss incidence rate for each total recordable case, lost workday case, and fatality trauma category (for example, the number of total recordable cases per full-time equivalent) was then multiplied by the involved worker full-time equivalent multiples to project the associated incidence. The involved worker total recordable case incidence rate used was that reported for the Trucking and Warehousing sector for 1998 because neither the Nuclear Regulatory Commission nor the Bureau of Labor Statistics maintains data on commercial power reactor industrial safety losses. The total recordable case incidence rate, 145,700 cases in a workforce of 1.74 million workers (8.4 total recordable cases per 100 full-time equivalents), is the averaged loss experience for 1998. The Trucking and Warehousing sector was chosen because DOE assumed the industrial operations and hazards associated with activities in this sector would be representative of those encountered in handling spent nuclear fuel casks at commercial power reactor sites and DOE facilities. Because lost workday cases are linked to the total recordable case experience (that is, each lost workday case would have to be included in the total recordable case category), the same period of record and facilities was used in the selection of the involved worker lost workday case incidence rate [80,800 lost workday cases in a workforce of 1.74 million workers (4.6 lost workday cases per 100 full-time equivalents)].

The involved worker fatality incidence rate reported by the Bureau of Labor Statistics (1.8 fatalities among 100,000 workers) for the Trucking and Warehousing sector during the DIRS 148091-BLS (1998, all) period of record was used.

DOE used the same Bureau of Labor Statistics data sources to estimate total recordable case, lost workday case, and fatality incidence rates for noninvolved workers.

J.1.4.1.3 *Industrial Safety Impacts of DOE Loading Operations*

The technical approach and loss multipliers discussed in Section J.1.4.1.2 for commercial power reactor sites analysis were used for the analysis of spent nuclear fuel and high-level radioactive waste loading impacts at DOE sites. Because no information existed on the high-level radioactive waste loading duration for the truck and rail transportation modes, DOE assumed that the number of full-time equivalent involved workers for the two transportation modes would be the same as that for the DOE sites shipping spent nuclear fuel. For those sites, the average number of full-time equivalent workers would be about 0.07 and 0.12 per shipment for the truck and rail transportation modes, respectively.

J.1.4.2 Transportation Accident Scenarios

J.1.4.2.1 *Radiological Impacts of Transportation Accidents*

Potential consequences and risks of transportation would result from three possible types of accidents: (1) accidents in which there is no effect on the cargo and the safe containment by transportation packages is maintained, (2) accidents in which there is no breach of containment, but there is loss of shielding because of lead shield displacement, and (3) accidents that release and disperse radioactive material from safe containment in transportation packages. Such accidents, if they occurred, would lead to impacts to human health and the environment. The following sections describe the methods for analyzing the risks and consequences of accidents that could occur in the course of transporting spent nuclear fuel and high-level radioactive waste to a nuclear waste repository at the Yucca Mountain site. They discuss the bases for, and methods for, determining rates at which accidents are assumed to occur, the severity of these accidents, and the amounts of materials that could be released. Accident rates, severities, and the corresponding quantities of radioactive materials that could be released are essential data used in the analyses. Appendix A presents the quantities of radioactive materials in a typical pressurized-water reactor spent nuclear fuel assembly used in the analysis of accident consequences and risks. Legal-weight truck casks would usually contain four pressurized-water reactor spent nuclear fuel assemblies, and rail casks would usually contain 24 (see Table J-3).

In addition to accident rates and severities, an important variable in assessing impacts from transportation accident scenarios is the type of material that would be shipped. Accordingly, this appendix presents information used in the analyses of impacts of accidents that could occur in the course of transporting commercial pressurized- and boiling-water reactor fuels, DOE spent nuclear fuels, and DOE high-level radioactive waste.

For exposures to ionizing radiation and radioactive materials following accidents, risks were analyzed in terms of dose and latent cancer fatalities to the public and workers. The analyses of risk also addressed the potential for fatalities that would be the direct result of mechanical forces and other nonradiological effects that occur in everyday vehicle and industrial accidents.

The transportation of spent nuclear fuel and high-level radioactive waste from the 77 sites to the Yucca Mountain site would be conducted in a manner that complied fully with regulations of the U.S. Department of Transportation and Nuclear Regulatory Commission. These regulations specify requirements that promote safety and security in transportation. The requirements apply to carrier

POTENTIAL EFFECTS OF HUMAN ERROR ON ACCIDENT IMPACTS

The accident scenarios described in this chapter would be mostly a direct consequence of error on the part of transport vehicle operators, operators of other vehicles, or persons who maintain vehicles and rights-of-way. The number and severity of the accidents would be minimized through the use of trained and qualified personnel.

Others have argued that other kinds of human error could also contribute to accident consequences: (1) undetected error in the design and certification of transportation packaging (cask) used to ship radioactive material, (2) hidden or undetected defects in the manufacture of these packages, and (3) error in preparing the packages for shipment. DOE has concluded that regulations and regulatory practices of the Nuclear Regulatory Commission and the Department of Transportation address the design, manufacture, and use of transportation packaging and are effective in preventing these kinds of human error by requiring:

- Independent Nuclear Regulatory Commission review of designs to ensure compliance with requirements (10 CFR Part 71)
- Nuclear Regulatory Commission-approved and audited quality assurance programs for design, manufacturing, and use of transportation packages

In addition, Federal provisions (10 CFR Part 21) provide additional assurance of timely and effective actions to identify and initiate corrective actions for undetected design or manufacturing defects. Furthermore, conservatism in the approach to safety incorporated in the regulatory requirements and practices provides confidence that design or manufacturing defects that might remain undetected or operational deficiencies would not lead to a meaningful reduction in the performance of a package under normal or accident conditions of transportation.

operations; in-transit security; vehicles; shipment preparations; documentation; emergency response; quality assurance; and the design, certification, manufacture, inspection, use, and maintenance of packages (casks) that would contain the spent nuclear fuel and high-level radioactive waste.

Because of the high level of performance required by regulations for transportation casks (49 CFR Part 173 and 10 CFR Part 71), the Nuclear Regulatory Commission estimates that in more than 99.99 percent of rail and truck accidents no cask contents would be released (DIRS 152476-Sprung et al. 2000, pp. 7-73 to 7-76). The 0.007 percent of accidents, including those for which there is no release and those that could cause a release of radioactive materials, can be described by a spectrum of accident severity. In general, as the severity of an accident increases, the fraction of radioactive material contents that could be released from transportation casks also increases. However, as the severity of an accident increases it is generally less likely to occur. DIRS 152476-Sprung et al. (2000, all) developed an accident analysis methodology that uses this concept of a spectrum of severe accidents to calculate the probabilities and consequences of accidents that could occur in transporting highly radioactive materials.

The analysis in DIRS 152476-Sprung et al. (2000, pp. 7-74 and 7-76), which DOE adopted for the analysis in the EIS, estimates that 0.01 percent of accidents to steel-lead-steel casks could result in some lead displacement and consequent loss of shielding. The analysis evaluated the radiological impacts (population dose risk) of shielding loss and the impacts of potential releases of radioactive material. The loss-of-shielding analysis included estimates of radiological impacts for the percentage of accidents in which there would be neither loss of shielding nor release of radioactive material. In such accidents, the vehicle carrying the spent nuclear fuel would be stopped along the route for an extended period and nearby residents would not be evacuated.

Although the approach of DIRS 152476-Sprung et al. (2000, pp. 7-7 to 7-12), which is used in this EIS, provides a method for determining the frequency with which severe accidents can be expected to occur, their severity, and their consequences, a method does not exist for predicting where along routes accidents would occur. Therefore, the analyses of impacts presented here used the approach used in RADTRAN 5 (DIRS 155430-Neuhauser, Kanipe, and Weiner 2000, all). This method assumes that accidents could occur at any location along routes, with their frequency of occurrence being determined by the accident rate characteristic of the states through which the route passes, the length of the route, and the number of shipments that travel the route.

The transportation accident scenario analysis evaluated radiological impacts to populations and to hypothetical maximally exposed individuals and estimated fatalities that could occur from traffic accidents. It included both rail and legal-weight truck transportation. The analysis used the RADTRAN 5 (DIRS 150898-Neuhauser and Kanipe 2000, all; DIRS 155430-Neuhauser, Kanipe, and Weiner 2000, all) and RISKIND (DIRS 101483-Yuan et al. 1995, all) models and computer programs to determine accident consequences and risks. DOE has used both codes in recent DOE environmental impact statements (DIRS 101802-DOE 1995, Volume 1, Appendix J; DIRS 101812-DOE 1996, Appendix E; DIRS 101816-DOE 1997, Appendixes F and G) that address impacts of transporting radioactive materials. The analyses used the following information to determine the consequences and risks of accidents for populations:

- Routes from the 77 sites to the repository and their lengths in each state and population zone
- The number of shipments that would be transported over each route
- State-specific accident rates
- The kind and amount of radioactive material that would be transported in shipments
- The type of cask used in spent nuclear fuel and high-level radioactive waste transportation
- Probabilities of amount of lead displacement that would result in loss of shielding
- Probabilities of release and fractions of cask contents that could be released in accidents
- The number of people who could be exposed to radiological material from accidents and how far they lived from the routes
- The length of time people could be exposed to external radiation in accidents that do not involve releases of radioactive material
- Exposure scenarios that include multiple exposure pathways, state-specific agricultural factors, and atmospheric dispersion factors for neutral and stable conditions applicable to the entire country for calculating radiological impacts

The analysis used the same routes and lengths of travel as the analysis of incident-free transportation impacts discussed above.

DOE used the CALVIN computer code discussed earlier, the DOE Throughput Study (DIRS 100265-CRWMS M&O 1997, all), and information provided by the DOE National Spent Nuclear Fuel Program (DIRS 104778-Jensen 1998, all) to calculate the number of shipments from each site and, thus, the number of shipments that would use a particular route.

TRANSPORTATION ACCIDENT RADIOLOGICAL DOSE RISK

The risk to the general public of radiological consequences from transportation accidents is called *dose risk* in this EIS. Dose risk is the sum of the products of the probabilities (dimensionless) and the consequences (in person-rem) of all potential transportation accidents.

The probability of a single accident is usually determined by historical information on accidents of a similar type and severity. The consequences are estimated by analysis of the quantity of radionuclides likely to be released, potential exposure pathways, potentially affected population, likely weather conditions, and other information.

As an example, the dose risk from a single accident that had a probability of 0.001 (1 chance in 1,000), and would cause a population dose of 22,000 person-rem in a population if it did occur, would be 22 person-rem. If that population was subject to 1,000 similar accident scenarios, the total dose risk would be 22,000 person-rem. Using the conversion factor of 0.0005 latent cancer fatality per person-rem, an analysis would estimate a health and safety risk of 11 latent cancer fatalities from this population dose risk.

The state-specific accident rates (accidents and fatalities per kilometer of vehicle travel) used in the analysis included accident statistics for commercial motor carrier operations for the Interstate Highway System, other U.S. highways, and state highways for each of the 48 contiguous states (DIRS 103455-Saricks and Tompkins 1999, all). The analysis also used average accident and fatality rates for railroads in each state. The data specifically reflect accident and fatality rates that apply to commercial motor carriers and railroads.

Appendix A contains information on the radioactive material contents of shipments. Appendix A, Section A.2.1.5 describes the characteristics of the spent nuclear fuel and high-level radioactive waste that would be shipped. The analysis assumed that the inventory of radioactive materials in shipments would be representative pressurized-water reactor spent nuclear fuel that had been removed from reactors for 15 years. Appendix A describes this inventory. The estimated impacts would be less if the analysis used the characteristics of a typical boiling-water reactor spent nuclear fuel, DOE spent nuclear fuel (including naval spent nuclear fuel, which the analysis assumed would be removed from reactors 5 years before its shipment to the repository), or high-level radioactive waste. Section J.1.2.1.1 describes the casks.

The analysis also used the number of people who potentially would be close enough to transportation routes at the time of an accident to be exposed to radiation or radioactive material released from casks, and the distances these people would be from the accidents. It used the HIGHWAY and INTERLINE computer programs to determine this estimated number of people and their distances from accidents. HIGHWAY and INTERLINE used 1990 Census data for this analysis. In addition, the analysis escalated impacts to account for changes in population from 1990 to 2035 using Bureau of the Census projections. The analysis assumed that the region of influence extended 80 kilometers (50 miles) from an accident involving a release of radioactive material, and 800 meters (0.5 mile) on either side of the route for accidents with no release.

Accident Severity Categories and Conditional Probabilities

For accidents involving release of radioactive material, DIRS 152476-Sprung et al. (2000, pp. 7-73 to 7-76) organizes truck and rail accident scenarios according to estimated severity, likelihood of that severity, and releases that might result. Nineteen scenarios for legal-weight truck and 21 scenarios for rail were postulated. Classification matrices were made for four generic casks and pressurized-water and boiling-water reactor commercial spent nuclear fuel types. Figures J-8a and J-8b show the classification matrices for the cask and fuel used in the analysis of impacts presented in this EIS: steel-depleted uranium-steel casks for truck shipments of pressurized-water reactor fuel and steel-lead-steel casks for rail shipments of pressurized-water reactor fuel. Use of data from DIRS 152476-Sprung et al. (2000, pp. 7-73 to 7-76) for other cask types and for boiling-water reactor spent nuclear fuel would lead to smaller impacts.

Figures J-8a and J-8b have been moved to Volume IV of this EIS.

Accident severity is a function of two variables. The first variable is the mechanical force that occurs in impacts. In the figures, mechanical force is represented by the impact velocity along the vertical axis of the matrix. The second variable is thermal energy, or the heat input to a cask engulfed by fire, also along the horizontal axis. Thermal energy is represented by the midpoint temperature of a cask's lead shield wall following heating, as in a fire.

Because all accident scenarios that would involve casks can be described in these terms, the severity of accidents can be analyzed independently of specific accident sequences. In other words, any sequence of events that results in an accident in which a cask is subjected to mechanical forces, within a certain range of values, and possibly fire is assigned to the accident severity category associated with the applicable ranges for the two parameters. This accident severity scheme enables analysis of a manageable number of accident situations while accounting for all reasonably foreseeable transportation accidents, including accidents with low probabilities but high consequences and those with high probabilities but low consequences. The scheme also encompasses by inference all scenarios that result in a particular outcome.

For the analysis of impacts, a conditional probability was assigned to each accident severity category. Figures J-8a and J-8b show the conditional probabilities developed in DIRS 152476-Sprung et al. (2000, pp. 7-73 to 7-76) for the accident severity matrix. These conditional probabilities were used in the analysis of impacts presented in this appendix. The conditional probabilities are the chances that accidents will involve the mechanical forces and the heat energy in the ranges that apply to the categories. For example, accidents that would fall into Cell 19 in the lower left corner of Figure J-8a, which represents the least severe accident in the matrix, would be likely to make up 99.993 percent of all accidents that would involve truck shipments of casks carrying spent nuclear fuel. The mechanical forces and heat in accidents in this category would not exceed the regulatory design standards for casks. Using the information in the figure, in an accident in this category the safety function of the cask would not be lost and the temperature of the cask would not change. These conditions are within the range of damage that would occur to casks subjected to the hypothetical accident conditions tests that Nuclear Regulatory Commission regulations require a cask to survive (10 CFR Part 71). Accidents in Cell 7 or Cell 12, for example, which would cause considerable damage to a cask, are very severe but very infrequent. Cell 7 accidents would occur an estimated 3 times in each 1 trillion truck accidents, and Cell 12 accidents would occur an estimated 2 times in each 100 trillion truck accidents.

The probabilities shown in each cell of Figures J-8a and J-8b are the conditional probabilities derived from event trees (for example, DIRS 152476-Sprung et al. 2000, p. 7-10) that are assigned to each severity category. These conditional probabilities are the chances that, if an accident occurs, that accident will involve the impact speed and the heat energy in the ranges that apply to the categories. The analysis of accident risks presented in this appendix used the frequency that would be likely for accidents in each of the severity categories. This frequency was determined by multiplying the category's conditional probability by the accident rates for each state's urban, suburban, and rural population zones and by the shipment distances in each of these zones, and then adding the results. The accident rates in the population density zones in each state are distinct and correspond to traffic conditions, including average vehicle speed, traffic density, and other factors, including rural, suburban, or urban location.

Accident Releases

To assess radiological consequences, cask release fractions for each accident severity category for each chemically and physically distinct radioisotope were calculated (DIRS 152476-Sprung et al. 2000, Sections 7.3 and 7.4). The *release fraction* of each isotope is the fraction of that isotope in the cask that could be released from the cask in a given severity of accident. Release fractions vary according to spent nuclear fuel type and the physical/chemical properties of the radioisotopes. Almost all of the radionuclides in spent nuclear fuel are chemically stable and do not react chemically when released. All are physically stable and most are in solid form. Gaseous radionuclides, such as krypton-85, could be released if both the fuel cladding and cask containment boundary were compromised. Volatile radionuclides, like radiocesium iodide, could be released in part, and would also deposit on the inside of the cask, depending on the temperature of the cask.

DIRS 152476-Sprung et al. (2000, p. 7-71) developed release fractions for commercial spent nuclear fuel from both boiling-water and pressurized-water reactors. Figures J-8a and J-8b provide examples of these release fractions. The analysis estimated the amount of radioactive material released from a cask in an accident by multiplying the approximate release fraction by the number of fuel assemblies in a cask (see Table J-3) and the radionuclide activity of a spent nuclear fuel assembly (see Appendix A). To provide perspective, the release fraction for a category 6 accident involving a large rail cask carrying 60 assemblies of spent boiling-water reactor fuel could result in an estimated release of about 48 curies of cesium isotopes. For this analysis, the release fractions developed by DIRS 152476-Sprung et al. (2000, pp. 7-73 to 7-76) were used for commercial pressurized-water and boiling-water reactor fuel. In addition, the analysis used release fractions for spent nuclear fuel from training, research and isotope reactors built by General Atomics (commonly called *TRIGA* spent nuclear fuel), aluminum-based fuel, uranium-carbide fuel, and vitrified high-level radioactive waste.

Accidental Loss of Shielding

Under accident conditions, a reduction in the radiation shielding provided by the spent nuclear fuel cask could occur. An accident where shielding is lost or its effectiveness reduced is often referred to as a loss of shielding accident. Shielding could be lost in high-impact collisions, which could cause lead shielding in a cask to slump towards the point of impact, or in a long-duration, intense fire, which could cause lead shielding to melt and expand. As the lead shielding cooled and solidified, it could shrink and possibly leave voids. Puncture of the cask could result in loss of melted lead. Loss of shielding can occur only in casks that use lead as shielding; it cannot occur in casks that use steel or depleted uranium for shielding.

Using the data presented in Table 8.12 from DIRS 152476-Sprung et al. (2000, pp. 8-47 to 8-50), conditional probabilities, radiation dose rates, and an exposure factor for calculating collective dose were developed for 6 accident severity categories that represent a complete spectrum of loss of shielding accidents (see Table J-19) for 4 cask types. The exposure factors were calculated using RADTRAN 5 assuming that a population from 30 to 800 meters (98 to 2,600 feet) was exposed for 12 hours. Unit risk factors were calculated by multiplying the exposure factor by the accident conditional probability. Category 1 represents accidents where there was no loss of shielding and resulting radiation dose rate and exposure factor are for an undamaged cask. This is the only category applicable to steel or depleted uranium casks. Categories 2 through 6 represent accidents that involve various impact speeds and temperatures. Table J-20 shows the relationship of the 6 accident severity categories for loss of shielding presented here to the 21 rail accident cases and 19 truck accident cases discussed in DIRS 152476-Sprung et al. (2000, pp. 7-73 through 7-76).

Table J-19. Loss-of-shielding conditional probabilities, radiation dose rates, and exposure factors for four cask types and six accident severity categories.[a]

Cask type	Conditional probability	Radiation dose rate (rem per hour)[b]	Exposure factor (person-rem per person/km^2)[c]
Steel-lead-steel rail			
Category 1	0.9999	1.4×10^{-2}	3.9×10^{-5}
Category 2	6.4×10^{-6}	8.2	7.2×10^{-3}
Category 3	4.9×10^{-5}	2.4	2.0×10^{-3}
Category 4	4.5×10^{-7}	1.3×10^{1}	1.2×10^{-2}
Category 5	2.4×10^{-5}	2.9	2.4×10^{-3}
Category 6	5.2×10^{-9}	2.4×10^{1}	3.0×10^{-2}
Steel-lead-steel truck			
Category 1	0.9999	1.4×10^{-2}	3.9×10^{-5}
Category 2	4.5×10^{-7}	1.3×10^{1}	7.1×10^{-3}
Category 3	4.9×10^{-5}	2.4	8.5×10^{-4}
Category 4	6.4×10^{-6}	8.2	3.5×10^{-3}
Category 5	2.4×10^{-5}	2.9	1.0×10^{-3}
Category 6	5.2×10^{-9}	2.4×10^{1}	2.2×10^{-2}
Monolithic rail			
Category 1	1.0000	1.4×10^{-2}	3.9×10^{-5}
Category 2	0.0	1.4×10^{-2}	3.9×10^{-5}
Category 3	0.0	1.4×10^{-2}	3.9×10^{-5}
Category 4	0.0	1.4×10^{-2}	3.9×10^{-5}
Category 5	0.0	1.4×10^{-2}	3.9×10^{-5}
Category 6	0.0	1.4×10^{-2}	3.9×10^{-5}
Steel-depleted uranium-steel rail			
Category 1	1.0000	1.4×10^{-2}	3.9×10^{-5}
Category 2	0.0	1.4×10^{-2}	3.9×10^{-5}
Category 3	0.0	1.4×10^{-2}	3.9×10^{-5}
Category 4	0.0	1.4×10^{-2}	3.9×10^{-5}
Category 5	0.0	1.4×10^{-2}	3.9×10^{-5}
Category 6	0.0	1.4×10^{-2}	3.9×10^{-5}

a. Source: Calculated by RADTRAN 5.
b. Radiation dose rate at 1 meter from the cask.
c. km^2 = square kilometer; 1 square kilometer = 0.39 square miles or 247.1 acres.

Table J-20. Grouping of accident cases into accident categories.[a]

Accident category	Rail accident cases	Truck accident cases
Category 1	21	19
Category 2	1, 7, 8, 9	2, 10, 11, 12
Category 3	20	18
Category 4	2, 10, 11, 12	1, 7, 8, 9
Category 5	4, 5, 6	4, 5, 6
Category 6	3, 13, 14, 15, 16, 17, 18, 19	3, 13, 14, 15, 16, 17

a. Source: Adapted from DIRS 152476-Sprung et al. (2000, Table 8.12).

The unit risk factor for a category was multiplied by the shipment distance, the number of shipments, the accident rate, and the population density to yield the radiation dose to the exposed population for the category. The radiation doses for all categories were summed to yield the overall radiation dose from all categories of loss of shielding accidents.

Atmospheric Conditions

For the analyses of accident risk and consequences, releases of radioactive materials from casks during and following severe accidents were assumed to be into the air where these materials would be carried by wind. Because it is not possible to predict specific locations where transportation accidents would occur, average U.S. atmospheric conditions were used.

RADTRAN 5, which DOE used in the analysis, contains embedded tables giving the "footprint" of the dispersed plume in curves of constant concentration, called isopleths, for each of the six Pasquill stability classes (DIRS 155430-Neuhauser, Kanipe, and Weiner 2000, Chapter 4). These tables incorporate wind speed, downwind distance, area of the footprint, and dilution of the plume. Dispersion of releases from an accident are then modeled by combining these tables to represent national average weather conditions. The RADTRAN 5/database combination was then used in the analysis to calculate an accident *dose risk* incorporating the risk from inhaled and ingested radioactive material, and external radiation from radioactive material deposited on the ground and suspended in the air.

Table J-21 lists the frequency at which atmospheric stability and wind speed conditions occur in the contiguous United States. The data, which are averages for 177 meteorological data collection locations, were used in conjunction with the RADTRAN 5/database to calculate the population (collective) dose risk from any accident, as well as with the RISKIND computer program (DIRS 101483-Yuan et al. 1995, all). RISKIND was used to estimate the consequences of maximum reasonably foreseeable accidents and acts of sabotage.

Table J-21. Frequency of atmospheric and wind speed conditions – U.S. averages.[a]

Atmospheric stability class	Wind speed condition						
	WS(1)	WS(2)	WS(3)	WS(4)	WS(5)	WS(6)	Total
A	0.00667	0.00444	0.00000	0.00000	0.00000	0.00000	0.01111
B	0.02655	0.02550	0.01559	0.00000	0.00000	0.00000	0.06764
C	0.01400	0.02931	0.05724	0.01146	0.00122	0.00028	0.11351
D	0.03329	0.07231	0.15108	0.16790	0.03686	0.01086	0.47230
E	0.00040	0.04989	0.06899	0.00146	0.00016	0.00003	0.12093
F	0.10771	0.08710	0.00110	0.00000	0.00000	0.00000	0.19591
G	0.01713	0.00146	0.00000	0.00000	0.00000	0.00000	0.01859
F+G	0.12485	0.08856	0.00110	0.00000	0.00000	0.00000	0.21451
Totals	*0.20576*	*0.27000*	*0.29401*	*0.18082*	*0.03825*	*0.01117*	*1.00000*
Wind speed (meters per second)[b]	0.89	2.46	4.47	6.93	9.61	12.52	

a. Source: DIRS 104800-CRWMS M&O (1999, p. 40).
b. To convert meters per second to miles per hour, multiply by 2.237.

In calculating estimated values for consequences, RISKIND used the atmospheric stability and wind speed data to analyze the dispersion of radioactive materials in the atmosphere that could follow releases in severe accidents. Using the results of the dispersion analysis, RISKIND calculated values for radiological consequences (population dose and dose to a maximally exposed individual). These results were placed in order from largest to smallest consequence. Following this order, the probabilities of the atmospheric conditions associated with each set of consequences were incorporated to provide a cumulative probability. This procedure was followed to identify the most severe accident consequences that would have a cumulative estimated annual frequency of occurrence of at least 1 in 10 million. The procedure was carried out separately for urban and rural accidents and for neutral and stable atmospheric conditions.

Exposure Pathways

Radiation doses from released radioactive material were calculated for an individual who is postulated to be near the scene of an accident and for populations within 80 kilometers (50 miles) of an accident location. Doses were determined for rural, suburban, and urban population groups. Dose calculations considered a variety of exposure pathways, including inhalation and direct exposure (cloudshine and immersion in a plume of radioactive material) from a passing cloud of contaminants; ingestion from contaminated crops; direct exposure from radioactivity deposited on the ground (groundshine); and inhalation of radioactive particles resuspended by wind from the ground.

Emergency Response, Interdiction, Dose Mitigation, and Evacuation

The RADTRAN 5 computer program that DOE used to estimate radiological risks allows the user to include assumptions about the postaccident remediation of radioactive material contamination of land where people live. The analysis using the program assumed that, after an accident, contaminants would continue to contribute to population dose through three pathways—groundshine, inhalation of resuspended particulates, and, for accidents in rural areas, ingestion of foods produced on the contaminated lands. It also assumed that medical and other interdiction would not occur to reduce concentrations of radionuclides absorbed or deposited in human tissues as a result of accidents.

For a discussion of emergency response to transportation accidents, see Appendix M, Section M.5.

Similarly, the RISKIND (DIRS 101483-Yuan et al. 1995, all) computer program includes assumptions about response, interdiction, dose mitigation, and evacuation for calculating radiological consequences (dose to populations and maximally exposed individuals). In estimating consequences of maximum reasonably foreseeable accidents during the transportation of spent nuclear fuel and high-level radioactive waste to the repository, the analysis assumed the following:

- Populations would continue to live on contaminated land for 1 year.
- There would be no radiological dose to populations from ingestion of contaminated food. Food produced on land contaminated by a maximum reasonably foreseeable accident would be embargoed from consumption.
- Medical and other interdiction would not occur to reduce concentrations of radionuclides absorbed or deposited in human tissues as a result of an accident.

The analysis of a maximum foreseeable loss-of-shielding accident assumed that the vehicle would be stopped at the site of the accident for 12 hours.

Emergency management personnel (first responders) would be between 2 and 10 meters (6.6 and 33 feet) from the vehicle for about an hour to secure the vehicle and keep people away. For about half of this time, the emergency personnel would be exposed to that section of the cask where shielding had been lost.

The analysis of radiological risks to populations and estimates of consequences of maximum reasonably foreseeable accidents did not explicitly address local, difficult-to-evacuate populations such as those in prisons, hospitals, nursing homes, or schools. However, the analysis addressed the potential for accidents to occur in urban areas with high population densities and used the assumptions regarding interdiction, evacuation, and other intervention actions discussed above. These assumptions encompass the consequences and risks that could arise as a result of time to implement measures to mitigate the consequences for some population groups.

Health Risk Conversion Factors

The health risk conversion factors used to estimate expected latent cancer fatalities from radiological exposures are presented in International Commission on Radiological Protection Publication 60 (DIRS 101836-ICRP 1991, p. 22). These factors are 0.0005 latent cancer fatality per person-rem for members of the public and 0.0004 latent cancer fatality per person-rem for workers. For accidents in which individuals would receive doses greater than 20 rem over a short period (high dose/high dose rate), the factors would be 0.0010 latent cancer fatality per rem for a member of the public and 0.0008 latent cancer fatality per rem for workers.

Assessment of Accident Risk

The RADTRAN 5 database (DIRS 155430-Neuhauser, Kanipe, and Weiner 2000, all) was used in calculating risks from transportation of spent nuclear fuel and high-level radioactive waste. The code calculated unit-risk factors (person-rem per person per square kilometer per curie) for the radionuclides of concern in the inventory being shipped (see Appendix A). The unit-risk factors from RADTRAN 5 were combined with conditional accident probabilities, state-specific accident rates, release fractions for each of the six accident severity categories, for each mode of transportation, cask, and spent nuclear fuel or high-level radioactive waste form. For each site traversed, results of this analysis were combined with urban, suburban, and rural distances and population densities, and with the number of shipments. Ingestion dose risks were calculated separately by combining conditional accident probabilities, state-specific accident rates, release fractions for each of the six accident severity collective categories, and rural distances and numbers of shipments for each state with the state-specific food transfer factors. The accident dose risks were estimated in terms of collective radiation dose to the population within 80 kilometers (50 miles).

The analysis first calculated unit risk factors for a shipment. This was done for the three types of population zones in each state and for each accident severity category. The unit risk factors were for one person per square kilometer per kilometer of route traveled. The unit risk factors were multiplied by the population densities (based on 1990 Census data) along the routes. These population densities are modeled as being within 800 meters (0.5 mile) of the routes. The accident dose risk calculation then assumed that the population density in the 800-meter band along the route is the same out to 80 kilometers (50 miles) from the route and multiplies the unit risk factor by this population density, yielding a dose risk in person-rem per kilometer of route for each transportation mode, for each type of impact, and for each state through which a shipment would pass. The resultant dose risks (person-rem per kilometer) for all the applicable accident severity categories were summed for each population zone for each state. Also, for the three types of population zone in a state, the lengths through areas of each type were summed for the route used in the analysis. This yielded route lengths for each population zone in each state. The sum of the route lengths and the sum of the dose risks per kilometer for each population zone were multiplied together. This was repeated for each population zone in each state through which a shipment would pass. The resulting impacts were then multiplied by a scaling factor that is the ratio of the population in a state based on the 1990 Census to projected population in 2035. The results were summed to provide estimates of the accident dose risk (in person-rem) for a shipment.

Estimating Consequences of Maximum Reasonably Foreseeable Accident Scenarios

In addition to analyzing the radiological and nonradiological risks that would result from the transportation of spent nuclear fuel and high-level radioactive waste to the repository, DOE assessed the consequences of maximum reasonably foreseeable accidents using the analysis from DIRS 152476-Sprung et al. (2000, pp. 7-30 to 7-70) for releases of material from a spent nuclear fuel cask during an accident. This analysis provided information about the magnitude of impacts that could result from the most severe accident that could reasonably be expected to occur, although it could be highly unlikely. DOE concluded that, as a practical matter, events with a probability less than 1×10^{-7} (1 chance in 10 million) per year rarely need to be examined (DIRS 104601-DOE 1993, p. 28). This would be equivalent to about once in the course of 15 billion legal-weight truck shipments. For perspective, an accident this severe in commercial truck transportation would occur about once in 50 years on U.S. highways. Thus, the analysis of maximum reasonably foreseeable accidents postulated to occur during the transportation of spent nuclear fuel and high-level radioactive waste evaluated only consequences for accidents with a probability greater than 1×10^{-7} per year. The consequences were determined for atmospheric conditions that could prevail during accidents and for physical and biological pathways that would lead to exposure of members of the public and workers to radioactive materials and ionizing radiation. The analysis used the RISKIND code (DIRS 101483-Yuan et al. 1995, all) to estimate doses for individuals and populations. In addition to the accidents with a probability greater than 1×10^{-7} per year, the analysis estimated the consequences from all accident severity categories presented in DIRS 152476-Sprung et al. (2000, pp. 7-73 and 7-76) for a steel-depleted uranium-steel truck cask and a steel-lead-steel rail cask. The following list describes those severity categories:

Rail Accident Descriptions

- *Case 20:* Case 20 is a long-duration (many hours), high-temperature fire that would engulf a cask. Conditions reported in the Baltimore Sun Times for the Baltimore Tunnel Fire (DIRS 156753-Ettlin 2001, all; DIRS 156754-Rascovar 2001, all), which occurred in July 2001—a fire of 820°C (1,500°F) that burned for up to 5 days—would be similar to the conditions for a Case 20 accident.

- *Cases 19, 18, 17, and 16:* Case 19 is a high-speed (more than 120 miles per hour) impact into a hard object such as a train locomotive severe enough to cause failure of cask seals and puncture through the cask's shield wall. The impact would be followed by a very long duration (many hours), high-temperature engulfing fire. Case 18, Case 17, and Case 16 are accidents that would also involve very long duration fires, failures of cask seals, and puncture of cask walls. However, these accidents would be progressively less severe in terms of impact speeds. The impact speeds range from 90 to 120 miles for Case 18, 60 to 90 miles per hour for Case 17, and 30 to 60 miles per hour for Case 16.

- *Cases 15, 12, 9, and 6:* Case 15 is a high-speed (more than 120 miles per hour) impact into a hard surface such as granite severe enough to cause failure of cask seals. The impact would be followed by a long duration (many hours), high-temperature engulfing fire. Case 12, Case 9, and Case 6 are also accidents that would involve long duration fires, and failures of cask seals. However, these accidents would be progressively less severe in terms of impact speeds ranging from 90 to 120 miles for Case 12, 60 to 90 miles per hour for Case 9, and 30 to 60 miles per hour for Case 6.

- *Cases 14, 11, 8, and 5:* Case 14 is a high-speed (more than 120 miles per hour) impact into a hard surface such as granite severe enough to cause failure of cask seals. The impact would be followed by a high-temperature engulfing fire that burned for hours. Case 11, Case 8, and Case 5 are also accidents that would involve fires that would burn for hours, and failures of cask seals. However, these accidents would be progressively less severe in terms of impact speeds ranging from 90 to 120 miles for Case 11, 60 to 90 miles per hour for Case 8, and 30 to 60 miles per hour for Case 5.

- *Cases 13, 10, 7, and 4:* Case 13 is a high-speed (more than 120 miles per hour) impact into a hard surface such as granite severe enough to cause failure of cask seals. The impact would be followed by an engulfing fire lasting more than ½ hour up to a few hours. Case 10, Case 7, and Case 4 are accidents that would involve long duration fires, and failures of cask seals. However, these accidents are progressively less severe in terms of impact speeds ranging from 90 to 120 miles for Case 10, 60 to 90 miles per hour for Case 7, and 30 to 60 miles per hour for Case 4. An accident involving the impact of a jet engine from a passenger aircraft on a rail cask would be no more severe than a Case 4 accident (DIRS 157210-BSC 2001, all).

- *Cases 3, 2, and 1:* Case 3 is a high-speed (more than 120 miles per hour) impact into a hard surface such as granite severe enough to cause failure of cask seals—no fire. Case 2 and Case 1 are accidents that would also not involve fire but would have progressively lower impact speeds - 90 to 120 miles for Case 2 and 60 to 90 miles per hour for Case 1.

Truck Accident Descriptions

- *Case 18:* Case 18 is a long-duration (many hours), high-temperature fire that would engulf a cask. Conditions reported in the Baltimore Sun Times for the Baltimore Tunnel Fire (DIRS 156753-Ettlin 2001, all; DIRS 156754-Rascovar 2001, all), which occurred in July 2001—a fire of 820°C (1,500°F) that burned for up to 5 days—would be similar to the conditions for a Case 18 accident.

- *Cases 17, 16, 15, and 14:* Case 17 is a high-speed (more than 120 miles per hour) impact into a hard object such as a train locomotive severe enough to cause failure of cask seals and puncture through the cask's shield wall. The impact would be followed by a very long duration (many hours), high-temperature engulfing fire. Case 16, Case 15, and LST 14 are accidents that would also involve very long duration fires, failures of cask seals, and puncture of cask walls. However, these accidents would be progressively less severe in terms of impact speeds. The impact speeds range from 90 to 120 miles for Case 16, 60 to 90 miles per hour for Case 15, and 30 to 60 miles per hour for Case 14.

- *Cases 13, 10, 7, and 4:* Case 13 is a high-speed (more than 120 miles per hour) impact into a hard surface such as granite severe enough to cause failure of cask seals. The impact would be followed by a long duration (many hours), high-temperature engulfing fire. Case 10, Case 7, and Case 4 are also accidents that would involve long duration fires, and failures of cask seals. However, these accidents would be progressively less severe in terms of impact speeds ranging from 90 to 120 miles for Case 10, 60 to 90 miles per hour for Case 7, and 30 to 60 miles per hour for Case 4.

- *Cases 12, 9, 6, and 3:* Case 12 is a high-speed (more than 120 miles per hour) impact into a hard surface such as granite severe enough to cause failure of cask seals. The impact would be followed by a high-temperature engulfing fire that burned for hours. Case 9, Case 6, and Case 3 are also accidents that would involve fires that would burn for hours, and failures of cask seals. However, these accidents would be progressively less severe in terms of impact speeds ranging from 90 to 120 miles for Case 9, 60 to 90 miles per hour for Case 6, and 30 to 60 miles per hour for Case 3.

- *Cases 11, 8, 5, and 2:* Case 11 is a high-speed (more than 120 miles per hour) impact into a hard surface such as granite severe enough to cause failure of cask seals. The impact would be followed by an engulfing fire lasting more than ½ hour up to a few hours. Case 8, Case 5, and Case 2 are accidents that would involve long duration fires, and failures of cask seals. However, these accidents are progressively less severe in terms of impact speeds ranging from 90 to 120 miles for Case 8, 60 to 90 miles per hour for Case 5, and 30 to 60 miles per hour for Case 2. An accident involving the impact of a jet engine from a passenger aircraft on a truck cask would be no more severe than any Case 11 accident (DIRS 157210-BSC 2001, all).

- *Case 1:* Case 1 is a high-speed (more than 120 miles per hour) impact into a hard surface such as granite severe enough to cause failure of cask seals—no fire.

The analysis assumed maximum reasonably foreseeable accident scenarios could occur anywhere, either in rural or urbanized areas. The probability of such an accident would depend on the amount of exposure to the transportation accident environment. In this case, exposure would be the product of the cumulative shipment distance and the applicable accident rates. However, because of large differences in exposure, principally because of the large differences in the distances traveled in the two types of population areas, a severe accident scenario that might be reasonably foreseeable in a rural area might not be reasonably foreseeable in an urbanized area. Thus, a reasonably foreseeable accident postulated to occur in a rural area (most travel would occur in rural areas), under meteorological conditions that would be exceeded (resulting in greater consequences) only 5 percent of the time, might not be reasonably foreseeable in an urbanized area where shipments would travel relatively few kilometers. Table J-22 lists the probabilities and consequences of severe rail cask accidents during national transportation based on the analysis of releases from spent fuel casks presented in DIRS 152476-Sprung et al. (2000, pp. 7-75 to 7-76) for urban

Table J-22. Frequency and consequence of rail accidents.[a]

Rail cask					
Case	Expected frequency	Total exposure (person-rem)	Case	Expected frequency	Total exposure (person-rem)
Urban Area - Stability Class F			Rural Area - Stability Class F		
19	7.67×10^{-19}	254,377	19	4.71×10^{-18}	419
15	7.67×10^{-16}	254,377	15	4.71×10^{-15}	419
14	5.77×10^{-15}	242,817	14	3.54×10^{-14}	400
13	2.07×10^{-13}	230,214	13	1.27×10^{-12}	379
16	2.32×10^{-12}	220,788	16	1.43×10^{-11}	364
3	2.51×10^{-11}	219,698	3	1.54×10^{-10}	361
18	9.74×10^{-17}	173,447	18	5.99×10^{-16}	285
12	9.74×10^{-14}	173,447	12	5.99×10^{-13}	285
11	7.34×10^{-13}	171,358	11	4.51×10^{-12}	282
6	6.16×10^{-10}	159,807	6	3.78×10^{-9}	264
10	2.62×10^{-11}	149,279	10	1.61×10^{-10}	246
2	3.18×10^{-9}	149,266	2	1.95×10^{-8}	245
17	1.41×10^{-15}	112,468	17	8.63×10^{-15}	185
9	1.41×10^{-12}	81,049	9	8.63×10^{-12}	134
20	2.75×10^{-7}	9,893	20	1.69×10^{-6}	16.3
8	1.05×10^{-11}	3,416	8	6.47×10^{-11}	5.63
7	3.79×10^{-10}	3,060	7	2.33×10^{-9}	5.04
1	4.59×10^{-8}	2,933	1	2.82×10^{-7}	4.83
5	4.61×10^{-9}	1,745	5	2.83×10^{-8}	2.88
4	1.66×10^{-7}	1,346	4	1.02×10^{-6}	2.22

a. Source: DIRS 152476-Sprung et al. (2000, p. 7-75).

area and rural area population and stability class F weather conditions. Stability class D consequences were analyzed but, because the consequences are smaller than those of class F stability conditions, they are not presented. Similarly, Table J-23 lists the probabilities and consequences of severe truck accidents for stability class F conditions.

For the mostly rail scenario, legal-weight truck accidents would not be reasonably foreseeable. For rail accidents, the severity case, which is reasonably foreseeable and would have the greatest consequences, is Case 20 with an expected frequency of 2.8×10^{-7} and consequences of 9,900 person-rem.

For the mostly legal-weight truck scenario, in which only naval spent nuclear fuel would be shipped by rail, the likelihood would be less than 1×10^{-7} per year for the most severe rail accident to occur in an urbanized area. Thus, the highest severity rail accidents would only be reasonably foreseeable in rural areas under average (50-percent) meteorological conditions (probability greater than 1 in 10 million per year). For truck accidents in urban areas, the severity case, which is reasonably foreseeable and has the greatest consequences, is Case 18 with an expected frequency of 2.3×10^{-7} and consequences of 1,100 person-rem.

The analysis of maximum reasonably foreseeable accidents evaluated all the accidents for steel-depleted uranium-steel truck and steel-lead-steel rail casks from DIRS 152476-Sprung et al. (2000, pp. 7-73 and 7-76). However, only accidents from Tables J-22 and J-23 that have an expected frequency greater than 1×10^{-7} would be reasonably foreseeable.

Table J-24 summarizes the accidents with the greatest consequences that would be reasonably foreseeable. Although stability class D accidents are reasonably foreseeable, the consequences from stability class F accidents would be greater as listed in Table J-24.

Table J-23. Frequency and consequence of truck accidents.[a]

Truck cask					
Case	Expected frequency	Total exposure (person-rem)	Case	Expected frequency	Total exposure (person-rem)
Urban Area - Stability Class F			Rural Area - Stability Class F		
14	2.8×10^{-12}	36,798	14	1.6×10^{-11}	60.7
15	1.3×10^{-16}	18,919	15	7.6×10^{-16}	31.1
4	2.8×10^{-9}	8,484	4	1.6×10^{-8}	14
7	1.3×10^{-13}	5,203	7	7.6×10^{-13}	8.57
12	9.8×10^{-16}	1,251	12	5.5×10^{-15}	2.07
9	7.7×10^{-14}	1,251	9	4.4×10^{-13}	2.07
11	6.0×10^{-12}	1,146	11	3.4×10^{-11}	1.88
8	4.7×10^{-10}	1,146	8	2.7×10^{-9}	1.88
1	6.2×10^{-10}	1,125	1	3.5×10^{-9}	1.85
18	2.3×10^{-7}	1,083	18	1.3×10^{-6}	1.79
6	3.7×10^{-12}	723	6	2.1×10^{-11}	1.19
5	2.0×10^{-8}	581	5	1.1×10^{-7}	0.92
3	1.1×10^{-8}	291	3	6.4×10^{-8}	0.48
2	2.5×10^{-6}	225	2	1.4×10^{-5}	0.37
17	0	N/A[b]	17	0	N/A[b]
16	0	N/A	16	0	N/A
13	0	N/A	13	0	N/A
10	0	N/A	10	0	N/A

a. Source: DIRS 152476-Sprung et al. (2000, p. 7-74).
b. N/A = not applicable, because probability is zero.

Table J-24. Consequences (person-rem) of maximum reasonably foreseeable accidents in national transportation.[a]

Case	Urban (person-rem)	Rural (person-rem)	MEI (rem)[b]
Rail (Case 20)	9,893	16	29
Truck (Case 18)	1,083	2	3

a. All accidents are modeled in with stability class F conditions.
b. MEI = maximally exposed individual.

The analysis of consequences of maximum reasonably foreseeable accidents used data from the 1990 census escalated to 2035 to estimate the size of populations in urbanized areas that could receive exposures to radioactive materials. The analysis used estimated populations in successive 8-kilometer (5-mile)-wide annular rings around the centers of the 21 large urbanized areas (cities and metropolitan areas) in the continental United States (DIRS 104800-CRWMS M&O 1999, p. 22).

The average population for each ring was used to form a population distribution for use in the analysis. To be conservative in estimating consequences, the analysis assumed that accidents in urbanized areas would occur at the center of the population zone, where the population density would be greatest. This assumption resulted in conservative estimates of collective dose to exposed populations.

J.1.4.2.2 *Methods and Approach for Analysis of Nonradiological Impacts of Transportation Accidents*

Nonradiological accident risks are risks of traffic fatalities. Traffic fatality rates are reported by state and Federal transportation departments as fatalities per highway vehicle- or train-kilometer traveled. The fatalities are caused by physical trauma in accidents. For nonradiological accident risks estimated in this

EIS for legal-weight truck transportation, accident fatality risks were based on state-level fatality rates for Interstate Highways (DIRS 103455-Saricks and Tompkins 1999, all). Accident fatality risks for rail transportation were also calculated using state-specific rates (DIRS 103455-Saricks and Tompkins 1999, all). Section J.2.2 discusses methods and data used to analyze accidents for barge transportation.

For truck transportation, the rates in DIRS 103455-Saricks and Tompkins (1999, Table 4) are specifically for heavy combination trucks involved in interstate commerce. Heavy combination trucks are multiaxle tractor-trailer trucks having a tractor and one to three freight trailers connected to each other. This kind of truck with a single trailer would be used to ship spent nuclear fuel and high-level radioactive waste. Truck accident rates were determined for each state based on statistics compiled by the U.S. Department of Transportation Office of Motor Carriers for 1994 through 1996. The report presents accident involvement and fatality counts, estimated kilometers of travel by state, and the corresponding average accident involvement, fatality, and injury rates for the 3 years investigated. Fatalities include crew members and all others attributed to accidents. Although escort vehicles would not be heavy combination trucks, the fatality rate data used for truck shipments of loaded and empty spent fuel casks were also used to estimate fatalities from accidents that would involve escort vehicles.

Rail accident rates were computed and presented similarly to truck accident rates, but a railcar is the unit of haulage. The state-specific rail accident involvement and fatality rates are based on statistics compiled by the Federal Railroad Administration for 1994 through 1996. Rail accident rates include both mainline accidents and those occurring in railyards. The per-railcar rate in DIRS 103455-Saricks and Tompkins (1999, Table 6) was multiplied by 4.2, the average number of railcars involved in an accident.

The accident rates used to estimate traffic fatalities were computed using data for all interstate shipments, independent of the cargoes. Shippers and carriers of radioactive material generally have a higher-than-average awareness of transport risk and prepare cargoes and drivers accordingly (DIRS 101920-Saricks and Kvitek 1994, all). These effects were not given credit in the assessment.

J.1.4.2.3 *Data Used To Estimate Incident Rates for Rail and Motor Carrier Accidents*

In analyzing potential impacts of transporting spent nuclear fuel and high-level radioactive waste, DOE considered both incident-free transportation and transportation accidents. Potential incident-free transportation impacts would include those caused by exposing the public and workers to low levels of radiation and other hazards associated with the normal movement of spent nuclear fuel and high-level radioactive waste by truck, rail, or barge. Impacts from accidents would be those that could result from exposing the public and workers to radiation, as well as vehicle-related fatalities.

In its analysis of impacts from transportation accidents, DOE relied on data collected by the U.S. Department of Transportation and others (for example, the American Petroleum Institute) to develop estimates of accident likelihood and their ranges of severity (DIRS 101828-Fischer et al. 1987, pp. 7-25 and 7-26). Using these data, the analysis estimated that as many as 66 accidents could occur over 24 years in the course of shipping spent nuclear fuel to the repository by legal-weight trucks; 8 rail accidents that involved a railcar carrying a cask could occur if most shipments were by rail; and no accidents would be likely for the limited use of barges.

Furthermore, in using data collected by the U.S. Department of Transportation, the analysis considered the range of accidents, from slightly more than "fender benders" to high-speed crashes, that the DOE carrier would have to report in accordance with the requirements of U.S. Department of Transportation regulations. The accidents that could occur would be unlikely to be severe enough to affect the integrity of the shipping casks.

The following paragraphs discuss reporting and definitions for transportation accidents and the relationships of these to data used in analyzing transportation impacts in this EIS.

J.1.4.2.3.1 Transportation Accident Reporting and Definitions. In the United States, the reporting of transportation accidents and incidents involving trucks, railroads, and barges follows requirements specified in various Federal and state regulations.

Motor Carrier Accident Reporting and Definitions

Regulations generally require the reporting of motor carrier accidents (regardless of the cargo being carried) if there are injuries, fatalities, or property damage. These regulations have evolved through the years, mostly in response to increasing values of transportation equipment and commodities. For example, the Federal requirements in the following text box establish a functional threshold for damage to vehicles rather than a value-of-damage threshold, which was used until the 1980s. Nonetheless, many states continue to use value thresholds (for example, Ohio uses $500) for vehicle damage when documenting reportable accidents.

Until March 4, 1993, Federal regulations (49 CFR Part 394) required motor carriers to submit accident reports to the Federal Highway Administration Motor Carrier Management Information System using the so-called "50-T" reporting format. The master file compiled from the data on these reports in the Federal Highway Administration Office of Motor Carriers was the basis of accident, fatality, and injury rates developed for the 1994 study of transportation accident rates (DIRS 101920-Saricks and Kvitek 1994, all).

The Final Rule (58 *FR* 6726; February 2, 1993) modified the carrier reporting requirement; rather than submitting reports, carriers now must maintain a register of accidents that meet the definition of an accident for 1 year after such an accident occurs. Carriers must make the contents of such a register available to Federal Highway Administration agents investigating specific accidents. They must also give "...all reasonable assistance in the investigation of any accident including providing a full, true, and correct answer to any question of inquiry" to determine if 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 rule change 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 of 1991 (Public Law 102-240, 105 Stat. 1914), was established under the Motor Carrier Safety Assistance Program.

Under Section 408 of Title IV of the Motor Carrier Act of 1991 (Public Law 102-240, 105 Stat. 2140), a component of the Intermodal Surface Transportation Efficiency Act, the Secretary of Transportation is authorized to make grants to states to help them achieve uniform implementation of the police 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. They are entered in a Federally maintained SAFETYNET database on approximately a weekly basis. The SAFETYNET database, in turn, is compiled and managed as part of the Motor Carrier Management Information System.

Because DIRS 152476-Sprung et al. (2000, all) is the fundamental source for data that describes the severity of transportation accidents used in this EIS, the relative constancy of the definition of *accident* is important in establishing confidence in estimated impact results. Thus, although the transportation environment has changed over the 40 years of data collection, the constancy of the definition of *accident* tends to provide confidence that the distribution of severity for reported accidents has remained relatively the same. That is, low-consequence, fender-bender accidents are the most common, high-consequence, highly energetic accidents are rare, and the proportions of these have remained roughly the same.

COMMERCIAL MOTOR VEHICLE ACCIDENT
(49 CFR 390.5)

An occurrence involving a commercial motor vehicle operating on a public road in interstate or intrastate commerce that results in:

- A fatality
- Bodily injury to a person who, as a result of the injury, immediately receives medical treatment away from the scene of the accident
- One or more motor vehicles incurring disabling damage as a result of the accident, requiring the motor vehicle to be transported away from the scene by a tow truck or other motor vehicle

The term accident does not include:

- An occurrence involving only boarding and alighting from a stationary motor vehicle
- An occurrence involving only the loading or unloading of cargo
- An occurrence in the course of the operation of a passenger car or a multipurpose passenger vehicle by a motor carrier and is not transporting passengers for hire or hazardous materials of a type and quantity that require the motor vehicle to be marked or placarded in accordance with 49 CFR 177, Subpart 823

Changes in the transportation environment, such as changes in speed limits and safety technology, tend to change the accident rate (accidents per vehicle-kilometer of travel). Overall, however, given that the definition of *accident* does not change, such changes do not greatly affect the distribution of accident severities. For example, recent increases in speed limits from 105 to 121 kilometers (65 to 75 miles) per hour represent about a 25-percent increase in the maximum mechanical energy of vehicles. Other information aside, this increase could lead to the conclusion that the resulting distribution of accidents would show an increase for the most severe accidents in comparison to minor accidents. However, the speed limit increases do not represent a corresponding increase in actual traffic speeds, and would be unlikely to change the distribution of velocities and, thus, mechanical energies, of severe accidents from those reported in DIRS 152476-Sprung et al. (2000, all), which ranged to faster than 193 kilometers (120 miles) per hour.

Rail Carrier Accident Reporting and Definitions

As with regulations governing the reporting of motor carrier accidents, Federal Railroad Administration regulations generally require the reporting of accidents if there are injuries, fatalities, or property damage. These regulations have evolved through the years, mostly in response to increasing values of transportation equipment and commodities. For example, the Federal requirements in the following text box establish a value-based reporting threshold for damage to vehicles; the value has been indexed to inflation since 1975.

Rail carriers covered by these requirements must fulfill several bookkeeping tasks. The Federal Railroad Administration requires the submittal of a monthly status report, even if there were no reportable events during the period. This report must include accidents and incidents, and certain types of incidents require immediate telephone notification. Logs of reportable injuries and on-track incidents must be maintained by the railroads on which they occur, and a listing of such events must be posted and made available to employees and to the Federal Railroad Administration, along with required records and reports, on request. The data entries extracted from the reporting format are consolidated into an accident/incident database that separates reportable *accidents* from grade-crossing *incidents*. These are processed annually into event, fatality, and injury count tables in the Federal Railroad Administration's *Accident/Incident Bulletin* (DIRS 103455-Saricks and Tompkins 1999, all), which the Office of Safety publishes on the Internet (*safetydata.fra.dot.gov/officeofsafety*).

RAILROAD ACCIDENT/INCIDENT
(49 CFR 225.11)

- An impact between railroad on-track equipment and an automobile, bus, truck, motorcycle, bicycle, farm vehicle or pedestrian at a highway-rail grade crossing
- A collision, derailment, fire, explosion, act of God, or other event involving operation of railroad on-track equipment (standing or moving) that results in reportable damages greater than the current reporting threshold to railroad on-track equipment, signals, track, track structures, and roadbed
- An event arising from the operation of a railroad which results in:
  - Death to any person
  - Injury to any person that requires medical treatment
  - Injury to a railroad employee that results in:
    - A day away from work
    - Restricted work activity or job transfer
    - Loss of consciousness
    - Occupational illness

In contrast to the regulations for motor carriers discussed above, the Federal Railroad Administration regulations cited above call for the reporting of accidents and incidents. The Administration defines an *accident* as "an event involving on-track railroad equipment that results in damage to the railroad on-track equipment, signals, track, or track structure, and roadbed at or exceeding the dollar damage threshold" (49 CFR 225.11). Train *incidents* are defined as "events involving on-track railroad equipment [and non-train incidents arising from the operation of a railroad] that result in the reportable death and/or injury or illness of one or more persons, but do not result in damage at or beyond the damage threshold" (49 CFR 225.11). Because damage to casks containing spent nuclear fuel will necessarily involve severe accidents (hence, substantial damage), DIRS 152476-Sprung et al. (2000, all) used only train accidents to form the basis for developing the conditional probabilities of accident severities.

As with motor carrier operations, the constancy of the definition of a train accident is important in establishing confidence in the impact. For rail accidents the transportation environment has not changed dramatically over the years of data collection, and the definition of *accident* has remained essentially unchanged (with adjustments for inflation). The constancy of the definition provides confidence that the distribution of severity for reported accidents has remained relatively the same—low-consequence, limited-damage accidents are the most common and high-consequence, highly energetic accidents are rare, and their proportions have remained about the same. Changes in the rail transportation environment, as in safety and operations technology (for example, shelf-type couplers and tankcar head protection), have resulted in lower accident rates (per railcar-kilometer of travel) and, in some cases, less severe accidents. However, because the definition of *accident* has not changed appreciably, the changes that have occurred are not the kind that would greatly affect the relative proportions of minor and severe accidents.

Reporting and Definitions for Marine Casualties and Incidents

As with the regulations governing the reporting of motor carrier and rail accidents, U.S. law (46 U.S.C. 6101 to 6103) requires operators to report marine casualties and incidents if there are injuries, fatalities, or property damage. In addition, the law requires the reporting of significant harm to the environment.

MARINE CASUALTY AND INCIDENT
(46 U.S.C. 6101 to 6103)

Criteria have been established for the required reporting (by vessel operators and owners) of marine casualties and incidents involving all United States flag vessels occurring anywhere in the world and any foreign flag vessel operating on waters subject to the jurisdiction of the United States. An incident must be reported within five days if it results in:

- The death of an individual
- Serious injury to an individual
- "Material" loss of property (threshold not specified; previously was $25,000)
- Material damage affecting the seaworthiness or efficiency of the vessel
- Significant harm to the environment

The states collect casualty data for incidents occurring in navigable waterways within their borders, and there is a uniform state marine casualty reporting system for transmitting these reports to Federal jurisdiction (the U.S. Coast Guard). Coast Guard Headquarters receives quarterly extracts of the Marine Safety Information System developed from these sources. This system is a network database into which Coast Guard investigators enter cases at each marine safety unit. The analysis uses a Relational Database Management System. The Coast Guard Office of Investigations and Analysis compiles and processes the casualty reports into the formats and partitioned data sets that comprise the Marine Safety Information System database, which includes maritime accidents, fatalities, injuries, and pollution spills dating to 1941 (however, the file is complete only from about 1991 to the present).

Hazardous Material Transportation Accident and Incident Reporting and Definitions

Radioactive material is a subset of the more general term *hazardous material,* which includes commodities such as gasoline and chemical products. The U.S. Department of Transportation Office of Hazardous Materials estimates that there are more than 800,000 hazardous materials shipments per day, of which about 7,700 shipments contain radioactive materials.

Hazardous materials transportation regulations (49 CFR 171) contain no distinction between an *accident* and an *incident,* and *incident* is the term used to describe situations that must be reported. Hazardous materials regulations (49 CFR 171.15) require the reporting of incidents if:

- A person is killed
- A person receives injuries requiring hospitalization
- The estimated property damage is greater than $50,000
- An evacuation of the public occurs lasting one or more hours
- One or more major transportation arteries are closed or shutdown for one or more hours
- The operational flight pattern or routine of an aircraft is altered
- Fire, breakage, spillage, or suspected radioactive contamination occurs involving shipment of radioactive material
- Fire, breakage, spillage, or suspected contamination occurs involving shipment of infectious agents

- There has been a release of a marine pollutant in a quantity exceeding 450 liters (about 120 gallons) for liquids or 400 kilograms (about 880 pounds) for solids

- There is a situation that, in the judgement of the carrier, should be reported to the U.S. Department of Transportation even though it does not meet the above criteria

These criteria apply to loading, unloading, and temporary storage, as well as to transportation. The criteria involving infectious agents or aircraft are unlikely to be used for spent nuclear fuel or high-level radioactive waste shipments. Based on these criteria, reportable motor vehicle and rail transportation situations are far more exclusionary than hazardous material situations.

Carriers (not law enforcement officials) are required to report hazardous materials incidents to the U.S. Department of Transportation. These reports are compiled in the Hazardous Materials Incident Report database. In addition, U.S. Nuclear Regulatory Commission regulations (10 CFR 20.2201, 20.2202, 20.2203) require the reporting of a loss of radioactive materials, exposure to radiation, or release of radioactive materials.

Sandia National Laboratories maintains the Radioactive Materials Incident Report database, which contains incident reports from the Hazardous Materials Incident Report database that involve radioactive material. In addition, the Radioactive Materials Incident Report database contains data from the U.S. Nuclear Regulatory Commission, state radiation control offices, the DOE Unusual Occurrence Report database, and media coverage of radioactive materials transportation incidents. DIRS 101802-DOE (1995, Volume 1, Appendix I, pp. I-117) and DIRS 102172-McClure and Fagan (1998, all) discuss historic incidents involving spent nuclear fuel that are reported in the Radioactive Materials Incident Report database as well as incidents that took place prior to the existence of this database. The database characterizes incidents in three categories: transportation accidents, handling accidents, and reported incidents. However, the definitions of these categories are not consistent with the definitions used in other U.S. Department of Transportation databases. For example, from 1971 through 1998, the Radioactive Materials Incident Report database lists one transportation accident involving a loaded rail shipment of spent nuclear fuel. However, based on current Federal Railroad Administration reporting requirements, this occurrence probably would be listed as a grade-crossing incident, not an accident. For this reason and because of the small number of occurrences in the database involving spent nuclear fuel, the EIS analysis did not use the Radioactive Materials Incident Report database to estimate transportation accident rates.

J.1.4.2.3.2 Accident Rates for Transportation by Heavy-Combination Truck, Railcar, and Barge in the United States. DIRS 103455-Saricks and Tompkins (1999, all) developed estimates of accident rates for heavy-combination trucks, railcars, and barges based on data available for 1994 through 1996. The estimates provide an update for accident rates published in 1994 (DIRS 101920-Saricks and Kvitek 1994, all) that reflected rates from almost a decade earlier.

Rates for Accidents in Interstate Commerce for Heavy-Combination Trucks

DIRS 103455-Saricks and Tompkins (1999, all) developed basic descriptive statistics for state-specific rates of accidents involving interstate-registered combination trucks for 1994, 1995, and 1996. The accident rate over all road types for 1994 was 2.98×10^{-7} accident per truck-kilometer (DIRS 103455-Saricks and Tompkins 1999, Table 3a); for 1995 it was 2.97×10^{-7} accident per truck-kilometer (DIRS 103455-Saricks and Tompkins 1999, Table 3b); and for 1996 it was 3.46×10^{-7} accident per truck-kilometer (DIRS 103455-Saricks and Tompkins 1999, Table 3c). The composite mean from 1994 through 1996 was 3.21×10^{-7} accident per truck-kilometer.

During the 24 years of the Proposed Action, the *mostly legal-weight truck* national transportation scenario would involve about 53,000 truck shipments of spent nuclear fuel and high-level radioactive waste.

Based on the data in DIRS 103455-Saricks and Tompkins (1999, Table 4), the transportation analysis estimated that those shipments could involve as many as 66 accidents. During the same period, the *mostly rail* scenario would involve about 1,100 truck shipments, and the analysis estimated that as many as one truck accident could occur during these shipments. More than 99.99 percent of these accidents would not generate forces capable of causing functional damage to the casks, and would have no radiological consequences. A small fraction of the accidents could generate forces capable of damaging the cask.

Rates for Freight Railcar Accidents

Results for accident rates for freight railcar shipments from DIRS 103455-Saricks and Tompkins (1999, all), show that domestic rail freight accidents, fatalities, and injuries on Class 1 and 2 railroads have remained stable or declined slightly since the late 1980s. Based on data from 1994 through 1996, these rates are 5.39×10^{-8}, 8.64×10^{-8}, and 1.05×10^{-8} per railcar-kilometer, respectively (DIRS 103455-Saricks and Tompkins 1999, Table 6). This conclusion is based on applying denominators that do *not* include train and car kilometers for intermodal shipments (containers and trailers-on-flatcar) not loaded by the carriers themselves. Thus, the actual denominators are probably higher and the rates consequently lower, by about 20 percent.

During the 24 years of the Proposed Action, the *mostly rail* national transportation scenario would involve as many as 10,000 rail shipments of spent nuclear fuel and high-level radioactive waste. Based on the data in DIRS 103455-Saricks and Tompkins (1999, Table 6), the analysis estimated that these shipments could involve eight accidents. More than 99.99 percent of these accidents would not generate forces capable of causing functional damage to the cask; these accidents would have no radiological consequences. A small fraction of the accidents could generate forces capable of damaging the cask. For the *mostly legal-weight truck* scenario, rail accidents would be unlikely during the 300 railcar shipments of naval spent nuclear fuel.

Rates for Barge Accidents

Waterway results show a general improvement over mid-1980s rates. The respective rates for 450-metric-ton (500-ton) shipments for waters internal to the coast (rivers, lakes, canals, etc.) for accident and incident involvements and fatalities were 1.68×10^{-6} and 8.76×10^{-9} per shipment-kilometer, respectively (DIRS 103455-Saricks and Tompkins 1999, Table 8b). Rates for lake shipping were lower—2.58×10^{-7} and 0 per shipment-kilometer, for accidents and incidents and for fatalities, respectively. Coastal casualty involvement rates have risen in comparison to the data recorded about 10 years ago, and are comparable to rates for internal waters—5.29×10^{-7} and 8.76×10^{-9} per shipment-kilometer (DIRS 103455-Saricks and Tompkins 1999, Table 9b).

During the 24 years of the Proposed Action, the *mostly rail* national transportation scenario could involve the use of barges to ship spent nuclear fuel from 17 commercial sites. Based on the data in DIRS 103455-Saricks and Tompkins (1999, all), the analysis estimated that less than one accident could occur during such shipments. A barge accident severe enough to cause measurable damage to a shipping cask would be highly unlikely.

Rates for Safe Secure Trailer Accidents

DOE uses safe secure trailers to transport hazardous cargoes in the continental United States. The criteria used for reporting accidents involving these trailers are damage in excess of $500, a fire, a fatality, or damage sufficient for the trailer to be towed. From 1975 through 1998, 14 accidents involved safe secure trailers over about 54 million kilometers (about 34 million miles) of travel, which yields a rate of 2.6×10^{-7} accident per kilometer (4.2×10^{-7} per mile). This rate is comparable to the rate estimated by DIRS 103455-Saricks and Tompkins (1999, Table 4) for heavy combination trucks, 3.2×10^{-7} accident per kilometer (5.1×10^{-7} per mile).

J.1.4.2.3.3 Accident Data Provided by the States of Nevada, California, South Carolina, Illinois, and Nebraska. In May 1998, DOE requested the 48 contiguous states to provide truck and rail transportation accident data for use in this EIS. Five states responded – Nevada, California, Illinois, Nebraska, and South Carolina (DIRS 104728-Denison 1998, all; DIRS 103709-Caltrans 1997, all; DIRS 104801-Wort 1998, all; DIRS 104783-Kohles 1998, all; DIRS 103725-SCDPS 1997, all). No states provided rail information.

- *Nevada.* Nevada provided a highway accident rate of 1.1×10^{-6} accident per kilometer (1.8×10^{-6} per mile) for interstate carriers over all road types. This is higher than the accident rate estimated by DIRS 103455-Saricks and Tompkins (1999, Table 4); 2.5×10^{-7} accident per kilometer (3.9×10^{-7} per mile) for heavy trucks over all road types in Nevada from 1994 to 1996.

  The definition of *accident* used in DIRS 103455-Saricks and Tompkins (1999, p. 4) is the Federal definition (fatality, injury, or tow-away); in Nevada the accident criteria are fatality, injury, or $750 property damage. Based on national data from the U.S. Department of Transportation Office of Motor Carrier Information Analysis (DIRS 103721-FHWA 1997, p. 2; DIRS 102231-FHWA 1998, pp. 1 and 2), using the Federal definition would reduce the accident rate from 1.1×10^{-6} to about 4.1×10^{-7} accident per kilometer (1.8×10^{-6} to 6.7×10^{-7} per mile). The radiological accident risk in Nevada for the mostly legal-weight truck scenario would increase over 24 years from 0.0002 latent cancer fatality to about 0.0005 latent cancer fatality (a likelihood of 5 in 10,000 of one latent cancer fatality) if the accident rate reported by DIRS 103455-Saricks and Tompkins (1999, p. 33) for Nevada were replaced by the rate of 4.1×10^{-7} per kilometer. Thus, the impacts of the rate for accidents involving large trucks on Nevada highways reported by Nevada (DIRS 104728-Denison 1998, all) would be comparable to the impacts derived using the rate estimated by DIRS 103455-Saricks and Tompkins (1999, p. 33).

- *California.* California responded with highway accident rates that included all vehicles (cars, buses, and trucks). The accident rate for Interstate highways was 4.2×10^{-7} accident per kilometer (6.8×10^{-7} per mile) for all vehicles in 1996. This rate is higher than the accident rate estimated by DIRS 103455-Saricks and Tompkins (1999, Table 4), 1.6×10^{-7} accident per kilometer (2.6×10^{-7} per mile) for heavy trucks on California interstate highways from 1994 to 1996.

  The definition of *accident* in DIRS 103455-Saricks and Tompkins (1999, p. 4) is the Federal definition (fatality, injury, or tow-away); in California the accident criteria are fatality, injury, or $500 property damage. Based on national data from DIRS 103721-FHWA (1997, p. 2) and DIRS 102231-FHWA (1998, pp. 1 and 2), using the Federal definition would reduce the accident rate from 4.2×10^{-7} to about 1.6×10^{-7} accident per kilometer (6.8×10^{-7} to 2.6×10^{-7} per mile). In addition, the rate provided by California was for all vehicles. Based on national data from the U.S. Department of Transportation Bureau of Transportation Statistics, using the accident rate for large trucks would reduce the all-vehicle accident rate from 1.6×10^{-7} to about 1.3×10^{-7} accident per kilometer (2.6×10^{-7} to 2.1×10^{-7} per mile) for large trucks. This rate is slightly less than the rate estimated by DIRS 103455-Saricks and Tompkins (1999, Table 4), 1.6×10^{-7} accident per kilometer.

- *Illinois.* Illinois provided highway data for semi-trucks from 1991 through 1995 over all road types. Over this period, the accident rate was 1.8×10^{-6} accident per kilometer (2.9×10^{-6} per mile). From 1994 through 1996, DIRS 103455-Saricks and Tompkins (1999, all) estimated an accident rate of 3.0×10^{-7} accident per kilometer (4.8×10^{-7} per mile) for heavy trucks over all road types in Illinois.

  The definition of *accident* used in DIRS 103455-Saricks and Tompkins (1999, p. 4) is the Federal definition (fatality, injury, or tow-away); in Illinois the accident criteria are fatality, injury, or $500 property damage. Based on national data from the U.S. Department of Transportation Office of Motor Carrier Information Analysis (DIRS 103721-FHWA 1997, p. 2; DIRS 102231-FHWA 1998, pp. 1 and 2), using the Federal definition would reduce the accident rate from 1.8×10^{-6} to about 6.7×10^{-7} accident per kilometer (2.9×10^{-6} to 1.1×10^{-6} per mile). This rate is comparable to the rate estimated by DIRS 103455-Saricks and Tompkins (1999, all).

- *Nebraska.* Nebraska provided a highway accident rate of 2.4×10^{-7} accident per kilometer (3.8×10^{-7} per mile) for 1997. Nebraska did not specify if the rate was for interstate highways, but it is for interstate truck carriers. This rate is slightly less than the accident rate estimated by DIRS 103455-Saricks and Tompkins (1999, all) for Nebraska interstates, 3.2×10^{-7} accident per kilometer (5.1×10^{-7} per mile) for heavy trucks from 1994 through 1996.

- *South Carolina.* South Carolina responded with highway accident rates that included all types of tractor/trailers (for example, mobile homes, semi-trailers, utility trailers, farm trailers, trailers with boats, camper trailers, towed motor homes, petroleum tankers, lowboy trailers, auto carrier trailers, flatbed trailers, and twin trailers). The rate was 8.3×10^{-7} accident per kilometer (1.3×10^{-6} per mile), for all road types. [This is higher than the accident rate estimated by DIRS 103455-Saricks and Tompkins (1999, all), 4.7×10^{-7} accident per kilometer (7.6×10^{-7} per mile) for heavy trucks on all road types in South Carolina from 1994 through 1996].

  The definition of *accident* in DIRS 103455-Saricks and Tompkins (1999, p. 4) is the Federal definition (fatality, injury, or tow-away); in South Carolina the accident criteria are fatality, injury, or $1,000 property damage. Based on national data from the U.S. Department of Transportation Office of Motor Carrier Information Analysis (DIRS 103721-FHWA 1997, p. 2; DIRS 102231-FHWA 1998, pp. 1 and 2), using the Federal definition of an accident would reduce the accident rate from 8.3×10^{-7} to about 3.1×10^{-7} accident per kilometer (1.3×10^{-6} to 5.0×10^{-7} per mile), which is slightly less than the rate estimated by DIRS 103455-Saricks and Tompkins (1999, all), 4.7×10^{-7} accident per kilometer (7.6×10^{-7} per mile). In addition, the accident rate estimated by DIRS 103455-Saricks and Tompkins (1999, all) was based on Motor Carrier Management Information System vehicle configuration codes 4 through 8 (truck/trailer, bobtail, tractor/semi-trailer, tractor/double, and tractor/triple), while the rate obtained from South Carolina included all truck/trailer combinations. Including all of the combinations tends to increase accident rates; for example, light trucks have higher accident rates than heavy trucks (DIRS 148081-BTS 1999, Table 3-22).

DOE evaluated the effect of using the data provided by the five states on radiological accident risk for the mostly legal-weight truck national transportation scenario. If the data used in the analysis for the five states (DIRS 103455-Saricks and Tompkins 1999, Table 4) were replaced by the data provided by the states with the adjustments discussed, the change in the resulting estimate of radiological accident risk would be small, increasing from 0.067 to 0.071 latent cancer fatality. Using the unadjusted data provided by those states would result in an increase in accident risk from 0.067 to 0.093 latent cancer fatality.

J.1.4.2.4 *Transportation Accidents Involving Nonradioactive Hazardous Materials*

The analysis of impacts of transportation accidents involving the transport of nonradioactive hazardous materials to and from Yucca Mountain used information presented in two U.S. Department of Transportation reports (DIRS 103718-DOT 1998, Table 1; DIRS 103708-BTS 1996, p. 43) on the annual number of hazardous materials shipments in the United States and the number of deaths caused by hazardous cargoes in 1995. In total, there are about 300 million annual shipments of hazardous materials; only a small fraction involve radioactive materials. In 1995, 6 fatalities occurred because of hazardous cargoes. These data suggest a rate of 2 fatalities per 100 million shipments of hazardous materials. DOE anticipates about 40,000 shipments of nonradioactive hazardous materials (including diesel fuel and laboratory and industrial chemicals) to and from the Yucca Mountain site during construction, operation and monitoring, and closure of the repository. Assuming that the rate for fatalities applies to the transportation of nonradioactive hazardous materials to and from Yucca Mountain, DOE does not expect fatalities from 40,000 shipments of these materials.

J.1.4.2.5 *Cost of Cleanup and Ecological Restoration Following a Transportation Accident*

Cost of Cleanup. According to the Nuclear Regulatory Commission report *Reexamination of Spent Fuel Shipment Risk Estimates* (DIRS 152476-Sprung et al. 2000, pp. 7-73 to 7-76), in more than 99.99 percent of accidents radioactive material would not be released from the cask. After initial safety precautions had been taken, the cask would be recovered and removed from the accident scene. Because no radioactive material would be released, based on reported experience with two previous accidents (DIRS 156110-FEMA 2000, Appendix G, Case 4 and Case 5), the economic costs of these accidents would be minimal.

For the 0.01 percent of accidents severe enough to cause a release of radioactive material from a cask, a number of interrelated factors would affect costs of cleaning up resulting radioactive contamination after the accident. Included are: the severity of the accident and the initial level of contamination; the weather at the time and following; the location and size of the affected land area and how the land is used; the standard established for the allowable level of residual contamination following cleanup and the decontamination method used; and the technical requirements for and location for disposal of contaminated materials.

Because it would be necessary to specify each of the factors to estimate clean up costs, any estimate for a single accident would be highly uncertain and speculative. Nonetheless, to provide a gauge of the costs that could be incurred DOE examined past studies of costs of cleanup following hypothetical accidents that would involve uncontrolled releases of radioactive materials.

A study of the impacts of transporting radioactive materials conducted by the Nuclear Regulatory Commission in 1977 estimated that costs could range from about $1 million to $100 million for a transportation accident that involved a 600-curie release of a long-lived radionuclide (DIRS 101892-NRC 1977, Table 5-11). These estimates would be about 3 times higher if escalated for inflation from 1977 to the present. In 1980 DIRS 155054-Finley et al. (1980, Table 6-9) estimated that costs could range from about $90 million to $2 billion for a severe spent nuclear fuel transportation accident in an urban area. DIRS 154814-Sandquist et al. (1985, Table 3-7) estimated that costs could range from about $200,000 to $620 million. In this study, Sandquist estimated that contamination would affect between 0.063 to 4.3 square kilometers (16 to 1,100 acres). A study by DIRS 152083-Chanin and Murfin (1996, Chapter 6) estimated the costs of cleanup following a transportation accident in which plutonium would be dispersed. This study developed cost estimates for cleaning up and remediating farmland, urban areas, rangeland, and forests. The estimates ranged from $38 million to $400 million per square kilometer that would need to be cleaned up. The study also evaluated the costs of expedited cleanups in urban areas for light, moderate, and heavy contamination levels. These estimates ranged from $89 million to $400 million per square kilometer.

The National Aeronautics and Space Administration studied potential accidents for the Cassini mission, which used a plutonium powered electricity generator. The Agency estimated that costs of cleaning up radioactive material contamination on land following potential launch and reentry accidents. The estimate for the cost following a launch accident ranged from $7 million to $70 million (DIRS 155551-NASA 1995, Chapter 4) with an estimated contaminated land area of about 1.4 square kilometers (350 acres). The Agency assumed cleanup costs would be $5 million per square kilometer if removal and disposal of contaminated soil were not required and $50 million per square kilometer if those activities were required. For a reentry accident that would occur over land, the study estimated that the contaminated land area could range from about 1,500 to 5,700 square kilometers (370,000 to 1.4 million acres) (DIRS 155551-NASA 1995, Chapter 4) with cleanup costs possibly exceeding a total of $10 billion. In a more recent study of potential consequences of accidents that could involve the Cassini mission, NASA estimated that costs could range from $7.5 million to $1 billion (DIRS 155550-NASA 1997, Chapter 4). The contaminated land area associated with these costs ranged from 1.5 to 20 square kilometers (370 to 4,900 acres). As in the 1995 study, these estimates were based on cleanup costs in the range of $5 million to $50 million per square kilometer.

Using only the estimates provided by these studies, the costs of cleanup following a severe transportation accident involving spent nuclear fuel where radioactive material was released could be in the range from $300,000 (after adjusting for inflation from 1985 to the present) to $10 billion. Among the reasons for this wide range are different assumptions made regarding the factors that must be considered: 1) the severity of the assumed accident and resulting contamination levels, 2) accident location and use of affected land areas, 3) meteorological conditions, 4) cleanup levels and decontamination methods, and 5) disposal of contaminated materials. However, the extreme high estimates of costs are based on assumptions that all factors combine in the most disadvantageous way to create a "worst case." Such worst cases are not reasonably foreseeable. Conversely, estimates as low as $300,000 may also not be realistic for all of the direct and indirect costs of cleaning up following an accident severe enough to cause a release of radioactive materials.

To gauge the range of costs that it could expect for severe accidents in transporting spent nuclear fuel to a Yucca Mountain repository, DOE considered the spectrum of accidents that are reasonably foreseeable (see Section J.1.4.2.1) and the amount of radioactive material that could be released in each such accident and compared this to the estimates of releases used by the various studies discussed above. Based on 2 million curies of radioactive material in a rail casks loaded with spent nuclear fuel, about 13 curies (mostly cesium) would be released in a maximum reasonably foreseeable accident. This is about 100 times less than used by Sandquist in his study (1,630 curies) and 50 times less than the release used in the estimates provided by the Nuclear Regulatory Commission in 1977 (600 curies). The estimated frequency for an accident this severe to occur is about 3 times in 10 million years. Based on the prior studies (where estimated releases exceeded those estimated in this appendix for a maximum reasonably foreseeable accident) and the amount of radioactive material that could be released in a maximum reasonably foreseeable accident, the Department believes that the cost of cleaning up following such an accident could be a few million dollars. Nonetheless, as stated above, the Department also believes that estimates of such costs contain great uncertainty and are speculative; they could be less or 10 times greater depending on the contributing factors.

For perspective, the current insured limit of responsibility for an accident involving releases of radioactive materials to the environment is $9.43 billion (see Appendix M). The annual cost of transporting spent nuclear fuel and high-level radioactive waste to Yucca Mountain would be about $200 million.

Ecological Restoration. Following a severe transportation accident, it might be necessary to restore the ecology of an area after the area was remediated. DIRS 152083-Chanin and Murfin (1996, all) present a review of the scope of ecological restoration that can be accomplished and the requirements that would apply in the event of an accident where environmental damage resulting from cleaning up radioactive material contamination would in turn result in a need for environmental restoration. The restoration that would be necessary following an accident cannot be predicted. It would depend on the environmental factors involved—1) the levels of contamination from the accident, 2) cleanup levels and decontamination methods used, and 3) location and ecology of the affected land areas—and the restoration goal that was used. DIRS 152083-Chanin and Murfin (1996, Chapter 6) observe

> *"[a] long-standing definition of the preferred goal of site restoration is to establish an ecological community as similar as possible to that which existed before an accident. Alternative goals are to*

establish a similar, but not identical, community; to establish an entirely different but valued community; or, if none of the foregoing is feasible, to establish some less-valued community."

The costs discussed above include costs for environmental restoration.

DIRS 152083-Chanin and Murfin (1996, all) provide the following assessments of environmental restoration that could be accomplished following clean up of contamination from an accident.

- Unassisted restoration of desert land is difficult, but assisted restoration can be very successful.
- Grasslands may be restored naturally provided only limited soil has been removed. Assisted restoration of prairies is also successful.
- Total restoration of forests may not be possible if the area is too large for natural reseeding; an alternative use may have to be found for forestland.
- Restoration of farmland is relatively simple.
- Restoration of urban land to building sites is simple.
- Restoration to parkland is possible, but more costly.

J.2 Evaluation of Rail and Intermodal Transportation

DOE could use several modes of transportation to ship spent nuclear fuel from the 72 commercial and 5 DOE sites. Legal-weight trucks could transport spent nuclear fuel and high-level radioactive waste in truck casks that would weigh approximately 22,500 kilograms (25 tons) when loaded. For sites served by railroads, railcars could be used to ship rail casks directly to the Yucca Mountain site, if a branch rail line was built in Nevada, or to an intermodal transfer station in Nevada if heavy-haul trucks were used. Rail casks would weigh as much as 136,000 kilograms (150 tons).

For sites that have the capability to load rail casks but are not served by a railroad, DOE could use heavy-haul trucks or, for sites on navigable waterways, barges to transport casks to nearby railheads.

For rail shipments, DOE could request the railroads to provide dedicated trains to transport casks from the sites to a destination in Nevada or could deliver railcars with loaded casks to the railroads as general freight for delivery in Nevada.

In addition, DOE evaluated the potential for including two other scenarios: (1) a different mostly rail scenario in which railcars would transport legal-weight truck casks and (2) a large-scale barge scenario.

J.2.1 LEGAL-WEIGHT TRUCK CASKS ON RAILCARS SCENARIO

DOE assessed the sensitivity of transportation impacts to assumptions related to transportation scenarios. The analysis evaluated a variation of the mostly rail scenario in which shipments would be made using casks much smaller than rail casks—legal-weight truck casks—shipped to Nevada on railcars then transported on legal-weight trucks from a rail siding to Yucca Mountain. Under this scenario, because all shipments (except shipments of naval spent nuclear fuel) would use legal-weight truck casks, the number of railcar shipments would be about 53,000 over the 24 years of the Proposed Action. This would be the same as the number of legal-weight truck plus naval spent nuclear fuel shipments in the mostly legal-weight truck scenario.

DOE estimated impacts of this variation of the mostly rail transportation scenario by scaling from the impacts estimated for the mostly rail scenario. The analysis used the ratio of the number of railcars that would be shipped to the number of railcar shipments estimated for the mostly rail scenario and assumed each shipment would include an escort car and five railcars carrying legal-weight truck casks. The estimated number of public incident-free latent cancer fatalities would be approximately 4, and the estimated number of traffic fatalities would be 8. The total of these estimates, 12, is about 1.5 times the DOE revised estimate of a total of 7 fatalities (2.5 latent cancer fatalities plus 4.5 traffic fatalities) for the legal-weight truck scenario.

DOE determined that while this scenario would be feasible, it would not be practical. The number of shipping casks and railcar shipments would be greater by a factor of 5 than for the mostly rail scenario and the additional cost to the Program would be more than $1 billion. In addition, the truck-casks-on-railcars scenario would lead to the highest estimates of occupational health and public health and safety impacts, most coming from rail-traffic related facilities.

J.2.2 LARGE-SCALE BARGE SCENARIO

In response to public comments on the 1986 Environmental Assessment for the Yucca Mountain Site, Research and Development Area, Nevada (DIRS 104731-DOE 1986, p. C.2-40), DOE described barge transportation as a feasible alternative that could play a secondary or supplementary role in the transportation of radioactive wastes to a repository. In the Final Environmental Impact Statement on Management of Commercially Generated Radioactive Waste (DIRS 104832-DOE 1980, Volume A, pp. 4.64 and 4.65), DOE concluded that barge transport is an alternative when both the nuclear powerplant and the encapsulation or storage facility are on navigable waterways. That EIS observed that barge transport suggests high payloads and low tariffs, but cost gains in these two areas could be offset by the longer estimated transit times for barge shipments. The EIS also observed that casks for barge shipment of spent nuclear fuel probably would be similar, if not identical, to those used for rail transport.

The most likely way in which DOE would use barge transportation to make shipments to a repository would be to complete a leg of the trip that also involved two land legs. Even though many generator sites are adjacent to or near navigable waterways, shipping casks cannot be loaded directly onto barges in all cases. It would be necessary to use heavy-haul trucks or railcars to transport the casks from the generator site's cask loading facilities to a barge slip or dock. The casks would then either be rolled onto the barge using the land vehicle and a loading ramp and secured to the barge deck or hoisted from the land vehicle to the barge and secured. At the destination end of the barge leg of the trip, the cask would either be rolled off the barge using a ramp and a heavy-haul truck or hoisted from the barge deck onto a railcar or heavy-haul truck. The cask probably would then be transported from the destination port to Nevada by rail and not by heavy-haul truck. Thus, if casks were rolled off barges to heavy-haul trucks, they would need to be transferred to railcars. The maximum use of barge transportation would require transport through the Panama Canal for shipments from generator sites in the middle and eastern part of the United States. Such use could result in 70 percent fewer land travel kilometers than the mostly rail or mostly legal-weight truck scenario.

Analyses in the 1986 Environmental Assessment (DIRS 104731-DOE 1986, p. A-69) showed that the use of barge transportation would generally increase occupational exposure for normal shipment operations and could increase exposure of the public because of intermodal transfers. From the analyses, reactor-specific results suggest that under several circumstances the barge mode could reduce risk. The analyses concluded that the consequences of accidents from barges would be of the same magnitude as those for other modes.

Because, as discussed above, DOE could use barge transportation only in conjunction with land modes, DOE did not evaluate barge as an alternative major modal scenario as it did for the mostly rail and mostly legal-weight truck modal scenarios. Rather, for the 17 commercial generator sites not served by railroads but situated near or adjacent to navigable waterways, DOE evaluated and compared the potential use of barges and heavy-haul trucks to transport casks containing spent nuclear fuel from these sites to nearby railheads. The analysis assumed barges or heavy-haul trucks would be offloaded at the railheads and the casks would be transferred to railcars for shipment to Nevada.

DOE eliminated the large-scale barge scenario from further consideration in the EIS because it would be overly complex, requiring greater logistical complexity than either rail or legal-weight truck transportation; a much greater number of large rail casks than rail transport; much greater cost than either rail or legal-weight truck transportation; long transport distances potentially requiring the transit of the Panama Canal outside U.S. territorial waters; transport on intercoastal and coastal waterways of coastal states and on major rivers through and bordering states; extended transportation times; intermodal transfer operations at ports; and land transport from a western port to Yucca Mountain. If in the future DOE concluded that barge transportation was reasonable and proposed to make use of it, the Department would conduct additional National Environmental Policy Act evaluations to assess potential impacts of the greater use.

J.2.3 EFFECTS OF USING DEDICATED TRAINS OR GENERAL FREIGHT SERVICE

The Association of American Railroads recommends that only special (dedicated) trains move spent nuclear fuel and certain other forms of radioactive materials (DIRS 103718-DOT 1998, p. 2-6). In developing its recommendation, the Association concluded that the use of special trains would provide operational (for railroads and shippers) and safety advantages over shipments that used general freight service. Notwithstanding this recommendation, the U.S. Department of Transportation study (DIRS 103718-DOT 1998, all) compared dedicated and regular freight service using factors that measure impacts to overall public safety. The results of this study indicated that dedicated trains could provide advantages over regular trains for incident-free transportation but could be less advantageous for accident risks. However, available information does not indicate a clear advantage for the use of either dedicated trains or general freight service. Thus, DOE has not determined the commercial arrangements it would request from railroads for shipment of spent nuclear fuel and high-level radioactive waste. Table J-25 compares the dedicated and general freight modes. These comparisons are based on the findings of the U.S. Department of Transportation study and the Association of American Railroads.

J.2.4 IMPACTS OF THE SHIPMENT OF COMMERCIAL SPENT NUCLEAR FUEL BY BARGE AND HEAVY-HAUL TRUCK FROM 24 SITES NOT SERVED BY A RAILROAD

The mostly rail scenario includes 24 sites that do not have direct rail access. For those sites, heavy-haul trucks would be used to haul the spent nuclear fuel casks to the nearest railhead. As shown in Figure J-9 (a multipage figure), 17 of the 24 sites are on navigable waterways, so barge transport could be a feasible way to move spent nuclear fuel to the closest railhead with barge access. This section estimates the changes in impacts to the mostly rail scenario if barge transport replaced heavy-haul truck transport for these 17 sites.

J.2.4.1 Routes for Barges and Heavy-Haul Trucks

The distances from the 24 sites to railheads range from about 6 to 75 kilometers (4 to 47 miles). DOE used the HIGHWAY computer code to estimate routing for heavy-haul trucks (DIRS 104780-Johnson et al. 1993, all). The INTERLINE computer code (DIRS 104781-Johnson et al. 1993, all) was used to generate route-specific distances that would be traveled by barges. Table J-26 lists estimates for route lengths for barges and heavy-haul trucks. Table J-27 lists the number of shipments from each site.

Table J-25. Comparison of general freight and dedicated train service.

Attribute	General freight	Dedicated train
Overall accident rate for accidents that could damage shipping casks	Same as mainline railroad accident rates	Expected to be lower than general freight service because of operating restrictions and use of the most up-to-date railroad technology.
Grade crossing, trespasser, worker fatalities	Same as mainline railroad rates for fatalities	Uncertain. Greater number of trains could result in more fatalities in grade crossing accidents. Fewer stops in classification yards could reduce work related fatalities and trespasser fatalities.
Security	Security provided by escorts required by NRC[a] regulations	Security provided by escorts required by NRC regulations; fewer stops in classification yards than general freight service.
Incident-free dose to public	Low, but more stops in classification yards than dedicated trains. However, classification yards would tend to be remote from populated areas.	Lower than general freight service. Dedicated trains could be direct routed with fewer stops in classification yards for crew and equipment changes.
Radiological risks from accidents	Low, but greater than dedicated trains	Lower than general freight service because operating restrictions and equipment could contribute to lower accident rates and reduced likelihood of maximum severity accidents.
Occupational dose	Duration of travel influences dose to escorts	Shorter travel time would result in lower occupational dose to escorts.
Utilization of resources	Long cross-country transit times could result in least efficient use of expensive transportation cask resources; best use of railroad resources; least reliable delivery scheduling; most difficult to coordinate state notifications.	Direct through travel with on-time deliveries would result in most efficient use of cask resources; least efficient use of railroad resources. Railroad resource demands from other shippers could lead to schedule and throughput conflicts. Easiest to coordinate notification of state officials.

a. NRC = U.S. Nuclear Regulatory Commission.

J.2.4.2 Analysis of Incident-Free Impacts for Barge and Heavy-Haul Truck Transportation

J.2.4.2.1 *Radiological Impacts of Incident-Free Transportation*

This section compares radiological and nonradiological impacts to populations, workers, and maximally exposed individuals for the mostly rail case when casks from heavy-haul truck transport would be switched to barge for 17 of the 24 heavy haul truck sites. To make the comparison, the analysis retained any assumptions not affected by the mode change for the 17 sites. Thus:

- The seven sites that would ship by heavy-haul truck and do not have barge access would ship by heavy-haul truck in the barge case.

- The sites that would ship by legal-weight truck in the mostly rail case still ship by legal-weight truck for the barge analysis.

- For the rail segments of the routes that would use barge transport, separate INTERLINE runs determined the routes from the closest barge dock with rail access to each of the six end nodes in Nevada. While these routes are normally the same outside the origin state, no restrictions were imposed on INTERLINE requiring that the routes outside the origin state be the same.

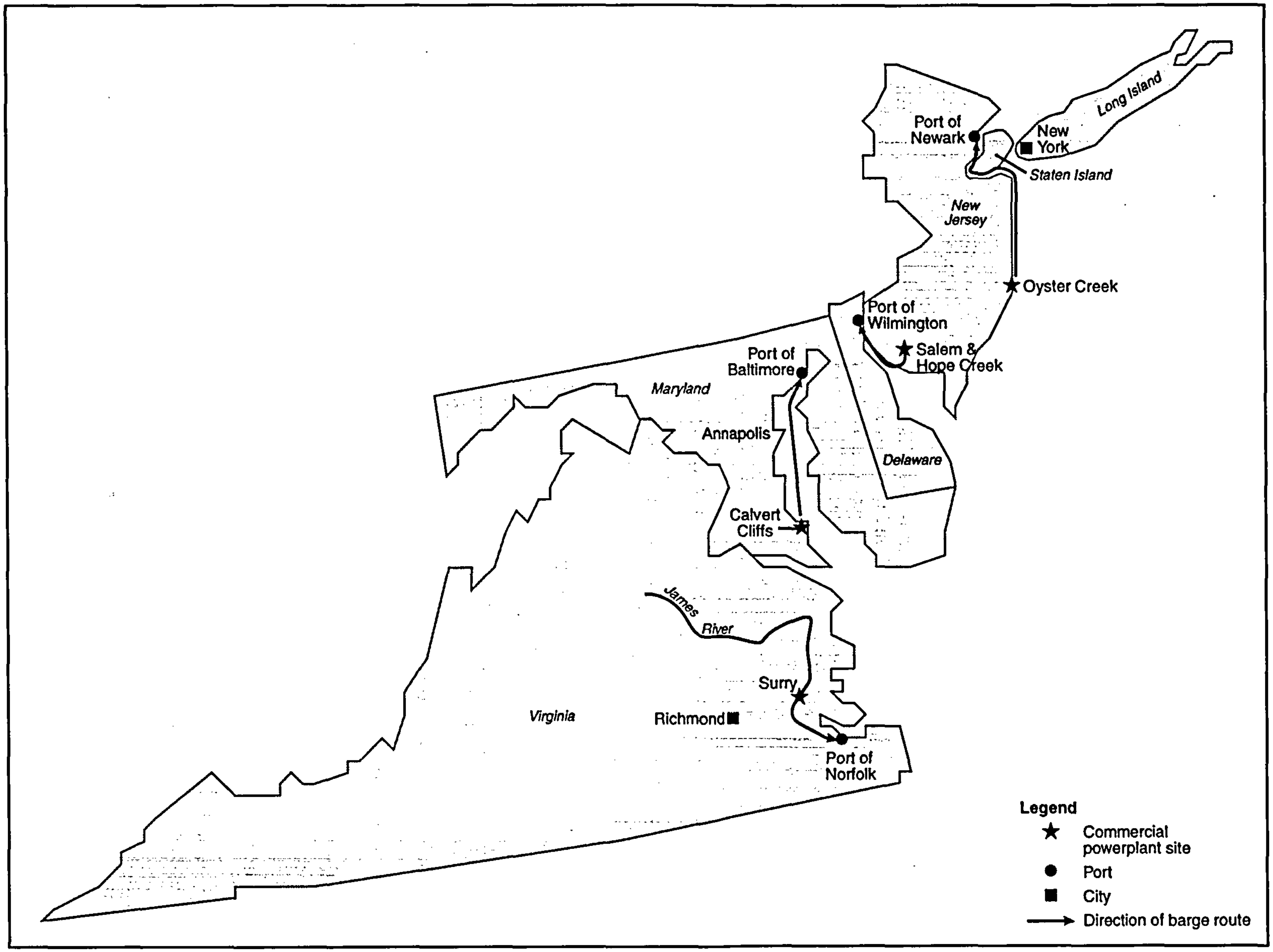


Figure J-9. Routes analyzed for barge transportation from sites to nearby railheads (page 1 of 4).

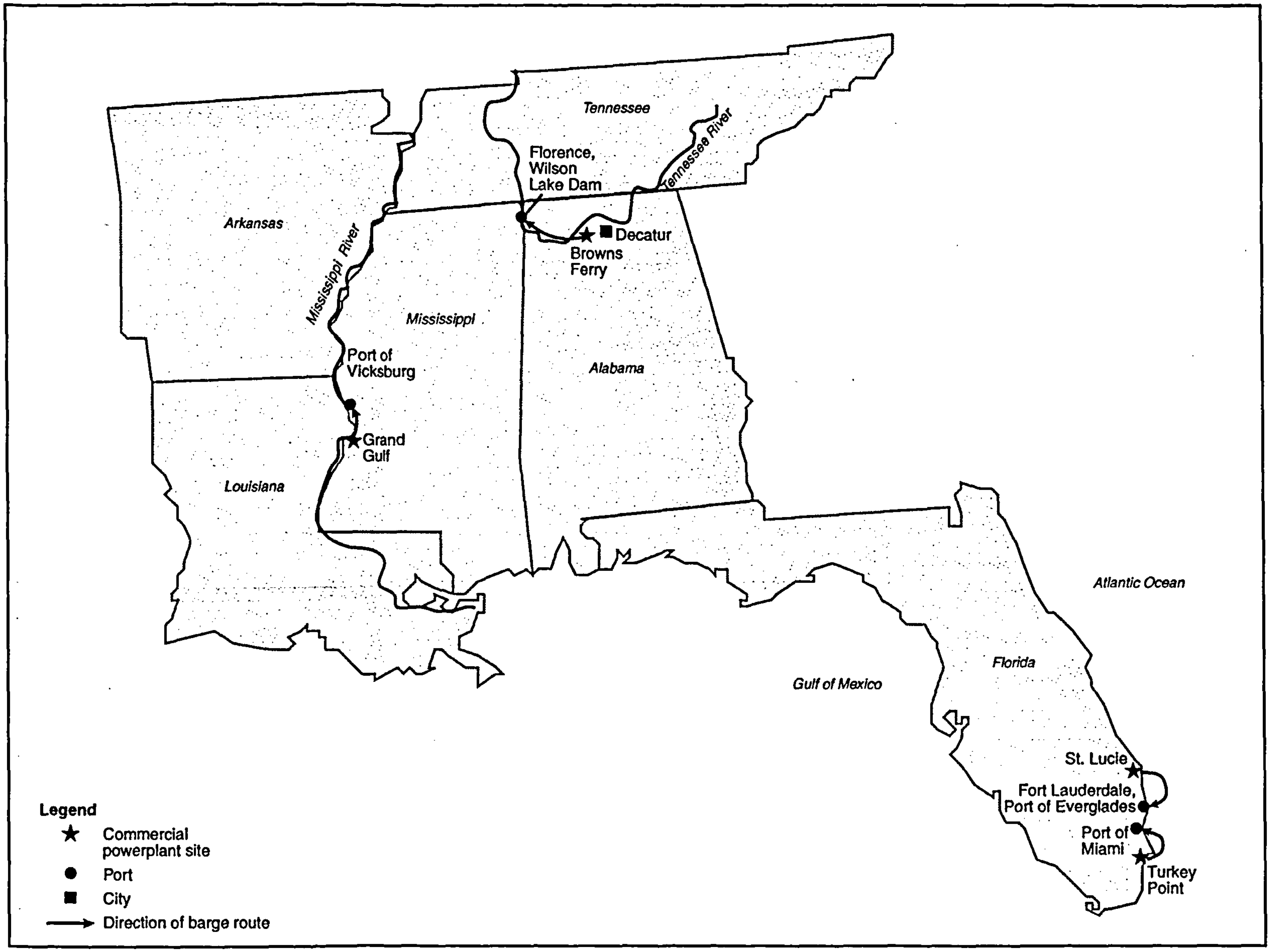


Figure J-9. Routes analyzed for barge transportation from sites to nearby railheads (page 2 of 4).

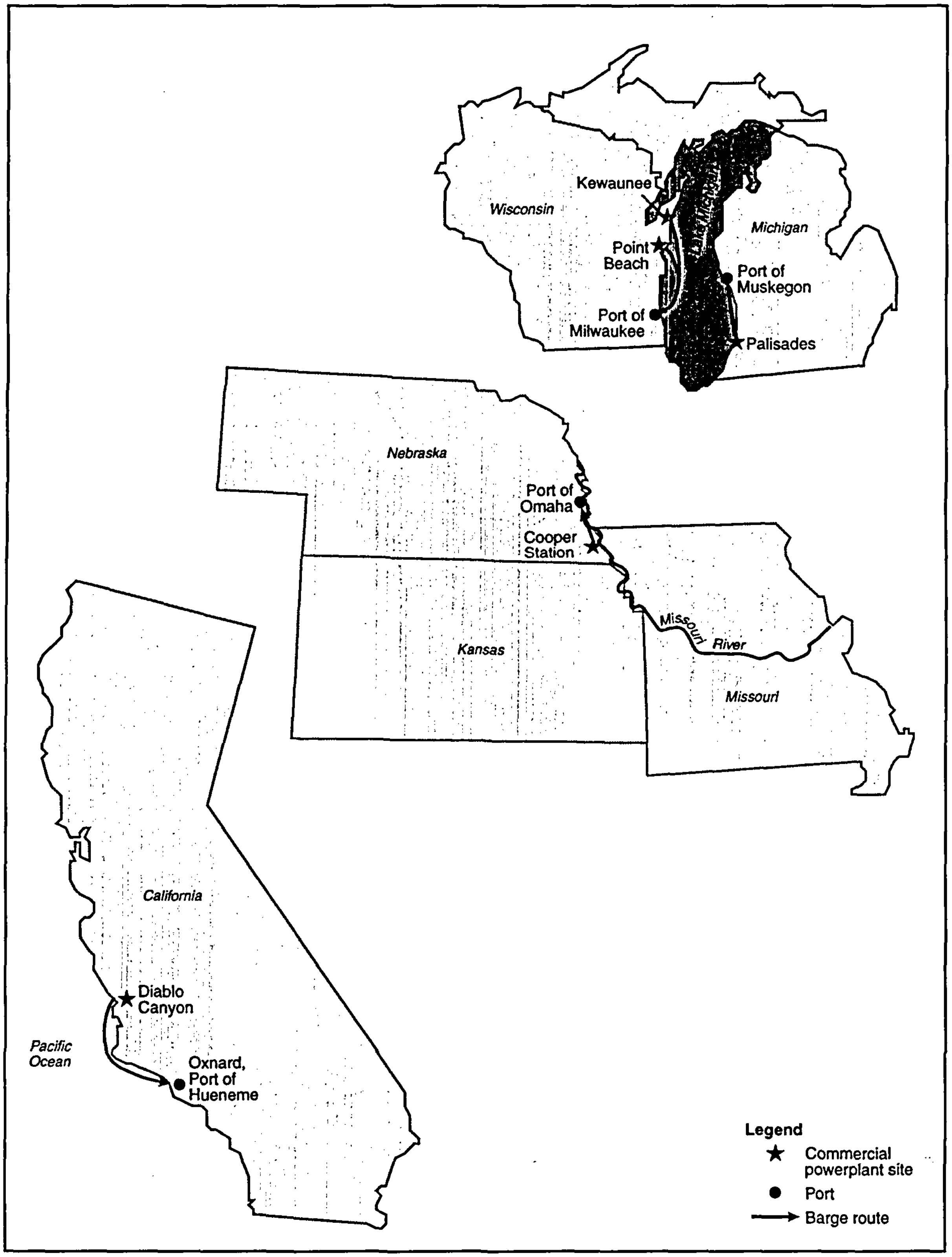


Figure J-9. Routes analyzed for barge transportation from sites to nearby railheads (page 3 of 4).

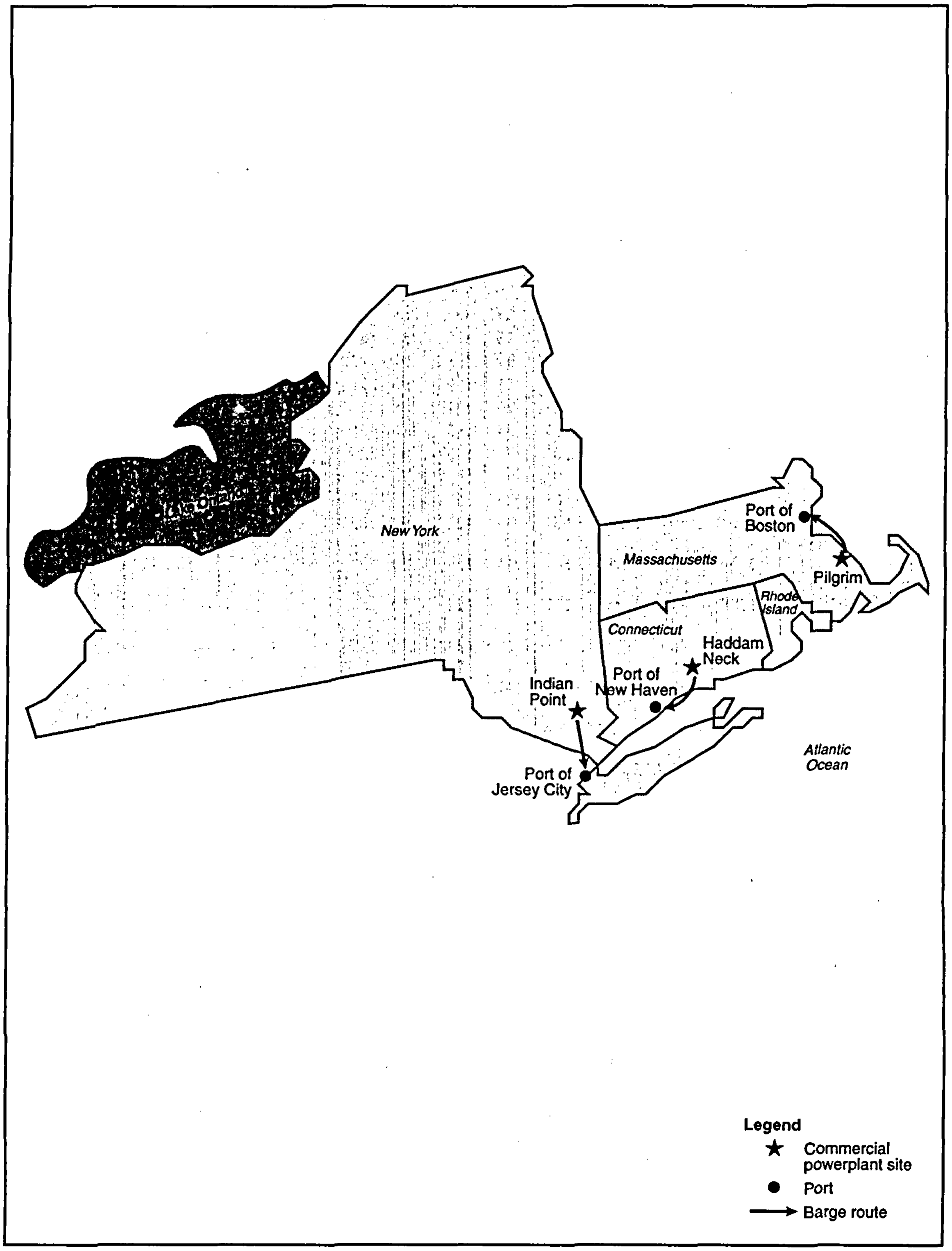


Figure J-9. Routes analyzed for barge transportation from sites to nearby railheads (page 4 of 4).

Table J-26. National transportation distances from commercial sites to Nevada ending rail nodes (kilometers).[a,b]

Site (intermodal rail node)[c]	Rail transportation				Barge transportation			
	Total[d]	Rural	Suburban	Urban	Total[d]	Rural	Suburban	Urban
Browns Ferry NP[e]	3,279 - 3,656	2,985 - 3,306	260 - 300	34 - 49	57	51	5	0
Calvert Cliffs NP	4,028 - 4,404	3,270 - 3,592	610 - 650	148 - 162	99	98	2	0
Cooper NP	2,029 - 2,405	1,910 - 2,231	98 - 138	21 - 36	117	100	16	1
Diablo Canyon NP	582 - 1,453	375 - 1,006	112 - 311	94 - 136	143	143	0	0
Grand Gulf NP	3,298 - 3,665	2,859 - 3,333	270 - 373	28 - 67	51	51	0	0
Haddam Neck NP	4,339 - 4,716	3,316 - 3,637	842 - 882	182 - 197	99	89	10	0
Hope Creek NP	4,229 - 4,605	3,458 - 3,779	655 - 695	116 - 131	30	30	0	0
Indian Point NP	4,351 - 4,727	3,425 - 3,746	766 - 806	160 - 175	68	13	39	15
Kewaunee NP	2,864 - 3,241	2,506 - 2,827	291 - 331	68 - 82	177	171	1	5
Oyster Creek NP	4,337 - 4,714	3,420 - 3,741	765 - 806	152 - 167	130	77	36	17
Palisades NP	3,060 - 3,436	2,607 - 2,929	355 - 395	97 - 112	256	256	0	0
Pilgrim NP	4,393 - 4,769	3,338 - 3,659	858 - 899	196 - 211	74	41	33	0
Point Beach NP	2,864 - 3,241	2,506 - 2,827	291 - 331	68 - 82	169	163	1	5
Salem NP	4,229 - 4,605	3,458 - 3,779	655 - 695	116 - 131	34	34	0	0
St. Lucie NP	4,840 - 5,136	3,934 - 4,205	756 - 842	87 - 139	140	50	52	38
Surry NP	4,403 - 4,780	3,773 - 4,094	554 - 595	76 - 90	71	60	8	3
Turkey Point NP	4,882 - 5,178	3,937 - 4,208	765 - 851	117 - 169	54	53	0	1
Big Rock Point NP HH – 20.0 kilometers	3,258 - 3,595	2,766 - 3,059	399 - 431	93 - 105	--[f]	--	--	--
Callaway NP HH – 18.5 kilometers	2,491 - 2,868	2,352 - 2,674	119 - 159	20 - 35	--	--	--	--
Fort Calhoun NP HH – 6.0 kilometers	1,997 - 2,373	1,905 - 2,227	81 - 122	10 - 25	--	--	--	--
Ginna NP HH – 35.1 kilometers	3,532 - 3,869	2,792 - 3,086	604 - 636	136 - 147	--	--	--	--
Oconee NP HH – 17.5 kilometers	3,999 - 4,375	3,470 - 3,792	475 - 515	54 - 68	--	--	--	--
Peach Bottom NP HH – 58.9 kilometers	4,110 - 4,486	3,383 - 3,704	616 - 656	111 - 126	--	--	--	--
Yankee Rowe NP HH – 10.1 kilometers	3,998 - 4,335	3,083 - 3,376	752 - 784	164 - 175	--	--	--	--

a. To convert kilometers to miles, multiply by 0.62137.
b. Distances estimated using INTERLINE computer program. Salem/Hope Creek treated as two sites.
c. Intermodal rail nodes selected for purpose of analysis. Source: (DIRS 104800-CRWMS M&O 1999, all).
d. Totals might differ from sums of rural, suburban, and urban distances due to method of calculation and rounding.
e. NP = nuclear plant.
f. -- = sites not located on a navigable waterway.

The analysis included radiological impacts of intermodal transfers at the interchange from heavy-haul trucks to railcars or barges to railcars. Workers would be exposed to radiation from casks during transfer operations. However, because the transfers would occur in terminals and berths remote from public access, public exposures would be small. Impacts of constructing intermodal transfer facilities were not included because intermodal transfers were assumed to take place at existing facilities.

The analysis assumed that heavy-haul trucks would travel at a lower speed than legal-weight trucks and that barge transport would be even slower. The assumed speed was 40 kilometers (25 miles) per hour and 8 kilometers (5 miles) per hour for heavy-haul truck and barge transport, respectively. These speeds were assumed to be independent of any population zone. Because travel distances to nearby railheads are short in relation to the distances traveled by rail, the expected impacts of heavy-haul truck and barge transportation would be much smaller than those of national rail shipments. The analysis of impacts for barge shipments assumed that the transport would employ commercial vessels operated by maritime

Table J-27. Barge shipments and ports.

Plant name	State	Number of shipments: Proposed Action	Module 1	Module 2	Barge ports assumed for barge-to-rail intermodal transfer
Browns Ferry 1	AL	122	247	248	Wilson Loading Dock
Browns Ferry 2	AL	0	0	1	Wilson Loading Dock
Browns Ferry 3	AL	51	120	121	Wilson Loading Dock
Diablo Canyon 1	CA	60	148	150	Port Huememe
Diablo Canyon 2	CA	61	160	162	Port Huememe
Haddam Neck	CT	40	40	42	Port of New Haven
St. Lucie 1	FL	12	13	16	Port Everglades
St. Lucie 2	FL	61	147	150	Port Everglades
Turkey Point 3	FL	52	85	87	Port of Miami
Turkey Point 4	FL	52	86	88	Port of Miami
Calvert Cliffs 1	MD	169	320	323	Port of Baltimore
Calvert Cliffs 2	MD	0	0	3	Port of Baltimore
Pilgrim	MA	24	18	19	Port of Boston
Palisades	MI	70	122	125	Port of Muskegon
Grand Gulf 1	MS	80	215	216	Port of Vicksburg
Cooper Station	NE	42	124	125	Port of Omaha
Hope Creek	NJ	67	105	106	Port of Wilmington
Oyster Creek 1	NJ	64	110	111	Port of Newark
Salem 1	NJ	59	101	103	Port of Wilmington
Salem 2	NJ	54	108	110	Port of Wilmington
Indian Point 1	NY	0	0	1	Port of Jersey City
Indian Point 2	NY	35	34	36	Port of Jersey City
Indian Point 3	NY	22	19	21	Port of Jersey City
Surry 1	VA	197	330	332	Port of Norfolk
Surry 2	VA	0	0	2	Port of Norfolk
Kewaunee	WI	64	110	111	Port of Milwaukee
Point Beach 1	WI	130	213	215	Port of Milwaukee
Point Beach 2	WI	0	0	2	Port of Milwaukee
Totals		*1,575*	*2,952*	*3,004*	

carriers on navigable waterways and that these shipments would follow direct routing from the sites to nearby railheads. For both modes, intermodal transfers would be necessary to transfer the casks to railcars.

The analysis estimated radiological impacts during transport for workers and the general population. For heavy-haul truck shipments, workers included vehicle drivers and escorts. For barge shipments, workers included five crew members on board during travel. In both the heavy-haul truck and barge cases, the workers would be far enough from the cask such that the major exposure would occur during periodic walkaround inspections. In both cases, consistent with the as-low-as-reasonably-achievable requirement guiding worker exposure, the analysis assumed that only one individual would perform these inspections. The general population for truck shipments included persons within 800 meters (about 2,600 feet) of the road (offlink), persons sharing the road (onlink), and persons at stops. The general population for barging included persons within a range of 200 to 1,000 meters (about 660 to 3,300 feet) of the route. Consistent with normal barge operations, the periodic walkaround inspections would occur while the barge was in motion and there was sufficient crew on board to eliminate the need for intermediate rest stops. Consistent with the RADTRAN 5 modeling, onlink exposures to members of the public during barging were assumed to be negligible. Incident-free unit risk factors were developed to calculate occupational and general population collective doses. Table J-28 lists the unit risk factors for heavy-haul truck and barge shipments. These factors reflect the effects of slower operating speeds for those vehicles in comparison to those for legal-weight trucks.

Table J-29 lists the incident-free impacts using the three shipment scenarios listed above. Impacts of intermodal transfers are included in the results. Occupational impacts would include the estimated radiological exposures of security escorts.

Table J-28. Risk factors for incident-free heavy-haul truck and barge transportation of spent nuclear fuel and high-level radioactive waste.

Mode	Exposure group	Incident-free risk factors (person-rem per kilometer)[a] Rural	Suburban	Urban
Heavy-haul truck	*Occupational*			
	Onlink[b]	5.54×10^{-6}	5.54×10^{-6}	5.54×10^{-6}
	Stops[b]	1.45×10^{-5}	1.45×10^{-5}	1.45×10^{-5}
	General population			
	Offlink[c]	6.24×10^{-8}	6.24×10^{-8}	6.24×10^{-8}
	Onlink[b]	1.01×10^{-4}	7.94×10^{-5}	2.85×10^{-4}
	Stops[b]	3.96×10^{-9}	3.96×10^{-9}	3.96×10^{-9}
	Overnight stop	2.62×10^{-3}		
Barge	*Occupational*[d]	2.11×10^{-6}	2.11×10^{-6}	2.11×10^{-6}
	General population			
	Offlink[c]	1.72×10^{-7}	1.72×10^{-7}	1.72×10^{-7}
	Onlink[b]	0.0	0.0	0.0
	Stops	0.0	0.0	0.0

a. The unit dose factors are developed from the equations in DIRS 155430-Neuhauser, Kanipe, and Weiner (2000, all) in the same way as the unit dose factors in Section J.1.3.
b. Onlink and stopped risk factors consider the exposure to the general population sharing the road and the crew transporting the cask. These factors must be multiplied by the number of shipments and the distance in kilometers in the zone for each segment of the route. The onlink vehicle density for rural transportation in Nevada was estimated using the annual average daily traffic on I-15 at the California-Nevada border (DIRS 103405-NDOT 1997, p. 4).
c. Offlink general population included persons from 30 to 800 meters (about 100 to 2,600 feet) of the road or railway and from 200 and 1,000 meters (about 650 and 3,300 feet) for barge. This risk factor must be multiplied by the number of shipments, distance in kilometers in the zone, and the population density (individuals per square kilometer) in the zone for each segment of the route.
d. Because heavy-haul vehicles cannot be in transit in Nevada for more than 12 hours, an overnight stop is modeled for routes that would require trips longer than 12 hours. This stop is not modeled for the short distances between reactor sites and railheads for indirect rail sites. When used, the factor is multiplied by the number of shipments.

Table J-29. Comparison of population doses and impacts from incident-free national transportation mostly rail heavy-haul truck scenario, mostly rail barge scenario, and mostly truck scenario.[a,b]

Category	Mostly rail (heavy-haul truck)[c]	Mostly rail (barge from 17 of 24 heavy-haul sites)[c]	Mostly truck
Involved worker			
Collective dose (person-rem)	4,300	4,400	14,100
Estimated LCFs[d]	1.7	1.7	5.6
Public			
Collective dose (person-rem)	1,500	1,400	5,000
Estimated LCFs	0.8	0.7	2.5
Maximally exposed individual			
Dose (rem)	0.29	0.29	3.2
Estimated emissions fatalities	0.0001[e]	0.0001[e]	0.0016[f]

a. Impacts are totals for all shipments over 24 years.
b. Includes impacts from intermodal transfer station (see Section 6.3.3.1).
c. Nevada impacts for the mostly rail routes have been averaged to show the effects of using barges at the origin.
d. LCF = latent cancer fatality.
e. Resident near a rail stop.
f. Person at a service station.

As indicated in Table J-29, the differences between the two mostly rail scenarios, heavy-haul truck and barge to nearby railheads, would be much smaller than the differences between the mostly rail scenarios and the mostly truck scenario. Considering only the mostly rail case options, heavy-haul and barge, the slower speed of the barge would tend to make barge exposures higher and the closest distance to resident population, 30 meters (100 feet) versus 200 meters (660 feet) for heavy-haul and barge, respectively, would tend to make barge exposures lower. Differences in the total exposed population or travel distances between the heavy-haul truck and barge routes could result in differences in the collective dose. Table J-29 indicates that the collective dose to the general public would be about the same as the barge case. Because workers would be well away from the cask during transport, the collective dose to workers would depend totally on the number of inspections performed during transit. Table J-29 indicates that these differences would be small. Based on this table, the barge scenario would have approximately the same impacts as the heavy-haul truck scenario that DOE used as a basis for the mostly rail results in Section J.1.3 and J.1.4.

J.2.4.2.2 *Nonradiological Impacts of Incident-Free Transportation (Vehicle Emissions)*

Table J-30 compares the estimated number of fatalities from vehicle emissions from shipments, assuming the use of heavy-haul trucks or barges to ship to nearby railheads.

Table J-30. Estimated population health impacts from vehicle emissions during incident-free national transportation for mostly rail heavy-haul truck and barge scenarios and the mostly legal-weight truck scenario.[a]

Category	Mostly rail (heavy-haul from 24 sites)	Mostly rail (heavy-haul truck from 7 sites and barge from 17)	Mostly truck
Estimated fatalities	0.63	0.62	0.93

a. Impacts are totals over 24 years, including impacts from an intermodal transfer station (see Chapter 6, Section 6.3.3.1).

J.2.4.3 Analysis of Impacts of Accidents for Barge and Heavy-Haul Truck Transportation

J.2.4.3.1 *Radiological Impacts of Accidents*

The analysis of risks from accidents during heavy-haul truck, rail, and legal-weight truck transport of spent nuclear fuel and high-level radioactive waste used the RADTRAN 5 computer code (DIRS 150898-Neuhauser and Kanipe 2000, all; DIRS 155430-Neuhauser, Kanipe, and Weiner 2000, all) in conjunction with an Access database and the analysis approach discussed in Section J.1.4.2. The analysis of risks due to barging used the same methodology with the exception of conditional probabilities. For barge shipments, the conditional accident probabilities and release fractions (Table J-31) for each cask response category were based on a review of other barge accident analyses.

The definitions of the accident severities listed in Table J-31 are based on the analyses reported in DIRS 152476-Sprung et al. (2000, pp. 7-75 to 7-76). DOE used the same accident severity category definitions as those used in the rail analysis described in Section J.1.4.2. If radioactive material was shipped by barge, both water and land contamination would be possible. DIRS 104784-Ostmeyer (1986, all) analyzed the potential importance of water pathway contamination for a spent nuclear fuel transportation accident risk using a "worst-case" water contamination scenario. The analysis showed that the impacts of the water contamination scenario would be about one-fiftieth of the impacts of a comparable accident on land. Therefore, the analysis assumed that deposition would occur over land, not water. DOE used population distributions developed from 1990 Census data to calculate route-specific collective doses. Table J-32 lists the total accident risk for mostly rail case heavy-haul truck scenario, the mostly rail case barge scenario, and the mostly truck scenario. Additional information is in Volume IV.

J.2.4.3.2 *Nonradiological Accident Risks*

As listed in Table J-32, the estimated total fatalities for the mostly rail heavy-haul truck scenario, the mostly rail barge scenario, and the mostly truck scenario would be 2.7, 2.7, and 4.5, respectively. There is essentially no difference between the two mostly rail scenarios. The only significant differences are between those scenarios, and the mostly truck case.

Table J-31. Release fractions and conditional probabilities for spent nuclear fuel transported by barge.

Severity category	Case	Conditional probability	Release fractions (pressurized-water reactor/boiling-water reactor)				
			Krypton	Cesium	Ruthenium	Particulates	Crud
1	21	0.994427	0.0	0.0	0.0	0.0	0.0
2	1, 4, 5, 7, 8	5.00×10^{-3}	$1.96 \times 10^{-1}/2.35 \times 10^{-2}$	$5.87 \times 10^{-9}/7.04 \times 10^{-10}$	$1.34 \times 10^{-7}/1.47 \times 10^{-8}$	$1.34 \times 10^{-7}/1.47 \times 10^{-8}$	$1.37 \times 10^{-3}/5.59 \times 10^{-4}$
3	20	5.00×10^{-6}	$8.39 \times 10^{-1}/8.39 \times 10^{-1}$	$1.68 \times 10^{-5}/1.68 \times 10^{-5}$	$2.52 \times 10^{-7}/2.52 \times 10^{-7}$	$2.52 \times 10^{-7}/2.52 \times 10^{-7}$	$9.44 \times 10^{-3}/9.44 \times 10^{-2}$
4	2, 3, 10	5.00×10^{-4}	$8.00 \times 10^{-1}/8.00 \times 10^{-1}$	$8.71 \times 10^{-6}/8.71 \times 10^{-6}$	$1.32 \times 10^{-5}/1.32 \times 10^{-5}$	$1.32 \times 10^{-5}/1.32 \times 10^{-5}$	$4.42 \times 10^{-3}/4.42 \times 10^{-2}$
5	6	0.0	$8.35 \times 10^{-1}/8.37 \times 10^{-1}$	$3.60 \times 10^{-5}/4.12 \times 10^{-5}$	$1.37 \times 10^{-5}/1.82 \times 10^{-5}$	$1.37 \times 10^{-5}/1.82 \times 10^{-5}$	$5.36 \times 10^{-3}/5.43 \times 10^{-3}$
6	9,11,12,13,14,15,16, 17,18,19	1.30×10^{-6}	$8.47 \times 10^{-1}/8.45 \times 10^{-1}$	$5.71 \times 10^{-5}/7.30 \times 10^{-5}$	$4.63 \times 10^{-5}/5.94 \times 10^{-5}$	$1.43 \times 10^{-5}/1.96 \times 10^{-5}$	$1.59 \times 10^{-2}/1.60 \times 10^{-2}$

Table J-32. Comparison of accident risks for the mostly rail heavy-haul truck and barge shipping scenarios.[a]

Category	Mostly rail (heavy-haul option–24 sites)	Mostly rail (barge option–17 of 24 heavy-haul sites)	Mostly truck
Population dose (person-rem)	0.89	1.5	0.5
Estimated LCFs[b]	0.00045	0.001	0.0002
Traffic fatalities[c]	2.7	2.7	4.5

a. Impacts are totals over 24 years.
b. LCF = latent cancer fatality.
c. Traffic fatality impacts for mostly rail scenarios are the average of the range of estimated traffic fatality impacts (2.3 to 3.1) for national transportation for the Proposed Action.

J.2.4.3.3 *Maximum Reasonably Foreseeable Accidents*

From a consequence standpoint, because DOE used the same accident severity bins for rail, heavy-haul truck, and barge transport, the consequences of a release would be the same if the accident occurred in a zone having the same population density. The population densities for barge and heavy-haul truck transport are similar to those for rail. Because the total shipping distance traveled by barge or heavy-haul truck would be a small fraction of the total distance traveled, the maximum reasonably foreseeable accident would be a rail accident. Only minor barge or heavy-haul truck transport accidents would meet the 1×10^{-7} criterion used to identify reasonably foreseeable accidents.

J.3 Nevada Transportation

With the exceptions of the possible construction of a branch rail line or upgrade of highways for use by heavy-haul trucks and the construction of an intermodal transfer station, the characteristics of the transportation of spent nuclear fuel and high-level radioactive waste in Nevada would be similar to those for transportation in other states across the nation. Unless the State of Nevada designated alternative or additional preferred routes as prescribed under regulations of the U.S. Department of Transportation (49 CFR 397.103), Interstate System Highways (I-15) would be the preferred routes used by legal-weight trucks carrying spent nuclear fuel and high-level radioactive waste. Unless alternative or non-Interstate System routes have been designated by states, Interstate System highways would also be the preferred routes used by legal-weight trucks in other states during transit to Nevada.

In Nevada as in other states, rail shipments would, for the most part, be transported on mainline tracks of major railroads. Operations over a branch rail line in Nevada would be similar to those on a mainline railroad, except the frequency of train travel would be much lower. Shipments in Nevada that used heavy-haul trucks would use Nevada highways in much the same way that other overdimensional, overweight trucks use the highways along with other commercial vehicle traffic.

Some State- and county-specific assumptions were used to analyze human health and safety impacts in Nevada. A major difference would be that much of the travel in the State would be in rural areas where population densities are much lower than those of many other states. Another difference would be for travel in an urban area in the state. The most populous urban area in Nevada is the Las Vegas metropolitan area, which is also a major resort area with a high percentage of nonresidents. The analysis also addressed the channeling of shipments from the commercial and DOE sites into the transportation arteries in the southern part of the State. Finally, the analysis addressed the commuter and commercial travel that would occur on highways in the southern part of the State as a consequence of the construction, operation and monitoring, and closure of the proposed repository.

This section presents information specific to Nevada that DOE used to estimate impacts for transportation activities that would take place in the State. It includes results for cumulative impacts that would occur in Nevada for transportation associated with Inventory Modules 1 and 2.

J.3.1 TRANSPORTATION MODES, ROUTES, AND NUMBER OF SHIPMENTS

J.3.1.1 Routes in Nevada for Legal-Weight Trucks

The analysis of impacts that would occur in Nevada used the characteristics of highways in Nevada that would be used for shipments of spent nuclear fuel and high-level radioactive waste by legal-weight trucks. Specifically, the base case for the analysis used routing for the Las Vegas Northern and Western Beltway to transport spent nuclear fuel and high-level radioactive waste. The distance and population density by county was obtained from Geographical Information System data for the State of Nevada using 1990 Census data. The population density data was escalated to 2035.

Figure J-10 shows the routes in Nevada that legal-weight trucks would use unless the State designated alternative or additional preferred routes. The figure shows estimates for the number of legal-weight truck shipments that would travel on each route segment for the mostly legal-weight truck and mostly rail transportation scenarios. The inset on Figure J-10 shows the Las Vegas Beltway and the routes DOE anticipates legal-weight trucks traveling to the repository would use.

J.3.1.2 Highway and Rail Routes in Nevada for Transporting Rail Casks

The rail and heavy-haul truck implementing alternatives for transportation in Nevada include five possible rail corridors and five possible routes for heavy-haul trucks; the corridors and routes for these implementing alternatives are shown in Figures J-11 and J-12. These figures also show the estimated number of rail shipments that would enter the State on mainline railroads. These numbers indicate shipments that would arrive from the direction of the bordering state for each of the implementing alternatives for the mostly rail transportation scenario.

Table J-33 lists the total length and cumulative distance in rural, suburban, and urban population zones and the population density in each population zone in the State of Nevada used to analyze impacts of the implementing alternatives. Table J-34 lists the cumulative distance in rural, suburban, and urban population zones and the population density in each population zone for existing commercial rail lines in Nevada. DOE based the estimated population that would live along each branch rail line on population densities in census blocks along the candidate rail corridors in Nevada. The populations are based on 1990 Census data escalated to 2035. For this analysis, the ending rail nodes in Nevada for commercial rail lines would be origins for the rail and heavy-haul truck alternatives listed in Table J-33. Table J-35 lists the total population that lives within 800 meters (0.5 mile) of rail lines in Nevada.

Nevada Heavy-Haul Truck Scenario
Tables J-36 through J-40 summarize the road upgrades for each of the five possible routes for heavy-haul trucks that DOE estimates would be needed before routine use of a route to ship casks containing spent nuclear fuel and high-level radioactive waste.

Nevada Rail Corridors
Under the mostly rail scenario, DOE could construct and operate a branch rail line in Nevada. Based on the studies listed below, DOE has narrowed its consideration for a new branch rail line to five potential rail corridors—Carlin, Caliente, Caliente-Chalk Mountain, Jean, and Valley Modified. DOE identified the five rail corridors through a process of screening potential rail alignments that it had studied in past years. Several studies evaluated rail transportation.

- The *Feasibility Study for Transportation Facilities to Nevada Test Site* study (DIRS 104777-Holmes & Narver 1962, all) determined the technical and economic feasibility of constructing and operating a railroad from Las Vegas to Mercury.

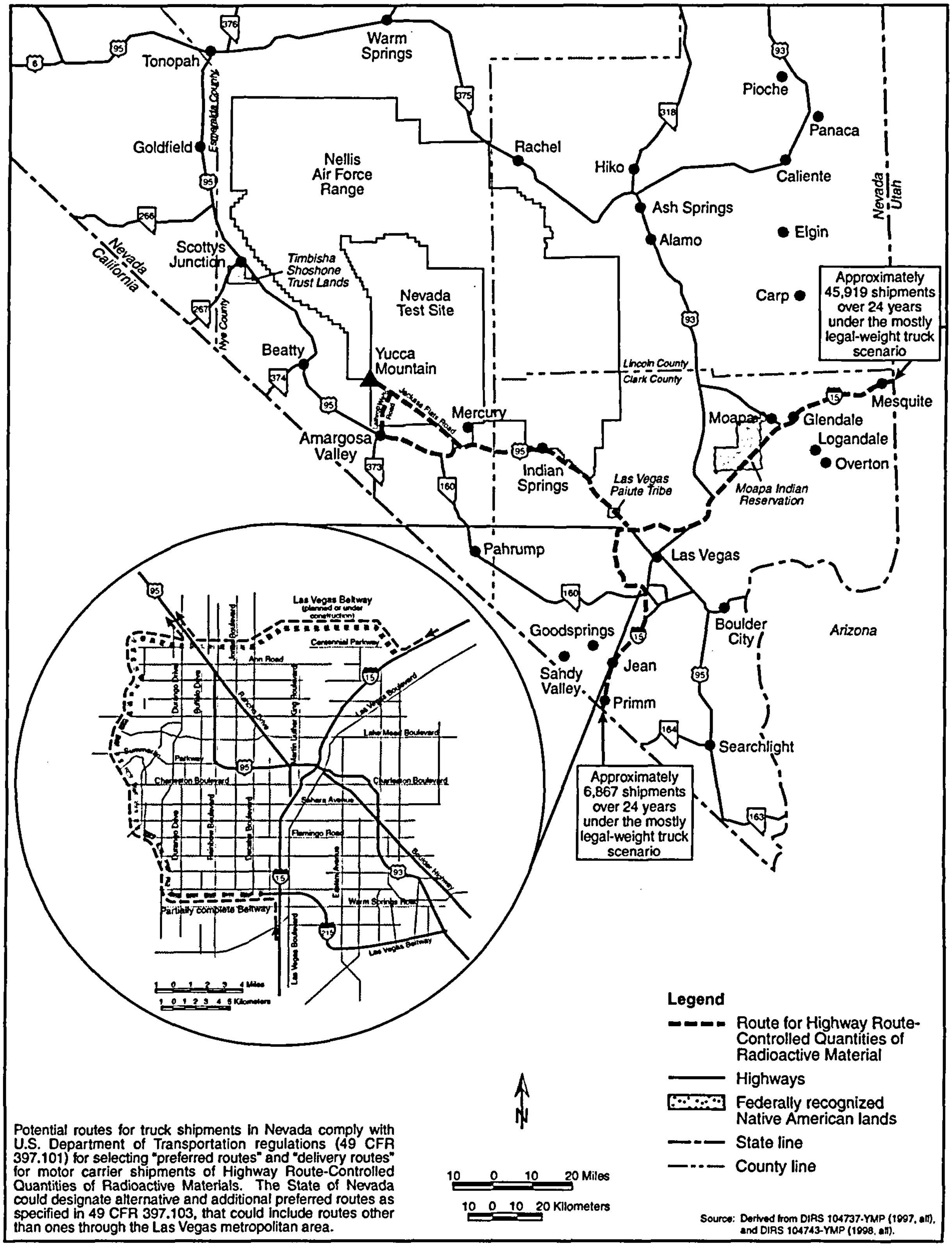


Figure J-10. Potential Nevada routes for legal-weight trucks and estimated number of shipments.

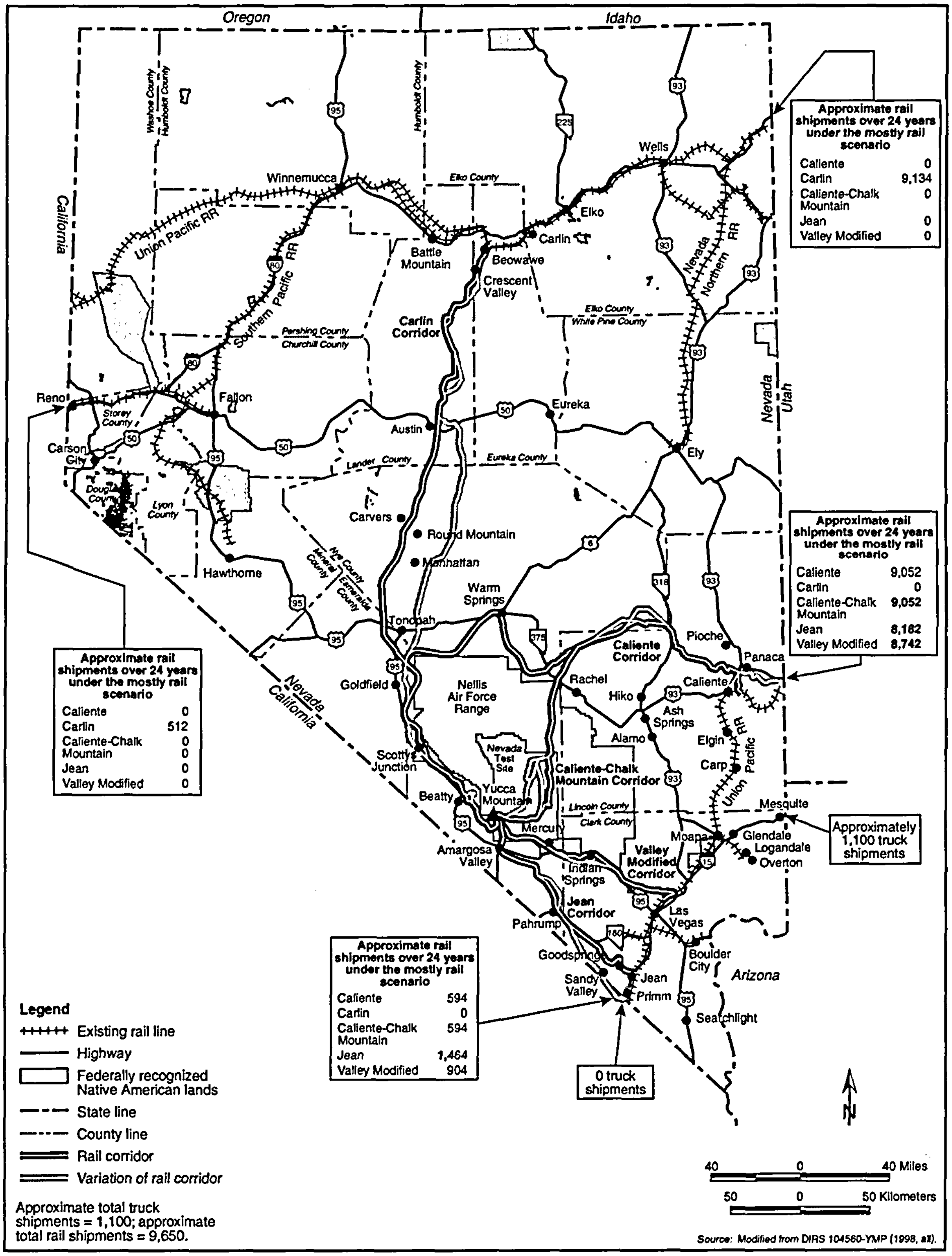


Figure J-11. Potential Nevada rail routes to Yucca Mountain and estimated number of shipments.

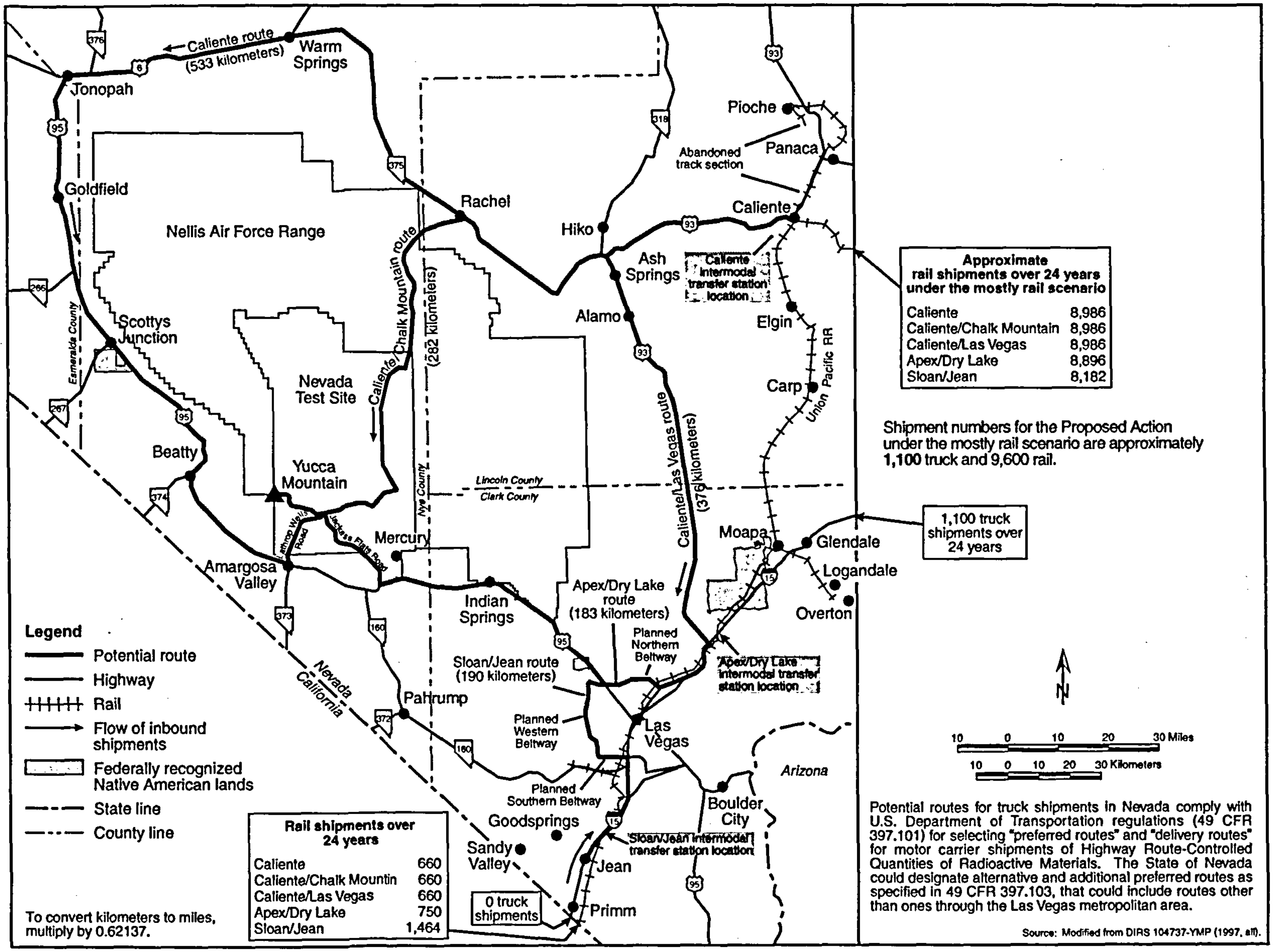


Figure J-12. Potential Nevada routes for heavy-haul trucks and estimated number of shipments.

Table J-33. Routing characteristics in Nevada for legal-weight truck, rail and heavy-haul truck implementing alternatives.

		Distance (kilometers)[a]				Population density (persons per square kilometer)		
Route	County	Urban	Suburban	Rural	Total	Urban	Suburban	Rural
Legal-weight truck route in Nevada using the Las Vegas Beltway								
Northern route	Clark	0.0	19.9	187.5	207.4	0.0	577	10.6
Northern route	Nye	0.0	0.0	64.7	64.7	0.0	0.0	0.0
Southern route	Clark	0.0	41.9	126.9	168.8	0.0	577	3.5
Southern route	Nye	0.0	0.0	64.7	64.7	0.0	0.0	0.0
Rail alternatives								
Caliente-Chalk Mountain	Lincoln	0.0	0.0	158.0	158.0	0.0	0.0	0.0
Caliente-Chalk Mountain	Nye	0.0	0.0	188.0	188.0	0.0	0.0	0.0
Caliente	Esmeralda	0.0	0.0	4.0	4.0	0.0	0.0	0.3
Caliente	Lincoln	0.0	0.0	148.5	148.5	0.0	0.0	0.0
Caliente	Nye	0.0	0.0	360.8	360.8	0.0	0.0	0.1
Carlin	Eureka	0.0	0.0	29.8	29.8	0.0	0.0	0.1
Carlin	Lander	0.0	0.0	158.7	158.7	0.0	0.0	0.0
Carlin	Esmeralda	0.0	0.0	41.0	41.0	0.0	0.0	0.4
Carlin	Nye	0.0	0.0	291.5	291.5	0.0	0.0	0.6
Jean	Clark	0.0	0.0	82.4	82.4	0.0	0.0	0.8
Jean	Nye	0.0	0.0	98.2	98.2	0.0	0.0	0.2
Apex	Clark	0.0	0.0	99.5	99.5	0.0	0.0	0.1
Apex	Nye	0.0	0.0	59.2	59.2	0.0	0.0	0.0
Heavy-haul alternatives								
Apex/Dry Lake	Clark	0.0	19.9	104.0	123.9	0.0	577	2.9
Apex/Dry Lake	Nye	0.0	0.0	59.4	59.4	0.0	0.0	0.001
Caliente	Esmeralda	0.0	0.0	71.6	71.6	0.0	0.0	2.0
Caliente	Lincoln	0.0	0.0	148.5	148.5	0.0	0.0	0.8
Caliente	Nye	0.0	4.7	308.5	313.2	0.0	261	0.7
Caliente/Las Vegas	Clark	0.0	19.9	147.3	167.2	0.0	577	2.1
Caliente/Las Vegas	Lincoln	0.0	0.0	149.7	149.7	0.0	0.0	0.8
Caliente/Las Vegas	Nye	0.0	0.0	59.4	59.4	0.0	0.0	0.001
Caliente/Chalk Mountain	Lincoln	0.0	0.0	146.9	146.9	0.0	0.0	0.9
Caliente/Chalk Mountain	Nye	0.0	0.0	135.3	135.3	0.0	0.0	0.0
Jean/Sloan	Clark	0.0	41.9	88.6	130.5	0.0	577	5.3
Jean/Sloan	Nye	0.0	0.0	59.4	59.4	0.0	0.0	0.0006

a. To convert kilometers to miles, multiply by 0.62137.

- The *Preliminary Rail Access Study* (DIRS 104792-YMP 1990, all) identified 13 and evaluated 10 rail corridor alignment options. This study recommended the Carlin, Caliente, and Jean Corridors for detailed evaluation.

- *The Nevada Railroad System: Physical, Operational, and Accident Characteristics* (DIRS 104735-YMP 1991, all) described the operational and physical characteristics of the current Nevada railroad system.

- The *High Speed Surface Transportation Between Las Vegas and the Nevada Test Site (NTS)* report (DIRS 104786-Cook 1994, all) explored the rationale for a potential high-speed rail corridor between Las Vegas and the Nevada Test Site to accommodate personnel.

- The *Nevada Potential Repository Preliminary Transportation Strategy, Study 1* (DIRS 104795-CRWMS M&O 1995, all), reevaluated 13 previously identified rail routes and evaluated a new route called the Valley Modified route. This study recommended four rail corridors for detailed evaluation—Caliente, Carlin, Jean, and Valley Modified.

Table J-34. Routing characteristics in Nevada for existing commercial rail lines.

			Distance (kilometers)[a]				Population density (persons per square kilometer)		
End node	Route	County	Urban	Suburban	Rural	Total	Urban	Suburban	Rural
Beowawe	NV existing rail via Utah	Eureka	0.0	0.0	31.5	31.5	0.0	0.0	0.1
Beowawe	NV existing rail via Utah	Elko	0.0	11.3	218.1	229.3	0.0	463.4	2.0
Beowawe	NV existing rail via Reno	Humboldt	0.0	6.4	103.8	110.2	0.0	431.4	5.5
Beowawe	NV existing rail via Reno	Pershing	0.0	3.2	117.8	121.0	0.0	377.0	2.6
Beowawe	NV existing rail via Reno	Lander	0.0	3.2	41.0	44.3	0.0	577.3	3.5
Beowawe	NV existing rail via Reno	Eureka	0.0	0.0	22.7	22.7	0.0	0.0	0.1
Beowawe	NV existing rail via Reno	Washoe	3.2	23.3	26.8	53.4	1,953.2	517.6	14.9
Beowawe	NV existing rail via Reno	Churchill	0.0	0.0	66.8	66.8	0.0	0.0	0.0
Beowawe	NV existing rail via Reno	Storey	0.0	2.4	18.0	20.4	0.0	199.9	8.7
Beowawe	NV existing rail via Reno	Lyon	0.0	3.2	14.7	18.0	0.0	586.9	12.9
Jean	NV existing rail Jean from south	Clark	0.0	0.0	41.7	41.7	0.0	0.0	1.0
Jean	NV existing rail Jean from north	Clark	3.2	17.7	110.0	130.9	1,879.6	750.6	0.8
Jean	NV existing rail Jean from north	Lincoln	0.0	1.6	167.8	169.4	0.0	294.3	0.8
Apex	NV existing rail Apex from north	Lincoln	0.0	1.6	167.8	169.4	0.0	294.3	0.8
Apex	NV existing rail Apex from north	Clark	0.0	0.0	50.8	50.8	0.0	0.0	2.0
Apex	NV existing rail Apex from south	Clark	3.2	17.7	100.9	121.8	1,879.6	750.6	1.4
Caliente	NV existing routing to Caliente from north	Lincoln	0.0	0.0	64.7	64.7	0.0	0.0	0.8
Caliente	NV existing routing to Caliente from south	Clark	3.2	17.7	151.7	172.6	1,879.6	750.6	1.6
Caliente	NV existing routing to Caliente from south	Lincoln	0.0	1.6	103.1	104.7	0.0	294.3	0.9
Eccles	NV existing routing to Eccles from north	Lincoln	0.0	0.0	56.3	56.3	0.0	0.0	0.0
Eccles	NV existing routing to Eccles from south	Clark	3.2	17.7	151.7	172.6	1,879.6	750.6	1.6
Eccles	NV existing routing to Eccles from south	Lincoln	0.0	1.6	111.4	113.1	0.0	294.3	1.3
Dry Lake	NV existing routing to Dry Lake from north	Lincoln	0.0	1.6	167.8	169.4	0.0	294.3	0.8
Dry Lake	NV existing routing to Dry Lake from north	Clark	0.0	0.0	50.8	50.8	0.0	0.0	2.0
Dry Lake	NV existing routing to Dry Lake from south	Clark	3.2	17.7	100.9	121.8	1,879.6	750.6	1.4

a. To convert kilometers to miles, multiply by 0.62157.

Table J-35. Populations in Nevada within 800 meters (0.5 mile) of routes.[a,b]

Transportation scenario	Population 2035 projections
Legal-weight truck routes[a]	190,000/300,000
Rail routes Nevada border to branch rail line[b]	
Caliente (from the North – UT)	110
Caliente (from the South – CA)	115,000
Beowawe (from the east – UT)	21,000
Beowawe (from the west – CA)	98,000
Eccles (from the North – UT)	3
Eccles (from the south – CA)	115,000
Jean (from the North – UT)	114,000
Jean (from the South – CA)	250
Dry Lake (from the North – UT)	1,900
Dry Lake (from the South – CA)	113,000
Branch rail lines	
Caliente	140
Carlin	1,280
Caliente-Chalk Mountain	31
Jean	520
Valley Modified	75
Heavy-haul routes	
Caliente	11,000
Caliente/Chalk Mountain	740
Caliente/Las Vegas	187,000
Sloan/Jean	390,000
Apex/Dry Lake	186,000

a. The estimated populations represent using the route from the north and from the south, respectively.

b. The analysis assumed there would be an average of 800,000 visitors per day to Las Vegas.

Table J-36. Potential road upgrades for Caliente route.[a]

Route	Upgrades
Intermodal transfer station to U.S. 93	Pave existing gravel road.
U.S. 93 to State Route 375	Asphalt overlay on existing pavement, truck lanes where grade is greater than 4 percent (minimum distance of 460 meters[b] per lane), turnout lanes every 32 kilometers[c] (distance of 305 meters per lane), widen road.
State Route 375 to U.S. 6	Remove existing pavement, increase road base and overlay to remove frost restrictions, truck lanes where grade is greater than 4 degrees (minimum distance of 460 meters per lane), turnout lanes every 32 kilometers (distance of 305 meters per lane), widen road.
U.S. 6 to U.S. 95	Same as State Route 375 to U.S. 6.
U.S. 95 to Lathrop Wells Road	Remove existing pavement on frost restricted portion, increase base and overlay to remove frost restrictions, turnout lanes every 8 kilometers (distance of 305 meters per lane), construct bypass around intersection at Beatty, bridge upgrade near Beatty.
Lathrop Wells Road to Yucca Mountain site	Asphalt overlay on existing roads.

a. Source: DIRS 154448-CRWMS M&O (1998, all).

b. To convert meters to feet, multiply by 3.2808.

c. To convert kilometers to miles, multiply by 0.62137.

Table J-37. Potential road upgrades for Caliente/Chalk Mountain route.[a]

Route	Upgrades
Intermodal transfer station to U.S. 93	Pave existing gravel road.
U.S. 93 to State Route 375	Asphalt overlay on existing pavement, truck lanes where grade is greater than 4 percent (minimum distance of 460 meters[b] per lane), turnout lanes every 32 kilometers[c] (distance of 305 meters per lane), widen road
State Route 375 to Rachel	Remove existing pavement, increase road base and overlay to remove frost restrictions, turnout lanes every 32 kilometers (distance of 305 meters per lane), widen road.
Rachel to Nellis Air Force Range[d]	Pave existing gravel road.
Nellis Air Force Range Roads	Rebuild existing road.
Nevada Test Site Roads	Asphalt overlay on existing roads.

a. Source: DIRS 155436-CRWMS M&O (1997, all).
b. To convert meters to feet, multiply by 3.2808.
c. To convert kilometers to miles, multiply by 0.62137.
d. Also known as the Nevada Test and Training Range.

Table J-38. Potential road upgrades for Caliente/Las Vegas route.[a]

Route	Upgrades
Intermodal transfer station to U.S. 93	Pave existing gravel road.
U.S. 93 to Interstate 15	Asphalt overlay on existing pavement, truck lanes where grade is greater than 4 percent (minimum distance 460 meters[b] per lane), turnout lanes every 32 kilometers[c] (distance of 305 meters per lane), widen road, rebuild Interstate 15 interchange.
Interstate 15 to U.S. 95	Increase existing two-lane Las Vegas Beltway to four lanes, asphalt overlay on U.S. 95.
U.S. 95 to Mercury	Asphalt overlay on U.S. 95.
Mercury Exit to Yucca Mountain site	Asphalt overlay on Jackass Flats Road, rebuild road when required.

a. Source: DIRS 154448-CRWMS M&O (1998, all).
b. To convert meters to feet, multiply by 3.2808.
c. To convert kilometers to miles, multiply by 0.62137.

Table J-39. Potential road upgrades for Apex/Dry Lake route.[a]

Route	Upgrades
Intermodal transfer station to Interstate 15	Rebuild frontage road to U.S. 93. Rebuild U.S. 93/Interstate 15 interchange.
Interstate 15 to U.S. 95	Increase existing two-lane Las Vegas Beltway to four lanes.
U.S. 95 to Mercury Exit	Asphalt overlay on U.S. 95.
Mercury Exit to Yucca Mountain site	Asphalt overlay on Jackass Flats Road, rebuild road when required.

a. Source: DIRS 154448-CRWMS M&O (1998, all).

Table J-40. Potential road upgrades for Sloan/Jean route.[a]

Route	Upgrades
Intermodal transfer station to Interstate 15	Overlay and widen existing road to Interstate 15 interchange, rebuild Interstate 15 interchange.
Interstate 15 to U.S. 95	Increase existing two-lane Las Vegas Beltway to four lanes.
U.S. 95 to Mercury Exit	Asphalt overlay on U.S. 95.
Mercury Exit to Yucca Mountain site	Asphalt overlay on Jackass Flats Road, rebuild road when required.

a. Source: DIRS 154448-CRWMS M&O (1998, all).

- The *Nevada Potential Repository Preliminary Transportation Strategy, Study 2* (DIRS 101214-CRWMS M&O 1996, all), further refined the analyses of potential rail corridor alignments presented in Study 1.

Public comments submitted to DOE during hearings on the scope of this environmental impact statement resulted in addition of a fifth corridor—Caliente-Chalk Mountain.

DOE has identified 0.4-kilometer (0.25-mile)-wide corridors along each route within which it would need to obtain a right-of-way to construct a rail line and an associated access road. A corridor defines the boundaries of the route by identifying an established "zone" for the location of the railroad. For this analysis, DOE identified a single alignment for each of the corridors. These single alignments are representative of the range of alignments that DOE has considered for the corridors from engineering design and construction viewpoints. The following paragraphs describe the alignments that have been identified for the corridors. Before siting a branch rail line, DOE would conduct engineering studies in each corridor to determine a specific alignment for the roadbed, track, and right-of-way for a branch rail line.

Caliente Corridor Implementing Alternative. The Caliente Corridor originates at an existing siding to the Union Pacific mainline railroad near Caliente, Nevada. The Caliente and Carlin Corridors converge near the northwest boundary of the Nellis Air Force Range (also known as the Nevada Test and Training Range). Past this point, they are identical. The Caliente Corridor is 513 kilometers (320 miles) long from the Union Pacific line connection to the Yucca Mountain site. Table J-41 lists possible alignment variations for this corridor.

Carlin Corridor Implementing Alternative. The Carlin Corridor originates at the Union Pacific main line railroad near Beowawe in north-central Nevada. The corridor is about 520 kilometers (331 miles) long from the tie-in point with the Union Pacific line to the Yucca Mountain site. Table J-42 lists possible variations in the alignment of this corridor.

Caliente-Chalk Mountain Corridor Implementing Alternative. The Caliente-Chalk Mountain Corridor is identical to the Caliente Corridor until it approaches the northern boundary of the Nellis Air Force Range (also known as the Nevada Test and Training Range). At this point the Caliente-Chalk Mountain Corridor turns south through the Nellis Air Force Range and the Nevada Test Site to the Yucca Mountain site. The corridor is 345 kilometers (214 miles) long from the tie-in point at the Union Pacific line to the Yucca Mountain site. Table J-43 lists possible alignment variations for this corridor.

Jean Corridor Implementing Alternative. The Jean Corridor originates at the existing Union Pacific mainline railroad near Jean, Nevada. The corridor is 181 kilometers (112 miles) long from the tie-in point at the Union Pacific line to the Yucca Mountain site. Table J-44 lists possible variations for this corridor.

Valley Modified Corridor Implementing Alternative. The Valley Modified Corridor originates at an existing rail siding off the Union Pacific mainline railroad northeast of Las Vegas. The corridor is about 159 kilometers (98 miles) long from the tie-in point with the Union Pacific line to the Yucca Mountain site. Table J-45 lists the possible variations in alignment for this corridor.

Land Use Conflicts Along Potential Rail Corridors in Nevada

Figures J-13 through J-20 show potential land-use conflicts along candidate rail corridors for construction of a branch rail line in Nevada.

Table J-41. Possible variations of the Caliente Corridor.[a]

Variation	Description[b]
Eccles Option	Included in corridor description. Crosses private land and BLM lands. No ROWs crossed.
Caliente Option[c]	Connects with Union Pacific line at existing siding in Town of Caliente. Crosses approximately twice the amount of private lands than the primary alignment. Crosses 2 ROWs – 1 telephone and 1 road (U.S. 93).
Crestline Option[c]	Connects with Union Pacific line near east end of existing siding at Crestline. Crosses approximately twice the private land as the corridor. Crosses 2 ROWs – 1 telephone and 1 road.
White River Alternate[c]	Avoids potential conflict of the corridor with Weepah Spring Wilderness Study Area. Would cross approximately 0.012 square kilometer (3 acres) of private land.
Garden Valley Alternate[c]	Puts more distance between corridor and private lands in Garden Valley and Coal Valley. Crosses 2 road ROWs and 2 pipelone ROWs. Crosses approximately same amount of private land as corridor.
Mud Lake Alternate[c]	Travels farther from west edge of Mud Lake, which has known important archaeological sites. Mud Lake contains 4 possible route variations that are located on BLM lands.
Goldfield Alternate[c]	Avoids crossing Nellis Air Force Range boundary near Goldfield, avoiding potential land-use conflicts with Air Force. Crosses mostly BLM lands but also crosses approximately 0.75 square kilometer of private lands.
Bonnie Claire Alternate[c]	Avoids crossing Nellis Air Force Range boundary near Scottys Junction, avoiding potential land-use conflicts with Air Force. Crosses mostly BLM lands but also crosses approximately 0.43 square kilometer of private property. Crosses a BLM utility corridor, 3 road ROWs, 2 telephone ROWs, and 4 power ROWs. Crosses Timbisha Shoshone trust lands parcel.
Oasis Valley Alternate[c]	Enables flexibility in crossing environmentally sensitive Oasis Valley area. If DOE selected a route through this area, further studies would ensure small environmental impacts.
Beatty Wash Alternate[c]	Provides alternate corridor through Beatty Wash that is longer, but requires less severe earthwork than the corridor.

a. Source: DIRS 131242-CRWMS M&O (1997, all).
b. Abbreviations: BLM = Bureau of Land Management; ROW = right-of-way.
c. Common with Carlin Corridor.

Minority Populations Along Potential Transportation Routes in Nevada

Census Bureau information available to DOE and considered in this EIS includes geographical identification of census blocks containing minority populations within the environmental justice definition used by DOE (that is, a minority population is one in which the percent of the population of an area's racial or ethnic minority is 44.8 percentage points or more of the total population).

There is no corresponding census block information for low-income populations. To provide the information on minority census blocks to decisionmakers and the public, DOE has prepared a set of maps (Figures J-21 through J-30) showing the location of minority census blocks near potential transportation corridors. The maps depict 6-kilometer bands on each side of each corridor.

Darkly shaded areas represent minority blocks in or near the 6-kilometer bands. Lightly shaded areas represent the balance of land within the 6-kilometer bands. Dotted areas of intermediate shading represent Native American lands. All lands shown on maps and not represented as minority block or Native American is land that does not have a minority population within the definition used in this EIS (see Chapter 3, Section 3.1.13.1) to consider environmental justice concerns.

Table J-42. Possible variations of the Carlin Corridor.[a]

Variation	Description[b]
Crescent Valley Alternate	Diverges from the corridor near Cortez Mining Operation where it would cross a proposed pipeline ROW that would supply water to the Dean Ranch; travels through nonagricultural lands adjacent to alkali flats but would affect larger area of private land. Crosses 2 existing roads, one of which has an established ROW.
Wood Spring Canyon Alternate	Diverges from the corridor and use continuous 2-percent grade to descend from Dry Canyon Summit in Toiyabe range; is shorter than the corridor segment but would have steeper grade. Continues on BLM land.
Rye Patch Alternate	Travels through Rye Patch Canyon, which has springs, riparian areas, and game habitats; diverts from the corridor, maintaining distance of 420 meters[c] from Rye Patch Spring and at least 360 meters from riparian areas throughout Rye Patch Canyon, except at crossing of riparian area near south end of canyon; avoids game habitat (sage grouse strutting area). Passes through a BLM utility corridor, one road and one road ROW (U.S. 50).
Steiner Creek Alternate	Diverges from the corridor at north end of Rye Patch Canyon. Avoids crossing private lands, two known hawk-nesting areas, and important game habitat (sage grouse strutting area) in the corridor. Passes close to Steiner Creek WSA.
Smoky Valley Option	Travels through less populated valley than Monitor Valley Option. Crosses more ROWs than Monitor Valley Option. Passes through all BLM land until route enters NTS. Passes through a Desert Land Entry area.
Monitor Valley Option	Travels through less populated Monitor Valley (in comparison to Big Smoky Valley). Crosses the Monitor, Ralston, and Potts grazing allotments. Also passes through 2 areas with application to Desert Land Entry Program. Passes 2 road ROWs, 1 telephone, 1 pipeline, and 3 powerline ROWs.
Mud Lake Alternate[d]	Travels farther from west edge of Mud Lake, which has known important archaeological sites. Mud Lake contains 4 possible route variations that are located on BLM lands.
Goldfield Alternate[d]	Avoids crossing Nellis Air Force Range boundary near Goldfield, avoiding potential land-use conflicts with Air Force. Crosses mostly BLM lands but also crosses approximately 0.75 square kilometer[e] of private lands.
Bonnie Claire Alternate[d]	Avoids crossing Nellis Air Force Range boundary near Scottys Junction, avoiding potential land-use conflicts with Air Force. Crosses mostly BLM lands but also crosses approximately 0.43 square kilometer of private property. Crosses a BLM utility corridor, 3 road ROWs, 2 telephone ROWs, and 4 power ROWs. Crosses Timbisha Shoshone trust lands parcel.
Oasis Valley Alternate[d]	Enables flexibility in crossing environmentally sensitive Oasis Valley area. If DOE selected a route through this area, further studies would ensure small environmental impacts.
Beatty Wash Alternate[d]	Provides alternate corridor through Beatty Wash that is longer, but requires less severe earthwork than the corridor.

a. Source: DIRS 131242-CRWMS M&O (1997, all).
b. Abbreviations: BLM = Bureau of Land Management; NTS = Nevada Test Site; ROW = right-of-way; WSA = Wilderness Study Area.
c. To convert meters to feet, multiply by 3.2808.
d. Common with Caliente corridor.
e. To convert square kilometers to acres, multiply by 247.1.

Although the populations of most census blocks are small, the size of many blocks is large. The depiction of minority blocks does not show the location of any residences within blocks. Census bureau data did not include residential locations. No inference should be drawn from these maps as to the location of residences within depicted areas.

Table J-43. Possible variations of the Caliente-Chalk Mountain Corridor.

Variation	Description
Caliente Option	Same as Table J-41. Connects with Union Pacific Line at existing siding in Town of Caliente.
Eccles Option	Same as Table J-41.
Orange Blossom Option	Crosses Nevada Test Site land. Bypasses roads and facilities.
Crestline Option	Same as Table J-41. Connects with Union Pacific line near east end of existing siding at Caliente.
White River Alternate	Same as Table J-41. Avoids potential conflict with Weepah Springs Wilderness Study Area.
Garden Valley Alternate	Same as Table J-41. Puts more distance between rail corridor and private lands in Garden Valley and Coal Valley.
Mercury Highway Option	To provide flexibility in choosing path through Nevada Test Site, travels north through center of Nevada Test Site. Requires slightly less land [approximately 0.2 square kilometers (50 acres)] than corridor. Crosses Mercury Highway.
Topopah Option	To provide flexibility in choosing path through Nevada Test Site, travels north along western boundary of Nevada Test Site.
Mine Mountain Alternate	Provides flexibility in minimizing impacts to local archaeological sites.
Area 4 Alternate	Provides flexibility in choosing path through Nevada Test Site. Crosses Mercury Highway. Requires slightly less land.

a. Source: DIRS 155628-CRWMS M&O (1997, all).

J.3.1.3 Sensitivity of Analysis Results to Routing Assumptions

In addition to analyzing the impacts of using highway routes that would meet U.S. Department of Transportation requirements for transporting spent nuclear fuel, DOE evaluated how the estimated impacts would differ if legal-weight trucks used other routes in Nevada. Six other routes identified in a 1989 study by the Nevada Department of Transportation (DIRS 103072-Ardila-Coulson 1989, pp. 36 and 45) were selected for this analysis. The Nevada Department of Transportation study described the routes as follows:

Route A. Minimum distance and minimum accident rate.
South on U.S. 93A, south on U.S. 93, west on U.S. 6, south on Nevada 318, south on U.S. 93, south on I-15, west on Craig Road, north on U.S. 95

Route B. Minimum population density and minimum truck accident rate.
Both of these two routes use the U.S. 6 truck bypass in Ely.

Alternative route possibilities were identified between I-15 at Baker, California and I-40 at Needles, California to Mercury. These alternative routes depend upon the use of U.S. 95 in California, California 127 and the Nipton Road.

Route C. From Baker with California 127.
North on California 127, north on Nevada 373, south on U.S. 95

Route D. From Baker without California 127.
North on I-15, west on Nevada 160, south on U.S. 95

Route E. From Needles with U.S. 95, California 127, and the Nipton Road.
North on U.S. 95, west on Nevada 164, west on I-15, north on California 127, north on Nevada 373, south on U.S. 95

Route F. From Needles without California 127 and the Nipton Road.
West on I-40, east on I-15, west on Nevada 160, south on U.S. 95

Table J-44. Possible variations of the Jean Corridor.[a]

Variation	Description[b]
North Pahrump Valley Alternate	Minimizes impacts to approximately 4 kilometers[c] of private land on northeast side of Pahrump. Abuts Toiyabe National Forest and a BLM corridor. Travels within a BLM utility corridor. Crosses approximately twice as much BLM lands as corridor and 0.0999 square kilometer[d] of private land compared to 3.5 square kilometers.
Wilson Pass Option	Crosses 2 pipeline ROWs, 3 road/highway ROWs, 2 powerline ROWs. Enter BLM utility corridor for approximately 46 kilometers. Passes within 1.6 kilometers of Toiyabe National Forest and close to 3 mines. Also passes through BLM Class II visual resource lands.
Stateline Pass Option	Provides option to crossing Spring Mountains at Wilson Pass; diverges from corridor in Pahrump Valley; parallels Nevada-California border, traveling along southwestern edge of Spring Mountains and crossing border twice. Bypasses private land crossed by primary alignment. Origination of option would conflict with the proposed Ivanpah Valley Airport. Crosses 2 pipeline ROWs, 2 road ROWs, 1 powerline, 1 telephone ROW, 1 withdrawal area (unexplained), a BLM utility corridor, and 1 community pit. Passes close to Stateline WSA. Crosses Black Butte and Roach Lake grazing allotments.

a. Source: DIRS 131242-CRWMS M&O (1997, all).
b. Abbreviations: BLM = Bureau of Land Management; ROW = right-of-way; WSA = Wilderness Study Area.
c. To convert kilometers to miles, multiply by 0.62137.
d. To convert square kilometers to acres, multiply by 247.1.

Table J-45. Possible variations of the Valley Modified Corridor.[a]

Variation	Description[b]
Indian Hills Alternate	Avoids entrance to Nellis Air Force Range north of Town of Indian Springs by traveling south of town. U.S. Fish and Wildlife Service land. Crosses 1 road, 2 telephone, and 2 powerline ROWs. Passes almost entirely within BLM utility corridor. Passes through a land withdrawal area.
Sheep Mountain Alternate	Increases distance from private land in Las Vegas and proposed 30-square-kilometer[c] BLM land exchange with city. Crosses small parcels (approximately 0.18 square kilometer) of private land. Crosses 3 powerline ROWs. Passes through Nellis Small Arms Range, Nellis WSAs A, B, and C, the Desert National Wildlife Range, and the Quail Spring WSA.
Valley Connection	Locates transfer operations at Union Pacific Valley Yard rather than Dike siding. Overflights of Dike siding from Nellis Air Force Base could conflict with switching operations. Crosses slightly more private land.

a. Source: DIRS 131242-CRWMS M&O (1997, all).
b. Abbreviations: BLM = Bureau of Land Management; ROW = right-of-way; WSA = Wilderness Study Area.
c. To convert square kilometers to acres, multiply by 247.1.

Table J-46 identifies the sensitivity cases evaluated based on the Nevada Department of Transportation routes. Tables J-47 and J-48 list the range of impacts in Nevada of using these different routes for the mostly legal-weight truck analysis scenario. The tables compare the impacts estimated for the highways identified in the Nevada study to those estimated for shipments that would follow routes allowed by current U.S. Department of Transportation regulations for Highway Route-Controlled Quantities of Radioactive Materials. Because the State of Nevada has not designated alternative or additional preferred routes for use by these shipments, as permitted under U.S. Department of Transportation regulations (49 CFR 397.103), DOE has assumed that shipments of spent nuclear fuel and high-level radioactive waste would enter Nevada on I-15 from either the northeast or southwest. The analysis assumed that shipments traveling on I-15 from the northeast would use the northern Las Vegas Beltway to connect to U.S. 95 and continue to the Nevada Test Site. Shipments from the southwest on I-15 would use the southern and western Las Vegas Beltway to connect to U.S. 95 and continue to the Nevada Test Site.

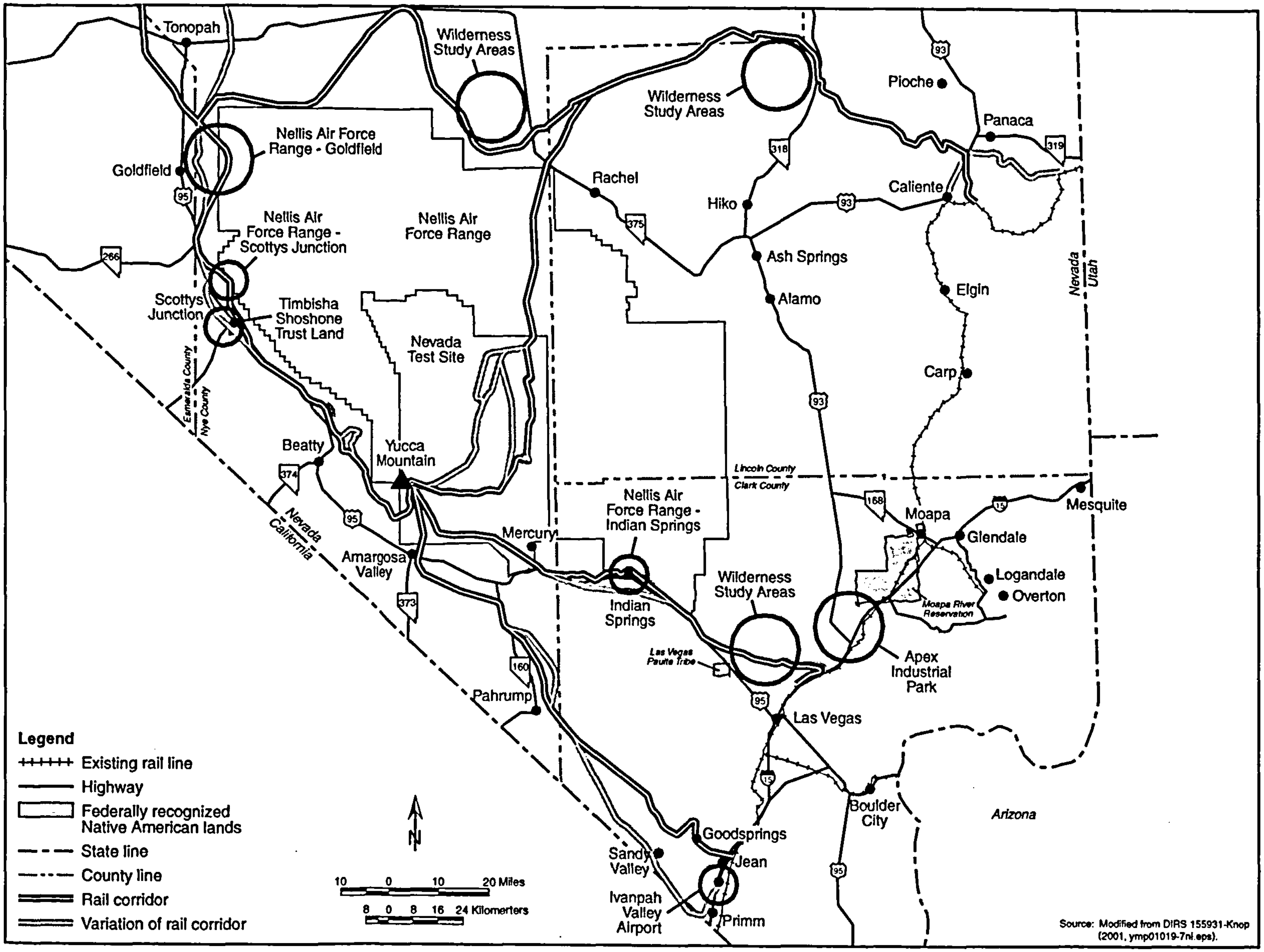


Figure J-13. Land-use conflicts along Nevada rail corridors, overview.

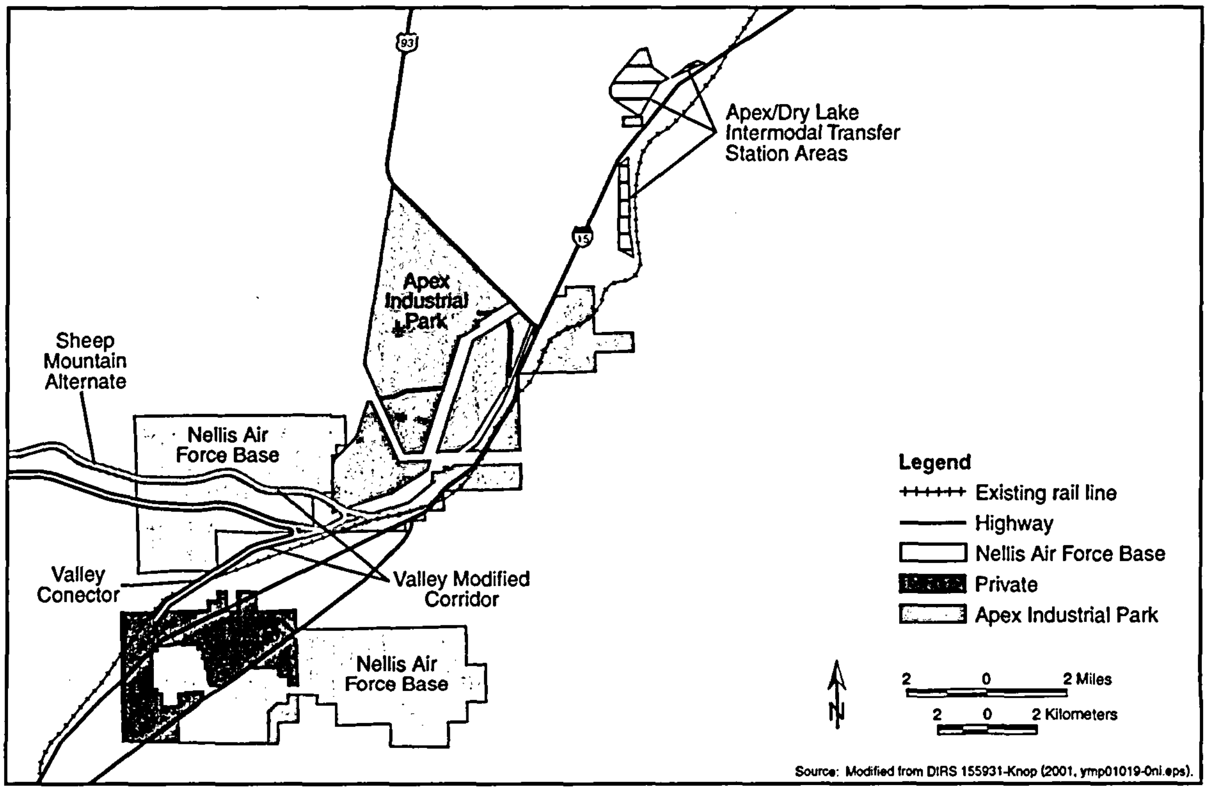


Figure J-14. Land-use conflicts along Nevada rail corridors, Apex Industrial Park.

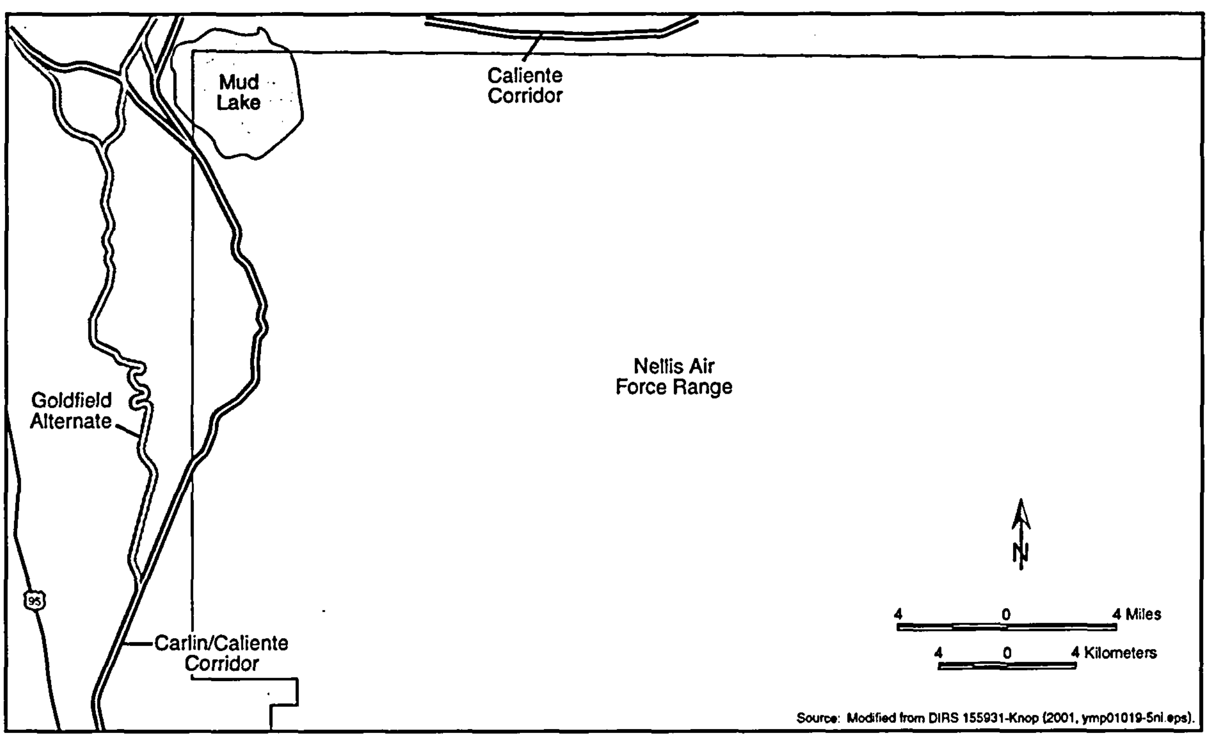


Figure J-15. Land-use conflicts along Nevada rail corridors, Nellis Air Force Range, Goldfield area.

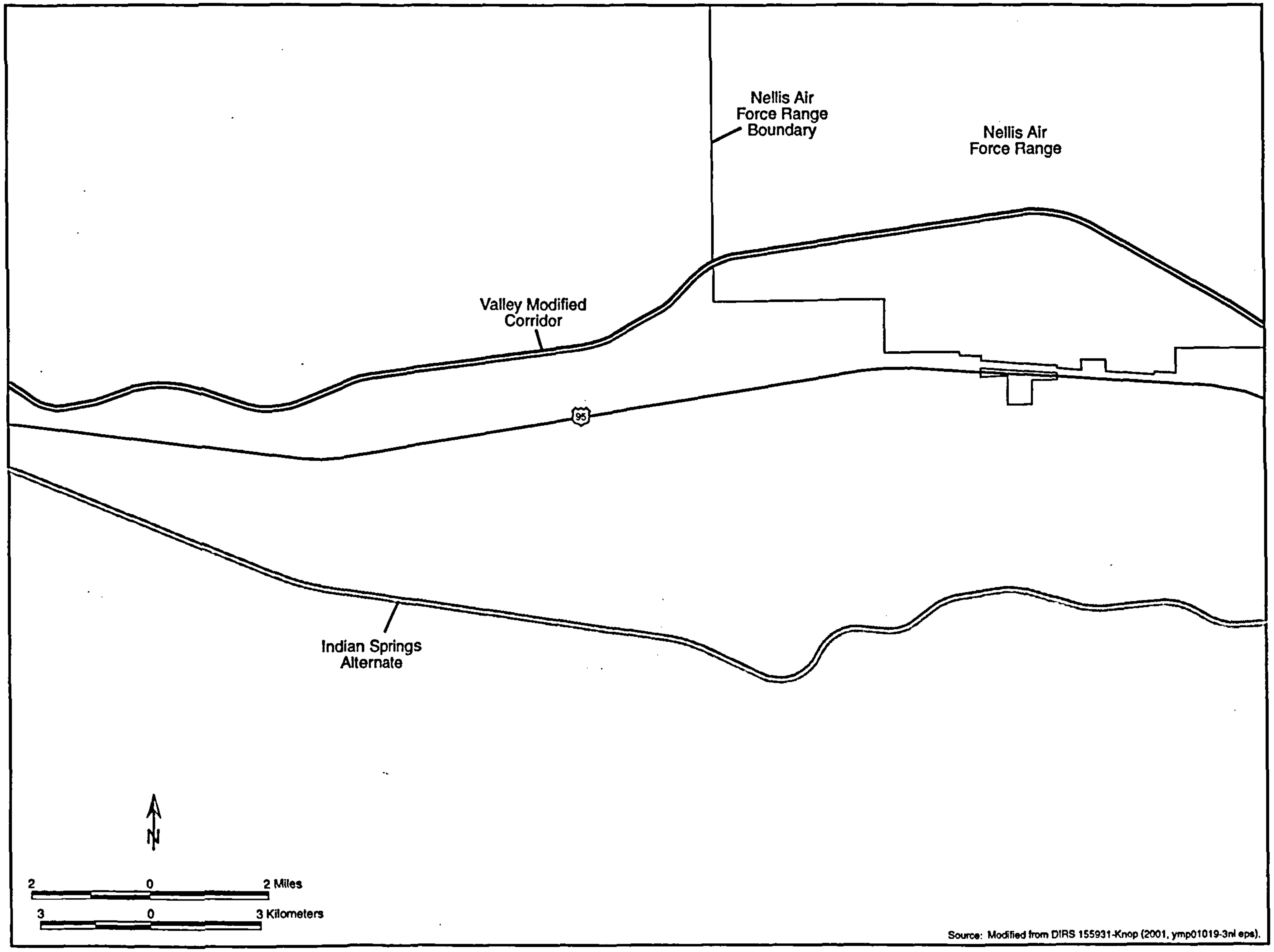


Figure J-16. Land-use conflicts along Nevada rail corridors, Nellis Air Force Range, Indian Springs area.

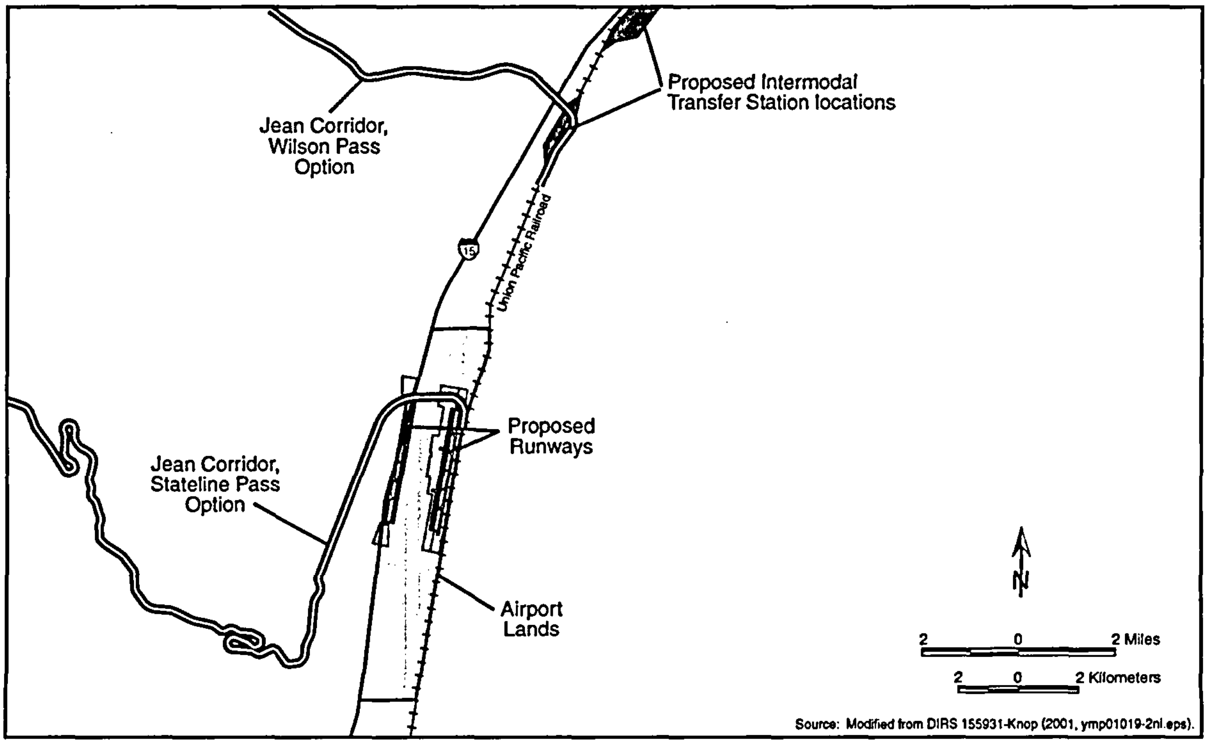


Figure J-17. Land-use conflicts along Nevada rail corridors, Ivanpah Valley Airport Public Lands Transfer Act.

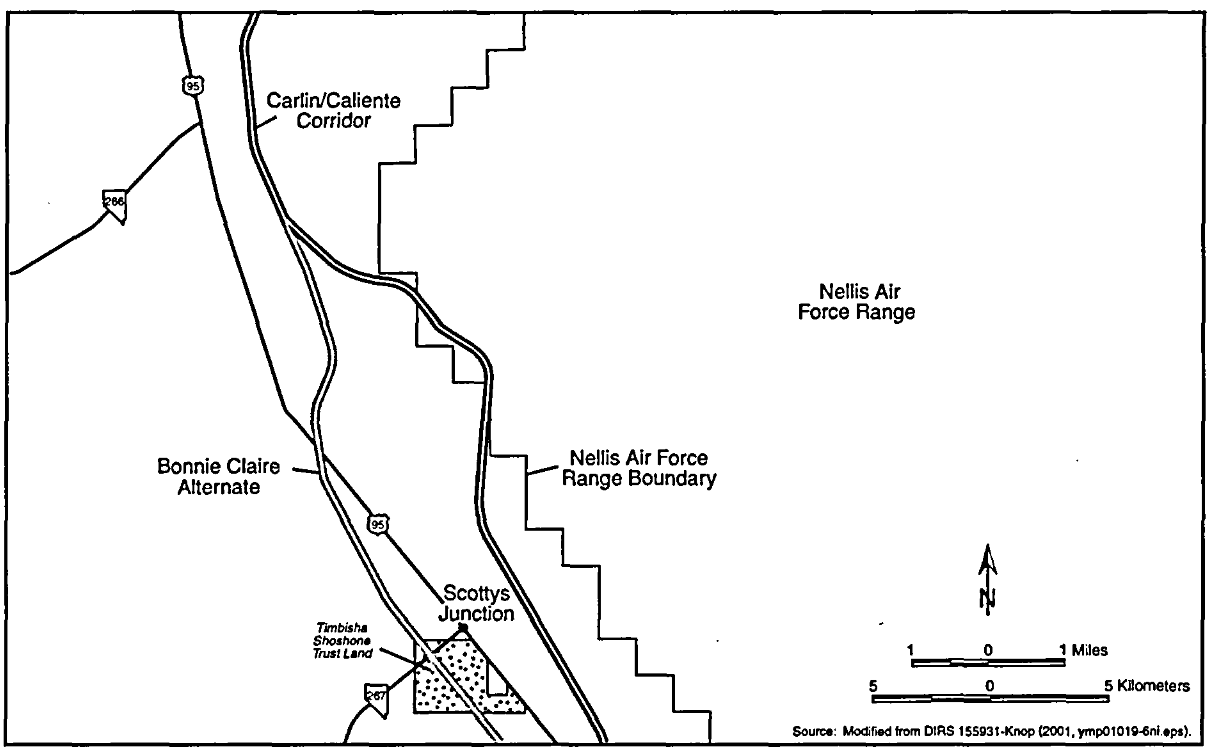


Figure J-18. Land-use conflicts along Nevada rail corridors, Nellis Air Force Range, Scottys Junction area.

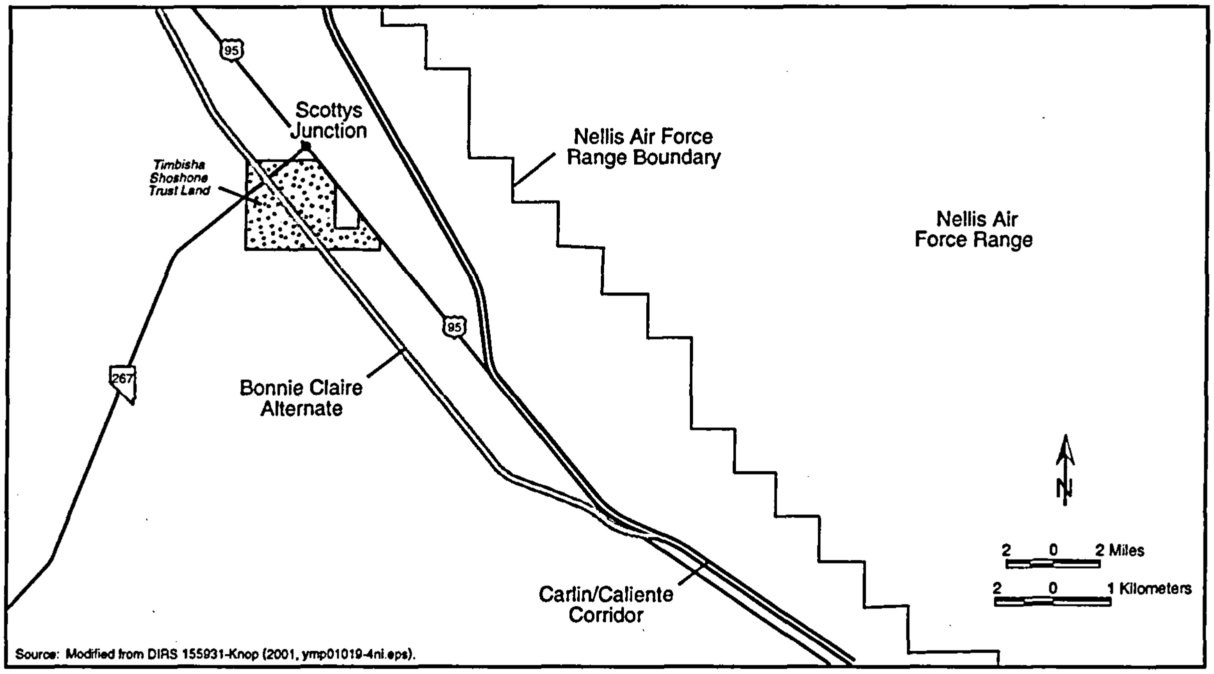


Figure J-19. Land-use conflicts along Nevada rail corridors, Timbisha Shoshone Trust Lands.

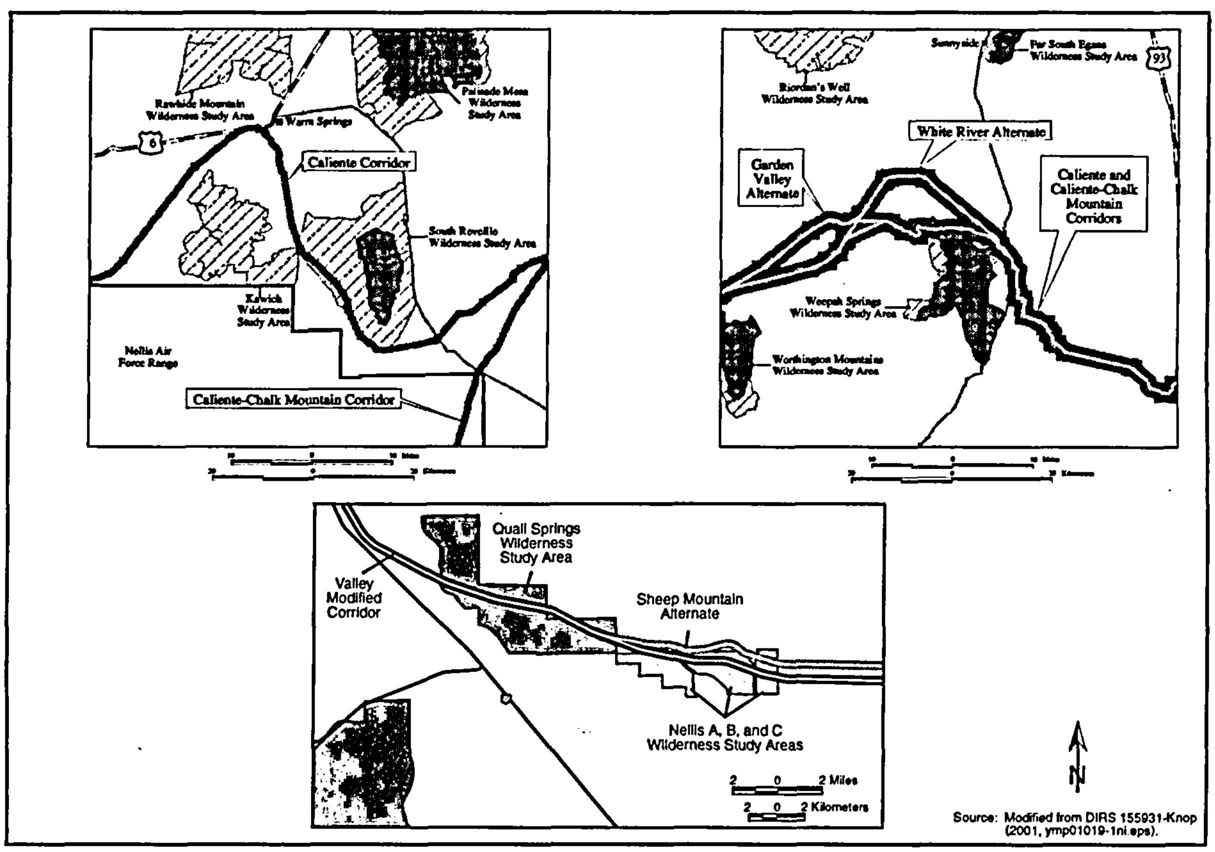


Figure J-20. Land-use conflicts along Nevada rail corridors, Wilderness Study Areas.

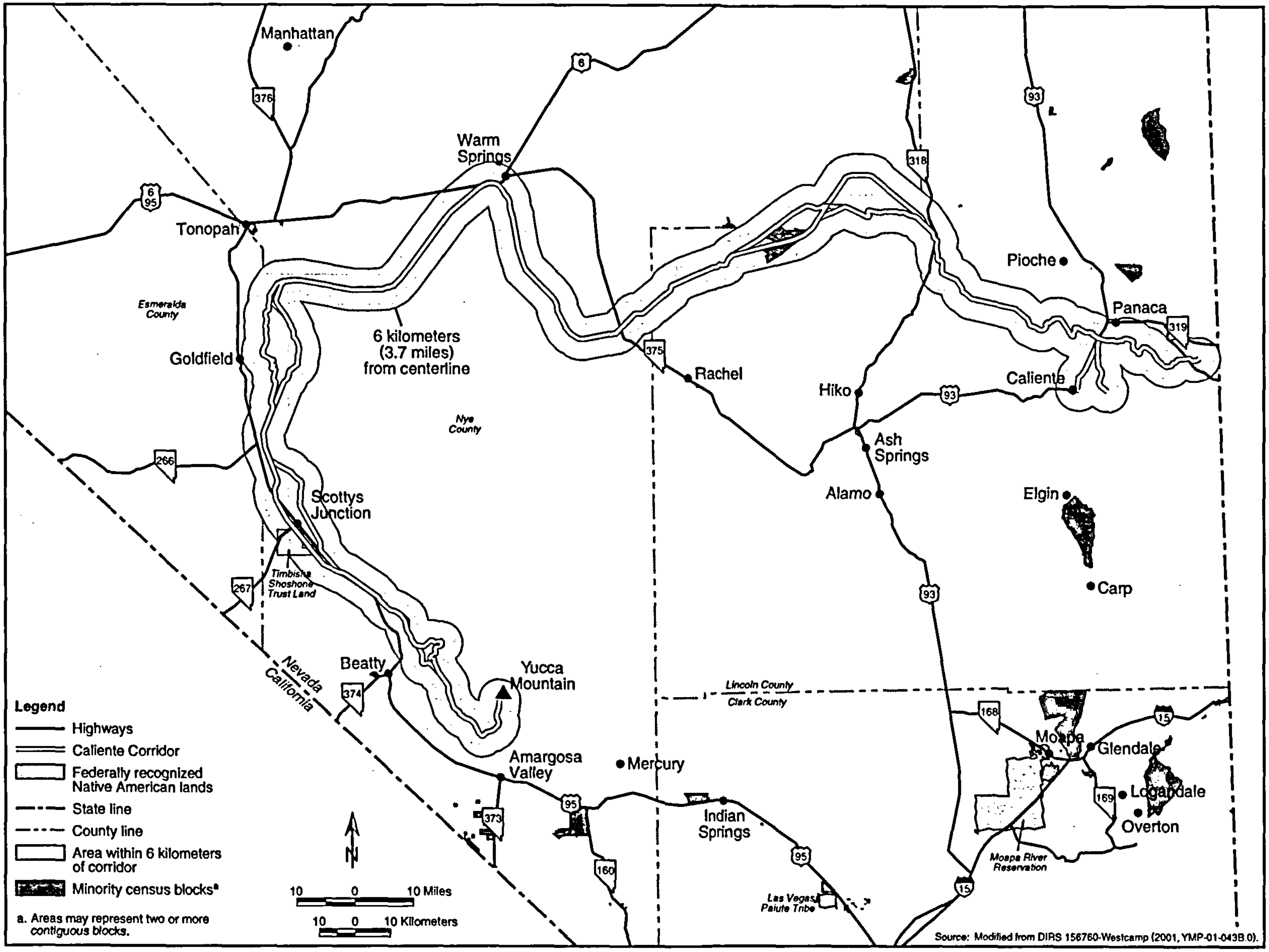


Figure J-21. Nevada minority census blocks in relation to the Caliente Corridor.

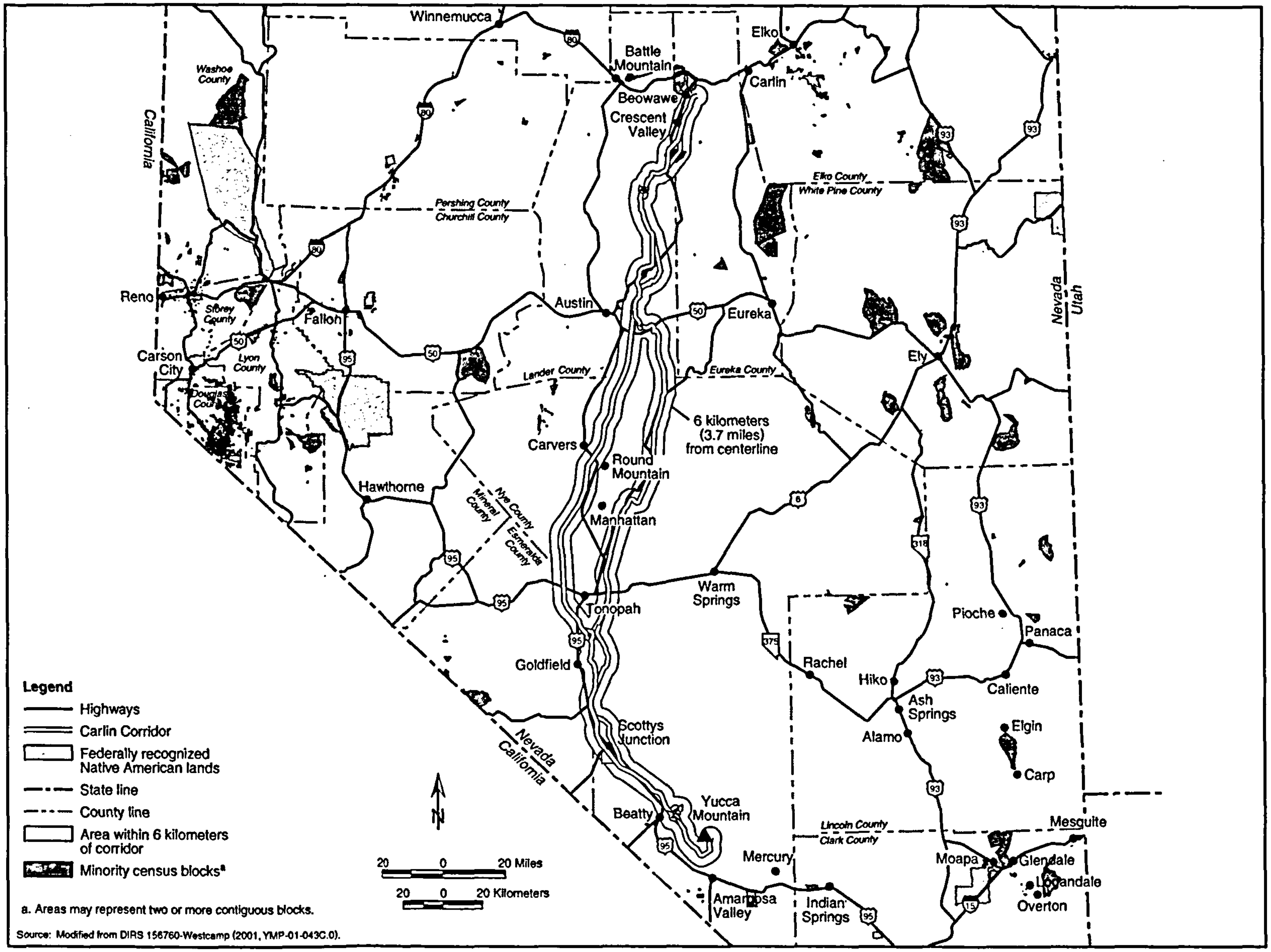


Figure J-22. Nevada minority census blocks in relation to the Carlin Corridor.

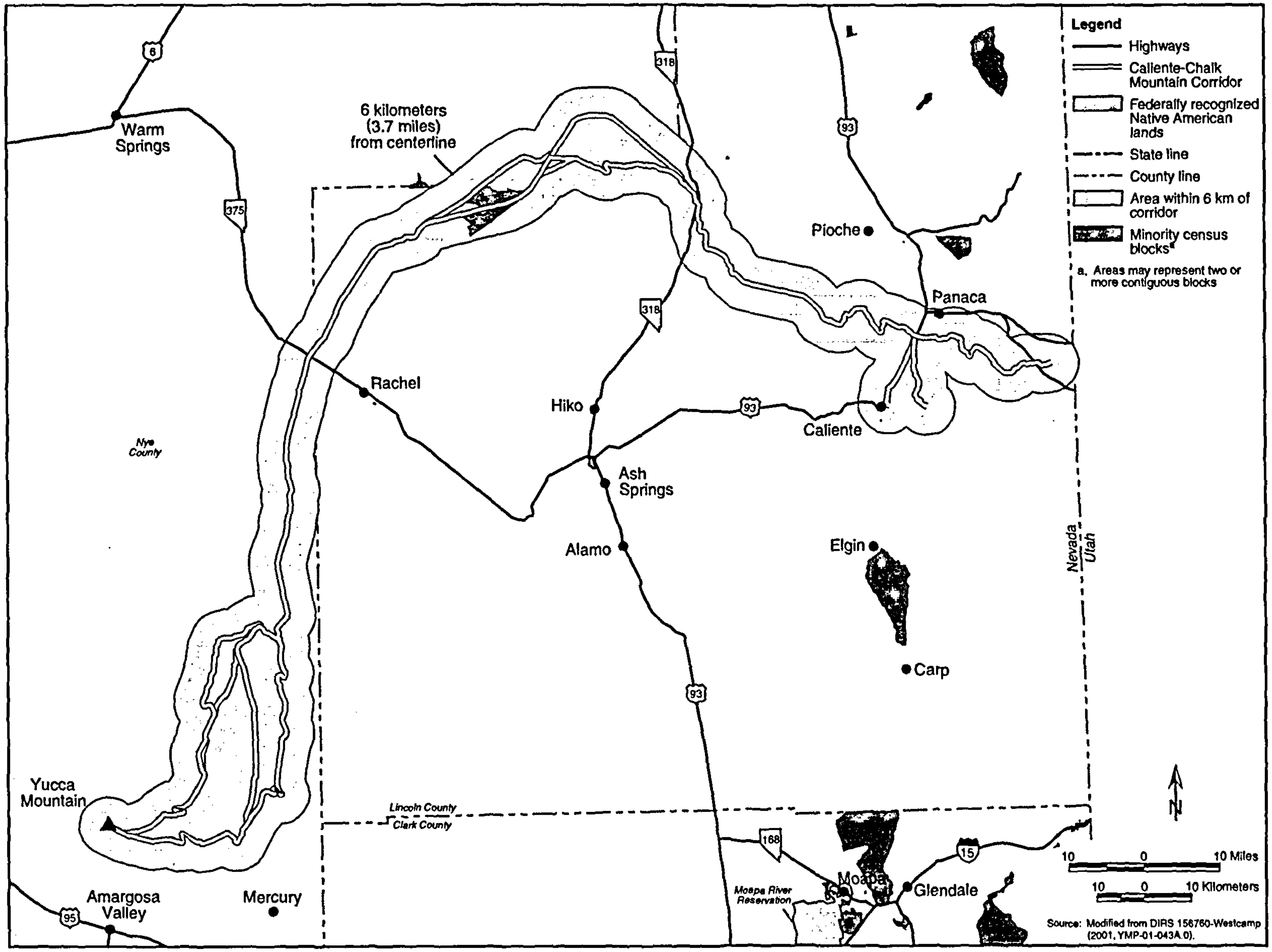


Figure J-23. Nevada minority census blocks in relation to the Caliente-Chalk Mountain Corridor.

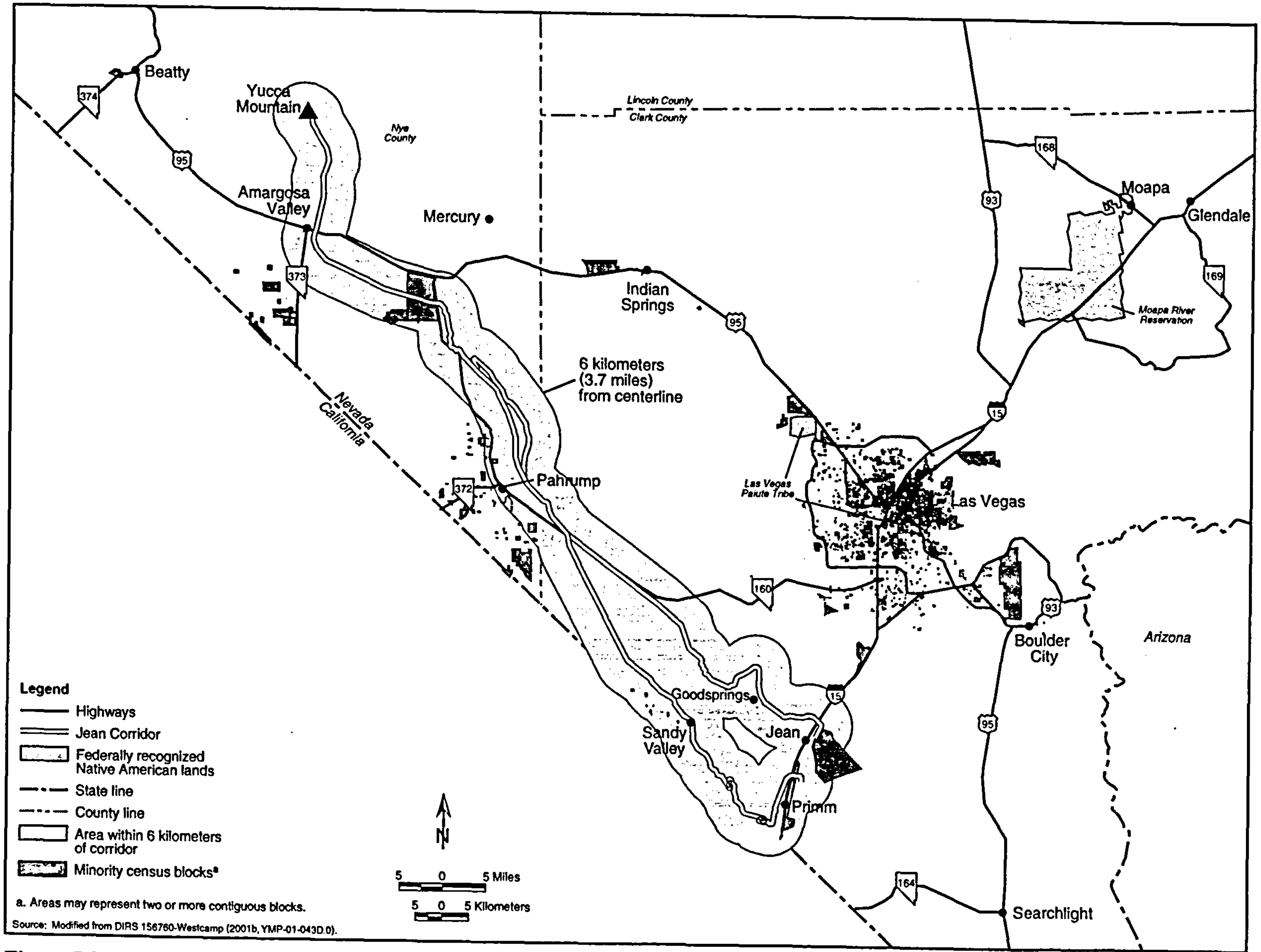


Figure J-24. Nevada minority census blocks in relation to the Jean Corridor.

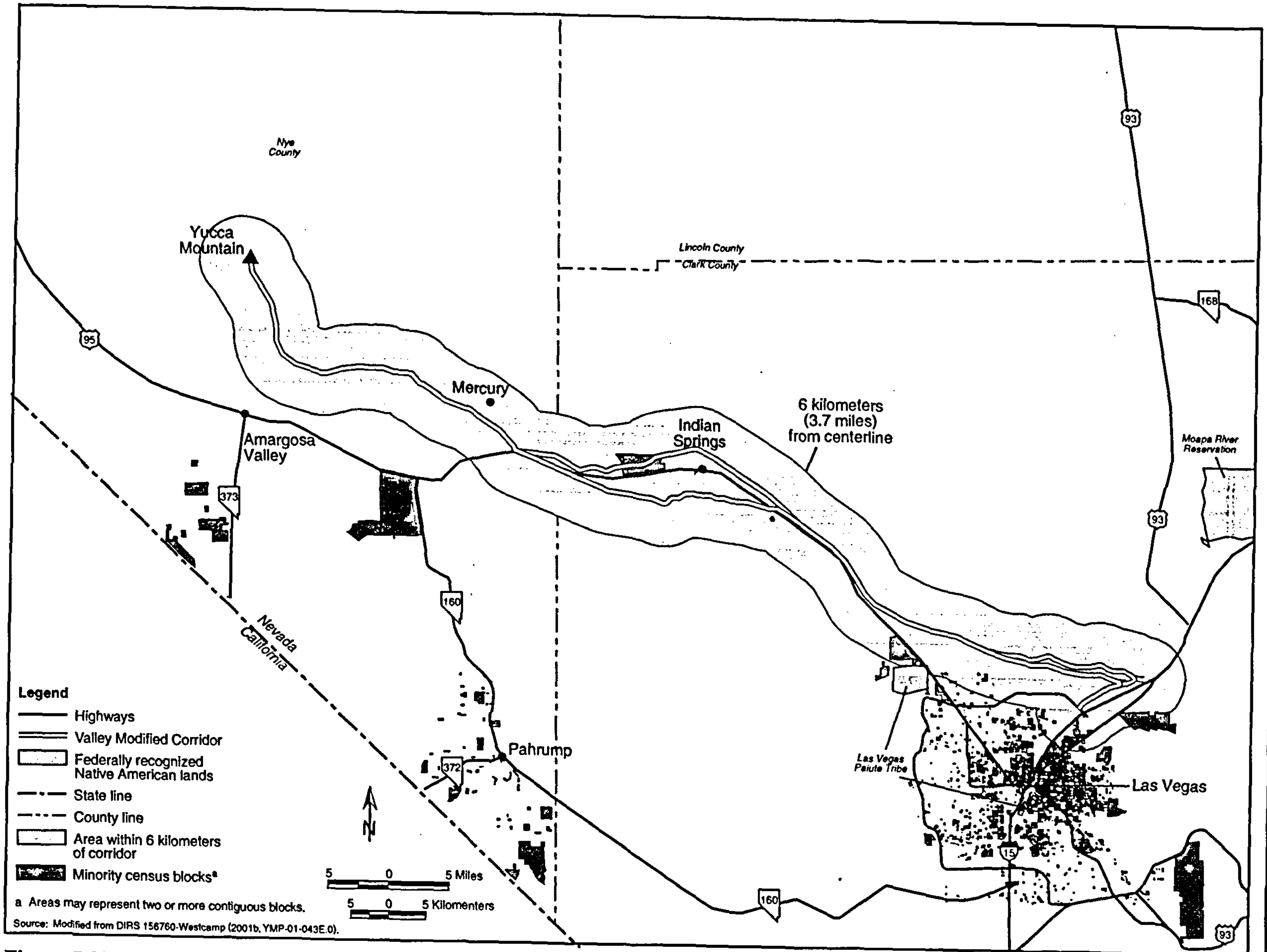


Figure J-25. Nevada minority census blocks in relation to the Valley Modified Corridor.

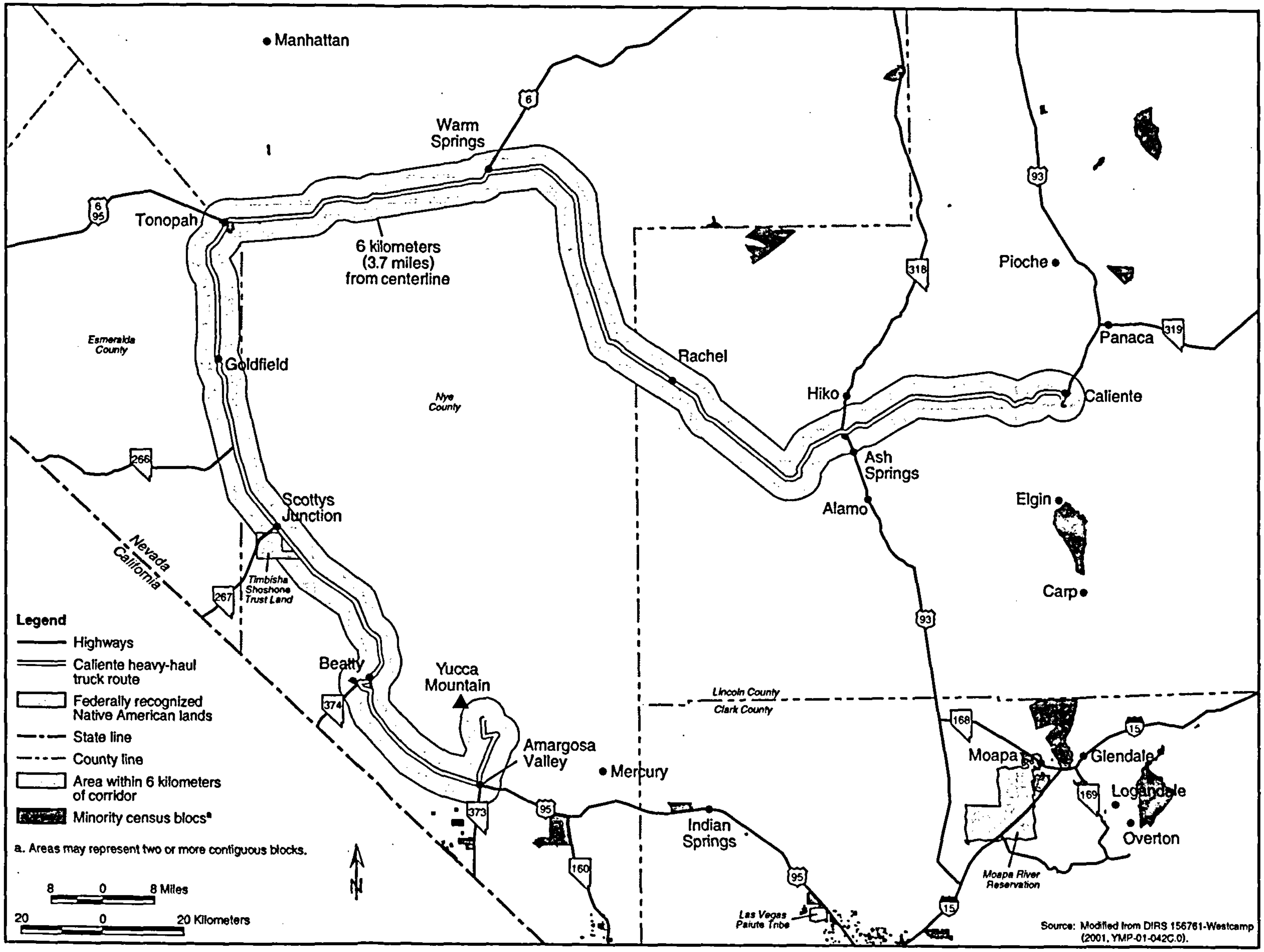


Figure J-26. Nevada minority census blocks in relation to the Caliente heavy-haul truck implementing alternative.

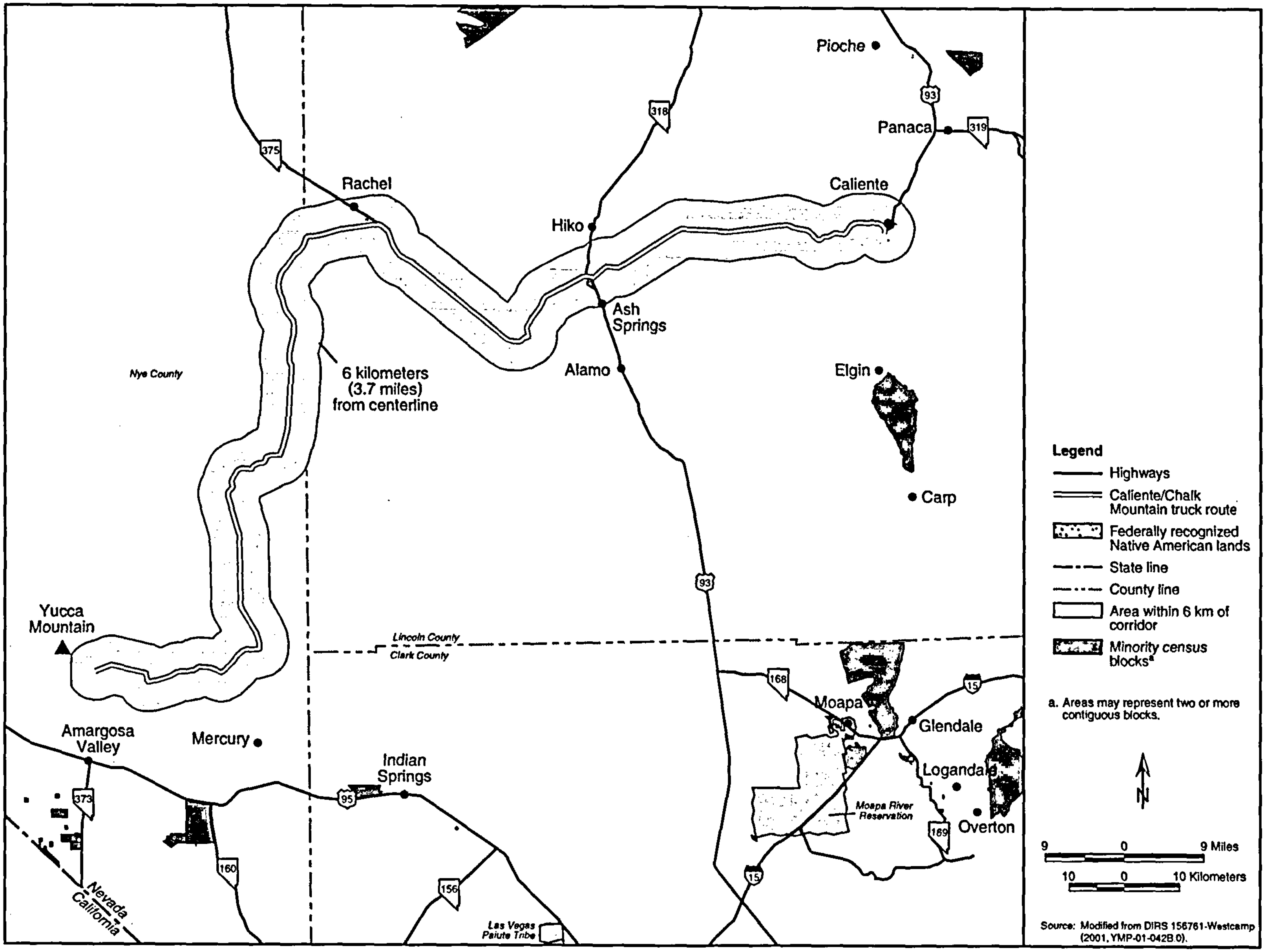


Figure J-27. Nevada minority census blocks in relation to the Caliente/Chalk Mountain route for heavy-haul trucks.

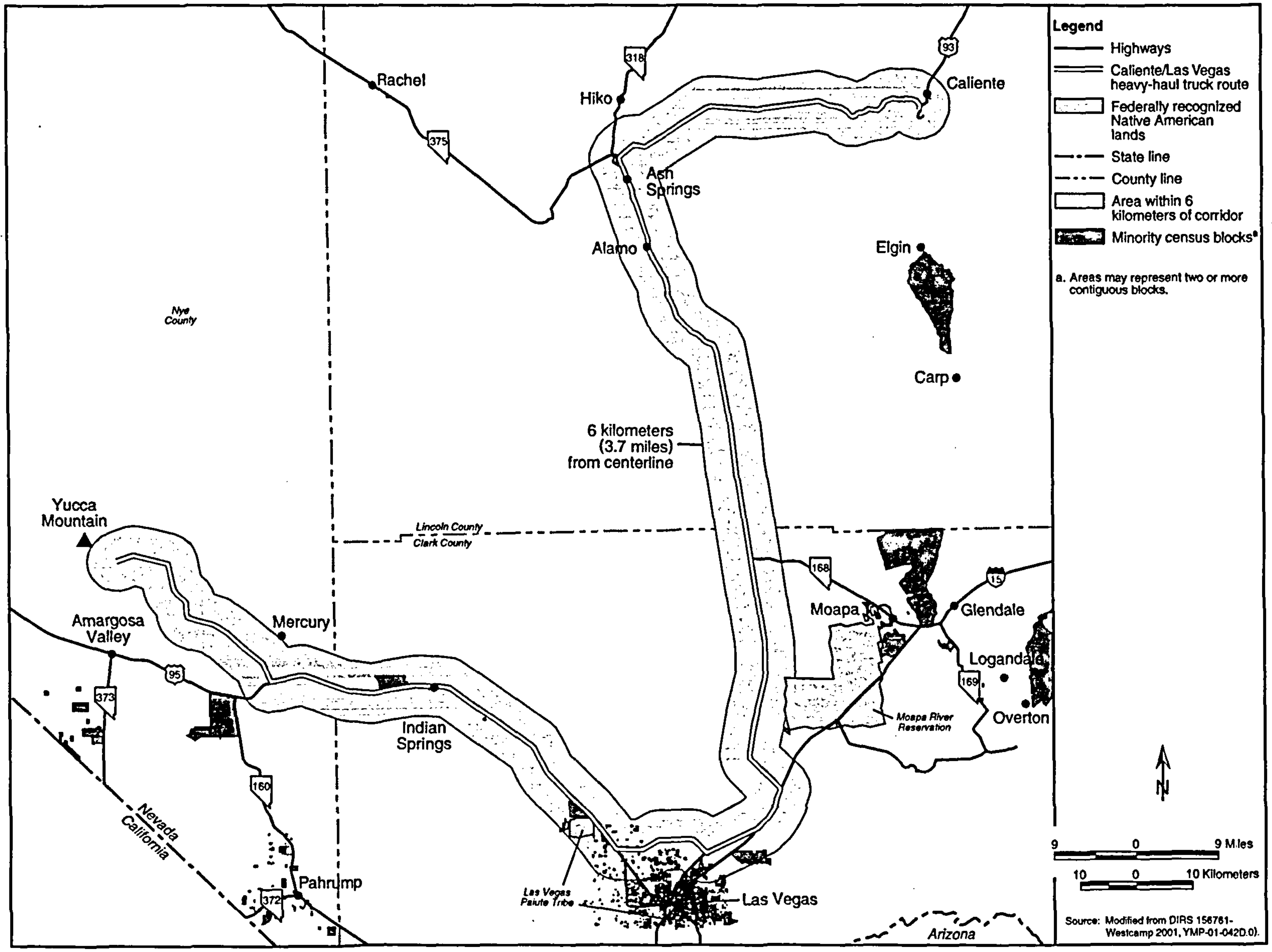


Figure J-28. Nevada minority census blocks in relation to the Caliente/Las Vegas route for heavy-haul trucks.

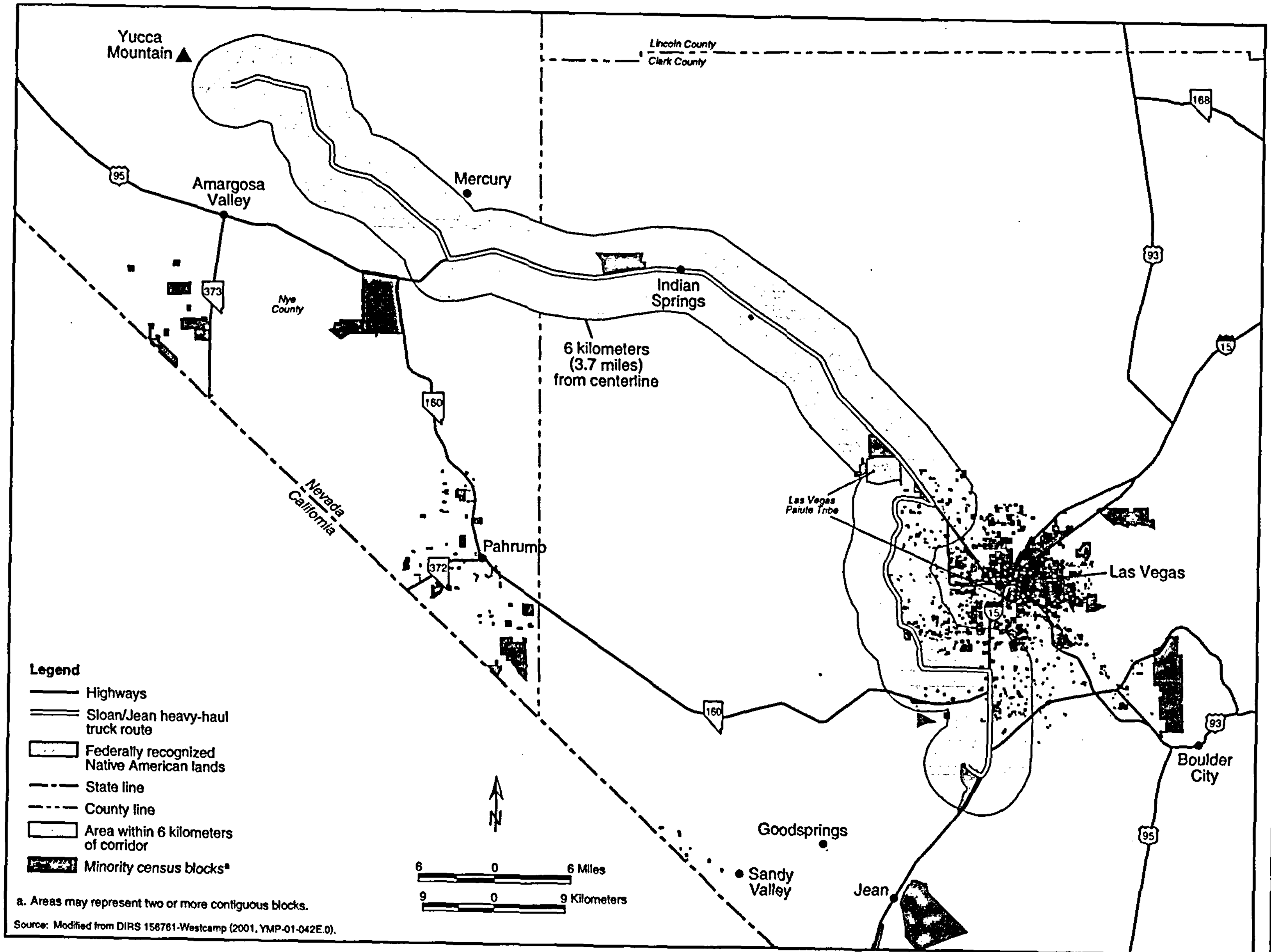


Figure J-29. Nevada minority census blocks in relation to the Sloan/Jean route for heavy-haul trucks.

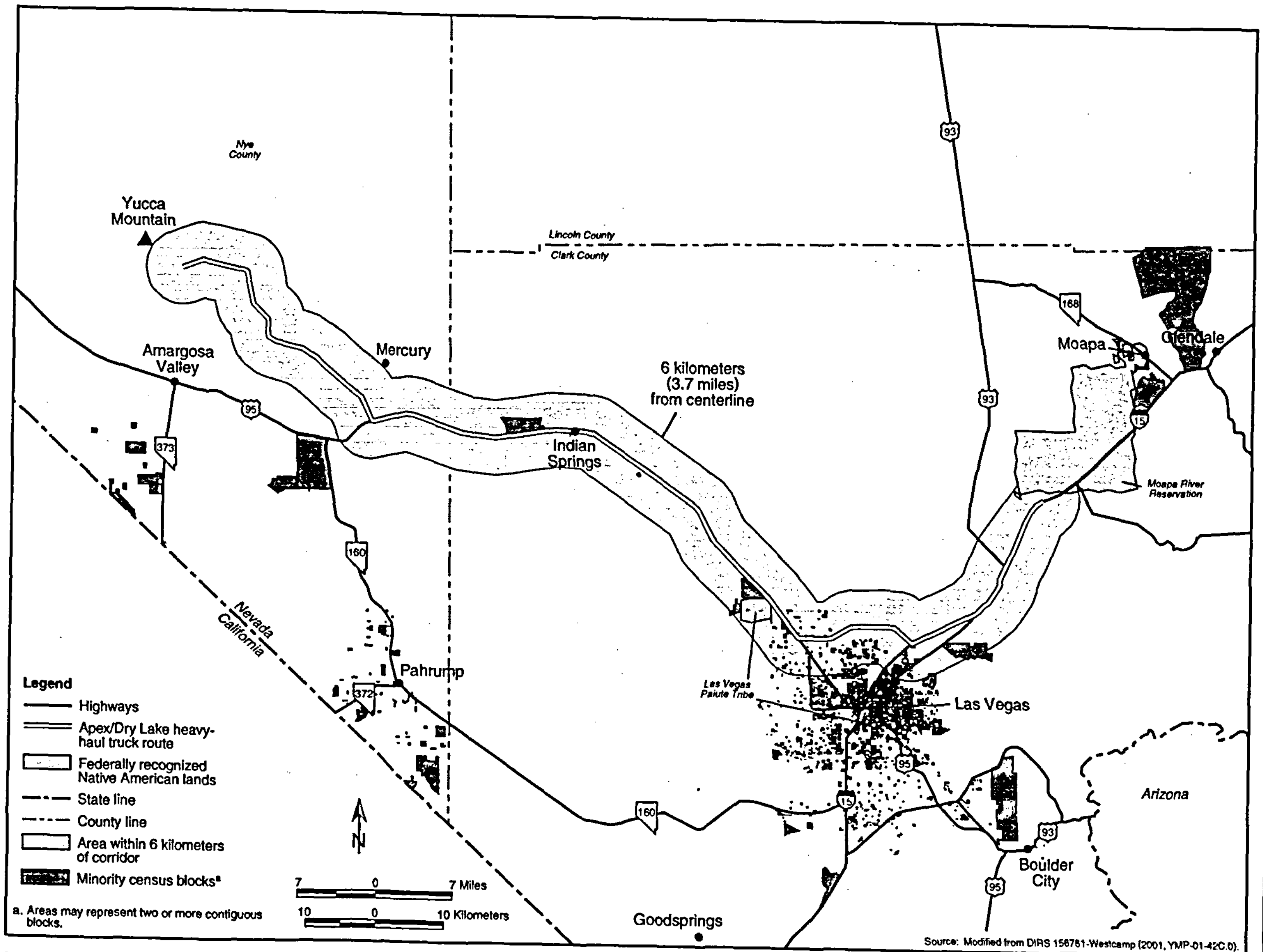


Figure J-30. Nevada minority census blocks in relation to the Apex/Dry Lake route for heavy-haul trucks.

Table J-46. Nevada routing sensitivity cases analyzed for a legal-weight truck.

Case	Description
Case 1	To Yucca Mountain via Barstow, California, using I-15 to Nevada 160 to Nevada 160 (Nevada D and F)
Case 2	To Yucca Mountain via Barstow using I-15 to California route 127 to Nevada 373 to US 95 (Nevada C)
Case 3	To Yucca Mountain via Needles using U.S. 95 to Nevada 164 to I-15 to California 127 to Nevada 373 and U.S. 95 (Nevada E)
Case 4	To Yucca Mountain via Needles using U.S. 95 to Nevada 164 to I-15 to Nevada 160 (variation of Nevada E)
Case 5	To Yucca Mountain via Wendover using U.S. 93 Alternate to U.S. 93 to U.S. 6 to U.S. 95 (Nevada B)
Case 6	To Yucca Mountain via Wendover using U.S. 93 Alternate to U.S. 93 to Nevada 318 to U.S. 93 to I-15 to the Las Vegas Beltway to U.S. 95 (Nevada A)
Case 7	To Yucca Mountain via Las Vegas using I-15 (for shipments entering Nevada at both the Arizona and California borders) to U.S. 95 (Spaghetti Bowl interchange)

J.3.2 ANALYSIS OF INCIDENT-FREE TRANSPORTATION IN NEVADA

The analysis of incident-free impacts to populations in Nevada addressed transportation through urban, suburban, and rural population zones. The population densities used in the analysis were determined using Geographic Information System methods, population data from the 1990 Census, and projected populations along the Las Vegas Beltway (DIRS 155112-Berger 2000, pp. 59 to 64). The analysis extrapolated impacts to account for population growth to 2035. The populations within the 800-meter (0.5-mile) regions of influence used to evaluate the impacts of incident-free transportation for legal-weight truck, heavy-haul truck, and rail shipments are listed in Table J-35. The table lists the estimated 2035 populations.

Average highway vehicle densities for Nevada were calculated from vehicle traffic counts on Interstate and primary U.S. highways in Nevada counties that would be used for transporting spent nuclear fuel and high-level radioactive waste (DIRS 156930-NDOT 2001, all). The analysis used the average speed of trains on a branch rail line in Nevada from (DIRS 101214-CRWMS M&O 1996, Volume 1, Section 4, Branch Line Operations Plan). Heavy-haul trucks in Nevada would be escorted. The analysis assumed that heavy-haul truck shipments would originate in Caliente, Nevada, and would stop overnight en route to the repository. Input parameters for analysis of incident-free transportation in Nevada that differ from, or are additional to, values used to analyze impacts outside the State, are listed in Table J-49. Parameters not listed in this table are the same as those listed in Tables J-15 and J-17. Unit risk factors for incident-free transportation in Nevada are listed in Table J-50.

Results for incident-free transportation of spent nuclear fuel and high-level radioactive waste for Inventory Modules 1 and 2 are presented in Section J.3.4.

J.3.3 ANALYSIS OF TRANSPORTATION ACCIDENT SCENARIOS IN NEVADA

Section J.1.4 discusses the methodology for estimating the risks of accidents that could occur during rail and truck transportation of spent nuclear fuel and high-level radioactive waste. Section J.3.5 describes the results of the accident risk analysis for Inventory Modules 1 and 2.

J.3.3.1 Intermodal Transfer Station Accident Methodology

Shipping casks would arrive at an intermodal transfer station in Nevada by rail, and a gantry crane would transfer them from the railcars to heavy-haul trucks for transportation to the repository. The casks, which would not be opened or altered in any way at the intermodal transfer station, would be certified by the Nuclear Regulatory Commission and would be designed for accident conditions specified in 10 CFR Part 71. Impact limiters, which would protect casks against collisions during transportation, would remain in place during transfer operations at the intermodal transfer station.

Table J-47. Comparison of national impacts from the sensitivity analyses.

Impact	Base case	Case 1 Barstow via Nevada 160	Case 2 Barstow via California 127	Case 3 Needles via Nevada 160	Case 4 Needles via U.S. 95	Case 5 Wendover via U.S. 95	Case 6 Wendover via Las Vegas Beltway	Case 7 I-15 and U.S. 95 (Spaghetti Bowl)
Public incident-free dose (person-rem)	5,000	5,200	5,100	4,900	5,000	4,600	4,800	5,100
Occupational incident-free dose (person-rem)	14,000	15,000	15,000	14,000	14,000	15,000	15,000	14,000
Nonradioactive pollution health effects	0.93	0.93	0.93	0.89	0.88	0.79	0.81	1.1
Public incident-free risk of latent cancer fatality	2.5	2.6	2.6	2.4	2.5	2.3	2.4	2.6
Occupational incident-free risk of latent cancer fatality	5.6	6	5.8	5.6	5.7	5.9	5.9	5.6
Radiological accident risk (person-rem)	0.46	0.36	0.35	0.35	0.35	0.39	0.4	0.52
Radiological accident risk of latent cancer fatality	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0003
Traffic fatalities	4.5	4.5	4.2	4.3	4.2	4.9	5	4.5

Table J-48. Comparison of Nevada impacts from the sensitivity analyses.

Impact	Base case	Case 1 Barstow via Nevada 160	Case 2 Barstow via California 127	Case 3 Needles via Nevada 160	Case 4 Needles via U.S. 95	Case 5 Wendover via U.S. 95	Case 6 Wendover via Las Vegas Beltway	Case 7 I-15 and U.S. 95 (Spaghetti Bowl)
Public incident-free dose (person-rem)	340	180	35	170	83	360	490	480
Occupational incident-free dose (person-rem)	1,900	1,800	1,200	1,800	1,400	3,400	3,500	1,900
Nonradioactive pollution health effects	0.09	0.01	<0.005	0.01	<0.005	0.03	0.04	0.21
Public incident-free risk of latent cancer fatality	0.17	0.09	0.02	0.08	0.04	0.18	0.24	0.24
Occupational incident-free risk of latent cancer fatality	0.75	0.72	0.47	0.7	0.54	1.4	1.4	0.74
Radiological accident risk (person-rem)	0.052	0.005	0.002	0.004	0.002	0.015	0.027	0.11
Radiological accident risk of latent cancer fatality	0.000026	0.000003	0.000001	0.000002	0.000001	0.000008	0.000013	0.000055
Traffic fatalities	0.5	0.4	0.1	0.4	0.2	1.3	1.3	0.5

Table J-49. Input parameters and parameter values used for incident-free Nevada truck and rail transportation different from national parameters.

Parameter	Legal-weight truck	Rail	Heavy-haul truck
Speed (kilometers per hour)[a]			
Rural		50	
One-way traffic count (vehicles per hour)			
Rural	(b)		
Suburban	(b)		
Urban	(b)		
Truck crew dose at walkaround inspections			
Distance of crew from cargo (meters)[c]			30
Truck escort dose at walkaround inspections			
Distance of one inspector (meters)			1
Distance of 3 other escorts (meters)			60
Guards at overnight stop[d]			
Distance of 4 guards from cargo (meters)			60
Time of overnight stop (hours)			12

a. To convert kilometers to miles, multiply by 0.62137.
b. County-specific average traffic counts (DIRS 156930-NDOT 2001, all)
c. To convert meters to feet, multiply by 3.2808.
d. Crew and escorts are far enough away from the cargo and shielded sufficiently that they receive no dose from the cargo during the overnight stop. Number of guards and length of overnight stop are assumptions for analysis purposes.

Table J-50. Per-shipment unit risk factors for incident-free transportation of spent nuclear fuel and high-level radioactive waste in Nevada.

Factor	Heavy-haul truck	Rail	Legal-weight truck
Public			
Off-link [rem per (persons per square kilometers) per kilometer]			
Rural	6.24×10^{-8}	5.01×10^{-8}	2.89×10^{-8}
Suburban	6.24×10^{-8}	6.24×10^{-8}	3.18×10^{-8}
Urban	6.24×10^{-8}	1.04×10^{-7}	3.18×10^{-8}
On-link (person-rem per kilometer)[a]			
Rural	1.46×10^{-4}	2.00×10^{-7}	1.38×10^{-5}
Suburban	1.12×10^{-4}	1.55×10^{-6}	3.89×10^{-5}
Urban	5.40×10^{-4}	4.29×10^{-6}	1.87×10^{-4}
Residents near rest/refueling stops (rem per (persons per square kilometer) per kilometer)			
Rural	3.96×10^{-9}	1.24×10^{-7}	5.50×10^{-9}
Suburban	3.96×10^{-9}	1.24×10^{-7}	5.50×10^{-9}
Urban	3.96×10^{-9}	1.24×10^{-7}	5.50×10^{-9}
Residents near classification stops [rem per (persons per square kilometer)]			
Suburban	1.59×10^{-5}		
Public near rest/refueling stops (person-rem per kilometer)			7.86×10^{-6}
Workers			
Classification stop (person-rem)		8.07×10^{-3}	
In-transit stop (person-rem per kilometer)		1.45×10^{-5}	
In moving vehicle (person-rem per kilometer)			
Rural	5.54×10^{-6}		4.52×10^{-5}
Suburban	5.54×10^{-6}		4.76×10^{-5}
Urban	5.54×10^{-6}		4.76×10^{-5}
Crew, walkaround inspection (person-rem per kilometer)	6.27×10^{-7}		1.93×10^{-5}
Escort, walkaround inspection (person-rem per kilometer)	1.50×10^{-5}		
Guards at overnight stops (person-rem)	2.62×10^{-3}		

a. Listed values for on-link unit risk factors are based on Clark County traffic counts. The analysis used country-specific counts for each country through which shipments would pass.

DOE performed an accident screening process to identify credible accidents that could occur at an intermodal transfer station with the potential for compromising the integrity of the casks and releasing radioactive material. The external events listed in Table J-51 were considered, along with an evaluation of their potential applicability.

As indicated from Table J-51, the only accident-initiating event identified from among the feasible external events was the aircraft crash. Such events would be credible only for casks being handled or on transport vehicles at an intermodal transfer station in the Las Vegas area (Apex/Dry Lake or Sloan/Jean).

For a station in the Las Vegas area, an aircraft crash would be from either commercial aircraft operations at McCarran airport or military operations from Nellis Air Force Base.

Among the internal events, the only potential accident identified was a drop of the cask during transfer operations. This accident would bound the other events considered, including drops from the railcar or truck (less fall height would be involved than during the transfer operations). Collisions, derailments, and other accidents involving the transport vehicles at the intermodal transfer station would not damage the casks due to the requirement that they be able to withstand high-speed impacts and the low velocities of the transport vehicles at the intermodal transfer station.

Accident Analysis

1. *Cask Drop Accident.* The only internal event retained after the screening process was a failure of the gantry crane (due to mechanical failure or human error) during the transfer of a shipping cask from a railcar to a heavy-haul truck. The maximum height between the shipping cask and the ground during the transfer operation would be less than 6 meters (19 feet) (DIRS 104849-CRWMS M&O 1997, all). The casks would be designed to withstand a 9-meter (30-foot) drop. Therefore, the cask would be unlikely to fail during the event, especially because the impact energy from the 6-meter drop would be only 65 percent of the minimum design requirement.

2. *Aircraft Crash Accident.* This section, including Tables J-52 and J-53, has been moved to Volume IV of this EIS.

J.3.4 IMPACTS IN NEVADA FROM INCIDENT-FREE TRANSPORTATION FOR INVENTORY MODULES 1 AND 2

This section presents the analysis of impacts to occupational and public health and safety in Nevada from incident-free transportation of spent nuclear fuel and high-level radioactive waste in Inventory Modules 1 and 2. The analysis assumed that the routes, population densities, and shipment characteristics (for example, radiation from shipping casks) for shipments under the Proposed Action and Inventory Modules 1 and 2 would be the same. The only difference was the projected number of shipments that would travel to the repository.

The following sections provide detailed information on the range of potential impacts to occupational and public safety and health from incident-free transportation of Modules 1 and 2 that result from legal-weight trucks and the 10 alternative transportation routes considered in Nevada. National impacts of incident-free transportation of Modules 1 and 2 incorporating Nevada impacts are discussed together with other cumulative impacts in Chapter 8.

J.3.4.1 Mostly Legal-Weight Truck Scenario

Tables J-54 and J-55 list estimated incident-free impacts in Nevada for the mostly legal-weight truck scenario for shipments of materials included in Inventory Modules 1 and 2.

Table J-51. Screening analysis of external events considered potential accident initiators at intermodal transfer station.

Event	Applicability
Aircraft crash	Retained for further evaluation
Avalanche	(a)
Coastal erosion	(a)
Dam failure	See flooding
Debris avalanching	(a)
Dissolution	(b)
Epeirogenic displacement (tilting of the earth's crust)	(c)
Erosion	(b)
Extreme wind	(c)
Extreme weather	(e)
Fire (range)	(b)
Flooding	(d)
Denudation (loss of land cover)	(b)
Fungus, bacteria, algae	(b)
Glacial erosion	(b)
High lake level	(b)
High tide	(a)
High river stage	See flooding
Hurricane	(a)
Inadvertent future intrusion	(b)
Industrial activity	Bounded by aircraft crash
Intentional future intrusion	(b)
Lightning	(c)
Loss of off/on site power	(c)
Low lake level	(b)
Meteorite impact	(e)
Military activity	Retained for further evaluation
Orogenic diastrophism (tectonic ground movement)	(e)
Pipeline accident	(b)
Rainstorm	See flooding
Sandstorm	(c)
Sedimentation	(b)
Seiche (sudden water-level change)	(a)
Seismic activity, uplifting	(c)
Seismic activity, earthquake	(c)
Seismic activity, surface fault	(c)
Seismic activity, subsurface fault	(c)
Static fracturing	(b)
Stream erosion	(b)
Subsidence	(c)
Tornado	(c)
Tsunami (tidal wave)	(a)
Undetected past intrusions	(b)
Undetected geologic features	(b)
Undetected geologic processes	(c)
Volcanic eruption	(e)
Volcanism, magmatic activity	(e)
Volcanism, ash flow	(c)
Volcanism, ash fall	(b)
Waves (aquatic)	(a)

a. Conditions at proposed sites do not allow event.
b. Not a potential accident initiator.
c. Bounded by cask drop accident considered in the internal events analysis.
d. Shipping cask designed for event.
e. Not credible, see evaluation for repository.

Table J-54. Population doses and radiological impacts from incident-free Nevada transportation for mostly legal-weight truck scenario–Modules 1 and 2.[a]

Category	Legal-weight truck shipments	Rail shipments of naval spent nuclear fuel[b]	Total[c]
Module 1			
Involved worker			
Collective dose (person-rem)	3,700	21	3,700
Estimated latent cancer fatalities	1.5	0.008	1.5
Public			
Collective dose (person-rem)	680	10	690
Estimated latent cancer fatalities	0.34	0.005	0.35
Module 2			
Involved worker			
Collective dose (person-rem)	3,800	23	3,900
Estimated latent cancer fatalities	1.5	0.009	1.5
Public			
Collective dose (person-rem)	700	13	710
Estimated latent cancer fatalities	0.35	0.007	0.36

a. Impacts are totals for shipments over 38 years.
b. Includes impacts at intermodal transfer stations.
c. Totals might differ from sums due to rounding.

Table J-55. Population health impacts from vehicle emissions during incident-free Nevada transportation for the mostly legal-weight truck scenario–Modules 1 and 2.[a]

Vehicle emission-related fatalities	Legal-weight truck shipments	Rail shipments of naval spent nuclear fuel[b]	Total[c]
Module 1	0.17	0.0069	0.18
Module 2	0.18	0.0081	0.19

a. Impacts are totals for shipments over 38 years.
b. Includes heavy-haul truck shipments in Nevada.
c. Totals might differ from sums due to rounding.

J.3.4.2 Nevada Rail Implementing Alternatives

Table J-56 lists the range of estimated incident-free impacts in Nevada for the operation of a branch rail line to ship the materials included in Inventory Modules 1 and 2. It lists impacts that would result from operations for a branch line in each of the five possible rail corridors DOE is evaluating. These include the impacts of about 3,100 legal-weight truck shipments from commercial sites that could not use rail casks to ship spent nuclear fuel.

J.3.4.3 Nevada Heavy-Haul Truck Implementing Alternatives

Radiological Impacts

Intermodal Transfer Station Impacts. Involved worker exposures (the analysis assumed that the noninvolved workers would receive no radiation exposure and thus required no further analysis) would occur during both inbound (to the repository) and outbound (to the 77 sites) portions of the shipment campaign. DOE used the same involved worker level of effort it used in the analysis of intermodal transfer station worker industrial safety impacts to estimate collective involved worker radiological impacts (that is, 16 full-time equivalents per year). The collective worker radiation doses were adapted from a study (DIRS 104791-DOE 1992, all) of a spent nuclear fuel transportation system, which was also performed for the commercial sites. That study found that the collective worker doses that could be incurred during similar inbound and outbound transfer operations of a single loaded (with commercial

Table J-56. Radiological and nonradiological impacts from incident-free Nevada transportation for the rail implementing alternatives–Modules 1 and 2.[a]

Category	Legal-weight truck shipments	Rail shipments	Total[b]
Involved worker			
Collective dose (person-rem)	110	1,300 - 1,900	1,400 - 2,000
Estimated latent cancer fatalities	0.04	0.52 - 0.76	0.56 - 0.8
Public			
Collective dose (person-rem)	19	106 - 640	130 - 659
Estimated latent cancer fatalities	0.01	0.05 - 0.32	0.07 - 0.33
Estimated vehicle emission-related fatalities	0.0046	0.012 - 0.38	0.016 - 0.38

a. Impacts are totals for shipments over 38 years.
b. Totals might differ from sums due to rounding.

spent nuclear fuel) and unloaded cask were approximately 0.027 and 0.00088 person-rem per cask, respectively, as listed in Table J-57.

Table J-57. Collective worker doses (person-rem) from transportation of a single cask.[a,b]

Inbound	Inbound CD[b]	Outbound	Outbound CD
Receive transport vehicle and loaded cask. Monitor, inspect, unhook offsite drive unit, and attach onsite drive unit.	6.3×10^{-3}	Receive transport vehicle and empty cask. Monitor, inspect, unhook offsite drive unit, and attach onsite drive unit.	0.0
Move cask to parking area and wait for wash down station. Attach to carrier puller when ready.	1.4×10^{-3}	Move cask to parking area and wait for wash down station. Attach to carrier puller when ready.	5.4×10^{-4}
Move cask to receiving and handling area.	9.2×10^{-5}	Move cask to receiving and handling area.	8.0×10^{-6}
Remove cask from carrier and place on cask cart.	4.3×10^{-3}	Remove cask from carrier and place on cask cart.	2.2×10^{-4}
Connect onsite drive unit and move cask to inspection area; disconnect onsite drive unit.	7.0×10^{-4}	Connect onsite drive unit and move cask to inspection area; disconnect onsite drive unit.	3.3×10^{-5}
Hook up offsite drive unit, move to gatehouse, perform final monitoring and inspection of cask.	1.4×10^{-2}	Hook up offsite drive unit, move to gatehouse, perform final monitoring and inspection of cask.	8.3×10^{-5}
Notify appropriate organizations of the shipment's departure.	0.0	Notify appropriate organizations of the shipment's departure.	0.0
Total	2.7×10^{-2}	*Total*	8.8×10^{-4}

a. Adapted from DIRS 104791-DOE (1992, Table 4.2).
b. Values are rounded to two significant figures; therefore, totals might differ from sums of values.
c. CD = collective dose (person-rem per cask).

The analysis used these inbound and outbound collective dose factors to calculate the involved worker impacts listed in Table J-58 for Module 1 and Module 2 inventories in the same manner it used for commercial power reactor spent nuclear fuel impacts. The number of inbound and outbound shipments for Module 1 and Module 2 inventories is from Section J.1.2. The worker impacts reflect two-way operations.

Incident-Free Transportation. Table J-59 lists the range of estimated incident-free impacts in Nevada for the use of heavy-haul trucks to ship the materials included in Inventory Modules 1 and 2. It lists impacts that would result from operations on each of the five possible highway routes in Nevada DOE is evaluating. These include impacts of about 3,100 legal-weight truck shipments from commercial sites under Modules 1 and 2 that could not ship spent nuclear fuel using rail casks while operational.

Table J-58. Doses and radiological health impacts to involved workers from intermodal transfer station operations – Modules 1 and 2.[a,b]

	Module 1		Module 2	
Group	Dose (millirem)	Latent cancer fatality	Dose (millirem)	Latent cancer fatality
Maximally exposed individual worker	12	0.005[c]	12	0.005
Involved worker population	500	0.20[d]	520	0.21

a. Includes estimated impacts from handling 300 shipments of Naval spent nuclear fuel that would be shipped by rail under the mostly legal-weight truck transportation scenario.
b. Totals for 38 years of operations.
c. The estimated probability of a latent cancer fatality in an exposed individual.
d. The estimated number of latent cancer fatalities in an exposed involved worker population.

Table J-59. Radiological and nonradiological health impacts from incident-free transportation for the heavy-haul truck implementing alternatives – Modules 1 and 2.[a]

Category	Legal-weight truck shipments	Rail and heavy-haul truck shipments[b]	Total[c]
Involved worker			
Collective dose (person-rem)	110	2,100 - 3,100	2,200 - 3,300
Estimated latent cancer fatalities	0.04	0.85 - 1.3	0.89 - 1.3
Public			
Collective dose (person-rem)	19	100 - 580	120 - 600
Estimated latent cancer fatalities	0.01	0.05 - 0.29	0.06 - 0.3
Estimated vehicle emission-related fatalities	0.0046	0.0096 - 0.35	0.014 - 0.35

a. Impacts are totals for 38 years.
b. Includes impacts to workers at an intermodal transfer station.
c. Totals might differ from sums due to rounding.

J.3.5 IMPACTS IN NEVADA FROM TRANSPORTATION ACCIDENTS FOR INVENTORY MODULES 1 AND 2

The analysis assumed that the routes, population densities, and shipment characteristics (for example, assumed radioactive material contents of shipping casks) for the Proposed Action and Inventory Modules 1 and 2 would be the same. The only difference would be the projected number of shipments that would travel to the repository. As listed in Table J-1, Module 2 would include about 3 percent more shipments than Module 1.

J.3.5.1 Mostly Legal-Weight Truck Scenario

Radiological Impacts

The analysis estimated the radiological impacts of accidents in Nevada for the mostly legal-weight truck scenario for shipments of the materials included in Inventory Modules 1 and 2. The radiological health impacts associated with both Modules 1 and 2 would be 0.1 person-rem (see Table J-60). These impacts would occur over 38 years in a population of more than 1 million people who lived within 80 kilometers (50 miles) of the Nevada routes that DOE would use. This dose risk would lead to less than 1 chance in 1,000 of an additional cancer fatality in the exposed population. For comparison, in Nevada about 240,000 in a population of 1 million people would suffer fatal cancers from other causes (DIRS 153066-Murphy 2000, p. 83).

Traffic Fatalities

The analysis estimated traffic fatalities from accidents involving the transport of spent nuclear fuel and high-level radioactive waste by legal-weight trucks in Nevada for the mostly legal-weight truck scenario for shipments of the materials included in Inventory Modules 1 and 2. It estimated that there would be

Table J-60. Accident impacts for Modules 1 and 2 – Nevada transportation.[a]

Transportation scenario	Dose risk (person-rem)	Latent cancer fatalities	Traffic fatalities
Legal-weight truck	0.1[b]	0.0001	0.97
Legal-weight truck for the mostly rail scenario	0.003	0.000001	0.03
Mostly rail (Nevada rail implementing alternatives)			
Caliente	0.0012	0.000001	0.12
Carlin	0.0026	0.000001	0.16
Caliente-Chalk Mountain	0.0011	0.000001	0.08
Jean	0.01	0.000005	0.09
Valley Modified	0.0017	0.000001	0.08
Mostly rail (Nevada heavy-haul implementing alternatives)			
Caliente	0.015	0.000008	1.2
Caliente/Chalk Mountain	0.002	0.000001	0.62
Caliente/Las Vegas	0.092	0.00005	0.83
Apex/Dry Lake	0.091	0.00005	0.44
Sloan/Jean	0.2	0.0001	0.46

a. Impacts over 38 years.
b. Estimates of dose risk are for the transportation of the materials included in Module 2. Estimates of dose risk for transportation of the materials in Module 1 would be slightly (about 3 percent) lower.

0.97 fatality over 38 years for Module 1 or Module 2 (see Table J-60). The estimate of traffic fatalities includes the risk of fatalities from 300 shipments of naval spent nuclear fuel.

J.3.5.2 Nevada Rail Implementing Alternatives

Industrial Safety Impacts

Table J-61 lists the estimated industrial safety impacts in Nevada for the operation of a branch rail line to ship the materials included in Inventory Modules 1 and 2. The table lists impacts that would result from operations for a branch line in each of the five possible rail corridors in Nevada that DOE is evaluating.

Table J-61. Rail corridor operation worker physical trauma impacts (Modules 1 and 2).

Worker group and impact category	Corridor: Caliente	Carlin	Caliente-Chalk Mountain	Jean	Valley Modified
Involved workers					
TRC[a]	150	150	150	115	115
LWC[b]	82	82	82	63	63
Fatalities	0.41	0.41	0.41	0.31	0.31
Noninvolved workers[c]					
TRC	9	9	9	7	7
LWC	3	3	3	2	2
Fatalities	0.01	0.01	0.01	0.01	0.01
All workers (totals)[d]					
TRC	160	160	160	120	120
LWC	85	85	85	65	65
Fatalities	0.42	0.42	0.42	0.32	0.32
Traffic fatalities[e]	1.1	1.1	1.1	0.83	0.83

a. TRC = total recordable cases (injury and illness).
b. LWC = lost workday cases.
c. Noninvolved worker impacts are based on 25 percent of the involved worker level of effort.
d. Totals might differ from sums due to rounding.
e. Fatalities from accidents during commutes to and from jobs for involved and noninvolved workers.

The representative workplace loss incidence rate for each impact parameter (as compiled by the Bureau of Labor Statistics) was used as a multiplier to convert the operations crew level of effort to expected industrial safety losses. The involved worker full-time equivalent multiples that DOE would assign to operate each rail corridor each year was estimated to be 36 to 47 full-time equivalents, depending on the corridor for the period of operations [scaled from cost data in DIRS 101214-CRWMS M&O (1996, Appendix E)]. Noninvolved worker full-time equivalent multiples were unavailable, so DOE assumed that the noninvolved worker level of effort would be similar to that for the repository operations work force—about 25 percent of that for involved workers. The Bureau of Labor Statistics loss incidence rate for each total recordable case, lost workday, and fatality trauma category (for example, the number of total recordable cases per full-time equivalent) was multiplied by the involved and noninvolved worker full-time equivalent multiples to project the associated trauma incidence.

The Bureau of Labor Statistics involved worker total recordable case incidence rate, 145,700 total recordable cases in a workforce of 1,739,000 workers (0.084 total recordable case per full-time equivalent) reflects losses in the Trucking and Warehousing sector during the 1998 period of record. The same Bureau of Labor Statistics period of record and industry sector was used to select the involved worker lost workday case incidence rate [80,000 lost workday cases in a workforce of 1,739,000 workers (0.046 lost workday case per full-time equivalent)]. The involved worker fatality incidence rate, 23.4 fatalities in a workforce of 100,000 workers (0.00023 fatality per full-time equivalent) reflects losses in the Transportation and Material Moving Occupations sector during the 1998 period of record.

The noninvolved worker total recordable case incidence rate of 61,000 total recordable cases in a workforce of 3,170,300 workers (0.019 total recordable case per full-time equivalent) reflects losses in the Engineering and Management Services sector during the Bureau of Labor Statistics 1998 period of record. DOE used the same period of record and industry sector to select the noninvolved worker lost workday case incidence rate [22,400 lost workday cases in a workforce of 3,170,300 workers (0.071 lost workday case per full-time equivalent)]. The noninvolved worker fatality incidence rate, 1.6 fatalities in a workforce of 100,000 workers (0.00002 fatality per full-time equivalent) reflects losses in the Managerial and Professional Specialties sector during the 1998 period of record.

Table J-61 lists the results of these industrial safety calculations for the five candidate corridors under Inventory Modules 1 and 2. The table also lists estimates of the number of traffic fatalities that would occur in the course of commuting by workers to and from their construction and operations jobs. These estimates used national statistics for average commute distances [18.5 kilometers (11.5 miles) one-way (DIRS 102064-FHWA 1999, all)] and fatality rates for automobile traffic [1 per 100 million kilometers (1.5 per 100 million miles) (DIRS 148080-BTS 1998, all)].

Radiological Impacts of Accidents

The analysis estimated the radiological impacts of accident scenarios in Nevada for the Nevada rail implementing alternatives for shipments of the materials included in Inventory Modules 1 and 2. Table J-60 lists the radiological dose risk and associated risk of latent cancer fatalities. The risks include accident risks in Nevada from approximately 3,100 legal-weight truck shipments from commercial sites that could not ship spent nuclear fuel in rail casks while operational. The analysis assumed that those sites would upgrade their crane capacity after reactor shutdown to allow the use of rail casks. The risks would occur over 38 years.

Traffic Fatalities

Traffic fatalities from accidents involving transport of spent nuclear fuel and high-level radioactive waste by rail in Nevada were estimated for the Nevada rail implementing alternatives for shipments of materials included in Inventory Modules 1 and 2. Table J-60 lists the estimated number of fatalities that would occur over 38 years for a branch rail line along each of the five candidate rail corridors. These estimates include accident risks in Nevada from about 3,100 legal-weight truck shipments from commercial generators that could not ship spent nuclear fuel in rail casks while operational.

J.3.5.3 Nevada Heavy-Haul Truck Implementing Alternatives

Industrial Safety Impacts

Tables J-62 and J-63 list the estimated industrial safety impacts in Nevada for operations of heavy-haul trucks (principally highway maintenance safety impacts) and operation of an intermodal transfer station that would transfer loaded and unloaded rail casks between rail cars and heavy-haul trucks for shipments of the materials included in Inventory Modules 1 and 2. Table J-62 lists the estimated industrial safety impacts in Nevada for the operation of a heavy-haul route to the Yucca Mountain site. Table J-63 lists impacts that would result from the operation of an intermodal transfer station for any of the five candidate routes DOE is evaluating that heavy-haul trucks could use in Nevada.

Table J-62. Industrial health impacts from heavy-haul truck route operations (Modules 1 and 2).

Worker group and impact category	Corridor				
	Caliente	Caliente/Chalk Mountain	Caliente/Las Vegas	Sloan/ Jean	Apex/Dry Lake
Involved workers					
TRC[a]	350	350	320	190	190
LWC[b]	190	190	180	100	100
Fatalities	1.0	1.0	0.9	0.5	0.5
Noninvolved workers[c]					
TRC	20	20	18	11	11
LWC	8	8	7	4	4
Fatalities	0.02	0.02	0.02	0.01	0.01
All workers (totals)[d]					
TRC	370	370	340	200	200
LWC	200	200	180	110	110
Fatalities	0.99	0.99	0.99	0.53	0.53
Traffic fatalities[e]	2.6	2.3	2.6	1.4	1.4

a. TRC = total recordable cases (injury and illness).
b. LWC = lost workday cases.
c. Noninvolved worker impacts are based on 25 percent of the involved worker level of effort.
d. Totals might differ from sums due to rounding.
e. Fatalities from accidents during commutes to and from jobs for involved and noninvolved workers.

Table J-63. Annual physical trauma impacts to workers from intermodal transfer station operations (Module 1 or 2).

Involved workers			Noninvolved workers[a]			All workers		
TRC[b]	LWC[c]	Fatalities	TRC	LWC	Fatalities	TRC	LWC	Fatalities
85	47	0.23	5	2	0.01	90	48	0.24

a. The noninvolved worker impacts are based on 25 percent of the involved worker level of effort.
b. TRC = total recordable cases of injury and illness.
c. LWC = lost workday cases.

Radiological Impacts of Accidents

The analysis estimated the radiological impacts of accidents in Nevada for the Nevada heavy-haul truck implementing alternatives for shipments of the materials included in Inventory Modules 1 and 2.

Table J-60 lists the radiological dose risk and associated risk of latent cancer fatalities. The risks include accident risks in Nevada from approximately 3,100 legal-weight truck shipments from commercial generating sites that could not ship spent nuclear fuel in rail casks while operational. The risk would occur over 38 years.

Traffic Fatalities

The analysis estimated traffic fatalities from accidents involving the transport of spent nuclear fuel and high-level radioactive waste (including the rail portion of transportation to and from an intermodal transfer station) in Nevada for the heavy-haul truck implementing alternatives for shipments of the materials included in Inventory Modules 1 and 2. Table J-60 lists the estimated number of fatalities that would occur over 38 years for a branch rail line and for each of the five candidate routes for heavy-haul trucks. The estimate for traffic fatalities includes accident risk in Nevada from about 3,100 legal-weight truck shipments from commercial generators that could not ship spent nuclear fuel in rail casks while operational.

J.3.6 IMPACTS FROM TRANSPORTATION OF OTHER MATERIALS

Other types of transportation activities associated with the Proposed Action would involve shipments of materials other than the spent nuclear fuel and high-level radioactive waste discussed in previous sections. These activities would include the transportation of people (commuter transportation). This section evaluates occupational and public health and safety and air quality impacts from the shipment of:

- Construction materials, consumables, and personnel for repository construction and operation, including repository components (disposal containers, emplacement pallets, drip shields, and solar panels).
- Waste including low-level waste, construction and demolition debris, sanitary and industrial solid waste, and hazardous waste
- Office and laboratory supplies, mail, and laboratory samples

The analysis included potential impacts of transporting these materials for the flexible design, in which the repository would be open for 76 years after emplacement, and for several lower-temperature operating scenarios that would leave the repository open and ventilated for 125 to 300 years, a surface facility that would provide storage during a cooling period, and the use of derated waste packages. The analysis assumed that material would be shipped across the United States to Nevada by rail, but that DOE would not build a rail line to the proposed repository, because the larger number of truck shipments would lead to higher impacts than those for rail shipments, as discussed above. In addition, because the construction schedule for a new rail line would coincide with the schedule for the construction of repository facilities, trucks would deliver materials for repository construction.

Rail service would benefit the delivery of the 11,300 disposal containers from manufacturers. Two 33,000-kilogram (about 73,000-pound) disposal containers and their 700-kilogram (about 1,500-pound) lids (DIRS 155347-CRWMS M&O 1999, all) would be delivered on a railcar—a total of 5,650 railcar deliveries over the 24-year period of the Proposed Action (8,400 railcar deliveries if DOE used 17,000 derated waste packages). These containers would be delivered to the repository along with shipments of spent nuclear fuel and high-level radioactive waste or separately on supply trains along with shipments of materials and equipment.

Disposal container components that would weigh as much as 34 metric tons (37.5 tons) would be transported to Nevada by rail and transferred to overweight trucks for shipment to the repository site. Overweight truck shipments would move the 11,300 (or 17,000 if derated) containers from a railhead to the site. The State of Nevada routinely provides permits to motor carriers for overweight, overdimension loads if the gross vehicle weight does not exceed 58.5 metric tons (64.5 tons) (DIRS 155347-CRWMS M&O 1999, Request #046).

J.3.6.1 Transportation of Personnel and Materials to Repository

The following paragraphs describe impacts that would result from the transportation of construction materials, consumables, repository components, supplies, mail, laboratory samples, and personnel to the repository site during the construction, operation and monitoring, and closure phases of the Proposed Action.

Human Health and Safety

Most construction materials, construction equipment, and consumables would be transported to the Yucca Mountain site on legal-weight trucks. Heavy and overdimensional construction equipment would be delivered by trucks under permits issued by the Nevada Department of Transportation. The analysis assumed that repository components would be manufactured somewhere in the central United States, while other materials and consumables would originate in Nevada. DOE estimates that about 37,000 to 41,000 rail and truck shipments over 5 years would be necessary to transport materials, supplies, and equipment to the site during the construction phase, depending on the operating mode. Surface facilities for aging would require more construction materials.

In addition to construction materials, supplies, equipment, and repository components, trucks would deliver consumables to the repository site. These would include diesel fuel, cement, and other materials that would be consumed in daily operations.

Over the 24-year period of operation, the repository would receive between 6,600 and 10,000 shipments from across the United States, and between 47,000 and 62,000 shipments in Nevada of supplies, materials, equipment, repository components, and consumables, including cement and other materials for underground excavation. The analysis assumed that the Nevada shipments would originate in the Las Vegas metropolitan area. In addition, an estimated 53,000 shipments of office and laboratory supplies and equipment, mail, and laboratory samples would occur during the 24 years of operation. About 27 million to 41 million vehicle kilometers nationally (17 million to 25 million vehicle miles) of travel, and about 34 million to 40 million kilometers (21 million to 25 million miles) in Nevada would be involved. Impacts would include vehicle emissions, consumption of petroleum resources, increased truck traffic on regional highways, and fatalities from accidents. Similarly, there would be about 43 to 760 shipments nationally, and 190,000 to 720,000 shipments in Nevada during the 76-to-300-year monitoring period after emplacement operations and about 35,000 shipments, more than 99 percent in Nevada, during closure activities. Table J-64 summarizes these impacts.

Table J-64. Human health and safety impacts from national and Nevada shipments of material to the repository.

Phase	Kilometers[a] traveled (millions)	Traffic fatalities	Fuel consumption (millions of liters)[b]	Vehicle emissions-related fatalities
Construction (5 years)	8.9 - 10	0.15 - 0.21	2.9 - 10	0.019 - 0.022
Emplacement and development (24 years)	61 - 81	2.7 - 3.9	430 - 650	0.14 - 0.19
Monitoring (76 to 300 years)	47 - 170	0.8 - 3.0	13 - 65	0.10 - 0.36
Closure (10 to 17 years)	8.4 - 8.9	0.14 - 0.17	2.2 - 8.1	0.018 - 0.019
Totals[c]	*130 - 270*	*3.8 - 7.2*	*450 - 720*	*0.27 - 0.59*

a. To convert kilometers to miles, multiply by 0.62137.
b. To convert liters to gallons, multiply by 0.26418.
c. Totals might not equal sums due to rounding.

During the construction phase, many employees would use their personal automobiles to travel to construction areas on the repository site and to highway or rail line construction sites. The estimated average annual level of direct employment during repository surface and subsurface construction would be between 1,500 and 1,600 workers, depending on the operating mode. Current Nevada Test Site employees can ride DOE-provided buses to and from work; similarly, buses probably would be available for repository construction workers. The use of buses and car pools would result in an average vehicle occupancy of 8.6 persons per vehicle. Table J-65 summarizes the anticipated number of traffic-accident-related injuries and fatalities and the estimated consumption of gasoline that would occur from this travel activity. The greatest impact of this traffic would be added congestion at the northwestern Las Vegas Beltway interchange with U.S. Highway 95. Current estimates call for traffic at this interchange during rush hours to be as high as 1,000 vehicles an hour (DIRS 103710-Clark County 1997, Table 3-12, p. 3-43). The additional traffic from repository construction, assuming that the peak traffic would be 3 times the average, would be an estimated 600 vehicles per hour and would add about 35 percent to traffic volume at peak rush hour and would contribute to congestion although congestion in this area would be generally low.

Table J-65. Health impacts and fuel consumption from transportation of construction and operations workers.

Phase	Kilometers[a] traveled (in millions)	Traffic fatalities	Fuel consumption (millions of liters)[b]	Vehicle emissions-related fatalities
Construction	51 - 56	0.51 - 0.56	8.5 - 8.7	0.067 - 0.074
Emplacement and development (24 years)	290 - 440	2.9 - 4.4	48 - 73	0.38 - 0.58
Monitoring (76 to 300 years)	87 - 280	0.87 - 2.8	14 - 45	0.11 - 0.36
Closure	48 - 62	0.48 - 0.62	8.0 - 10	0.063 - 0.082
Totals[c]	*480 - 800*	*4.8 - 8.0*	*79 - 130*	*0.63 - 1.1*

a. To convert kilometers to miles, multiply by 0.62137.
b. To convert liters to gallons, multiply by 0.26418.
c. Totals might not equal sums due to rounding.

The average annual employment during emplacement and development operations would be between 1,700 and 2,600 workers. As mentioned above, DOE provides bus service from the Las Vegas area to and from the Nevada Test Site. Table J-65 summarizes the anticipated number of traffic-accident-related fatalities and the estimated consumption of gasoline that would occur from this travel activity. The greatest impact of this traffic would be increased congestion at the northwestern Las Vegas Beltway interchange with U.S. 95. As many as 600 to 850 vehicles an hour at peak rush hour would contribute to the congestion. Approximately 130 to 160 people would be employed annually during monitoring and about 460 to 600 would be employed annually during closure. The number of vehicles associated with these levels of employment, about 70 at most, would contribute negligibly to congestion.

Table J-66 lists the impacts associated with the delivery of fabricated disposal container components from a manufacturing site to the repository. A total of 11,300 containers (17,000 under the derated waste package scenario) would be delivered; if a rail line to Yucca Mountain was not available, the mode of transportation would be a combination of rail and overweight truck. The analysis assumes that the capacity of each railcar would be two containers and that the capacity of a truck would be one container, so there would be 5,650 railcar shipments to Nevada and 11,300 truck shipments to the Yucca Mountain site (8,400 rail shipments and 17,000 truck shipments if derated waste packages were used). The analysis estimated impacts for one national rail route representing a potential route from a manufacturing facility to a Nevada rail siding. The analysis estimated the impacts of transporting the containers from this siding over a single truck route—the Apex/Dry Lake route analyzed for the transportation of spent nuclear fuel and high-level radioactive waste by heavy-haul trucks. Although the actual mileage from a manufacturing facility could be shorter, DOE decided to select a distance that represents a conservative

Table J-66. Impacts of disposal container shipments for 24 years of the Proposed Action.[a]

Type of shipment	Number of shipments	Vehicle emissions-related health effects	Traffic fatalities
Rail and truck	5,650 - 8,400 rail/ 11,300 - 17,000 truck	0.088 - 0.13	2.2 - 3.2

a. Impacts of transporting drip shields and emplacement pallets are included in results listed in Table J-64.

estimate [4,439 kilometers (2,758 miles)]. The impacts are split into two subcategories—health effects from vehicle emissions and fatalities from transportation accidents.

Air Quality

The exhaust from vehicles involved in the transport of personnel and materials to the repository would emit carbon monoxide, nitrogen dioxide, sulfur dioxide, and particulate matter (PM_{10}). Because carbon monoxide is the principal pollutant of interest for evaluating impacts caused by motor vehicle emissions, the analysis focused on it. Table J-67 indicates the basis for selecting carbon monoxide as the principal pollutant of concern.

Table J-67. Listed pollutants and pollutant of interest.

Listed pollutant	Gasoline emissions	Diesel emissions
Carbon monoxide	Total emissions into the basin are larger than for diesel	More per vehicle-mile, but total emissions are less
Sulfur dioxide	Very minor problem with modern gasoline	Emits slightly more than gasoline
Nitrogen oxides	Limit less restrictive than carbon monoxide limit	
Particulate matter	Dust,[b] asphalt, and combustion particles	
Ozone	Limit less restrictive than carbon monoxide limit[c]	
Lead	Not a problem with modern gasoline	Does not produce lead

a. Source: 40 CFR 93.153.
b. Of most concern from earthmoving rather than fuel emissions (see DIRS 155557-Clark County 2001, all).
c. Ozone is not an emission but a product of sunlight acting on hydrocarbons and nitrogen oxides.

The analysis assumed that most of the personnel who would commute to the repository would reside in the Las Vegas area and that most of the materials would travel to the repository from the Las Vegas area. To estimate maximum potential emissions to the Las Vegas Valley airshed, which is in nonattainment for carbon monoxide (DIRS 101826-FHWA 1996, pp. 3-53 and 3-54), the analysis assumed that all personnel and material would travel from the center of Las Vegas to the repository. Table J-68 lists the estimated annual amount of carbon monoxide that would be emitted to the valley airshed during the phases of the repository project and the percent of the corresponding threshold level. Although it can be a health hazard (see Table J-65), its emission rate in the Las Vegas basin would be below the standard.

Table J-68. Annual range of carbon monoxide emitted to Las Vegas Valley airshed from transport of personnel and material to repository (kilograms per year)[a] for all modes of the Proposed Action.

Phase	Annual emission rate	Percent of GCR threshold level[b]
Construction	41,000 - 45,000	45 - 50
Emplacement and development	44,000 - 62,000	49 - 69
Operations and monitoring period	6,400 - 8,200	7 - 9
Closure	33,000 - 39,000	36 - 43

a. To convert kilograms to tons, multiply by 0.0011023.
b. GCR = General Conformity Rule; the emission threshold level for carbon monoxide in a nonattainment area is 91,000 kilograms (100 tons) per year (40 CFR 93.153).

As listed in Table J-68, the annual amount of carbon monoxide emitted to the nonattainment area would be below the threshold level during all phases of the Proposed Action. In the operation phase, the estimated annual amount of carbon monoxide emitted would be greatest (49 to 69 percent) to the threshold level. Relative to the vehicle emissions from the repository-bound high-level radioactive waste and spent nuclear fuel, the emissions from the transport of personnel and materials is substantially greater for all transportation implementing alternatives.

DOE conducted a conformity review using the guidance in DIRS 155566-DOE (2000, all) to estimate carbon monoxide emissions from the transportation of personnel, materials, and supplies through the Las Vegas air basin under each transportation implementing alternative. The transportation of personnel, materials, and supplies would be the main repository-related contributor of carbon monoxide to the nonattainment area. Compared to the total from all sources in the nonattainment area, the transportation of personnel, materials, and supplies to Yucca Mountain would add, at most, an additional 0.07 percent to the 2000 daily levels of carbon monoxide in the air basin (DIRS 156706-Clark County 2000, Appendix A, Table 1-3).

For areas that are in attainment, pollutant concentrations in the ambient air probably would increase due to the additional traffic but, given the relatively small amount of traffic that passes through these areas, the additional traffic would be unlikely to cause the ambient air quality standards to be exceeded.

Noise

Traffic-related noise on major transportation routes used by the workforce would likely increase. The analysis of impacts from traffic noise assumed that the workforce would come from Nye County (20 percent) and Clark County (80 percent). During the period of maximum employment in 2015, the analysis estimated a daily maximum of 576 vehicles would pass through the Gate 100 entrance at Mercury during rush hour [compared to a baseline of 232 vehicles per hour (DIRS 101811-DOE 1996, pp. 4-43 and 4-45)]. One-hour equivalent rush hour noise levels resulting from increased traffic would increase by 3.4 dBA at Indian Springs and 4.4 dBA at Mercury over background noise levels of 66.6 and 65.5 dBA, respectively. The increase could be perceptible to the community but, because of its short duration and existing highway noise, would be unlikely to result in an adverse public response.

J.3.6.2 Impacts of Transporting Wastes from the Repository

During repository construction and operations, DOE would ship waste and sample material from the repository. The waste would include hazardous, mixed, and low-level radioactive waste. Samples would include radioactive and nonradioactive hazardous materials shipped to laboratories for analysis. In addition, nonhazardous solid waste could be shipped from the repository site to the Nevada Test Site for disposal. However, as noted in Chapter 2, DOE proposes to include an industrial landfill on the repository site. Table J-69 summarizes the health impacts from wastes that DOE would ship from the repository.

Table J-69. Health impacts and fuel consumption from transportation of waste from the Yucca Mountain repository.

Phase	Kilometers[a] traveled (in millions)	Traffic fatalities	Fuel consumption (millions of liters)[b]	Vehicle emissions-related fatalities
Construction	0.37 - 0.39	0.0061 - 0.0066	0.086 - 0.092	0.00077 - 0.0082
Emplacement and development (24 years)	2.8 - 3.1	0.047 - 0.051	0.67 - 0.72	0.0040 - 0.0043
Monitoring (76 to 300 years)	1.8 - 6.2	0.031 - 0.10	0.44 - 1.5	0.0026 - 0.0088
Closure	0.67 - 0.88	0.011 - 0.020	0.16 - 0.24	0.0014 - 0.0025
Totals[c]	6.1 - 11	0.10 - 0.18	1.4 - 2.5	0.0093 - 0.016

a. To convert kilometers to miles, multiply by 0.62137.
b. To convert liters to gallons, multiply by 0.26418.
c. Totals might not equal sums due to rounding.

Occupational and Public Health and Safety

The quantities of hazardous waste that DOE would ship to approved facilities off the Nevada Test Site would be relatively small and would present little risk to public health and safety. This waste could be shipped by rail (if DOE built a rail line to the repository site) or by legal-weight truck to permitted disposal facilities. The principal risks associated with shipments of these materials would be related to traffic accidents. These risks would include 0.01 fatality for the combined construction, operation and monitoring, and closure phases for hazardous wastes.

DOE probably would ship low-level radioactive waste by truck to existing disposal facilities on the Nevada Test Site. Although these shipments would not use public highways, DOE estimated their risks. As with shipments of hazardous waste, the principal risk in transporting low-level radioactive waste would be related to traffic accidents. Because traffic on the Nevada Test Site is regulated by the Nye County Sheriff's Department, DOE assumed that accident rates on the site are similar to those of secondary highways in Nevada. Low-level radioactive waste would not be present during the construction of the repository. Therefore, accidents involving such waste could occur only during the operation and monitoring and the closure phases, although most of this waste would be generated during the construction and operation and monitoring phases. DOE estimates between 0.0038 and 0.0053 traffic fatality from the transportation of low-level radioactive waste during the repository construction, operation and monitoring, and closure phases. Table J-69 lists the impacts of transporting wastes, including hazardous waste, sanitary waste, construction debris, and low-level radioactive waste.

Air Quality

The quantities of hazardous waste that DOE would ship to approved facilities off the Nevada Test Site would be relatively small. Vehicle emissions due to these shipments would present little risk to public health and safety.

Biological Resources and Soils

The transportation of people, materials, and wastes during the construction, operation and monitoring, and closure phases of the repository could involve between 610 and 1,100 million vehicle-kilometers (between 380 and 680 million vehicle-miles) of travel on highways in southern Nevada depending on the repository operating mode. This travel would use existing highways that pass through desert tortoise habitat. Individual desert tortoises probably would be killed. However, because populations of the species are low in the vicinity of the routes (DIRS 103160-Bury and Germano 1994, pp. 57 to 72), few would be lost. Thus, the loss of individual desert tortoises due to repository traffic would not be likely to be a threat to the conservation of this species. In accordance with requirements of Section 7 of the Endangered Species Act (16 U.S.C. 1531 *et seq.*), DOE would consult with the Fish and Wildlife Service and would comply with mitigation measures resulting from that consultation to limit losses of desert tortoises from repository traffic.

J.3.6.3 Impacts from Transporting Other Materials and People in Nevada for Inventory Modules 1 and 2

The analysis evaluated impacts to occupational and public health and safety in Nevada from the transport of materials, wastes, and workers (including repository-related commuter travel) for construction, operation and monitoring, and closure of the repository that would occur for the receipt and emplacement of materials in Inventory Modules 1 and 2. The analysis assumed that the routes and transportation characteristics (for example, accident rates) for transportation associated with the Proposed Action and Inventory Modules 1 and 2 would be the same. The only difference would be the projected number of trips for materials, wastes, and workers traveling to the repository.

Table J-70 lists estimated incident-free (vehicle emissions) impacts and traffic (accident) fatality impacts in Nevada for the transportation of materials, wastes, and workers (including repository-related commuter travel) for the construction, operation and monitoring, and closure of the repository that would occur for the receipt and emplacement of the materials in Inventory Modules 1 and 2. The range includes all lower-temperature repository operating mode scenarios.

Table J-70. Health impacts from transportation of materials, consumables, personnel, and waste for Modules 1 and 2.[a]

Phase	Kilometers traveled (millions)[b]	Traffic fatalities	Emission-related health effects
Construction	61 - 67	0.67 - 0.74	0.086 - 0.096
Emplacement and Development	510 - 640	8.5 - 9.8	0.78 - 0.92
Operation and Monitoring	150 - 480	1.9 - 6.1	0.24 - 0.79
Closure	59 - 97	0.65 - 1.0	0.084 - 0.13
Totals	*820 - 1,200*	*12 - 18*	*1.2 - 1.9*

a. Numbers are rounded.
b. To convert kilometers to miles, multiply by 0.62137.
c. Totals might not equal sums due to rounding.

Even with the increased transportation of the other materials included in Module 1 or 2, DOE expects that the transportation of materials, consumables, personnel, and waste to and from the repository would be minor contributors to all transportation on a local, state, and national level. Public and worker health impacts would be small from transportation accidents involving nonradioactive hazardous materials. On average, in the United States there is about 1 fatality caused by the hazardous material being transported for each 30 million shipments by all modes (DIRS 103717-DOT 1998, p. 1; DIRS 103720-DOT Undated, Exhibit 2b).

J.4 State-Specific Impacts and Route Maps

This section contains maps and tables that illustrate the estimated impacts to 45 states and the District of Columbia (Alaska and Hawaii are not included; estimated impacts in Montana, North Dakota, and Rhode Island would be zero). As discussed previously in this appendix, DOE used state- and route-specific data to estimate transportation impacts. At this time, about 10 years before shipments could begin, DOE has not determined the specific routes it would use to ship spent nuclear fuel and high-level radioactive waste to the proposed repository. Therefore, the transportation routes discussed in this section might not be the exact routes actually used for shipments to Yucca Mountain. Nevertheless, because the analysis is based primarily on the existing Interstate Highway System and rail rolling stock, the analysis presents a representative estimate of what the actual transportation impacts would likely be.

In addition, under the national mostly rail transportation scenario, potential impacts in each state vary according to the ending node in Nevada. There are six different points of transfer from national to Nevada transportation (Caliente, Dry Lake, Jean, Beowawe, Eccles, and Apex). The routes used in the national analysis depend on the transfer point through which the shipments would pass. Tables J-71 through J-92 list the transportation impacts for 47 of the states and the District of Colombia, and Figures J-31 through J-52 are maps of the routes analyzed for each region.

In Nevada, the impacts vary according to the rail or heavy-haul implementing alternative. Figure J-53 shows the potential routes in the State of Nevada, and Table J-93 lists the impacts in Nevada for each of the eight implementing alternatives.

Table J-71. Estimated transportation impacts for the States of Alabama and Georgia.

State and impact category	Mostly legal-weight truck	Mostly rail					
		Ending rail node in Nevada[a]					
		Caliente[b]	Dry Lake[c]	Jean[d]	Beowawe[e]	Eccles[f]	Apex[g]
ALABAMA							
Shipments							
Truck (originating/total)	1,755/1,755	0/0	0/0	0/0	0/0	0/0	0/0
Rail (originating/total)	0/0	283/2,413	283/2,413	283/2,413	283/2,413	283/2,413	283/2,413
Radiological impacts							
Incident-free impacts							
Population (person-rem/LCFs)[h]	$5.0\times10^{0}/2.5\times10^{-3}$	$3.7\times10^{1}/1.8\times10^{-3}$	$3.7\times10^{1}/1.8\times10^{-3}$	$4.9\times10^{0}/2.4\times10^{-3}$	$3.7\times10^{1}/1.8\times10^{-3}$	$3.7\times10^{1}/1.8\times10^{-3}$	$3.7\times10^{1}/1.8\times10^{-3}$
Workers (person-rem/LCFs)	$4.2\times10^{1}/1.7\times10^{-2}$	$2.1\times10^{1}/8.2\times10^{-3}$	$2.1\times10^{1}/8.2\times10^{-3}$	$2.2\times10^{1}/8.8\times10^{-3}$	$2.1\times10^{1}/8.2\times10^{-3}$	$2.1\times10^{1}/8.2\times10^{-3}$	$2.1\times10^{1}/8.2\times10^{-3}$
Accident dose risk							
Population (person-rem/LCFs)	$4.6\times10^{-4}/2.3\times10^{-7}$	$3.1\times10^{-4}/1.5\times10^{-7}$	$3.1\times10^{-4}/1.5\times10^{-7}$	$7.0\times10^{-4}/3.5\times10^{-7}$	$3.1\times10^{-4}/1.5\times10^{-7}$	$3.1\times10^{-4}/1.5\times10^{-7}$	$3.1\times10^{-4}/1.5\times10^{-7}$
Nonradiological impacts							
Vehicle emissions (LCFs)	1.0×10^{-3}	8.4×10^{-4}	8.4×10^{-4}	1.4×10^{-3}	8.4×10^{-4}	8.4×10^{-4}	8.4×10^{-4}
Fatalities	0.003	0.009	0.009	0.011	0.009	0.009	0.009
GEORGIA							
Shipments							
Truck (originating/total)	1,664/13,169	0/491	0/491	0/491	0/491	0/491	0/491
Rail (originating/total)	0/0	321/2,561	321/2,561	321/2,359	321/2,561	321/2,561	321/2,561
Radiological impacts							
Incident-free impacts							
Population (person-rem/LCFs)[h]	$2.2\times10^{2}/1.1\times10^{-1}$	$1.0\times10^{2}/5.0\times10^{-2}$	$1.0\times10^{2}/5.0\times10^{-2}$	$9.4\times10^{1}/4.7\times10^{-2}$	$1.0\times10^{2}/5.0\times10^{-2}$	$1.0\times10^{2}/5.0\times10^{-2}$	$1.0\times10^{2}/5.0\times10^{-2}$
Workers (person-rem/LCFs)	$4.0\times10^{2}/1.6\times10^{-1}$	$1.2\times10^{2}/4.8\times10^{-2}$	$1.2\times10^{2}/4.8\times10^{-2}$	$1.1\times10^{2}/4.4\times10^{-2}$	$1.2\times10^{2}/4.8\times10^{-2}$	$1.2\times10^{2}/4.8\times10^{-2}$	$1.2\times10^{2}/4.8\times10^{-2}$
Accident dose risk							
Population (person-rem/LCFs)	$5.6\times10^{-2}/2.8\times10^{-5}$	$1.4\times10^{-2}/7.2\times10^{-6}$	$1.4\times10^{-2}/7.2\times10^{-6}$	$1.2\times10^{-2}/6.1\times10^{-6}$	$1.4\times10^{-2}/7.2\times10^{-6}$	$1.4\times10^{-2}/7.2\times10^{-6}$	$1.4\times10^{-2}/7.2\times10^{-6}$
Nonradiological impacts							
Vehicle emissions (LCFs)	6.4×10^{-2}	4.8×10^{-2}	4.8×10^{-2}	4.4×10^{-2}	4.8×10^{-2}	4.8×10^{-2}	4.8×10^{-2}
Fatalities	0.22	0.10	0.10	0.09	0.10	0.10	0.10

a. Under the mostly rail scenario, rail shipments would arrive in Nevada at one of six existing rail nodes. Impacts would vary according to the node. From that node, DOE would use one of the rail or heavy-haul implementing alternatives to complete the transportation to Yucca Mountain (see Section J.1.2).

b. For heavy-haul truck transportation, the Caliente junction is the location of the proposed Caliente intermodal transfer station for heavy-haul trucks near the town of Caliente in eastern Nevada. Rail shipments terminating at this junction would continue to Yucca Mountain on heavy-haul trucks on one of the Caliente, Caliente/Chalk Mountain, or Caliente/Las Vegas routes. For branch rail line transportation, railcars would transfer via the Caliente Option to the Caliente Corridor at the Caliente junction.

c. For heavy-haul truck transportation, the Dry Lake junction is near the location of the proposed Apex/Dry Lake intermodal transfer station for heavy-haul trucks in southeast Nevada. Rail shipments terminating at this junction would continue to Yucca Mountain on heavy-haul trucks on the Apex/Dry Lake route.

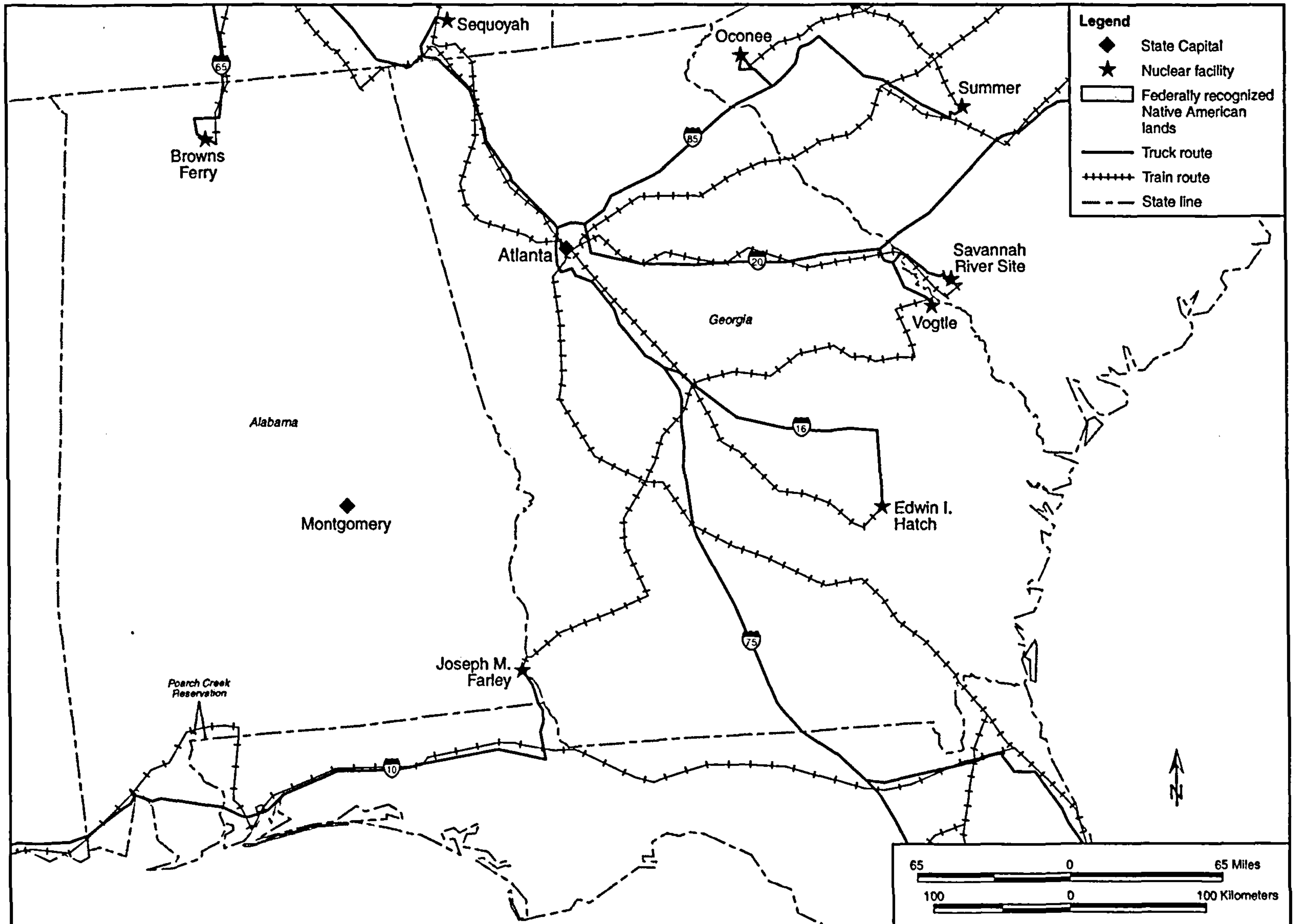
d. For heavy-haul truck transportation, the Jean junction is near the location of the proposed Sloan/Jean intermodal transfer station for heavy-haul trucks in southern Nevada. Rail shipments terminating at this junction would continue to Yucca Mountain on heavy-haul trucks on the Sloan/Jean route. For branch rail line transportation, railcars would transfer from the mainline railroad via the Wilson Pass or Stateline Pass Option of the Jean Corridor, near the Jean junction.

e. For branch rail line transportation, railcars would transfer from the mainline railroad at the Beowawe junction in north-central Nevada to the Carlin Corridor.

f. For branch rail line transportation, railcars would transfer from the mainline railroad at the Eccles junction east of Caliente, Nevada, via the Eccles Option or nearby via the Crestline Option of the Caliente or Caliente-Chalk Mountain Corridor. Impacts in states outside Nevada would be the same for the Eccles and Crestline Options of the Caliente and Caliente-Chalk Mountain Corridors.

g. For branch rail line transportation, railcars would transfer from the mainline railroad at the Apex junction in southeast Nevada, possibly via the Valley Connection, to the Valley Modified Corridor.

h. LCF = latent cancer fatality.



These routes represent the routes analyzed in Chapter 6 and might not be the routes actually used for shipments to the proposed repository at Yucca Mountain. Truck routes comply with U.S. Department of Transportation routing regulations. Rail routes are based on maximizing the distance on mainline track and minimizing the overall distance and number of interchanges between railroads.

Figure J-31. Highway and rail routes used to analyze transportation impacts - Alabama and Georgia.

Table J-72. Estimated transportation impacts for the State of Arkansas.

Impact category	Mostly legal-weight truck	Mostly rail						
		Ending rail node in Nevada[a]						
		Caliente[b]	Dry Lake[c]	Jean[d]	Beowawe[e]	Eccles[f]	Apex[g]
ARKANSAS							
Shipments							
Truck (originating/total)	794/794	0/0	0/0	0/0	0/0	0/0	0/0
Rail (originating/total)	0/0	121/201	121/201	121/121	121/258	121/201	121/201
Radiological impacts							
Incident-free impacts							
Population (person-rem/LCFs)[h]	$2.3\times10^{0}/1.1\times10^{-3}$	$1.1\times10^{0}/5.4\times10^{-4}$	$1.1\times10^{0}/5.4\times10^{-4}$	$9.5\times10^{-1}/4.8\times10^{-4}$	$1.2\times10^{0}/5.8\times10^{-4}$	$1.1\times10^{0}/5.4\times10^{-4}$	$1.1\times10^{0}/5.4\times10^{-4}$
Workers (person-rem/LCFs)	$2.1\times10^{1}/8.3\times10^{-3}$	$7.8\times10^{0}/3.1\times10^{-3}$	$7.8\times10^{0}/3.1\times10^{-3}$	$6.6\times10^{0}/2.6\times10^{-3}$	$8.7\times10^{0}/3.5\times10^{-3}$	$7.8\times10^{0}/3.1\times10^{-3}$	$7.8\times10^{0}/3.1\times10^{-3}$
Accident dose risk							
Population (person-rem/LCFs)	$4.6\times10^{-5}/2.3\times10^{-8}$	$3.8\times10^{-4}/1.9\times10^{-7}$	$3.8\times10^{-4}/1.9\times10^{-7}$	$2.4\times10^{-4}/1.2\times10^{-7}$	$4.7\times10^{-4}/2.4\times10^{-7}$	$3.8\times10^{-4}/1.9\times10^{-7}$	$3.8\times10^{-4}/1.9\times10^{-7}$
Nonradiological impacts							
Vehicle emissions (LCFs)	1.9×10^{-4}	2.0×10^{-4}	2.0×10^{-4}	1.3×10^{-4}	2.4×10^{-4}	2.0×10^{-4}	2.0×10^{-4}
Fatalities	1.2×10^{-3}	3.7×10^{-3}	3.7×10^{-3}	1.6×10^{-3}	5.3×10^{-3}	3.7×10^{-3}	3.7×10^{-3}

a. Under the mostly rail scenario, rail shipments would arrive in Nevada at one of six existing rail nodes. Impacts would vary according to the node. From that node, DOE would use one of the rail or heavy-haul implementing alternatives to complete the transportation to Yucca Mountain (see Section J.1.2).

b. For heavy-haul truck transportation, the Caliente junction is the location of the proposed Caliente intermodal transfer station for heavy-haul trucks near the town of Caliente in eastern Nevada. Rail shipments terminating at this junction would continue to Yucca Mountain on heavy-haul trucks on one of the Caliente, Caliente/Chalk Mountain, or Caliente/Las Vegas routes. For branch rail line transportation, railcars would transfer via the Caliente Option to the Caliente Corridor at the Caliente junction.

c. For heavy-haul truck transportation, the Dry Lake junction is near the location of the proposed Apex/Dry Lake intermodal transfer station for heavy-haul trucks in southeast Nevada. Rail shipments terminating at this junction would continue to Yucca Mountain on heavy-haul trucks on the Apex/Dry Lake route.

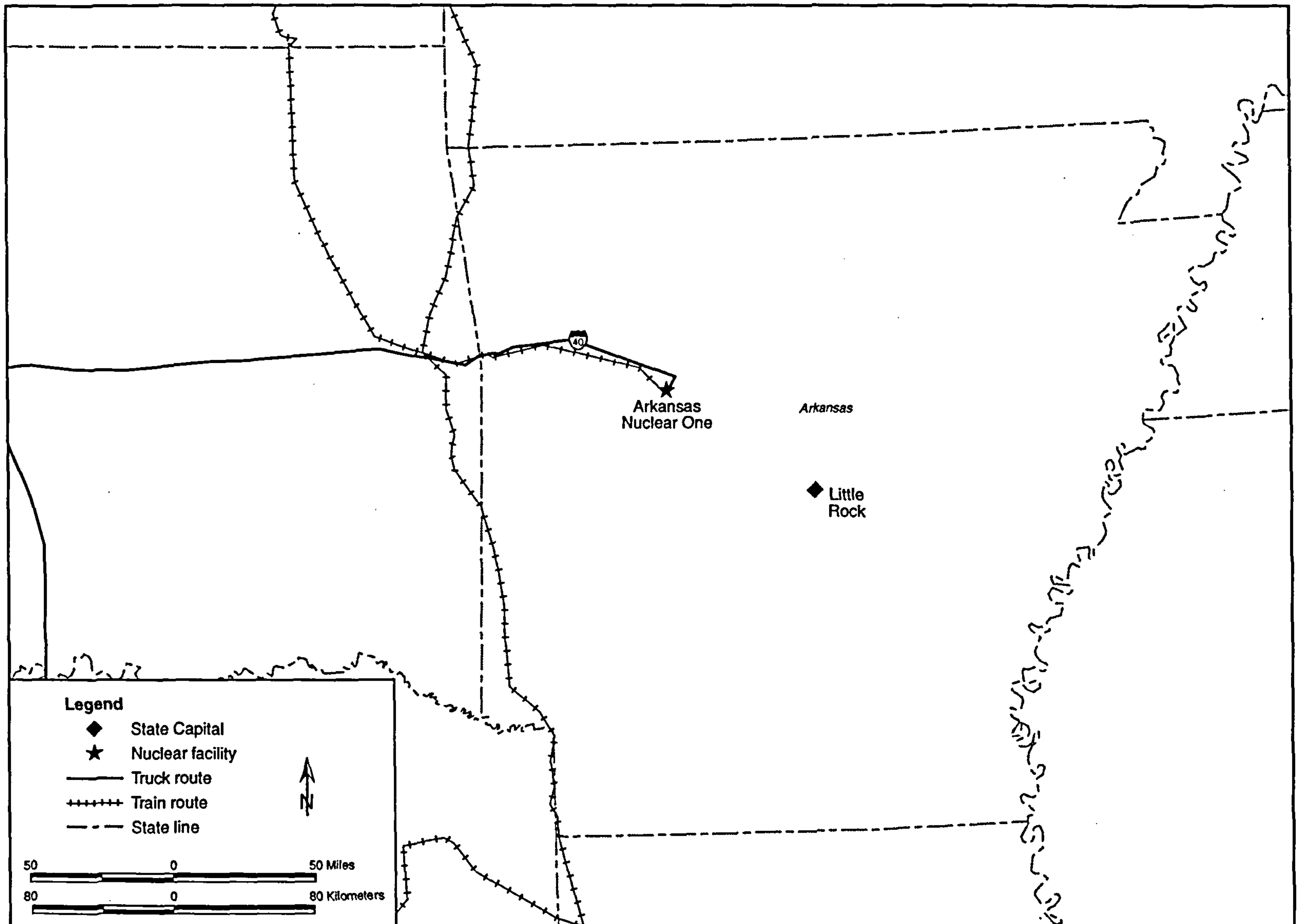
d. For heavy-haul truck transportation, the Jean junction is near the location of the proposed Sloan/Jean intermodal transfer station for heavy-haul trucks in southern Nevada. Rail shipments terminating at this junction would continue to Yucca Mountain on heavy-haul trucks on the Sloan/Jean route. For branch rail line transportation, railcars would transfer from the mainline railroad via the Wilson Pass or Stateline Pass Option of the Jean Corridor, near the Jean junction.

e. For branch rail line transportation, railcars would transfer from the mainline railroad at the Beowawe junction in north-central Nevada to the Carlin Corridor.

f. For branch rail line transportation, railcars would transfer from the mainline railroad at the Eccles junction east of Caliente, Nevada, via the Eccles Option or nearby via the Crestline Option of the Caliente or Caliente-Chalk Mountain Corridor. Impacts in states outside Nevada would be the same for the Eccles and Crestline Options of the Caliente and Caliente-Chalk Mountain Corridors.

g. For branch rail line transportation, railcars would transfer from the mainline railroad at the Apex junction in southeast Nevada, possibly via the Valley Connection, to the Valley Modified Corridor.

h. LCF = latent cancer fatality.



These routes represent the routes analyzed in Chapter 6 and might not be the routes actually used for shipments to the proposed repository at Yucca Mountain. Truck routes comply with U.S. Department of Transportation routing regulations. Rail routes are based on maximizing the distance on mainline track and minimizing the overall distance and number of interchanges between railroads.

Figure J-32. Highway and rail routes used to analyze transportation impacts - Arkansas.

Table J-73. Estimated transportation impacts for the States of Arizona and New Mexico.

Impact category	Mostly legal-weight truck	Mostly rail					
		Ending rail node in Nevada[a]					
		Caliente[b]	Dry Lake[c]	Jean[d]	Beowawe[e]	Eccles[f]	Apex[g]
ARIZONA							
Shipments							
Truck (originating/total)	1,118/51,036	0/1,079	0/1,079	0/1,079	0/1,079	0/1,079	0/1,079
Rail (originating/total)	0/0	193/374	193/431	193/1,145	193/193	193/308	193/585
Radiological impacts							
Incident-free impacts							
Population (person-rem/LCFs)[h]	$9.2\times10^{1}/4.6\times10^{-2}$	$5.5\times10^{0}/2.7\times10^{-3}$	$6.1\times10^{0}/3.1\times10^{-3}$	$1.3\times10^{1}/6.7\times10^{-3}$	$3.4\times10^{0}/1.7\times10^{-3}$	$4.7\times10^{0}/2.3\times10^{-3}$	$7.9\times10^{0}/4.0\times10^{-3}$
Workers (person-rem/LCFs)	$3.2\times10^{2}/1.3\times10^{-1}$	$2.3\times10^{1}/9.0\times10^{-3}$	$2.5\times10^{1}/1.0\times10^{-2}$	$5.5\times10^{1}/2.2\times10^{-2}$	$1.5\times10^{1}/6.0\times10^{-3}$	$2.0\times10^{1}/7.9\times10^{-3}$	$3.1\times10^{1}/1.3\times10^{-2}$
Accident dose risk							
Population (person-rem/LCFs)	$1.2\times10^{-3}/6.1\times10^{-7}$	$3.6\times10^{-4}/1.8\times10^{-7}$	$4.7\times10^{-4}/2.3\times10^{-7}$	$1.7\times10^{-3}/8.5\times10^{-7}$	$3.8\times10^{-5}/1.9\times10^{-8}$	$2.3\times10^{-4}/1.2\times10^{-7}$	$6.7\times10^{-4}/3.4\times10^{-7}$
Nonradiological impacts							
Vehicle emissions (LCFs)	6.2×10^{-3}	1.2×10^{-3}	1.5×10^{-3}	5.1×10^{-3}	1.1×10^{-4}	7.8×10^{-4}	2.4×10^{-3}
Fatalities	8.9×10^{-2}	7.8×10^{-3}	9.4×10^{-3}	2.9×10^{-2}	2.8×10^{-3}	6.0×10^{-3}	1.4×10^{-2}
NEW MEXICO							
Shipments							
Truck (originating/total)	0/3,999	0/0	0/0	0/0	0/0	0/0	0/0
Rail (originating/total)	0/0	0/181	0/238	0/952	0/154	0/115	0/392
Radiological impacts							
Incident-free impacts							
Population (person-rem/LCFs)[b]	$5.5\times10^{1}/2.8\times10^{-2}$	$3.4\times10^{-1}/1.7\times10^{-4}$	$4.4\times10^{-1}/2.2\times10^{-4}$	$2.3\times10^{0}/1.2\times10^{-3}$	$9.2\times10^{-3}/4.6\times10^{-6}$	$2.1\times10^{-1}/1.1\times10^{-4}$	$7.3\times10^{-1}/3.6\times10^{-4}$
Workers (person-rem/LCFs)	$1.4\times10^{2}/5.8\times10^{-2}$	$3.1\times10^{0}/1.2\times10^{-3}$	$4.0\times10^{0}/1.6\times10^{-3}$	$2.3\times10^{1}/9.3\times10^{-3}$	$1.3\times10^{0}/5.2\times10^{-4}$	$1.9\times10^{0}/7.8\times10^{-4}$	$6.6\times10^{0}/2.7\times10^{-3}$
Accident dose risk							
Population (person-rem/LCFs)	$1.6\times10^{-3}/8.2\times10^{-7}$	$3.9\times10^{-5}/2.0\times10^{-8}$	$5.3\times10^{-5}/2.7\times10^{-8}$	$3.0\times10^{-4}/1.5\times10^{-7}$	$1.2\times10^{-6}/6.1\times10^{-10}$	$2.4\times10^{-5}/1.2\times10^{-8}$	$7.9\times10^{-5}/3.9\times10^{-8}$
Nonradiological impacts							
Vehicle emissions (LCFs)	1.0×10^{-2}	1.9×10^{-4}	2.4×10^{-4}	1.3×10^{-3}	4.3×10^{-6}	1.2×10^{-4}	4.0×10^{-4}
Fatalities	0.053	0.001	0.002	0.010	0.001	0.001	0.003

a. Under the mostly rail scenario, rail shipments would arrive in Nevada at one of six existing rail nodes. Impacts would vary according to the node. From that node, DOE would use one of the rail or heavy-haul implementing alternatives to complete the transportation to Yucca Mountain (see Section J.1.2).

b. For heavy-haul truck transportation, the Caliente junction is the location of the proposed Caliente intermodal transfer station for heavy-haul trucks near the town of Caliente in eastern Nevada. Rail shipments terminating at this junction would continue to Yucca Mountain on heavy-haul trucks on one of the Caliente, Caliente/Chalk Mountain, or Caliente/Las Vegas routes. For branch rail line transportation, railcars would transfer via the Caliente Option to the Caliente Corridor at the Caliente junction.

c. For heavy-haul truck transportation, the Dry Lake junction is near the location of the proposed Apex/Dry Lake intermodal transfer station for heavy-haul trucks in southeast Nevada. Rail shipments terminating at this junction would continue to Yucca Mountain on heavy-haul trucks on the Apex/Dry Lake route.

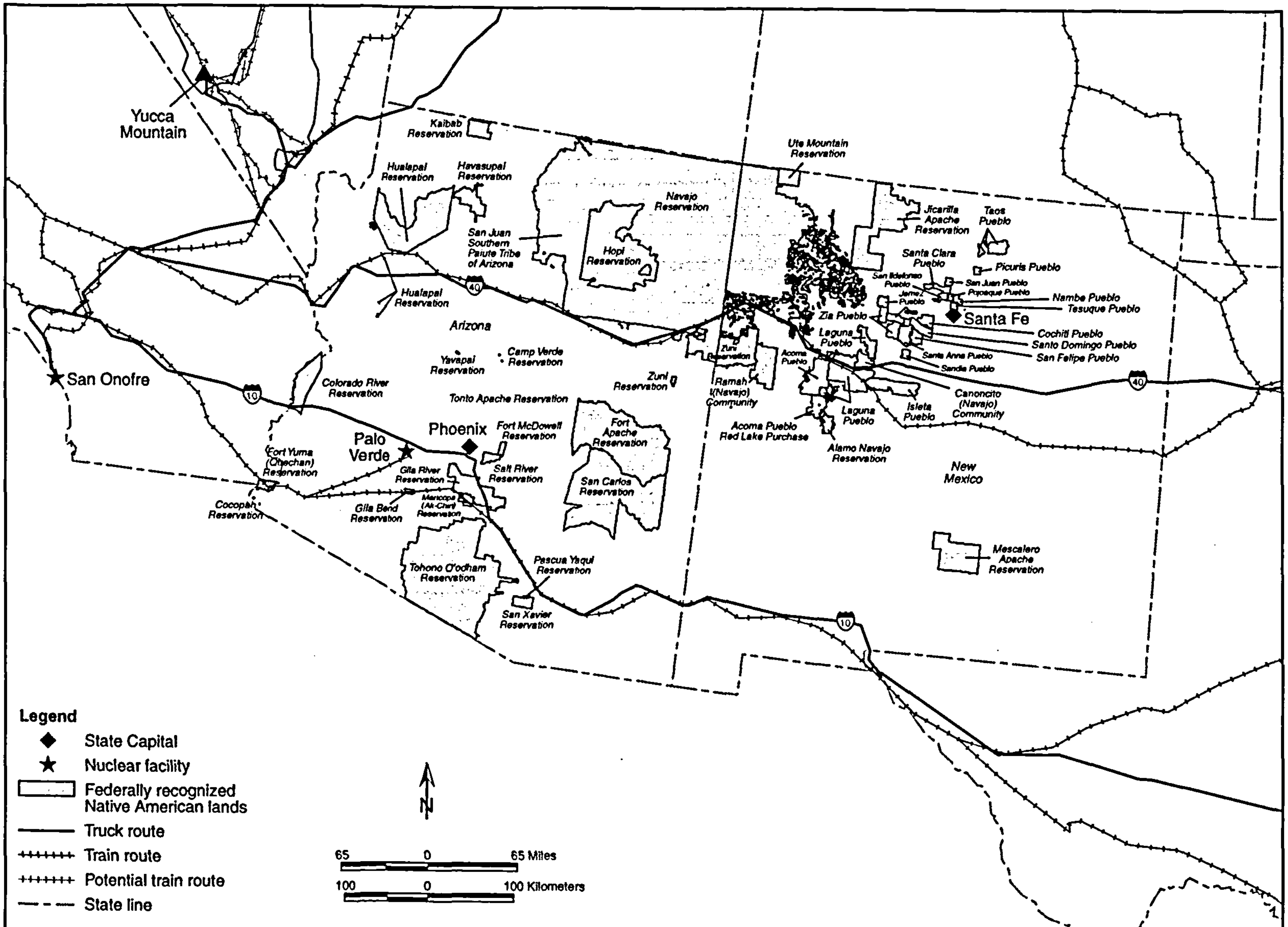
d. For heavy-haul truck transportation, the Jean junction is near the location of the proposed Sloan/Jean intermodal transfer station for heavy-haul trucks in southern Nevada. Rail shipments terminating at this junction would continue to Yucca Mountain on heavy-haul trucks on the Sloan/Jean route. For branch rail line transportation, railcars would transfer from the mainline railroad via the Wilson Pass or Stateline Pass Option of the Jean Corridor, near the Jean junction.

e. For branch rail line transportation, railcars would transfer from the mainline railroad at the Beowawe junction in north-central Nevada to the Carlin Corridor.

f. For branch rail line transportation, railcars would transfer from the mainline railroad at the Eccles junction east of Caliente, Nevada, via the Eccles Option or nearby via the Crestline Option of the Caliente or Caliente-Chalk Mountain Corridor. Impacts in states outside Nevada would be the same for the Eccles and Crestline Options of the Caliente and Caliente-Chalk Mountain Corridors.

g. For branch rail line transportation, railcars would transfer from the mainline railroad at the Apex junction in southeast Nevada, possibly via the Valley Connection, to the Valley Modified Corridor.

h. LCF = latent cancer fatality.



These routes represent the routes analyzed in Chapter 6 and might not be the routes actually used for shipments to the proposed repository at Yucca Mountain. Truck routes comply with U.S. Department of Transportation routing regulations. Rail routes are based on maximizing the distance on mainline track and minimizing the overall distance and number of interchanges between railroads.

Figure J-33. Highway and rail routes used to analyze transportation impacts - Arizona and New Mexico.

Table J-74. Estimated transportation impacts for the State of California.

Impact category	Mostly legal-weight truck	Mostly rail: Ending rail node in Nevada[a]					
		Caliente[b]	Dry Lake[c]	Jean[d]	Beowawe[e]	Eccles[f]	Apex[g]
CALIFORNIA							
Shipments							
Truck (originating/total)	1,750/6,867	0/0	0/0	0/0	0/0	0/0	0/0
Rail (originating/total)	0/0	286/660	286/750	286/1,464	286/512	286/594	286/904
Radiological impacts							
Incident-free impacts							
Population (person-rem/LCFs)[h]	$1.3\times10^{2}/6.3\times10^{-2}$	$4.8\times10^{1}/2.4\times10^{-2}$	$5.3\times10^{1}/2.6\times10^{-2}$	$6.6\times10^{1}/3.3\times10^{-2}$	$6.9\times10^{1}/3.4\times10^{-2}$	$4.6\times10^{1}/2.3\times10^{-2}$	$5.7\times10^{1}/2.9\times10^{-2}$
Workers (person-rem/LCFs)	$2.7\times10^{2}/1.1\times10^{-1}$	$4.5\times10^{1}/1.8\times10^{-2}$	$5.0\times10^{1}/2.0\times10^{-2}$	$7.7\times10^{1}/3.1\times10^{-2}$	$5.2\times10^{1}/2.1\times10^{-2}$	$4.2\times10^{1}/1.7\times10^{-2}$	$5.7\times10^{1}/2.3\times10^{-2}$
Accident dose risk							
Population (person-rem/LCFs)	$9.7\times10^{-3}/4.9\times10^{-6}$	$2.2\times10^{-2}/1.1\times10^{-5}$	$2.5\times10^{-2}/1.3\times10^{-5}$	$3.2\times10^{-2}/1.6\times10^{-5}$	$3.4\times10^{-2}/1.7\times10^{-5}$	$2.1\times10^{-2}/1.1\times10^{-5}$	$2.7\times10^{-2}/1.3\times10^{-5}$
Nonradiological impacts							
Vehicle emissions (LCFs)	4.3×10^{-2}	2.1×10^{-2}	2.3×10^{-2}	3.0×10^{-2}	3.1×10^{-2}	2.0×10^{-2}	2.5×10^{-2}
Fatalities	0.052	0.061	0.073	0.131	0.073	0.055	0.087

a. Under the mostly rail scenario, rail shipments would arrive in Nevada at one of six existing rail nodes. Impacts would vary according to the node. From that node, DOE would use one of the rail or heavy-haul implementing alternatives to complete the transportation to Yucca Mountain (see Section J.1.2).

b. For heavy-haul truck transportation, the Caliente junction is the location of the proposed Caliente intermodal transfer station for heavy-haul trucks near the town of Caliente in eastern Nevada. Rail shipments terminating at this junction would continue to Yucca Mountain on heavy-haul trucks on one of the Caliente, Caliente/Chalk Mountain, or Caliente/Las Vegas routes. For branch rail line transportation, railcars would transfer via the Caliente Option to the Caliente Corridor at the Caliente junction.

c. For heavy-haul truck transportation, the Dry Lake junction is near the location of the proposed Apex/Dry Lake intermodal transfer station for heavy-haul trucks in southeast Nevada. Rail shipments terminating at this junction would continue to Yucca Mountain on heavy-haul trucks on the Apex/Dry Lake route.

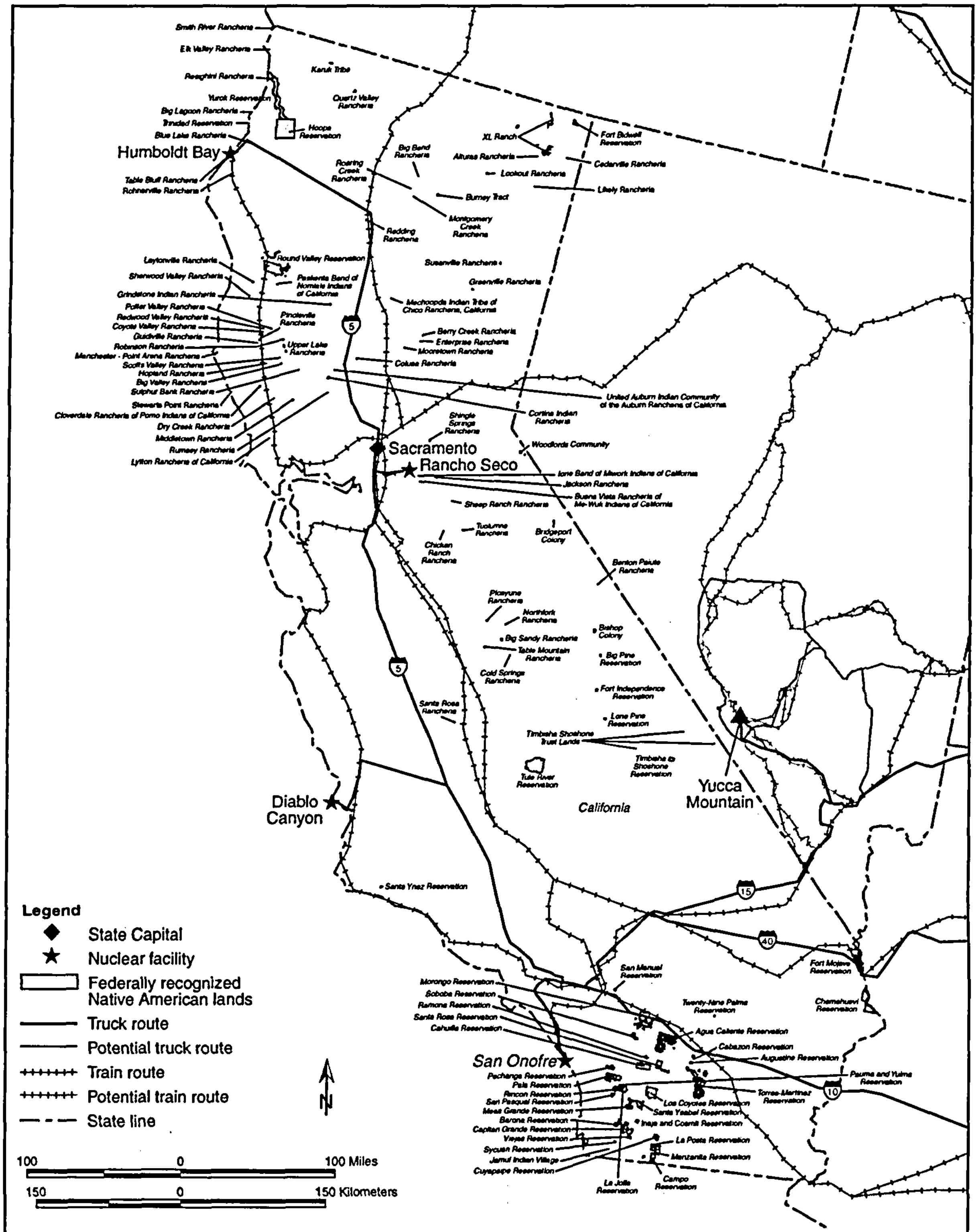
d. For heavy-haul truck transportation, the Jean junction is near the location of the proposed Sloan/Jean intermodal transfer station for heavy-haul trucks in southern Nevada. Rail shipments terminating at this junction would continue to Yucca Mountain on heavy-haul trucks on the Sloan/Jean route. For branch rail line transportation, railcars would transfer from the mainline railroad via the Wilson Pass or Stateline Pass Option of the Jean Corridor, near the Jean junction.

e. For branch rail line transportation, railcars would transfer from the mainline railroad at the Beowawe junction in north-central Nevada to the Carlin Corridor.

f. For branch rail line transportation, railcars would transfer from the mainline railroad at the Eccles junction east of Caliente, Nevada, via the Eccles Option or nearby via the Crestline Option of the Caliente or Caliente-Chalk Mountain Corridor. Impacts in states outside Nevada would be the same for the Eccles and Crestline Options of the Caliente and Caliente-Chalk Mountain Corridors.

g. For branch rail line transportation, railcars would transfer from the mainline railroad at the Apex junction in southeast Nevada, possibly via the Valley Connection, to the Valley Modified Corridor.

h. LCF = latent cancer fatality.



These routes represent the routes analyzed in Chapter 6 and might not be the routes actually used for shipments to the proposed repository at Yucca Mountain. Truck routes comply with U.S. Department of Transportation routing regulations. Rail routes are based on maximizing the distance on mainline track and minimizing the overall distance and number of interchanges between railroads.

Figure J-34. Highway and rail routes used to analyze transportation impacts - California.

Table J-75. Estimated transportation impacts for the States of Colorado, Kansas, and Nebraska (page 1 of 2).

Impact category	Mostly legal-weight truck	Mostly rail					
		Ending rail node in Nevada[a]					
		Caliente[b]	Dry Lake[c]	Jean[d]	Beowawe[e]	Eccles[f]	Apex[g]
COLORADO							
Shipments							
Truck (originating/total)	312/708	0/0	0/0	0/0	0/0	0/0	0/0
Rail (originating/total)	0/0	36/7,904	36/7,847	36/7,133	36/8,085	36/7,970	36/7,693
Radiological impacts							
Incident-free impacts							
Population (person-rem/LCFs)[h]	$4.4\times10^{0}/2.2\times10^{-3}$	$1.6\times10^{1}/8.2\times10^{-3}$	$1.4\times10^{1}/7.1\times10^{-3}$	$3.2\times10^{0}/1.6\times10^{-3}$	$2.0\times10^{1}/1.0\times10^{-2}$	$1.9\times10^{1}/9.4\times10^{-3}$	$8.5\times10^{0}/4.3\times10^{-3}$
Workers (person-rem/LCFs)	$1.8\times10^{1}/7.4\times10^{-3}$	$4.0\times10^{1}/1.6\times10^{-2}$	$3.7\times10^{1}/1.5\times10^{-2}$	$1.2\times10^{1}/4.9\times10^{-3}$	$4.7\times10^{1}/1.9\times10^{-2}$	$4.5\times10^{1}/1.8\times10^{-2}$	$2.7\times10^{1}/1.1\times10^{-2}$
Accident dose risk							
Population (person-rem/LCFs)	$3.4\times10^{-4}/1.7\times10^{-7}$	$5.2\times10^{-3}/2.6\times10^{-6}$	$4.4\times10^{-3}/2.2\times10^{-6}$	$7.9\times10^{-4}/3.9\times10^{-7}$	$6.6\times10^{-3}/3.3\times10^{-6}$	$6.1\times10^{-3}/3.1\times10^{-6}$	$3.0\times10^{-3}/1.5\times10^{-6}$
Nonradiological impacts							
Vehicle emissions (LCFs)	4.9×10^{-4}	8.0×10^{-3}	6.9×10^{-3}	1.4×10^{-3}	9.9×10^{-3}	9.2×10^{-3}	4.0×10^{-3}
Fatalities	0.005	0.024	0.021	0.007	0.028	0.026	0.015
KANSAS							
Shipments							
Truck (originating/total)	396/396	0/0	0/0	0/0	0/0	0/0	0/0
Rail (originating/total)	0/0	63/4,253	63/4,253	63/4,249	63/4,310	63/4,253	63/4,253
Radiological impacts							
Incident-free impacts							
Population (person-rem/LCFs)[h]	$6.0\times10^{0}/3.0\times10^{-3}$	$1.7\times10^{1}/8.4\times10^{-3}$	$1.7\times10^{1}/8.4\times10^{-3}$	$1.8\times10^{1}/9.2\times10^{-3}$	$1.7\times10^{1}/8.5\times10^{-3}$	$1.7\times10^{1}/8.4\times10^{-3}$	$1.7\times10^{1}/8.4\times10^{-3}$
Workers (person-rem/LCFs)	$2.6\times10^{1}/1.0\times10^{-2}$	$8.3\times10^{1}/3.3\times10^{-2}$	$8.3\times10^{1}/3.3\times10^{-2}$	$8.6\times10^{1}/3.5\times10^{-2}$	$8.4\times10^{1}/3.4\times10^{-2}$	$8.3\times10^{1}/3.3\times10^{-2}$	$8.3\times10^{1}/3.3\times10^{-2}$
Accident dose risk							
Population (person-rem/LCFs)	$2.4\times10^{-4}/1.2\times10^{-7}$	$7.9\times10^{-3}/3.9\times10^{-6}$	$7.9\times10^{-3}/3.9\times10^{-6}$	$8.7\times10^{-3}/4.3\times10^{-6}$	$8.0\times10^{-3}/4.0\times10^{-6}$	$7.9\times10^{-3}/3.9\times10^{-6}$	$7.9\times10^{-3}/3.9\times10^{-6}$
Nonradiological impacts							
Vehicle emissions (LCFs)	4.6×10^{-4}	8.5×10^{-3}	8.5×10^{-3}	9.3×10^{-3}	8.6×10^{-3}	8.5×10^{-3}	8.5×10^{-3}
Fatalities	0.003	0.049	0.049	0.051	0.050	0.049	0.049
NEBRASKA							
Shipments							
Truck (originating/total)	532/40,799	0/1,079	0/1,079	0/1,079	0/1,079	0/1,079	0/1,079
Rail (originating/total)	0/0	103/7,657	103/7,657	103/7,097	103/7,714	103/7,657	103/7,657
Radiological impacts							
Incident-free impacts							
Population (person-rem/LCFs)[h]	$6.4\times10^{2}/3.2\times10^{-1}$	$6.2\times10^{1}/3.1\times10^{-2}$	$6.2\times10^{1}/3.1\times10^{-2}$	$5.9\times10^{1}/2.9\times10^{-2}$	$6.3\times10^{1}/3.1\times10^{-2}$	$6.2\times10^{1}/3.1\times10^{-2}$	$6.2\times10^{1}/3.1\times10^{-2}$
Workers (person-rem/LCFs)	$2.0\times10^{3}/7.8\times10^{-1}$	$3.9\times10^{2}/1.6\times10^{-1}$	$3.9\times10^{2}/1.6\times10^{-1}$	$3.7\times10^{2}/1.5\times10^{-1}$	$4.0\times10^{2}/1.6\times10^{-1}$	$3.9\times10^{2}/1.6\times10^{-1}$	$3.9\times10^{2}/1.6\times10^{-1}$
Accident dose risk							
Population (person-rem/LCFs)	$3.0\times10^{-2}/1.5\times10^{-5}$	$3.9\times10^{-2}/2.0\times10^{-5}$	$3.9\times10^{-2}/2.0\times10^{-5}$	$3.6\times10^{-2}/1.8\times10^{-5}$	$4.0\times10^{-2}/2.0\times10^{-5}$	$3.9\times10^{-2}/2.0\times10^{-5}$	$3.9\times10^{-2}/2.0\times10^{-5}$
Nonradiological impacts							
Vehicle emissions (LCFs)	5.7×10^{-2}	2.4×10^{-2}	2.4×10^{-2}	2.3×10^{-2}	2.4×10^{-2}	2.4×10^{-2}	2.4×10^{-2}
Fatalities	0.83	0.18	0.18	0.17	0.18	0.18	0.18

a. Under the mostly rail scenario, rail shipments would arrive in Nevada at one of six existing rail nodes. Impacts would vary according to the node. From that node, DOE would use one of the rail or heavy-haul implementing alternatives to complete the transportation to Yucca Mountain (see Section J.1.2).

b. For heavy-haul truck transportation, the Caliente junction is the location of the proposed Caliente intermodal transfer station for heavy-haul trucks near the town of Caliente in eastern Nevada. Rail shipments terminating at this junction would continue to Yucca Mountain on heavy-haul trucks on one of the Caliente, Caliente/Chalk Mountain, or Caliente/Las Vegas routes. For branch rail line transportation, railcars would transfer via the Caliente Option to the Caliente Corridor at the Caliente junction.

Table J-75. Estimated transportation impacts for the States of Colorado, Kansas, and Nebraska (page 2 of 2).

c. For heavy-haul truck transportation, the Dry Lake junction is near the location of the proposed Apex/Dry Lake intermodal transfer station for heavy-haul trucks in southeast Nevada. Rail shipments terminating at this junction would continue to Yucca Mountain on heavy-haul trucks on the Apex/Dry Lake route.

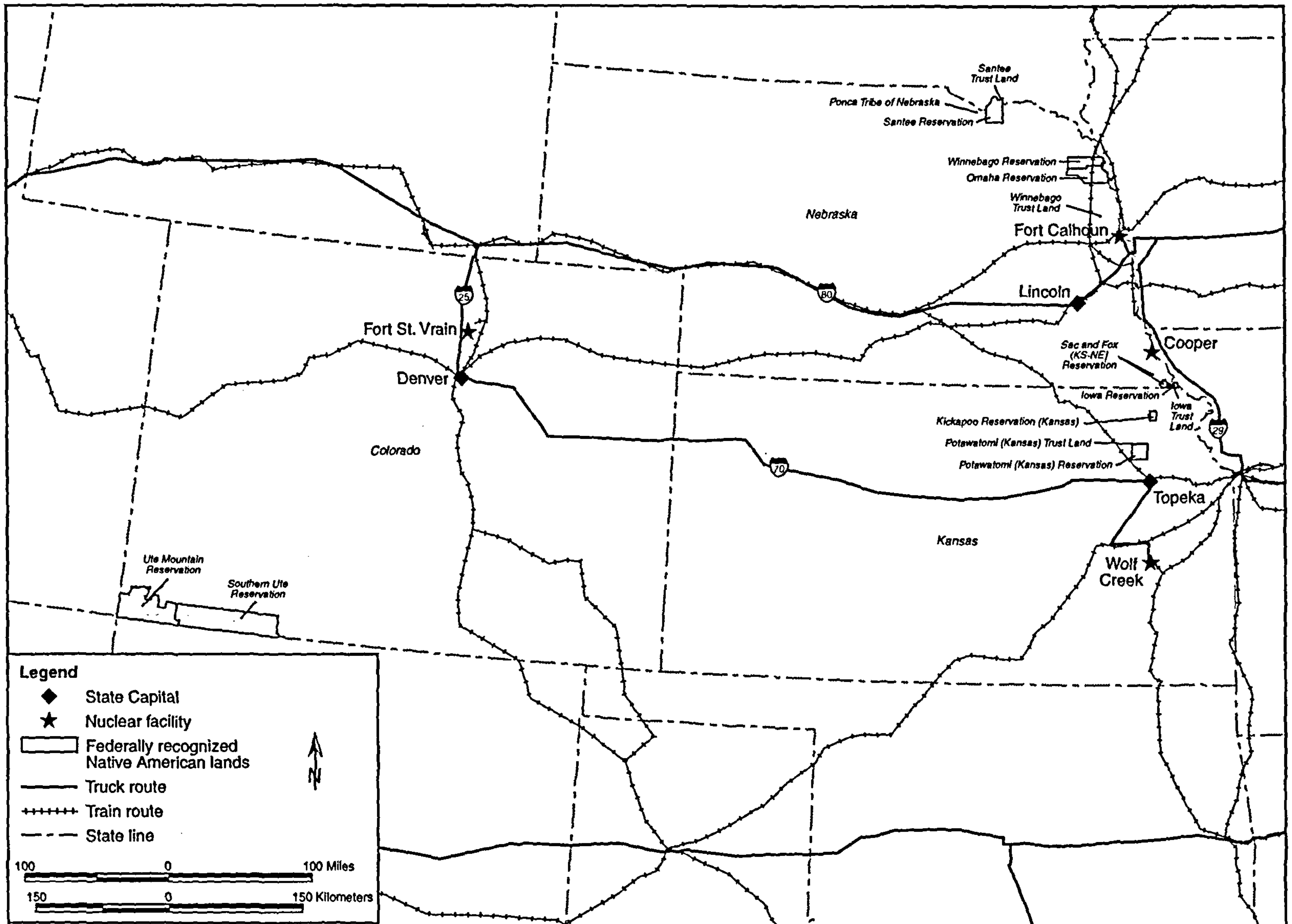
d. For heavy-haul truck transportation, the Jean junction is near the location of the proposed Sloan/Jean intermodal transfer station for heavy-haul trucks in southern Nevada. Rail shipments terminating at this junction would continue to Yucca Mountain on heavy-haul trucks on the Sloan/Jean route. For branch rail line transportation, railcars would transfer from the mainline railroad via the Wilson Pass or Stateline Pass Option of the Jean Corridor, near the Jean junction.

e. For branch rail line transportation, railcars would transfer from the mainline railroad at the Beowawe junction in north-central Nevada to the Carlin Corridor.

f. For branch rail line transportation, railcars would transfer from the mainline railroad at the Eccles junction east of Caliente, Nevada, via the Eccles Option or nearby via the Crestline Option of the Caliente or Caliente-Chalk Mountain Corridor. Impacts in states outside Nevada would be the same for the Eccles and Crestline Options of the Caliente and Caliente-Chalk Mountain Corridors.

g. For branch rail line transportation, railcars would transfer from the mainline railroad at the Apex junction in southeast Nevada, possibly via the Valley Connection, to the Valley Modified Corridor.

h. LCF = latent cancer fatality.



These routes represent the routes analyzed in Chapter 6 and might not be the routes actually used for shipments to the proposed repository at Yucca Mountain. Truck routes comply with U.S. Department of Transportation routing regulations. Rail routes are based on maximizing the distance on mainline track and minimizing the overall distance and number of interchanges between railroads.

Figure J-35. Highway and rail routes used to analyze transportation impacts - Colorado, Kansas, and Nebraska.

Table J-76. Estimated transportation impacts for the States of Connecticut, Rhode Island, and New York (page 1 of 2).

		Mostly rail					
		Ending rail node in Nevada[a]					
Impact category	Mostly legal-weight truck	Caliente[b]	Dry Lake[c]	Jean[d]	Beowawe[e]	Eccles[f]	Apex[g]
CONNECTICUT							
Shipments							
Truck (originating/total)	1,247/1,247	0/0	0/0	0/0	0/0	0/0	0/0
Rail (originating/total)	0/0	295/295	295/295	295/295	295/295	295/295	295/295
Radiological impacts							
Incident-free impacts							
Population (person-rem/LCFs)[h]	$1.5\times10^{1}/7.5\times10^{-3}$	$9.1\times10^{0}/4.6\times10^{-3}$	$9.1\times10^{0}/4.6\times10^{-3}$	$9.1\times10^{0}/4.6\times10^{-3}$	$9.1\times10^{0}/4.6\times10^{-3}$	$9.1\times10^{0}/4.6\times10^{-3}$	$9.1\times10^{0}/4.6\times10^{-3}$
Workers (person-rem/LCFs)	$3.4\times10^{1}/1.4\times10^{-2}$	$1.7\times10^{1}/7.0\times10^{-3}$	$1.7\times10^{1}/7.0\times10^{-3}$	$1.7\times10^{1}/7.0\times10^{-3}$	$1.7\times10^{1}/7.0\times10^{-3}$	$1.7\times10^{1}/7.0\times10^{-3}$	$1.7\times10^{1}/7.0\times10^{-3}$
Accident dose risk							
Population (person-rem/LCFs)	$8.2\times10^{-3}/4.1\times10^{-6}$	$1.6\times10^{-1}/8.2\times10^{-5}$	$1.6\times10^{-1}/8.2\times10^{-5}$	$.6\times10^{-1}/8.2\times10^{-5}$	$1.6\times10^{-1}/8.2\times10^{-5}$	$1.6\times10^{-1}/8.2\times10^{-5}$	$1.6\times10^{-1}/8.2\times10^{-5}$
Nonradiological impacts							
Vehicle emissions (LCFs)	6.5×10^{-3}	3.4×10^{-3}	3.4×10^{-3}	3.4×10^{-3}	3.4×10^{-3}	3.4×10^{-3}	3.4×10^{-3}
Fatalities	0.005	0.135	0.135	0.135	0.135	0.135	0.135
RHODE ISLAND							
Shipments	0/0	0/0	0/0	0/0	0/0	0/0	0/0
Truck (originating/total)	0/0	0/0	0/0	0/0	0/0	0/0	0/0
Rail (originating/total)	0/0	0/0	0/0	0/0	0/0	0/0	0/0
Radiological impacts	0/0	0/0	0/0	0/0	0/0	0/0	0/0
Incident-free impacts	0/0	0/0	0/0	0/0	0/0	0/0	0/0
Population (person-rem/LCFs)[h]	0/0	0/0	0/0	0/0	0/0	0/0	0/0
Workers (person-rem/LCFs)	0/0	0/0	0/0	0/0	0/0	0/0	0/0
Accident dose risk	0/0	0/0	0/0	0/0	0/0	0/0	0/0
Population (person-rem/LCFs)	0/0	0/0	0/0	0/0	0/0	0/0	0/0
Nonradiological impacts	0/0	0/0	0/0	0/0	0/0	0/0	0/0
Vehicle emissions (LCFs)	0/0	0/0	0/0	0/0	0/0	0/0	0/0
Fatalities	0/0	0/0	0/0	0/0	0/0	0/0	0/0
NEW YORK							
Shipments							
Truck (originating/total)	2,571/5,287	426/580	426/580	426/580	426/580	426/580	426/580
Rail (originating/total)	0/0	350/861	350/861	350/861	350/861	350/861	350/861
Radiological impacts							
Incident-free impacts							
Population (person-rem/LCFs)[h]	$6.3\times10^{1}/3.2\times10^{-2}$	$3.1\times10^{1}/1.6\times10^{-2}$	$3.1\times10^{1}/1.6\times10^{-2}$	$3.1\times10^{1}/1.6\times10^{-2}$	$3.1\times10^{1}/1.6\times10^{-2}$	$3.1\times10^{1}/1.6\times10^{-2}$	$3.1\times10^{1}/1.6\times10^{-2}$
Workers (person-rem/LCFs)	$1.6\times10^{2}/6.2\times10^{-2}$	$6.7\times10^{1}/2.7\times10^{-2}$	$6.7\times10^{1}/2.7\times10^{-2}$	$6.7\times10^{1}/2.7\times10^{-2}$	$6.7\times10^{1}/2.7\times10^{-2}$	$6.7\times10^{1}/2.7\times10^{-2}$	$6.7\times10^{1}/2.7\times10^{-2}$
Accident dose risk							
Population (person-rem/LCFs)	$7.0\times10^{-3}/3.5\times10^{-6}$	$4.9\times10^{-2}/2.4\times10^{-5}$	$4.9\times10^{-2}/2.4\times10^{-5}$	$4.9\times10^{-2}/2.4\times10^{-5}$	$4.9\times10^{-2}/2.4\times10^{-5}$	$4.9\times10^{-2}/2.4\times10^{-5}$	$4.9\times10^{-2}/2.4\times10^{-5}$
Nonradiological impacts							
Vehicle emissions (LCFs)	1.4×10^{-2}	1.3×10^{-2}	1.3×10^{-2}	1.3×10^{-2}	1.3×10^{-2}	1.3×10^{-2}	1.3×10^{-2}
Fatalities	0.042	0.122	0.122	0.122	0.122	0.122	0.122

a. Under the mostly rail scenario, rail shipments would arrive in Nevada at one of six existing rail nodes. Impacts would vary according to the node. From that node, DOE would use one of the rail or heavy-haul implementing alternatives to complete the transportation to Yucca Mountain (see Section J.1.2).

b. For heavy-haul truck transportation, the Caliente junction is the location of the proposed Caliente intermodal transfer station for heavy-haul trucks near the town of Caliente in eastern Nevada. Rail shipments terminating at this junction would continue to Yucca Mountain on heavy-haul trucks on one of the Caliente, Caliente/Chalk Mountain, or Caliente/Las Vegas routes. For branch rail line transportation, railcars would transfer via the Caliente Option to the Caliente Corridor at the Caliente junction.

Table J-76. Estimated transportation impacts for the States of Connecticut, Rhode Island, and New York (page 2 of 2).

c. For heavy-haul truck transportation, the Dry Lake junction is near the location of the proposed Apex/Dry Lake intermodal transfer station for heavy-haul trucks in southeast Nevada. Rail shipments terminating at this junction would continue to Yucca Mountain on heavy-haul trucks on the Apex/Dry Lake route.

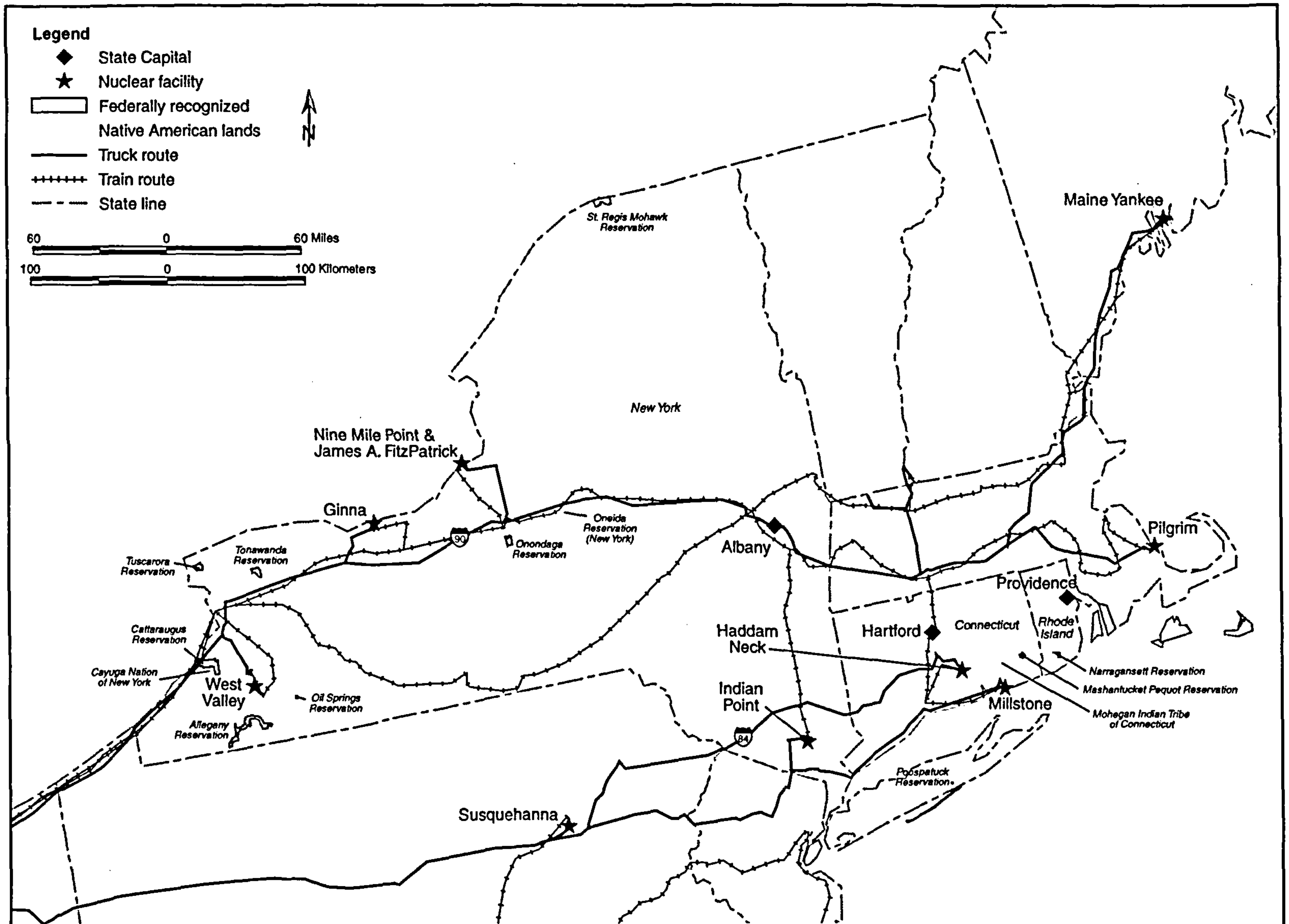
d. For heavy-haul truck transportation, the Jean junction is near the location of the proposed Sloan/Jean intermodal transfer station for heavy-haul trucks in southern Nevada. Rail shipments terminating at this junction would continue to Yucca Mountain on heavy-haul trucks on the Sloan/Jean route. For branch rail line transportation, railcars would transfer from the mainline railroad via the Wilson Pass or Stateline Pass Option of the Jean Corridor, near the Jean junction.

e. For branch rail line transportation, railcars would transfer from the mainline railroad at the Beowawe junction in north-central Nevada to the Carlin Corridor.

f. For branch rail line transportation, railcars would transfer from the mainline railroad at the Eccles junction east of Caliente, Nevada, via the Eccles Option or nearby via the Crestline Option of the Caliente or Caliente-Chalk Mountain Corridor. Impacts in states outside Nevada would be the same for the Eccles and Crestline Options of the Caliente and Caliente-Chalk Mountain Corridors.

g. For branch rail line transportation, railcars would transfer from the mainline railroad at the Apex junction in southeast Nevada, possibly via the Valley Connection, to the Valley Modified Corridor.

h. LCF = latent cancer fatality.



These routes represent the routes analyzed in Chapter 6 and might not be the routes actually used for shipments to the proposed repository at Yucca Mountain. Truck routes comply with U.S. Department of Transportation routing regulations. Rail routes are based on maximizing the distance on mainline track and minimizing the overall distance and number of interchanges between railroads.

Figure J-36. Highway and rail routes used to analyze transportation impacts - Connecticut, Rhode Island, and New York.

Table J-77. Estimated transportation impacts for the States of Delaware, Maryland, Virginia, West Virginia, and the District of Columbia (page 1 of 3).

Impact category	Mostly legal-weight truck	Mostly rail						
		Ending rail node in Nevada[a]						
		Caliente[b]	Dry Lake[c]	Jean[d]	Beowawe[e]	Eccles[f]	Apex[g]
DELAWARE							
Shipments							
Truck (originating/total)	0/1,077	0/0	0/0	0/0	0/0	0/0	0/0
Rail (originating/total)	0/0	0/0	0/0	0/0	0/0	0/0	0/0
Radiological impacts							
Incident-free impacts							
Population (person-rem/LCFs)[h]	$1.6\times10^{0}/8.2\times10^{-4}$	$0.0\times10^{0}/0.0\times10^{0}$	$0.0\times10^{0}/0.0\times10^{0}$	$0.0\times10^{0}/0.0\times10^{0}$	$0.0\times10^{0}/0.0\times10^{0}$	$0.0\times10^{0}/0.0\times10^{0}$	$0.0\times10^{0}/0.0\times10^{0}$
Workers (person-rem/LCFs)	$1.7\times10^{0}/6.9\times10^{-4}$	$0.0\times10^{0}/0.0\times10^{0}$	$0.0\times10^{0}/0.0\times10^{0}$	$0.0\times10^{0}/0.0\times10^{0}$	$0.0\times10^{0}/0.0\times10^{0}$	$0.0\times10^{0}/0.0\times10^{0}$	$0.0\times10^{0}/0.0\times10^{0}$
Accident dose risk							
Population (person-rem/LCFs)	$5.2\times10^{-4}/2.6\times10^{-7}$	$0.0\times10^{0}/0.0\times10^{0}$	$0.0\times10^{0}/0.0\times10^{0}$	$0.0\times10^{0}/0.0\times10^{0}$	$0.0\times10^{0}/0.0\times10^{0}$	$0.0\times10^{0}/0.0\times10^{0}$	$0.0\times10^{0}/0.0\times10^{0}$
Nonradiological impacts							
Vehicle emissions (LCFs)	6.4×10^{-4}	0.0×10^{0}	0.0×10^{0}	0.0×10^{0}	0.0×10^{0}	0.0×10^{0}	0.0×10^{0}
Fatalities	3.1×10^{-4}	0.0×10^{0}	0.0×10^{0}	0.0×10^{0}	0.0×10^{0}	0.0×10^{0}	0.0×10^{0}
MARYLAND							
Shipments							
Truck (originating/total)	867/1,944	0/0	0/0	0/0	0/0	0/0	0/0
Rail (originating/total)	0/0	169/312	169/312	169/312	169/312	169/312	169/312
Radiological impacts							
Incident-free impacts							
Population (person-rem/LCFs)[h]	$2.5\times10^{1}/1.3\times10^{-2}$	$1.0\times10^{1}/5.0\times10^{-3}$	$1.0\times10^{1}/5.0\times10^{-3}$	$1.0\times10^{1}/5.0\times10^{-3}$	$1.0\times10^{1}/5.0\times10^{-3}$	$1.0\times10^{1}/5.0\times10^{-3}$	$1.0\times10^{1}/5.0\times10^{-3}$
Workers (person-rem/LCFs)	$4.8\times10^{1}/1.9\times10^{-2}$	$1.3\times10^{1}/5.1\times10^{-2}$	$1.3\times10^{1}/5.1\times10^{-2}$	$1.3\times10^{1}/5.1\times10^{-2}$	$1.3\times10^{1}/5.1\times10^{-2}$	$1.3\times10^{1}/5.1\times10^{-2}$	$1.3\times10^{1}/5.1\times10^{-2}$
Accident dose risk							
Population (person-rem/LCFs)	$6.6\times10^{-3}/3.3\times10^{-6}$	$3.2\times10^{-3}/1.6\times10^{-6}$	$3.2\times10^{-3}/1.6\times10^{-6}$	$3.2\times10^{-3}/1.6\times10^{-6}$	$3.2\times10^{-3}/1.6\times10^{-6}$	$3.2\times10^{-3}/1.6\times10^{-6}$	$3.2\times10^{-3}/1.6\times10^{-6}$
Nonradiological impacts							
Vehicle emissions (LCFs)	8.4×10^{-3}	3.8×10^{-3}	3.8×10^{-3}	3.8×10^{-3}	3.8×10^{-3}	3.8×10^{-3}	3.8×10^{-3}
Fatalities	0.007	0.007	0.007	0.007	0.007	0.007	0.007

Table J-77. Estimated transportation impacts for the States of Delaware, Maryland, Virginia, West Virginia, and the District of Columbia (page 2 of 3).

Impact category	Mostly legal-weight truck	Mostly rail					
		Ending rail node in Nevada[a]					
		Caliente[b]	Dry Lake[c]	Jean[d]	Beowawe[e]	Eccles[f]	Apex[g]
VIRGINIA							
Shipments							
Truck (originating/total)	1,538/3,409	0/0	0/0	0/0	0/0	0/0	0/0
Rail (originating/total)	0/0	340/340	340/340	340/340	340/340	340/340	340/340
Radiological impacts							
Incident-free impacts							
Population (person-rem/LCFs)[h]	$2.2\times10^{1}/1.1\times10^{-2}$	$9.6\times10^{0}/4.8\times10^{-3}$	$9.6\times10^{0}/4.8\times10^{-3}$	$9.6\times10^{0}/4.8\times10^{-3}$	$9.6\times10^{0}/4.8\times10^{-3}$	$9.6\times10^{0}/4.8\times10^{-3}$	$9.6\times10^{0}/4.8\times10^{-3}$
Workers (person-rem/LCFs)	$8.2\times10^{1}/3.3\times10^{-2}$	$2.6\times10^{1}/1.0\times10^{-2}$	$2.6\times10^{1}/1.0\times10^{-2}$	$2.6\times10^{1}/1.0\times10^{-2}$	$2.6\times10^{1}/1.0\times10^{-2}$	$2.6\times10^{1}/1.0\times10^{-2}$	$2.6\times10^{1}/1.0\times10^{-2}$
Accident dose risk							
Population (person-rem/LCFs)	$2.1\times10^{-3}/1.1\times10^{-6}$	$2.1\times10^{-3}/1.0\times10^{-6}$	$2.1\times10^{-3}/1.0\times10^{-6}$	$2.1\times10^{-3}/1.0\times10^{-6}$	$2.1\times10^{-3}/1.0\times10^{-6}$	$2.1\times10^{-3}/1.0\times10^{-6}$	$2.1\times10^{-3}/1.0\times10^{-6}$
Nonradiological impacts							
Vehicle emissions (LCFs)	3.4×10^{-3}	2.8×10^{-3}	2.8×10^{-3}	2.8×10^{-3}	2.8×10^{-3}	2.8×10^{-3}	2.8×10^{-3}
Fatalities	0.027	0.011	0.011	0.011	0.011	0.011	0.011
WEST VIRGINIA							
Shipments							
Truck (originating/total)	0/3,409	0/0	0/0	0/0	0/0	0/0	0/0
Rail (originating/total)	0/0	0/509	0/509	0/509	0/509	0/509	0/509
Radiological impacts							
Incident-free impacts							
Population (person-rem/LCFs)[h]	$3.4\times10^{1}/1.7\times10^{-2}$	$1.6\times10^{0}/8.1\times10^{-4}$	$1.6\times10^{0}/8.1\times10^{-4}$	$1.6\times10^{0}/8.1\times10^{-4}$	$1.6\times10^{0}/8.1\times10^{-4}$	$1.6\times10^{0}/8.1\times10^{-4}$	$1.6\times10^{0}/8.1\times10^{-4}$
Workers (person-rem/LCFs)	$6.2\times10^{1}/2.5\times10^{-2}$	$6.6\times10^{0}/2.6\times10^{-3}$	$6.6\times10^{0}/2.6\times10^{-3}$	$6.6\times10^{0}/2.6\times10^{-3}$	$6.6\times10^{0}/2.6\times10^{-3}$	$6.6\times10^{0}/2.6\times10^{-3}$	$6.6\times10^{0}/2.6\times10^{-3}$
Accident dose risk							
Population (person-rem/LCFs)	$1.8\times10^{-3}/9.2\times10^{-7}$	$3.9\times10^{-4}/2.0\times10^{-7}$	$3.9\times10^{-4}/2.0\times10^{-7}$	$3.9\times10^{-4}/2.0\times10^{-7}$	$3.9\times10^{-4}/2.0\times10^{-7}$	$3.9\times10^{-4}/2.0\times10^{-7}$	$3.9\times10^{-4}/2.0\times10^{-7}$
Nonradiological impacts							
Vehicle emissions (LCFs)	6.9×10^{-3}	8.5×10^{-4}	8.5×10^{-4}	8.5×10^{-4}	8.5×10^{-4}	8.5×10^{-4}	8.5×10^{-4}
Fatalities	0.032	0.004	0.004	0.004	0.004	0.004	0.004

Table J-77. Estimated transportation impacts for the States of Delaware, Maryland, Virginia, West Virginia, and the District of Columbia (page 3 of 3).

Impact category	Mostly legal-weight truck	Mostly rail					
		Ending rail node in Nevada[a]					
		Caliente[b]	Dry Lake[c]	Jean[d]	Beowawe[e]	Eccles[f]	Apex[g]
DISTRICT OF COLUMBIA							
Shipments							
Truck (originating/total)	0/0	0/0	0/0	0/0	0/0	0/0	0/0
Rail (originating/total)	0/0	0/312	0/312	0/312	0/312	0/312	0/312
Radiological impacts							
Incident-free impacts							
Population (person-rem/LCFs)[h]	$0.0\times10^{0}/0.0\times10^{0}$	$2.7\times10^{0}/1.3\times10^{-3}$	$2.7\times10^{0}/1.3\times10^{-3}$	$2.7\times10^{0}/1.3\times10^{-3}$	$2.7\times10^{0}/1.3\times10^{-3}$	$2.7\times10^{0}/1.3\times10^{-3}$	$2.7\times10^{0}/1.3\times10^{-3}$
Workers (person-rem/LCFs)	$0.0\times10^{0}/0.0\times10^{0}$	$5.9\times10^{-1}/2.4\times10^{-4}$	$5.9\times10^{-1}/2.4\times10^{-4}$	$5.9\times10^{-1}/2.4\times10^{-4}$	$5.9\times10^{-1}/2.4\times10^{-4}$	$5.9\times10^{-1}/2.4\times10^{-4}$	$5.9\times10^{-1}/2.4\times10^{-4}$
Accident dose risk							
Population (person-rem/LCFs)	$0.0\times10^{0}/0.0\times10^{0}$	$5.0\times10^{-2}/2.5\times10^{-5}$	$5.0\times10^{-2}/2.5\times10^{-5}$	$5.0\times10^{-2}/2.5\times10^{-5}$	$5.0\times10^{-2}/2.5\times10^{-5}$	$5.0\times10^{-2}/2.5\times10^{-5}$	$5.0\times10^{-2}/2.5\times10^{-5}$
Nonradiological impacts							
Vehicle emissions (LCFs)	0.0×10^{0}	1.2×10^{-3}	1.2×10^{-3}	1.2×10^{-3}	1.2×10^{-3}	1.2×10^{-3}	1.2×10^{-3}
Fatalities	0.0×10^{0}	4.8×10^{-3}	4.8×10^{-3}	4.8×10^{-3}	4.8×10^{-3}	4.8×10^{-3}	4.8×10^{-3}

a. Under the mostly rail scenario, rail shipments would arrive in Nevada at one of six existing rail nodes. Impacts would vary according to the node. From that node, DOE would use one of the rail or heavy-haul implementing alternatives to complete the transportation to Yucca Mountain (see Section J.1.2).

b. For heavy-haul truck transportation, the Caliente junction is the location of the proposed Caliente intermodal transfer station for heavy-haul trucks near the town of Caliente in eastern Nevada. Rail shipments terminating at this junction would continue to Yucca Mountain on heavy-haul trucks on one of the Caliente, Caliente/Chalk Mountain, or Caliente/Las Vegas routes. For branch rail line transportation, railcars would transfer via the Caliente Option to the Caliente Corridor at the Caliente junction.

c. For heavy-haul truck transportation, the Dry Lake junction is near the location of the proposed Apex/Dry Lake intermodal transfer station for heavy-haul trucks in southeast Nevada. Rail shipments terminating at this junction would continue to Yucca Mountain on heavy-haul trucks on the Apex/Dry Lake route.

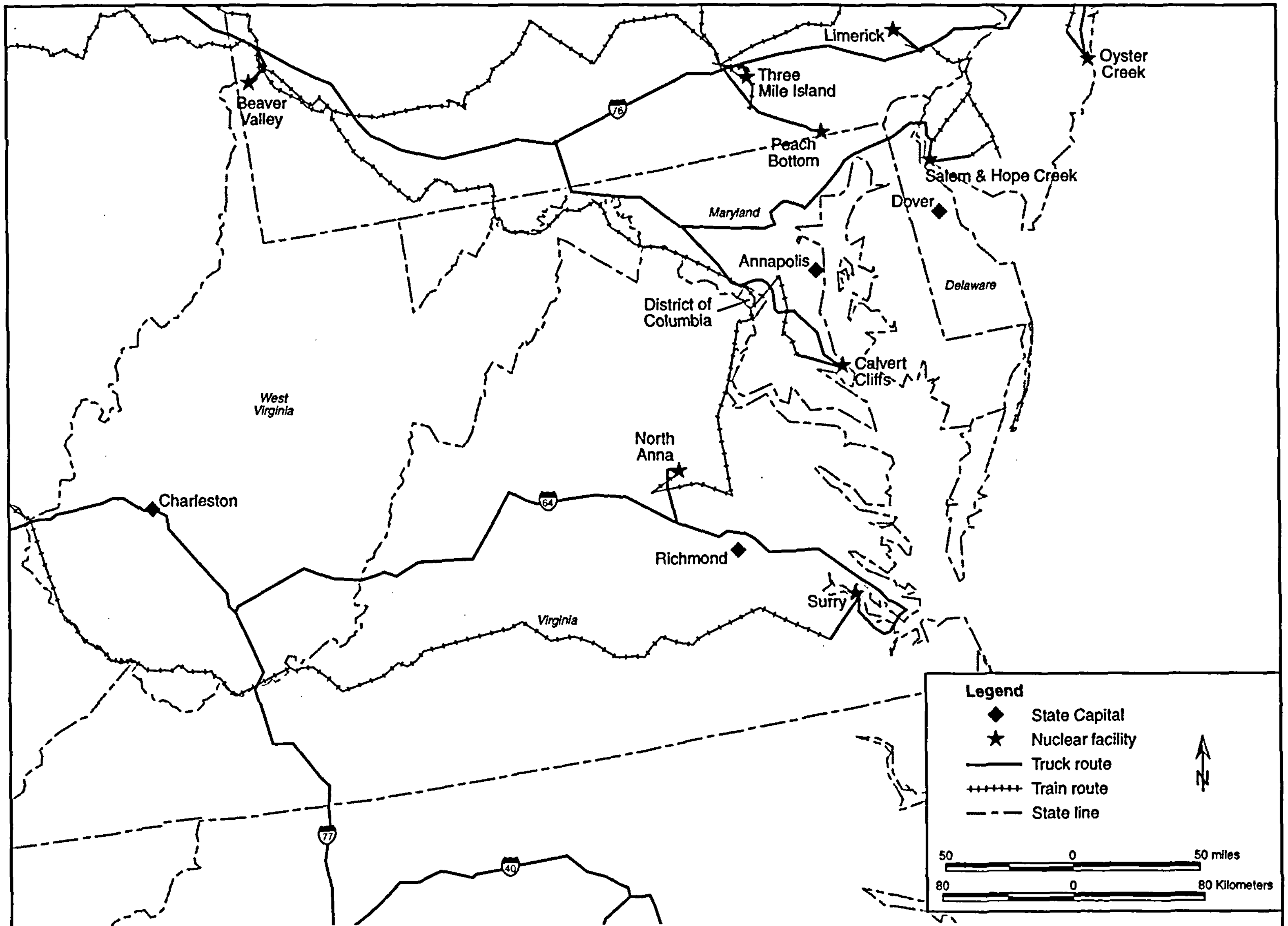
d. For heavy-haul truck transportation, the Jean junction is near the location of the proposed Sloan/Jean intermodal transfer station for heavy-haul trucks in southern Nevada. Rail shipments terminating at this junction would continue to Yucca Mountain on heavy-haul trucks on the Sloan/Jean route. For branch rail line transportation, railcars would transfer from the mainline railroad via the Wilson Pass or Stateline Pass Option of the Jean Corridor, near the Jean junction.

e. For branch rail line transportation, railcars would transfer from the mainline railroad at the Beowawe junction in north-central Nevada to the Carlin Corridor.

f. For branch rail line transportation, railcars would transfer from the mainline railroad at the Eccles junction east of Caliente, Nevada, via the Eccles Option or nearby via the Crestline Option of the Caliente or Caliente-Chalk Mountain Corridor. Impacts in states outside Nevada would be the same for the Eccles and Crestline Options of the Caliente and Caliente-Chalk Mountain Corridors.

g. For branch rail line transportation, railcars would transfer from the mainline railroad at the Apex junction in southeast Nevada, possibly via the Valley Connection, to the Valley Modified Corridor.

h. LCF = latent cancer fatality.



These routes represent the routes analyzed in Chapter 6 and might not be the routes actually used for shipments to the proposed repository at Yucca Mountain. Truck routes comply with U.S. Department of Transportation routing regulations. Rail routes are based on maximizing the distance on mainline track and minimizing the overall distance and number of interchanges between railroads.

Figure J-37. Highway and rail routes used to analyze transportation impacts - Delaware, Maryland, Virginia, West Virginia, and the District of Columbia.

Table J-78. Estimated transportation impacts for the State of Florida.

Impact category	Mostly legal-weight truck	Mostly rail					
		Ending rail node in Nevada[a]					
		Caliente[b]	Dry Lake[c]	Jean[d]	Beowawe[e]	Eccles[f]	Apex[g]
FLORIDA							
Shipments							
Truck (originating/total)	1,666/2,359	491/491	491/491	491/491	491/491	491/491	491/491
Rail (originating/total)	0/0	202/202	202/202	202/202	202/202	202/202	202/202
Radiological impacts							
Incident-free impacts							
Population (person-rem/LCFs)[h]	$4.5\times10^{1}/2.2\times10^{-2}$	$2.3\times10^{1}/1.2\times10^{-2}$	$2.3\times10^{1}/1.2\times10^{-2}$	$2.8\times10^{1}/1.4\times10^{-2}$	$2.3\times10^{1}/1.2\times10^{-2}$	$2.3\times10^{1}/1.2\times10^{-2}$	$2.3\times10^{1}/1.2\times10^{-2}$
Workers (person-rem/LCFs)	$1.1\times10^{2}/4.3\times10^{-2}$	$4.2\times10^{1}/1.7\times10^{-2}$	$4.2\times10^{1}/1.7\times10^{-2}$	$5.0\times10^{1}/2.0\times10^{-2}$	$4.2\times10^{1}/1.7\times10^{-2}$	$4.2\times10^{1}/1.7\times10^{-2}$	$4.2\times10^{1}/1.7\times10^{-2}$
Accident dose risk							
Population (person-rem/LCFs)	$1.5\times10^{-3}/7.4\times10^{-7}$	$7.4\times10^{-3}/3.7\times10^{-6}$	$7.4\times10^{-3}/3.7\times10^{-6}$	$9.9\times10^{-3}/5.0\times10^{-6}$	$7.4\times10^{-3}/3.7\times10^{-6}$	$7.4\times10^{-3}/3.7\times10^{-6}$	$7.4\times10^{-3}/3.7\times10^{-6}$
Nonradiological impacts							
Vehicle emissions (LCFs)	1.4×10^{-2}	8.2×10^{-3}	8.2×10^{-3}	1.1×10^{-2}	8.2×10^{-3}	8.2×10^{-3}	8.2×10^{-3}
Fatalities	0.019	0.025	0.025	0.047	0.025	0.025	0.025

a. Under the mostly rail scenario, rail shipments would arrive in Nevada at one of six existing rail nodes. Impacts would vary according to the node. From that node, DOE would use one of the rail or heavy-haul implementing alternatives to complete the transportation to Yucca Mountain (see Section J.1.2).

b. For heavy-haul truck transportation, the Caliente junction is the location of the proposed Caliente intermodal transfer station for heavy-haul trucks near the town of Caliente in eastern Nevada. Rail shipments terminating at this junction would continue to Yucca Mountain on heavy-haul trucks on one of the Caliente, Caliente/Chalk Mountain, or Caliente/Las Vegas routes. For branch rail line transportation, railcars would transfer via the Caliente Option to the Caliente Corridor at the Caliente junction.

c. For heavy-haul truck transportation, the Dry Lake junction is near the location of the proposed Apex/Dry Lake intermodal transfer station for heavy-haul trucks in southeast Nevada. Rail shipments terminating at this junction would continue to Yucca Mountain on heavy-haul trucks on the Apex/Dry Lake route.

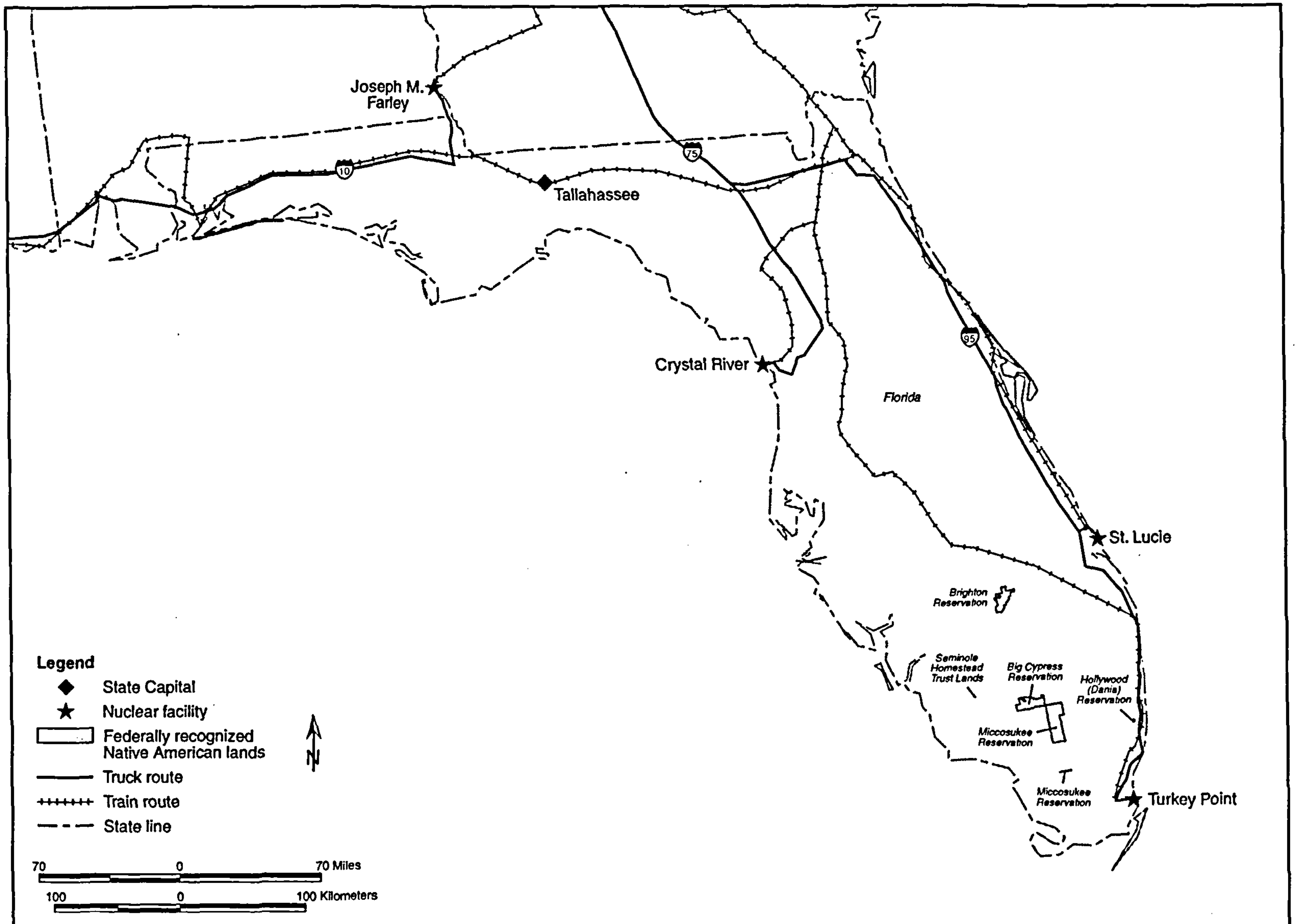
d. For heavy-haul truck transportation, the Jean junction is near the location of the proposed Sloan/Jean intermodal transfer station for heavy-haul trucks in southern Nevada. Rail shipments terminating at this junction would continue to Yucca Mountain on heavy-haul trucks on the Sloan/Jean route. For branch rail line transportation, railcars would transfer from the mainline railroad via the Wilson Pass or Stateline Pass Option of the Jean Corridor, near the Jean junction.

e. For branch rail line transportation, railcars would transfer from the mainline railroad at the Beowawe junction in north-central Nevada to the Carlin Corridor.

f. For branch rail line transportation, railcars would transfer from the mainline railroad at the Eccles junction east of Caliente, Nevada, via the Eccles Option or nearby via the Crestline Option of the Caliente or Caliente-Chalk Mountain Corridor. Impacts in states outside Nevada would be the same for the Eccles and Crestline Options of the Caliente and Caliente-Chalk Mountain Corridors.

g. For branch rail line transportation, railcars would transfer from the mainline railroad at the Apex junction in southeast Nevada, possibly via the Valley Connection, to the Valley Modified Corridor.

h. LCF = latent cancer fatality.



These routes represent the routes analyzed in Chapter 6 and might not be the routes actually used for shipments to the proposed repository at Yucca Mountain. Truck routes comply with U.S. Department of Transportation routing regulations. Rail routes are based on maximizing the distance on mainline track and minimizing the overall distance and number of interchanges between railroads.

Figure J-38. Highway and rail routes used to analyze transportation impacts - Florida.

Table J-79. Estimated transportation impacts for the State of Iowa.

Impact category	Mostly legal-weight truck	Mostly rail					
		Ending rail node in Nevada[a]					
		Caliente[b]	Dry Lake[c]	Jean[d]	Beowawe[e]	Eccles[f]	Apex[g]
IOWA							
Shipments							
Truck (originating/total)	324/40,539	0/1,079	0/1,079	0/1,079	0/1,079	0/1,079	0/1,079
Rail (originating/total)	0/0	57/3,301	57/3,301	57/3,301	57/3,301	57/3,301	57/3,301
Radiological impacts							
Incident-free impacts							
Population (person-rem/LCFs)[h]	2.7×10^{2}/1.4×10^{-1}	6.2×10^{1}/3.1×10^{-2}	6.2×10^{1}/3.1×10^{-2}	6.0×10^{1}/3.0×10^{-2}	6.2×10^{1}/3.1×10^{-2}	6.2×10^{1}/3.1×10^{-2}	6.2×10^{1}/3.1×10^{-2}
Workers (person-rem/LCFs)	8.7×10^{2}/3.5×10^{-1}	1.4×10^{2}/5.7×10^{-2}	1.4×10^{2}/5.7×10^{-2}	1.3×10^{2}/5.4×10^{-2}	1.4×10^{2}/5.7×10^{-2}	1.4×10^{2}/5.7×10^{-2}	1.4×10^{2}/5.7×10^{-2}
Accident dose risk							
Population (person-rem/LCFs)	4.2×10^{-3}/2.1×10^{-6}	5.8×10^{-2}/2.9×10^{-5}	5.8×10^{-2}/2.9×10^{-5}	5.4×10^{-2}/2.7×10^{-5}	5.8×10^{-2}/2.9×10^{-5}	5.8×10^{-2}/2.9×10^{-5}	5.8×10^{-2}/2.9×10^{-5}
Nonradiological impacts							
Vehicle emissions (LCFs)	1.4×10^{-2}	2.7×10^{-2}	2.7×10^{-2}	2.6×10^{-2}	2.7×10^{-2}	2.7×10^{-2}	2.7×10^{-2}
Fatalities	0.25	0.09	0.09	0.09	0.09	0.09	0.09

a. Under the mostly rail scenario, rail shipments would arrive in Nevada at one of six existing rail nodes. Impacts would vary according to the node. From that node, DOE would use one of the rail or heavy-haul implementing alternatives to complete the transportation to Yucca Mountain (see Section J.1.2).

b. For heavy-haul truck transportation, the Caliente junction is the location of the proposed Caliente intermodal transfer station for heavy-haul trucks near the town of Caliente in eastern Nevada. Rail shipments terminating at this junction would continue to Yucca Mountain on heavy-haul trucks on one of the Caliente, Caliente/Chalk Mountain, or Caliente/Las Vegas routes. For branch rail line transportation, railcars would transfer via the Caliente Option to the Caliente Corridor at the Caliente junction.

c. For heavy-haul truck transportation, the Dry Lake junction is near the location of the proposed Apex/Dry Lake intermodal transfer station for heavy-haul trucks in southeast Nevada. Rail shipments terminating at this junction would continue to Yucca Mountain on heavy-haul trucks on the Apex/Dry Lake route.

d. For heavy-haul truck transportation, the Jean junction is near the location of the proposed Sloan/Jean intermodal transfer station for heavy-haul trucks in southern Nevada. Rail shipments terminating at this junction would continue to Yucca Mountain on heavy-haul trucks on the Sloan/Jean route. For branch rail line transportation, railcars would transfer from the mainline railroad via the Wilson Pass or Stateline Pass Option of the Jean Corridor, near the Jean junction.

e. For branch rail line transportation, railcars would transfer from the mainline railroad at the Beowawe junction in north-central Nevada to the Carlin Corridor.

f. For branch rail line transportation, railcars would transfer from the mainline railroad at the Eccles junction east of Caliente, Nevada, via the Eccles Option or nearby via the Crestline Option of the Caliente or Caliente-Chalk Mountain Corridor. Impacts in states outside Nevada would be the same for the Eccles and Crestline Options of the Caliente and Caliente-Chalk Mountain Corridors.

g. For branch rail line transportation, railcars would transfer from the mainline railroad at the Apex junction in southeast Nevada, possibly via the Valley Connection, to the Valley Modified Corridor.

h. LCF = latent cancer fatality.

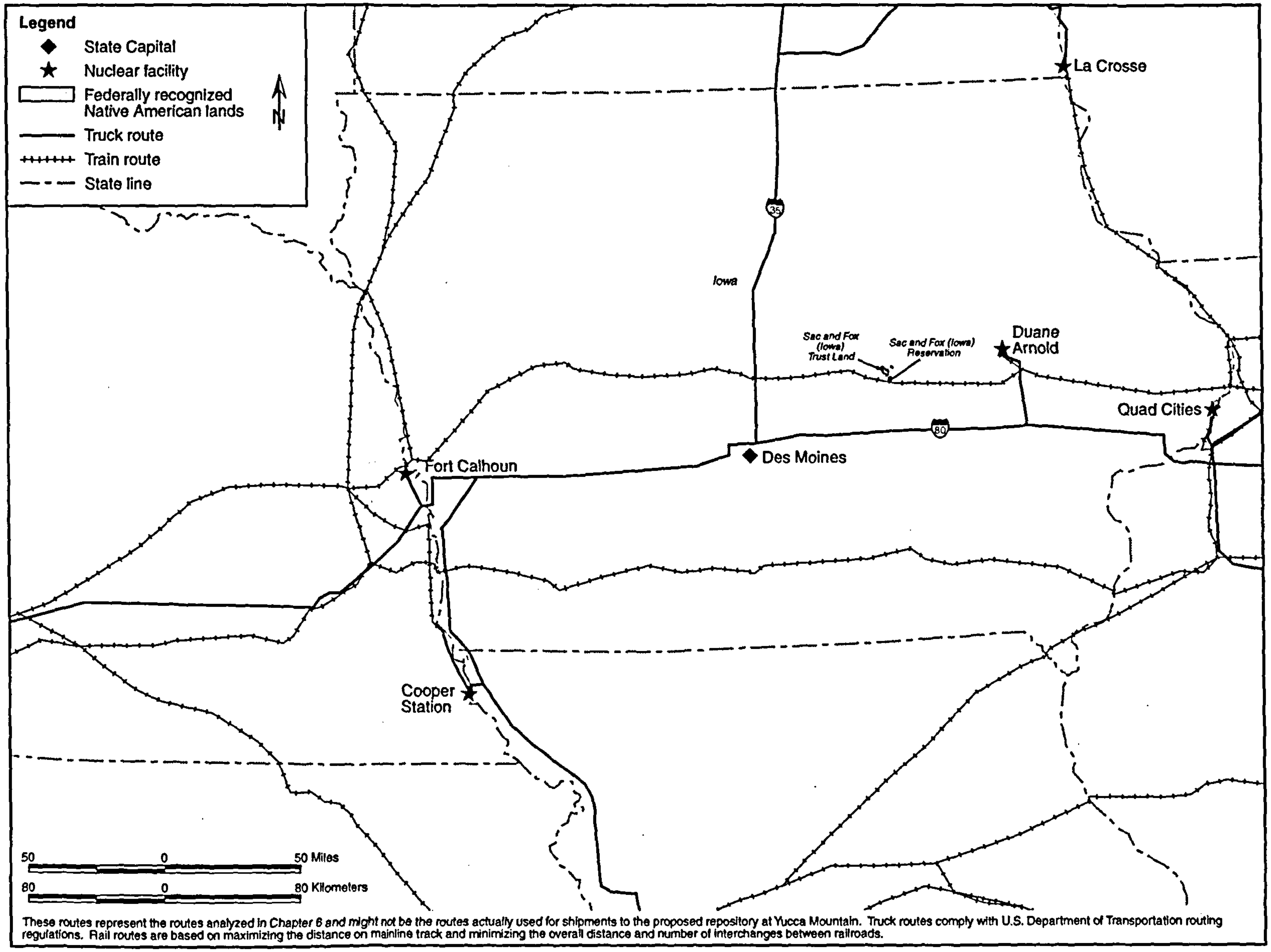


Figure J-39. Highway and rail routes used to analyze transportation impacts - Iowa.

Table J-80. Estimated transportation impacts for the States of Idaho, Oregon, and Washington (page 1 of 2).

Impact category	Mostly legal-weight truck	Mostly rail: Ending rail node in Nevada[a]					
		Caliente[b]	Dry Lake[c]	Jean[d]	Beowawe[e]	Eccles[f]	Apex[g]
IDAHO							
Shipments							
Truck (originating/total)	1,088/4,412	0/0	0/0	0/0	0/0	0/0	0/0
Rail (originating/total)	300/300	433/1,082	433/1,049	433/1,049	433/1,049	433/1,082	433/1,049
Radiological impacts							
Incident-free impacts							
Population (person-rem/LCFs)[h]	$4.2\times10^{1}/2.1\times10^{-2}$	$1.4\times10^{1}/7.0\times10^{-3}$	$1.4\times10^{1}/7.0\times10^{-3}$	$4.8\times10^{1}/2.4\times10^{-2}$	$1.4\times10^{1}/7.0\times10^{-3}$	$1.4\times10^{1}/7.0\times10^{-3}$	$1.4\times10^{1}/7.0\times10^{-3}$
Workers (person-rem/LCFs)	$1.4\times10^{2}/5.5\times10^{-2}$	$4.7\times10^{1}/1.9\times10^{-2}$	$4.7\times10^{1}/1.9\times10^{-2}$	$1.7\times10^{2}/6.8\times10^{-2}$	$4.7\times10^{1}/1.9\times10^{-2}$	$4.7\times10^{1}/1.9\times10^{-2}$	$4.7\times10^{1}/1.9\times10^{-2}$
Accident dose risk							
Population (person-rem/LCFs)	$1.7\times10^{-3}/8.7\times10^{-7}$	$7.9\times10^{-4}/4.0\times10^{-7}$	$7.9\times10^{-4}/4.0\times10^{-7}$	$2.4\times10^{-3}/1.2\times10^{-6}$	$7.9\times10^{-4}/4.0\times10^{-7}$	$7.9\times10^{-4}/4.0\times10^{-7}$	$7.9\times10^{-4}/4.0\times10^{-7}$
Nonradiological impacts							
Vehicle emissions (LCFs)	5.2×10^{-3}	4.2×10^{-3}	4.2×10^{-3}	8.0×10^{-3}	4.2×10^{-3}	4.2×10^{-3}	4.2×10^{-3}
Fatalities	0.018	0.039	0.039	0.048	0.039	0.039	0.039
OREGON							
Shipments							
Truck (originating/total)	195/3,324	0/0	0/0	0/0	0/0	0/0	0/0
Rail (originating/total)	0/0	33/649	33/649	33/649	33/649	33/649	33/649
Radiological impacts							
Incident-free impacts							
Population (person-rem/LCFs)[h]	$2.3\times10^{1}/1.2\times10^{-2}$	$3.7\times10^{0}/1.8\times10^{-3}$	$4.4\times10^{0}/2.2\times10^{-3}$	$4.4\times10^{0}/2.2\times10^{-3}$	$4.4\times10^{0}/2.2\times10^{-3}$	$3.7\times10^{0}/1.8\times10^{-3}$	$4.4\times10^{0}/2.2\times10^{-3}$
Workers (person-rem/LCFs)	$7.9\times10^{1}/3.2\times10^{-2}$	$1.8\times10^{1}/7.3\times10^{-3}$	$1.8\times10^{1}/7.2\times10^{-3}$	$1.8\times10^{1}/7.2\times10^{-3}$	$1.8\times10^{1}/7.2\times10^{-3}$	$1.8\times10^{1}/7.3\times10^{-3}$	$1.8\times10^{1}/7.2\times10^{-3}$
Accident dose risk							
Population (person-rem/LCFs)	$4.4\times10^{-4}/2.2\times10^{-7}$	$1.7\times10^{-3}/8.5\times10^{-7}$	$2.5\times10^{-3}/1.2\times10^{-6}$	$2.5\times10^{-3}/1.2\times10^{-6}$	$2.5\times10^{-3}/1.2\times10^{-6}$	$1.7\times10^{-3}/8.5\times10^{-7}$	$2.5\times10^{-3}/1.2\times10^{-6}$
Nonradiological impacts							
Vehicle emissions (LCFs)	1.5×10^{-3}	1.7×10^{-3}	2.1×10^{-3}	2.1×10^{-3}	2.1×10^{-3}	1.7×10^{-3}	2.1×10^{-3}
Fatalities	0.048	0.023	0.022	0.022	0.022	0.023	0.022

Table J-80. Estimated transportation impacts for the States of Idaho, Oregon, and Washington (page 2 of 2).

Impact category	Mostly legal-weight truck	Mostly rail: Ending rail node in Nevada[a]						
		Caliente[b]	Dry Lake[c]	Jean[d]	Beowawe[e]	Eccles[f]	Apex[g]
WASHINGTON							
Shipments							
Truck (originating/total)	3,129/3,324	0/0	0/0	0/0	0/0	0/0	0/0
Rail (originating/total)	0/0	616/616	616/616	616/616	616/616	616/616	616/616
Radiological impacts							
Incident-free impacts							
Population (person-rem/LCFs)[h]	$9.7\times10^{0}/4.9\times10^{-3}$	$1.1\times10^{1}/5.7\times10^{-3}$	$1.1\times10^{1}/5.7\times10^{-3}$	$1.1\times10^{1}/5.7\times10^{-3}$	$1.1\times10^{1}/5.7\times10^{-3}$	$1.1\times10^{1}/5.7\times10^{-3}$	$1.1\times10^{1}/5.7\times10^{-3}$
Workers (person-rem/LCFs)	$7.6\times10^{1}/3.0\times10^{-2}$	$3.2\times10^{1}/1.3\times10^{-2}$	$3.2\times10^{1}/1.3\times10^{-2}$	$3.2\times10^{1}/1.3\times10^{-2}$	$3.2\times10^{1}/1.3\times10^{-2}$	$3.2\times10^{1}/1.3\times10^{-2}$	$3.2\times10^{1}/1.3\times10^{-2}$
Accident dose risk							
Population (person-rem/LCFs)	$8.8\times10^{-4}/4.4\times10^{-7}$	$6.7\times10^{-4}/3.4\times10^{-7}$	$6.7\times10^{-4}/3.4\times10^{-7}$	$6.7\times10^{-4}/3.4\times10^{-7}$	$6.7\times10^{-4}/3.4\times10^{-7}$	$6.7\times10^{-4}/3.4\times10^{-7}$	$6.7\times10^{-4}/3.4\times10^{-7}$
Nonradiological impacts							
Vehicle emissions (LCFs)	2.7×10^{-3}	2.2×10^{-3}	2.2×10^{-3}	2.2×10^{-3}	2.2×10^{-3}	2.2×10^{-3}	2.2×10^{-3}
Fatalities	0.001	0.005	0.005	0.005	0.005	0.005	0.005

a. Under the mostly rail scenario, rail shipments would arrive in Nevada at one of six existing rail nodes. Impacts would vary according to the node. From that node, DOE would use one of the rail or heavy-haul implementing alternatives to complete the transportation to Yucca Mountain (see Section J.1.2).

b. For heavy-haul truck transportation, the Caliente junction is the location of the proposed Caliente intermodal transfer station for heavy-haul trucks near the town of Caliente in eastern Nevada. Rail shipments terminating at this junction would continue to Yucca Mountain on heavy-haul trucks on one of the Caliente, Caliente/Chalk Mountain, or Caliente/Las Vegas routes. For branch rail line transportation, railcars would transfer via the Caliente Option to the Caliente Corridor at the Caliente junction.

c. For heavy-haul truck transportation, the Dry Lake junction is near the location of the proposed Apex/Dry Lake intermodal transfer station for heavy-haul trucks in southeast Nevada. Rail shipments terminating at this junction would continue to Yucca Mountain on heavy-haul trucks on the Apex/Dry Lake route.

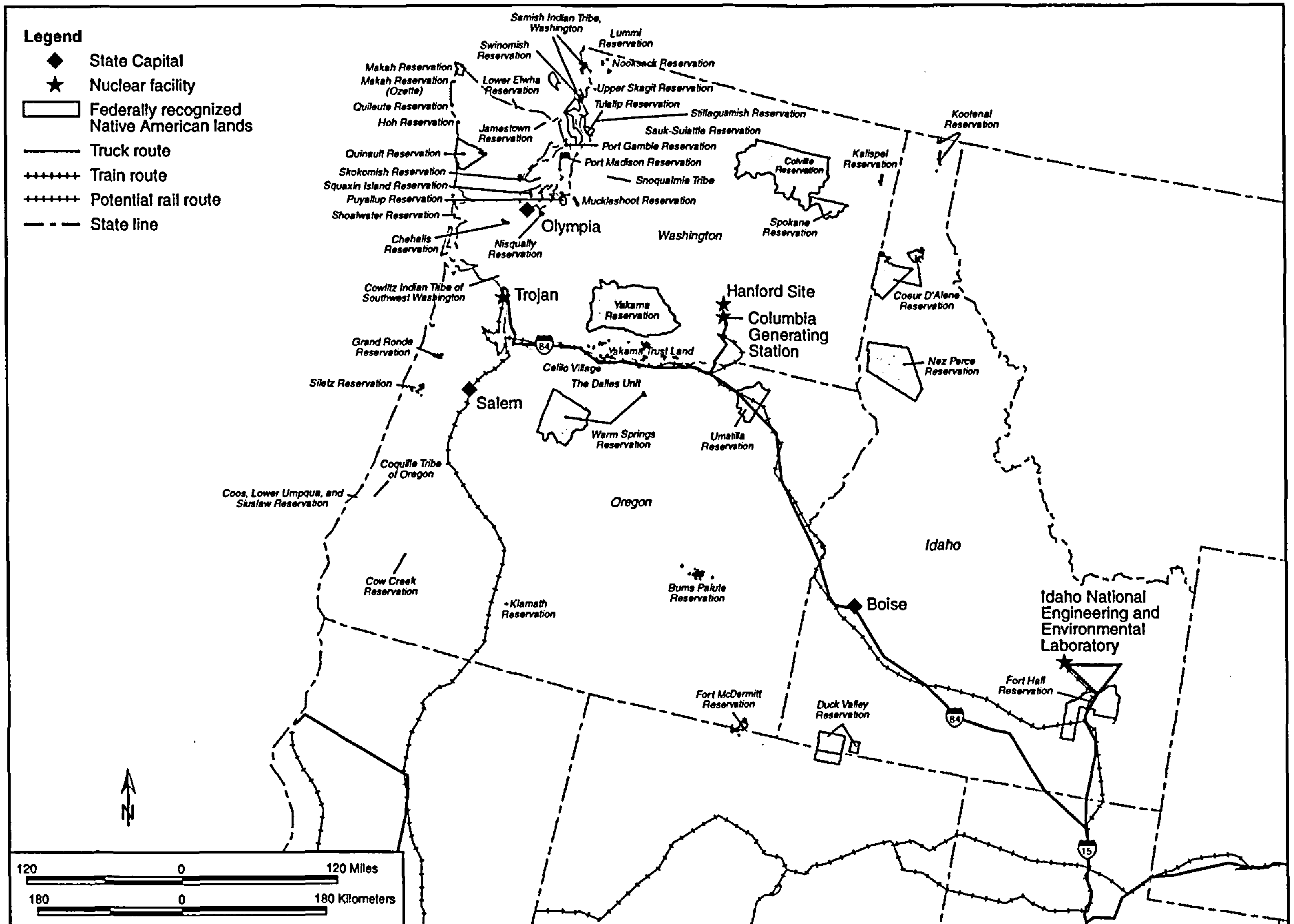
d. For heavy-haul truck transportation, the Jean junction is near the location of the proposed Sloan/Jean intermodal transfer station for heavy-haul trucks in southern Nevada. Rail shipments terminating at this junction would continue to Yucca Mountain on heavy-haul trucks on the Sloan/Jean route. For branch rail line transportation, railcars would transfer from the mainline railroad via the Wilson Pass or Stateline Pass Option of the Jean Corridor, near the Jean junction.

e. For branch rail line transportation, railcars would transfer from the mainline railroad at the Beowawe junction in north-central Nevada to the Carlin Corridor.

f. For branch rail line transportation, railcars would transfer from the mainline railroad at the Eccles junction east of Caliente, Nevada, via the Eccles Option or nearby via the Crestline Option of the Caliente or Caliente-Chalk Mountain Corridor. Impacts in states outside Nevada would be the same for the Eccles and Crestline Options of the Caliente and Caliente-Chalk Mountain Corridors.

g. For branch rail line transportation, railcars would transfer from the mainline railroad at the Apex junction in southeast Nevada, possibly via the Valley Connection, to the Valley Modified Corridor.

h. LCF = latent cancer fatality.



These routes represent the routes analyzed in Chapter 6 and might not be the routes actually used for shipments to the proposed repository at Yucca Mountain. Truck routes comply with U.S. Department of Transportation routing regulations. Rail routes are based on maximizing the distance on mainline track and minimizing the overall distance and number of interchanges between railroads.

Figure J-40. Highway and rail routes used to analyze transportation impacts - Idaho, Oregon, and Washington.

Table J-81. Estimated transportation impacts for the States of Indiana, Michigan, and Ohio (page 1 of 2).

Impact category	Mostly legal-weight truck	Mostly rail: Ending rail node in Nevada[a]					
		Caliente[b]	Dry Lake[c]	Jean[d]	Beowawe[e]	Eccles[d]	Apex[e]
INDIANA							
Shipments							
Truck (originating/total)	0/17,258	0/580	0/580	0/580	0/580	0/580	0/580
Rail (originating/total)	0/0	0/5,980	0/5,980	0/5,778	0/5,980	0/5,980	0/5,980
Radiological impacts							
Incident-free impacts							
Population (person-rem/LCFs)[b]	$1.2\times10^{2}/6.0\times10^{-2}$	$5.5\times10^{1}/2.7\times10^{-2}$	$5.5\times10^{1}/2.7\times10^{-2}$	$5.4\times10^{1}/2.7\times10^{-2}$	$5.5\times10^{1}/2.7\times10^{-2}$	$5.5\times10^{1}/2.7\times10^{-2}$	$5.5\times10^{1}/2.7\times10^{-2}$
Workers (person-rem/LCFs)	$2.5\times10^{2}/9.9\times10^{-2}$	$8.1\times10^{1}/3.2\times10^{-2}$	$8.1\times10^{1}/3.2\times10^{-2}$	$7.9\times10^{1}/3.2\times10^{-2}$	$8.1\times10^{1}/3.2\times10^{-2}$	$8.1\times10^{1}/3.2\times10^{-2}$	$8.1\times10^{1}/3.2\times10^{-2}$
Accident dose risk							
Population (person-rem/LCFs)	$8.8\times10^{-3}/4.4\times10^{-6}$	$2.4\times10^{-2}/1.2\times10^{-5}$	$2.4\times10^{-2}/1.2\times10^{-5}$	$2.3\times10^{-2}/1.2\times10^{-5}$	$2.4\times10^{-2}/1.2\times10^{-5}$	$2.4\times10^{-2}/1.2\times10^{-5}$	$2.4\times10^{-2}/1.2\times10^{-5}$
Nonradiological impacts							
Vehicle emissions (LCFs)	2.5×10^{-2}	2.6×10^{-2}	2.6×10^{-2}	2.6×10^{-2}	2.6×10^{-2}	2.6×10^{-2}	2.6×10^{-2}
Fatalities	0.05	0.12	0.12	0.12	0.12	0.12	0.12
MICHIGAN							
Shipments							
Truck (originating/total)	1,728/1,728	0/0	0/0	0/0	0/0	0/0	0/0
Rail (originating/total)	0/0	287/287	287/287	287/287	287/287	287/287	287/287
Radiological impacts							
Incident-free impacts							
Population (person-rem/LCFs)[b]	$8.7\times10^{0}/4.3\times10^{-3}$	$4.7\times10^{0}/2.4\times10^{-3}$	$4.7\times10^{0}/2.4\times10^{-3}$	$4.7\times10^{0}/2.4\times10^{-3}$	$4.7\times10^{0}/2.4\times10^{-3}$	$4.7\times10^{0}/2.4\times10^{-3}$	$4.7\times10^{0}/2.4\times10^{-3}$
Workers (person-rem/LCFs)	$4.9\times10^{1}/2.0\times10^{-2}$	$1.7\times10^{1}/6.7\times10^{-3}$	$1.7\times10^{1}/6.7\times10^{-3}$	$1.7\times10^{1}/6.7\times10^{-3}$	$1.7\times10^{1}/6.7\times10^{-3}$	$1.7\times10^{1}/6.7\times10^{-3}$	$1.7\times10^{1}/6.7\times10^{-3}$
Accident dose risk							
Population (person-rem/LCFs)	$6.0\times10^{-4}/3.0\times10^{-7}$	$4.9\times10^{-3}/2.4\times10^{-6}$	$4.9\times10^{-3}/2.4\times10^{-6}$	$4.9\times10^{-3}/2.4\times10^{-6}$	$4.9\times10^{-3}/2.4\times10^{-6}$	$4.9\times10^{-3}/2.4\times10^{-6}$	$4.9\times10^{-3}/2.4\times10^{-6}$
Nonradiological impacts							
Vehicle emissions (LCFs)	1.4×10^{-3}	1.6×10^{-3}	1.6×10^{-3}	1.6×10^{-3}	1.6×10^{-3}	1.6×10^{-3}	1.6×10^{-3}
Fatalities	0.006	0.010	0.010	0.010	0.010	0.010	0.010
OHIO							
Shipments							
Truck (originating/total)	636/12,121	0/580	0/580	0/580	0/580	0/580	0/580
Rail (originating/total)	0/0	106/2,381	106/2,381	106/2,381	106/2,381	106/2,381	106/2,381
Radiological impacts							
Incident-free impacts							
Population (person-rem/LCFs)[b]	$1.6\times10^{2}/7.9\times10^{-2}$	$8.5\times10^{1}/4.3\times10^{-2}$	$8.5\times10^{1}/4.3\times10^{-2}$	$8.5\times10^{1}/4.3\times10^{-2}$	$8.5\times10^{1}/4.3\times10^{-2}$	$8.5\times10^{1}/4.3\times10^{-2}$	$8.5\times10^{1}/4.3\times10^{-2}$
Workers (person-rem/LCFs)	$3.2\times10^{2}/1.3\times10^{-1}$	$9.1\times10^{1}/3.6\times10^{-2}$	$9.1\times10^{1}/3.6\times10^{-2}$	$9.1\times10^{1}/3.6\times10^{-2}$	$9.1\times10^{1}/3.6\times10^{-2}$	$9.1\times10^{1}/3.6\times10^{-2}$	$9.1\times10^{1}/3.6\times10^{-2}$
Accident dose risk							
Population (person-rem/LCFs)	$7.7\times10^{-3}/3.8\times10^{-6}$	$2.6\times10^{-2}/1.3\times10^{-5}$	$2.6\times10^{-2}/1.3\times10^{-5}$	$2.6\times10^{-2}/1.3\times10^{-5}$	$2.6\times10^{-2}/1.3\times10^{-5}$	$2.6\times10^{-2}/1.3\times10^{-5}$	$2.6\times10^{-2}/1.3\times10^{-5}$
Nonradiological impacts							
Vehicle emissions (LCFs)	3.1×10^{-2}	3.9×10^{-2}	3.9×10^{-2}	3.9×10^{-2}	3.9×10^{-2}	3.9×10^{-2}	3.9×10^{-2}
Fatalities	0.04	0.08	0.08	0.08	0.08	0.08	0.08

a. Under the mostly rail scenario, rail shipments would arrive in Nevada at one of six existing rail nodes. Impacts would vary according to the node. From that node, DOE would use one of the rail or heavy-haul implementing alternatives to complete the transportation to Yucca Mountain (see Section J.1.2).

b. For heavy-haul truck transportation, the Caliente junction is the location of the proposed Caliente intermodal transfer station for heavy-haul trucks near the town of Caliente in eastern Nevada. Rail shipments terminating at this junction would continue to Yucca Mountain on heavy-haul trucks on one of the Caliente, Caliente/Chalk Mountain, or Caliente/Las Vegas routes. For branch rail line transportation, railcars would transfer via the Caliente Option to the Caliente Corridor at the Caliente junction.

c. For heavy-haul truck transportation, the Dry Lake junction is near the location of the proposed Apex/Dry Lake intermodal transfer station for heavy-haul trucks in southeast Nevada. Rail shipments terminating at this junction would continue to Yucca Mountain on heavy-haul trucks on the Apex/Dry Lake route.

Table J-81. Estimated transportation impacts for the States of Indiana, Michigan, and Ohio (page 2 of 2).

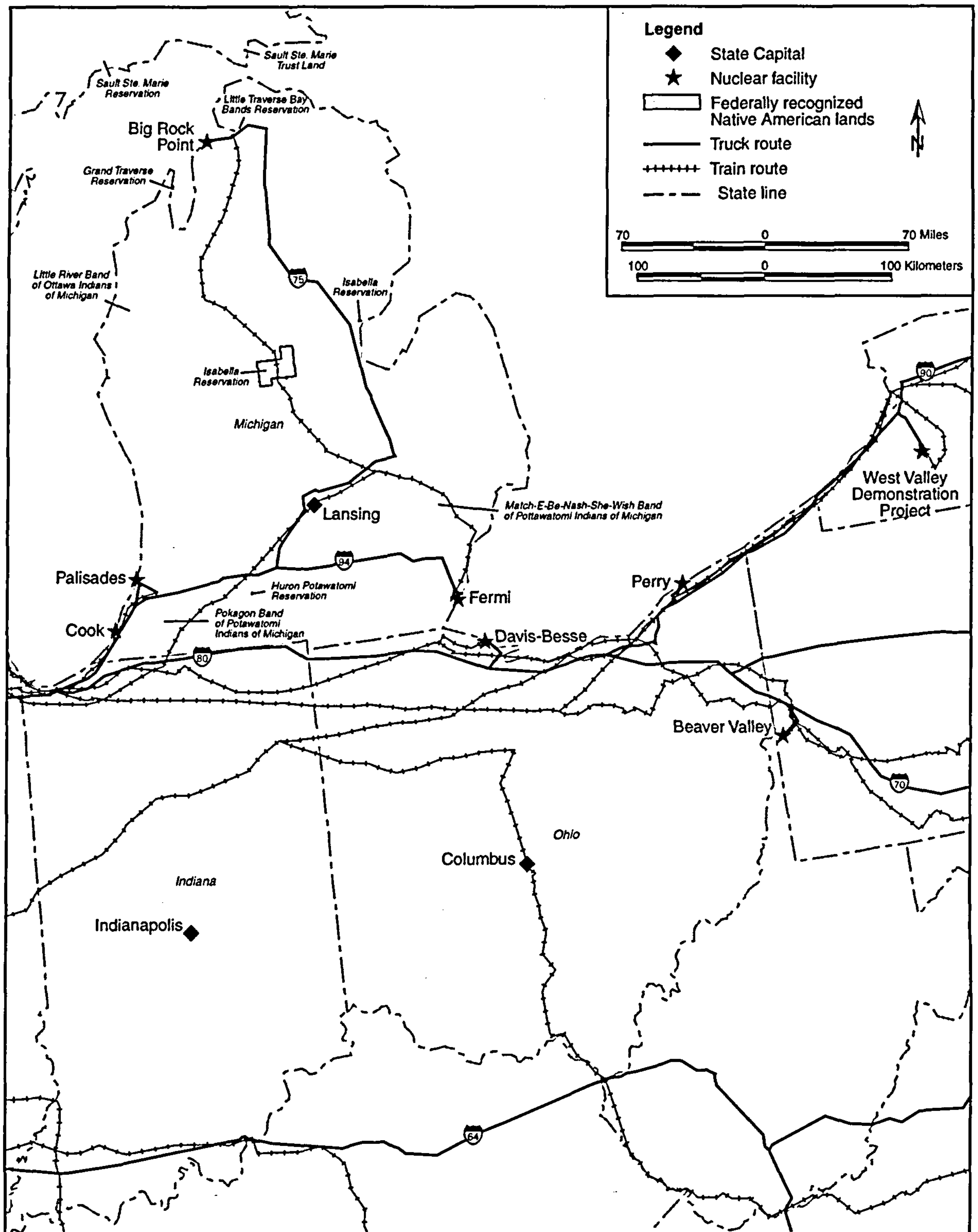
d. For heavy-haul truck transportation, the Jean junction is near the location of the proposed Sloan/Jean intermodal transfer station for heavy-haul trucks in southern Nevada. Rail shipments terminating at this junction would continue to Yucca Mountain on heavy-haul trucks on the Sloan/Jean route. For branch rail line transportation, railcars would transfer from the mainline railroad via the Wilson Pass or Stateline Pass Option of the Jean Corridor, near the Jean junction.

e. For branch rail line transportation, railcars would transfer from the mainline railroad at the Beowawe junction in north-central Nevada to the Carlin Corridor.

f. For branch rail line transportation, railcars would transfer from the mainline railroad at the Eccles junction east of Caliente, Nevada, via the Eccles Option or nearby via the Crestline Option of the Caliente or Caliente-Chalk Mountain Corridor. Impacts in states outside Nevada would be the same for the Eccles and Crestline Options of the Caliente and Caliente-Chalk Mountain Corridors.

g. For branch rail line transportation, railcars would transfer from the mainline railroad at the Apex junction in southeast Nevada, possibly via the Valley Connection, to the Valley Modified Corridor.

h. LCF = latent cancer fatality.



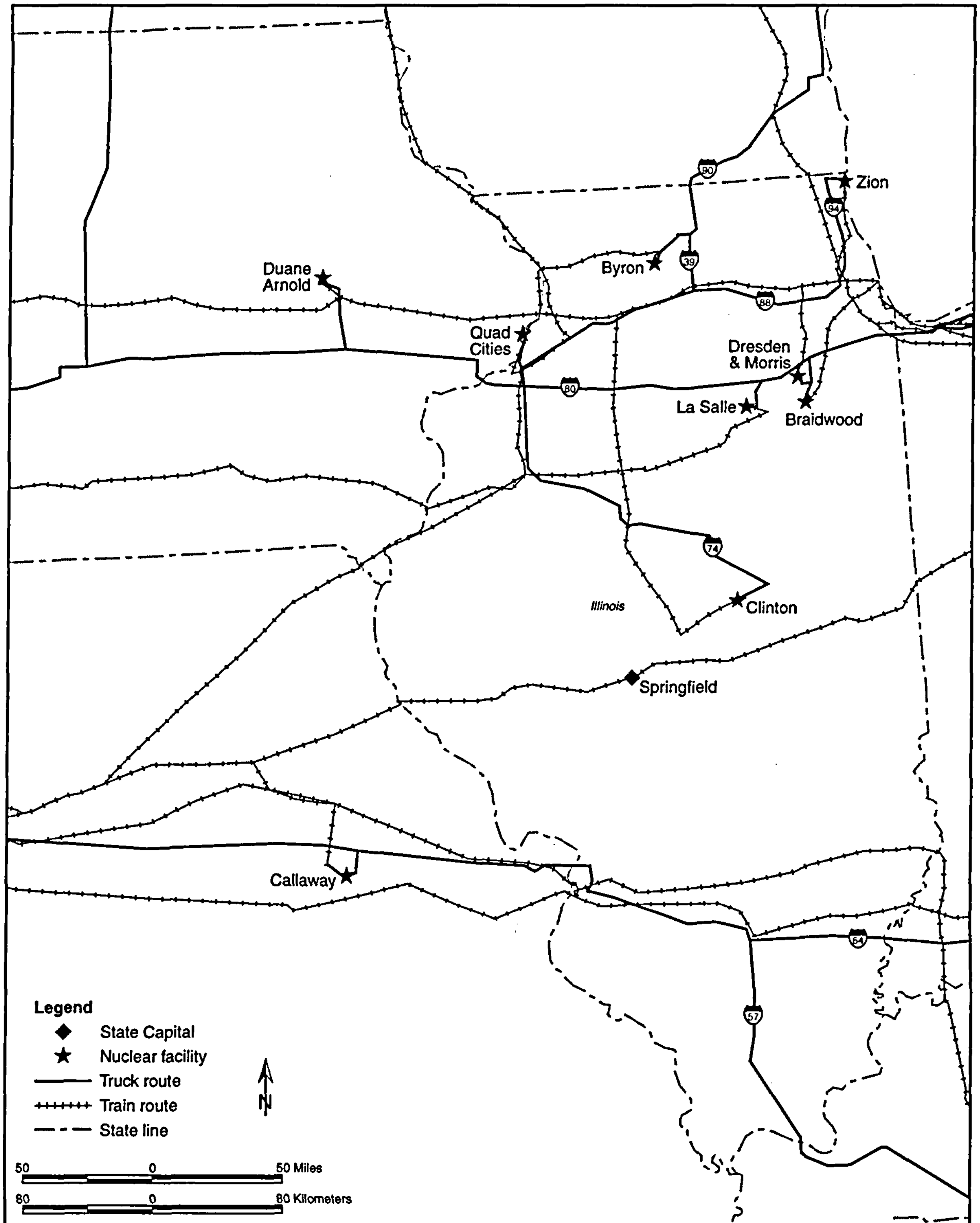
These routes represent the routes analyzed in Chapter 6 and might not be the routes actually used for shipments to the proposed repository at Yucca Mountain. Truck routes comply with U.S. Department of Transportation routing regulations. Rail routes are based on maximizing the distance on mainline track and minimizing the overall distance and number of interchanges between railroads.

Figure J-41. Highway and rail routes used to analyze transportation impacts - Indiana, Michigan, and Ohio.

Table J-82. Estimated transportation impacts for the State of Illinois.

Impact category	Mostly legal-weight truck	Mostly rail					
		Ending rail node in Nevada[a]					
		Caliente[b]	Dry Lake[c]	Jean[d]	Beowawe[e]	Eccles[f]	Apex[g]
ILLINOIS							
Shipments							
Truck (originating/total)	5,306/38,549	0/1,071	0/1,071	0/1,071	0/1,071	0/1,071	0/1,071
Rail (originating/total)	0/0	861/7,027	861/7,027	861/6,825	861/7,027	861/7,027	861/7,027
Radiological impacts							
Incident-free impacts							
Population (person-rem/LCFs)[h]	$2.8\times10^{2}/1.4\times10^{-1}$	$1.8\times10^{2}/8.9\times10^{-2}$	$1.8\times10^{2}/8.9\times10^{-2}$	$1.8\times10^{2}/7.4\times10^{-2}$	$1.8\times10^{2}/8.9\times10^{-2}$	$1.8\times10^{2}/8.9\times10^{-2}$	$1.8\times10^{2}/8.9\times10^{-2}$
Workers (person-rem/LCFs)	$7.6\times10^{2}/3.1\times10^{-1}$	$1.9\times10^{2}/7.5\times10^{-2}$	$1.9\times10^{2}/7.5\times10^{-2}$	$1.8\times10^{2}/7.4\times10^{-2}$	$1.9\times10^{2}/7.5\times10^{-2}$	$1.9\times10^{2}/7.5\times10^{-2}$	$1.9\times10^{2}/7.5\times10^{-2}$
Accident dose risk							
Population (person-rem/LCFs)	$1.6\times10^{-2}/8.1\times10^{-6}$	$1.6\times10^{-1}/7.9\times10^{-5}$	$1.6\times10^{-1}/7.9\times10^{-5}$	$1.5\times10^{-1}/7.7\times10^{-5}$	$1.6\times10^{-1}/7.9\times10^{-5}$	$1.6\times10^{-1}/7.9\times10^{-5}$	$1.6\times10^{-1}/7.9\times10^{-5}$
Nonradiological impacts							
Vehicle emissions (LCFs)	4.5×10^{-2}	8.0×10^{-2}	8.0×10^{-2}	7.9×10^{-2}	8.0×10^{-2}	8.0×10^{-2}	8.0×10^{-2}
Fatalities	0.17	0.19	0.19	0.18	0.19	0.19	0.19

a. Under the mostly rail scenario, rail shipments would arrive in Nevada at one of six existing rail nodes. Impacts would vary according to the node. From that node, DOE would use one of the rail or heavy-haul implementing alternatives to complete the transportation to Yucca Mountain (see Section J.1.2).
b. For heavy-haul truck transportation, the Caliente junction is the location of the proposed Caliente intermodal transfer station for heavy-haul trucks near the town of Caliente in eastern Nevada. Rail shipments terminating at this junction would continue to Yucca Mountain on heavy-haul trucks on one of the Caliente, Caliente/Chalk Mountain, or Caliente/Las Vegas routes. For branch rail line transportation, railcars would transfer via the Caliente Option to the Caliente Corridor at the Caliente junction.
c. For heavy-haul truck transportation, the Dry Lake junction is near the location of the proposed Apex/Dry Lake intermodal transfer station for heavy-haul trucks in southeast Nevada. Rail shipments terminating at this junction would continue to Yucca Mountain on heavy-haul trucks on the Apex/Dry Lake route.
d. For heavy-haul truck transportation, the Jean junction is near the location of the proposed Sloan/Jean intermodal transfer station for heavy-haul trucks in southern Nevada. Rail shipments terminating at this junction would continue to Yucca Mountain on heavy-haul trucks on the Sloan/Jean route. For branch rail line transportation, railcars would transfer from the mainline railroad via the Wilson Pass or Stateline Pass Option of the Jean Corridor, near the Jean junction.
e. For branch rail line transportation, railcars would transfer from the mainline railroad at the Beowawe junction in north-central Nevada to the Carlin Corridor.
f. For branch rail line transportation, railcars would transfer from the mainline railroad at the Eccles junction east of Caliente, Nevada, via the Eccles Option or nearby via the Crestline Option of the Caliente or Caliente-Chalk Mountain Corridor. Impacts in states outside Nevada would be the same for the Eccles and Crestline Options of the Caliente and Caliente-Chalk Mountain Corridors.
g. For branch rail line transportation, railcars would transfer from the mainline railroad at the Apex junction in southeast Nevada, possibly via the Valley Connection, to the Valley Modified Corridor.
h. LCF = latent cancer fatality.



These routes represent the routes analyzed in Chapter 6 and might not be the routes actually used for shipments to the proposed repository at Yucca Mountain. Truck routes comply with U.S. Department of Transportation routing regulations. Rail routes are based on maximizing the distance on mainline track and minimizing the overall distance and number of interchanges between railroads.

Figure J-42. Highway and rail routes used to analyze transportation impacts - Illinois.

Table J-83. Estimated transportation impacts for the States of Kentucky and Tennessee.

Impact category	Mostly legal-weight truck	Mostly rail					
		Ending rail node in Nevada[a]					
		Caliente[b]	Dry Lake[c]	Jean[d]	Beowawe[e]	Eccles[f]	Apex[g]
KENTUCKY							
Shipments							
Truck (originating/total)	0/18,435	0/491	0/491	0/491	0/491	0/491	0/491
Rail (originating/total)	0/0	0/3,312	0/3,312	0/3,110	0/3,312	0/3,312	0/3,312
Radiological impacts							
Incident-free impacts							
Population (person-rem/LCFs)[h]	$8.3\times10^{1}/4.2\times10^{-2}$	$2.0\times10^{1}/1.0\times10^{-2}$	$2.0\times10^{1}/1.0\times10^{-2}$	$1.9\times10^{1}/9.6\times10^{-3}$	$2.0\times10^{1}/1.0\times10^{-2}$	$2.0\times10^{1}/1.0\times10^{-2}$	$2.0\times10^{1}/1.0\times10^{-2}$
Workers (person-rem/LCFs)	$2.2\times10^{2}/8.7\times10^{-2}$	$4.9\times10^{1}/1.9\times10^{-2}$	$4.9\times10^{1}/1.9\times10^{-2}$	$4.7\times10^{1}/1.9\times10^{-2}$	$4.9\times10^{1}/1.9\times10^{-2}$	$4.9\times10^{1}/1.9\times10^{-2}$	$4.9\times10^{1}/1.9\times10^{-2}$
Accident dose risk							
Population (person-rem/LCFs)	$5.2\times10^{-3}/2.6\times10^{-6}$	$4.2\times10^{-3}/2.1\times10^{-6}$	$4.2\times10^{-3}/2.1\times10^{-6}$	$3.9\times10^{-3}/2.0\times10^{-6}$	$4.2\times10^{-3}/2.1\times10^{-6}$	$4.2\times10^{-3}/2.1\times10^{-6}$	$3.9\times10^{-3}/2.0\times10^{-6}$
Nonradiological impacts							
Vehicle emissions (LCFs)	1.1×10^{-2}	9.7×10^{-3}	9.7×10^{-3}	9.3×10^{-3}	9.7×10^{-3}	9.7×10^{-3}	9.7×10^{-3}
Fatalities	0.086	0.041	0.041	0.039	0.041	0.041	0.041
TENNESSEE							
Shipments							
Truck (originating/total)	802/15,026	0/491	0/491	0/491	0/491	0/491	0/491
Rail (originating/total)	0/0	121/3,312	121/3,312	121/3,110	121/3,312	121/3,312	121/3,312
Radiological impacts							
Incident-free impacts							
Population (person-rem/LCFs)[h]	$1.4\times10^{2}/6.9\times10^{-2}$	$5.5\times10^{1}/2.7\times10^{-2}$	$5.5\times10^{1}/2.7\times10^{-2}$	$5.1\times10^{1}/2.5\times10^{-2}$	$5.5\times10^{1}/2.7\times10^{-2}$	$5.5\times10^{1}/2.7\times10^{-2}$	$5.5\times10^{1}/2.7\times10^{-2}$
Workers (person-rem/LCFs)	$3.1\times10^{2}/1.2\times10^{-1}$	$8.2\times10^{1}/3.3\times10^{-2}$	$8.2\times10^{1}/3.3\times10^{-2}$	$7.7\times10^{1}/3.1\times10^{-2}$	$8.2\times10^{1}/3.3\times10^{-2}$	$8.2\times10^{1}/3.3\times10^{-2}$	$8.2\times10^{1}/3.3\times10^{-2}$
Accident dose risk							
Population (person-rem/LCFs)	$4.7\times10^{-3}/2.4\times10^{-6}$	$1.1\times10^{-2}/5.5\times10^{-6}$	$1.1\times10^{-2}/5.5\times10^{-6}$	$9.0\times10^{-3}/4.5\times10^{-6}$	$1.1\times10^{-2}/5.5\times10^{-6}$	$1.1\times10^{-2}/5.5\times10^{-6}$	$1.1\times10^{-2}/5.5\times10^{-6}$
Nonradiological impacts							
Vehicle emissions (LCFs)	2.8×10^{-2}	2.7×10^{-2}	2.7×10^{-2}	2.5×10^{2}	2.7×10^{-2}	2.7×10^{-2}	2.7×10^{-2}
Fatalities	0.09	0.07	0.07	0.07	0.07	0.07	0.07

a. Under the mostly rail scenario, rail shipments would arrive in Nevada at one of six existing rail nodes. Impacts would vary according to the node. From that node, DOE would use one of the rail or heavy-haul implementing alternatives to complete the transportation to Yucca Mountain (see *Section J.1.2*).

b. For heavy-haul truck transportation, the Caliente junction is the location of the proposed Caliente intermodal transfer station for heavy-haul trucks near the town of Caliente in eastern Nevada. Rail shipments terminating at this junction would continue to Yucca Mountain on heavy-haul trucks on one of the Caliente, Caliente/Chalk Mountain, or Caliente/Las Vegas routes. For branch rail line transportation, railcars would transfer via the Caliente Option to the Caliente Corridor at the Caliente junction.

c. For heavy-haul truck transportation, the Dry Lake junction is near the location of the proposed Apex/Dry Lake intermodal transfer station for heavy-haul trucks in southeast Nevada. Rail shipments terminating at this junction would continue to Yucca Mountain on heavy-haul trucks on the Apex/Dry Lake route.

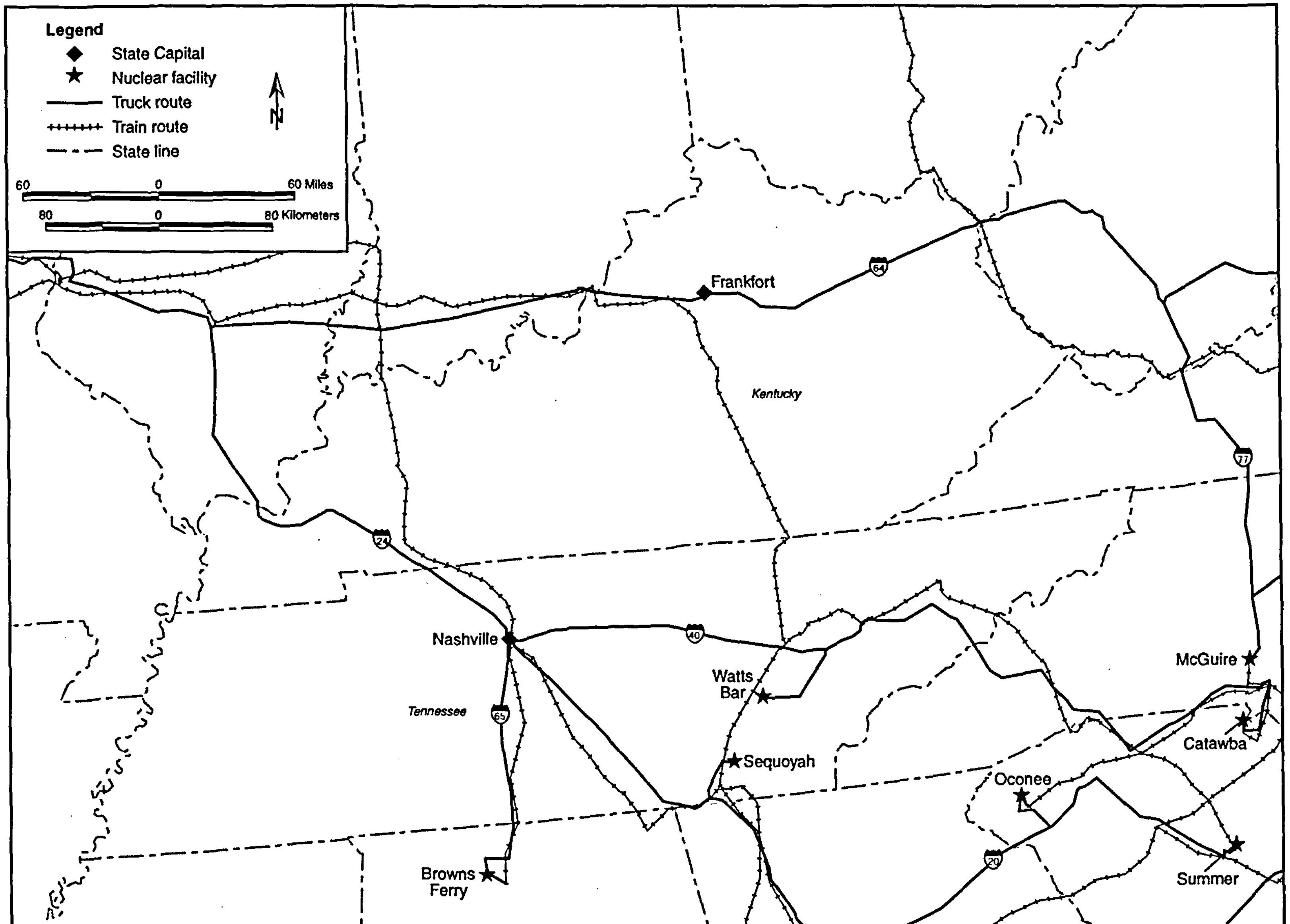
d. For heavy-haul truck transportation, the Jean junction is near the location of the proposed Sloan/Jean intermodal transfer station for heavy-haul trucks in southern Nevada. Rail shipments terminating at this junction would continue to Yucca Mountain on heavy-haul trucks on the Sloan/Jean route. For branch rail line transportation, railcars would transfer from the mainline railroad via the Wilson Pass or Stateline Pass Option of the Jean Corridor, near the Jean junction.

e. For branch rail line transportation, railcars would transfer from the mainline railroad at the Beowawe junction in north-central Nevada to the Carlin Corridor.

f. For branch rail line transportation, railcars would transfer from the mainline railroad at the Eccles junction east of Caliente, Nevada, via the Eccles Option or nearby via the Crestline Option of the Caliente or Caliente-Chalk Mountain Corridor. Impacts in states outside Nevada would be the same for the Eccles and Crestline Options of the Caliente and Caliente-Chalk Mountain Corridors.

g. For branch rail line transportation, railcars would transfer from the mainline railroad at the Apex junction in southeast Nevada, possibly via the Valley Connection, to the Valley Modified Corridor.

h. LCF = latent cancer fatality.



These routes represent the routes analyzed in Chapter 6 and might not be the routes actually used for shipments to the proposed repository at Yucca Mountain. Truck routes comply with U.S. Department of Transportation routing regulations. Rail routes are based on maximizing the distance on mainline track and minimizing the overall distance and number of interchanges between railroads.

Figure J-43. Highway and rail routes used to analyze transportation impacts - Kentucky and Tennessee.

Table J-84. Estimated transportation impacts for the States of Louisiana and Mississippi.

Impact category	Mostly legal-weight truck	Mostly rail: Ending rail node in Nevada[a]					
		Caliente[b]	Dry Lake[c]	Jean[d]	Beowawe[e]	Eccles[f]	Apex[g]
LOUISIANA							
Shipments							
Truck (originating/total)	727/2,012	0/0	0/0	0/0	0/0	0/0	0/0
Rail (originating/total)	0/0	123/203	123/203	123/405	123/203	123/203	123/203
Radiological impacts							
Incident-free impacts							
Population (person-rem/LCFs)[h]	$2.6\times10^{1}/1.3\times10^{-2}$	$2.9\times10^{0}/1.5\times10^{-3}$	$2.6\times10^{0}/1.3\times10^{-3}$	$7.5\times10^{0}/3.8\times10^{-3}$	$3.0\times10^{0}/1.5\times10^{-3}$	$2.9\times10^{0}/1.5\times10^{-3}$	$2.6\times10^{0}/1.3\times10^{-3}$
Workers (person-rem/LCFs)	$7.7\times10^{1}/3.1\times10^{-2}$	$1.1\times10^{1}/4.3\times10^{-3}$	$1.0\times10^{1}/4.1\times10^{-3}$	$1.7\times10^{1}/6.7\times10^{-3}$	$1.1\times10^{1}/4.4\times10^{-3}$	$1.1\times10^{1}/4.3\times10^{-3}$	$1.0\times10^{1}/4.1\times10^{-3}$
Accident dose risk							
Population (person-rem/LCFs)	$1.3\times10^{-3}/6.6\times10^{-7}$	$2.9\times10^{-3}/1.5\times10^{-6}$	$2.5\times10^{-3}/1.3\times10^{-6}$	$9.3\times10^{-3}/4.6\times10^{-6}$	$3.0\times10^{-3}/1.5\times10^{-6}$	$2.9\times10^{-3}/1.5\times10^{-6}$	$2.5\times10^{-3}/1.3\times10^{-6}$
Nonradiological impacts							
Vehicle emissions (LCFs)	3.91×10^{-3}	1.06×10^{-3}	8.98×10^{-4}	3.31×10^{-3}	1.08×10^{-3}	1.06×10^{-3}	8.98×10^{-4}
Fatalities	0.018	0.018	0.016	0.037	0.018	0.018	0.016
MISSISSIPPI							
Shipments							
Truck (originating/total)	592/1,285	0/0	0/0	0/0	0/0	0/0	0/0
Rail (originating/total)	0/0	80/80	80/80	80/282	80/80	80/80	80/80
Radiological impacts							
Incident-free impacts							
Population (person-rem/LCFs)[h]	$2.8\times10^{0}/1.4\times10^{-3}$	$6.2\times10^{-1}/3.1\times10^{-4}$	$6.2\times10^{-1}/3.1\times10^{-4}$	$2.7\times10^{0}/1.3\times10^{-3}$	$6.2\times10^{-1}/3.1\times10^{-4}$	$6.2\times10^{-1}/3.1\times10^{-4}$	$6.2\times10^{-1}/3.1\times10^{-4}$
Workers (person-rem/LCFs)	$1.8\times10^{1}/7.3\times10^{-3}$	$4.3\times10^{0}/1.7\times10^{-3}$	$4.3\times10^{0}/1.7\times10^{-3}$	$6.1\times10^{1}/2.4\times10^{-3}$	$4.3\times10^{0}/1.7\times10^{-3}$	$4.3\times10^{0}/1.7\times10^{-3}$	$4.3\times10^{0}/1.7\times10^{-3}$
Accident dose risk							
Population (person-rem/LCFs)	$2.3\times10^{-5}/1.1\times10^{-8}$	$1.1\times10^{-5}/5.7\times10^{-9}$	$1.1\times10^{-5}/5.7\times10^{-9}$	$3.3\times10^{-3}/1.7\times10^{-6}$	$1.1\times10^{-5}/5.7\times10^{-9}$	$1.1\times10^{-5}/5.7\times10^{-9}$	$1.1\times10^{-5}/5.7\times10^{-9}$
Nonradiological impacts							
Vehicle emissions (LCFs)	2.7×10^{-4}	8.5×10^{-6}	8.5×10^{-6}	1.1×10^{-3}	8.5×10^{-6}	8.5×10^{-6}	8.5×10^{-6}
Fatalities	5.9×10^{-4}	3.7×10^{-4}	3.7×10^{-4}	4.3×10^{-3}	3.7×10^{-4}	3.7×10^{-4}	3.7×10^{-4}

a. Under the mostly rail scenario, rail shipments would arrive in Nevada at one of six existing rail nodes. Impacts would vary according to the node. From that node, DOE would use one of the rail or heavy-haul implementing alternatives to complete the transportation to Yucca Mountain (see Section J.1.2).

b. For heavy-haul truck transportation, the Caliente junction is the location of the proposed Caliente intermodal transfer station for heavy-haul trucks near the town of Caliente in eastern Nevada. Rail shipments terminating at this junction would continue to Yucca Mountain on heavy-haul trucks on one of the Caliente, Caliente/Chalk Mountain, or Caliente/Las Vegas routes. For branch rail line transportation, railcars would transfer via the Caliente Option to the Caliente Corridor at the Caliente junction.

c. For heavy-haul truck transportation, the Dry Lake junction is near the location of the proposed Apex/Dry Lake intermodal transfer station for heavy-haul trucks in southeast Nevada. Rail shipments terminating at this junction would continue to Yucca Mountain on heavy-haul trucks on the Apex/Dry Lake route.

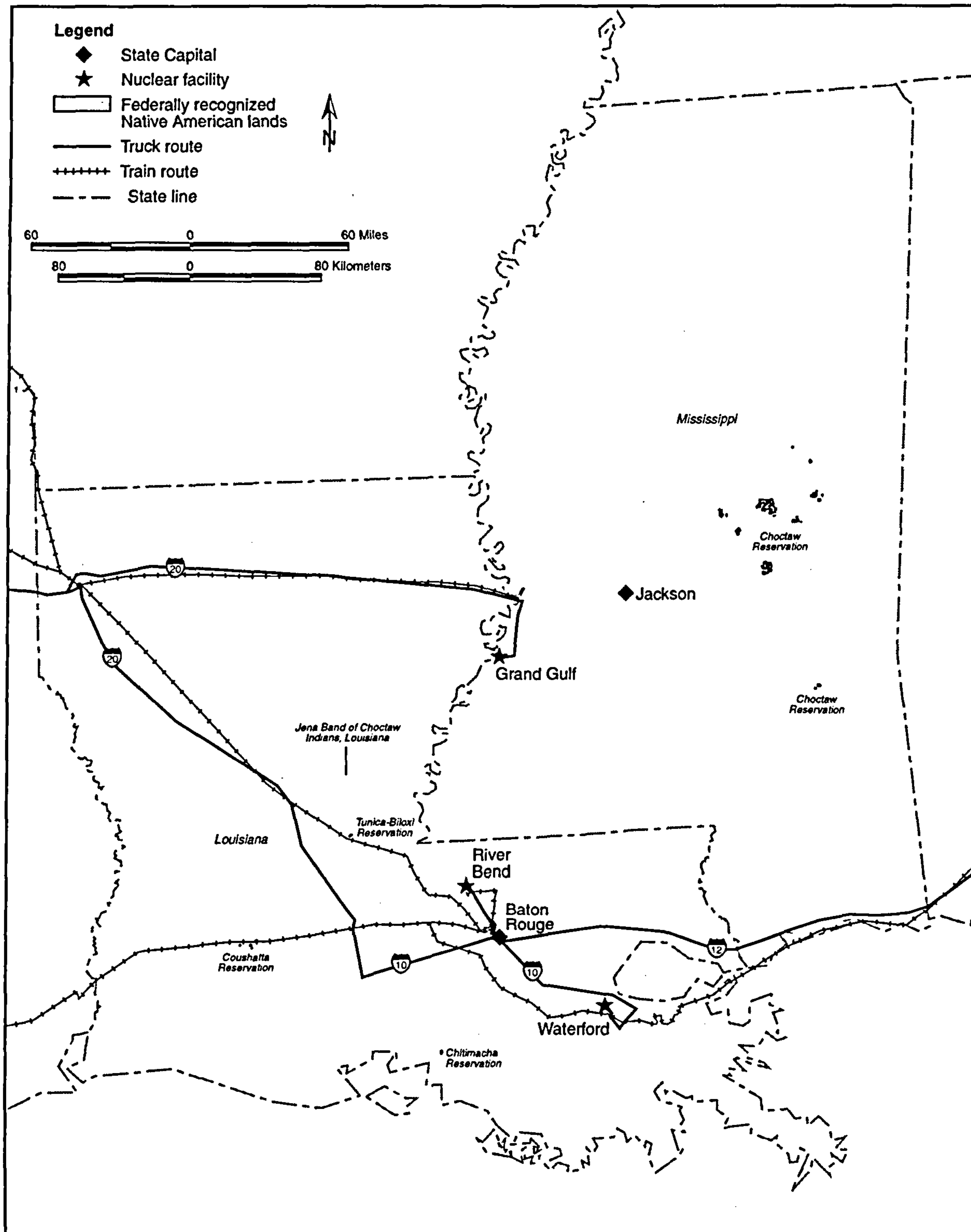
d. For heavy-haul truck transportation, the Jean junction is near the location of the proposed Sloan/Jean intermodal transfer station for heavy-haul trucks in southern Nevada. Rail shipments terminating at this junction would continue to Yucca Mountain on heavy-haul trucks on the Sloan/Jean route. For branch rail line transportation, railcars would transfer from the mainline railroad via the Wilson Pass or Stateline Pass Option of the Jean Corridor, near the Jean junction.

e. For branch rail line transportation, railcars would transfer from the mainline railroad at the Beowawe junction in north-central Nevada to the Carlin Corridor.

f. For branch rail line transportation, railcars would transfer from the mainline railroad at the Eccles junction east of Caliente, Nevada, via the Eccles Option or nearby via the Crestline Option of the Caliente or Caliente-Chalk Mountain Corridor. Impacts in states outside Nevada would be the same for the Eccles and Crestline Options of the Caliente and Caliente-Chalk Mountain Corridors.

g. For branch rail line transportation, railcars would transfer from the mainline railroad at the Apex junction in southeast Nevada, possibly via the Valley Connection, to the Valley Modified Corridor.

h. LCF = latent cancer fatality.



These routes represent the routes analyzed in Chapter 6 and might not be the routes actually used for shipments to the proposed repository at Yucca Mountain. Truck routes comply with U.S. Department of Transportation routing regulations. Rail routes are based on maximizing the distance on mainline track and minimizing the overall distance and number of interchanges between railroads.

Figure J-44. Highway and rail routes used to analyze transportation impacts - Louisiana and Mississippi.

Table J-85. Estimated transportation impacts for the States of Maine, Massachusetts, New Hampshire, and Vermont (page 1 of 2).

		Mostly rail					
	Mostly legal-weight truck	Ending rail node in Nevada[a]					
Impact category		Caliente[b]	Dry Lake[c]	Jean[d]	Beowawe[e]	Eccles[f]	Apex[g]
MAINE							
Shipments							
Truck (originating/total)	356/356	0/0	0/0	0/0	0/0	0/0	0/0
Rail (originating/total)	0/0	55/55	55/55	55/55	55/55	55/55	55/55
Radiological impacts							
Incident-free impacts							
Population (person-rem/LCFs)[h]	$1.9\times10^{0}/9.5\times10^{-4}$	$5.2\times10^{-1}/2.6\times10^{-4}$	$5.2\times10^{-1}/2.6\times10^{-4}$	$5.2\times10^{-1}/2.6\times10^{-4}$	$5.2\times10^{-1}/2.6\times10^{-4}$	$5.2\times10^{-1}/2.6\times10^{-4}$	$5.2\times10^{-1}/2.6\times10^{-4}$
Workers (person-rem/LCFs)	$9.9\times10^{0}/4.0\times10^{-3}$	$3.2\times10^{0}/1.3\times10^{-3}$	$3.2\times10^{0}/1.3\times10^{-3}$	$3.2\times10^{0}/1.3\times10^{-3}$	$3.2\times10^{0}/1.3\times10^{-3}$	$3.2\times10^{0}/1.3\times10^{-3}$	$3.2\times10^{0}/1.3\times10^{-3}$
Accident dose risk							
Population (person-rem/LCFs)	$2.2\times10^{-4}/1.1\times10^{-7}$	$1.1\times10^{-3}/5.6\times10^{-7}$	$1.1\times10^{-3}/5.6\times10^{-7}$	$1.1\times10^{-3}/5.6\times10^{-7}$	$1.1\times10^{-3}/5.6\times10^{-7}$	$1.1\times10^{-3}/5.6\times10^{-7}$	$1.1\times10^{-3}/5.6\times10^{-7}$
Nonradiological impacts							
Vehicle emissions (LCFs)	2.9×10^{-4}	1.7×10^{-4}	1.7×10^{-4}	1.7×10^{-4}	1.7×10^{-4}	1.7×10^{-4}	1.7×10^{-4}
Fatalities	9.7×10^{-4}	2.9×10^{-3}	2.9×10^{-3}	2.9×10^{-3}	2.9×10^{-3}	2.9×10^{-3}	2.9×10^{-3}
MASSACHUSETTS							
Shipments							
Truck (originating/total)	456/1,469	154/154	154/154	154/154	154/154	154/154	154/154
Rail (originating/total)	0/0	39/511	39/511	39/511	39/511	39/511	39/511
Radiological impacts							
Incident-free impacts							
Population (person-rem/LCFs)[h]	$1.5\times10^{1}/7.3\times10^{-3}$	$7.9\times10^{0}/4.0\times10^{-3}$	$7.9\times10^{0}/4.0\times10^{-3}$	$7.9\times10^{0}/4.0\times10^{-3}$	$7.9\times10^{0}/4.0\times10^{-3}$	$7.9\times10^{0}/4.0\times10^{-3}$	$7.9\times10^{0}/4.0\times10^{-3}$
Workers (person-rem/LCFs)	$3.0\times10^{1}/1.2\times10^{-2}$	$1.3\times10^{1}/1.5\times10^{-3}$	$1.3\times10^{1}/1.5\times10^{-3}$	$1.3\times10^{1}/1.5\times10^{-3}$	$1.3\times10^{1}/1.5\times10^{-3}$	$1.3\times10^{1}/1.5\times10^{-3}$	$1.3\times10^{1}/1.5\times10^{-3}$
Accident dose risk							
Population (person-rem/LCFs)	$4.8\times10^{-4}/2.4\times10^{-7}$	$1.5\times10^{-2}/7.3\times10^{-6}$	$1.5\times10^{-2}/7.3\times10^{-6}$	$1.5\times10^{-2}/7.3\times10^{-6}$	$1.5\times10^{-2}/7.3\times10^{-6}$	$1.5\times10^{-2}/7.3\times10^{-6}$	$1.5\times10^{-2}/7.3\times10^{-6}$
Nonradiological impacts							
Vehicle emissions (LCFs)	3.7×10^{-3}	3.3×10^{-3}	3.3×10^{-3}	3.3×10^{-3}	3.3×10^{-3}	3.3×10^{-3}	3.3×10^{-3}
Fatalities	0.001	0.068	0.068	0.068	0.068	0.068	0.068
NEW HAMPSHIRE							
Shipments							
Truck (originating/total)	277/633	0/0	0/0	0/0	0/0	0/0	0/0
Rail (originating/total)	0/0	49/104	49/104	49/104	49/104	49/104	49/104
Radiological impacts							
Incident-free impacts							
Population (person-rem/LCFs)[h]	$4.9\times10^{-1}/2.5\times10^{-4}$	$4.4\times10^{-1}/2.2\times10^{-4}$	$4.4\times10^{-1}/2.2\times10^{-4}$	$4.4\times10^{-1}/2.2\times10^{-4}$	$4.4\times10^{-1}/2.2\times10^{-4}$	$4.4\times10^{-1}/2.2\times10^{-4}$	$4.4\times10^{-1}/2.2\times10^{-4}$
Workers (person-rem/LCFs)	$5.7\times10^{0}/2.3\times10^{-3}$	$2.7\times10^{0}/1.1\times10^{-3}$	$2.7\times10^{0}/1.1\times10^{-3}$	$2.7\times10^{0}/1.1\times10^{-3}$	$2.7\times10^{0}/1.1\times10^{-3}$	$2.7\times10^{0}/1.1\times10^{-3}$	$2.7\times10^{0}/1.1\times10^{-3}$
Accident dose risk							
Population (person-rem/LCFs)	$4.2\times10^{-5}/2.1\times10^{-8}$	$8.5\times10^{-4}/4.3\times10^{-7}$	$8.5\times10^{-4}/4.3\times10^{-7}$	$8.5\times10^{-4}/4.3\times10^{-7}$	$8.5\times10^{-4}/4.3\times10^{-7}$	$8.5\times10^{-4}/4.3\times10^{-7}$	$8.5\times10^{-4}/4.3\times10^{-7}$
Nonradiological impacts							
Vehicle emissions (LCFs)	8.9×10^{-5}	1.4×10^{-4}	1.4×10^{-4}	1.4×10^{-4}	1.4×10^{-4}	1.4×10^{-4}	1.4×10^{-4}
Fatalities	1.2×10^{-4}	1.0×10^{-3}	1.0×10^{-3}	1.0×10^{-3}	1.0×10^{-3}	1.0×10^{-3}	1.0×10^{-3}

Table J-85. Estimated transportation impacts for the States of Maine, Massachusetts, New Hampshire, and Vermont (page 2 of 2).

Impact category	Mostly legal-weight truck	Mostly rail					
		Ending rail node in Nevada[a]					
		Caliente[b]	Dry Lake[c]	Jean[d]	Beowawe[e]	Eccles[f]	Apex[g]
VERMONT							
Shipments							
Truck (originating/total)	380/380	0/0	0/0	0/0	0/0	0/0	0/0
Rail (originating/total)	0/0	73/192	73/192	73/192	73/192	73/192	73/192
Radiological impacts							
Incident-free impacts							
Population (person-rem/LCFs)[h]	$4.1\times10^{-1}/2.1\times10^{-4}$	$1.6\times10^{-1}/7.8\times10^{-5}$	$1.6\times10^{-1}/7.8\times10^{-5}$	$1.6\times10^{-1}/7.8\times10^{-5}$	$1.6\times10^{-1}/7.8\times10^{-5}$	$1.6\times10^{-1}/7.8\times10^{-5}$	$1.6\times10^{-1}/7.8\times10^{-5}$
Workers (person-rem/LCFs)	$7.5\times10^{0}/3.0\times10^{-3}$	$3.6\times10^{0}/1.4\times10^{-3}$	$3.6\times10^{0}/1.4\times10^{-3}$	$3.6\times10^{0}/1.4\times10^{-3}$	$3.6\times10^{0}/1.4\times10^{-3}$	$3.6\times10^{0}/1.4\times10^{-3}$	$3.6\times10^{0}/1.4\times10^{-3}$
Accident dose risk							
Population (person-rem/LCFs)	$2.4\times10^{-5}/1.2\times10^{-8}$	$7.0\times10^{-5}/3.5\times10^{-8}$	$7.0\times10^{-5}/3.5\times10^{-8}$	$7.0\times10^{-5}/3.5\times10^{-8}$	$7.0\times10^{-5}/3.5\times10^{-8}$	$7.0\times10^{-5}/3.5\times10^{-8}$	$7.0\times10^{-5}/3.5\times10^{-8}$
Nonradiological impacts							
Vehicle emissions (LCFs)	8.9×10^{-5}	1.6×10^{-5}	1.6×10^{-5}	1.6×10^{-5}	1.6×10^{-5}	1.6×10^{-5}	1.6×10^{-5}
Fatalities	1.1×10^{-4}	1.5×10^{-4}	1.5×10^{-4}	1.5×10^{-4}	1.5×10^{-4}	1.5×10^{-4}	1.5×10^{-4}

a. Under the mostly rail scenario, rail shipments would arrive in Nevada at one of six existing rail nodes. Impacts would vary according to the node. From that node, DOE would use one of the rail or heavy-haul implementing alternatives to complete the transportation to Yucca Mountain (see Section J.1.2).

b. For heavy-haul truck transportation, the Caliente junction is the location of the proposed Caliente intermodal transfer station for heavy-haul trucks near the town of Caliente in eastern Nevada. Rail shipments terminating at this junction would continue to Yucca Mountain on heavy-haul trucks on one of the Caliente, Caliente/Chalk Mountain, or Caliente/Las Vegas routes. For branch rail line transportation, railcars would transfer via the Caliente Option to the Caliente Corridor at the Caliente junction.

c. For heavy-haul truck transportation, the Dry Lake junction is near the location of the proposed Apex/Dry Lake intermodal transfer station for heavy-haul trucks in southeast Nevada. Rail shipments terminating at this junction would continue to Yucca Mountain on heavy-haul trucks on the Apex/Dry Lake route.

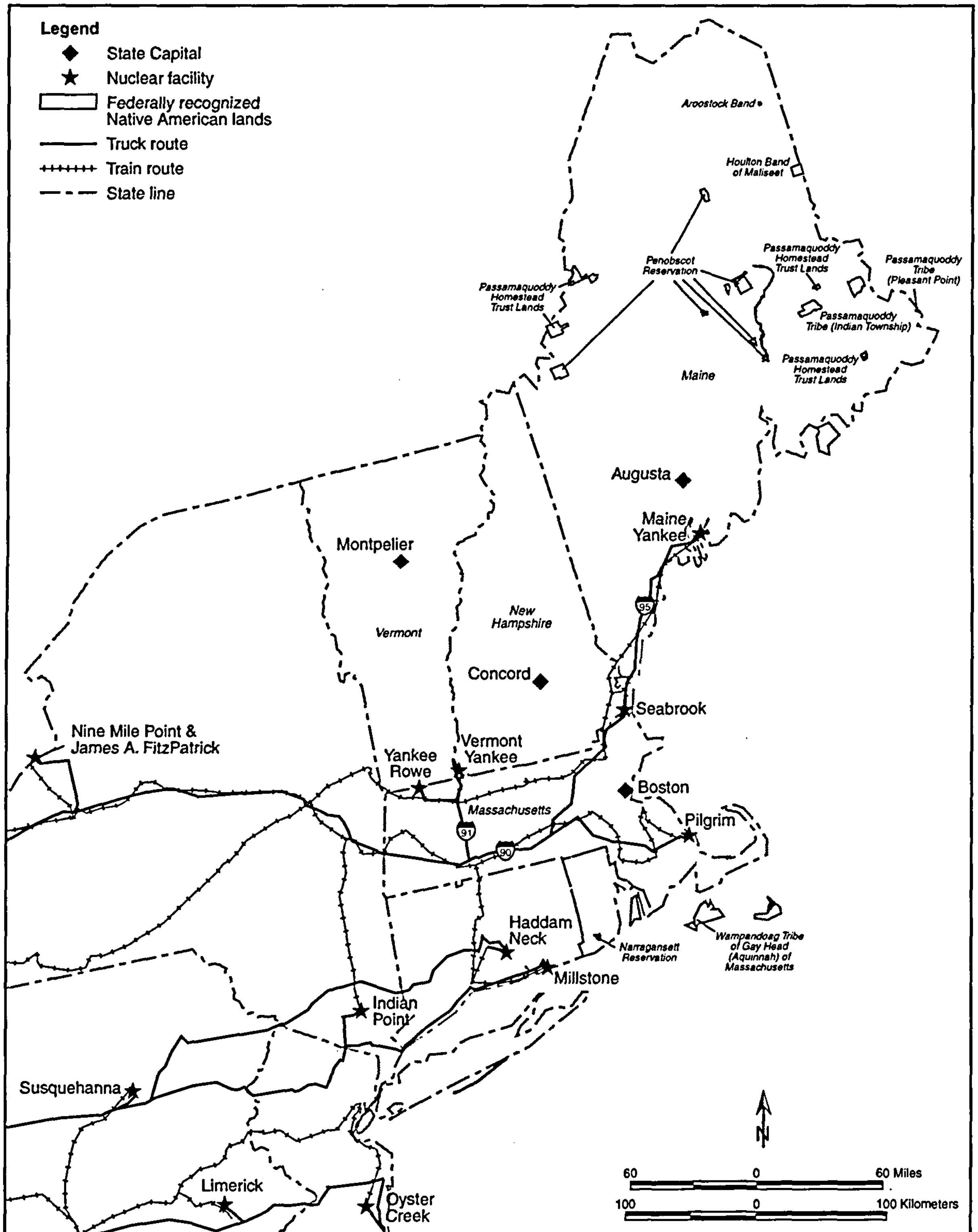
d. For heavy-haul truck transportation, the Jean junction is near the location of the proposed Sloan/Jean intermodal transfer station for heavy-haul trucks in southern Nevada. Rail shipments terminating at this junction would continue to Yucca Mountain on heavy-haul trucks on the Sloan/Jean route. For branch rail line transportation, railcars would transfer from the mainline railroad via the Wilson Pass or Stateline Pass Option of the Jean Corridor, near the Jean junction.

e. For branch rail line transportation, railcars would transfer from the mainline railroad at the Beowawe junction in north-central Nevada to the Carlin Corridor.

f. For branch rail line transportation, railcars would transfer from the mainline railroad at the Eccles junction east of Caliente, Nevada, via the Eccles Option or nearby via the Crestline Option of the Caliente or Caliente-Chalk Mountain Corridor. Impacts in states outside Nevada would be the same for the Eccles and Crestline Options of the Caliente and Caliente-Chalk Mountain Corridors.

g. For branch rail line transportation, railcars would transfer from the mainline railroad at the Apex junction in southeast Nevada, possibly via the Valley Connection, to the Valley Modified Corridor.

h. LCF = latent cancer fatality.



These routes represent the routes analyzed in Chapter 6 and might not be the routes actually used for shipments to the proposed repository at Yucca Mountain. Truck routes comply with U.S. Department of Transportation routing regulations. Rail routes are based on maximizing the distance on mainline track and minimizing the overall distance and number of interchanges between railroads.

Figure J-45. Highway and rail routes used to analyze transportation impacts - Maine, Massachusetts, New Hampshire, and Vermont.

Table J-86. Estimated transportation impacts for the States of Minnesota and Wisconsin (page 1 of 2).

		Mostly rail						
		Ending rail node in Nevada						
Impact category	Mostly legal-weight truck	Caliente[b]	Dry Lake[c]	Jean[d]	Beowawe[e]	Eccles[f]	Apex[g]
MINNESOTA								
Shipments								
Truck (originating/total)	922/959	8/8	8/8	8/8	8/8	8/8	8/8
Rail (originating/total)	0/0	135/135	135/135	135/135	135/135	135/135	135/135
Radiological impacts							
Incident-free impacts							
Population (person-rem/LCFs)[h]	$7.0\times10^{0}/3.5\times10^{-3}$	$3.1\times10^{0}/1.5\times10^{-3}$	$3.1\times10^{0}/1.5\times10^{-3}$	$3.1\times10^{0}/1.5\times10^{-3}$	$3.1\times10^{0}/1.5\times10^{-3}$	$3.1\times10^{0}/1.5\times10^{-3}$	$3.1\times10^{0}/1.5\times10^{-3}$
Workers (person-rem/LCFs)	$3.1\times10^{1}/1.2\times10^{-2}$	$9.9\times10^{0}/4.0\times10^{-3}$	$9.9\times10^{0}/4.0\times10^{-3}$	$9.9\times10^{0}/4.0\times10^{-3}$	$9.9\times10^{0}/4.0\times10^{-3}$	$9.9\times10^{0}/4.0\times10^{-3}$	$9.9\times10^{0}/4.0\times10^{-3}$
Accident dose risk							
Population (person-rem/LCFs)	$4.1\times10^{-4}/2.1\times10^{-7}$	$2.2\times10^{-3}/1.1\times10^{-6}$	$2.2\times10^{-3}/1.1\times10^{-6}$	$2.2\times10^{-3}/1.1\times10^{-6}$	$2.2\times10^{-3}/1.1\times10^{-6}$	$2.2\times10^{-3}/1.1\times10^{-6}$	$2.2\times10^{-3}/1.1\times10^{-6}$
Nonradiological impacts							
Vehicle emissions (LCFs)	1.5×10^{-3}	1.1×10^{-3}	1.1×10^{-3}	1.1×10^{-3}	1.1×10^{-3}	1.1×10^{-3}	1.1×10^{-3}
Fatalities	1.4×10^{-3}	3.3×10^{-3}	3.3×10^{-3}	3.3×10^{-3}	3.3×10^{-3}	3.3×10^{-3}	3.3×10^{-3}
WISCONSIN							
Shipments							
Truck (originating/total)	996/996	0/0	0/0	0/0	0/0	0/0	0/0
Rail (originating/total)	0/0	186/186	186/186	186/186	186/186	186/186	186/186
Radiological impacts							
Incident-free impacts							
Population (person-rem/LCFs)[h]	$1.1\times10^{1}/5.7\times10^{-3}$	$4.5\times10^{0}/2.2\times10^{-3}$	$4.5\times10^{0}/2.2\times10^{-3}$	$4.5\times10^{0}/2.2\times10^{-3}$	$4.5\times10^{0}/2.2\times10^{-3}$	$4.5\times10^{0}/2.2\times10^{-3}$	$4.5\times10^{0}/2.2\times10^{-3}$
Workers (person-rem/LCFs)	$3.7\times10^{1}/1.5\times10^{-2}$	$1.3\times10^{1}/5.3\times10^{-3}$	$1.3\times10^{1}/5.3\times10^{-3}$	$1.3\times10^{1}/5.3\times10^{-3}$	$1.3\times10^{1}/5.3\times10^{-3}$	$1.3\times10^{1}/5.3\times10^{-3}$	$1.3\times10^{1}/5.3\times10^{-3}$
Accident dose risk							
Population (person-rem/LCFs)	$2.3\times10^{-3}/1.1\times10^{-6}$	$4.2\times10^{-3}/2.1\times10^{-6}$	$4.2\times10^{-3}/2.1\times10^{-6}$	$4.2\times10^{-3}/2.1\times10^{-6}$	$4.2\times10^{-3}/2.1\times10^{-6}$	$4.2\times10^{-3}/2.1\times10^{-6}$	$4.2\times10^{-3}/2.1\times10^{-6}$
Nonradiological impacts							
Vehicle emissions (LCFs)	3.4×10^{-3}	1.5×10^{-3}	1.5×10^{-3}	1.5×10^{-3}	1.5×10^{-3}	1.5×10^{-3}	1.5×10^{-3}
Fatalities	0.005	0.006	0.006	0.006	0.006	0.006	0.006

a. Under the mostly rail scenario, rail shipments would arrive in Nevada at one of six existing rail nodes. Impacts would vary according to the node. From that node, DOE would use one of the rail or heavy-haul implementing alternatives to complete the transportation to Yucca Mountain (see Section J.1.2).

b. For heavy-haul truck transportation, the Caliente junction is the location of the proposed Caliente intermodal transfer station for heavy-haul trucks near the town of Caliente in eastern Nevada. Rail shipments terminating at this junction would continue to Yucca Mountain on heavy-haul trucks on one of the Caliente, Caliente/Chalk Mountain, or Caliente/Las Vegas routes. For branch rail line transportation, railcars would transfer via the Caliente Option to the Caliente Corridor at the Caliente junction.

c. For heavy-haul truck transportation, the Dry Lake junction is near the location of the proposed Apex/Dry Lake intermodal transfer station for heavy-haul trucks in southeast Nevada. Rail shipments terminating at this junction would continue to Yucca Mountain on heavy-haul trucks on the Apex/Dry Lake route.

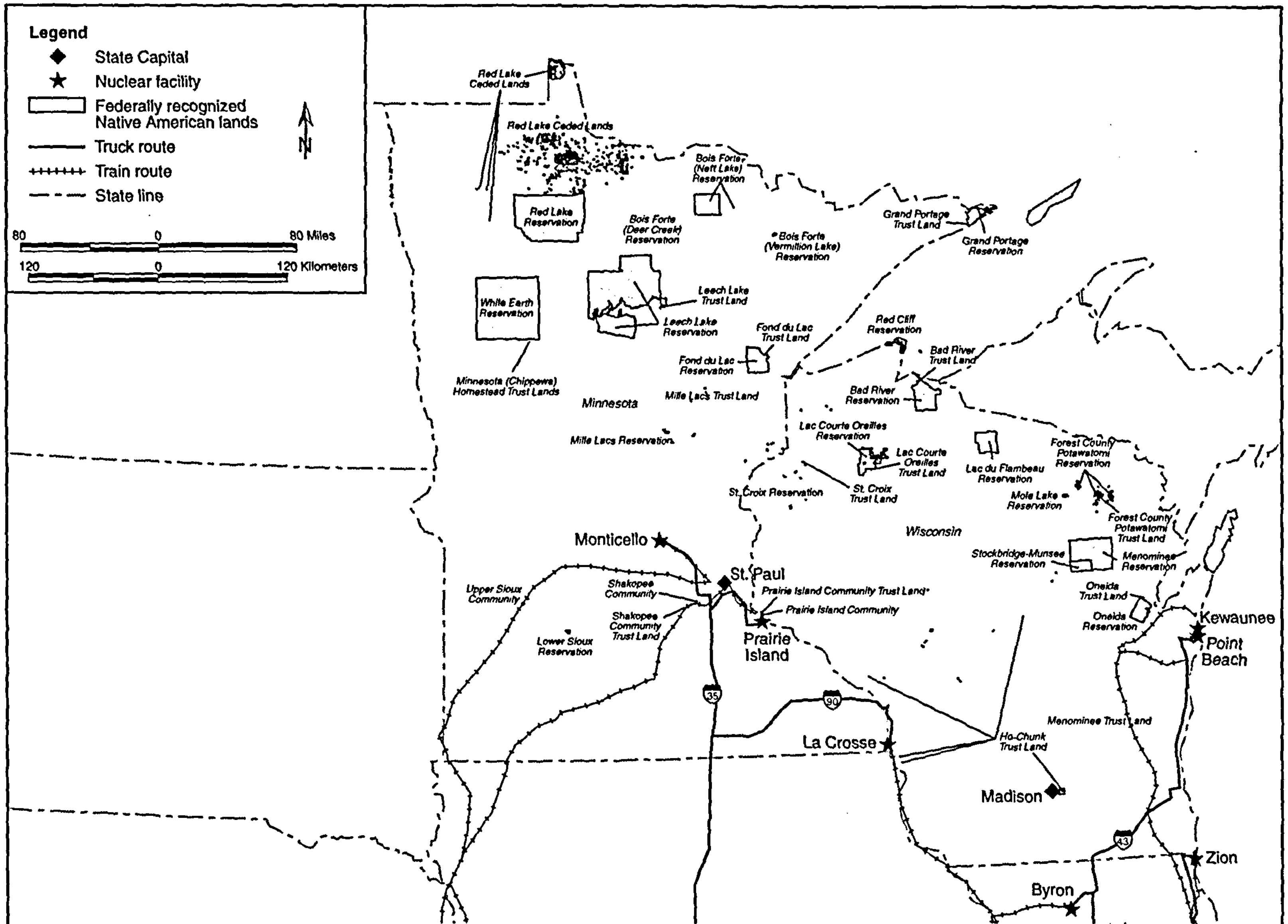
d. For heavy-haul truck transportation, the Jean junction is near the location of the proposed Sloan/Jean intermodal transfer station for heavy-haul trucks in southern Nevada. Rail shipments terminating at this junction would continue to Yucca Mountain on heavy-haul trucks on the Sloan/Jean route. For branch rail line transportation, railcars would transfer from the mainline railroad via the Wilson Pass or Stateline Pass Option of the Jean Corridor, near the Jean junction.

e. For branch rail line transportation, railcars would transfer from the mainline railroad at the Beowawe junction in north-central Nevada to the Carlin Corridor.

f. For branch rail line transportation, railcars would transfer from the mainline railroad at the Eccles junction east of Caliente, Nevada, via the Eccles Option or nearby via the Crestline Option of the Caliente or Caliente-Chalk Mountain Corridor. Impacts in states outside Nevada would be the same for the Eccles and Crestline Options of the Caliente and Caliente-Chalk Mountain Corridors.

g. For branch rail line transportation, railcars would transfer from the mainline railroad at the Apex junction in southeast Nevada, possibly via the Valley Connection, to the Valley Modified Corridor.

h. LCF = latent cancer fatality.



These routes represent the routes analyzed in Chapter 6 and might not be the routes actually used for shipments to the proposed repository at Yucca Mountain. Truck routes comply with U.S. Department of Transportation routing regulations. Rail routes are based on maximizing the distance on mainline track and minimizing the overall distance and number of interchanges between railroads.

Figure J-46. Highway and rail routes used to analyze transportation impacts - Minnesota and Wisconsin.

Table J-87. Estimated transportation impacts for the State of Missouri.

Impact category	Mostly legal-weight truck	Mostly rail						
		Ending rail node in Nevada[a]						
		Caliente[b]	Dry Lake[c]	Jean[d]	Beowawe[e]	Eccles[f]	Apex[g]
MISSOURI							
Shipments							
Truck (originating/total)	435/19,142	0/491	0/491	0/491	0/491	0/491	0/491
Rail (originating/total)	0/0	71/4,069	71/4,069	71/4,065	71/4,126	71/4,069	71/4,069
Radiological impacts							
Incident-free impacts							
Population (person-rem/LCFs)[h]	$3.5\times10^{2}/1.7\times10^{1}$	$8.2\times10^{1}/4.1\times10^{-2}$	$8.2\times10^{1}/4.1\times10^{-2}$	$7.8\times10^{1}/3.9\times10^{-2}$	$8.3\times10^{1}/4.2\times10^{-2}$	$8.2\times10^{1}/4.1\times10^{-2}$	$8.2\times10^{1}/4.1\times10^{-2}$
Workers (person-rem/LCFs)	$7.5\times10^{2}/3.0\times10^{1}$	$1.4\times10^{2}/5.5\times10^{-2}$	$1.4\times10^{2}/5.5\times10^{-2}$	$1.4\times10^{2}/5.5\times10^{-2}$	$1.4\times10^{2}/5.6\times10^{-2}$	$1.4\times10^{2}/5.5\times10^{-2}$	$1.4\times10^{2}/5.5\times10^{-2}$
Accident dose risk							
Population (person-rem/LCFs)	$4.8\times10^{-2}/2.4\times10^{-5}$	$1.8\times10^{-2}/8.8\times10^{-6}$	$1.8\times10^{-2}/8.8\times10^{-6}$	$1.6\times10^{-2}/7.9\times10^{-6}$	$1.8\times10^{-2}/8.9\times10^{-6}$	$1.8\times10^{-2}/8.8\times10^{-6}$	$1.8\times10^{-2}/8.8\times10^{-6}$
Nonradiological impacts							
Vehicle emissions (LCFs)	7.5×10^{-2}	3.8×10^{-2}	3.8×10^{-2}	3.6×10^{-2}	3.8×10^{-2}	3.8×10^{-2}	3.8×10^{-2}
Fatalities	0.28	0.086	0.086	0.085	0.086	0.086	0.086

a. Under the mostly rail scenario, rail shipments would arrive in Nevada at one of six existing rail nodes. Impacts would vary according to the node. From that node, DOE would use one of the rail or heavy-haul implementing alternatives to complete the transportation to Yucca Mountain (see Section J.1.2).

b. For heavy-haul truck transportation, the Caliente junction is the location of the proposed Caliente intermodal transfer station for heavy-haul trucks near the town of Caliente in eastern Nevada. Rail shipments terminating at this junction would continue to Yucca Mountain on heavy-haul trucks on one of the Caliente, Caliente/Chalk Mountain, or Caliente/Las Vegas routes. For branch rail line transportation, railcars would transfer via the Caliente Option to the Caliente Corridor at the Caliente junction.

c. For heavy-haul truck transportation, the Dry Lake junction is near the location of the proposed Apex/Dry Lake intermodal transfer station for heavy-haul trucks in southeast Nevada. Rail shipments terminating at this junction would continue to Yucca Mountain on heavy-haul trucks on the Apex/Dry Lake route.

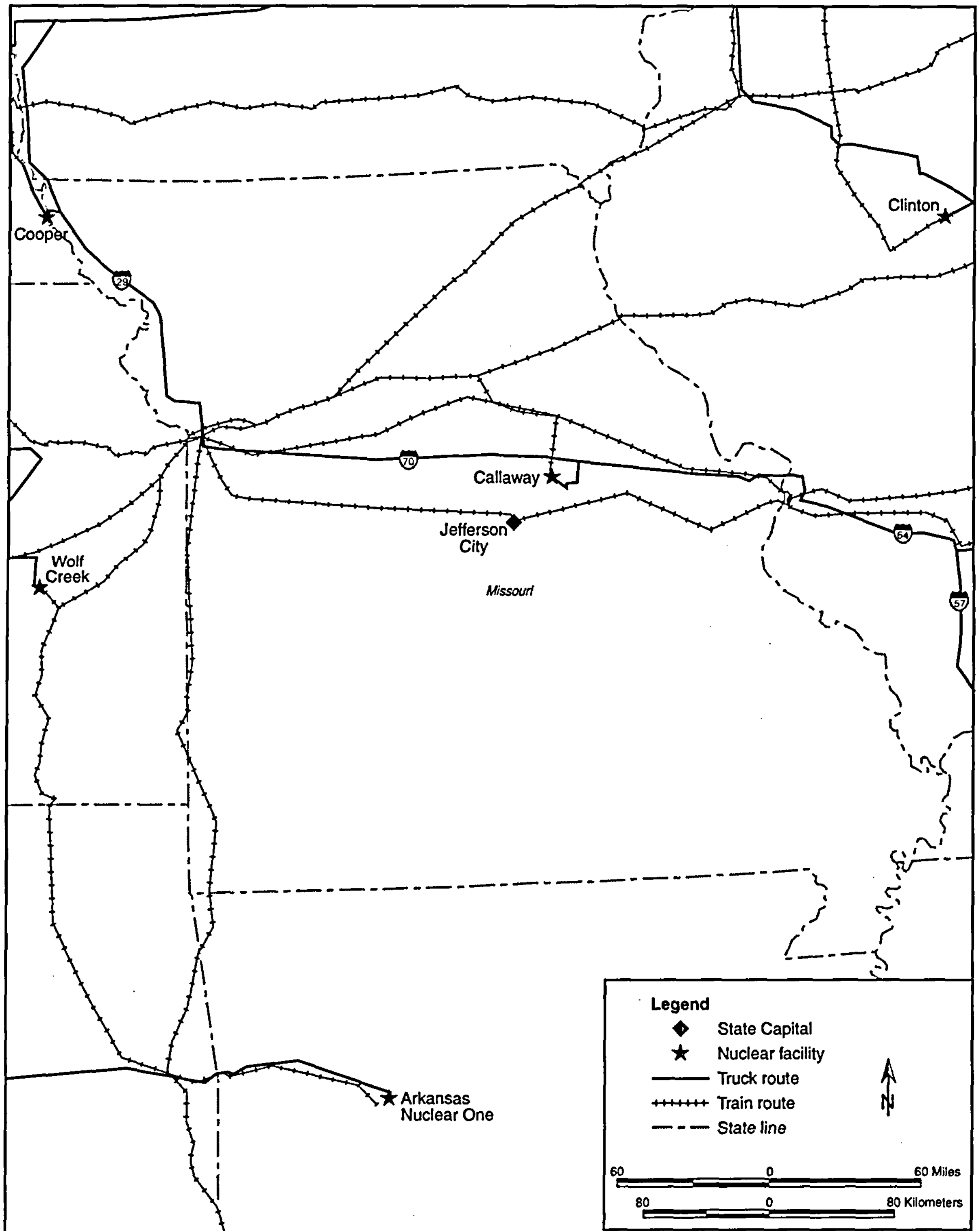
d. For heavy-haul truck transportation, the Jean junction is near the location of the proposed Sloan/Jean intermodal transfer station for heavy-haul trucks in southern Nevada. Rail shipments terminating at this junction would continue to Yucca Mountain on heavy-haul trucks on the Sloan/Jean route. For branch rail line transportation, railcars would transfer from the mainline railroad via the Wilson Pass or Stateline Pass Option of the Jean Corridor, near the Jean junction.

e. For branch rail line transportation, railcars would transfer from the mainline railroad at the Beowawe junction in north-central Nevada to the Carlin Corridor.

f. For branch rail line transportation, railcars would transfer from the mainline railroad at the Eccles junction east of Caliente, Nevada, via the Eccles Option or nearby via the Crestline Option of the Caliente or Caliente-Chalk Mountain Corridor. Impacts in states outside Nevada would be the same for the Eccles and Crestline Options of the Caliente and Caliente-Chalk Mountain Corridors.

g. For branch rail line transportation, railcars would transfer from the mainline railroad at the Apex junction in southeast Nevada, possibly via the Valley Connection, to the Valley Modified Corridor.

h. LCF = latent cancer fatality.



These routes represent the routes analyzed in Chapter 6 and might not be the routes actually used for shipments to the proposed repository at Yucca Mountain. Truck routes comply with U.S. Department of Transportation routing regulations. Rail routes are based on maximizing the distance on mainline track and minimizing the overall distance and number of interchanges between railroads.

Figure J-47. Highway and rail routes used to analyze transportation impacts - Missouri.

Table J-88. Estimated transportation impacts for the States of Montana, North Dakota, and South Dakota (page 1 of 2).

Impact category	Mostly legal-weight truck	Mostly rail					
		Ending rail node in Nevada[a]					
		Caliente[b]	Dry Lake[c]	Jean[d]	Beowawe[e]	Eccles[f]	Apex[g]
MONTANA							
Shipments							
Truck (originating/total)	0/0	0/0	0/0	0/0	0/0	0/0	0/0
Rail (originating/total)	0/0	0/0	0/0	0/0	0/0	0/0	0/0
Radiological impacts							
Incident-free impacts							
Population (person-rem/LCFs)[h]	0/0	0/0	0/0	0/0	0/0	0/0	0/0
Workers (person-rem/LCFs)	0/0	0/0	0/0	0/0	0/0	0/0	0/0
Accident dose risk							
Population (person-rem/LCFs)	0	0	0	0	0	0	0
Nonradiological impacts							
Vehicle emissions (LCFs)	0	0	0	0	0	0	0
Fatalities	0	0	0	0	0	0	0
NORTH DAKOTA							
Shipments							
Truck (originating/total)	0/0	0/0	0/0	0/0	0/0	0/0	0/0
Rail (originating/total)	0/0	0/0	0/0	0/0	0/0	0/0	0/0
Radiological impacts							
Incident-free impacts							
Population (person-rem/LCFs)[h]	0/0	0/0	0/0	0/0	0/0	0/0	0/0
Workers (person-rem/LCFs)	0/0	0/0	0/0	0/0	0/0	0/0	0/0
Accident dose risk							
Population (person-rem/LCFs)	0	0	0	0	0	0	0
Nonradiological impacts							
Vehicle emissions (LCFs)	0	0	0	0	0	0	0
Fatalities	0	0	0	0	0	0	0
SOUTH DAKOTA							
Shipments							
Truck (originating/total)	0/0	0/0	0/0	0/0	0/0	0/0	0/0
Rail (originating/total)	0/0	0/32	0/32	0/32	0/32	0/32	0/32
Radiological impacts							
Incident-free impacts							
Population (person-rem/LCFs)[h]	$0.0\times10^{0}/0.0\times10^{0}$	$1.8\times10^{-3}/9.0\times10^{-7}$	$1.8\times10^{-3}/9.0\times10^{-7}$	$1.8\times10^{-3}/9.0\times10^{-7}$	$1.8\times10^{-3}/9.0\times10^{-7}$	$1.8\times10^{-3}/9.0\times10^{-7}$	$1.8\times10^{-3}/9.0\times10^{-7}$
Workers (person-rem/LCFs)	$0.0\times10^{0}/0.0\times10^{0}$	$4.0\times10^{-2}/1.6\times10^{-5}$	$4.0\times10^{-2}/2.0\times10^{-5}$	$4.0\times10^{-2}/1.6\times10^{-5}$	$4.0\times10^{-2}/1.6\times10^{-5}$	$4.0\times10^{-2}1.6\times10^{-5}$	$4.0\times10^{-2}/1.6\times10^{-5}$
Accident dose risk							
Population (person-rem/LCFs)	$0.0\times10^{0}/0.0\times10^{0}$	$7.3\times10^{-6}/3.7\times10^{-9}$	$7.3\times10^{-6}/3.7\times10^{-9}$	$7.3\times10^{-6}/3.7\times10^{-9}$	$7.3\times10^{-6}/3.7\times10^{-9}$	$7.3\times10^{-6}/3.7\times10^{-9}$	$7.3\times10^{-6}/3.7\times10^{-9}$
Nonradiological impacts							
Vehicle emissions (LCFs)	0.00×10^{0}	1.04×10^{-6}	1.04×10^{-6}	1.04×10^{-6}	1.04×10^{-6}	1.04×10^{-6}	1.04×10^{-6}
Fatalities	0.0×10^{0}	2.1×10^{-5}	2.1×10^{-5}	2.1×10^{-5}	2.1×10^{-5}	2.1×10^{-5}	2.1×10^{-5}

a. Under the mostly rail scenario, rail shipments would arrive in Nevada at one of six existing rail nodes. Impacts would vary according to the node. From that node, DOE would use one of the rail or heavy-haul implementing alternatives to complete the transportation to Yucca Mountain (see Section J.1.2).

b. For heavy-haul truck transportation, the Caliente junction is the location of the proposed Caliente intermodal transfer station for heavy-haul trucks near the town of Caliente in eastern Nevada. Rail shipments terminating at this junction would continue to Yucca Mountain on heavy-haul trucks on one of the Caliente, Caliente/Chalk Mountain, or Caliente/Las Vegas routes. For branch rail line transportation, railcars would transfer via the Caliente Option to the Caliente Corridor at the Caliente junction.

Table J-88. Estimated transportation impacts for the States of Montana, North Dakota, and South Dakota (page 2 of 2).

c. For heavy-haul truck transportation, the Dry Lake junction is near the location of the proposed Apex/Dry Lake intermodal transfer station for heavy-haul trucks in southeast Nevada. Rail shipments terminating at this junction would continue to Yucca Mountain on heavy-haul trucks on the Apex/Dry Lake route.

d. For heavy-haul truck transportation, the Jean junction is near the location of the proposed Sloan/Jean intermodal transfer station for heavy-haul trucks in southern Nevada. Rail shipments terminating at this junction would continue to Yucca Mountain on heavy-haul trucks on the Sloan/Jean route. For branch rail line transportation, railcars would transfer from the mainline railroad via the Wilson Pass or Stateline Pass Option of the Jean Corridor, near the Jean junction.

e. For branch rail line transportation, railcars would transfer from the mainline railroad at the Beowawe junction in north-central Nevada to the Carlin Corridor.

f. For branch rail line transportation, railcars would transfer from the mainline railroad at the Eccles junction east of Caliente, Nevada, via the Eccles Option or nearby via the Crestline Option of the Caliente or Caliente-Chalk Mountain Corridor. Impacts in states outside Nevada would be the same for the Eccles and Crestline Options of the Caliente and Caliente-Chalk Mountain Corridors.

g. For branch rail line transportation, railcars would transfer from the mainline railroad at the Apex junction in southeast Nevada, possibly via the Valley Connection, to the Valley Modified Corridor.

h. LCF = latent cancer fatality.

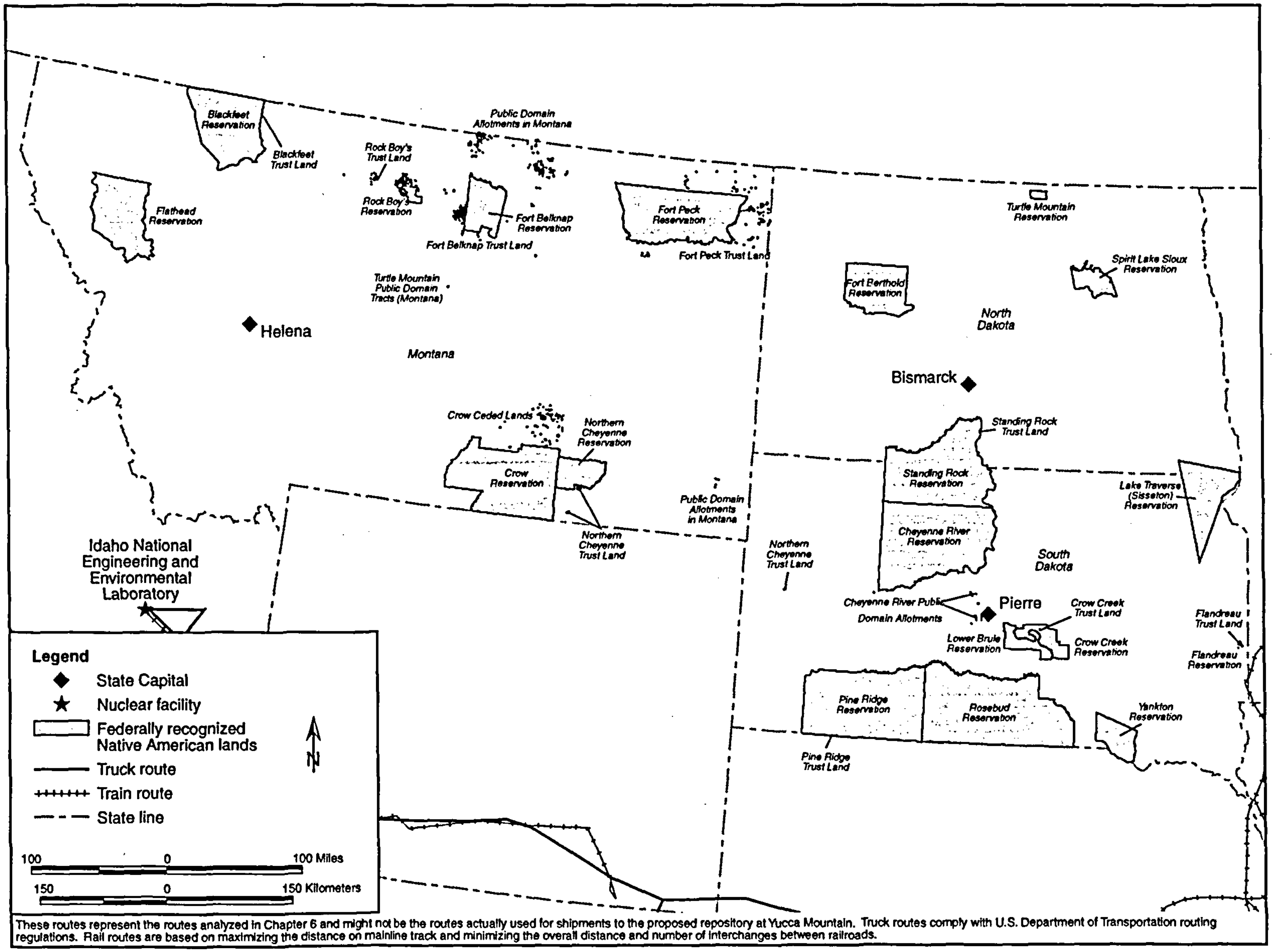


Figure J-48. Highway and rail routes used to analyze transportation impacts - Montana, North Dakota, and South Dakota.

Table J-89. Estimated transportation impacts for the States of New Jersey and Pennsylvania.

Impact category	Mostly legal-weight truck	Mostly rail: Ending rail node in Nevada[a] — Caliente[b]	Dry Lake[c]	Jean[d]	Beowawe[e]	Eccles[f]	Apex[g]
NEW JERSEY							
Shipments							
Truck (originating/total)	1,528/3,245	0/335	0/335	0/335	0/335	0/335	0/335
Rail (originating/total)	0/0	244/244	244/244	244/244	244/244	244/244	244/244
Radiological impacts							
Incident-free impacts							
Population (person-rem/LCFs)[h]	$1.2\times10^{1}/6.1\times10^{-3}$	$1.0\times10^{1}/5.1\times10^{-3}$	$1.0\times10^{1}/5.1\times10^{-3}$	$1.0\times10^{1}/5.1\times10^{-3}$	$1.0\times10^{1}/5.1\times10^{-3}$	$1.0\times10^{1}/5.1\times10^{-3}$	$1.0\times10^{1}/5.1\times10^{-3}$
Workers (person-rem/LCFs)	$4.6\times10^{1}/1.8\times10^{-2}$	$1.7\times10^{1}/6.9\times10^{-3}$	$1.7\times10^{1}/6.9\times10^{-3}$	$1.7\times10^{1}/6.9\times10^{-3}$	$1.7\times10^{1}/6.9\times10^{-3}$	$1.7\times10^{1}/6.9\times10^{-3}$	$1.7\times10^{1}/6.9\times10^{-3}$
Accident dose risk							
Population (person-rem/LCFs)	$2.9\times10^{-3}/1.5\times10^{-6}$	$1.3\times10^{-2}/6.7\times10^{-6}$	$1.3\times10^{-2}/6.7\times10^{-6}$	$1.3\times10^{-2}/6.7\times10^{-6}$	$1.3\times10^{-2}/6.7\times10^{-6}$	$1.3\times10^{-2}/6.7\times10^{-6}$	$1.3\times10^{-2}/6.7\times10^{-6}$
Nonradiological impacts							
Vehicle emissions (LCFs)	3.3×10^{-3}	3.4×10^{-3}	3.4×10^{-3}	3.4×10^{-3}	3.4×10^{-3}	3.4×10^{-3}	3.4×10^{-3}
Fatalities	0.007	0.022	0.022	0.022	0.022	0.022	0.022
PENNSYLVANIA							
Shipments							
Truck (originating/total)	3,803/11,485	0/580	0/580	0/580	0/580	0/580	0/580
Rail (originating/total)	0/0	661/2,078	661/2,078	661/2,078	661/2,078	661/2,078	661/2,078
Radiological impacts							
Incident-free impacts							
Population (person-rem/LCFs)[h]	$1.0\times10^{2}/5.1\times10^{-2}$	$6.9\times10^{1}/3.4\times10^{-2}$	$6.9\times10^{1}/3.4\times10^{-2}$	$6.9\times10^{1}/3.4\times10^{-2}$	$6.9\times10^{1}/3.4\times10^{-2}$	$6.9\times10^{1}/3.4\times10^{-2}$	$6.9\times10^{1}/3.4\times10^{-2}$
Workers (person-rem/LCFs)	$3.1\times10^{2}/1.2\times10^{-1}$	$9.4\times10^{1}/3.8\times10^{-2}$	$9.4\times10^{1}/3.8\times10^{-2}$	$9.4\times10^{1}/3.8\times10^{-2}$	$9.4\times10^{1}/3.8\times10^{-2}$	$9.4\times10^{1}/3.8\times10^{-2}$	$9.4\times10^{1}/3.8\times10^{-2}$
Accident dose risk							
Population (person-rem/LCFs)	$1.0\times10^{-2}/5.1\times10^{-6}$	$5.5\times10^{-2}/2.7\times10^{-5}$	$5.5\times10^{-2}/2.7\times10^{-5}$	$5.5\times10^{-2}/2.7\times10^{-5}$	$5.5\times10^{-2}/2.7\times10^{-5}$	$5.5\times10^{-2}/2.7\times10^{-5}$	$5.5\times10^{-2}/2.7\times10^{-5}$
Nonradiological impacts							
Vehicle emissions (LCFs)	1.3×10^{-2}	2.9×10^{-2}	2.9×10^{-2}	2.9×10^{-2}	2.9×10^{-2}	2.9×10^{-2}	2.9×10^{-2}
Fatalities	0.099	0.066	0.066	0.066	0.066	0.066	0.066

a. Under the mostly rail scenario, rail shipments would arrive in Nevada at one of six existing rail nodes. Impacts would vary according to the node. From that node, DOE would use one of the rail or heavy-haul implementing alternatives to complete the transportation to Yucca Mountain (see Section J.1.2).

b. For heavy-haul truck transportation, the Caliente junction is the location of the proposed Caliente intermodal transfer station for heavy-haul trucks near the town of Caliente in eastern Nevada. Rail shipments terminating at this junction would continue to Yucca Mountain on heavy-haul trucks on one of the Caliente, Caliente/Chalk Mountain, or Caliente/Las Vegas routes. For branch rail line transportation, railcars would transfer via the Caliente Option to the Caliente Corridor at the Caliente junction.

c. For heavy-haul truck transportation, the Dry Lake junction is near the location of the proposed Apex/Dry Lake intermodal transfer station for heavy-haul trucks in southeast Nevada. Rail shipments terminating at this junction would continue to Yucca Mountain on heavy-haul trucks on the Apex/Dry Lake route.

d. For heavy-haul truck transportation, the Jean junction is near the location of the proposed Sloan/Jean intermodal transfer station for heavy-haul trucks in southern Nevada. Rail shipments terminating at this junction would continue to Yucca Mountain on heavy-haul trucks on the Sloan/Jean route. For branch rail line transportation, railcars would transfer from the mainline railroad via the Wilson Pass or Stateline Pass Option of the Jean Corridor, near the Jean junction.

e. For branch rail line transportation, railcars would transfer from the mainline railroad at the Beowawe junction in north-central Nevada to the Carlin Corridor.

f. For branch rail line transportation, railcars would transfer from the mainline railroad at the Eccles junction east of Caliente, Nevada, via the Eccles Option or nearby via the Crestline Option of the Caliente or Caliente-Chalk Mountain Corridor. Impacts in states outside Nevada would be the same for the Eccles and Crestline Options of the Caliente and Caliente-Chalk Mountain Corridors.

g. For branch rail line transportation, railcars would transfer from the mainline railroad at the Apex junction in southeast Nevada, possibly via the Valley Connection, to the Valley Modified Corridor.

h. LCF = latent cancer fatality.

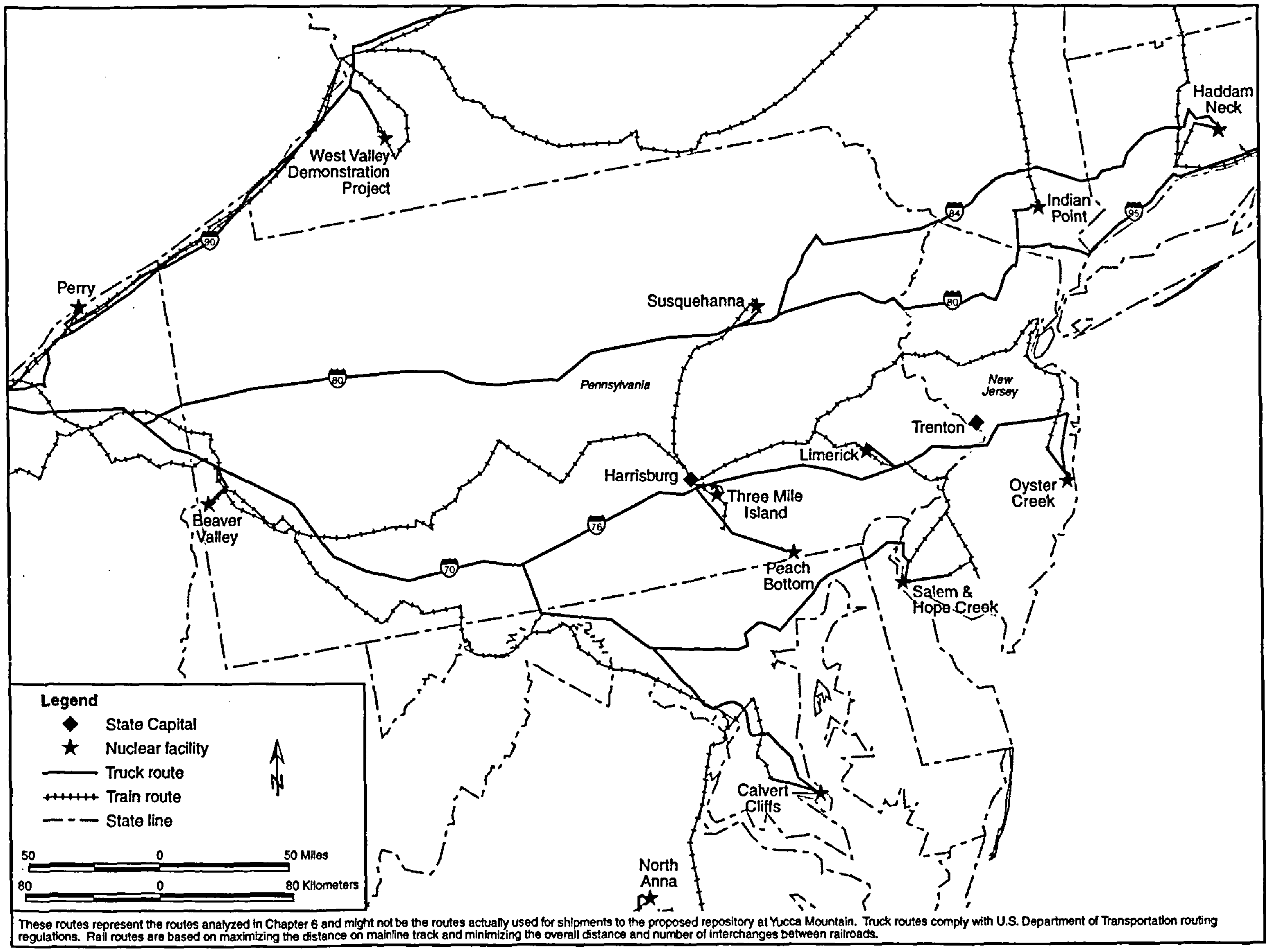


Figure J-49. Highway and rail routes used to analyze transportation impacts - New Jersey and Pennsylvania.

Table J-90. Estimated transportation impacts for the States of North Carolina and South Carolina.

Impact category	Mostly legal-weight truck	Mostly rail: Ending rail node in Nevada[a] Caliente[b]	Dry Lake[c]	Jean[d]	Beowawe[e]	Eccles[f]	Apex[g]
NORTH CAROLINA							
Shipments							
Truck (originating/total)	1,871/2,508	0/0	0/0	0/0	0/0	0/0	0/0
Rail (originating/total)	0/0	486/943	486/943	486/943	486/943	486/943	486/943
Radiological impacts							
Incident-free impacts							
Population (person-rem/LCFs)[h]	$2.7\times10^{1}/1.4\times10^{-2}$	$1.1\times10^{1}/5.7\times10^{-3}$	$1.1\times10^{1}/5.7\times10^{-3}$	$1.1\times10^{1}/5.7\times10^{-3}$	$1.1\times10^{1}/5.7\times10^{-3}$	$1.1\times10^{1}/5.7\times10^{-3}$	$1.1\times10^{1}/5.7\times10^{-3}$
Workers (person-rem/LCFs)	$8.4\times10^{1}/3.4\times10^{-2}$	$3.4\times10^{1}/1.4\times10^{-2}$	$3.4\times10^{1}/1.4\times10^{-2}$	$3.4\times10^{1}/1.4\times10^{-2}$	$3.4\times10^{1}/1.4\times10^{-2}$	$3.4\times10^{1}/1.4\times10^{-2}$	$3.4\times10^{1}/1.4\times10^{-2}$
Accident dose risk							
Population (person-rem/LCFs)	$3.5\times10^{-3}/1.7\times10^{-6}$	$4.2\times10^{-3}/2.1\times10^{-6}$	$4.2\times10^{-3}/2.1\times10^{-6}$	$4.2\times10^{-3}/2.1\times10^{-6}$	$4.2\times10^{-3}/2.1\times10^{-6}$	$4.2\times10^{-3}/2.1\times10^{-6}$	$4.2\times10^{-3}/2.1\times10^{-6}$
Nonradiological impacts							
Vehicle emissions (LCFs)	6.3×10^{-3}	4.1×10^{-3}	4.1×10^{-3}	4.1×10^{-3}	4.1×10^{-3}	4.1×10^{-3}	4.1×10^{-3}
Fatalities	0.023	0.052	0.052	0.052	0.052	0.052	0.052
SOUTH CAROLINA							
Shipments							
Truck (originating/total)	9,832/9,832	0/0	0/0	0/0	0/0	0/0	0/0
Rail (originating/total)	0/0	1,899/2,385	1,899/2,385	1,899/2,385	1,899/2,385	1,899/2,385	1,899/2,385
Radiological impacts							
Incident-free impacts							
Population (person-rem/LCFs)[h]	$1.3\times10^{1}/6.5\times10^{-3}$	$1.8\times10^{1}/8.9\times10^{-3}$	$1.8\times10^{1}/8.9\times10^{-3}$	$1.8\times10^{1}/8.9\times10^{-3}$	$1.8\times10^{1}/8.9\times10^{-3}$	$1.8\times10^{1}/8.9\times10^{-3}$	$1.8\times10^{1}/8.9\times10^{-3}$
Workers (person-rem/LCFs)	$2.1\times10^{2}/8.4\times10^{-2}$	$1.1\times10^{2}/4.3\times10^{-2}$	$1.1\times10^{2}/4.3\times10^{-2}$	$1.1\times10^{2}/4.3\times10^{-2}$	$1.1\times10^{2}/4.3\times10^{-2}$	$1.1\times10^{2}/4.3\times10^{-2}$	$1.1\times10^{2}/4.3\times10^{-2}$
Accident dose risk							
Population (person-rem/LCFs)	$1.1\times10^{-3}/5.4\times10^{-7}$	$4.6\times10^{-3}/2.3\times10^{-6}$	$4.6\times10^{-3}/2.3\times10^{-6}$	$4.6\times10^{-3}/2.3\times10^{-6}$	$4.6\times10^{-3}/2.3\times10^{-6}$	$4.6\times10^{-3}/2.3\times10^{-6}$	$4.6\times10^{-3}/2.3\times10^{-6}$
Nonradiological impacts							
Vehicle emissions (LCFs)	1.4×10^{-3}	4.3×10^{-3}	4.3×10^{-3}	4.3×10^{-3}	4.3×10^{-3}	4.3×10^{-3}	4.3×10^{-3}
Fatalities	0.03	0.08	0.08	0.08	0.08	0.08	0.08

a. Under the mostly rail scenario, rail shipments would arrive in Nevada at one of six existing rail nodes. Impacts would vary according to the node. From that node, DOE would use one of the rail or heavy-haul implementing alternatives to complete the transportation to Yucca Mountain (see Section J.1.2).

b. For heavy-haul truck transportation, the Caliente junction is the location of the proposed Caliente intermodal transfer station for heavy-haul trucks near the town of Caliente in eastern Nevada. Rail shipments terminating at this junction would continue to Yucca Mountain on heavy-haul trucks on one of the Caliente, Caliente/Chalk Mountain, or Caliente/Las Vegas routes. For branch rail line transportation, railcars would transfer via the Caliente Option to the Caliente Corridor at the Caliente junction.

c. For heavy-haul truck transportation, the Dry Lake junction is near the location of the proposed Apex/Dry Lake intermodal transfer station for heavy-haul trucks in southeast Nevada. Rail shipments terminating at this junction would continue to Yucca Mountain on heavy-haul trucks on the Apex/Dry Lake route.

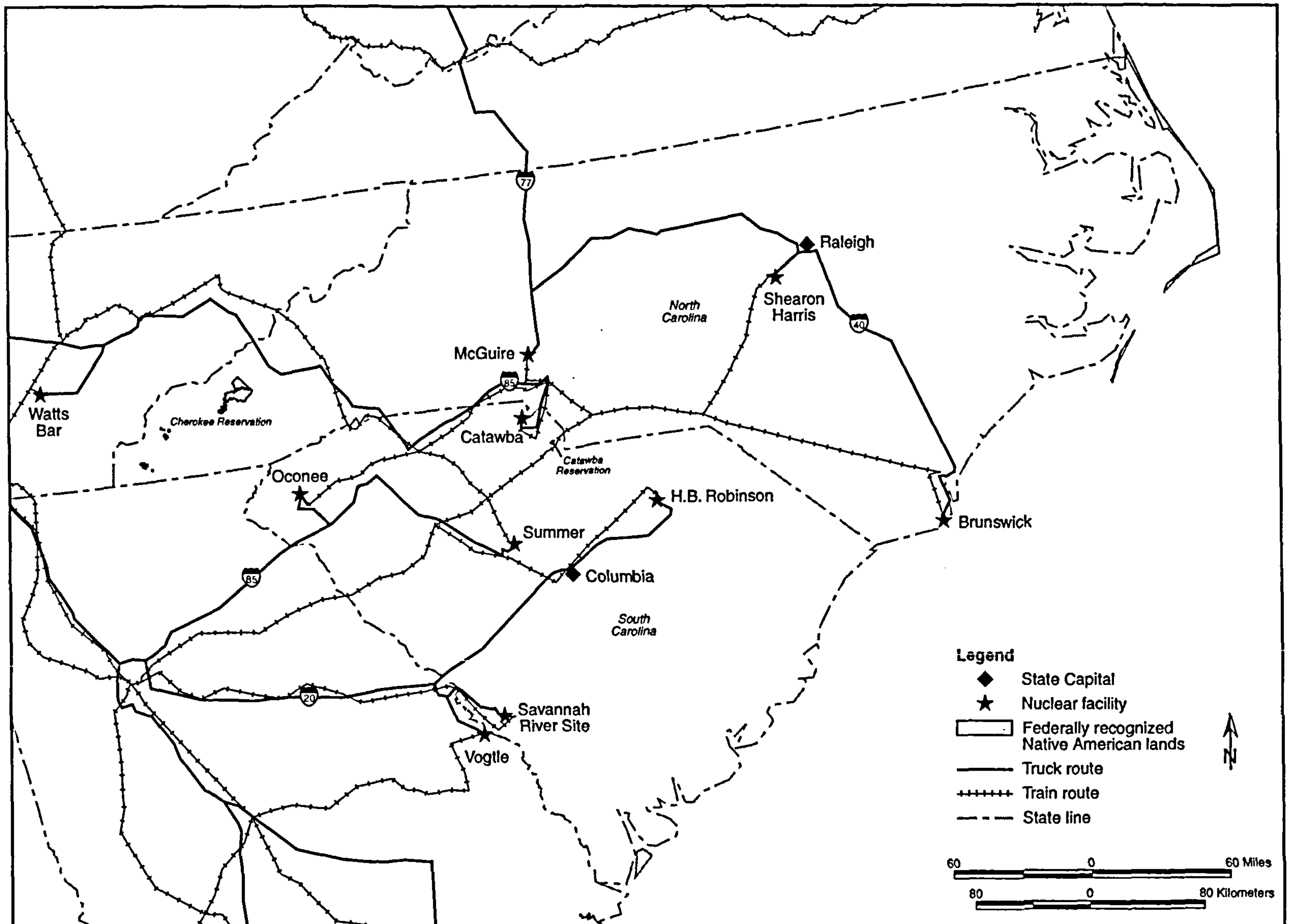
d. For heavy-haul truck transportation, the Jean junction is near the location of the proposed Sloan/Jean intermodal transfer station for heavy-haul trucks in southern Nevada. Rail shipments terminating at this junction would continue to Yucca Mountain on heavy-haul trucks on the Sloan/Jean route. For branch rail line transportation, railcars would transfer from the mainline railroad via the Wilson Pass or Stateline Pass Option of the Jean Corridor, near the Jean junction.

e. For branch rail line transportation, railcars would transfer from the mainline railroad at the Beowawe junction in north-central Nevada to the Carlin Corridor.

f. For branch rail line transportation, railcars would transfer from the mainline railroad at the Eccles junction east of Caliente, Nevada, via the Eccles Option or nearby via the Crestline Option of the Caliente or Caliente-Chalk Mountain Corridor. Impacts in states outside Nevada would be the same for the Eccles and Crestline Options of the Caliente and Caliente-Chalk Mountain Corridors.

g. For branch rail line transportation, railcars would transfer from the mainline railroad at the Apex junction in southeast Nevada, possibly via the Valley Connection, to the Valley Modified Corridor.

h. LCF = latent cancer fatality.



These routes represent the routes analyzed in Chapter 6 and might not be the routes actually used for shipments to the proposed repository at Yucca Mountain. Truck routes comply with U.S. Department of Transportation routing regulations. Rail routes are based on maximizing the distance on mainline track and minimizing the overall distance and number of interchanges between railroads.

Figure J-50. Highway and rail routes used to analyze transportation impacts - North Carolina and South Carolina.

Table J-91. Estimated transportation impacts for the States of Oklahoma and Texas.

Impact category	Mostly legal-weight truck	Mostly rail: Ending rail node in Nevada[a]					
		Caliente[b]	Dry Lake[c]	Jean[d]	Beowawe[e]	Eccles[f]	Apex[g]
OKLAHOMA							
Shipments							
Truck (originating/total)	0/3,471	0/0	0/0	0/0	0/0	0/0	0/0
Rail (originating/total)	0/0	0/412	0/355	0/399	0/439	0/478	0/201
Radiological impacts							
Incident-free impacts							
Population (person-rem/LCFs)[h]	$4.1\times10^{1}/2.0\times10^{-2}$	$4.1\times10^{-1}/2.0\times10^{-4}$	$4.1\times10^{-1}/2.0\times10^{-4}$	$3.3\times10^{-1}/1.6\times10^{-4}$	$5.2\times10^{-1}2.6\times10^{-4}$	$4.0\times10^{-1}/2.0\times10^{-4}$	$4.0\times10^{-1}/2.0\times10^{-4}$
Workers (person-rem/LCFs)	$1.1\times10^{2}/4.2\times10^{-2}$	$3.9\times10^{0}/1.5\times10^{-3}$	$3.6\times10^{0}/1.4\times10^{-3}$	$5.3\times10^{0}/2.1\times10^{-3}$	$4.5\times10^{0}/1.8\times10^{-3}$	$3.0\times10^{0}/1.7\times10^{-3}$	$3.0\times10^{0}/1.2\times10^{-3}$
Accident dose risk							
Population (person-rem/LCFs)	$2.6\times10^{-3}/1.3\times10^{-6}$	$3.4\times10^{-4}/1.7\times10^{-7}$	$3.4\times10^{-4}/1.7\times10^{-7}$	$3.1\times10^{-4}/1.6\times10^{-7}$	$4.2\times10^{-4}/2.1\times10^{-7}$	$3.5\times10^{-4}/1.7\times10^{-7}$	$3.3\times10^{-4}/1.6\times10^{-7}$
Nonradiological impacts							
Vehicle emissions (LCFs)	6.4×10^{-3}	2.3×10^{-4}	2.3×10^{-4}	1.8×10^{-4}	2.9×10^{-4}	2.3×10^{-4}	2.3×10^{-4}
Fatalities	0.043	0.005	0.005	0.007	0.006	0.006	0.004
TEXAS							
Shipments							
Truck (originating/total)	1,193/3,999	0/0	0/0	0/0	0/0	0/0	0/0
Rail (originating/total)	0/0	269/472	269/472	269/952	269/472	269/472	269/472
Radiological impacts							
Incident-free impacts							
Population (person-rem/LCFs)[h]	$7.9\times10^{1}/4.0\times10^{-2}$	$1.8\times10^{1}/9.1\times10^{-3}$	$1.9\times10^{1}/9.3\times10^{-3}$	$4.1\times10^{1}/2.0\times10^{-2}$	$1.9\times10^{1}/9.6\times10^{-3}$	$1.8\times10^{1}/9.0\times10^{-3}$	$2.1\times10^{1}/1.0\times10^{-2}$
Workers (person-rem/LCFs)	$1.9\times10^{2}/7.6\times10^{-2}$	$4.4\times10^{1}/1.8\times10^{-2}$	$4.5\times10^{1}/1.8\times10^{-2}$	$8.2\times10^{1}/3.3\times10^{-2}$	$3.9\times10^{1}/1.5\times10^{-2}$	$4.3\times10^{1}/1.7\times10^{-2}$	$4.8\times10^{1}/1.9\times10^{-2}$
Accident dose risk							
Population (person-rem/LCFs)	$1.7\times10^{-2}/8.6\times10^{-6}$	$7.0\times10^{-3}/3.5\times10^{-6}$	$7.3\times10^{-3}/3.7\times10^{-6}$	$2.0\times10^{-2}/9.9\times10^{-6}$	$7.2\times10^{-3}/3.6\times10^{-6}$	$7.1\times10^{-3}/3.5\times10^{-6}$	$8.1\times10^{-3}/4.0\times10^{-6}$
Nonradiological impacts							
Vehicle emissions (LCFs)	1.96×10^{-2}	7.47×10^{-3}	7.77×10^{-3}	1.87×10^{-2}	8.10×10^{-3}	7.60×10^{-3}	8.84×10^{-3}
Fatalities	0.07	0.05	0.05	0.14	0.04	0.05	0.05

a. Under the mostly rail scenario, rail shipments would arrive in Nevada at one of six existing rail nodes. Impacts would vary according to the node. From that node, DOE would use one of the rail or heavy-haul implementing alternatives to complete the transportation to Yucca Mountain (see Section J.1.2).

b. For heavy-haul truck transportation, the Caliente junction is the location of the proposed Caliente intermodal transfer station for heavy-haul trucks near the town of Caliente in eastern Nevada. Rail shipments terminating at this junction would continue to Yucca Mountain on heavy-haul trucks on one of the Caliente, Caliente/Chalk Mountain, or Caliente/Las Vegas routes. For branch rail line transportation, railcars would transfer via the Caliente Option to the Caliente Corridor at the Caliente junction.

c. For heavy-haul truck transportation, the Dry Lake junction is near the location of the proposed Apex/Dry Lake intermodal transfer station for heavy-haul trucks in southeast Nevada. Rail shipments terminating at this junction would continue to Yucca Mountain on heavy-haul trucks on the Apex/Dry Lake route.

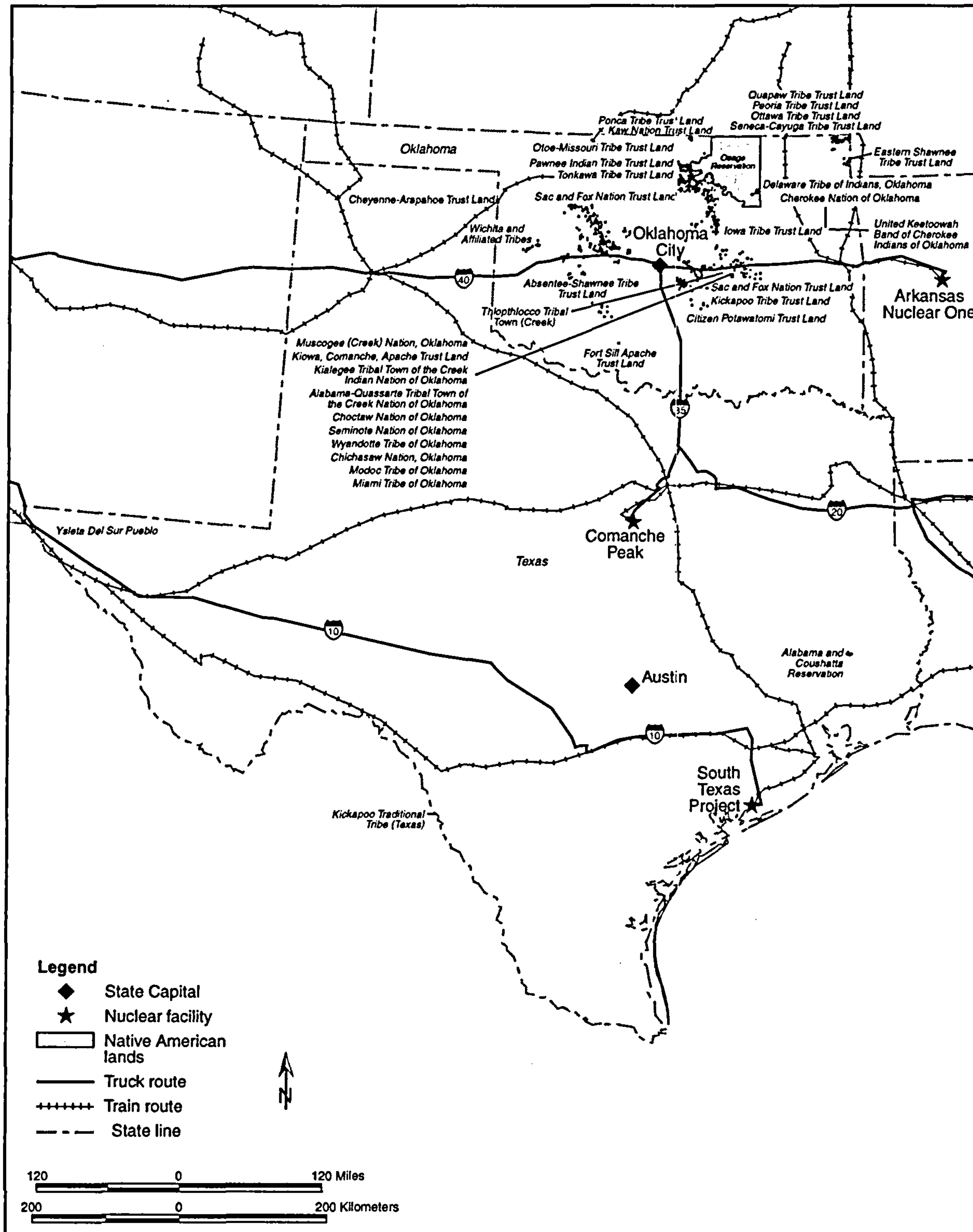
d. For heavy-haul truck transportation, the Jean junction is near the location of the proposed Sloan/Jean intermodal transfer station for heavy-haul trucks in southern Nevada. Rail shipments terminating at this junction would continue to Yucca Mountain on heavy-haul trucks on the Sloan/Jean route. For branch rail line transportation, railcars would transfer from the mainline railroad via the Wilson Pass or Stateline Pass Option of the Jean Corridor, near the Jean junction.

e. For branch rail line transportation, railcars would transfer from the mainline railroad at the Beowawe junction in north-central Nevada to the Carlin Corridor.

f. For branch rail line transportation, railcars would transfer from the mainline railroad at the Eccles junction east of Caliente, Nevada, via the Eccles Option or nearby via the Crestline Option of the Caliente or Caliente-Chalk Mountain Corridor. Impacts in states outside Nevada would be the same for the Eccles and Crestline Options of the Caliente and Caliente-Chalk Mountain Corridors.

g. For branch rail line transportation, railcars would transfer from the mainline railroad at the Apex junction in southeast Nevada, possibly via the Valley Connection, to the Valley Modified Corridor.

h. LCF = latent cancer fatality.



These routes represent the routes analyzed in Chapter 6 and might not be the routes actually used for shipments to the proposed repository at Yucca Mountain. Truck routes comply with U.S. Department of Transportation routing regulations. Rail routes are based on maximizing the distance on mainline track and minimizing the overall distance and number of interchanges between railroads.

Figure J-51. Highway and rail routes used to analyze transportation impacts - Oklahoma and Texas.

Table J-92. Estimated transportation impacts for the States of Utah and Wyoming.

Impact category	Mostly legal-weight truck	Mostly rail: Ending rail node in Nevada[a]					
		Caliente[b]	Dry Lake[c]	Jean[d]	Beowawe[e]	Eccles[f]	Apex[g]
UTAH							
Shipments							
Truck (originating/total)	0/45,919	0/1,079	0/1,079	0/1,079	0/1,079	0/1,079	0/1,079
Rail (originating/total)	0/300	0/8,986	0/8,896	0/8,182	0/9,134	0/9,052	0/8,742
Radiological impacts							
Incident-free impacts							
Population (person-rem/LCFs)[h]	$9.6\times10^{2}/4.8\times10^{-1}$	$1.8\times10^{2}/8.8\times10^{-2}$	$1.8\times10^{2}/8.8\times10^{-2}$	$1.1\times10^{3}/5.6\times10^{-1}$	$1.8\times10^{2}/8.8\times10^{-2}$	$1.8\times10^{2}/8.8\times10^{-2}$	$1.7\times10^{2}/8.6\times10^{-2}$
Workers (person-rem/LCFs)	$1.9\times10^{3}/7.4\times10^{-1}$	$3.6\times10^{2}/1.4\times10^{-1}$	$3.6\times10^{2}/1.4\times10^{-1}$	$2.2\times10^{3}/8.8\times10^{-1}$	$3.6\times10^{2}/1.4\times10^{-1}$	$3.6\times10^{2}/1.4\times10^{-1}$	$3.6\times10^{2}/1.4\times10^{-1}$
Accident dose risk							
Population (person-rem/LCFs)	$1.0\times10^{-1}/5.2\times10^{-5}$	$7.2\times10^{-2}/3.6\times10^{-5}$	$7.2\times10^{-2}/3.6\times10^{-5}$	$1.8\times10^{-1}/8.8\times10^{-5}$	$7.2\times10^{-2}/3.6\times10^{-5}$	$7.2\times10^{-2}/3.6\times10^{-5}$	$7.2\times10^{-2}/3.6\times10^{-5}$
Nonradiological impacts							
Vehicle emissions (LCFs)	2.8×10^{-1}	8.7×10^{-2}	8.7×10^{-2}	3.6×10^{-1}	8.7×10^{-2}	8.7×10^{-2}	8.4×10^{-2}
Fatalities	0.71	0.58	0.58	1.25	0.58	0.58	0.57
WYOMING							
Shipments							
Truck (originating/total)	0/41,507	0/1,079	0/1,079	0/1,079	0/1,079	0/1,079	0/1,079
Rail (originating/total)	0/0	0/7,347	0/7,347	0/7,065	0/7,440	0/7,347	0/7,347
Radiological impacts							
Incident-free impacts							
Population (person-rem/LCFs)[h]	$5.4\times10^{2}/2.7\times10^{-1}$	$4.4\times10^{1}/2.2\times10^{-2}$	$4.4\times10^{1}/2.2\times10^{-2}$	$4.3\times10^{1}/2.1\times10^{-2}$	$4.4\times10^{1}/2.2\times10^{-2}$	$4.4\times10^{1}/2.2\times10^{-2}$	$4.4\times10^{1}/2.2\times10^{-2}$
Workers (person-rem/LCFs)	$1.7\times10^{3}/6.9\times10^{-1}$	$3.8\times10^{2}/1.5\times10^{-1}$	$3.8\times10^{2}/1.5\times10^{-1}$	$3.7\times10^{2}/1.5\times10^{-1}$	$3.8\times10^{2}/1.5\times10^{-1}$	$3.8\times10^{2}/1.5\times10^{-1}$	$3.8\times10^{2}/1.5\times10^{-1}$
Accident dose risk							
Population (person-rem/LCFs)	$3.9\times10^{-2}/1.9\times10^{-5}$	$7.1\times10^{-3}/3.6\times10^{-6}$	$7.1\times10^{-3}/3.6\times10^{-6}$	$6.8\times10^{-3}/3.4\times10^{-6}$	$7.2\times10^{-3}/3.6\times10^{-6}$	$7.1\times10^{-3}/3.6\times10^{-6}$	$7.1\times10^{-3}/3.6\times10^{-6}$
Nonradiological impacts							
Vehicle emissions (LCFs)	38.7×10^{-3}	15.9×10^{-3}	15.9×10^{-3}	15.4×10^{-3}	16.1×10^{-3}	15.9×10^{-3}	15.9×10^{-3}
Fatalities	0.58	0.06	0.06	0.06	0.06	0.06	0.06

a. Under the mostly rail scenario, rail shipments would arrive in Nevada at one of six existing rail nodes. Impacts would vary according to the node. From that node, DOE would use one of the rail or heavy-haul implementing alternatives to complete the transportation to Yucca Mountain (see Section J.1.2).

b. For heavy-haul truck transportation, the Caliente junction is the location of the proposed Caliente intermodal transfer station for heavy-haul trucks near the town of Caliente in eastern Nevada. Rail shipments terminating at this junction would continue to Yucca Mountain on heavy-haul trucks on one of the Caliente, Caliente/Chalk Mountain, or Caliente/Las Vegas routes. For branch rail line transportation, railcars would transfer via the Caliente Option to the Caliente Corridor at the Caliente junction.

c. For heavy-haul truck transportation, the Dry Lake junction is near the location of the proposed Apex/Dry Lake intermodal transfer station for heavy-haul trucks in southeast Nevada. Rail shipments terminating at this junction would continue to Yucca Mountain on heavy-haul trucks on the Apex/Dry Lake route.

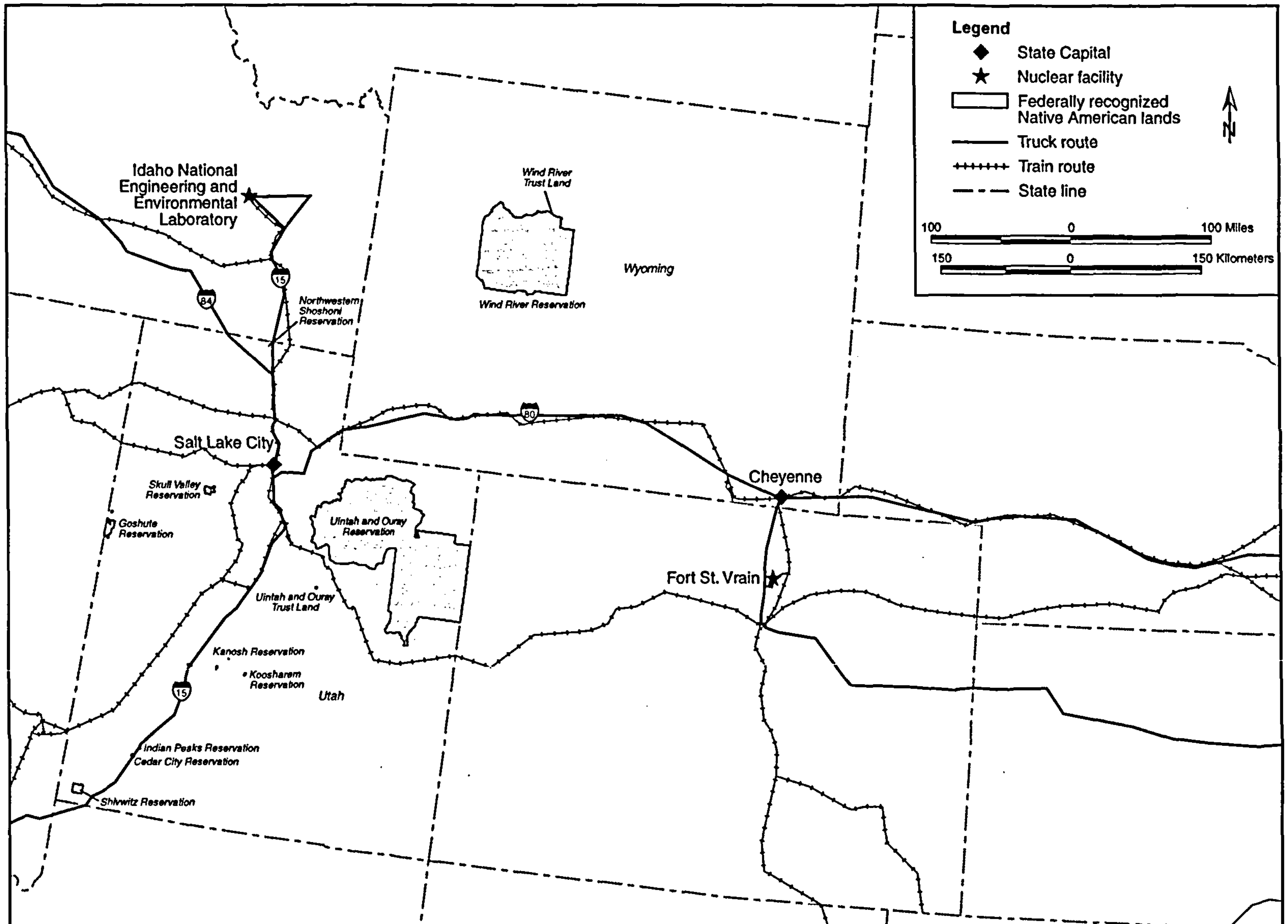
d. For heavy-haul truck transportation, the Jean junction is near the location of the proposed Sloan/Jean intermodal transfer station for heavy-haul trucks in southern Nevada. Rail shipments terminating at this junction would continue to Yucca Mountain on heavy-haul trucks on the Sloan/Jean route. For branch rail line transportation, railcars would transfer from the mainline railroad via the Wilson Pass or Stateline Pass Option of the Jean Corridor, near the Jean junction.

e. For branch rail line transportation, railcars would transfer from the mainline railroad at the Beowawe junction in north-central Nevada to the Carlin Corridor.

f. For branch rail line transportation, railcars would transfer from the mainline railroad at the Eccles junction east of Caliente, Nevada, via the Eccles Option or nearby via the Crestline Option of the Caliente or Caliente-Chalk Mountain Corridor. Impacts in states outside Nevada would be the same for the Eccles and Crestline Options of the Caliente and Caliente-Chalk Mountain Corridors.

g. For branch rail line transportation, railcars would transfer from the mainline railroad at the Apex junction in southeast Nevada, possibly via the Valley Connection, to the Valley Modified Corridor.

h. LCF = latent cancer fatality.



These routes represent the routes analyzed in Chapter 6 and might not be the routes actually used for shipments to the proposed repository at Yucca Mountain. Truck routes comply with U.S. Department of Transportation routing regulations. Rail routes are based on maximizing the distance on mainline track and minimizing the overall distance and number of interchanges between railroads.

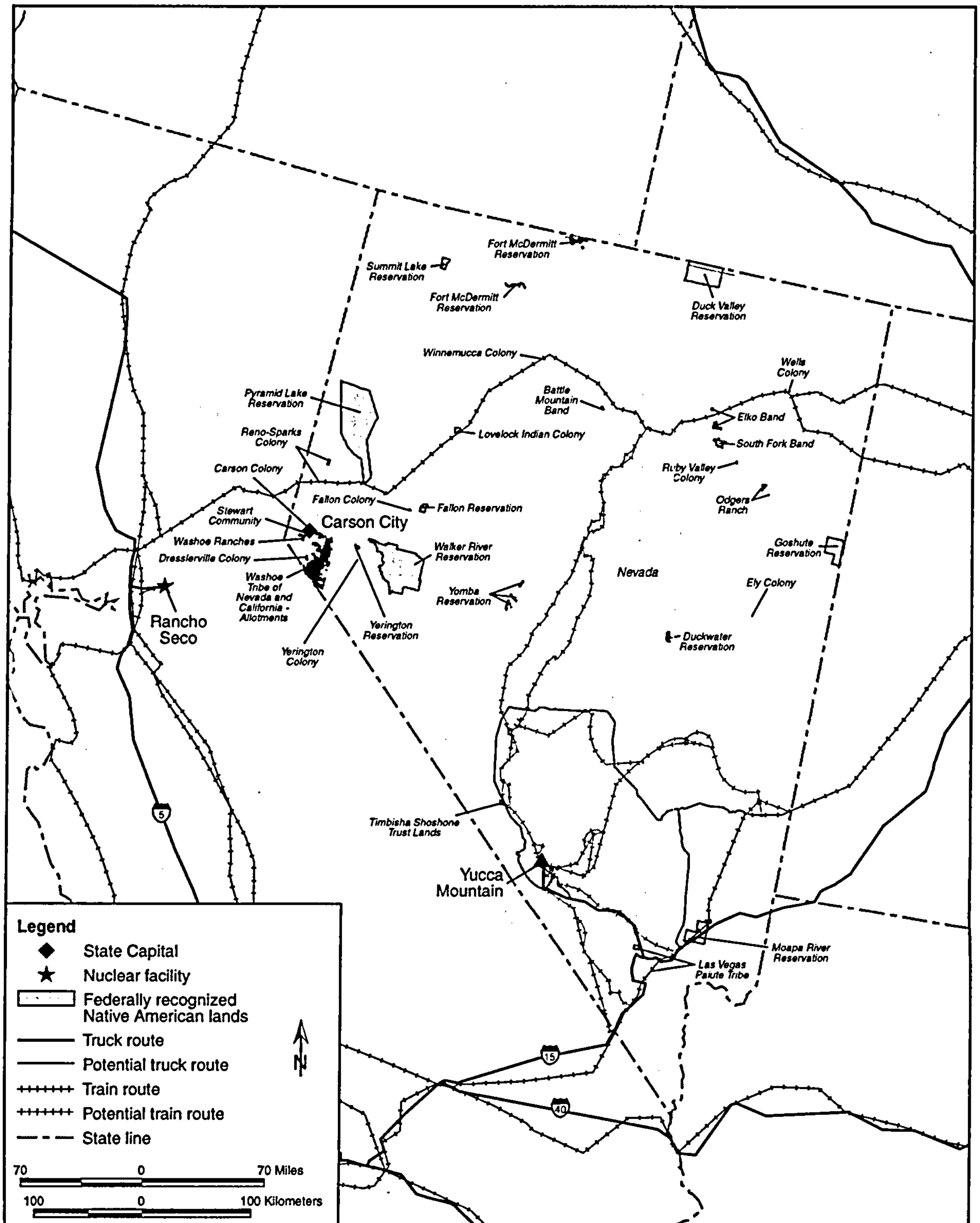
Figure J-52. Highway and rail routes used to analyze transportation impacts - Utah and Wyoming.

Table J-93. Estimated transportation impacts for the State of Nevada.

Impact category	Mostly legal-weight truck	Mostly rail: Rail implementing alternatives: Caliente	Carlin	Caliente-Chalk Mountain	Jean	Valley Modified	Mostly rail: Heavy-haul implementing alternatives: Caliente	Caliente/Chalk Mountain	Caliente/Las Vegas	Sloan/Jean	Apex/Dry Lake
NEVADA											
Shipments											
Truck (originating/total)	0/52,786	0/1,079	0/1,079	0/1,079	0/1,079	0/1,079	0/1,079	0/1,079	0/1,079	0/1,079	0/1,079
Rail (originating/total)	0/300	0/9,646	0/9,646	0/9,646	0/9,646	0/9,646	0/9,646	0/9,646	0/9,646	0/9,646	0/9,646
Radiological impacts											
Incident-free impacts											
Population (person-rem/LCFs)[a]	3.5×10^2/ 1.8×10^{-1}	1.9×10^1/ 9.4×10^{-3}	3.8×10^1/ 1.9×10^{-2}	1.8×10^1/9.1×10^{-3}	1.6×10^2/ 7.8×10^{-2}	2.6×10^1/ 1.3×10^{-2}	7.9×10^1/ 3.9×10^{-2}	6.3×10^1/3.2×10^{-2}	2.2×10^2/ 1.1×10^{-1}	3.3×10^2/ 1.7×10^{-1}	1.6×10^2/ 7.8×10^{-2}
Workers (person-rem/LCFs)	1.9×10^3/ 7.5×10^{-1}	8.3×10^2/ 3.3×10^{-1}	9.6×10^2/ 3.8×10^{-1}	7.3×10^2/2.9×10^{-1}	7.4×10^2/ 3.0×10^{-1}	7.0×10^2/ 2.8×10^{-1}	1.4×10^3/ 5.5×10^{-1}	9.8×10^2/3.9×10^{-1}	1.1×10^3/ 4.5×10^{-1}	9.3×10^2/ 3.7×10^{-1}	8.9×10^2/ 3.5×10^{-1}
Accident dose risk											
Population (person-rem/LCFs)	5.3×10^{-2}/ 2.6×10^{-5}	1.7×10^{-3}/ 8.6×10^{-7}	2.6×10^{-3}/ 1.3×10^{-6}	1.7×10^{-3}/8.5×10^{-7}	7.1×10^{-3}/ 3.6×10^{-6}	2.1×10^{-3}/ 1.0×10^{-6}	1.0×10^{-2}/ 5.1×10^{-6}	2.0×10^{-3}/1.0×10^{-6}	5.6×10^{-2}/ 2.8×10^{-5}	1.2×10^{-1}/ 6.0×10^{-5}	5.6×10^{-2}/ 2.8×10^{-5}
Nonradiological impacts											
Vehicle emissions (LCFs)	9.3×10^{-2}	7.1×10^{-3}	1.8×10^{-2}	7.7×10^{-3}	7.7×10^{-2}	1.1×10^{-2}	1.6×10^{-2}	7.9×10^{-3}	6.4×10^{-2}	1.9×10^{-1}	6.6×10^{-2}
Fatalities	0.49	0.07	0.09	0.05	0.06	0.05	0.60	0.33	0.43	0.25	0.23

a. Includes impacts of an intermodal transfer station.

b. LCF = latent cancer fatality.



These routes represent the routes analyzed in Chapter 6 and might not be the routes actually used for shipments to the proposed repository at Yucca Mountain. Truck routes comply with U.S. Department of Transportation routing regulations. Rail routes are based on maximizing the distance on mainline track and minimizing the overall distance and number of interchanges between railroads.

Figure J-53. Highway and rail routes used to analyze transportation impacts - Nevada.

REFERENCES

Note: In an effort to ensure consistency among Yucca Mountain Site Characterization Project documents, DOE has altered the format of the references and some of the citations in the text in this Final EIS from those in the Draft EIS. The following list contains notes where applicable for references cited differently in the Draft EIS.

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Chemical Technology Division

Transportation Routing Analysis Geographic Information System (WebTRAGIS) User's Manual

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ACRONYMS AND ABBREVIATIONS

*BRG	Barge, inland waterway
*M-M	Merchant Marine, deep draft waterway
<TR>	Terminal Railroad
AAR	Association of American Railroads
AMTK	Amtrak (National Railroad Passenger Corporation)
CFR	Code of Federal Regulations
CN	Canada
CSXT	CSX Transportation
DOE	Department of Energy
DOT	Department of Transportation
EM	Office of Environmental Restoration and Waste Management
ESRI	Environmental Systems Research Institute, Inc.
FIPS	Federal Information Processing Standards
FRA	Federal Railroad Administration
GIS	Geographic Information System
GUI	Graphical user interface
HM-164	Hazardous Materials Docket Number 164
HRCQ	Highway Route Controlled Quantity
IAIS	Iowa Interstate
IC	Illinois Central
ID	Identification
LAT/LON	Latitude/longitude
L/D	Lock and Dam
NS	Norfolk Southern
ORNL	Oak Ridge National Laboratory
PC	Personal computer
PPU	Peoria and Pekin Union
SMIP	Safety Metrics Indicator Program
TIGER	Topologically Integrated Geographic Encoding and Referencing system
TRAGIS	Transportation Routing Analysis Geographic Information System
UP	Union Pacific
USGS	United States Geological Survey
WebTRAGIS	Transportation Routing Analysis Geographic Information System
WIPP	Waste Isolation Pilot Plant
WWW	World wide web

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TRANSPORTATION ROUTING ANALYSIS GEOGRAPHIC INFORMATION SYSTEM (TRAGIS) USER'S MANUAL

1. INTRODUCTION

In the early 1980s, Oak Ridge National Laboratory (ORNL) developed two transportation routing models: HIGHWAY, which predicts truck transportation routes, and INTERLINE, which predicts rail transportation routes. Both of these models have been used by the U.S. Department of Energy (DOE) community for a variety of routing needs over the years. One of the primary uses of the models has been to determine population-density information, which is used as input for risk assessment with the RADTRAN model, which is available on the TRANSNET computer system. During the recent years, advances in the development of geographic information systems (GISs) have resulted in increased demands from the user community for a GIS version of the ORNL routing models. In April 1994, the DOE Transportation Management Division (EM-261) held a Baseline Requirements Assessment Session with transportation routing experts and users of the HIGHWAY and INTERLINE models. As a result of the session, the development of a new GIS routing model, Transportation Routing Analysis GIS (TRAGIS), was initiated.

TRAGIS is a user-friendly, GIS-based transportation and analysis computer model. The older HIGHWAY and INTERLINE models are useful to calculate routes, but they cannot display a graphic of the calculated route. Consequently, many users have experienced difficulty determining the proper node for facilities and have been confused by or have misinterpreted the text-based listing from the older routing models. Some of the primary reasons for the development of TRAGIS are (a) to improve the ease of selecting locations for routing, (b) to graphically display the calculated route, and (c) to provide for additional geographic analysis of the route.

TRAGIS was originally written with the ArcView™ software, which is marketed by Environmental Systems Research Institute, Inc. (ESRI). ArcView is a versatile multifunctional GIS package. TRAGIS was written primarily in ArcView Avenue language, but several functions in TRAGIS (including the routing routines) were written in the C++ programming language. TRAGIS operates on a UNIX® platform, primarily because of the size of the routing databases in the model. Additionally, several platform incompatibilities exist between the UNIX and Windows™ versions of ArcView. These incompatibilities make it difficult to run TRAGIS under the Windows platform. Also, each user must have a licensed copy of the ArcView™ software. This requirement would get very expensive as the number of users increases.

Accessibility to DOE users has been a problem because TRAGIS was written for a SUN™ UNIX workstation. At that time the UNIX workstation was fast enough for the mapping features, but Windows personal computers (PCs) were not. Now that the speed and capability of Windows personal computers have increased dramatically, they are fully capable of performing the mapping function satisfactorily. The need to make TRAGIS more available to the DOE community indicated that development of the next version of TRAGIS as a world wide web (WWW) application might be the best option. Since the main routing software was written in C++, it could be compiled for either a PC or a UNIX machine. Also, the user interface of TRAGIS was separate from the routing engine, it would be easier to build a new user interface and use essentially the same routing engine. During the development of WebTRAGIS (web-based TRAGIS), however, it was discovered that extensive modification of the routing engine in C++ was required to give it a simple universal interface. This modification was completed, and now the routing engine can easily be used in other programs, such as Batch-TRAGIS for pass through analysis and for generating Safety Metrics Indicator Program (SMIP) normalization data, and the engine is expected to be used for TRANSCOST.

WebTRAGIS was developed to be accessible over the WWW using the capabilities of the Internet Explorer 5.0™ web browser. WebTRAGIS consists of an access-controlled web page with a custom-built ActiveX™ control, which serves as the user interface to the routing engine, which resides on the server and is sent the route description-information. The routing engine uses the information to calculate the route and then generates output listings as text files. The user interface can then pick up and display the output files. Since the mapping feature is still slow, especially when map data are sent over the internet, two different user interfaces were built—one with the mapping feature and one without the mapping feature. The user interface without the mapping feature is obviously much faster and will operate quickly and efficiently over the WWW. It is basically a direct replacement for HIGHWAY and INTERLINE with an easy-to-use Windows interface. The user's interface with the mapping feature is slower, and in order to keep the speed to an acceptable level, the large data files must reside on the user's PC. Therefore, it was decided to deploy the mapping version as a client-server application, where the map data files and user interface software reside on the user's PC and the routing engine and its large data files reside on the server. The client communicates over the internet with the server. The software was written to minimize the data transmission, so the speed of operation is virtually the same whether one is connected via a modem or a high-speed internet connection.

WebTRAGIS is designed to use the rail, highway, and waterway transportation modes for routing. The rail network used in the initial version of the model is the same database as that used in the INTERLINE model. This database, which was developed for the Federal Rail Administration (FRA) in the mid-1970s, is not a fixed-scale database and has been extensively modified since its inception by ORNL. Currently, a 1:100,000-scale database is being developed, and when this network is completed, it will be incorporated into WebTRAGIS. The road database is a 1:100,000-scale database, which was developed from the U.S. Geological Survey (USGS) Digital Line Graphs and the U.S. Bureau of Census Topologically Integrated Geographic Encoding and Referencing (TIGER) system. This waterway network information, for the inland waterway systems, is based on the USGS 1:2,000,000-U.S. Geodata. Deep-water routes are depicted in WebTRAGIS as straight-line segments. It is planned to incorporate a 1:100,000-scale waterway database for the model so that all modes are at a consistent scale.

One of the features of WebTRAGIS is a consistent user interface between and among the transportation modes. Functions are similar for running rail, highway, or waterway routes. Some variations occur, such as prompts requesting the name of the railroad company to be used. However, when a user learns one portion of the WebTRAGIS system, it is not difficult for that person to run other portions of the model.

WebTRAGIS allows the selection of the origin and destination of a route from a list of node names. When selecting nodes, the program displays a list of state abbreviations from which the user selects a state. Next, a list of node names within that state is displayed. The user can scroll through this list and select a node. After a node is selected, WebTRAGIS displays the selected node's identification (ID) number. In addition to nodes at city locations and within the network, the WebTRAGIS databases contain hundreds of specific nodes for locations of commercial nuclear reactors, DOE sites, military installations, and other important nuclear-related sites.

After an origin and a destination are selected, the model is ready to calculate a route based on criteria established by option selections. A default set of criteria is active for each transportation mode in the model. After completing the route calculation, WebTRAGIS displays the standard route listing. The user can also view a detailed listing of the route and population-density information, which can be used with the RADTRAN risk model.

Option settings provide a mechanism to change various parameters used by the model for route calculations. Examples of some of the options include adjusting the penalty factors for the mainline classifications for rail routing, using preferred highway routes for radioactive materials, and running alternative routes for the different transportation modes in WebTRAGIS.

WebTRAGIS also provides functions to temporarily modify the routing networks. The user can select individual nodes and links or an entire state in which all nodes and links are blocked from the network.

This user's manual has six sections following this introductory section. Section 2 is a general overview of the WebTRAGIS. This section is very useful if the user has not worked with graphical user interface (GUI) programs. Rail, highway, and waterway features are discussed in Sects. 3–5, respectively. Section 6 describes the operation of the mapping functions.

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2. GENERAL OVERVIEW OF WebTRAGIS

WebTRAGIS is written to operate as a Windows application for Microsoft Windows 32-bit operating systems. A 32-bit Windows PC with a copy of Internet Explorer (Version 5.0 or later) is necessary in order to use the WebTRAGIS software. The software is distributed as an ActiveX control or a downloadable client-server application. Instructions for installing the software are provided on the WWW page.

To start WebTRAGIS with mapping, click on START - Programs - TRAGIS - Tragis. Accessing the WWW page and logging on to the system will start WebTRAGIS without mapping. It will take a few seconds for WebTRAGIS to connect across the internet to the databases needed for the model. After the loading, the model will display a username window, which is used to control user access to the WebTRAGIS routing engine (Fig. 2.1).

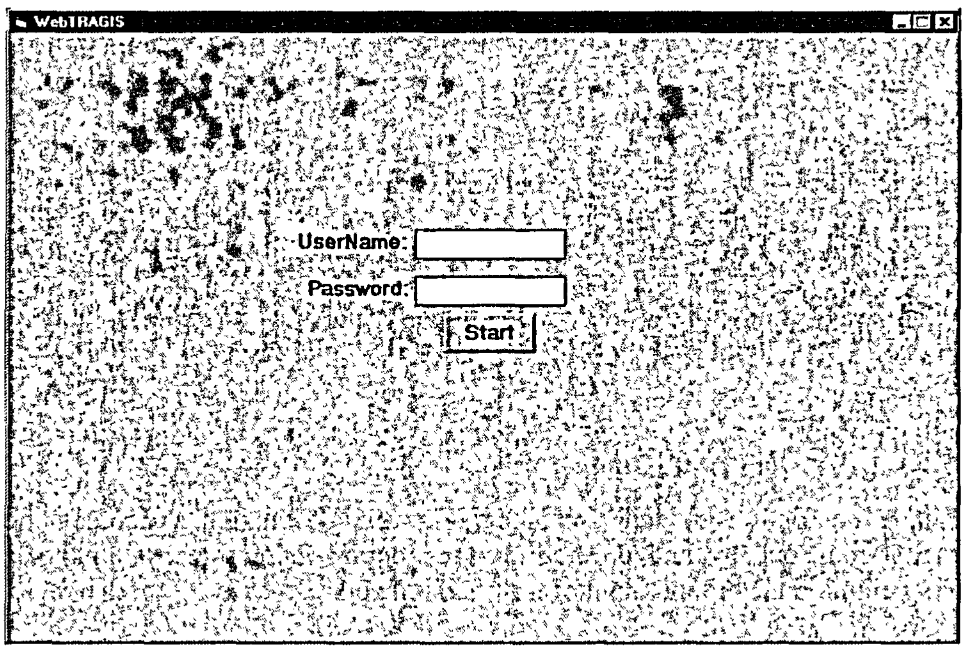

Fig. 2.1. Logon screen.

2.1 WebTRAGIS LAYOUT

WebTRAGIS has several tabs of options. It opens to the 'Select Origin and Destination' tab. Figure 2.2 shows how WebTRAGIS appears when the program has finished loading and the user has entered their username and password. There are five tabs on the WebTRAGIS WWW home page. There are six tabs on the WebTRAGIS with maps program—the same 5 that are on the WWW page plus a tab for maps.

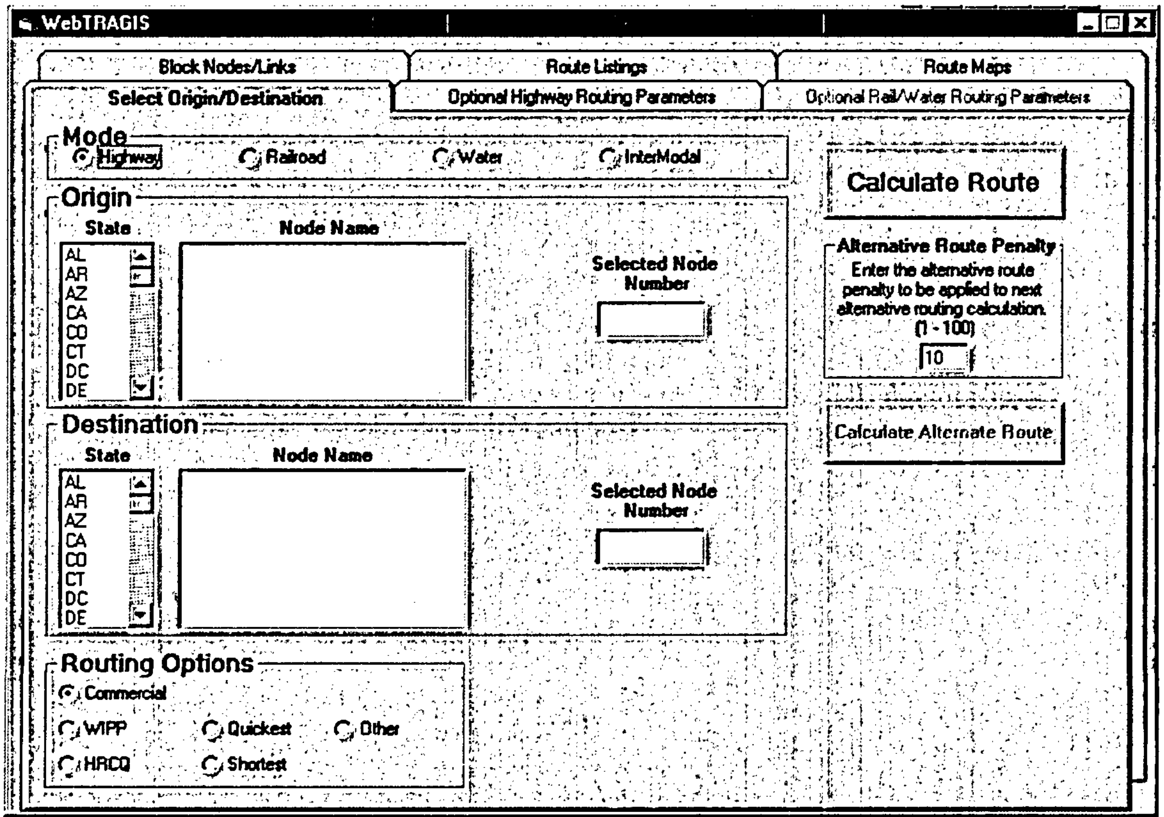

Fig. 2.2. WebTRAGIS.

2.1.1 Tab 1—Select Origin/Destination

This tab contain several options for selection mode; origin and destination, and route options; input of alternative route penalty; and, depending on the routing option selected, input of preferred route-weighting factor; and input of time and mile bias.

2.1.2 Tab 2—Optional Highway Routing Parameters

This tab contains six optional routing parameters. They are selection of one or two drivers, highway inspection, date and time options, toll-bias factor, other constraints, and road-lane-type penalty.

2.1.3 Tab 3—Optional Rail/Water Routing Parameters

This tab contains three optional routing parameters for railroads and two for water routing. The three railroad options are (1) Change Originating Railroad Preference, (2) Change Rail Line Type Weighting Factors, and (3) Modify Rail Transfer Penalties. The two water options are (1) Select Water Route Type and (2) Modify Mode Transfer Penalty.

2.1.4 Tab 4—Block Nodes/Links

This tab contains four ways for blocking available routing features: block nodes, block links, block states, and block railroad companies.

2.1.5 Tab 5—Route Listings

This tab allows the user to view and print the input file and the four route output files. These are the detailed input file and the standard route listing, detailed route listing, population density, and the route latitude/longitude (LAT/LON) listing. After completing the route calculation, the standard listing is automatically displayed.

2.1.6 Tab 6—Route Maps

This tab is available only on the WebTRAGIS with the Maps version. On this tab are several buttons; these buttons are described in detail in Sect. 6 of this manual.

2.2 RUNNING WebTRAGIS

The remainder of this manual will be based on the individual transportation mode chosen within WebTRAGIS. Rail routing will be discussed first and next by highway and water routing. The long-range plans for WebTRAGIS include full intermodal capabilities so that users can route via two or three modes. In the initial version of WebTRAGIS, intermodal capabilities, as envisioned, do not exist as yet because of funding constraints. As an interim measure, an additional mode is available in WebTRAGIS. The rail-water mode is available for rail-waterway intermodal routing. This feature is not discussed in this manual; the functions of this combination mode are described in both the rail (Sect. 3) and waterway (Sect. 5) portions of this manual.

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3. RAIL ROUTING

The WebTRAGIS model calculates rail routes that simulate the routing practices of the railroad companies in the United States. The basic concept of determining rail routes is to calculate the shortest path based on travel distance and traffic density on rail segments. Each segment of the rail-network database has a distance, in miles, and a variable signifying the volume of traffic density. The traffic-density information is divided into four classes as follows:

> A–mainline—more than 20-million gross ton miles per year,
> B–mainline—between 5- and 20-million gross ton miles per year,
> A–branchline—between 1- and 5-million gross ton miles per year, and
> B–branchline—less than 1-million gross ton miles per year.

In addition to biasing the distance based on traffic density, the model also penalizes changing from one rail carrier to another. Finally, the model also reduces the impedance values on the originating rail carrier. These features replicate the practice of actual rail routing—which is that the originating carrier will attempt to keep the shipment on its system for as much of the total route as possible.

To set WebTRAGIS to calculate rail routes, the user needs to move the pointer over the Mode on the **Select Origin/Destination** tab and click the **Rail** option. This selects the mode Rail as the currently active mode in WebTRAGIS. After the rail mode is selected, the entire rail node listing is loaded, and the appropriate optional parameters are made visible. Figure 3.1 shows the display of WebTRAGIS after the rail network is activated.

3.1 SELECT ORIGIN/DESTINATION TAB

3.1.1 Selecting Origin

After the rail network is initialized, select the origin and destination for calculating a route. The first step is to select an origin for a route by first selecting the state, next selecting the node name, and then selecting the railroad company if more than one railroad services the selected node. The selected rail node number and railroad abbreviation are displayed. Repeat for selection of the destination. (The abbreviation CN represents Canada. Several rail lines in the current rail database extend into Canada.)

Figure 3.1 shows an example of node names for the state of Tennessee. In this example, the list has been scrolled about midway through the list of nodes (as is indicated by the position of the marker on the scroll bar), and the Knoxville node has been highlighted. After the desired node has been selected, a listing of all available railroads providing service at this location is identified. Then select one of the railroads by highlighting it. If there is only one servicing railroad company, it is automatically selected. WebTRAGIS now displays the selected node number and railroad company.

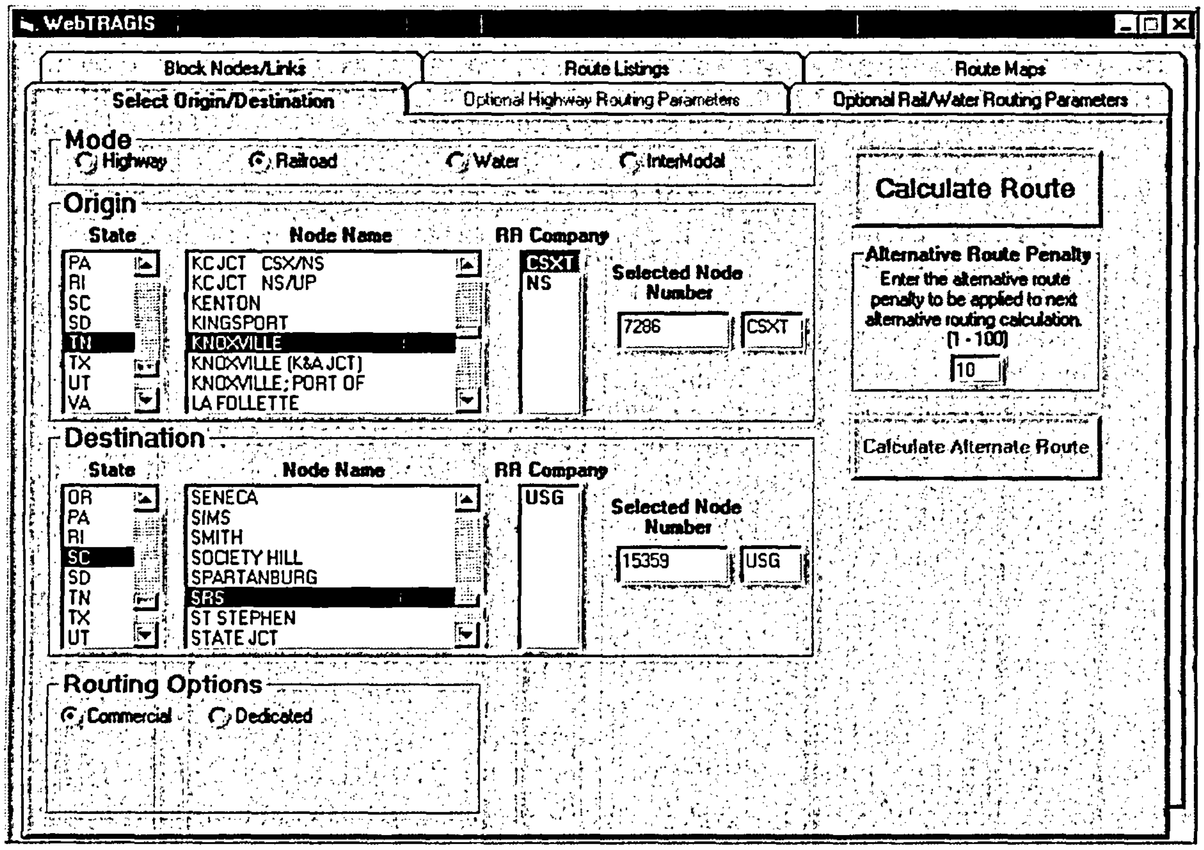

Fig. 3.1. Rail mode activated.

3.1.2 Selecting Destination

This same process is repeated for a destination location for a route. Selection of the route destination is the last required step before a route can be calculated. Press the **Calculate Route** button on the right side of the screen. The different origin or destination can be selected after a route has already been calculated. When this is done, the information from the previously calculated route is discarded, and all current information is used for the new route. The earlier destination or other selections will not be considered in the new route.

3.1.3 Routing Options

The routing type option is shown in Fig. 3.1. This option allows a choice between the default general commercial freight routing option or the dedicated-train routing option. With the dedicated-train routing option, the transfer penalty between railroad systems and the originating railroad advantage are eliminated. To switch between these two, click the appropriate choice.

3.14 Calculate Route and Calculate Alternative Route

After a destination has been determined, click the **Calculate Route** button on the right side of the screen. If an origin or a destination is not selected, a message reminding you to select these will be displayed. WebTRAGIS will calculate the rail route and then display a window that shows the standard listing for the route.

After a route has been calculated, the **Calculate Alternative Route** button becomes active, allowing the user to generate alternative routes. To calculate an alternative route, go back to the Select Origin/Destination tab and then click the **Calculate Alternative Route** button. When an alternative route (or another route) is calculated, it overwrites all of the output files from the previous route. Therefore, you must save or print all route files before running an alternative (or another) route. An alternative route is generated by penalizing the links comprising the current route by the Alternative Route Penalty Factor in preparation for running the alternative route when the **Calculate Alternative Route** is clicked.

3.2 ROUTE LISTINGS TAB

The **Route Listings** tab provides access to input and output listings of routes and population-density information of the most recently calculated route. The displayed listing can be saved or printed. Figure 3.2 shows the route listings.

The standard listing identifies only the origin and destination, any transfer locations, and larger cities along the route. This listing also identifies the railroad used for each portion of the route, a cumulative mileage figure for each location listed, a breakdown of mileage by railroad and line classification, and a summary of mileage by state.

The detailed listing provides much more information on the route. Every node on the route is listed along with information on link characteristics. Not every node in the database has a name, so node numbers are listed. Link information includes the link number; the distance of the link; the line classification code; a traffic volume code; a speed limit for freight trains; and if the operating railroad is using trackage rights over this line, the abbreviation of the railroad owning the tracks. As with the standard listing, summary information by railroad and state follows the route listing.

The population-density information is viewed by clicking the **Population Data** button. A listing of the population density information for the route is displayed. The basic table includes 12 population-density categories ranging from 0 to over 9996 people per square mile. The entries in the table show the distance that the route travels in each category. At the end of the table, summary information is provided for the route. This information combines the data from the 12 categories into rural, suburban, and urban groups and also provides a weighted population-density value for each of these groups. This information is used as input for routing risk analysis using the RADTRAN or RISKIND computer codes.

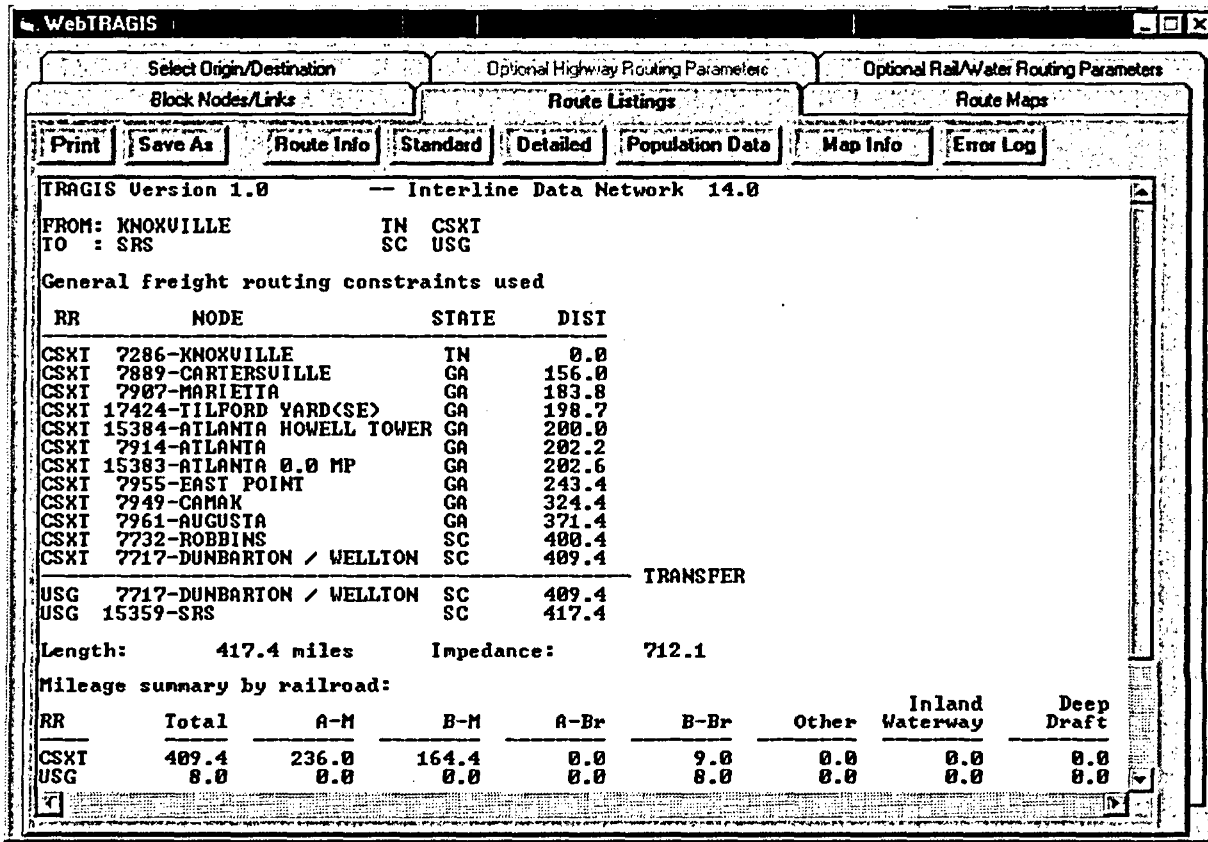

Fig. 3.2. Rail-route listings.

The final items on the **Route Listings** tab are the **Print** and **Save As** buttons. When the **Print** button is clicked, the listing currently being viewed is sent to the printer. (Note: Be sure to display the desired information to the screen before printing). When the **Save As** button is clicked, a file selection dialog box is displayed. The file name and location can then be selected, and the listing currently being displayed can be saved to that selected file.

3.3 OPTIONAL RAIL/WATER ROUTING PARAMETERS TAB

The **Optional Rail/Water Routing Parameters** tab provides access to a number of parameters that control the routing functions. When rail is the active mode, **Optional Rail/Water Routing Parameters** tab is available, and the **Optional Highway Routing Parameters** tab is not.

When the **Optional Rail/Water Routing Parameters** tab is selected, a window of the rail options is displayed. Figure 3.3 shows the rail options window. Within this window, available options can be selected. Click on the item of interest to select it. The following sections discuss the various rail options.

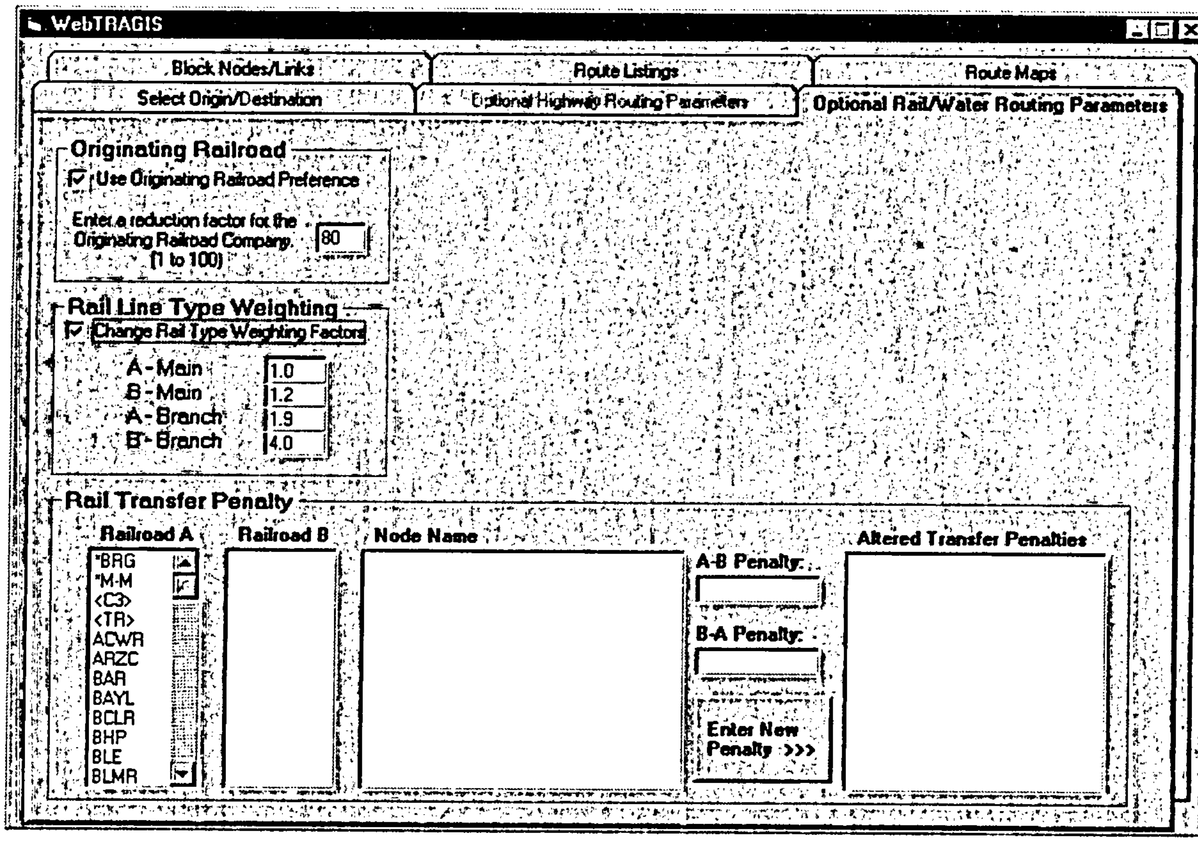

Fig. 3.3. Optional rail-routing parameters.

3.3.1 Rail Line Type Weighting

The weighting factor option allows adjustments to the factors that are used to calculate routes. This window is shown in Fig. 3.3. The default values are displayed for each penalty factor. Any of the variables can have a new value assigned by entering a new value in the appropriate box. The appropriate factors are multiplied by the distance of each link or railroad. Using the default values, an A-Mainline link has an impedance that is the same as its distance, whereas the impedance of a B-Branchline link is four times its distance.

3.3.2 Originating Railroad Preference

The impedance of the originating railroad is multiplied by a factor of 80%. This percentage reduces the impedance of the originating railroad, thereby encouraging the shipment to remain with the originating railroad as long as practicable.

3.4 BLOCK NODES/LINKS TAB

The **Block Nodes/Links** tab allows the user to block portions of the rail database or different rail companies. These features can be useful when there is a need to analyze various scenarios (e.g., determining a route that avoids a damaged bridge or section of rail line and analyzing rail mergers). The **Block Nodes/Links** tab has three functional groupings. The first group involves blocking nodes. The second group involves blocking links. Finally, the last group allows for the blocking of individual railroad companies. The window is shown in Fig. 3.4 below.

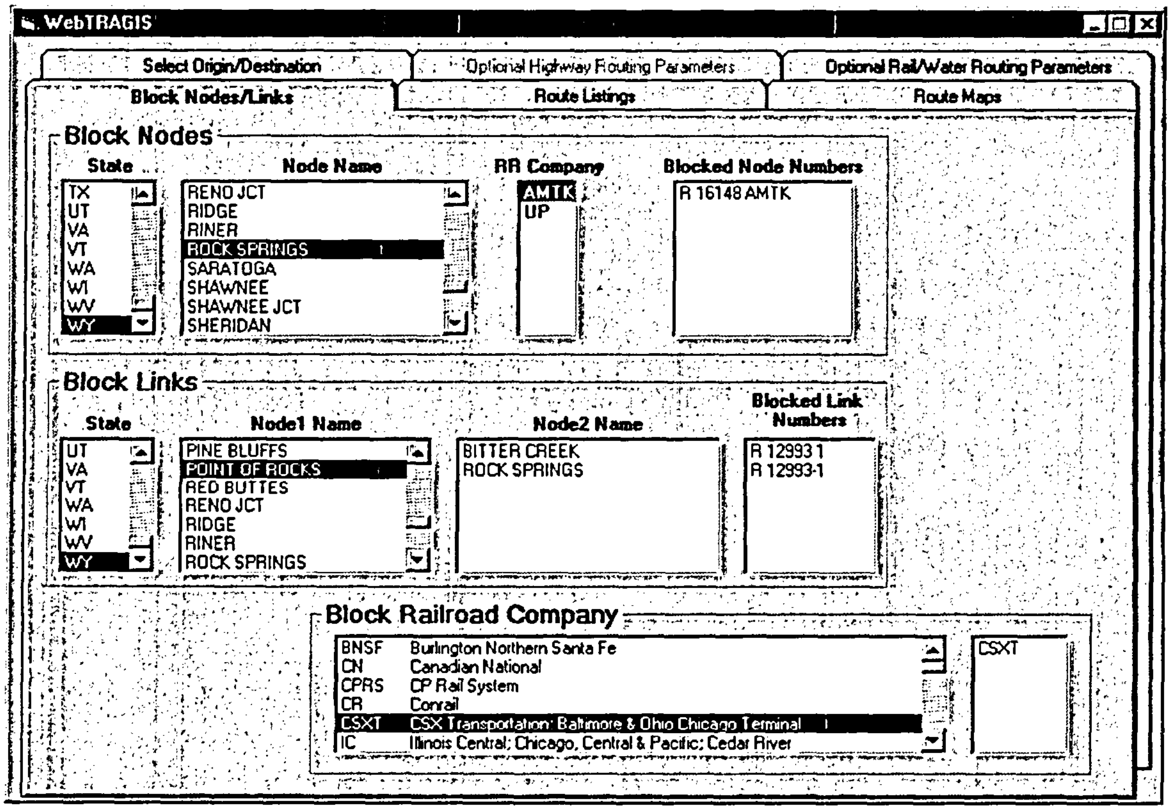

Fig. 3.4. Rail node/link blocking.

3.4.1 Node Blocking

To block a rail node, click the state of interest and find the node name to be blocked. As an example, Rock Springs, Wyoming, is served by the Union Pacific (UP) and by Amtrak (AMTK), the national rail passenger service. For other nodes, several rail companies could be listed. Thus, a node could be blocked for one railroad, but remain available for another. To remove an entry from the **Blocked Nodes** list, double-click on it.

3.4.2 Link Blocking

To block a link, click the state of interest and find the node of one end of the link to be blocked. Then select the other end node of the link. The blocked link is then displayed. (Note: There are two entries shown, one ending in '1' and the other ending in '-1'). These block the link in both directions.

3.4.3 Block Railroad Company

The rail network in WebTRAGIS is subdivided into 94 subnetworks. The **Block Railroad Company** tab provides a method to remove a railroad subnetwork from consideration. Figure 3.4 shows the rail system window as it would be displayed. The window provides a list of the railroad names for the rail systems in the rail database. A number of rail systems are comprised of several separate railroads that are owned by a single company. An example, shown on Fig. 3.4, is the Illinois Central (IC), which also owns the Chicago, Central & Pacific and the Cedar River. To remove a rail system from consideration, scroll through the list to locate the desired railroad and double-click on the name to block it. The abbreviation will appear in the box to the right.

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4. HIGHWAY ROUTING

The WebTRAGIS model can calculate a number of different types of highway routes. By default, the model calculates commercial highway routes; but with the change of an option, the model can determine routes that meet the U.S. Department of Transportation (DOT) regulations for shipments of highway route-controlled quantities (HRCQ) of radioactive material, specified routes for shipments to WIPP, the shortest, or the quickest route.

To set WebTRAGIS to calculate highway routes, the user needs to move the pointer over the Mode on the **Select Origin/Destination** tab and click the **Highway** option. This selects the mode Highway as the currently active mode in WebTRAGIS. After the **Highway** mode is selected, the entire highway node listing is loaded, and the appropriate optional parameters are activated. Figure 4.1 shows the display of WebTRAGIS after the highway network is activated.

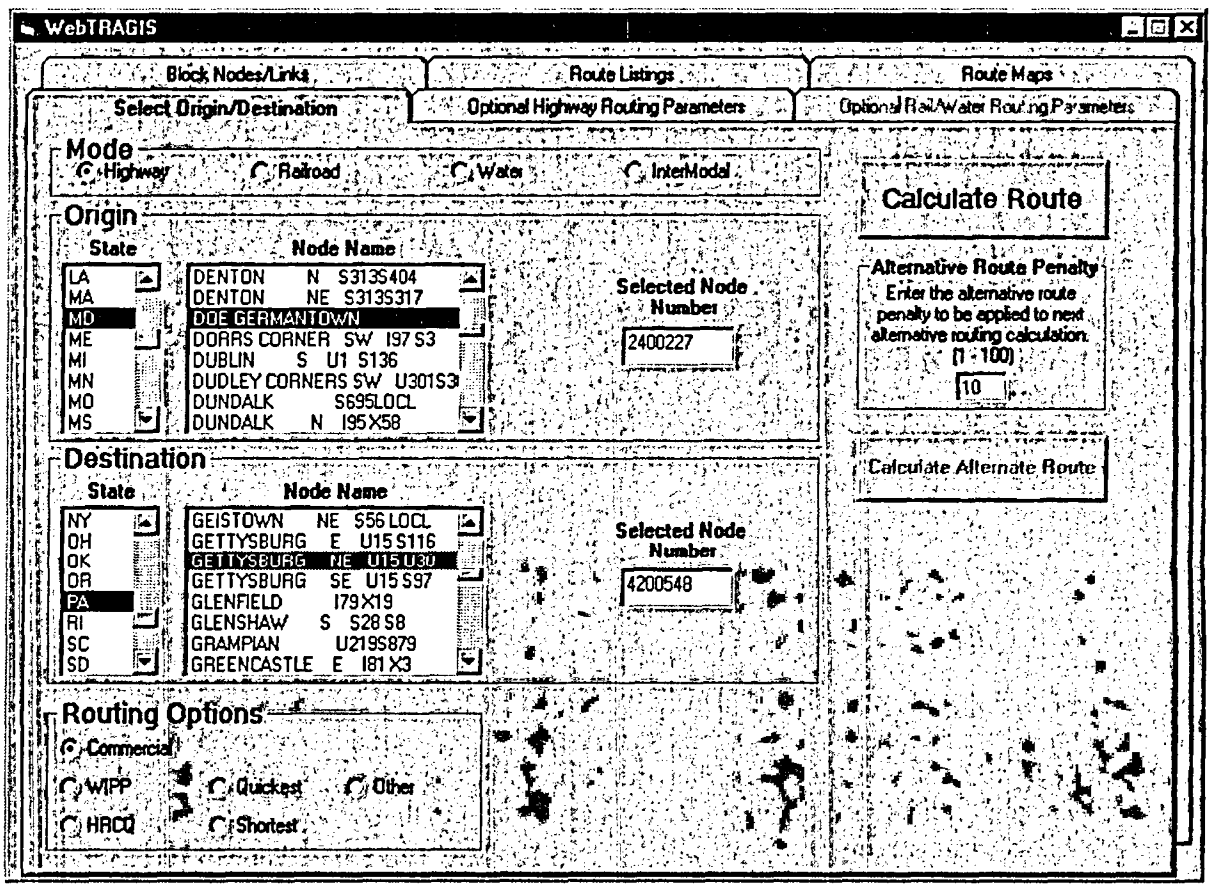

Fig. 4.1. Highway routing.

4.1 SELECT ORIGIN/DESTINATION TAB

4.1.1 Selecting Origin

After the highway network is initialized, select the origin and destination for calculating a route. The first step is to select an origin for a route by first selecting the state, and then selecting the node name. The selected highway node number is displayed. Repeat for selection of the destination. Figure 4.1 shows an example of node names for the state of Maryland. In this example, the list has been scrolled partway through the list of nodes (as is indicated by the position of the marker on the scroll bar), and the DOE-Germantown node has been highlighted. WebTRAGIS now displays the selected node number.

4.1.2 Selecting Destination

This same process is repeated for a destination location for a route. Selection of the route destination is the last required step before a route can be calculated. For this example, Gettysburg, Pennsylvania has been selected. Press the **Calculate Route** button on the right side of the screen. A different origin or destination may be selected after a route has been calculated. When this is done, the information from the previously calculated route is discarded, and all current information is used for the new route. An earlier destination or other selections will not be considered in the new route.

4.1.3 Routing Options

The **Routing Options** are shown in Fig. 4.1. These options allow a choice between the Commercial (default), HRCQ, WIPP, Quickest, Shortest, and Other routing options. Click the appropriate choice.

4.1.4 Calculate Route and Calculate Alternative Route

After a destination has been determined, click the **Calculate Route** button on the right side of the screen. If an origin or destination is not selected, a message reminding you to select these will be displayed. WebTRAGIS will calculate the highway route, and then display a window which shows the standard listing for the route.

After a route has been calculated, the **Calculate Alternative Route** button becomes active allowing the user to generate alternative routes. To calculate an alternative route, go back to the **Select Origin/Destination** tab, and then click the **Calculate Alternative Route** button. When an alternative route (or another route) is calculated, it overwrites all of the output files from the previous route. Therefore, you must save or print all route files before running an alternative (or another) route. An alternative route is generated by penalizing the links comprising the current route by the Alternative Route Penalty Factor in preparation for running the alternative route when the **Calculate Alternative Route** is clicked.

4.2 ROUTE LISTINGS TAB

The **Route Listings** tab provides access to the input and output listings of routes and population-density information of the most recently calculated route. The displayed listing can be saved or printed (Fig. 4.2).

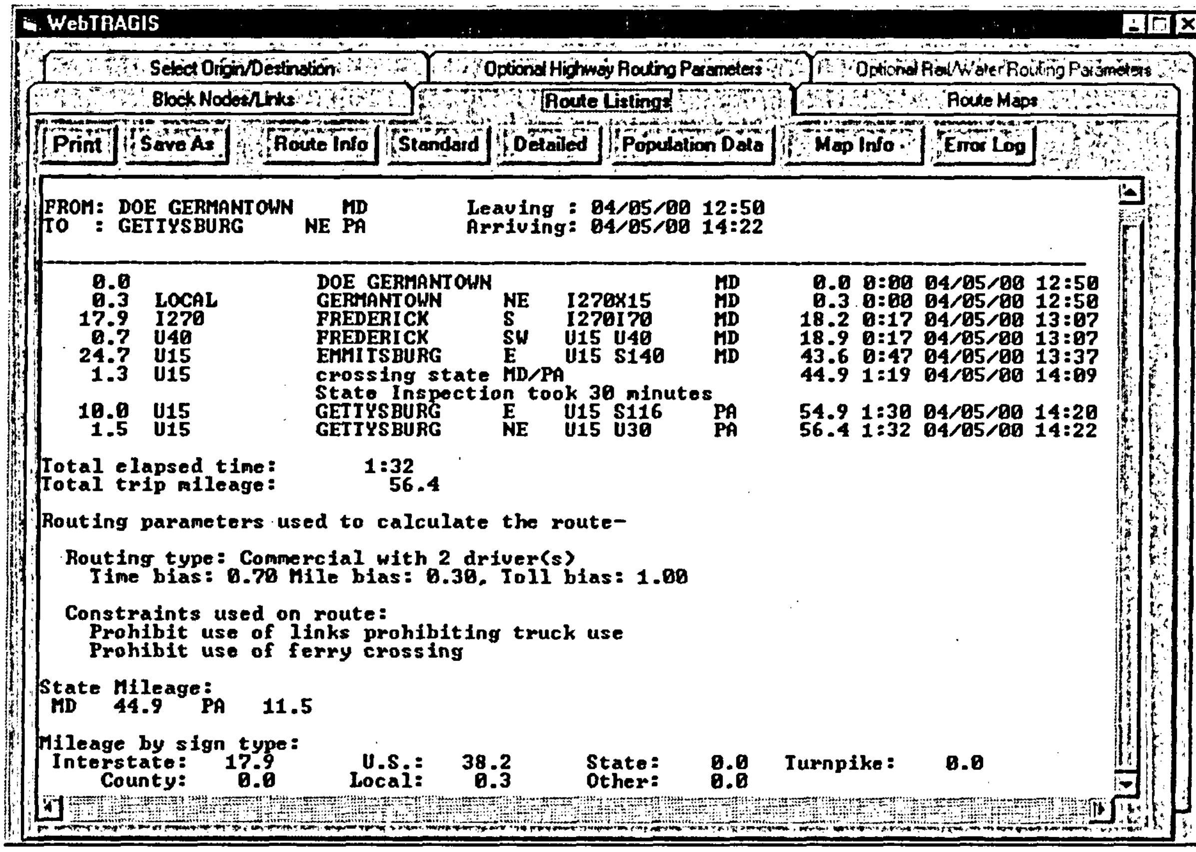

Fig. 4.2 Highway-route listings.

For highway routes, standard and detailed route listings are available. The standard listing is the shorter route listing, which is the one used most often (Fig. 4.2). This listing is for a route between DOE offices in Germantown, Maryland, and Gettysburg, Pennsylvania. The origin and destination, along with the departure and arrival date and time, are identified at the top of the listing. Next, a description of the route is provided. The first column is the distance, in miles, between each location in the listing. Following this is an identification of the road. Up to two road identifications are listed (e.g., a dual-designation road such as I-40/I-75). The first letter of the road number is a designation of the road type. Interstate highways start with an I, U.S. highways start with an U, state highways start with an S, turnpikes and tollways start with a T, county roads start with a C, and local roads start with an L. Other types of roads, such as farm-to-market roads in Texas, may start with other letters. The route number or an alphabetic abbreviation of the road follows the designation letter. Next the name of the node is listed. In some cases, actual facilities are identified, such as DOE-Germantown. Most often, nodes are identified by the nearest town or city, followed by the direction that this location is from the named location. Junction information is provided to assist in the node description. This information may include the two roads that form an intersection or the interstate route number and the exit number. The state is identified, and this identification is followed by a cumulative mileage and time columns. Finally, the date and time when the shipment is expected to pass the node are given. By default, the model assumes the departure time to be the current time from the computer. The user can set the departure time through the **Optional Highway Routing Parameters** tab, which is discussed in Sect. 4.3.

In the example shown in Fig. 4.2, the route originates at DOE-Germantown at 12:50 p.m. The route travels 0.3 miles on a local road and turns onto I-270 at Exit 15. This location is northeast of Germantown, Maryland. After traveling 17.9 miles on I-270, the shipment exits the Interstate at the junction of I-270 and I-70, south of Frederick, and then travels 0.7 miles on U.S. 40 to the junction of U.S. 15 and U.S. 40, southwest of Frederick, Maryland. At this location, the length of the route is 18.9 miles, and the trip has taken about 18 minutes. The route follows U.S. 15 for 24.7 miles to Emmitsburg, Maryland. This location is the last node encountered on the route in Maryland. (At least one line will appear in the route listing for every state that is on a route.) After another 12.8 miles on U.S. 15, the shipment arrives at the destination, which is Gettysburg, Pennsylvania. The location of this node is northeast of town at the junction of U.S. 15 and 30.

Following the route description, a summary of the total elapsed time and trip mileage is given. The routing parameters used to calculate the route is also provided along with a summary of mileage by state and a breakdown of mileage by highway sign type.

The detailed route listing is basically the same as the standard route listing other than that every node on the route is listed on the description. The length of a route listing for a cross-country route can be very long.

Population-density information can be obtained for the most recent calculated route by choosing the **Population** button in **the Route Listings** tab. A window is generated that lists the population-density information for the route. The basic table includes 12 population-density categories ranging from 0 to over 9996 people per square mile. The entries in the table show the distance that the route covers in each category. At the end of the table, summary information is provided for the route. This information combines the data from the 12 categories into rural, suburban, and urban groups and also provides a weighted population-density value for each of these groups. This information is useful as input for routing risk analysis using the RADTRAN computer code at Sandia National Laboratories or the RISKIND computer code at Argonne National Laboratory.

4.3 OPTIONAL HIGHWAY ROUTING PARAMETERS TAB

The **Optional Highway Routing Parameters** tab provides access to a number of parameters that control the routing functions. Selecting the **Optional Highway Routing Parameters** tab, a window like that shown in Fig. 4.3 is displayed. This window identifies all the options that are available for road routing. To select an option, click on the appropriate option.

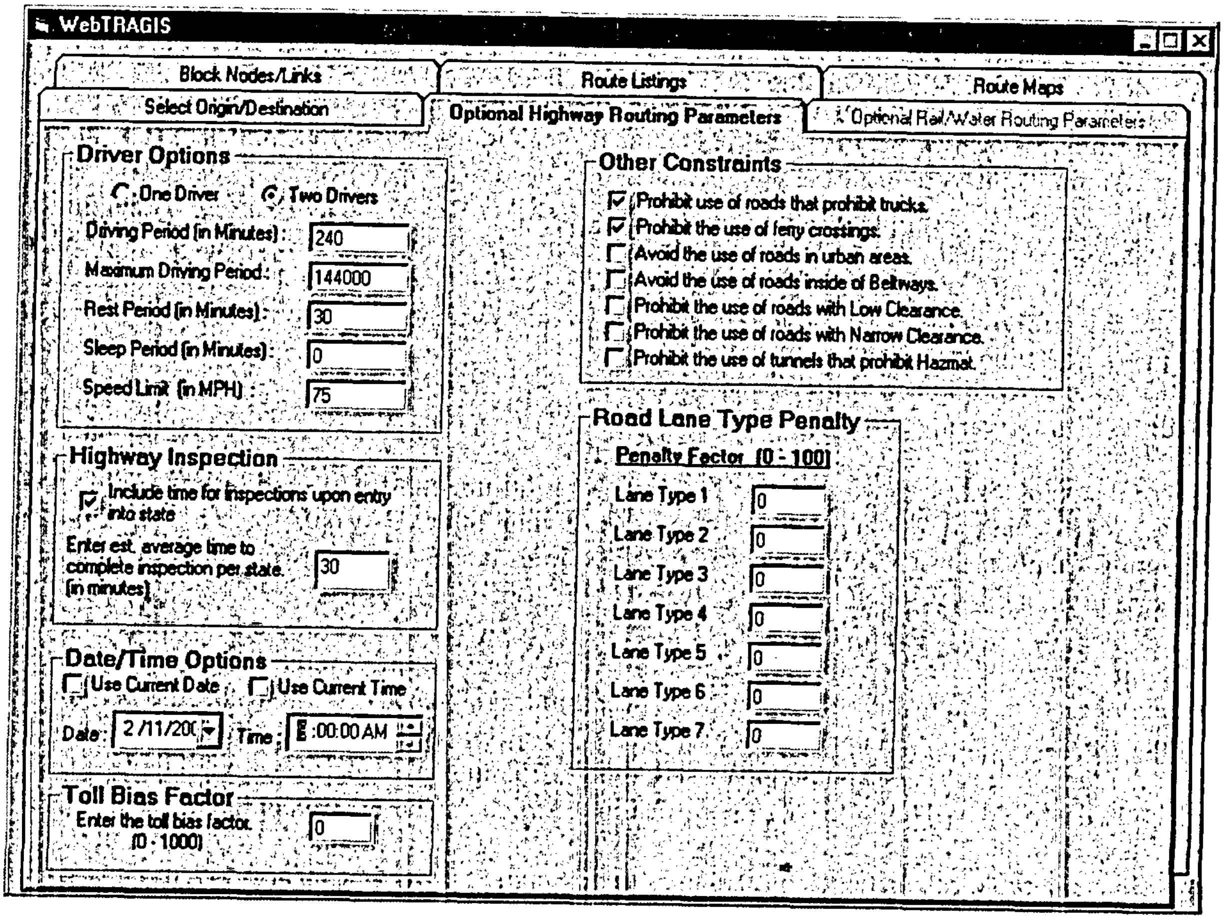

Fig. 4.3. Optional highway routing parameters.

4.3.1 Driver Options

When changing the **Driver Options** is desired, the user must select between the one or two drivers options. Figure 4.3 shows this option. The default is **Two Drivers.** Each of these options has several parameters that may be changed for a particular route. Double-click on either of the options to view the additional parameters. You may change these parameters by editing the displayed values.

4.3.1.1 One Driver

The next four items in this option window involve the periods of time for driving and resting. With a **One Driver** shipment, the default follows a pattern that the driver works for 5 hours and then takes a 0.5-hour break. After this break, another 5 hours of driving can occur, for a total of 10 hours, before an 8-hour rest period is required. You can change the amount of driving time before the short break and between major rest periods by entering new values in the driving time fields. The latter two lines request the length of the short and long break periods, respectively.

The final item of this option permits you to specify the maximum speed that a shipment will travel. Congressional action in 1995 lifted national speed limits and allowed states to specify their own limits. In certain cases, an upper limit may need to be specified for the speed of the shipment. The default value for this variable in WebTRAGIS is 75 mph. To specify a maximum travel speed of 55 mph, the model will use the speed specified in the truck database—except that those links with speeds higher will be assumed to be the value the user specified. Adjusting this value may affect the route calculation; it is also used to determine arrival times that are identified on the route listing.

4.3.1.2 *Two Drivers*

These items in this option window involve the periods of time for driving and resting. With two drivers, the default follows a pattern of 4 hours of driving followed by a 0.5-hour break. This pattern is followed throughout the duration of the shipment because one driver can rest while the other is driving.

The final item of this option allows the maximum speed of a shipment to be specified. Congressional action in 1995 lifted national speed limits and allowed states to specify their own limits. In certain cases, an upper limit may need to be specified for the speed for the shipment. The default value for this variable in WebTRAGIS is 75 mph. To specify a maximum speed of 55 mph, the model will use the speed specified in the truck database—except that those links with higher speeds will be assumed to be the value the user specified. Adjusting this value will not affect the route calculation; it is also used to determine arrival times that are identified on the route listing.

4.3.2 State Inspection

WebTRAGIS has an option to perform state inspections of a shipment when that shipment is transported into a new state. Figure 4.3 is the option that is displayed when the **Highway Inspection** option is checked. If the user clicks the checkbox below **Highway Inspection,** the inspection time box is displayed. The default value is 30-minutes; this value can be changed by entering a new value.

This option will create a delay every time the calculated route crosses a state boundary to simulate the delay a shipment may experience if a state inspection is required. Use of this option will not change a route (e.g., such as minimizing the number of states traversed). It will increase only the travel time for the shipment.

4.3.3 Date/Time Options

This option allows the user to specify the departure date and time for the shipment. By default, WebTRAGIS uses the current date and time from the computer. If the departure date needs to be specified, select the date with the drop-down calendar, as shown in Fig. 4.3. The departure time can be entered using the drop-down selector. If the route origin is not located in the same time zone as the computer running WebTRAGIS, the input time will be adjusted by the model (e.g., if the origin is in the central time zone, the departure time is specified as 16:30, and the computer is in the eastern time zone, WebTRAGIS will adjust the departure time to 3:30 p.m.).

4.3.4 Other Routing Constraints

Figure 4.3 shows the **Other Constraints** option. Checking the box before the item can activate any of these constraints. Two of the constraints are automatically activated by WebTRAGIS: the commercial truck and ferry crossing constraints.

The commercial truck constraint prohibits the program from using any route that restricts commercial truck traffic. An example of this is the Baltimore-Washington Parkway; no commercial truck traffic is allowed on this road. Thus, for any routing of commercial traffic, this constraint needs to be active.

Several ferry crossings are in the WebTRAGIS road database, such as those between Long Island, New York, and Connecticut. The ferry-crossing constraint prohibits the use of a ferry on a route. To use the ferries that are in the database, the user would uncheck the box **(Prohibit the use of ferry crossings)**.

Roads that pass through urbanized areas with populations exceeding 100,000 are identified in the road database. By checking this option, **Avoid the use of roads in urban areas,** the model will not use any roads within any urbanized areas.

Another available constraint restricts the use of all roads within interstate beltways of larger metropolitan areas. This constraint is not related to the HRCQ-preferred routing (HM-164) option. Use of this constraint will cause the route to avoid going within the major beltways in large cities. To activate this constraint, check the box, **Avoid the use of roads inside of Beltways.**

The next two constraints involve low clearance and narrow road clearance. Road segments with height clearances of less than 13 ft 6 in and width restrictions of 8 ft or less are identified and will prohibit the use of these road segments. Each of these constraints can be activated when checking the box for the appropriate restriction.

The final constraint is identified as a tunnel. All tunnels that have hazardous materials restrictions are identified in the road database, and when this item is activated, the program will prohibit calculating routes that include these restricted tunnels.

4.4 BLOCK NODES/LINKS TAB

The **Block Nodes/Links** tab allows the blocking of a portion of the road database. This feature can be useful for analysis of various scenarios such as road closures, construction zones, or damaged bridges. You can block portions of the road database by selecting nodes, links, or entire states. Figure 4.4 shows the Block Nodes/Links window.

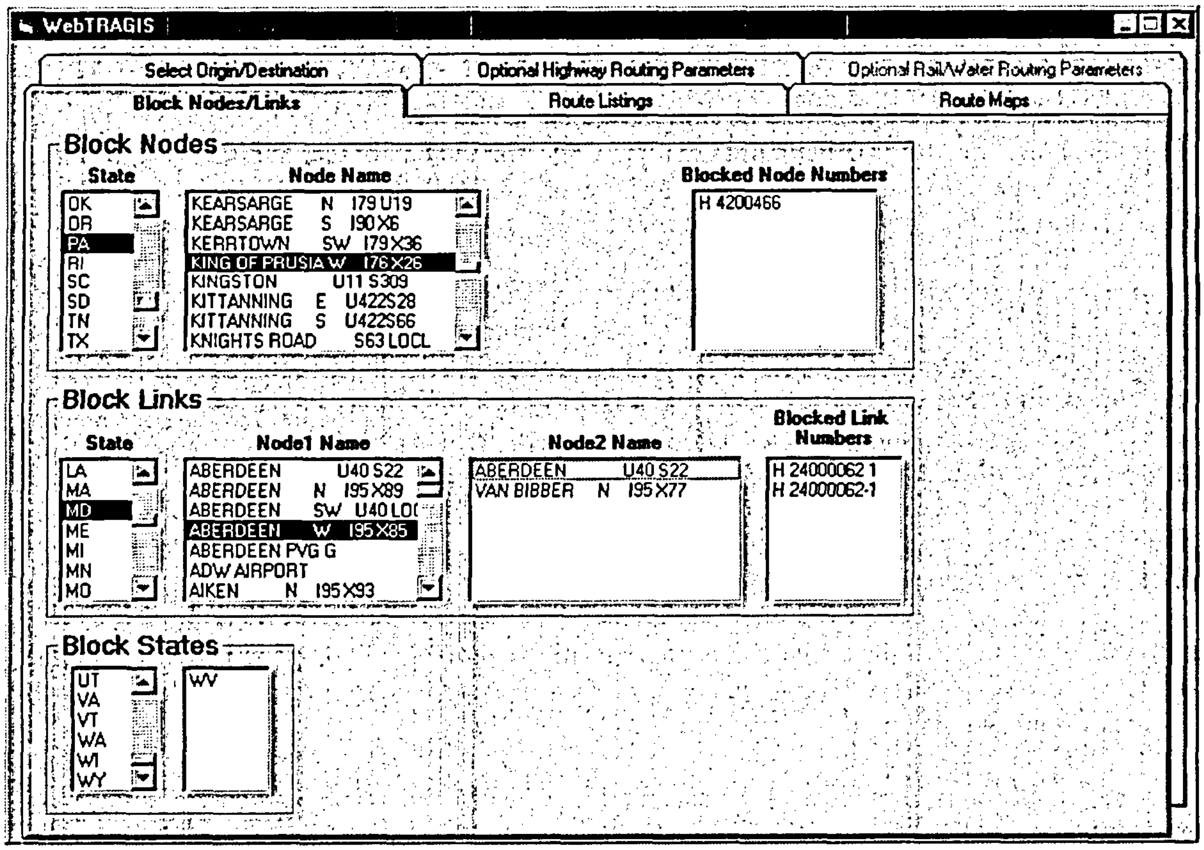

Fig. 4.4. Highway node/link blocking.

4.4.1 Node Blocking

Nodes can be blocked in the road database by making all the links that emanate from the node ineligible for routing. To block a node, select the state in which the node exists. The **Node Name** list will be populated with node names for that state. Now select the node to be blocked by scrolling to the name and clicking on it. The node number will then appear in the **Blocked Node Numbers** list.

The node numbers are six or seven digits. The right-most five digits are unique to the node within a state, and the digits to the left of the five digits are the state Federal Information Processing Standard (FIPS) code for the state. For example, code 47 is Tennessee. A node number may be removed from the **Blocked Node Numbers** list by double-clicking on it.

4.4.2 Link Blocking

Since a link is defined by its nodes, you will be choosing the link by selecting its endpoints. Block links in the road database by first choosing the **State**. After a state is chosen, the **Node1 Name** list will be populated. The **Node2 Name** list will be populated with all of the nodes connected to **Node1**. Select **Node2** from the list in **Node2 Name** list. The **Blocked Link Numbers** list will now contain two entries, the first ending with a '1' and the second ending with a '-1'. These block the link in both directions. If you want to block a link in only one direction, double click on the undesired entry, and it will be removed from the list.

4.4.3 State Blocking

An entire state can be temporarily removed from the road routing database by selecting the state (or states) from the **Blocked States** list. The blocked states will appear in the list to the right. A state may be removed from this list by double-clicking on the state abbreviation. Figure 4.4 shows that an alphabetical list of state abbreviations is displayed in a list. Scroll through the list and click the state to be removed.

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5. WATERWAY ROUTING

Waterway routing is available to users of WebTRAGIS. The waterway database consists of both inland waterways and deep-water routes. Inland waterways include all channels with a minimum depth of 9 feet. The deep-water network consists of connections between ports on the Pacific Ocean, Gulf of Mexico, Atlantic Ocean, and Great Lakes regions. Transfers between the inland and deep-water routes are treated as break-of-bulk points.

To set WebTRAGIS to calculate water routes, the user needs to move the pointer over the **Mode** on the **Select Origin/Destination** tab and click the **Water** option. This selects the mode **Water** as the currently active mode in WebTRAGIS. After the **Water** mode is selected, the entire water node listing is loaded, and the appropriate optional parameters are made active. Figure 5.1 shows the display of WebTRAGIS after the water network is activated.

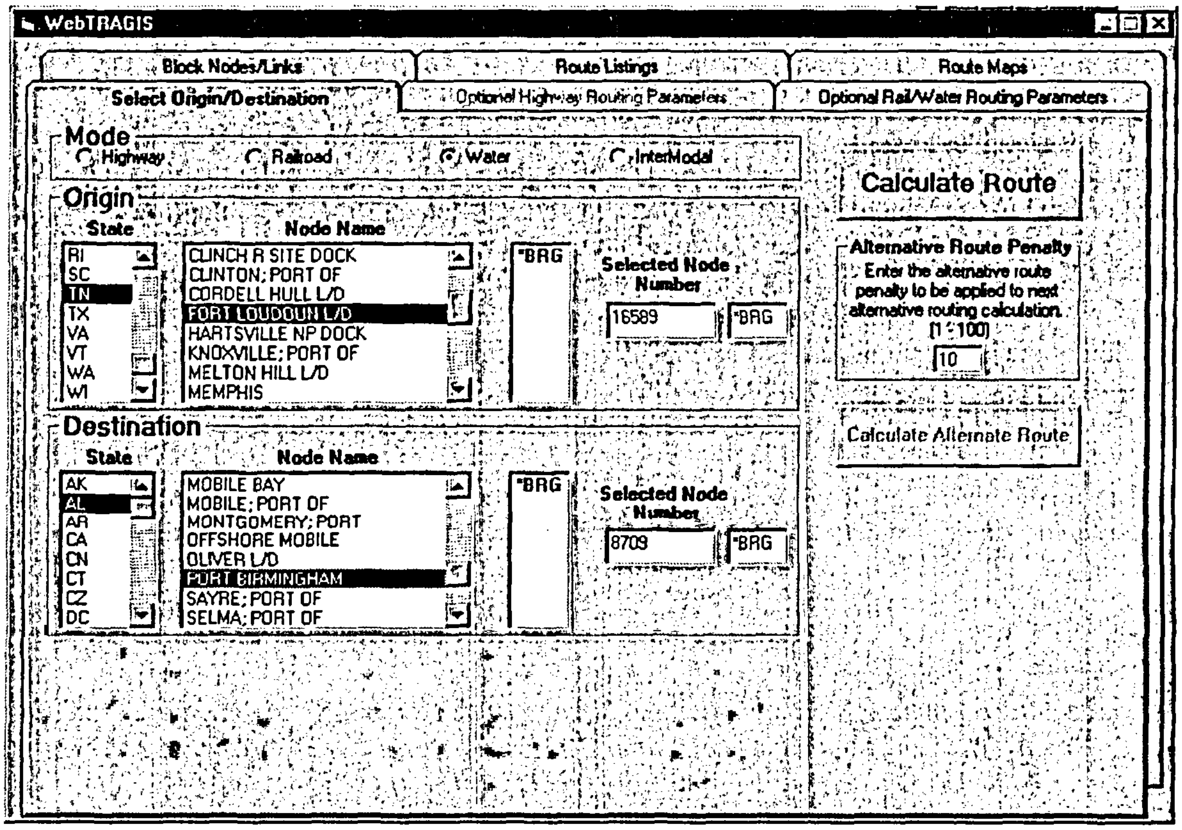

Fig. 5.1. Water routing.

5.1 SELECT ORIGIN/DESTINATION TAB

5.1.1 Selecting Origin

After the water network is initialized, select the **Origin** and **Destination** for calculating a route. The first step is to select an origin for a route by first selecting the state, then selecting the node name, and then selecting the subnetwork if more than one services the selected node. The **Selected Node Number** and subnetwork abbreviation are displayed.

Figure 5.1 shows an example of node names for the state of Tennessee. In this example, the list has been scrolled about midway through the list of nodes (as is indicated by the position of the marker on the scroll bar), and the Knoxville node has been highlighted. After the desired node has been selected, a listing of all available subnetworks providing service at this location is identified. Then select one of the railroads by highlighting it. If there is only one servicing subnetwork, it is automatically selected. WebTRAGIS now displays the selected node and subnetwork.

5.1.2 Selecting Destination

This same process is repeated for a destination location for a route. Selection of the route destination is the last required step before a route can be calculated. Press the **Calculate Route** button on the right side of the screen. A different **Origin** or **Destination** can be selected after a route has already been calculated. When this is done, the information from the previously calculated route is discarded, and all current information is used for the new route. The earlier destination or other selections will not be considered in the new route.

5.1.3 Calculate Route and Calculate Alternative Route

After a destination has been determined, click the **Calculate Route** button on the right side of the screen. If an origin or destination is not selected, a message reminding you to select these will be displayed. WebTRAGIS will calculate the water route and then display a window that shows the standard listing for the route.

After a route has been calculated, the **Calculate Alternative Route** button becomes active, allowing the user to generate alternative routes. To calculate an alternative route, go back to the **Select Origin/Destination** tab, and then click the **Calculate Alternative Route** button. When an alternative route (or another route) is calculated, it overwrites all of the output files from the previous route. Therefore, you must save or print all route files before running an alternative (or another) route.

5.2 ROUTE LISTINGS TAB

The **Route Listings** tab provides access to input and output listings of routes and population-density information of the most recently calculated route. The displayed listing can be saved or printed. Figure 5.2 shows the route listings.

The standard listing identifies only the origin and destination, any transfer locations, and larger cities along the route. This listing also identifies the subnetwork used for each portion of the route, a cumulative mileage figure for each location listed, a breakdown of mileage by subnetwork and line classification, and a summary of mileage by state.

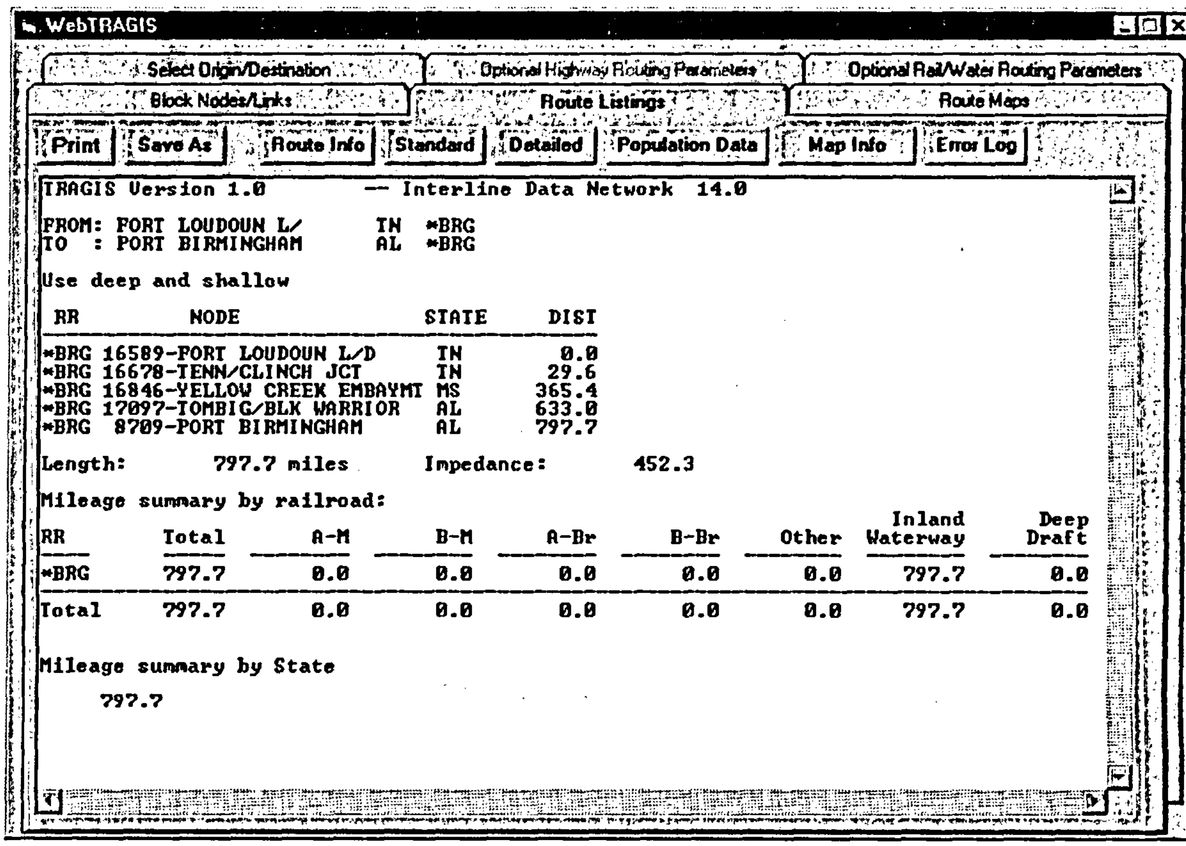

Fig. 5.2. Water-route listings.

The detailed listing provides much more information on the route. Every node on the route is listed along with information on link characteristics. Not every node in the database has a name, so node numbers are listed. Link information includes the link number; the distance of the link; the line classification code; a traffic volume code; a speed limit for freight trains; and, if the operating railroad is using trackage rights over this line, the abbreviation of the railroad owning the tracks. These items specific to railroad will be blank for water routes. As with the standard listing, summary information by subnetwork and state follows the route listing.

The population-density information is viewed by clicking the **Population Data** button. A listing of the population density information for the route is displayed. The basic table includes 12 population-density categories ranging from 0 to over 9996 people per square mile. The entries in the table show the distance the route travels in each category. At the end of the table, summary information is provided for the route. This information combines the data from the 12 categories into rural, suburban, and urban groups and also provides a weighted population-density value for each of these groups. This information is used as input for routing risk analysis using the RADTRAN or RISKIND computer codes.

The final items on the **Route Listings Tab** are the **Print** and **Save As** button. When the **Print** button is clicked, the listing currently being viewed is sent to the printer. (Note: Be sure to display the desired information to the screen before printing). When the **Save As** button is clicked, a file selection dialog box is displayed. The file name and location can then be selected, and the listing currently being displayed is saved to that selected file.

5.3 OPTIONAL RAIL/WATER ROUTING PARAMETERS TAB

The **Optional Rail/Water Routing Parameters** tab provides access to a number of parameters that control the routing functions. When water is the active mode, **Optional Rail/Water Routing Parameters** tab is available, and the **Optional Highway Routing Parameters** tab is not.

When the **Optional Rail/Water Routing Parameters** tab is selected, a window of the water options is displayed. Figure 5.3 shows the water options window. Within this window, available options can be selected. Click on the item of interest to select them. The following sections discuss the various water options.

5.3.1 Select Water Route Type

The user can select the type of water route to be used, such as **Deep Water** route, **Shallow Water** route, or **Both** (deep and shallow).

5.3.2 Modify Mode Transfer Penalty

This allows the user to modify the transfer penalty from deep water to shallow water or the reverse. This is intended to cause the model to minimize the transfers similar to industry practice. The user selects the modes and enters the desired transfer penalty. (**Note: This procedure is for experienced users only.**)

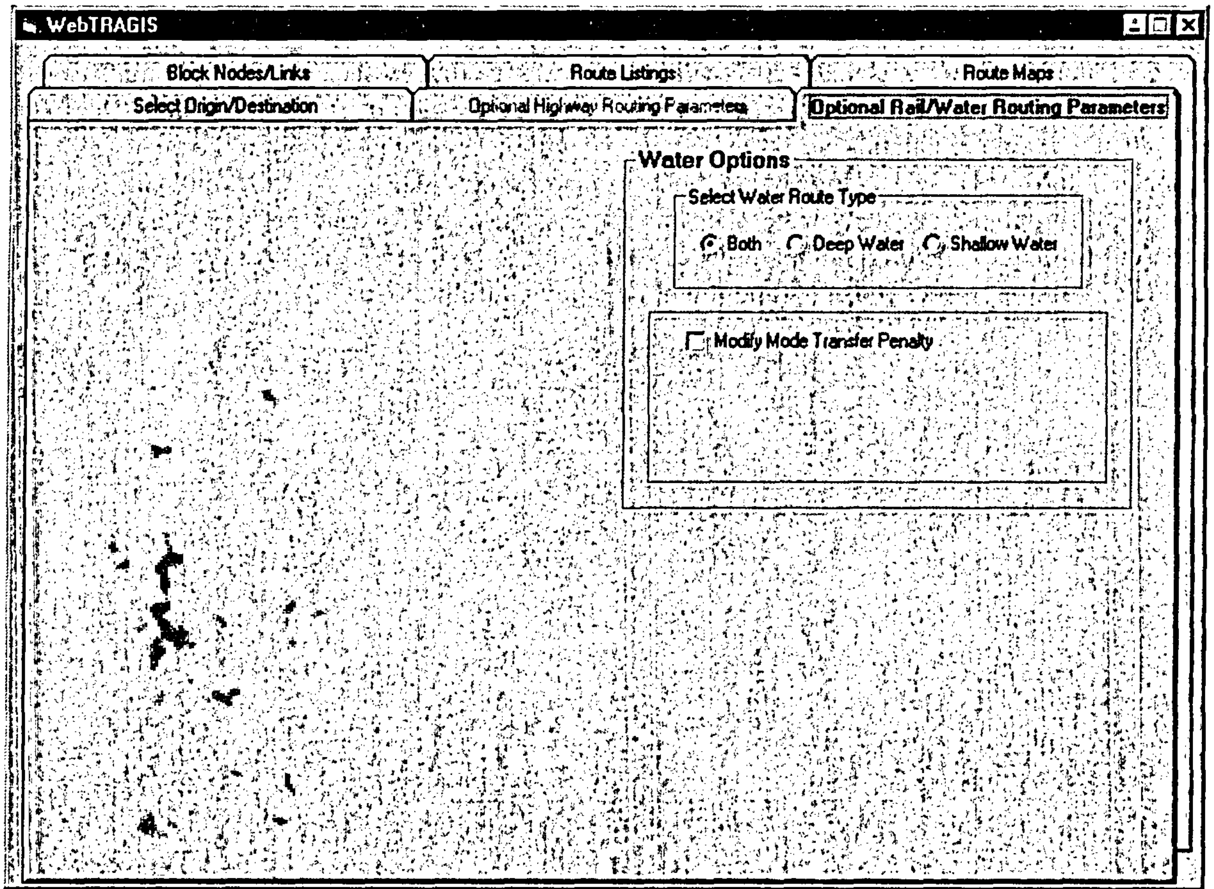

Fig. 5.3. Water options window.

5.4 BLOCK NODES/LINKS TAB

The **Block Nodes/Links** tab allows the user to block portions of the route database. These features can be useful when there is a need to analyze various scenarios. The **Block Nodes/Links** tab has two grouping of commands. The first group involves blocking nodes. The second group involves blocking links. This window is shown in Fig. 5.4.

5.4.1 Node Blocking

Nodes can be blocked in the database by making all the links that emanate from the node ineligible for routing. To block a node, select the state in which the node exists. The Node Name list will be populated with node names for that state. Now select the node to be blocked by scrolling to the name and clicking on it. The node number will then appear in the **Blocked Node Numbers** list.

5.4.2 Link Blocking

Since a link is defined by its nodes, you will be choosing the link by selecting its end points. **Block Links** in the road database by first choosing the **State.** After a state is chosen, the **Node1 Name** list will be populated. The **Node2 Name** list will be populated will all of the nodes connected to **Node1.** Select **Node2** from the list in **Node2 Name** list. The **Blocked Link Numbers** list will now contain two entries, the first ending with a '1' and the second ending with a '-1'. These block the link in both directions. If you want to block a link in only one direction, double click on the undesired entry and it will be removed from the list.

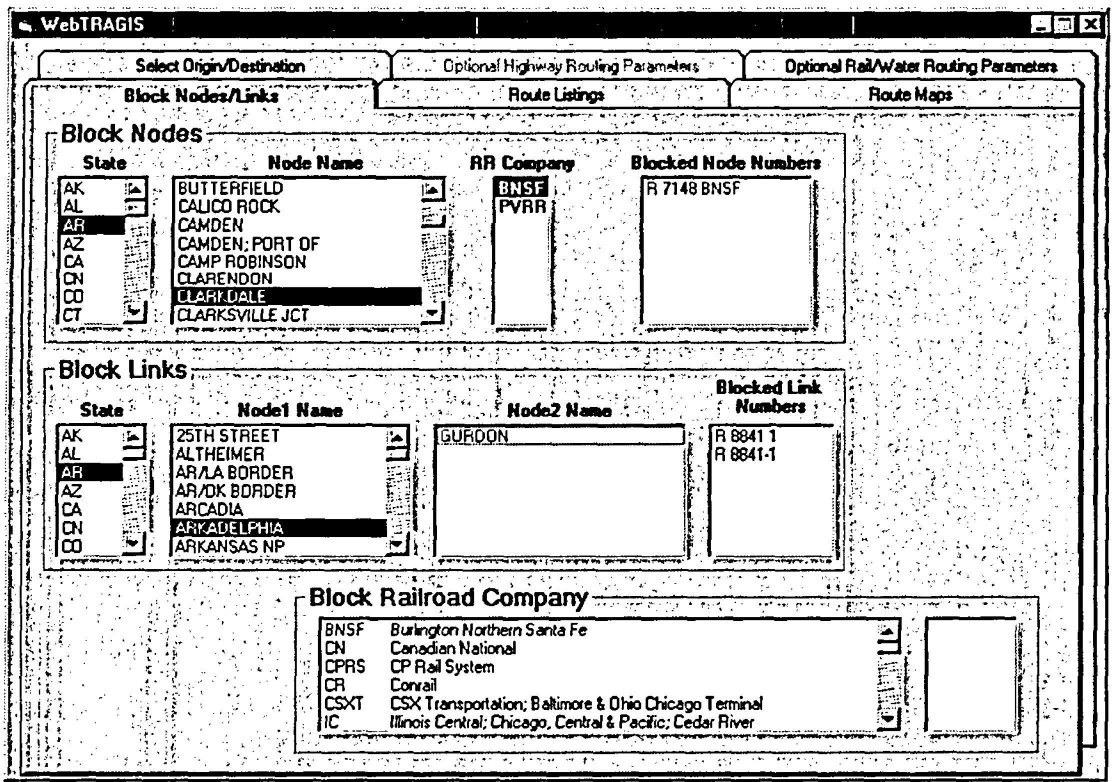

Fig. 5.4. Water node/link blocking.

6. ROUTE MAPS

6.1 BUTTON BAR ITEMS ON ROUTE MAPS TAB

There are several buttons on the **Route Maps** tab. These buttons are useful for the mapping feature (Fig. 6.1). Each button has a popup box with a short description of its function and is described with more detail in the following sections.

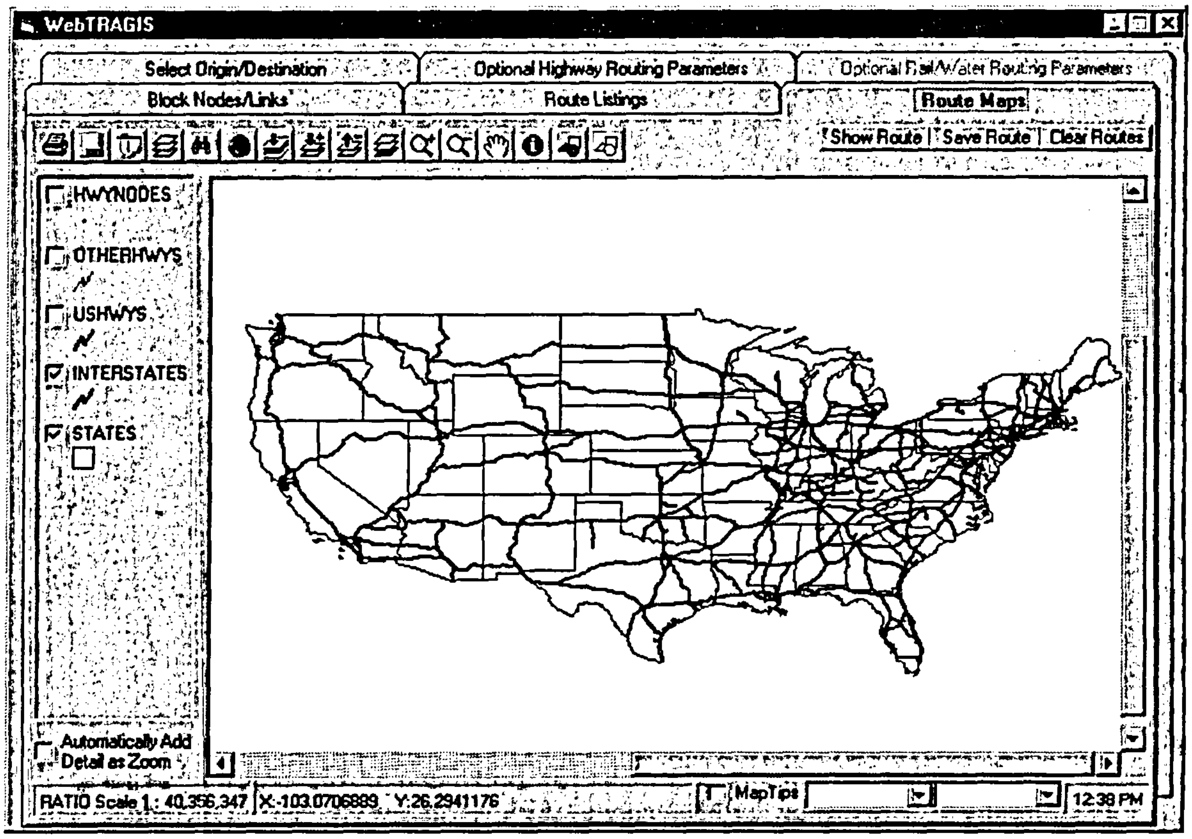

Fig. 6.1 Route maps.

6.1.1 Print

The **Print** button is symbolized by a icon of a printer. This button allows the printing of the current map display.

6.1.2 Save As

A floppy disk icon symbolizes the **Save As** button. This button allows saving the current map display as an enhanced windows metafile or as a bitmap file. The default is as an enhanced metafile because a metafile can be resized without appreciable loss of detail. This makes insertion of maps into a document easy.

6.1.3 Copy

The **Copy** button is symbolized by a paper clip on a piece of paper. This button copies the currently displayed map onto the Windows clipboard, so it can be pasted into Windows applications.

6.1.4 Map Properties

Three-colored layers symbolize the **Map Properties** button. This button opens a window that allows the user to change properties of the map.

6.1.5 Search

The **Search Map Information Files** button is symbolized by a binocular. The maps have data elements associated with them, such as highway sign, speed limit, node names, etc. This button opens a window that allows the user to search these data elements.

6.1.6 Display Full Extent of Map

The **Display Full Extent of Map** button is symbolized by a globe. This button zooms out to fill the map display with the entire map.

6.1.7 Display Map to Extent of Active Layer

The **Display Map to Extent of Active Layer** button is symbolized by an arrow pointing into three gray layers. This button zooms out to fill the map display with the current layer data.

6.1.8 Add Map Layer

The **Add Map Layer** button is symbolized by an arrow pointing into colored layers with a plus sign. This is usually used to display a route that was saved earlier. Click this button, and a file selection dialog box will allow the selection of a map layer to display.

6.1.9 Remove Active Map Layer

The **Remove Active Map Layer** button is symbolized by an arrow pointing out of colored layers with a minus sign. Choose a map layer by clicking on the title of the map layer in the legend, and then click this button to delete layer from the map.

6.1.10 Modify Map Layer Properties

The **Modify Map Layer Properties** button is symbolized by colored layers with green, yellow, and red layers. This button opens a window to allow the user to modify the properties of the current map layer. The current layer is denoted by an outline on the legend.

6.1.11 Zoom In

The **Zoom In** button is symbolized by a magnifying glass containing a plus sign. This tool is used to zoom in or to enlarge an area within the display. To perform a zoom in, choose the zoom in tool so that the button icon appears depressed. When moving the pointing device over the display window, the pointer icon appears as the magnifying glass with a plus sign in it. Position the pointing device at a corner of the area desired to be enlarged while holding down the left mouse button. Move the pointer to the opposite corner of the desired area and release. The display window is redrawn.

6.1.12 Zoom Out

The **Zoom Out** tool is symbolized by a magnifying glass containing a minus sign. This tool is used to show a larger geographic area in the display. To zoom out, use the left mouse button to choose the **Zoom Out** button. The **Zoom Out** tool functions in a way opposite that of the zoom in tool. If the click-and-drag method is used, the smaller the area that is defined, the more area will be displayed after the zoom out.

6.1.13 Pan

A hand symbolizes the **Pan** tool item. This tool will pan or drag the display in the direction the cursor is moved in order to reposition the map within the window. As with other tools, first choose the **Pan** tool and then move the pointer over the display window. The pointer will be displayed as a hand. Hold the left mouse button down and drag the display within the window.

6.1.14 Identify

The **Identify** tool button has a lowercase I inside a black circle. This tool is used to display information about features in the map display. To use this tool, first choose the identity tool in the tool bar. Next, examine the legend box to determine which theme is currently highlighted (the item that appears to have a highlight box around it). To change the highlighted theme, move the pointer over the theme name and click either the left or right mouse button. Now click on a feature in the display, and an identity-results window will appear which lists all the attribute variables and their values for that feature. To remove the identity-results window, move the pointer over the title bar of this window and press the **X** button.

6.1.15 Add Graphics to Map

Colored geometric shapes symbolize the **Add Graphics to Map** button. This tool allows the user to draw dots, straight lines, multiple-point lines, rectangles, circles, and polygons. To select the appropriate item, press the **Add Graphics to Map** button. A new tool bar will appear showing icons for the different features available. After selecting a type of feature to draw, the symbol can be drawn. The technique used for each type of draw tool varies; either click at one spot (to locate a dot); multiple spots with a double-click to end (to draw lines, rectangles, and polygons); or click, hold, move, and release (to draw circles).

6.1.16 Remove Graphics

Gray geometric shapes symbolize the **Remove Graphics** button. The **Remove Graphics** tool is the right-most item on the tool bar. Clicking this button will remove all graphics added to the map with the **Insert Graphics** button.

6.2 SHOW ROUTE

Depressing the **Show Route** button converts the data from the last route calculated and displays the route on the map.

6.3 SAVE ROUTE

The **Save Route** button saves the last route calculated in the map layer format so that the route can be displayed later using the **Add Map Layer.** This is useful when it is desired to display several routes on a single map.

6.4 CLEAR ROUTES

Depressing the **Clear Routes** button clears all routes from the displayed map.

6.5 OTHER ITEMS

At the bottom of the map is a status bar. The first item displays the scale at which the map is currently displayed. The second item displayed the X, Y coordinates of the map cursor. The display is in decimal degrees.

The third item contains a check box titled "MapTips" and two drop down lists. Checking this box will display information associated with the map available for display. The first drop-down list shows the map layers. The second drop-down list shows the data elements available for the map layer selected by the first drop-down list. Select the desired map layer in the first drop-down list. Next select the desired data item from the second drop-down list; then hold the cursor still over the map feature. After a second or so, a box will appear showing the data item related to that map feature.

The fourth item displays the computer's clock.

7. CONCLUSION

WebTRAGIS provides a major change in technology from the earlier routing models developed at ORNL. The HIGHWAY and INTERLINE models were developed at a time when text based programs were the standard form. Additional improvements will be made to WebTRAGIS to improve and enhance the performance of the model.

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Health Risks From Exposure to Low Levels of Ionizing Radiation

BEIR VII–Phase 2

Committee to Assess Health Risks from Exposure to Low Levels of Ionizing Radiation

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RADTRAN 5 User Guide

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RADTRAN 5 User Guide

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Abstract

This User Guide for the RADTRAN 5 computer code for transportation risk analysis describes basic risk concepts and provides the user with step-by-step directions for creating input files by means of either the RADDOG input file generator software or a text editor. It also contains information on how to interpret RADTRAN 5 output, how to obtain and use several types of important input data, and how to select appropriate analysis methods. Appendices include a glossary of terms, a listing of error messages, data-plotting information, images of RADDOG screens, and a table of all data in the internal radionuclide library.

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1. Introduction and Overview

The RADTRAN computer code is used for risk and consequence analysis of radioactive material transportation. A variety of radioactive materials (RAM) is transported annually within this country and internationally. The shipments are carried out by overland modes (mainly truck and rail), marine vessels, and aircraft. Transportation workers and persons residing near or sharing transportation links with these shipments may be exposed to radiation from RAM packages during routine transport operations; exposures may also occur as a result of accidents. Risks and consequences associated with such exposures are the focus of the RADTRAN 5 code.

The User Guide specifies and describes the required data, control inputs, input sequences, analyst options, and other information and activities necessary for execution of RADTRAN 5.

1.1 History of RADTRAN

Sandia National Laboratories (SNL) in Albuquerque, New Mexico, developed the RADTRAN code. It was first released in 1977 (Taylor and Daniel, 1977) in conjunction with the preparation of NUREG-0170 (NRC, 1977). The analytical capabilities of the code have been expanded and refined in subsequent releases. RADTRAN II was released in 1983 (Madsen et al., 1983), and RADTRAN III was released in 1986 (Madsen et al., 1986). RADTRAN 4 (Neuhauser and Kanipe, 1992) represented a major new direction for RADTRAN development. The analyst now could carry out route-specific analyses by assigning route-segment-specific values for a number of parameters (population density, vehicle speed, traffic count, etc.) to up to 60 route segments per run. These route-specific capabilities were improved and expanded in RADTRAN 5, and a number of features have been added.

1.2 Features of RADTRAN 5

RADTRAN 5 may be used to evaluate radiological[1] consequences of routine, accident-free transportation of radioactive materials, as well as radiological and nonradiological consequences and risks from accidents that might occur during transportation of such materials. RADTRAN 5 produces estimates of incident-free population dose, accident dose-risk, nonradiological traffic mortality, and a suite of individual dose estimates. Doses and dose risks[2] may be converted to health risks. Calculation of incident-free population dose considers persons adjacent to the route (off-link), persons in vehicles sharing the route (on-link), crew members, and persons at stops. Potential dose risks are calculated for populations downwind from hypothetical releases associated with accidents of varying severities.

1 A unit risk factor for latent cancer fatalities putatively caused by vehicle emissions is available in RADTRAN, but the postulated health effect of such emissions is speculative at best.

2 Dose-risk is the product of a given consequence dose and its probability of occurrence.

1.3 Route-Specific Analysis

RADTRAN 5 permits route-specific analyses to be performed. A route may be subdivided into segments with independent, analyst-assigned values for population density and other route-specific parameters. Features include (1) an expansion of the number of parameters that can be made segment-specific, (2) the capability to treat individual stops separately, and (3) the capability to treat each handling separately.

The internal library of radionuclide-related parameter values contains data on 60 of the most commonly transported radionuclides. The analyst can also independently define additional radionuclides.

1.4 User-Definable and Standard Parameters

Nearly all RADTRAN 5 parameters are user-definable. An array of "standard" or recommended values for many parameters is available. The analyst may employ all, some, or none of these values, as the needs of the analysis dictate. Parameters are defined and discussed in detail in Chapter 3. Analysis strategies are addressed in Chapter 4.

1.5 Maximum Individual Accident Dose

RADTRAN 5 permits direct estimation of individual accident doses by a method that parallels the population-dose consequence calculation. The calculations differ in two essential features. (1) The minimum centerline downwind distance associated with a given time-integrated concentration may be included in the appropriate input-data array. The analyst may calculate distance values with dispersion codes such as INPUFF (Petersen et al., 1984). (2) The calculated population dose in an isopleth is divided by the total population in that isopleth. This simple arithmetic operation yields a mean individual dose to persons within a given isopleth, which may then be associated with the minimum centerline distance value for that isopleth. This capability was tested as an independent code, called TICLD (Transportation Individual Centerline Dose), prior to being incorporated into RADTRAN 5 (Weiner, Neuhauser, and Kanipe, 1993).

1.6 Ingestion Dose Model

A development goal has been to keep RADTRAN calculational methodologies reasonably parallel to the MACCS code (Melcor Accident Consequence Calculational System), now in its second major release, MACCS2 (Chanin and Young, 1997). COMIDA2, which is based on a dynamic food chain model (Abbot and Rood, 1994a,b), is the ingestion model used in MACCS2. Values of ingestion-dose per activity unit of ground deposition have been pre-calculated for most radionuclides in the internal library.[3] The COMIDA2 module of MACCS2 may be used

[3] Ingestion factors are not calculated for radionuclides with half-lives of less than 1 hour.

directly to obtain values for unusual radionuclides or unusual situations. The dose values for prompt health effects also have been updated to be consistent with MACCS2.

1.7 Nonradiological Fatalities

The expected numbers of fatalities from mechanical effects of traffic accidents are calculated in RADTRAN 5 under keyword NONRAD.[4]

1.8 Sensitivity and Uncertainty Analysis

In previous releases of RADTRAN, the sensitivity of the incident-free dose result to variation of the input parameters could be analyzed. The analysis method depends on obtaining partial derivatives of linear equations in RADTRAN. With the advent of the capability to consider the neutron component of dose rate (if any) explicitly, the calculation of incident-free dose could involve nonlinear relationships for which the partial-derivative method might prove inadequate. The partial-derivative method is still available, but other methods also may be employed. Sensitivity and uncertainty measures for RADTRAN analyses now may be obtained with the assistance of a separate computer code, the Latin Hypercube Sampling (LHS) code (Iman & Shortencarier, 1984). The LHS code can be used as a "shell" with RADTRAN (Mills et al., 1995) and is available on TRANSNET, the RADTRAN Internet site (see Chapter 3, Section 3.2.1). Classical Monte Carlo methods have been applied in the past (e.g., Neuhauser & Reardon, 1986) and still may be used.

1.9 Mathematical Models in RADTRAN 5

RADTRAN 5 models yield conservative estimates of integrated population dose and other metrics in a way that can be supported by readily available data. Data gathering is usually the most expensive and time-consuming part of performing a risk analysis. An example of unobtainable data is detailed meteorological information for each point or segment of a route. The limitations imposed by data availability are explicitly acknowledged in the development of RADTRAN 5.

All route segments are modeled as straight lines without grade or curves, providing ease of calculation and yielding slightly conservative dose estimates (because the dose calculation involves integration to infinite distance from the package although actual route segments have finite lengths). All highway and rail links are treated as being one lane (or track) wide for the purpose of estimating distances to population beside the road or railroad. However, they are treated as being two lanes wide (one lane or track in each direction) for the purpose of estimating doses to persons in vehicles sharing the road or railroad. The first treatment achieves symmetry

---

[4] Only fatalities from accidents are calculated; hypothetical fatalities from inhalation of vehicle exhaust particulates are no longer calculated because toxicity thresholds for exhaust constituents are now well known and the unit-risk-factor approach can no longer be justified (see Chapter 5).

(and, hence, mathematical simplicity) around the lane in which the shipment is traveling. The second treatment (one lane each direction) yields the smallest perpendicular distance and, hence, the highest incident-free dose to persons in vehicles traveling in the opposite direction. Thus, for this latter purpose, all rail routes are modeled as having double tracks, when in fact double tracks are not common. Such departures from absolute parallelism with physical reality have been used to simplify a calculation without either underestimating or greatly overestimating dose or risk, and to reduce expensive data-gathering requirements. Details of the RADTRAN 5 mathematical modeling may be found in the RADTRAN 5 Technical Manual (Neuhauser, Kanipe and Weiner, 1999).

1.10 Technical Information Summary

RADTRAN 5 is written in ANSI Standard FORTRAN 77 (ANSI, 1978) and is operational on a HP-UNIX computer at SNL in Albuquerque, New Mexico. Execution time for a single problem is usually between a few seconds and about a minute, depending on the length of input and output files. The input file is named R5IN.DAT. There are a total of 73 subroutines and functions in RADTRAN 5. The main routine is named RADTRN. Instructions for creating input files and for saving and renaming output files are given in Chapter 3. The results of intermediate accident-risk calculations are written to R5INTERM.DAT. Probability-consequence pairs are written to R5PLOT0.DAT, R5PLOT1.DAT, and R5PLOT2.DAT for later graphical or quality-assurance applications (see Appendix B). RADTRAN 5 has been recompiled with a FORTRAN 95 compiler; the compiled product is RADTRAN5 PC, runs locally on a PC (currently in beta-test version).

1.11 Outline of User Guide

Chapter 2 defines essential terms and concepts that are used throughout this guide. Chapter 3 provides instructions for data entry and Chapter 4 is a guide to the output. Chapter 5 discusses options and strategies for performing analyses with RADTRAN 5 and describes the basic output. Appendix A is a Glossary of Terms. Appendix B describes the data from intermediate calculations written to output file R5INTERM.DAT and contains instructions on how to generate probability-consequence plots of the data with output files R5PLOT0.DAT, R5PLOT1.DAT and R5PLOT2.DAT. Appendix C contains a list of RADTRAN 5 error messages and suggested error-correction strategies. Appendix D contains the Radionuclide Data Library.

2. Transportation Risk - Concepts and Overview

A number of terms used throughout this User Guide have specific meanings in the fields of radiological risk analysis and radioactive materials (RAM) transportation. The most important of these, along with terms for underlying concepts of radioactivity and risk, are defined and explained in this chapter. A full Glossary of Terms may be found in Appendix A.

2.1 Risk and Risk Assessment

Risk is commonly defined as the product of a consequence and its probability of occurrence. What this means in the context of RADTRAN 5 is that transportation risks, like the risks associated with any complex process, may be decomposed into "what can happen...how likely things are to happen, and the consequences for each set [of things that can happen]" (Helton, 1991). As the terminology in this definition implies, set theory provides an ideal framework for formal expressions of risk.

For accident risk assessment, the answer to the first question ("What can happen?") is that the set of all accidents can be expressed as disjoint sets of accidents (S_i, i=1,...nS). In other words, sets of accidents such that

(1) no two sets contain any accidents in common (i.e., are disjoint),

(2) each set consists of accidents with similar outcomes, and

(3) the sets are jointly exhaustive (that is, all the sets taken together include the entire range of accidents from low consequence to high consequence).

"How likely things are to happen" can be defined as the probability that an accident in set S_i will take place. The "consequences for each set" consist of one or more specified consequence results (population dose, early morbidity, etc.) (Helton, 1991).

In accident risk analysis with RADTRAN 5, the set of all accidents for the mode(s) being analyzed must be divided by the analyst into subsets (i.e., into the subsets S_i, i=1,...,nS), as described above. The subsets also must satisfy the other conditions described in the previous paragraph. The term "similar outcomes" refers to similar package damage and not to any other features such as driver mortality or time of day. The subsets and their probabilities are most commonly developed by means of event-tree analysis, but are not required to be. In RADTRAN, these subsets are referred to as *accident-severity categories.*

Corresponding probabilities are obtained from the products of accident rate and *severity fraction* values.

Severity fraction is defined as the conditional probability, given that an accident occurs, that it will be of a specified severity (i.e., belong to a given accident subset). Examples of accident-severity category development include the work of Wilmot (1981), Fischer et al. (1987), and Sprung et al. (1998; 2000).

RADTRAN calculates distinct probability-consequence products for up to six exposure pathways for each accident-severity category for all route segments. These products are summed and printed in the main output file. The individual probabilities, consequences, and products are also saved and written to supplementary output files (R5INTERM.DAT, R5PLOT0.DAT, R5PLOT1.DAT, and R5PLOT2.DAT), as discussed in Appendix B.

2.2 Terms used in Radioactive-Material Transportation

2.2.1 Package and Packaging

The terms "package" and "packaging" are defined in Volume 10 of the Code of Federal Regulations (CFR), Title 71.4 (10 CFR 71.4). Briefly, in radioactive-material transportation, a *package* consists of a *packaging* and its *radioactive contents*. A packaging consists of one or more receptacles and wrappers and their contents, excluding radioactive materials but including absorbent material, spacing structures, thermal insulation, radiation shielding, devices for cooling and absorbing mechanical shock, external fittings, neutron moderators, nonfissile neutron absorbers, and other supplementary equipment. The radioactive contents may consist of one or more radioactive materials, which are defined in the next section.

2.2.2 Radioactive Materials, Physical-Chemical Forms, Isotopes, and Radionuclides

The *radioactive contents* of a package are defined by regulation as *radioactive material* (10 CFR 71.4), which is often abbreviated as RAM. A radioactive material must contain at least one *radionuclide*. The term radionuclide refers only to unstable nuclides that emit ionizing radiation.

The description of a radioactive material (package contents) in a RADTRAN 5 analysis must include a user-assigned name, also referred to as a *package identifier*. Each material has one or more *physical-chemical forms,* which are assigned via the constituent radionuclides. Physical-chemical form is a function of physical properties [i.e., whether the material is a monolithic solid, divided solid (powders of various types), liquid, or gas] and chemical properties (such as melting point or oxidation state) that might affect dispersion or toxicity in potential accidents.

RADTRAN 5 permits the analyst to identify one or more physical-chemical forms for each material. Each such form is known as a *physical-chemical group*, and each must be assigned a *physical-chemical-group identifier,* as shown in Box 2-1. Each radionuclide in a material must be assigned to at least one group. Properties such as deposition velocity, which depend on physical state (particle size in the case of deposition velocity), are assigned to the physical-

BOX 2-1
PACKAGE IDENTIFIERS, PHYSICAL-CHEMICAL GROUPS, AND NUCLIDES

Examples of Package Identifiers (Material Names) (analyst assigned):
UO2 POWDR for Uranium Dioxide Powder
VHLW for Vitrified High-Level Waste
MOLYGEN for Molybdenum-99 Generator

Examples of Physical-Chemical Group Identifiers (analyst assigned):
VOLSOL for volatile solids (e.g., radioruthenium)
GAS for gaseous materials such as tritium gas
POWDR1 for a metal oxide such as uranium dioxide with a 1-mm average particle diameter

Examples of Radionuclides and their RADTRAN 5 Identifiers (fixed; analyst cannot vary)
Uranium-235; identifier is U235
Cesium-137; identifier is CS137
Molybdenum-99; identifier is MO99

chemical group. Photon energy, on the other hand, is a property of atoms and so is assigned to individual nuclides. Physical-chemical properties of materials cannot be supplied in advance by RADTRAN. Most radionuclide properties, however, are supplied in the internal library of radionuclide data (see Chapter 3). The notable exception to this is, of course, the radionuclide inventory, i.e., the amount of each radionuclide that is present in the package. Nuclide identifiers, when entered in the format recognized by the RADTRAN 5 internal library (see box for examples), will cause all recorded nuclide properties to be automatically entered in the input file.

2.2.3 Shipment and Related Terms

Shipment, Conveyance, Vehicle, Vessel

A *shipment* is defined as the set of all packages in one or more conveyances, traveling together as a unit. A *conveyance* is any *vehicle*, *vessel*, railcar, or aircraft used to transport packages. Although the term vehicle generally refers to trucks, vans, etc. for highway-mode transportation, the terms vehicle and conveyance are often used interchangeably. The term vessel refers only to ships and barges for waterway-mode transportation. More than one package of radioactive material may be transported together in a single conveyance. In the rail mode, more than one conveyance may be transported at the same time in a single shipment (i.e., several railcars in a single train).

Transportation Modes and Vehicles

Commercial transportation involves one or more of the five basic modes: highway, railway, waterway, passenger air, and cargo air. Five variants of highway and two variants of waterway mode have been included in RADTRAN 5 for analyst convenience. The modes and variants available in RADTRAN 5 are listed in Table 2-1, which also indicates the conveyance types most likely to be used with each mode or variant. The old designators used in previous releases of RADTRAN are included for the convenience of long-time RADTRAN users. Each of the transportation modes and variants available in RADTRAN 5 is assigned a numerical mode-identifier (Table 2-1). Potential operational differences within the rail mode (e.g., the differences between general rail freight and dedicated rail) are addressed with user-assigned variable values discussed elsewhere in this User Guide.

The analyst also identifies the transportation conveyance (the vehicle) and creates an alphanumeric identifier for each vehicle in a RADTRAN analysis (e.g., SEMI-TRUCK for a tractor-trailer and DELIVERY for a van). Each conveyance type is assigned to a transportation mode (see Table 2-1). The analyst also must enter information associated with the conveyance, such as number of crew members. Up to 12 distinct conveyance types may be described in a single RADTRAN 5 run. Each conveyance must be assigned to at least one mode, but assignment variations are permitted since more than one conveyance or mode may be used to get a single package or a shipment to its final destination. When more than one mode is used, the one in which the majority of the transportation occurs may be referred to as the *primary mode*, while others are referred to as *secondary modes*. A secondary mode is required when material must be moved to its primary-mode conveyance (e.g., an airplane) from its origin point or from the primary mode to its final destination by another vehicle, usually a truck or van.

Table 2-1. RADTRAN 5 Modes and Common Conveyance Types

Mode	Mode Number	Conveyance Types Associated with Mode	Old Name (RADTRAN 4)
HIGHWAY	1	Any truck; usually a tractor-trailer (also called a "semi" or a combination truck)	TRUCK
RAILWAY	2	One or more railcars in a single train	RAIL
WATERWAY_A	3	Any vessel; usually barge	BARGE
WATERWAY_B	4	Any vessel; usually ocean-going ship (>3000 gross tons)	SHIP
CARGO_AIR	5	Any plane carrying only cargo	CARGO_AIR
PASNGR_AIR	6	Any plane carrying passengers & cargo	PASS_AIR
HIGHWAY_A	7	Any truck; usually small truck or passenger van	P_VAN
HIGHWAY_B	8	Any truck; usually cargo van/delivery truck as secondary vehicle with tractor-trailer as primary mode	CVAN_T
HIGHWAY_C	9	Any truck, usually cargo van/delivery truck as secondary vehicle with rail as primary mode	CVAN_R
HIGHWAY_D	10	Any truck; usually cargo van/delivery truck as secondary vehicle with cargo air as primary mode	CVAN-CA

Terms Associated with Stops and Handlings

The term *stop* refers to any of the various events that may occur in the course of transportation during which a conveyance remains stationary. A *handling* is a special type of stop that is treated separately in RADTRAN 5. In all stops, the shipment is modeled as a stationary point- or line-source; the duration of the stop and the number and average distance (or population density) of persons in the vicinity of a stop are problem-specific input parameters. The RADTRAN 5 stop model is flexible and can be used to describe most transportation-related stops with little difficulty. Common types of stops modeled are listed in Box 2-2 and described briefly below:

Box 2-2 - Common Types of Stops
-Rest/Refueling (Highway mode)
-Classification (Rail mode)
-Port Call (Water modes)
Intermodal Transfer (any 2 modes)
Storage (any mode)

- Rest/Refueling Stops (HIGHWAY Mode). For commercial truck shipments, most stop time is incurred at commercial truck stops. Data for this type of stop have been published (Griego et al., 1996; Madsen and Wilmot, 1983). In the case of delivery vans, especially when used as a secondary mode, the stop time is incurred primarily at traffic stops and at intermediate destinations (when packages are delivered to two or more destinations by the same conveyance).

- Classification Stops (RAILWAY Mode). The majority of stop time for trains is incurred at classification yards, which may be thought of as "nodes" along the rail network where trains are broken down and reassembled into new trains according to their ultimate destination on the network. Railcars are inspected at classification stops, and rail inspectors may be exposed as a result. Other personnel in the rail yard also would come within various distances of cars carrying radioactive material while performing their duties. Ostmeyer (1986) models this type of stop, and rail worker doses are automatically calculated in RADTRAN 5 according to the Ostmeyer model. However, the stop model is used to assess the area surrounding the classification yard.

- Port Calls (WATERWAY Modes). Most stop time in maritime modes is incurred in ports either at the dock or in an anchorage. Inspectors from the U.S. Coast Guard, the port authority, and possibly the carrier or shipper, may incur exposure during inspection of packages in the cargo areas. Transportation by ship or barge is nearly always a primary mode used in conjunction with a secondary surface mode. Therefore, exposures incurred during or after loading and offloading a ship or barge fall under the heading of intermodal transfers, which are discussed below.

- Intermodal Transfers. Packages may be carried part of the way by one mode, removed from the first conveyance, placed in another, and transported all or part of the remaining distance by a second mode. Each change from one mode to another is defined as an intermodal transfer. One or more intermodal transfers may be required to get a package from its origin point to its final destination. For example, carriage of a package by vessel (ship or barge) is usually preceded by carriage by truck or rail from the package's origin point to a marine port, where the package is loaded onto a vessel (1st intermodal transfer). At the final port of call, the package is usually offloaded to a truck or railcar that carries the package to its final destination (2nd intermodal transfer). Doses to port workers (except handlers) incurred during an intermodal transfer can be calculated with the RADTRAN STOP model (Neuhauser and Weiner, 1992a:b)

- Storage. Temporary storage may be associated with intermodal transfer. Warehouse employees and other workers may be exposed during storage. Storage is modeled in the same manner as an ordinary stop with appropriate input values, as described by Neuhauser and Weiner (1992a).

2.3 Two Options in Stop Model

A stop can be modeled in two ways, as described in Box 2-3. Either radius values and population densities or distances and numbers of persons are assigned by the analyst. RADTRAN 5 allows the analyst to separately label each stop, although stops also can be treated in an aggregate manner. In the latter case, for example, all fuel stops might be treated as a single stop equal in duration to the sum of the durations of individual stops, with average or bounding values for other parameters.

Box 2-3. Two Ways to Estimate Potentially Exposed Population at a Stop

1. Population Density within annular area(s) – User specifies population density and two or more different radial distances
2. Number of Persons at an average radial distance – User specifies number of persons and one radial distance

2.4 Separate Model for Handling and Inspection

Handlings and inspections are special types of stop-related activities that are treated separately under keyword HANDLING. Handlers and inspectors are routinely located closer to a package or shipment for longer periods of time than most other persons at stops. Thus, they constitute special subgroups of potentially exposed persons for whom dose estimates may be separately calculated (Weiner and Neuhauser, 1992a,b). A line-source method of calculating handling dose is used for all but the smallest packages. Doses for handling the latter are calculated with an empirical factor. As noted in the section on stops, intermodal transfers have characteristics of both a stop and a handling.

Commercial maritime carriers usually plan a sequence of port calls to take on and discharge cargo in the course of a single voyage. Radioactive materials packages that may be onboard would experience stop time at each such intermediate port, but measurable exposure would normally be limited to hold inspectors, and the latter are modeled under keyword HANDLING.

Inspection/Weigh Station stops are often associated with state and national boundary crossings. Trucks and railcars carrying radioactive materials may be required to stop at a state boundary for inspection. Exposure of inspectors located at short distances from the shipment should be modeled with the HANDLING subroutine, while exposure of weigh-station operators and other personnel located at greater distances from the shipment should be considered under the keyword STOP.

3. Creating an Input File for RADTRAN

3.1 Access to RADTRAN 5

Analysts may access RADTRAN 5 by two means. The recommended method is to access the code by Internet via Sandia National Laboratories' TRANSNET system. The other method is to install an executable version on a UNIX workstation or mainframe computer. An executable version that operates under DOS or Windows is being developed.

3.1.1 The TRANSNET System

TRANSNET is a collection of risk, systems analysis, routing, and economic codes and related databases pertaining to RAM transportation. TRANSNET resides on a dedicated computer at Sandia National Laboratories. After obtaining a user name and password, analysts may access TRANSNET at no charge with a personal computer and an Internet connection. At present, TRANSNET is accessible only through a secure shell program.

3.1.2 Executable RADTRAN 5

Executable copies of RADTRAN 5 that run on a workstation or mainframe computer may be obtained by contacting the address shown in Box 3-1. RADTRAN 5 is resident at SNL on a Hewlett-Packard 700 Series computer running with a UNIX operating system. Other systems will also support RADTRAN 5. Details on installing RADTRAN 5 are machine-dependent; directions are provided at the time of request and are not discussed further in this User Guide. As previously noted, RADTRAN5 PC is now in beta-test form and may be generally available by 2004.

Box 3-1
FOR TRANSNET ACCESS consult
http://ttd.sandia.gov/risk/transnet.htm.

3.2 Accessing RADTRAN 5 on TRANSNET

Instructions for obtaining a secure shell program as well as access to TRANSNET may be found at http://ttd.sandia.gov/risk/transnet.htm. Basic hardware and software requirements for accessing TRANSNET are a personal computer, workstation, or other computer, and

- an Internet Service Provider (ISP), a web browser, and Secure Shell software;
- or a network or Ethernet board, a direct cable link to the Internet, and Secure Shell software

These topics are discussed in the revised "Guide to TRANSNET Communications and Operations," which is sent to users on request. TRANSNET cannot be accessed without an SNL-issued user name and password.

The RADTRAN Web Site may be accessed at http://ttd.sandia.gov/risk/radtran.htm. This URL is case-sensitive. Electronic versions of this User Guide, other code documentation, and up-to-date information regarding persons to contact, etc., are posted at this site.

3.3 RADTRAN 5 Input File Generator Software (RADDOG)

RADTRAN 5 input files may be created on the TRANSNET system by means of menus produced by the RADTRAN 5 Input File Generator (RADDOG).

The TRANSNET Guide provides general information on navigating the TRANSNET menus, and these menus lead to the TRANSNET RADTRAN 5.2.5 Control Menu (Figure 3-1) as follows:

- On the TRANSNET Main Menu, select Risk Assessment
- On the Risk Assessment menu, select RADTRAN 5..

3.3.1 RADTRAN 5 Control Menu[5]

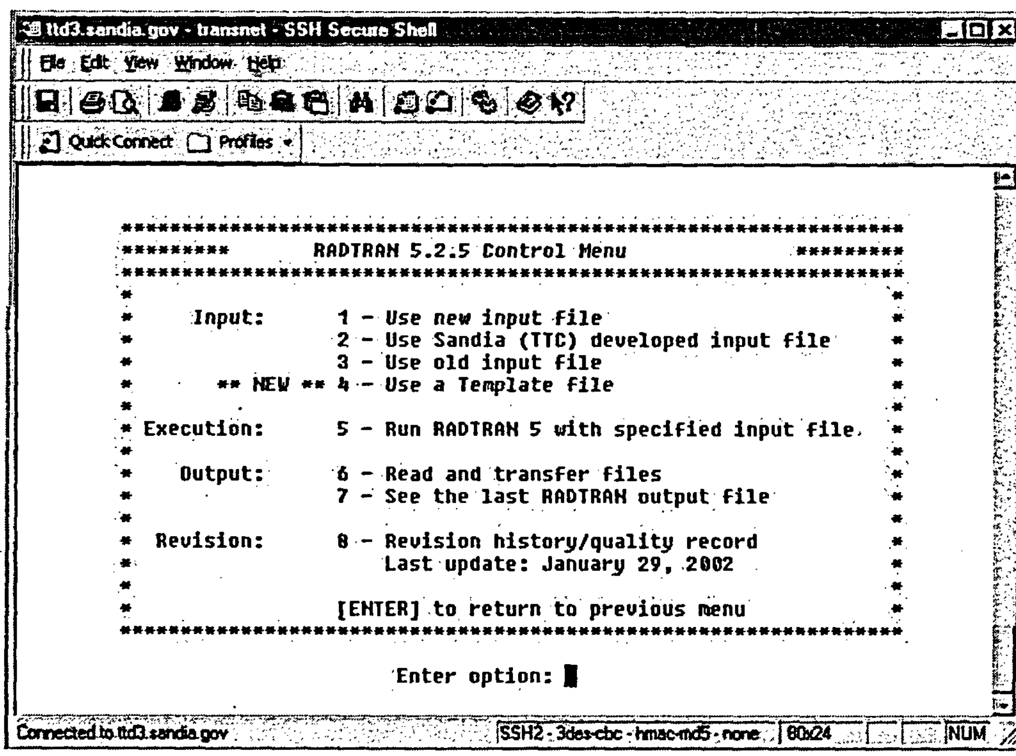

Figure 3-1 TRANSNET Control Menu

5 Figures 3-1 through 3-20 are screen prints using two different secure shell screens, SSH and F-Secure. The two shells have identical functionality.

3.3.2 Main Menu for the Menu System (RADDOG)

If the analyst enters the number 1 as an option, the RADDOG Main Menu, shown in Figure 3-2, appears.

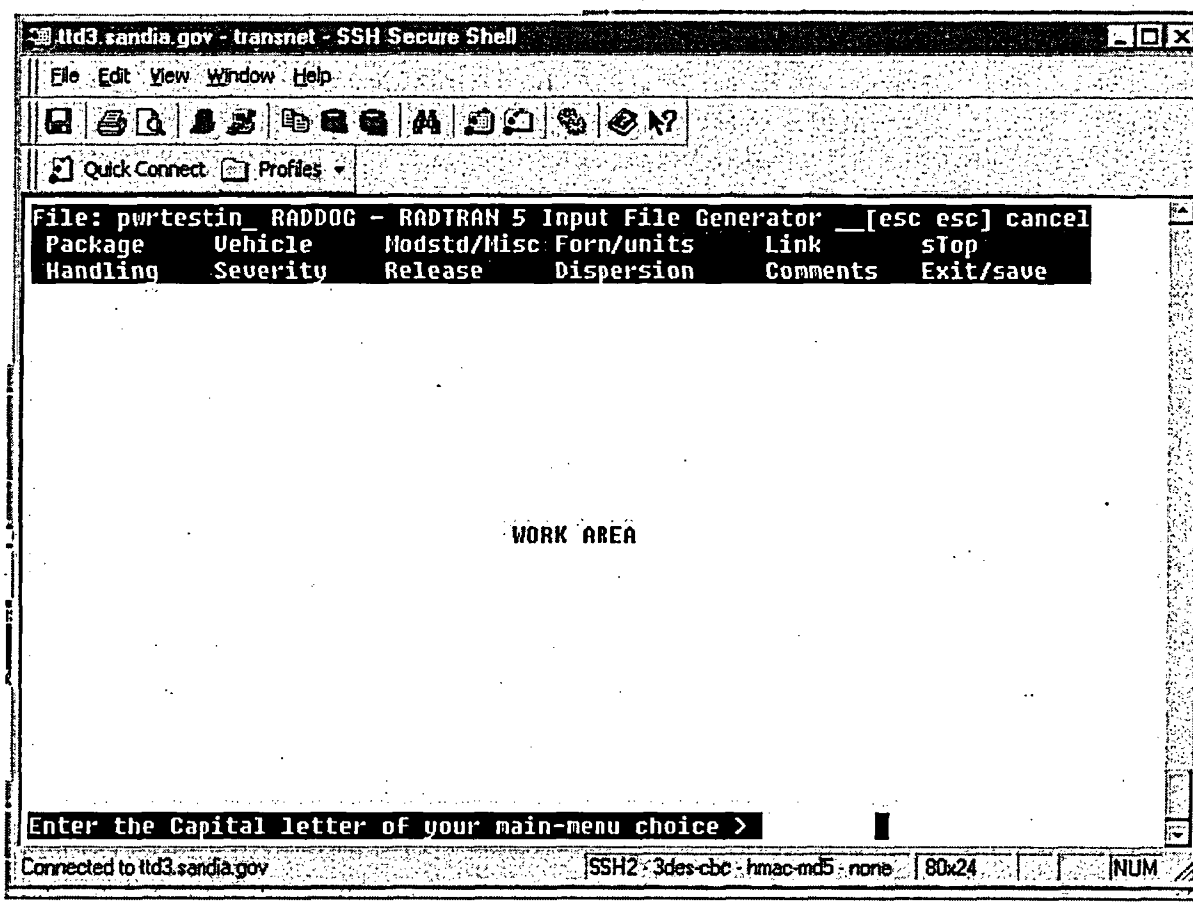

Figure 3-2. RADDOG Main Menu

The work area of the Main Menu is blank. Twelve headings appear at the top of the Main Menu screen. Each heading except the last (Exit/save) represents one or more subordinate menus in which various types of input data are entered.

A command line appears at the bottom of every menu screen. The text on the command line tells the analyst what commands may be used for each screen; the blinking cursor following the informational text indicates where typed commands entered by the analyst will appear. The command line of the Main Menu informs the analyst that he or she must enter the capitalized letter of a heading in order to bring up the menu screen(s) for that class of data. For example, enter "T" for the stop menu screen.

If the analyst selects a TTC file or an old input file, a message asking "Do you want to open or modify this file?" appears. Answering "yes" brings up the screen shown in Figure 3-2, to which the name of the selected file has been added at the top.

3.4 RADTRAN 5 Data-Entry Menus

Data-entry menus are subordinate to the RADDOG Main Menu and are reached by typing the appropriate heading letter. For example, typing "P" on the Main Menu command line (with no carriage return) brings up the Package screen (Figure 3-3). Data must be entered by typing in the appropriate alphanumeric; the program does not respond to mouse signals. Text on the screen can only be edited from left to right and top to bottom. Movement between columns is accomplished by using the tab or arrow key. There is no copy-and-paste utility. Typing "Q" in a column while editing exits the analyst from that column. Data can be saved only by typing "E" for Exit after returning to the Main Menu and naming the file by following on-screen instructions.

Data are entered and modified in the same manner on every screen brought up under each heading at the top of the Main Menu. The preferred order is to work sequentially from left to right, starting with "Package," because some values that appear in later screens depend on those entered in earlier screens.

The data entries for each menu are discussed in somewhat greater detail in Section 3.7.

3.4.1 Package Menu

Selecting "P" for "Package" brings up the screen shown in Figure 3-3

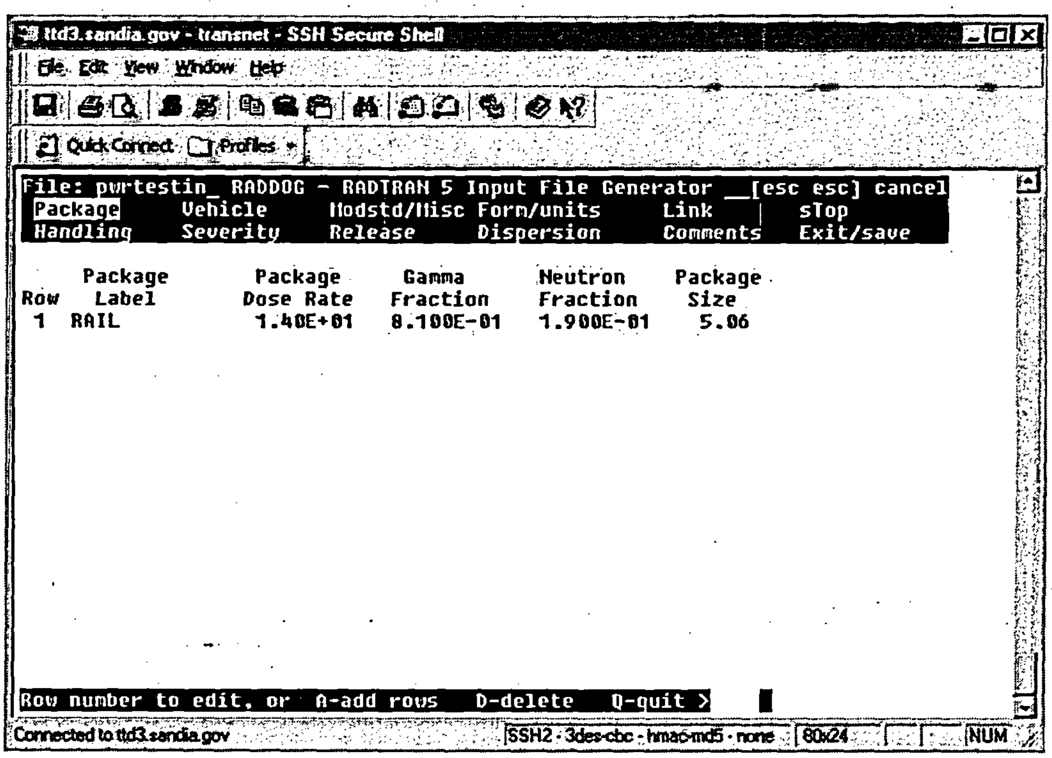

Figure 3-3. Package Menu

The word "Package" is now highlighted on the screen, and column headings for package-related parameters appear in the Work Area. The analyst is prompted to enter an alphanumeric package label and appropriate numerical values in the remaining columns in the row. If the analyst were modifying an existing file, he or she would first enter the number of the row to be modified. A duplicate number appears under the "Row" heading. When data entry is complete, typing "Q" (for quit) brings up the screen shown in Figure 3-4. Note that if no data are entered, the analyst is prompted for a name for the package.

Radionuclide Sub-menu

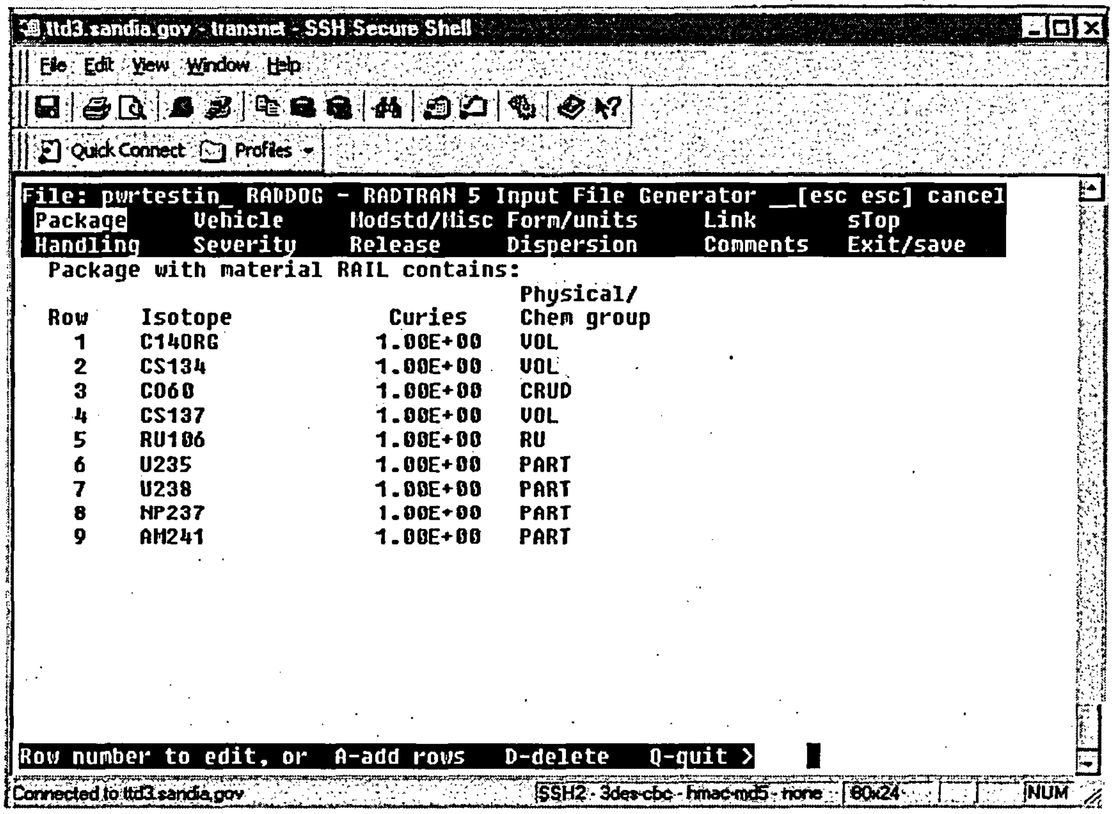

Figure 3-4.Radionuclide Sub-menu to the Package Menu

If the analyst enters a radionuclide name or symbol that is not is the RADTRAN internal library, a prompt will appear asking if the name is correct. Responding "yes" (i.e., that a radionuclide name that is not in the internal library is entered deliberately) brings up a screen on which the half-life, photon energy and dose conversion factors for the radionuclide can be entered by the analyst.[6] The radionuclide screen (Figure 3-4) can accommodate up to 200 radionuclides. Up to 15 different physical/chemical groups can be designated, and their names are user-defined. Editing any row requires first entering the number of the row to be modified. Typing "Q" in a row causes exit from that row.

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6 Federal Guidance Reports 11 and 12, and the Health Physics Handbook (Shleien et al, 1996) are appropriate sources for this information.

3.4.2 Vehicle Menu

Quitting the screen of Figure 3-4 returns the analyst to the RADDOG Main Menu (Figure 3-2). Selecting "V" brings up the vehicle screen shown in Figure 3-5.

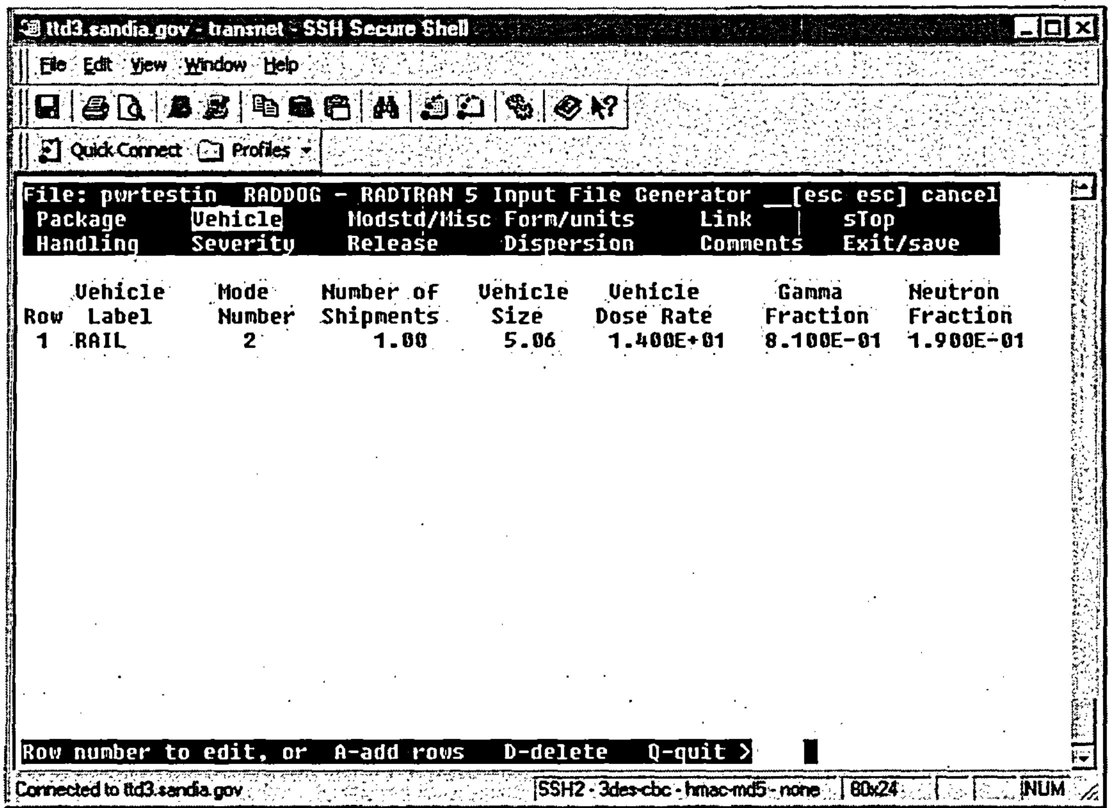


Figure 3-5. Vehicle Menu

The remaining vehicle parameters: crew size, distance of the crew from the source ("crew distance"), crew shielding ('crew modfac"), end dimension of the package ("crew view"), and number of packages per vehicle, are entered by quitting the screen in Figure 3-5. Editing any row requires first entering the number of the row to be modified. Typing "Q" in a row causes exit from that row.

3.4.3 STANDARD Parameter Value Menu

Quitting the last "vehicle" screen returns the analyst to the RADDOG Main Menu (Figure 3-2). Selecting "M" brings up a screen on which the analyst will be prompted to choose the STANDARD input file or the ZERO input file. The STANDARD input file continues a number of commonly used parameter values which the analyst can change if he or she desires to do so. In the ZERO file, all of these parameter values are zero, and the analyst must supply values. Use of the STANDARD file is recommended. Entering "S" to read in the STANDARD file brings up the screen shown in Figure 3-6. Opening an old file or a TTC file brings up the screen of

Figure 3-6 when "M" is selected. The analyst is free to substitute values for any of the STANDARD parameter values.

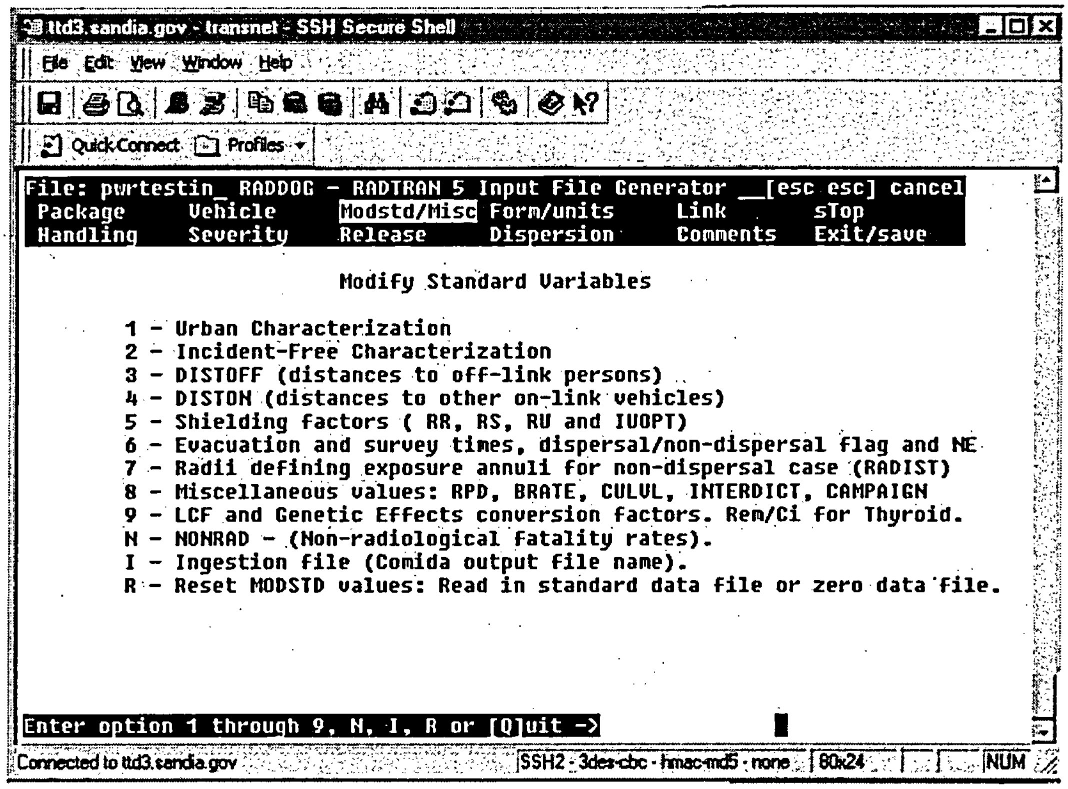


Figure 3-6. STANDARD Values Top-level Menu

3.4.4 Form and Units Menu

Selecting "F" from the Main Menu brings up the screen shown in Figure 3-7, which allows the analyst to select output as person-rem (and rem) or as latent cancer fatalities (LCF), and to choose to express doses output in Standard International units.

3.4.5 Links Menu

Selecting "L" from the Main Menu brings up the screen shown in Figure 3-8: the "Links" screen. A *link*, in RADTRAN parlance, is a route segment. Each link is characterized by its length in km, the off-link population density in persons/km^2, the total vehicle density in vehicles/hour, persons per vehicle and the vehicle accident rate in accidents/km. Each link should also be characterized in the column "Pop Zone" as rural (R), suburban (S), or urban (U), based on the population density in the 800-meter-wide strip along each side of the link. [7] The road type (column "RD") must also be designated:

[7] The usual divisions are R<59 persons/km^2, 59<S<1830 persons/km^2, U>1830 persons/km^2.

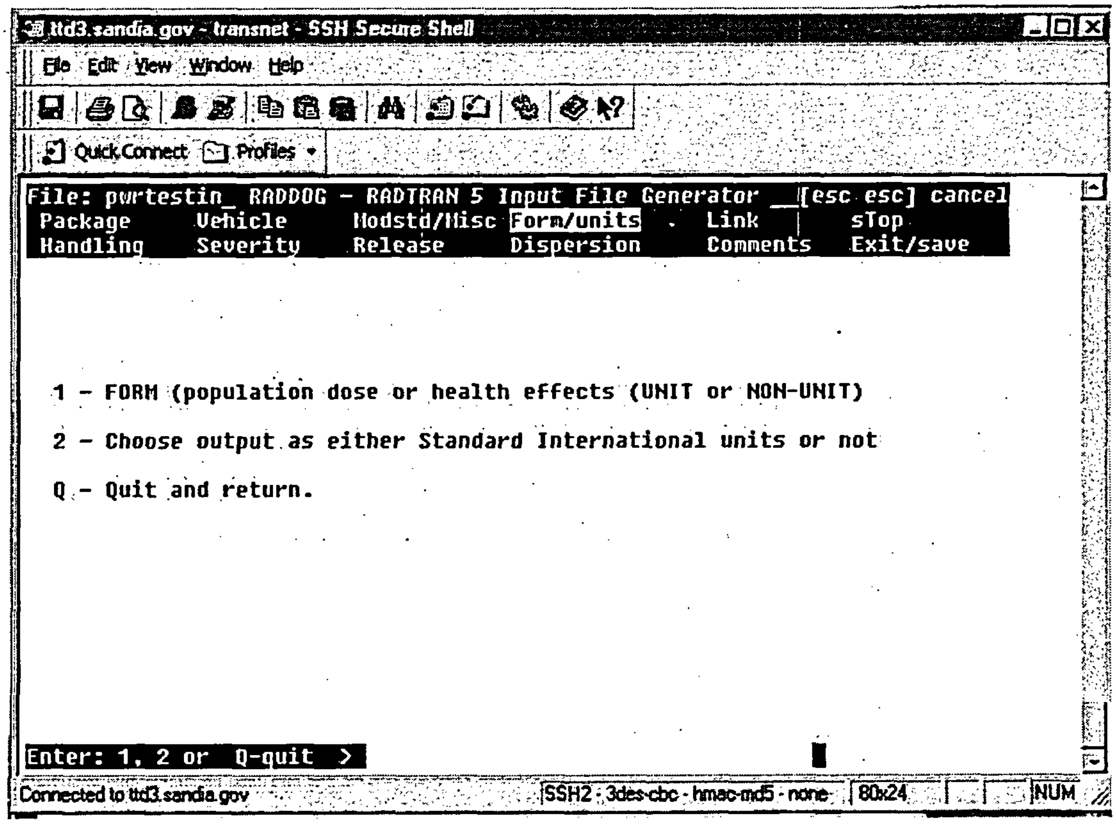


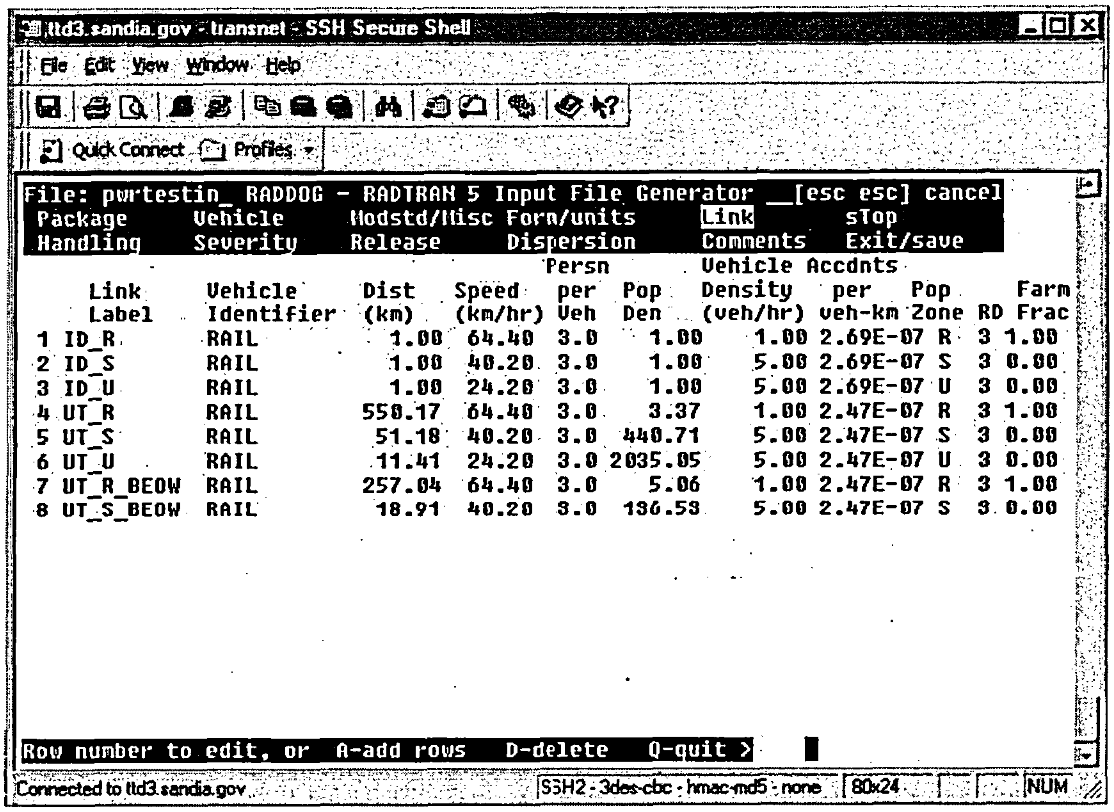
Figure 3-7. Form/units Menu

- RD=1: Interstate or primary US highway
- RD=2: Secondary road
- RD=3: Rail
- RD=4: Waterway

The fraction of land devoted to farming may be designated only for rural links. Note also that a new vehicle name cannot be added at this screen; the menu system will only accept vehicle identifiers that have been added at the "Vehicle" screen (Figure 3-5).

Accident frequency is usually state-by-state, and may be obtained from the U. S. Bureau of Transportation Statistics (http://www.bts.gov) or from a compilation of statistics like Saricks and Tompkins (1999). National average vehicle densities are approximately 470, 760, and 2800 vehicles per hour for rural, suburban, and urban links, respectively, but more accurate estimates may also be found on the Bureau of Transportation Statistics website.

As with similar screens, editing any row requires first entering the number of the row to be modified. Typing "Q" in a row causes exit from that row.


ttd3.sandia.gov - transnet - SSH Secure Shell

File Edit View Window Help

Quick Connect Profiles

File: pwrtestin_ RADDOG - RADTRAN 5 Input File Generator __[esc esc] cancel

Package Vehicle Modstd/Misc Forn/units Link sTop

Handling Severity Release Dispersion Comments Exit/save

	Link Label	Vehicle Identifier	Dist (km)	Speed (km/hr)	Persn per Veh	Pop Den	Vehicle Density (veh/hr)	Accdnts per veh-km	Pop Zone	RD	Farm Frac
1	ID_R	RAIL	1.00	64.40	3.0	1.00	1.00	2.69E-07	R	3	1.00
2	ID_S	RAIL	1.00	40.20	3.0	1.00	5.00	2.69E-07	S	3	0.00
3	ID_U	RAIL	1.00	24.20	3.0	1.00	5.00	2.69E-07	U	3	0.00
4	UT_R	RAIL	550.17	64.40	3.0	3.37	1.00	2.47E-07	R	3	1.00
5	UT_S	RAIL	51.18	40.20	3.0	440.71	5.00	2.47E-07	S	3	0.00
6	UT_U	RAIL	11.41	24.20	3.0	2035.05	5.00	2.47E-07	U	3	0.00
7	UT_R_BEOW	RAIL	257.04	64.40	3.0	5.06	1.00	2.47E-07	R	3	1.00
8	UT_S_BEOW	RAIL	18.91	40.20	3.0	136.53	5.00	2.47E-07	S	3	0.00

Row number to edit, or A-add rows D-delete Q-quit >

Connected to ttd3.sandia.gov SSH2 - 3des-cbc - hmac-md5 - none 80x24 NUM

Figure 3-8. Links Menu

3.4.6 Stops Menu

Selecting "T" from the Main menu brings up the "stops" screen, shown in Figure 3-9. Parameters of the stop dose calculation are the distance that the receptor population is from the source (the vehicle) and the exposure time. The analyst names the stop (e.g., refueling, overnight, inspection, etc.). The vehicle name must be the same as a name entered in the "Vehicle" screen.

The value entered in the column "Population Density" depends on whether a population in an annular area around the source is being modeled, or whether people all at the same distance from the source are being modeled. If the minimum distance from the source (see Figure 3-9) is different from the maximum distance, RADTRAN 5 will read the value in the "Population Density or No. Persons" column as a population density, and this will be indicated in the column headed "This Stop Using." If the minimum distance from the source is the same as the maximum distance, RADTRAN 5 will read the value in the "Population Density or No. Persons" column as the number of people. The shield factor is the fraction of ionizing radiation that reaches the receptor; i.e., Shield Factor = 1 means no shielding. Further discussion of stop modeling is presented in Chapter 5.

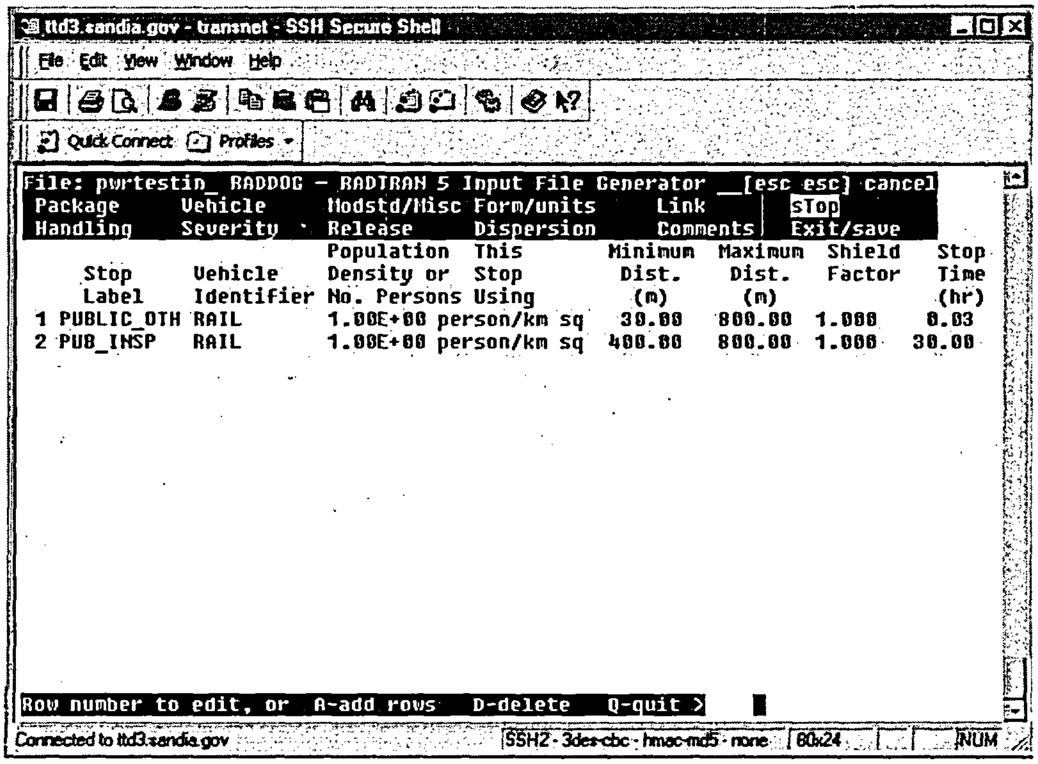


Figure 3-9. Stop Menu

3.4.7 Handling Menu

Selecting "H" on the Main Menu opens the handling screen shown in Figure 3-10. The data needs are self explanatory.

3.4.8 Severity Fraction Menus

Selecting "S" on the Main Menu opens the Severity screen shown in Figure 3-11. On this screen the analyst selects the number of *severity categories*; that is, the number of groups of accidents to be considered. For example, if the analyst selects three severity categories (NSEV = 3), one category would be minor accidents that have no impact on the cargo, one category would be accidents in which half the contents of the package were released, and one would be accidents in which all the contents were released.

The number of categories is an index only, and does not indicate how frequent or likely such accidents would be. Frequency is discussed in the screen shown in Figure 3-12.

Selecting "Severity" from the menu shown in Figure 3-11 prompts the analyst to select the transportation mode of the shipment (highway, rail, etc.) and then opens the screen shown in Figure 3-12.

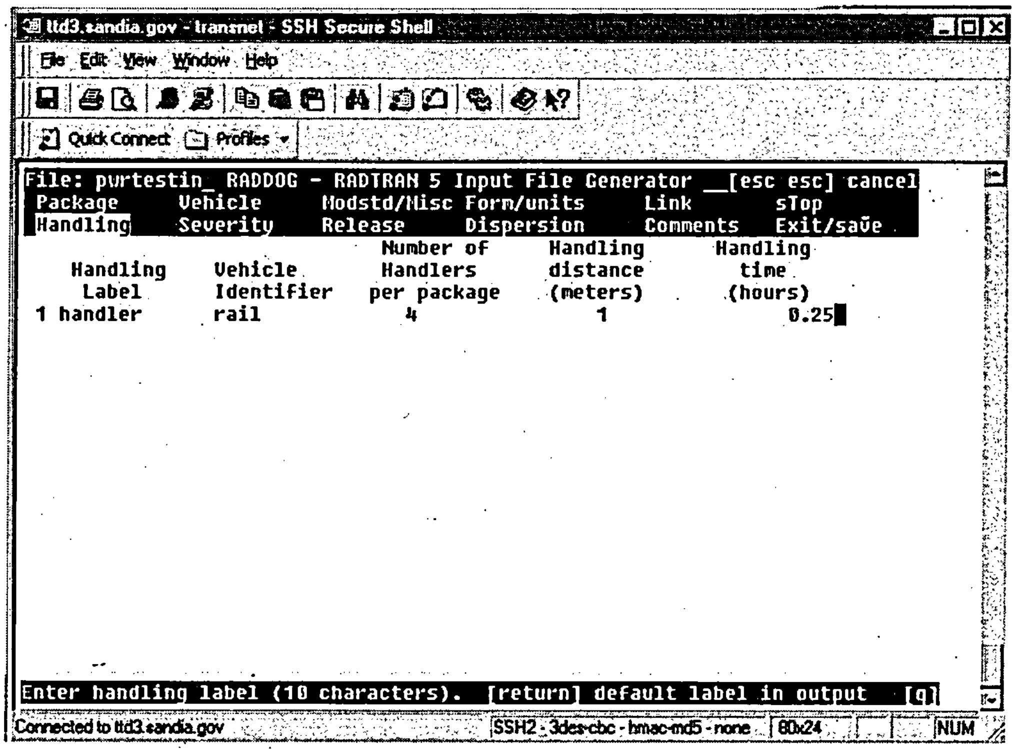


Figure 3-10. Handling Menu

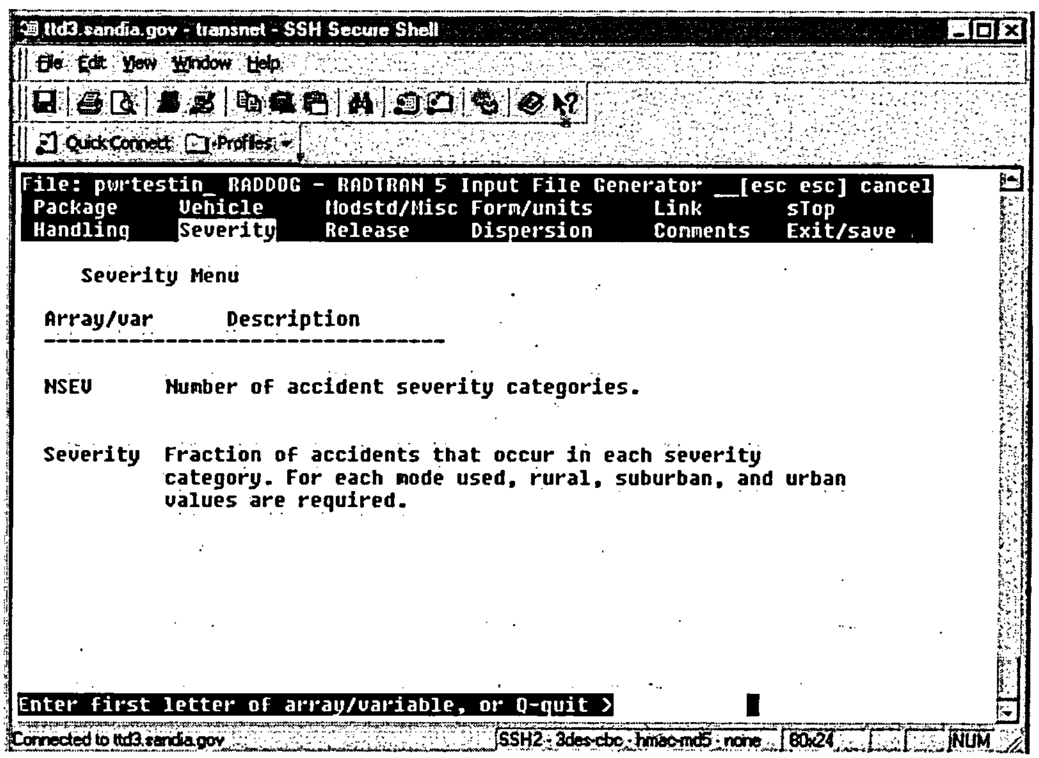


Figure 3-11. First Severity Menu

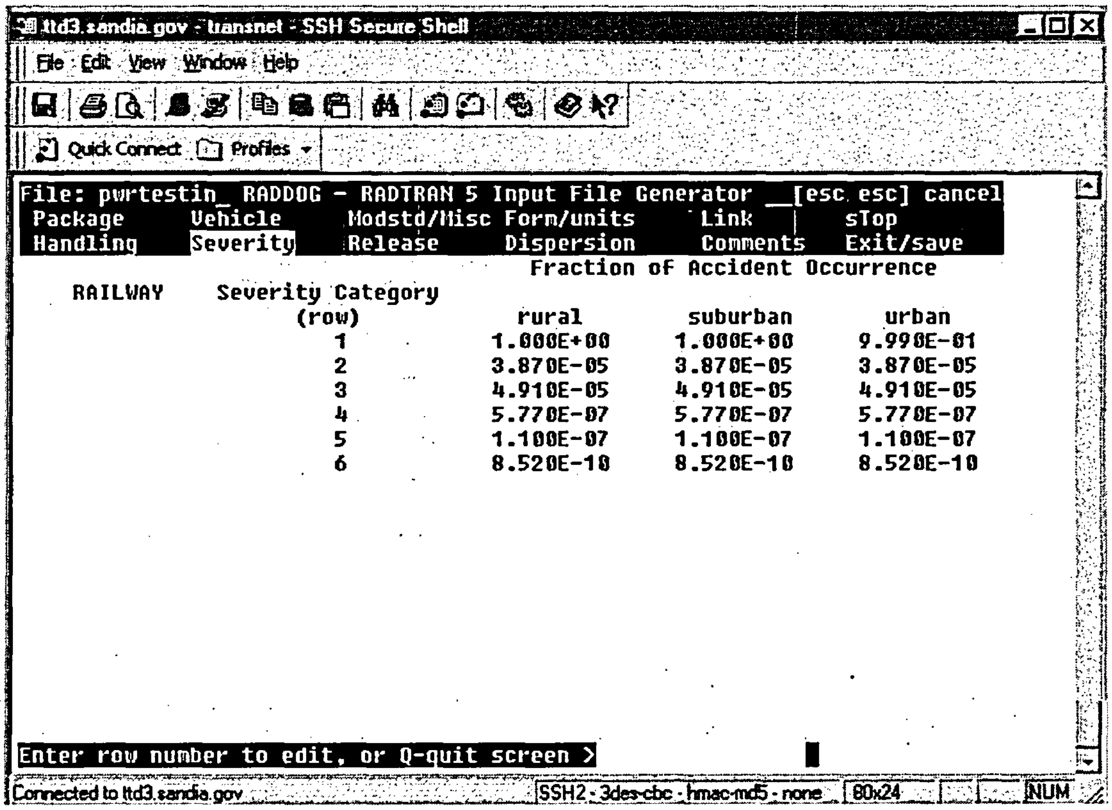


Figure 3-12. Second Severity Menu

On each row, the analyst enters the *severity fraction* for that particular severity category. The *severity fraction* is the conditional probability that, if an accident occurs, it will be an accident of that particular severity. The severity fraction can also be considered the frequency of accidents of that particular type. In the example of three severity categories, for Category 1, minor accidents with no release, the severity fraction could be 0.999. For Categories 2 and 3, the severity fractions could be 0.0007 and 0.0003, respectively.

RADTRAN 5 requires that severity fractions be entered for rural, suburban, and urban accident scenarios, even if the severity fractions are the same for a particular severity category; e.g., for Category 1, in the example, the rural severity fraction, the suburban severity fraction, and the urban severity fraction, would all be 0.999). Although there would appear to be more minor accidents on urban than on rural route segments, and fewer, but very severe, accidents on rural than on suburban route segments, data are not generally available to support different severity fractions. Severity fractions and the sources where they may be obtained are discussed further in Chapter 5.

3.4.9 Release Fraction, Aerosol Fraction, Respirable Fraction Menus

Selecting "R" on the Main Menu opens the Release Menu shown in Figure 3-13.

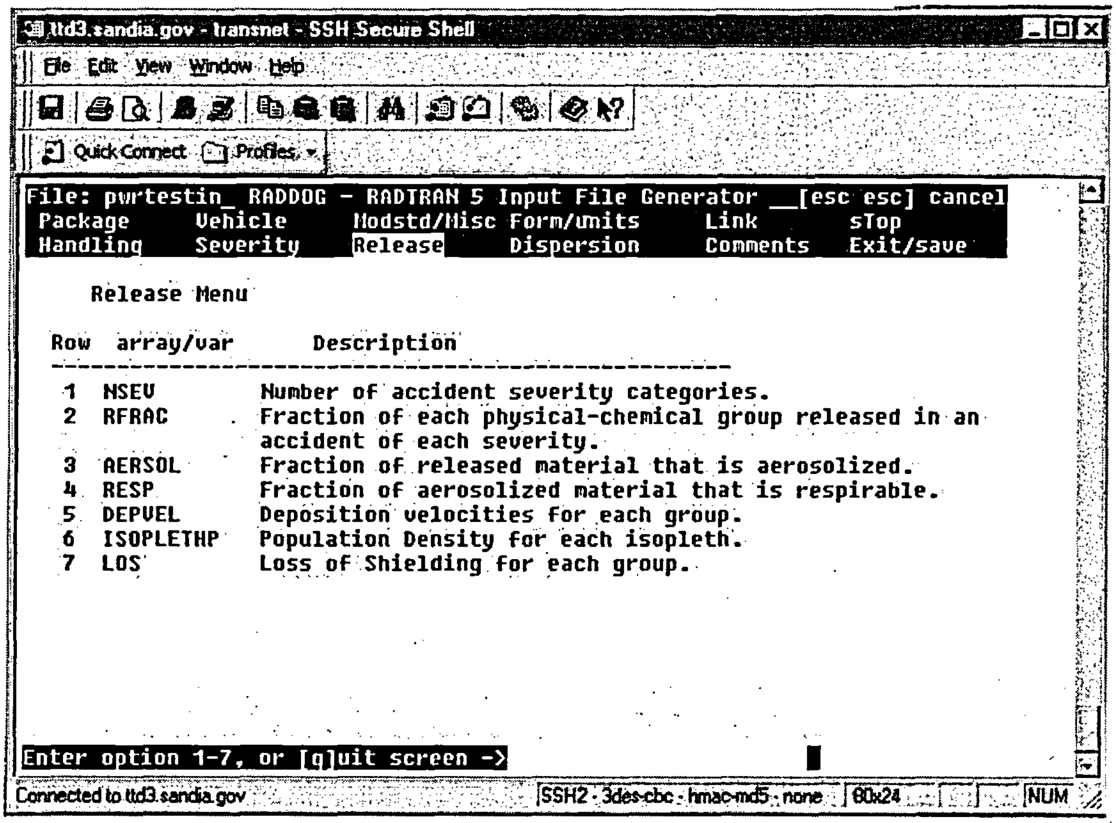


Figure 3-13. Release Menu

The screen show in Figure 3-13 opens windows for the analyst to indicate the release, aerosol, and respiratory fractions associated with each severity fraction, and the deposition velocities for each physical/chemical group. Figure 3-14 is the screen that opens when 2 (RFRAC) is selected from the screen of Figure 3-13. A similar screen is opened when 3 (AERSOL) or 4 (RESP) is selected. Selecting any of the physical chemical groups shown in the screen of Figure 3-14 will open a screen like that of Figure 3-15.

Selecting 5 from the Release Menu (Figure 3-13) opens the screen of Figure 3-16 to allow selection of deposition velocities.

3.4.10 Dispersion Menus

Selecting "D" from the Main Menu opens the dispersion screen shown in Figure 3-17. The analyst can select one of two ways to model air dispersion (of material released in an accident). Selecting "C" from the menu shown in Figure 3-17 opens a screen showing isopleth areas, dilution factors, and isopleth centerline distances from the source to 120 km. downwind of the source, calculated for national average meteorology. The analyst can substitute values that have been calculated externally to RADTRAN if he or she so desires.

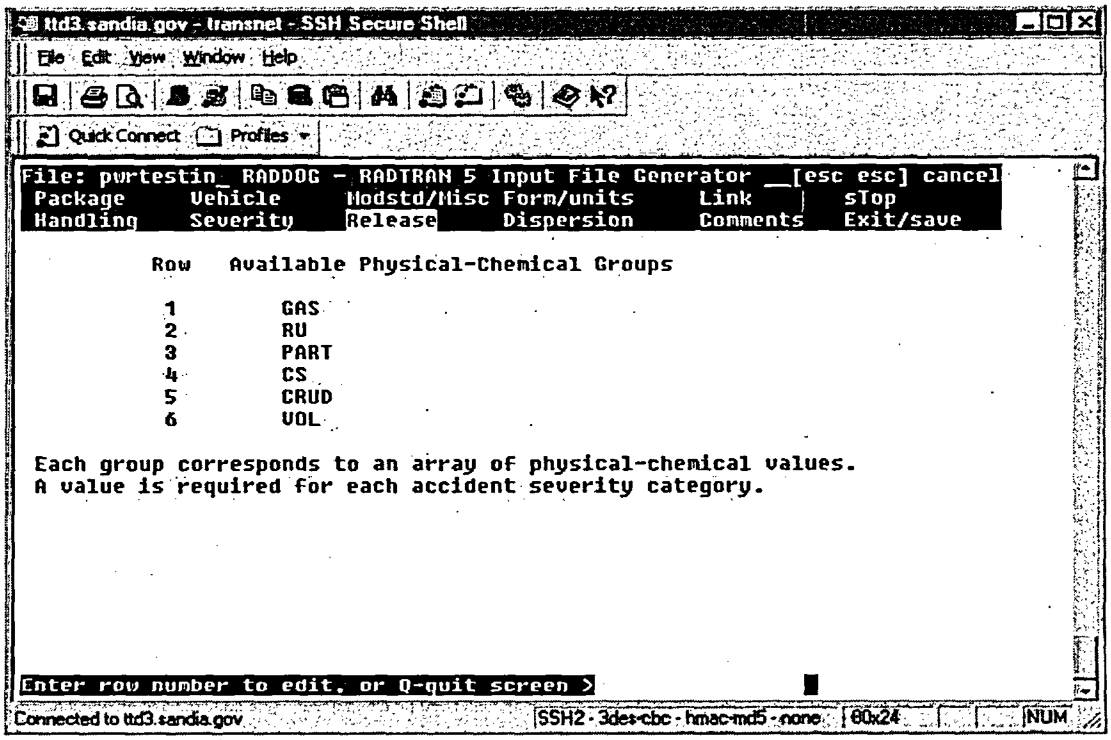


Figure 3-14. Main Release Fraction Screen

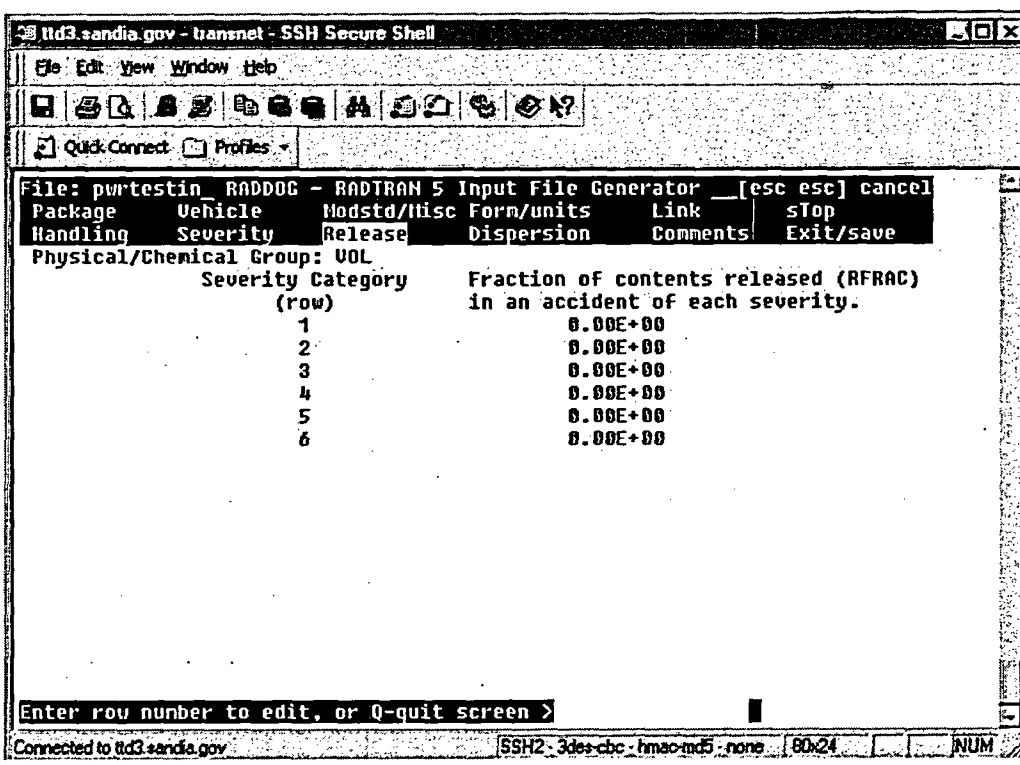


Figure 3-15. Release Fraction Screen for Volatile Substances

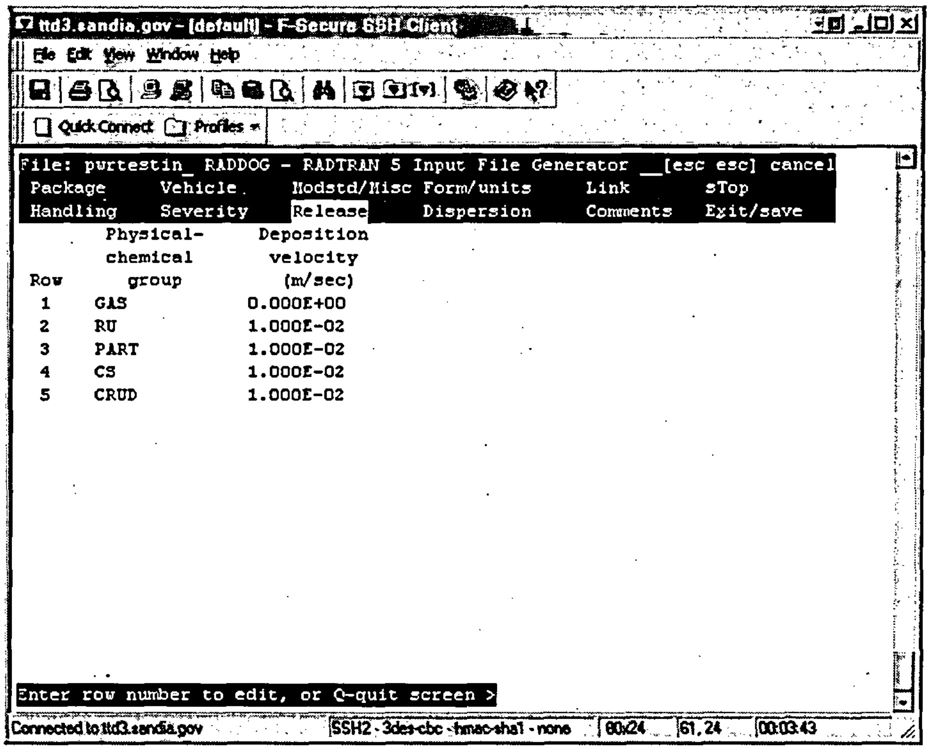


Figure 3-16. Deposition Velocity Screen

Alternatively, the analyst can select "P" and open the screen shown in Figure 3-18, which allows input of the fractional occurrence of each Pasquill stability class.

3.4.11 Comments

Selecting "C" from the Main Menu opens the "Comments" screen shown in Figure 3-20. Within "Comments," the analyst may type up to 60 lines of text to indicate the nature of the analysis being performed. Comment lines document the purpose and pertinent technical details of an input file. They are an excellent record-keeping tool that the analyst is strongly encouraged to utilize. Later sections of this chapter contain information about the types and sources of input data.

3.4.12 Completing the RADTRAN Input File

When data entry is complete, select the final Main Menu heading, "Exit/save." The analyst is prompted to enter a title for the file. Since the completed file is read into the RADTRAN 5 input file RT5IN.DAT, and RT5IN.DAT is overwritten by each new input file, the analyst is also prompted to save the file as MYFILE.in5. This MYFILE.in5 file is then saved in the analyst's file area on TRANSNET and may be called up as an "old input file" using the TRANSNET Main Menu (see Figure 3-1). Note that the file created with the menu system is not saved until

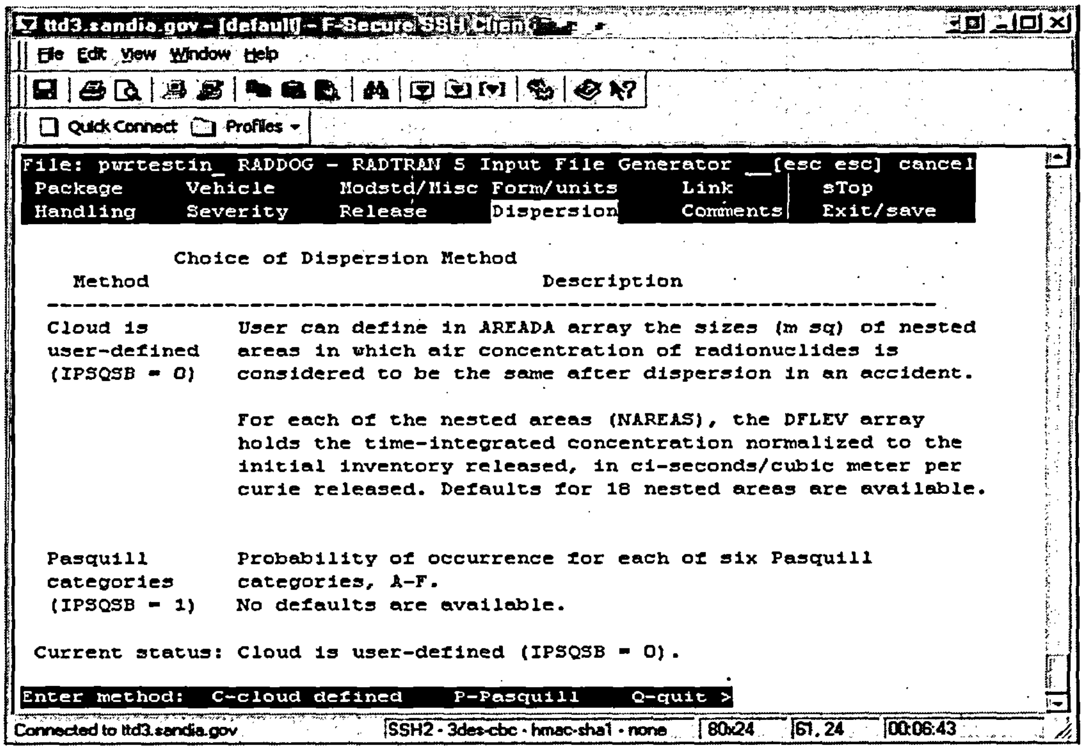


Figure 3-17. First Dispersion Screen

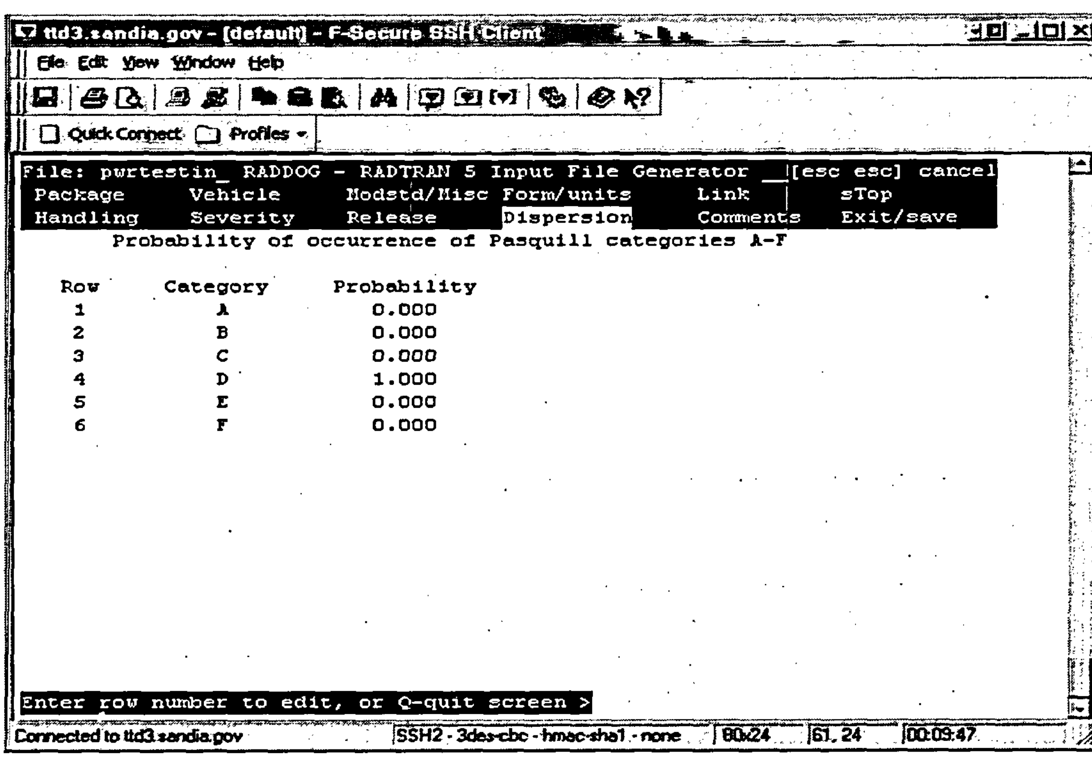


Figure 3-18. Pasquill Stability Class Menu

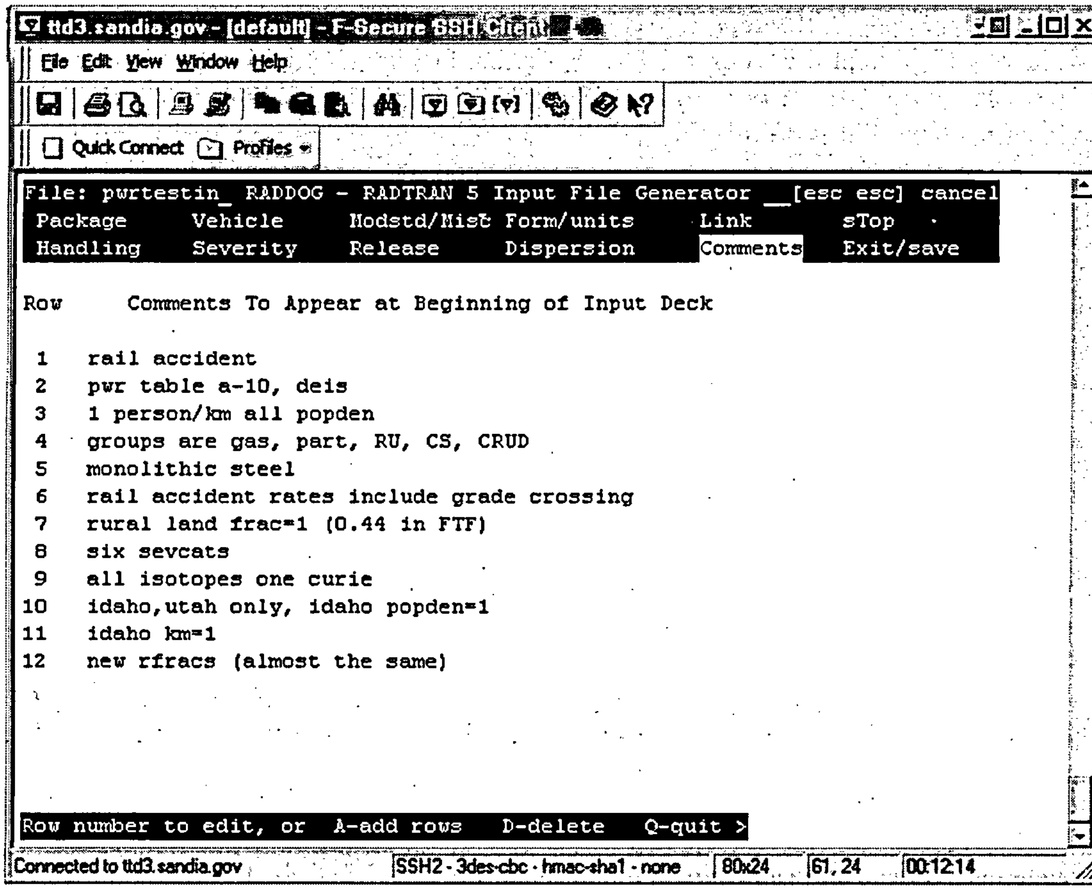


Figure 3-19. Comments Screen

the Exit/save menu is invoked. Further instructions for running the file in RADTRAN may be found in Section 3.5. A typical input text file may be found in Chapter 4, Figures 4A to 4D.

3.5 Running RADTRAN 5 on TRANSNET

Exiting the "Exit/save" screen returns the analyst to the RADTRAN 5.2.5 Control Menu (Figure 3-1).

To run the newly created input file in RADTRAN, select "Run RADTRAN 5 with the specified input file." The analyst will then be prompted for the level of output (see Section 3.6.3 and the description of PARM therein), and should recognize that the nuclide specific BYISO.OUT file is output only for levels 2, 3, and 4. RADTRAN should take only a few moments to run. When the run is complete, the analyst will see the words SUCCESSFUL COMPLETION on the screen; then the prompt will reappear.

The name of the main RADTRAN output file is R5OUT.DAT. It can be viewed immediately by selecting 7 on the RADTRAN 5.2.5 Control Menu. It can also be viewed with an editor, renamed, copied, or deleted. The output file can be downloaded from the file listing of SSH2, or copied to a Word or Excel file from PuTTY. Regardless of the method used to create an input file, the output will always be in the format described in this chapter and in Chapter 4. The nuclide specific output file is BYISO.OUT. If this file is to be saved, it should also be renamed.

If a run cannot be completed successfully, the message 'INPUT ERROR' or the message 'ERROR - OUTPUT FILE INCOMPLETE' will appear on the screen. In the former case, the analyst is advised to examine the input echo in the output file (R5OUT.DAT) to see where execution stopped and then to correct the problem in the input file. In the latter case, the output file (R5OUT.DAT) should contain one or more additional error messages that describe the problem(s). Error messages and suggested correction strategies are listed in Appendix B.

3.6 Input File Structure

3.6.1 Creating Input Files Using a Text Editor

TRANSNET users may also create input files with a text editor (e.g., Microsoft™ Editor or Vi™) without using the menus. This is discussed further and in detail in Section 3.7. In fact, after they have gained some experience with the code, TRANSNET users often find that the text-editor method is faster than using the menus. If RADTRAN is run locally on a workstation or personal computer, the RADTRAN input file must be created using a text editor.

The first step is to create and name a blank input-data file (e.g., MYFILE.DAT or MYFILE.IN5). It should be an ordinary text file and be located in same directory as RADTRAN 5 when using a workstation, or uploaded to the analysts file area on TRANSNET. Before uploading a new input file for use with TRANSNET, it must have a .IN5 file extension in order for the menus to function properly. Any available text editor may be used to create the file. Consult the software manual for the specific editor you are using for necessary instructions. Data entry in RADTRAN 5 is in free format and is keyword-based. The keyword-based system allows most of the data to be entered with any number of intervening spaces or carriage returns. Keywords and data can appear anywhere in an 80-character line. After data entry is complete, the file should be copied and renamed as described previously.

3.6.2 RADTRAN 5 Input File Structure – Fields, Field Values, Delimiters, and Keywords

A RADTRAN input file is an ASCII text file that consists of keywords, numbers, and alphanumeric labels entered as fields of ten characters or less which are separated by one or more of the following delimiters: a blank space, comma, equal sign, or right and left parentheses. The term *field value* may refer to a keyword, a number, or a label. Fields may appear anywhere in the 80-character line, but may not be split and continued on the next line. Field values must not contain embedded blanks, commas, equal signs, or parentheses, because these are delimiter characters that denote the end of a field.

A master list of all keywords is included at the end of this chapter in Section 3.11. First-level keywords must be entered before any associated second- and third-level keywords. Following the entry of a first-level keyword and a space, second-level keywords, followed by third-level keywords, may be entered on the same line or the following line(s); each is followed by the required data. A first-level keyword is not always followed by a second- or third-level keyword. As the DIMEN keyword in the Master List illustrates, data may directly follow a first-level keyword, separated by spaces or other delimiters. The "or" separating two keywords in the Master List indicates that the analyst may enter one of the keywords, but not both, in a single analysis. Finally, the Description column of the Master List briefly describes the type of data to be entered after each keyword and gives the units that must be used. Where an array of numbers must be entered, the array is described in detail in the following text.

Integer data can be entered as real numbers; they will be truncated. Real variables can be entered as integers, in which case they will be converted internally. Entry format can be either exponential (e.g., 9.99E+1, see Box 3-2) or decimal (e.g., 99.9).

A special delimiter character, the asterisk [*], may be entered in numeric-array fields to designate a repeat character. For example, to repeat the number 10.1 six times, enter 6*10.1. Blanks cannot separate the numbers and the asterisk delimiter. The asterisk must ***not*** be used in the data for DIMEN or PARM or in any alphanumeric-label field.

Box 3-2 EXPONENTIAL NOTATION

Exponential notation is the most convenient means of writing very large and very small numbers.

For example, the small number 0.00000052 can best be expressed in exponential form. That is, as 5.2E-7. The notation means the number 5.2 is multiplied by the number 10^{-7} (0.0000001), which is 10 with the exponent –7.

Exponential notation may be used to express any number in RADTRAN 5. It must be used to enter numbers with more than 10 characters.

Any field consisting of two ampersands (&&) followed by a delimiter (usually a space) causes all subsequent information on that line, regardless of its content, to be entered as a comment line. Examples of the use of comment lines are given in sample files later in this chapter.

Special keywords that are never followed by data are also noted in the Master List. They are EOF (End of File), EOI (End of Input), and END (marks end of data entry for keyword PACKAGE).

3.6.3 Required Keywords Begin an Input File

To begin building a data set, five first-level keywords are usually entered: TITLE, INPUT, FORM, DIMEN, and PARM. TITLE, INPUT, FORM, and DIMEN are always entered. Values are entered for PARM when the choice for INPUT is entered (see below); therefore, this keyword is only entered if the analyst does not wish to accept them. Each of these keywords is discussed below.

TITLE. The first input line must be a title record. The line must begin with the keyword TITLE followed by at least one space. Since entry is on an 80-character line and since fields may not be continued on a second line, this means that the actual letter count of a user-assigned title may not exceed 74 alphanumeric characters in length. The analyst will find that it pays to develop as descriptive a title as possible.

INPUT. The second line of the input file must start with the keyword INPUT followed by either the keyword STANDARD or the keyword ZERO. STANDARD will bring up values for a number of RADTRAN 5 parameters; these are mainly parameters with values that are seldom altered (e.g., breathing rate, building shielding factors). These are discussed in greater detail in Section 3.9. ZERO initializes all input-data values to zero. The analyst then must enter specific values for the parameters under keywords MODSTD and FLAGS, which are described later in this section.

FORM. The third line of the input file must start with the keyword FORM followed by at least one space and either UNIT or NONUNIT (second-level keywords). This determines the form of the output: either UNIT for population dose or NONUNIT for health effects.

DIMEN. Three ordered numeric fields each separated by a delimiter (see Box 3-3) must follow DIMEN. They specify the dimensions of the following arrays:

Box 3-3 DIMEN Example

```
DIMEN  6 10 18
```

- NSEV Field. The number of accident-severity categories that will be used in the analysis (maximum = 30);

- NRADIAL Field. The number of radial distances to be used in nondispersal accident analysis (maximum = 15);

- NISOPLETH Field. The number of downwind dose and deposition areas to be used in dispersal accident analysis (maximum = 30).

PARM. With PARM, the analyst selects settings for four flags, which in turn control certain code functions. The flags, in order of entry, are:

- The plot flag for placing data in output files for probability-consequence plots; the STANDARD value is yes (1); to not produce those files, set flag to zero.

- The selection flag with which the analyst selects incident-free analysis (1), accident analysis (2), or both (3); the STANDARD value is both (=3);

- The output flag for choosing the level of output; the STANDARD value is the full output (3). If set to 1, a short summary is printed; if set to 2, the output contains more detailed tables of input and results; if set to 3, consequence tables are added to level 2 output; if set to 4, sensitivity analysis is added to level 3 output. If the output flag is set to 2, 3, or 4 (but not 1), the accident dose risk for each radionuclide is output in a file called BYISO.OUT.

- The Pasquill flag for selecting Pasquill stability categories (1) or user-supplied time-integrated concentration isopleths and areas (0); the STANDARD value is zero.

If the analyst wishes to alter the settings of any of the flags subordinate to PARM, the keyword PARM should be entered and followed by four numbers indicating the new settings. If the analyst omits PARM, then the standard settings for all flags are used.

3.6.4 Flags

In addition to the flags already discussed under keyword PARM, an additional flag, the Exclusive Use flag, is associated with the keyword VEHICLE.

<u>Exclusive-Use Flag</u>

An exclusive-use shipment is a shipment that carries only radioactive-material packages and no other cargo. Exclusive use is denoted by placing a negative sign in front of the mode designator in the VEHICLE array. In the absence of a negative sign, the shipment is considered non-exclusive-use for regulatory check purposes.

Several flags may be found in the STANDARD (RT5STD.DAT) file and may be reset under the keyword MODSTD. They are described in this section.

<u>Flags in the STANDARD file</u>

1. <u>IACC</u>. The standard value for the IACC flag is 2. This setting directs the code to work through all exposure pathways associated with atmospheric dispersal of package contents during an accident. The alternative value of IACC = 1, denotes non-dispersal and is used to examine particular scenarios such as loss-of-shielding or accidents involving non-dispersible package contents (also called "special form" materials).

2. <u>ITRAIN</u>. This flag, used only for rail mode, denotes whether shipment is by general freight (ITRAIN = 1) or by dedicated rail (ITRAIN = 2). The standard setting is 1. The main difference between the two options is the exposures of rail workers in railyards. The rail-worker dose is the weighted sum of the doses for all close-proximity rail-worker groups. The doses are calculated primarily with a line-source model. Occasionally a point-source model for worker groups that are consistently present but are somewhat distant from the RAM car(s). For general freight, dose is calculated with the modifying factors b_1 through b_7, which have units of person-hr/km and are derived from Wooden (1987) as described in Appendix B of the RADTRAN 5 Technical Manual (Neuhauser, Kanipe, and Weiner, 2000). For dedicated rail, worker dose is calculated with factors b_8 through b_{11}. If no rail-mode transportation is to be analyzed, then the flag setting is ignored.

3. IUOPT. This flag is used to select a building shielding option. For the STANDARD value (IUOPT = 2), persons in buildings are exposed at reduced rates and the reduction in dose rate is a function of the shielding factors RR, RS, and RU, which are described later in this chapter. Setting the IUOPT flag to 1 is equivalent to full shielding (everyone indoors is fully shielded and receives no dose). Setting the IUOPT flag to 3 is equivalent to no shielding (being indoors provides no protection and is the same as being outdoors). If the STANDARD setting is accepted, the analyst may still separately alter the values of the individual shielding factors.

4. REGCHECK. The STANDARD setting is REGCHECK = 1, which causes a series of regulatory checks to be performed. If any circumstances are identified that violate the regulatory requirements (e.g., package dose rate exceeds regulatory maximum), then the appropriate parameter values are reset to the regulatory maximum and the calculation continues. A message informing the analyst is printed in the output. The analyst may set REGCHECK = 0, which bypasses the regulatory-check subroutine. This flag setting can be useful for analysis of a shipment operating under waivers of various types (e.g., certain radiopharmaceutical shipments (Finley, McClure and Reardon, 1988)).

3.6.5 Accident-Related Keywords and Parameters

After TITLE, INPUT, FORM, DIMEN (and sometimes PARM) have been entered, the first-order keywords SEVERITY and RELEASE, with associated second- and third-order keywords are entered as shown in Box 3-4.

NPOP=1, 2, 3 refers to rural, suburban, and urban populations, respectively. NMODE=1 is highway, NMODE=2 is rail, etc., as shown in Table 2-1. The numbers listed under NMODE are the severity fractions (NSEV=4 in the example in Box 3-4).

Potential releases of radioactive material in accidents, and the fractions of material aerosolized and respirable, depend on the physical and chemical behavior of the radionuclides released, rather than on their radiological characteristics. The second order keywords GROUP are listed under RELEASE, and the third order keywords RFRAC (released fraction), AERSOL, and RESP (respirable fraction) are listed following each GROUP. The numerical values are that fractions of the transported material in each category. The third order keyword LOS refers here to the fraction of shielding lost, and is part of a loss-of-shielding model in RADTRAN that is not generally used (loss of lead shielding is discussed in greater detail in Chapter 5. DEPVEL is the deposition velocity and is also a function of physical and chemical behavior.

The first order keyword PSPROB is entered if the analyst elects to specify the fraction of each Pasquill stability class. If the analyst uses the isopleths and dilution factors for national average meteorology, PSPROB need not be entered. National average meteorology values are part of the STANDARD values.

Box 3-4 Example of Data Entry under Keywords SEVERITY and RELEASE

```
SEVERITY
   NPOP=1
     NMODE=1
       1.00E+00  6.06E-05  5.86E-06  4.95E-07
   NPOP=2
     NMODE=1
       1.00E+00  6.06E-05  5.86E-06  4.95E-07
   NPOP=3
     NMODE=1
       1.00E+00  6.06E-05  5.86E-06  4.95E-07
RELEASE
   GROUP=GAS
      RFRAC
 0.00E+00  1.96E-01  8.39E-01  8.00E-01        AERSOL
       1.00E+00  1.00E+00  1.00E+00  1.00E+00
      RESP
       1.00E+00  1.00E+00  1.00E+00  1.00E+00
     LOS
      0.00E+00  0.00E+00   0.00E+00    0.00E+00
      DEPVEL 0.000000
    GROUP=VOLATILE
      . . . . .
PSPROB
      0.00E+00  0.00E+00  0.00E+00  1.00E+00  0.00E+00
```

The next first-level keyword is DEFINE. The syntax for any user-added radionuclide is, e.g. DEFINE Se-79, and the parameters for each radionuclide are listed in the DEFINE statement for that radionuclide. This is discussed further in Section 3.8.

3.6.6 Package and Incident-Free Parameters

The hierarchical relationship between keywords is:

- a package must be described before it can be associated with a VEHICLE;
- a vehicle must be described before it can be associated with a LINK; and
- a nonstandard radionuclide (i.e., one described under keyword DEFINE) must be described before the assigned radionuclide can be associated with a material or a package.

The hierarchical relationship between the keywords must be observed.

Package-Specific Parameters

Since it is impossible to predict in advance what combination(s) of packaging and contents will be analyzed, all package-specific parameters must be provided by the analyst. Values for the following five parameters are entered after the keyword PACKAGE (Box 3-5).

1. Alphanumeric identifier, up to ten characters in length (e.g., SPENTFUEL)

2. Package dose rate 1 m from surface of package (mrem/hr)

3. Fraction of dose rate that is gamma radiation

4. Fraction of dose rate that is neutron radiation

5. Characteristic Package Dimension (m). Assignment of characteristic package dimension is discussed in Chapter 4.

A list of the radionuclides in a package must appear below the PACKAGE line. Data for each radionuclide must be entered on a separate line. Three pieces of information, each separated by a space must appear on each radionuclide line. They are:

1. Radionuclide name in required format

2. Amount of the radionuclide in the package (Ci)

3. Identifier for physical-chemical group to which the radionuclide is assigned (e.g., VOLATILE)

The radionuclide list must be terminated by the keyword END as shown in Box 3-5.

Box 3-5 Example of Data Entry under Keyword PACKAGE

```
PACKAGE SPENTFUEL 1.368E+001 1.000 0.000 5.20
    CO60    9.220E+001 CRUD
    KR85    6.100E+003 GAS
    SR90    5.960E+004 FPROD
    RU106   1.620E+004 RUTHENIUM
    CS134   2.740E+004 VOLATILE
    CS137   8.760E+004 VOLATILE
    CE144   1.220E+004 CE_EU
    EU154   7.000E+003 CE_EU
    PU238   2.960E+003 ACTINIDE
    PU239   4.100E+002 ACTINIDE
    PU240   4.680E+002 ACTINIDE
    PU241   1.260E+005 ACTINIDE
    AM241   1.290E+003 ACTINIDE
    AM243   1.990E+001 ACTINIDE
    CM244   1.790E+003 ACTINIDE
    END
```

Vehicle-Specific Parameters
The following are entered following the keyword VEHICLE:

- Mode number (see Table 2-1) modified by the Exclusive-Use Flag (a negative sign) if necessary (see Section 3.3.1.3).
- Alphanumeric vehicle identifier, up to 10 characters in length (e.g., PHARM_1).
- Dose rate at one meter from the surface of the vehicle (mrem/hr)
- Fraction of dose rate that is gamma radiation
- Fraction of dose rate that is neutron radiation
- Characteristic vehicle dimension (m)
- Number of shipments to be carried out in the specified vehicle type
- Number of crew members
- Average distance (m) of crew members from the geometric center(s) of one or more radioactive-material package(s)
- Crew Modification Factor, a fractional multiplier that can be used to account for mitigating factors such as shielded crew cabs in semi-trucks. If there are no such mitigating factors then the Crew Modification Factor should be set to unity.
- Crew View Package Dimension (m), which accounts for situations in which the regular Characteristic Package Dimension (e.g., the length of a cylinder) would overestimate dose rate to crew compartment (in the example, the diameter of the cylinder would give a better estimate). This is discussed more fully in Chapter 5.

The VEHICLE line must be followed by any package identifiers (alphanumeric identifiers that the analyst creates under keyword PACKAGE), which indicate what kinds of packages are carried in the specified conveyance. Each package type is listed on a separate line; the package identifier is followed by at least one space and a numeral indicating the number of packages of that type being carried in the vehicle. In the example in Box 3-6, four packages of type PHARM_1 and five packages of type PHARM_2 are being carried by non-exclusive-use highway mode in a vehicle identified as VAN. The vehicle (VAN) has a maximum dose rate of 1.9 mrem/h (measured at 1 meter from the side of the van) that is 100% gamma radiation and 0% neutron radiation. The remaining values tell us that:

- the van is 3.5 m in length;
- one (1) shipment is being analyzed;
- there is one (1) crew member (driver),

- who averages a distance of 2.0 m from the packages,
- who is unshielded (i.e., the cab has a shielding factor of 1.0),
- and who is exposed, in this case, to a close-packed array of packages with an overall characteristic dimension of 1.5 m.

Box 3-6 Example of Data Entry under Keyword VEHICLE

```
VEHICLE 1 VAN 1.9 1.0 0.0 3.5 1 1 2.0 1.0 1.5
 PHARM_1 4
 PHARM_2 5
```

Keyword MODSTD

The first order keyword MODSTD follows keyword VEHICLE. As previously discussed, the analyst lists under MODSTD the value of any STANDARD parameter that is changed from the STANDARD value, as shown in Box 3-7. SRANDARD values are discussed in greater detail in Section 3.9. If all STANDARD values are accepted, the keyword MODSTD need not be used. If the ZERO file was chosen in place of the STANDARD file, values must be entered under MODSTD for all STANDARD parameters needed for the particular analysis.

Values for the flags that differ from the STANDARD values are entered under the keyword FLAGS which follows MODSTD, as shown in Box 3-7. EOF must follow the last data entry of these three: FLAGS, MODSTD, or VEHICLE.

Box 3-7 Example of Data Entry under Keyword MODSTD

```
MODSTD
   BDF 1.000E+00
   UBF 1.000E+00
   USWF 0.000E+00
   FMINCL 1.000E+00
   RR 1.000E+00
   RS 1.000E+00
   RU 1.000E+00
FLAGS
   REGCHECK 0
   IUOPT 3
EOF
```

3.6.7 Route-Specific Parameters

The keyword EOF must appear before values entered with the route-specific parameters LINK, STOP, and HANDLING are entered but after all other data have been entered.

Keyword LINK
Following the keyword LINK (which follows the last EOF), an array of twelve parameters is entered for each route-segment. Each route-segment array must be on a separate line. Two of the parameters, fraction of land under cultivation and vehicle occupancy, are new to the LINK array. The full array now is:

- Alphanumeric segment identifier (user-defined)
- Vehicle identifier (must be previously defined; see Section 3.4.2)
- Segment length (km)
- Velocity (km/hr)
- Vehicle occupancy (persons/vehicle)
- Population density (persons/km^2) of area surrounding route segment
- Vehicle density (persons/vehicle)
- Accident rate (accidents/vehicle-km)
- Segment character (R=rural, S=suburban, U=urban)
- Segment type (1=interstate; 2 = non-interstate; 3 = any other mode)
- Fraction of land under cultivation (for rural segments only).

Keyword STOP
Following the keyword STOP, an array of seven parameters is entered.

Each stop must be described on a separate line. The stop parameter array is:

- Alphanumeric stop identifier, up to 10 characters (user defined)
- Vehicle identifier (previously defined)
- Option #1 - population density (persons/km^2) or Option #2 - number of persons
- Minimum radius of annular area
- Maximum radius of annular area; if the minimum radius is the same as the maximum radius, RADTRAN will recognize the population as the number of persons. If the minimum and maximum radii are different, RADTRAN will recognize the population as persons/km^2.
- Shielding fraction
- Stop time (hr).

Keyword HANDLING
Following the keyword HANDLING, an array of five parameters is entered.

Each handling must be described on a separate line. The handling parameter array is:

- Alphanumeric handling identifier, up to 10 characters (user-defined);
- Vehicle identifier (previously defined);
- Number of handlers;
- Average source-to-handler distance (m);
- Handling time per package (hr/package).

End of the Input File
Following the keywords LINK, STOP, or HANDLER, whichever has the last data entry, and after all data has been entered, EOF (end of file) and EOI (end of input) must be entered. The keyword EOI must be entered on the last line of the input file.

3.7 Running RADTRAN 5 On a Workstation or With a Text File

An input file must be named R5IN.DAT if it is run in RADTRAN5 on a workstation. It can be uploaded to the analyst's file area on TRANSNET as a *filename*.in5 file. The RADTRAN 5 output file is always initially named R5OUT.DAT. When running on a workstation and dealing with many separate input files, which have been saved under other filenames, it is best to copy one file at a time just before beginning to run each one. The corresponding output file also should be renamed at once, as described in the following section. To begin a run on a workstation with the properly named input file, type the name of the executable RADTRAN 5 file, usually "rt5." On TRANSNET, after uploading the file, the analyst selects 3 ("use old input file") from the RADTRAN 5.2.5 Main Menu (Figure 3-1), selects the file just uploaded, does not open it, and when the Main Menu reappears, runs RADTRAN.

The code should take only a few moments to run. When the run is complete, the analyst will see the words SUCCESSFUL COMPLETION on the screen; then the prompt will appear. The name of the main RADTRAN output file is R5OUT.DAT, and the name of the radionuclide-specific accident dose risk output file is BYISO.OUT. Both files can be printed, viewed with an editor, renamed, or copied.

If a run cannot be completed successfully, the message 'INPUT ERROR' or the message 'ERROR – OUTPUT FILE INCOMPLETE' will appear on the screen. In the former case, the analyst is advised to examine the input echo in the output file (R5OUT.DAT) to see where execution stopped and then to correct the problem in the input file. In the latter case, the output file (R5OUT.DAT) should contain one or more additional error messages that describe the problem(s). Error messages and suggested correction strategies are listed in Appendix D.

If the analyst wishes to save an output file, then the file must be renamed. Otherwise, the file will be overwritten after subsequent runs. Workstation users must remember to copy and rename the file; they will not be prompted as TRANSNET users are. The analyst also should be aware that additional output files are generated for each run which are not normally displayed but which the analyst may wish to save. They contain the probability-consequence data pairs used in accident-risk calculations. These data also may be used to generate tabular or graphic displays of probability-consequence relationships, as discussed in Appendix C. The output files are:

- R5INTERM.DAT, which contains unsorted intermediate data.
- R5PLOT0 .DAT, which contains the sorted dose (person-rem) or latent cancer fatality consequences with summed probabilities;
- R5PLOT1.DAT, which contains the sorted genetic effects consequences with summed probabilities; and
- R5PLOT2.DAT, which contains maximum individual doses with summed probabilities.
- INGVAL.OUT, which contains the raw output data from COMIDA2 for ingestion dose calculation.

These files must be separately copied and renamed if the analyst wishes to save them as well.

3.8 RADTRAN 5_PC: Running Locally on a Personal Computer

RADTRAN 5_PC, a version of RADTRAN 5 that can be run locally on a personal computer, is available from Sandia National Laboratories.[8] The program runs RADTRAN 5 in a DOS window from a batch file, RT5.BAT, which reads RADTRAN input files with a *.in5 file extension. At present, RADTRAN 5_PC will run only under Windows 2000 or Windows XP. Input files may either be generated directly as text files, structured according to Section 3.6, or may be copied from the analyst's TRANSNET file area. To perform an analysis using RADTRAN 5_PC:

- Copy input files (*filename*.in5) into the directory that contains RT5.BAT.
- Click on the RT5.BAT icon. A DOS (command line) window will open.
- Following directions on the DOS window, type in the name of the input file without the .in5 file extension.
- A message indicating normal execution will follow.

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8 To obtain a copy, contact the Principal Investigator, RADTRAN, Department 6141, Sandia National Laboratories Mail Stop 0718, Albuquerque, NM 87185-0718.

- The output file (*filename*.out) will be located in the same directory and can be opened with Notepad, WordPad, Excel, or Word. If the output flag under PARM (Section 3.6.3) is set to 2, 3, or 4, the BYSIO.OUT file will be appended automatically to the output file.

3.9 Radionuclide Data

Values of radionuclide-specific parameters are available for 60 commonly encountered radionuclides in an internal database in RADTRAN 5. The values are based on the radiation risk approach in ICRP Publication 26 et seq. (ICRP, 1977, 1979-1982, 1984, and 1986) as updated in BEIR V (NAS/NRC, 1990). Half-life of each Radionuclide is in days. The doses are total effective dose equivalents, which are sums of the effective dose equivalents for external exposures and committed effective dose equivalents (CEDEs) for internal exposures and are presented in conventional units (rem per curie). The analyst may substitute values for any or all of these parameters by means of the DEFINE keyword. Any values supplied by the analyst should be in rem/curie for radiation doses and days for half-life.

ICRP Publications 60 and 68 (ICRP, 1991, 1994) use modified organ weighting, express total effective dose equivalent as effective dose, and express CEDE as equivalent dose. The ICRP findings, when adjusted for low-dose and low-dose rate, yield nearly the same total risk factor for fatal cancer as BEIR V (1990). Although "there is much uncertainty and a certain arbitrariness in the determination of the distribution of fatal cancer probability among tissues and organs," [ICRP Publication 60 (p. 123)], the same source notes that "The total risk of fatal cancer, on the other hand is comparatively robust."

In both models the dose-effect relationship conforms to the linear, no-threshold "hypothesis" (LNTH). Use of the LNTH has the advantages of mathematical simplicity and acceptability for demonstrations of regulatory compliance, but effects at low doses are overestimated, possibly to a significant degree.[9] Thus, latent cancer fatality estimates derived from both models are conservative, especially for the rather low doses typically associated with potential transportation-related exposures.

In previous releases of RADTRAN, 1-year organ doses attributable to the inhalation pathway were calculated for lung, marrow, gonads, and thyroid (radioiodines only). The results were used to estimate early effects. In order to achieve the early-effects threshold for the gonads (7 rem), however, a receptor would have to inhale many curies of any of the commonly encountered radionuclides. Threshold dose to the most sensitive organ, bone marrow, would usually be exceeded at inhalation levels well below what is required to reach this gonad threshold. Thyroid doses from radioiodine inhalation, however, can be significant even if relatively small amounts are inhaled. For these reasons, early effects continue to be estimated for inhalation-pathway doses to the lung, marrow, and thyroid, but gonad dose calculation is omitted.

[9] There is an ongoing controversy in the health physics community regarding the LNTH and its applicability at low doses.

3.9.1 Structure of the RADTRAN 5 Radionuclide Library

The RADTRAN 5 radionuclide library contains values for the parameters listed in each subsection of this section. The entire radionuclide-data library is printed in Appendix D.

Half-life (days)
In RADTRAN 5, the unit for half-life is days. All values are taken from ICRP Publication 38 (ICRP, 1983).

Photon energy (MeV/disintegration)
The energy value of photons emitted by a radionuclide is used to calculate groundshine dose for that radionuclide. The units are million electron volts (MeV)/disintegration. All values are taken from ICRP Publication 38 (ICRP, 1983). To simplify the analysis, each decay, regardless of whether it is a single photon or a cascade, is treated as a single photon decay with an energy equal to the difference between the initial and ground states of the radionuclide. The values given are derived from the column titled "y(i)xE(i)" (i.e., the average energy emitted per transformation) in Section 3 of ICRP Publication 38.

Photons emitted by short-lived daughter products (half-life less than a few hours) of certain radionuclides have been added to the nominal photon energy (if any) of the parent radionuclide, but the half-life of the daughter is neglected. In other words, the parent radionuclide is treated as though every transformation produced a photon equal in energy to that of the parent (if any) plus that of the daughter. This approach was used only for radionuclides that have half-lives that are large in comparison with the half-lives of the daughter nuclides; this gives a conservative value for photon energy for the analyses performed by RADTRAN 5 without complex calculations. In cases where the daughters are gamma emitters while the parent nuclides are not, potentially important sources of gamma radiation are adequately accounted for with this approach.

Radionuclides for which short-lived daughter decays have been included are the following:

- molybdenum-99, which has a daughter, technetium-99m (87.6 percent yield), with a half-life of 6 hr and a photon energy of 1.26E-01 MeV/transformation;
- ruthenium-103, which has a daughter, rhodium-103m (99.7 percent yield), with a half-life of 56 min and a photon energy of 1.75E-03 MeV/transformation;
- ruthenium-106, which has a daughter, rhodium-106 (100 percent yield), with a half-life of 29.9 sec and a photon energy of 2.01E-01 MeV/transformation;
- cesium-137, which has a daughter, barium-137m (94.6 percent yield), with a half-life of 2.6 min and a photon energy of 5.96E-01 MeV/transformation; and
- cerium-144, which has a daughter, praseodymium-144 (98.2 percent yield), with a half-life of 17.3 min and a photon energy of 3.18E-02 MeV/transformation. The remainder of the yield is also a short-lived radionuclide, praseodymium-144m, but its photon energy is very low and is neglected here.

Cloudshine dose factor (rem-m^3/Ci-sec)
The units of this parameter are rem-m^3/Ci-sec. This factor is the effective dose-rate factor for immersion in air uniformly contaminated with the specified radionuclide, and it is used to calculate cloudshine dose. All values were taken from DOE-0070 (DOE, 1988a) and converted from mrem-m^3/µCi-yr to rem-m^3/Ci-sec.

Groundshine dose factor (rem-m^2/µCi-day)
The units of this parameter are rem-m^2 /µCi-day. This factor describes the effective dose rate 1 meter above a uniformly contaminated plane surface. All values are taken from Federal Guidance Report 12 (EPA, 1993). No credit is taken for surface roughness.

50-yr committed effective dose equivalent for inhalation (rem/Ci inhaled)
This parameter describes long-term whole-body internal radiation dose (50-yr-dose commitment) resulting from inhalation of respirable aerosol particles of each radionuclide. Units are rem/Ci of respirable aerosol inhaled. Most values are for 0.3 micron AMAD (activity median aerodynamic diameter) particle size, calculated with the equations in Section 1.2.2 of DOE-0071 (DOE, 1988b), which was also the source of values for this parameter (for the highest lung retention class for each radionuclide).

The activity mean aerodynamic diameter (AMAD) of 0.3 micron was selected for a specific reason. A population of aerosol particles of plutonium or other dense material with an AMAD of 0.3 micron has a particle-size distribution such that virtually all the particles could lodge in the pulmonary region of the lung (i.e., are less than 10 microns and greater than 0.1 micron in diameter) (ICRP, 1977). This particle-size assumption was considered somewhat conservative for dense materials such as uranium, plutonium, other transuranics, and spent-fuel particulates. Since they are also among the most frequently analyzed materials, 0.3-micron AMAD values were used for the internal library data. The newest ICRP model, however, no longer supports use of such low AMADs, and future inhalation dose factors will be calculated on the basis of 1 micron AMAD particles, the minimum now recommended by the ICRP (ICRP, 1994, p.3). The analyst may redefine an radionuclide already in the library for a new particle-size distribution by use of the DEFINE function of RADTRAN 5.

Particle size is not a factor for those radionuclides that would be in the gaseous state if released: tritium gas (H3GAS), carbon-14 dioxide gas (C14GAS), and the noble gases. A 1.0-micron AMAD particle size was assigned to two additional materials in the database: tritiated water (H3WTR) and organic forms of carbon-14 (C14ORG). The former would be in vapor or microdroplet form; and the latter usually would be in soot or particulate form.

50-yr committed effective gonad dose for inhalation (rem/Ci inhaled)
This parameter describes long-term organ dose (50-yr-dose commitment) to the gonads resulting from inhalation of respirable aerosol particles of an radionuclide. Units are rem/Ci of respirable aerosol inhaled. The value is used in calculation of genetic effects.

1-yr lung dose for inhalation (rem/Ci inhaled)
The units are rem/Ci inhaled. This parameter describes the one-year committed dose to the lung from inhalation of respirable aerosol of a given radionuclide. It is used to calculate early

fatalities and early morbidities. The values are taken from Dunning (1983) for the highest lung retention class for which values were given for each radionuclide.

1-yr marrow dose for inhalation (rem/Ci inhaled)
The units are rem/Ci inhaled. This parameter describes the one-year committed dose to bone marrow from inhalation of respirable aerosol of the given radionuclide. It is used to calculate early fatalities and early morbidities. The values were taken from Dunning (1983) for the highest lung retention class for which values were given for each radionuclide.

Alphanumeric identifier for ingestion model (not functional)
This identifies the radionuclide for the ingestion-dose calculations. COMIDA-derived dose factors (person-Sv/m^2 and Sv/m^2) are converted to person-rem/m^2 and rem/m^2 and are used to calculate ingestion doses.

3.9.2 Radionuclide Names and Values and the DEFINE option

To analyze a package containing nuclides not found in the internal library, the analyst must employ the DEFINE capability of RADTRAN 5 to add new nuclides to the internal library. The DEFINE capability may also be used to define composite "radionuclides" that are weighted-averages of several radionuclides.

Radionuclide names must be in standardized format to call the proper values for half-life, photon energy, etc. from the internal radionuclide-data library. Analysts always have the option of defining radionuclides; the only restriction on names assigned to user-defined radionuclides is that they may not exceed 10 alphanumeric characters.

3.10 STANDARD Parameters and MODSTD Data

STANDARD values are available for a large number of input variables used in incident-free dose calculations. Although the STANDARD values appear in the menu system under the Main Menu selection "Modstd/Misc" (e.g. Figures 3-6 and 3-7), they are not included in the input file (R5IN.DAT). They are called by RADTRAN with the keyword STANDARD from an input text file called RT5STD.DAT. If the analyst uses the menu system to change any of the STANDARD values, the value input by the analyst is written, with its keyword, under the first-level keyword MODSTD (the STANDARD values do not change). An analyst creating a file without using the menu system should take care to write his or her user-input value, with its keyword, under the keyword MODSTD. Table 2 shows the data in the MODSTD array and gives the associated second-level keywords for workstation users. The analyst may accept none, some, or all of the STANDARD values. The input variables and their values are listed and described in this next section

<u>ADJACENT</u> See DISTON

CAMPAIGN This keyword specifies the duration of the shipping campaign in years. The value calculated with CAMPAIGN is the total number of off-link persons exposed. This result may be used to perform external calculations of annual off-link dose. Annual dose values may be compared with total dose in multi-year shipping campaigns and are useful for assessing regulatory compliance with standards based on annual doses. The STANDARD value is 1.0 year, meaning a period of 365.25 consecutive days.

DDRWEF This keyword applies to rail mode only and specifies the Distance Dependent Rail Worker Exposure Factor. This factor is used to calculate the component of rail-worker dose that depends on distance traveled (e.g., exposure related to engine changes, crew shift-changes, etc., while en route). The STANDARD value of 0.0018 inspections/km is taken from Ostmeyer (1986).

DISTOFF This keyword specifies a set of three distances, in meters, used in off-link dose calculations for highway, rail, and barge modes. The three distances are: (1) the minimum perpendicular distance over which the off-link dose calculation will be integrated; (2) the minimum pedestrian-walkway width, for instances in which dose to pedestrians beside the link is calculated (see RPD for discussion of pedestrian density); and (3) the maximum perpendicular distance over which the off-link dose calculation will be integrated. DISTOFF must be followed one or more keywords that specify values for various link types. The STANDARD values, which are supplied for each link type, are from NUREG-0170 (NRC, 1977). The link types and values for each are:

FREEWAY Any limited-access divided highway. [30, 30, 800]

SECONDARY Any non-limited-access highway that is not a city street (27, 30, 800)

STREET Any city street. [5, 8, 800]

RAIL Any rail right-of-way in the U.S. [30, 30, 800]

WATER Any vessel. [200,200,800]

Note that the values are the same for FREEWAY and RAIL. Setting the first two values equal to each other is equivalent to a sidewalk width of zero and means there are no sidewalks or similar close-in areas where unshielded persons (pedestrians, bicyclists, etc.) may reasonably be expected to be found. For STREET, the sidewalk is modeled as being 3 m wide (Finley et al. 1980). The values for WATER conservatively model a narrow navigable waterway (e.g., Houston Ship Channel) and are taken from NUREG-0170 (NRC, 1977). The WATER values are the ones most likely to require modification by the analyst since other bodies of water that might be modeled have ship-to-shore distances that greatly exceed 200 m and even 800 m.

DISTON This keyword specifies a perpendicular distance (i.e., a distance measured along a line at right angles to the line of travel of the RAM shipment) between the RAM shipment and other traffic lanes, in meters. For three link types, DISTON represents the *average* perpendicular distance between the shipment *centerline* and the *centerline* of oncoming traffic lanes(s). In the passing-vehicle case, DISTON represents the distance between the shipment *centerline* and the *centerline* of adjacent passing vehicles (HIGHWAY mode only). DISTON must be followed by a second keyword that specifies the link type. The STANDARD values in parentheses in the following list are taken from Madsen et al. (1986, p. 36-37).

FREEWAY Any limited-access, divided highway [15.0 m];

SECONDARY Any non-limited access highway [3 m]; STREET Any city street [3 m];

RAIL Any rail right-of-way [3 m].

An additional parameter for highway mode only is ADJACENT It represents the minimum perpendicular distance between shipment centerline and centerline of adjacent passing vehicles [4 m].

The FREEWAY value is based on the Madsen et al. (1986) model of a minimal Interstate configuration of four lanes with an average lane width of 5 m, in the most typical traffic configuration. The latter refers to the RAM shipment being in the outside lane, oncoming traffic in the corresponding outside lane, and passing vehicles in the inner lanes. The SECONDARY and STREET values are smaller because these roadways are modeled as being only 2 lanes wide with an average lane width of 3 m. The RAIL value is based on the minimum clearance between passing trains on double rail segments. The ADJACENT value represents the median value for all Interstate and secondary-road lane widths.

<u>FMINCL</u> This keyword is applied to rail mode only and specifies the minimum number of railcar classifications or inspections per one-way trip. The STANDARD value is 2 since there are always at least two inspections per one-way trip – one at the beginning and one at the end of each trip (Wooden, 1986).

<u>FNOATT</u> This parameter is applied to passenger-air mode only and specifies the Number of Flight Attendants. The STANDARD value is 4 (NRC, 1977).

<u>FREEWAY</u> See DISTOFF and DISTON

<u>MITDDIST</u> This parameter is used to calculate the maximum individual “in-transit” dose to a member of the public; it represents the minimum perpendicular distance, in meters, from the shipment centerline to an individual standing beside the road or railroad while a shipment passes. The STANDARD value is 30.0 m (NRC, 1977).

<u>MITDVEL</u> This parameter is used to calculate the maximum individual “in-transit” dose; it represents the minimum velocity, in km/hr, of a shipment. The STANDARD value is 24.0 km/hr (15 mph) (NRC, 1977).

<u>RAIL</u> See DISTOFF and DISTON

<u>RPD</u> This parameter is the Ratio of Pedestrian Density. It is used to calculate the density of unshielded persons on sidewalks and elsewhere in urban areas when the IUOPT Flag is not equal to 3 by indexing it to the population density of the surrounding area. RPD is also used in the

calculation of accident consequences. The STANDARD is 6.0, which is based on empirical data from New York City (Finley, 1980). It means that the pedestrian density is six times the residential population density. This figure is likely to be conservative for most other urban areas, but similar data are seldom collected in other cities.

RR This parameter specifies the Rural Shielding Factor. The STANDARD value is 1.0 (i.e., no shielding). Although even wood-frame construction provides some shielding, the Rural Shielding Factor is set to 1.0 to conservatively account for the fact that rural economies involve a relatively large fraction of outdoor employment (farming, ranching, etc.). RR is used in incident-free dose and in dose-risk calculation for non-dispersal accidents.

RS This parameter specifies the Suburban Shielding Factor. The STANDARD value is 0.87, which represents a residential structure of wood-frame construction (Taylor and Daniel, 1982, p.12). RS is used in incident-free dose and in dose-risk calculations for non-dispersal accidents.

RU This parameter specifies the Urban Shielding Factor. The STANDARD value is 0.018, which represents an urban commercial building constructed of concrete block (Taylor and Daniel, 1982, p.12). RU is used in incident-free dose and in dose-risk calculations for non-dispersal accidents.

SECONDARY See DISTOFF and DISTON

SMALLPKG This parameter specifies the first Package Size Threshold. This parameter is used to determine the handling method that will be used for a package, which, in turn, is used in the calculation of handler dose. If a package is designated as "small" then an empirical algorithm for handling dose is used; if package dimensions exceed the threshold then another method is used. The STANDARD value for SMALLPKG is 0.5 m (Javitz, 1985). Although it is highly unlikely that this value will need to be altered, the analyst has the option to do so.

STREET See DISTOFF and DISTON

3.11 Data for Accident Risk Calculation by Mode and Material Type

3.11.1 STANDARD Values for Accident Risk Analysis

The most important arrays in accident-risk calculation do not have STANDARD values. They are:

- accident-severity fractions (keyword SEVERITY),
- shielding degradation fractions (keyword LOS)
- release fractions (second-level keyword RFRAC under keyword RELEASE),

Box 3-8	Population-Density Zones
Rural (NPOP=1)	Mean = 6 persons/km^2 (Range = 0 to 66 persons/km^2)
Suburban (NPOP=2)	Mean = 719 persons/km^2 (Range = 67 to 1670 persons/km^2)
Urban (NPOP=3)	Mean = 3861 persons/km^2 (Range > 1670 persons/km^2)

- aerosol fractions (second-level keyword AERSOL under keyword RELEASE), and
- respirable fractions (second-level keyword RESP under keyword RELEASE).

The package- and problem-specific nature of these parameters makes it impossible to develop values for them *a priori*. Severity-related parameters may be defined for up to three population-density zones (second-level keyword NPOP under keyword SEVERITY). NPOP has three values: NPOP =1 indicates rural; NPOP =2 indicates suburban; and NPOP=3 indicates urban. The mean and range for each population-density zone (see Box 3-8) are taken from the demographic model in NUREG-0170 (NRC, 1977).

3.11.2 Atmospheric Dispersion Parameters

STANDARD values are available for both atmospheric dispersion options. The analyst may select one of two alternative analytical models with the Pasquill flag under the keyword PARM. If the Pasquill flag is set to 1, then six sets of tabular data (area, downwind distance, and time-integrated concentration) for Pasquill atmospheric-stability categories A through F are called up. The values in the tables are for a conservative instantaneous release—a small-diameter (10 m), ground-level "puff"—and are derived from Gaussian dispersion calculations in Turner (1969). These values are fixed and may not be changed, but there are no pre-assigned values for the probabilities of occurrence, which must be assigned by the analyst.

If the Pasquill flag is set to 2 (or any integer other than 1), then a table of user-definable areas and time-integrated concentrations is called up. National-average values are supplied as STANDARD values (Table 3-1). Like the six Pasquill category tables, this option represents a conservative, idealized, small-diameter, ground-level dispersion pattern (no thermal buoyancy) and is also derived from Turner (1969). The innermost isopleth covers only about 460 m^2 (a little under 5000 ft^2) and has a maximum downwind extent of about 33 m (108 ft); the outermost isopleth covers 1.35 billion m^2 (about 521 sq. mi.) and has a maximum downwind extent of about 120 km (about 75 mi.). Since only one set of dispersion values is applied to the analysis in this option, probability of occurrence is not specified by the analyst.

3.11.3 Other Accident Parameters with STANDARD Values

Other accident-related parameters for which STANDARD values are available are listed in this section. Some of the values entered for these parameters are applied to all route segments in an analysis. Other parameters used in accident-risk calculations vary by route segment and can have no STANDARD value; they are discussed separately.

BDF This is the Building Dose Factor. This factor describes the entrainment of aerosol particles in ventilation systems (i.e., the fraction of particles of an external aerosol that remain in aerosol form after passing through a ventilation system). The BDF is used to modify inhalation doses to persons in urban structures. The STANDARD value of 0.05 represents a conservative average across a series of building types, including residential, office, and industrial structures (Engelmann, 1990). This value is about five times higher than the value for high-rise buildings with air-conditioning systems used by Finley et al., (1980) for New York City, which has been used in RADTRAN in the past.

BRATE This factor represents breathing rate and is used for calculation of inhalation doses. The breathing rate (BRATE = 3.30E-04 m^3/sec) of the Reference Man (70-kg adult male at light work) derived from Shleien 1992; Table 12.6) has been used as the STANDARD value. The value in the cited table has been converted from liters per hour to m^3/sec.

CULVL This factor describes Clean-Up Level, which is the required level to which contaminated surfaces must be cleaned up. The STANDARD value is the EPA guideline of 0.2 $\mu Ci/m^2$ (EPA, 1977). This value applies to the sum of deposited activity over all radionuclides of a multi-radionuclide material. Although never officially adopted by the EPA or superseded by another standard, this value has become a *de facto* standard (Chanin and Murfin, 1996). This is a controversial issue at present, and analysts who can justify use of more realistic values are urged to do so.

EVACUATION This parameter specifies evacuation time in days following a dispersal accident, where this includes time to respond to the accident and carry out a course of action. The STANDARD value is 24 h (one day). Mills et al. (1995) analyzed 66 verified hazmat accidents in which evacuations were carried out and found that the mean evacuation time was approximately one hour. Even when response time is added, a 24-hour (one-day) value for this variable is conservative. [For non-dispersal accident evacuation, see TIMENDE.]

GECON This parameter specifies the Genetic Effects Conversion Factor. The STANDARD value is 1.0E-04 genetic effects/rem. This value is consistent with the recommendations of BEIR V (NRC/NAS, 1990) and ICRP 60 (ICRP, 1991). Estimates based on the only genetic effects (untoward pregnancy outcome and F_1 mortality) to have been documented in the atomic-bomb survivors have extremely high statistical and model uncertainties. Animal data, which is more reliable, consistently yield lower estimates. As noted in BEIR V, the recommended value is "probably ...too high rather than too low" (NRC/NAS, 1990, p. 77).

INTERDICT This parameter specifies the threshold value for interdiction of contaminated land. The STANDARD value is 40, i.e., a value 40 times greater than CULVL, and it was taken from NUREG-0170 (NRC, 1977).

Table 3-1. STANDARD Isopleths and Time-Integrated Concentrations (Ci-sec/m³/Ci released)

Isopleth Area (m^2)	Downwind Centerline Distance (m)	Time-Integrated Concentration
4.590E+02	3.345E+01	3.420E-03
1.530E+03	6.804E+01	1.720E-03
3.940E+03	1.051E+02	8.580E-04
1.250E+04	2.439E+02	3.420E-04
3.040E+04	3.694E+02	1.720E-04
6.850E+04	5.614E+02	8.580E-05
1.760E+05	1.018E+03	3.420E-05
4.450E+05	1.628E+03	1.720E-05
8.590E+05	2.308E+03	8.580E-06
2.550E+06	4.269E+03	3.420E-06
4.450E+06	5.468E+03	1.720E-06
1.030E+07	1.114E+04	8.580E-07
2.160E+07	1.310E+04	3.420E-07
5.520E+07	2.133E+04	1.720E-07
1.770E+08	4.050E+03	8.580E-08
4.890E+08	6.999E+04	5.420E-08
8.120E+08	8.986E+04	4.300E-08
1.350E+09	1.209E+05	3.420E-08

LCFCON This parameter specifies the Latent Cancer Fatality (LCF) Conversion Factors; units are LCFs per rem. The STANDARD values are 5.0E-04 LCF/rem for the general public and 4.0E-04 LCF/rem for workers. They have been adjusted for low-dose and low-dose-rate decrease in effects with a DDRRF (Dose and Dose Rate Reduction Factor) of 2. These values are consistent with the recommendations of BEIR V (NRC/NAS, 1990) and ICRP 60 (ICRP, 1991). The dose-response relationship is assumed to be linear with no threshold in order to agree with current regulations. However, the majority of available data indicate that the actual dose-response relationship at very low doses is likely to be considerably less and, as noted in BEIR V, is not incompatible with zero (NRC/NAS, 1990, p. 181). Thus, cancer risk estimates obtained from RADTRAN 5 will be generally conservative.

LOS The parameter is used to analyze loss-of-shielding accidents. It represents the fractional degradation of package shielding for each severity category in the analysis. Values may be any number between zero and 1.0.

NE This parameter is the neutron emission factor; it may be used to model neutron emissions following a loss-of-shielding accident. For commonly encountered radionuclides that spontaneously emit neutrons (curium-242, curium-244, and californium-242), the NE values are already available in the radionuclide library. All other radionuclides have no assigned NE factor. The NE keyword is applied only when the analyst wishes to assign a new value to an existing radionuclide or to a new material. The analyst must enter NE followed by the radionuclide name in standard format (or exactly as entered under keyword DEFINE) and the emission factor value in neutrons/s-Ci. The analyst must repeat the process (i.e., type NE followed by radionuclide name and NE factor value) for each radionuclide desired.

RADIST This parameter is used to specify an array of Radial Distances, which are used to define annular areas for dose-calculation purposes when the IACC Flag is set to 1.

RPCTHYROID This parameter is used to specify one-year CEDE (rem per curie) to the thyroid from inhalation of radionuclides of iodine for estimation of early-mortality risk. Radioiodine mainly travels to and irradiates a single organ, the thyroid. In previous releases of RADTRAN, however, the 50-year CEDE was used to approximate the one-year dose. One-year committed doses to the thyroid have been calculated directly for RADTRAN 5. This new parameter was not included in the internal radionuclide database, since it would have meant adding a new column containing zeros for all radionuclides but the radioiodines. The information has been included under the PRCTHYROID keyword instead. The STANDARD values are 1.27E+06 for iodine-131, 5.77E+06 for iodine-129, and 9.25E+05 for iodine-125.

SURVEY This parameter is used to specify the time (in days) required to survey contaminated land following a dispersal accident. The amount of deposited material removed by radioactive decay is calculated beginning with time of initial deposition. The longer a deposited material remains on the ground, the more is removed by decay and spread by forces such as wind and rain. The actual elapsed time between accident occurrence and completion of a survey is impossible to determine in advance, but is likely to be prolonged because of governmental and regulatory complexities. The STANDARD value is set to an unrealistically brief, but radiologically conservative, 10 days (NRC, 1977).

TIMENDE This parameter specifies the time, in days, required to effect evacuation following a non-dispersal accident. Three values are entered, one for each population-density zone (rural, suburban, and urban, in that order). TIMENDE represents the time required to move potentially exposed members of the public to safe distances beyond the areas specified by the RADIST keyword. The three STANDARD values are 0.67, 0.67, and 0.42 hours (Mills et al., 1995) [for dispersal accident evacuation, see EVACUATION]

UBF This parameter is the Urban Building Fraction; it describes either the fraction of the population that is indoors or the fraction of the area that is occupied by buildings, depending on the type of population model being used. The STANDARD value of 0.52 is for the latter model, and is taken from Finley et al. (1980). The value is most accurate for large cities such as New York and is somewhat conservative for smaller cities.

USWF This parameter is the Urban Sidewalk Fraction; it specifies the fraction of the population that is out of doors or the fraction of the population that occupies sidewalks, depending on the type of population model being used. The STANDARD pre-assigned value of 0.1 is for the latter model, and is taken from Finley et al. (1980). As with the UBF, this value is suitable for large cities and is conservative for smaller cities.

3.11.4 MASTER LIST OF RADTRAN 5 KEYWORDS

FIRST LEVEL	SECOND LEVEL	THIRD LEVEL	DESCRIPTION
TITLE	---	----	User-defined alphanumeric title; preferably descriptive
INPUT	STANDARD or ZERO	----	Analyst elects whether to use standard input values or not
DIMEN	---	----	Enter three (3) values: NSEV, NRADIAL, NISOPLETH
PARM	---	----	Sets four (4) flags
FORM	UNIT or NONUNIT	----	Analyst selects output format: dose (UNIT) or health effects (NONUNIT)
INGFILE	---	----	For ingestion dose; Enter COMIDA output filename if other than default
LOS	---	----	Enter shielding degradation fraction for each severity category
SEVERITY	NPOP	NMODE	Enter probabilities for NSEV severity categories for NPOP =1, 2, and 3 and for each Mode
RELEASE	GROUP	RFRAC	Release fraction for Group p
	---	AERSOL	Aerosol fraction for Group p
	---	RESP	Respirable fraction for Group p
	---	DEPVEL	Deposition velocity. for Group p
	CLINE	----	Centerline downwind distance (m)
	AREADA	----	Isopleth area (m^2) for n areas
	DFLEV	----	Time-integrated concentrations for n areas (Ci-sec/m^2)
	PSPROB	----	Pasquill probabilities (6 values)
	ISOPLETHP	----	Populations of NISOPLETH isopleths; see DIMEN)
DEFINE	---	----	Radionuclide name followed by 10 values
NONRAD	HIGHWAY GENERAL DEDICATED	NPOP NPOP NPOP	Highway fatality rates (km^{-1}) General rail fatality (km^{-1}) Dedicated rail fatality rates (km^{-1})
TRANSFER	GAMMA NEUTRON	----	Coefficients for gamma radiation Coefficients for neutron radiation
PACKAGE	[END]	-----	Enter 5-variable array for each package

FIRST LEVEL	SECOND LEVEL	THIRD LEVEL	DESCRIPTION
			type followed by radionuclide contents followed by END
VEHICLE	----	----	Enter 11-variable array for each vehicle type followed by the package(s) on the vehicle
MODSTD	SMALLPKG	----	Size of smallest package for nondispersal analysis
	TIMENDE	----	Evacuation time (3-number array), non-dispersal
	UBF	----	Urban Building Fraction
	USWF	----	Urban Sidewalk Fraction
	EVACUATION	----	Evacuation time (days)
	SURVEY	----	Survey interval (days)
	INTERDICT	----	Interdiction threshold
	DISTOFF	FREEWAY	Enter 3-variable array
	---	SECONDARY	Enter 3-variable array
	---	STREET	Enter 3-variable array
	---	RAIL	Enter 3-variable array
	---	WATER	Enter 3-variable array
	DISTON	FREEWAY	Minimum perpendicular distance to vehicle traveling opposite direction (m)
	---	SECONDARY	Minimum perpendicular distance to vehicle traveling opposite direction (m)
	---	STREET	Minimum perpendicular distance
	---	RAIL	Minimum perpendicular distance (m)
	---	WATER	Minimum perpendicular distance to vehicle Traveling opposite direction (m)
	MITDDIST	----	Distance for Maximum In-Transit Dose (m)
	MITDVEL	----	Speed for Maximum In-Transit Dose (m/s)
	CAMPAIGN	----	Campaign duration (years)
	DDRWEF	----	Distance-dependent rail worker exposure factor (inspections/km)
	RADIST	NPOP	Enter NRADIAL distances (see DIMEN) for loss-of-shielding exposure in NPOP = 1, 2, and 3
	BDF	----	Building Dose Factor
	CULVL	----	Clean-up Level (uCi/m^2)
	BRATE	----	Breathing Rate (m^3/s)
	FMINCL	----	Minimum no. of rail classifications and/or inspections
	RPD	----	Ratio of Pedestrian Density
	RR	----	Rural shielding factor

FIRST LEVEL	SECOND LEVEL	THIRD LEVEL	DESCRIPTION
	RS	----	Suburban shielding factor
	RU	----	Urban shielding factor
	FNOATT	----	Number of flight attendants
	NE	----	(radionuclide name) neutron emission factor (neutrons/sec/Ci)
	RPCTHYROID	----	1-yr dose to thyroid via inhalation (rem per curie)
	LCFCON	----	Latent cancer fatalities conversion factors (2-number array)
	GECON	----	Genetic effects conversion factor
FLAGS	ITRAIN	---	1=General freight; 2=Dedicated Rail
	IUOPT	----	Shielding Options
	IACC	----	1=nondispersal; 2=dispersal
	REGCHECK	----	1=regulatory checks performed 2=regulatory checks not performed
EOF			"End of File" special keyword
LINK	---	----	Enter 11-variable array for each link (route segment)
STOP	---	----	Enter 7-variable array for each stop
HANDLING	---	----	Enter 5-variable array for each handling
EOF			"End of File" special keyword
EOI			"End of Input" special keyword; terminates input

4. RADTRAN 5 OUTPUT

The RADTRAN 5 output consists of several types of results and tables. Output may be requested in short or long formats. The short or summary format is the first type. It consists of the Input Echo and summary tables of output. Full-length output consists of the Input Echo, all of the input data in tabular form, and detailed tables of output values as well as the summary tables.

4.1 The Input Echo

The first part of the output for any RADTRAN 5 run is the Input Echo, which is a repeat or "echo" of the input file. The echo shows the following:

- All STANDARD parameters with either the STANDARD values (analyst entered STANDARD after keyword INPUT) or with all values set to zero (analyst entered ZERO after keyword INPUT);
- User-defined values of parameters without STANDARD values;
- User-defined values of those parameters with STANDARD values which the analyst altered (following the keyword MODSTD); and
- All comment lines (lines beginning with &&).

The echo preserves all parameter values in an input file and, thus, is useful for quality-assurance purposes. The Input Echo is always part of the output file. Any RADTRAN 5 output lacking Input Echo pages should be considered potentially corrupt, incomplete and unsuitable for either publication or quality assurance.

The example in Figures 4A-4D illustrates how an input file for a complex material (in this example, spent nuclear fuel) might be constructed. A single input file has been divided into four functional parts to illustrate the roles of the disparate types of data that must be entered. The data in Figures 4A-4D are based an actual input file, but are used here for illustrative purposes only. The top of Figure 4A shows comment lines and the TITLE, INPUT, FORM, DIMEN, and PARM initialization lines. Then, beginning in Figure 4A and continuing in 4B are input for the accident-severity categories. Release, aerosol, and respirable fractions are defined for each physical-chemical group. In this example, five distinct physical-chemical groups have been defined (CRUD, GAS, VOLATILE, CE_EU, and RUTHENIUM). The use of the DEFINE function also is illustrated in Figure 4B with a cobalt radioisotope. Figure 4C shows how MODSTD parameters are assigned when the analyst does not wish to accept the STANDARD values. Settings under the keywords FLAGS and PACKAGE are also illustrated in this figure. Fifteen radionuclides and their properties are listed under the material SPENT FUEL, the only material in the package being analyzed. Finally, the package is assigned to a vehicle (TRUCK

```
&& Edited Fri Feb 21 11:07:45 1997
&& This file has been altered
&& The data contained in this input file are for test purposes only.
        TITLE EXAMPLE FILE
INPUT STANDARD
FORM UNIT
DIMEN 6 10 18
PARM 1 3 4 0
SEVERITY
 NPOP=1
  NMODE=1
 6.03E-001 3.94E-001 3.00E-003 3.00E-006 5.00E-006 7.00E-006
  NMODE=2
 6.23E-001 3.74E-001 3.00E-003 3.00E-006 5.00E-006 7.00E-006
 NPOP=2
  NMODE=1
 6.02E-001 3.94E-001 4.00E-003 4.00E-006 3.00E-006 2.00E-006
  NMODE=2
 6.22E-001 3.74E-001 4.00E-003 4.00E-006 3.00E-006 2.00E-006
 NPOP=3
  NMODE=1
 6.04E-001 3.95E-001 3.80E-004 3.80E-007 2.50E-007 1.30E-007
  NMODE=2
 6.24E-001 3.75E-001 3.80E-004 3.80E-007 2.50E-007 1.30E-007
RELEASE
 GROUP=CRUD
   RFRAC
0.00E+000 0.00E+000 1.20E-002 1.20E-002 1.20E-002 1.20E-002
   AERSOL
        0.00E+000 0.00E+000 1.00E+000 1.00E+000 1.00E+000 1.00E+000
   RESP
   0.00E+000 0.00E+000 5.00E-002 5.00E-002 5.00E-002 5.00E-002
   DEPVEL 0.0100
 GROUP=GAS
   RFRAC
   0.00E+000 0.00E+000 0.00E+000 1.00E-002 1.00E-001 1.10E-001
   AERSOL
   0.00E+000 0.00E+000 0.00E+000 1.00E+000 1.00E+000 1.00E+000
   RESP
   0.00E+000 0.00E+000 0.00E+000 1.00E+000 1.00E+000 1.00E+000
   DEPVEL 0.0000
```

Figure 4a. RADTRAN 5 Input Echo-Initialization and Accident Severities

```
GROUP=VOLATILE
   RFRAC
    0.00E+000 0.00E+000 0.00E+000 1.00E-008 2.00E-004 2.80E-004
AERSOL
    0.00E+000 0.00E+000 0.00E+000 1.00E+000 1.00E+000 1.00E+000
   RESP
0.00E+000 0.00E+000 0.00E+000 5.00E-002 1.00E+000 1.00E+000
   DEPVEL  0.0100
 GROUP=CE_EU
RFRAC
    0.00E+000 0.00E+000 0.00E+000 1.00E-008 5.00E-008 5.00E-008
AERSOL
    0.00E+000 0.00E+000 0.00E+000 1.00E+000 1.00E+000 1.00E+000
   RESP
    0.00E+000 0.00E+000 0.00E+000 5.00E-002 1.00E+000 1.00E+000
   DEPVEL  0.0100
 GROUP=ACTINIDE
   RFRAC
    0.00E+000 0.00E+000 0.00E+000 1.00E-008 5.00E-008 5.00E-008
   AERSOL
    0.00E+000 0.00E+000 0.00E+000 1.00E+000 1.00E+000 1.00E+000
   RESP
    0.00E+000 0.00E+000 0.00E+000 5.00E-002 5.00E-002 5.00E-002
   DEPVEL  0.0100
GROUP=RUTHENIUM
   RFRAC
    0.00E+000 0.00E+000 0.00E+000 1.00E-008 1.00E-006 4.20E-005
   AERSOL
    0.00E+000 0.00E+000 0.00E+000 1.00E+000 1.00E+000 1.00E+000
   RESP
    0.00E+000 0.00E+000 0.00E+000 5.00E-002 5.00E-002 5.00E-002
   DEPVEL  0.0100

DEFINE CO60
    1.93E+003 2.50E+000 4.60E-001 7.60E-004 3.50E+005 2.50E+004
    2.00E+000 0.00E+000 0.00E+000
```

Figure 4b. RADTRAN 5 Input Echo-Accident Severities (cont'd) and DEFINE

```
MODSTD
  UBF 6.000E-001
  USWF 5.000E-002
  MITDDIST 3.000E+001
  MITDVEL 2.400E+001
  DISTON FREEWAY  1.200E+001
  TIMENDE 1.000E+000 1.000E+000 2.500E-001
  CULVL 2.200E-002
  INTERDICT 4.000E+001
FLAGS
  REGCHECK 1
  IUOPT 2
  IACC 2
PACKAGE  SPENTFUEL 1.368E+001 1.000 0.000   5.20
     CO60     9.220E+001 CRUD
     KR85     6.100E+003 GAS
     SR90     5.960E+004 ACTINIDE
     RU106    1.620E+004 RUTHENIUM
     CS134    2.740E+004 VOLATILE
     CS137    8.760E+004 VOLATILE
     CE144    1.220E+004 CE_EU
     EU154    7.000E+003 CE_EU
     PU238    2.960E+003 ACTINIDE
     PU239    4.100E+002 ACTINIDE
     PU240    4.680E+002 ACTINIDE
     PU241    1.260E+005 ACTINIDE
     AM241    1.290E+003 ACTINIDE
     AM243    1.990E+001 ACTINIDE
     CM244    1.790E+003 ACTINIDE
     END
VEHICLE  1  TRUCK     1.368E+001 1.000 0.000   5.20   1.00
                 2.00  10.00 1.000   5.20
     SPENTFUEL    1.00
EOF
```

Figure 4c. RADTRAN 5 Input Echo-MODSTD; Flags; Package; Vehicle

```
LINK 1 RURAL  TRUCK  2915.34 88.6 2.0  6.00 470.00 1.37E-007 R 1
LINK 2 RURAL  TRUCK  971.78 88.6 2.0  6.00 470.00 1.37E-007 R 2
LINK 3 SUBURB TRUCK  623.03 88.6 2.0 719.00 780.00 3.00E-006 S 1
LINK 4 SUBURB TRUCK  207.68 40.3 2.0 719.00 780.00 3.00E-006 S 2
LINK 5 SUBURB TRUCK   69.22 44.3 2.0 719.00 1560.00 3.00E-006 S 1
LINK 6 SUBURB TRUCK   23.07 20.2 2.0 719.00 1560.00 3.00E-006 S 2
LINK 7 URBAN TRUCK   6.18 88.6 2.0 3861.00 2800.00 1.60E-005 U 1
LINK 8 URBAN TRUCK   0.33 24.1 2.0 3861.00 2800.00 1.60E-005 U 2
STOP STOP_TRUCK TRUCK  50.00 20.00  20.00 1.000 52.990
HANDLING LOAD   TRUCK    3.00   1.00  0.25
EOF
EOI
```

Figure 4d. RADTRAN 5 Input Echo-Route-Specific Data

under keyword VEHICLE). Figure 4D shows how route-specific features (links, stops, and handlings) are described. This sample file shows several features of RADTRAN 5, such as:

- separation of radionuclides in the material (listed under keyword PACKAGE) into more than one physical-chemical group (listed under keyword GROUP) and
- how data entered for route segments (keyword LINK), stops (keyword STOP), and handlings (keyword HANDLING) should appear.

4.2 Consequences of Incident-Free Transportation

After the input data summary tables, actual RADTRAN 5 calculational output begins with the heading "INCIDENT-FREE SUMMARY." The first table of output is titled "In-Transit Population Exposure in Person-Rem" (Box 4-1). Doses to passengers, crew, members of the public residing near the link (off-link) and sharing the link (on-link) for each route segment (link) are given in this table, as are subtotals for rural, suburban, and urban segments, and totals according to segment type and exposure group.

Box 4-1

INCIDENT-FREE SUMMARY

******** **** *******

IN-TRANSIT POPULATION EXPOSURE IN PERSON-REM

	PASSENGER	CREW	OFF LINK	ON LINK	TOTALS
RURAL1	0.00E+00	6.84E+01	4.02E-01	1.82E+01	8.69E+01
RURAL2	0.00E+00	2.28E+01	1.60E-01	1.50E+01	3.79E+01
SUBURB1	0.00E+00	1.46E+01	8.96E+00	6.44E+00	3.00E+01
SUBURB2	0.00E+00	1.07E+01	8.02E+00	2.62E+01	4.49E+01
SUBURB3	0.00E+00	3.25E+00	1.99E+00	5.94E+00	1.12E+01
SUBURB4	0.00E+00	2.37E+00	1.78E+00	2.39E+01	2.80E+01
URBAN1	0.00E+00	1.45E-01	9.87E-03	2.29E-01	3.84E-01
URBAN2	0.00E+00	2.85E-02	9.52E-02	4.27E-01	5.50E-01
URBAN3	0.00E+00	3.24E-02	2.20E-03	2.13E-01	2.47E-01
URBAN4	0.00E+00	6.87E-03	2.30E-02	4.32E-01	4.62E-01
RURAL	0.00E+00	9.12E+01	5.62E-01	3.31E+01	1.25E+02
SUBURB	0.00E+00	3.09E+01	2.07E+01	6.24E+01	1.14E+02
URBAN	0.00E+00	2.13E-01	1.30E-01	1.30E+00	1.64E+00
TOTALS:	0.00E+00	1.22E+02	2.14E+01	9.69E+01	2.41E+02

Doses incurred at stops and during handling are tabulated separately. The stop example shown in Box 4-2 is for a shipment of PWR spent fuel. The words "POINT-SOURCE DOSE" indicate that a point-source model was used to perform the calculation. The point-source model is selected when the analyst places receptors at radial distances from the shipment greater than two characteristic package dimensions. Box 4-3 shows a similar calculation for handling (e.g. loading of a spent fuel cask onto a truck by a crane). A line-source model is used in the latter case because of the handlers' proximity to the cask.

Incident-free doses are consequences. If the transportation event being analyzed actually takes place, then these types of doses will be incurred. In RADTRAN 5, the probability term is 1.0, although it is actually equal to 1.0 minus the very small probability of an accident. The analyst may request that dose output be multiplied by what are often called "stochastic risk factors" to

Box 4-2 SAMPLE OUTPUT TABLE FOR STOP DOSE: 1 STOP BY TRUCK

STOP EXPOSURE IN PERSON-REM

POINT-SOURCE DOSE STOP_TRUCK 9.6E-01

Box 4-3 SAMPLE OUTPUT TABLE FOR HANDLING DOSE: LOADING

HANDLING EXPOSURE IN PERSON-REM

HANDLING	VEHICLE	MATERIAL	DOSE
LOAD	TRUCK	SPENTFUEL	2.32E-01

TOTAL: 2.32E-01

estimate potential health effects (NONUNIT after keyword FORM). The resultant estimates of potential health effects are *risk estimates*, because a "stochastic risk factor" is itself a probability term. It means that, for a large population receiving a given collective dose, there will be, on the average, some number of excess health effects observed as a result of the exposure. The results of accident dose-risk calculations, which are discussed in the next section, are true risks. That is, each dose consequence term has been multiplied by a probability of occurrence. Dose risks can also be converted into health risks; doing so entails an additional multiplication by an additional probability (the risk factor). Health-effects risk estimates are secondary or derivative values and should not be reported alone without the associated dose-risk values.

4.3 Importance Analysis

An importance analysis is performed for incident-free doses on a link-by-link basis. The importance analysis describes the change in the output resulting from a 1% change in an input variable. All input variables that affect the incident-free dose calculation are listed in descending order from the largest positive change to the largest negative change. The actual value of the change in the output and the percentage change are listed in the output table (Box 4-4). This analysis will not yield accurate results if the package has a large neutron component because the method used to determined dose versus distance for neutron radiation is not amenable to the partial-derivative approach used to generate the importance analysis. However, for all applications where packages are modeled as emitting 100% gamma radiation, the importance analysis is reliable.

4.4 Population Risks and Consequences from Accidents

The primary accident-related output of RADTRAN 5 depends on whether UNIT or NONUNIT was entered under keyword FORM (see Chapter 3). If UNIT was selected, then the output consists of tables of dose risks and doses (primary consequences). A sample consequence calculation for spent fuel shipment by truck is shown in Box 4-5. The results are broken down by accident severity (rows) and by route segment (columns). When large numbers of route

Box 4-4 Example of Importance Analysis Output for a Single Link

INCIDENT-FREE IMPORTANCE ANALYSIS SUMMARY
ESTIMATES THE PERSON-REM INFLUENCE OF A ONE PERCENT INCREASE IN THE PARAMETER

LINK	PARAMETER	IMPORTANCE	CHANGE
SEG1			
	DOSE RATE FOR VEHICLE (TI)	8.693E-01	10.0000 %
	NUMBER OF SHIPMENTS	8.693E-01	10.0000 %
	DISTANCE TRAVELED	8.693E-01	10.0000 %
	NUMBER OF CREW MEMBERS	6.837E-01	7.8657 %
	K ZERO FOR CREW DOSE	6.837E-01	7.8657 %
	CREW DOSE ADJUSTMENT FACTOR	6.837E-01	7.8657 %
	K ZERO FOR VEHICLE	1.855E-01	2.1343 %
	NUMBER OF PEOPLE PER VEHICLE	1.815E-01	2.0881 %
	TRAFFIC COUNT	1.815E-01	2.0881 %
	SHIELDING FACTOR (RR,RS,RU)	4.020E-03	0.0462 %
	POPULATION DENSITY	4.020E-03	0.0462 %
	NUMBER OF FLIGHT ATTENDANTS	0.000E+00	0.0000 %
	RATIO OF PEDESTRIAN DENSITY (RPD)	0.000E+00	0.0000 %
	DIST DEP RAIL WORKR EXPOSR FACTR	0.000E+00	0.0000 %
	VELOCITY	-1.051E+00	-12.0881 %
	DISTANCE FROM SOURCE TO CREW	-1.367E+00	-15.7314 %

BOX 4-5 ACCIDENT CONSEQUENCES TABLE IN OUTPUT - EXAMPLE

RADIOLOGICAL CONSEQUENCES
50-YEAR POPULATION DOSE IN PERSON-REM

CATEGORY	SEG1	SEG2	SEG3	SEG4	SEG5	SEG6
1	000E+00	000E+00	000E+00	000E+00	000E+00	000E+00
2	000E+00	000E+00	000E+00	000E+00	000E+00	000E+00
3	2.53E+00	2.53E+00	3.03E+02	3.03E+02	4.97E+02	4.97E+02
4	2.53E+00	2.53E+00	3.03E+02	3.03E+02	4.97E+02	4.97E+02
5	2.69E+01	2.69E+01	3.23E+03	3.23E+03	5.29+03	5.29E+03
6	3.57E+01	3.57E+01	4.28E+03	4.28E+03	7.02E+03	7.02E+03

BOX 4-6 INGESTION CONSEQUENCES TABLE IN OUTPUT
(CALCULATED FOR RURAL LINKS ONLY)

RADIOLOGICAL CONSEQUENCES IN PERSON-REM
50 YEAR SOCIETAL INGESTION DOSE - EFFECTIVE

LINK	SEVER: 1	SEVER: 2	SEVER: 3	SEVER: 4	SEVER: 5	SEVER: 6
SEG1	0.00E+00	0.00E+00	1.72E+00	1.75E+00	3.01E+02	4.07E+02
SEG2	0.00E+00	0.00E+00	1.72E+00	1.75E+00	3.01E+02	4.07E+02

BOX 4-7 EXPECTED VALUES OF POPULATION RISK IN PERSON-REM

(By link, for groundshine, inhalation, resuspension, and cloudshine exposure pathways; ingestion calculated separately)

LINK	GROUND	INHALED	RESUSPD	CLOUDSH	TOTAL
SEG1	2.14E-03	2.61E-06	1.01E-05	1.75E-07	2.16E-03
SEG2	7.15E-04	8.71E-07	3.35E-06	5.83E-08	7.19E-04
SEG3	1.55E+00	1.71E-03	6.55E-03	1.29E-04	1.56E+00
SEG4	5.16E-01	5.69E-04	2.18E-03	4.29E-05	5.19E-01
SEG5	1.27E-02	1.39E-05	5.32E-05	1.06E-06	1.28E-02
SEG6	6.79E-04	7.41E-07	2.84E-06	5.65E-08	6.83E-04
RURAL	2.86E-03	3.48E-06	1.34E-05	2.33E-07	2.88E-03
SUBURB	2.30E+00	2.53E-03	9.70E-03	1.91E-04	2.31E+00
URBAN	1.49E-02	1.63E-05	6.24E-05	1.24E-06	1.50E-02
TOTALS:	2.31E+00	2.55E-03	9.78E-03	1.92E-04	2.33E+00

BOX 4-8 SOCIETAL DOSE RISK FOR INGESTION

(PERSON-REM)

LINK	GONADS	EFFECTIVE
SEG1	2.82E-03	2.57E-03
SEG2	9.40E-04	8.57E-04
TOTAL	3.76E-03	3.43E-03

SOCIETAL INGESTION RISK BY ORGAN - PERSON-REM

LINK	BREAST	LUNGS	RED MARROW	BONE SURF.	THYROID	REMAIN-DER
SEG1	1.62E-03	1.53E-03	1.80E-03	1.55E-03	1.48E-03	3.78E-03
SEG2	5.39E-04	5.10E-04	6.01E-04	5.17E-04	4.93E-04	1.26E-03
TOTAL	2.16E-03	2.04E-03	2.40E-03	2.07E-03	1.97E-03	5.04E-03

segments are analyzed in a single run, this part of the output can be many pages long. Because ingestion doses are societal (i.e., affect the general population rather than only the population under the plume footprint), they are calculated and tabulated separately (Box 4-6). Population dose-risks for all pathways except ingestion are given in the output table shown in Box 4-7 for the same sample file. Dose-risks are given for each route segment, broken down by exposure pathway. Non-ingestion consequence and risk results are summed by population-density category to give summations for the total rural, suburban, and urban links traversed by the shipments under analysis. Ingestion dose-risks can only be incurred if a dispersion accident takes place in an agricultural (rural) area and if no interdiction or other preventive measures are taken. For convenience, ingestion doses are assigned to rural route segments, although persons everywhere are potentially affected (Box 4-8). This should not be forgotten when the analyst is assessing dose-risks for the other areas. Ideally, the ingestion dose-risk should be distributed among all population groups on the basis of population weighting or other apportionment methods.

If NONUNIT was selected under keyword FORM, then the output consists of tables of projected health-effects (secondary consequences). An example is shown in Box 4-9.

Box 4-9 HEALTH EFFECTS OUTPUT - EXAMPLE

EXPECTED VALUES OF POPULATION RISK IN LATENT CANCER FATALITIES

	GROUND	INHALED	RESUSPD	CLOUDSH	TOTAL
Link 1	1.06E-06	1.09E-09	4.21E-09	8.86E-11	1.07E-06
Link 2	3.53E-07	3.63E-10	1.40E-09	2.95E-11	3.55E-07
Link 3	7.66E-04	6.93E-07	2.66E-06	6.52E-08	7.69E-04
Link 4	2.55E-04	2.31E-07	8.87E-07	2.17E-08	2.56E-04
Link 5	8.51E-05	7.70E-08	2.96E-07	7.24E-09	8.54E-05
Link 6	2.83E-05	2.57E-08	9.85E-08	2.41E-09	2.85E-05
Link 7	1.29E-05	1.15E-08	4.42E-08	1.10E-09	1.29E-05
Link 8	6.78E-07	6.06E-10	2.33E-09	5.79E-11	6.81E-07
Link 9	1.43E-06	1.28E-09	4.91E-09	1.22E-10	1.44E-06
Link 10	7.54E-08	6.73E-11	2.58E-10	6.43E-12	7.57E-08
RURAL	1.41E-06	1.45E-09	5.61E-09	1.18E-10	1.42E-06
SUBURB	1.13E-03	1.03E-06	3.94E-06	9.66E-08	1.14E-03
URBAN	1.51E-05	1.35E-08	5.17E-08	1.29E-09	1.51E-05
TOTALS:	1.15E-03	1.04E-06	4.00E-06	9.80E-08	1.16E-03

4.5 Interdiction Table

A table indicating how many, if any, isopleth areas would be interdicted for each accident-severity category also is included in the output. Interdiction is based on ground deposition levels. When an area is interdicted, persons in the affected area will already have received an inhalation dose and an external radiation (cloudshine) dose from passage of the plume, and be exposed to external radiation from ground-deposited particulates (groundshine) for the time that elapses prior to evacuation. The values in the interdiction table depend on user-supplied information on interdiction action levels and parameters describing atmospheric dispersion (if any) in each accident-severity category. See Section 4.5.2 for a sample dose calculation. An example of an interdiction table is shown in Box 4-10.

Box 4-10 INTERDICTION AREAS TABLE - EXAMPLE

```
AREAS WITH TOTAL CONTAMINATION RATIO GREATER THAN 40.000
(THE AREAS MARKED WITH AN 'X' ARE INTERDICTED AND HAVE
NO 50 YEAR GROUNDSHINE DOSE AND NO INGESTION DOSE.)

 AREA/SEVERITY  1  2  3  4  5  6
     1          -  -  X  X  X  X
     2          -  -  X  X  X  X
     3          -  -  X  X  X  X
     4          -  -  -  -  X  X
     5          -  -  -  -  X  X
     6          -  -  -  -  X  X
```

4.6 Early Fatality Calculations

Two other types of impacts are calculated regardless of whether UNIT or NONUNIT output was selected. They are:

- risk of early fatality (also known as nonstochastic or prompt effects) from radiation exposure, and

- risk of early fatality from nonradiological causes (i.e., from ordinary traffic accidents).

4.6.1 Radiological Early Fatality Risk

The example shown in Box 4-11 is an actual result from a sample file. Results are calculated for each route segment (identified by user-defined labels) under LINK column. The total is also calculated. In this example, **no** member of the public would receive a prompt dose exceeding the early-fatality threshold in any severity of accident. The example is typical of most analyses. Among the few instances in which non-zero fatality risks would be predicted in this category are loss-of-shielding accidents for medical gamma sources such as cobalt-60 or cesium-137.

Box 4-11 EARLY FATALITY OUTPUT

LINK	EARLY FATALITIES
SEG1	0.00E+00
SEG2	0.00E+00
SEG 3	0.00E+00

4.6.2 Nonradiological Fatality Risk

The results for nonradiological fatality-risk output formerly were broken down on the basis of "normal" and "accident," where "normal" refers to health risk from vehicle emissions, and "accident" refers to death from physical trauma following an accident. The emergence of considerable data regarding threshold values for the various chemical constituents of vehicle exhaust has made linear extrapolation untenable, and the "normal" factor is now omitted. Effects in the Normal Occupational category were always extremely small, and their omission will have no effect on the result at the recommended two-digit level of reporting. Results for accident-related fatalities are broken down into occupational (OCC) and non-occupational (NON-OCC) categories. There are two reasons for this:

- The probability of an effect and the population of radioactive shipment crewmembers are both very small.
- The sub-populations most at risk (e.g., persons with severe respiratory problems) are usually not employed in the transportation sector.
- The Accident Non-Occupational category reflects the chance of a member of the public being killed in a transportation accident in each of the various roadway-type categories. The Accident Occupational category values indicate expected driver/crew deaths from physical trauma. Standard values for both categories are obtained from national and state statistics, but the analyst may substitute other values available to him or her. Non-radiological risks are usually several orders of magnitude larger than other risks computed by RADTRAN

4.7 Individual Dose Calculations

4.7.1 Maximum Individual In-Transit Dose (incident-free)

The maximum individual in-transit dose for incident-free transportation calculates a dose to an individual located at a specified distance from a transport link (highway, railroad, and waterway) during the passage of one or more shipments at a specified speed. The user may define the distance and speed values. In previous releases of RADTRAN, distance and speed were fixed at 30 m and 15 mph, respectively; but are now definable by the user.

4.7.2 Maximum Individual Downwind Doses (following a dispersion accident)

Maximum individual downwind doses are calculated at the mean downwind centerline distance for each isopleth. The doses are the sums of individual doses from the three so-called "prompt" exposure pathways --- cloudshine, inhalation, and the first several hours of groundshine (exact number of hours determined by user-supplied value of the EVACUATION parameter). The output resembles the example in Box 4-12, where the downwind distance is given under the column heading CNTRLINE. Individual doses are given for each accident severity category in the analysis. The example gives a single row, but the actual output would contain as many rows as there were isopleths. The values may be used, for example, to determine whether Federal exposure guidelines might be exceeded and, if so, at what distances from an accident site.

4.8 Population Data in Output

RADTRAN 5 performs three calculations that provide the user with quantitative information about potentially exposed populations. They are listed and discussed in this section.

Box 4-12 Maximum Individual Dose Output: Example [only first row shown]

```
MAXIMUM INDIVIDUAL CONSEQUENCE (DOSE IN REM)
FROM INHALATION, CLOUDSHINE, AND GROUNDSHINE EXPOSURE
DURING EVACUATION

CNTR LINE   SEVER: 1  SEVER: 2  SEVER: 3  SEVER: 4  SEVER: 5
SEVER: 6
 3.34E+01   0.00E+00  0.00E+00  3.05E-02  3.20E-02  1.87E+00
2.76E+00
```

4.8.1 Population within User-Specified Distance of Route

Incident-free dose to the public is integrated over a user-specified perpendicular distance (in meters) from the shipment centerline. This distance is designated by keyword DISTOFF (STANDARD value for DISTOFF = 800m). Population density values are generally derived from census data either directly or by means of a routing code. RADTRAN 5 calculates the total population within the DISTOFF distance along each route segment from distance and population-density input. For multiyear shipment campaigns, however, a simple algebraic calculation will underestimate the total potentially exposed population because no account would be taken of the residence times of various fractions of the population. Therefore, RADTRAN 5 includes a model that uses 1990 census statistics to correct for the movement of persons into and out of a contaminated area (Smith et al, 1996).

4.8.2 Population Potentially Exposed to Radiation from Dispersed Particulates

Uniform Population Density

The total population within a user-specified dispersion isopleth pattern is calculated and written to a table in the output file. Unless the user specifies otherwise, this calculation proceeds on the basis of two simplifying assumptions:

- the distribution of population under the footprint of the dispersion cloud is uniform
- the population density within the bandwidth that is used in incident-free calculations is assigned to the entire area under the plume footprint.

Because of the simplifying assumption of uniform population density, wind direction has no effect on the results. Thus, wind direction is not a RADTRAN input variable. Furthermore, wind direction, even if known for all locations, would not greatly affect the results of a risk analysis over a long route (Mills and Neuhauser, 1999b). For very short routes, use of the simplifying assumptions could yield results different from, although not necessarily less than, actual values.

Non-Uniform Densities Defined with ISOPLETHP

In a new feature, users can examine potential doses calculated with a nonuniform population distribution under the plume footprint. RADTRAN 5 contains a separate, optional subroutine that allows the user to assign distinct population densities to each isopleth (second-level keyword ISOPLETHP under RELEASE). The resulting dose-risks are tabulated and printed in the output. There are no STANDARD values for this calculation, and the first alternative (uniform population distribution) is used if ISOPLETHP is not entered. ISOPLETHP is intended to be a supplementary tool to assist the analyst in assessing potential accident consequences at specific locations. For example, wind-direction related differences in downwind population densities might be examined with this tool. However, the lack of wind rose data for most locations on most routes limit this application to special cases.

4.9 Population Changes over Time

RADTRAN 5 allows the user to account for population in-migration and out-migration over time. The feature is intended for use in the analysis of multi-shipment campaigns that take place over more than one year. The user enters the duration of the campaign in years under keyword CAMPAIGN. By means of an algorithm based on Census Bureau demographic data, the total number of persons residing within the specified bandwidth around the transportation route(s) under analysis is calculated for the specified period of time (Smith and Neuhauser, 1995). The output of CAMPAIGN is the total population that has lived along the route during the shipping campaign, and does not provide the time that any segment of that population lived along the route. It should therefore not be used to calculate population doses, and is not incorporated into RADTRAN calculations.

5. ANALYSIS METHODS

Analysis procedures and strategies are considered in this chapter.

5.1 PACKAGE and SHIPMENT Values

5.1.1 Package and Conveyance Dimensions

All RAM packages have an external dose rate, but not all have a transport index (TI), although this is often confused with dose rate. TI is a regulatory quantity that applies only to certain package types, as defined in regulations of the International Atomic Energy Agency, the U.S. Department of Transportation and the U.S. Nuclear Regulatory Commission (NRC) (49 CFR Part 173 and 10 CFR Part 71, respectively). In 10 CFR Part 71 and elsewhere, TI is defined as the maximum radiation, in millirem per hour, at any point 1 meter from the external surface of a package. For exclusive-use shipments, however, the regulations abandon the TI concept. Instead, they regulate the dose rate at 2 m from the "vertical planes projected by the outer lateral surfaces" of the railcar or vehicle. Values for dose rate 1 m from the surfaces of package(s) and conveyance(s) must be entered in RADTRAN 5 regardless of which regulations govern the package(s) being analyzed.

RADTRAN is designed to take advantage of the fact that this dose rate at 1 meter from the package surface is a maximum and either is directly measured for regulatory compliance purposes or can be calculated from a similar maximum measured at 2 meters. Real 3-D packages, however, often have dose rates that are considerably less than the maximum at many other points on the package or conveyance surface (Figure 5-1A). For example, dose rates at 1 m from the surface of a Defense High Level Waste rail cask may vary by three orders of magnitude from 32.9 mrem/hr at cask midpoint to 0.02 mrem/hr at the corner (Wan & Scheringer, 1983). Differences of one order of magnitude for gamma readings and two orders of magnitude for neutron readings were recorded at the cask surface on a TN-24 spent-fuel-storage cask with aged fuel contents (EPRI, 1987).

RADTRAN 5 does not account for the dose-rate variation described above. No generalized method of predicting field shape from package shape now exists, even for isotropically radiating materials, and few package contents are isotropically radiating. Many package contents display complex field-strength variations (e.g., spent fuel). In the absence of a general method, the approach taken in RADTRAN is necessarily geometrically simple and conservative. The package is modeled as an isotropically radiating sphere that emits the effective dose rate at a radius equal to $\{[(0.5)\text{CPD}] + 1\}$, where CPD is the Characteristic Package Dimension (Figure 5-1B). The CPD is an actual package dimension. For example, in cylindrical packages (e.g., most spent fuel casks), the characteristic package dimension is equal to length.[10] For a sphere, it is the diameter, and for a cubical package it is the longest internal diagonal.

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[10] For analysis of a package or vehicle with a characteristic dimension greater than 4 m, the basic formula for calculating K_0 significantly overestimates the actual dose rate, and RADTRAN 5 automatically makes an adjustment. For a package dimension greater than 4 m, the

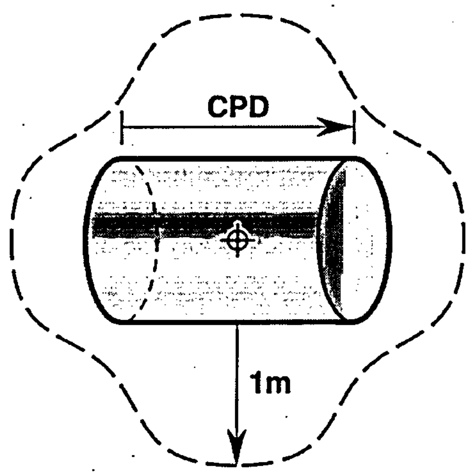

Figure 5-1a. Example of Realistic Radiation Field Strength Isobar [-----] Around a Cylindrical Package with a CPD Equal to Length and a Maximum Dose Rate at 1 meter as indicated. (Not to Scale)

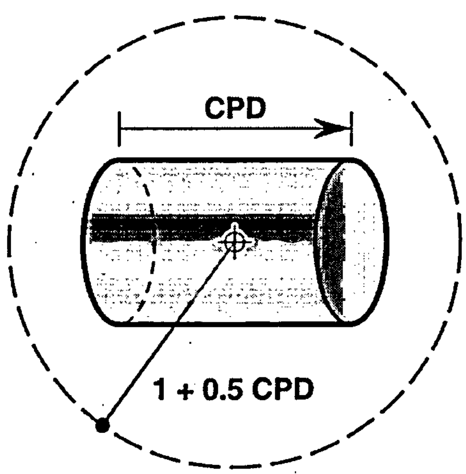

Figure 5-1b. Radiation Field is converted in RADTRAN 5 into a spherical, isotropically radiating field with its centerpoint at the geometric center of the package. The Field Strength at the radial distance of 0.5CPD + 1 is equal to the Maximum Dose Rate at 1 meter. (Not to Scale)

The RAM-carrying vehicle is also assigned a characteristic dimension. The user enters values for characteristic dimensions (in meters) for each package and vehicle type. The code calculates a coefficient, K_0, from the CPD. K_0 is often called the 'shape factor,' and it is used in subsequent

value for the actual characteristic package or vehicle dimension is replaced with a value for an effective package dimension, which is calculated by RADTRAN 5 according to the following equation:

$$D_{eff} = 2 \cdot (1 + 0.5\, D_{act})^{3/4} - 0.55$$

where D_{eff} = effective dimension and D_{act} = actual dimension.

dose calculations.[11] RADTRAN incident-free results are highly sensitive to the value of K_o, and the user should select values of dose rate and CPD with great care.

The third type of CPD is "crew-view" CPD. It is the characteristic dimension of a package silhouette as viewed from the crew's vantage point. It is often markedly different from the silhouette of the same package for other exposure groups (e.g., handlers). For cubical packages the "crew-view" is the diagonal across one side; for spherical packages, it is the diameter, just as for the regular CPD (Figure 5-2). The application of the crew-view CPD is discussed in Section 5.1.3.

As noted above, the entire shipment also is assigned a characteristic vehicle dimension (CVD). For example, the trailer of a tractor-trailer carrying a packed array of radiopharmaceutical packages may be treated as a single entity for the purpose of calculating external radiation doses. Finley et al, (1988) contains an example of this application.

5.1.2 Package and Shipment Dose Rates

Dose-rate values are among the most important data entered in a RADTRAN 5 input file. Recall that the maximum dose rate in mrem/hr at any point 1 m from a package or at 2 m from the vertical planes projected by the outer lateral surfaces of the transportation vehicle is regulated by law. Recall also that the maximum dose rate at 1 m is a RADTRAN 5 input value, which is used to estimate conservatively the field strength around the package or shipment.

The field-strength estimate for each package is used to calculate handler dose. The field-strength estimate around a vehicle (shipment) is used to calculate doses to persons beside the transport link (off-link), doses to persons sharing the transport link (on-link), and doses to persons at stops. The following guidance indicates the best ways of handling various package/shipment configurations.

Single-Package Shipments.
This is the simplest case. The shipment dose rate may be set equal to package dose rate, which normally is conservative. However, if the package is significantly narrower or shorter than the conveyance in which it is transported, then the actual shipment-level dose rate should be calculated or measured and used instead. The source-to-crew distance is usually the distance from the center of the package to the crew compartment. However, if a distinct crew-view dimension is used, then the same dose rate is used but the source-to-crew distance is measured from the end of the package closest to the crew compartment.

Multiple-Package Shipments.

- **Arrays.** This configuration usually applies to small packages. In most cases, numerous packages fill the space available for cargo or palletized groups of packages are evenly distributed within the space. The shipment dimension (CVD) represents the conveyance

[11] For close-proximity exposure groups, a line-source model is used (Weiner & Neuhauser, 1992).

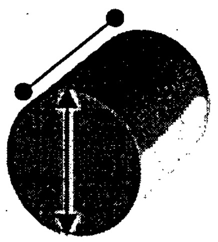

Figure 5-2a. The Characteristic Package Dimension (CPD) of a Cylinder Is Length (meters)[●——●] Crew-View CPD is Diameter (meters) [◄–►]

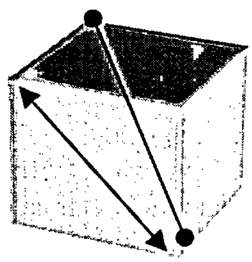

Figure 5-2b. CPD of a Cube is Longest Internal Diagonal (meters) Crew-View CPD is Diagonal on a Side (meters)

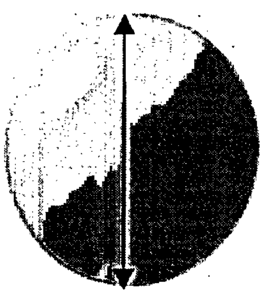

Figure 5-2c. CPD and Crew-View CPD of a Sphere are Both Equal to the Diameter (meters).

cargo space (usually trailer or railcar length). One should note that the estimate of dose rate at any given distance from a shipment increases nonlinearly with increasing shipment dimension for a fixed shipment dose rate (DR_v). Use of a shipment dimension greater than approximately 10 m is not recommended.

One still enters individual package dose rates as well as a shipment-level dose rate for the conveyance. The shipment dose rate is not equal to the sum of the package dose rates. It must be measured directly or calculated by hand because self-shielding usually makes the shipment dose rate significantly smaller than the sum of the individual package dose rates. An example of this approach may be found in Finley et al. (1988). Individual package dose rates also are required, however, because doses to handlers are always calculated on the package level.

- **Two or a Few packages.** These are often special cases involving Type B packages. Individual cobalt-60 pins for commercial irradiators, for example, might be shipped in the following configuration: one per package; two packages at a time; truck mode. The vehicle-level dimension selected by the user to represent such a shipment depends on package placement within the cargo space. Type B and other heavy packages are generally evenly spaced to distribute the load. For example, in the case of two packages shipped in a single trailer, they could be tied down at the centerpoints of the two halves (measured from front to back) of the trailer bed. Total trailer length could be the CVD for this configuration; the maximum dose rate 1 meter from the trailer edge midpoint would have to be measured or calculated DR_v (Figure 5-3, Option 1). Alternatively, one could model the same example as two shipments each with a CVD equal to half the trailer length and with shipment dose rates measured at 1 m from the midpoint of each trailer half (see Option 2). For a 7×3-m trailer and packages 1-m in diameter, Option 1, with the larger vehicle dimension, yields a dose result that is about 40% higher than for Option 2. This occurs because of the nonlinear nature of the k_0 and DR_v functions. As noted above, this nonlinearity tends to increasingly overestimate the dose-rate values as CVD increases. Therefore, Option 1 may be preferred for analyses where conservatism is desired, but Option 2 gives a better dose estimate.

- **Other Configurations.** There are many possible arrangements of packages within a vehicle, and RADTRAN permits all variations to be characterized. Among special cases one might encounter are those in which the edge of the trailer or railcar is coincident with the edge of the package (e.g., TRUPACT shipments to the Waste Isolation Pilot Plant). If it is a single package, the vehicle and package dose rates are equal. When a package occupies most or all of the cargo space available (e.g., many spent-fuel casks), the package CPD is set equal to the CVD.

Crew Shielding

Crew shielding may be directly accounted for in RADTRAN 5 by means of the crew modification factor. In previous releases of RADTRAN, crew shielding could only be accounted for indirectly by artificially increasing the source-to-crew distance. With the crew modification factor, the user can easily account for shielding that may be installed in cabs of semi-tractors or ship's bulkheads, for example. Data that must be supplied by the user are:

- The "crew-view" dimension. Conveyances such as combination trucks often have "crew-view" dimensions that are smaller than those used to calculate doses for members of the public.

- The crew-to-source distance, which should be measured from the closest edge of the package or packed array to the center of the closest location for a crewmember (usually the crew cabin).

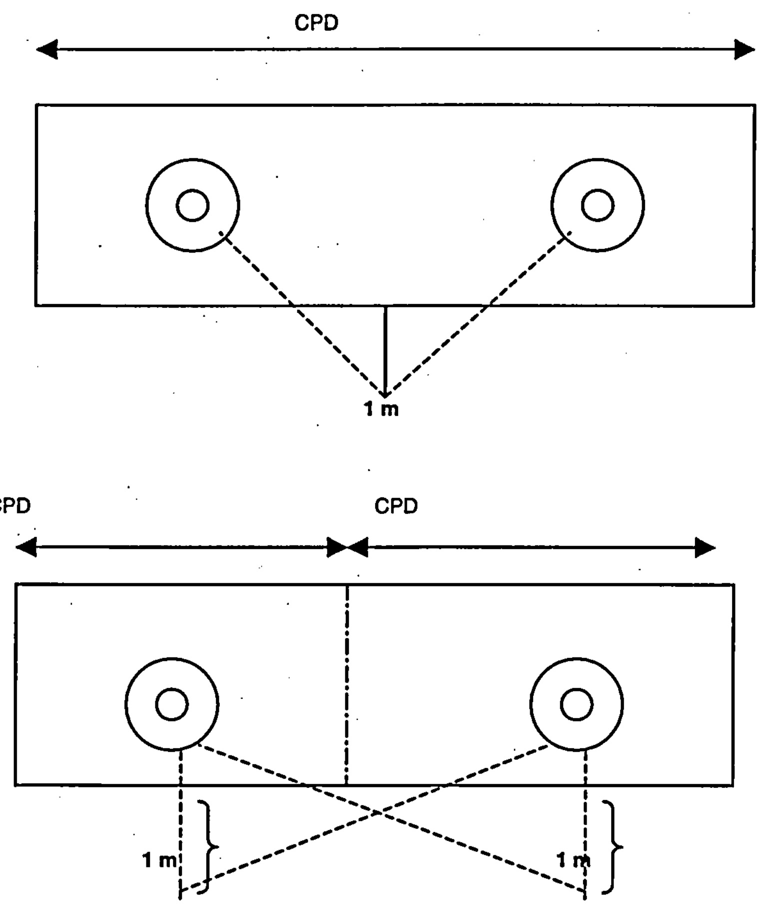

Figure 5-3. (a) Option 1 - Models Two or a Few Packages Widely Separated in the Same Conveyance - Model as Single Shipment with CPD Equal to Trailer or Railcar Length and Dose Rate Calculated at 1 m from Midpoint of Trailer or Railcar. (b) Option 2 – Models Two or a Few Packages Widely Separated in the Same Conveyance – Model as Two or More Separate Shipments each with CPD Equal to a Fraction of Trailer or Railcar Length and Dose Rate at 1 m from Midpoint of each Fraction of Trailer or Railcar.

5.2 Gamma and Neutron Components of Dose Rate

Values for a neutron component of dose rate for fission neutrons are available for use in RADTRAN 5. The derivation of these values was originally given in the RADTRAN 4 Technical Manual (Neuhauser and Kanipe, 1989). To summarize briefly, they were obtained with neutron cross-section data from the ENDF/B-V (Magurno, 1983) cross-section data library generated with the NJOY code (MacFarlane, 1982). The source was assigned an energy spectrum obtained from Oak Ridge National Laboratory calculations of the neutron flux at the surface of a lead-shielded spent fuel shipping cask. The neutron transport calculations were performed with the ONEDANT code, which solves the 1-D, multigroup, Boltzmann transport equation by the discrete ordinates method (O'Dell, 1982). The ENDF library, NJOY system, and

ONEDANT code are discussed and evaluated for use in transportation analysis by Parks et al. (1988).

To be compatible with the RADTRAN calculational strategy, the neutron rate as a function of distance is expressed in the following form

$$DR(x) = K\, e^{-\mu x}\,(1 + a_1 x + a_2 x^2 + a_3 x^3 + a_4 x^4)/x^2 ,$$

where

DR(x) = the dose rate as a function of x
x = distance in meters from the source
K = constant, and
μ = linear absorption coefficient for the surrounding medium (air).

The linear absorption coefficient for air (μ_{air}) was assigned a value of 7.42E-03 m^{-1} (Madsen et al., 1986; p. 43). Four unitless coefficients (a_1, a_2, a_3, and a_4) were then derived for fitting the shape of the dose rate-vs.-distance curve to the shape of the selected neutron transport curve in air at 50 percent relative humidity. These values are:

a_1 = 2.02E-02
a_2 = 6.17E-05
a_3 = 3.17E-08
a_4 = 0.0.

Although it is unlikely that another neutron transport curve might be appropriate, the user is allowed to enter new values for the coefficients into the input data file with keyword TRANSFER (see Chapter 3 for discussion of data entry). All four coefficients must be entered even if only one changes in value. Workstation/mainframe users enter them as the last four numbers in the five-number array under the second-level keyword NEUTRON and the first-level keyword TRANSFER (Table 3-2). The first number in this array is the linear absorption coefficient (μ), which also may be redefined by the user.

A similar treatment is possible for gamma radiation (second-level keyword GAMMA under TRANSFER), but the atmospheric effect (i.e., attenuation and buildup in air) is comparatively insignificant. Therefore, for gamma radiation the values of μ, a_1, a_2, a_3, and a_4 are set to zero in order to reduce the exponential term in the dose rate equation to unity. The equation for gamma thus reduces to the form used for a gamma point or line source in the RADTRAN calculational strategy, namely, $DR = K/x^2$ or $DR = K\chi/x$ (Madsen et al., 1986, p. 13).

Separation of dose rate into neutron and gamma components is useful only for packages in which a significant fraction of the external dose rate is attributable to neutrons (e.g., aged spent fuel). A breakdown of the gamma and neutron components of dose rate at 1 meter for representative truck and rail casks and fuel ages of from 5 to 25 years is given in Parks, Hermann and Knight (1985). For most materials, the user should treat the external radiation field as consisting solely of gamma radiation. The user always has the option of performing external transport calculations and curve fitting to obtain new coefficients. An analysis of a multiple-package shipment containing dissimilar packages should *not* rely on extrapolation from package-by-package gamma-neutron breakdown, because of differential shielding and absorption by surrounding packages. The calculated or measured *shipment-level dose rate* may be split into gamma and neutron components, if necessary, that are derived from measurement or modeling of the shipment configuration.

5.3 Multiple-Radionuclide Materials

5.3.1 Assignment of Physical-Chemical Groups

Few radioactive materials consist of single radionuclides; most are mixtures. The physical and chemical properties of radionuclides and their compounds vary widely, and the behavior of radionuclides and their compounds in response to mechanical and thermal forces potentially encountered during accidents depends strongly on these properties. The first step toward accounting for them is to list all of the important radionuclides in the package(s) being analyzed under the PACKAGE keyword. **The importance of an accurate radionuclide inventory cannot be underestimated.** When analyzing numerous small packages with variable contents, however, one may use statistical methods. Allow the code to automatically enter radionuclide-specific data directly from the internal radionuclide library whenever possible. Data entry is thereby simplified, and by reducing the amount of hand-entered data, the frequency of input errors is reduced. Complex materials containing up to 200 radionuclides can be modeled realistically. Methods are available, however, to reduce the number of nuclides considered without loss of accuracy, and are discussed in Section 5.2.2.

The second step is to determine whether physically and chemically distinct groups of elements are represented in the material(s) being considered. Examples of chemically distinct groups are noble gases (e.g., krypton), volatiles (e.g., cesium in various forms), and transuranic oxides (e.g., plutonium oxide). An element may fall into more than one group in a material. An example of an radionuclide that may be in two distinct groups is cobalt-60 in pressurized water reactor (PWR) spent fuel. The radionuclide is an activation product and is found (1) in metallic fittings of fuel assemblies and (2) in crud on the surface of the fuel rods. The former is in a non-dispersable form that does not contribute to potential releases in severe accidents, but the latter may be spalled off of the fuel rods following impact. The resulting particulates may then be available for release. Since cobalt-60 produces a high-energy gamma, it is very important to model this element correctly. Only the cobalt-60 in crud should be modeled as available for release in analyses of PWR spent fuel.

For a given material, only elements with similar release behavior in all accident-severity categories should be grouped together. For example, ruthenium and cesium are volatile elements which will behave similarly in many thermal environments, but ruthenium may undergo chemical changes in a severe fire and an oxidizing environment that cesium does not. Therefore, these two chemical species should be assigned to two separate physical-chemical groups.

The designed-in flexibility of RADTRAN 5 allows each group to be treated separately. Since as many as 15 physically and chemically distinct groups of elements may be used in a single analysis, even the most complex materials can be modeled. An example of a complex material (spent fuel) is given in the sample input file in Chapter 3.

Each physical-chemical group must be assigned appropriate values for the release fractions (RFRAC), aerosol fractions (AERSOL), respirable aerosol fractions (RESP), and deposition velocity (DEPVEL). The dispersibility categories used in earlier releases of RADTRAN are no longer used in RADTRAN 5. However, the table of former default values for these categories remains a reasonable guide to AERSOL and RESP values in the absence of any better information, and it is reproduced here from Neuhauser & Kanipe (1992).

Table 5-1. General Guide to AERSOL and RESP Values Suitable for All Severity Categories

Material Type	*Aerosol Fraction*	*Respirable Fraction*
Immobilized	1E-06	0.05
Loose Chunks	1E-02	0.05
Large Powder	1.5E-01	0.05
Small Powder or Nonvolatile Liquid	1E-01	0.05
Flammable	1E+00	1
Liquid	1E+00	1
Gas	1E+00	1
Undispersed (Loss-of-Shielding)	0	0

In summary, each radioactive element or compound is assigned to a group according to its physical and chemical properties. An element also may be assigned to more than one group if it appears in more than one physical-chemical form in the material being analyzed.

For shipments carrying packages with more than one type of contents, each package type must be separately characterized. The behavior of a multiple-package array in potential accident conditions is often different from the behavior of a single package, even if the packages are all identical. In an impact accident, for example, packages on the struck side of the vehicle generally will absorb more impact force than packages on the opposite side. Certain accident scenarios may involve what is referred to as inertial crush; when the force is translated from one package to the next in a manner such that package(s) distant from the impact point may be most affected. Packages also may act as thermal barriers in a fire accident, shielding other packages beyond them. Factors such as these must be considered and evaluated on a shipment-specific basis before assigning release fractions, etc.

5.3.2 Use of a Relative Hazard Index to Reduce Large Radionuclide Inventories

If the number of radionuclides in a material is large, as in spent fuel, for example, then radionuclides that contribute very small fractions to the overall hazard may be disregarded to simplify the analysis. The use of a relative hazard index for RAM transportation analyses was pioneered by Sandia National Laboratories. Various types of indices are discussed below.

Effective Dose Equivalent Factors

These factors give dose per unit intake for inhalation and ingestion for each radionuclide and are compiled and updated regularly by the DOE and the EPA (e.g., DOE, 1988a,b and EPA, 1993). When each is multiplied by the package inventory of the appropriate radionuclide, the resulting list represents the relative hazard of the material. For example, the data in DOE (1988b) was used to select those radionuclides that contribute to 99.9% of the total health hazard in a recent DOE EIS dealing with research reactor spent fuel (DOE, 1995).

Maximum Permissible Concentrations (MPCs) and similar metrics

Atmospheric dispersion generally represents the primary, and often the only, means of dispersing radionuclides beyond the immediate vicinity of an accident site, even in extremely severe accidents and even for waterway modes. For this reason, values such as the International Commission on Radiological Protection (ICRP) Maximum Permissible Concentrations in Air (MPCs), Annual Limits on Intake (ALIs), and Derived Air Concentrations (DACs) are attractive candidates for use in developing a relative hazard index. All three are described in ICRP (1979) and ICRP (1990). For example, Maximum Permissible Concentrations in Air (MPC_{air}) were used to develop a radiological hazard (RADHAZ) index for radionuclides present in ten-year-old PWR spent-fuel during analysis of repository alternatives (Wilmot et al., 1983). The authors used the following relationships:

$$\frac{\text{Inventory of radionuclide i (Ci)}}{MPC_{air}\text{ for radionuclide i}} = RADHAZ_i$$

and

$$\sum RADHAZ_i \text{ over all radionuclides in spent fuel} = \text{Total Radiological Hazard (for inhalation pathway).}$$

Retaining only those radionuclides that contribute, by summation on a rank-order basis, to 99.9% of the total radiological hazard (inhalation), Wilmot et al. (1983) reduced the size of the radionuclide list entered into RADTRAN to less than 10 without noticeably affecting the result. The radionuclides that were retained were cobalt-60, strontium-90, ruthenium-106, europium-155, cesium-134, cesium-137, and several radionuclides of plutonium.

Activity Limits

A similar method, based on Activity Limits (particularly A_2 values) can be used. The International Atomic Energy Agency (IAEA) defines A_2 as "the maximum activity of radioactive material, other than special form radioactive material, permitted in a Type A package" (IAEA, Safety Series 6, 1985). A Type A package meets the General Requirements for All Packagings and Packages, but is not accident-resistant, as are Type B packages.

This approach yields a nuclide list similar to that obtained with MPCs for the spent-fuel example above. With five-year-old spent fuel, additional elements such as americium and curium are included in the list. None of these methods should be applied blindly, however. Krypton-85, for example, is generally included in the final radionuclide list for spent fuel (e.g., Wilmot et al., 1983; DOE, 1995). Although krypton-85 is inert and poses a relatively low hazard, it is present in spent fuel as a gas and much of the inventory would be released in the event of a severe accident, rather than remain trapped in the fuel and cask structures as many solids would. Thus, it is reasonable to include this radionuclide regardless of its hazard index. Similarly, radionuclides that are present in large amounts by mass, even thought their specific activities are low (e.g., uranium in spent fuel), or that are highly biologically active (e.g., tritium and iodine-131) should not be automatically excluded on the basis of a numerical hazard ranking alone.

In summary, the user may apply a relative hazard index to a multiple-nuclide material in order to simplify an analysis. However, special features such as gaseous state, mass fraction, and biological activity, should be considered when compiling a defensible final list.

Historical Methods

Two methods that were used to simplify computations when computers were less powerful and access to them more limited should be mentioned, although they are seldom, if ever, used today. The first was a weighted-average method, used to approximate the gamma source strength of spent fuel in NUREG-0170 for loss-of shielding accidents (NRC, 1977, Tables A-5 and A-6). Today, it is recommended that measured surface-dose-rate values be used.

Also in NUREG-0170, the entire inventory of volatile fission products in spent fuel was modeled as cesium-137, the single most hazardous radionuclide in this class (NRC, 1977, Table A-5). This historical method yields results that are too high. The practice is obsolete since it is now easy to realistically model the actual radionuclide inventories of spent fuels and most other complex materials.

5.4 Route Data

This section deals with analyses in which the routes being analyzed are defined by a set of route segments. Additional RADTRAN applications of route segments are discussed in Section 5.5.3.

5.4.1 Aggregate Route Segments and Other Data

An aggregate route segment is defined as the sum of all portions of a route that satisfy some predefined criterion. For purposes of analysis, it is treated as a single route segment. The resulting collective or aggregate route segment has all properties specified by the criterion except length. The length of the aggregate segment is equal to the sum of the portions as defined above.

Route-segment aggregates, however defined, must be jointly inclusive and mutually exclusive. In other words, (a) the sum of the lengths of all the various route-segment aggregates must equal the total length of the route and (b) no individual segment of the route can be a member of more than one aggregation class defined by the criteria.

The most common aggregation criterion is population density. This criterion was used in NUREG-0170 (NRC, 1977), and has been used in numerous risk analyses since (e.g., Wilmot et al., 1983; DOE, 1995). Aggregated population-density data are readily obtained from the output of transportation routing codes such as HIGHWAY (Johnson et al., 1993) for truck mode and INTERLINE 5.0 (Johnson et al., 1992) for rail mode. Both of these codes, developed at Oak Ridge National Laboratory (ORNL), yield aggregate data for each node-to-node interval along the route. That is, all the rural segments between two major intersections are summed, as are the suburban and urban segments, respectively.

Stops may also be treated in an aggregate manner, especially when several similar stops may occur in the course of a single shipment. Madsen and Wilmot (1983) provide this information for long-distance truck shipments. Similar data for rail operations in the Unites States was collated by Ostmeyer, 1986, from information found in Wooden, 1986. This is discussed at greater length in Section 5.3.4.

5.4.2 Linear Route-Specific Analysis

This section consists primarily of suggestions and useful information to assist the user in describing and analyzing route-related data. To perform linear route-specific analyses, a route is usually broken into

(a) links or segments, each of which represents a portion of the actual route,
(b) stops, each of which represents a stop along the route, and
(c) handlings, each of which represents a loading, unloading, or intermodal transfer event that occurs during the trip(s) being analyzed.

Up to 60 distinct route segments, seven stops, and eight handlings may be analyzed in a single computer run. If the number of route segments, stops, or handlings exceeds the maximum number per run for RADTRAN, then the user must perform multiple runs. The results of multiple runs may be collated in spreadsheets such as Microsoft Excel™ to yield total risk and consequence values for a complex problem.

5.4.3 Summation Check

As noted above, the sum of the segment lengths should equal the total route length. Because there can be no internal check to ensure that this condition is satisfied, the analyst must perform this check. This check is most easily performed when data are entered in a spreadsheet, which is another reason why the use of spreadsheets is recommended for keeping tracking of the large amounts of data required by RADTRAN 5. The use of spreadsheets in building input files is discussed in Neuhauser et al. (1995).

5.4.4 Population Density

High-resolution sources of population data are available. The Bureau of the Census is the single best source of digitized data for the United States. Census data must be converted into population-density values suitable for use in RADTRAN. The population density within a predetermined bandwidth (usually 1600-m) of the highway or railroad must be determined for overland modes. Population densities under a plume footprint must also be determined if the user is applying the ISOPLETHP option. Methods for developing these population data with a GIS (Graphical Information System) have been developed at SNL (Mills, Neuhauser, and Kanipe, 1995). ORNL also has updated its previous routing codes (HIGHWAY and INTERLINE) with a GIS platform, TRAGIS, that also includes 2000 U. S. Census figures (Johnson et al., 2000).

5.5 Accident Rate

The units for this variable are usually accidents per vehicle-kilometer. National accident-rate data are compiled and published annually by various groups in the U.S. Department of Transportation (USDOT) such as the National Transportation Safety Board (NTSB) and the Federal Rail Administration (FRA). Some of these data are available in electronic format (e.g., DOT, 1994). The relationship between accidents and railroad track class is discussed in McClure et al. (1988). The U.S. Coast Guard collects U.S. maritime accident data. Lloyd's of London maintains the Lloyd's Maritime Information Service accident reports, which are available for a fee.

Less comprehensive but locally more detailed data can sometimes be obtained from state and municipality highway or transportation departments (e.g., Smith, 1982).

In most cases, data collected in the United States are reported either in terms of accidents per one million vehicle-miles or in tabular form with two columns of data (total number of accidents and total millions of vehicle-miles traveled). The latter are often embedded in tables with various other data and must be extracted by the user. The data are not broken down into convenient rural, suburban, and urban categories. For example, the category labeled as URBAN by the USDOT usually is designated according to political boundaries (i.e., city limits) rather than actual population densities. Accident rates must be converted to metric units. Methods for developing rural, suburban, and urban rates are discussed in NRC (1977), Wilmot (1983), and DOE (2002a).

When analyzing carriage by a specific type of vehicle, an accident rate for that vehicle type should be used whenever available, rather than less vehicle-specific values. For example, nearly all Highway Route Controlled Quantity (HRCQ) shipments of radioactive materials by highway mode are carried by combination trucks (tractor-trailers), and USDOT data are available for this truck type. The latter should be used in preference, for example, to data from the All Vehicles category. The data source and category should always be stated in the documentation of an analysis.

Most data sources, whether they explicitly state so or not, include only reportable accidents (i.e., those that exceed some dollar value in damages or those that involved a fatality). Correcting for underreporting only serves to raise the fraction of accidents of low severity (and hence to lower the fraction of high-severity accidents) and so is usually neglected. Accident-rate data for more than one year may be averaged, if desired, and the use of multiple years of data is recommended.

The accident-rate parameter is sometimes written less than rigorously as accidents/kilometer, but this should not be interpreted to mean an accident count per kilometer of roadway or railroad. The number of accidents that have occurred in a given route segment, if left unadjusted for usage of that route segment, is an improper (and useless) value. The denominator should always be taken as referring to vehicle-kilometers unless explicitly stated otherwise.

For air and maritime modes, accidents per voyage or accidents per air transit are often the forms in which data are presented. They can be converted to accidents/vehicle-kilometer if nautical-mile or air-mile distance values, or average trip distances, or some similar parameter can also be obtained. If they are used without modification, comment lines should be added to any analysis that uses an alternative form of accident-rate data to make sure improper comparisons are not made with other risks calculated on a per vehicle-kilometer basis.

5.6 Vehicle Density and Vehicle Occupancy

The DOT sources cited above also supply data on vehicle density for highway mode travel. For most analyses performed at Sandia, average vehicle occupancy is conservatively set to two, although it is usually closer to one (e.g., DOT, 1994).

5.7 Segment Character Designation

Although segment-specific population densities must be entered, the user is asked, in addition, to indicate whether each segment is rural, suburban, or urban in character. The user enters R, S, or U to indicate rural, suburban, or urban character, respectively. Character designation controls the selection of accident-severity fractions, controls whether an ingestion-dose calculation is performed, and determines the selection of building-shielding factors (RR, RS, and RU [see Keyword Master List, Section 3.11]).

If the segment character designation is R, then the ingestion pathway is included, but if a segment is designated as S or U, ingestion is not calculated. However, the ingestion code (COMIDA) also gives a calculation for a so-called "maximum man," who is essentially a subsistence farmer (Abbott and Rood, 1994a,b). This dose value is always included in the RADTRAN output. It will bound any doses potentially incurred by a suburban resident with a backyard tomato plot, for example, in the unlikely event that the individual continues to grow and eat tomatoes subsequent to a contamination event.

In addition, if a segment is designated U, then expected values of total inhalation dose are modified to account for its two main components:

1. Dose for persons indoors, and

2. Dose for persons outdoors.

To obtain the first value, the baseline total inhalation dose is calculated on the basis of a uniform population density; then that dose is multiplied by the product of Urban Building Fraction (UBF) and Building Dose Factor (BDF). The UBF accounts for the fraction of persons indoors (or the amount of land surface occupied by buildings rather than streets, sidewalks, parking lots, parks, etc.), and the BDF accounts for the partial removal of particulates by building ventilation systems (Finley et al., 1980). The UBF has a STANDARD value of 0.9; the BDF has a STANDARD value of 0.05 (Englemann, 1990). Both the UBF and BDF may be altered, of course.

The second term, which accounts for inhalation dose to persons outside of buildings (e.g., pedestrians, shoppers, and commuters), is calculated separately. In this term, the base dose value is multiplied by the product of Urban Sidewalk Fraction (USWF) and Ratio of Pedestrian Density to residential population density (RPD). The STANDARD values for USWF and RPD are 0.1 and 6.0, respectively (Finley et al., 1980). The RPD allows the user to account for non-residents, and all of them are modeled as being out of doors. The sum of the two terms is the adjusted collective inhalation dose.

5.8 Link Type

Link type is used to distinguish between various roadway types for highway modes only (truck, commercial van, and passenger van). If the user sets the link type to 1, then the route segment is modeled as a limited-access divided highway (i.e., an Interstate highway or other highway built to similar engineering standards). If the link type is set to 2, then the combination of zone designation and link type determines how the roadway is modeled. If the link type is set to 2 and the zone is designated either R or S, then the roadway is modeled as a non-limited-access, non-divided highway (e.g., an U.S. highway). If the link type is set to 2 and the segment is designated as U in character, then the roadway in that segment is modeled as a city street. For all other modes, the link type is set to 3.

This scheme is diagrammed as follows.

Link Type 1 ⇒ Limited-Access Divided Highway; Any Population Density

Link Type 2 ⇒ Zone R or S ↣ U.S. Highway (non-limited-access, non-divided)

Zone U ↣ City Street

Link Type 3 ⇨ Any Non-Highway Mode

This flexibility is important even for highway-route controlled quantity (HRCQ) shipments such as spent fuel, which are required by DOT routing regulations to use interstate highways. Access routes to and from the interstates and state-designated alternate routes, which often must be evaluated in environmental documents, can be analyzed readily by use of the link-type settings. Differences in accident rates, population densities, traffic densities and other factors that may change according to road type, must be accounted for if the analysis is to be meaningful. In a recent example, an Interstate route from Florida to Washington State was compared with a route that avoided urban areas by traveling on U.S. Highways (Mills and Neuhauser, 1998).

5.9 Fraction of Land under Cultivation

The user may enter values from 0.0 to 1.0 for this parameter only if the link is identified as R (rural in character; see Link Type above). If a link is identified as S or U (suburban or urban), then the RADDOG input file generator code automatically enters a zero for this parameter. If the user is manually creating an input file, then he or she must enter a zero value for all non-rural segments. The variable is used in the ingestion-dose calculation and accounts for the fraction of area in agricultural production, as opposed to the area occupied by roads, driveways, dwellings, barns, commercial buildings, parking lots, parks, forests, etc. No account is taken of seasonal differences. There is no STANDARD value for this parameter. Maximum values for this parameter are available from publications of the U.S. Bureau of the Census, but only for counties, a relatively low level of resolution.

If one wishes to "force" calculation of an ingestion dose for a link that is actually suburban or urban in character, then the user can designate the link as rural and enter a value for the fraction of land under cultivation. The latter value should be at least a factor of 4 or 5 smaller than the rural value. For example, the *County and City Data Book* (USBC, 1988) lists St Louis County, Missouri, which includes the City of St. Louis, as having 42,000 acres in cropland. The total area of the county is 506 square miles and the average population density was 1962 persons per square mile in 1988. At that time the fraction of land under cultivation in this highly urban county was approximately 0.13 (13%). Nearby Atchison County, Missouri, on the other hand, which is predominately rural (population density was 14.6 persons per square mile) had a fraction of land under cultivation of 0.77 (77%) in the same year. That is over five times the value for St. Louis County.

5.10 Population under Plume

Accidents may occur that result in airborne dispersion of RAM package contents. These accidents are characterized with the user entries for accident rate, severity fraction, release fraction, aerosol fraction, respirable fraction, and meteorological conditions. As in previous releases of RADTRAN, the area under the dispersion plume, the so-called plume "footprint" can be modeled as having the same population density as the bandwidth around the transportation corridor. This is normally acceptable for probabilistic analysis purposes. The population density in this bandwidth (usually 1600 m wide) is the basis for designation as rural, suburban or urban; off-link populations for incident-free dose calculations are located within the bandwidth. However, this modeling assumption leads to excessively large overestimates of downwind population for urban route segments. It is possible, but less likely, that a plume originating in a rural or suburban route segment would encounter higher density areas shortly beyond the bandwidth boundary. In order to better characterize such specific situations, an individual population density for each downwind isopleth may now be entered under the ISOPLETHP keyword. The Bureau of the Census is the best source of digitized information on population distribution in the United States. The population data must be used in conjunction with a GIS system to obtain useful plume footprint values.

5.11 Nonlinear Applications

In the so-called nonlinear applications of RADTRAN 5, the links do not represent a sequential or aggregated set of route segments that define a route. This freedom to define route segments in nontraditional ways that has been built into RADTRAN 5 is extremely useful. The user can analyze and compare the same route or route segment(s) in a variety of conditions. Examples of applications include:

- comparisons of daytime and nighttime population densities (e.g., Mills and Neuhauser, 1999a);
- comparisons of rush-hour and non-rush-hour traffic conditions;
- comparisons of current and projected population densities (e.g., Neuhauser and Weiner, 1992a)
- doses in enclosed spaces such as airplanes from leaking radioactive material package(s) (Neuhauser, 1992).

This powerful analytical tool is limited in usefulness only by the quality and quantity of data available to the user.

5.12 Stop Data

To review from Chapter 3, for each stop (or an aggregate of similar stops), the user assigns values to the following stop parameters:

- alphanumeric identifier, up to 10 characters;
- vehicle identifier (previously defined under keyword VEHICLE);
- population density (persons/km^2) *or* number of persons (#);

- minimum radius of annular area (m);
- maximum radius of annular area (m);
- shield fraction;
- stop time (hr).

There are two alternative methods for estimating the size of the potentially exposed population. In the first method, the minimum and maximum radii are set equal to each other; this is interpreted by the code to mean that dose will be calculated at an *average radial distance* from the shipment. In this option, the third value in the array is interpreted to mean *number of persons present at the stop.* These persons are modeled as if they were located at the specified average radial distance from the shipment(s) for the duration of the stop. In the second method, the maximum and minimum radii are not equal. This is interpreted by the code to mean that it should compute the area of an annulus (with the vehicle at its center) that has an inner radius equal to the smaller of the two radius values and an outer radius equal to the larger of the two values. The third value in the array is then taken to be a *population density,* which is used to calculate the number of persons within the annulus (the product of the population density and the calculated annular area).

The user must be careful not to get the two stop options confused. For example, entering a population-density value, rather than a count, along with an average distance (i.e., making the two radial distances equal), would mean the density would be interpreted as a specific number of persons located at that average distance. The result would usually be considerably in error. Studies that provide information on the values of these parameters for highway mode include Madsen and Wilmot (1983) and Griego et al. (1996).

If more than one stop is expected (e.g., cross-country truck shipment) and if exact stop locations cannot be known in advance, then the total expected stop time may be allocated to a single "aggregate" stop with average parameter values. For materials shipped by common carrier, this is often the only workable method. For truck shipments the aggregated stop time has been conservatively estimated to be equal to 0.011 hours per kilometer of travel (Madsen and Wilmot, 1983). This value includes rest stops, meal stops, and overnight stops on long trips. The use of aggregate stops for highway mode is common because one can expect truck stop locations to be restricted or predesignated only when one is analyzing heavily controlled or monitored shipments. Most train stops are in railyards, and several reports have examined the potential for rail worker dose (Wooden, 1986; Ostmeyer, 1986; ORNL, 1990). In the case of carriage by vessel, port-call stops are usually known well in advance and may last 24 hours or longer (Neuhauser and Weiner, 1992b).

5.13 Use of Stop Model for LOS Analyses with Robust or Special-Form Materials

The LOS model in RADTRAN 5 is suitable for use with many RAM shipments such as radiopharmaceuticals, which are typically shipped in small amounts in non-accident-resistant Type A packages. For shipments of these materials, moderate to severe accidents can be expected to result in complete loss of contents of all affected packages. The LOS model in RADTRAN 5 is intended for such situations. The contents are presumed to be lying on the ground or on some vehicle surface in a manner that permits little self-shielding. Thus, the entire radionuclide inventory is multiplied by a gamma photon energy or neutron emission factor, as appropriate, to calculate a source strength. However, this approach is inappropriate for special-form materials and other robust materials such as spent fuel that can be expected largely to retain their structural integrity even in extremely severe accidents. In the latter case, the annular-area option of the stop model should be used to estimate LOS doses. The source strength should be estimated from the product of the surface dose rate of the material and whatever shielding factor is appropriate to account for only partial degradation of the packaging. "Virtual vehicles" can be set up to model different degrees of loss of shielding (DOE, 2002a, Appendix J).

5.14 Handling Data

To review the discussion in Chapter 3, for each handling, the user assigns values to the following parameters following the keyword HANDLING:

- alphanumeric identifier, up to 10 characters;
- vehicle identifier (previously defined under keyword VEHICLE);
- number of handlers;
- average source-to-handler distance (m);
- handling time per package (hr/package).

The values of the last three parameters listed are a function of package size. Large containerized packages that are handled by spreader crane require several handlers. To move such a package from a truck to a ship's hold, for example, requires a crane operator, a spotter, and four or more additional workers (Neuhauser and Weiner, 1992b; Weiner and Neuhauser, 1992a). The package is modeled as a line source or a point source depending on distance. The average source-to-handler distance may be only a few meters, in which case a line source model is used. For packages that are smaller than a spent fuel cask but still large enough to require movement by forklift or similar equipment, the average source-to-handler distance decreases but so does the number of handlers. Finally, small packages that can be picked up and moved by hand (e.g., many radiopharmaceuticals) are analyzed in RADTRAN 5 by use of an empirical factor that relates handling time per package, source-to-handler distance, and other factors (keyword SMALLPKG; see Section 3.6).

5.15 Use of HANDLING or STOPS to Model Inspector Dose

Highly regulated shipments (e.g., spent fuel) are often subjected to redundant radiological and mechanical inspections by various government entities, carrier representatives, shippers of record, etc. Each inspection adds an increment of inspector dose. Inspectors generally must be close to the package/conveyance being inspected; their exposure may be modeled by use of the HANDLING or STOPS subroutine. Suggested parameter values are discussed in Ostmeyer (1986) for rail mode and Weiner and Neuhauser (1992a,b) for ship and highway modes.

5.16 Evacuation Time

The time (in days) that is required to evacuate a nearby population from the vicinity of an accident location is entered under the keyword EVACUATION.[12] The time is composed of (a) response time (i.e., the time it takes responders to reach the accident site, assess the hazard and initiate evacuation), and (b) actual evacuation time. The STANDARD value is one day. Evidence exists, however, to support use of a considerably lower value. A distribution of actual evacuation times from actual hazardous materials accidents is given in Mills, Neuhauser, and Smith (1995), and the mode (the "mean" of a log-normal distribution) is approximately one hour (0.04 day). Using Latin Hypercube Sampling (LHS) methods (Iman and Shortencarier, 1984) to sample from this distribution or a similar one developed by the user is the best way to deal with the uncertainty in this parameter (see Mills, Neuhauser and Kanipe (1995) for applications of LHS to RADTRAN).

5.17 Post-Accident Options

RADTRAN 5 contains decision logic that is based on calculated ground deposition and user-defined action thresholds. There are three possible courses of action:

1. If the ground deposition (Ci/m^3) exceeds the minimum clean-up level (keyword CULVL, Section 3.6), then the area under the plume is modeled as being evacuated at the end of the time entered under keyword EVACUATION (see Section 4.4);
2. If the ratio of ground deposition to clean-up level exceeds the maximum threshold (keyword INTERDICT), then the area is modeled as being permanently interdicted. That is, no residents return to the area and no additional dose is accumulated by these residents beyond what was already received in the hours prior to evacuation;

[12] The term "evacuation" in RADTRAN refers collectively to activities separately labeled as "evacuation" and "relocation" in the MACCS code used by the NRC for fixed site analysis.

3. If the first but not the second threshold value is exceeded, then the area is modeled as being cleaned to acceptable levels, after which returning population are modeled as being chronically exposed to residual material at the action-threshold level.

As noted previously, the STANDARD value of the time required for surveying potentially contaminated areas (keyword SURVEY) is 10 days, which is less, probably considerably less, than such an activity would be expected to take in reality (Chanin and Murfin, 1996). However, in view of the uncertainty in estimating this parameter value, the short 10-day value has been used because it is *radiologically conservative*; that is, it minimizes time for radioactive decay and thereby maximizes exposure from any short-lived radionuclides at all subsequent times. The time required for clean-up is not explicitly accounted for, but actual clean-up times are most likely to be years or even decades (Chanin and Murfin, 1996). Because it is assumed that cleanup would always result in subsequent exposure of returning population to contamination at the minimum action-threshold level, however, actual clean-up time does not greatly influence the population-dose calculation.

5.18 Output Options

There are two output formats: dose and health effect. Both types of output are usually desired for an analysis. Radiological risks should always be presented at a minimum in the dose format (expected population dose-risk) since it is the least derivative of the two values. Expected health effects (e.g., latent cancer fatalities) may be obtained by a second run of the code or by calculations external to the code. In both output options, early radiological fatality and nonradiological fatality calculations are always performed.

<u>Box 5-1</u>

RADTRAN 5 Exposure Pathways

Direct Exposure to Package
Loss of Shielding (LOS)
and
5 Dispersion Pathways:
Cloudshine
Inhalation
Groundshine
Resuspension
Ingestion (societal)

The population-dose output format is selected on the FORM menu screen. Workstation users should enter the keyword UNIT on the FORM line. Doses are calculated for the exposure pathways shown in the box. Three of the dispersion-pathways results are what are called "prompt" doses. That is, doses that occur during or within a few hours of cloud passage. They are cloudshine, inhalation, and groundshine during evacuation. For each radionuclide in a material, effective dose equivalents for inhalation, cloudshine, and ingestion are taken from the radionuclide library. Groundshine and LOS doses are calculated from radionuclide-specific photon-energy data (except for LOS doses for special-form materials; see Section 5.3.4). The resuspension pathway is merely a delayed, chronic inhalation pathway, corrected when necessary for clean-up, weathering, and radioactive decay.

The health-effects output format may be selected by either selecting it on the FORM menu screen or entering the keyword NONUNIT. If NONUNIT is selected, then STANDARD values of health-effects multipliers may be used for latent-cancer fatalities and hereditary disorders, or the user may supply others. As noted in Chapter 4, health-effect risks are given for each route segment and for each exposure pathway. Tables give the risks related to loss-of-shielding (LOS) exposures, all dispersion-related exposures except ingestion, and societal ingestion. The conversion factors, e.g. LCF per person-rem, are listed in the tabulations of input data. If the stop model is used to perform an LOS analysis, then the user must estimate early effects (morbidities and mortalities) externally.

5.19 Early Effects

Early or deterministic health effects only occur at high radiation doses. Their severity increases with increasing dose, and a threshold exists below which no effect is observed. They also may be called acute, deterministic, or prompt effects. Persons in close proximity to intense gamma and/or neutron sources during a loss-of-shielding accident could receive acute doses above the effects' thresholds; as could persons in the innermost isopleths who are exposed via the inhalation or groundshine pathways following a dispersal accident. Symptoms may appear within a few hours or days following exposure. Depending on dose, effects exhibit a range of severity from short-term anorexia or vomiting, hair loss, and erythema (skin reddening), which are accounted for in the morbidity estimates, up to and including mortality, which is accounted for separately.

5.19.1 Mortality

Mortality may be observed in a fraction of a population exposed to high doses delivered over short periods of time. Death may occur in days, weeks or months, depending on the magnitude of the dose, post-exposure medical treatment, and initial health status of the affected individual(s). The likelihood of mortality decreases if the dose is fractionated or protracted (ICRP, 1984). The one-year dose is calculated and used to estimate mortalities in RADTRAN 5. The probability of death for a given acute bone marrow or lung dose is listed in an internal data table in RADTRAN 5 (see Table 5-2). This table is used to estimate mortality associated with doses calculated in an analysis. The data are derived from Evans et al. (1985) and are consistent with those used in the MACCS2 code. A mortality estimate is performed and printed regardless of the output option selected.

5.19.2 Morbidity

Morbidities or non-lethal clinical effects are also estimated in RADTRAN 5. As in previous releases of RADTRAN, several organ-specific effects are evaluated for the inhalation pathway. The organs included are:

- Lung
- Upper Gastrointestinal Tract (stomach)
- Bone Marrow
- Thyroid (radioiodine only)

The bone marrow and upper GI tract (stomach) are relatively radiosensitive, and the morbidity thresholds are lowest for these two organs. Lung tissue is among the most radiation resistant, and it has the highest morbidity threshold. Thyroid morbidity (noncancerous nodules and hypothyroidism) results almost exclusively from intake of radioiodine.

Table 5-2. Mortality – Dose Relationship for Marrow and Lung Exposure

Marrow Dose (rem)	Fatality Incidence	Marrow Dose (rem)	Fatality Incidence	Lung Dose (rem)	Fatality Incidence
<160	0.00000	570	0.99482	<500	0.00000
160	0.00913	580	0.99679	525	0.00759
170	0.01234	590	0.99808	550	0.01050
180	0.01639	600	0.99889	575	0.01430
190	0.02143	610	0.99938	600	0.01922
200	0.02761	620	0.99967	625	0.02549
210	0.03510	630	0.99983	650	0.03341
220	0.04408	640	0.99992	675	0.04329
230	0.05475	650	0.99996	700	0.05548
240	0.06729	660	0.99998	725	0.07038
250	0.08188	6700	0.99999	750	0.08837
260	0.09872	>670	1.00000	775	0.10988
270	0.11797			800	0.13529
280	0.13977			825	0.16498
290	0.16425			850	0.19925
300	0.19150			875	0.23830
310	0.22155			900	0.28218
320	0.25438			925	0.33077
330	0.28990			950	0.38372
340	0.32798			975	0.44042
350	0.36838			1000	0.50000
360	0.41078			1025	0.56130
370	0.45481			1050	0.62293
380	0.50000			1075	0.68335

Table 5-2. Mortality – Dose Relationship for Marrow and Lung Exposure (continued)

Marrow Dose (rem)	Fatality Incidence	Marrow Dose (rem)	Fatality Incidence	Lung Dose (rem)	Fatality Incidence
390	0.54583			1100	0.74095
400	0.59172			1125	0.79420
410	0.63706			1150	0.84178
420	0.68123			1175	0.88274
430	0.72363			1200	0.91656
440	0.76371			1225	0.94326
450	0.80096			1250	0.96331
460	0.83499			1275	0.97755
470	0.86552			1300	0.98709
480	0.89237			1325	0.99306
490	0.91551			1350	0.99653
500	0.93502			1375	0.99840
510	0.95111			1400	0.99933
520	0.96406			1425	0.99974
530	0.97423			1450	0.99991
540	0.98199			1475	0.99997
550	0.98776			1500	0.99999
560	0.99192			>1500	1.00000

5.20 Unit-Risk Factors

The Unit-Risk Factor Method was developed in the early 1980s by Sandia National Laboratories, which also performed the first analyses in which this method was used (Wilmot et al., 1983; Neuhauser et al., 1984; Cashwell et al., 1986). Other analyses in which it has been used include DOE (1995; 2002a, b). The method is suitable for certain applications, such as comparisons of alternative packagings and content loading, or for instances where a very large number of different routes, different cargo inventories, or different types of receptor populations are analyzed.

A unit-risk factor is a quantitative transportation risk (e.g., dose-risk, fatality-risk) calculated by setting one or more of the RADTRAN input parameters equal to 1.0. Dose (consequence) from incident-free transportation may also be calculated using a unit factor which, for convenience, is also called a unit risk factor. Risk and dose are then calculated by multiplying the unit risk factor by the appropriate parameter values.

Table 5-1 shows examples of unit risk factors (DOE, 2002a). A different set of parameters was set to 1.0 for each unit risk factor, and each unit risk factor has a different set of units.

Table 5-3. Examples of Unit Risk Factors

Width Receptor	Route Segment Type	Unit Risk Factors		
		Barge	Rail	Truck
Off-link public [rem per (persons/km^2) per km]	R	1.72E-7	3.90E-8	2.89E-8
	S	1.72E-7	6.24E-8	3.18E-8
	U	1.72E-7	1.04E-7	3.18E-8
On-link public (person-rem per km per vehicles/hr)	R		1.21E-7	9.53E-6
	S		1.55E-6	2.75E-5
	U		4.29E-6	9.88E-5
Public at rest stops (person-rem/km	R			5.50E-9
	S			5.50E-9
	U			5.50E-9
Residents near rail classification stops [person-rem per (persons/km^2) per km^2]	S		1.59E-5	
Worker in a moving vehicle (person-rem/km)	R	2.11E-6		4.52E-5
	S	2.11E-6		4.76E-5
	U	2.11E-6		4.76E-5
Worker at classification stop (person-rem)			4.64E-2	

Off-link public dose
Number of shipments, kilometers for each route segment, and population density (persons/km^2) all =1.0. The unit risk factor is then multiplied externally (e.g., in a spreadsheet) by the number of shipments, kilometers, and population densities for each route segment.

On-link public dose
Number of shipments and kilometers for each route segment =1.0. The unit risk factor is then multiplied externally (e.g., in a spreadsheet) by the number of shipments and by kilometers for each route segment.

Dose to public at rest stops
Number of shipments, population density, and number of rest stops per km=1.0. Time density, and distance from the source were input for one rest stop. The unit risk factor is then multiplied externally (e.g., in a spreadsheet) by the number of shipments, the population density for each segment type, and by the number of rest stops per km.

The unit risk factor approach is useful when the analyst wishes to evaluate a large number of alternatives that differ from each other in only one or a very few package-related or route-related features.

To develop route-level unit-risk factors, reasonably consistent *route subclasses* must be identified. A route subclass can be defined as an aggregate of all portions of a route that have some common property or combination of properties. The term "property" means a route-related RADTRAN variable (e.g., population density between a specified range, traffic count within a specified range, etc.). The most common route subclasses are based on population density (rural, suburban, and urban).

External calculations are not covered by RADTRAN software QA, and it is incumbent on the user to demonstrate their correctness. In some cases, radiological unit-risk factors could not be used in the absence of a linear-no-threshold (LNT) hypothesis. The LNT hypothesis for health effects of radiation exposure is currently being reexamined by various national and international bodies.

Unit-risk factors for nonradiological fatalities do not suffer from a similar dependency on a linear hypothesis, with the exception of the so-called incident-free factor, which was intended to account for health effects of inhalation of diesel exhaust. The factor values were originally assigned on the basis of a rather generic assessment by Rao et al. (1981) in which an LNT relationship was assumed.[13] Beginning at about the same time, the effects of many components of diesel exhaust (e.g., benzene) had begun to be better characterized (Wark and Warner, 1981). Exposure thresholds have now been identified for most of these components (e.g., 10 ppm for benzene; see Calabrese and Kenyon, 1991). In view of these developments, the use of an incident-free risk factor for nonradiological fatalities based on an LNT hypothesis can no longer be justified. Therefore, no STANDARD value has been recommended for the incident-free risk factor for nonradiological fatalities in RADTRAN 5, and the variable may be removed in a future release of the code.

[13] Values were assigned for urban areas only and were 1.0E-07 fatalities/vehicle-km for highway, 1.3E-07 fatalities/vehicle-km for commercial rail, and 6.5E-07 fatalities/vehicle-km for dedicated rail.

6. REFERENCES

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APPENDIX A Glossary of Terms

Many of the definitions given in this section are taken from ***The Health Physics and Radiological Health Handbook*** (Shleien, 1992). Some have been abridged or otherwise edited.

Absorbed dose—The energy imparted by *ionizing radiation* per unit mass of irradiated material. The units of absorbed dose are the *rad* and the *gray.*

Activity Mean Aerodynamic Diameter (AMAD)—The diameter of a unit-density sphere with the same terminal settling velocity in air as that of an aerosol particle the radioactivity of which is the median for the entire aerosol.

Air modes—Carriage of *packages* by *cargo air craft* or *passenger air craft.*

Atom—The smallest particle of an element that cannot be divided or broken up by chemical means. An atom consists of a nucleus, which contains protons and *neutrons*, and *electrons* that orbit the nucleus.

Attenuation—The process by which a beam of radiation is reduced in intensity when passing through some material.

Attenuation Coefficient—Of a substance, for a parallel beam of specified radiation: the quantity μ in the expression μdx for the fraction removed by attenuation in passing through a thin layer of thickness dx of that substance. The *linear attenuation coefficient* is expressed in terms of length (meters).

Beta radiation—Charged particles emitted from atomic nuclei during *radioactive decay.* A negatively charged beta particle is identical to an *electron.*

Cask—A heavily shielded accident-resistant container (*packaging*) used to ship and/or store highly *radioactive materials* such as *spent fuel.*

Cargo air mode—Carriage of *packages* by cargo aircraft.

Carrier—A company engaged in the transportation of passengers or property by land or water as a common, contract, or private carrier, or by civil aircraft.

Cloudshine—Gamma radiation from airborne materials in an airborne plume.

Collective Dose—The sum of the individual *doses* received in a given period of time by a specified population from exposure to a specified source of *radiation.*

Committed Dose Equivalent—The dose equivalent to organs and tissues that will be received from an intake of radioactive material by an individual during the 50-year period following the intake. The ICRP defines this as the committed equivalent dose.

Committed Effective Dose—See *committed effective dose equivalent.*

Committed Effective Dose Equivalent (CEDE)—The sum of the products of the weighting factors applicable to each of the body organs or tissues that are irradiated and the *committed dose equivalent* to these organs or tissues. The ICRP defines this as the *committed effective dose.*

Contamination—The deposition of unwanted radioactive material on the surfaces of structures, areas, objects, or personnel.

Conveyance—Any *vehicle, vessel* or *aircraft* that might be used for the transportation of *radioactive material.*

Crud—A colloquial term for corrosion and wear products (rust particles, etc.) that become *radioactive* under a radiation flux. Sometimes found on the exterior surfaces of *spent fuel.* Derived from the term Chalk River Unidentified Deposits, which relates to the Chalk River reactor in Canada where crud was first observed.

Cumulative Dose—The total dose resulting from repeated exposures to *radiation* of the same region or of the whole body over a period of time.

Curie—A unit used to describe the intensity of *radioactivity* in a material. The curie is equal to 37 billion disintegrations per second, which is approximately the rate of decay of 1 gram of radium. Named for Marie and Pierre Curie who discovered radium in 1898.

Daughter Products—*Radionuclides* that are formed by the *radioactive decay* of some other radionuclide.

Decay, Radioactive—The decrease in the amount of any *radioactive* material with the passage of time, due to the spontaneous emission from the atomic nuclei of either alpha or *beta* particles, often accompanied by *gamma radiation.* (See *half-life; radioactive*)

Decontamination—The reduction or removal of contaminating radioactive material from a structure, area, object, or person.

Dose or Radiation Dose—A generic term that means *absorbed dose equivalent, effective dose equivalent, committed dose equivalent, committed effective dose equivalent,* or *total effective dose equivalent.*

Dose Equivalent—The product of the *absorbed dose*, the *quality factor*, and all other necessary modifying factors at the location of interest. The units of dose equivalent are the rem and sievert (Sv).

Dose Rate—The *radiation dose* delivered per unit time, e.g., rem per hour.

Effective Dose Equivalent—The sum of the products of the dose equivalent to the organ or tissue and the *weighting factors* applicable to each of the organs or tissues that are irradiated.

Electron—An elementary particle with a unit negative charge. See *beta radiation.*

Element—One of the 103 known chemical substances that cannot be broken down further without changing its chemical properties. Examples are hydrogen, nitrogen, gold, lead, and uranium.

Evacuation—The urgent removal of people from an area to avoid or reduce high-level, short-term exposure, usually from an airborne plume or from deposited activity.

Exclusive-use—A term used to describe a shipment in which the conveyance carries radioactive-material packages exclusively and no other cargo.

Exposure—A measure of the ionization produced in air by X or gamma radiation; units of exposure in the air are the Roentgen or coulomb per kilogram (SI units).

Fission Gases—Those fission products that exist in the gaseous state. Primarily the *noble gases* (krypton, xenon, radon, etc.)

Flux—A term applied to the amount of some type of *radiation* crossing a certain area per unit time. The unit of flux is number of particles, photons, etc. per square centimeter per second.

Gamma Radiation—High-energy, short wavelength electromagnetic radiation emitted from the nucleus of an atom. Gamma radiation frequently accompanies alpha and beta particle emissions and always accompanies fission. Gamma rays are very penetrating and are best stopped or shielded against by dense materials such as lead or uranium.

Gaussian—Pertaining to or having properties of the probability density function that is also called the Normal Distribution or bell curve; named after 19th Century German mathematician Karl F. Gauss.

Genetic Effect—An effect in a descendant resulting from the modification of genetic material in a parent.

Gray (Gy)—The SI unit of *absorbed dose.* One gray is equal to an absorbed dose of 1 Joule per kilogram (100 *rad*).

Groundshine—Gamma radiation from radioactive materials deposited on the ground.

Half-life—The time in which half the atoms of a particular *radioactive* substance disintegrate to another nuclear form.

Health Effects—See *stochastic effects* and *nonstochastic effects.*

Ion—An *atom* that has too many or too few *electrons*, causing it to be chemically active.

Ionizing radiation—Any *radiation* capable of displacing electrons from atoms or molecules, thereby producing *ions*. Includes: alpha, beta, gamma, X-rays, neutrons, and ultraviolet light.

Isotope—One of two or more atoms with the same number of protons, but different number of neutrons, in their nuclei. Isotopes have very nearly the same chemical properties, but very often different physical properties (for example, carbon-12 and -13 are *stable*, carbon-14 is *radioactive*).

Joule (J)—A unit of energy equal to 1 watt-second or .239 calories. Named after English physicist James P. Joule (1818-1889).

Linear Attenuation Coefficient—See *attenuation coefficient.*

Maritime modes—See *Waterway modes.*

Member of the Public—An individual in an unrestricted area. An individual is not a member of the public during any period in which the individual receives an *occupational dose.*

Molecule—A group of *atoms* held together by chemical bonds. A molecule is the smallest unit of a compound that can exist by itself and retain all its chemical properties.

Neutron—An uncharged elementary particle found in the nucleus of every *atom* heavier than hydrogen.

Noble Gas—A gaseous chemical element that does not readily enter into chemical combination with other elements. An inert gas. (See *fission gases*)

Nonstochastic effects—Health effects, the severity of which varies with the dose and for which a threshold is believed to exist (also called deterministic, early, or prompt effects). Usually follow exposure within a few hours or days; effects range from short-term nausea and skin-reddening up to, for supralethal doses, death within a few days.

Nuclide—A general term referring to all known isotopes, both *stable* and *unstable,* of a chemical *element.* See also *radionuclide.*

Occupational Dose—The dose received by an individual in a restricted area or in the course of employment in which the individual's assigned duties involve exposure to radiation and to radioactive material from licensed and unlicensed sources of radiation, whether in the possession of the licensee or other person.

Overland modes of transportation—Carriage of *packages* by *highway* or *rail* modes.

Package—A *packaging* and its *radioactive* contents.

Packaging—The assembly of components necessary to ensure compliance with packaging requirements. 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 *vehicle*, tie-down system, and auxiliary equipment may be designated as part of the packaging.

Parent—A *radionuclide* that upon *radioactive decay* or disintegration yields another nuclide (the *daughter*).

Pasquill System—Also called the Pasquill-Gifford System. A widely used empirical system for assigning Gaussian diffusion parameters to atmospheric releases of pollutants, including radionuclides. Six classes of atmospheric stability may be specified in RADTRAN 5; they range from highly unstable (Class A) to moderately stable (Class F). The frequency of occurrence of each class is recorded by many weather stations.

Passenger air mode—Carriage of *packages* by passenger aircraft.

Photon—A quantum (or packet) of energy emitted in the form of *radiation. Gamma rays* and X-rays are examples of photons.

Point Source—Ideally, a source with infinitesimal dimensions. Practically, a source of radiation the dimensions of which are small compared with the viewing distance.

Public Dose—The population *dose* received by *members of the public* from exposure to *radiation* and to radioactive material. It does not include *occupational dose.*

Pressurized Water Reactor (PWR)—A power reactor in which heat is transferred from the core to a heat exchanger by high-temperature water kept under high pressure.

Quality Factor—The modifying factor that is used to derive *dose equivalent* from *absorbed dose.*

Rad— A unit of *absorbed dose.* One rad is equal to an absorbed dose of 100 ergs/gram or 0.01 J per kg (0.01 gray).

Radiation (ionizing radiation)—*Alpha* particles, *beta* particles, *gamma* rays, X-rays, *neutrons* and other particles capable of producing *ions.*

Radioactive—Exhibiting *radioactivity.*

Radioactive Decay—See *Decay, radioactive.*

Radioactive Isotope—A *radioisotope.*

Radioactivity—The spontaneous emission of *radiation,* from the nucleus of an unstable *isotope.*

Radioisotope—An unstable *isotope* of an *element* that *decays* or disintegrates spontaneously, emitting *radiation.*

Radionuclide—A general term referring to all known *unstable* or *radioactive* isotopes of a chemical *element.* A *radioisotope.*

Rail mode—Carriage of one or more *packages* by one or more railcars in a train traveling on a railroad.

Reference Man—A hypothetical aggregation of human physical and physiological characteristics arrived at by international consensus. These standards are used to relate biological insult from radiation to a common base.

Rem—A unit of *dose equivalent.* The *dose equivalent* in rem is equal to the *absorbed dose* in *rad* multiplied by the *quality factor* (1 rem = 0.01 sievert). Rem was originally an abbreviation for "Roentgen equivalent man (or mammal). See also *sievert.*

Shielding—Any material or obstruction that absorbs *radiation* and thus tends to protect persons or materials from the effects of *ionizing radiation.*

Short-lived daughters—*Radioactive* progeny of *radioactive isotopes* that have *half-lives* on the order of a few hours or less.

Sievert (Sv)—The SI unit of *dose equivalent.* The dose equivalent in sieverts is equal to the *absorbed dose* in *gray* multiplied by a *quality factor* (1 Sv = 100 *rem*).

Spent Fuel (spent nuclear fuel)—Nuclear reactor fuel that has been used to the extent that it can no longer effectively sustain a chain reaction; also applied less accurately to fuel that has been used to any extent in a reactor and permanently removed from the reactor.

Stable Isotope—An *isotope* that does not undergo *radioactive decay.*

Stochastic Effects—Health effects that occur randomly and for which the probability of the effect occurring, rather than its severity, is assumed to be a linear function of dose without threshold. Genetic effects and cancer incidence are examples of stochastic effects of exposure to radiation.

Survey—An evaluation of the radiological conditions and potential hazards incident to the release or presence of *radioactive material.* When appropriate, such an evaluation includes a physical survey of the location of radioactive material and measurements or calculations of levels of radiation or concentrations or quantities of radioactive material present.

Transport Index (TI)—A dimensionless number, rounded up to the first decimal place, placed on the label of a package to designate the degree of control to be exercised by the carrier during transportation. The TI is derived from the maximum radiation level in millirem per hour at 1 meter from the external surface of the package.

Truck—Any of several types of *vehicles* used in the carriage of *packages* by *highway mode*

Unstable Isotope—A *radionuclide* or *radioisotope.*

Unit-Risk Factor—A risk (e.g., dose-risk, fatality-risk) associated with transportation of a given radioactive material shipment for a unit distance of travel, usually 1 km.

Van—Any of a class of medium-sized *vehicles* often used for the carriage of small *packages* such as radiopharmaceuticals by *highway mode.*

Vehicle—Motorized *conveyance* used for transportation of *packages* by *highway* mode. *Trucks* and *vans* are vehicles.

Vessel—Any conveyance used for the transportation of *packages* by *waterway modes. Ships* and *barges* are vessels.

Waterway Modes—Carriage of *packages* by *barge* or *ship* (also called *maritime modes*).

APPENDIX B Intermediate Data and Plots

Ordered pairs of probability and consequence values are written to output files R5PLOT0.DAT, R5PLOT1.DAT and R5PLOT2.DAT. These files contain, respectively, dose or latent-cancer-fatality (LCF) estimates, genetic-effects estimates, and maximum-individual-dose estimates. Associated summed probabilities are also included in these files. R5INTERM.DAT contains all of the data necessary to produce each of these files. These data can be used for probability-consequence plotting and sensitivity analysis. R5INTERM.DAT is intended to preserve the numerous intermediate probability and consequence calculations that are performed in RADTRAN 5 prior to the generation of the ordered-pair files and the final products and summations which are the actual risk values. Additional features of the ordered-pairs files are implemented by the subroutine PAIRS, which reads consequence and probability data from R5INTERM.DAT by using keywords within the file to locate the data. The probabilities are link-specific, and the consequence types are dispersion-cloud-specific. This means that for each link analyzed, up to six separate dispersion clouds and associated sets of consequence values, corresponding to up to six Pasquill atmospheric stability categories, may be given for each consequence type. Corresponding probability arrays also are constructed. If the pre-calculated Pasquill dispersion clouds are used, then each probability value is multiplied by the appropriate Pasquill probability. If the Pasquill dispersion data are not used, then a single set of dispersion data is used.

For each link in a given analysis, the accident rates are written to R5INTERM.DAT. The total number of expected accidents for all shipments is written for each link. A record is written for each radionuclide in each material for each mode in the link. The record gives estimates of either dose or latent cancer fatalities, genetic effects, and maximum individual consequences. The expected numbers of accidents and Pasquill categories are given at the link level, whereas dose and health-effects estimates are calculated at the radionuclide-level.

The order in which the values are written to the file R5INTERM.DAT is as follows:

The first number in the file R5INTERM.DAT is the number of severity categories (NSEV) used in the analysis to describe the spectrum of accidents. The descriptor line PASQUILL CATEGORY AND PROBABILITY is followed by the Pasquill category number and the fraction; if the run is not a Pasquill run then the category number will be 1 and be assigned a fraction of 1.0. Descriptor line LINK is followed by the link number, the vehicle identifier, and the vehicle number, then the descriptor ACCIDENT RATE followed by the accident rate multiplied by the severity fraction. There will be NSEV values. Next is the descriptor EXPECTED NUMBER OF ACCIDENTS (PROBABILITY) which is then followed by the accident rate multiplied by the product of the distance traveled and the number of shipments. Again, there will be NSEV values. Descriptor lines ISOTOPES are listed after the LINK descriptor. Each ISOTOPES descriptor is followed by the isotope number, the curie value times the number of packages, and the half-life of the isotope. The next line lists the nuclide name, the physical-chemical group to which it was assigned, and the material in which it is contained. For each radionuclide there are three associated descriptors. The first is LCF (NON-UNIT) OR PERSON-REM (UNIT) CONSEQUENCE DATA. The values for this descriptor are, as indicated, either latent cancer fatality data or person-rem dose vales for each severity category. The next descriptor is GE CONSEQUENCE DATA. The values following this will be zero if health effects output was not chosen. Otherwise; the genetic effects data will be listed for each severity category. Finally, the descriptor MAXIMUM INDIVIDUAL DOSE is listed followed by maximum individual dose consequences for each severity category.

The above order is repeated for each Pasquill category if the run uses the Pasquill atmospheric dispersion option. Each link is listed and within each link all radionuclides are listed with their associated descriptors and values. Below is an example of the subroutine PAIRS which is used to produce the probability-consequence pairs in files R5PLOT0.DAT, R5PLOT1.DAT and R5PLOT2.DAT. PAIRS is written so that it can be used as a stand-alone program.

```
      SUBROUTINE PAIRS
C      PROGRAM PAIRS
C
C     THIS SUBROUTINE (PROGRAM) READS IN DATA FROM R5INTERM.DAT
C     PRODUCED BY
C     RADTRAN AND PRODUCES 3 FILES OF ORDERED PAIRS OF NUMBERS.
C     THE FIRST NUMBER IS A CONSEQUENCE AND THE SECOND IS A SUMMED
C     PROBABILITY. THE SUMMED PROBABILITIES INDICATE THE PROBABILITY
C     OF A PARTICULAR CONSEQUENCE OR WORSE. CONSEQUENCES WITH
C     ZERO PROBABILITIES ARE IGNORED AND NOT PRINTED.
C     1. R5PLOT0.DAT CONTAINS SORTED LCF OR PERSON-REM CONSEQUENCES
C        WITH SUMMED PROBABILITIES.
C     2. R5PLOT1.DAT CONTAINS SORTED GENETIC EFFECTS CONSEQUENCES
C        WITH SUMMED PROBABILITIES.
C     4. R5PLOT2.DAT CONTAINS SORTED MAXIMUM INDIVIDUAL DOSE
C      CONSEQUENCES WITH SUMMED PROBABILITIES.
C
C .... 20*60*6=7200    SEVERITIES*LINKS*PASQUILL CATEGORIES

      PARAMETER (LENGTH=7200)

      REAL CONLCF(LENGTH), CONGE(LENGTH), CONMAX(LENGTH)

C .... CONLCF > CONSEQUENCE OF LCF (OR PERSON-REM)
C .... CONGE  > CONSEQUENCE OF GENETIC EFFECTS
C .... CONMAX > CONSEQUENCE OF MAXIMUM INDIVIDUAL DOSE

      REAL CLCF(20), CGE(20)

C .... TEMPORARY VARS TO HOLD EACH ISOTOPE'S NSEV VALUES FOR LCF AND C
    GE
```

```
      REAL PRLCF(LENGTH), PRGE(LENGTH), PRMAX(LENGTH)

C .... PRLCF  > PROBABILITY OF LCFs (OR PERSON-REM)
C .... PRGE   > PROBABILITY OF GENETIC EFFECTS
C .... PRMAX  > PROBABILITY OF MAXIMUM INDIVIDUAL DOSE

      CHARACTER TEST*10

      REAL DUMMY(20), PROB(20), PASQPR
C .... PROB HOLDS THE PROBABILITY FOR A LINK
C .... PASQPR HOLDS THE PASQUILL PROBABILITY (WILL BE 1.0 IF
C .... PASQUILL NOT USED IN RADTRAN)

      LOGICAL EOF
      DATA EOF / .FALSE. /

C .... COMMENT OUT NEXT LINE IF USED AS A SUBROUTINE INSIDE RADTRAN
C       OPEN (UNIT=8, STATUS='OLD', FILE='R5INTERM.DAT')
      REWIND (8)
      OPEN (UNIT=10, STATUS='UNKNOWN', FILE='R5PLOT0.DAT')
      OPEN (UNIT=11, STATUS='UNKNOWN', FILE='R5PLOT1.DAT')
      OPEN (UNIT=12, STATUS='UNKNOWN', FILE='R5PLOT2.DAT')

   10 CONTINUE
C ... CONTINUE READING R5INTERM.DAT - FOR SEPARATE RUNS

      READ (8,'(I5)',END=1000) NSEV
      LOOP = -1
C .... LOOP KEEPS TRACK OF THE NUMBER OF DIFFERENT OUTPUT GROUPS
C       DIFFERENT VEHICLES AND/OR DIFFERENT PASQUILL CATEGORIES)
C       STARTS AT ZERO
      DO 15 I = 1, LENGTH
       CONLCF(I) = 0.0
       CONGE(I) = 0.0
   15 CONTINUE

      IF (EOF) THEN
C ...... WRITE EOF TO THE OUTPUT FILES --- VARIABLE EOF WILL NOT BE TRUE
C ...... UNLESS A DATA SET HAS BEEN READ -- IF THERE IS ONLY ONE DATA SET
C ......OR IT IS THE LAST DATA SET THEN THE ABOVE READ WILL HAVE FOUND
C       THE END OF FILE. MARKER AND WOULD SKIP THIS AND GO TO THE END C
   IN THIS WAY THERE WILL BE NO ENDING EOF AND NO EOF AT ALL FOR
C       JUST ONE DATA SET
       WRITE (10,'("      EOF")')
       WRITE (11,'("      EOF")')
```

```
      WRITE (12,'("       EOF")')
      EOF = .FALSE.
     ENDIF

   20 CONTINUE
C .... CONTINUE READING DATA FROM R5INTERM.DAT WHILE NOT EOF

      READ (8,'(A10)',END=1000) TEST

      IF (TEST.EQ.'       EOF') THEN
       EOF = .TRUE.

      ELSEIF (TEST.EQ.'      LINK') THEN
       READ (8,'()')
       READ (8,'()')
C . . . . SKIP THE ACCRAT ARRAY -- NOT USED FOR THIS APPLICATION
       READ (8, 100) (DUMMY(I),I = 1, NSEV)
       READ (8,'()')
       READ (8, 100) (PROB(I),I = 1, NSEV)
       LOOP = LOOP + 1

      ELSEIF (TEST.EQ.'  PASQUILL') THEN
       READ (8,'(I6,1PE10.2)') IDUM, PASQPR

      ELSEIF (TEST.EQ.'   ISOTOPE') THEN
       READ (8,'()')
       READ (8,'()')
       READ (8,'()')
       READ (8, 100) (CLCF(I), I = 1, NSEV)
       READ (8,'()')
       READ (8, 100) (CGE(I), I = 1, NSEV)

       DO 30 I = 1, NSEV
        PP = PROB(I)*PASQPR
        INDEX = LOOP*NSEV+I
        PRLCF(INDEX) = PP
        PRGE(INDEX) = PP
C . . . . . SUM THE COSEQUENCES OVER ISOTOPES
        CONLCF(INDEX) = CONLCF(INDEX) + CLCF(I)
        CONGE(INDEX) = CONGE(INDEX) + CGE(I)
   30   CONTINUE

      ELSEIF (TEST.EQ.'   MAXIMUM') THEN
       READ (8, 100) (CONMAX(LOOP*NSEV+I),I = 1, NSEV)
```

```
      DO 45 I = 1, NSEV
       PRMAX(LOOP*NSEV+I) = PROB(I)*PASQPR
 45    CONTINUE

      ELSE
       WRITE (10,'(A)') ' ERROR IN R5INTERM.DAT'
       WRITE (11,'(A)') ' ERROR IN R5INTERM.DAT'
       WRITE (12,'(A)') ' ERROR IN R5INTERM.DAT'
       STOP 'ERROR IN R5INTERM.DAT'
      ENDIF

      IF (.NOT.EOF) GOTO 20

C .... FOUND END OF A DATA SET IN R5INTERM.DAT

C
      LEN = (LOOP+1)*NSEV
C .... SORT BY CONSEQUENCE IN DECREASING ORDER CARRYING THE
C      PROBABILITY ALONG
      CALL SSORT (CONLCF, PRLCF, LEN, -2)
      CALL SSORT (CONGE, PRGE, LEN, -2)
      CALL SSORT (CONMAX, PRMAX, LEN, -2)

C .... SUM1 AND SUM2 HOLD PROBABILITY SUMS
      SUM1 = 0.0
      SUM2 = 0.0
      DO 50 I = 1, LEN
       IF (PRLCF(I).NE.0.0) THEN
C.....SKIP IT IF THE PROBABILITY IS ZERO
        SUM1 = SUM1 + PRLCF(I)
        WRITE (10,200) CONLCF(I), SUM1
       ENDIF
       IF (PRGE(I).NE.0.0) THEN
C.....SKIP IT IF THE PROBABILITY IS ZERO
        SUM2 = SUM2 + PRGE(I)
        WRITE (11,200) CONGE(I), SUM2
       ENDIF
 50   CONTINUE

      SUM1 = 0.0
      DO 70 I = 1, LEN
       IF (PRMAX(I).NE.0.0) THEN
C.....SKIP IT IF THE PROBABILITY IS ZERO
        SUM1 = SUM1 + PRMAX(I)
        WRITE (12,200) CONMAX(I), SUM1
```

```
      ENDIF
   70 CONTINUE

      GOTO 10

 1000 CONTINUE
C .... END OF FILE MARKER WAS READ ....

  100 FORMAT (8(E10.3))
  200 FORMAT (2(1PE10.2))
C     STOP
      RETURN
      END
```

In the subroutine PAIRS, the consequence types are sorted and printed in decreasing order (highest first) and the corresponding probability array is re-ordered accordingly. When the consequences are printed, zero-probability consequences are omitted. The probabilities associated with each non-zero consequence are summed and printed at the same time that the consequences are printed. The resulting ordered pairs can be used for producing consequence vs. probability plots such as Cumulative Complementary Density Functions (CCDFs) in which the probability associated with each consequence represents the probability of the corresponding consequence being equal to or greater than the given value.

If the original output was requested in terms of dose rather than health effects, then doses will be written in R5PLOT0.DAT as indicated, but all consequence values in R5PLOT1.DAT will be zero and should be neglected. If R5INTERM.DAT contains more than one data set (indicated by the key word EOF after each data set), then each data set in R5PLOT0.DAT, R5PLOT1.DAT, and R5PLOT2.DAT will be separated by the word EOF. If there is only one data set, then no EOF is printed and all values in these files will be numeric.

To plot the values contained in the file R5PLOT0.DAT, R5PLOT1.DAT and R5PLOT2.DAT simply:

1. download the file (it is an ASCII text file),

2. open a spreadsheet program,

3. import the ASCII text file, and

4. create a plot using the program's capabilities.

Figure B-1 shows an example is given below of a plot created from the R5PLOT0.DAT data loaded into the spreadsheet program, Microsoft Excel.™ The accompanying data table, Table B-1, also was created by the spreadsheet program from the downloaded R5PLOT0.DAT file.

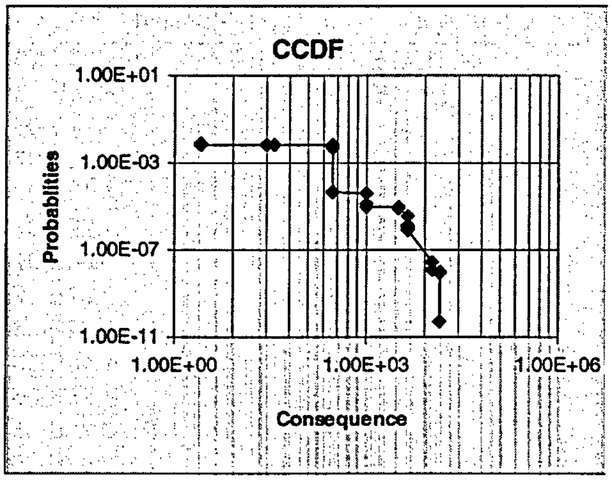

Figure B.1. Sample Probability-Consequence Plot

Table B-1. Probability-Consequence Pairs Used in Sample Plot

CONSEQUENCE	PROBABILITY
1.41E+05	5.08E-10
1.41E+05	8.74E-08
1.41E+05	9.71E-08
1.41E+05	1.02E-07
1.06E+05	1.20E-07
1.06E+05	1.29E-07
1.06E+05	1.30E-07
1.06E+05	2.97E-07
4.34E+04	8.72E-06
4.34E+04	1.15E-05
4.34E+04	1.25E-05
4.34E+04	3.78E-05
3.27E+04	7.57E-05
3.27E+04	7.71E-05
3.27E+04	8.13E-05
3.27E+04	9.39E-05
9.85E+03	9.39E-05
9.85E+03	9.39E-05
9.85E+03	9.39E-05
9.85E+03	9.42E-05
9.85E+03	1.22E-04
9.85E+03	1.24E-04
9.85E+03	3.78E-04
9.85E+03	3.91E-04
3.03E+03	4.42E-04
3.03E+03	4.47E-04
3.03E+03	4.49E-04
3.03E+03	4.66E-04
3.03E+03	5.10E-02
3.03E+03	5.28E-02
3.03E+03	6.96E-02
3.03E+03	7.53E-02
3.63E+02	7.53E-02
3.63E+02	7.53E-02
2.73E+02	7.53E-02
2.73E+02	7.53E-02
2.53E+01	7.53E-02
2.53E+01	7.53E-02
2.53E+01	8.34E-02
2.53E+01	8.61E-02
0.00E+01	8.85E-02
0.00E+01	1.33E-01
0.00E+01	1.63E-01

Table B-1. Probability-Consequence Pairs Used in Sample Plot (continued)

CONSEQUENCE	PROBABILITY
0.00E+01	1.64E-01
0.00E+01	1.78E-01
0.00E+01	5.16E-00
0.00E+01	7.70E-00
0.00E+01	1.53E+01
0.00E+01	1.57E+01
0.00E+01	1.67E+01
0.00E+01	1.73E+01
0.00E+01	1.89E+01
0.00E+01	2.06E+01
0.00E+01	2.08E+01
0.00E+01	2.08E+01
0.00E+01	2.12E+01
0.00E+01	2.14E+01
0.00E+01	2.20E+01
0.00E+01	2.23E+01
0.00E+01	2.31E+01

APPENDIX C Error Messages

The following is a listing of error messages for RADTRAN. This listing does not include device error messages that the user may receive from the system on which RADTRAN is installed. Device error messages are system-specific, and RADTRAN may be installed on a variety of systems. Many of the RADTRAN error messages are self-explanatory, but explanations are provided below to assist the user. Error messages appear in the main output file. In general, when an error occurs, the remainder of the output file will not be printed because calculation was terminated. With a few exceptions, which are noted below, recovery from RADTRAN errors consists of correcting value(s) in the input file and re-running RADTRAN.

ERROR MESSAGE LISTING IN ALPHABETICAL ORDER

AVINT INTEGRATION RETURNED ERROR = n

This message will only appear if there is an error within the SLATEC math routine AVINT. If this message appears, the copy of the code being used may have been corrupted. In this event, please contact the code developer, Sandia National Laboratories.

CAN ONLY DEFINE A MAXIMUM OF n VEHICLES.

where

n = maximum number of vehicles allowed

User entered more than the maximum allowed number of vehicles under the keyword VEHICLE.

CONVERGENCE FAILED IN SUBROUTINE BESSL

The user should never receive this message during proper use of RADTRAN because the input parameters for the BESSL routine are not user-definable. If this message appears, the copy of the code being used may have been corrupted. In this event, please contact the code developer, Sandia National Laboratories.

DIMEN REQUIRES ONLY THREE VALUES

The three values are: number of severity categories, number of radial distances, and number of isopleth areas. The previous release of RADTRAN required 4 values after the keyword DIMEN, but RADTRAN 5 requires only the three values listed.

ERROR IN OPENING INGESTION FILE s

where

s = ingestion file name

The ingestion file name entered in the input file is incorrect. Either the file does not exist or the name is typed incorrectly. One should be aware that on a UNIX system filenames are *case sensitive.* If this message occurs with the file name given in the standard values data file, then the problem may be code-related. In this event, please contact the code developer, Sandia National Laboratories.

ERROR IN R5INTERM.DAT

If an error is encountered reading R5INTERM.DAT, then this error message is printed in R5PLOT0.DAT, R5PLOT1.DAT, and R5PLOT2.DAT.

ERROR IN PROBABILITIES FOR PASQUILL CATEGORIES x SUM = y

where

x = set of six values representing the frequencies of occurrence of the six Pasquill stability categories $[x_1\ x_2\ x_3\ x_4\ x_5\ x_6]$*; and*
y = sum of the Pasquill probabilities.

This error message indicates that the sum of the probabilities of occurrence of the six Pasquill atmospheric stability categories is not equal to one. The sum of the probabilities of these categories must be adjusted to equal 1.0 before the code can run.

ERROR TOLERANCE NOT MET IN QUAD1

This message only appears if the limits of integration exceed the abilities of the QUAD1 subroutine. Since the user does not control these values, this message should not appear during proper use. If it does, then the copy of the code being used may have been corrupted. In this event, please contact the code developer, Sandia National Laboratories.

EXCEEDED NUMBER OF SEGMENTS ALLOWED

MAXIMUM NUMBER OF STOPS ALLOWED IS m_s

NUMBER OF STOPS ENTERED IS n_s

MAXIMUM NUMBER OF HANDLINGS ALLOWED IS m_h
NUMBER OF HANDLINGS ENTERED IS n_h

MAXIMUM NUMBER OF LINKS ALLOWED IS m_l
NUMBER OF LINKS ENTERED IS n_l

where

m = maximum number of stops (m_s), handlings (m_h), or links (m_l)
n = number of stops (n_s), handlings (n_h), or links (n_l)

Too many stops, handlings, or links were entered in the input file. The user must reduce the number of stops, handlings or links.

EXPECTED A NUMERIC VALUE, FOUND: s

where

s = character string read in from input.

This message appears if the user enters a character string instead of a numeric value where the latter is required.

FINDI FAILED ON BSKIN CALL

This message indicates that the user has input a value for μ (linear absorption coefficient), which is used in the gamma and neutron dose calculations, of less than zero. The coefficient must have a positive value.

FIRST KEYWORD MUST BE 'TITLE'. THE NEXT KEYWORD MUST THEN BE 'INPUT' WITH SECOND LEVEL KEYWORD 'STANDARD' FOR STANDARD DATA INPUT FILE, OR 'ZERO' FOR ZEROED OUT DATA INPUT FILE.

The user did not follow the required order for the first three lines of input in the input file.

FRACTIONS OF GAMMA AND NEUTRON MUST SUM TO 1.0
THE FRACTION OF GAMMA IS n AND THE FRACTION OF NEUTRON IS m

The sum of the fractions of the dose rate at 1 meter that are gamma and neutron radiations, respectively, must be 1.0. The user must adjust the values so that n + m = 1.0 before the code will run.

GOTO ERROR AT s

where

s = name of subroutine which had an error in a GOTO statement.

This message should not appear during proper use of RADTRAN. It indicates a programming error with a computed GOTO statement. If it does appear, then the copy of the code being used may have been corrupted. In this event, please contact the code developer, Sandia National Laboratories.

GROUP s DOES NOT HAVE RELEASE FRACTIONS ASSIGNED ABOVE.

where

s = physical-chemical group name

User entered a physical-chemical group designator that had not been defined. The user must define a physical-chemical group under the keyword RELEASE before assigning release fractions, aerosol fractions, or respirable fractions to the group.

INVALID IACC VALUE IN EARLY

The IACC value is a flag used to indicate that a material contains dispersible (IACC = 2) or nondispersable (IACC = 1) isotopes. The user should never receive this message during proper use of RADTRAN because IACC is only set to 1 or 2. If this message should appear, contact the code developer (Sandia National Laboratories).

ISOTOPE NAMED s NOT DEFINED

where

s = isotope name

User entered an isotope name s that has not previously been defined. The user must define it under keyword DEFINE.

MATERIAL s NOT PREVIOUSLY DEFINED

where

s = material name

User entered a material name that had not previously been defined. The user must define it under keyword PACKAGE.

MATERIAL s PREVIOUSLY DEFINED

where

s = material name

User attempted to define a material under keyword PACKAGE with the same name as a material that has previously been defined.

MODE TYPE CANNOT BE ZERO

A mode type of 0 was entered. Allowable mode types are 1 through 10.

s IS INCLUDED IN PHOTON ENERGY OF PARENT ISOTOPE. TO INCLUDE THIS ISOTOPE SEPARATELY, PLEASE DEFINE USING ANOTHER SYMBOL COMBINATION.

where

s = isotope name

The user has attempted to define an isotope with a name that is a reserved word indicating that the isotope in question is a daughter product of one of the library isotopes. This is a precaution to prevent the user from unknowingly adding daughter products that have already been taken into account elsewhere. The user is not prevented from defining any isotope; however, the designator must differ from those in the daughter isotopes list.

THE DISTANCE FROM SOURCE TO CREW MEMBERS IS x METERS.
THE EFFECTIVE CHARACTERISTIC VEHICLE DIMENSION IS y METERS.
THE CREW DISTANCE MUST BE GREATER THAN 1/2 OF VEHICLE DIMENSION.

The distance from source to crew members is not large enough. Too small value for x will cause crew members to be effectively *inside* of the package; x must be > 1/2 y.

TOO MANY MATERIALS, MAX IS n

where

n = maximum number of materials allowed.

This message indicates that a new material name was entered that increased the number of materials to more than the maximum allowed. The user must delete at least one material from the input file.

TOO MANY ISOTOPES IN THE MATERIAL

This message appears when the user has included more isotopes in a material description than is allowed. All materials must be modeled as consisting of no more than 200 isotopes.

TOO MANY PHYSICAL-CHEMICAL GROUP TYPES, THE MAXIMUM IS n

where

n = maximum number of physical-chemical groups allowed.

This message indicates that a new physical-chemical group was entered that increased the number of groups to more than the maximum allowed. The user must delete at least one from the input file.

UNKNOWN IDENTIFIER DETECTED ON INPUT s

where

s = character string read in from input.

This message appears when a character string that is not a keyword has been used in a keyword location. This message can result from either a spelling error or improper location of the character string.

VALUE ENTERED IS x,
VALUE MUST BE GREATER THAN OR EQUAL TO y

where

x = input value entered by the user
y = maximum value allowed

The message appears when the input file contains a value that is not within the prescribed allowable range for a particular variable. In the output file the line that is echoed just before this message will contain the erroneous value.

VALUE ENTERED IS x,
VALUE MUST BE LESS THAN OR EQUAL TO y

where

x = input value entered by the user
y = maximum value allowed

The message appears when the input file contains a value that is not within the prescribed allowable range for a particular variable. In the output file the line that is echoed just before this message will contain the erroneous value.

VEHICLE s NOT PREVIOUSLY DEFINED

where

s = vehicle name

An attempt was made to enter a vehicle name that had not previously been defined under keyword VEHICLE.

APPENDIX D STANDARD Parameter Values

Urban characteristics

1	Building dose factor;	(BDF)	5.000E-02
2	Urban building fraction;	(UBF)	9.000E-01
3	Urban sidewalk fraction;	(USWF)	1.000E-01

Incident-Free characteristics

1	Small package size for handling;	(SMALLPKG)	5.000E-01
2	Number of flight attendants for PASNGR_AIR mode	(FNOATT)	4.000E+00
3	Dedicated trains? (1=not dedicated, 2=dedicated);	(ITRAIN)	1
4	Minimum rail classifications (inspections);	(FMINCL)	2.000E+00
5	Distance-depend rail worker exposure factor (class./km)	(DDRWEF)	1.800E-03
6	Maximum In-Transit Dose: distance(m);	(MITDDIST)	3.000E+01
7	Maximum In-Transit Dose: velocity(km/hr);	(MITDVEL)	2.400E+01
8	Regulatory checks: (1= do checks, 0= don't);	(REGCHECK)	1

HIGHWAY values under second-level keyword DISTOFF

1	FREEWAY	distance to curb	3.000E+01
2		distance to outer sidewalk edge	3.000E+01
3		maximum distance of exposure	8.000E+02
4	SECONDARY	distance to curb	2.700E+01
5		distance to outer sidewalk edge	3.000E+01
6		maximum distance of exposure	8.000E+02
7	STREET	distance to curb	5.000E+00
8		distance to outer sidewalk edge	8.000E+00
9		maximum distance of exposure	8.000E+02

RAILWAY and WATERWAY values under second-level keyword DISTOFF

1	RAILWAY	distance to pedestrians	3.000E+01
2		distance to outer edge of pedestrian concentration	3.000E+01
3		maximum distance of exposure	8.000E+02
4	WATERWAY	distance to pedestrians	2.000E+02
5		distance to outer edge of pedestrian concentration	2.000E+02
6		maximum distance of exposure	1.000E+03

Values under second-level keyword DISTON

1	FREEWAY perpendicular distance of vehicle in opposite direction	1.500E+01
2	SECONDARY perpendicular distance vehicle in opposite direction	3.000E+00
3	STREET perpendicular distance of vehicle in opposite direction	3.000E+00
4	RAIL perpendicular distance of vehicle in opposite direction	3.000E+00
5	ADJACENT distance of adjacent vehicle	4.000E+00

Standard Variables that describe shielding

1	IUOPT; (1, 2 or 3)	2
2	Rural shielding factor; (RR)	1.000E+00
3	Suburban shielding factor; (RS)	8.700E-01
4	Urban shielding factor; (RU)	1.800E-02

NOTE: Building shielding option flag (IUOPT)
= 1, Buildings provide %100 shielding. RR,RS and RU do not apply.
= 2, Buildings provide partial shielding. RR,RS and RU are used.
= 3, Buildings provide no shielding. RR,RS and RU do not apply.

Standard variables that describe evacuation times and set the dispersal/non-dispersal flag.

1 Evacuation time for groundshine in days;	(EVACUATION)	1.000E+00
2 Survey interval time for groundshine in days;	(SURVEY)	1.000E+01
3 Accident flag: 1= non-dispersal, 2= dispersal;	(IACC)	2
4 Rural evac time in hours for non-dispersal accidents.	(TIMENDE)	6.700E-01
5 Suburban evac time in hours for non-dispersal accidents.	(TIMENDE)	6.700E-01
6 Urban evac time in hours for non-dispersal accidents.	(TIMENDE)	4.200E-01
7 Neutron Emission values		

Miscellaneous Standard Variables

1 Ratio of sidewalk and/or pedestrians density	(RPD)	6.000E+00
2 Breathing rate; (cubic meters/sec);	(BRATE)	3.300E-04
3 Clean-up level; (micro Ci/meter sq);	(CULVL)	2.000E-01
4 Interdiction threshold;	(INTERDICT)	4.000E+01
5 Campaign time for total exposed population (years);	(CAMPAIGN)	1.000E+00

Non-radiological Fatalities per Kilometer Traveled

	Emissions	Accident		
	Occupational	Non-Occ	Occupational	Non-Occ
1 Highway – Rural	0.000E+00	0.000E+00	1.500E-08	5.300E-08
2 Highway - Suburban	0.000E+00	.000E+00	3.700E-09	1.300E-08
3 Highway – Urban	0.000E+00	1.000E-07	2.100E-09	7.500E-09
4 General Freight- R	0.000E+00	0.000E+00	1.810E-09	2.640E-08
5 General Freight- S	0.000E+00	0.000E+00	1.810E-09	2.640E-08
6 General Freight- U	0.000E+00	1.300E-07	1.810E-09	2.640E-08
7 Dedicated Rail- R	0.000E+00	0.000E+00	1.270E-07	1.850E-06
8 Dedicated Rail- S	0.000E+00	0.000E+00	1.270E-07	1.850E-06
9 Dedicated Rail- U	0.000E+00	6.500E-07	1.270E-07	1.850E-06

1. RADDOG Opening Screen

(NRC 2004) Draft Environmental Impact Statement for an Early Site Permit (ESP) at the North Anna ESP Site, NUREG-1811, Office of Nuclear Reactor Regulation, U.S. Nuclear Regulatory Commission, Washington, DC, November 2004.

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5.12

(BLS 2003a) Section 4.1
Section 5.12
V-344

BLS 2003a

TABLE 1. **Incidence rates[1] of nonfatal occupational injuries and illnesses by industry and case types, 2003**

Industry[2]	NAICS code[3]	2003 Annual average employment[4] (thousands)	Total recordable cases	Cases with days away from work, job transfer, or restriction: Total	Cases with days away from work[5]	Cases with job transfer or restriction	Other recordable cases
Private industry[6]		106,183.1	5.0	2.6	1.5	1.1	2.4
Goods producing[6]		22,597.1	6.7	3.7	1.9	1.8	3.0
Natural resources and mining[6,7]		1,465.1	5.1	2.8	1.8	1.0	2.3
Agriculture, forestry, fishing and hunting[6]	11	965.0	6.2	3.3	2.1	1.2	2.9
Crop production[6]	111	430.8	6.1	3.3	2.1	1.2	2.8
Oilseed and grain farming[6]	1111	11.3	2.5	1.0	.8	.2	1.4
Vegetable and melon farming[6]	1112	87.3	5.1	2.5	1.7	.8	2.6
Fruit and tree nut farming[6]	1113	129.3	6.0	3.1	2.5	.6	2.9
Greenhouse, nursery, and floriculture production[6]	1114	149.1	6.4	3.8	1.9	1.9	2.6
Other crop farming[6]	1119	53.8	–	–	2.3	1.5	–
Animal production[6]	112	139.3	8.2	3.8	2.3	1.5	–
Cattle ranching and farming[6]	1121	71.1	–	3.0	2.3	.7	–
Beef cattle ranching and farming, including feedlots[6]	11211	22.7	9.3	5.2	3.8	1.4	4.1
Dairy cattle and milk production[6]	11212	48.3	–	2.0	1.6	.4	–
Hog and pig farming[6]	1122	16.3	8.3	4.3	3.2	1.2	4.0
Poultry and egg production[6]	1123	37.9	8.2	4.8	1.6	3.2	3.4
Forestry and logging	113	72.8	6.2	4.2	4.0	.3	2.0
Logging	1133	66.6	6.4	4.4	4.1	.3	2.0
Fishing, hunting and trapping	114	10.1	1.5	1.2	.9	.2	.4
Support activities for agriculture and forestry	115	311.9	5.5	2.9	1.6	1.3	2.6
Support activities for crop production	1151	270.1	5.8	3.0	1.6	1.5	2.7
Support activities for crop production	11511	270.1	5.8	3.0	1.6	1.5	2.7
Soil preparation, planting, and cultivating	115112	22.7	5.7	3.8	1.2	2.6	1.9
Crop harvesting, primarily by machine	115113	10.4	4.7	.6	.3	.3	4.0
Postharvest crop activities (except cotton ginning)	115114	66.5	8.7	5.5	3.2	2.3	3.2
Farm labor contractors and crew leaders	115115	144.2	4.3	2.2	1.1	1.2	–
Farm management services	115116	17.0	8.1	1.6	.9	.6	6.5
Support activities for animal production	1152	25.4	4.0	2.4	1.8	.6	1.6
Support activities for forestry	1153	16.4	2.7	1.3	1.1	.2	1.4
Mining[7]	21	500.1	3.3	2.0	1.4	.6	1.2
Oil and gas extraction	211	120.3	1.8	.8	.6	.2	1.0
Oil and gas extraction	2111	120.3	1.8	.8	.6	.2	1.0
Oil and gas extraction	21111	120.3	1.8	.8	.6	.2	1.0
Crude petroleum and natural gas extraction	211111	115.6	1.7	.8	.6	.2	.9
Mining (except oil and gas)[8]	212	200.3	4.6	3.1	2.4	.8	1.4

See footnotes at end of table.

TABLE 1. *Incidence rates[1] of nonfatal occupational injuries and illnesses by industry and case types, 2003* — Continued

Industry[2]	NAICS code[3]	2003 Annual average employment[4] (thousands)	Total recordable cases	Cases with days away from work, job transfer, or restriction			Other recordable cases
				Total	Cases with days away from work[5]	Cases with job transfer or restriction	
Coal mining[8]	2121	68.8	6.2	4.4	4.1	0.3	1.8
Coal mining[8]	21211	68.8	6.2	4.4	4.1	.3	1.8
Bituminous coal and lignite surface mining[8]	212111	32.4	3.2	2.2	2.0	.2	1.0
Bituminous coal underground mining[8]	212112	35.8	9.0	6.5	6.2	.4	2.5
Anthracite mining[8]	212113	.6	6.0	3.9	3.6	([9])	2.1
Metal ore mining[8]	2122	26.3	3.7	2.2	1.3	.9	1.5
Iron ore mining[8]	21221	5.3	3.3	1.7	1.3	.3	1.6
Gold ore and silver ore mining[8]	21222	9.1	3.7	2.3	1.0	1.3	1.4
Gold ore mining[8]	212221	8.3	3.6	2.2	.9	1.2	1.4
Silver ore mining[8]	212222	.9	4.5	3.3	([9])	2.0	([9])
Copper, nickel, lead, and zinc mining[8]	21223	8.4	3.2	1.9	1.3	.6	1.3
Lead ore and zinc ore mining[8]	212231	1.3	4.9	2.6	2.4	([9])	2.3
Copper ore and nickel ore mining[8]	212234	7.1	2.7	1.7	.9	.8	1.0
Other metal ore mining[8]	21229	3.4	4.6	2.9	1.9	1.0	1.6
Uranium-radium-vanadium ore mining[8]	212291	.4	([9])	([9])	([9])	([9])	([9])
All other metal ore mining[8]	212299	3.0	4.6	3.0	1.9	1.0	1.7
Nonmetallic mineral mining and quarrying[8]	2123	105.1	3.7	2.5	1.5	1.0	1.2
Stone mining and quarrying[8]	21231	46.9	4.0	2.7	1.6	1.1	1.2
Dimension stone mining and quarrying[8]	212311	6.7	5.4	4.0	2.6	1.4	1.4
Crushed and broken limestone mining and quarrying[8]	212312	26.1	3.8	2.6	1.5	1.1	1.2
Crushed and broken granite mining and quarrying[8]	212313	5.1	3.0	2.0	.9	1.1	1.0
Other crushed and broken stone mining and quarrying[8]	212319	9.0	4.4	3.1	1.8	1.2	1.3
Sand, gravel, clay, and ceramic and refractory minerals mining and quarrying[8]	21232	44.0	3.3	2.2	1.4	.8	1.1
Construction sand and gravel mining[8]	212321	31.9	3.4	2.3	1.5	.8	1.1
Kaolin and ball clay mining[8]	212324	4.4	2.4	1.4	.9	.6	.9
Clay and ceramic and refractory minerals mining[8]	212325	4.4	4.0	2.6	1.5	1.1	1.3
Other nonmetallic mineral mining and quarrying[8]	21239	14.3	3.9	2.6	1.4	1.2	1.3
Potash, soda, and borate mineral mining[8]	212391	3.6	4.7	3.2	1.9	1.3	1.5
Phosphate rock mining[8]	212392	2.1	2.9	1.8	.5	1.3	1.1
Other chemical and fertilizer mineral mining[8]	212393	2.9	4.3	2.8	1.5	1.4	1.4
All other nonmetallic mineral mining[8]	212399	5.6	3.6	2.3	1.4	.9	1.3
Support activities for mining	213	179.5	2.7	1.5	.9	.6	–
Support activities for mining	2131	179.5	2.7	1.5	.9	.6	–
Support activities for mining	21311	179.5	2.7	1.5	.9	.6	–
Drilling oil and gas wells	213111	51.5	4.0	2.3	1.5	.8	1.7
Support activities for oil and gas operations	213112	121.0	–	1.2	.6	.6	–
Construction		6,672.4	6.8	3.6	2.6	1.0	3.2

See footnotes at end of table.

TABLE 1. **Incidence rates[1] of nonfatal occupational injuries and illnesses by industry and case types, 2003** — Continued

Industry[2]	NAICS code[3]	2003 Annual average employment[4] (thousands)	Total recordable cases	Cases with days away from work, job transfer, or restriction: Total	Cases with days away from work, job transfer, or restriction: Cases with days away from work[5]	Cases with days away from work, job transfer, or restriction: Cases with job transfer or restriction	Other recordable cases
Construction	23	6,672.4	6.8	3.6	2.6	1.0	3.2
Construction of buildings	236	1,565.4	5.7	3.0	2.2	.8	2.7
Residential building construction	2361	834.0	5.3	3.0	2.4	–	2.3
Nonresidential building construction	2362	731.4	6.1	3.1	2.0	1.1	3.0
Heavy and civil engineering construction	237	891.5	6.5	3.5	2.4	1.2	3.0
Utility system construction	2371	368.0	6.9	3.8	2.6	1.2	3.1
Land subdivision	2372	84.6	3.1	.8	.5	.3	2.3
Highway, street, and bridge construction	2373	332.3	7.6	4.5	3.0	1.5	3.1
Other heavy and civil engineering construction	2379	106.6	4.3	1.9	1.1	.7	2.4
Specialty trade contractors	238	4,215.5	7.3	3.9	2.8	1.1	3.4
Foundation, structure, and building exterior contractors	2381	945.6	8.8	5.1	3.7	1.4	3.7
Poured concrete foundation and structure contractors	23811	198.2	9.6	5.4	3.7	1.7	4.1
Structural steel and precast concrete contractors	23812	83.3	9.6	5.3	3.6	1.7	–
Framing contractors	23813	136.9	12.0	6.4	4.9	1.5	5.6
Masonry contractors	23814	222.0	7.5	4.4	3.4	1.0	3.1
Glass and glazing contractors	23815	52.1	7.4	3.1	2.1	1.0	4.3
Roofing contractors	23816	177.8	8.7	5.6	3.8	1.8	3.1
Siding contractors	23817	38.9	–	4.5	3.8	.7	1.5
Other foundation, structure, and building exterior contractors	23819	36.3	5.6	3.2	2.4	.8	2.4
Building equipment contractors	2382	1,804.7	7.1	3.3	2.4	1.0	3.8
Electrical contractors	23821	853.4	6.2	2.8	2.1	.7	3.4
Plumbing, heating, and air-conditioning contractors	23822	848.2	8.3	4.0	2.7	1.3	4.3
Other building equipment contractors	23829	103.2	4.4	2.3	1.6	.7	2.1
Building finishing contractors	2383	878.4	6.9	4.2	3.1	1.1	2.7
Drywall and insulation contractors	23831	320.1	7.4	4.3	2.9	1.4	3.1
Painting and wall covering contractors	23832	213.2	4.1	2.7	2.1	.5	–
Flooring contractors	23833	79.0	5.6	3.6	3.1	.6	2.0
Tile and terrazzo contractors	23834	58.1	–	–	–	1.5	–
Finish carpentry contractors	23835	143.4	8.1	5.3	3.9	1.4	2.8
Other building finishing contractors	23839	64.5	9.0	–	3.3	1.6	4.0
Other specialty trade contractors	2389	586.8	6.1	3.3	2.4	.9	2.7
Site preparation contractors	23891	301.8	5.2	3.2	2.4	.8	2.0
All other special trade contractors	23899	285.0	7.0	3.5	2.4	1.1	–
Manufacturing		14,459.7	6.8	3.8	1.6	2.2	3.1
Manufacturing	31-33	14,459.7	6.8	3.8	1.6	2.2	3.1
Food manufacturing	311	1,513.4	8.6	5.5	1.9	3.7	3.1
Animal food manufacturing	3111	49.5	8.0	–	2.5	2.9	2.5

See footnotes at end of table.

TABLE 1. **Incidence rates[1] of nonfatal occupational injuries and illnesses by industry and case types, 2003** — Continued

Industry[2]	NAICS code[3]	2003 Annual average employment[4] (thousands)	Total recordable cases	Cases with days away from work, job transfer, or restriction: Total	Cases with days away from work, job transfer, or restriction: Cases with days away from work[5]	Cases with days away from work, job transfer, or restriction: Cases with job transfer or restriction	Other recordable cases
Animal food manufacturing	31111	49.5	8.0	–	2.5	2.9	2.5
Dog and cat food manufacturing	311111	18.0	5.1	2.8	.7	2.1	2.3
Other animal food manufacturing	311119	31.5	9.7	–	3.7	3.4	2.7
Grain and oilseed milling	3112	61.7	7.3	3.9	1.8	2.0	3.4
Flour milling and malt manufacturing	31121	20.2	7.6	4.2	2.4	1.8	3.4
Starch and vegetable fats and oils manufacturing	31122	27.1	7.2	3.4	1.4	2.0	3.8
Breakfast cereal manufacturing	31123	14.4	6.9	4.3	1.7	2.5	2.6
Sugar and confectionery product manufacturing	3113	84.8	8.2	4.6	1.6	3.0	3.6
Sugar manufacturing	31131	14.4	12.1	6.0	2.3	3.8	6.0
Sugarcane mills	311311	4.8	12.7	6.3	2.4	4.0	6.3
Chocolate and confectionery manufacturing from cacao beans	31132	8.9	7.5	4.3	1.6	2.6	3.3
Confectionery manufacturing from purchased chocolate	31133	39.1	7.4	4.2	1.3	2.9	3.2
Nonchocolate confectionery manufacturing	31134	22.4	6.6	4.3	1.7	2.7	2.3
Fruit and vegetable preserving and specialty food manufacturing	3114	183.6	8.1	5.0	1.9	3.2	3.1
Frozen food manufacturing	31141	92.9	8.3	5.2	1.9	3.3	3.0
Frozen fruit, juice, and vegetable manufacturing	311411	36.3	9.8	5.9	2.6	3.3	3.8
Frozen specialty food manufacturing	311412	56.6	7.3	4.8	1.4	3.4	2.5
Fruit and vegetable canning, pickling, and drying	31142	90.7	7.9	4.8	1.8	3.0	3.1
Fruit and vegetable canning	311421	67.5	7.9	4.9	2.0	2.9	3.0
Specialty canning	311422	11.4	5.8	3.0	.8	2.1	2.8
Dried and dehydrated food manufacturing	311423	11.8	9.9	6.3	1.7	4.6	3.6
Dairy product manufacturing	3115	135.2	9.1	6.1	3.2	2.9	3.0
Dairy product (except frozen) manufacturing	31151	113.4	9.4	6.2	3.4	2.8	3.2
Fluid milk manufacturing	311511	56.8	10.2	7.5	4.2	3.3	2.7
Creamery butter manufacturing	311512	2.1	12.4	8.6	4.0	4.6	3.8
Cheese manufacturing	311513	38.0	9.8	5.6	3.0	2.6	4.1
Dry, condensed, and evaporated dairy product manufacturing	311514	16.5	5.7	2.6	1.6	1.0	3.1
Ice cream and frozen dessert manufacturing	31152	21.8	7.4	5.3	1.8	3.5	2.1
Animal slaughtering and processing	3116	512.4	10.3	6.8	1.4	5.4	3.5
Animal slaughtering and processing	31161	512.4	10.3	6.8	1.4	5.4	3.5
Animal (except poultry) slaughtering	311611	154.6	12.9	8.9	1.8	7.1	4.1
Meat processed from carcasses	311612	110.0	11.2	7.0	2.1	4.8	4.2
Rendering and meat byproduct processing	311613	8.1	11.4	6.4	3.6	2.8	5.0
Poultry processing	311615	239.6	8.1	5.3	.8	4.6	2.8
Seafood product preparation and packaging	3117	43.3	8.3	5.0	3.0	2.0	3.3
Seafood product preparation and packaging	31171	43.3	8.3	5.0	3.0	2.0	3.3
Fresh and frozen seafood processing	311712	37.8	7.8	4.8	2.8	2.0	3.0
Bakeries and tortilla manufacturing	3118	291.5	7.1	4.4	1.9	2.5	2.7
Bread and bakery product manufacturing	31181	216.0	6.7	4.1	1.7	2.3	2.6
Retail bakeries	311811	70.6	1.8	1.0	.7	.3	.8

See footnotes at end of table.

TABLE 1. Incidence rates[1] of nonfatal occupational injuries and illnesses by industry and case types, 2003 — Continued

Industry[2]	NAICS code[3]	2003 Annual average employment[4] (thousands)	Total recordable cases	Cases with days away from work, job transfer, or restriction: Total	Cases with days away from work[5]	Cases with job transfer or restriction	Other recordable cases
Commercial bakeries	311812	135.2	8.4	5.3	2.1	3.2	3.1
Frozen cakes, pies, and other pastries manufacturing	311813	10.2	8.5	4.1	2.2	1.8	4.4
Cookie, cracker, and pasta manufacturing	31182	59.5	9.7	5.8	2.6	3.2	3.9
Cookie and cracker manufacturing	311821	35.4	10.3	5.7	2.3	3.4	4.6
Flour mixes and dough manufacturing from purchased flour	311822	15.8	9.5	6.6	3.7	2.9	2.9
Dry pasta manufacturing	311823	8.4	7.3	4.4	1.4	3.0	2.9
Tortilla manufacturing	31183	16.0	3.6	3.0	.9	2.1	.6
Other food manufacturing	3119	151.4	6.7	4.4	1.6	2.8	2.3
Snack food manufacturing	31191	45.7	6.4	4.1	1.8	2.2	2.3
Roasted nuts and peanut butter manufacturing	311911	11.0	6.8	4.4	2.1	2.3	2.5
Other snack food manufacturing	311919	34.7	6.2	4.0	1.7	2.2	2.3
Coffee and tea manufacturing	31192	13.1	7.9	3.7	2.0	1.7	4.2
Flavoring syrup and concentrate manufacturing	31193	11.3	2.1	1.2	.6	.6	.9
Seasoning and dressing manufacturing	31194	27.9	6.4	4.9	2.1	2.8	1.5
Mayonnaise, dressing, and other prepared sauce manufacturing	311941	12.4	6.4	4.7	2.3	2.4	1.8
Spice and extract manufacturing	311942	15.4	6.3	5.1	2.0	3.0	1.3
All other food manufacturing	31199	53.5	7.8	–	1.3	–	2.5
Perishable prepared food manufacturing	311991	26.3	–	–	1.2	–	2.4
All other miscellaneous food manufacturing	311999	27.2	6.1	3.4	1.5	1.9	2.7
Beverage and tobacco product manufacturing	312	199.4	10.7	7.1	3.2	3.9	3.6
Beverage manufacturing	3121	168.7	11.8	8.0	3.6	4.4	3.8
Soft drink and ice manufacturing	31211	105.0	13.9	9.9	4.6	5.3	4.0
Soft drink manufacturing	312111	80.6	13.8	9.8	4.4	5.4	4.0
Bottled water manufacturing	312112	17.0	16.7	11.9	5.9	6.0	4.8
Breweries	31212	26.5	5.7	2.6	1.1	1.5	3.1
Wineries	31213	29.9	9.4	6.1	2.2	3.9	3.3
Distilleries	31214	7.2	9.2	5.5	1.9	3.6	3.7
Tobacco manufacturing	3122	30.7	4.5	2.0	1.3	.7	2.5
Tobacco product manufacturing	31222	26.9	4.2	1.9	1.3	.6	2.3
Cigarette manufacturing	312221	19.2	3.8	1.6	1.4	.2	2.2
Other tobacco product manufacturing	312229	7.7	5.3	2.8	1.1	1.7	2.4
Textile mills	313	261.3	5.0	2.8	.8	1.9	2.2
Fiber, yarn, and thread mills	3131	57.9	5.2	2.4	.4	2.0	2.8
Fiber, yarn, and thread mills	31311	57.9	5.2	2.4	.4	2.0	2.8
Yarn spinning mills	313111	42.7	5.9	2.6	.4	2.3	3.2
Yarn texturizing, throwing, and twisting mills	313112	12.3	3.4	1.9	.3	1.6	1.5
Fabric mills	3132	128.8	4.5	2.7	.8	1.9	1.8
Broadwoven fabric mills	31321	79.6	4.1	2.5	.5	2.0	1.6
Narrow fabric mills and schiffli machine embroidery	31322	15.5	4.8	2.4	1.3	1.1	2.4
Narrow fabric mills	313221	14.2	5.0	2.5	1.3	1.1	2.5

See footnotes at end of table.

TABLE 1. **Incidence rates[1] of nonfatal occupational injuries and illnesses by industry and case types, 2003** — Continued

Industry[2]	NAICS code[3]	2003 Annual average employment[4] (thousands)	Total recordable cases	Cases with days away from work, job transfer, or restriction: Total	Cases with days away from work[5]	Cases with job transfer or restriction	Other recordable cases
Nonwoven fabric mills	31323	17.2	6.1	4.0	1.6	2.4	2.1
Knit fabric mills	31324	16.5	4.2	2.6	.9	1.8	1.6
Weft knit fabric mills	313241	7.5	5.8	3.5	1.1	2.4	2.3
Other knit fabric and lace mills	313249	9.0	2.8	1.9	.6	1.2	.9
Textile and fabric finishing and fabric coating mills	3133	74.6	5.7	3.2	1.3	1.9	2.5
Textile and fabric finishing mills	31331	63.8	5.2	3.1	1.1	1.9	2.2
Broadwoven fabric finishing mills	313311	37.0	5.8	3.0	1.3	1.8	2.7
Textile and fabric finishing (except broadwoven fabric) mills	313312	26.8	4.5	3.1	1.0	2.1	1.5
Fabric coating mills	31332	10.7	8.0	3.9	2.4	1.6	4.1
Textile product mills	314	182.6	5.5	3.2	1.3	1.9	2.3
Textile furnishings mills	3141	105.7	5.0	2.9	1.2	1.7	2.1
Carpet and rug mills	31411	49.0	4.9	2.7	.9	1.8	2.2
Curtain and linen mills	31412	56.7	5.0	3.1	1.5	1.6	1.9
Curtain and drapery mills	314121	18.0	5.6	2.2	1.7	.6	3.3
Other household textile product mills	314129	38.7	4.8	3.5	1.4	2.1	1.3
Other textile product mills	3149	76.9	6.2	3.5	1.4	2.1	2.7
Textile bag and canvas mills	31491	30.0	7.2	3.6	1.7	1.8	3.7
Canvas and related product mills	314912	21.0	7.1	3.4	2.0	1.5	3.7
All other textile product mills	31499	47.0	5.7	3.5	1.3	2.3	2.1
Tire cord and tire fabric mills	314992	5.0	7.9	5.3	1.8	3.4	2.6
All other miscellaneous textile product mills	314999	36.8	3.9	2.1	1.0	1.1	1.7
Apparel manufacturing	315	309.0	3.6	1.9	.9	1.0	1.7
Apparel knitting mills	3151	43.5	4.8	2.2	.8	1.4	2.6
Hosiery and sock mills	31511	28.3	5.1	2.2	.9	1.3	3.0
Other hosiery and sock mills	315119	18.4	6.1	2.4	.9	1.5	3.6
Other apparel knitting mills	31519	15.2	4.1	2.3	.6	1.7	1.9
Outerwear knitting mills	315191	11.7	4.2	2.3	–	1.8	1.9
Underwear and nightwear knitting mills	315192	3.5	4.1	2.2	1.0	1.2	1.8
Cut and sew apparel manufacturing	3152	241.2	3.4	1.9	.9	1.0	1.5
Men's and boys' cut and sew apparel contractors	315211	25.7	–	2.2	1.3	.9	2.7
Men's and boys' cut and sew apparel manufacturing	31522	61.3	5.4	3.1	1.4	1.6	2.3
Men's and boys' cut and sew work clothing manufacturing	315225	12.1	6.0	3.7	1.4	2.3	2.4
Women's and girls' cut and sew apparel manufacturing	31523	56.6	2.8	1.8	.9	.9	1.1
Women's and girls' cut and sew dress manufacturing	315233	10.8	1.8	1.2	.3	.9	.6
Women's and girls' cut and sew suit, coat, tailored jacket, and skirt manufacturing	315234	5.0	4.1	2.9	1.1	1.8	1.3
Women's and girls' cut and sew other outerwear manufacturing	315239	28.5	2.8	1.5	.8	.6	1.3
Other cut and sew apparel manufacturing	31529	21.9	4.4	2.2	1.0	1.2	2.1
All other cut and sew apparel manufacturing	315299	17.8	4.5	2.3	1.0	1.3	2.2
Apparel accessories and other apparel manufacturing	3159	24.3	3.5	1.6	.7	.9	1.9

See footnotes at end of table.

TABLE 1. **Incidence rates[1] of nonfatal occupational injuries and illnesses by industry and case types, 2003** — Continued

Industry[2]	NAICS code[3]	2003 Annual average employment[4] (thousands)	Total recordable cases	Cases with days away from work, job transfer, or restriction: Total	Cases with days away from work[5]	Cases with job transfer or restriction	Other recordable cases
Apparel accessories and other apparel manufacturing	31599	24.3	3.5	1.6	0.7	0.9	1.9
Leather and allied product manufacturing	316	45.6	7.8	4.8	2.1	2.7	3.0
Footwear manufacturing	3162	19.9	8.0	4.3	1.7	2.6	3.7
Footwear manufacturing	31621	19.9	8.0	4.3	1.7	2.6	3.7
Rubber and plastics footwear manufacturing	316211	2.4	15.5	11.9	3.9	8.0	3.7
Men's footwear (except athletic) manufacturing	316213	9.4	7.1	2.7	1.2	1.5	4.4
Women's footwear (except athletic) manufacturing	316214	5.3	5.6	2.7	.8	2.0	2.8
Other leather and allied product manufacturing	3169	17.8	7.2	5.4	2.3	3.0	1.9
Other leather and allied product manufacturing	31699	17.8	7.2	5.4	2.3	3.0	1.9
Wood product manufacturing	321	534.3	10.0	5.4	2.8	2.6	4.6
Sawmills and wood preservation	3211	116.3	10.1	5.1	2.7	2.4	4.9
Sawmills and wood preservation	32111	116.3	10.1	5.1	2.7	2.4	4.9
Sawmills	321113	103.7	10.0	5.2	2.7	2.5	4.9
Wood preservation	321114	12.6	10.4	5.0	3.0	2.0	5.3
Veneer, plywood, and engineered wood product manufacturing	3212	112.7	8.7	4.6	2.2	2.4	4.1
Veneer, plywood, and engineered wood product manufacturing	32121	112.7	8.7	4.6	2.2	2.4	4.1
Hardwood veneer and plywood manufacturing	321211	23.3	6.2	3.2	1.2	2.0	3.0
Softwood veneer and plywood manufacturing	321212	20.9	3.8	2.2	.9	1.2	1.7
Truss manufacturing	321214	41.9	14.7	7.8	3.7	4.1	6.9
Reconstituted wood product manufacturing	321219	18.4	3.8	1.7	.8	.9	2.1
Other wood product manufacturing	3219	305.2	10.5	5.8	3.1	2.7	4.7
Millwork	32191	150.0	10.0	5.5	2.7	2.8	4.5
Wood window and door manufacturing	321911	71.8	11.3	5.9	2.6	3.3	5.4
Cut stock, resawing lumber, and planing	321912	18.9	10.7	7.6	4.5	3.1	3.2
Other millwork (including flooring)	321918	59.3	8.2	4.3	2.3	2.0	3.9
Wood container and pallet manufacturing	32192	57.4	9.2	5.9	3.6	2.3	3.3
All other wood product manufacturing	32199	97.7	12.1	6.3	3.5	2.8	5.7
Manufactured home (mobile home) manufacturing	321991	45.2	14.9	6.9	2.9	4.0	8.0
Prefabricated wood building manufacturing	321992	24.3	11.1	6.8	4.7	2.1	4.3
All other miscellaneous wood product manufacturing	321999	28.3	8.3	5.0	3.4	1.6	3.3
Paper manufacturing	322	514.1	4.8	2.9	1.5	1.4	1.9
Pulp, paper, and paperboard mills	3221	150.0	3.8	1.9	1.1	.8	1.9
Pulp mills	32211	7.0	3.4	1.8	1.0	.8	1.6
Paper mills	32212	104.2	4.0	1.9	1.2	.8	2.0
Paper (except newsprint) mills	322121	94.2	3.7	1.7	1.0	.7	1.9
Paperboard mills	32213	38.8	3.5	1.9	1.0	.9	1.7
Converted paper product manufacturing	3222	364.1	5.2	3.2	1.7	1.6	2.0
Paperboard container manufacturing	32221	194.1	4.7	2.9	1.3	1.6	1.8
Corrugated and solid fiber box manufacturing	322211	122.3	4.7	2.9	1.4	1.5	1.8
Folding paperboard box manufacturing	322212	38.2	5.0	2.7	1.3	1.3	2.3

See footnotes at end of table.

TABLE 1. Incidence rates[1] of nonfatal occupational injuries and illnesses by industry and case types, 2003 — Continued

Industry[2]	NAICS code[3]	2003 Annual average employment[4] (thousands)	Total recordable cases	Cases with days away from work, job transfer, or restriction: Total	Cases with days away from work[5]	Cases with job transfer or restriction	Other recordable cases
Fiber can, tube, drum, and similar products manufacturing	322214	12.8	4.2	2.5	1.2	1.3	1.7
Nonfolding sanitary food container manufacturing	322215	15.2	5.3	3.7	.9	2.8	1.7
Paper bag and coated and treated paper manufacturing	32222	77.8	5.3	3.4	2.0	1.4	1.9
Coated and laminated packaging paper and plastics film manufacturing	322221	16.9	4.5	2.9	1.3	1.6	1.6
Coated and laminated paper manufacturing	322222	33.3	5.5	3.4	2.1	1.3	2.1
Uncoated paper and multiwall bag manufacturing	322224	13.3	5.5	2.9	2.1	.7	2.6
Stationery product manufacturing	32223	37.4	5.6	3.6	1.5	2.1	2.0
Envelope manufacturing	322232	19.7	5.6	3.4	1.6	1.8	2.2
Other converted paper product manufacturing	32229	54.8	6.5	4.1	2.4	1.6	2.4
Sanitary paper product manufacturing	322291	35.5	4.5	2.8	1.5	1.3	1.7
All other converted paper product manufacturing	322299	19.3	10.7	6.7	4.3	2.3	4.0
Printing and related support activities	323	672.3	4.5	2.7	1.2	1.5	1.9
Printing and related support activities	3231	672.3	4.5	2.7	1.2	1.5	1.9
Printing	32311	615.6	4.7	2.7	1.3	1.5	2.0
Commercial lithographic printing	323110	267.3	4.9	2.9	1.4	1.5	1.9
Commercial gravure printing	323111	17.3	5.4	2.9	1.3	1.5	2.5
Commercial flexographic printing	323112	41.3	5.2	3.8	1.5	2.3	1.4
Commercial screen printing	323113	64.9	4.3	2.2	1.4	.8	2.2
Quick printing	323114	71.9	1.7	.8	.5	.3	.9
Digital printing	323115	18.2	6.7	3.7	.8	2.9	3.0
Manifold business forms printing	323116	41.9	5.8	3.3	1.7	1.6	2.6
Books printing	323117	34.2	6.0	3.8	1.1	2.7	2.2
Blankbook, looseleaf binders, and devices manufacturing	323118	11.2	5.2	2.8	1.2	1.6	2.5
Other commercial printing	323119	47.4	4.8	2.6	1.2	1.4	2.3
Tradebinding and related work	323121	22.7	4.3	2.9	1.1	1.8	1.4
Petroleum and coal products manufacturing	324	115.5	2.8	1.6	.9	.7	1.2
Petroleum and coal products manufacturing	3241	115.5	2.8	1.6	.9	.7	1.2
Petroleum refineries	32411	71.4	1.5	.7	.4	.4	.8
Asphalt paving, roofing, and saturated materials manufacturing	32412	28.2	5.2	3.5	2.0	1.5	1.7
Asphalt paving mixture and block manufacturing	324121	14.5	5.4	3.5	2.5	1.1	1.9
Asphalt shingle and coating materials manufacturing	324122	13.7	5.0	3.4	1.5	1.9	1.6
Other petroleum and coal products manufacturing	32419	15.9	4.2	2.2	1.6	.6	2.0
Petroleum lubricating oil and grease manufacturing	324191	10.3	3.3	2.0	1.6	.5	1.3
All other petroleum and coal products manufacturing	324199	5.6	6.0	2.6	1.7	.9	3.4
Chemical manufacturing	325	905.5	3.4	2.0	.9	1.0	1.4
Basic chemical manufacturing	3251	162.5	2.6	1.6	.7	.9	1.1
Petrochemical manufacturing	32511	32.1	1.4	.7	.3	.4	.7
Industrial gas manufacturing	32512	22.4	1.6	1.3	.9	.4	.3
Synthetic dye and pigment manufacturing	32513	20.0	2.7	1.9	.6	1.3	.8

See footnotes at end of table.

TABLE 1. **Incidence rates[1] of nonfatal occupational injuries and illnesses by industry and case types, 2003** — Continued

Industry[2]	NAICS code[3]	2003 Annual average employment[4] (thousands)	Total recordable cases	Cases with days away from work, job transfer, or restriction			Other recordable cases
				Total	Cases with days away from work[5]	Cases with job transfer or restriction	
Inorganic dye and pigment manufacturing	325131	11.5	2.9	2.4	0.8	1.5	–
Other basic inorganic chemical manufacturing	32518	45.9	2.8	1.4	.7	.7	1.4
Alkalies and chlorine manufacturing	325181	8.5	3.2	1.8	.5	1.3	1.4
All other basic inorganic chemical manufacturing	325188	35.2	2.8	1.3	.7	.6	1.5
Other basic organic chemical manufacturing	32519	42.1	3.8	2.4	.9	1.4	1.4
All other basic organic chemical manufacturing	325199	34.3	2.6	1.7	.4	1.3	.9
Resin, synthetic rubber, and artificial and synthetic fibers and filaments manufacturing	3252	111.3	2.8	1.5	.8	.8	1.2
Resin and synthetic rubber manufacturing	32521	74.1	2.9	1.4	.8	.6	1.5
Plastics material and resin manufacturing	325211	60.6	2.6	1.1	.7	.5	1.5
Synthetic rubber manufacturing	325212	13.5	4.3	2.8	1.5	1.3	1.5
Artificial and synthetic fibers and filaments manufacturing	32522	37.2	2.6	1.8	.7	1.1	.8
Cellulosic organic fiber manufacturing	325221	10.9	2.5	1.5	.6	.9	.9
Noncellulosic organic fiber manufacturing	325222	26.3	2.6	1.8	.7	1.2	.7
Pesticide, fertilizer, and other agricultural chemical manufacturing	3253	41.8	–	2.2	1.1	1.1	1.8
Fertilizer manufacturing	32531	24.7	4.5	2.3	1.2	1.1	2.2
Phosphatic fertilizer manufacturing	325312	8.1	4.6	2.5	.9	1.7	2.0
Pesticide and other agricultural chemical manufacturing	32532	17.1	3.2	1.9	.8	1.1	1.3
Pharmaceutical and medicine manufacturing	3254	291.8	2.8	1.6	.9	.8	1.2
Pharmaceutical and medicine manufacturing	32541	291.8	2.8	1.6	.9	.8	1.2
Medicinal and botanical manufacturing	325411	23.8	3.6	2.5	1.5	.9	1.2
Pharmaceutical preparation manufacturing	325412	228.3	2.7	1.5	.7	.8	1.2
In-vitro diagnostic substance manufacturing	325413	14.0	3.8	2.1	.9	1.2	1.7
Paint, coating, and adhesive manufacturing	3255	69.8	4.9	2.8	1.4	1.5	2.0
Paint and coating manufacturing	32551	45.9	5.1	2.8	1.5	1.4	2.2
Adhesive manufacturing	32552	23.9	4.4	2.8	1.1	1.7	1.6
Soap, cleaning compound, and toilet preparation manufacturing	3256	117.2	4.1	2.3	1.0	1.3	1.8
Soap and cleaning compound manufacturing	32561	62.5	4.1	2.1	.8	1.2	2.1
Soap and other detergent manufacturing	325611	28.6	4.3	2.1	.9	1.2	2.2
Polish and other sanitation good manufacturing	325612	27.8	3.5	2.0	.7	1.2	1.5
Toilet preparation manufacturing	32562	54.7	4.0	2.6	1.2	1.4	1.4
Other chemical product and preparation manufacturing	3259	111.0	5.0	3.0	1.2	1.8	2.0
Explosives manufacturing	32592	5.9	3.8	2.5	1.3	1.2	1.4
All other chemical product and preparation manufacturing	32599	92.1	5.0	3.1	1.2	1.9	1.9
Custom compounding of purchased resins	325991	22.3	8.5	5.8	2.7	3.1	2.6
Photographic film, paper, plate, and chemical manufacturing	325992	33.3	5.0	3.0	1.1	1.9	2.0
All other miscellaneous chemical product and preparation manufacturing	325998	36.5	2.9	1.5	.3	1.1	1.5
Plastics and rubber products manufacturing	326	814.6	7.4	4.4	1.7	2.8	2.9
Plastics product manufacturing	3261	637.7	7.0	4.2	1.5	2.6	2.9

See footnotes at end of table.

TABLE 1. **Incidence rates[1] of nonfatal occupational injuries and illnesses by industry and case types, 2003** — Continued

Industry[2]	NAICS code[3]	2003 Annual average employment[4] (thousands)	Total recordable cases	Cases with days away from work, job transfer, or restriction: Total	Cases with days away from work[5]	Cases with job transfer or restriction	Other recordable cases
Unsupported plastics film, sheet, and bag manufacturing	32611	88.3	6.8	4.1	1.8	2.3	2.7
Unsupported plastics bag manufacturing	326111	26.3	8.3	5.3	2.6	2.7	3.0
Unsupported plastics film and sheet (except packaging) manufacturing	326113	55.9	–	3.7	1.6	2.1	2.6
Plastics pipe, pipe fitting, and unsupported profile shape manufacturing	32612	57.7	6.4	3.6	1.5	2.1	2.8
Unsupported plastics profile shape manufacturing	326121	28.1	5.8	3.2	1.5	1.7	2.6
Plastics pipe and pipe fitting manufacturing	326122	29.6	6.9	3.9	1.5	2.4	2.9
Laminated plastics plate, sheet, and shape manufacturing	32613	20.8	6.2	3.0	.6	2.4	3.3
Polystyrene foam product manufacturing	32614	28.8	5.2	2.3	1.4	.9	2.9
Urethane and other foam product (except polystyrene) manufacturing	32615	31.6	5.4	4.1	1.4	2.7	1.3
Plastics bottle manufacturing	32616	36.3	6.8	4.2	1.0	3.3	2.5
Other plastics product manufacturing	32619	374.2	7.5	4.5	1.6	2.9	3.1
Resilient floor covering manufacturing	326192	5.9	3.8	3.1	1.0	2.1	.7
All other plastics product manufacturing	326199	345.8	7.2	4.1	1.5	2.6	3.1
Rubber product manufacturing	3262	176.9	8.7	5.4	2.1	3.3	3.3
Tire manufacturing	32621	72.0	8.9	5.6	2.3	3.3	3.3
Tire manufacturing (except retreading)	326211	64.3	8.7	5.5	2.3	3.2	3.1
Rubber and plastics hoses and belting manufacturing	32622	27.9	6.6	3.3	1.3	2.0	3.3
Other rubber product manufacturing	32629	76.9	9.2	6.0	2.3	3.7	3.2
Rubber product manufacturing for mechanical use	326291	46.7	9.9	6.4	2.3	4.1	3.5
All other rubber product manufacturing	326299	30.3	8.1	5.4	2.3	3.1	2.8
Nonmetallic mineral product manufacturing	327	496.0	7.9	4.6	2.2	2.4	3.3
Clay product and refractory manufacturing	3271	66.6	9.0	6.0	2.3	3.7	3.1
Pottery, ceramics, and plumbing fixture manufacturing	32711	32.0	9.2	6.6	2.1	4.5	2.6
Vitreous china plumbing fixture and china and earthenware bathroom accessories manufacturing	327111	8.7	13.9	11.0	1.8	9.2	2.9
Vitreous china, fine earthenware, and other pottery product manufacturing	327112	16.9	7.2	4.6	2.3	2.3	2.6
Porcelain electrical supply manufacturing	327113	6.5	7.0	4.6	2.3	2.3	2.4
Clay building material and refractories manufacturing	32712	34.6	8.9	5.5	2.4	3.1	3.4
Brick and structural clay tile manufacturing	327121	13.0	9.8	5.2	2.3	2.9	4.6
Glass and glass product manufacturing	3272	116.0	8.4	4.6	1.8	2.8	3.8
Glass and glass product manufacturing	32721	116.0	8.4	4.6	1.8	2.8	3.8
Flat glass manufacturing	327211	13.6	7.5	4.1	1.5	2.5	3.4
Other pressed and blown glass and glassware manufacturing	327212	27.6	8.4	5.3	2.1	3.2	3.0
Glass container manufacturing	327213	20.0	10.0	5.5	1.7	3.8	4.5
Glass product manufacturing made of purchased glass	327215	54.9	8.0	3.9	1.6	2.3	4.1
Cement and concrete product manufacturing	3273	225.1	8.0	4.8	2.6	2.2	3.2

See footnotes at end of table.

TABLE 1. **Incidence rates[1] of nonfatal occupational injuries and illnesses by industry and case types, 2003** — Continued

Industry[2]	NAICS code[3]	2003 Annual average employment[4] (thousands)	Total recordable cases	Cases with days away from work, job transfer, or restriction: Total	Cases with days away from work[5]	Cases with job transfer or restriction	Other recordable cases
Ready-mix concrete manufacturing	32732	116.3	6.8	4.2	2.9	1.4	2.6
Concrete pipe, brick, and block manufacturing	32733	32.1	9.7	5.4	2.5	3.0	4.2
Concrete block and brick manufacturing	327331	20.7	10.2	5.5	2.9	2.6	4.7
Concrete pipe manufacturing	327332	11.4	8.8	5.4	1.8	3.6	3.4
Other concrete product manufacturing	32739	60.2	10.4	6.3	2.6	3.7	4.1
Lime and gypsum product manufacturing	3274	18.8	3.5	1.0	.5	.5	2.5
Gypsum product manufacturing	32742	14.7	4.0	1.3	.6	.7	2.6
Other nonmetallic mineral product manufacturing	3279	69.5	7.0	4.0	2.3	1.7	2.9
Abrasive product manufacturing	32791	11.9	7.5	4.9	2.4	2.6	2.6
All other nonmetallic mineral product manufacturing	32799	57.6	6.9	3.8	2.3	1.6	3.0
Cut stone and stone product manufacturing	327991	22.6	5.5	3.3	2.9	.4	2.2
Mineral wool manufacturing	327993	19.6	8.4	4.2	2.0	2.2	4.2
Primary metal manufacturing	331	474.5	9.6	4.8	2.1	2.7	4.8
Iron and steel mills and ferroalloy manufacturing	3311	101.5	7.0	3.8	1.6	–	3.2
Iron and steel mills and ferroalloy manufacturing	33111	101.5	7.0	3.8	1.6	–	3.2
Iron and steel mills	331111	98.4	6.9	–	1.6	–	3.1
Steel product manufacturing from purchased steel	3312	59.6	10.5	6.1	2.8	3.4	4.4
Iron and steel pipe and tube manufacturing from purchased steel	33121	26.1	8.9	5.2	2.4	2.9	3.7
Rolling and drawing of purchased steel	33122	33.6	–	–	3.0	3.7	4.8
Rolled steel shape manufacturing	331221	24.6	–	7.1	2.9	4.2	4.5
Alumina and aluminum production and processing	3313	74.9	6.6	3.7	1.5	2.2	2.9
Alumina and aluminum production and processing	33131	74.9	6.6	3.7	1.5	2.2	2.9
Primary aluminum production	331312	14.1	8.1	5.1	1.9	3.2	3.1
Aluminum sheet, plate, and foil manufacturing	331315	16.7	5.3	2.8	1.5	1.3	2.5
Nonferrous metal (except aluminum) production and processing	3314	73.3	7.9	4.5	1.8	2.7	3.3
Nonferrous metal (except aluminum) smelting and refining	33141	10.8	7.1	3.8	1.8	2.0	3.2
Primary smelting and refining of nonferrous metal (except copper and aluminum)	331419	8.9	6.6	3.8	2.1	1.8	2.8
Copper rolling, drawing, extruding, and alloying	33142	39.1	7.8	4.8	1.6	3.2	3.0
Copper rolling, drawing, and extruding	331421	16.5	10.0	6.3	2.7	3.5	3.8
Copper wire (except mechanical) drawing	331422	21.1	5.8	3.6	.8	2.8	2.3
Nonferrous metal (except copper and aluminum) rolling, drawing, extruding, and alloying	33149	23.4	8.4	4.4	2.2	2.2	4.0
Foundries	3315	165.2	13.1	5.6	2.6	3.0	7.4
Ferrous metal foundries	33151	91.8	15.2	6.1	2.7	3.4	9.1
Iron foundries	331511	61.8	16.0	5.8	2.7	3.1	–
Steel investment foundries	331512	12.2	10.6	6.2	1.9	4.3	4.4
Steel foundries (except investment)	331513	17.7	15.2	7.2	3.1	4.1	7.9
Nonferrous metal foundries	33152	73.4	10.4	5.0	2.5	2.5	5.4
Aluminum die-casting foundries	331521	31.2	11.7	5.4	2.5	2.9	6.3

See footnotes at end of table.

TABLE 1. **Incidence rates[1] of nonfatal occupational injuries and illnesses by industry and case types, 2003** — Continued

Industry[2]	NAICS code[3]	2003 Annual average employment[4] (thousands)	Total recordable cases	Cases with days away from work, job transfer, or restriction: Total	Cases with days away from work, job transfer, or restriction: Cases with days away from work[5]	Cases with days away from work, job transfer, or restriction: Cases with job transfer or restriction	Other recordable cases
Aluminum foundries (except die-casting)	331524	20.6	10.7	6.0	3.0	3.0	4.6
Fabricated metal product manufacturing	332	1,476.2	8.5	4.2	2.0	2.2	4.3
Forging and stamping	3321	108.2	10.5	4.7	2.4	2.3	5.8
Forging and stamping	33211	108.2	10.5	4.7	2.4	2.3	5.8
Iron and steel forging	332111	24.5	14.7	6.4	3.4	3.0	8.3
Custom roll forming	332114	6.3	8.9	5.1	2.2	2.9	3.9
Metal stamping	332116	56.8	9.8	4.4	2.1	2.3	5.3
Powder metallurgy part manufacturing	332117	10.2	8.7	3.4	2.7	.7	5.3
Cutlery and handtool manufacturing	3322	60.3	8.0	3.6	1.6	1.9	–
Cutlery and handtool manufacturing	33221	60.3	8.0	3.6	1.6	1.9	–
Cutlery and flatware (except precious) manufacturing	332211	9.8	14.6	4.8	2.9	1.9	9.8
Hand and edge tool manufacturing	332212	39.6	7.0	3.1	1.2	1.9	3.8
Architectural and structural metals manufacturing	3323	379.6	9.9	5.0	2.3	2.7	4.9
Plate work and fabricated structural product manufacturing	33231	162.9	10.4	5.0	2.9	2.2	5.3
Prefabricated metal building and component manufacturing	332311	30.3	6.4	3.1	1.7	1.4	3.3
Fabricated structural metal manufacturing	332312	88.6	12.3	5.6	3.4	–	6.7
Plate work manufacturing	332313	44.0	9.1	5.3	2.5	2.7	3.8
Ornamental and architectural metal products manufacturing	33232	216.8	9.5	4.9	1.9	3.0	4.6
Metal window and door manufacturing	332321	82.3	9.4	5.5	1.5	4.0	3.9
Sheet metal work manufacturing	332322	96.5	8.8	3.8	2.0	1.8	5.0
Ornamental and architectural metal work manufacturing	332323	37.9	11.1	6.2	2.5	3.7	4.9
Boiler, tank, and shipping container manufacturing	3324	91.3	7.2	3.5	1.7	1.7	3.7
Power boiler and heat exchanger manufacturing	33241	19.8	7.3	3.5	2.2	1.3	3.9
Metal tank (heavy gauge) manufacturing	33242	23.3	5.5	3.1	1.6	1.5	2.4
Metal can, box, and other metal container (light gauge) manufacturing	33243	48.3	7.9	3.7	1.6	2.1	4.2
Metal can manufacturing	332431	24.9	8.0	3.3	1.2	2.1	4.7
Other metal container manufacturing	332439	23.3	7.8	4.1	2.0	2.1	3.7
Hardware manufacturing	3325	39.3	8.0	4.2	1.7	2.5	3.8
Hardware manufacturing	33251	39.3	8.0	4.2	1.7	2.5	3.8
Spring and wire product manufacturing	3326	64.9	10.7	5.3	3.1	2.2	5.4
Spring and wire product manufacturing	33261	64.9	10.7	5.3	3.1	2.2	5.4
Spring (light gauge) manufacturing	332612	12.2	6.9	3.4	2.1	1.3	3.5
Other fabricated wire product manufacturing	332618	48.3	11.3	5.6	3.2	2.4	5.7
Machine shops; turned product; and screw, nut, and bolt manufacturing	3327	308.9	7.6	3.7	2.1	1.6	3.9
Machine shops	33271	223.8	7.5	3.5	2.1	1.3	4.0
Turned product and screw, nut, and bolt manufacturing	33272	85.1	7.9	4.2	1.8	2.4	3.7
Precision turned product manufacturing	332721	42.3	7.6	3.8	1.5	2.3	3.8
Bolt, nut, screw, rivet, and washer manufacturing	332722	42.9	8.2	4.6	2.1	2.4	3.6

See footnotes at end of table.

TABLE 1. **Incidence rates[1] of nonfatal occupational injuries and illnesses by industry and case types, 2003** — Continued

Industry[2]	NAICS code[3]	2003 Annual average employment[4] (thousands)	Total recordable cases	Cases with days away from work, job transfer, or restriction			Other recordable cases
				Total	Cases with days away from work[5]	Cases with job transfer or restriction	
Coating, engraving, heat treating, and allied activities	3328	142.1	7.7	4.2	2.0	2.2	3.4
Coating, engraving, heat treating, and allied activities	33281	142.1	7.7	4.2	2.0	2.2	3.4
Metal heat treating	332811	17.9	9.8	4.8	2.8	1.9	5.1
Metal coating, engraving (except jewelry and silverware), and allied services to manufacturers	332812	49.2	8.9	5.3	2.2	3.1	3.5
Electroplating, plating, polishing, anodizing, and coloring	332813	75.0	6.4	3.4	1.7	1.7	3.0
Other fabricated metal product manufacturing	3329	281.5	7.5	3.7	1.5	2.2	3.8
Metal valve manufacturing	33291	99.4	7.0	3.5	1.4	2.1	3.5
Industrial valve manufacturing	332911	24.0	–	4.4	1.5	2.9	3.6
Fluid power valve and hose fitting manufacturing	332912	37.0	4.0	2.2	.8	1.5	1.7
Plumbing fixture fitting and trim manufacturing	332913	16.4	6.2	3.0	1.2	1.8	3.2
Other metal valve and pipe fitting manufacturing	332919	22.0	11.4	5.0	2.7	2.4	6.3
All other fabricated metal product manufacturing	33299	182.1	7.8	3.8	1.6	2.3	4.0
Ball and roller bearing manufacturing	332991	35.1	6.4	3.0	.9	2.0	3.5
Small arms ammunition manufacturing	332992	7.5	4.8	2.4	1.2	1.1	2.5
Ammunition (except small arms) manufacturing	332993	18.6	2.4	1.0	.6	.4	1.4
Small arms manufacturing	332994	9.7	8.5	4.0	1.7	2.3	4.5
Other ordnance and accessories manufacturing	332995	4.0	3.0	.8	.4	.4	2.1
Fabricated pipe and pipe fitting manufacturing	332996	27.7	8.4	4.5	2.6	1.9	3.9
Enameled iron and metal sanitary ware manufacturing	332998	13.2	11.2	6.1	1.7	4.4	5.2
All other miscellaneous fabricated metal product manufacturing	332999	60.3	10.2	5.0	2.0	3.0	5.2
Machinery manufacturing	333	1,145.8	6.9	3.1	1.5	1.6	3.8
Agriculture, construction, and mining machinery manufacturing	3331	188.7	7.3	3.5	1.8	1.7	3.8
Agricultural implement manufacturing	33311	75.9	7.6	3.6	1.5	2.1	4.0
Farm machinery and equipment manufacturing	333111	54.7	7.8	3.5	1.6	1.9	4.3
Lawn and garden tractor and home lawn and garden equipment manufacturing	333112	21.2	7.1	3.8	1.1	2.7	3.2
Construction machinery manufacturing	33312	58.4	9.1	4.5	2.6	1.9	4.6
Mining and oil and gas field machinery manufacturing	33313	54.4	5.1	2.4	1.5	.9	2.7
Mining machinery and equipment manufacturing	333131	11.0	7.9	3.8	2.7	1.0	4.1
Oil and gas field machinery and equipment manufacturing	333132	43.4	4.4	2.0	1.2	.8	2.4
Industrial machinery manufacturing	3332	121.4	6.3	2.7	1.6	1.1	3.6
Other industrial machinery manufacturing	33329	98.2	6.3	2.9	1.7	1.2	3.4
Printing machinery and equipment manufacturing	333293	14.1	7.2	3.4	1.9	1.6	3.8
Food product machinery manufacturing	333294	19.5	7.0	3.4	1.3	2.2	3.6
Semiconductor machinery manufacturing	333295	16.6	2.0	1.2	.6	.6	.8
All other industrial machinery manufacturing	333298	27.8	7.5	3.7	2.8	.9	3.8
Commercial and service industry machinery manufacturing	3333	118.2	5.2	2.0	.9	1.1	–
Commercial and service industry machinery manufacturing	33331	118.2	5.2	2.0	.9	1.1	–
Automatic vending machine manufacturing	333311	6.3	5.7	4.2	1.2	3.1	1.5

See footnotes at end of table.

TABLE 1. Incidence rates[1] of nonfatal occupational injuries and illnesses by industry and case types, 2003 — Continued

Industry[2]	NAICS code[3]	2003 Annual average employment[4] (thousands)	Total recordable cases	Cases with days away from work, job transfer, or restriction			Other recordable cases
				Total	Cases with days away from work[5]	Cases with job transfer or restriction	
Commercial laundry, drycleaning, and pressing machine manufacturing	333312	3.6	10.1	3.2	1.5	1.7	6.9
Office machinery manufacturing	333313	11.6	2.1	1.3	.7	.6	.9
Optical instrument and lens manufacturing	333314	22.8	3.6	1.5	.8	.7	2.1
Photographic and photocopying equipment manufacturing	333315	17.3	1.5	.8	.3	.4	.8
Other commercial and service industry machinery manufacturing	333319	56.6	–	2.4	1.1	1.3	–
Ventilation, heating, air-conditioning, and commercial refrigeration equipment manufacturing	3334	156.7	8.7	4.4	1.9	2.5	4.3
Ventilation, heating, air-conditioning, and commercial refrigeration equipment manufacturing	33341	156.7	8.7	4.4	1.9	2.5	4.3
Air purification equipment manufacturing	333411	18.1	9.6	4.4	2.1	2.3	5.2
Industrial and commercial fan and blower manufacturing	333412	11.1	11.3	4.8	2.4	2.4	6.4
Heating equipment (except warm air furnaces) manufacturing	333414	19.9	8.1	4.4	1.8	2.6	3.7
Air-conditioning and warm air heating equipment and commercial and industrial refrigeration equipment manufacturing	333415	107.6	8.3	4.3	1.8	2.5	4.0
Metalworking machinery manufacturing	3335	203.4	7.0	2.5	1.1	1.4	4.6
Metalworking machinery manufacturing	33351	203.4	7.0	2.5	1.1	1.4	4.6
Industrial mold manufacturing	333511	43.2	–	2.2	1.0	1.2	–
Machine tool (metal cutting types) manufacturing	333512	26.8	5.9	1.8	1.1	.7	4.1
Machine tool (metal forming types) manufacturing	333513	13.0	8.4	4.5	2.6	2.0	3.9
Special die and tool, die set, jig, and fixture manufacturing	333514	79.1	–	3.0	1.0	1.9	–
Cutting tool and machine tool accessory manufacturing	333515	28.7	3.9	1.3	1.0	.3	2.5
Engine, turbine, and power transmission equipment manufacturing	3336	93.8	7.0	3.7	1.8	1.9	3.3
Engine, turbine, and power transmission equipment manufacturing	33361	93.8	7.0	3.7	1.8	1.9	3.3
Turbine and turbine generator set units manufacturing	333611	19.8	3.6	2.4	1.2	1.1	1.3
Speed changer, industrial high-speed drive, and gear manufacturing	333612	12.9	9.0	5.5	2.2	3.4	3.5
Mechanical power transmission equipment manufacturing	333613	16.6	6.8	4.1	2.0	2.1	2.7
Other engine equipment manufacturing	333618	44.4	8.0	3.6	1.8	1.7	4.4
Other general purpose machinery manufacturing	3339	263.7	6.7	3.2	1.5	1.8	3.5
Pump and compressor manufacturing	33391	50.7	6.7	3.0	1.2	1.8	3.7
Pump and pumping equipment manufacturing	333911	28.0	8.4	3.8	1.4	2.4	4.6
Air and gas compressor manufacturing	333912	19.9	4.9	2.2	1.1	1.1	2.8
Material handling equipment manufacturing	33392	74.1	7.6	3.7	1.9	1.8	3.9
Conveyor and conveying equipment manufacturing	333922	30.3	5.6	2.7	1.4	1.3	2.9
Overhead traveling crane, hoist, and monorail system manufacturing	333923	12.5	11.2	6.2	3.2	3.0	5.0
Industrial truck, tractor, trailer, and stacker machinery manufacturing	333924	22.2	8.8	3.9	1.9	2.0	4.9
All other general purpose machinery manufacturing	33399	139.0	6.2	3.0	1.3	1.7	3.2

See footnotes at end of table.

TABLE 1. Incidence rates[1] of nonfatal occupational injuries and illnesses by industry and case types, 2003 — Continued

Industry[2]	NAICS code[3]	2003 Annual average employment[4] (thousands)	Total recordable cases	Cases with days away from work, job transfer, or restriction			Other recordable cases
				Total	Cases with days away from work[5]	Cases with job transfer or restriction	
Power-driven handtool manufacturing	333991	14.4	2.5	1.2	0.6	0.6	1.4
Welding and soldering equipment manufacturing	333992	13.9	5.8	3.6	1.3	2.3	2.1
Packaging machinery manufacturing	333993	18.1	4.0	2.3	1.1	1.2	1.8
Industrial process furnace and oven manufacturing	333994	12.3	–	5.7	1.8	4.0	7.5
Fluid power cylinder and actuator manufacturing	333995	15.6	7.6	4.3	1.7	2.6	3.3
Fluid power pump and motor manufacturing	333996	20.7	6.3	3.3	1.6	1.6	3.0
All other miscellaneous general purpose machinery manufacturing	333999	39.6	6.1	2.4	1.2	1.2	3.7
Computer and electronic product manufacturing	334	1,354.0	2.4	1.2	.6	.6	1.1
Computer and peripheral equipment manufacturing	3341	222.1	–	.8	.4	.5	–
Computer and peripheral equipment manufacturing	33411	222.1	–	.8	.4	.5	–
Electronic computer manufacturing	334111	122.1	–	.8	.4	.4	–
Computer storage device manufacturing	334112	30.9	1.3	.6	–	.4	.7
Computer terminal manufacturing	334113	17.6	.7	.3	.3	–	.4
Communications equipment manufacturing	3342	153.9	1.8	.9	.3	.6	.9
Telephone apparatus manufacturing	33421	49.8	1.3	.7	.2	.5	.6
Radio and television broadcasting and wireless communications equipment manufacturing	33422	77.3	2.2	1.2	.4	.8	1.0
Audio and video equipment manufacturing	3343	37.7	4.6	2.7	.9	1.7	2.0
Semiconductor and other electronic component manufacturing	3344	460.8	2.6	1.4	.7	.6	1.2
Semiconductor and other electronic component manufacturing	33441	460.8	2.6	1.4	.7	.6	1.2
Bare printed circuit board manufacturing	334412	66.3	4.1	2.3	1.4	.9	1.8
Semiconductor and related device manufacturing	334413	225.4	1.6	.9	.4	.5	.8
Electronic capacitor manufacturing	334414	9.3	3.8	2.0	1.3	.6	1.8
Electronic connector manufacturing	334417	15.0	2.6	1.4	.6	.7	1.2
Printed circuit assembly (electronic assembly) manufacturing	334418	48.7	–	.9	.4	.5	1.0
Other electronic component manufacturing	334419	65.9	2.9	1.5	.9	.7	1.4
Navigational, measuring, electromedical, and control instruments manufacturing	3345	430.7	2.4	1.2	.6	.7	1.2
Navigational, measuring, electromedical, and control instruments manufacturing	33451	430.7	2.4	1.2	.6	.7	1.2
Electromedical and electrotherapeutic apparatus manufacturing	334510	55.5	2.5	1.2	.4	.8	1.3
Search, detection, navigation, guidance, aeronautical, and nautical system and instrument manufacturing	334511	145.7	1.7	.7	.3	.4	.9
Automatic environmental control manufacturing for residential, commercial, and appliance use	334512	30.7	6.1	3.8	1.3	2.5	2.3
Instruments and related products manufacturing for measuring, displaying, and controlling industrial process variables	334513	57.7	2.1	1.0	.5	.5	1.1
Totalizing fluid meter and counting device manufacturing	334514	15.0	4.2	2.9	2.2	.8	1.3

See footnotes at end of table.

TABLE 1. **Incidence rates[1] of nonfatal occupational injuries and illnesses by industry and case types, 2003** — Continued

Industry[2]	NAICS code[3]	2003 Annual average employment[4] (thousands)	Total recordable cases	Cases with days away from work, job transfer, or restriction			Other recordable cases
				Total	Cases with days away from work[5]	Cases with job transfer or restriction	
Instrument manufacturing for measuring and testing electricity and electrical signals	334515	46.5	2.1	1.3	0.7	0.6	0.8
Analytical laboratory instrument manufacturing	334516	32.1	2.3	.9	.4	.5	1.4
Irradiation apparatus manufacturing	334517	11.3	1.7	1.0	.3	.8	.7
Other measuring and controlling device manufacturing	334519	29.1	2.3	1.0	.5	.5	1.3
Manufacturing and reproducing magnetic and optical media	3346	48.7	2.5	1.5	1.0	.6	1.0
Manufacturing and reproducing magnetic and optical media	33461	48.7	2.5	1.5	1.0	.6	1.0
Prerecorded compact disc (except software), tape, and record reproducing	334612	23.7	4.1	2.6	1.5	1.0	1.5
Electrical equipment, appliance, and component manufacturing	335	457.8	6.1	3.1	1.2	1.9	2.9
Electric lighting equipment manufacturing	3351	67.2	5.9	3.5	1.3	2.2	2.3
Electric lamp bulb and part manufacturing	33511	15.6	4.1	1.5	1.0	.6	2.6
Lighting fixture manufacturing	33512	51.6	6.4	4.1	1.4	2.7	2.2
Residential electric lighting fixture manufacturing	335121	15.9	6.9	5.3	2.5	2.8	1.6
Commercial, industrial, and institutional electric lighting fixture manufacturing	335122	24.5	6.8	3.8	1.1	2.6	3.0
Other lighting equipment manufacturing	335129	11.2	4.9	3.4	.7	2.7	1.6
Household appliance manufacturing	3352	92.6	8.0	3.9	1.3	2.5	4.1
Small electrical appliance manufacturing	33521	21.8	7.0	3.8	1.9	1.9	3.2
Electric housewares and household fan manufacturing	335211	13.6	7.9	4.7	2.1	2.6	3.2
Household vacuum cleaner manufacturing	335212	8.2	5.6	2.4	1.5	.9	3.2
Major appliance manufacturing	33522	70.8	8.2	3.9	1.2	2.7	4.3
Household cooking appliance manufacturing	335221	18.9	7.8	4.2	.8	3.4	3.6
Household refrigerator and home freezer manufacturing	335222	22.9	7.3	3.8	1.4	2.4	3.5
Electrical equipment manufacturing	3353	158.9	5.5	2.6	1.2	1.4	2.9
Electrical equipment manufacturing	33531	158.9	5.5	2.6	1.2	1.4	2.9
Power, distribution, and specialty transformer manufacturing	335311	27.0	6.3	4.0	1.8	2.2	2.3
Motor and generator manufacturing	335312	53.3	6.1	2.7	1.3	1.4	3.4
Switchgear and switchboard apparatus manufacturing	335313	33.8	6.0	2.9	1.2	1.7	3.1
Relay and industrial control manufacturing	335314	44.9	3.9	1.4	.8	.7	2.5
Other electrical equipment and component manufacturing	3359	139.1	5.6	3.1	1.2	1.9	2.5
Primary battery manufacturing	335912	12.0	6.4	3.0	1.2	1.9	3.3
Communication and energy wire and cable manufacturing	33592	22.1	4.3	3.0	1.4	1.6	1.2
Other communication and energy wire manufacturing	335929	11.2	5.7	4.1	2.3	1.8	1.6
Wiring device manufacturing	33593	57.3	6.1	3.5	1.0	2.5	2.6
Current-carrying wiring device manufacturing	335931	44.4	6.2	3.5	.9	2.6	2.7
Noncurrent-carrying wiring device manufacturing	335932	12.9	5.8	3.4	1.5	2.0	2.4
All other electrical equipment and component manufacturing	33599	31.6	4.4	2.1	1.3	.9	2.3
All other miscellaneous electrical equipment and component manufacturing	335999	24.7	3.4	1.3	.8	.4	2.2

See footnotes at end of table.

TABLE 1. **Incidence rates[1] of nonfatal occupational injuries and illnesses by industry and case types, 2003** — Continued

Industry[2]	NAICS code[3]	2003 Annual average employment[4] (thousands)	Total recordable cases	Cases with days away from work, job transfer, or restriction: Total	Cases with days away from work[5]	Cases with job transfer or restriction	Other recordable cases
Transportation equipment manufacturing	336	1,753.7	9.3	5.1	1.8	3.3	4.1
Motor vehicle manufacturing	3361	258.1	15.2	9.3	2.2	7.1	5.9
Automobile and light duty motor vehicle manufacturing	33611	227.3	14.9	9.4	2.2	7.2	5.5
Automobile manufacturing	336111	150.5	13.3	8.2	2.2	5.9	5.1
Light truck and utility vehicle manufacturing	336112	76.8	18.0	11.7	2.0	9.7	6.3
Motor vehicle body and trailer manufacturing	3362	152.8	12.2	5.9	2.6	3.3	6.3
Motor vehicle body and trailer manufacturing	33621	152.8	12.2	5.9	2.6	3.3	6.3
Motor vehicle body manufacturing	336211	62.5	10.4	5.2	2.5	2.8	5.1
Truck trailer manufacturing	336212	30.8	13.6	5.8	2.7	3.1	7.8
Motor home manufacturing	336213	19.6	14.0	5.0	1.2	3.8	9.0
Travel trailer and camper manufacturing	336214	39.9	–	–	3.3	4.3	–
Motor vehicle parts manufacturing	3363	699.7	9.0	5.1	1.7	3.4	3.9
Motor vehicle gasoline engine and engine parts manufacturing	33631	85.5	8.1	4.2	1.6	2.6	4.0
Carburetor, piston, piston ring, and valve manufacturing	336311	17.5	7.0	3.0	1.2	1.9	4.0
Gasoline engine and engine parts manufacturing	336312	68.0	8.4	4.4	1.6	2.8	4.0
Motor vehicle electrical and electronic equipment manufacturing	33632	100.8	6.5	4.1	1.7	2.4	2.5
Other motor vehicle electrical and electronic equipment manufacturing	336322	83.6	6.1	3.8	1.7	2.1	2.3
Motor vehicle steering and suspension components (except spring) manufacturing	33633	43.8	7.8	4.3	1.4	2.9	3.5
Motor vehicle brake system manufacturing	33634	45.9	–	–	2.2	–	–
Motor vehicle transmission and power train parts manufacturing	33635	89.5	10.5	5.2	1.1	4.0	5.4
Motor vehicle seating and interior trim manufacturing	33636	61.1	–	–	1.8	–	2.7
Motor vehicle metal stamping	33637	100.1	12.2	–	2.0	–	5.2
Other motor vehicle parts manufacturing	33639	173.0	7.9	4.7	2.0	2.8	3.2
Motor vehicle air-conditioning manufacturing	336391	13.7	7.7	4.7	.8	3.9	3.1
All other motor vehicle parts manufacturing	336399	159.3	7.9	4.7	2.1	2.7	3.2
Aerospace product and parts manufacturing	3364	438.1	4.7	2.4	1.0	1.4	2.2
Aerospace product and parts manufacturing	33641	438.1	4.7	2.4	1.0	1.4	2.2
Aircraft manufacturing	336411	207.2	5.6	3.1	1.3	1.8	2.5
Aircraft engine and engine parts manufacturing	336412	80.9	3.5	1.7	.7	1.0	1.8
Other aircraft parts and auxiliary equipment manufacturing	336413	80.2	6.0	2.8	1.3	1.5	3.2
Guided missile and space vehicle manufacturing	336414	50.8	1.5	.8	.3	.5	.7
Guided missile and space vehicle propulsion unit and propulsion unit parts manufacturing	336415	12.4	2.1	1.1	.6	.5	.9
Railroad rolling stock manufacturing	3365	22.9	6.2	2.9	1.5	1.3	3.4
Ship and boat building	3366	143.8	11.0	5.8	2.9	2.9	5.2
Ship and boat building	33661	143.8	11.0	5.8	2.9	2.9	5.2
Ship building and repairing	336611	90.8	11.5	6.2	3.3	3.0	5.3
Boat building	336612	53.0	10.2	5.0	2.3	2.7	5.2

See footnotes at end of table.

TABLE 1. **Incidence rates[1] of nonfatal occupational injuries and illnesses by industry and case types, 2003** — Continued

Industry[2]	NAICS code[3]	2003 Annual average employment[4] (thousands)	Total recordable cases	Cases with days away from work, job transfer, or restriction			Other recordable cases
				Total	Cases with days away from work[5]	Cases with job transfer or restriction	
Other transportation equipment manufacturing	3369	38.3	8.5	3.8	1.6	2.1	4.7
Other transportation equipment manufacturing	33699	38.3	8.5	3.8	1.6	2.1	4.7
Motorcycle, bicycle, and parts manufacturing	336991	18.5	10.2	4.0	1.8	2.3	6.2
Furniture and related product manufacturing	337	570.3	8.7	4.7	1.9	2.8	4.1
Household and institutional furniture and kitchen cabinet manufacturing	3371	380.5	8.8	4.5	1.8	2.7	4.3
Wood kitchen cabinet and countertop manufacturing	33711	153.0	8.5	4.4	2.1	2.3	4.1
Household and institutional furniture manufacturing	33712	227.6	9.0	4.6	1.6	3.0	4.4
Upholstered household furniture manufacturing	337121	85.8	8.4	4.6	1.2	3.4	3.8
Nonupholstered wood household furniture manufacturing	337122	93.7	9.5	4.7	1.9	2.8	4.8
Metal household furniture manufacturing	337124	10.2	11.1	5.6	1.7	3.9	5.5
Institutional furniture manufacturing	337127	28.9	8.8	4.4	1.9	2.5	4.4
Office furniture (including fixtures) manufacturing	3372	138.2	8.8	4.8	2.0	2.8	4.0
Office furniture (including fixtures) manufacturing	33721	138.2	8.8	4.8	2.0	2.8	4.0
Wood office furniture manufacturing	337211	25.7	6.8	3.5	1.4	2.1	3.3
Custom architectural woodwork and millwork manufacturing	337212	14.3	8.3	5.4	2.3	3.1	2.9
Office furniture (except wood) manufacturing	337214	28.6	6.7	3.8	1.3	2.5	2.9
Showcase, partition, shelving, and locker manufacturing	337215	69.6	10.5	5.6	2.5	3.1	4.9
Other furniture related product manufacturing	3379	51.6	8.2	5.1	1.9	3.2	3.0
Mattress manufacturing	33791	30.2	9.7	6.1	2.1	4.0	3.5
Blind and shade manufacturing	33792	21.4	6.1	3.7	1.6	2.2	2.3
Miscellaneous manufacturing	339	663.6	5.0	2.7	1.2	1.5	2.3
Medical equipment and supplies manufacturing	3391	302.7	3.9	2.1	.8	1.2	1.9
Medical equipment and supplies manufacturing	33911	302.7	3.9	2.1	.8	1.2	1.9
Laboratory apparatus and furniture manufacturing	339111	14.8	6.1	1.6	.6	1.0	4.5
Surgical and medical instrument manufacturing	339112	104.3	3.6	2.1	.7	1.4	1.5
Surgical appliance and supplies manufacturing	339113	88.0	5.3	2.9	1.4	1.6	2.4
Ophthalmic goods manufacturing	339115	31.8	4.0	2.3	.9	1.4	1.6
Dental laboratories	339116	48.3	.9	.1	.1	.1	.8
Other miscellaneous manufacturing	3399	360.9	5.9	3.3	1.5	1.8	2.6
Jewelry and silverware manufacturing	33991	46.4	2.5	1.4	.8	.7	1.1
Jewelry (except costume) manufacturing	339911	30.7	2.2	1.2	.7	.4	1.1
Silverware and hollowware manufacturing	339912	2.8	6.2	3.6	1.2	2.4	2.6
Sporting and athletic goods manufacturing	33992	59.6	7.6	4.7	1.5	3.2	2.9
Doll, toy, and game manufacturing	33993	20.9	4.4	3.4	1.2	2.2	1.0
Doll and stuffed toy manufacturing	339931	3.2	1.0	(9)	(9)	(9)	.8
Game, toy, and children's vehicle manufacturing	339932	17.8	5.0	4.0	1.4	2.5	1.1
Office supplies (except paper) manufacturing	33994	27.5	4.3	2.9	1.2	1.7	1.4
Pen and mechanical pencil manufacturing	339941	6.9	5.3	4.2	1.6	2.7	1.1
Lead pencil and art good manufacturing	339942	10.4	4.9	3.1	.9	2.2	1.7

See footnotes at end of table.

TABLE 1. **Incidence rates[1] of nonfatal occupational injuries and illnesses by industry and case types, 2003** — Continued

Industry[2]	NAICS code[3]	2003 Annual average employment[4] (thousands)	Total recordable cases	Cases with days away from work, job transfer, or restriction			Other recordable cases
				Total	Cases with days away from work[5]	Cases with job transfer or restriction	
Sign manufacturing	33995	69.3	7.8	3.0	2.0	1.0	–
All other miscellaneous manufacturing	33999	137.3	6.0	3.6	1.6	1.9	2.4
Gasket, packing, and sealing device manufacturing	339991	37.0	5.6	3.6	1.4	2.2	2.0
Musical instrument manufacturing	339992	14.3	7.5	4.2	3.1	1.1	3.3
Fastener, button, needle, and pin manufacturing	339993	7.0	6.6	3.5	1.3	2.2	3.1
All other miscellaneous manufacturing	339999	60.5	6.0	3.6	1.5	2.0	2.4
Service providing		83,394.6	4.4	2.3	1.4	.9	2.1
Trade, transportation, and utilities[10]		25,041.8	5.5	3.2	1.9	1.3	2.4
Wholesale trade	42	5,589.0	4.7	2.8	1.5	1.3	1.9
Merchant wholesalers, durable goods	423	2,929.2	4.3	2.4	1.3	1.0	2.0
Motor vehicle and motor vehicle parts and supplies merchant wholesalers	4231	339.4	6.2	3.2	1.7	1.5	3.0
Furniture and home furnishing merchant wholesalers	4232	110.2	4.1	2.1	1.3	.8	1.9
Lumber and other construction materials merchant wholesalers	4233	228.4	7.1	4.3	2.4	1.9	2.8
Professional and commercial equipment and supplies merchant wholesalers	4234	646.6	2.0	1.1	.7	.5	.9
Electrical goods merchant wholesalers	4236	346.6	2.3	1.2	.6	.6	1.1
Hardware, and plumbing and heating equipment and supplies merchant wholesalers	4237	229.3	5.0	2.7	1.4	–	2.3
Machinery, equipment, and supplies merchant wholesalers	4238	645.3	4.6	2.4	1.6	.7	2.2
Miscellaneous durable goods merchant wholesalers	4239	264.2	5.1	2.7	1.8	.9	2.4
Merchant wholesalers, nondurable goods	424	1,998.4	5.7	3.7	1.9	1.8	2.0
Paper and paper product merchant wholesalers	4241	153.4	4.1	2.6	1.6	1.0	1.5
Drugs and druggists' sundries merchant wholesalers	4242	213.5	2.9	–	.9	.8	–
Apparel, piece goods, and notions merchant wholesalers	4243	148.8	–	–	.9	1.1	–
Grocery and related product merchant wholesalers	4244	677.3	7.5	5.4	2.6	2.8	2.1
Farm product raw material merchant wholesalers	4245	74.1	–	2.8	2.1	.6	–
Chemical and allied products merchant wholesalers	4246	130.1	3.0	1.8	1.0	.8	1.3
Petroleum and petroleum products merchant wholesalers	4247	104.9	4.5	2.4	1.7	.8	2.1
Beer, wine, and distilled alcoholic beverage merchant wholesalers	4248	135.1	10.9	7.4	3.6	3.8	3.5
Miscellaneous nondurable goods merchant wholesalers	4249	361.2	4.2	2.5	1.3	1.2	1.7
Wholesale electronic markets and agents and brokers	425	661.4	2.9	1.5	–	.5	1.4
Wholesale electronic markets and agents and brokers	4251	661.4	2.9	1.5	–	.5	1.4
Retail trade	44-45	14,930.8	5.3	2.7	1.6	1.2	2.6
Motor vehicle and parts dealers	441	1,878.8	5.1	2.2	1.5	.7	2.9
Automobile dealers	4411	1,250.5	5.1	2.0	1.4	.6	3.1

See footnotes at end of table.

TABLE 1. Incidence rates[1] of nonfatal occupational injuries and illnesses by industry and case types, 2003 — Continued

Industry[2]	NAICS code[3]	2003 Annual average employment[4] (thousands)	Total recordable cases	Cases with days away from work, job transfer, or restriction: Total	Cases with days away from work[5]	Cases with job transfer or restriction	Other recordable cases
New car dealers	44111	1,135.7	5.3	2.1	1.5	0.6	3.2
Used car dealers	44112	114.9	–	1.1	.8	.3	–
Other motor vehicle dealers	4412	149.4	3.7	1.7	1.2	.4	2.1
Recreational vehicle dealers	44121	35.8	4.9	2.0	1.5	.5	2.8
Motorcycle, boat, and other motor vehicle dealers	44122	113.6	3.3	1.5	1.1	.4	1.8
Automotive parts, accessories, and tire stores	4413	478.8	5.7	3.0	1.9	1.1	2.8
Automotive parts and accessories stores	44131	321.9	5.2	2.6	1.7	.9	2.6
Tire dealers	44132	156.9	6.6	3.6	2.2	–	3.0
Furniture and home furnishings stores	442	547.7	5.2	2.7	1.6	1.1	2.6
Furniture stores	4421	283.5	4.9	2.8	1.5	1.3	2.1
Home furnishings stores	4422	264.1	5.7	2.6	1.8	.8	3.1
Floor covering stores	44221	100.4	–	2.5	1.8	.7	–
Other home furnishings stores	44229	163.7	5.6	2.6	1.8	.8	3.0
Electronics and appliance stores	443	517.6	3.3	1.3	.7	.6	2.0
Electronics and appliance stores	4431	517.6	3.3	1.3	.7	.6	2.0
Appliance, television, and other electronics stores	44311	336.6	4.3	1.6	.9	.7	2.7
Computer and software stores	44312	161.0	1.5	.7	.4	.3	.8
Camera and photographic supplies stores	44313	20.0	1.6	.9	.7	.2	.7
Building material and garden equipment and supplies dealers	444	1,190.6	6.4	3.4	2.0	1.4	3.0
Building material and supplies dealers	4441	1,041.6	6.4	3.3	2.0	1.3	3.1
Home centers	44411	560.1	7.2	3.6	2.2	1.4	3.6
Paint and wallpaper stores	44412	41.8	2.8	2.0	1.3	.8	.8
Hardware stores	44413	164.6	3.7	1.8	1.3	.5	2.0
Other building material dealers	44419	275.0	6.7	3.8	2.1	1.7	3.0
Lawn and garden equipment and supplies stores	4442	149.0	6.1	3.5	1.8	1.7	2.6
Outdoor power equipment stores	44421	31.1	5.7	3.7	1.5	2.2	2.0
Nursery and garden centers	44422	118.0	6.3	3.5	1.9	1.6	2.8
Food and beverage stores	445	2,842.4	6.8	3.6	2.1	1.5	3.2
Grocery stores	4451	2,454.9	7.2	3.7	2.3	1.5	3.5
Supermarkets and other grocery (except convenience) stores	44511	2,309.5	7.4	3.9	2.3	1.5	3.5
Convenience stores	44512	145.5	–	1.6	1.5	.1	–
Specialty food stores	4452	248.9	5.0	3.1	1.5	1.6	1.9
Meat markets	44521	50.1	3.7	1.3	.9	.4	2.4
Fish and seafood markets	44522	14.6	2.5	1.6	.8	.7	.9
Fruit and vegetable markets	44523	46.4	4.0	2.5	1.1	1.4	1.6
Other specialty food stores	44529	137.8	6.2	4.2	2.0	2.2	2.0
Beer, wine, and liquor stores	4453	138.5	3.9	2.3	1.2	1.1	1.6
Health and personal care stores	446	935.8	2.6	1.2	.8	.4	1.4
Health and personal care stores	4461	935.8	2.6	1.2	.8	.4	1.4
Pharmacies and drug stores	44611	680.1	2.9	1.4	1.0	.4	1.5

See footnotes at end of table.

TABLE 1. Incidence rates[1] of nonfatal occupational injuries and illnesses by industry and case types, 2003 — Continued

Industry[2]	NAICS code[3]	2003 Annual average employment[4] (thousands)	Total recordable cases	Cases with days away from work, job transfer, or restriction: Total	Cases with days away from work[5]	Cases with job transfer or restriction	Other recordable cases
Cosmetics, beauty supplies, and perfume stores	44612	96.9	1.8	0.6	0.5	0.1	1.3
Optical goods stores	44613	64.8	1.3	.4	.4	([9])	.9
Other health and personal care stores	44619	93.9	1.6	1.0	.6	.4	.6
Gasoline stations	447	879.2	3.7	1.7	1.2	.5	1.9
Gasoline stations	4471	879.2	3.7	1.7	1.2	.5	1.9
Gasoline stations with convenience stores	44711	750.4	3.7	1.7	1.2	.5	2.0
Other gasoline stations	44719	128.7	3.4	1.7	1.3	.4	1.6
Clothing and clothing accessories stores	448	1,309.2	2.8	1.0	.7	.3	1.8
Clothing stores	4481	962.2	3.4	1.2	.9	.3	2.2
Men's clothing stores	44811	74.6	1.6	.5	.4	.1	1.1
Women's clothing stores	44812	247.3	2.4	.5	.5	.1	1.8
Children's and infants' clothing stores	44813	61.9	–	1.5	1.2	.3	–
Family clothing stores	44814	421.4	4.8	1.9	1.3	.7	2.9
Clothing accessories stores	44815	40.6	1.6	.1	.1	([9])	1.5
Other clothing stores	44819	116.4	1.7	.7	.6	.1	1.0
Shoe stores	4482	178.1	1.4	.6	.5	.2	.7
Jewelry, luggage, and leather goods stores	4483	168.8	1.0	.3	.3	([11])	.7
Jewelry stores	44831	155.7	1.0	.3	.2	([11])	.7
Luggage and leather goods stores	44832	13.2	2.1	1.0	.9	([9])	1.2
Sporting goods, hobby, book, and music stores	451	655.3	3.6	1.3	.7	.6	2.3
Sporting goods, hobby, and musical instrument stores	4511	440.4	4.0	1.5	.8	.7	2.5
Sporting goods stores	45111	207.2	2.8	1.1	.5	.5	1.7
Hobby, toy, and game stores	45112	144.4	6.3	2.2	1.2	1.0	4.1
Sewing, needlework, and piece goods stores	45113	54.2	4.4	1.7	.6	1.1	2.7
Musical instrument and supplies stores	45114	34.6	1.5	.5	.4	.1	.9
Book, periodical, and music stores	4512	214.9	2.7	.9	.6	.3	1.8
Book stores and news dealers	45121	156.9	3.3	1.1	.7	.3	2.3
Prerecorded tape, compact disc, and record stores	45122	58.1	.9	.6	.4	.2	.3
General merchandise stores	452	2,813.4	7.2	4.3	1.9	2.3	2.9
Department stores	4521	1,610.5	7.1	4.1	2.1	2.0	3.0
Other general merchandise stores	4529	1,202.9	7.3	4.5	1.8	2.7	2.8
Warehouse clubs and superstores	45291	891.4	7.9	5.2	1.9	3.3	2.7
All other general merchandise stores	45299	311.5	5.1	2.0	–	.5	3.1
Miscellaneous store retailers	453	937.5	3.6	1.9	1.3	.7	1.7
Florists	4531	111.3	2.0	1.1	.8	.3	.9
Office supplies, stationery, and gift stores	4532	419.3	3.7	1.8	1.1	.7	1.9
Office supplies and stationery stores	45321	182.1	3.5	1.6	1.0	.6	1.9
Gift, novelty, and souvenir stores	45322	237.2	3.8	–	1.2	.7	–
Used merchandise stores	4533	108.1	4.9	3.0	1.7	1.2	1.9
Other miscellaneous store retailers	4539	298.7	3.6	2.1	1.4	.6	1.6

See footnotes at end of table.

TABLE 1. **Incidence rates[1] of nonfatal occupational injuries and illnesses by industry and case types, 2003** — Continued

Industry[2]	NAICS code[3]	2003 Annual average employment[4] (thousands)	Total recordable cases	Cases with days away from work, job transfer, or restriction			Other recordable cases
				Total	Cases with days away from work[5]	Cases with job transfer or restriction	
Pet and pet supplies stores	45391	81.0	4.3	2.7	1.7	1.0	1.6
Art dealers	45392	25.0	4.7	1.6	.8	.8	3.1
Manufactured (mobile) home dealers	45393	28.7	4.1	2.4	1.9	.4	1.7
All other miscellaneous store retailers	45399	164.0	3.0	–	1.3	.5	1.3
Nonstore retailers	454	423.4	5.6	3.5	1.7	1.8	2.1
Electronic shopping and mail-order houses	4541	214.7	4.7	2.8	1.0	1.8	2.0
Vending machine operators	4542	53.6	–	–	3.5	2.5	3.1
Direct selling establishments	4543	155.1	5.6	3.6	2.1	–	1.9
Fuel dealers	45431	101.2	6.6	4.3	2.5	–	2.4
Other direct selling establishments	45439	54.0	3.5	2.4	1.3	1.1	1.1
Transportation and warehousing[10]	48-49	3,946.2	7.8	5.4	3.5	1.8	2.4
Air transportation	481	527.0	11.0	8.0	5.8	2.2	3.0
Scheduled air transportation	4811	484.1	11.7	8.6	6.2	2.4	3.1
Nonscheduled air transportation	4812	43.0	3.9	1.6	1.3	.4	2.3
Rail transportation[10]	482	–	2.9	2.2	2.0	.2	.7
Water transportation	483	53.1	–	2.3	1.8	.4	1.1
Deep sea, coastal, and Great Lakes water transportation	4831	32.9	3.6	2.7	2.4	–	1.0
Inland water transportation	4832	20.2	3.1	1.8	1.2	.6	1.3
Truck transportation	484	1,322.4	6.8	4.5	3.4	1.1	2.3
General freight trucking	4841	931.4	7.1	4.7	3.5	1.2	2.4
General freight trucking, local	48411	230.3	6.1	4.5	3.5	–	1.6
General freight trucking, long-distance	48412	701.1	7.4	4.8	3.5	1.2	2.7
Specialized freight trucking	4842	391.0	6.1	4.1	3.1	1.0	2.0
Used household and office goods moving	48421	98.7	7.3	5.6	2.9	–	1.7
Specialized freight (except used goods) trucking, local	48422	190.5	5.5	3.4	3.0	.4	2.1
Specialized freight (except used goods) trucking, long-distance	48423	101.9	6.2	4.1	3.6	.4	–
Transit and ground passenger transportation	485	375.4	6.4	3.8	2.8	1.0	2.6
Urban transit systems	4851	36.8	10.4	7.7	5.9	1.8	2.8
Interurban and rural bus transportation	4852	21.9	8.8	5.8	4.0	1.8	3.1
Taxi and limousine service	4853	66.4	2.9	2.1	1.7	.4	.8
Taxi service	48531	31.0	4.3	3.0	2.2	.8	1.3
Limousine service	48532	35.4	1.6	1.2	1.2	([9])	.4
School and employee bus transportation	4854	161.3	–	3.3	2.5	.8	–
Charter bus industry	4855	32.7	3.9	2.6	1.9	.6	1.4
Other transit and ground passenger transportation	4859	56.3	6.5	4.1	2.7	1.4	2.4
Pipeline transportation	486	40.3	2.1	1.0	.5	.5	1.1
Pipeline transportation of natural gas	4862	27.9	2.4	1.1	.4	.7	1.3
Scenic and sightseeing transportation	487	26.7	3.9	2.3	1.9	.4	1.6
Support activities for transportation	488	513.2	5.6	3.5	2.4	1.1	2.1

See footnotes at end of table.

TABLE 1. **Incidence rates[1] of nonfatal occupational injuries and illnesses by industry and case types, 2003** — Continued

Industry[2]	NAICS code[3]	2003 Annual average employment[4] (thousands)	Total recordable cases	Cases with days away from work, job transfer, or restriction: Total	Cases with days away from work[5]	Cases with job transfer or restriction	Other recordable cases
Support activities for air transportation	4881	133.7	6.7	4.0	2.2	1.8	2.7
Support activities for water transportation	4883	92.7	9.3	5.8	5.3	.5	3.5
Support activities for road transportation	4884	71.5	4.2	2.9	2.5	.4	1.3
Motor vehicle towing	48841	44.1	3.6	2.7	2.4	.3	.9
Other support activities for road transportation	48849	27.4	5.3	3.3	2.7	.6	2.1
Freight transportation arrangement	4885	166.3	3.0	2.1	1.2	.8	.9
Other support activities for transportation	4889	28.8	7.0	4.5	1.6	3.0	2.5
Couriers and messengers	492	565.1	12.1	8.8	5.5	3.3	3.3
Couriers	4921	517.6	12.8	9.4	5.8	3.6	3.4
Warehousing and storage	493	519.6	10.1	7.3	3.0	4.4	2.7
Warehousing and storage	4931	519.6	10.1	7.3	3.0	4.4	2.7
General warehousing and storage	49311	431.3	10.1	7.5	3.1	4.3	2.6
Refrigerated warehousing and storage	49312	41.9	13.1	9.0	2.4	–	4.1
Other warehousing and storage	49319	37.8	6.3	4.6	2.1	2.6	1.7
Utilities	22	575.9	4.4	2.2	1.2	1.0	2.2
Utilities	221	575.9	4.4	2.2	1.2	1.0	2.2
Electric power generation, transmission and distribution	2211	417.6	4.1	2.0	1.0	.9	2.1
Electric power generation	22111	255.1	3.5	1.7	.8	.9	1.8
Electric power transmission, control, and distribution	22112	162.6	4.9	2.4	1.4	1.0	2.6
Natural gas distribution	2212	111.2	4.8	2.4	1.2	1.1	2.4
Water, sewage and other systems	2213	47.0	6.6	3.9	2.4	1.5	2.6
Water supply and irrigation systems	22131	36.5	6.1	3.9	2.5	1.5	2.2
Information		3,180.8	2.2	1.1	.8	.3	1.1
Information	51	3,180.8	2.2	1.1	.8	.3	1.1
Publishing industries (except Internet)	511	929.5	2.3	1.1	.7	.4	1.2
Newspaper, periodical, book, and directory publishers	5111	692.2	2.9	1.5	.9	.6	1.5
Newspaper publishers	51111	382.6	3.8	2.0	1.2	.8	1.8
Periodical publishers	51112	148.9	1.1	.6	.4	.2	.5
Book publishers	51113	80.9	–	1.3	.6	.6	.8
Directory and mailing list publishers	51114	48.0	1.7	.5	.4	.1	1.1
Other publishers	51119	31.8	5.4	1.5	.8	.7	3.9
Software publishers	5112	237.3	–	.2	.1	–	–
Motion picture and sound recording industries	512	368.5	–	–	.5	.2	–
Motion picture and video industries	5121	343.5	–	.7	.5	.2	–
Motion picture and video production	51211	176.5	1.3	.7	.5	.2	.7
Motion picture and video exhibition	51213	136.6	–	.6	.5	–	–

See footnotes at end of table.

TABLE 1. **Incidence rates[1] of nonfatal occupational injuries and illnesses by industry and case types, 2003** — Continued

Industry[2]	NAICS code[3]	2003 Annual average employment[4] (thousands)	Total recordable cases	Cases with days away from work, job transfer, or restriction: Total	Cases with days away from work[5]	Cases with job transfer or restriction	Other recordable cases
Postproduction services and other motion picture and video industries	51219	20.5	1.6	0.3	0.3	(9)	1.3
Broadcasting (except Internet)	515	323.9	2.0	1.0	.6	.4	1.0
Radio and television broadcasting	5151	238.3	–	.5	.4	.1	.8
Television broadcasting	51512	128.7	1.9	.9	.7	.2	1.1
Cable and other subscription programming	5152	85.5	3.8	2.2	1.1	1.1	1.6
Telecommunications	517	1,079.1	–	–	1.1	–	–
Wireless telecommunications carriers (except satellite)	5172	189.4	.8	.3	.3	.1	.5
Telecommunications resellers	5173	158.4	–	–	–	.2	–
Satellite telecommunications	5174	17.2	4.3	1.9	1.9	–	2.4
Cable and other program distribution	5175	132.5	–	–	–	.9	–
Internet service providers, web search portals, and data processing services	518	402.2	1.4	.5	.3	.2	–
Internet service providers and web search portals	5181	121.2	.9	.3	.2	(11)	.6
Data processing, hosting, and related services	5182	281.0	–	.6	.3	.3	–
Other information services	519	48.1	2.1	1.5	1.3	–	.6
Other information services	5191	48.1	2.1	1.5	1.3	–	.6
Libraries and archives	51912	27.1	2.9	2.2	2.0	–	–
Financial activities		7,826.9	1.7	.8	.6	.2	.9
Finance and insurance	52	5,782.1	1.1	.4	.3	.1	.7
Monetary authorities - central bank	521	22.8	3.1	1.4	.7	.7	1.7
Credit intermediation and related activities	522	2,780.4	1.1	.4	.3	.1	.7
Depository credit intermediation	5221	1,742.1	1.3	.4	.3	.1	.9
Commercial banking	52211	1,271.4	1.3	.3	.3	.1	1.0
Savings institutions	52212	247.9	1.4	.6	.5	.1	.8
Credit unions	52213	203.1	1.2	.5	.4	.1	.7
Other depository credit intermediation	52219	19.7	1.1	.4	.3	–	.7
Nondepository credit intermediation	5222	746.8	.8	.3	.2	.1	.5
Credit card issuing	52221	133.3	1.0	.4	.3	.1	.6
Sales financing	52222	103.5	.7	.2	.2	(11)	.5
Other nondepository credit intermediation	52229	509.9	.7	.3	.2	.1	.4
Activities related to credit intermediation	5223	291.6	–	.4	.3	.1	.4
Financial transactions processing, reserve, and clearinghouse activities	52232	82.9	1.2	.7	.4	.3	.5
Other activities related to credit intermediation	52239	90.9	.8	.5	.5	–	.3
Securities, commodity contracts, and other financial investments and related activities	523	757.0	.5	.2	.1	.1	.3
Securities and commodity contracts intermediation and brokerage	5231	483.0	.3	.1	.1	(11)	.2

See footnotes at end of table.

TABLE 1. **Incidence rates[1] of nonfatal occupational injuries and illnesses by industry and case types, 2003** — Continued

Industry[2]	NAICS code[3]	2003 Annual average employment[4] (thousands)	Total recordable cases	Cases with days away from work, job transfer, or restriction			Other recordable cases
				Total	Cases with days away from work[5]	Cases with job transfer or restriction	
Investment banking and securities dealing	52311	165.9	0.2	0.1	0.1	–	0.1
Securities brokerage	52312	292.3	.4	.1	.1	(11)	.2
Securities and commodity exchanges	5232	9.3	1.7	1.2	.7	.5	.5
Other financial investment activities	5239	264.8	.7	.4	.2	.1	.4
Miscellaneous intermediation	52391	24.2	2.8	1.0	.3	.7	1.9
Portfolio management	52392	97.2	.6	.3	.3	(11)	.2
Investment advice	52393	95.3	.4	.2	.1	(11)	.3
All other financial investment activities	52399	48.1	.8	.4	.3	.1	.3
Insurance carriers and related activities	524	2,137.9	1.2	.5	.4	.1	.7
Insurance carriers	5241	1,299.9	1.5	.6	.4	.2	.9
Direct life, health, and medical insurance carriers	52411	661.0	1.8	.7	.5	.2	1.1
Direct insurance (except life, health, and medical) carriers	52412	607.3	1.2	.5	.4	.1	.7
Reinsurance carriers	52413	31.6	.9	.4	.3	.1	.5
Agencies, brokerages, and other insurance related activities	5242	838.1	.6	.3	.2	.1	.3
Insurance agencies and brokerages	52421	630.5	.5	.3	.2	.1	.2
Other insurance related activities	52429	207.6	1.2	.4	.3	.1	.8
Funds, trusts, and other financial vehicles	525	83.9	1.0	.5	.3	.2	.5
Insurance and employee benefit funds	5251	47.2	.7	.4	.3	–	–
Other investment pools and funds	5259	36.7	1.3	.5	.3	.2	.8
Real estate and rental and leasing	53	2,044.9	3.9	2.1	1.5	.6	1.8
Real estate	531	1,381.3	3.6	1.9	1.4	.5	1.7
Lessors of real estate	5311	603.0	4.4	2.4	1.7	.6	2.0
Lessors of residential buildings and dwellings	53111	379.0	4.8	2.5	1.8	.8	2.3
Lessors of nonresidential buildings (except miniwarehouses)	53112	147.2	3.9	–	–	.3	1.6
Lessors of miniwarehouses and self-storage units	53113	34.5	3.1	2.0	1.5	.5	1.1
Lessors of other real estate property	53119	42.4	3.8	1.6	1.0	.6	2.2
Offices of real estate agents and brokers	5312	309.1	–	.7	.6	.1	–
Activities related to real estate	5313	469.2	3.7	2.1	1.6	.5	1.6
Real estate property managers	53131	393.8	4.3	2.4	1.8	.6	1.8
Offices of real estate appraisers	53132	42.5	.7	.3	.3	(11)	.4
Other activities related to real estate	53139	32.8	1.0	.6	.3	.3	.4
Rental and leasing services	532	637.2	4.7	2.5	1.6	1.0	2.2
Automotive equipment rental and leasing	5321	193.0	5.3	2.9	2.0	.9	2.4
Passenger car rental and leasing	53211	132.9	4.8	–	1.9	.9	1.9
Truck, utility trailer, and RV (recreational vehicle) rental and leasing	53212	60.2	6.4	2.9	2.1	.8	3.4
Consumer goods rental	5322	281.6	4.0	2.1	1.3	.9	1.9
Consumer electronics and appliances rental	53221	29.0	8.3	6.4	3.7	2.6	1.9
Formal wear and costume rental	53222	16.5	2.6	.5	.5	(9)	2.1
Video tape and disc rental	53223	153.1	2.3	.6	.5	.1	1.7

See footnotes at end of table.

TABLE 1. Incidence rates[1] of nonfatal occupational injuries and illnesses by industry and case types, 2003 — Continued

Industry[2]	NAICS code[3]	2003 Annual average employment[4] (thousands)	Total recordable cases	Cases with days away from work, job transfer, or restriction: Total	Cases with days away from work[5]	Cases with job transfer or restriction	Other recordable cases
Other consumer goods rental	53229	82.9	4.7	2.5	1.3	1.2	2.1
General rental centers	5323	61.6	7.0	4.6	2.2	2.3	2.5
Commercial and industrial machinery and equipment rental and leasing	5324	101.0	3.7	1.7	1.1	.6	2.0
Construction, transportation, mining, and forestry machinery and equipment rental and leasing	53241	53.2	3.3	1.9	1.2	.7	1.4
Office machinery and equipment rental and leasing	53242	10.5	1.1	.6	.5	(9)	.5
Other commercial and industrial machinery and equipment rental and leasing	53249	37.3	4.9	1.6	1.0	.7	3.3
Lessors of nonfinancial intangible assets (except copyrighted works)	533	26.4	1.2	.9	.7	–	–
Professional and business services		15,858.5	2.5	1.4	.9	.5	1.1
Professional, scientific, and technical services	54	6,638.7	1.3	.6	.4	.2	.7
Professional, scientific, and technical services	541	6,638.7	1.3	.6	.4	.2	.7
Legal services	5411	1,146.2	.7	.4	.3	.1	.3
Accounting, tax preparation, bookkeeping, and payroll services	5412	830.6	.9	.3	.2	.1	–
Accounting, tax preparation, bookkeeping, and payroll services	54121	830.6	.9	.3	.2	.1	–
Offices of certified public accountants	541211	371.4	.3	.1	.1	(11)	.3
Tax preparation services	541213	88.9	.4	.2	.1	.1	.2
Other accounting services	541219	232.9	1.2	.6	.4	.2	.6
Architectural, engineering, and related services	5413	1,223.6	1.5	.7	.5	.2	.8
Architectural services	54131	180.7	.5	.1	.1	(9)	.4
Landscape architectural services	54132	42.1	2.3	1.1	.6	.4	1.2
Engineering services	54133	760.5	1.6	.8	.5	.3	.8
Drafting services	54134	10.0	(9)	(9)	(9)	(9)	(9)
Building inspection services	54135	15.3	1.3	.7	.7	(9)	.6
Surveying and mapping (except geophysical) services	54137	58.3	2.7	1.1	.8	.3	1.6
Testing laboratories	54138	143.5	2.0	.9	.6	.3	1.0
Specialized design services	5414	121.0	1.4	.7	.6	.1	.7
Computer systems design and related services	5415	1,107.8	.6	.3	.2	.1	.3
Computer systems design and related services	54151	1,107.8	.6	.3	.2	.1	.3
Custom computer programming services	541511	489.1	.5	.2	.2	(11)	.2
Computer systems design services	541512	448.0	.6	.2	.2	.1	.3
Computer facilities management services	541513	57.3	1.9	1.1	.7	.4	.7
Other computer related services	541519	113.3	.5	.2	.1	.1	.2
Management, scientific, and technical consulting services	5416	753.6	1.1	.5	.3	.2	–
Management consulting services	54161	634.0	1.1	.4	.2	.2	–
Environmental consulting services	54162	61.8	.8	.2	.1	.1	.5
Scientific research and development services	5417	534.6	2.1	–	.4	–	1.1

See footnotes at end of table.

TABLE 1. **Incidence rates[1] of nonfatal occupational injuries and illnesses by industry and case types, 2003** — Continued

Industry[2]	NAICS code[3]	2003 Annual average employment[4] (thousands)	Total recordable cases	Cases with days away from work, job transfer, or restriction			Other recordable cases
				Total	Cases with days away from work[5]	Cases with job transfer or restriction	
Advertising and related services	5418	430.1	1.7	1.0	0.6	0.4	0.7
Other professional, scientific, and technical services	5419	491.3	4.6	1.7	1.0	–	2.8
Marketing research and public opinion polling	54191	106.1	.7	.3	.2	.2	.3
Photographic services	54192	83.4	1.9	1.0	.6	.4	1.0
Veterinary services	54194	249.9	7.6	–	1.5	–	5.0
All other professional, scientific, and technical services	54199	43.2	2.7	1.6	1.0	.6	1.1
Management of companies and enterprises	55	1,660.1	3.0	1.6	.9	.7	1.3
Administrative and support and waste management and remediation services	56	7,559.6	4.0	2.4	1.6	.8	1.6
Administrative and support services	561	7,241.4	3.7	2.1	1.4	.6	1.6
Facilities support services	5612	106.6	–	–	–	1.1	1.7
Employment services	5613	3,227.3	4.4	–	1.4	–	–
Employment placement agencies	56131	264.0	–	–	–	.6	1.1
Employee leasing services	56133	822.9	–	–	–	.5	–
Business support services	5614	739.5	1.1	–	–	.1	.5
Document preparation services	56141	38.2	1.4	.9	.9	(9)	.5
Telephone call centers	56142	352.6	–	–	–	(11)	.5
Collection agencies	56144	145.1	.8	.3	.3	.1	.4
Other business support services	56149	86.9	1.0	.8	.7	.1	.2
Travel arrangement and reservation services	5615	236.9	–	–	–	.3	1.0
Travel agencies	56151	121.0	.4	.2	.1	(11)	.3
Tour operators	56152	29.4	1.5	.8	.6	.2	.7
Other travel arrangement and reservation services	56159	86.5	–	–	–	.6	2.0
Investigation and security services	5616	708.0	2.6	1.2	1.0	.3	1.4
Services to buildings and dwellings	5617	1,627.8	5.1	3.0	2.2	.8	2.1
Exterminating and pest control services	56171	90.7	–	–	–	.5	1.5
Janitorial services	56172	860.0	4.9	2.9	1.9	–	2.0
Landscaping services	56173	557.5	5.2	3.1	2.4	–	2.2
Carpet and upholstery cleaning services	56174	46.4	–	1.9	1.1	.7	–
Other support services	5619	292.1	5.3	3.2	–	1.1	–
Waste management and remediation services	562	318.2	8.3	5.7	3.5	2.2	2.6
Waste collection	5621	113.0	9.9	7.1	4.2	–	2.9
Waste treatment and disposal	5622	106.8	8.2	5.8	3.4	2.3	2.4
Remediation and other waste management services	5629	98.4	6.3	4.0	2.6	1.3	2.3
Remediation services	56291	61.8	4.8	3.4	2.2	1.2	1.4
All other waste management services	56299	28.8	7.7	5.1	3.8	1.4	2.5
Education and health services		15,738.0	6.0	2.9	1.6	1.3	3.1

See footnotes at end of table.

TABLE 1. **Incidence rates[1] of nonfatal occupational injuries and illnesses by industry and case types, 2003** — Continued

Industry[2]	NAICS code[3]	2003 Annual average employment[4] (thousands)	Total recordable cases	Cases with days away from work, job transfer, or restriction: Total	Cases with days away from work[5]	Cases with job transfer or restriction	Other recordable cases
Educational services	61	2,016.2	2.7	1.2	0.8	–	1.5
Educational services	611	2,016.2	2.7	1.2	.8	–	1.5
Elementary and secondary schools	6111	555.5	–	–	1.0	–	1.9
Junior colleges	6112	41.4	1.5	.5	.4	0.1	1.0
Colleges, universities, and professional schools	6113	963.1	2.7	1.2	.8	.4	1.5
Business schools and computer and management training	6114	80.1	.6	.3	.2	(11)	.4
Business and secretarial schools	61141	15.0	.8	.4	.4	(9)	.5
Computer training	61142	20.9	.3	(9)	(9)	(9)	.2
Professional and management development training	61143	44.2	.8	.3	.3	(11)	.4
Technical and trade schools	6115	96.6	2.0	1.2	.7	.5	.8
Other schools and instruction	6116	220.7	–	.6	.5	.2	–
Fine arts schools	61161	57.2	.5	.4	.3	.1	.1
Sports and recreation instruction	61162	54.7	–	.6	.3	.3	–
Language schools	61163	14.9	.9	.3	.2	(9)	.7
All other schools and instruction	61169	94.0	1.2	.8	.7	.1	.4
Health care and social assistance	62	13,721.9	6.5	3.1	1.7	1.4	3.3
Ambulatory health care services	621	4,783.4	3.3	1.2	.8	.4	2.1
Offices of physicians	6211	2,006.6	2.5	.6	.4	.2	1.9
Offices of dentists	6212	744.2	1.7	.3	.3	.1	1.4
Offices of other health practitioners	6213	505.7	–	–	–	.3	.5
Outpatient care centers	6214	428.0	4.8	1.5	–	.5	3.3
Medical and diagnostic laboratories	6215	179.7	3.0	1.1	.7	.5	1.9
Home health care services	6216	723.6	5.9	3.3	2.4	1.0	2.6
Other ambulatory health care services	6219	195.5	9.4	4.4	2.8	–	4.9
Hospitals	622	4,201.3	8.7	3.6	2.0	1.6	5.1
Nursing and residential care facilities	623	2,776.5	10.1	6.3	3.2	3.1	3.9
Social assistance	624	1,960.7	4.1	2.3	1.4	.9	1.8
Leisure and hospitality		12,162.2	5.1	2.1	1.3	.8	3.0
Arts, entertainment, and recreation	71	1,816.9	5.9	2.9	1.6	1.4	3.0
Performing arts, spectator sports, and related industries	711	383.3	6.7	2.6	1.6	1.0	4.1
Performing arts companies	7111	120.0	6.0	1.9	1.4	.5	4.1
Spectator sports	7112	131.0	–	4.5	2.5	2.0	–
Promoters of performing arts, sports, and similar events	7113	72.8	6.1	1.7	1.4	.3	4.4
Independent artists, writers, and performers	7115	44.0	3.2	1.0	.6	.5	2.2
Museums, historical sites, and similar institutions	712	115.4	4.2	2.2	1.6	.6	2.0
Amusement, gambling, and recreation industries	713	1,318.2	5.8	3.1	1.5	1.6	2.7

See footnotes at end of table.

TABLE 1. **Incidence rates[1] of nonfatal occupational injuries and illnesses by industry and case types, 2003** — Continued

Industry[2]	NAICS code[3]	2003 Annual average employment[4] (thousands)	Total recordable cases	Cases with days away from work, job transfer, or restriction: Total	Cases with days away from work[5]	Cases with job transfer or restriction	Other recordable cases
Amusement parks and arcades	7131	152.9	12.2	8.6	2.5	6.2	3.6
Gambling industries	7132	130.9	5.7	3.8	1.6	2.2	2.0
Other amusement and recreation industries	7139	1,034.5	4.8	2.1	1.4	.7	2.7
Accommodation and food services	72	10,345.3	5.0	2.0	1.3	.7	3.0
Accommodation	721	1,768.0	6.7	3.6	1.9	1.6	3.2
Traveler accommodation	7211	1,705.9	6.7	3.5	1.9	1.7	3.1
Hotels (except casino hotels) and motels	72111	1,402.4	6.8	3.6	2.0	1.6	3.2
Casino hotels	72112	277.3	6.4	3.3	–	2.0	3.2
Other traveler accommodation	72119	26.2	3.1	2.5	2.4	([9])	.7
RV (recreational vehicle) parks and recreational camps	7212	50.5	–	–	4.0	1.2	4.1
Rooming and boarding houses	7213	11.7	1.6	.8	.6	–	.9
Food services and drinking places	722	8,577.3	4.6	1.6	1.1	.5	3.0
Full-service restaurants	7221	4,072.1	4.5	1.4	1.0	.4	3.1
Limited-service eating places	7222	3,612.2	4.9	1.8	1.3	.6	3.1
Drinking places (alcoholic beverages)	7224	375.9	–	–	–	.2	–
Other services		3,777.7	3.4	1.7	1.1	.6	1.7
Other services, except public administration	81	3,777.7	3.4	1.7	1.1	.6	1.7
Repair and maintenance	811	1,224.3	4.2	2.1	1.4	.7	2.1
Automotive repair and maintenance	8111	889.7	4.3	2.1	1.4	.7	2.2
Electronic and precision equipment repair and maintenance	8112	101.0	2.2	1.2	1.0	.2	1.0
Commercial and industrial machinery and equipment (except automotive and electronic) repair and maintenance	8113	153.5	5.1	2.4	1.7	.7	2.8
Personal and household goods repair and maintenance	8114	80.1	4.8	3.3	2.1	1.2	1.5
Personal and laundry services	812	1,258.9	2.8	1.7	.9	.7	1.2
Personal care services	8121	543.4	.9	.4	.3	.1	.5
Death care services	8122	138.4	2.9	1.7	1.2	.5	1.2
Drycleaning and laundry services	8123	355.7	4.9	3.1	1.5	1.6	1.8

See footnotes at end of table.

TABLE 1. **Incidence rates[1] of nonfatal occupational injuries and illnesses by industry and case types, 2003** — *Continued*

Industry[2]	NAICS code[3]	2003 Annual average employment[4] (thousands)	Total recordable cases	Cases with days away from work, job transfer, or restriction			Other recordable cases
				Total	Cases with days away from work[5]	Cases with job transfer or restriction	
Other personal services	8129	221.4	3.6	2.0	1.3	0.7	1.6
Religious, grantmaking, civic, professional, and similar organizations	813	1,294.5	2.9	1.3	.9	.4	1.6

[1] The incidence rates represent the number of injuries and illnesses per 100 full-time workers and were calculated as: (N/EH) x 200,000, where

N = number of injuries and illnesses
EH = total hours worked by all employees during the calendar year
200,000 = base for 100 equivalent full-time workers (working 40 hours per week, 50 weeks per year)

[2] Totals include data for industries not shown separately.
[3] *North American Industry Classification System* — United States, 2002
[4] Employment is expressed as an annual average and is derived primarily from the BLS-Quarterly Census of Employment and Wages (QCEW) program.
[5] Days-away-from-work cases include those that result in days away from work with or without job transfer or restriction.
[6] Excludes farms with fewer than 11 employees.
[7] Data for Mining (Sector 21 in the *North American Industry Classification System*— United States, 2002) include establishments not governed by the Mine Safety and Health Administration rules and reporting, such as those in Oil and Gas Extraction and related support activities. Data for mining operators in coal, metal, and nonmetal mining are provided to BLS by the Mine Safety and Health Administration, U.S. Department of Labor. Independent mining contractors are excluded from the coal, metal, and nonmetal mining industries. These data do not reflect the changes the Occupational Safety and Health Administration made to its recordkeeping requirements effective January 1, 2002; therefore, estimates for these industries are not comparable to estimates in other industries.
[8] Data for mining operators in this industry are provided to BLS by the Mine Safety and Health Administration, U.S. Department of Labor. Independent mining contractors are excluded. These data do not reflect the changes the Occupational Safety and Health Administration made to its recordkeeping requirements effective January 1, 2002; therefore, estimates for these industries are not comparable to estimates in other industries.
[9] Fewer than 15 cases.
[10] Data for employers in railroad transportation are provided to BLS by the Federal Railroad Administration, U.S. Department of Transportation. These data do not reflect the changes the Occupational Safety and Health Administration made to its recordkeeping requirements effective January 1, 2002; therefore, estimates for these industries are not comparable to estimates in other industries.
[11] Incidence rate less than 0.05.

NOTE: Because of rounding, components may not add to totals. Dash indicates data not available.
SOURCE: Bureau of Labor Statistics, U.S. Department of Labor

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Table 6. Incidence rates [1] of nonfatal occupational injuries and illnesses by industry and case types, 2003

Georgia

Industry[2]	NAICS code[3]	2003 Average annual employment[4] (000's)	Total recordable cases	Cases with days away from work, job transfer, or restriction			Other recordable cases
				Total	Cases with days away from work[5]	Cases with job transfer or restriction	
Private industry[6]		3,139.4	4.3	2.1	1.1	1.1	2.2
Goods producing[6]		676.4	5.4	2.8	1.2	1.6	2.6
Natural resources and mining[6,7]		30.6	4.5	2.2	1.0	1.3	2.3
Agriculture, forestry, fishing and hunting[6]	11	23.4	5.4	2.6	1.1	1.4	2.9
Crop production[6]	111	8.8	7.0	2.8	1.7	1.1	4.2
Support activities for agriculture and forestry	115	4.5	3.0	1.1	0.9	(11)	1.9
Mining[7]	21	7.1	2.2	1.4	0.6	0.9	0.8
Construction		196.1	5.0	2.6	1.6	1.0	2.4
Construction	23	196.1	5.0	2.6	1.6	1.0	2.4
Construction of buildings	236	44.0	3.9	2.5	1.5	–	1.4
Residential building construction	2361	19.8	2.5	1.5	1.4	0.1	0.9
Nonresidential building construction	2362	24.1	–	–	–	–	–
Heavy and civil engineering construction	237	31.3	5.7	3.0	1.7	1.3	2.6
Utility system construction	2371	15.0	4.9	2.8	1.9	0.9	2.1
Highway, street, and bridge construction	2373	10.2	8.3	4.3	1.5	2.7	4.0
Other heavy and civil engineering construction	2379	2.6	3.5	2.4	2.4	(11)	1.1
Specialty trade contractors	238	120.8	5.2	2.6	1.7	0.9	2.6
Foundation, structure, and building exterior contractors	2381	23.0	5.1	2.6	1.5	1.1	2.5
Building equipment contractors	2382	58.9	5.4	2.2	1.5	0.7	3.2
Electrical contractors	23821	27.8	5.3	2.1	1.6	0.5	3.2
Plumbing, heating, and air-conditioning contractors	23822	26.8	5.8	2.5	1.5	1.0	3.3
Other building equipment contractors	23829	4.3	4.1	1.8	1.4	0.4	2.4
Building finishing contractors	2383	20.0	3.9	2.8	1.7	1.1	1.1
Other specialty trade contractors	2389	18.9	6.0	3.4	2.5	0.9	2.6
Manufacturing		449.7	5.7	2.9	1.0	1.9	2.7

See footnotes at end of table.

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Table 6. Incidence rates [1] of nonfatal occupational injuries and illnesses by industry and case types, 2003 – Continued

Georgia

Industry[2]	NAICS code[3]	2003 Average annual employment[4] (000's)	Total recordable cases	Cases with days away from work, job transfer, or restriction: Total	Cases with days away from work[5]	Cases with job transfer or restriction	Other recordable cases
Manufacturing	31-33	449.7	5.7	2.9	1.0	1.9	2.7
Food manufacturing	311	65.6	6.4	4.1	1.1	3.1	2.3
Animal slaughtering and processing	3116	37.1	7.5	4.5	0.9	3.6	3.0
Animal slaughtering and processing	31161	37.1	7.5	4.5	0.9	3.6	3.0
Poultry processing	311615	30.7	6.9	4.4	0.6	3.8	2.5
Bakeries and tortilla manufacturing	3118	10.4	5.6	4.0	2.5	1.5	1.6
Beverage and tobacco product manufacturing	312	6.0	6.9	2.9	1.7	1.2	4.0
Textile mills	313	37.9	4.4	1.9	0.3	1.7	2.5
Fiber, yarn, and thread mills	3131	15.4	5.0	2.6	0.2	2.3	2.5
Fiber, yarn, and thread mills	31311	15.4	5.0	2.6	0.2	2.3	2.5
Yarn spinning mills	313111	11.1	5.9	3.0	0.2	2.8	2.9
Fabric mills	3132	17.2	3.4	1.6	0.3	1.4	1.7
Broadwoven fabric mills	31321	13.9	3.5	1.7	0.3	1.4	1.8
Textile and fabric finishing and fabric coating mills	3133	5.4	6.0	1.1	0.4	0.6	4.9
Textile product mills	314	38.6	4.1	2.1	0.4	1.7	2.0
Textile furnishings mills	3141	34.5	4.0	1.9	0.3	1.6	2.1
Carpet and rug mills	31411	31.2	3.9	1.8	0.2	1.6	2.2
Curtain and linen mills	31412	3.3	4.9	3.4	1.5	1.9	1.5
Other textile product mills	3149	4.1	5.6	4.3	1.1	3.2	1.3
Apparel manufacturing	315	9.1	4.5	3.3	0.9	2.4	1.2
Cut and sew apparel manufacturing	3152	8.3	4.8	3.5	1.0	2.5	1.3
Wood product manufacturing	321	23.3	7.1	3.9	2.1	1.8	3.3
Sawmills and wood preservation	3211	5.7	5.1	2.8	1.7	1.1	2.3
Veneer, plywood, and engineered wood product manufacturing	3212	5.7	3.4	1.5	1.1	0.4	1.9
Other wood product manufacturing	3219	11.8	10.3	5.7	2.7	3.0	4.6
Paper manufacturing	322	24.6	3.2	1.8	0.9	0.9	1.4
Pulp, paper, and paperboard mills	3221	9.5	2.9	1.8	1.0	0.8	1.1
Paper mills	32212	4.8	3.6	2.6	1.7	1.0	1.0
Converted paper product manufacturing	3222	15.1	3.4	1.7	0.9	0.9	1.6
Printing and related support activities	323	21.1	3.4	1.1	0.7	0.4	2.2
Printing and related support activities	3231	21.1	3.4	1.1	0.7	0.4	2.2
Printing	32311	18.3	2.9	1.2	0.8	0.4	1.7
Commercial lithographic printing	323110	6.5	2.7	1.1	0.8	–	1.6
Chemical manufacturing	325	21.5	3.2	1.5	0.7	0.8	1.7
Plastics and rubber products manufacturing	326	24.0	7.1	4.7	1.8	2.9	2.4

See footnotes at end of table.

Table 6. Incidence rates [1] of nonfatal occupational injuries and illnesses by industry and case types, 2003 – Continued

Georgia

Industry[2]	NAICS code[3]	2003 Average annual employment[4] (000's)	Total recordable cases	Cases with days away from work, job transfer, or restriction: Total	Cases with days away from work [5]	Cases with job transfer or restriction [6]	Other recordable cases
Plastics product manufacturing	3261	18.1	6.5	4.7	1.6	3.1	1.9
Rubber product manufacturing	3262	6.0	8.9	5.0	2.6	2.4	3.9
Nonmetallic mineral product manufacturing	327	18.7	6.8	3.8	2.0	1.8	3.0
Primary metal manufacturing	331	7.9	6.2	3.1	0.7	2.4	3.1
Nonferrous metal (except aluminum) production and processing	3314	2.2	6.8	5.4	1.0	4.4	1.3
Fabricated metal product manufacturing	332	25.7	8.5	3.6	1.7	1.8	4.9
Architectural and structural metals manufacturing	3323	10.5	5.2	2.6	1.6	1.0	2.6
Machinery manufacturing	333	23.3	8.2	2.9	1.2	1.7	5.2
Computer and electronic product manufacturing	334	14.0	2.5	1.0	0.4	0.6	1.5
Electrical equipment, appliance, and component manufacturing	335	16.6	5.0	3.1	0.5	2.6	1.9
Transportation equipment manufacturing	336	41.7	6.6	3.4	0.9	2.5	3.3
Motor vehicle manufacturing	3361	5.0	15.7	9.9	1.9	8.0	5.9
Aerospace product and parts manufacturing	3364	16.4	3.1	1.5	0.4	1.1	1.5
Aerospace product and parts manufacturing	33641	16.4	3.1	1.5	0.4	1.1	1.5
Furniture and related product manufacturing	337	14.1	6.9	3.4	1.3	2.1	3.5
Miscellaneous manufacturing	339	14.4	5.7	2.1	0.6	1.5	3.6
Service providing		2,459.9	4.0	1.9	1.0	0.9	2.1
Trade, transportation, and utilities[8]		818.1	4.9	2.7	1.3	1.4	2.2
Wholesale trade	42	205.2	3.9	2.3	1.0	1.4	1.5
Merchant wholesalers, durable goods	423	108.5	3.5	1.9	0.9	1.0	1.6
Motor vehicle and motor vehicle parts and supplies merchant wholesalers	4231	10.5	5.0	2.1	0.7	1.4	2.9
Lumber and other construction materials merchant wholesalers	4233	10.6	7.1	4.1	1.6	2.5	3.0
Professional and commercial equipment and supplies merchant wholesalers	4234	28.7	1.1	0.6	0.2	0.3	0.5
Electrical goods merchant wholesalers	4236	12.2	1.3	0.9	0.3	0.6	0.4
Machinery, equipment, and supplies merchant wholesalers	4238	21.5	2.5	1.6	1.2	0.4	0.9
Merchant wholesalers, nondurable goods	424	59.3	5.5	4.0	1.3	2.6	1.5
Grocery and related product merchant wholesalers	4244	20.5	7.1	6.1	1.5	4.5	1.1
Miscellaneous nondurable goods merchant wholesalers	4249	9.4	5.3	3.0	2.4	0.6	2.3
Wholesale electronic markets and agents and brokers	425	37.5	2.4	1.2	0.6	0.6	1.3
Retail trade	44-45	445.0	4.7	2.2	1.1	1.0	2.6
Motor vehicle and parts dealers	441	59.9	5.0	1.5	0.9	0.6	3.5

See footnotes at end of table.

Table 6. Incidence rates [1] of nonfatal occupational injuries and illnesses by industry and case types, 2003 -- Continued

Georgia

Industry[2]	NAICS code[3]	2003 Average annual employment[4] (000's)	Total recordable cases	Cases with days away from work, job transfer, or restriction: Total	Cases with days away from work[5]	Cases with job transfer or restriction	Other recordable cases
Automobile dealers	4411	39.7	5.4	1.4	0.9	0.5	4.0
Furniture and home furnishings stores	442	18.8	5.1	2.0	1.2	0.8	3.1
Electronics and appliance stores	443	13.4	3.2	0.5	0.4	0.2	2.6
Building material and garden equipment and supplies dealers	444	39.1	5.0	2.4	1.1	1.3	2.5
Building material and supplies dealers	4441	34.5	5.4	2.7	1.3	1.4	2.7
Home centers	44411	19.5	6.9	3.4	1.6	1.8	3.5
Other building material dealers	44419	9.6	4.2	1.9	0.9	1.0	2.3
Food and beverage stores	445	79.8	6.0	3.0	1.9	1.2	3.0
Grocery stores	4451	70.4	6.3	3.2	2.0	1.2	3.2
Health and personal care stores	446	25.9	1.9	0.6	0.3	0.3	1.3
Gasoline stations	447	28.4	3.2	1.2	1.2	(")	2.0
Clothing and clothing accessories stores	448	40.1	3.3	1.1	0.7	0.4	2.2
Sporting goods, hobby, book, and music stores	451	16.1	3.4	1.1	0.5	0.6	2.3
General merchandise stores	452	88.4	5.6	3.1	1.4	1.8	2.5
Department stores	4521	75.2	5.4	3.1	1.3	1.8	2.3
Other general merchandise stores	4529	13.1	6.9	2.9	1.7	1.2	4.0
Transportation and warehousing[9]	48-49	147.5	6.8	4.6	2.3	2.4	2.1
Air transportation	481	38.7	7.2	5.3	2.7	2.5	1.9
Scheduled air transportation	4811	38.0	7.2	5.3	2.8	2.6	1.9
Rail transportation[9]	482	--	2.1	1.6	1.6	(")	0.4
Truck transportation	484	46.0	6.3	4.6	2.5	2.1	1.8
Support activities for transportation	488	15.9	4.5	2.3	1.3	0.9	2.3
Couriers and messengers	492	18.9	9.3	6.6	3.6	3.0	2.7
Warehousing and storage	493	22.6	7.9	5.2	1.0	4.2	2.8
Utilities	22	20.4	4.4	1.5	0.9	0.6	2.9
Utilities	221	20.4	4.4	1.5	0.9	0.6	2.9
Electric power generation, transmission and distribution	2211	17.9	4.5	1.5	0.9	0.7	3.0
Information		122.5	2.0	0.7	0.4	0.3	1.3
Information	51	122.5	2.0	0.7	0.4	0.3	1.3
Newspaper publishers	51111	13.4	3.3	1.8	0.6	1.3	1.5

See footnotes at end of table.

Table 6. Incidence rates [1] of nonfatal occupational injuries and illnesses by industry and case types, 2003 – Continued

Georgia

Industry[2]	NAICS code[3]	2003 Average annual employment[4] (000's)	Total recordable cases	Cases with days away from work, job transfer, or restriction: Total	Cases with days away from work[5]	Cases with job transfer or restriction	Other recordable cases
Telecommunications	517	51.4	2.0	0.9	0.5	0.4	1.1
Financial activities		212.2	1.5	0.7	0.4	0.2	0.9
Finance and insurance	52	153.7	0.8	0.3	0.2	0.1	0.6
Credit intermediation and related activities	522	77.7	1.0	0.3	0.3	([10])	0.7
Real estate and rental and leasing	53	58.4	3.4	1.8	1.1	0.7	1.6
Real estate	531	36.8	2.7	1.6	1.1	0.6	1.1
Rental and leasing services	532	20.6	4.9	2.1	1.2	0.9	2.8
Automotive equipment rental and leasing	5321	7.4	–	1.7	1.4	0.3	–
Professional and business services		491.3	2.6	1.4	0.8	0.6	1.1
Professional, scientific, and technical services	54	193.6	1.2	0.6	0.4	0.2	0.6
Management of companies and enterprises	55	51.7	2.9	1.3	0.5	0.8	1.7
Administrative and support and waste management and remediation services	56	246.0	3.7	2.2	1.2	1.0	1.5
Administrative and support services	561	238.1	3.5	2.1	1.1	–	1.4
Waste management and remediation services	562	7.8	7.8	3.9	2.2	1.7	3.8
Education and health services		377.4	5.6	2.2	1.3	1.0	3.4
Educational services	61	50.9	2.5	0.8	0.7	0.1	1.8
Health care and social assistance	62	326.5	6.1	2.4	1.4	1.1	3.7
Ambulatory health care services	621	121.6	2.3	0.8	0.7	0.1	1.5
Hospitals	622	109.6	9.3	3.3	1.5	1.9	5.9
Nursing and residential care facilities	623	48.9	10.2	5.4	2.9	2.4	4.8
Social assistance	624	46.4	4.0	1.4	1.1	0.4	2.5
Leisure and hospitality		348.6	4.9	1.7	1.1	0.6	3.2

See footnotes at end of table.

Table 6. Incidence rates [1] of nonfatal occupational injuries and illnesses by industry and case types, 2003 – Continued

Georgia

Industry[2]	NAICS code[3]	2003 Average annual employment[4] (000's)	Total recordable cases	Cases with days away from work, job transfer, or restriction: Total	Cases with days away from work[5]	Cases with job transfer or restriction	Other recordable cases
Arts, entertainment, and recreation	71	36.8	4.4	1.5	0.8	0.6	3.0
Performing arts, spectator sports, and related industries	711	8.1	2.5	0.6	0.4	([11])	1.8
Amusement, gambling, and recreation industries	713	26.7	5.1	1.9	1.0	0.8	3.3
Accommodation and food services	72	311.8	4.9	1.7	1.2	0.5	3.2
Accommodation	721	40.4	5.5	2.2	1.0	1.2	3.3
Traveler accommodation	7211	39.8	5.5	2.2	1.0	1.2	3.3
Food services and drinking places	722	271.4	4.8	1.6	1.2	0.4	3.2
Other services		92.9	3.4	1.6	0.9	0.7	1.8
Other services, except public administration	81	92.9	3.4	1.6	0.9	0.7	1.8
Repair and maintenance	811	35.8	4.4	2.3	1.2	1.0	2.1

See footnotes at end of table.

Table 6. Incidence rates [1] of nonfatal occupational injuries and illnesses by industry and case types, 2003 – Continued

Georgia

Industry[2]	NAICS code[3]	2003 Average annual employment[4] (000's)	Total recordable cases	Cases with days away from work, job transfer, or restriction: Total	Cases with days away from work[5]	Cases with job transfer or restriction	Other recordable cases
Automotive repair and maintenance	8111	26.5	4.9	2.6	1.3	1.2	2.4
Personal and laundry services	812	34.9	2.1	1.5	0.7	0.8	0.6
Religious, grantmaking, civic, professional, and similar organizations	813	22.3	3.5	0.6	0.6	([11])	2.9

[1] Incidence rates represent the number of injuries and illnesses per 100 full-time workers and were calculated as: (N/EH) x 200,000 where

N = number of injuries and illnesses
EH = total hours worked by all employees during the calendar year
200,000 = base for 100 equivalent full-time workers (working 40 hours per week, 50 weeks per year).

[2] Totals include data for industries not shown separately.
[3] *North American Industry Classification System* Manual, 2002 Edition
[4] Employment is expressed as an annual average and is derived primarily from the BLS-State Quarterly Census of Employment and Wages.
[5] Days-away-from-work cases include those that result in days away from work with or without job transfer or restriction.
[6] Excludes farms with fewer than 11 employees.
[7] Data for mining (Sector 21 in the North American Industry Classification System -- United States, 2002) include establishments not governed by the Mine Safety and Health Administration (MSHA) rules and reporting, such as those in oil and gas extraction and related support activities. Data for mining operators in coal, metal, and nonmetal mining are provided to BLS by the Mine Safety and Health Administration, U.S. Department of Labor. Independent mining contractors are excluded from the coal, metal, and nonmetal mining industries. These data do not reflect the changes the Occupational Safety and Health Administration made to its recordkeeping requirements effective January 1, 2002; therefore estimates for these industries are not comparable to estimates in other industries.
[8] Data for mining operators in this industry are provided to BLS by the Mine Safety and Health Administration, U.S. Department of Labor. Independent mining contractors are excluded. These data do not reflect the changes the Occupational Safety and Health Administration made to its recordkeeping requirements effective January 1, 2002; therefore estimates for these industries are not comparable to estimates in other industries.
[9] Data for employers in rail transportation are provided to BLS by the Federal Railroad Administration, U.S. Department of Transportation. These data do not reflect the changes the Occupational Safety and Health Administration made to its recordkeeping requirements effective January 1, 2002; therefore estimates for these industries are not comparable to estimates in other industries.
[10] Incidence rate less than 0.05.
[11] Fewer than 15 cases.

NOTE: Because of rounding, components may not add to totals.
– Indicates data not available.

SOURCE: Bureau of Labor Statistics, U.S. Department of Labor, Survey of Occupational Injuries and Illnesses, in cooperation with participating State agencies.
- Reissued June 2005. For information see http://www.bls.gov/iif/osh_notice05.htm