CHAPTER 2

RISK ANALYSIS OF ROUTINE TRANSPORTATION

2.1 Introduction

NUREG-0170 (NRC, 1977) was the first comprehensive assessment of the environmental and health impact of transporting radioactive materials, and documented estimates of the radiological consequences and risks associated with the shipment by truck, train, plane, or barge of about 25 different radioactive materials, including power reactor spent fuel. However, little actual data on spent nuclear fuel transportation was available in 1977 and computational modeling of such transportation accidents and risks was primitive compared to today's capabilities.

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The RADTRAN computer code (Taylor and Daniel, 1977) is the computational tool used in this chapter to estimate risks from routine[1] transportation of spent nuclear fuel. RADTRAN was initially developed by NRC for the NUREG-0170 risk assessment. During the past several decades, the calculation method and RADTRAN code have been improved to stay current with computer technology, and supporting input data have been collected and organized. The basic RADTRAN analysis approach has not changed since the original development of the code, and the risk assessment method employed in the RADTRAN code is accepted worldwide; about 25 percent of the five hundred RADTRAN users are international.[2]

RADTRAN 6.0, integrated with the input file generator RADCAT, (Neuhauser et al., 2000;[3] Weiner et al., 2009) is the version used in this study. The incident-free module of RADTRAN, the model used for the analysis in this chapter, was validated by measurement (Steinman et al., 2002), and verification and validation of RADTRAN 6.0 are documented in Dennis, et al. (2008).

This chapter discusses the risks to the public and workers when transportation of the casks containing spent fuel takes place without incident, and the transported casks are undamaged. Non-radiological vehicular accident risk, which is orders of magnitude larger than the radiological transportation risk, is not analyzed in this study[4]. The risks and consequences of accidents and incidents interfering with routine transportation are discussed in Chapter 5.

This chapter includes the following:

- A brief discussion of ionizing radiation emitted during transportation.
- A description of the RADTRAN model of routine transportation.
- Radiation doses from a single routine shipment to:

[1] The term "routine transportation" is used throughout this document to mean incident or accident-free transportation
[2] The currently registered RADTRAN users are listed on a restricted-access web site at Sandia National Laboratories.
[3] Neuhauser, et al (2000) is the technical manual for RADTRAN 5, and is cited because the basic equations for the incident-free analyses in RADTRAN 6 are the same as those in RADTRAN 5. The technical manual for RADTRAN 6 is not yet available.
[4] Non-radiological vehicular risks are not compared to radiological risks because the radiological risks are expressed as doses rather than health effects.

- Members of the public who live along the transportation route and near stops
- Occupants of vehicles that share the route with the radioactive shipment
- Various groups of people at stops
- Workers

Detailed results of the RADTRAN calculations for this analysis are provided in Appendix II. A discussion of RADTRAN use and applications are provided in Weiner, et al (2009).

2.2 Radiation Emitted during Routine Transportation

The RADTRAN model for calculating radiation doses is based on the well-understood behavior of ionizing radiation. Like all radiation, ionizing radiation moves in straight lines. It can be absorbed by various materials, including air. Absorption of ionizing radiation depends on the energy and type of radiation and on the absorbing material.

Spent nuclear fuel, the subject of this analysis, is extremely radioactive, emitting ionizing radiation in the form of alpha, beta, gamma, and neutron radiation. The casks that are used to transport spent nuclear fuel have exceedingly thick walls that absorb most of the emitted ionizing radiation and thereby shield the public and the workers. Figure 2-1 shows two generic cask diagrams on which the shielding is identified.

Comment [MF1]: Remind readers that the calculations are for 3 actual cask designs and Fig. 2-1 shows a typical cross section.

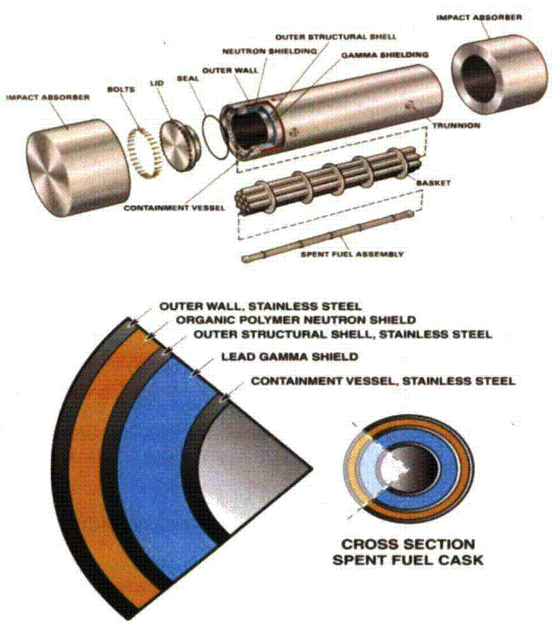

Figure 2-1. The upper sketch is an exploded view of a generic spent fuel cask. The lower sketch is a cross-section of the layers of the cask wall. (Sandia National Laboratories archive)

Alpha and beta radiation cannot penetrate the walls of the casks (both are actually absorbed well by a few millimeters of paper or plastic). The steel and lead (if present) layers of the cask wall absorb most of the gamma and a smaller portion of the neutron radiation emitted by spent fuel, although adequate neutron shielding also requires a layer of a neutron absorber like a polymer or boron compound. In certifying spent fuel casks, the NRC allows escape of gamma and neutron radiation from the cask at a very low dose rate. For spent uranium-based fuel, the emitted dose rate is almost entirely due to gamma radiation while outside the cask, the neutron and gamma radiation doses are typically comparable to each other.

Absorbed radiation dose is measured in sieverts (Sv) in the Standard International system. The average background radiation dose to an individual in the United States from naturally occurring and some medical sources is 0.0036 Sv per year (Shleien et al., 1998, Figure 1.1),[5] a single dental x-ray delivers a dose of 4 x 10^{-5} Sv, and a single mammogram delivers 1.3 x 10^{-4} Sv (Stabin, 2009). The average radiation dose rate from a spent fuel cask allowed by regulation is 0.1 mSv per hour (or ~75% of a single mammogram), measured at two meters from the outside of the cask (10 CFR71.47(b)(3)), or about 0.14 mSv/hour at one meter from a cask four to five meters long.

The external radiation doses from the casks in this study (Figures 1-2 to 1-4) at one meter from the cask, as reported in the cask Safety Analysis Reports, are shown in Table 2-1. Measured values for the Rail-Steel and Truck-DU cask were not available, but it was assumed to meet the NRC standard of 10 CFR Part 71 (Holtec, 2004; NAC, 2004, General Atomics, 1998).

Table 2-1. External radiation doses from the casks in this study

	Truck-DU	Rail-Lead	Rail-Steel
Transportation mode	Highway	Rail	Rail
Dose rate Sv/hr at 1 m	0.00014	0.00014	0.000103
Gamma fraction	0.77	0.89	0.90
Neutron fraction	0.23	0.11	0.10

The calculated radiation dose to workers and members of the public from a routine shipment is based on the external dose rate at one meter from the spent fuel cask, as shown in Figure 2-2. This dose rate, when expressed in mSv per hour multiplied by 100, is called the transport index, or TI. Although the radioactive content of the spent fuel in the cask determines the shielding needed to meet the regulated external dose rate, it does not enter into the calculation of doses from routine transportation. Doses from the external radiation from the cask depend on the external dose rate (TI), the distance of the receptor from the cask, and on the exposure time.

[5] Recent increased diagnostic use of ionizing radiation, as in computerized tomography, has suggested increasing the average background to 0.006Sv (600 mrem).

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Comment [s2]: Sentence implies there is an "unallowed" dose rate - I suggest changing "allowed dose rate" to "dose rate from a cask". Also, "almost entirely due to gamma"? Table 2-1 shows a 23% fraction of neutrons for the truck cask and we know there is a higher proportion of dose from neutron as the burnup increases. Why is this statement necessary? Is there some deficiency in how neutrons are handled in report? At least I would suggest: "majority of the dose rate from a cask is due to gamma radiation." And if RADTRAN does not use the splits and assumes the dose is all gamma, then that should be stated – but that is not the inference from Appendix V. (CParks)

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2.3. The RADTRAN Model of Routine, Incident-Free Transportation

2.3.1 The Basic RADTRAN Model

For analysis of routine transportation, RADTRAN models the cask as a sphere with a radiation source at its center, and assumes that the dimensions of the trailer or railcar carrying the cask are the same as the cask dimensions. The emission rate of the radiation source is based on the dose rate at one meter from the cask, which NRC identifies as the transport index (TI). The TI is modeled as a virtual source at the center of the sphere. The diameter of this spherical model, called the "critical dimension," is the longest dimension of the actual spent fuel cask.

Comment [h15]: Is this an important assumption?

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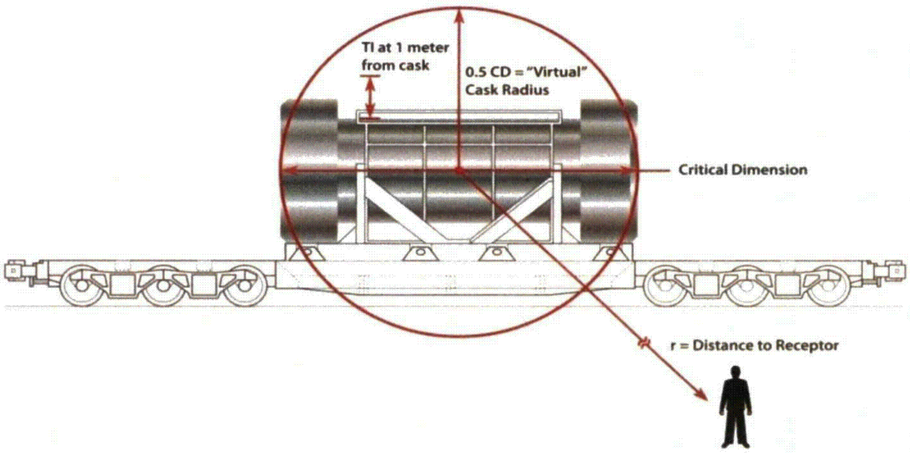

Figure 2-2. RADTRAN model of the vehicle in routine, incident-free transportation. The cask in this diagram is positioned horizontally, and the critical dimension is the cask length.

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When the distance to the receptor (*r* in Figure 2-2) is much larger than the critical dimension, RADTRAN models the dose to the receptor as proportional to $1/r^2$. When the distance to the receptor *r* is similar to or less than the critical dimension, as for crew or first responders, RADTRAN models the dose to the receptor as proportional to $1/r$. The dose calculated by the RADTRAN spherical model overestimates the measured dose by a few percent (Steinman et al., 2002).

2.3.2 Individual and Collective Doses

The dose to workers and the public from a cask during routine transportation depends on the time that the workers or public are exposed to the cask, their distance from the cask, and the cask's external radiation field. When the vehicle carrying the cask is traveling along the route, the faster the vehicle goes, the less dose anyone along the vehicle's route receives. Therefore, an individual member of the public gets the largest dose from a moving vehicle when he or she is as close as possible to the vehicle, and the vehicle is traveling as slowly as possible. For trucks and trains carrying spent fuel, a speed of 24 km per hour (kph) and distance of 30 meters (about 100 feet) are assumed for maximum exposure.[6] Table 2-1 shows the dose to an individual member of the public under these conditions. These doses are on the same order as one minute of average background: 6.9 x 10^{-9} Sv.

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[6] Thirty meters is typically as close as a person on the side of the road can get to a vehicle traveling on an interstate highway.

Table 2-1. Maximum individual in-transit doses

Package	Dose
Rail-Lead	5.7E-09 Sv
Rail-Steel	4.3E-09 Sv
Truck-DU	6.7E-09 Sv

Comment [s17]: There are two tables marked Table 2-1 – one on p. 16 and one on p. 18. The text referencing the tables needs to be corrected per change. (CParks)

Comment [MF18]: This is the second Table 2-1.

When a vehicle carrying a spent fuel cask travels along a route, the people who live along that route and the people in vehicles that share the route are exposed to the external radiation from the cask. Doses to groups of people are collective doses; the units of collective dose are person-Sv. A collective dose, sometimes called a population dose, is essentially an average individual dose multiplied by the number of people exposed.[7] As shown in Figure 2-3, RADTRAN calculates collective doses along transportation routes by integrating over the width of a band along the route where the population resides (the *r* in Figure 2-2) and then integrating along the route. Collective doses to people on both sides of the route are included. The exposed population is in a band 770 meters (about a half mile) on either side of the route: from 30 meters (100 feet) from the center of the route to 800 meters.

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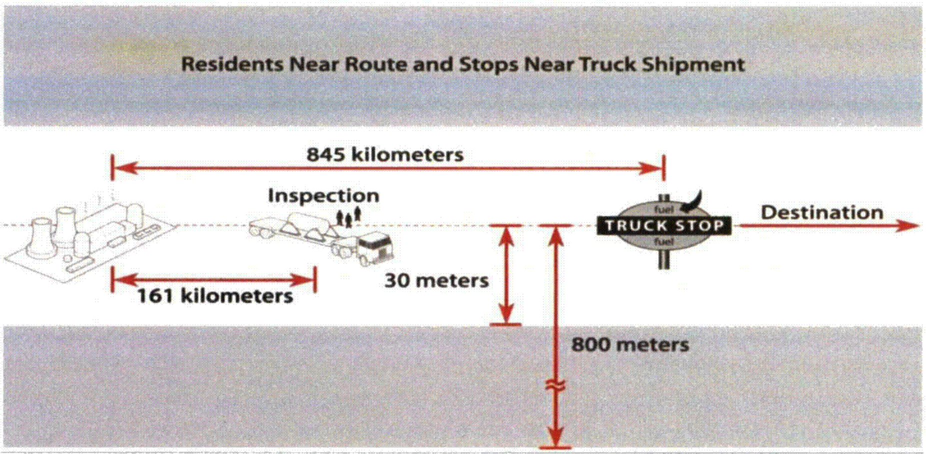

Figure 2-3. Diagram of a truck route as modeled in RADTRAN (not to scale)

Occupants of vehicles that share the route with the radioactive shipment also receive a radiation dose from the spent fuel cask. The collective dose to occupants depends on the average number of occupants per vehicle and the number of vehicles per hour that pass the radioactive shipment in both directions.

Any route can be divided into as many sections as desired for dose calculation; e.g., the dose to residents of a single house or city block. However, as a practical matter, routes are divided into rural, suburban, and urban segments according to the population per square mile (population

[7] A detailed discussion of collective dose is in Appendix II.

density). Table 2-2 summarizes the characteristics of each population type that are part of the dose calculation by RADTRAN. References for these parameter values are in the Table 2-2 footnotes.

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Table 2-2. Characteristics of rural, suburban, and urban routes used in RADTRAN

	Highway			Rail		
	Rural	**Suburban**	**Urban**	**Rural**	**Suburban**	**Urban**
Population density per km^2 (per mi^2)[a]	0 to 54 (0 to 139)	54 to 1286 (139 to 3326)	>1286 (>3326)	0 to 54 (0 to 139)	54 to 1286 (139 to 3326)	>1286 (>3326)
Nonresident/ resident ratio[b]	NA	NA	6	NA	NA	6
Shielding by buildings[b]	0	13%	98.2%	0	13%	98.2%
U.S. average vehicle speed[c] kph (mph)[c,d]	108 (67)	108 (67)	101(63)	40 (27)	40 (27)	24 (15)
U.S . average vehicles per	1119	2464	5384	17	17	17
Occupants of other vehicles[e], [g]	1.5	1.5	1.5	1	1	5

[a]Johnson and Michelhaugh, 2003, . [b]Weiner, et al. 2009, [c]DOT, 2004a, . [d]DOT,2004b, [e] Weiner, et al. 2009, Appendix D, [f]DOT, 2009; these are average railcars per hour, [g]DOT, 2008, Table 1-11.

Each route clearly has a distribution of rural, urban and suburban areas, as shown by the example of the truck route in Figure 2-4.

Comment [MF20]: Suggest adding a column to show where values come from. That is, the population density is calculated using TRAGIS, the nonresident/resident ration is only for urban areas, the shielding by buildings is from historic RADTRAN use, the occupants of other vehicles is from engineering judgment.

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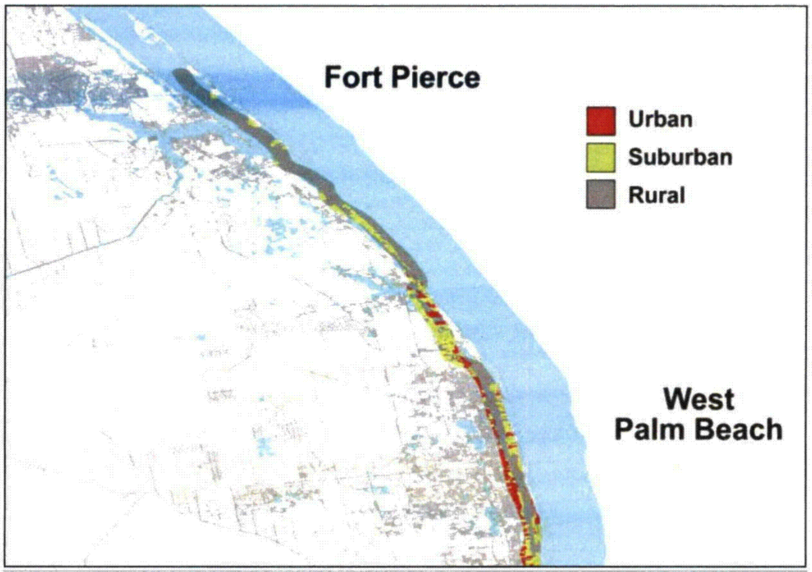

Figure 2-4. A segment of U.S.1/1A along the Florida coast. The gray band indicating a rural route is actually located on the western (land) side of the Intracoastal Waterway. (courtesy of G. Scott Mills)

Figure 2-4 shows a segment of highway U.S. 1 along the Florida coast and Intracoastal Waterway from West Palm Beach to Fort Pierce. The broad stripe along the coastline of the Intracoastal Waterway is the half-mile band on either side of the highway. The red areas represent urban populations, the yellow areas, suburban, and the gray areas, rural. Instead of analyzing each separate rural, urban, and suburban segment of this stretch of highway, each type of each is combined for RADTRAN dose calculations. The routing code TRAGIS (Johnson and Michelhaugh, 2003) provides these combinations for each state traversed by a particular route. Table 2-3 shows this TRAGIS output for a sample rail route from Kewaunee Nuclear Plant, WI to Oak Ridge National Laboratory in Tennessee.

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Table 2-3. Rail route segment lengths and population densities, Kewaunee NP to ORNL

State	Kilometers (miles)			Persons/km^2 (persons/mi^2)		
	Rural	Suburban	Urban	Rural	Suburban	Urban
Illinois	12 (7.5)	63 (39)	45 (28)	26 (67)	504 (1305)	2593 (6710)
Indiana	171 (106)	51 (32)	11 (6.6)	17 (44)	351 (909)	2310 (5977)
Kentucky	254 (158)	84 (52)	13 (7.8)	17(45)	312 (806)	2532 (6551)
Ohio	201 (125)	117 (73)	29 (18)	15 (38)	402 (1041)	2243 (5802)
Tennessee	56 (35)	23 (14)	1 (0.6)	17 (44)	330 (855)	2084 (5392)

Wisconsin	148 (92)	92 (57)	28 (17)	18 (46)	434 (1124)	2410 (6234)

The maps of Figures 2-5 through 2-8 show the sixteen truck and sixteen rail routes analyzed in this report. The maps are adapted from the output of the routing code TRAGIS (Johnson and Michelhaugh, 2003).

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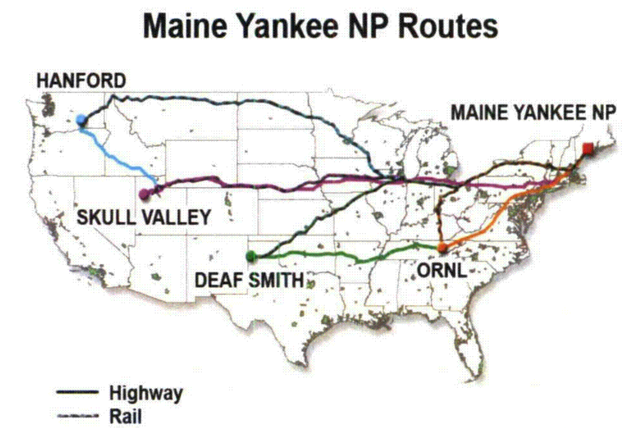

Figure 2-5. Highway and rail routes from Maine Yankee Nuclear Plant site.

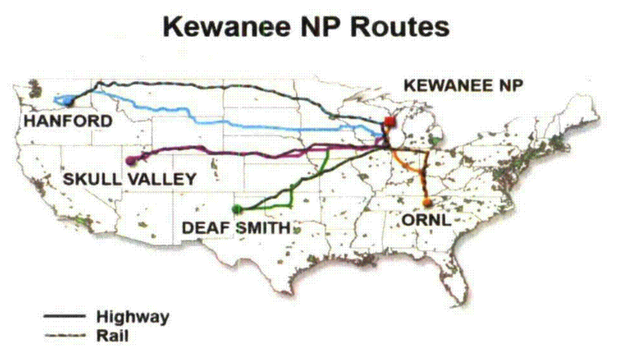

Figure 2-6. Highway and rail routes from Kewaunee Nuclear Plant.

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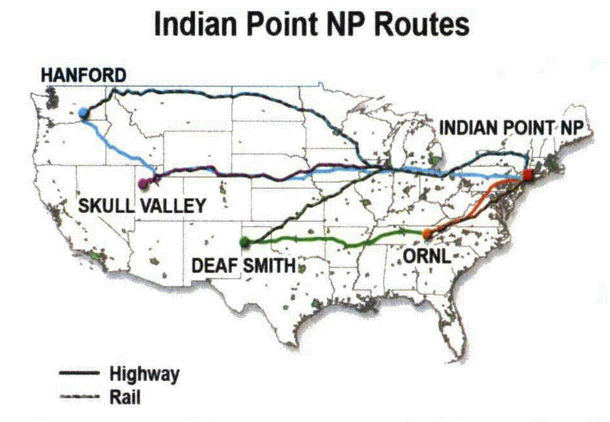

Figure 2-7. Highway and rail routes from Indian Point Nuclear Plant.

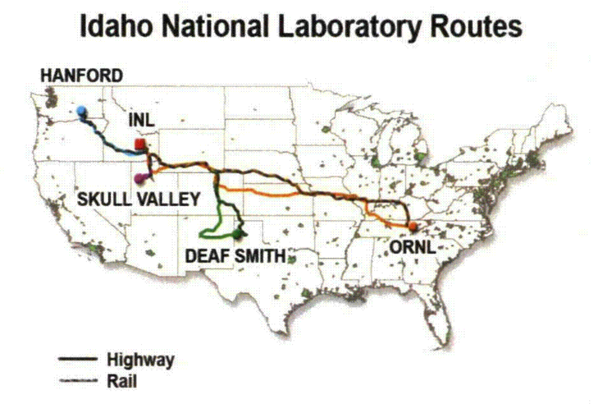

Figure 2-8. Highway and rail routes from Idaho National Laboratory.

The route segment lengths and population densities are entered into RADTRAN, which calculates the collective doses to residents along these route segments. Collective doses, which depend on route length and on the populations along the route, were calculated for one shipment over each of 32 routes. Collective doses are reported as person-Sv.

Comment [h26]: I thought there were 16 routes?

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The sites where the shipments originated include two nuclear generating plants (Indian Point and Kewaunee), a storage site at a fully decommissioned nuclear plant (Maine Yankee), and a National Laboratory (Idaho National Laboratory). The routes modeled are shown in Table 2-4. Both truck and rail versions of each route were analyzed.

These routes represent a variety of route lengths and populations. The routes include eastern U.S., western U.S., and cross country routes, are of varying lengths, and include a variety of urban areas. Two of the three nuclear plants chosen as origin sites: Kewaunee, WI and Maine Yankee, ME and two of the destination sites, Hanford, WA and Skull Valley TX are origins and destinations used in NUREG/CR-6672. Indian Point Nuclear Plant, NY involves a somewhat different set of cross-country and east coast routes than Maine Yankee, and is an operating nuclear plant while Maine Yankee has been decommissioned and is now only a surface storage facility. The destination sites include two proposed repository sites (Deaf Smith County, TX and Hanford, WA) (DOE, 1986), the site of the proposed Private Fuel Storage facility (Skull Valley, UT), and a National Laboratory site (Oak Ridge, TN; ORNL). The chosen origin and destination sites do not represent any planned spent fuel transportation plans, but provide a good representation of the lengths and population densities that could be encountered during any shipment of spent fuel.

Route segments and population densities are provided by TRAGIS. Population densities were updated from the 2000 census using the 2008 Statistical Abstract (U.S. Bureau of the Census 2008, Tables 13 and 21), though updates were made only when the difference between the 2008 and 2000 population densities was one percent or more. The collective doses reported in Table 2-5 and Table 2-6 are in units of person-Sv.

Table 2-4. Specific routes modeled. Urban kilometers are included in total kilometers.

Origin	Destination	Population within 800 m (1/2 mile)		Kilometers		Urban Kilometers	
		Rail	Truck	Rail	Truck	Rail	Truck
Maine Yankee Site, ME	Hanford, WA	1,146,479	980,355	5051	5011	235	116
	Deaf Smith County, TX	1,321,023	1,248,079	3360	3593	210	164
	Skull Valley, UT	1,199,091	934,336	4248	4173	235	115
	Oak Ridge, TN	1,119,154	1,336,208	2124	1747	161	135
Kewaunee NP, WI	Hanford, WA	779,613	419,951	3026	3451	60	57
	Deaf Smith County, TX	677,072	418,424	1881	2145	110	60
	Skull Valley, UT	472,098	354,911	2753	2619	125	51
	Oak Ridge, TN	806,116	522,128	1394	1272	126	92
Indian Point NP, NY	Hanford, WA	1,146,246	751,189	4779	4512	228	97
	Deaf Smith County, TX	1,027,974	376,259	3071	3071	204	207
	Skull Valley, UT	956,210	705,170	3975	3671	229	97
	Oak Ridge, TN	1,517,759	464,070	1263	1254	207	60
Idaho National Lab, ID	Hanford, WA	593,681	107,325	1062	958	20	15
	Deaf Smith County, TX	298,589	310,351	1912	2290	40	52
	Skull Valley, UT	164,399	102,341	454	466	26	19
	Oak Ridge, TN	169,707	494,068	3304	3286	74	62

Table 2-5 and Table 2-6 present collective doses for rail and truck, respectively, for each of the sixteen origin/destination pairs. State by state collective doses are tabulated in Appendix II.

Comment [h27]: Of the myriad of potential routes, the logic for the inclusion of these (especially as they don't necessarily represent planned fuel shipment routes) is not evident. Although there is much mentioned here about the routes, there is no clear exposition of these routes. I think this is a very important point. Many different approaches can be taken (greatest expected number of fuel shipment source locations, most likely final repository or reprocessing facility, etc.). However, only a loose collection of qualitative reasons for the representative nature of these routes is presented here. It is not a convincing argument as to why this represents the best/bounding choice for a critical aspect of this risk assessment.

Comment [MF28]: Suggest moving this paragraph to earlier in the document. Suggest moving it to right after Table 2-2.

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Comment [MF29]: Are these updates made by TRAGIS or by SNL –it is not clear form the text.

Comment [MF30]: This paragraph states that population was obtained from the 2008 Statistical Abstract. But the population values were obtained from TRAGIS, which uses LandScanUSA processed 2000 Census block count values.

Comment [MF31]: 1.Page 23, Table 2-4. We have tried to validate these numbers by recalculating the routes with TRAGIS. The cells highlighted in green have been verified as perfect matches. Yellow cells are off by less than 1%. Brown cells are off by 1-10%. Red cells are off by more than 10%. Please refer to original text to compare the original values of the red cells. For most truck routes the number match, except the overall distance of the route is off by several kilometers. But there are several routes were the population is drastically different. For all rail routes, the population was incorrect for each. Generally, the distances of the routes were close. Only two rail routes differ in actual routing; Indian Point NP to Oak Ridge and INL to Oak Ridge. There should be serious concern about the validity of the input into the RADTRAN assessment of the routes.
Origin ...

Table 2-5. Collective doses (person-Sv) for rail transportation

FROM	TO	Rail-Lead				Rail-Steel			
		Rural	Suburban	Urban	Total	Rural	Suburban	Urban	Total
MAINE YANKEE	ORNL	2.5E-05	2.9E-04	1.4E-05	3.3E-04	1.9E-05	2.2E-04	1.1E-05	2.5E-04
	DEAF SMITH	3.0E-05	3.5E-04	1.8E-05	4.0E-04	2.3E-05	2.7E-04	1.4E-05	3.0E-04
	HANFORD	3.8E-05	4.1E-04	2.1E-05	4.7E-04	2.9E-05	3.1E-04	1.6E-05	3.6E-04
	SKULL VALLEY	4.2E-05	4.1E-04	1.4E-05	4.7E-04	3.2E-05	3.2E-04	1.1E-05	3.6E-04
KEWAUNEE	ORNL	1.7E-05	1.7E-04	1.1E-05	2.0E-04	1.3E-05	1.3E-04	8.1E-06	1.5E-04
	DEAF SMITH	1.3E-05	1.5E-04	9.2E-06	1.7E-04	1.0E-05	1.2E-04	7.1E-06	1.3E-04
	HANFORD	1.6E-05	1.5E-04	4.7E-06	1.7E-04	1.2E-05	1.1E-04	3.6E-06	1.2E-04
	SKULL VALLEY	2.3E-05	1.9E-04	1.1E-05	2.2E-04	1.7E-05	1.4E-04	8.0E-06	1.7E-04
INDIAN POINT	ORNL	1.2E-05	2.3E-04	5.8E-05	3.0E-04	9.1E-06	1.7E-04	1.7E-05	2.0E-04
	DEAF SMITH	2.7E-05	2.3E-04	1.9E-05	2.8E-04	2.0E-05	2.1E-04	1.4E-05	2.5E-04
	HANFORD	3.5E-05	3.4E-04	2.1E-05	4.0E-04	2.5E-05	2.3E-05	9.0E-06	5.8E-05
	SKULL VALLEY	3.6E-05	3.2E-04	2.1E-05	3.8E-04	2.8E-05	2.4E-04	1.6E-05	2.9E-04
IDAHO NATIONAL LAB	ORNL	2.8E-05	1.8E-04	6.0E-06	2.1E-04	2.2E-05	1.4E-04	4.5E-06	1.7E-04
	DEAF SMITH	1.1E-05	8.9E-05	8.9E-06	1.1E-04	7.7E-06	6.8E-05	6.8E-06	8.2E-05
	HANFORD	8.5E-06	4.7E-05	1.7E-06	5.8E-05	6.5E-06	3.6E-05	1.3E-06	4.4E-05
	SKULL VALLEY	4.9E-06	4.1E-05	2.3E-06	4.8E-05	3.7E-06	3.1E-05	1.8E-06	3.6E-05

Comment [h32]: A sample calculation (included in Appendix II) with RADTRAN input and output would be useful for this major result. Any choice of route is acceptable. The other dose results can be compared to ensure consistency is apparent.

Table 2-6. Collective doses (person-Sv) for truck transportation

FROM	TO	Truck–DU				
		Rural	**Suburban**	**Urban**	**Urban Rush Hour[a]**	**Total**
MAINE YANKEE	ORNL	7.9E-06	1.4E-04	2.9E-06	2.6E-07	1.51E-04
	DEAF SMITH	1.4E-05	1.9E-04	3.3E-06	3.4E-07	2.08E-04
	HANFORD	2.2E-05	1.7E-04	2.3E-06	4.2E-07	1.95E-04
	SKULL VALLEY	1.8E-05	1.5E-04	2.3E-06	4.2E-07	1.71E-04
KEWAUNEE	ORNL	6.5E-06	7.4E-05	1.8E-06	2.7E-07	8.26E-05
	DEAF SMITH	1.1E-05	6.3E-05	1.2E-06	2.5E-07	7.55E-05
	HANFORD	1.4E-05	6.6E-05	1.1E-06	6.6E-08	8.12E-05
	SKULL VALLEY	1.2E-05	5.0E-05	1.1E-06	9.5E-08	6.32E-05
INDIAN POINT	ORNL	6.1E-06	8.9E-05	1.2E-06	2.6E-07	9.66E-05
	DEAF SMITH	1.1E-05	1.1E-04	1.6E-06	3.4E-07	1.23E-04
	HANFORD	2.1E-05	1.2E-04	1.9E-06	4.2E-07	1.43E-04
	SKULL VALLEY	1.7E-05	1.1E-04	1.9E-06	4.2E-07	1.29E-04
IDAHO NATIONAL LAB	ORNL	1.4E-05	8.4E-05	1.2E-06	2.7E-07	9.95E-05
	DEAF SMITH	7.3E-06	4.9E-05	1.1E-06	2.5E-07	5.77E-05
	HANFORD	4.2E-06	2.0E-05	3.0E-07	6.6E-08	2.46E-05
	SKULL VALLEY	2.0E-06	1.6E-05	4.3E-07	9.5E-08	1.85E-05

[a]During rush hour the truck speed is halved and the vehicle density is doubled.

Comment [h33]: Similar to Table 2-5, a sample calculation (included in Appendix II) with RADTRAN input and output would be useful for this major result. Any choice of route is acceptable. The other dose results can be compared to ensure consistency is apparent.

Comment [h34]: A ratio of the doses for rail transport to truck transport indicates that most rail transport results in higher collective doses (average value of 67% of rail dose for truck transport doses (likely due to lower rail transit speeds perhaps and greater percentage of urban route lengths). However, this INDIAN POINT TO HANFORD route is an anomaly with the TRUCK route a factor of 2.47 times higher than the RAIL route. This suggests an error in this route calculation.

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Collective dose is best used in making comparisons; e.g., in comparing the risks of routine transportation along different routes, by different modes (truck or rail), or in different casks. Several such comparisons can be made from the results shown in Tables 2-5 and 2-6.

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- Urban residents sustain a slightly larger dose from a single rail shipment than from a truck shipment on the same state route, even though urban population densities are similar and the external dose rates from the cask are nearly the same. As shown in Table 2-4, most (though not all) rail routes have more urban miles than the analogous truck route. Train tracks go from city center to city center, while trucks carrying spent fuel must use interstates and bypasses. In several cases shown in Table 2-4, the rail route had twice as many urban miles as the corresponding truck route.

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Comment [MF35]: Should also note that the this is at ½ the speed, also.

- Overall, collective doses are larger for a single shipment on rail routes than truck routes because the rail routes are often longer, especially in the western U.S., where there is rarely a choice of railroads.

The collective doses shown in Table 2-5 and Table 2-6 are all very small. However, they are not the only doses the people along the route receive. Background radiation is 0.0036 Sv per year in the U.S., or 4.1 x 10^{-7} Sv/ hour. The contribution of a single shipment to the population's collective dose is illustrated by the following example of the Maine Yankee to ORNL truck route:

- From Table 2-6 the total collective dose for this segment 1.5 x 10^{-4} person-Sv
- From Table 2-4, there are 1.34 million people within a half mile of the route.
- Background is 4.1 x 10^{-7} Sv/hour. Everyone is exposed to this background all the time, whether a shipment occurs or not.
- A truck traveling at an average of 108 kph travels the 1747 km in 16 hours.
- During those 16 hours, the 1.34 million people will have received a collective background dose of 8.81 person-Sv, about 60,000 times the collective dose from the shipment.
- The total collective dose during a shipment to this 1.34 million people is not 1.5 x 10^{-4} person-Sv), but 8.81015 person-Sv, of which the fraction due to spent fuel transport is vanishingly small at 1.7e-6.
- The NRC recommends that collective dose be used only in comparisons (NRC, 2008).
- The appropriate comparison between the collective dose from this shipment of spent fuel is thus not a comparison between 1.5 x 10^{-4} person-Sv from the shipment and zero dose if there is no shipment, but between 8.81015 person-Sv if there is a shipment and 8.81000 person-Sv if there is no shipment.

A more complete discussion of collective dose is in Appendix II, Section II.6.

2.3.3 Doses to members of the public occupying vehicles that share the route

Rail

Much of the United States rail is either double track or equipped with "passing tracks" that let one train pass another. When a train passes the train carrying the spent fuel cask, occupants of the passing train will receive some of the external radiation. The great majority of trains in United States carry freight, and the only occupants of the passing train are crew members. Only about one railcar in 60 has an occupant.

The dose to occupants of other trains in this situation depends on train speed and the external dose rate from the spent fuel casks. Table 2-7 shows the collective dose to public passengers of trains sharing the route, assuming for calculation purposes that occupants of trains are represented by one person in each passing railcar in rural and suburban areas, and five people in urban areas.[8] The rural and suburban collective doses are probably unrealistically large, since most freight rail going through rural and many suburban areas never encounters a passenger train. Data were not available to account for the occupancy of actual passenger trains, including light rail, that share rail routes with freight trains.

Comment [h36]: Table 2-7 doesn't reflect collective dose for transit. Table 2.6 appears to be the correct table. However the value from this table is 1.5e-4, NOT 1.5e-5

Comment [s37]: The value of 1.5 x 10^{-5} person-Sv occurs 3 times in the bullets section, the value should be 1.5 x 10^{-4} (according to Table 2-6) and the 600,000 should be 60,000 and the 8.810015 values are actually 8.81015 (2 occurrences).

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Comment [h38]: Table 2.5 doesn't represent populations. I think you mean Table 2.4

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Comment [h39]: Added this.

Comment [MF40]: Are these numbers only for residents on route or do they also include traffic on route or residents near truck stops? Please be specific.

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Comment [MF41]: These are good, but a similar summary of the maximum exposed person would also be beneficial.

Comment [h42]: Reference?

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[8] The five persons per railcar in urban areas are assumed to include occupants of passenger trains. Passenger trains carry more than five per car, but the majority of railcars even in urban areas carry freight only. This estimate is consistent with estimates made in past studies.

Table 2-7. Collective doses (person-Sv) to occupants of trains sharing the route

SHIPMENT ORIGIN	SHIPMENT DESTINATION	Rail-Lead			Rail-Steel		
		Rural	Suburban	Urban	Rural	Suburban	Urban
MAINE YANKEE	ORNL	2.8E-05	2.6E-05	2.1E-05	2.1E-05	2.0E-05	1.7E-05
	DEAF SMITH	5.4E-05	1.9E-05	2.7E-05	4.1E-05	1.4E-05	2.2E-05
	HANFORD	8.0E-05	2.3E-05	2.9E-05	6.1E-05	1.8E-05	2.4E-05
	SKULL VALLEY	6.9E-05	2.6E-05	2.3E-05	5.2E-05	2.0E-05	1.9E-05
KEWAUNEE	ORNL	1.9E-05	9.9E-06	1.6E-05	1.5E-05	7.5E-06	1.3E-05
	DEAF SMITH	3.4E-05	7.4E-06	1.4E-05	2.5E-05	5.6E-06	1.2E-05
	HANFORD	3.5E-05	9.5E-06	7.8E-06	2.7E-05	7.2E-06	6.4E-06
	SKULL VALLEY	5.0E-05	1.1E-05	1.6E-05	3.8E-05	8.4E-06	1.3E-05
INDIAN POINT	ORNL	1.3E-05	1.1E-05	2.7E-05	9.8E-06	8.7E-06	2.2E-05
	DEAF SMITH	5.1E-05	1.5E-05	2.6E-05	3.9E-05	1.2E-05	2.2E-05
	HANFORD	6.1E-05	2.0E-05	2.9E-05	4.6E-05	1.5E-05	2.4E-05
	SKULL VALLEY	6.2E-05	1.9E-05	5.3E-06	4.7E-05	1.4E-05	4.0E-06
IDAHO NATIONAL LAB	ORNL	6.5E-05	1.0E-05	9.6E-06	4.9E-05	7.6E-06	7.9E-06
	DEAF SMITH	3.9E-05	4.6E-06	5.2E-06	2.9E-05	3.5E-06	4.3E-06
	HANFORD	2.2E-05	2.5E-06	2.6E-06	1.6E-05	1.9E-06	2.1E-06
	SKULL VALLEY	7.8E-06	2.1E-06	3.3E-06	5.9E-06	1.6E-06	2.7E-06

Comment [h43]: An example calculation of this major result in the Appendix would be useful.

Comment [h44]: Similar to Tables 2-5 and 2.6, this result seems anomalous. The ratio of the other train route collective doses to the doses incurred with shared routes seems disproportionate. The other routes are all in the 10-18 multiple range (with the shared routes offering the lesser of the two doses). However this route's ratio is only 2.42. This hints at a possible calculational error for this route.

Truck

Unlike the train situation, a truck carrying spent fuel shares the primary highway system with many cars, light trucks, and other vehicles, as shown in Figure 2-9, a model of the RADTRAN calculation. The occupants of any car or truck that passes the spent fuel cask in either direction will sustain a small radiation dose.

The radiation dose to occupants of other vehicles depends on the exposure distance and time, the number of other vehicles on the road, and the number of people in the other vehicles. Occupants of the vehicles that share the route are closer to the cask than residents or others beside the route. Occupants of vehicles moving in the opposite direction from the cask are exposed to radiation from the cask for considerably less time because the vehicles involved are moving past each other. The exposure time for vehicles traveling in the same direction as the cask is assumed to be the time needed to travel the link at the average speed. A more complete discussion of the calculation method is in Appendix II and Neuhauser, et al,(2000).The number of other vehicles that share truck routes is very large: the average number of vehicles per hour on U.S. interstate and primary highways in 2004[9] (Weiner, et al., 2009, Appendix D) were:

Comment [h45]: This is very conservative as it assumes the car travels next to the shipment the entire segment length. This is not realistic, but does provide a potential bound.

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- 1119 on rural segments, about 2 ½ times the 1977 vehicle density.
- 2464 on suburban segments, almost four times the 1977 vehicle density.

[9] 2004 is the most recent year for which data have been validated.

- 5384 on urban segments, about twice the 1977 vehicle density.

Each vehicle was assumed to have an average of one and a half occupants, since the majority of cars and light trucks traveling on freeways have one or two occupants. State highway departments provide traffic count data but do not provide vehicle occupancy data. If two occupants had been assumed, the collective doses would have been one-third larger.

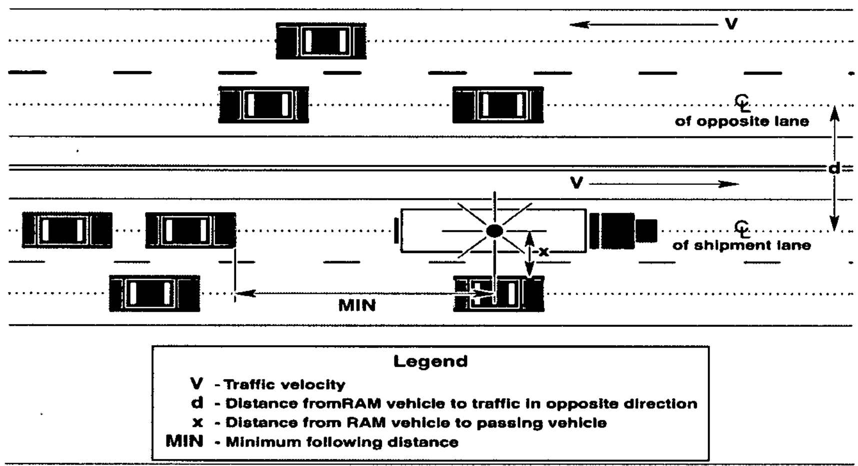

Figure 2-9. Diagram for calculating radiation doses to occupants of other vehicles (from Neuhauser et al., 2000)

Detailed discussion and state-by-state results are presented in Appendix II. The collective doses for truck traffic are shown in Table 2-8.

Table 2-8. Collective doses (person-Sv) to occupants of vehicles sharing truck routes

Comment [h46]: An example calculation of this major result in the Appendix would be useful.

ORIGIN	DESTINATION	TRUCK-DU			
		Rural	Suburban	Urban	Urban Rush Hour
MAINE YANKEE	ORNL	1.3E-04	2.3E-04	5.4E-05	5.0E-06
	DEAF SMITH	2.9E-04	3.6E-04	7.5E-05	1.5E-05
	HANFORD	4.4E-04	2.9E-04	4.1E-05	4.0E-06
	SKULL VALLEY	5.0E-04	2.8E-04	4.3E-05	4.0E-06
KEWAUNEE	ORNL	9.6E-05	1.4E-04	4.8E-05	4.0E-06
	DEAF SMITH	1.8E-04	8.9E-05	2.2E-05	2.0E-06
	HANFORD	3.4E-04	1.4E-04	3.3E-05	3.0E-06
	SKULL VALLEY	2.5E-04	8.6E-05	2.5E-05	1.0E-05
INDIAN POINT	ORNL	1.8E-04	2.1E-04	3.3E-05	3.0E-06
	DEAF SMITH	2.8E-04	3.1E-04	5.6E-05	5.0E-06
	HANFORD	4.2E-04	2.2E-04	4.8E-05	4.0E-06
	SKULL VALLEY	3.6E-04	2.2E-04	4.5E-05	4.0E-06
IDAHO NATIONAL LAB	ORNL	3.0E-04	1.5E-04	2.4E-05	2.0E-06
	DEAF SMITH	2.2E-04	7.3E-05	2.7E-05	1.8E-05
	HANFORD	1.0E-04	8.5E-05	9.0E-06	1.0E-06
	SKULL VALLEY	3.7E-05	2.3E-05	8.0E-06	1.0E-06

2.3.4 Doses at Stops

Both trucks and trains stop occasionally on long trips. Common carrier freight trains stop to exchange freight cars, to change crews, and, when necessary, to change railroads. The rail stops at the origin and destination of a trip are called "classification stops" and are 27 hours long. Spent fuel casks may be carried on dedicated trains as well as on regular freight trains, although in practice, previous spent fuel shipments have been carried on dedicated trains. The shipments in this analysis are assumed to use dedicated rail. A dedicated train is a train that carries a single cargo from origin to destination; coal unit trains are a good example of dedicated trains.

Comment [h47]: Reference?

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When a train is stopped, the dose to anyone nearby depends on the distance between that person and the cask and the time that the individual is exposed. The people exposed at a rail stop include:

- Railyard workers (including inspectors)
- Train crew
- Residents who live near the rail yard

Comment [h48]: Are intermodal transportation activities considered in this analysis? For these would the collective doses to the public be considered in this section under "Stops"?

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The semi-tractor trucks that carry TRUCK-DU casks each have two 80-gallon fuel tanks, and generally stop to refuel when half of the fuel is gone, approximately every 525 miles (DOE, 2002). Trucks carrying spent fuel are also stopped at the origin and destination of each trip. Mandatory rest and crew changes are combined with refueling stops whenever possible.

The people likely to be exposed at a refueling truck stop are:

- The truck crew of two; usually one crew member at a time will fill the tanks.
- Other people who are using the truck stop, since these trucks stop at public truck stops.
- Residents of areas near the stop.

A number of states inspect spent fuel cask shipments when the trucks enter the state. Inspection stations may be combined with truck weigh stations, so that inspectors of both the truck carrying spent fuel and trucks carrying other goods can be exposed as well as the crew from other trucks. When the vehicle is stopped, doses to receptors depend only on distance from the source and exposure time, so that any situation in which the cask and the receptor stay at a fixed distance from each other can be modeled as a stop. Such stop-like exposure situations include inspections, vehicle escorts, vehicle crew when the vehicle is in transit, and occupants of other vehicles near the stopped vehicle. Any of these situations can be modeled in RADTRAN. Details of the calculations performed for these situations in this analysis may be found in Appendix II.

Figure 2-10 is a diagram of the model used to calculate doses at truck stops. The inner circle defines the area occupied by people who share the stop with the spent fuel truck, who are between the truck and the building, and who are not shielded from the truck's external radiation.

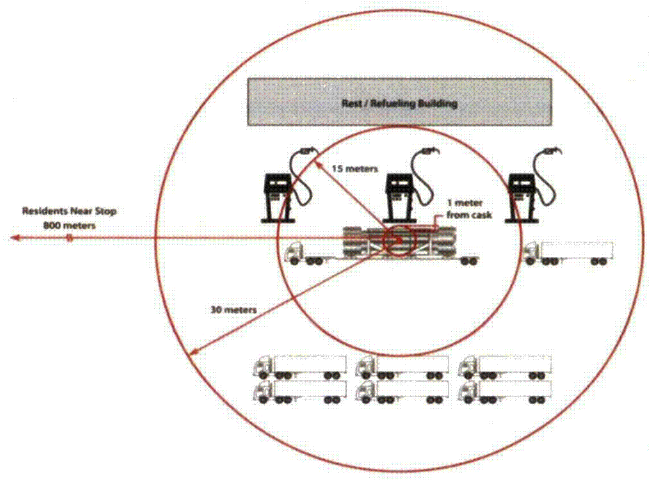

Figure 2-10. Diagram of truck stop model (not to scale)

Table 2-9 lists some sample input data used to calculate doses at stops.

Table 2-9. Some sample data for calculating doses at stops

Data	Interstate Highway	Freight Rail
Minimum distance from nearby residents (m)	30	200
Maximum distance from nearby residents (m)	800	800
Stop time for rail classification (hours)	NA	27
Stop time in transit for railroad change (hours)	NA	0.5
Stop time at truck stops (hours)	0.83	NA
Minimum distance to people sharing the stop (m.)	1[a]	NA
Maximum distance to people sharing the stop (m.)	15[a]	NA

[a]From Griego et al., 1996

Comment [h49]: Reference for values included in the table.

Rail

Trains are stopped for classification for 27 hours at the beginning and end of a trip. The collective dose to the railyard workers at these classification stops from the radioactive cargo, for the two rail casks studied, is:

- For the Rail-Lead: 1.5×10^{-5} person-Sv
- For the Rail-Steel: 1.1×10^{-5} person-Sv

Comment [h50]: How many people is this based upon?

The average dose to an individual living 200 to 800 meters from a classification yard, as calculated by RADTRAN, is

- 0.35×10^{-5} Sv from the Rail-Lead
- 0.27×10^{-5} Sv from the Rail-Steel

Comment [h51]: How many shipment stops is this based upon?

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Table 2-10 shows the doses at stops to yard workers and residents near the stop for the Maine Yankee-to Hanford rail route. Because different routes have different in-transit stops and stop times for crew changes and inspections, a representative result is given here instead of presenting results for an entire route or for all sixteen routes.

Table 2-10. Collective doses at rail stops on the Maine Yankee-to-Hanford route (person-Sv)

Comment [h52]: An example calculation for this result in the Appendix would be useful and help answer the two preceding comments [h48] and [h49]

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Stop	Route type and State	Time (hours)	Railyard worker		Residents near stop	
			Rail-Lead	Rail-All Steel	Rail-Lead	Rail-All Steel
1	Suburban, ME	4.0	2.2 E-05	1.6 E-05	3.4 E-05	2.6 E-05
2	Rural, NY	4.0	2.2 E-05	1.6 E-05	9.2 E-06	6.9 E-06
3	Suburban, IL	2.0	1.1 E-05	8.1 E-06	1.2 E-04	9.4 E-05

Comment [MF53]: This table disagrees with Table II-24, page 284 of Appendix II by a factor of 10 – both tables are supposed to be the same.

Truck

Table 2-11 shows the collective doses to residents near stops for the rural and suburban segments of the 16 routes studied. Urban stops were not modeled because trucks carrying Truck - DU casks of spent fuel are unlikely to stop in urban areas. A more detailed discussion of these calculations is in Appendix II.

Table 2-11. Collective doses to residents near truck stops (person-Sv)

Origin	Route	Type	Persons/km^2	Number of stops	Dose
MAINE YANKEE	ORNL	Rural	19.9	1.73	1.1E-06
		Suburban	395	2.09	2.3 E-05
	Deaf Smith	Rural	18.6	2.47	1.5 E-06
		Suburban	371	1.6	1.7 E-05
	Hanford	Rural	15.4	4.33	2.2 E-06
		Suburban	325	1.5	1.4 E-05
	Skull Valley	Rural	16.9	3.5	1.9 E-06
		Suburban	332.5	1.3	1.2 E-05
KEWAUNEE	ORNL	Rural	19.8	0.81	5.2 E-07
		Suburban	361	0.59	6.0 E-06
	Deaf Smith	Rural	361305	2.0	8.6 E-07
		Suburban	339	0.52	5.0 E-06
	Hanford	Rural	10.5	3.4	1.2 E-06
		Suburban	316	0.60	5.4 E-06
	Skull Valley	Rural	12.5	2.6	1.1 E-06
		Suburban	324.5	0.44	4.1 E-06
INDIAN POINT	ORNL	Rural	20.5	0.71	4.7 E-07
		Suburban	388	0.71	7.8 E-06
	Deaf Smith	Rural	17.1	2.3	1.3 E-06
		Suburban	370	1.2	1.3 E-05
	Hanford	Rural	13.0	4.1	1.8 E-06
		Suburban	338	1.1	1.1 E-05
	Skull Valley	Rural	14.2	3.3	1.5 E-06
		Suburban	351	0.93	9.3 E-06
IDAHO NATIONAL LAB	ORNL	Rural	12.4	3.1	1.3 E-06
		Suburban	304	0.72	6.3 E-06
	Deaf Smith	Rural	7.8	2.3	5.8 E-07
		Suburban	339	0.35	3.4 E-06
	Hanford	Rural	6.5	0.43	9.0E-08
		Suburban	200	0.57	3.2 E-06
	Skull Valley	Rural	10.1	0.42	1.4 E-07
		Suburban	343	0.11	1.1 E-06

Comment [h54]: Example calculation for the results in this table would be useful.

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The rural and suburban population densities in Table 2-12 are the averages for the entire route. An analogous calculation can be made for each state traversed. However, in neither case can one determine beforehand exactly where the truck will stop to refuel. In some cases (e.g., INL to Skull Valley) the truck may not stop at all; the total distance from INL to the Skull Valley site is only 466.2 km (290 miles). The route from Indian Point to ORNL illustrates another situation. This route is 1028 km (639 miles) long, and would thus include one truck stop, which could be in either a rural or a suburban area. The results shown in Table 2-11 are general average doses at stops.

2.4 Doses to Workers

Radiation doses to workers are limited in accordance with the regulations of 10 CFR Part 20 and the practice of ALARA: maintaining the worker exposure to ionizing radiation "as low as reasonably achievable." ALARA applies to occupational doses because workers are potentially exposed to much larger doses than the general public. For example, the cab of a truck carrying a loaded TRUCK-DU cask is shielded so that 63% of the radiation from the end of the cask is blocked. In addition, the time that a truck crew can spend in the vehicle with a loaded cask is limited.

Occupational doses from routine, incident-free radioactive materials transportation include doses to truck and train crew, railyard workers, inspectors and escorts.

Table 2-12 summarizes the occupational doses. Workers who handle spent fuel containers in storage, loading and unloading casks from vehicles or during intermodal transfer are not addressed in this analysis. Truck refueling stops in the U.S. no longer have attendants who refuel trucks.[10] Gas station and truck stop workers are in concrete or brick buildings and would be shielded from the radiation with the same shielding as in urban housing (98% shielded).

Comment [MF55]: Notes from meeting at SNL indicate that dose to workers loading and unloading is not included. This should be mentioned. IF the dose is negligible, this should also be mentioned.

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Table 2-12

[10] The State of Oregon still requires gas station attendants to refuel cars and light duty vehicles, but heavy truck crew do their own refueling.

Table 2-12. Occupational doses per shipment from routine incident-free transportation

Cask and route type	Rail crew : 3 people (person-Sv/hour)	Truck crew: 2 people; (person-Sv/hour)	Escort: (Sv/hour)	Inspector (Sv per inspection)	Truck stop worker (Sv/hour per stop)	Rail classification yard workers: (person-Sv) (see p. 16)
Rail-Lead rural/suburban	5.4E-09	*	5.8E-06	*	*	1.5E-05
Rail-Lead	9.1E-08	*	5.8E-06	*	*	
Rail-Steel rural/suburban	4.1E-09	*	4.4E-06	*	*	1.1E-05
Rail-Steel urban	6.8E-09	*	4.4E-06	*	*	*
TRUCK-DU rural/suburban	*	3.8E-09	3.2E-09	3.2E-09	2.0E-09	*
TRUCK-DU urban	*	3.6E-09	3.2E-09	*	*	*

* Not applicable for this combination of cask type and dose type.

Comment [h56]: Example calculation in the Appendix for this table would be useful.

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2.5 Unit Risk

RADTRAN, the model used for the calculation of transportation risk, multiplies numbers. The only calculation that RADTRAN makes which is not a simple multiplication is calculating emissions from the spherical model shown in Figure 2-2. For routine transportation, all other parameters multiply the result of this calculation. RADTRAN can be programmed to calculate the collective dose from a passing vehicle for a population density of one person per square kilometer and one kilometer of a route. This type of calculation is called a unit risk calculation. The result may then be multiplied by the population per square kilometer and the route length in kilometers (if the area along the route is 800 meters wide on either side of the route), and divided by the vehicle speed.

2.6 Conclusions

As Chapter 1 states, risk is a projection of possible effects, and a code that estimates risk can never be completely precise because the input data are themselves estimates and projections. The risk assessment code RADTRAN slightly overestimates doses, and no estimate of dose can substitute for an actual measurement. Therefore, the doses calculated in this chapter should be regarded as overestimates.

Both the individual and collective doses are calculated for a single shipment and, even though overestimated, they are uniformly very small. Maximally exposed individual doses are comparable to background and less than doses from many medical diagnostic procedures. Collective doses are orders of magnitude less than collective background dose, as shown in Figure 2-11. The NRC recommends that collective doses (average doses integrated over a population) only be used only for comparisons (NRC, 2008). The proper comparison for collective doses is between the background collective dose plus the shipment dose and the

Comment [h57]: EDITORIAL: In what ways are the doses overestimates? A brief description of the major conservatisms that lead to these overestimates would be very useful.

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Comment [MF58]: This is not clear since many non-conservatism are included as assumptions.

Comment [MF59]: Were any of these reported in the chapter? The conclusions should not introduce new material.

background dose if there is no shipment. The collective dose is not zero in the absence of a shipment.

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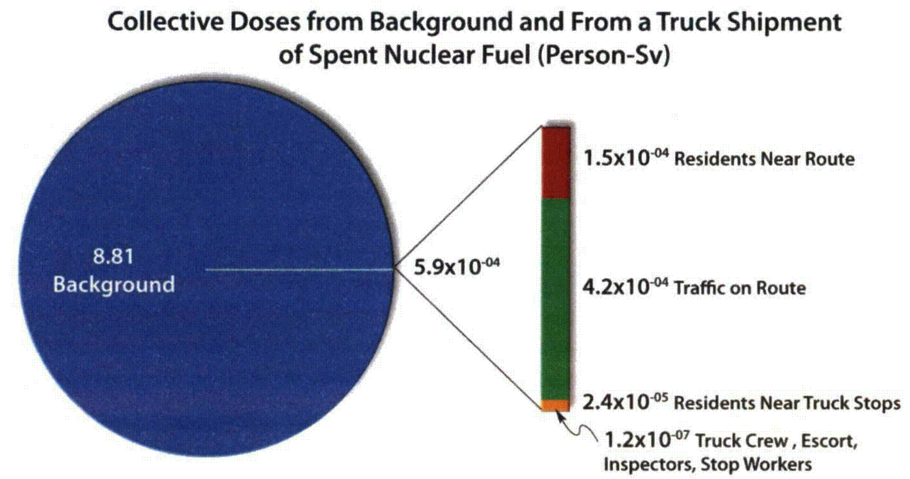

Figure 2-11. Collective doses from background and from one of the truck shipments of spent nuclear fuel (person-Sv)