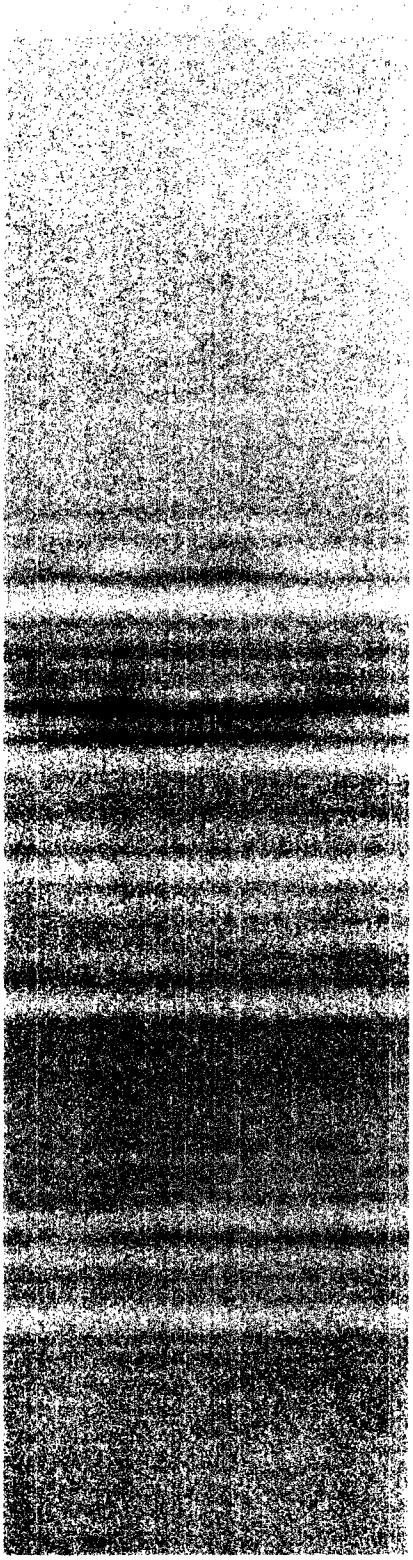
APPENDIX II

DETAILS OF RISK ANALYSIS OF ROUTINE, INCIDENT-FREE TRANSPORTATION



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APPENDIX II

DETAILS OF RISK ANALYSIS OF ROUTINE, INCIDENT-FREE TRANSPORTATION

II.1 Introduction

NUREG-0170 (NRC, 1977) 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. The estimates were calculated using Version 1 of the RADTRAN code (Taylor and Daniel, 1977), which was developed for the NRC by Sandia National Laboratories specifically to support the conduct of the NUREG-0170 study. RADTRAN Version 6, integrated with the input file generator RADCAT, (Neuhauser, et al.[1], 2000; Weiner, et al., 2009) is the computational tool used in this study.

The basic risk assessment method employed in the RADTRAN code is widely accepted[2]. Changes to the code are tracked by a software quality assurance plan that is consistent with American National Standards Institute guidelines. The incident-free module of an earlier version of RADTRAN, RADTRAN 5.25, was validated by measurement (Steinman, et al, 2002); this module is the same in RADTRAN 6.0, the version used in the current study. Verification and validation of RADTRAN 6.0 are documented in Dennis, et al. (2008).

II.2 The RADTRAN Model of Routine Transportation

II.2.1 Description of the RADTRAN Program

RADTRAN calculates the radiological consequences and risks associated with the shipment of a specific radioactive material in a specific package along a specific route. Shipments that take place without the occurrence of accidents are routine, incident free shipments, and the radiation doses to various receptors (exposed persons) are called "incident-free doses." Since the probability of routine, incident-free shipment is essentially equal to one, RADTRAN calculates a dose rather than a risk for such shipments.[3] The dose from a routine shipment is based on the external dose from the part of the vehicle carrying the radioactive cargo, referred to as the "vehicle" in this discussion of RADTRAN. Doses to receptors from the external radiation from the vehicle depend on the distance between the receptor and the radioactive cargo being transported and the exposure time. Exposure time is the length of time the receptor is exposed to

---

[1] 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, and the technical manual for RADTRAN 6 is not yet available.

[2] RADTRAN was used to calculate risks for, e.g., NUREG 0170 (NRC, 1977), the Yucca Mountain FEIS (DOE, 2002), the re-certification of the Waste Isolation Pilot Plant. RADTRAN today has 600 registered users, about 25 precent of whom are U.S. government contractors and about 25 percent of whom are international. The list of users is proprietary.

[3] The probability of an incident or accident transportation depends on the trip length and would be about 10^{-3}, for a cross-country trip, the probability of routine transportation on such a trip is 1-0.001, or 0.999, or essentially one. For a shorter trip the probability of routine transportation is even closer to one

external emissions from the radioactive cargo. The doses in routine transportation depend only on the external dose rate from the cargo and not on the radioactive inventory of the cargo.

RADTRAN models the vehicle as a spherical radiation source traveling along the route. The source strength is the transport index (TI), 100 times the dose rate in mSv/hour[4] at 1 m from the cask, which is treated as an isotropically radiating virtual source at the center of the sphere, as shown in Figure II-1. (see Neuhauser, et al. for a detailed explanation)

Deleted: RADTRAN 6.0, integrated with the input file generator RADCAT, (Neuhauser, et al., 2000; 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).¶

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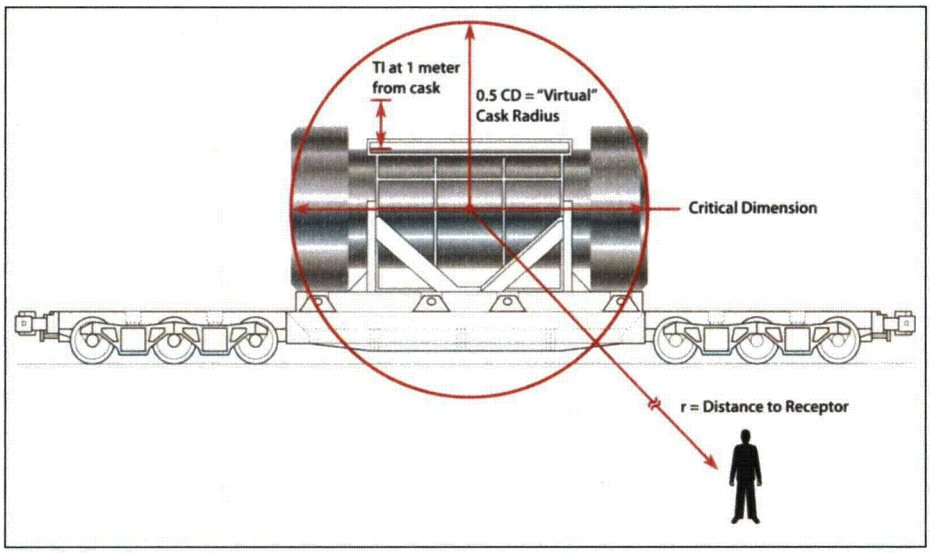

Figure II-1. RADTRAN model of the vehicle in routine, incident-free transportation.

When the distance to the receptor r 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 TIs for the Rail-Lead and the Rail-Steel casks were calculated from the dose rates at 2 meters as reported in the Safety Analysis Reports of these casks (Holtec International, 2004, NAC international, 2004) and are shown in Table II-1.

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The basic equation for calculating incident-free doses to a population along a transportation route is Equation II-1:

---

[4] One mSv = 100 mrem. Thus, 100 times the dose rate in mSv/hr at one meter from the package is equivalent to the dose rate in mrem/hr.

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(II-1) $$D(x) = \frac{Qk_0 DR_v}{V} \int_{-\infty}^{\infty} \int_{x\min}^{x\max} \left\{ \frac{(\exp(-\mu r))(B(r))}{r\sqrt{r^2 - x^2}} \right\} dx dr$$

where x is the distance between the receptor and the source, perpendicular to the route

Q includes factors that correct for unit differences

k_0 is the package shape factor[5]

DR_v is the vehicle external dose rate: the TI

V is the vehicle speed

μ is the radiation attenuation factor

B is the radiation buildup factor

r is the distance between the receptor and the source along the route

Details of the application of this and similar equations may be found in Neuhauser et al (2000).

External radiation from casks carrying used nuclear fuel includes both gamma and neutron radiation. For calculating doses from gamma radiation, RADTRAN uses Equation II-2,

(II-2) $$(e^{-\mu r}) * B(r) = 1$$

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for conservatism. For calculating doses from neutron radiation, on the other hand, RADTRAN uses Equation II-3

(II-3) $$(e^{-\mu r}) * B(r) = (e^{-\mu r}) * (1 + a_1 r + a_2 r^2 + a_3 r^3 + a_4 r^4)$$

where the coefficients are characteristics of the material.

Deleted: The default coefficients in RADTRAN are those for steel.

Equation II-2 can be rewritten (Neuhausr et al, 2000) as Equation II-4

(II-4) $$D(x) = \frac{Qk_0 DR_v}{V} \left[f_\gamma * I_\gamma + f_n * I_n \right]$$

where f_γ is the gamma fraction of the external radiation

f_n is the neutron fraction of the external radiation

I_γ is the double integral in Equation II-1using Equation II-2

I_n is the double integral in Equation II-1using Equation II-3

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[5] For details on the package shape factor, please see Equations 4 and 5 and accompanying text of Neuhauser et al., (2000).

Collective (population) doses are calculated by integrating over the band along the route where the population resides (the *x* integration in Equation II-1) and then integrating along the route from minus to plus infinity (-∞ to ∞) (the *r* integration in Equation II-1). This is illustrated for a truck route in Figure II-2. The *x* integration limits in Figure II-2 are not to scale: *xmin* is usually 30 m. (200 m near a rail classification stop) and *xmax* is usually 800 m. Integration of x to distances greater than 800 results in risks not significantly different from integration to 800 meters, since the decrease in dose with distance is exponential.

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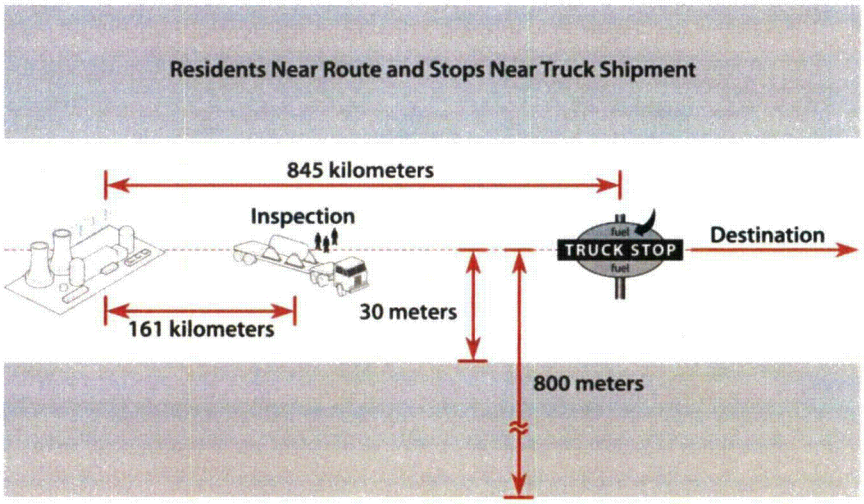

Figure II-2. Diagram of a truck route as modeled in RADTRAN; 845 km is the average distance a very large truck travels on half of its fuel capacity. The 161 km (100 miles) is the distance between spent fuel shipment inspections required by regulation (DOE, 2002).

Variants of Equation II-1 are used to calculate doses to members of the public at stops, vehicle crew members and other workers, occupants of vehicles that share the route with the vehicle carrying the radioactive cargo, and any other receptor identified. Figure II-3 is a diagram of the model used to calculate doses at truck stops. The inner circle defines the area occupied by people who are between the spent fuel truck and the building, and who are not shielded from the truck's external radiation. The dimensions of this circle and the average number of people who occupy it, along with the method used to determine these, are found in Griego et al. (1996).

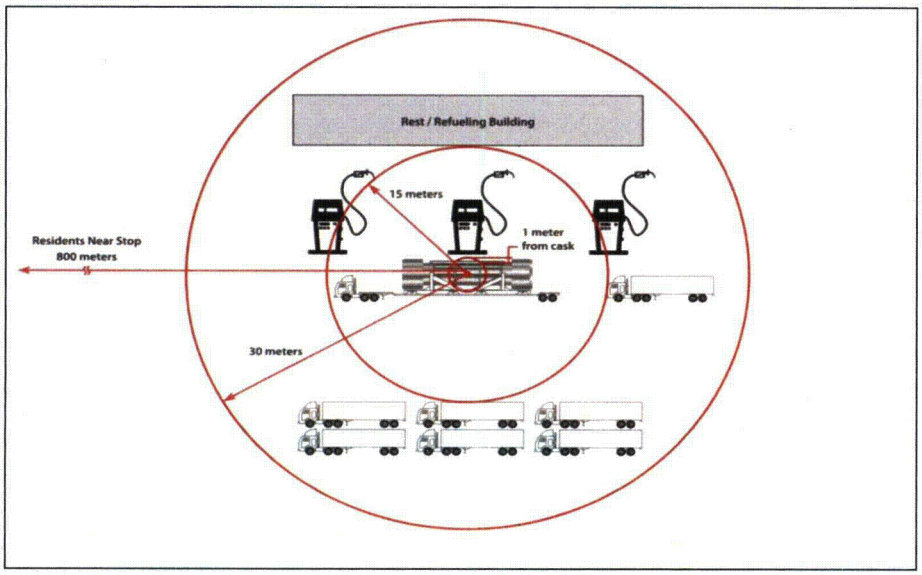

Figure II-3. Diagram of truck stop model.

II.2.2 The RADTRAN Software

This section is a brief description of the RADTRAN software program. A full description of the software and how to use it may be found in the RADCAT User Guide (Weiner, et al., 2009).

The equations that RADTRAN uses, variants of Equation II-1, are programmed in FORTRAN 95. RADTRAN reads in

- an input text file that contains the input parameters as defined by the RADTRAN user,
- a text file that contains an internal library of 148 radionuclides with their associated dose conversion factors and half-lives,
- a binary file that contains the societal ingestion doses for one curie of each radionuclide in the internal radionuclide library, and
- dilution factors and isopleths areas for several weather patterns.

Only the first of these is used in calculating doses from incident-free transportation; the other three are used in the accident analysis and will be discussed in Appendix V.

The input text file can be written directly using a text editor, or can be constructed using the input file generator RADCAT. RADCAT, programmed in XML and running under Java Webstart, provides a series of screens that guide the user in entering values for RADTRAN input parameters. Figure II-4 shows a RADCAT screen.

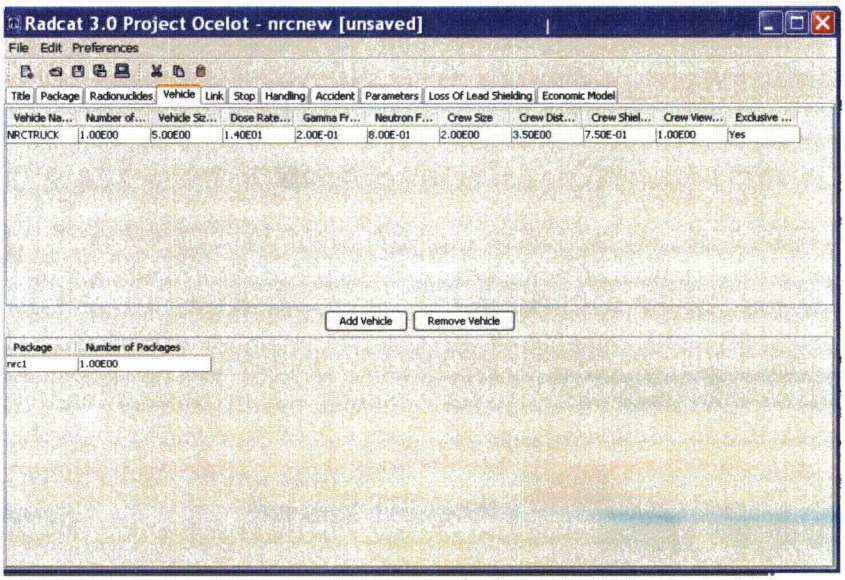

Figure II-4. RADCAT vehicle screen.

RADTRAN output is a text file that can be saved as text or as a spreadsheet.

II.3 RADTRAN Input Parameters

II.3.1 Vehicle-specific Input Parameters

RADTRAN does not allow for the offset of the package from the trailer edge, so the physical dimensions of the package are considered the physical dimensions of the vehicle. Table II-1 shows the vehicle-specific input parameters to RADTRAN and shows the parameter values used in this analysis. The Rail-Steel is modeled transporting canistered fuel; the Rail-Lead is modeled transporting uncanistered fuel. The Truck-DU is a truck cask; the other two are rail casks. In this analysis, the Truck-DU is assumed to be transported by truck; the Rail-Lead and the Rail-Steel, by rail.

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Table II-1. Vehicle-specific parameters

	1. Truck-DU	2. Rail-Lead	3. Rail-Steel

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4. Transportation mode	Highway	Rail	Rail
Length (critical dimension)	5.94 m	4.90m	5.08 m
Diameter ("crew view")	2.29 m	2.5 m	3.2 m
Distance from cargo to crew cab	3.5 m	150 m minimum	150 m minimum
TI	14	14.02	10.34
Gamma fraction	0.77	0.89	0.90
Neutron fraction	0.23	0.11	0.10
Number of packages per vehicle	1 per truck	1 per railcar	1 per railcar
Number of crew	2	3	3
Exclusive use?	yes	NA	NA
Dedicated rail	NA	yes	yes
17 × 17 PWR assemblies	4	26	24

II.3.2 Route-Specific Input Parameters

These are shown in

Table II-2 for a unit risk calculation. They are the common input parameters for the 16 specific routes analyzed.

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Table II-2. Route parameters for unit risk calculation (DOT 2004a, b)

Parameter	Interstate Highway	Freight Rail
Rural Vehicle speed (U.S. average kph)	108	40.4
Suburban Vehicle speed (U.S. average kph)	102	40.4
Urban Vehicle speed (U.S. average kph)	97	24
Rural Vehicle density (U.S. average vehicles/hr)	1119	17[a]
Suburban Vehicle density (U.S. average vehicles/hr)	2464	17
Urban Vehicle density (U.S. average vehicles/hr)	5384	17
Persons per vehicle	1.5	2
Farm fraction	0.5	0.5
Minimum distance of stop from nearby residents (m)	30	200
Maximum distance of stop from nearby residents (m)	800	800
Stop time for classification (hours)	NA	27
Stop time in transit for railroad change (hours)	NA	variable
Stop time for truck inspections (hours)	0.75	NA
Stop time at truck stops (hours)	0.83	NA
Average number of people sharing the stop	6.9[b]	NA
Minimum distance to people sharing the stop (m)	1[b]	NA
Maximum distance to people sharing the stop (m)	15[b]	NA
Truck stop worker distance from cask (m)	15	NA
Truck stop worker shielding factor	0.018	NA
Truck crew shielding factor	0.377	NA
Escort distance from cask (m)	4	16

[a]Railcars per hr; [b]Griego et al, 1996.

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II.3.3. Other Parameters

RADTRAN includes a set of parameters whose values are not generally known by the user and which have been used routinely in transportation risk assessments. RADTRAN contains default values for these parameters, but all default values can be changed by the user.

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Table II-3 lists the parameter values used in the incident-free analysis.

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Table II-3

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Table II-3

Table II-3. Parameter values in the RADTRAN 6 analysis

Parameter	Value
Shielding factor for residents (fraction of energy impacting the receptor): R= rural, S=suburban, U=urban	R=1.0
	S=0.87
	U=0.018
Fraction of outside air in urban buildings	0.25
Fraction of urban population on sidewalk	0.48
Fraction of urban population in buildings	0.52
Ratio of non-residents to residents in urban areas	6
Distance from in-transit shipment for maximum exposure in m. (RMEI exposure)	30
Vehicle speed for maximum exposure in km/hr. (RMEI exposure)	24
Distance from in-transit shipment to nearest resident in rural and suburban areas, m	30
Distance from in-transit shipment to nearest resident in urban areas, m	27
Population bandwidth, m	800
Distance between vehicles (trains), m	3.0
Minimum number of rail classification stops	1

Additional input parameters are rural, suburban, and urban route lengths and population densities, characteristics of stops along a route and the TI of the package.

II.3.4 RADTRAN input and output files

Figure II-5 shows the incident-free unit risk input file for the Truck-DU cask. Figure II-6 shows the incident-free unit risk input files for the Rail-lead-steel and Rail-steel casks. In the interests of space, only the portion of the input files relevant to routine incident-free transportation are shown.

```
OUTPUT CI_REM
FORM UNIT
DIMEN 1 0 18
PARM 0 1 3 0
PACKAGE GA4 14.0 0.77 0.22999999999999998 5.94
VEHICLE -1 GA_4 1.400000E01 0.77 0.23 5.94 1.0 2.0 3.5 0.38 2.29
GA4 1.0
FLAGS
IACC 2
IUOPT 2
REGCHECK 0
MODSTD
DISTOFF FREEWAY 3.000000E01 3.000000E01 8.000000E02
DISTOFF SECONDARY 2.700000E01 3.000000E01 8.000000E02
DISTOFF STREET 5.000000E00 8.000000E00 8.000000E02
DISTON
FREEWAY 1.500000E01
SECONDARY 3.000000E00
STREET 3.000000E00
ADJACENT 4.000000E00
MITDDIST 3.000000E01
MITDVEL 2.400000E01
RR 1.000000E00
RU 1.800000E-02
RS 8.700000E-01
LINK R GA_4 1.0 108.0 1.5 1.0 1119.0 1.0 0.0 R 1 0.5
LINK S GA_4 1.0 108.0 1.5 1.0 2464.0 1.0 0.0 S 1 0.0
LINK U GA_4 0.9 102.0 1.5 1.0 5384.0 1.0 0.0 U 1 0.0
LINK U_RUSH GA_4 0.1 51.0 1.5 1.0 10760.0 1.0 0.0 U 1 0.0
STOP STOP_1 GA_4 9180.0 1.0 15.0 1.0 0.83
STOP RURAL GA_4 1.0 30.0 800.0 1.0 0.83
STOP SUBURBAN GA_4 1.0 30.0 800.0 0.87 0.83
STOP URBAN GA_4 1.0 30.0 800.0 0.018 0.83
EOF
```

Figure II-5. RADTRAN unit risk input file for the Truck-DU cask.

```
RADTRAN 6      July 2008
 && SEE APPENDIX A.2 FOR DETAILS
 && UNIT RISK FACTOR
 && INCIDENT-FREE TRANSPORT
 && AVERGE TI
 && PWR 35GHWD/MTHM BURNUP   10 YEAR COOLED  24 ASSEMBLIES
 &&.REMARK
 TITLE NAC-STC
 OUTPUT CI_REM
 FORM UNIT
 DIMEN 1 0 18
 PARM 0 1 3 0
 PACKAGE NAC-STC 14.02 0.89 0.10999999999999999 4.9
 PACKAGE HI-STAR_100 10.034 0.9 0.09999999999999998 5.08
VEHICLE -2 NAC-STC 1.400000E01 0.89 0.11 4.9 1.0 3.0 150.0 1.0 2.5
       NAC-STC 1.0
       HI-STAR 0.0
 VEHICLE -2 HI-STAR 1.030000E01 0.9 0.1 5.08 1.0 3.0 150.0 1.0 3.2
       NAC-STC 0.0
       HI-STAR 1.0
 FLAGS
    IACC 2
    ITRAIN 2
    IUOPT 2
    REGCHECK 0
 MODSTD
    DDRWEF 1.800000E-03
    FMINCL 1.000000E00
    DISTOFF RAIL 3.000000E01 3.000000E01 8.000000E02
    DISTON
     RAIL 3.000000E00
    MITDDIST 3.000000E01
    MITDVEL 2.400000E01
    RPD 6.000000E00
    RR 1.000000E00
    RU 1.800000E-02
    RS 8.700000E-01
 LINK NAC_R NAC-STC 1.0 40.4 3.0 1.0 8.0 1.0 0.0 R 3 0.5
 LINK NAC_S NAC-STC 1.0 40.4 3.0 1.0 8.0 1.0 0.0 S 3 0.0
 LINK NAC_U NAC-STC 1.0 24.0 3.0 1.0 17.0 1.0 0.0 U 3 0.0
 LINK HISTAR_R HI-STAR 1.0 40.4 3.0 1.0 8.0 1.0 0.0 R 3 0.5
 LINK HISTAR_S HI-STAR 1.0 40.4 3.0 1.0 8.0 1.0 0.0 S 3 0.0
 LINK HISTAR_U HI-STAR 1.0 24.0 3.0 1.0 17.0 1.0 0.0 U 3 0.0
 STOP CLASSIFICATION NAC-STC 1.0 200.0 800.0 1.0 27.0
 STOP CLASSIFICATION HI-STAR 1.0 200.0 800.0 1.0 27.0
 EOF
```

Figure II-6. RADTRAN unit risk input file for the Rail-Lead and Rail-Steel casks.

II.4. Routes

This study analyzes both the per-km doses from a single shipment on rural, suburban, and urban route segments and doses to receptors from a single shipment on 16 representative routes, chosen

to represent a range of route lengths and a variety of populations. The actual truck and rail routes were selected for a number of reasons. The combination of four origins and four destinations represent a variety of route lengths and population densities and both private and government facilities, a large number of states, and includes origins and destinations that were included in the analyses of NUREG/CR-6672, thereby permitting comparison of results between the studies.

Power reactor spent fuel (SNF) and high-level radioactive waste (HLW) are currently stored at 77 locations in the U.S. (67 nuclear generating plants, five storage facilities at sites of decommissioned nuclear plants, and five DOE defense facilities). The origin sites (Table II-4) include two nuclear generating plants (Indian Point and Kewaunee), a storage site (Maine Yankee), and a National Laboratory (Idaho National Laboratory). The destination sites include the two proposed repository sites not characterized (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). The routes modeled are shown in Table II-4. The populations within 800 meters of the route were determined from output of the WebTRAGIS (Johnson and Michelhaugh, 2003) routing code, modified by the increase in population between 2000 and 2006 (see Table II-5). Both truck and rail versions of each route are analyzed. These routes are used for illustrative purposes. No actual spent fuel shipments on these routes are occurring or planned.

Table II-4. Specific routes modeled (urban kilometers are included in total kilometers)

Origin	Destination	Population within 800 m (1/2 mile)		Total Kilometers		Urban Kilometers	
		Rail	Truck	Rail	Truck	Rail	Truck
Maine Yankee Site, ME	Hanford, WA	1,647,190	1,129,685	5084	5013	355	116
	Deaf Smith County, TX	1,321,024	1,427,973	3362	3596	211	165
	Skull Valley, UT	1,451,325	1,068,032	4068	4174	207	115
	Oak Ridge, TN	1,146,478	1,137,834	2125	3495	161	135
Kewaunee NP, WI	Hanford, WA	476,914	423,163	3028	2620	60	52
	Deaf Smith County, TX	677,072	494,920	1882	2146	110	60
	Skull Valley, UT	806,115	505,226	2755	3453	126	58
	Oak Ridge, TN	779,613	646,034	1395	1273	126	92
Indian Point NP, NY	Hanford, WA	961,026	869,763	4781	4515	229	97
	Deaf Smith County, TX	1,027,974	968,282	3088	3074	204	109
	Skull Valley, UT	1,517,758	808,107	3977	3670	229	97
	Oak Ridge, TN	1,146,245	561,723	1264	1254	207	60
Idaho National Lab, ID	Hanford, WA	164,399	132,662	1062	959	20	15
	Deaf Smith County, TX	298,590	384,912	1913	2291	40	52
	Skull Valley, UT	169,707	132,939	455	466	26	19
	Oak Ridge, TN	593,680	569,240	3306	3287	75	63

Route segments and population densities are provided by WebTRAGIS. WebTRAGIS uses census data from the 2000 census (NOTE: it is expected that 2010 census will be available in

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WebTRAGIS in the near future, and the final version of this document will be updated). In the meantime, updated population data to 2006 were provided in the 2008 Statistical Abstract (U.S. Census Bureau, 2008). Table 13 of U.S. Census Bureau (2008) shows the percent increase in population for each of the 50 states of the United States, as well as for the U. S. as a whole, and Table 20 shows the percent increase in population for all metropolitan areas in the U.S. with more than 250,000 people. Data from these two tables were combined to give population multipliers for states along routes for which the collective dose and the population increase were significant enough to make a correction.

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The population multipliers used are shown in Table II-5, "Significant" was taken to mean that the population difference was more than 1% (i.e., multipliers between 0.99 and 1.01 were not considered significant). The state-specific multiplier was applied to rural and suburban routes through the state (even though some of these routes would be within the largest metropolitan area), and the multiplier for the largest metropolitan area in that state was applied to the urban route segments (even though some of the urban segments may not be within the largest metropolitan area). For states without a metropolitan area with more than 250,000 people (Delaware, Montana, North Dakota, South Dakota, Vermont and Wyoming), the state-wide increase was used.

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Table II-5. Population multipliers

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5. State	6. Rural, Suburban, Urban Designation	7. Population Multiplier	8. State	9. Rural, Suburban, Urban Designation	10. Population Multiplier
Arkansas	Rural, Suburban	1.051	New Hampshire	Rural, Suburban	1.064
	Urban	1.069		Urban	1.058
Colorado	Rural, Suburban	1.105	New Jersey	Rural, Suburban	1.037
	Urban	1.105		Urban	1.027
Connecticut	Rural, Suburban	1.029	New Mexico	Rural, Suburban	1.075
	Urban	1.020		Urban	1.119
Delaware	Rural, Suburban	1.089	New York	Rural, Suburban	1.017
	Urban	1.089		Urban	1.027
District of Columbia	Rural, Suburban	1.017	Ohio	Rural, Suburban	1.011
	Urban[a]	1.017		Urban	0.984
Idaho	Rural, Suburban	1.133	Oklahoma	Rural, Suburban	1.037
	Urban	1.221		Urban	1.070
Illinois	Rural, Suburban	1.033	Oregon	Rural, Suburban	1.082
	Urban	1.045		Urban	1.109
Indiana	Rural, Suburban	1.038	Pennsylvania	Rural, Suburban	1.013
	Urban	1.092		Urban	1.025
Iowa	Rural, Suburban	1.019	South Dakota	Rural, Suburban	1.036
	Urban	1.110		Urban	1.036
Kansas	Rural, Suburban	1.028	Tennessee	Rural, Suburban	1.061
	Urban	1.037		Urban	1.109
Kentucky	Rural, Suburban	1.041	Texas	Rural, Suburban	1.127
	Urban	1.051		Urban	1.163
Maine	Rural, Suburban	1.037	Utah	Rural, Suburban	1.142
	Urban	1.054		Urban	1.102
Maryland	Rural, Suburban	1.060	Vermont	Rural, Suburban	1.025
	Urban	1.103		Urban	1.025
Massachusetts	Rural, Suburban	1.014	Virginia	Rural, Suburban	1.080
	Urban	1.014		Urban	1.103
Minnesota	Rural, Suburban	1.050	Washington	Rural, Suburban	1.085
	Urban	1.069		Urban	1.072
Missouri	Rural, Suburban	1.044	Wisconsin	Rural, Suburban	1.036
	Urban	1.036		Urban	1.006
Montana	Rural, Suburban	1.047	Wyoming	Rural, Suburban	1.043
	Urban	1.047		Urban	1.043
Nebraska	Rural, Suburban	1.033			
	Urban	1.072			

[a]For the urban areas within the District of Columbia, the growth rate of the District was used rather than the growth rate of metropolitan Washington. The growth rate of metropolitan Washington was used for urban areas within Maryland and Virginia.

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Parameters like population density and route segment lengths, that are specific to each route, were developed using WebTRAGIS. Figure II-7 through Figure II-10 are WebTRAGIS maps showing the routes.

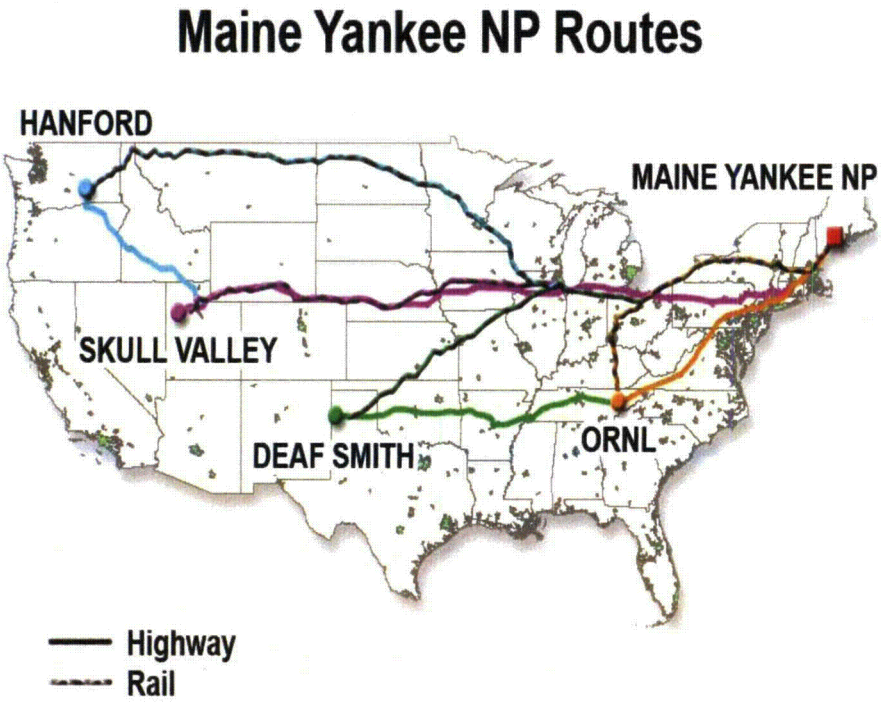

Figure II-7. Highway and rail routes from the Maine Yankee Nuclear Plant (NP) site.

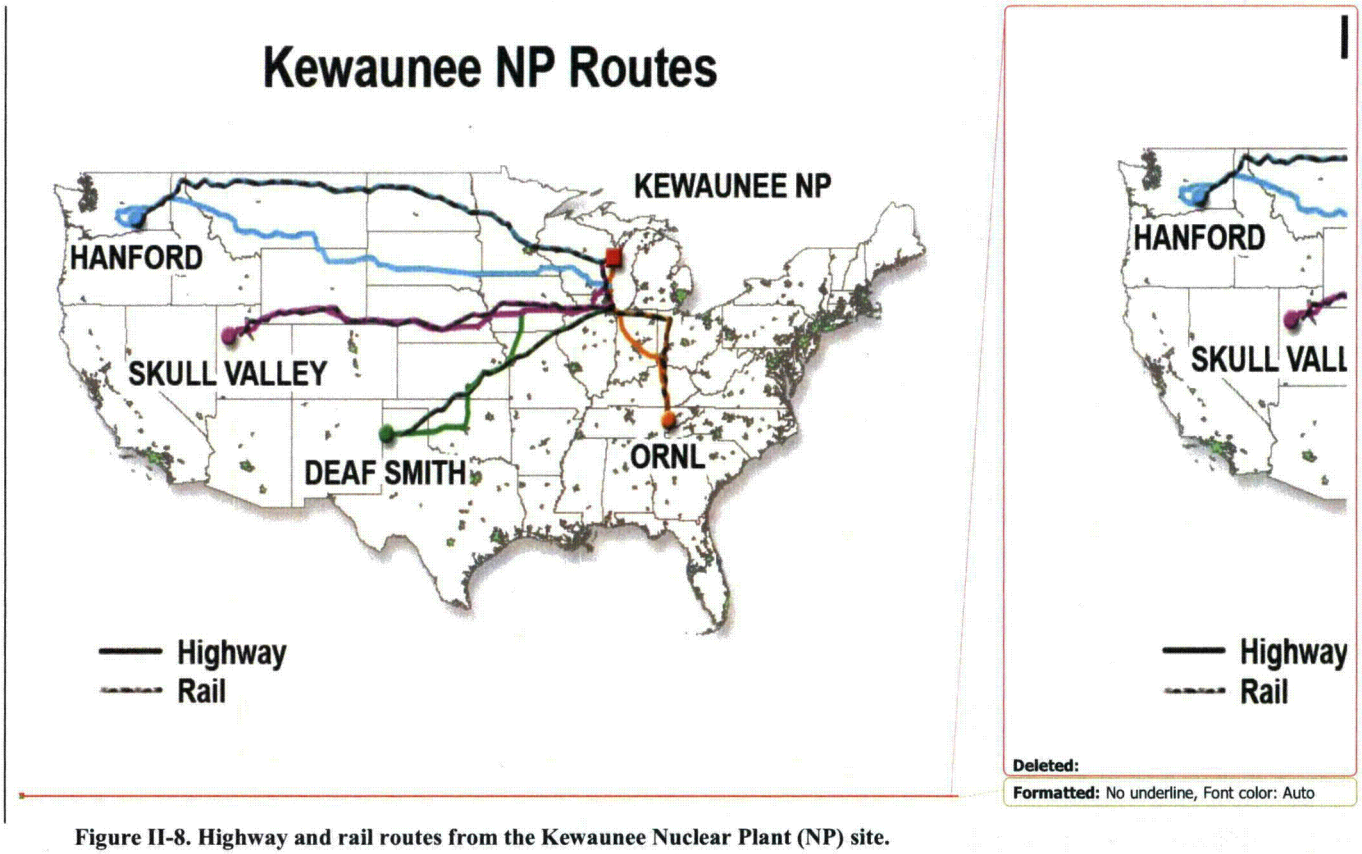

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Figure II-8. Highway and rail routes from the Kewaunee Nuclear Plant (NP) site.

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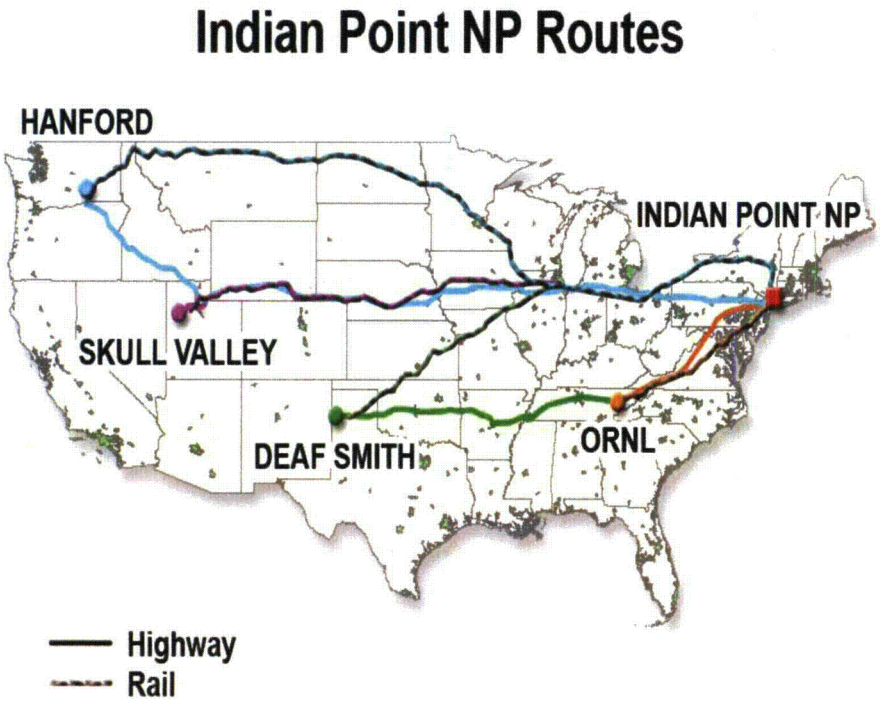

Figure II-9. Highway and rail routes from Indian Point Nuclear Plant (NP).

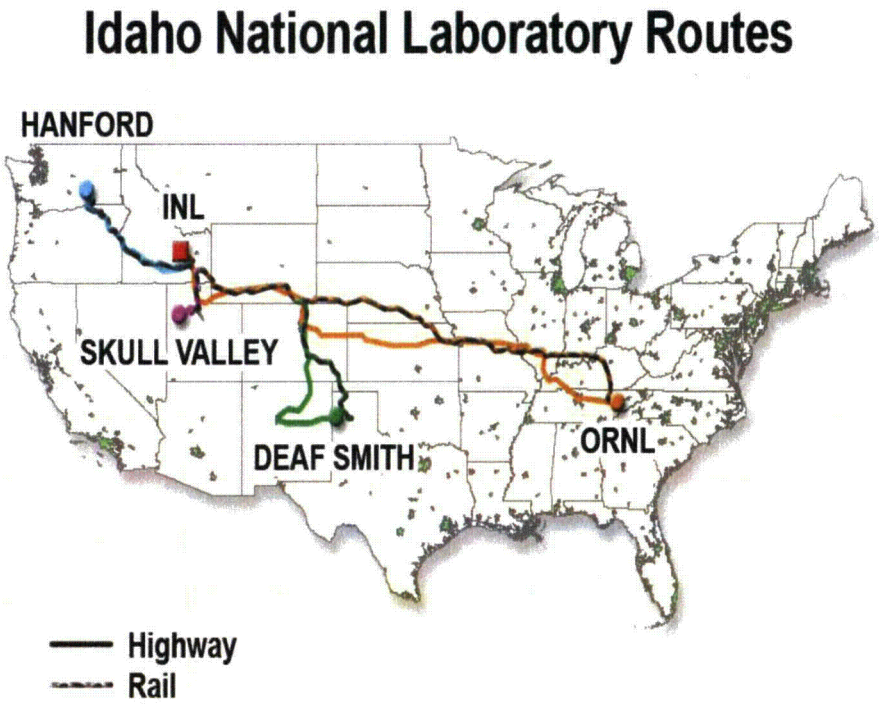

Figure II-10. Highway and rail routes from Idaho National Laboratory (INL).

II.5 Results

II.5.1 Maximally Exposed Resident In-Transit Dose

The largest dose from a moving vehicle to an individual member of the public is sustained when that individual is 30 meters (a conservative estimate of the interstate right-of-way) from the moving vehicle, and the vehicle is moving at the slowest speed it would be likely to maintain. This speed is 24 kph (16 mph) for both rail and truck. Table II-6 shows the maximum individual dose, in Sv, for each package. These doses are directly proportional to the external dose rate (TI) of each package. For comparison, a single dental x-ray delivers a dose of 4×10^{-5} Sv (Stabin, 2009), about 7000 times the doses shown in Table II-6.

Table II-6. Maximum individual doses.

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11. Package (mode)	12. Dose in Sv
Truck-DU (truck)	6.7×10^{-9}
Rail-Lead (rail)	5.7×10^{-9}
Rail-Steel (rail)	4.3×10^{-9}

Figures II-11 and II-12 show the portion of the RADTRAN output file that reflects these doses.

```
RUN DATE: [ 03-02-2010   AT 18:07 ]            PAGE   11
                    TRUCK URF -- PUBLIC

              MAXIMUM INDIVIDUAL IN-TRANSIT DOSE
                       GA_4        6.70E-07 REM
```

Figure II-11. RADTRAN output for maximum individual truck doses.

```
RUN DATE: [ 02-19-2010   AT 10:55 ]            PAGE   10
                         NAC-STC
              MAXIMUM INDIVIDUAL IN-TRANSIT DOSE


                    NAC-STC      5.67E-07 REM

                    HI-STAR      4.30E-07 REM
```

Figure II-12. RADTRAN output for maximum individual rail doses.

II.5.2 Unit Risk: Rail Routes

The doses to railyard workers along the route, to residents and others along the route, and to occupants of vehicles that share the route from a single shipment (one rail cask) traveling one km past a population density of one person/km^2 are shown in Table II-7. The dose units are person-Sv. The doses are calculated assuming one cask on a train, because railcar-km is the unit usually used to describe freight rail transport. The data in this table may be used to calculate collective doses along routes as follows:

This is a conservatively calculated dose that assumes that the railyard crew receives a fraction of the classification yard dose when the train stops. The railyard crew dose is multiplied by the length of each type of route traveled. The classification yard occupational collective dose (Wooden, 1986), assuming a 30-hour classification stop, is integrated into RADTRAN. This integrated dose was adjusted to reflect the 27-hour stop (

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- Table II-3) (DOT, 2004b).

- The area of the band occupied by the population along the route is equal to the product of the kilometers traveled and the band width (usually 800 m on each side of the route). RADTRAN calculates the dose to a resident along the route by integrating over this area. This "unit dose to a resident along the route" is multiplied by the area of the band and the appropriate population density (obtained from a routing code like WebTRAGIS).

Table II-7. Individual doses ("unit doses" or "unit risks") to various receptors for rail routes. The units of the dose to the residents near a railyard where the train has stopped, Sv- km^2/hour, reflect the output of the RADTRAN stop model, which incorporates the area occupied.

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13. Cask and route type	Resident along route, Sv	Resident near railyard 14. Sv-km²/hour	Occupants of vehicles sharing the route 15. person-Sv
Rail-Lead rural	7.3E-10	3.5E-07	1.6 E-08
Rail-Lead suburban	6.3E-10	3.5E-07	1.6 E-08
Rail-Lead urban	2.2E-11	3.5E-07	4.6 E-08
Rail-Steel rural	5.6E-10	2.7E-07	1.2E-08
Rail-Steel suburban	4.8E-10	2.7E-07	1.2E-08
Rail-Steel urban	1.7E-11	2.7E-07	3.5E-08

Figure II-13 shows the RADTRAN output for Table II-7 (in rem). The relevant data in the output are in bold print.

```
IN-TRANSIT POPULATION EXPOSURE IN PERSON-REM

   LINK        CREW       OFF LINK    ON LINK
 NAC_R       4.32E-05    7.29E-08    1.63E-06
 NAC_S       4.32E-05    6.34E-08    1.63E-06
 NAC_U       7.28E-05    2.21E-09    4.63E-06
 HISTAR_R    3.27E-05    5.55E-08    1.24E-06
 HISTAR_S    3.27E-05    4.83E-08    1.24E-06
 HISTAR_U    5.51E-05    1.68E-09    3.50E-06

STOP EXPOSURE IN PERSON-REM

ANNULAR AREA    CLASSIFICA    3.51E-05
ANNULAR AREA    CLASSIFICA    2.66E-05
```

Figure II-13. RADTRAN output for Table II-7.

II.5.3 Unit risk: truck routes

The doses to truck crew, residents and others along the route, and to occupants of vehicles that share the route from a single shipment (one truck cask) traveling one kilometer past a population density of one person/km² are shown in Table II-8. The dose units are person-Sv. Rural, suburban, and urban doses to residents living near stops are calculated by multiplying the appropriate stop dose -truck stops are not typically located in urban areas) by the appropriate population density (obtained from a routing code like WebTRAGIS). The number of stops on each route segment is calculated by dividing the length of the route segment by 845 km (average distance between refueling stops for a large semi-detached trailer truck (DOE, 2002, Appendix J). The area of the band occupied by the population along the route is equal to the kilometers traveled multiplied by, e.g., 1.6 for a band width of 800 m on each side of the route.

Table II-8. Individual dose ("unit risk") to various receptors along truck routes. Unit risks are shown for each EPA region (see Table II-18).

	Resident	Resident	Occupants of vehicles sharing route, person-Sv

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	along route Sv	near stops Sv-km²/hour	EPA Regions									
			1	2	3	4	5	6	7	8	9	10
Truck-DU rural	3.1E-10	3.26E-08	4.8E-08	1.1E-07	2.3E-07	1.6E-07	1.3E-07	9.9E-08	1.0E-07	8.8E-08	1.6E-07	1.2E-07
Truck-DU suburban	2.7E-10	2.84E-08	8.0E-08	2.3E-07	4.0E-07	3.1E-07	2.7E-07	1.7E-07	1.8E-07	2.2E-07	4.1E-07	2.9E-07
Truck-DU urban	5.2E-12		2.4E-07	4.6E-07	6.4E-07	6.2E-07	4.9E-07	3.3E-07	2.7E-07	4.1E-07	8.4E-07	6.3E-07
Truck-DU urban rush hour	1.2E-12[a]		2.2E-07	4.3E-07	5.9E-07	5.8E-07	4.5E-07	3.1E-07	2.5E-07	3.8E-07	7.7E-07	5.8E-07
6.9 people sharing stop (person-Sv)		2.3E-04										

[a]One-tenth of the urban route segment is considered "rush-hour km" – equivalent to the truck spending 10% of the urban transit distance during rush hour. RADTRAN has historically assumed that the vehicle density doubles during rush hour and the vehicle speed is halved. The slower vehicle speed impacts the dose to urban residents along the route, but the vehicle density does not. Both factors influence the dose to occupants of vehicles sharing the route. The unit risk factors in the table incorporate the 9/10 of the distance during non-rush hour and 1/10 of the distance during rush hour, so both factors should be multiplied by the total urban distance.

II.5.4 Doses along selected routes.

Doses to receptors along the routes shown in Table II-5 are presented below.

II.5.4.1 Collective doses to receptors along the route

Using route data from Web TRAGIS, collective doses from incident-free transportation were calculated. For rural and suburban route segments, collective doses calculated were doses sustained by the resident population. Non-resident populations were included with residents as receptors along the urban segments of the routes. Table II-9 to

Table II-12 show collective doses along rail routes and Table II-13 to Table II-16, along highway routes. Blank cells in the tables indicate that no route miles for that population type was present along that route (e.g., not all routes transit urban areas in all states).

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Table II-9. Collective doses to residents along the route (person-Sv) from rail transportation; shipment origin INL

DEST. AND ROUTE	Rail-Lead				Rail-Steel			
	Rural	Suburban	Urban	Total	Rural	Suburban	Urban	Total
ORNL								
Colorado	1.3E-07	5.8E-07		7.1E-07	1.0E-07	4.4E-07		5.4E-07
Idaho	1.7E-06	7.6E-06	3.4E-07	9.7E-06	1.3E-06	5.8E-06	2.6E-07	7.4E-06
Illinois	1.8E-06	1.7E-05	4.5E-07	1.9E-05	1.3E-06	1.3E-05	3.4E-07	1.4E-05
Indiana	1.7E-06	8.2E-06	1.8E-07	1.0E-05	1.3E-06	6.3E-06	1.4E-07	7.7E-06
Kansas	1.3E-06	6.6E-06	1.6E-07	8.1E-06	9.7E-07	5.0E-06	1.2E-07	6.1E-06
Kentucky	2.6E-06	2.1E-05	8.6E-07	2.5E-05	2.0E-06	1.6E-05	6.6E-07	1.9E-05
Missouri	2.4E-06	2.2E-05	1.1E-06	2.6E-05	1.8E-06	1.7E-05	8.7E-07	2.0E-05
Nebraska	3.5E-06	1.2E-05	3.5E-07	1.6E-05	2.7E-06	9.5E-06	2.6E-07	1.2E-05
Tennessee	1.2E-06	7.8E-06	4.2E-08	9.1E-06	9.4E-07	6.0E-06	3.2E-08	6.9E-06
Wyoming	1.4E-06	8.8E-06	2.1E-07	1.0E-05	1.1E-06	6.7E-06	1.6E-07	7.9E-06
DEAF SMITH								
Colorado	3.3E-06	4.1E-05	1.7E-06	4.6E-05	2.5E-06	3.2E-05	1.3E-06	3.5E-05
Idaho	1.7E-06	7.6E-06	3.4E-07	9.7E-06	1.3E-06	5.8E-06	2.6E-07	7.4E-06
Oklahoma	1.1E-07	1.8E-07		2.9E-07	8.3E-08	1.4E-07		2.2E-07
Texas	4.1E-07	3.4E-06	5.9E-08	3.8E-06	3.1E-07	2.6E-06	4.4E-08	2.9E-06
Wyoming	1.1E-06	6.0E-06	1.5E-07	7.3E-06	8.5E-07	4.6E-06	1.2E-07	5.6E-06
HANFORD								
Idaho	3.7E-06	1.6E-05	**6.0E-07**	2.0E-05	2.8E-06	1.2E-05	4.6E-07	1.5E-05
Oregon	1.4E-06	9.2E-06	2.2E-07	1.1E-05	1.1E-06	7.0E-06	1.7E-07	8.3E-06
Washington	1.2E-07	4.4E-06	2.6E-07	4.7E-06	8.9E-08	3.3E-06	2.0E-07	3.6E-06
SKULL VALLEY								
Idaho	1.4E-06	6.6E-06	3.3E-07	8.3E-06	1.1E-06	5.0E-06	2.5E-07	6.3E-06
Utah	1.6E-06	1.9E-05	1.1E-06	2.2E-05	1.2E-06	1.4E-05	8.5E-07	1.6E-05

Sample calculation: Urban route from INL to Hanford through Idaho, Rail-Lead cask

RADTRAN output (unit risk): 2.21E-09 person-rem (from Figure II-13)
Population density: 2281 persons/km^2
Population multiplier: 1.133
Route segment length: 10.5 km
Population (collective) dose = 2.21E-09*2281*1.133*10.5 = 6.00E-05 person-rem
Convert to SI units: 6.00E-05 person-rem*0.01person-Sv/person-rem = 6.00E-07 person-Sv
Blank cell indicates no route miles of this population density.

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Table II-10. Collective doses to residents along the route (person-Sv), rail transportation, shipment origin Indian Point

DEST. AND ROUTES	Rail-Lead				Rail-Steel			
	Rural	Suburban	Urban	Total	Rural	Suburban	Urban	Total
ORNL								
Delaware	1.2E-08	7.3E-06	8.2E-07	8.2E-06	9.5E-09	5.6E-06	6.3E-07	6.2E-06
DC	3.2E-09	8.9E-07	4.5E-07	1.3E-06	2.4E-09	6.8E-07	3.5E-07	1.0E-06
Maryland	6.9E-07	2.2E-05	2.0E-06	2.5E-05	5.3E-07	1.7E-05	1.5E-06	1.9E-05
New Jersey	4.0E-07	1.2E-05	1.4E-06	1.4E-05	3.1E-07	9.1E-06	1.1E-06	1.0E-05
New York	3.0E-08	1.6E-06	3.4E-06	5.0E-06	2.3E-08	1.3E-06	2.5E-06	3.8E-06
Pennsylvania	4.9E-08	8.6E-06	3.2E-06	1.2E-05	3.8E-08	6.5E-06	2.4E-06	9.0E-06
Tennessee	2.2E-06	3.0E-05	6.6E-07	3.3E-05	1.7E-06	2.3E-05	5.0E-07	2.5E-05
Virginia	4.1E-06	5.9E-05	2.3E-06	6.5E-05	3.1E-06	4.5E-05	1.7E-06	5.0E-05
DEAF SMITH								
Illinois	1.5E-06	2.7E-05	2.4E-06	3.1E-05	1.1E-06	2.0E-05	1.8E-06	2.3E-05
Indiana	2.1E-06	1.1E-05	**5.4E-07**	1.4E-05	1.6E-06	8.6E-06	4.1E-07	1.1E-05
Iowa	3.0E-07	6.2E-07	3.1E-08	9.5E-07	2.3E-07	4.8E-07	2.4E-08	7.2E-07
Kansas	2.0E-06	1.8E-05	7.9E-07	2.1E-05	1.5E-06	1.4E-05	6.0E-07	1.6E-05
Missouri	1.2E-06	7.0E-06	2.4E-07	8.5E-06	9.2E-07	5.4E-06	1.8E-07	6.5E-06
New York	5.5E-06	6.1E-05	4.9E-06	7.1E-05	4.2E-06	4.6E-05	3.7E-06	5.4E-05
Ohio	2.5E-06	3.2E-05	2.3E-06	3.6E-05	1.9E-06	2.4E-05	1.7E-06	2.8E-05
Oklahoma	4.5E-07	4.0E-06	5.2E-08	4.5E-06	3.4E-07	3.1E-06	3.9E-08	3.4E-06
Pennsylvania	4.1E-07	9.3E-06	4.9E-07	1.0E-05	3.1E-07	7.1E-06	3.7E-07	7.8E-06
Texas	7.3E-07	5.1E-06	1.2E-07	6.0E-06	5.6E-07	3.9E-06	9.4E-08	4.5E-06
HANFORD								
Idaho	9.8E-07	6.7E-06	9.6E-08	7.8E-06	7.5E-07	5.1E-06	7.3E-08	5.9E-06
Illinois	1.4E-06	2.1E-05	2.2E-06	2.4E-05	1.0E-06	1.6E-05	1.7E-06	1.9E-05
Indiana	2.1E-06	1.1E-05	5.4E-07	1.4E-05	1.6E-06	8.6E-06	4.1E-07	1.1E-05
Minnesota	3.2E-06	2.9E-05	1.2E-06	3.4E-05	2.4E-06	2.2E-05	8.9E-07	2.6E-05
Montana	2.2E-06	1.3E-05	1.4E-07	1.6E-05	1.7E-06	1.0E-05	1.1E-07	1.2E-05
New York	5.5E-06	6.1E-05	4.9E-06	7.1E-05	4.2E-06	4.6E-05	3.7E-06	5.4E-05
North Dakota	1.0E-06	8.2E-06	2.6E-07	9.5E-06	7.7E-07	6.3E-06	2.0E-07	7.2E-06
Ohio	2.5E-06	3.2E-05	2.3E-06	3.6E-05	1.9E-06	2.4E-05	1.7E-06	2.8E-05
Pennsylvania	4.1E-07	9.3E-06	4.9E-07	1.0E-05	3.1E-07	7.1E-06	3.7E-07	7.8E-06
Washington	1.1E-06	1.3E-05	6.5E-07	1.5E-05	8.5E-07	1.0E-05	5.0E-07	1.2E-05
Wisconsin	1.7E-06	8.2E-06	3.7E-07	1.0E-05	1.3E-06	6.2E-06	2.8E-07	7.8E-06
SKULL VALLEY								
Colorado	1.3E-07	5.8E-07		7.1E-07	1.0E-07	4.4E-07		5.4E-07
Illinois	1.3E-06	2.1E-05	2.7E-06	2.5E-05	9.9E-07	1.6E-05	2.1E-06	1.9E-05
Indiana	2.1E-06	1.1E-05	5.4E-07	1.4E-05	1.6E-06	8.6E-06	4.1E-07	1.1E-05
Iowa	4.0E-06	1.8E-05	3.4E-07	2.2E-05	3.1E-06	1.4E-05	2.6E-07	1.7E-05
Nebraska	4.2E-06	2.0E-05	6.2E-07	2.5E-05	3.2E-06	1.5E-05	4.7E-07	1.9E-05
New York	5.5E-06	6.1E-05	4.9E-06	7.1E-05	4.2E-06	4.6E-05	3.7E-06	5.4E-05
Ohio	2.5E-06	3.2E-05	2.3E-06	3.6E-05	1.9E-06	2.4E-05	1.7E-06	2.8E-05
Pennsylvania	4.1E-07	9.3E-06	4.9E-07	1.0E-05	3.1E-07	7.1E-06	3.7E-07	7.8E-06
Utah	1.3E-06	1.8E-05	1.1E-06	2.0E-05	9.7E-07	1.4E-05	8.6E-07	1.6E-05
Wyoming	1.4E-06	9.5E-06	2.3E-07	1.1E-05	1.0E-06	7.2E-06	1.8E-07	8.4E-06

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Sample calculation: Urban route from Indian Point to Deaf Smith through Indiana, Rail-Lead cask

RADTRAN output (unit risk): 2.21E-09 person-rem (from Figure II-13)
Population density: 2305.9 persons/km^2
Population multiplier: 1.0
Route segment length: 10.6 km
Population (collective) dose = 2.21E-09*2305.9*1.0 *10.6 = 5.40 E-05 person-rem
Convert to SI units: 5.40E-05 person-rem*0.01person-Sv/person-rem = 5.40E-07 person-Sv

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Table II-11. Collective doses to residents along the route (person-Sv) rail transportation; shipment origin Kewaunee

DEST. AND ROUTES	Rail-Lead				Rail-Steel			
	Rural	Suburban	Urban	Total	Rural	Suburban	Urban	Total
ORNL								
Illinois	2.4E-07	2.1E-05	2.5E-06	2.3E-05	1.8E-07	1.6E-05	1.9E-06	1.8E-05
Indiana	2.1E-06	1.1E-05	5.4E-07	1.4E-05	1.6E-06	8.6E-06	4.1E-07	1.1E-05
Kentucky	3.2E-06	1.6E-05	7.0E-07	2.0E-05	2.4E-06	1.3E-05	5.3E-07	1.5E-05
Ohio	2.2E-06	3.0E-05	1.4E-06	3.3E-05	**1.6E-06**	2.3E-05	1.1E-06	2.5E-05
Tennessee	7.4E-07	5.0E-06	4.1E-08	5.7E-06	5.6E-07	3.8E-06	3.1E-08	4.4E-06
Wisconsin	1.9E-06	2.5E-05	1.5E-06	2.9E-05	1.5E-06	1.9E-05	1.1E-06	2.2E-05
DEAF SMITH								
Illinois	1.6E-06	3.5E-05	3.0E-06	4.0E-05	1.2E-06	2.7E-05	2.3E-06	3.0E-05
Iowa	3.0E-07	6.2E-07	3.1E-08	9.5E-07	2.3E-07	4.8E-07	2.4E-08	7.2E-07
Kansas	2.0E-06	1.8E-05	7.9E-07	2.1E-05	1.5E-06	1.4E-05	6.0E-07	1.6E-05
Missouri	1.2E-06	7.0E-06	2.8E-07	8.5E-06	9.2E-07	5.4E-06	2.2E-07	6.5E-06
Oklahoma	4.5E-07	4.0E-06	5.2E-08	4.5E-06	3.4E-07	3.1E-06	3.9E-08	3.4E-06
Texas	7.3E-07	5.1E-06	1.2E-07	6.0E-06	5.6E-07	3.9E-06	9.4E-08	4.6E-06
Wisconsin	1.9E-06	2.5E-05	1.5E-06	2.9E-05	1.5E-06	1.9E-05	1.1E-06	2.2E-05
HANFORD								
Idaho	9.8E-07	6.7E-06	9.6E-08	7.8E-06	7.5E-07	5.1E-06	7.3E-08	5.9E-06
Minnesota	3.3E-06	3.0E-05	9.2E-07	3.5E-05	2.5E-06	2.3E-05	7.0E-07	2.6E-05
Montana	2.2E-06	1.3E-05	1.4E-07	1.3E-05	1.7E-06	1.0E-05	1.1E-07	1.0E-05
North Dakota	1.0E-06	8.2E-06	2.6E-07	9.5E-06	7.7E-07	6.3E-06	2.0E-07	7.2E-06
Washington	1.1E-06	1.3E-05	6.5E-07	1.5E-05	8.5E-07	1.0E-05	5.0E-07	1.2E-05
Wisconsin	3.5E-06	2.2E-05	8.9E-07	2.6E-05	2.7E-06	1.7E-05	6.8E-07	2.0E-05
SKULL VALLEY								
Colorado	1.3E-07	5.8E-07	0.0E+00	7.1E-07	1.0E-07	4.4E-07	0.0E+00	5.4E-07
Illinois	1.4E-06	2.7E-05	2.8E-06	3.1E-05	1.1E-06	2.1E-05	2.1E-06	2.4E-05
Iowa	4.0E-06	1.8E-05	3.4E-07	2.2E-05	3.1E-06	1.4E-05	2.6E-07	1.7E-05
Nebraska	4.2E-06	2.0E-05	6.2E-07	2.5E-05	3.2E-06	1.5E-05	4.7E-07	1.9E-05
Utah	1.3E-06	1.8E-05	1.1E-06	2.0E-05	9.7E-07	1.4E-05	8.6E-07	1.6E-05
Wisconsin	1.9E-06	2.5E-05	1.5E-06	2.9E-05	1.5E-06	1.9E-05	1.1E-06	2.2E-05
Wyoming	1.4E-06	9.5E-06	2.3E-07	1.1E-05	1.0E-06	7.2E-06	1.8E-07	8.4E-06

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Sample calculation: Rural route from Kewaunee to ORNL through Ohio, Rail-steel cask

RADTRAN output (unit risk): 5.55E-08 person-rem (from Figure II-13)
Population density: 14.8 persons/km^2
Population multiplier: 1.0
Route segment length: 200.6 km
Population (collective) dose = 5.55E-08*14.8*1.0*200.6 = 1.65E-04 person-rem
Convert to SI units: 1.65E-04 person-rem*0.01person-Sv/person-rem = 1.65E-06 person-Sv

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Table II-12. Collective doses to residents along the route (person-Sv) rail shipment origin Maine Yankee

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DEST. AND ROUTES	Rail-Lead				Rail-Steel			
	Rural	Suburban	Urban	Total	Rural	Suburban	Urban	Total
ORNL								
Kentucky	3.2E-06	1.6E-05	7.0E-07	2.0E-05	2.4E-06	1.3E-05	5.3E-07	1.5E-05
Maine	9.3E-07	1.6E-05	6.2E-07	1.7E-05	7.1E-07	1.2E-05	4.7E-07	1.3E-05
Massachusetts	1.3E-06	2.9E-05	1.8E-06	3.2E-05	1.0E-06	2.2E-05	1.4E-06	2.4E-05
New Hampshire	3.8E-07	7.5E-06	2.5E-07	8.2E-06	2.9E-07	5.7E-06	1.9E-07	6.2E-06
New York	4.8E-06	5.2E-05	1.8E-06	5.9E-05	3.7E-06	4.0E-05	1.4E-06	4.5E-05
Ohio	3.6E-06	4.9E-05	3.2E-06	5.6E-05	2.7E-06	3.7E-05	2.5E-06	4.3E-05
Pennsylvania	4.2E-07	9.4E-06	5.1E-07	1.0E-05	3.2E-07	7.2E-06	3.9E-07	7.9E-06
Tennessee	7.4E-07	5.0E-06	4.1E-08	5.7E-06	5.6E-07	3.8E-06	3.1E-08	4.4E-06
Vermont	6.7E-08	5.2E-07		5.9E-07	5.1E-08	4.0E-07		4.5E-07
DEAF SMITH								
Illinois	1.5E-06	2.7E-05	2.4E-06	3.1E-05	1.1E-06	2.0E-05	1.8E-06	2.3E-05
Indiana	2.1E-06	1.1E-05	5.4E-07	1.4E-05	1.6E-06	8.6E-06	4.1E-07	1.1E-05
Iowa	3.0E-07	6.2E-07	3.1E-08	9.5E-07	2.3E-07	4.8E-07	2.4E-08	7.2E-07
Kansas	2.0E-06	1.8E-05	7.9E-07	2.1E-05	1.5E-06	1.4E-05	6.0E-07	1.6E-05
Maine	9.3E-07	1.6E-05	6.2E-07	1.7E-05	7.1E-07	1.2E-05	4.7E-07	1.3E-05
Massachusetts	1.3E-06	2.9E-05	1.8E-06	3.2E-05	1.0E-06	2.2E-05	1.4E-06	2.4E-05
Missouri	1.2E-06	7.0E-06	2.4E-07	8.5E-06	9.2E-07	5.4E-06	1.8E-07	6.5E-06
New Hampshire	3.8E-07	7.5E-06	2.5E-07	8.2E-06	2.9E-07	5.7E-06	1.9E-07	6.2E-06
New York	4.8E-06	5.2E-05	1.8E-06	5.9E-05	3.7E-06	4.0E-05	1.4E-06	4.5E-05
Ohio	2.5E-06	3.2E-05	2.3E-06	3.6E-05	1.9E-06	2.4E-05	1.7E-06	2.8E-05
Oklahoma	4.3E-07	3.9E-06	4.9E-08	4.5E-06	3.3E-07	3.0E-06	3.7E-08	3.4E-06
Pennsylvania	4.1E-07	9.3E-06	4.9E-07	1.0E-05	3.1E-07	7.1E-06	3.7E-07	7.8E-06
Texas	7.3E-07	5.1E-06	1.2E-07	6.0E-06	5.6E-07	3.9E-06	9.4E-08	4.5E-06
Vermont	6.7E-08	5.2E-07		5.9E-07	5.1E-08	4.0E-07		4.5E-07
HANFORD								
Idaho	9.8E-07	6.7E-06	9.6E-08	7.8E-06	7.5E-07	5.1E-06	7.3E-08	5.9E-06
Illinois	1.4E-06	2.1E-05	2.2E-06	2.4E-05	1.0E-06	1.6E-05	1.7E-06	1.9E-05
Indiana	2.1E-06	1.1E-05	5.4E-07	1.4E-05	1.6E-06	8.6E-06	4.1E-07	1.1E-05
Maine	9.3E-07	1.6E-05	6.2E-07	1.7E-05	7.1E-07	1.2E-05	4.7E-07	1.3E-05
Massachusetts	1.3E-06	2.9E-05	1.8E-06	3.2E-05	1.0E-06	2.2E-05	1.4E-06	2.4E-05
Minnesota	3.2E-06	2.9E-05	1.2E-06	3.4E-05	2.4E-06	2.2E-05	8.9E-07	2.6E-05
Montana	2.2E-06	1.3E-05	1.4E-07	1.6E-05	1.7E-06	1.0E-05	1.1E-07	1.2E-05
New Hampshire	3.8E-07	7.5E-06	2.5E-07	8.2E-06	2.9E-07	5.7E-06	1.9E-07	6.2E-06
New York	4.8E-06	5.2E-05	2.2E-06	5.9E-05	3.7E-06	4.0E-05	1.7E-06	4.5E-05
North Dakota	1.0E-06	8.2E-06	2.6E-07	9.5E-06	7.7E-07	6.3E-06	2.0E-07	7.2E-06
Ohio	2.5E-06	3.2E-05	2.3E-06	3.6E-05	1.9E-06	2.4E-05	1.7E-06	2.8E-05

Table II-12. Collective doses to residents along the route (person-Sv) rail shipment origin Maine Yankee -- continued

DEST. AND ROUTES	Rail-Lead				Rail-Steel			
	Rural	Suburban	Urban	Total	Rural	Suburban	Urban	Total
HANFORD (cont.)								
Pennsylvania	4.1E-07	9.3E-06	4.9E-07	1.0E-05	3.1E-07	7.1E-06	3.7E-07	7.8E-06
Vermont	6.7E-08	5.2E-07		5.9E-07	5.1E-08	4.0E-07		4.5E-07
Washington	1.1E-06	1.3E-05	6.5E-07	1.5E-05	8.5E-07	1.0E-05	5.0E-07	1.2E-05
Wisconsin	1.7E-06	8.2E-06	3.7E-07	1.0E-05	1.3E-06	6.2E-06	2.8E-07	7.8E-06
SKULL VALLEY								
Colorado	1.3E-07	5.8E-07		7.1E-07	1.0E-07	4.4E-07		5.4E-07
Illinois	1.3E-06	2.2E-05	2.7E-06	2.6E-05	1.0E-06	1.7E-05	2.0E-06	2.0E-05
Indiana	2.1E-06	1.1E-05	5.4E-07	1.4E-05	1.6E-06	8.6E-06	4.1E-07	1.1E-05
Iowa	4.0E-06	1.8E-05	3.4E-07	2.2E-05	3.1E-06	1.4E-05	2.6E-07	1.7E-05
Maine	9.6E-07	1.6E-05	1.6E-07	1.7E-05	7.3E-07	1.2E-05	1.2E-07	1.3E-05
Massachusetts	6.5E-07	2.8E-05	8.5E-07	3.0E-05	4.9E-07	2.1E-05	6.5E-07	2.3E-05
Nebraska	4.2E-06	2.0E-05	6.2E-07	2.5E-05	**3.2E-06**	1.5E-05	4.7E-07	1.9E-05
New Hampshire	1.1E-07	3.7E-06	4.9E-08	3.8E-06	8.6E-08	2.8E-06	3.7E-08	2.9E-06
New York	4.8E-06	5.2E-05	1.8E-06	5.9E-05	3.7E-06	4.0E-05	1.4E-06	4.5E-05
Ohio	2.5E-06	3.2E-05	2.3E-06	3.6E-05	1.9E-06	2.4E-05	1.7E-06	2.8E-05
Pennsylvania	4.1E-07	9.3E-06	4.9E-07	1.0E-05	3.1E-07	7.1E-06	3.7E-07	7.8E-06
Utah	1.3E-06	1.8E-05	1.1E-06	2.0E-05	9.7E-07	1.4E-05	8.6E-07	1.6E-05
Vermont	6.7E-08	5.2E-07	0.0E+00	5.9E-07	5.1E-08	4.0E-07	0.0E+00	4.5E-07
Wyoming	1.4E-06	9.5E-06	2.3E-07	1.1E-05	1.0E-06	7.2E-06	1.8E-07	8.4E-06

Sample calculation: Rural route from Maine Yankee to Skull Valley through Nebraska, Rail-steel cask

RADTRAN output (unit risk): 5.55E-08 person-rem (from Figure II-13)
Population density: 9.3 persons/km^2
Population multiplier: 1.0
Route segment length: 621.7 km
Population (collective) dose = 5.55E-08*9.3*1.0*621.7 = 3.21E-04 person-rem
Convert to SI units: 3.17E-04 person-rem*0.01person-Sv/person-rem = 3.21E-06 person-Sv

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Table II-13. Collective doses to residents along the route (person-Sv) from truck transportation (Truck-DU); shipment origin Maine Yankee

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DESTINATION	ROUTES	Rural	Suburban	Urban	Urban Rush Hour	TOTAL
ORNL	Connecticut	2.8E-07	1.5E-05	5.6E-07	1.2E-07	1.58E-05
	Maine	4.0E-07	7.3E-06	6.6E-08	1.5E-08	7.74E-06
	Maryland	3.4E-08	1.3E-06	1.3E-08	3.0E-09	1.33E-06
	Massachusetts	2.7E-07	1.2E-05	2.0E-07	4.5E-08	1.23E-05
	New Hampshire	4.7E-08	1.5E-06	7.4E-09	1.6E-09	1.59E-06
	New Jersey	1.8E-07	6.4E-06	3.1E-07	6.9E-08	6.92E-06
	New York	**2.1E-09**	1.7E-06	5.1E-07	1.1E-07	2.28E-06
	Pennsylvania	1.1E-06	1.3E-05	1.6E-07	3.6E-08	1.42E-05
	Tennessee	7.6E-07	9.4E-06	7.9E-08	1.8E-08	1.02E-05
	Virginia	1.8E-06	1.9E-05	1.3E-07	2.8E-08	2.13E-05
	West Virginia	1.1E-07	2.6E-06	7.2E-09	1.6E-09	2.73E-06
DEAF SMITH	Connecticut	1.5E-06	9.9E-06	9.5E-08	2.1E-08	1.15E-05
	Maine	2.9E-07	1.5E-05	5.7E-07	1.3E-07	1.60E-05
	Maryland	4.0E-07	6.8E-06	3.7E-08	8.2E-09	7.28E-06
	Massachusetts	3.4E-08	1.3E-06	1.3E-08	3.0E-09	1.34E-06
	New Hampshire	2.7E-07	1.2E-05	2.0E-07	4.5E-08	1.23E-05
	New Jersey	4.7E-08	1.5E-06	7.4E-09	1.6E-09	1.59E-06
	New York	2.4E-07	8.6E-06	1.7E-07	3.9E-08	9.03E-06
	Oklahoma	2.4E-08	4.3E-06	2.0E-07	4.5E-08	4.53E-06
	Pennsylvania	1.6E-06	8.4E-06	1.1E-07	2.4E-08	1.02E-05
	Tennessee	9.4E-07	1.1E-05	1.3E-07	3.0E-08	1.19E-05
	Texas	2.9E-06	2.5E-05	3.9E-07	8.7E-08	2.83E-05
	Virginia	3.9E-07	2.2E-06	9.5E-08	2.1E-08	2.76E-06
	West Virginia	1.7E-06	1.8E-05	1.2E-07	2.7E-08	2.03E-05

Table II-13. Collective doses to residents along the route (person-Sv) from truck transportation (Truck-DU); shipment origin Maine Yankee -- continued

DESTINATION	ROUTES	Rural	Suburban	Urban	Urban Rush Hour	Total
HANFORD	Connecticut	2.7E-07	1.1E-05	3.0E-07	6.6E-09	1.18E-05
	Idaho	1.4E-06	6.6E-06	9.6E-08	2.1E-09	8.15E-06
	Illinois	8.1E-07	6.5E-06	1.2E-07	2.7E-09	7.42E-06
	Indiana	8.3E-07	7.1E-06	1.2E-07	2.6E-09	8.10E-06
	Iowa	1.9E-06	6.8E-06	5.8E-08	1.3E-09	8.73E-06
	Maine	4.0E-07	6.8E-06	3.7E-08	8.2E-10	7.28E-06
	Massachusetts	2.8E-07	1.2E-05	2.1E-07	4.6E-09	1.28E-05
	Nebraska	2.0E-06	5.4E-06	8.8E-08	2.0E-09	7.48E-06
	New Hampshire	4.7E-08	1.5E-06	7.4E-09	1.6E-10	1.59E-06
	New York	2.8E-07	5.7E-06	5.0E-08	1.1E-09	6.05E-06
	Ohio	1.3E-06	1.2E-05	1.7E-07	3.8E-09	1.39E-05
	Oregon	8.1E-07	2.9E-06	2.6E-08	5.8E-10	3.74E-06
	Pennsylvania	2.0E-06	1.1E-05	8.2E-08	1.8E-09	1.33E-05
	Utah	6.3E-07	4.0E-06	1.8E-08	4.1E-10	4.68E-06
	Washington	8.9E-08	8.4E-07	5.0E-08	1.1E-09	9.92E-07
	Wyoming	9.1E-07	3.6E-06	3.5E-08	7.8E-10	4.54E-06
SKULL VALLEY	Connecticut	2.7E-07	1.1E-05	3.0E-07	6.6E-09	1.18E-05
	Illinois	8.1E-07	6.5E-06	1.2E-07	2.7E-09	7.42E-06
	Indiana	8.3E-07	7.1E-06	1.2E-07	2.6E-09	8.10E-06
	Iowa	1.9E-06	6.8E-06	5.8E-08	1.3E-09	8.73E-06
	Maine	4.0E-07	6.8E-06	3.7E-08	8.2E-10	7.28E-06
	Massachusetts	2.7E-07	1.2E-05	2.0E-07	4.5E-09	1.23E-05
	Nebraska	2.0E-06	5.4E-06	8.8E-08	2.0E-09	7.48E-06
	New Hampshire	4.7E-08	1.5E-06	7.4E-09	1.6E-10	1.59E-06
	New York	2.8E-07	5.7E-06	5.0E-08	1.1E-09	6.05E-06
	Ohio	1.3E-06	1.2E-05	1.7E-07	3.8E-09	1.39E-05
	Pennsylvania	2.0E-06	1.1E-05	8.2E-08	1.8E-09	1.33E-05
	Utah	5.2E-07	4.6E-06	2.0E-07	4.5E-09	5.40E-06
	Wyoming	9.1E-07	3.6E-06	3.5E-08	7.8E-10	4.54E-06

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Sample calculation: Rural route from Maine Yankee to ORNL through New York, truck cask

RADTRAN output (unit risk): 3.05E-08 person-rem (from Table II-8)
Population density: 4.4 persons/km^2
Population multiplier: 1.0
Route segment length:1.6 km
Population (collective) dose = 3.05E-08*4.4*1.0*1.6 = 2.15E-07 person-rem
Convert to SI units: 2.15E-07 person-rem*0.01person-Sv/person-rem = 2.15E-09 person-Sv

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Table II-14 Collective doses to residents along the route (person-Sv) from truck transportation (Truck-DU); shipment origin Indian Point.

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DESTINATION	ROUTES	Rural	Suburban	Urban	U. Rush Hour	Total
ORNL	Maryland	5.4E-08	2.1E-06	3.0E-09	3.0E-09	1.3E-06
	New Jersey	3.9E-07	1.4E-05	3.9E-08	3.9E-08	9.0E-06
	New York	7.5E-08	7.0E-06	4.9E-08	4.9E-08	4.7E-06
	Pennsylvania	9.4E-07	1.1E-05	3.0E-08	3.0E-08	1.2E-05
	Tennessee	7.9E-07	9.7E-06	1.5E-08	1.5E-08	1.1E-05
	Virginia	1.7E-06	1.8E-05	2.7E-08	2.7E-08	2.0E-05
	West Virginia	1.1E-07	2.6E-06	1.6E-09	1.6E-09	2.7E-06
DEAF SMITH	Arkansas	2.3E-06	1.6E-05	2.2E-08	2.2E-08	1.1E-05
	Maryland	5.4E-08	2.1E-06	3.0E-09	3.0E-09	1.3E-06
	New Jersey	3.9E-07	1.4E-05	3.9E-08	3.9E-08	9.0E-06
	New York	4.7E-08	4.3E-06	4.9E-08	4.9E-08	4.7E-06
	Oklahoma	1.7E-06	8.7E-06	2.6E-08	2.6E-08	1.0E-05
	Pennsylvania	9.4E-07	1.1E-05	3.0E-08	3.0E-08	1.2E-05
	Tennessee	2.9E-06	2.5E-05	3.9E-07	8.7E-08	2.8E-05
	Texas	2.9E-06	2.5E-05	8.7E-08	2.1E-08	2.8E-06
	Virginia	3.9E-07	2.2E-06	2.1E-08	2.7E-08	2.0E-05
	West Virginia	1.7E-06	1.8E-05	2.7E-08	1.6E-09	2.7E-06
HANFORD	Idaho	**1.4E-06**	6.6E-06	1.6E-09	2.1E-08	8.1E-06
	Illinois	7.8E-07	6.3E-06	2.1E-08	2.7E-08	7.4E-06
	Indiana	8.6E-07	7.1E-06	2.7E-08	2.6E-08	8.1E-06
	Iowa	1.9E-06	6.8E-06	2.6E-08	1.3E-08	8.7E-06
	Nebraska	2.0E-06	5.4E-06	1.3E-08	2.0E-08	7.5E-06
	New Jersey	2.6E-07	6.7E-06	2.0E-08	3.2E-08	7.1E-06
	New York	4.7E-08	4.3E-06	3.2E-08	4.9E-08	4.7E-06
	Ohio	1.3E-06	1.2E-05	4.9E-08	3.8E-08	1.4E-05
	Oregon	8.9E-07	3.2E-06	3.8E-08	5.8E-09	4.1E-06
	Pennsylvania	1.8E-06	8.7E-06	5.8E-09	8.1E-09	1.1E-05
	Utah	6.3E-07	4.0E-06	8.1E-09	4.1E-09	4.7E-06
	Washington	8.9E-08	8.4E-07	4.1E-09	1.1E-08	9.9E-07
	Wyoming	9.1E-07	3.6E-06	1.1E-08	7.8E-09	4.5E-06
SKULL VALLEY	Illinois	8.1E-07	6.5E-06	7.8E-09	2.7E-08	7.4E-06
	Indiana	8.3E-07	7.1E-06	2.7E-08	2.6E-08	8.1E-06
	Iowa	1.9E-06	6.8E-06	2.6E-08	1.3E-08	8.7E-06
	Nebraska	2.0E-06	5.4E-06	1.3E-08	2.0E-08	7.5E-06
	New Jersey	2.6E-07	6.7E-06	2.0E-08	3.2E-08	7.1E-06
	New York	4.7E-08	4.3E-06	3.2E-08	4.9E-08	4.7E-06
	Ohio	1.3E-06	1.2E-05	4.9E-08	3.8E-08	1.4E-05
	Pennsylvania	1.8E-06	8.7E-06	3.8E-08	8.1E-09	1.1E-05
	Utah	5.1E-07	4.6E-06	8.1E-09	4.5E-08	5.4E-06
	Wyoming	9.1E-07	3.6E-06	4.5E-08	7.8E-09	4.5E-06

Sample calculation: Rural route from Indian Point to Hanford through Idaho, truck cask

RADTRAN output (unit risk): 3.05E-08 person-rem (from Table II-8)
Population density: 11.3 persons/km^2
Population multiplier: 1.133
Route segment length: 357 km
Population (collective) dose = 3.05E-08*11.3*1.133*357= 1.39E-04 person-rem
Convert to SI units: 1.39E-04 person-rem*0.01person-Sv/person-rem = 1.39E-06 person-Sv

Table II-15. Collective doses to residents along the route (person-Sv) from truck transportation (Truck-DU); shipment origin INL

DESTINATION	ROUTES	Rural	Suburban	Urban	Urban Rush Hour	Total
ORNL	Colorado	1.0E-06	4.7E-06	1.4E-07	3.1E-08	5.86E-06
	Idaho	6.3E-07	2.7E-06	2.4E-08	5.4E-09	3.32E-06
	Illinois	9.1E-07	6.0E-06	1.9E-08	4.3E-09	6.98E-06
	Kansas	1.6E-06	6.7E-06	1.1E-07	2.5E-08	8.50E-06
	Kentucky	5.8E-07	2.3E-06	1.8E-09	4.1E-10	2.86E-06
	Missouri	1.2E-06	1.5E-05	3.1E-07	6.9E-08	1.65E-05
	Tennessee	1.4E-06	8.8E-06	1.1E-07	2.5E-08	1.03E-05
	Utah	6.6E-07	4.2E-06	1.8E-08	4.1E-09	4.89E-06
	Wyoming	7.9E-07	2.5E-06	2.5E-08	5.5E-09	3.30E-06
DEAF SMITH	Colorado	1.3E-06	1.6E-05	4.4E-07	9.8E-08	1.74E-05
	Idaho	6.3E-07	2.7E-06	2.4E-08	5.4E-09	3.32E-06
	New	1.2E-06	5.6E-06	1.8E-07	4.1E-08	7.02E-06
	Texas	5.3E-08	9.4E-08			1.47E-07
	Utah	6.6E-07	**4.2E-06**	1.8E-08	4.1E-09	4.89E-06
	Wyoming	7.9E-07	2.5E-06	2.5E-08	5.5E-09	3.30E-06
HANFORD	Idaho	1.7E-06	8.7E-06	1.1E-07	2.5E-08	1.05E-05
	Oregon	3.0E-06	2.5E-08	5.6E-10	5.6E-09	3.83E-06
	Washington	8.4E-07	5.0E-08	1.1E-09	1.1E-08	9.92E-07
SKULL VALLEY	Idaho	6.3E-07	2.7E-06	2.4E-08	5.4E-09	3.32E-06
	Utah	6.0E-07	7.4E-06	2.4E-07	5.4E-08	8.33E-06

Sample calculation: Suburban route from INL to Deaf Smith through Utah, truck cask

RADTRAN output (unit risk): 2.73E-08 person-rem (from Table II-8)
Population density: 260.1persons/km^2
Population multiplier: 1.102
Route segment length: 53.4 km
Population (collective) dose = 2.73E-08*260.1*1.102*53.4= 4.18E-04 person-rem
Convert to SI units: 4.18E-04 person-rem*0.01person-Sv/person-rem = 4.18E-06 person-Sv

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Table II-16. Collective doses to residents along the route (person-Sv) from truck transportation (Truck-DU); shipment origin Kewaunee.

DESTINATION	ROUTES	Rural	Suburban	Urban	Urban Rush Hour	Total
ORNL	Illinois	2.1E-07	9.8E-06	3.6E-07	7.9E-08	1.05E-05
	Indiana	1.3E-06	1.2E-05	2.0E-07	4.5E-08	1.31E-05
	Kentucky	1.2E-06	1.0E-05	1.3E-07	2.9E-08	1.17E-05
	Ohio	5.9E-08	8.3E-07	1.1E-08	2.4E-09	9.04E-07
	Tennessee	3.6E-07	6.2E-06	7.8E-08	1.7E-08	6.67E-06
	Wisconsin	9.8E-07	7.6E-06	3.5E-07	7.8E-08	9.00E-06
DEAF SMITH	Illinois	7.5E-07	3.3E-06	1.2E-08	2.7E-09	4.02E-06
	Iowa	1.4E-06	7.4E-06	6.3E-08	1.4E-08	8.90E-06
	Kansas	1.0E-06	6.9E-06	1.6E-07	3.6E-08	8.16E-06
	Missouri	6.5E-07	6.1E-06	6.2E-08	1.2E-08	6.81E-06
	Oklahoma	1.1E-06	6.0E-06	1.8E-09	2.1E-08	7.18E-06
	Texas	3.9E-07	2.2E-06	9.5E-08	2.1E-08	2.76E-06
	Wisconsin	1.2E-06	7.6E-06	2.8E-07	6.1E-08	9.20E-06
HANFORD	Idaho	2.1E-07	4.1E-06	6.0E-08	1.1E-08	4.03E-06
	Minnesota	1.7E-06	2.7E-06	1.3E-08	2.9E-09	4.46E-06
	Montana	2.1E-06	8.2E-06	1.0E-07	2.2E-08	1.03E-05
	South Dakota	1.5E-06	3.9E-06	3.1E-08	6.9E-09	5.35E-06
	Washington	1.0E-06	9.2E-06	2.0E-07	4.5E-08	1.05E-05
	Wisconsin	2.1E-06	1.1E-05	2.7E-07	6.0E-08	1.38E-05
	Wyoming	5.6E-07	1.6E-06	2.2E-08	4.9E-09	2.21E-06
SKULL VALLEY	Illinois	7.5E-07	3.3E-06	1.2E-08	2.7E-09	4.02E-06
	Iowa	1.9E-06	6.8E-06	5.8E-08	1.3E-08	8.73E-06
	Nebraska	2.0E-06	5.4E-06	8.8E-08	2.0E-08	7.48E-06
	Utah	5.1E-07	4.6E-06	2.0E-07	4.5E-08	5.39E-06
	Wisconsin	1.2E-06	7.6E-06	**2.8E-07**	6.1E-08	9.20E-06
	Wyoming	9.1E-07	3.6E-06	3.5E-08	7.8E-09	4.54E-06

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Sample calculation: Urban route from Kewaunee to Skull Valley through Wisconsin, truck cask, not during rush hour

RADTRAN output (unit risk): 5.22E-10 person-rem (from Table II-8)
Population density: 2660 persons/km^2
Population multiplier: 1.0
Route segment length: 19.9 km
Population (collective) dose = 5.22E-10*2660*1.0*19.9 = 2.76E-05 person-rem
Convert to SI units: 2.76E-05 person-rem*0.01person-Sv/person-rem = 2.76E-07 person-Sv

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Collective dose is best used in making comparisons; e.g., in comparing the risks of routine transportation along different routes. All collective doses modeled are of the order of 10^{-5} person-Sv or less. The tables show that, in general, urban residents sustain a slightly larger dose

from rail transportation than from truck transportation on the same state route, even though urban population densities are similar; e.g., for the Maine urban segment of the Maine Yankee-to-ORNL route,

- the truck route urban population density is 2706 persons/km^2 and the collective dose is 6.6×10^{-8} person-Sv
- the rail route urban population density is 2527 persons/km^2, but the collective dose is 6.2×10^{-7} person-Sv from the Rail-Lead cask is almost 10 times larger than the dose from the Truck-DU cask, even though the external dose rates from the two casks are nearly the same.

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Doses from rail transportation through urban areas are larger than those from truck transportation because train transportation was designed, and train tracks were laid, to go from city center to city center. Trucks carrying spent fuel, on the other hand, are required to use the interstate highway system, and to use bypasses around cities where such bypasses exist. In the example presented, the truck traverses 5 km of urban route while the train traverses 13 urban km. In addition, the average urban train speed is 24 km/hour (15 mph) while the average urban truck speed is 102 km/hour (63.4 mph). A truck carrying a cask through an urban area at about four times the speed of a train carrying a similar cask will deliver ¼ the dose of the rail cask.

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II.5.4.2 Doses to occupants of vehicles sharing the route

The dose to occupants of vehicles sharing a highway route (the on-link dose) consists of the sum of three components:

- dose to persons in vehicles traveling in the opposite direction to the shipment
- dose to persons in vehicles traveling in the same direction as the shipment, and
- dose to persons in passing vehicles.

In the case of rail, there is a dose only to occupants of railcars (the rail analog to highway vehicles) traveling in the opposite direction, since passing on parallel track is rarely the case. RADTRAN uses Equation II-4 to calculate the dose to occupants of vehicles traveling in the opposite direction. The result is

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II-5 $$D_{opp} = 2 * \left(\frac{N * PPV}{V} \right) * \frac{Qk_0 DR_v}{V} \left[f_\gamma * I_\gamma + f_n * I_n \right]$$

Where D_{opp} is the dose to occupants of railcars traveling in the opposite direction
N is the number of railcars sharing the route
PPV is the number of passengers per railcar
And the other terms are defined as in preceding equations. The factor of two is included to account for the vehicle moving toward the radioactive cargo and then away from it and an additional factor of ($N*PPV/V$) for the dose to people in the oncoming vehicle, which is assumed

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to be traveling at the same speed as the cargo. N is the number of oncoming vehicles per hour and P is the number of persons per vehicle.

Rail

The dose to occupants of railcars other than the railcar carrying the radioactive cargo, and moving in the opposite direction, is provided in Table II-17. The vehicle occupancies used to calculate the table, one person on rural and suburban segments, and five people on urban segments, have been used historically in RADTRAN since 1988. The occupancy is consistent with the following considerations:

- Freight trains carry a crew of three, but all but one or two of the 60 to 120 cars on a freight train are unoccupied.
- Urban track carries almost all passenger rail traffic.
- Dose is calculated for one cask on a train, and rail statistics are per railcar, not per train.

The dose to occupants of other trains depends on train speed and the external dose rate from the spent fuel cask. Train speeds are available only for the entire U.S., not for each state. Therefore the doses to occupants of trains that share the route with either a loaded Rail-Lead cask or a loaded Rail-Steel cask are shown in Table II-17 for rural, suburban, and urban segments of each entire route, rather than state-by-state.

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Table II-17. Collective doses (person-Sv) to occupants of trains sharing the route.

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16. SHIPMENT ORIGIN/ DESTINATION	Rail-Lead Cask				Rail-Steel Cask			
	Rural	Suburban	Urban	Total	Rural	Suburban	Urban	Total
MAINE YANKEE								
ORNL	2.0E-05	1.2E-05	7.5E-06	4.0E-05	1.5E-05	9.3E-06	5.6E-06	3.0E-05
DEAF SMITH	3.8E-05	1.3E-05	9.7E-06	6.1E-05	2.9E-05	1.0E-05	7.4E-06	4.6E-05
HANFORD	6.2E-05	1.7E-05	1.6E-05	9.0E-05	4.7E-05	1.3E-05	1.2E-05	6.8E-05
SKULL VALLEY	4.8E-05	1.6E-05	**9.6E-06**	7.4E-05	3.6E-05	1.2E-05	7.3E-06	5.5E-05
KEWAUNEE								
ORNL	1.4E-05	7.0E-06	5.8E-06	2.7E-05	1.0E-05	5.3E-06	4.4E-06	2.0E-05
DEAF SMITH	2.4E-05	5.2E-06	5.1E-06	3.4E-05	1.8E-05	4.0E-06	3.9E-06	2.6E-05
HANFORD	4.2E-05	6.7E-06	2.8E-06	5.2E-05	3.2E-05	5.1E-06	2.1E-06	3.9E-05
SKULL VALLEY	3.5E-05	7.8E-06	5.8E-06	4.9E-05	2.7E-05	5.9E-06	4.4E-06	3.7E-05
INDIAN POINT								
ORNL	9.2E-06	8.1E-06	9.6E-06	2.7E-05	7.0E-06	6.1E-06	7.2E-06	2.0E-05
DEAF SMITH	3.6E-05	1.1E-05	9.4E-06	5.6E-05	2.8E-05	8.2E-06	7.1E-06	4.3E-05
HANFORD	6.0E-05	1.4E-05	1.1E-05	8.5E-05	4.6E-05	1.1E-05	8.0E-06	6.5E-05
SKULL VALLEY	4.8E-05	1.3E-05	1.1E-05	6.5E-05	3.6E-05	1.0E-05	8.0E-06	4.9E-05
INL								
ORNL	4.6E-05	7.1E-06	3.4E-06	5.7E-05	3.5E-05	5.4E-06	2.6E-06	4.3E-05
DEAF SMITH	2.7E-05	3.2E-06	1.9E-06	3.2E-05	2.1E-05	2.5E-06	1.4E-06	2.5E-05
HANFORD	1.5E-05	1.7E-06	9.3E-07	1.8E-05	1.2E-05	1.3E-06	7.0E-07	1.4E-05
SKULL VALLEY	5.5E-06	1.5E-06	1.2E-06	8.2E-06	4.2E-06	1.1E-06	9.0E-07	6.2E-06

Sample calculation: Urban segment from Maine Yankee to Skull Valley, rail-lead cask

RADTRAN output (unit risk): 4.63E-6 person-rem (from Figure II-13)
Route urban length: 207 km (from Table II-4)
Population (collective) dose = 4.63E-6*207= 9.58E-04 person-rem
Convert to SI units: 9.58E-04 person-rem*0.01person-Sv/person-rem = 9.58E-06 person-Sv

The number of occupants of other trains, the train speed, and the railcars per hour are incorporated into the RADTRAN calculation. This is then multiplied by the total rural, suburban, and urban kilometers, respectively, of the route.

Truck

Vehicle density data for large semi-detached trailer trucks traveling U.S. interstates and primary highways is available and well qualified. Every state records traffic counts on major (and most minor) highways and publishes these routinely. Average vehicle density data from each of the 10 EPA regions was used (Weiner, et al., 2009, Appendix D). The EPA regions were used because

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they include all of the "lower 48" U.S. states (Alaska and Hawaii are included in EPA Region 10 but are not considered in this risk assessment because no spent fuel will be shipped to or from them). Table II-18 shows the 10 EPA regions.

Table II-18. States comprising the ten EPA regions

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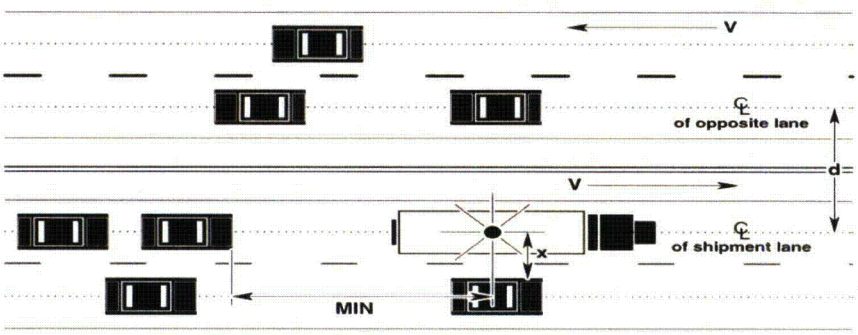
17. Region	18. States Included in Region	Vehicles per Hour		
		Rural	Suburban	Urban
1	Connecticut, Massachusetts, Maine, New Hampshire, Rhode Island, Vermont	439	726	2129
2	New Jersey, New York	1015	2094	4163
3	Delaware. Maryland, Pennsylvania, Virginia, West Virginia	2056	3655	5748
4	Alabama, Florida, Georgia, Kentucky, Mississippi, North Carolina, South Carolina,	1427	2776	5611
5	Illinois, Indiana, Michigan, Minnesota, Ohio, Wisconsin	1200	2466	4408
6	Arkansas, Louisiana, New Mexico, Oklahoma,	897	1498	3003
7	Iowa, Kansas, Missouri, Nebraska	926	1610	2463
8	Colorado, Montana, North Dakota, South Dakota, Utah, Wyoming	795	1958	3708
9	Arizona, California, Nevada	1421	3732	7517
10	Idaho, Oregon , Washington	1123	2670	5624

The calculation of doses to occupants sharing the highway route with the radioactive materials truck includes the dose to vehicles passing the radioactive cargo and vehicles in an adjoining lane, as well as vehicles traveling in the opposite direction. The equations that describe this calculation are Equations 28 and 34 of Neuhauser et al, 2000.

Figure II-14 is the diagram accompanying these equations and shows the parameters used in the calculation. Parameter values are in Table II-1.



Legend

V - Traffic velocity
d - Distance fromRAM vehicle to traffic in opposite direction
x - Distance from RAM vehicle to passing vehicle
MIN - Minimum following distance

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Figure II-14. Parameters for calculating doses to occupants of highway vehicles sharing the route with the radioactive shipment (from Figure 3-2 of Neuhauser, et al., 2000).

Table II-19 to Table II-22 show the doses to individuals in vehicles sharing the highway route with the truck carrying a loaded Truck-DU cask. The number of occupants of other vehicles, the vehicle speed, and the vehicles per hour are incorporated into the RADTRAN calculation. This is then multiplied by the rural, suburban, and urban kilometers, respectively, of each state transited.

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Table II-19

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Table II-19. Collective doses to persons sharing the route (person-Sv) from truck transportation (Truck-DU); shipment origin Maine Yankee

DESTINATION	ROUTES	Rural	Suburban	Urban	Urban Rush Hour	Total
ORNL	Connecticut	2.0E-06	9.2E-06	9.2E-06	8.5E-06	2.9E-05
	Maine	2.9E-06	6.7E-06	1.1E-06	1.0E-06	1.2E-05
	Maryland	1.3E-06	4.9E-06	9.0E-07	8.3E-07	8.0E-06
	Massachusetts	1.7E-06	8.7E-06	3.4E-06	3.2E-06	1.7E-05
	New Hampshire	3.7E-07	1.4E-06	1.9E-07	1.8E-07	2.1E-06
	New Jersey	4.5E-06	1.6E-05	6.6E-06	6.1E-06	3.3E-05
	New York	7.5E-07	2.1E-06	1.3E-05	1.2E-05	2.7E-05
	Pennsylvania	3.0E-05	4.8E-05	7.0E-06	6.5E-06	9.2E-05
	Tennessee	1.7E-05	3.2E-05	4.2E-06	3.9E-06	5.6E-05
	Virginia	6.4E-05	9.3E-05	6.2E-06	5.7E-06	1.7E-04
	West Virginia	2.8E-06	1.2E-05	4.5E-07	4.1E-07	1.5E-05
DEAF SMITH	Arkansas	3.1E-05	2.1E-05	2.8E-06	2.6E-06	5.8E-05
	Connecticut	2.0E-06	9.2E-06	9.2E-06	8.5E-06	2.9E-05
	Maine	2.9E-06	6.8E-06	7.3E-07	6.8E-07	1.1E-05
	Maryland	1.3E-06	4.9E-06	9.0E-07	8.3E-07	8.0E-06
	Massachusetts	1.7E-06	8.7E-06	3.4E-06	3.2E-06	1.7E-05
	New Hampshire	3.7E-07	1.4E-06	1.9E-07	1.8E-07	2.1E-06
	New Jersey	4.5E-06	1.6E-05	6.6E-06	6.1E-06	3.3E-05
	New York	7.5E-07	6.8E-06	6.9E-06	6.4E-06	2.1E-05
	Oklahoma	4.2E-05	1.6E-05	2.8E-06	2.6E-06	6.4E-05
	Pennsylvania	3.0E-05	4.8E-05	7.0E-06	6.5E-06	9.2E-05
	Tennessee	7.8E-05	8.6E-05	2.0E-05	1.8E-05	2.0E-04
	Texas	2.2E-05	3.1E-06	2.4E-06	2.2E-06	2.9E-05
	Virginia	6.4E-05	9.3E-05	6.2E-06	5.7E-06	1.7E-04
	West Virginia	2.8E-06	1.2E-05	4.5E-07	4.1E-07	1.5E-05

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Table II-19. Collective doses to persons sharing the route (person-Sv) from truck transportation (Truck-DU); shipment origin Maine Yankee -- continued

DESTINATION	ROUTES	Rural	Suburban	Urban	Urban Rush Hour	Total
HANFORD	Connecticut	1.7E-06	8.0E-06	5.1E-06	4.7E-06	2.0E-05
	Idaho	4.4E-05	2.3E-05	4.6E-06	4.2E-06	7.6E-05
	Illinois	2.4E-05	2.0E-05	5.0E-06	4.6E-06	5.4E-05
	Indiana	1.8E-05	2.6E-05	4.6E-06	4.3E-06	5.3E-05
	Iowa	4.0E-05	1.7E-05	1.4E-06	1.3E-06	6.0E-05
	Maine	2.9E-06	6.8E-06	7.3E-07	6.8E-07	1.1E-05
	Massachusetts	1.7E-06	8.7E-06	3.4E-06	3.2E-06	1.7E-05
	Nebraska	6.7E-05	1.3E-05	1.9E-06	1.8E-06	8.4E-05
	New Hampshire	3.7E-07	1.4E-06	1.9E-07	1.8E-07	2.1E-06
	New York	2.5E-06	4.6E-06	1.1E-06	9.9E-07	9.2E-06
	Ohio	2.8E-05	6.9E-05	4.0E-06	3.7E-06	1.0E-04
	Oregon	3.7E-05	9.5E-06	1.4E-06	1.3E-06	4.9E-05
	Pennsylvania	8.7E-05	6.9E-05	4.0E-06	3.7E-06	1.6E-04
	Utah	1.6E-05	1.1E-05	6.2E-07	5.7E-07	2.8E-05
	Washington	7.6E-06	2.1E-06	2.6E-06	2.4E-06	1.5E-05
	Wyoming	7.5E-05	1.0E-05	2.1E-06	2.0E-06	8.9E-05
SKULL VALLEY	Connecticut	1.7E-06	8.0E-06	5.1E-06	4.7E-06	2.0E-05
	Illinois	2.4E-05	2.0E-05	5.0E-06	4.6E-06	5.4E-05
	Indiana	1.8E-05	2.6E-05	4.6E-06	4.3E-06	5.3E-05
	Iowa	4.0E-05	1.7E-05	1.4E-06	1.3E-06	6.0E-05
	Maine	2.9E-06	6.8E-06	7.3E-07	6.8E-07	1.1E-05
	Massachusetts	1.7E-06	8.7E-06	3.4E-06	3.2E-06	1.7E-05
	Nebraska	6.7E-05	1.3E-05	1.9E-06	1.8E-06	8.4E-05
	New Hampshire	3.7E-07	4.8E-06	4.8E-07	4.4E-06	1.0E-05
	New York	5.8E-06	1.3E-05	2.1E-06	1.9E-06	2.3E-05
	Ohio	2.8E-05	4.1E-05	7.3E-06	6.7E-06	8.3E-05
	Pennsylvania	8.7E-05	6.9E-05	4.0E-06	3.7E-06	1.6E-04
	Utah	1.8E-05	8.1E-06	6.1E-06	5.6E-06	3.8E-05
	Wyoming	7.5E-05	1.0E-05	2.1E-06	2.0E-06	8.9E-05

Sample Calculation: Rural segment from Maine Yankee to ORNL through Connecticut (Region 1)

Unit risk (From Table II-8: 4.80E-08 Sv

Rural route segment length: 40.7 km

Dose to occupants of vehicles sharing the route: 4.80E-08*40.7 = 1.95E-06

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Table II-20. Collective doses to persons sharing the route (person-Sv) from truck transportation (Truck-DU); shipment origin Indian Point.

DESTINATION	ROUTES	Rural	Suburban	Urban	Urban RH	Total
ORNL	Maryland	1.3E-06	4.9E-06	9.0E-07	8.3E-07	7.9E-
	New Jersey	4.5E-06	1.6E-05	6.6E-06	6.1E-06	3.3E-
	New York	1.3E-06	6.5E-06	7.6E-06	7.0E-06	2.2E-
	Pennsylvania	3.0E-05	4.8E-05	7.0E-06	6.5E-06	9.2E-
	Tennessee	1.7E-05	3.4E-05	3.8E-06	3.5E-06	5.8E-
	Virginia	6.4E-05	9.3E-05	6.2E-06	5.7E-06	1.7E-
	West Virginia	6.4E-05	1.2E-05	4.5E-07	4.1E-07	7.7E-
DEAF SMITH	Arkansas	3.1E-05	2.1E-05	2.8E-06	2.6E-06	5.7E-
	Maryland	1.3E-06	4.9E-06	9.0E-07	8.3E-07	7.9E-
	New Jersey	4.5E-06	1.6E-05	6.6E-06	6.1E-06	3.3E-
	New York	1.3E-06	6.5E-06	7.6E-06	7.0E-06	2.2E-
	Oklahoma	4.2E-05	1.6E-05	2.8E-06	2.6E-06	6.3E-
	Pennsylvania	3.0E-05	4.8E-05	7.0E-06	6.5E-06	9.2E-
	Tennessee	7.8E-05	8.6E-05	2.0E-05	1.8E-05	2.0E-
	Texas	2.2E-05	3.1E-06	2.4E-06	2.2E-06	3.0E-
	Virginia	6.4E-05	9.3E-05	6.2E-06	5.7E-06	1.7E-
	West Virginia	2.8E-06	1.2E-05	4.5E-07	4.1E-07	1.6E-
HANFORD	Idaho	4.4E-05	2.3E-05	4.6E-06		7.6E-
	Illinois	2.4E-05	2.0E-05	5.0E-06	4.6E-06	5.4E-
	Indiana	1.8E-05	2.6E-05	4.6E-06	4.3E-06	5.3E-
	Iowa	4.0E-05	1.7E-05	1.4E-06	1.3E-06	6.0E-
	Nebraska	6.7E-05	1.3E-05	1.9E-06	1.8E-06	8.4E-
	New Jersey	4.8E-06	1.3E-05	5.6E-06	5.2E-06	2.9E-
	New York	1.3E-06	6.5E-06	7.6E-06	7.0E-06	2.2E-
	Ohio	1.5E-06	7.6E-06	8.1E-06	7.4E-06	2.5E-
	Oregon	3.7E-05	9.5E-06	1.4E-06	1.3E-06	4.9E-
	Pennsylvania	8.0E-05	5.7E-05	2.2E-06	2.0E-06	1.4E-
	Utah	1.6E-05	1.1E-05	6.2E-07	5.7E-07	2.8E-
	Washington	7.6E-06	2.1E-06	2.6E-06	2.4E-06	1.5E-
	Wyoming	7.5E-05	1.0E-05	2.1E-06	2.0E-06	8.9E-
SKULL VALLEY	Illinois	2.4E-05	2.0E-05	5.0E-06	4.6E-06	5.4E-
	Indiana	1.8E-05	2.6E-05	4.6E-06	4.3E-06	5.3E-
	Iowa	4.0E-05	1.7E-05	1.4E-06	1.3E-06	6.0E-
	Nebraska	6.7E-05	1.3E-05	1.9E-06	1.8E-06	8.4E-
	New Jersey	5.6E-06	1.5E-05	5.9E-06	5.5E-06	3.2E-
	New York	1.5E-06	7.6E-06	8.1E-06	7.4E-06	2.5E-
	Ohio	2.8E-05	4.1E-05	7.3E-06	6.7E-06	8.3E-
	Pennsylvania	8.0E-05	5.7E-05	2.2E-06	2.0E-06	1.4E-
	Utah	1.8E-05	8.1E-06	6.1E-06	5.6E-06	3.8E-
	Wyoming	7.5E-05	1.0E-05	2.1E-06	2.0E-06	8.9E-

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Sample Calculation: Urban rush hour segment from Indian Point to Hanford through Idaho (Region 10)
Unit risk (From Table II-8: 5.80E-07Sv
Urban route segment length: 7.3 km
Dose to occupants of vehicles sharing the route: 5.80E-07*7.3 = 4.23E-06

Table II-21. Collective doses to persons sharing the route (person-Sv) from truck transportation (Truck-DU); shipment origin INL

DESTINATION	ROUTES	Rural	Suburban	Urban	Urban Rush Hour	Total
ORNL	Colorado	3.1E-05	1.1E-05	4.0E-06	3.7E-06	5.0E-
	Idaho	2.2E-05	8.0E-06	1.3E-06	1.2E-06	3.3E-
	Illinois	2.5E-05	2.4E-05	1.1E-06	1.0E-06	5.1E-
	Kansas	6.2E-05	1.4E-05	2.7E-06	2.5E-06	8.1E-
	Kentucky	1.8E-05	1.1E-05	1.2E-07	1.2E-07	2.9E-
	Missouri	2.5E-05	2.3E-05	7.2E-06	6.7E-06	6.2E-
	Tennessee	3.3E-05	3.5E-05	5.2E-06	4.8E-06	7.8E-
	Utah	1.3E-05	1.1E-05	6.2E-07	5.7E-07	2.5E-
	Wyoming	7.5E-05	1.0E-05	2.1E-06	2.0E-06	8.9E-
DEAF SMITH	Colorado	3.9E-05	3.6E-05	1.9E-05	1.8E-05	1.1E-
	Idaho	2.2E-05	8.0E-06	1.3E-06	1.2E-06	3.3E-
	New Mexico	6.4E-05	9.8E-06	4.8E-06	4.4E-06	8.3E-
	Texas	7.7E-06	1.7E-07			7.9E-
	Utah	1.3E-05	**1.1E-05**	6.2E-07	5.7E-07	2.5E-
	Wyoming	7.0E-05	7.6E-06	1.5E-06	1.4E-06	8.1E-
HANFORD	Idaho	5.5E-05	6.3E-05	5.4E-06	5.0E-06	1.3E-
	Oregon	3.7E-05	2.0E-05	1.4E-06	1.3E-06	6.0E-
	Washington	7.6E-06	2.1E-06	2.6E-06	2.4E-06	1.5E-
SKULL VALLEY	Idaho	2.2E-05	8.0E-06	1.3E-06	1.2E-06	4.2E-
	Utah	1.5E-05	1.5E-05	7.2E-06	6.6E-06	4.4E-

Sample Calculation: Suburban segment from INL to Deaf Smith through Utah (Region 8)
Unit risk (From Table II-8: 2.20E-07 Sv
Suburban route segment length: 53.4 km
Dose to occupants of vehicles sharing the route: 2.15E-07*53.4 = 1.148E-05

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Table II-22. Collective doses to persons sharing the route (person-Sv) from truck transportation (Truck-DU); shipment origin Kewaunee.

DESTINATION	ROUTES	Rural	Suburban	Urban	Urban Rush Hour	Total
ORNL	Illinois	3.7E-06	2.0E-05	1.4E-05	1.3E-05	5.1E-
	Indiana	3.3E-05	3.8E-05	8.3E-06	7.7E-06	8.7E-
	Kentucky	2.7E-05	4.3E-05	7.2E-06	6.7E-06	8.4E-
	Ohio	1.4E-06	2.5E-06	5.4E-07	5.0E-07	4.9E-
	Tennessee	1.1E-05	1.8E-05	4.4E-06	4.1E-06	3.8E-
	Wisconsin	2.0E-05	2.1E-05	1.3E-05	1.2E-05	6.6E-
DEAF SMITH	Illinois	2.0E-05	1.2E-	5.9E-07	5.4E-07	3.3E-
	Iowa	3.2E-05	1.6E-05	1.6E-06	1.4E-06	5.1E-
	Kansas	2.9E-05	1.2E-05	3.5E-06	3.2E-06	4.8E-
	Missouri	1.4E-05	1.1E-05	1.3E-06	1.2E-06	2.8E-
	Oklahoma	3.4E-05	1.1E-05	2.8E-06	2.6E-06	5.0E-
	Texas	2.2E-05	3.1E-06	2.4E-06	2.2E-06	3.0E-
	Wisconsin	2.5E-05	2.3E-05	9.8E-06	9.0E-06	6.7E-
HANFORD	Idaho	9.3E-06	1.1E-05	3.0E-06	2.8E-06	2.6E-
	Minnesota	5.2E-05	1.3E-05	5.4E-07	5.0E-07	6.6E-
	Montana	9.6E-05	3.0E-05	5.4E-06	5.0E-06	1.4E-
	South Dakota	5.3E-05	1.2E-05	1.0E-06	9.5E-07	6.7E-
	Washington	4.6E-05	3.0E-05	1.1E-05	1.0E-05	9.7E-
	Wisconsin	4.6E-05	4.0E-05	9.9E-06	9.2E-06	1.1E-
	Wyoming	4.0E-05	4.1E-06	1.4E-06	1.3E-06	4.7E-
SKULL VALLEY	Illinois	2.0E-05	1.2E-05	5.9E-07	5.4E-07	3.3E-
	Iowa	4.0E-05	1.7E-05	1.4E-06	1.3E-06	6.0E-
	Nebraska	6.7E-05	1.3E-05	1.9E-06	1.8E-06	8.4E-
	Utah	2.4E-05	1.0E-05	8.8E-06	8.1E-06	4.4E-
	Wisconsin	2.5E-05	2.3E-05	**9.8E-06**	9.0E-06	6.7E-
	Wyoming	7.5E-05	1.0E-05	2.1E-06	2.0E-06	8.9E-

Sample Calculation: Urban segment from Kewaunee to Skull Valley through Wisconsin (Region 5) not during rush hour
Unit risk (From Table II-8: 4.90E-07 Sv
Urban route segment length: 19.9 km
Dose to occupants of vehicles sharing the route: 4.90E-07*19.9 = 9.75E-06

II.5.4.3 Doses from stopped vehicles

Rail

Trains are stopped in classification yards at the origin and destination of the trip. The usual length of these classification stops is 27 hours. The collective dose to the railyard workers at

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these classification stops from the radioactive cargo is calculated internally by RADTRAN and is based on calculations of Wooden (1986) which authors of this document have verified. This "classification yard dose" 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
- These collective doses include doses to the train crew while the train is in the yard.

The collective dose to people living near a classification yard is calculated by multiplying the average dose from the rail cask to an individual living near a classification yard, as shown in Table II-7, by the population density between 200 and 800 meters from the rail yard. The population density is obtained from WebTRAGIS, and the integration from 200 to 800 meters (Table II-2) is performed by RADTRAN.

Most train stops along any route are shown in the WebTRAGIS output for that route. The stops on the rail route from Maine Yankee to Hanford are shown in Table II-23 as an example.

Table II-23. Example of rail stops on the Maine Yankee-to-Hanford rail route

Stop	Reason	Route type (R, S, U)[a] and State	Time (hours)
Classification	Initial classification	S, ME	27
1	Railroad transfer (short line to ST)	S, ME	4.0
2	Railroad transfer (ST to CSXT)	R, NY	4.0
3	Railroad transfer (CSXT to IHB)	S, IL	2.0
4	Railroad transfer (IHB to BNSF)	S, IL	<<1
5	Railroad transfer (BNSF to UP)	S, WA	<<1
Classification	Final classification	S, WA	27

[a]Determined from the WebTRAGIS output

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Railyard worker collective doses can then be calculated for Stops 1, 2, and 3 in Table II-23. Parameter values are from Table II-23 and the classification yard dose above:

Dose: $(4/27)*(1.5 \times 10^{-5}) = 2.2 \times 10^{-6}$ person- Sv for the Rail-Lead cask.

Dose: $(4/27)*(1.1 \times 10^{-5}) = 1.6 \times 10^{-6}$ person-Sv for the Rail-Steel cask.

The factor of 4/27 is in the equation because the classification stop doses are calculated by RADTRAN for activities lasting a total of 27 hours, and the in-transit stops are for only four hours.

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

- 3.5×10^{-7} Sv from the Rail-Lead cask.
- 2.7×10^{-7} Sv from the Rail-Steel cask.

Collective doses to residents near a yard (a classification yard or railroad stop) are then calculated from the general expression:

Dose (person-Sv) = (Population density)*(Dose/hr to resident near yard)*(Stop time)*(shielding factor)

Thus, for a suburban population density of 373.8 persons/km^2 (the suburban population density through Maine along the Maine Yankee-to-Hanford route) living near Stop 1 in Table II-23,

Dose = (373.8 persons/km^2)*(3.5×10^{-7} Sv-km^2/hour)*(4 hours)*0.87 = 4.6×10^{-4} person-Sv.

Results for the stops are given in Table II-24.

Table II-24. Doses at rail stops on the Maine Yankee-to-Hanford rail route

Stop	Route type (R, S,	Time (hours)	Railyard worker dose (person-Sv)[b]		Residents near stop (person-Sv)	
			Rail-Lead	Rail-Steel	Rail-Lead	Rail-Steel
Classification, origin	S, ME	27	1.5E-05	1.1E-05	2.3E-05	1.8E-05
1	S, ME	4.0	2.16E-06	1.61E-06	4.6E-04	3.5E-04
2	R, NY	4.0	2.16E-06	1.61E-06	2.5E-05	1.9E-05
3	S, IL	2.0	1.08E-06	8.05E-07	2.9E-04	2.2E-04
Classification, destination	S, WA	27	1.5E-05	1.1E-05	1.9E-05	1.4E-05

[a]Determined from the WebTRAGIS output
[b]The yard worker dose depends only on the length of time the railcar is stopped in the yard, independent of population density and shielding factor.

Truck

Doses at truck stops are calculated differently. There are two types of receptors at a truck stop, in addition to the truck crew: residents who live near the stop and people who share the stop with the refueling truck. Griego, et al. (1996) conducted some time and motion studies at a number of truck stops. They found that the average number of people at a stop between the gas pumps and the nearest building was 6.9, the average distance from the fuel pump to the nearest building was 15 meters, and the longest refueling time for a large semi-detached trailer truck was 0.83 hour (50 minutes). With these parameters, the collective dose to the people sharing the stop would be

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2.3×10^{-4} person-Sv (Table II-8). The relationship between the collective dose and the number of receptors is not linear in this case.

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The collective dose to residents near the stop is calculated in the same way as for rail transportation, using data in Table II-8, the population density of the region around the stop, and the stop time.

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Dose (person-Sv) = (Population density)*(Dose/hr to resident near stop)*(Stop time)

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Thus, for a rural population density of 15.4 persons/km^2 (the average along the Maine Yankee-to-Hanford truck route):

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Dose/stop = (15.4 persons/km^2)*(3.3×10^{-8} Sv-km^2/hour)*(0.83 hours) = 4.2×10^{-5} person-Sv.

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The population density used in the calculation is the density around the truck stop; appropriate residential shielding factors are used in the calculation. Unlike a train, the truck will stop several times on any truck route to fill the fuel tanks. Very large trucks generally carry two 80-gallon tanks each and stop for fuel when the tanks are half empty. A semi carrying a Truck-DU cask can travel an average of 845 km (DOE, 2002) before needing to refuel. The number of refueling (and rest) stops depends on the length of each type of route segment. The following equations are used in this calculation

Route segment length (km)/(845 km/stop) = stops/route segment

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Dose (person-Sv) = (population/km^2)*(dose to resident near stop(Sv-km^2/hr))*
(stops/route segment)*(hours/stop)

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Table II-25 shows the collective doses to residents near stops for the rural and suburban segments of the 16 routes in Table II.4.1. Trucks carrying Truck-DU casks of spent fuel are unlikely to stop in urban areas.

The rural and suburban population densities in Table II-25 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 because the total distance from INL to the Skull Valley site is only 466.2 km. The route from Indian Point to ORNL illustrates another situation. This route is 1028 km long, and would thus include one truck stop, which could be in either a rural or a suburban area.

Table II-25. Collective doses to residents near truck stops

Origin	Route	Type	Persons/ km^2	Average number of stops	Person-Sv
Maine Yankee	ORNL	Rural	19.9	1.73	1.1E-06
		Suburban	395	2.09	2.3E-05
	Deaf Smith	Rural	18.6	2.47	1.5E-06
		Suburban	371	1.6	1.7E-05
	Hanford	Rural	15.4	4.33	2.2E-06
		Suburban	325	1.5	1.4E-05
	Skull Valley	Rural	16.9	3.5	1.9E-06
		Suburban	332.5	1.3	1.2E-05
Kewaunee	ORNL	Rural		0.81	5.2E-07
		Suburban	361	0.59	6.0E-06
	Deaf Smith	Rural	13.5	2.0	8.6E-07
		Suburban	339	0.52	5.0E-06
	Hanford	Rural	10.5	3.4	1.2E-06
		Suburban	316	0.60	5.4E-06
	Skull Valley	Rural	12.5	2.6	1.1E-06
		Suburban	324.5	0.44	4.1E-06
Indian Point	ORNL	Rural	20.5	0.71	4.7E-07
		Suburban	388	0.71	7.8E-06
	Deaf Smith	Rural	17.1	2.3	1.3E-06
		Suburban	370	1.2	1.3E-06
	Hanford	Rural	13.0	4.1	1.8E-06
		Suburban	338	1.1	1.1E-05
	Skull Valley	Rural	14.2	3.3	1.5E-06
		Suburban	351	0.93	9.3E-06
INL	ORNL	Rural	12.4	3.1	1.3E-06
		Suburban	304	0.72	6.3E-06
	Deaf Smith	Rural	7.8	2.3	5.8E-07
		Suburban	339	0.35	3.4E-06
	Hanford	Rural	6.5	0.43	9.0E-08
		Suburban	200	0.57	3.2E-06
	Skull Valley	Rural	10.1	0.42	1.4E-07
		Suburban	343	0.11	1.1E-06

[a]The number of stops is the kilometers of the route segment divided by 845 km, the distance between stops, so that it may be a fraction. Retaining the fraction allows the calculation to be repeated.

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II.5.4.4 Occupational Doses

Occupational doses from routine, incident-free radioactive materials transportation include doses to truck and train crew, railyard workers, inspectors, and escorts. Not included are workers who handle spent fuel containers in storage, loading and unloading casks from vehicles or during

intermodal transfer, and attendants who would refuel trucks, because truck refueling stops in the U.S. no longer have such attendants.[6]

Table II-26 summarizes the occupational doses.

Table II-26. Occupational doses per shipment from routine incident-free transportation

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

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19. Cask and route type	Train crew in transit[a]: 3 people; person-Sv	Truck crew in transit 2 people; person-Sv	Escort: Sv/hour[a]	Inspector: Sv/hour per inspection	Truck stop worker: Sv per shipment	Rail classification yard workers: person-Sv
Rail-Lead rural/suburban	5.4E-09		5.8 E-06			1.5E-05
Rail-Lead urban	9.1E-08		5.8 E-06			
Rail-Steel rural/suburban	4.1E-09		4.4 E-06			1.1E-05
Rail-Steel urban	6.8E-09		4.4 E-06			
Truck-DU rural/suburban		3.8E-07	3.2E-09	3.2E-09	2.0E-09	
Truck-DU urban		3.6E-07	3.2E-09			

[a]The truck crew is shielded while in transit to sustain a maximum dose of 0.02 mSv/hour

The doses to rail crew and rail escorts are similar. Spent fuel may be transported in dedicated trains so that both escorts and train crew are assumed to be within a railcar of the railcar carrying the spent fuel. Escorts in the escort car are not shielded, because they must maintain line-of-sight to the railcar carrying spent fuel. Train crew members are in a crew compartment and were assumed to have some shielding, resulting in an estimated dose about 25 percent less than the escort. The largest collective doses are to railyard workers. The number of workers in railyards is not a constant, and the number of activities that brings these workers into proximity with the shipment varies as well. This analysis assumes the dose to the worker doing an activity for each activity: inspection, coupling and decoupling the railcars, moving the railcar into position for coupling, etc. The differences between doses in the Rail-Lead case and the Rail-Steel case reflect the differences in cask dimensions and in external dose rate.

Truck crew members are shielded so that they receive a maximum dose of 2.0×10^{-5} Sv per hour. This regulatory maximum was imposed in the RADTRAN calculation. Truck inspectors generally spend about an hour within one meter of the cargo (Weiner and Neuhauser, 1992), resulting in a relatively large dose. An upper bound to the duration of a truck refueling stop is about 50 minutes (0.83 hours) (Griego et al,, 1996). The truck stop worker whose dose is reflected in Table II-26 is assumed to be outside (unshielded) at 15 meters from the truck during the stop. Truck stop workers that are in concrete or brick buildings would be shielded from any radiation.

II.6 Interpretation of Collective Dose

Collective dose is essentially the product of an average radiation dose and the number of people who receive that average dose. The following example – a state suburban segment on a particular route – is typical of all routes in all states; only the specific numbers change.

The following parameters characterize a representative segment of the Maine Yankee-to-Hanford truck route; the suburban segment through Illinois, shown below, is a representative example:

- Route segment length: 73 km

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- Suburban population density: 324 persons/km^2
- Area occupied by that population: 0.800 km × 2 × 73 = 116.8 km^2
- Total suburban population exposed to the shipment = 37,800 people
- From Table II-13, the collective radiation dose to that population, from routine, incident-free transportation, is 6.5×10^{-6} person-Sv.
- U.S. background is 0.0036 Sv per year or 4.1×10^{-7} Sv per hour. At an average speed of 108 kph, the population is exposed for 0.675 hour.

The background dose sustained by each member of this population is 2.8×10^{-7} Sv for a total collective dose of 0.0105 person-Sv. The total collective dose is thus 0.0105065 person-Sv with the shipment, and 0.0105000 person-Sv without the shipment. Estimates of the collective radiation risk from shipments of spent fuel are valid only when compared to the collective risk to the particular population when there is no shipment.

Collective Doses from Background and From a Truck Shipment of Spent Nuclear Fuel (Person-Sv)

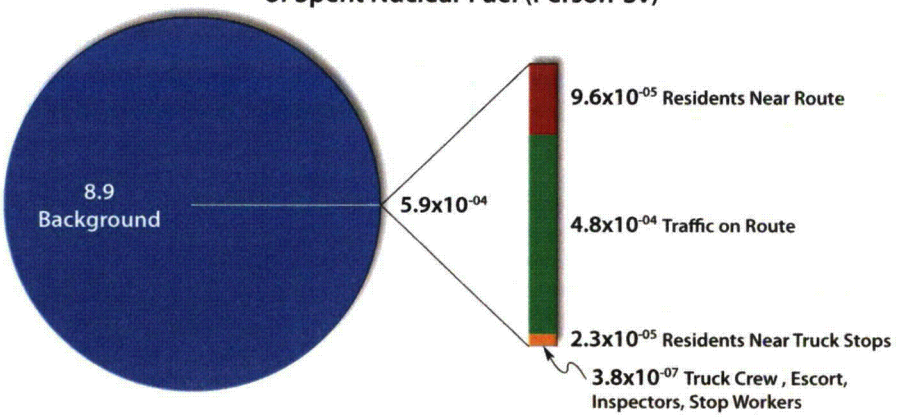

Figure II- 15Table II- 27

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