

## **APPENDIX A. RISK ANALYSIS OF ROUTINE, INCIDENT-FREE TRANSPORTATION**

### **A.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 I of the RADTRAN code (Taylor and Daniel, 1977), which was developed for the NRC by Sandia National Laboratories (SNL) specifically to support the conduct of the NUREG-0170 study. RADTRAN Version 6, integrated with the input file generator RADCAT, (Neuhauser, et al, 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. 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).

### **A.2 The RADTRAN Model of Routine Transportation**

#### **A.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 are called "incident-free doses." Since the probability of routine, incident-free shipment is essentially 100%, RADTRAN calculates a dose rather than a risk for such shipments. 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 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), the dose rate in mrem/hour 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 A.1

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

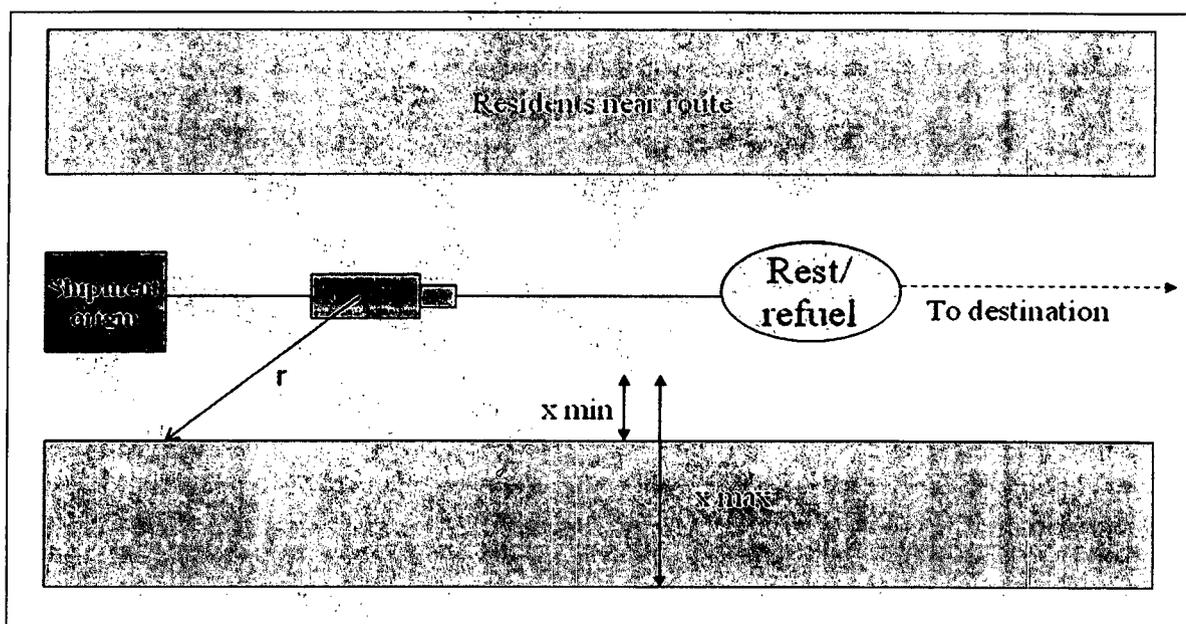
$$(e^{-\mu r}) * B(r) = 1 \quad (2)$$

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

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

where the coefficients are characteristics of the material. The default coefficients in RADTRAN are those for steel.

Collective (population) doses are calculated by integrating over the band along the route where the population resides (the  $x$  integration in Equation (1)) and then integrating along the route from minus to plus infinity ( $-\infty$  to  $\infty$ ) along the route (the  $r$  integration in Equation (1)). This is illustrated for a truck route in Figure A.2. The  $x$  integration limits in Figure A.2 are not to scale:  $x_{min}$  is usually a lane width (about 30 m.) and  $x_{max}$  is usually a half mile (800 m) or more.



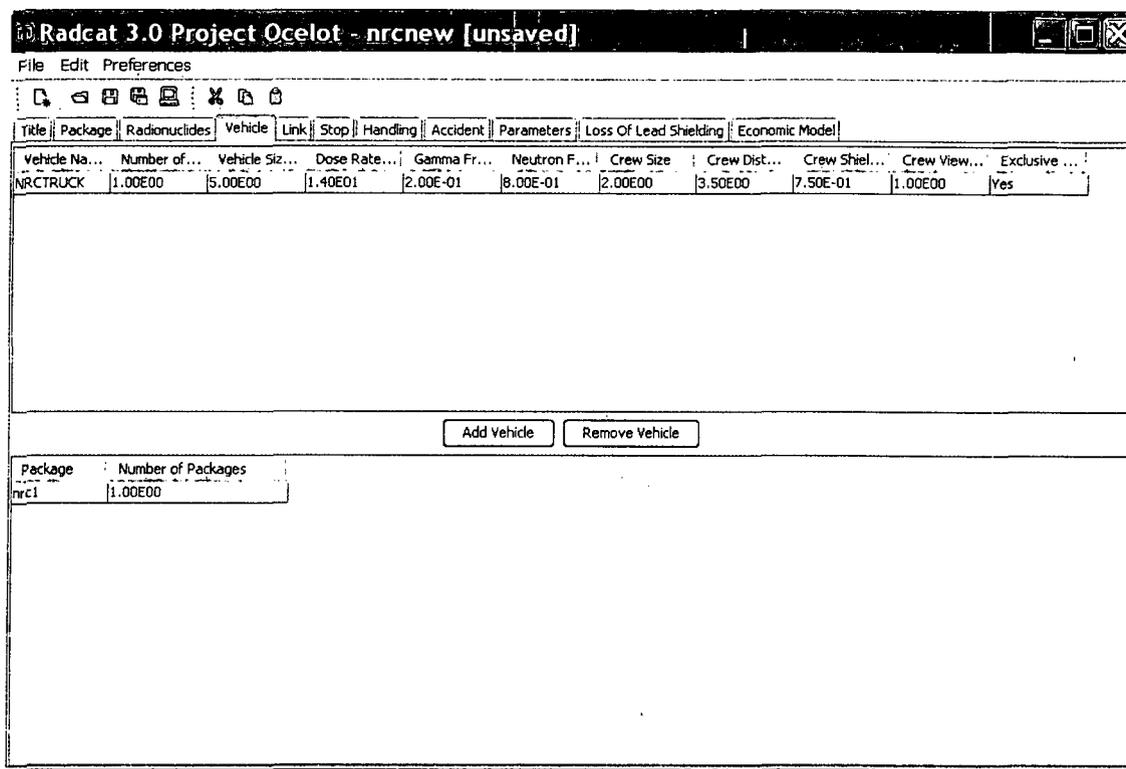
**Figure A.2. Diagram of a truck route as modeled in RADTRAN.**

Variants of Equation (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 A.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

- 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 E.

The input text file can be written directly using a text editor, or can be constructed using the input file generator RADCAT (Weiner, et al, 2009). 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 A.4 shows a RADCAT screen.



**Figure A.4. RADCAT vehicle screen.**

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

## **A.3 RADTRAN Input Parameters**

### **A.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 A.3-1 shows the vehicle-specific input parameters to RADTRAN and shows the parameter values used in this analysis. In this analysis, the GA-4 is assumed to be transported by truck; the NAC-STC

- Shielding from external radiation is different for residents of rural, suburban, or urban homes.
- Only rural route segments pass through farmland
- In urban areas, some residents are in buildings and some are outside on the sidewalk.
- Only urban areas experience rush hours, which have increased vehicle densities and decreased vehicle speeds.

RADTRAN uses residential population densities to calculate collective doses to residents along transportation routes. The 2000 census data is nine years old as of this writing; therefore, population data were corrected and updated. Updated population data to 2006 are 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 21 shows the percent increase in population for the 50 largest metropolitan areas in the U.S. 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.

The population multipliers used are shown in Table A.4-2. "Significant" was taken to mean that the multiplier was 1.01 or larger or 0.96 or smaller. The state-specific multiplier was applied to rural and suburban routes through the state, and the multiplier for the largest metropolitan area in that state was applied to the urban routes. For computational efficiency, and because multiplication is commutative, the multipliers were applied to the collective doses calculated using RADTRAN rather than to the WebTRAGIS populations.

**Table A.4-2. Population multipliers**

State	Rural, Suburban, Urban Designation	Population Multiplier	State	Rural, Suburban, Urban Designation	Population Multiplier
Arizona	R, S	1.202	Nevada	R, S	1.249
	U	1.242		U	1.292
Arkansas	R, S	1.051	New Mexico	R, S	1.075
	U	1.051		U	1.075
California	R, S	1.076	Oklahoma	R, S	1.037
	U	1.15		U	1.07
Colorado	R, S	1.105	Pennsylvania	R, S	1.013
	U	1.105		U	1.025
Georgia	R, S	1.144	Oregon	R, S	1.082
	U	1.21		U	1.109
Idaho	R, S	1.133	Tennessee	R, S	1.061
	U	1.133		U	1.109
Illinois	R, S	1.033	Texas	R, S	1.127
	U	0.959		U	1.175
Maryland	R, S	1.037	Utah	R, S	1.142
	U	1.041		U	1.102

for highways is found in Weiner, et al, (2009) Appendix D. Data for rail is from the Federal railroad Administration (reference TBA).

- Persons per vehicle is the average number of occupants of vehicles that share the route with the radioactive materials transport vehicle.

**Table A.3-2. Route parameters for unit risk calculation (USDOT 2004a, b)**

Parameter	Interstate	Freight Rail
<b>U. S. average vehicle speed , km/hr (mi/hr)<sup>a</sup></b>		
<b>Rural</b>	<b>108 (67)</b>	<b>43.4 (27)</b>
<b>Suburban</b>	<b>108 (67)</b>	<b>43.4 (27)</b>
<b>Urban</b>	<b>102 (63.4)</b>	<b>24 (15)</b>
<b>Vehicle density (U.S. average truck or railcar/hr)</b>		
<b>Rural</b>	<b>1119</b>	<b>67</b>
<b>Suburban</b>	<b>2464</b>	<b>67</b>
<b>Urban</b>	<b>5384</b>	<b>67</b>
<b>Persons per vehicle</b>	<b>1.5</b>	<b>1.5</b>
<b>Fraction of rural routes adjacent to farmland</b>	<b>0.5</b>	<b>0.5</b>
<b>Stops</b>		
<b>Minimum distance from nearby residents (m)</b>	<b>30</b>	<b>200</b>
<b>Maximum distance from nearby residents (m)</b>	<b>800</b>	<b>800</b>
<b>Stop time for rail classification (hours)</b>	<b>NA</b>	<b>27</b>
<b>Stop time in transit for railroad change (hours)</b>	<b>NA</b>	<b>0.5</b>
<b>Stop time at truck stops (hours)</b>	<b>0.83</b>	<b>NA</b>
<b>Average number of people sharing the stop</b>	<b>6.9<sup>b</sup></b>	<b>NA</b>
<b>Minimum distance to people sharing the stop (m.)</b>	<b>1<sup>b</sup></b>	<b>NA</b>
<b>Maximum distance to people sharing the stop (m.)</b>	<b>15<sup>b</sup></b>	<b>NA</b>
<b>Crew shielding (with no regulatory limit)<sup>c</sup></b>	<b>0.377</b>	<b>NA</b>

<sup>a</sup>The source for these data is the DOT Bureau of Transportation Statistics, [www.bts.gov](http://www.bts.gov).

<sup>b</sup>From Griego et al, 1996

<sup>c</sup>Calculated from crew doses run with and without the regulatory limit.

RADTRAN also includes a set of input 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. Table A.3-3 lists the default parameter values used in the incident-free analysis.

National Laboratory site (Oak Ridge, TN). The routes modeled are shown in Table A.4-1. Both truck and rail versions of each route are analyzed. Collective doses were calculated state by state. In each state traversed, rural, suburban, and urban route segments were aggregated.

**Table A.4-1. Specific routes modeled**

<b>Origin</b>	<b>Destination</b>
Maine Yankee site, ME	Hanford, WA
	Deaf Smith County, TX
	Skull Valley, UT
	Oak Ridge, TN
Kewaunee NP, WI	Hanford, WA
	Deaf Smith County, TX
	Skull Valley, UT
	Oak Ridge, TN
Indian Point NP, NY	Hanford, WA
	Deaf Smith County, TX
	Skull Valley, UT
	Oak Ridge, TN
Idaho National Lab, ID	Hanford, WA
	Deaf Smith County, TX
	Skull Valley, UT
	Oak Ridge, TN

## A.5 Results

### A.5.1 Maximum individual 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 (an interstate lane or shoulder width) from the moving vehicle, and the vehicle is moving at the slowest speed it would be likely to maintain. This speed is 24 km/hour (15 mph) for both rail and truck. Table A.5.1 shows the maximum individual dose, in rem, for each package. These doses are directly proportional to the external dose rate (TI) of each package. For comparison, the average U.S. external radiation dose is 0.360 rem (360 millirem) per year, or 4.11E-05 rem per hour.

**Table A.5-1. Maximum individual doses.**

<b>Package</b>	<b>Dose (rem)</b>
<b>NAC-STC (rail)</b>	5.67E-07
<b>HI-STAR 100 (rail)</b>	4.30E-07
<b>GA-4 (truck)</b>	6.70E-07

### A.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 1 km past a population density of one person/km<sup>2</sup> are shown in Table A.5-2. The dose units are person-millirem. The data in this table may be used to calculate collective doses along routes as follows:

- Multiply the crew dose by the kilometers of each type of route.
- 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. Therefore, multiply the "unit population along route" dose by this area and the appropriate population density (obtained from a routing code like WebTRAGIS). *Is this applying minimum distance dose to entire 800 m distance?*
- Rural, suburban, and urban doses to residents living near stops are calculated by multiplying the appropriate stop dose by (rural, suburban, urban) 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)). *# is same as in presentation, but basis has changed - How is that?*

**Table A.5-2. Average doses to various receptors (person-rem), truck routes.**

Cask and route type	Truck crew (2 people)	Unit resident population near stop (1 person/km <sup>2</sup> )	Unit population along route (1 person/km <sup>2</sup> )	Occupants of vehicles sharing the route (1.5 people)
GA-4 rural	3.77E-05	3.26E-06	3.05E-08	1.23E-05
GA-4 suburban	3.77E-05	2.84E-06	2.65E-08	2.65E-05
GA-4 urban	3.59E-05	5.87E-08	5.22E-10	5.99E-05
GA-4 urban rush hour	7.98E-06		1.16E-10	5.53E-05
6.9 people sharing stop		2.30E-03		

*not consistent w/ # in presentation*