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RADCAT 2.3 User Guide

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ABSTRACT

This document provides a detailed discussion and a guide for the use of the RADCAT 2.3 Graphical User Interface input file generator for the RADTRAN code. The differences between RADCAT 2.3 and RADCAT 2.2 can be attributed to the addition of the graphical outputs, and the revisions within RADTRAN 5.6. As of this writing, the RADTRAN version in use is RADTRAN 5.6.

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1. WELCOME TO RADTRAN / RADCAT

RADTRAN is a nationally accepted standard program and code for calculating the risks of transporting radioactive materials. The first versions of the program, RADTRAN I and II, were developed for NUREG-0170 (USNRC, 1977), the first environmental impact statement on transportation of radioactive materials. RADTRAN and its associated software have undergone a number of improvements and advances consistent with improvements in computer technology.

The version of RADTRAN currently bundled with RADCAT is RADTRAN 5.6.

2. DOWNLOADING AND CHECKING FOR THE LATEST VERSION

The RADCAT/RADTRAN package may be downloaded from: https://radtran.sandia.gov/radcat.

- On the web page, click on click here and fill out the application.
- You will be notified by email when you are approved,.
- When you are approved, you can click on Download RADCAT. You will be asked for your username. Your username is the email address you listed in the application.
- When you sign in, you **must** download the Java Runtime Environment if it is not already on your computer. To do this, go to http://www.java.com click on Java Software Download.
- Download the Windows online installation. (You may want to download and read the instructions, but it isn't absolutely necessary.)
- The download installs the Java Runtime Environment (JRE) on your PC. The most recent version of the Runtime Environment will download to you computer. If you are on a network, you may get a message indicating that you can't install. If this happens, you will need help from your network administrator to install it, or to give you access through a firewall. If you have a firewall (like ZoneAlarm) on the computer you are using, turn it off before installing the JRE. To gain access through a network firewall you'll need the proxy access and port number as shown in Figure 1. The proxy and port settings can be obtained from your network administrator.
- Once JRE is installed, you can go back to Download RADCAT on the Main Menu and download RADCAT. You will be asked to integrate it to the desktop environment, which is suggested. When you launch RADCAT (the application), you may get a notice that says there is no certificate of authenticity; launch the application anyway. The process for applying for the certificate may not be complete.
- If you wish to put the Java Runtime Environment icon on your desktop, go to C:\Program Files\Java\jre1.6.0_01\bin, find the coffee cup javaws.exe icon, and copy the icon to your desktop.
- Once you have installed JRE, you can launch RADCAT either from JRE or from the RADCAT icon. If you want to download the latest version, go back to https://radtran.sandia.gov/radcat, click on Download RADCAT, click on Launch the Application, and the latest version will be downloaded. You may get a notice that says there is no certificate of authenticity; launch the application anyway. The process for applying for the certificate may not be complete.
- JRE maintains a cache of recent RADCAT downloads with the associated date of download. To view the cache or start RADCAT from the cache, go to C:\Program Files\Java\jre1.6.0_01\bin, and click on the coffee cup javacpl.exe icon. The Java Control Panel dialog box will open. Click on "View" in the lower right hand corner of the dialog box and the Java Cache Viewer will open and show your cached RADCATs.

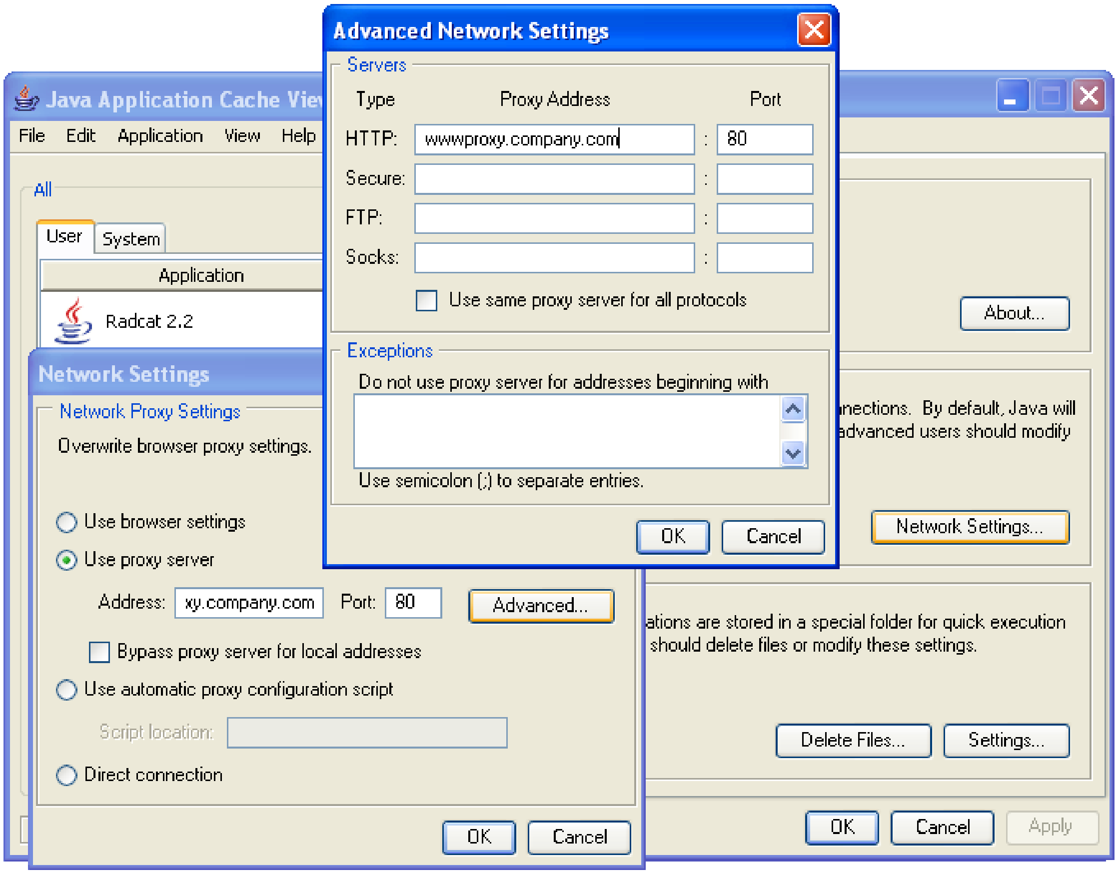


Figure 1: Proxy and Port Settings

When you download RADCAT, you will be prompted to save the icon on your desktop. A Java Web Start icon can also be placed on your desktop. RADCAT/RADTRAN can be opened at any time from the desktop icon.

Because of minor changes in the formatting of RADCAT and the addition of features, it is suggested that RADCAT be opened using Java Web Start, which will automatically update your version of RADCAT. Users will still be notified via email of any major changes or additions to RADCAT.

3. RUNNING RADTRAN WITH RADCAT

RADCAT will only **open** "*.rml" files. If you are using a "*.in5" or a "*.dat" file, **import** the file instead of opening it (see Section 3.1). Please note that a file using more than one transportation mode (e.g., both truck and rail in a single file) will not run under RADCAT. RADCAT will only run one mode at a time.

To run an existing input file with RADCAT, follow these steps:

1. Open RADCAT.

2. In RADCAT, choose the file to be run, either by using the **File** pull-down menu or by clicking on the **Open** icon. This is shown in Figure 2. The directory will appear and choose the file to be run. When the file has been selected, the title of the file will appear in the **Title** space.

3. Click on the **Run RADTRAN** icon (the icon showing a computer monitor). The output file will appear and can be saved.

3.1 IMPORTING OLD RADTRAN 5 FILES

RADCAT has the ability to import old RADTRAN 5 input files and convert them to be run by RADTRAN version 5.5 or later versions. This feature can be selected from the **File** pull-down menu by clicking on the **Import** icon, as shown in Figure 2. You must ensure that your input files are listed as a **"*.**in5**"** or a "*.dat" file in order for RADCAT to import and convert it properly.

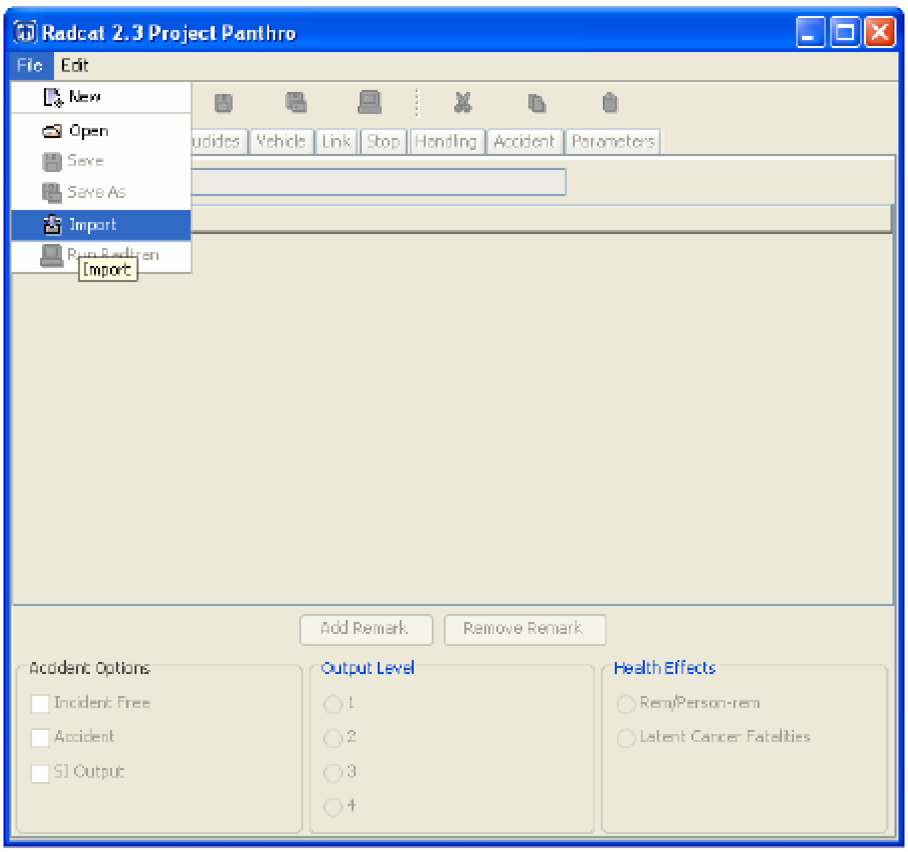


Figure 2: File Pull-down Menu

4. SAVING AN INPUT FILE

An input file may be saved at any time by clicking on the **Save** icon (the floppy disk icon). The **Save As** window will open and the user can save the file in the normal Windows manner. Your file should be saved as a **"***filename*.rml" file, and you will need to add the **"*.**rml**"** extension to your filename when saving it. RADTRAN will run the file even if it isn't saved, but the output won't make much sense. Save often.

5. GENERATING AN INPUT FILE WITH RADCAT

If you do not wish to use RADCAT to create a RADTRAN file, you may create an input file directly with a text editor. The reference sheet provided in Appendix A of this user guide will assist you in creating a text input file. Any input file created as a text file must be saved as a "*filename*.in5" file. When a *.in5 file is run using the **Run RADTRAN** icon in RADCAT, it must be imported into RADCAT (using the "Import" utility found on the File pull-down menu, not the "Open" utility) for RADTRAN to execute properly. Once the file is imported into RADCAT, it must be saved as a ".rml" file as described in Section 4 of this User Guide.

New

When the **New** icon is selected to create a new file, the **Mode Selection** dialog box appears. An example of the **Mode Selection** dialog box is shown in Figure 3. A selection of a transportation mode (highway, rail, or barge) must be made before a new file can be created. A file cannot be created with more than one mode. The mode is selected from the pull-down menu.

If a current file is already open, selecting the **New** icon will open a second Java window from which you will be able to select another transportation mode from the **Mode Selection** dialog box. This will not reset any of the information in the first open file.

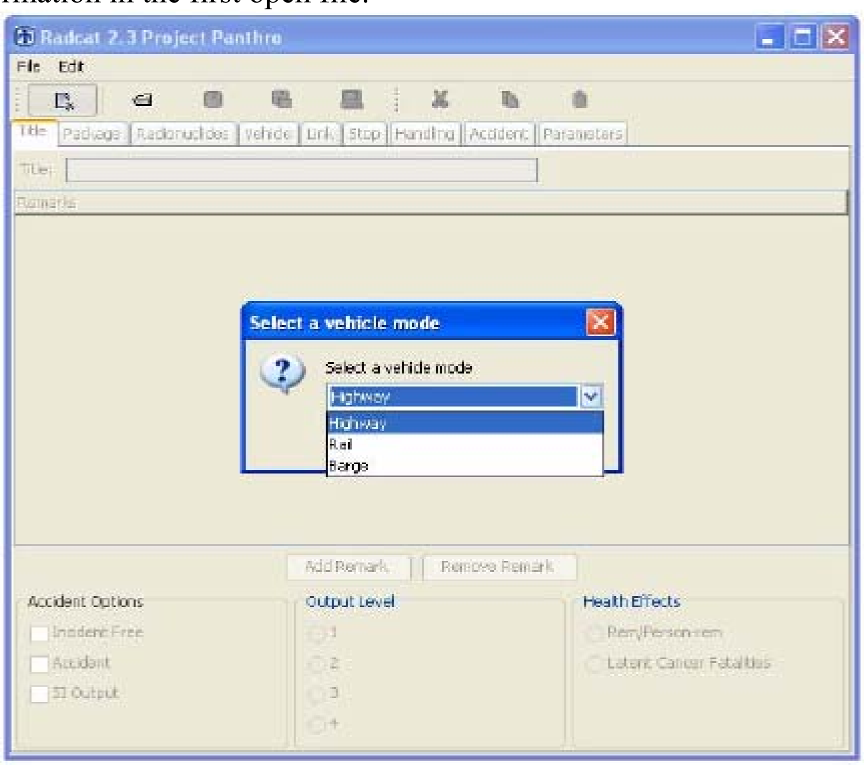


Figure 3: Mode Selection

Entering Data

Whenever an entry is made on a RADCAT tab, you must hit ENTER (depress the ENTER key).

Title

The default title in the **Title** box should be deleted, and you may type any name for your file in the **Title** box and hit "ENTER" to give your file a title. Your file <u>must</u> have a title. The **Title** box is shown in Figure 4.

Remarks

The **Remarks** screen is for you to annotate your file; e.g., give a brief description of the scenario, the sources of your input parameters, etc. When you click on **Add Remark** a line appears in the remarks screen. The word "REMARK" is on this line. You can delete it and enter your own remark. You must hit "ENTER" for your remarks to added for each line. Click on **Add Remark** to append additional remarks. **Remarks** is shown in Figure 4.

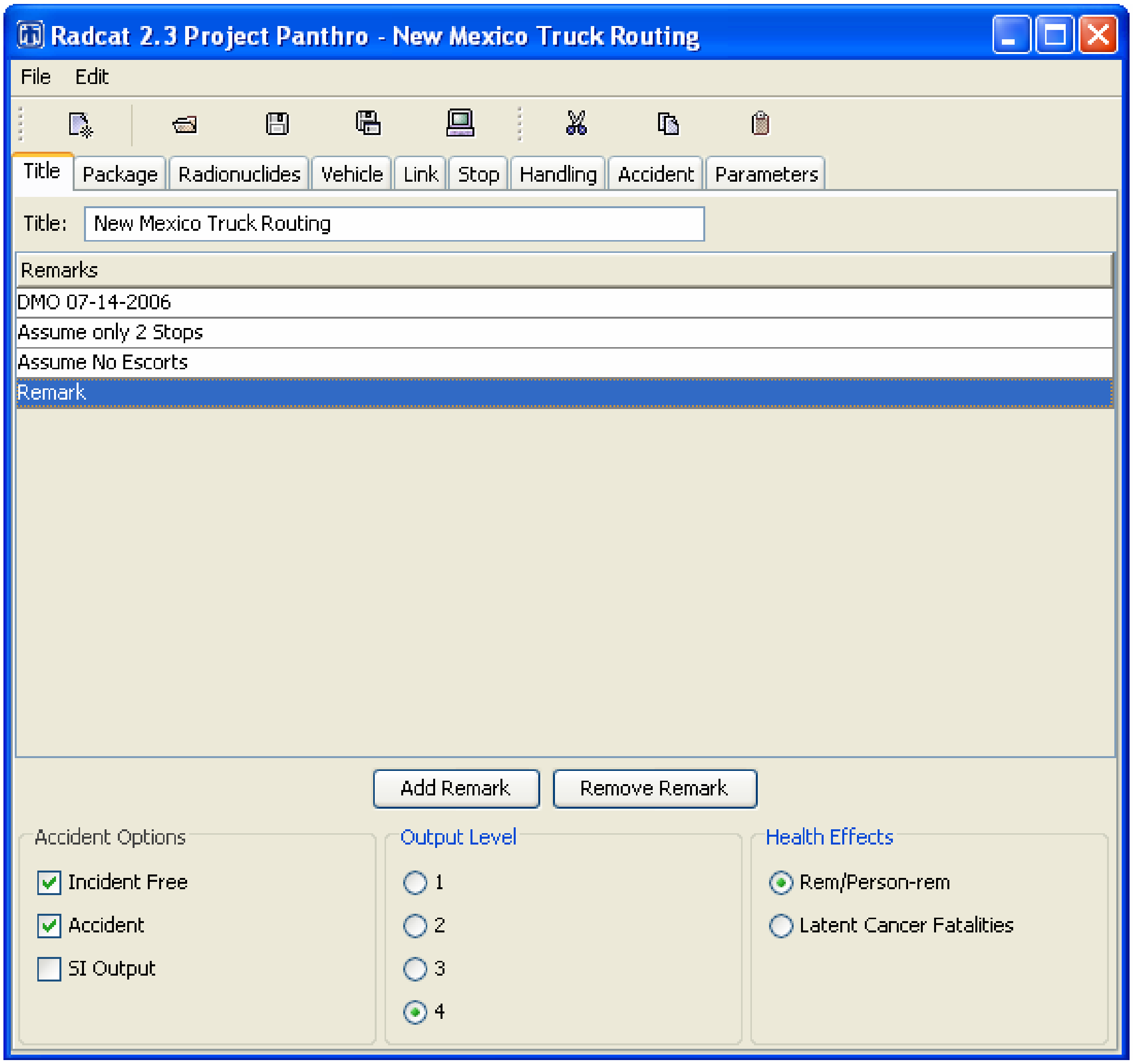


Figure 4: Title Tab

Accident Options

Checking the **Incident Free** box will result in analysis of routine, incident-free transportation only. If you choose this option, make sure the **Weather** tab (a tab option within the "Accident tab") is set for "National Average Weather," or RADTRAN will not run. Checking the **Accident** box will result in analysis of transportation accidents only. Even if you only wish to have accident output, you must enter non-zero data on the **Package, Vehicle,** and **Link** tabs. Checking both the **Incident Free** and **Accident,** boxes results in a full analysis of incident-free transportation and transportation accidents . Checking the **SI Output** will report the output in Standard International (SI) units. These options is shown in Figure 4.

Output Size

Four options are available for controlling output size:

1. Short output form. The input echo, incident-free, and accident and non-radiological risk tables are printed. The output file is approximately 10 pages long.
2. Output for #1 plus input tables, early effects values, ground contamination tables, intermediate tables, and total expected population dose tables are printed. the output file is approximately 28 pages long.
3. Output for #2 plus consequence tables. The output file is approximately 31 pages long.
4. Full output. Output for #3 plus sensitivity analysis. The output file is approximately 33 pages long.

This option is shown in Figure 4.

Effects

Effects may be reported in the output either as individual and collective doses or as latent cancer fatalities. The individual dose and collective dose outputs may be in historical units – rem and person-rem, as appropriate – or Standard International (SI) units – sievert (Sv) and person-sievert (person-Sv). RADTRAN calculates latent cancer fatality risk (LCF) by multiplying the dose in rem (or person-rem) by a linear conversion factor: 5×10^{-4} for public health risk and 4×10^{-4} for occupational health risk. The validity of this linear conversion for small individual or average doses has been called into question (Tubiana and Aurengo, 2005) and is included because it has been used extensively.[1] The user is encouraged to report results in units of dose rather than LCF. The federal interagency (ISCORS) conversion factor is 5.67×10^{-4} LCF/rem for both occupational and public exposure; this has not been incorporated into RADTRAN.

Some useful conversion factors are:

1 Sv = 100 rem
1 millisievert (mSv) = 100 mrem
1 gray (Gy) = 100 rad
1 becquerel (Bq) = one disintegration per second, the units of Bq are sec^{-1}
1 curie (Ci) = 3.7×10^{10} Bq

5.1 PACKAGE

When making a new input file or adding or deleting a package in an existing file, select the **Package** tab. When editing an existing file without adding or deleting a package, the order in which the tabs are opened will not make any difference. This is shown in Figure 5.

Name

Give your package a name in the left-hand column. You may delete "PACKAGE_1" and substitute any name that you like. A package name must be a continuous text string and may not contain any spaces.

[1] Use of a linear conversion factor has been the subject of skepticism for some time. The paper by Tubiana and Aurengo presents a summary and review of peer-reviewed molecular biologic and epidemiologic studies that support this skeptical view.

If you wish to transport more than one package, click the **Add Package** bar and add as many packages as you wish. You can give your added packages any names that you want to give them. You will be adding packages to vehicles in a later tab. The package tab is shown in Figure 5.

List all the packages that you will want for this run on this tab. You can add or delete packages only on this tab; you cannot add them or delete them from other tabs.

Long Dimension

Enter the largest dimension of the package in meters, e.g. length of a cylinder if larger than the diameter. In RADTRAN literature, for historical reasons, this dimension is called the "critical dimension", although it is not critical in the sense of nuclear criticality.

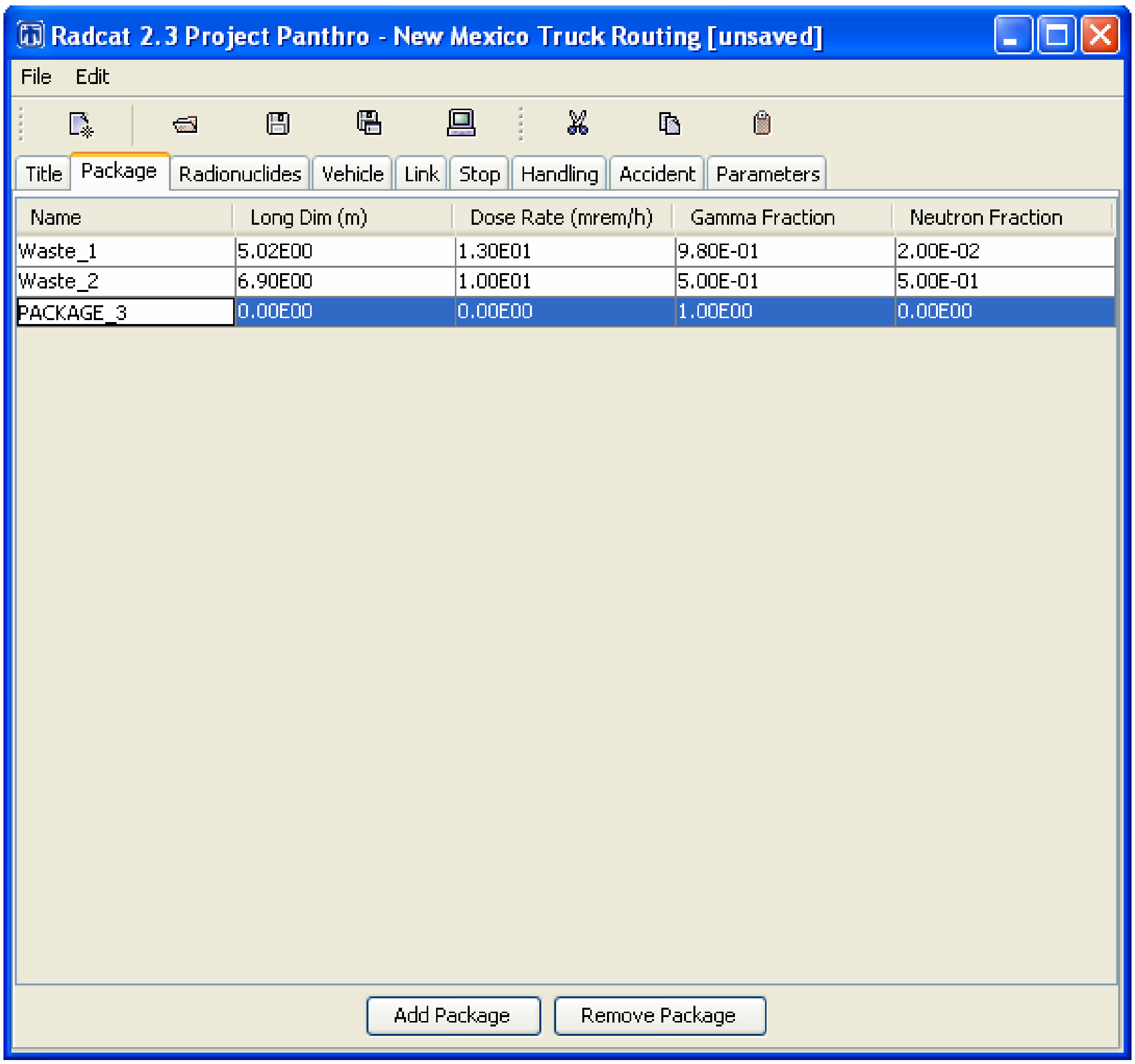


Figure 5: Package Tab

Dose Rate

Enter the external dose rate at one meter from the package surface, in units of mrem/hr. Note that the regulations of 10 CFR Part 71 specify that the external dose rate *at two meters* from the package surface should not exceed 10 mrem/hour. This is equivalent to 13.9 mrem/hr at one meter from the package surface for a "critical dimension" of about 5 meters. If the actual dose rate is not known, and one assumes that the shipper is abiding by regulations, one may use the 13 mrem/hr or 14 mrem/hr as the external dose rate at one meter, recognizing that either value is conservative. This is shown in Figure 5.

The **Parameters** tab includes a flag that reads "Imposed regulatory limit on vehicle external dose." When the flag is on, a regulatory constraint is imposed on the shipment. Selecting **YES** will cause RADTRAN to internally adjust the package length and dose rate so that the external dose rate at two meters does not exceed 10 mrem/hr, and thus may be modeling a different dose rate than the one you entered. If the regulatory constraint is in place, RADTRAN will print a message noting this in the output. If you want to lift this regulatory constraint, select **NO**. Some users prefer to lift this regulatory constraint (by selecting **NO)** so they always know exactly what they are modeling.

Remember that RADTRAN models the external dose rate as a virtual source at the center of the package. The distance between the source and the receptor must take this into account.

Gamma and Neutron Fractions

When you enter a value into either of these cells, RADCAT will automatically adjust the other cell so that the sum is equal to 1. This is shown in Figure 5.

5.2 RADIONUCLIDES

Select the **Radionuclides** tab next after the **Package** tab. When editing an existing file without adding or deleting a package, the order in which the tabs are opened will not make any difference. This is shown in Figure 6.

At the upper left of the **Radionuclides** screen is a pull-down menu of the packages you have created. Select the package whose inventory you wish to specify.

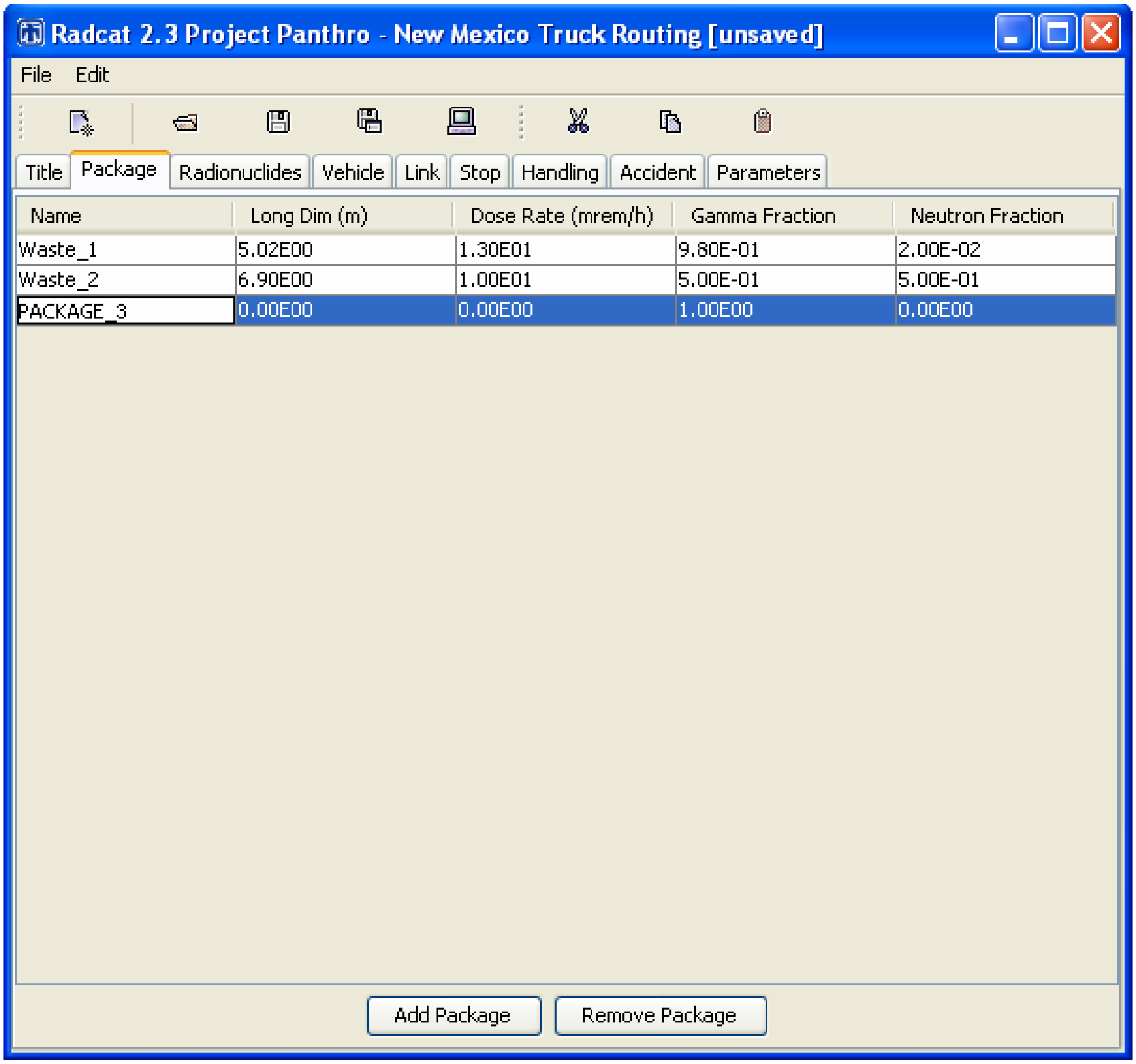


Figure 6: Radionuclides Tab with Package pull-down menu

Adding Radionuclides from the Internal Library

The window just below the package pull-down menu lists all of the radionuclides in the internal RADTRAN library. Radionuclides from the internal library may be added to your package by clicking on the **Add Library Radionuclide** arrow. The radioisotope name will then appear on the right-hand screen. Name the **Physical/Chemical Group** to which the radionuclide belongs. You may use any name you like, but the name can have no more than eight alpha-numeric characters and cannot contain any spaces. Remember that the release behavior in the event of an accident depends on the physical/chemical group (gas, particle, volatile substance, etc.). RADTRAN will accept up to 15 different physical chemical groups. Once you have added a **Physical/Chemical Group** name to your first radionuclide, the **Physical/Chemical Group** entry will become a pull-down menu that reflects your additions, so that you can select existing physical/chemical groups for other entries without re-typing the name each time. Physical/chemical groups must be entered at this screen; they cannot be entered on any other screen. This is shown in Figure 7.

Enter the number of curies of the radionuclide in the **Curies** column.

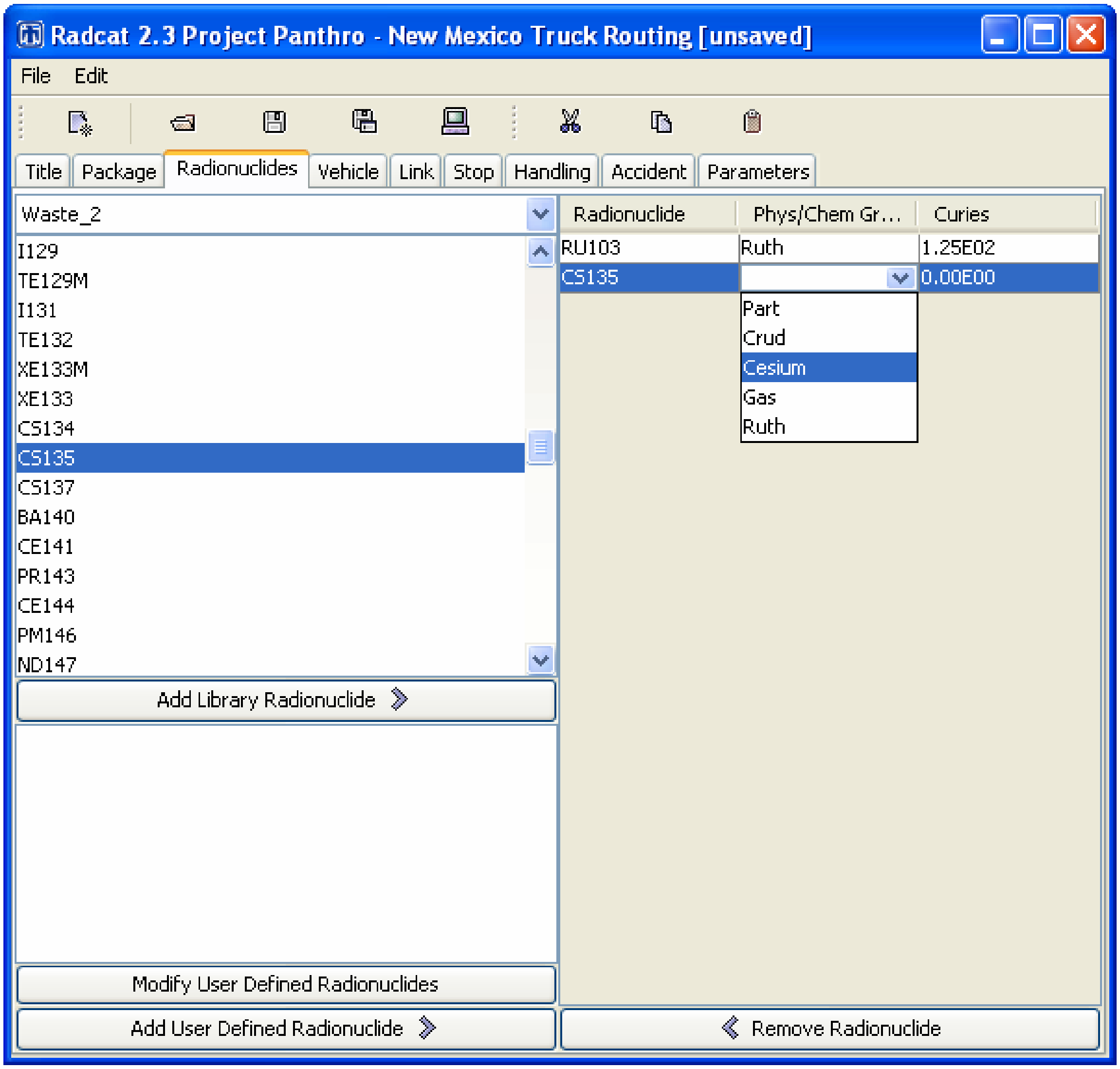


Figure 7: Radionuclides Tab with Physical / Chemical Group pull-down menu

Adding Radionuclides not in the Internal Library: User-Defined Radionuclides

If the radionuclide you wish to add is not in the internal library, it may be added to your package. To do this, first click on the **Modify User-Defined Radionuclides** bar. The **User Defined Radionuclides** screen will open. In this screen, you can click on the **Add User Defined Radionuclides** bar. You may then enter the name of the radionuclide in the left-hand cell (in place of ISOTOPE_1), and it may be up to eight characters long and must not contain any spaces. Ensure that there are no spaces in your radionuclide name. This is shown in Figure 8.

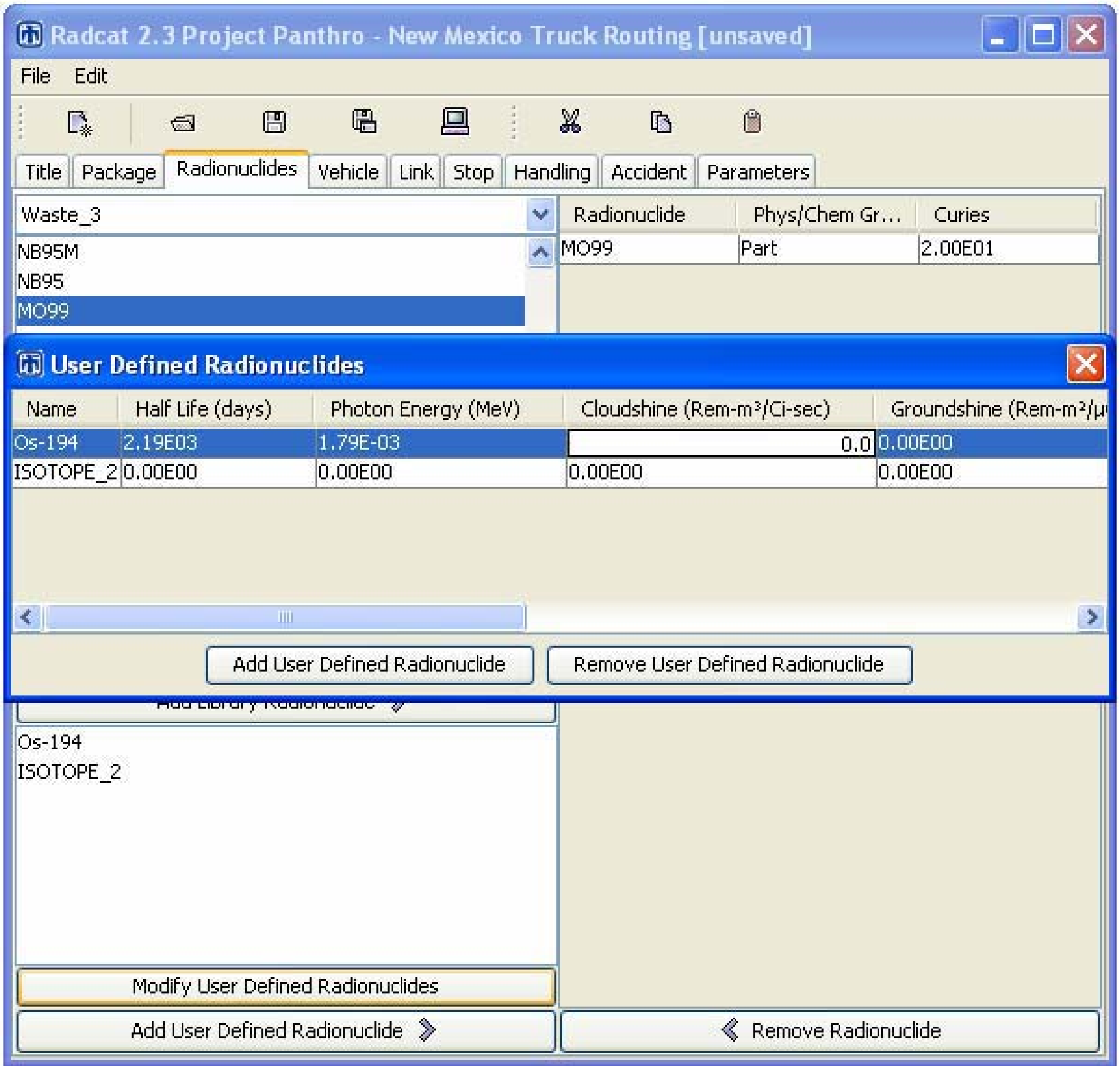


Figure 8: Radionuclides Tab with User Defined Radionuclides window

Half-lives may be found in the Chart of the Nuclides or the International Commission on Radiological Protection (ICRP) Publication 38, and dose conversion factors may be found in the Health Physics Handbook, Federal Guidance reports 12 and 13, ICRP Publication 72, and similar references. Dose conversion factors for radionuclides in the internal RADTRAN library are provided in Appendix B. Enter values for:

- Half-life in days,
- Photon Energy in MeV = Groundshine DCF/0.000304
- Cloudshine Dose Conversion Factor (DCF) in rem-m^3/Ci-sec,
- Groundshine DCF in rem-m^2/µCi-day,
- Inhalation DCF in rem/Ci,
- Gonad Inhalation DCF in rem/Ci,
- Lung Inhalation DCF in rem/Ci, and

- Marrow Inhalation DCF in rem/Ci.

Make sure you use the appropriate units. A value larger than zero for the half-life must be used for every user-defined radionuclide. RADTRAN will not run if there is a radionuclide with a half-life of zero or with a negative half life.

If values for the **Cloudshine** dose conversion factor, the **Groundshine** dose conversion factor, and/or the **Inhalation** dose conversion factor are not entered, RADTRAN will run but will report zero for the appropriate doses. If values for the **Gonad Inhalation**, **Lung Inhalation**, and/or **Marrow Inhalation** dose conversion factors are not entered, there will be no effect on cloudshine, groundshine, inhalation, or resuspension collective doses, but specific gonad inhalation, etc., doses will not be reported. It is important to note that the **Inhalation** dose is entered as the **Effective Dose** in the **User-Defined Isotope** window.

When you have added a user-defined radionuclide, the name of that radionuclide appears on the lower part of the **Radionuclides** tab. Using the **Add User Defined Radionuclide** arrow under that screen, you add the user-defined radionuclide to your package, and indicate the physical/chemical group and number of curies as before. If you wish to include a radionuclide in more than one **Physical/Chemical Group** (e.g., Co-60 as both CRUD and particulate), give the radionuclide a different name for each **Physical/Chemical Group** (e.g., CO60 – CRUD, CO-60 – particulate) and include one or both as a **User-Defined Isotope**.

Inhalation, resuspension, groundshine, and cloudshine doses are calculated for all radionuclides: both those in the internal library and those that are user-defined. However, the ingestion dose is calculated by RADTRAN only for radionuclides in the internal library and not for those radionuclides that are user-defined.

5.3 VEHICLE

The **Vehicle** parameters (external dose rate, length, etc) determine the dose to residents along the route, to occupants of vehicles sharing the route, and to the truck crew. The analogous **Package** parameters determine doses to handlers. If there is only one package per vehicle, as for a spent fuel or UF_6 package, or if all the packages can be modeled as one, as for the TRUPACT-II (which is actually three cylinders standing adjacent to each other), the largest dimension, external dose rate, and gamma and neutron fraction should be the same for the vehicle and package.

When making a new input file or adding or deleting a vehicle in an existing file, select the **Vehicle** tab next after the **Radionuclides** tab. When editing an existing file without adding or deleting a package, the order in which the tabs are opened doesn't make any difference. This is shown in Figure 9.

Vehicle Name

Provide a vehicle name in the left-hand column. The defaulted name may be substituted with any other name and additional vehicles can be given any name you wish to give them. A vehicle name must be a continuous text string and must not contain any spaces.

To analyze more than one vehicle, click the **Add Vehicle** bar and add the desired number of vehicles. This is shown in Figure 9. Add packages to vehicles as follows:

1. Click on the vehicle to which the desired package is to be added.

2. Then click on the package to be added, and enter the number of those packages that are to be added to the vehicle.

Adding the package to the vehicle adds the radionuclide contents of the package to the analysis. The radionuclide content is important to the accident analysis, though not to the incident-free analysis. Different packages may be added to a vehicle. When selecting the vehicle, the number of each of the packages on that vehicle shows up in the **Number of Packages** column. If a package is not on a particular vehicle, the **Number of Packages** column will show a zero. This is shown in Figure 9.

List all the desired vehicles on this tab. Vehicles cannot be added on other tabs, nor can they be deleted from other tabs. RADTRAN can handle as many as 20 vehicles in a single run.

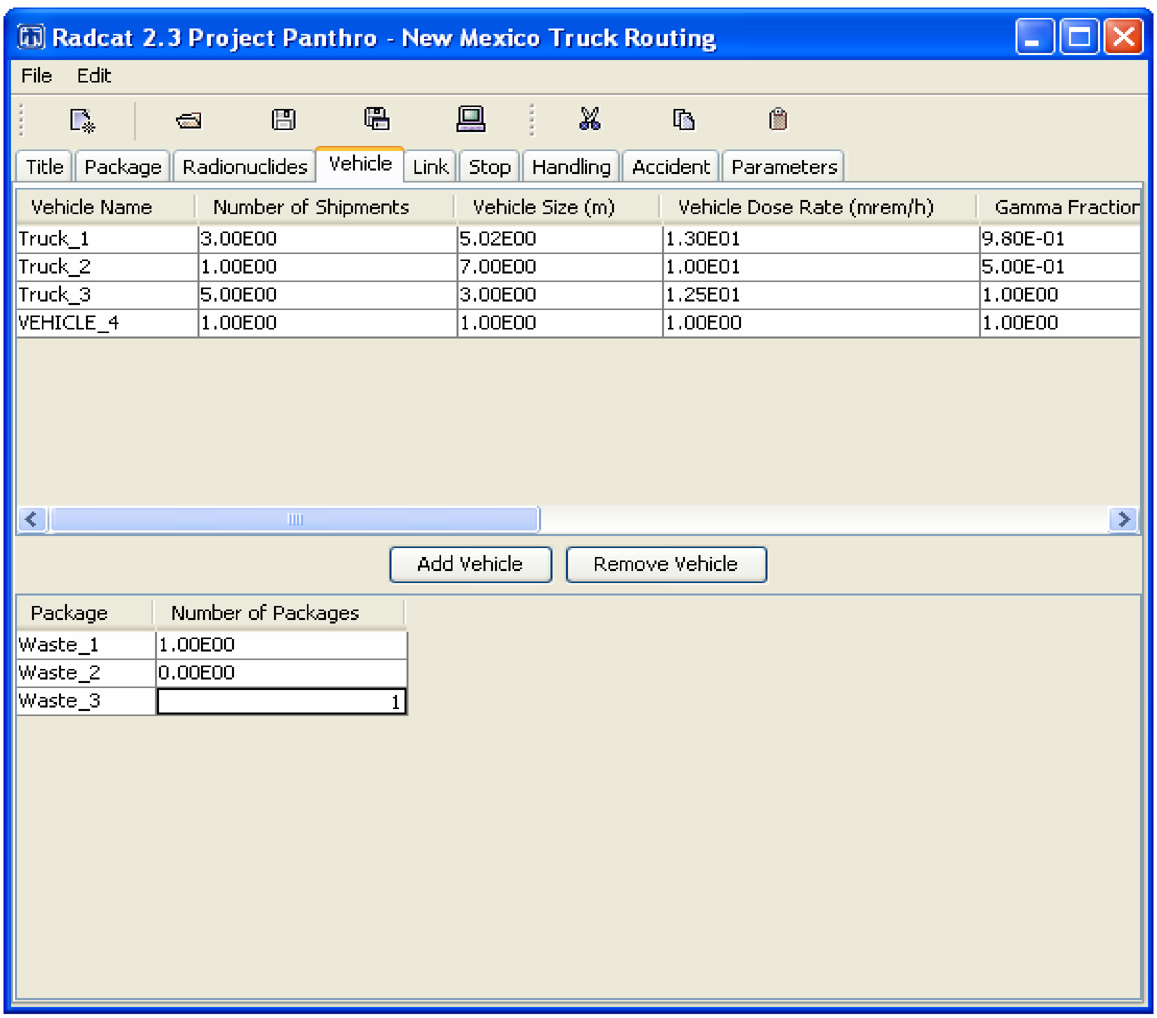


Figure 9: Vehicle Tab

Number of Shipments

Enter the number of shipments. This is shown in Figure 9. Note that RADTRAN calculates doses and dose risks for one shipment and multiplies that result by the number of shipments. The same result can be obtained, as many analysts prefer to do, by performing the RADTRAN analysis for one shipment and multiplying externally by the number of shipments.

Vehicle Size

Enter the maximum dimension of the cargo section of the vehicle, or of the part of the vehicle holding the packages, in meters. This is the "critical dimension" of the vehicle in RADTRAN. This is shown in Figure 9.

Vehicle Dose Rate

Enter the external dose rate, at one meter from the edge of the cargo-carrying part of the vehicle, in units of mrem/hr. Note that the regulations of 10 CFR Part 71 specify that the external dose rate *at two meters* from this edge should not exceed 10 mrem/hour. This is equivalent to 13.9 mrem/hr at one meter if the largest dimension is approximately 5 meters. If the actual dose rate is not known, and one assumes that the shipper is abiding by regulations, one may use the regulatory maximum, 13 or 14 mrem/hr, as the external dose rate, recognizing that this value is conservative. This is shown in Figure 9.

RADTRAN has a flag on the **Parameters** tab, Section 5.8, "Imposed regulatory limit on vehicle external dose," that imposes a regulatory constraint on the shipment. Selecting **YES** will cause RADTRAN to internally adjust the critical dimension and the dose rate so that the external dose rate at two meters does not exceed 10 mrem/hr, and thus may not use the dose rate you entered into the calculations. If you want to lift this regulatory constraint, select **NO**.

Remember that RADTRAN models the external dose rate as a source at the center of the package. The distance between the source and the receptor must take this into account.

Gamma and Neutron Fractions

Enter a value into either of these cells, RADCAT will automatically adjust the other cell so that the sum of both is equal to 1. This is shown in Figure 9.

Crew Size

For highway and barge travel, enter the number of crew members that will be traveling on the vehicle. This is shown in Figure 10. The crew on a train in transit is sufficiently far from the radioactive cargo, and is shielded by intervening rail cars, so that the crew is considered to receive zero dose. Therefore, for rail mode, neither the default values nor any numbers you may enter will be read by RADTRAN.

Crew Distance

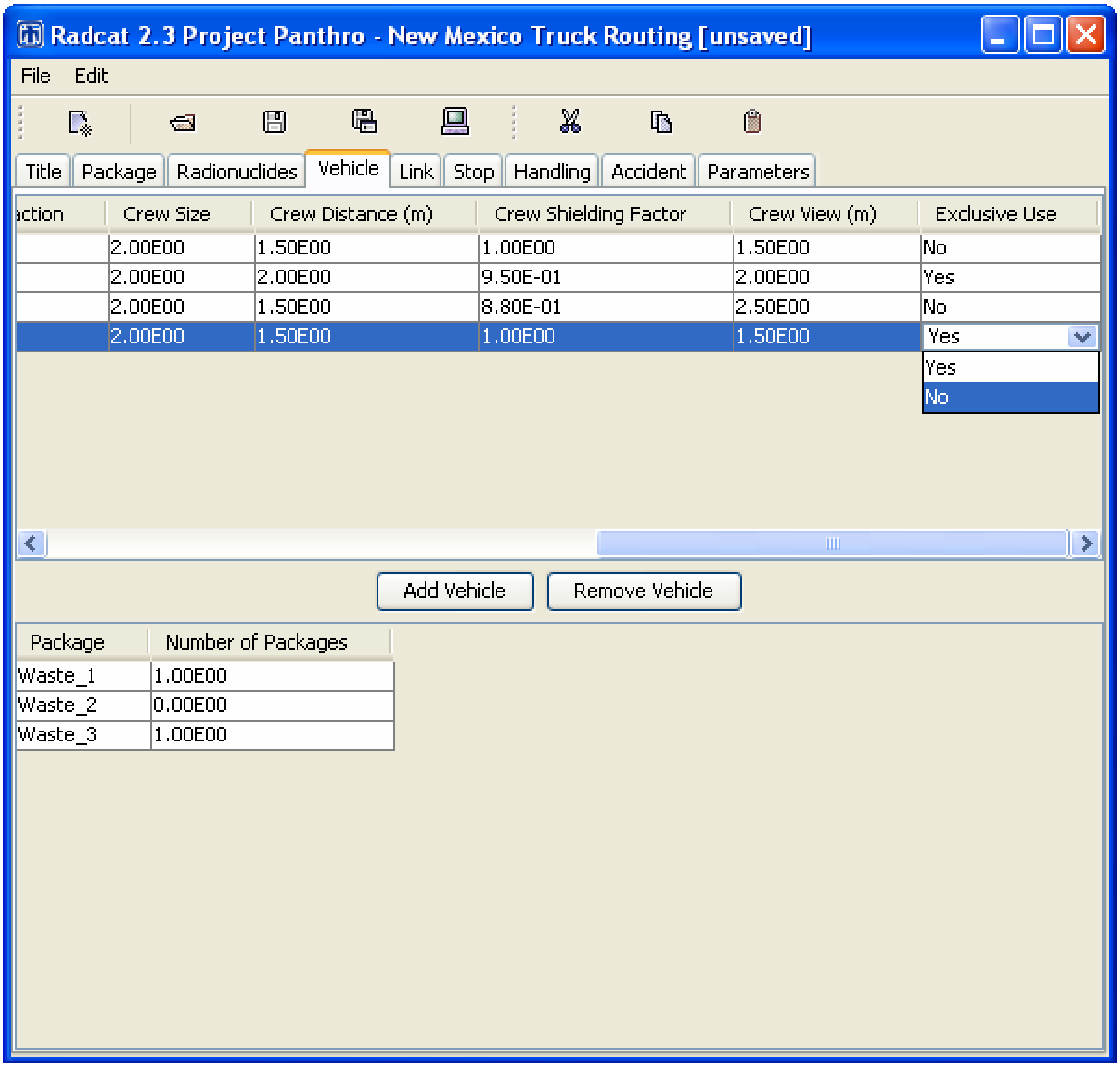
For highway and barge travel, enter the **Distance** in meters from the crew to the nearest surface of the cargo in the **Crew Distance (m)** column. This distance is about 2 to 3 meters for large trailer rigs but may be much longer for heavy haul trucks. This is shown in Figure 10. The crew on a train in transit is considered to receive zero dose.

"Crew" dose for rail shipments is the dose sustained by rail yard workers at stops along the route.

A barge usually has a crew of 10. Enter the average distance of the crew from the cargo.

Crew Shielding Factor

For highway and barge travel, enter a factor between 0 and 1 for crew shielding. This factor is the fraction of ionizing radiation to which the crew is exposed (the inverse of the shielding fraction). This means that 1 = no shielding, and 0 = 100% shielding. This is shown in Figure 10. The crew on a train in transit is at least 150 meters from the radioactive cargo, is shielded by intervening rail cars, and thus is considered to receive zero dose. Therefore, for rail mode, neither the default values nor any numbers you may enter will be read by RADTRAN.



action	Crew Size	Crew Distance (m)	Crew Shielding Factor	Crew View (m)	Exclusive Use
	2.00E00	1.50E00	1.00E00	1.50E00	No
	2.00E00	2.00E00	9.50E-01	2.00E00	Yes
	2.00E00	1.50E00	8.80E-01	2.50E00	No
	2.00E00	1.50E00	1.00E00	1.50E00	Yes

Package	Number of Packages
Waste_1	1.00E00
Waste_2	0.00E00
Waste_3	1.00E00

Figure 10: Vehicle Tab Continued

Crew View

The **Crew View** is the largest dimension, in meters, of the cargo that faces toward the crew. This is usually the diameter of a cylindrical cask or the diagonal end dimension of a rectangular container or array. This is shown in Figure 10 in the **Crew View (m)** column. The crew on a train in transit is sufficiently far from the radioactive cargo and is shielded by intervening rail cars, so that the crew is considered to receive zero dose. Therefore, for rail mode, neither the default values nor any numbers you may enter will be read by RADTRAN.

Exclusive Use

A pull-down menu allows the user to indicate whether the vehicle is exclusive use or not. This is shown in Figure 10 in the **Exclusive Use** column.

5.4 LINK

A "link" is a route segment. When making a new input file or adding or deleting a vehicle in an existing file, select the **Link** tab next after the **Vehicle** tab. If editing an existing file without adding or deleting a package, the order in which the tabs are opened doesn't make any difference. This is shown in Figure 13.

Note: The parameter values in this screen can be provided by a routing code or a geographic information system (GIS). The routing code WebTRAGIS is available from Oak Ridge National Laboratory at: https://tragis.ornl.gov/

Figures 11 and 12 show examples of WebTRAGIS routes. Figure 11 is an example of a truck route across New Mexico, and Figure 12 is an example of a barge route in Florida.

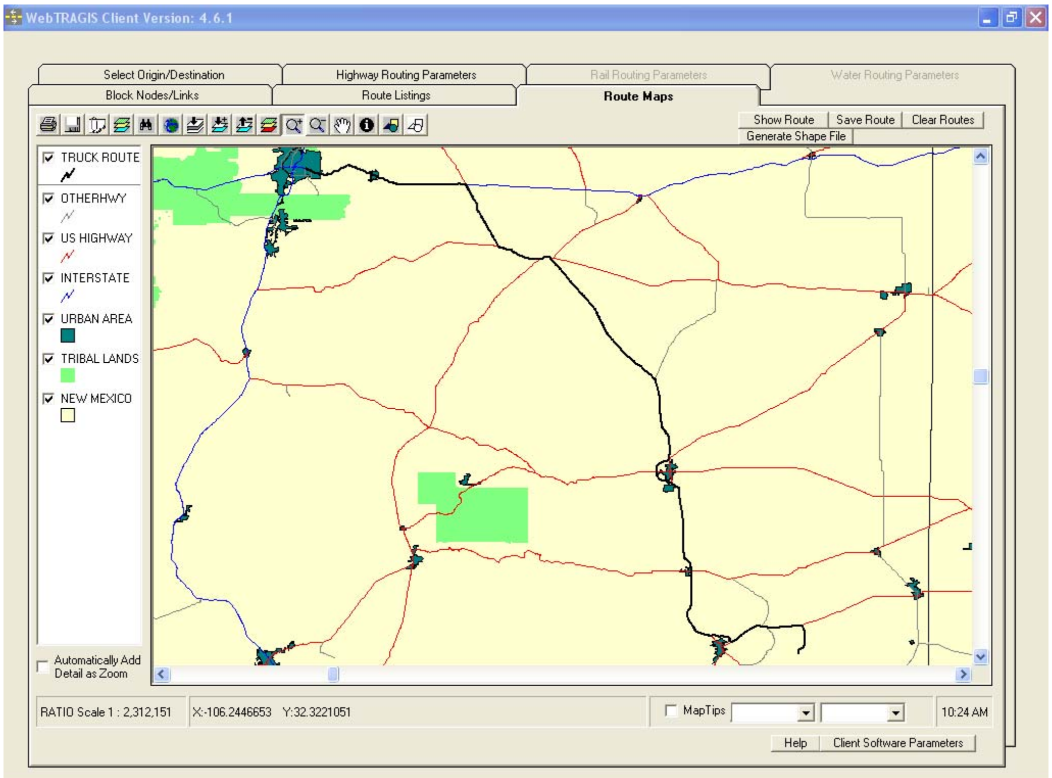


Figure 11: New Mexico Truck Route.

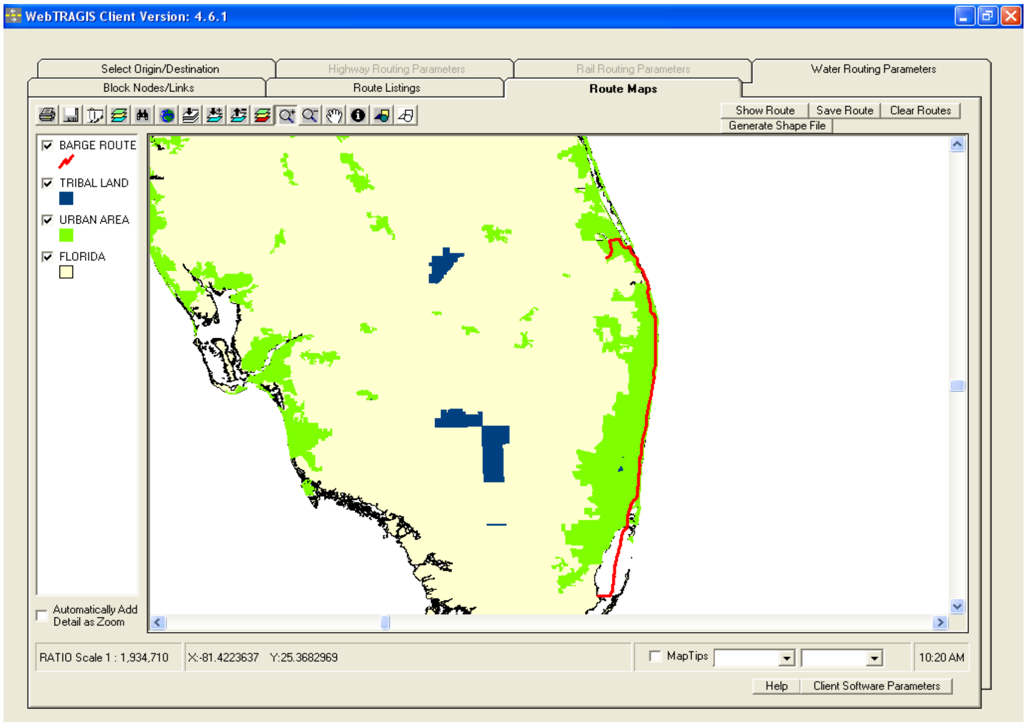


Figure 12: Florida Barge Route

Link Name

Give each link a name in the left-hand **Link Name** column. A link name must be a continuous text string and must not contain any spaces.

Links do not need to be consecutive. The user may divide the entire route into a rural link, which includes all rural segments, a suburban link, which includes all suburban segments, and an urban link, which includes all urban segments. Rush-hour periods can also be separate links. The designation of rural, suburban, or urban is defined by the resident population density along the route (see **Population Density**). This is shown in Figure 13 in the **Population Density (persons/km^2)** column.

Vehicle

Available vehicle names are on a pull-down menu in the **Vehicle** column. Note that vehicle names cannot be added or deleted at this screen. This is shown in Figure 13 in the **Vehicle** column.

Length

Enter the length of the route segment – the link – in kilometers, as obtained from a routing code like WebTRAGIS or from a GIS system or from a map (WebTRAGIS is almost universally used – See Section 4.5.1 of this Manual for Importing WebTRAGIS Data Listings). This is shown in Figure 13 in the **Length (km)** column.

Useful conversion factors are:

1 km = 0.6217 mile
1 mile = 1.608 km.
1 person/mi^2 = (1 person/mi^2)*(1 mi/1.608 km)^2 = 1 person/2.586 km^2

Speed

Enter the average speed of each vehicle on each link, in km/hr. This is shown in Figure 13 in the **Speed (km/h)** column. You may use any speeds you choose. Table 1 presents the state-by-state speed limits in both mph and kph.

Table 1. State by state highway speed limits

	Speed Limit (miles/hour)				Speed Limit (kilometers/hour)			
	Interstate				Interstate			
State	Rural	Urban	Other limited-access	Other roads	Rural	Urban	Other limited-access	Other roads
AL	70	65	65	65	113	105	105	105
AZ	75	55	55	55	121	88	88	88
AR	70, Trucks: 65	55	60	55	113,trucks 105	88	97	88
CA	70, Trucks: 55	65	70	65	113,trucks 88	105	113	105
CO	75	65	65	65	121	105	105	105
CT	65	55	65	55	105	88	105	88
DE	65	55	65	55	105	88	105	88
DC	NA	55	NA	25	NA	88	NA	40
FL	70	65	70	65	113	105	113	105
GA	70	65	65	65	113	105	105	105
ID	75, Trucks: 65	75	65	65	121,trucks 105	121	105	105
IL	65, Trucks: 55	55	65	55	105, trucks 88	88	105	88
IN	65, Trucks: 60	55	55	55	105, trucks 97	88	88	88
IA	65	55	65	55	105	88	105	88
KS	70	70	70	65	113	113	113	105
KY	65	65	65	55	105	105	105	88
LA	70	70	70	65	113	113	113	105
ME	65	65	65	60	105	105	105	97
MD	65	65	65	55	105	105	105	88
MA	65	65	65	55	105	105	105	88
MI	70, Trucks: 55	65	70	55	113, trucks 88	105	113	88
MN	70	65	65	55	113	105	105	88
MS	70	70	70	65	113	113	113	105
MO	70	60	70	65	113	97	113	105
MT	75, Trucks: 65	65	Day: 70, Night: 65	Day: 70, Night: 65	121, trucks 105	105	Day 113, night 105	Day 113, night 105
NE	75	65	65	60	121	105	105	97
NV	75	65	70	70	121	105	113	113

Table 1 – continued

	Speed Limit (miles/hour)				Speed Limit (kilometers/hour)			
	Interstate		Other limited-access	Other roads	Interstate		Other limited-access	Other roads
State	Rural	Urban			Rural	Urban		
NH	65	65	55	55	105	105	88	88
NJ	65	55	65	55	105	88	105	88
NM	75	75	65	55	121	121	105	88
NY	65	65	65	55	105	105	105	88
NC	70	70	70	55	113	113	113	88
ND	75	75	70	65	121	121	113	105
OH	65, Trucks: 55	65	55	55	105, trucks 88	105	88	88
OK	75	70	70	70	121	113	113	113
OR	65, Trucks: 55	55	55	55	105, trucks 88	88	88	88
PA	65	55	65	55	105	88	105	88
RI	65	55	55	55	105	88	88	88
SC	70	70	60	55	113	113	97	88
SD	75	75	65	65	121	121	105	105
TN	70	70	70	65	113	113	113	105
TX	Day: 75, Night/Truck: 65	Day: 70, Night: 65	Day: 75, Night/Truck: 65	Day: 60, Night: 55	121, Night/Truck 105	Day 113, Night 105	Day 121, Night/Truck 105	Day 97, Night 88
UT	75	65	75	65	121	105	121	105
VT	65	55	50	50	105	88	80	80
VA	65	65	65	55	105	105	105	88
WA	70, Trucks: 60	60	60	60	113. trucks 97	97	97	97
WV	70	55	65	55	113	88	105	88
WI	65	65	65	55	105	105	105	88
WY	75	60	65	65	121	97	105	105

SOURCE: Insurance Institute for Highway Safety - Highway Loss Data Institute, Maximum Posted Speed Limits for Passenger Vehicles, available at http://www.hwysafety.org/safety_facts/state_laws/speed_limit_laws.htm as of Oct. 11, 2004.

We have generally assumed that rush-hour speeds are about half of the speed limit. We have in the past used the following exceedingly conservative national average values in RADTRAN:

- Trucks on freeways, primary U.S. highways, or limited-access highways: 88 km/hr (55 mph), including trucks on interstate highways through urban areas.
- Trucks on two-lane rural roads: 72 km/hr (45 mph)
- Trucks on urban or suburban two-lane roads: 40 km/hr (25 mph)
- Trucks on city streets: 24 km/hr (15 mph)
- Trucks in rush-hour traffic: one-half the non-rush hour speed on the particular road type
- Trains on rural route segments: 64 km/hr (40 mph)
- Trains on suburban route segments: 40 km/hr (25 mph)
- Trains on urban route segments: 24 km/hr (15 mph)

Trains carrying large casks of radioactive material (spent fuel, UF_6) travel no faster than 50 mph, because radioactive materials are hazardous materials.

Population Density

Enter the population density in persons/km^2, as obtained from WebTRAGIS (See Section 4.5.1 of this Manual for Importing WebTRAGIS Data Listings), the City/County data book, or some other GIS system or source. This is shown in Figure 13. This population density is usually provided for a band one-half mile (800 meters) on either side of the route. Rural, suburban, and urban population densities are classified by WebTRAGIS according to the following scheme:

- rural: 0 to 139 persons/mi^2 (0 to 55 persons/km^2)
- suburban: 139 to 3326 persons/mi^2 (55 to 1300 persons/km^2)
- urban: more than 3326 persons/mi^2 (1300 persons/km^2)

The historic RADTRAN classifications are:

- rural: 0 to 66 persons/km^2
- suburban: 67 to 1670 persons/km^2)
- urban: more than 1670 persons/km^2)

National averages are approximately:

- rural: 6 persons/km^2
- suburban: 720 persons/km^2
- urban: 3800 persons/km^2

Population density and vehicle speed are important parameters in determining the off-link incident-free dose from radioactive materials transportation. Population density is important in determining accident dose risk.

Vehicle Density

Enter the vehicle density – the vehicles that share the route with the radioactive cargo – in vehicles per hour. This is shown in Figure 13 in the **Vehicle Density (vehicles/hr**) column. Sandia National Laboratories has recently updated highway vehicle densities; the Sandia study is reproduced in this User guide as Appendix D. The national average vehicle densities from the Sandia study are:

<u>Interstate Highways</u>

- rural: 1155 vehicles/hr
- suburban: 2414 vehicles/hr
- urban: 5490 vehicles/hr

<u>U.S. Highways</u>

- rural: 287 vehicles/hr

- suburban: 618 vehicles/hr
- urban: 1711 vehicles/hr

Appendix D includes average regional vehicle densities from the ten Environmental Protection Agency (EPA) regions and average vehicle densities from 21 states. More accurate vehicle densities can usually be obtained from state traffic counts. Rush-hour vehicle densities are assumed to double.

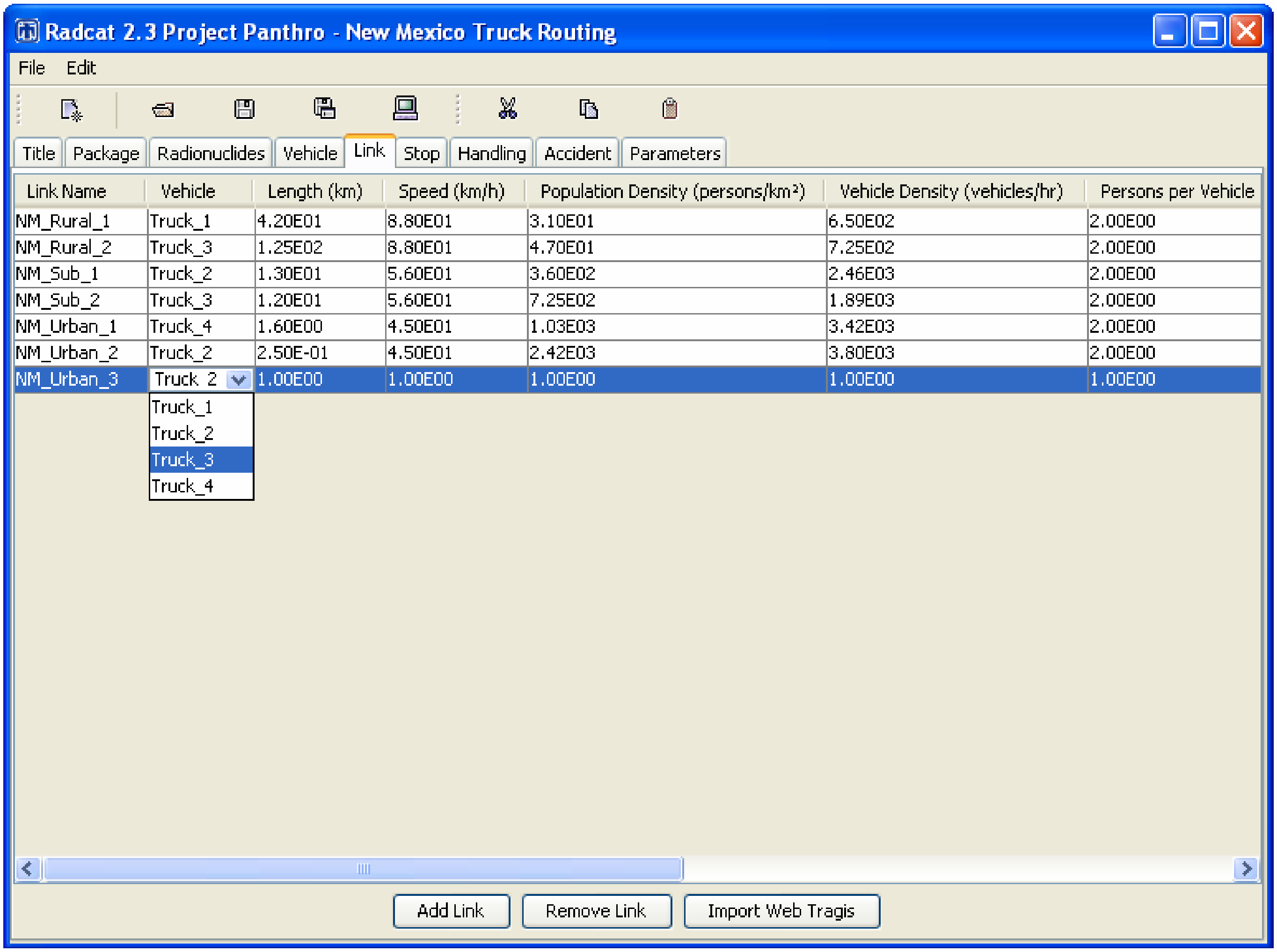


Figure 13: Link Tab

National average vehicle densities that were used in RADTRAN in the past are:

<u>Truck</u>

- rural: 460 vehicles/hr
- suburban: 780 vehicles/hr
- urban: 2800 vehicles/hr

These vehicle densities underestimate current average traffic density on interstate highways, and may overestimate traffic density on other highways.

Rail vehicle densities are:

- rural: 1 vehicle/hr
- suburban: 5 vehicles/hr
- urban: 5 vehicles/hr

Persons per Vehicle (Vehicle Occupancy)

Enter the average persons per vehicle for the route. This is shown in Figure 13 in the **Persons per Vehicle** column. For highway transportation, this is usually 1.5 or 2 persons per vehicle. For rail, since most rail transportation is freight, the number is usually 3 (the train crew). If passenger trains share the route, the average vehicle occupancy can be estimated.

The vehicle density and the vehicle occupancy are important parameters in determining the on-link incident-free dose from transportation of radioactive materials.

Accident Rate

Enter the vehicle accident rate for each route segment in accidents per vehicle-km. This is shown in Figure 14 in the **Accident Rate (accidents/veh-km)** column. Accident rates are usually reported by state and type of road or rail. Useful references for accident rates are:

- Saricks, C.L. and Tompkins, M.M. 1999. State-Level Accident Rates of Surface Freight Transportation: A Reexamination. ANL/ESD/TM-150. Argonne, Illinois: Argonne National Laboratory.

- The Bureau of Transportation Statistics web site: http://www.bts.gov. Table 2 shows state by state accident rates averaged for the years 2002-2005, from the national transportation surveys on this website. The data in Table 2 are for heavy (semi-detached) trucks.

Fatalities per Accident

Enter the number of fatalities per accident, as shown in Figure 14. Fatality rates are usually reported by state and type of road or rail. The Bureau of Transportation Statistics website provides traffic fatality information.

Zone

A pull-down menu allows the designation of each link as rural, suburban, or urban. These designations affect certain RADTRAN calculations within the code; e.g. rural, suburban, and urban areas have different shielding for residents, only a rural link can be associated with a non-zero farm fraction, urban links allow consideration of non-resident populations, etc. This is shown in Figure 14 in the **Zone** column.

Table 2. Highway truck accidents

State	Accidents/vehicle-km	State	Accidents/vehicle-km
Alabama	2.61E-06	Montana	3.78E-06
Arizona	1.70E-05	Nebraska	1.96E-06
Arkansas	2.70E-06	Nevada	8.37E-06
California	3.98E-06	New Hampshire	3.46E-06
Colorado	9.58E-07	New Jersey	5.19E-06
Connecticut	2.08E-06	New Mexico	4.78E-06
Delaware	1.90E-06	New York	1.21E-06
District of Columbia	6.83E-06	North Dakota	4.78E-06
Florida	1.27E-05	North Carolina	1.15E-06
Georgia	1.40E-06	Ohio	1.63E-06
Idaho	1.55E-06	Oklahoma	7.61E-06
Illinois	6.69E-06	Oregon	1.22E-06
Indiana	5.68E-06	Pennsylvania	2.45E-06
Iowa	1.32E-06	Rhode Island	2.18E-06
Kansas	1.63E-06	South Carolina	1.59E-06
Kentucky	2.50E-06	South Dakota	5.36E-06
Louisiana	3.29E-06	Tennessee	3.00E-06
Maine	2.85E-06	Texas	1.11E-05
Maryland	2.91E-06	Utah	2.04E-06
Massachusetts	4.09E-06	Vt (NH)	1.16E-06
Michigan	1.57E-06	Virginia	2.67E-06
Minnesota	1.20E-06	Washington	6.91E-06
Mississippi	1.43E-06	W. Virginia	1.55E-06
Missouri	1.50E-06	Wisconsin	1.79E-06
		Wyoming	5.21E-06

Type

A pull-down menu allows the designation of the road type as Interstate (Primary Highway) or Secondary Road for the Highway Mode. This is shown in Figure 14 in the **Type** column. The designation "Other" is for rail and barge routes only. The RADTRAN code uses this designation.

Farm Fraction

A fraction of land on rural route segments can be designated as farmland, and this fraction is then used in RADTRAN to calculate ingestion dose in the event of an accident. If you designate a farmland fraction on a suburban or urban route segment, RADTRAN will not read it. If you wish to designate a farmland fraction for a suburban link, simply designate that link as rural. Farm fraction is shown in Figure 14 in the **Farm Fraction** column.

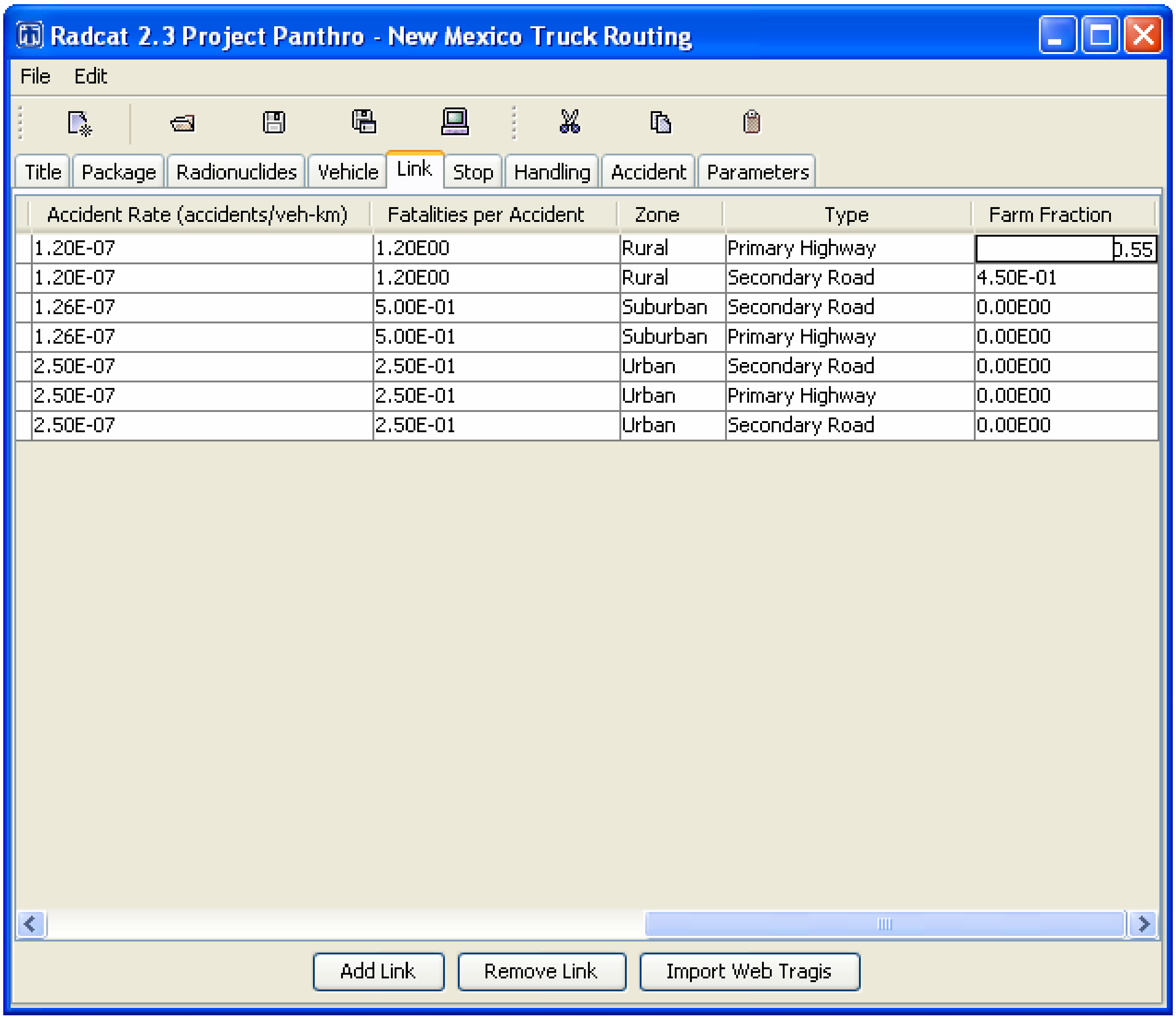
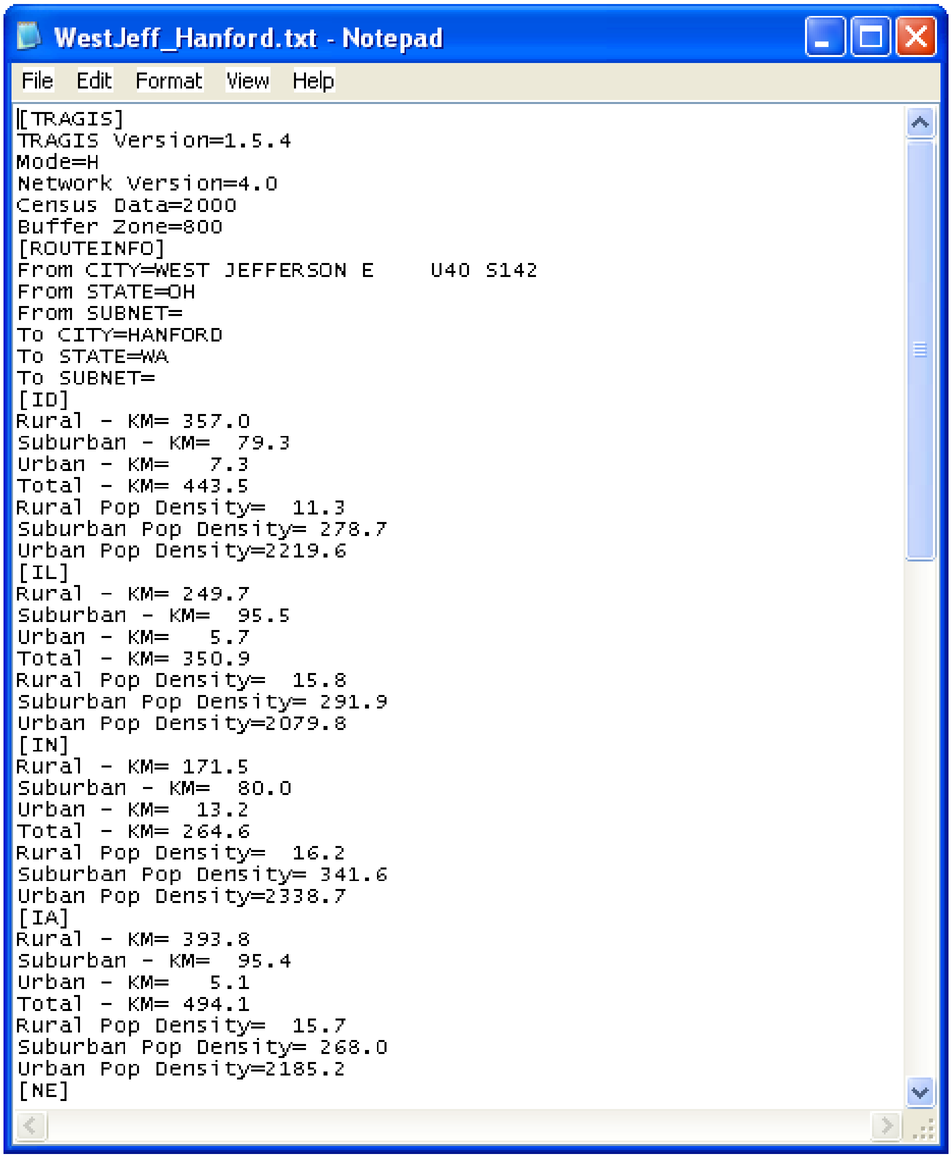


Figure 14: Link Tab Continued

5.4.1 Importing WebTRAGIS

The current version of WebTRAGIS has a RADTRAN Data Listing feature, which reports population densities (persons/km^2) and distances traveled (km) within each population zone (rural, suburban, and urban) for each state traversed as a text file. Figure 15 shows an example of a WebTRAGIS – RADTRAN Data Listing text file for a truck route from West Jefferson, Ohio to Hanford, Washington using routing rules of highway route controlled quantities of radioactive materials.




```
[TRAGIS]
TRAGIS Version=1.5.4
Mode=H
Network Version=4.0
Census Data=2000
Buffer Zone=800
[ROUTEINFO]
From CITY=WEST JEFFERSON E     U40 S142
From STATE=OH
From SUBNET=
To CITY=HANFORD
To STATE=WA
To SUBNET=
[ID]
Rural - KM= 357.0
Suburban - KM=  79.3
Urban - KM=   7.3
Total - KM= 443.5
Rural Pop Density=  11.3
Suburban Pop Density= 278.7
Urban Pop Density=2219.6
[IL]
Rural - KM= 249.7
Suburban - KM=  95.5
Urban - KM=   5.7
Total - KM= 350.9
Rural Pop Density=  15.8
Suburban Pop Density= 291.9
Urban Pop Density=2079.8
[IN]
Rural - KM= 171.5
Suburban - KM=  80.0
Urban - KM=  13.2
Total - KM= 264.6
Rural Pop Density=  16.2
Suburban Pop Density= 341.6
Urban Pop Density=2338.7
[IA]
Rural - KM= 393.8
Suburban - KM=  95.4
Urban - KM=   5.1
Total - KM= 494.1
Rural Pop Density=  15.7
Suburban Pop Density= 268.0
Urban Pop Density=2185.2
[NE]
```

Figure 15: WebTRAGIS – RADTRAN Data Listing Text File

This text file can be imported into RADCAT using the **Import Web Tragis** button on the **Link** tab. Before importing into RADTRAN, the RADTRAN Data Listing text file must be saved to your computer. The **Import Web Tragis** button will then open a search window for you to locate the WebTRAGIS – RADTRAN Data Listing text file. Figure 16 provides an example of the search window.

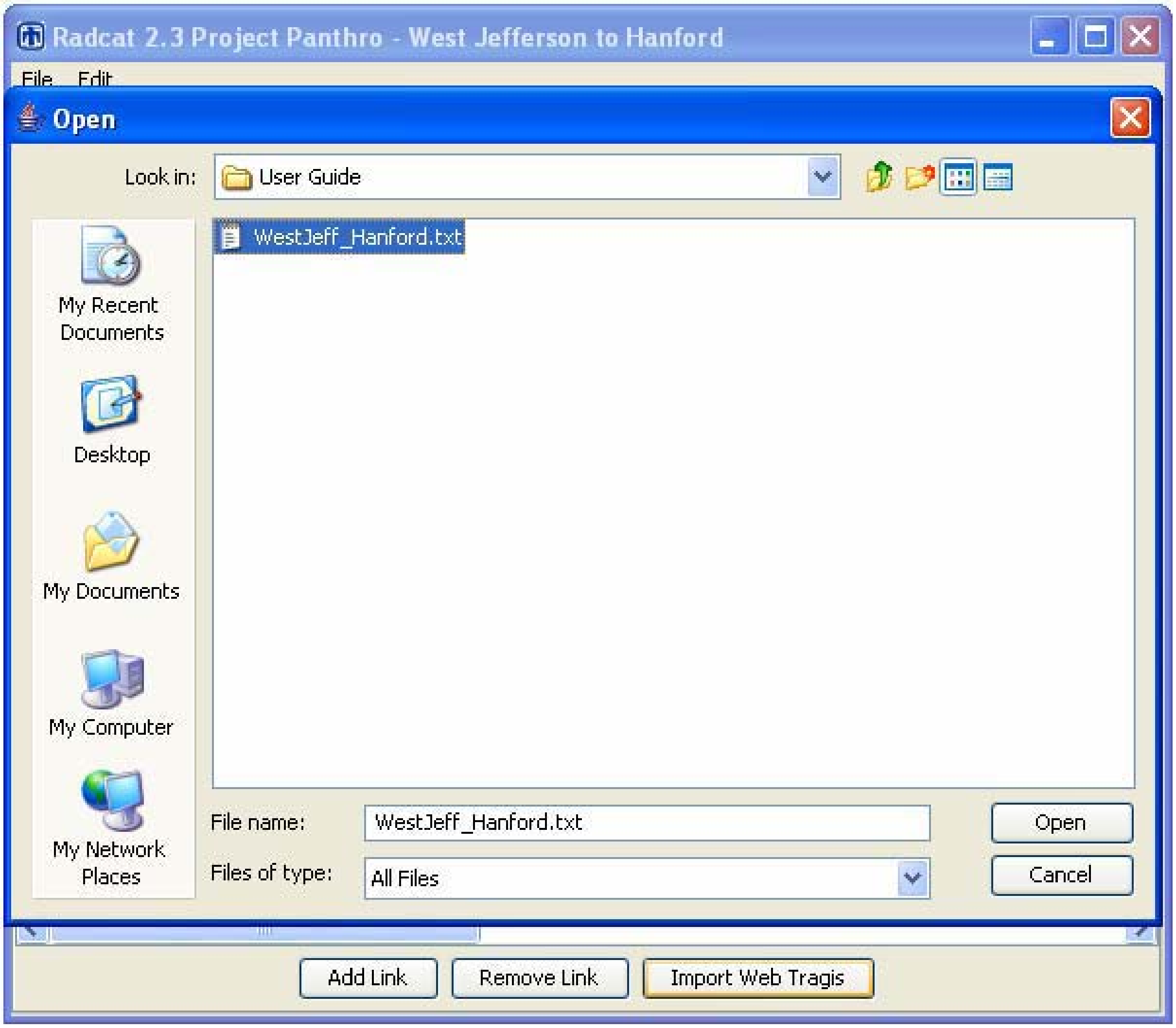
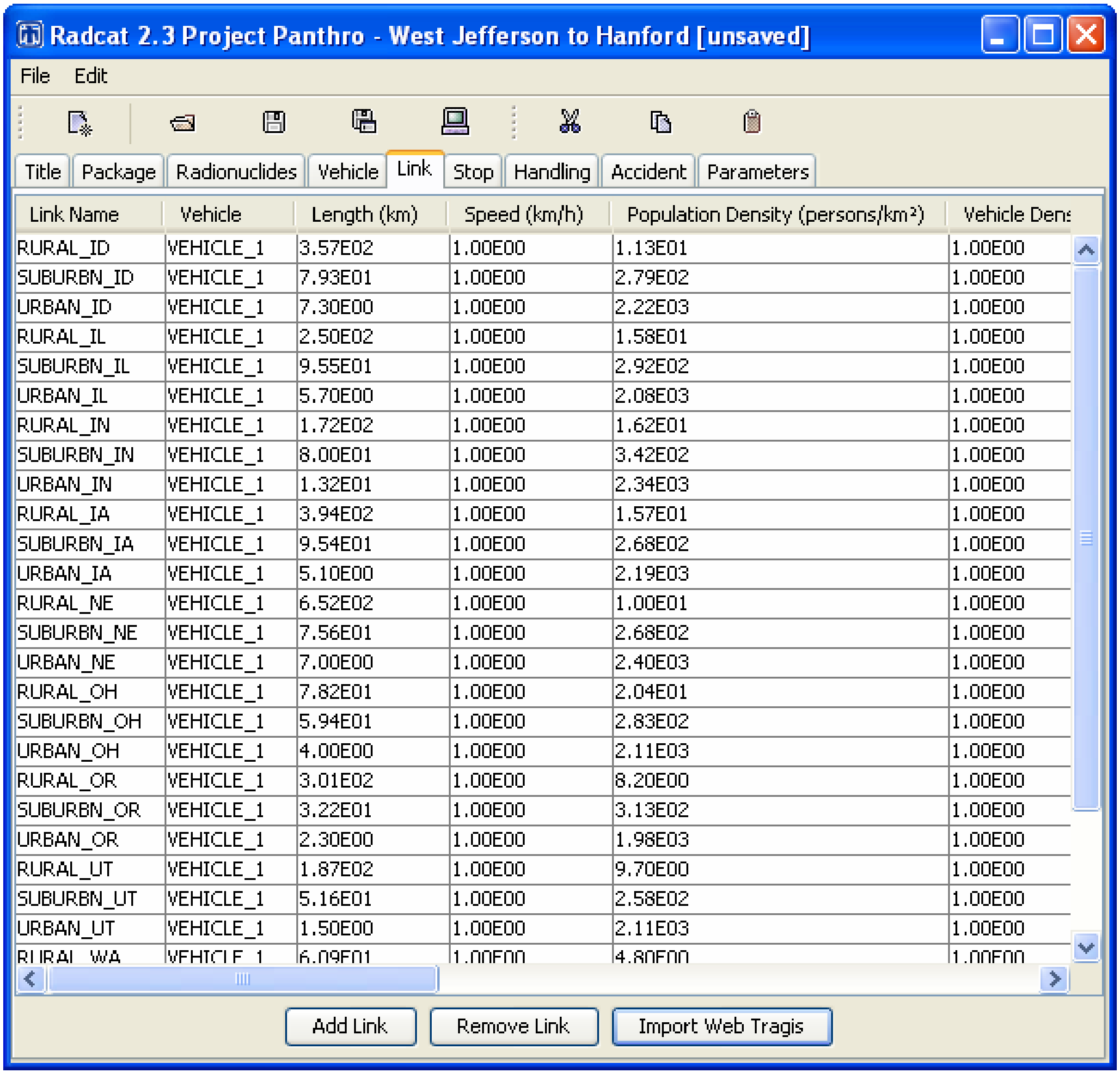


Figure 16: Import WebTRAGIS Search Window

An imported WebTRAGIS – RADTRAN Data Listing text file into RADCAT will list all the route segments for each state traversed according to population zones (rural, suburban, and urban). The population density, distance traveled, and population zone will be automatically filled in for each route. Figure 17 provides an example of the import feature in RADCAT. The following **Link** tab inputs will still need to be filled in by the user:

- Vehicle
- Speed
- Vehicle Density
- Persons per Vehicle
- Accident Rate
- Type (for Highway Mode only)
- Farm Fraction



Link Name	Vehicle	Length (km)	Speed (km/h)	Population Density (persons/km²)	Vehicle Dens
RURAL_ID	VEHICLE_1	3.57E02	1.00E00	1.13E01	1.00E00
SUBURBN_ID	VEHICLE_1	7.93E01	1.00E00	2.79E02	1.00E00
URBAN_ID	VEHICLE_1	7.30E00	1.00E00	2.22E03	1.00E00
RURAL_IL	VEHICLE_1	2.50E02	1.00E00	1.58E01	1.00E00
SUBURBN_IL	VEHICLE_1	9.55E01	1.00E00	2.92E02	1.00E00
URBAN_IL	VEHICLE_1	5.70E00	1.00E00	2.08E03	1.00E00
RURAL_IN	VEHICLE_1	1.72E02	1.00E00	1.62E01	1.00E00
SUBURBN_IN	VEHICLE_1	8.00E01	1.00E00	3.42E02	1.00E00
URBAN_IN	VEHICLE_1	1.32E01	1.00E00	2.34E03	1.00E00
RURAL_IA	VEHICLE_1	3.94E02	1.00E00	1.57E01	1.00E00
SUBURBN_IA	VEHICLE_1	9.54E01	1.00E00	2.68E02	1.00E00
URBAN_IA	VEHICLE_1	5.10E00	1.00E00	2.19E03	1.00E00
RURAL_NE	VEHICLE_1	6.52E02	1.00E00	1.00E01	1.00E00
SUBURBN_NE	VEHICLE_1	7.56E01	1.00E00	2.68E02	1.00E00
URBAN_NE	VEHICLE_1	7.00E00	1.00E00	2.40E03	1.00E00
RURAL_OH	VEHICLE_1	7.82E01	1.00E00	2.04E01	1.00E00
SUBURBN_OH	VEHICLE_1	5.94E01	1.00E00	2.83E02	1.00E00
URBAN_OH	VEHICLE_1	4.00E00	1.00E00	2.11E03	1.00E00
RURAL_OR	VEHICLE_1	3.01E02	1.00E00	8.20E00	1.00E00
SUBURBN_OR	VEHICLE_1	3.22E01	1.00E00	3.13E02	1.00E00
URBAN_OR	VEHICLE_1	2.30E00	1.00E00	1.98E03	1.00E00
RURAL_UT	VEHICLE_1	1.87E02	1.00E00	9.70E00	1.00E00
SUBURBN_UT	VEHICLE_1	5.16E01	1.00E00	2.58E02	1.00E00
URBAN_UT	VEHICLE_1	1.50E00	1.00E00	2.11E03	1.00E00
RURAL_WA	VEHICLE_1	6.09E01	1.00E00	4.80E00	1.00E00

Figure 17: Imported WebTRAGIS – RADTRAN Data Listing

5.5 STOPS

You may select the **Stop** tab after the **Link** tab. If editing an existing file without adding or deleting a package, the order in which the tabs are opened will not make any difference. Figure 18 shows the **Stop** tab.

Name

Give each **Stop** a **Name** in the left-hand column. A stop name must be a continuous text string and may not include any spaces. Aggregation of all stops of a particular type (e.g., inspection stops, refueling stops) may be done and the total time for those stops entered in the **Time** column. Different types of populations (e.g., other people at a refueling stop, residents near the stop) may be structured as different stops. This difference is shown in Figure 18.

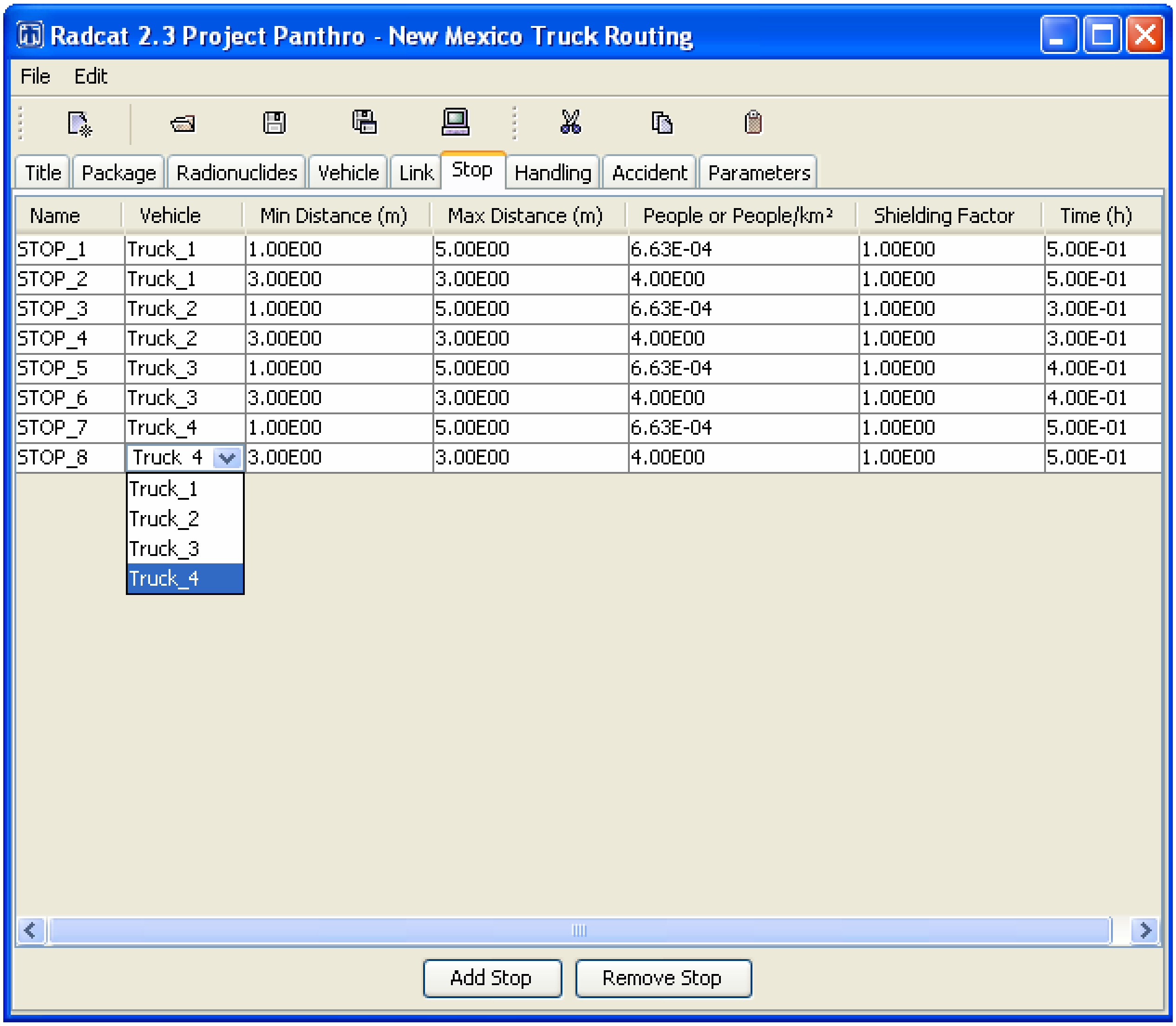


Figure 18: Stop Tab

Vehicle

Available vehicle names are on a pull-down menu in the **Vehicle** column. This is shown in Figure 18 in the **Vehicle** column. Note that vehicle names cannot be added or deleted at this tab.

Min Distance

Enter the shortest distance at the stop from the radioactive cargo to the receptor(s) whose dose from incident-free transportation will be calculated. This is shown in Figure 18. The **Min(imum)** and **Max(imum) Distance** columns define the area around the radioactive cargo in which there are receptors at that particular stop. The **Min(imum) Distance** cannot be less than 1.0 meter.

Max Distance

Enter the longest distance from the radioactive cargo to the receptor(s) whose dose from incident-free transportation will be calculated. This is shown in Figure 18. The **Min(imum)** and **Max(imum) Distance** define the area around the radioactive cargo in which there are receptors at that particular stop. The **Min(imum)** and **Max(imum) Distance** may be the same or may be different (see **People or People/km^2** below). The **Min(imum) Distance** can never be larger than the **Max(imum) Distance.**

People or People/km^2

This parameter defines the number of radiation receptors at each particular stop. Figure 19 is the diagram of a truck stop and illustrates the truck stop parameters.

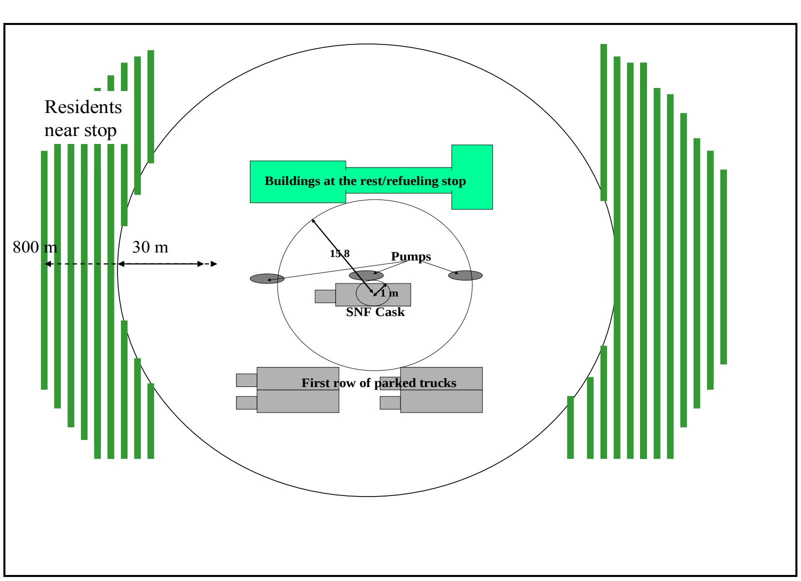


Figure 19. Truck Stop Diagram (not to scale). See discussion below.

The stop in Figure 19 would be modeled in RADTRAN as three separate stops:

- Stop 1: the crew of the truck carrying the SNF cask. One crew member refuels while the other goes into the truck stop building.
- Stop 2: the people in the area between the gas pumps and the building
- Stop 3: the residents around the truck stop

A rail stop would be modeled similarly.

For Stop 1, the **Min(imum)** and **Max(imum) Distance** are the same, RADTRAN reads the number in this column as the total number of people at that distance from the radioactive cargo. In this case there is one person about one meter from the cargo (the two crew members take turns filling the tanks). Thus, both the **Min(imum) Distance** and **Max(imum) Distance** = 1.0, and **People or People/km^2** = 1**.**

For Stop 2, the **Min(imum)** and **Max(imum) Distance** are different, so that RADTRAN reads the number in the **People or People/km^2** column as a population density: persons/km^2. This population density must be calculated off-line. In the case of Stop 2, let us assume 10 people around the cargo in an annular ring with a shortest distance to the cargo of 1 m and a longest distance of 15.8 m, the population density in this annular ring may be calculated as follows:

Inner radius = 1 meter.
Outer radius = 15.8 meters.

Area of annulus = $\pi*[(15.8)^2 - (1)^2] = 248.6\pi = 781 m^2 = 7.81 \times 10^{-4}$ km^2

Population density in the annulus = $10/(7.81 \times 10^{-4}) = 1.3 \times 10^4$ people/ km^2

Enter 1 meter for the **Min(imum) Distance,** 15.8 meters for the **Max(imum) Distance**, and then enter 1.3 x 10^4 for **People or People/km^2**.

For Stop 3, the area surrounding the stop, for which the population density is given on the **Links** screen or is otherwise known, that population density may be entered directly into the stop model. RADTRAN reads total population when the **Min(imum)** and **Max(imum) Distance** are the same, and reads population density when the **Min(imum)** and **Max(imum) Distance** are different. This is shown in Figure 18 in the **People or People/km^2** columns.

Shielding Factor

The **Shielding Factor** is the fraction of ionizing radiation to which the receptors are exposed; that is, the inverse of the amount of shielding. This means that 1 = no shielding and 0 = 100% shielding. Enter a number between 0 and 1 for the shielding factor for each stop. This is shown in Figure 18 in the **Shielding Factor** column.

Time

Enter the total time in hours for each type of stop, as shown in Figure 18 in the **Time (h)** column.

5.6 HANDLING

Handling refers to a potential dose from the cargo packages sustained by a handler during storage, loading, and unloading, and similar activities. Doses to handlers may also be calculated using the **Stop** tab and parameters.

When making a new input file or adding or deleting a vehicle in an existing file, select the **Handling** tab after the **Vehicle** tab. If editing an existing file without adding or deleting a package, the order in which the tabs are opened doesn't make any difference. This is shown in Figure 20.

Name

Give each group of **Handlers** a **Name** in the left-hand column. A handler name must be a continuous text string and must not contain any spaces. This is shown in Figure 20 in the **Name** column.

Vehicle

Available vehicle names are on a pull-down menu in the **Vehicle** column seen in Figure 20. Note that vehicle names cannot be added or deleted at this tab.

Number of Handlers

Enter the number of people in each group of handlers. This is shown in Figure 20 in the **Number of Handlers** column.

Distance

Enter the average distance from the radioactive cargo to the handler group whose dose from incident-free transportation will be calculated. This is shown in Figure 20 in the **Distance (m)** column.

Time

Enter the total time in hours that each group of handlers is handling the cargo. This is shown in Figure 19 in the **Time (h)** column.

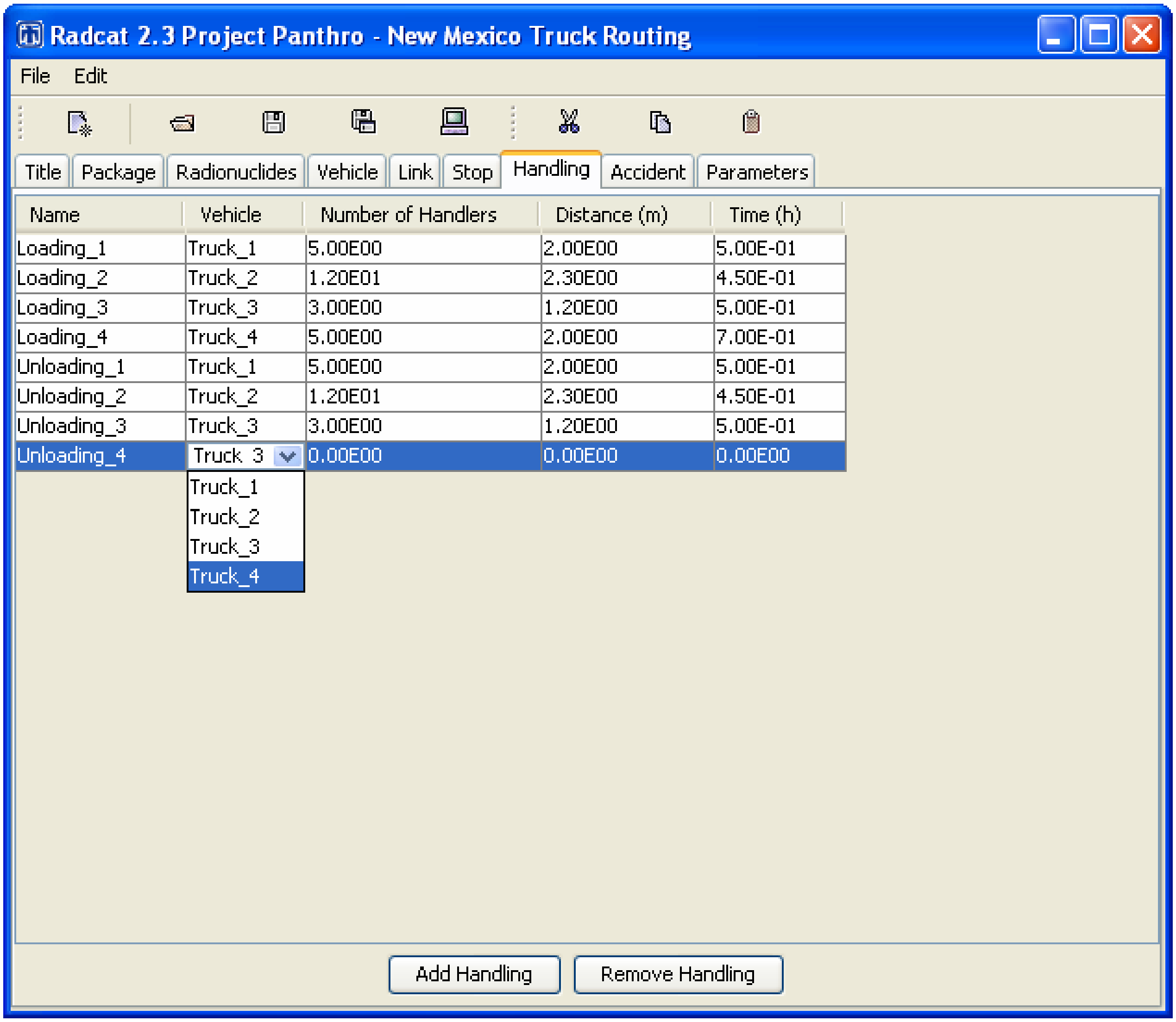


Figure 20: Handling Tab

5.7 ACCIDENTS

RADTRAN calculates both the risks and the consequences of accidents. The Technical Manual for RADTRAN discusses the equations that underlie the risk and consequence calculations. This section of the User Guide focuses on the inputs to the calculation.

The accident analysis requires a radionuclide inventory to be entered at the **Radionuclides** tab, and accident rates and population densities, at the **Link** tab. If no radionuclides have been put in the input file, RADTRAN will run but the accident outputs will be zeros.

When the **Accident** screen is opened, seven tabs appear:

- Probability
- Deposition Velocity
- Release
- Aerosol
- Respirable
- Isopleth P
- Weather

5.7.1 CONDITIONAL PROBABILITIES (SEVERITY FRACTIONS)

The **Probability** tab allows you to specify the conditional probability of an accident of a particular severity, given that an accident happens. Severity of an accident – how damaging the accident is – is a function of the transportation mode. The probability tab is shown in Figure 21.

Probability Fraction and Index

The **Probability Fraction** is the conditional probability of an accident of a particular severity (previously referred to in RADTRAN as "severity fraction"). The **Index** is a numbering system for **Probability Fractions** and simply enumerates them (note that the **Index** begins with zero). One **Probability Fraction** (usually the zeroth) should represent an accident in which there is neither a release of radioactive material nor loss of gamma shielding. The probability of this type of accident is usually more than 90%. This is shown in Figure 21. **Probability Fractions** may be obtained from studies of accidents as described in the following references:

Sprung, J.L., et al. 2000, "Reexamination of Spent Fuel Shipment Risk Estimates," NUREG/CR-6672, Washington, D.C.: U.S. Nuclear Regulatory Commission. Chapter 7, pp. 7-73 to 7-76.

DOE (U.S. Department of Energy), 2002, "Final Environmental Impact Statement for a Geologic Repository for the Disposal of Spent Nuclear Fuel and High-Level Radioactive Waste at Yucca Mountain, Nye County, Nevada," DOE/EIS-0250F, Washington, D.C.: U.S. Department of Energy. Appendix J and Transportation Health and Safety Calculation/Analysis Documentation, CAL-HSS-ND-000003, Section 5.3.2.

Fischer, L.E., et al. 1987. Shipping Container Response to Severe Highway and Railway Accident Conditions. NUREG/CR-4829. Two volumes. Washington, D.C.: U.S. Nuclear Regulatory Commission.

Probability Fractions should add to 1.00, though this is sometimes difficult to see with very small probability fractions. RADCAT does not force addition to 1.00. Enter the **Probability Fractions** in the right-hand column. Indices may only be added and deleted on this screen. This is shown in Figure 21.

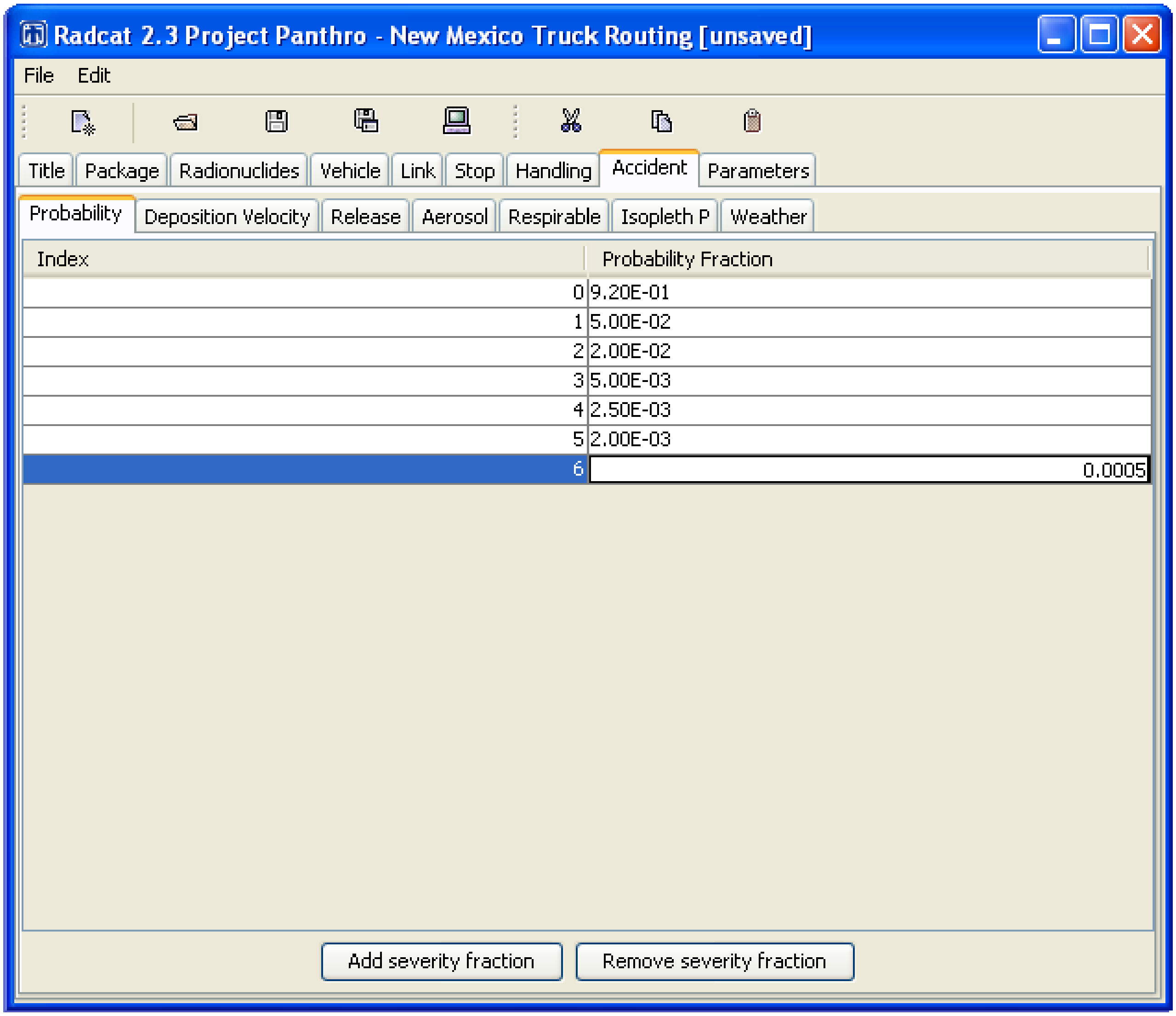


Figure 21: Accident / Probability Tab

5.7.2 DEPOSITION VELOCITY

Deposition Velocity depends on the size, density, and shape of the radionuclides that are released into the environment as a result of the accident. The **Group** column on the left has a pull-down menu of the physical chemical groups entered at the **Radionuclides** tab. Enter a **Deposition Velocity** in meters/sec for each **Group.** Gases do not deposit and thus have a **Deposition Velocity** = 0. A **Deposition Velocity** of 0.01 m/sec is often used as being generally representative of aerosol particles that can be dispersed over long distances. The **Deposition Velocity** should be small enough that the material is deposited in at least 2 isopleths. If the **Deposition Velocity** is too large RADTRAN will not finish the calculations. It is recommended that the **Deposition Velocity** be no larger than 0.1 m/sec for proper results. **Groups** may not be added or deleted at this screen. This is shown in Figure 22.

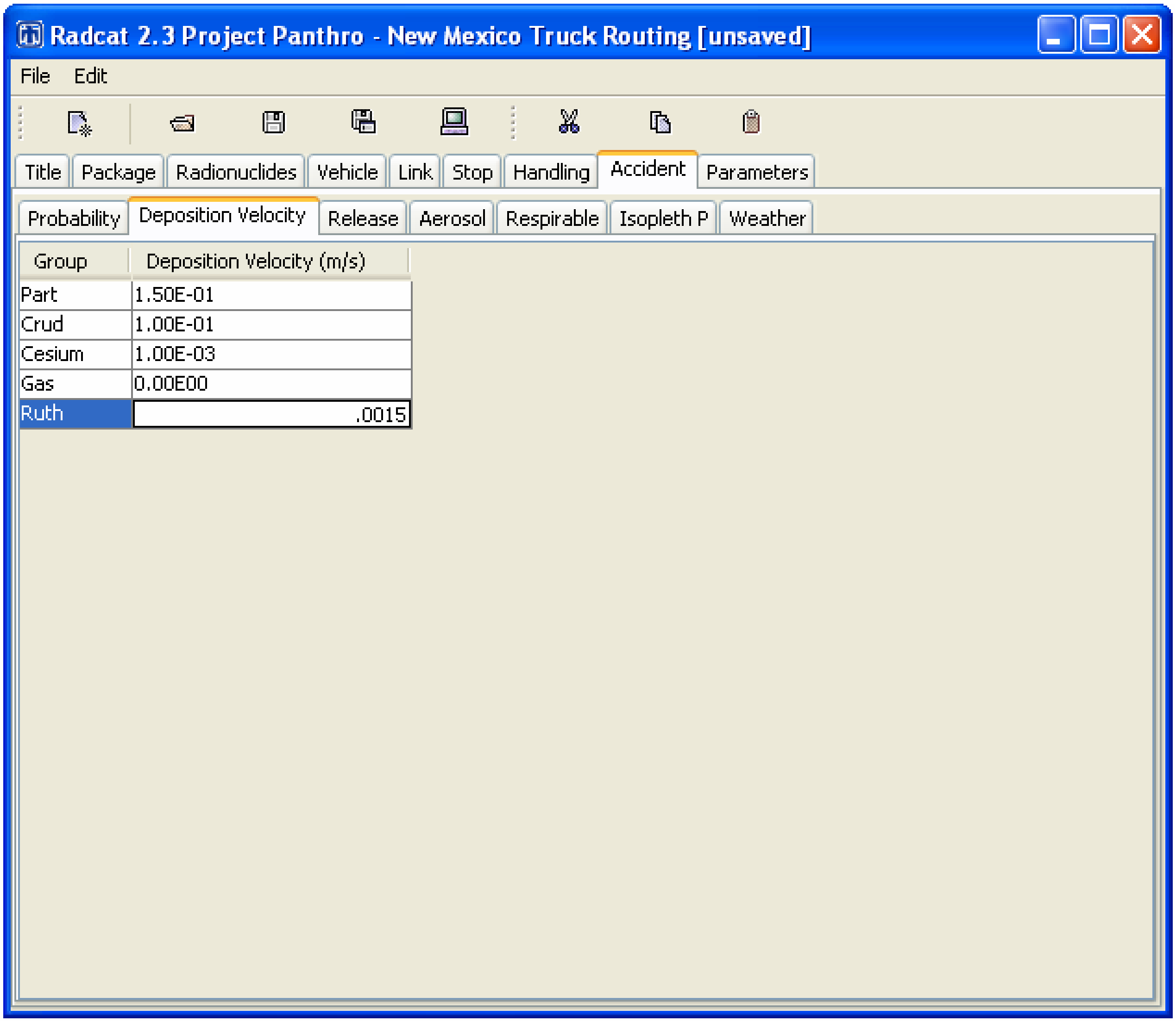


Figure 22: Accident / Deposition Velocity Tab

5.7.3 RELEASE FRACTION

Release Fraction, the fraction of each radionuclide in the cargo that could be released in an accident, depends on the physical and chemical behavior of the radionuclides and on the severity of the accident. The pull-down menu at the top allows selection of the physical/chemical **Group.** Groups may not be added or deleted at this tab. Select a physical/chemical **Group** from the pull-down menu. This is shown in Figure 23.

The left-hand column shows the **Index** number which is associated with the **Conditional Probability Index** for each **Probability Fraction.** Enter a **Release Fraction** for each **Index** and each **Group.** Indices may not be added or deleted at this screen.

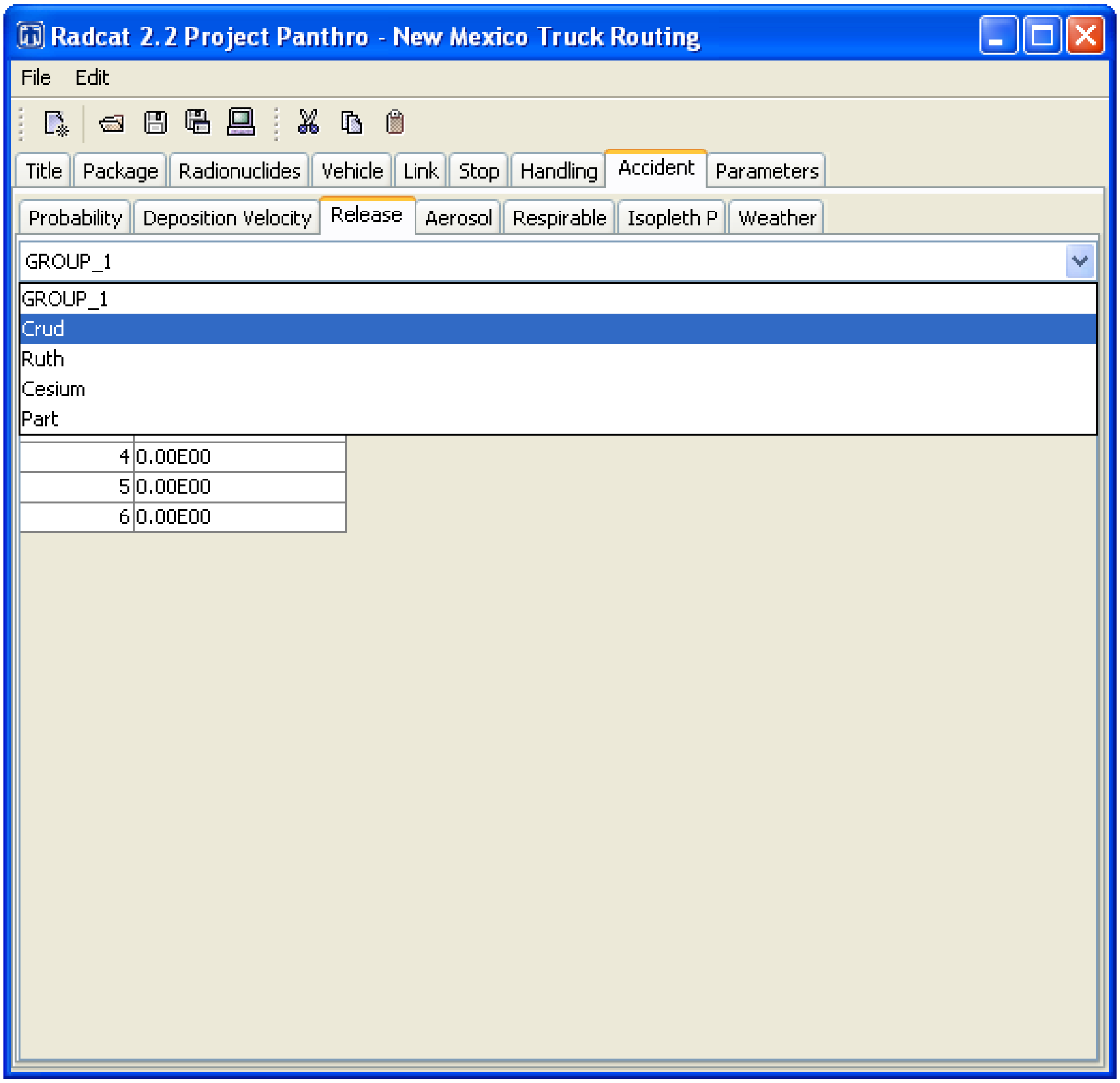


Figure 23: Accident / Release Tab

5.7.4 AEROSOL FRACTION

The **Aerosol Fraction,** the fraction of each **Release Fraction** that would be aerosolized in an accident, depends on the physical behavior of the radionuclides and on the severity of the accident. The pull-down menu at the top allows selection of the physical/chemical **Group.** Groups may not be added or deleted at this tab. Select a physical/chemical **Group** from the pull-down menu seen in Figure 24.

The left-hand column shows the **Index** number which is associated with the **Conditional Probability Index** for each **Probability Fraction.** Enter an **Aerosol Fraction** for each **Index** and each **Group.** In most accidents involving Type B casks or containers, only very small particles are released; in such cases, the **Aerosol Fraction** = 1. Indices may not be added or deleted at this screen.

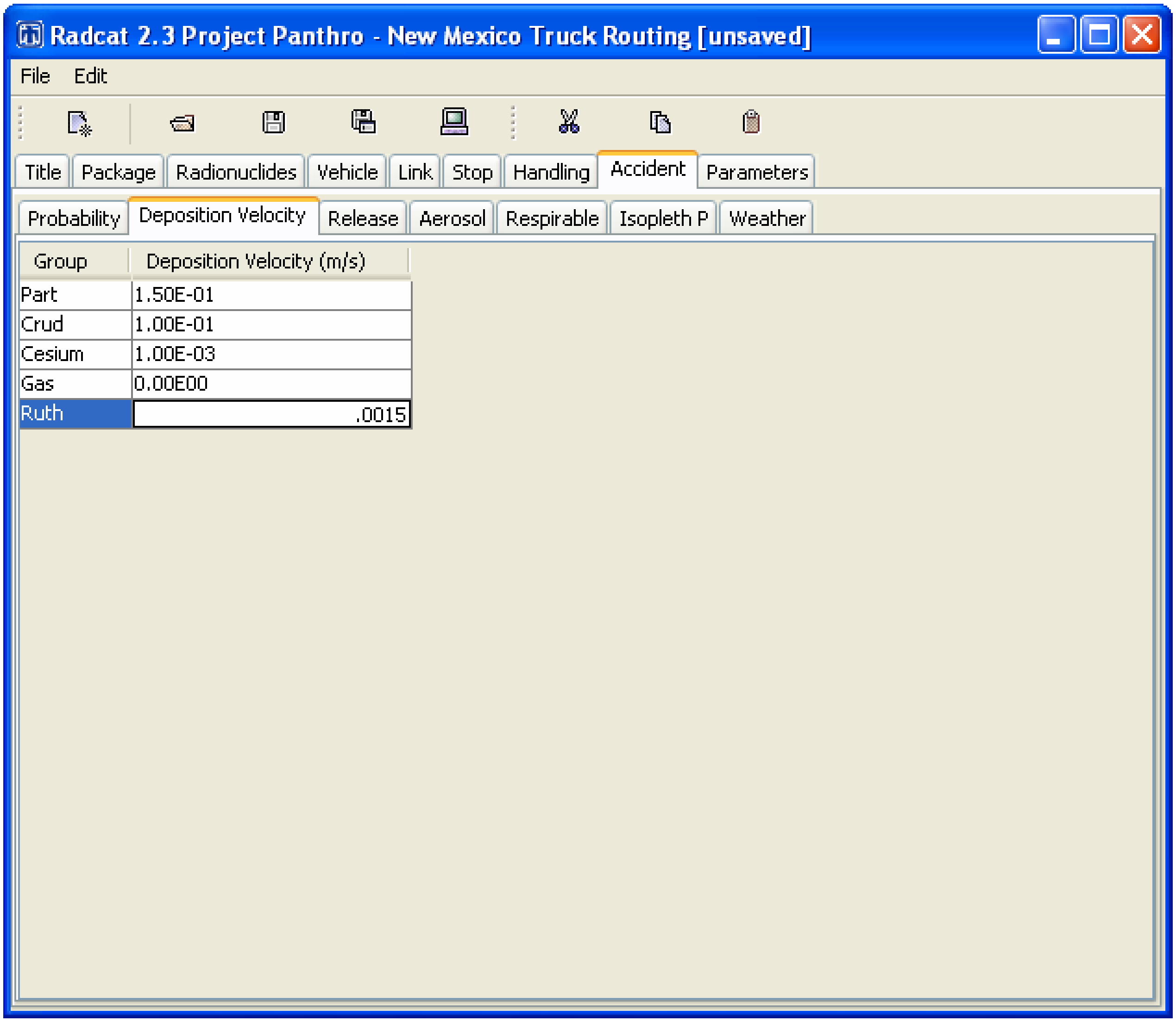


Figure 24: Accident / Aerosol Tab

5.7.5 RESPIRABLE FRACTION

The **Respirable Fraction,** the fraction of each **Aerosol Fraction** that consists of particles or droplets most of which are small enough to enter the lung alveoli (usually considered to be less than 10 microns in diameter)[2], depends on the physical and chemical behavior of the radionuclides and on the severity of the accident. The pull-down menu at the top allows selection of the physical/chemical **Group.** Groups may not be added or deleted at this tab. Select a physical/chemical **Group** from the pull-down menu seen in Figure 25.

The left-hand column shows the **Index** number which is associated with the **Conditional Probability Index** for each **Probability Fraction.** Enter a **Respirable Fraction** for each **Index** and each **Group.** The

[2] The inhalation dose conversion factors used in RADTRAN, which are from ICRP 72, include contributions from larger particles in the naso-pharyngeal system

Respirable Fraction is often between 0.05 and 0.1, but may be as much as 1.0. Indices may not be added or deleted at this screen.

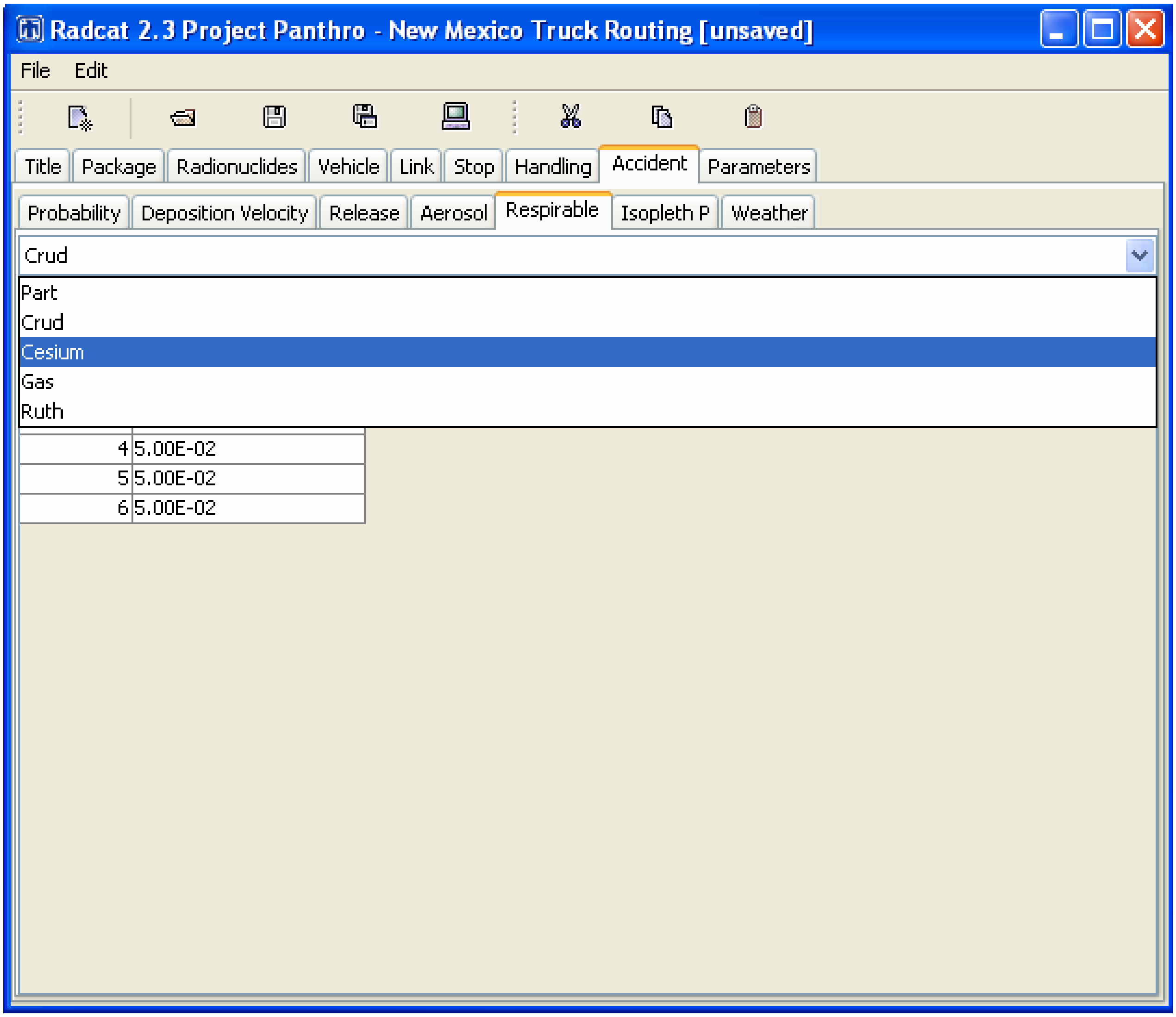


Figure 25: Accident / Respirable Tab

5.7.6 ISOPLETH P

RADTRAN provides two alternate methods of identifying the population that could experience the fallout from an accidental release of radioactive material. The default method takes the population density in the 800-meter band on either side of the transportation route, from the **Links** tab, and applies it to the footprint of the entire plume, encompassing all selected isopleths. The alternate method allows a different population density to be associated with (and entered for) each isopleth; the population densities must be obtained offline from a GIS system or some other population map. The **Isopleth P** tab provides you with a choice between the default and the alternate method.

Open the **Isopleth P** tab before you open the **Weather** tab. The two buttons at the top of the tab provide the choice between the default population density (the density in the 800-meter band) and user-supplied population densities. This is shown in Figure 26. User-supplied population densities in **Isopleth P** may only be used with the **Average** option on the **Weather** tab. If **Specify your own population densities** is selected, a population density must be added for each isopleth area by adding or removing population densities with the "Add Isopleth P" or "Remove Isopleth P" buttons respectively. If **Use the default population densities** is selected, the user can choose any of the options listed in the **Weather** tab, and the population densities listed in the **Link** tab will be used for the isopleth areas. Note that isopleth areas may not be added or deleted at this screen.

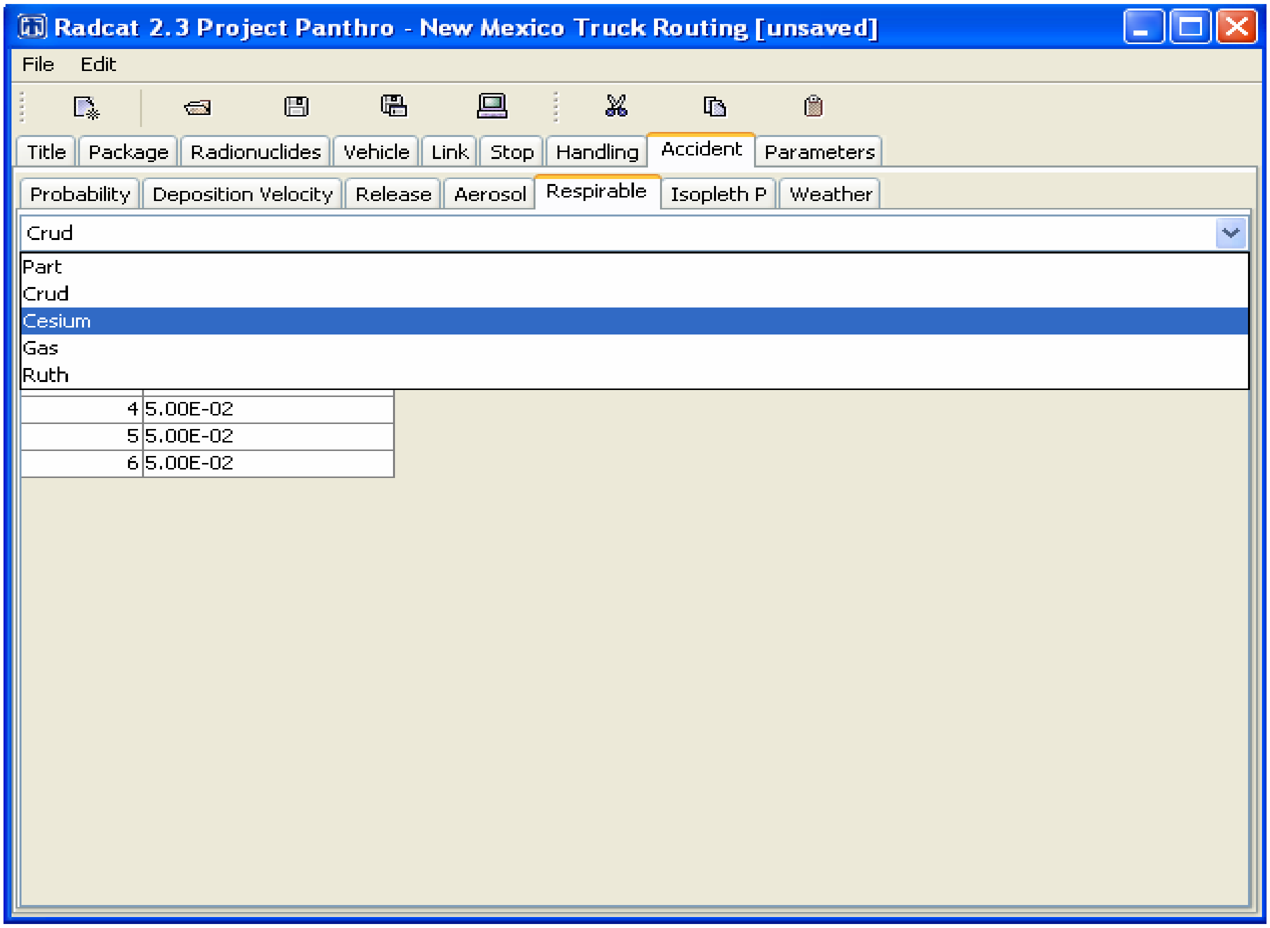


Figure 26: Accident / Isopleth P Tab

5.7.7 WEATHER

Open the **Weather** tab after you open the **Isopleth P** tab. If **Specify your own population densities** is selected on the **Isopleth P** tab, you must select the same number of dispersion areas as Isopleth P population densities. The number of dispersion areas may be added or removed using the bars at the bottom of the screen. This is shown in Figure 27. **Isopleth Areas**, maximum **Centerline Distances** for each area, and corresponding **Time Integrated Concentrations** may be calculated externally using any Gaussian dispersion program, and can be entered manually into the table on this screen. Note that you cannot add or delete population densities in this tab.

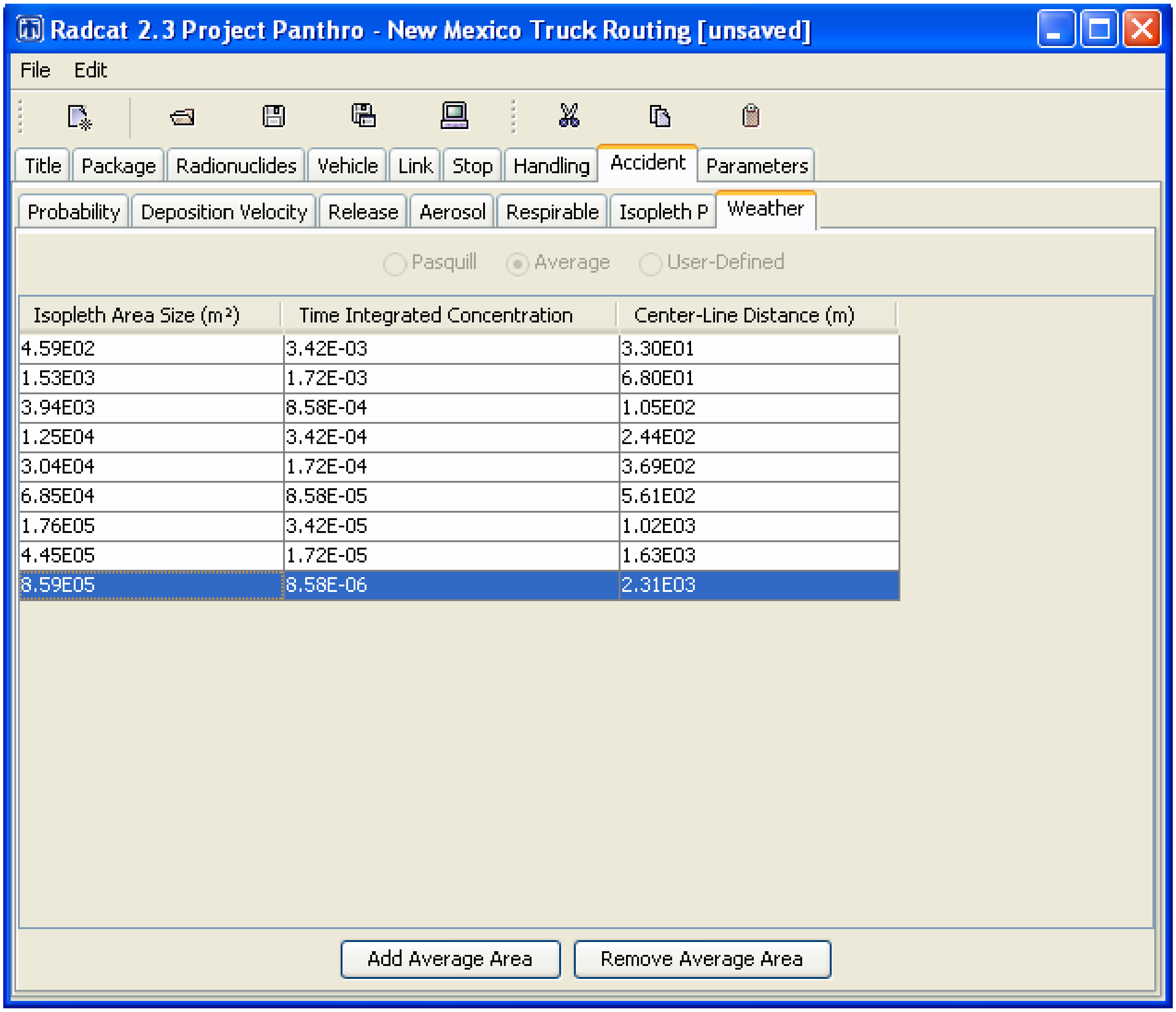


Figure 27: Accident / Weather Tab with User-Defined Dispersion Option

5.7.7.1 Weather and Use the default population densities

If **Use the default population densities** is selected in the **Isopleth P** tab, any of the three options shown in Figure 28, **Average, Pasquill,** or **User-Defined,** may be selected.

5.7.7.1.1 The Average Option

Choosing the **Average** option selects a set of **Isopleth Areas**, maximum **Centerline Distances** for each area, and corresponding **Time Integrated Concentration** (dilution, or Chi/Q, factors) based on U. S. national average meteorology and wind speed. This is shown in Figure 28. The number of areas may be added to or withdrawn using the bars at the bottom of the screen. RADTRAN cannot handle more than 18 isopleth areas is a single run.

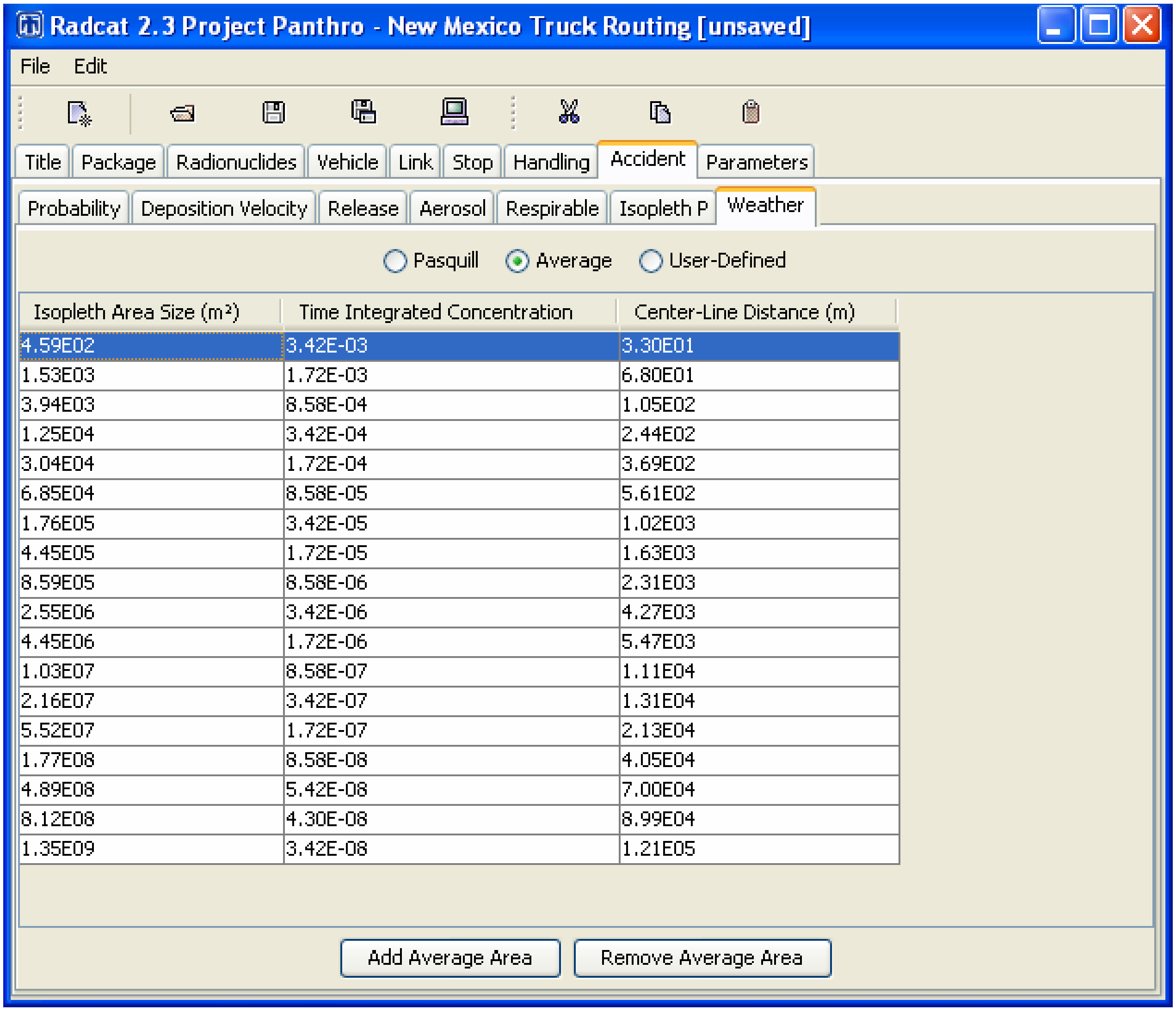


Figure 28: Accident / Weather Tab with National Average Weather Option

5.7.7.1.2 The Pasquill Option

Choosing the **Pasquill** option opens a screen listing the six meteorological **Pasquill Stability Classes** in the left-hand column and allows the user to enter the fraction of occurrence of each **Stability Class** in the **Fraction** column as seen in Figure 29. These fractions must total exactly 1 or RADTRAN will not execute. Note that in this option, wind speeds are constant for each **Stability Class,** as shown in Table 3.

Table 3: Pasquill Wind Speeds for Each Stability Class

Stability Class	**Wind Speed (m/sec)**
A	1
B	2
C	3
D	4
E	2.5
F/G	1

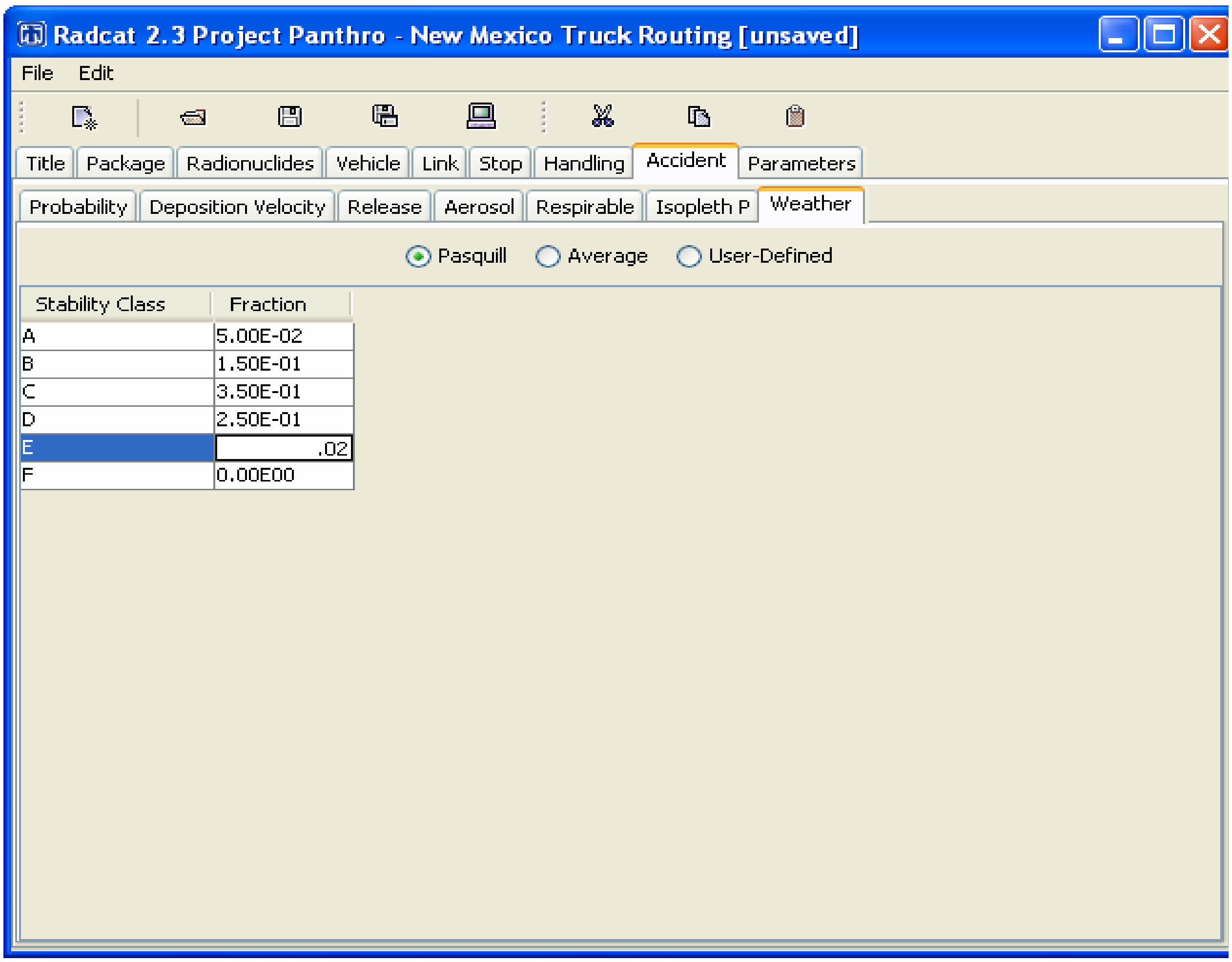


Figure 29: Accident / Weather Tab with Pasquill Option

5.7.7.1.3 The User-Defined Option

The **User-Defined** option allows modeling of higher temperature and elevated releases, rainout, and the application of user-defined wind speeds. Choosing the **User-Defined** option opens a screen listing the input parameters listed below and shown in Figure 30. Note that the user can only use this option for one specific type of cask, release location, and wind stability class.

1. **Release Height (m)** – This parameter allows the user to specify the release height for an atmospheric dispersion. "Effective release height" is generally the elevation at which the plume begins to move downwind.

2. **Heat Release (calories/sec)** – This parameter allows the user to incorporate the amount of thermally-induced buoyancy and momentum that will affect the effective release height.

3. **Cask Length (m)** – This cask length should be the same as the largest cask dimension indicated on the **Package** screen

4. **Cask Radius (m)** – This cask radius should be the same as indicated on the **Package** screen

5. **Wind Speed at Anemometer (m/sec)** – This parameter will allow the user to specify the wind speed at an anemometer reading site.

6. **Anemometer Height (m)** – This parameter will allow the user to correlate the anemometer wind speed with the wind speed at the effective release height, usually 10 meters).

7. **Ambient Temperature (degrees Kelvin, ^{o}K)** – This parameter adjusts the plume rise accordingly to adiabatic and potential temperature lapse rates. 293 ^{o}K = 20 ^{o}C = 68 ^{o}F; 273 ^{o}K = 0 ^{o}C = 32 ^{o}F

8. **Atmospheric Mixing Height (m)** – This parameter will allow the user to define the height to which the atmosphere is uniformly mixed, which is the *de facto* height to which the plume will rise. The mixing height can be determined analytically by finding the height above the ground of the intersection of the ambient temperature profile with the dry adiabatic lapse rate. If there is no temperature inversion, the mixing height can be infinite, but is often entered as a kilometer (1000 meters) or more.

9. **Rainfall Rate** – This parameter will allow the user to incorporate wet deposition by rain or snowfall into the dispersion model. It is recommended that this parameter be used for light and medium rainfall (a few millimeters per hour) since this model does not incorporate the surface runoff or washout which is experienced with heavy rainfall. The Solar and Meteorological Surface Observation Network has the following definitions for rainfall rates:

    - Light Drizzle: Up to 0.25 mm/hr
    - Medium Drizzle: 0.25 to 0.51 mm/hr
    - Heavy Drizzle: Greater than 0.51 mm/hr
    - Light Rainfall: Up to 2.5 mm/hr
    - Medium Rainfall: 2.5 to 7.6 mm/hr
    - Heavy Rainfall: Greater than 7.6 mm/hr

The following website can provide hourly rain data from the National Oceanic and Atmospheric Administration (NOAA) Forecast System Laboratory:
http://precip.fsl.noaa.gov/hourly_precip.html

10. **Dispersion Model** – This parameter will allow the user to choose between the Pasquill dispersion model, or the Briggs dispersion model. The former is suitable for ground-level releases and the latter is better for elevated releases.

11. **Stability Category** – This parameter will allow the user to determine which Pasquill stability class (A-F) will be used. In general, classes A, B, and C are consistent with increasing wind speed and unstable atmospheric conditions, class D is neutral (the ambient lapse rate is the same as the adiabatic lapse rate) and consistent with wind speeds about 4 to 5 m/sec, and classes E and F are consistent with very light winds, poor dispersion, and temperature inversions. Any text on air pollution can provide a complete discussion of Pasquill stability class. Two example references are Randerson (1984) and Wark, et al, 1998:

12. Release Location – This parameter allows the user to designate whether the release will be in a rural or suburban/urban location.

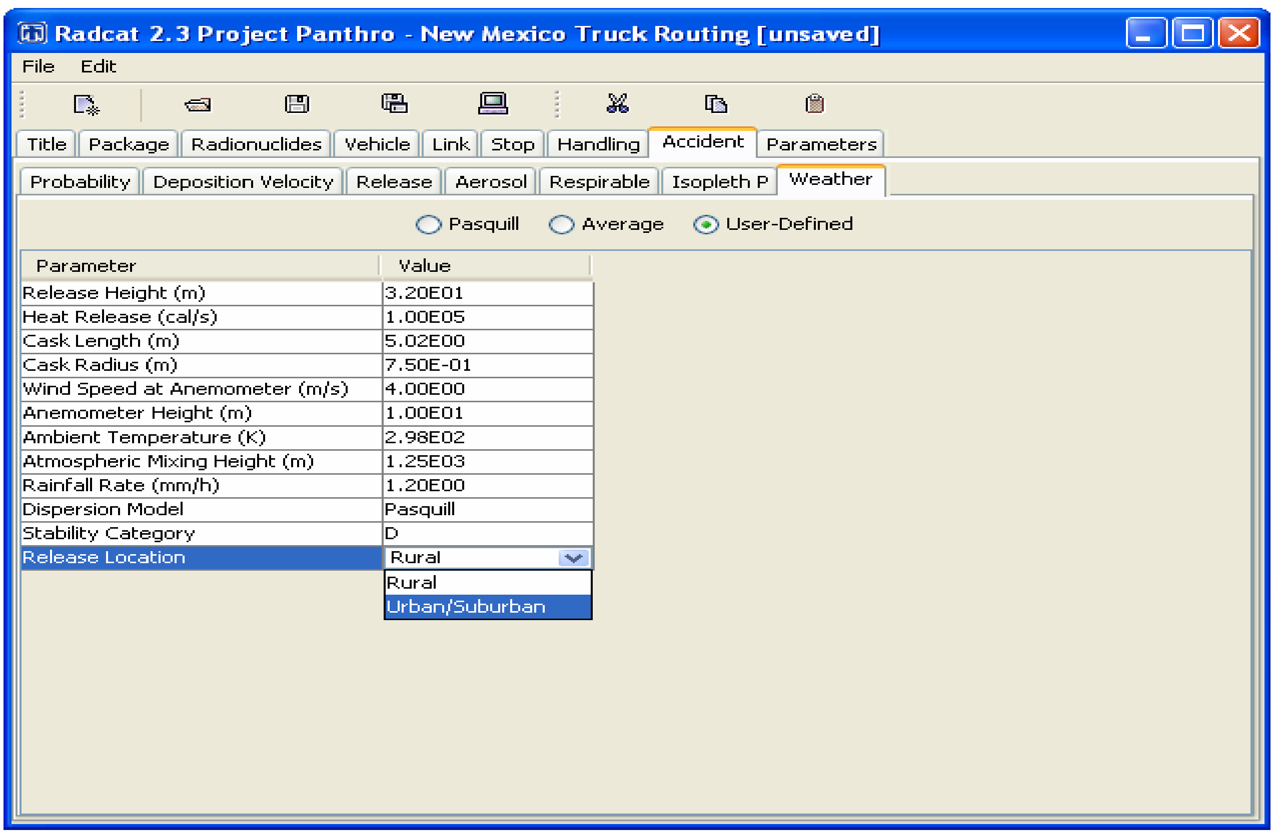


Figure 30: Accident / Weather Tab with User-Defined Option

5.7.8 COMBINING THE USER DEFINED OPTION WITH ISOPLETH P

As RADTRAN is currently configured, the Isopleth P option can be used only with national average weather

5.8 PARAMETERS

Figure 31 lists values that have historically been used in RADTRAN for a variety of parameters. Any of these values can be overwritten by the user. Figure 31 shows the **Parameters** tab for highway routes, Figure 32 shows the **Parameters** tab for rail routes and Figure 33 shows the **Parameters** tab for barge routes.

Shielding factor for residences

The shielding factor is inverse of the shielding fractions; i.e., a shielding factor of 1 indicates no shielding, and a shielding factor of zero indicates 100% shielding. The shielding factor is the fraction of ionizing radiation to which rural residents are exposed in their homes or other buildings in this zone. This is shown in Figures 31, 32, and 33. The standard (default) value is 1.0 (i.e., no shielding) for rural buildings, 0.87 for suburban buildings, and 0.018 for urban buildings.

Fraction of outside air in urban buildings

This fraction represents the fraction of aerosol particles in the outside air which may be entrained in building ventilation systems (i.e., the fraction of particles of an external aerosol that remain in aerosol form after passing through a ventilation system) to which people in urban structures are exposed. The fraction of outside air in urban buildings is used to calculate the inhalation and resuspension dose to that population. The standard (default) value of 0.05 represents a conservative average across a series of building types, including residential, office, and industrial structures (Engelmann, 1990). This value is about five times the value for high-rise buildings with air-conditioning systems used by Finley et al., (1980) for New York City, which has been used in RADTRAN in the past. This is shown in Figures 31, 32, and 33.

Fraction of population occupying the sidewalk

This parameter is the Urban Sidewalk Fraction; it specifies the fraction of population that is outdoors or the fraction of population that occupies sidewalks, depending on the type of population model being used. The standard (default) value of 0.1 is for the latter model, and is taken from Finley et al. (1980). This value is suitable for large cities and conservative for smaller cities. This is shown in Figures 31, 32, and 33.

Fraction of urban population inside buildings

This parameter is the Urban Building Fraction; it describes either the fraction of the population that is indoors or the fraction of the area that is occupied by buildings, depending on the type of population model being used. The standard (default) value is 0.52 is for the latter model, and is taken from Finley et al. (1980). The value is most accurate for large cities such as New York City and is somewhat conservative for smaller cities. This is shown in Figures 31, 32, and 33.

Ratio of pedestrians/km^2 to residential population/km^2

This ratio is used to calculate the density of unshielded persons on sidewalks and elsewhere in urban areas by indexing it to the population density of the surrounding area. This ratio can also serve as the ratio of non-resident (e.g., tourist) urban population to resident urban population, since the U. S. Census includes only resident population. The standard (default) value is 6.0, which is based on empirical data from New York City (Finley et al., 1980). This is shown in Figures 31, 32, and 33.

Minimum small package dimension for handling

This parameter specifies the first Package Size Threshold. In RADTRAN, This parameter determines the calculation of handler dose. If a package is designated as "small," i.e., smaller than the standard (default) threshold, the dose to the handler is calculated as originating in a uniform source. If package dimensions exceed the threshold, handler dose is calculated as directly proportional to exposure time and inversely proportional to the square of the distance from package to handler. The value is standard (default) 0.5 (Javitz, 1985). This is shown in Figures 31, 32, and 33.

Distance from shipment for maximum exposure

This parameter is used to calculate the maximum individual "in-transit" off-link dose to a member of the public. It represents the minimum distance, in meters, perpendicular to the route, from the shipment centerline to an individual standing beside the route right-of-way while a shipment passes. The standard (default) value is 30 meters (NRC, 1977). This is shown in Figures 31, 32, and 33.

Vehicle speed for maximum exposure

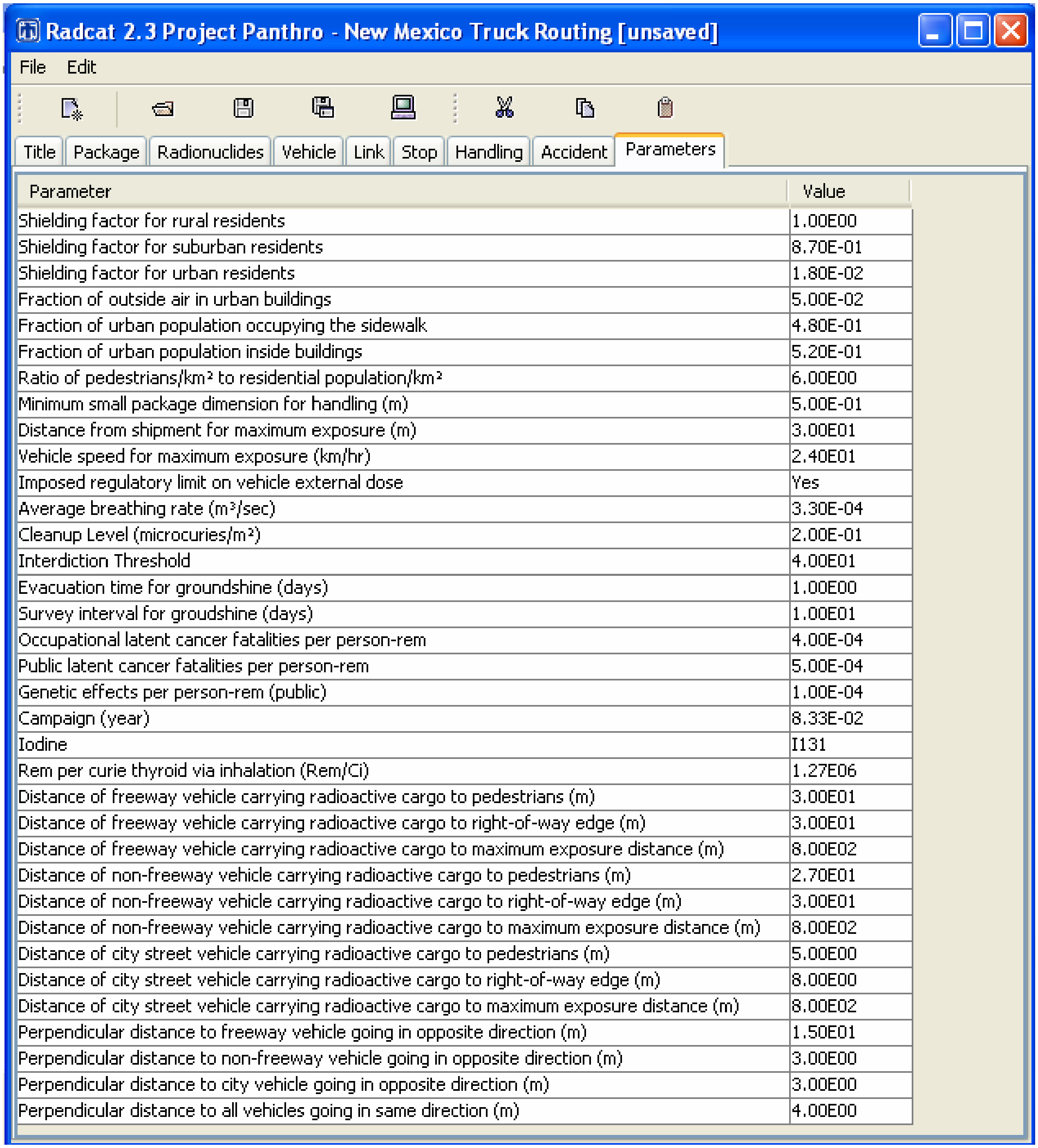
This parameter is used to calculate the maximum individual "in-transit" dose. It represents the minimum velocity, in km/hr, of a shipment. The standard (default) value is 24.0 km/hr (15 mph) (NRC, 1977). This is shown in Figures 31, 32, and 33.

Imposed regulatory limit on vehicle external dose

The standard (default) setting is "**YES**" which causes a series of regulatory checks to be performed. If any circumstances are identified that violate the regulatory requirements (e.g., package dose rate exceeds regulatory maximum), then the appropriate parameter values are reset to the regulatory maximum and the calculation continues. A message informing the analyst is printed in the output. The analyst may adjust the setting to "**NO**" which will bypass the regulatory check subroutine, and ensure that the package dose rate and package critical dimension used in RADTRAN calculations are those that the analyst has INPUT. This is shown in Figures 31, 32, and 33.

Average breathing rate

This parameter represents breathing rate and is used for calculation of inhalation doses. The standard (default) is 3.30E-04 m^3/sec. This breathing rate is taken from the Reference Man (70-kg adult male at light work derived from Shleien 1996; Table 12.6). The value in the cited table, 20 liters/minute, has been converted to m^3/sec. This is shown in Figures 31, 32, and 33.



Parameter	Value
Shielding factor for rural residents	1.00E00
Shielding factor for suburban residents	8.70E-01
Shielding factor for urban residents	1.80E-02
Fraction of outside air in urban buildings	5.00E-02
Fraction of urban population occupying the sidewalk	4.80E-01
Fraction of urban population inside buildings	5.20E-01
Ratio of pedestrians/km² to residential population/km²	6.00E00
Minimum small package dimension for handling (m)	5.00E-01
Distance from shipment for maximum exposure (m)	3.00E01
Vehicle speed for maximum exposure (km/hr)	2.40E01
Imposed regulatory limit on vehicle external dose	Yes
Average breathing rate (m³/sec)	3.30E-04
Cleanup Level (microcuries/m²)	2.00E-01
Interdiction Threshold	4.00E01
Evacuation time for groundshine (days)	1.00E00
Survey interval for groudshine (days)	1.00E01
Occupational latent cancer fatalities per person-rem	4.00E-04
Public latent cancer fatalities per person-rem	5.00E-04
Genetic effects per person-rem (public)	1.00E-04
Campaign (year)	8.33E-02
Iodine	I131
Rem per curie thyroid via inhalation (Rem/Ci)	1.27E06
Distance of freeway vehicle carrying radioactive cargo to pedestrians (m)	3.00E01
Distance of freeway vehicle carrying radioactive cargo to right-of-way edge (m)	3.00E01
Distance of freeway vehicle carrying radioactive cargo to maximum exposure distance (m)	8.00E02
Distance of non-freeway vehicle carrying radioactive cargo to pedestrians (m)	2.70E01
Distance of non-freeway vehicle carrying radioactive cargo to right-of-way edge (m)	3.00E01
Distance of non-freeway vehicle carrying radioactive cargo to maximum exposure distance (m)	8.00E02
Distance of city street vehicle carrying radioactive cargo to pedestrians (m)	5.00E00
Distance of city street vehicle carrying radioactive cargo to right-of-way edge (m)	8.00E00
Distance of city street vehicle carrying radioactive cargo to maximum exposure distance (m)	8.00E02
Perpendicular distance to freeway vehicle going in opposite direction (m)	1.50E01
Perpendicular distance to non-freeway vehicle going in opposite direction (m)	3.00E00
Perpendicular distance to city vehicle going in opposite direction (m)	3.00E00
Perpendicular distance to all vehicles going in same direction (m)	4.00E00

Figure 31: Parameters Tab with Highway Mode

Cleanup Level

This parameter is the desired concentration, in microcuries/m^2, to which a contaminated surface should be cleaned. The parameter is the total allowed activity of all deposited radionuclides. The standard (default) value is the EPA guidance of 0.2 µCi/m^2 (EPA, 1977). This is shown in Figures 31, 32, and 33.

Interdiction Threshold

This parameter specifies the threshold value for interdiction of contaminated land. The standard (default) value is 40, i.e., a value 40 times greater than the **Cleanup Level**, and it was taken from NUREG-0170 (NRC, 1977). This is shown in Figures 31, 32, and 33.

Evacuation time for groundshine

This parameter specifies evacuation time in days following a dispersal accident. The standard (default) value is 1.0 day (24 hours). Mills et al. (1995) analyzed 66 verified HazMat accidents in which evacuations were carried out and found that the mean evacuation time was approximately one hour. The resuspension model also uses this parameter as the time that the receptor is exposed to resuspended material. This time is an input to the calculation of the resuspension dose. If you wish to use a time for exposure to resuspended material different from the groundshine exposure time, you can run RADTRAN separately with a different groundshine exposure time. This is shown in Figures 31, 32, and 33.

Survey interval for groundshine

This parameter is used to specify the time (in days) required to survey contaminated land following a dispersal accident, during which time the residents of the area have been evacuated and are thus not exposed to the released radioactive material. However, RADTRAN calculates the "50-year consequence" by assuming that the residents return after cleanup and are exposed without shielding to the remaining radiation for 50 years. This is an exceedingly conservative assumption and yields unrealistically high doses. It will be corrected in RADTRAN 6. The standard (default) value for the survey interval is 10 days (NRC, 1977). This is shown in Figures 31, 32, and 33.

Occupational latent cancer fatalities per person-rem

This parameter specifies the occupational Latent Cancer Fatality (LCF) conversion factor for worker exposure; units are LCF's per rem. The standard (default) value for workers is 4.0×10^{-4} LCF/rem. This value, based on the linear non-threshold theory of radiation carcinogenesis, is consistent with the recommendations of BEIR VII (NRC/NAS, 2005) and ICRP 60 (ICRP, 1991). Another value that may be used for workers is 5.67×10^{-4} LCF/rem and is consistent with the recommendations from the Interagency Steering Committee on Radiation Standards (DOE 2002). The dose-response relationship is assumed to be a linear with no threshold in order to agree with current regulations. This is shown in Figures 31, 32, and 33.

Public latent cancer fatalities per person-rem

This parameter specifies the non-occupational Latent Cancer Fatality (LCF) conversion factor for public exposure; units are LCF's per rem. The standard (default) value for the public is 5.0×10^{-4} LCF/rem. This value, based on the linear non-threshold theory of radiation carcinogenesis, is consistent with the recommendations of BEIR VII (NRC/NAS, 2005) and ICRP 60 (ICRP, 1991). Another value for the public that may also be used is 5.67×10^{-4} and is consistent with the recommendations from the Interagency Steering Committee on Radiation Standards (DOE 2002). The dose-response relationship is assumed to be a linear with no threshold in order to agree with current regulations and practice. This is shown in Figures 31, 32, and 33.

However, the joint report of the French Academies of Science and Medicine, cited in Tubiana and Aurengo(2005) states:

> *Epidemiological studies have clearly shown that the carcinogenic risks of low doses (< 100 mSv) are very small, if any.... [Radiobiological] data show that the use of a linear no-threshold relationship is not justified for assessing by extrapolation the risk of low doses...since this extrapolation relies on the concept of a constant carcinogenic effect per unit dose, which is inconsistent with radiobiological data. [100 mSv = 10,000 mrem = 10 rem]*

Genetic effects per person-rem (public)

This parameter specifies the Genetic Effects Conversion Factor (GECF). The standard (default) value is 1.0 x 10^{-4} genetic effects/rem. Although this value is consistent with the recommendations of BEIR V (NRC/NAS, 1990) and ICRP 60 (ICRP, 1991), but it is questionable in light of the Tubiana and Aurengo (2005) paper. Moreover, BEIR V and ICRP 60 cite no evidence for this value. This is shown in Figures 31, 32, and 33.

Campaign

This parameter specifies the duration of the shipping campaign in years. The standard (default) value is 0.0833 years, an average month in an average year or $1/12^{th}$ of a year. This value calculates the total number of off-link persons exposed, using the Census Bureau algorithm for the average length of residence in the U.S. This result may be used to perform external calculations of the average off-link individual dose for the entire campaign. Although the total number of exposed persons is calculated, neither the time that each person is exposed nor the exposure time for the total group is calculated. **Campaign** is shown in Figures 31, 32, and 33.

Rem per curie thyroid via inhalation

This parameter is used to specify one-year Committed Effective Dose Equivalent (CEDE) in rem per Curie to the thyroid from inhalation of radionuclides of iodine for estimation of early-mortality risk. Radioiodine mainly travels to and irradiates a single organ, the thyroid. In previous releases the 50-year CEDE was used to approximate the one-year dose. One-year committed doses to the thyroid have been calculated directly from RADTRAN 5. This new parameter was not included in the internal radionuclide database, since it would have meant adding a new column containing zeros for all radionuclides except radioiodines. The information has been included in this parameter instead. The standard (default) values are 1.27 x 10^6 for Iodine-131, 5.77 x 10^6 for Iodine-129, and 9.25 x 10^5 for Iodine-125. This is shown in Figures 31, 32, and 33.

Distance of freeway vehicle carrying radioactive cargo to pedestrians

The standard (default) value is 30 meters and is taken from NUREG-0170 (NRC, 1977). This parameter is the minimum pedestrian-walkway width, for instances in which the dose to pedestrians beside the link is calculated. This parameter is the minimum perpendicular distance over which the off-link dose calculation will be integrated. This is shown in Figure 31. A freeway is any limited-access divided highway.

Distance of freeway vehicle carrying radioactive cargo to right-of-way edge

The standard (default) value is 30 meters and is taken from NUREG-0170 (NRC, 1977). This parameter is the maximum pedestrian-walkway width. This parameter is set equal to **Distance of freeway car carrying radioactive cargo to pedestrians**. This means that the sidewalk width is zero and thus there is no sidewalk available. This is shown in Figure 31. A freeway is any limited-access divided highway.

Distance of freeway vehicle carrying radioactive cargo to maximum exposure distance

The standard (default) value is 800 meters and is taken from NUREG-0170 (NRC, 1977). This parameter is the maximum perpendicular distance over which the off-link dose calculations will be integrated. This is shown in Figure 31. A freeway is any limited-access divided highway.

Distance of non-freeway vehicle carrying radioactive cargo to pedestrians

The standard (default) value is 27 meters and is taken from NUREG-0170(NRC, 1977). This parameter is the minimum pedestrian-walkway width, for instances in which doses to pedestrians beside the link is calculated. This parameter is the minimum perpendicular distance over which the off-link dose calculation will be integrated. This is shown in Figure 31. A non-freeway is any non-limited-access highway that is not a city street.

Distance of non-freeway vehicle carrying radioactive cargo to right-of-way edge

The standard (default) value is 30 meters and is taken from NUREG-0170 (NRC, 1977). This parameter is the maximum pedestrian-walkway width. This parameter is set 3 meters greater than the parameter, **Distance of non-freeway vehicle carrying radioactive cargo to pedestrians**. This means that the sidewalk width is 3 meters and will thus allow for an off-link dose to be calculated to unshielded persons (pedestrians, bicyclists, etc.) where they may reasonably be expected to be found. This is shown in Figure 31. A non-freeway is any non-limited-access highway that is not a city street.

Distance of non-freeway vehicle carrying radioactive cargo to maximum exposure distance

The standard (default) value is 800 meters and is taken from NUREG-0170 (NRC, 1977). This parameter is the maximum perpendicular distance over which the off-link dose calculations will be integrated. This is shown in Figure 31. A non-freeway is any non-limited-access highway that is not a city street.

Distance of city street vehicle carrying radioactive cargo to pedestrians

The standard (default) value is 5 meters and is taken from NUREG-0170 (NRC, 1977). This parameter is the minimum pedestrian-walkway width, for instances in which does to pedestrians beside the link is calculated. This parameter is the minimum perpendicular distance over which the off-link dose calculation will be integrated. This is shown in Figure 31. A city street is any city street.

Distance of city street vehicle carrying radioactive cargo to right-of-way edge

The standard (default) value is 8 meters and is taken from NUREG-0170 (NRC, 1977). This parameter is the maximum pedestrian-walkway width. This parameter is set 3 meters greater than the parameter, **Distance of city street car carrying radioactive cargo to pedestrians**. This means that the sidewalk width is 3 meters and will thus allow for an off-link dose to be calculated to unshielded persons (pedestrians, bicyclists, etc.) where they may reasonably be expected to be found. This is shown in Figure 31. A city street is any city street.

Distance of city street vehicle carrying radioactive cargo to maximum exposure distance

The standard (default) value is 800 meters and is taken from NUREG-0170 (NRC, 1977). This parameter is the maximum perpendicular distance over which the off-link dose calculations will be integrated. This is shown in Figures 31. A city street is any city street.

Perpendicular distance to freeway vehicle going in the opposite direction

The standard (default) value is 15 meters and is taken from Madsen et al. (1986 p. 36-37). This is shown in Figure 31. This parameter specifies the perpendicular distance (i.e. a distance measured along a line at right angles to the line of travel of the radioactive materials shipment) between the radioactive materials shipment and other traffic lanes, in meters. This is an average perpendicular distance between the shipment centerline and the centerline of oncoming traffic lanes. This value is based on a minimal Interstate configuration of four lanes with an average lane width of 5 meters, in the most typical traffic configuration. The latter refers to the radioactive materials shipment being in the outside lane, oncoming traffic in the corresponding outside lane, and passing vehicles in the inner lanes. A freeway is any limited-access divided highway.

Perpendicular distance to non-freeway vehicle going in the opposite direction

The standard (default) value is 3 meters and is taken from Madsen et al. (1986 p. 36-37). This is shown in Figure 31 . This parameter specifies the perpendicular distance (i.e. a distance measured along a line at right angles to the line of travel of the radioactive materials shipment) between the radioactive materials shipment and other traffic lanes, in meters. This is an average perpendicular distance between the shipment centerline and the centerline of oncoming traffic lanes. This value is based on a minimal road configuration of two lanes with an average lane width of 3 meters, in the most typical traffic configuration. A non-freeway is any non-limited-access highway that is not a city street.

Perpendicular distance to city vehicle going in the opposite direction

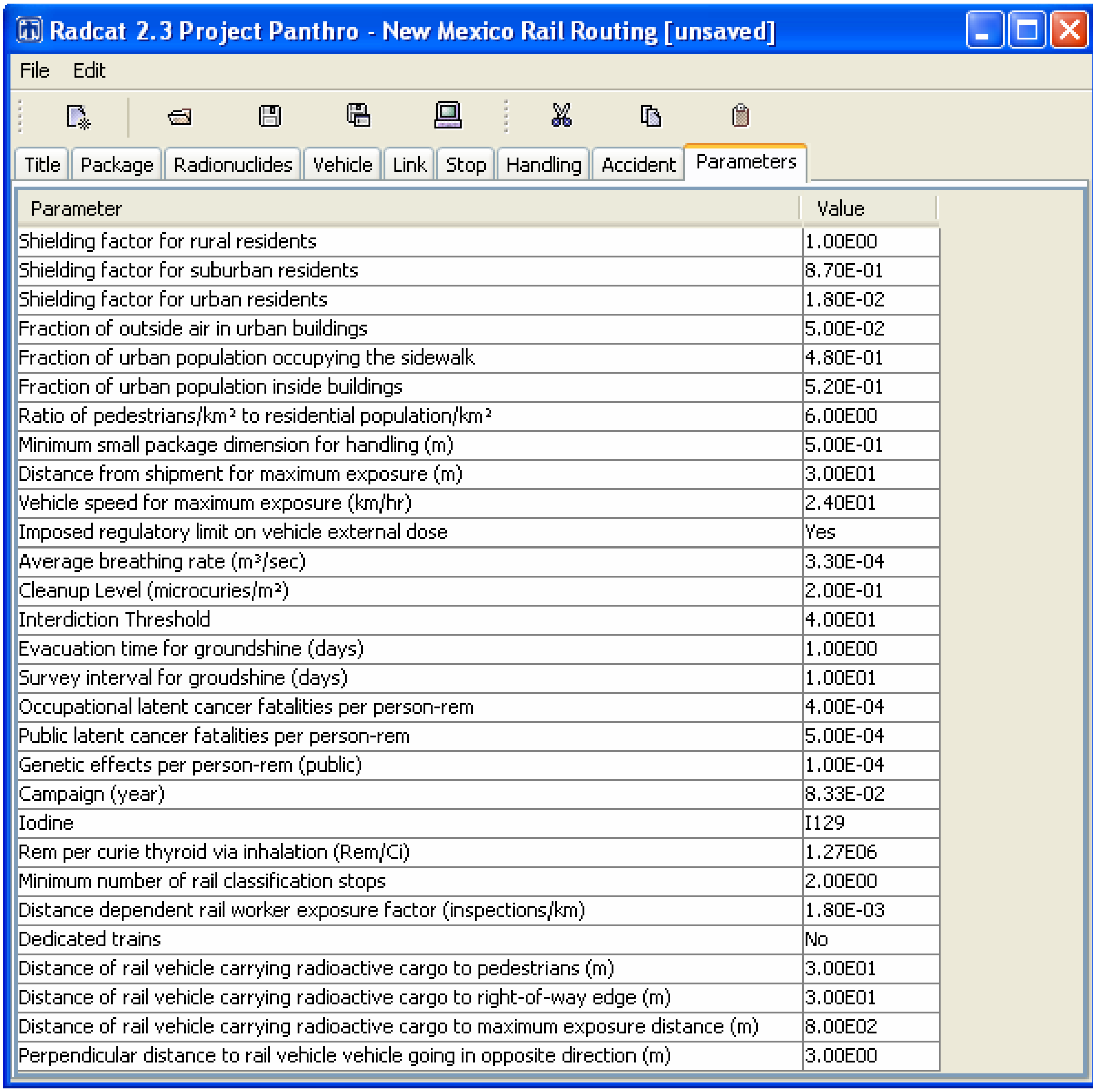
The standard (default) value is 3 meters and is taken from Madsen et al. (1986 p. 36-37). This is shown in Figure 31. This parameter specifies the perpendicular distance (i.e. a distance measured along a line at right angles to the line of travel of the radioactive materials shipment) between the radioactive materials shipment and other traffic lanes, in meters. This is an average perpendicular distance between the shipment centerline and the centerline of oncoming traffic lanes. This value is based on a minimal road configuration of two lanes with an average lane width of 3 meters, in the most typical traffic configuration. A city street is any city street.

Perpendicular distance of all vehicles going in the same direction

The standard (default) value is 4 meters and is taken from Madsen et al. (1986). This is shown in Figure 31. This parameter specifies the perpendicular distance (i.e. a distance measured along a line at right angles to the line of travel of the radioactive materials shipment) between the radioactive materials shipment and other traffic lanes, in meters. This is an average perpendicular distance between the shipment centerline and the centerline of adjacent passing vehicles. This value is based on the median value for all Interstate and secondary-road lane widths.

Minimum number of rail classification stops

This applies to rail mode only and specifies the minimum number of railcar classifications per trip. The standard (default) value is 2 since there are at least two inspections per trip – one at the beginning and one at the end of each trip (Wooden 1986). When the origin of a rail shipment is very different from its destination, it may be useful to change the value to 1. The collective dose to railyard workers at a 30-hour classification stop has been integrated into RADTRAN, and is multiplied by this number to give the dose to these workers at classification stops. The dose is the weighted sum of the doses for all close-proximity railyard worker groups, and is calculated primarily with a line-source model, though a point-source model is used when appropriate. For general freight, dose is calculated with the modifying factors b_1 through b_7, which have units of person-hr/km and are derived from Wooden (1987) as described in Appendix B of the RADTRAN 5 Technical Manual (Neuhauser, et al, 2000). This is shown in Figure 32.



Parameter	Value
Shielding factor for rural residents	1.00E00
Shielding factor for suburban residents	8.70E-01
Shielding factor for urban residents	1.80E-02
Fraction of outside air in urban buildings	5.00E-02
Fraction of urban population occupying the sidewalk	4.80E-01
Fraction of urban population inside buildings	5.20E-01
Ratio of pedestrians/km² to residential population/km²	6.00E00
Minimum small package dimension for handling (m)	5.00E-01
Distance from shipment for maximum exposure (m)	3.00E01
Vehicle speed for maximum exposure (km/hr)	2.40E01
Imposed regulatory limit on vehicle external dose	Yes
Average breathing rate (m³/sec)	3.30E-04
Cleanup Level (microcuries/m²)	2.00E-01
Interdiction Threshold	4.00E01
Evacuation time for groundshine (days)	1.00E00
Survey interval for groudshine (days)	1.00E01
Occupational latent cancer fatalities per person-rem	4.00E-04
Public latent cancer fatalities per person-rem	5.00E-04
Genetic effects per person-rem (public)	1.00E-04
Campaign (year)	8.33E-02
Iodine	I129
Rem per curie thyroid via inhalation (Rem/Ci)	1.27E06
Minimum number of rail classification stops	2.00E00
Distance dependent rail worker exposure factor (inspections/km)	1.80E-03
Dedicated trains	No
Distance of rail vehicle carrying radioactive cargo to pedestrians (m)	3.00E01
Distance of rail vehicle carrying radioactive cargo to right-of-way edge (m)	3.00E01
Distance of rail vehicle carrying radioactive cargo to maximum exposure distance (m)	8.00E02
Perpendicular distance to rail vehicle vehicle going in opposite direction (m)	3.00E00

Figure 32: Parameters Tab with Rail Mode

Distance dependent rail worker exposure factor per km

This parameter applies to rail mode only. It is used to calculate the component of rail-worker dose that depends on distance traveled (e.g., exposure related to stops between the shipment origin and destination). The standard (default) value of 0.0018 inspections/km is taken from Ostmeyer (1986). The 30-hour collective railyard worker dose is multiplied by this number and by the total shipment distance in kilometers to give the in-transit railyard worker dose. This is shown in Figure 32.

Dedicated Trains

This is only used for rail mode. It denotes whether the shipment is by general freight or key trains (**NO**) or by dedicated rail (**YES**). The standard (default) setting is **NO**. This is shown in Figure 32. The main difference between the two options is the exposure of rail workers in rail yards. For dedicated rail, worker dose is calculated with factors b_8 through b_{11} of Appendix B of the RADTRAN 5 Technical Manual (Neuhauser, et al, 2000).

Distance of rail car carrying radioactive cargo to pedestrians

The standard (default) value is 30 meters and is taken from NUREG-0170 (NRC, 1977). This parameter is the minimum perpendicular distance over which the off-link dose calculation will be integrated. This parameter is the minimum pedestrian-walkway width, for instances in which dose to pedestrians beside the link is calculated. This is shown in Figure 32. A rail route is any rail right-of-way in the U.S.

Distance of rail car carrying radioactive cargo to right-of-way edge

The standard (default) value is 30 meters and is taken from NUREG-0170 (NRC, 1977). This parameter is the maximum pedestrian-walkway width. This parameter is set equal to **Distance of rail car carrying radioactive cargo to pedestrians**. This means that the sidewalk width is zero and thus there is no sidewalk available. This is shown in Figure 32. A route is any rail right-of-way in the U.S.

Distance of rail car carrying radioactive cargo to maximum exposure distance

The standard (default) value is 800 meters and is taken from NUREG-0170 (NRC, 1977). This parameter is the maximum perpendicular distance over which the off-link dose calculations will be integrated. This is shown in Figure 32. A rail route is any rail right-of-way in the U.S.

Perpendicular distance to rail car vehicle going in the opposite direction

The standard (default) value is 3 meters and is taken from Madsen et al. (1986 p. 36-37). This is shown in Figure 32. This parameter specifies the perpendicular distance (i.e. a distance measured along a line at right angles to the line of travel of the radioactive materials shipment) between the radioactive materials shipment and other traffic lanes, in meters. This is an average perpendicular distance between the shipment centerline and the centerline of oncoming traffic lanes. This value is based on a minimum clearance between passing trains on double rail segments. A rail route is any rail right-of-way in the U.S.

Distance of waterway barge carrying radioactive cargo to pedestrians

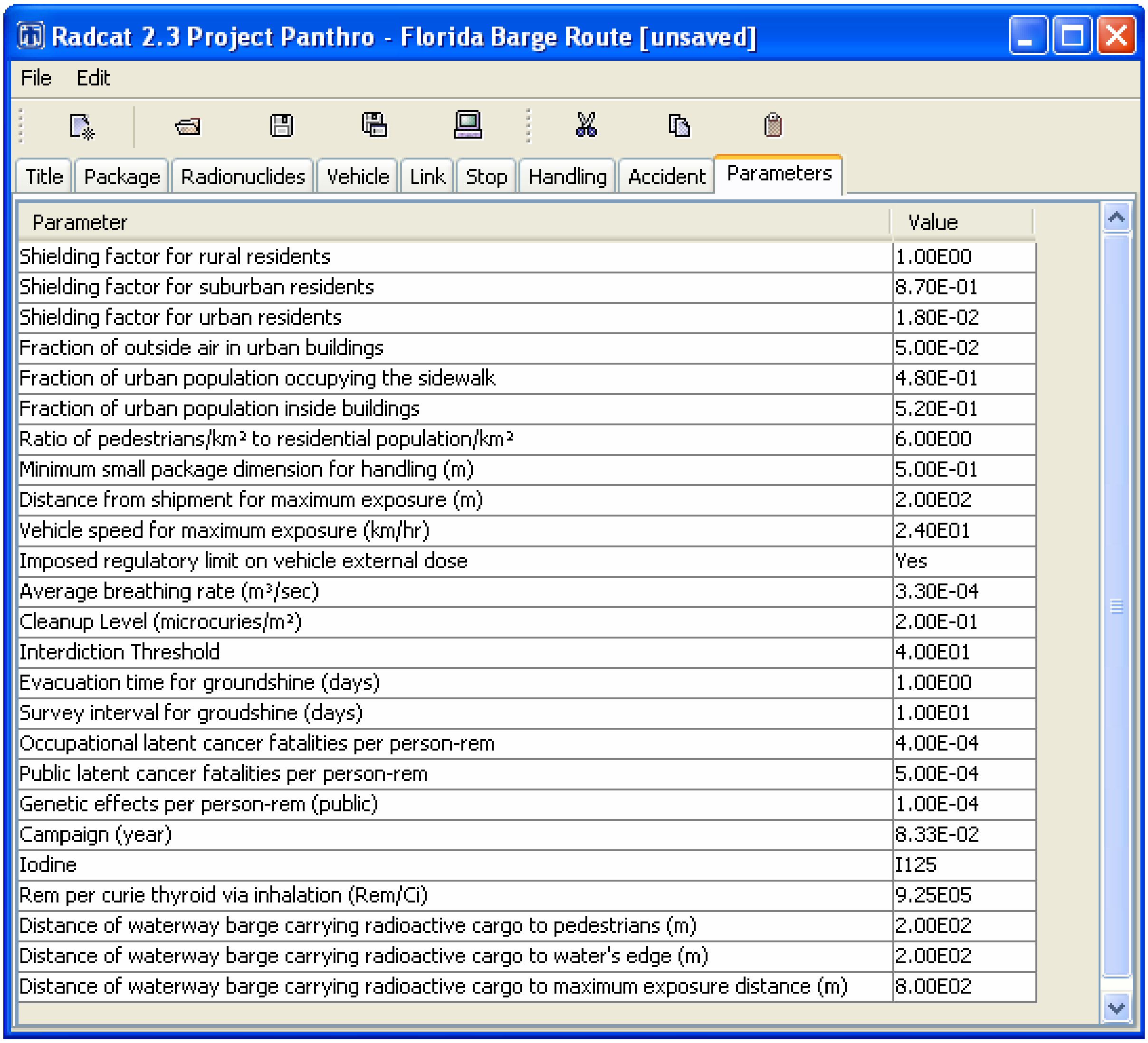
The standard (default) value is 200 meters and is taken from NUREG-0170 (NRC, 1977). This parameter is the minimum pedestrian-walkway width, for instances in which dose to pedestrians beside the link is calculated. This parameter is the minimum perpendicular distance over which the off-link dose calculation will be integrated. This is shown in Figure 33.

Distance of waterway barge carrying radioactive cargo to right-of-way edge

The standard (default) value is 200 meters and is taken from NUREG-0170 (NRC, 1977). This parameter is the maximum pedestrian-walkway width. This parameter is set equal to **Distance of waterway barge carrying radioactive cargo to pedestrians**. This means that the sidewalk width is zero and thus there is no sidewalk available. This is shown in Figure 33.

Distance of waterway barge carrying radioactive cargo to maximum exposure distance

The standard (default) value is 1000 meters and is taken from NUREG-0170 (NRC, 1977). This parameter is the maximum perpendicular distance over which the off-link dose calculations will be integrated. This is shown in Figure 33.



Parameter	Value
Shielding factor for rural residents	1.00E00
Shielding factor for suburban residents	8.70E-01
Shielding factor for urban residents	1.80E-02
Fraction of outside air in urban buildings	5.00E-02
Fraction of urban population occupying the sidewalk	4.80E-01
Fraction of urban population inside buildings	5.20E-01
Ratio of pedestrians/km² to residential population/km²	6.00E00
Minimum small package dimension for handling (m)	5.00E-01
Distance from shipment for maximum exposure (m)	2.00E02
Vehicle speed for maximum exposure (km/hr)	2.40E01
Imposed regulatory limit on vehicle external dose	Yes
Average breathing rate (m³/sec)	3.30E-04
Cleanup Level (microcuries/m²)	2.00E-01
Interdiction Threshold	4.00E01
Evacuation time for groundshine (days)	1.00E00
Survey interval for groudshine (days)	1.00E01
Occupational latent cancer fatalities per person-rem	4.00E-04
Public latent cancer fatalities per person-rem	5.00E-04
Genetic effects per person-rem (public)	1.00E-04
Campaign (year)	8.33E-02
Iodine	I125
Rem per curie thyroid via inhalation (Rem/Ci)	9.25E05
Distance of waterway barge carrying radioactive cargo to pedestrians (m)	2.00E02
Distance of waterway barge carrying radioactive cargo to water's edge (m)	2.00E02
Distance of waterway barge carrying radioactive cargo to maximum exposure distance (m)	8.00E02

Figure 33: Parameters Tab with Barge Mode

6. SPECIAL RADTRAN CASES

This section discusses special scenarios that users may encounter when creating RADTRAN inputs. This section is not comprehensive, and should be considered a 'work in progress.' Users are strongly encouraged to provide further input for this section.

6.1 On-link dose for a highway that parallels a rail line

The parameter ADJACENT specifies the average perpendicular distance (at right angles to the line of travel) between the radioactive materials shipment centerline and the center of other traffic lanes, in meters.

There are times when rail and/or barge shipments will travel on a route parallel to an adjacent highway. In such a case, occupants of vehicles on the highway going both in the same direction as the rail or barge shipment, as well as in the opposite direction, may receive an external dose from the rail and barge shipment. Although you will be in Rail or Barge Mode for your calculation, you may wish to use **Highway Mode** to determine the incident-free dose to the occupants of vehicles on the parallel highway.

Figure 34 is a diagram of the situation you are modeling.

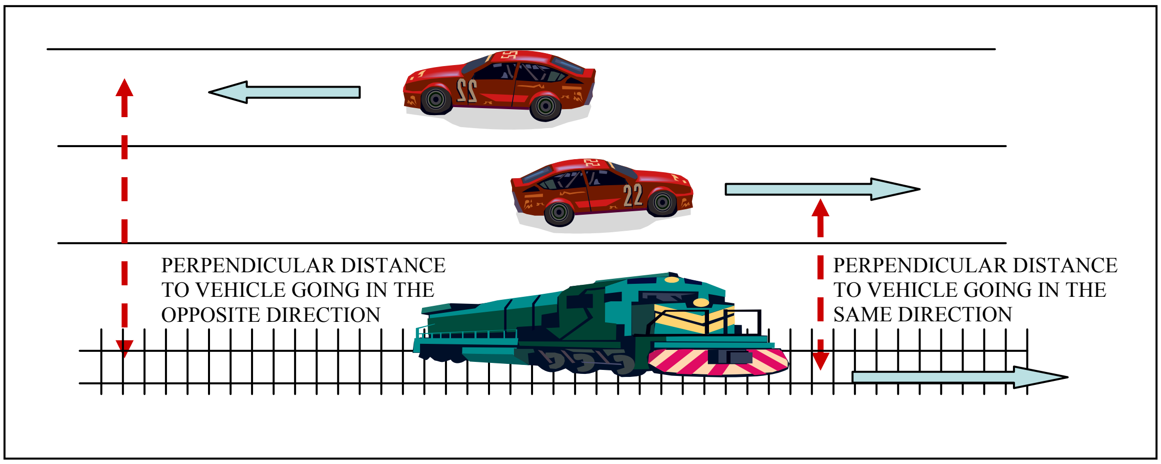


Figure 34: Diagram for the On-Link Dose on a Highway that Parallels a Rail Route

Structure the supplemental **Highway Mode** calculation as follows:

- Create a new RADCAT **Highway** file. This file will include some parameters from your rail (or barge) file and some that you will create for this file.
- You cannot just import the **Rail** (or **Barge**) file. Create a new package and vehicle that are the same as your rail (or barge) package and vehicle: use the rail (or barge)
    - package size,
    - package dose rate,
    - package gamma and neutron fractions,
    - add at least one radionuclide. It does not figure in the calculation, but RADTRAN hangs up without it.
    - vehicle size,
    - vehicle dose rate,
    - vehicle gamma and neutron fractions.
- What you put for crew parameters is up to you – they do not enter into this calculation.
- Make a link for each segment for which the train (or barge) parallels the highway. On the LINKS screen, the Vehicle Speed will be the speed of the train (or barge) and you will be assuming that

the vehicles on the highway are going at the same speed (which will make your answer slightly conservative). However,

  - "Vehicle Density" is the vehicle density -- vehicles per hour -- **on the highway**
  - "Persons per Vehicle" is the average occupancy of the vehicles **on the highway,**
  - "Type" will be the type of highway you are considering: primary highway or secondary road.

- The parameters on the **Parameter** tab that affect your calculation are:
  - Perpendicular distance to freeway vehicle going in opposite direction (m)
  - Perpendicular distance to non-freeway vehicle going in opposite direction (m)
  - Perpendicular distance to city vehicle going in opposite direction (m)
  - Perpendicular distance to all vehicles going in the same direction (m)

  The default values for these parameters are 15m, 3m, 3m, and 4m, respectively , and refer to the lane widths and distances between lane centers. RADTRAN will call the first parameter if your LINK is designated as "primary highway," the second and third if your LINK is designated as "secondary road."
- Estimate the distance, in meters, between the center of the highway lane closest to the train (or barge) and change the "perpendicular distance to all vehicles going in the same direction (m)" from its default of 4-meters to the value you have estimated.
- Add the distance between your highway lanes to that estimate, and substitute that sum for the default values for the other three "perpendicular distance..." parameters.

You can run RADTRAN for "Incident Free" only, but in any case ensure that the **Weather** tab is set for "National Average Weather," and the **Isopleth P** tab is set for "Use the default population densities." Otherwise, RADTRAN will not run. You should select Output Level 1 (the shortest output).

The only output result that should be taken from this modified Highway Mode is the **ONLINK** population dose for each link. This dose is taken from the **Incident-Free Summary**.

7. SAVING, RUNNING RADTRAN, EXITING

The input file can be saved with either the **Save** or the **Save As** icon. Your file will be saved as a **".rml**" file. You will need to add this extension to your filename when saving it. RADCAT does not automatically add the "**.rml**" extension when saving the file as seen in Figure 35. The file may be run in RADTRAN by clicking on the **Run RADTRAN** icon (the computer icon). RADTRAN can be run without saving, but it highly recommended that your file be saved and saved often.

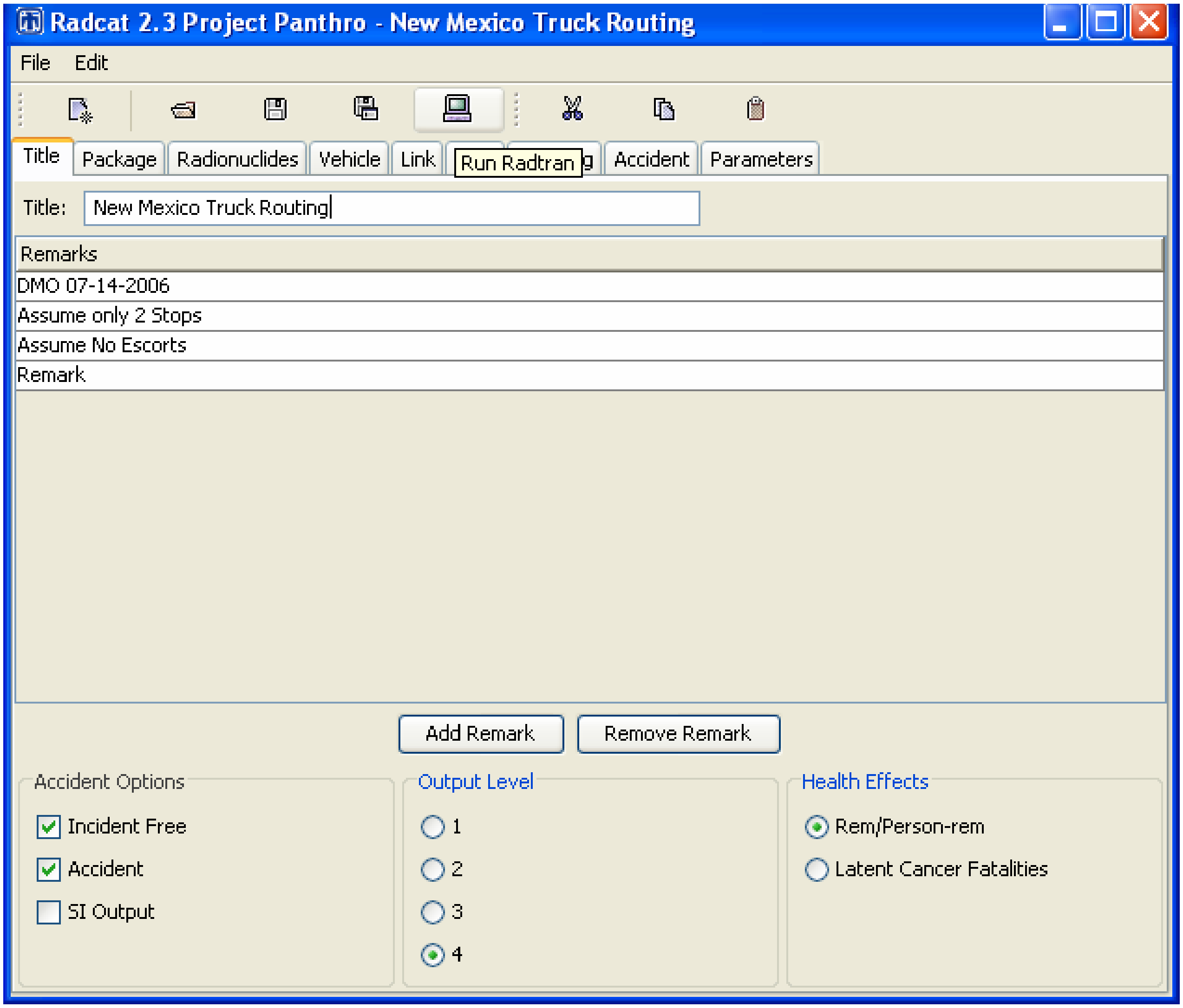


Figure 35: Saving a RADCAT input file

When RADTRAN is run, the output appears immediately on the screen, and may be printed and/or saved. The end of a typical output is shown in Figure 36. This output file can be saved as a text file (*filename*.txt), an excel file (*filename*.xls), or a word document (*filename*.doc). It can be saved to any folder on the computer or LAN. An incomplete output file indicates some error in the input file that caused RADTRAN to abort. This is rare when the input file is created using RADCAT. The error message that appears at the end of the output file in these cases is usually self-explanatory. Exit from RADTRAN/RADCAT by clicking on the "x" in the upper right-hand corner as seen in Figure 36.

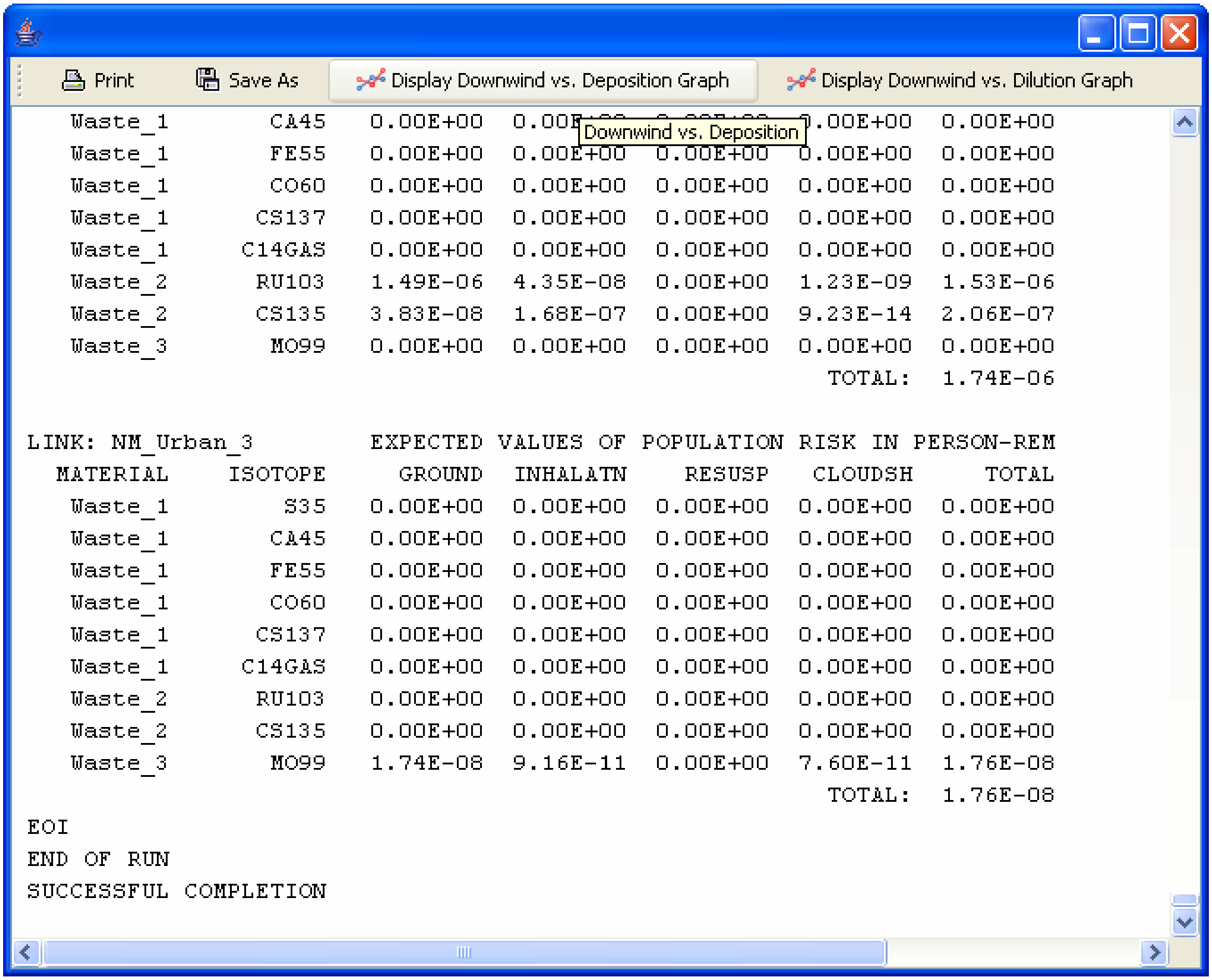


Figure 36: End of a RADTRAN output

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APPENDIX A: RADTRAN 5 REFERENCE SHEET

Creating RADTRAN 5.5 Files with a Text Editor

Note: When creating a text file like this it must be saved with the .in5 extension and then use the import feature to open it in RADCAT.

Key:
[Brackets] indicate an optional statement
{Braces} indicate a required value
ALL CAPS indicates a keyword that must be entered

TITLE **{alphanumeric title}**
INPUT **{STANDARD (Default values) or ZERO}**
[OUTPUT] **{BQ_SV for SI Units}**
FORM **{UNIT for population dose or NONUNIT for health effects}**
DIMEN **{# of severity categories} {# of nondispersal accident radii} {# of dispersal areas}**
PARM **{0 no plotting/1 plotting} {1 incident free/2 accident/3 both} {1/2/3/4 level of output} {0 User-supplied time-integrated concentration isopleths and areas/1 Pasquill stability fractions/2 User-defined metrological conditions}**
SEVERITY
    NPOP = **{1 rural}**
        NMODE = **{transport mode (see Mode Chart in Table A-1)}**
            {Severity Fraction 1} {Severity Fraction 2} {Severity Fraction 3...}
    NPOP = **{2 suburban}**
        NMODE = **{transport mode (see Mode Chart in Table A-1)}**
            {Severity Fraction 1} {Severity Fraction 2} {Severity Fraction 3...}
    NPOP = **{3 urban}**
        NMODE = **{transport mode (see Mode Chart in Table A-1)}**
            {Severity Fraction 1} {Severity Fraction 2} {Severity Fraction 3...}

RELEASE
    GROUP=**{group name}**
        RFRAC
            {Release Fraction 1} {Release Fraction 2} {Release Fraction 3...}
        AERSOL
            {Aerosol Fraction 1} {Aerosol Fraction 2} {Aerosol Fraction 3...}
        RESP
            {Respirable Fraction 1} {Respirable Fraction 2} {Respirable Fraction 3...}
        LOS
            {Loss of Shielding Fraction 1} {Loss of Shielding Fraction 2...}
        DEPVEL
            Deposition Velocity of Group (m/s)
    [GROUP=...]

    [ISOPLETHP]
        {Population density of isopleth 1} {Population density of isopleth 2...}
    [AREADA]
        {Area of Isopleth 1 (m^2)} {Area of Isopleth 2...}
    [DFLEV]
        {Dilution Factor for Isopleth 1} {Dilution Factor for Isopleth 2...}
    [CLINE]
        {Center-Line Distance for Isopleth 1 (m)} {Center-Line Distance for Isopleth 2...}

    [PSPROB]

{Pasquill Category A Fraction} {Pasquill Category B Fraction...}

[RISKIND] **(See Definitions for Input to the RISKIND Dispersion Model)**
&& USE_RADTRAN, REL_HT, HEAT_REL, SRC_WDTH, SRC_HT
0 10.0 100000 3.45 2.87
&& WS, ANEM_HT, AMB_T, HT_MIX, RAIN_RT
4.0 10.0 298.0 5000 0.0
&& (Pasquill-1, Briggs-2), Stability (A=1 through F=6)
1 4
&& (Rural-1, Urban/Suburban-2)
2

[DEFINE] **{Radionuclide Name}**
{Half-life (days)} {Photon Energy (MeV/disintegration)} {Cloudshine dose factor (rem-m^3/Ci-second)} {Groundshine dose factor (rem-m^3/μCi-day)} {50-yr committed effective dose equivalent for inhalation (rem/Ci inhaled)} {50-yr committed effective gonad dose for inhalation (rem/Ci inhaled)} {1-yr lung dose for inhalation (rem/Ci inhaled)} {1-yr marrow dose for inhalation (rem/Ci inhaled)}
{Name for COMIDA Ingestion Data (or NONE)}
[DEFINE] **{Radionuclide Name...}**

PACKAGE **{alphanumeric identifier} {dose rate at 1m (mrem/hr)} {gamma fraction} {neutron fraction} {package dimension (m)}**
{Radionuclide Name} {Package Inventory (Ci)} {Group Name}
[**{Radionuclide Name} {Package Inventory (Ci)} {Group Name...}**]
END

VEHICLE **{minus sign if shipment is exclusive} {transportation mode number (see mode chart)} {identifier} {dose rate at one meter from vehicle (mrem/hr)} {gamma fraction} {neutron fraction} {vehicle length (m)} {number of shipments} {number of crew members} {distance of crew from package (m)} {crew shielding factor} {crew view dimension (m)}**
{package identifier} {number of packages per shipment}
[**{package identifier} {number of packages per shipment...}**]

[FLAGS]
{see Flag Chart in Table A-2}
[MODSTD]
{see MODSTD Standard Values List}
EOF

LINK **{link identifier} {vehicle name} {segment length (km)} {velocity (kph)} {vehicle occupancy} {population density (persons/km^2)} {vehicle density} {accident rate (acc/km)} {R rural/S suburban/U urban} {1 interstate/2 non-interstate/3 other} {farm fraction}**
[LINK] **{link identifier...}**

STOP **{stop identifier} {vehicle name} {population density (annular) or number of persons (radial)} {minimum annular radius} {maximum annular radius (or same as minimum for radial)} {shielding fraction} {stop time (hr)}**
[STOP] **{stop identifier...}**

HANDLING **{handling identifier} {vehicle name} {number of handlers} {average handler distance} {handling time per package (hr)}**
[HANDLING] **{handling identifier...}**
EOF
EOI

Table A-1: Mode Chart

Mode	Mode Number	Conveyance Types Associated with Mode
HIGHWAY	1	Any truck; usually a tractor-trailer(also called a “semi” or a combination truck)
RAILWAY	2	One or more railcars in a single train
WATERWAY	3	Any vessel; usually barge

Table A-2 – Flag Chart

Flag Name	Flag Description	STANDARD (Default) Value
IACC	Setting this flag to 2 directs the code to work through all exposure pathways associated with atmospheric dispersal of package contents during an accident. The alternative value of IACC = 1 denotes non-dispersal and is no longer used in RADTRAN	2
ITRAIN	This flag, used only for rail mode, denotes whether shipment is by general freight (ITRAIN = 1) or by dedicated rail (ITRAIN = 2).	1
IUOPT	This flag is used to select a building shielding option. For the STANDARD value, persons in rural buildings are not shielded (100% exposure), persons in suburban dwellings are 87% exposed, and persons in urban dwellings are 18% exposed. Setting the IUOPT flag to 1 is equivalent to full shielding (everyone indoors is fully shielded and receives no dose). Setting the IUOPT flag to 3 is equivalent to no shielding (being indoors provides no protection and is the same as being outdoors).	2
REGCHECK	Setting this flag to 1 causes a series of regulatory checks to be performed. If any circumstances are identified that violate the regulatory requirements, then the appropriate parameter values are reset to the regulatory maximum and the calculation continues. The analyst may set REGCHECK = 0, which bypasses the regulatory-check subroutine.	1

MODSTD Name	Description	STANDARD (Default) Value
BDF	The Building Dose Factor describes the entrainment of aerosol particles in ventilation systems (i.e., the fraction of particles of an external aerosol that remain in aerosol form after passing through a ventilation system). The BDF is used to modify inhalation doses to persons in urban structures. The standard (default) value of 0.05 represents a conservative average across a series of building types, including residential, office, and industrial structures (Engelmann, 1990). This value is about five times higher than the value for high-rise buildings with air-conditioning systems used by Finley et al., (1980) for New York City, which has been used in RADTRAN in the past.	0.05
BRATE	This factor represents breathing rate and is used for calculation of inhalation doses. The breathing rate (BRATE = 3.30E-04 m^3/sec) of the Reference Man (70-kg adult male at light work) derived from Shleien, et al 1996; Table 12.6) has been used as the standard (default) value. The value in the cited table has been converted from liters per hour to m^3/sec.	3.30E-04
CULVL	This factor describes Clean-Up Level, which is the required level to which contaminated surfaces must be cleaned up. The standard (default) value is the EPA guideline of 0.2 $\mu Ci/m^2$ (EPA, 1977). This value applies to the sum of deposited activity over all radionuclides of a multi-radionuclide material. Analysts who can justify use of more realistic values are urged to do so.	0.2
EVACUATION	This parameter specifies evacuation time in days following a dispersal accident, where this includes time to respond to the accident and carry out a course of action. The standard (default) value is 24 h (1 day). Mills et al. (1995) analyzed 66 verified hazmat accidents in which evacuations were carried out and found that the mean evacuation time was approximately 1 hour. Even when response time is added, a 24-hour (1-day) value for this variable is conservative. This parameter defined the time of exposure to groundshine and to resuspended material.	1.0
MODSTD Name	Description	STANDARD (Default) Value

GECON	This parameter specifies the Genetic Effects Conversion Factor. The standard (default) value is 1.0E-04 genetic effects/rem. This value is consistent with the recommendations of BEIR V (NRC/NAS, 1990) and ICRP 60 (ICRP, 1991). Estimates based on the only genetic effects (untoward pregnancy outcome and F_1 mortality) to have been documented in the atomic-bomb survivors have extremely high statistical and model uncertainties. Animal data, which is more reliable, consistently yield lower estimates. As noted in BEIR V, the recommended value is "probably …too high rather than too low" (NRC/NAS, 1990, p. 77).	1.00E-04
INTERDICT	This parameter specifies the threshold value for interdiction of contaminated land. The standard (default) value is 40, i.e., a value 40 times greater than CULVL, and it was taken from NUREG-0170 (NRC, 1977).	40
LCFCON	This parameter specifies the Latent Cancer Fatality (LCF) Conversion Factors; units are LCFs per rem. The standard (default) values are 5.0E-04 LCF/rem for the general public and 4.0E-04 LCF/rem for workers. They have been adjusted for low-dose and low-dose-rate decrease in effects with a DDRRF (Dose and Dose Rate Reduction Factor) of 2. These values are consistent with the recommendations of BEIR VII (NRC/NAS,2005) and ICRP 60 (ICRP, 1991). The dose-response relationship is assumed to be linear with no threshold in order to agree with current regulations. However, the majority of available data indicate that the actual dose-response relationship at very low doses is likely to be considerably less and, as noted in BEIR VII, is not incompatible with zero (NRC/NAS, 2005). Thus, cancer risk estimates obtained from RADTRAN 5 will be generally conservative.	5.0E-04 for the public 4.04E-04 for workers
LOS	The parameter was used to analyze loss-of-shielding accidents. It is no longer used in RADTRAN analyses.	
NE	This parameter is the neutron emission factor; it may be used to model neutron emissions following a loss-of-shielding accident. For commonly encountered radionuclides that spontaneously emit neutrons (curium-242, curium-244, and californium-242), the NE values are already available in the radionuclide library. All other radionuclides have no assigned NE factor. The NE keyword is applied only when the analyst wishes to assign a new value to an existing radionuclide or to a new material. The analyst must enter NE followed by the radionuclide name in standard format (or exactly as entered under keyword DEFINE) and the emission factor value in neutrons/s-Ci. The analyst must repeat the process (i.e., type NE followed by radionuclide name and NE factor value) for each radionuclide desired.	
MODSTD Name	**Description**	**STANDARD (Default) Value**

MODSTD Name	Description	STANDARD (Default) Value
RADIST	This parameter is used to specify an array of Radial Distances, which are used to define annular areas for dose-calculation purposes when the IACC Flag is set to 1. It is no longer used in RADTRAN.	
RPCTHYROID	This parameter is used to specify 1-year CEDE (rem per curie) to the thyroid from inhalation of radionuclides of iodine for estimation of early-mortality risk. Radioiodine mainly travels to and irradiates a single organ, the thyroid. In previous releases of RADTRAN, however, the 50-year CEDE was used to approximate the 1-year dose. One-year committed doses to the thyroid have been calculated directly for RADTRAN 5. This new parameter was not included in the internal radionuclide database, since it would have meant adding a new column containing zeros for all radionuclides but the radioiodines. The information has been included under the RPCTHYROID keyword instead. The standard (default) values are 1.27E+06 for iodine-131, 5.77E+06 for iodine-129, and 9.25E+05 for iodine-125.	1.27E+06 for I-131 5.77E+06 for I-129 9.25E+05 for I-125
SURVEY	This parameter is used to specify the time (in days) required to survey contaminated land following a dispersal accident. The amount of deposited material removed by radioactive decay is calculated beginning with time of initial deposition. The longer a deposited material remains on the ground, the more is removed by decay and spread by forces such as wind and rain. The actual elapsed time between accident occurrence and completion of a survey is impossible to determine in advance, but is likely to be prolonged because of governmental and regulatory complexities. The standard (default) value is set to an unrealistically brief, but radiologically conservative, 10 days (NRC, 1977).	10
TIMENDE	This parameter specifies the time, in days, required to effect evacuation following a non-dispersal accident. It is no longer used in RADTRAN.	
UBF	This parameter is the Urban Building Fraction; it describes either the fraction of the population that is indoors or the fraction of the area that is occupied by buildings, depending on the type of population model being used. The standard (default) value of 0.52 is for the latter model, and is taken from Finley et al. (1980). The value is most accurate for large cities such as New York and is somewhat conservative for smaller cities.	0.52

USWF	This parameter is the Urban Sidewalk Fraction; it specifies the fraction of the population that is out of doors or the fraction of the population that occupies sidewalks, depending on the type of population model being used. The standard (default) pre-assigned value of 0.1 is for the latter model, and is taken from Finley et al. (1980). As with the UBF, this value is suitable for large cities and is conservative for smaller cities.	0.1
ADJACENT	See DISTON	
CAMPAIGN	This keyword specifies the duration of the shipping campaign in years. The value calculated with CAMPAIGN is the total number of off-link persons exposed. This result may be used to perform external calculations of annual off-link dose. Annual dose values may be compared with total dose in multi-year shipping campaigns and are useful for assessing regulatory compliance with standards based on annual doses. The standard (default) value is 0.0833 years. This is an average month in an average year, or 1/12th of a year.	0.0833
DDRWEF	This keyword applies to rail mode only and specifies the Distance Dependent Rail Worker Exposure Factor. This factor is used to calculate the component of rail-worker dose that depends on distance traveled (e.g., exposure related to engine changes, crew shift-changes, etc., while en route). The standard (default) value of 0.0018 inspections/km is taken from Ostmeyer (1986).	0.0018
MODSTD Name	**Description**	**STANDARD (Default) Value**

	This keyword specifies a set of three distances, in meters, used in off-link dose calculations for highway, rail, and barge modes. The three distances are: (1) the minimum perpendicular distance over which the off-link dose calculation will be integrated; (2) the minimum pedestrian-walkway width, for instances in which dose to pedestrians beside the link is calculated (see RPD for discussion of pedestrian density); and (3) the maximum perpendicular distance over which the off-link dose calculation will be integrated. DISTOFF must be followed one or more keywords that specify values for various link types. The standard (default) values, which are supplied for each link type, are from NUREG-0170 (NRC, 1977). The link types and values for each are:	
DISTOFF	FREEWAY Any limited-access divided highway. [30, 30, 800]	30, 30, 800
	SECONDARY Any non-limited-access highway that is not a city street (27, 30, 800)	27, 30, 800
	STREET Any city street. [5, 8, 800]	5,8,800
	RAIL Any rail right-of-way in the U.S. [30, 30, 800]	30, 30, 800
	WATER Any vessel. [200,200,800]	200, 200, 1000
	Note: that the values are the same for FREEWAY and RAIL. Setting the first two values equal to each other is equivalent to a sidewalk width of zero and means there are no sidewalks or similar close-in areas where unshielded persons (pedestrians, bicyclists, etc.) may reasonably be expected to be found. For STREET, the sidewalk is modeled as being 3 m wide (Finley et al. 1980). The values for WATER conservatively model a narrow navigable waterway (e.g., Houston Ship Channel) and are taken from NUREG-0170 (NRC, 1977). The WATER values are the ones most likely to require modification by the analyst since other bodies of water that might be modeled have ship-to-shore distances that greatly exceed 200 m and even 800 m.	
MODSTD Name	**Description**	**STANDARD (Default) Value**

DISTON	This keyword specifies a perpendicular distance (i.e., a distance measured along a line at right angles to the line of travel of the RAM shipment) between the RAM shipment and other traffic lanes, in meters. For three link types, DISTON represents the *average* perpendicular distance between the shipment *centerline* and the *centerline* of oncoming traffic lanes(s). In the passing-vehicle case, DISTON represents the distance between the shipment *centerline* and the *centerline* of adjacent passing vehicles (HIGHWAY mode only). DISTON must be followed by a second keyword that specifies the link type. The standard (default) values in parentheses in the following list are taken from Madsen et al. (1986, p. 36-37).	
	FREEWAY Any limited-access, divided highway [15.0 m];	15
	SECONDARY Any non-limited access highway [3 m];STREET Any city street [3 m];	3 for secondary roads 3 for city streets
	RAIL Any rail right-of-way [3 m].	3
	An additional parameter for highway mode only is ADJACENT It represents the minimum perpendicular distance between shipment centerline and centerline of adjacent passing vehicles [4 m].	4
	Note: The FREEWAY value is based on the Madsen et al. (1986) model of a minimal Interstate configuration of 4 lanes with an average lane width of 5 m, in the most typical traffic configuration. The latter refers to the RAM shipment being in the outside lane, oncoming traffic in the corresponding outside lane, and passing vehicles in the inner lanes. The SECONDARY and STREET values are smaller because these roadways are modeled as being only 2 lanes wide with an average lane width of 3 m. The RAIL value is based on the minimum clearance between passing trains on double rail segments. The ADJACENT value represents the median value for all Interstate and secondary-road lane widths.	
MODSTD Name	**Description**	**STANDARD (Default) Value**

FMINCL	This keyword is applied to rail mode only and specifies the minimum number of railcar classifications or inspections per one-way trip. The standard (default) value is 2 since there are always at least two inspections per one-way trip - one at the beginning and one at the end of each trip (Wooden, 1986).	2
FNOATT	This parameter is applied to passenger-air mode only and specifies the Number of Flight Attendants. The standard (default) value is 4 (NRC, 1977).	4
FREEWAY	See DISTOFF and DISTON	
MITDDIST	This parameter is used to calculate the maximum individual "in-transit" dose to a member of the public; it represents the minimum perpendicular distance, in meters, from the shipment centerline to an individual standing beside the road or railroad while a shipment passes. The standard (default) value is 30.0 m (NRC, 1977).	30
MITDVEL	This parameter is used to calculate the maximum individual "in-transit" dose; it represents the minimum velocity, in km/hr, of a shipment. The standard (default) value is 24.0 km/hr (15 mph) (NRC, 1977).	24
RAIL	See DISTOFF and DISTON	
MODSTD Name	**Description**	**STANDARD (Default) Value**

RPD	This parameter is the Ratio of Pedestrian Density. It is used to calculate the density of unshielded persons on sidewalks and elsewhere in urban areas when the IUOPT Flag is not equal to 3 by indexing it to the population density of the surrounding area. RPD is also used in the calculation of accident consequences. The standard (default) is 6.0, which is based on empirical data from New York City (Finley, 1980). It means that the pedestrian density is six times the residential population density. This figure is likely to be conservative for most other urban areas, but similar data are seldom collected in other cities.	6.0
RR	This parameter specifies the Rural Shielding Factor. The standard (default) value is 1.0 (i.e., no shielding). Although even wood-frame construction provides some shielding, the Rural Shielding Factor is set to 1.0 to conservatively account for the fact that rural economies involve a relatively large fraction of outdoor employment (farming, ranching, etc.). RR is used in incident-free dose and in dose-risk calculation for non-dispersal accidents.	1.0
RS	This parameter specifies the Suburban Shielding Factor. The standard (default) value is 0.87, which represents a residential structure of wood-frame construction (Taylor and Daniel, 1982, p.12). RS is used in incident-free dose and in dose-risk calculations for non-dispersal accidents.	0.87
RU	This parameter specifies the Urban Shielding Factor. The standard (default) value is 0.018, which represents an urban commercial building constructed of concrete block (Taylor and Daniel, 1982, p.12). RU is used in incident-free dose and in dose-risk calculations for non-dispersal accidents.	0.018
MODSTD Name	**Description**	**STANDARD (Default) Value**

SECONDARY	See DISTOFF and DISTON	
SMALLPKG	This parameter specifies the first Package Size Threshold. This parameter is used to determine the handling method that will be used for a package, which, in turn, is used in the calculation of handler dose. If a package is designated as "small" then an empirical algorithm for handling dose is used; if package dimensions exceed the threshold then another method is used. The standard (default) value for SMALLPKG is 0.5 m (Javitz, 1985). Although it is highly unlikely that this value will need to be altered, the analyst has the option to do so.	0.5
STREET	See DISTOFF and DISTON	

Definitions for Input to the User-defined Dispersion Model

USE_RADTRAN:	0 use RISKIND center line distances – **preferred** 1 use RADTRAN distances (only if REL_HT < 3 meters)
REL_HT:	Release Height (m)
HEAT_REL:	Heat Release (cal/sec)
SRC_WDTH:	Source Width or Cask Length (m)
SRC_HT:	Source Height or Cask Radius (m)
WS:	Wind Speed (m/sec)
ANEM_HT:	Anemometer Height (m)
AMB_T:	Ambient Temperature (K)
HT_MIX:	Atmospheric Mixing Height (m)
Pasquill/Briggs:	1 use the Pasquill-Gifford dispersion model with coefficients 2 use the Briggs dispersion model with coefficients
Stability:	Pasquill Stability Category A=1 through F=6
Rural – or – Suburban/Urban	1 use the rural terrain coefficients 2 use the suburban/urban terrain coefficients

APPENDIX B: DOSE CONVERSION FACTORS

Correspondence for the radionuclide arrays:

1. Half-Life (days). Source: ICRP 38 (as reported in Federal Guidance Report (FGR) 13)

2. Photon Energy (MeV). Source: ICRP 38 (this value is not used in RADTRAN 5.5)

3. Cloud/Immersion Dose Factor (rem-m^3/Ci-sec). Source: FGR 12 (multiply by $3.7x10^{12}$ to convert from SI units to historical units)

4. Groundshine Dose Factor (rem-m^2/µCi-day). Source: FGR 12 (multiply by $3.197x10^{11}$ to convert from SI units to historical units)

5. 50-year Effective Inhalation Dose Factor (rem/Ci). Source: ICRP 72 – 50-year Effective Inhalation Dose Type M to adult obtained from ICRP-DOSE CD v. 2.0.1 (multiply by $3.7x10^{12}$ to convert from SI units to historical units)

6. 50-year Gonad Inhalation Dose Factor (rem/Ci). Source: ICRP 72 – 50-year Testes Inhalation Dose Type M to adult obtained from ICRP-DOSE CD v. 2.0.1 (multiply by $3.7x10^{12}$ to convert from SI units to historical units)

7. 1-year Lung Inhalation Dose Factor (rem/Ci). Source: ICRP 72 – 1-year Lung Inhalation Dose Type M to adult obtained from ICRP-DOSE CD v. 2.0.1 (multiply by $3.7x10^{12}$ to convert from SI units to historical units)

8. 1-year Marrow Inhalation Dose Factor (rem/Ci). Source: ICRP 72 – 1-year Red Marrow Inhalation Dose Type M to adult obtained from ICRP-DOSE CD v. 2.0.1 (multiply by $3.7x10^{12}$ to convert from SI units to historical units)

9. Nuclide Name for Ingestion Data. Source: COMIDA2 – Names must match RT5INGEST.BIN

10. A1 Activity Limit Values (Ci). Source: 10CFR71 Appendix A – Revised 1/1/2004

11. A2 Activity Limit Values (Ci). Source: 10CFR71 Appendix A – Revised 1/1/2004

Inhalation values are based on 1.0-micron AMAD particle except for the following radionuclides:

- Kr-85, Xe-133M, and Xe-133 are gases.
- H-3(WTR) which is tritiated water.
- H-3(GAS) which is elemental hydrogen vapor.
- C-14(ORG) which is organic gases and vapors.
- C-14(GAS) which is carbon dioxide.

The inhalation dose conversion factors use a 1.0-micron AMAD particle as a conservative value. ICRP-66 uses a distribution from 1 to 5 microns and the occupational respirable size is 5.0-microns. The upper limit for truly respirable particles is 10.0-microns.

ICRP 72 gives dose commitments to adult members of the public at age 20 that are assumed to live another 50 yrs.

All dose conversion factors (DCFs) and photon energies are calculated for each individual radionuclide with the exception of the following radionuclides which have their progenies included:

- Mo-99 includes the weighted contribution from the short half-life of its Tc-99m daughter.
- Ru-103 includes the weighted contribution from its short half-life Rh-103m daughter.
- Ru-106 includes the weighted contribution from the short half-life of its Rh-106 daughter. Inhalation DCFs were determined with Ru-106 only. There is no information for Rh-106.
- Cs-137 includes the weighted contribution from the short half-life of its Ba-137m daughter. Inhalation DCFs were determined with Cs-137 only. There is no information for Ba-137m.
- Ce-144 includes the weighted contributions from the short half-lives of its Pr-144 and Pr-144m daughters. Inhalation DCFs were determined with Ce-144 and Pr-144. There is no information for Pr-144m.

Nuclide Name	Half Life (days)	Photon Energy (MeV)	Cloudshine (rem-m^3/Ci-sec)	Groundshine (rem-m^2/μCi-day)	Effective Inhalation (rem/Ci)
H-3 (WTR)	4.51E+03	0.00E+00	1.22E-06	0.00E+00	6.66E+01
H-3 (GAS)	4.51E+03	0.00E+00	1.22E-06	0.00E+00	6.66E-03
Be-10	5.84E+08	0.00E+00	4.14E-05	1.32E-07	3.55E+04
C-14 (ORG)	2.09E+06	0.00E+00	8.29E-07	5.15E-09	2.15E+03
C-14 (GAS)	2.09E+06	0.00E+00	8.29E-07	5.15E-09	2.29E+01
Na-22	9.49E+02	2.19E+00	4.00E-01	6.71E-04	4.81E+03
P-32	1.43E+01	0.00E+00	3.66E-04	9.30E-07	1.26E+04
S-35	8.74E+01	0.00E+00	8.99E-07	5.37E-09	5.18E+03
Cl-36	1.10E+08	1.55E-04	8.25E-05	2.15E-07	2.70E+04
Ca-41	5.11E+07	4.19E-04	0.00E+00	0.00E+00	3.52E+02
Ca-45	1.63E+02	4.35E-08	3.19E-06	1.47E-08	9.99E+03
Sc-46	8.38E+01	2.01E+00	3.69E-01	6.17E-04	2.52E+04
Cr-51	2.77E+01	3.26E-02	5.59E-03	9.85E-06	1.18E+02
Mn-54	3.13E+02	8.35E-01	1.51E-01	2.60E-04	5.55E+03
Fe-55	9.86E+02	1.69E-03	0.00E+00	0.00E+00	1.41E+03
Co-57	2.71E+02	1.25E-01	2.08E-02	3.68E-05	2.04E+03
Co-58	7.08E+01	9.75E-01	1.76E-01	3.04E-04	5.92E+03
Fe-59	4.45E+01	1.19E+00	2.21E-01	3.58E-04	1.37E+04
Ni-59	2.74E+07	2.41E-03	0.00E+00	0.00E+00	4.81E+02

Co-60	1.92E+03	2.50E+00	4.66E-01	7.51E-04	3.70E+04
Ni-63	3.50E+04	0.00E+00	0.00E+00	0.00E+00	1.78E+03
Zn-65	2.44E+02	5.84E-01	1.07E-01	1.77E-04	5.92E+03
Ga-67	3.26E+00	1.58E-01	2.66E-02	4.76E-05	8.88E+02
Kr-85	3.91E+03	2.21E-03	4.40E-04	8.44E-07	0.00E+00
Rb-86	1.87E+01	9.45E-02	1.78E-02	2.98E-05	3.44E+03
Rb-87	1.72E+13	0.00E+00	6.73E-06	2.81E-08	1.85E+03
Sr-89	5.05E+01	8.45E-05	2.86E-04	7.26E-07	2.26E+04
Sr-90	1.06E+04	0.00E+00	2.79E-05	9.08E-08	1.33E+05
Y-90	2.67E+00	1.69E-06	7.03E-04	1.70E-06	5.18E+03
Y-91	5.85E+01	3.61E-03	9.62E-04	1.84E-06	2.63E+04
Zr-93	5.58E+08	0.00E+00	0.00E+00	0.00E+00	3.70E+04
Zr-95	6.40E+01	7.39E-01	1.33E-01	2.31E-04	1.78E+04
Nb-94	7.41E+06	1.57E+00	2.85E-01	4.89E-04	4.07E+04
Nb-95m	3.61E+00	6.83E-02	1.08E-02	2.00E-05	2.92E+03
Nb-95	3.52E+01	7.66E-01	1.38E-01	2.39E-04	5.55E+03
Mo-99	2.75E+00	2.60E-01	4.60E-02	8.09E-05	3.36E+03

Nuclide Name	Gonad Inhalation (rem-Ci)	Lung Inhalation (rem/Ci)	Marrow Inhalation (rem-Ci)	COMIDA Name	A1 Limit (Ci)	A2 Limit (Ci)
H-3 (WTR)	6.66E+01	6.66E+01	6.66E+01	NONE	1080	1080
H-3 (GAS)	6.66E-03	6.66E-03	6.66E-03	NONE	1080	1080
Be-10	1.78E+03	2.00E+05	5.92E+03	Be-10	541	13.5
C-14 (ORG)	2.15E+03	2.15E+03	2.11E+03	NONE	1080	54.1
C-14 (GAS)	2.29E+01	2.29E+01	2.29E+01	NONE	1080	54.1
Na-22	3.00E+03	3.29E+03	5.55E+03	Na-22	13.5	13.5
P-32	6.29E+02	8.88E+04	7.77E+03	P-32	8.11	8.11
S-35	2.85E+01	4.44E+04	2.74E+01	S-35	1080	54.1
Cl-36	9.99E+02	2.04E+05	9.62E+02	Cl-36	541	13.5
Ca-41	3.48E+00	5.18E+02	1.96E+02	Ca-41	1080	1080
Ca-45	4.44E+01	7.77E+04	2.66E+03	Ca-45	1080	24.3
Sc-46	3.26E+02	1.63E+05	5.92E+03	Sc-46	13.5	13.5
Cr-51	1.18E+01	5.18E+02	4.81E+01	Cr-51	811	811
Mn-54	5.55E+02	2.22E+04	4.07E+03	Mn-54	27	27
Fe-55	3.52E+02	1.11E+03	6.66E+02	Fe-55	1080	1080
Co-57	1.85E+02	1.18E+04	4.81E+02	Co-57	216	216
Co-58	4.44E+02	3.29E+04	2.07E+03	Co-58	27	27
Fe-59	1.37E+03	8.51E+04	4.81E+03	Fe-59	21.6	21.6
Ni-59	2.89E+02	1.33E+03	4.07E+01	Ni-59	1080	1080
Co-60	7.03E+03	1.78E+05	1.07E+04	Co-60	10.8	10.8
Ni-63	7.03E+02	8.14E+03	1.04E+02	Ni-63	1080	811
Zn-65	2.29E+03	1.78E+04	4.07E+03	Zn-65	54.1	54.1
Ga-67	1.41E+01	5.92E+03	6.29E+01	Ga-67	162	162
Kr-85	0.00E+00	0.00E+00	0.00E+00	NONE	541	270
Rb-86	2.74E+03	2.81E+03	5.18E+03	Rb-86	8.11	8.11
Rb-87	1.44E+03	1.52E+03	2.85E+03	Rb-87	100000	100000
Sr-89	1.70E+02	1.67E+05	4.07E+03	Sr-89	16.2	13.5
Sr-90	1.04E+03	7.03E+05	4.07E+04	Sr-90	5.41	2.7
Y-90	1.33E+01	2.59E+04	3.70E+02	Y-90	5.41	5.41
Y-91	2.22E+02	1.85E+05	1.07E+04	Y-91	8.11	8.11
Zr-93	8.51E+00	9.99E+03	2.15E+03	Zr-93	1080	5.41
Zr-95	5.92E+02	1.15E+05	8.51E+03	Zr-95	27	24.3
Nb-94	4.44E+03	2.07E+05	1.26E+04	Nb-94	16.2	16.2
Nb-95m	3.03E+01	2.00E+04	2.37E+02	Nb-95m	27	24.3
Nb-95	2.22E+02	3.52E+04	1.52E+03	Nb-95	27	27
Mo-99	5.66E+01	1.99E+04	1.72E+02	Mo-99	16.2	13.5

Nuclide Name	Half Life (days)	Photon Energy (MeV)	Cloudshine (rem-m^3/Ci-sec)	Groundshine (rem-m^2/μCi-day)	Effective Inhalation (rem/Ci)
Tc-99	7.77E+07	0.00E+00	5.99E-06	2.49E-08	1.48E+04
Rh-102	1.06E+03	2.13E+00	3.85E-01	6.65E-04	2.55E+04
Ru-103	3.93E+01	4.70E-01	8.33E-02	1.48E-04	8.89E+03
Ru-106	3.68E+02	2.01E-01	3.85E-02	6.78E-05	1.04E+05
Pd-107	2.37E+09	0.00E+00	0.00E+00	0.00E+00	3.15E+02
Cd-109	4.64E+02	2.64E-02	1.09E-03	7.19E-06	2.44E+04
Ag-111	7.45E+00	2.63E-02	4.77E-03	8.54E-06	5.55E+03
In-111	2.83E+00	4.05E-01	6.88E-02	1.25E-04	8.51E+02
Cd-113m	4.96E+03	0.00E+00	2.57E-05	8.41E-08	1.92E+05
Sn-113	1.15E+02	2.28E-02	1.41E-03	6.81E-06	9.99E+03
In-114m	4.95E+01	9.42E-02	1.55E-02	2.93E-05	2.26E+04
Cd-115m	4.46E+01	2.19E-02	4.33E-03	7.48E-06	3.63E+03
Sn-119m	2.93E+02	1.15E-02	3.74E-04	3.32E-06	8.14E+03
Sn-121m	2.01E+04	4.94E-03	2.23E-04	1.56E-06	1.67E+04
Sn-123	1.29E+02	6.88E-03	1.49E-03	2.68E-06	3.00E+04
Te-123m	1.20E+02	1.48E-01	2.41E-02	4.57E-05	1.48E+04
Sb-124	6.02E+01	1.80E+00	3.39E-01	5.47E-04	2.37E+04
I-125	6.01E+01	4.20E-02	1.93E-03	1.37E-05	5.18E+03
Te-125m	5.80E+01	3.55E-02	1.68E-03	1.15E-05	1.26E+04
Sb-125	1.01E+03	4.30E-01	7.47E-02	1.36E-04	1.78E+04
Sn-125	9.64E+00	3.11E-01	5.85E-02	9.62E-05	1.15E+04
Sb-126	1.24E+01	2.83E+00	5.07E-01	8.89E-04	1.04E+04
Sn-126	3.65E+07	5.65E-02	7.81E-03	1.75E-05	1.04E+05
Sb-127	3.85E+00	6.85E-01	1.23E-01	2.16E-04	6.29E+03
Te-127m	1.09E+02	1.12E-02	5.44E-04	3.61E-06	2.74E+04
Te-127	3.90E-01	4.86E-03	8.95E-04	1.66E-06	4.81E+02
I-129	5.73E+09	2.46E-02	1.41E-03	8.25E-06	5.55E+04
Te-129m	3.36E+01	3.75E-02	5.74E-03	1.21E-05	2.44E+04
I-131	8.04E+00	3.80E-01	6.73E-02	1.20E-04	8.88E+03
Te-132	3.26E+00	2.33E-01	3.81E-02	7.29E-05	7.40E+03
Xe-133m	2.19E+00	4.07E-02	5.07E-03	1.30E-05	0.00E+00
Xe-133	5.25E+00	4.60E-02	5.77E-03	1.47E-05	0.00E+00
Cs-134	7.52E+02	1.55E+00	2.80E-01	4.86E-04	3.37E+04
Cs-135	8.40E+08	0.00E+00	2.09E-06	1.06E-08	1.15E+04
Cs-137	1.10E+04	5.69E-02	1.07E-01	1.77E-04	3.59E+04
Ba-140	1.27E+01	1.82E-01	3.17E-02	5.75E-05	1.89E+04

Nuclide Name	Gonad Inhalation (rem-Ci)	Lung Inhalation (rem/Ci)	Marrow Inhalation (rem-Ci)	COMIDA Name	A1 Limit (Ci)	A2 Limit (Ci)
Tc-99	3.40E+01	1.15E+05	3.15E+01	Tc-99	1080	24.3
Rh-102	9.62E+03	7.40E+04	1.11E+04	Rh-102	13.5	13.5
Ru-103	3.07E+02	6.67E+04	9.25E+02	Ru-103	54.1	24.3
Ru-106	9.62E+03	7.03E+05	6.29E+03	Ru-106	5.41	5.41
Pd-107	7.03E-01	1.96E+03	3.59E+00	Pd-107	100000	100000
Cd-109	1.89E+03	1.04E+05	7.03E+02	Cd-109	1080	27
Ag-111	5.18E+01	3.70E+04	6.66E+01	Ag-111	16.2	13.5
In-111	3.07E+01	3.55E+03	1.74E+02	In-111	54.1	54.1
Cd-113m	2.74E+04	1.63E+05	1.59E+03	Cd-113m	541	2.43
Sn-113	2.55E+02	7.03E+04	1.70E+03	Sn-113	108	108
In-114m	1.18E+03	1.15E+05	3.37E+04	In-114m	8.11	8.11
Cd-115m	4.44E+01	2.15E+04	1.18E+02	Cd-115m	8.11	8.11
Sn-119m	1.33E+02	5.92E+04	7.03E+02	Sn-119m	1080	1080
Sn-121m	5.18E+02	1.22E+05	1.55E+03	Sn-121m	1080	24.3
Sn-123	4.07E+02	2.26E+05	2.78E+03	Sn-123	16.2	13.5
Te-123m	1.26E+02	1.11E+05	3.37E+03	Te-123m	189	189
Sb-124	5.18E+02	1.63E+05	4.44E+03	Sb-124	16.2	13.5
I-125	7.77E+00	5.92E+03	6.29E+01	I-125	541	54.1
Te-125m	4.44E+01	9.62E+04	1.52E+03	Te-125m	811	243
Sb-125	7.77E+02	1.17E+05	3.15E+03	Sb-125	54.1	24.3
Sn-125	8.88E+01	7.40E+04	1.22E+03	Sn-125	5.41	5.41
Sb-126	3.66E+02	6.29E+04	2.37E+03	Sb-126	10.8	10.8
Sn-126	9.25E+03	6.29E+05	2.41E+04	Sn-126	8.11	8.11
Sb-127	7.40E+01	4.07E+04	4.44E+02	Sb-127	541	13.5
Te-127m	1.30E+02	2.07E+05	7.40E+03	Te-127m	541	13.5
Te-127	2.70E+00	2.78E+03	6.29E+00	NONE	541	13.5
I-129	5.18E+01	6.66E+04	1.26E+02	I-129	10000	100000
Te-129m	1.70E+02	1.78E+05	4.44E+03	Te-129m	16.2	13.5
I-131	3.44E+01	3.55E+04	2.07E+02	I-131	81.1	13.5
Te-132	2.52E+02	3.70E+04	8.14E+02	Te-132	10.8	10.8
Xe-133m	0.00E+00	0.00E+00	0.00E+00	NONE	16.2	13.5
Xe-133	0.00E+00	0.00E+00	0.00E+00	NONE	541	541
Cs-134	7.40E+03	1.78E+05	1.15E+04	Cs-134	16.2	13.5
Cs-135	8.51E+02	8.51E+04	6.66E+02	Cs-135	1080	24.3
Cs-137	5.55E+03	2.18E+05	6.29E+03	Cs-137	54.1	13.5
Ba-140	1.89E+02	1.30E+05	2.37E+03	Ba-140	10.8	10.8

Nuclide Name	Half Life (days)	Photon Energy (MeV)	Cloudshine (rem-m^3/Ci-sec)	Groundshine (rem-m^2/μCi-day)	Effective Inhalation (rem/Ci)
Ce-141	3.25E+01	7.61E-02	1.27E-02	2.36E-05	1.18E+04
Pr-143	1.36E+01	8.90E-09	7.77E-05	2.24E-07	8.14E+03
Ce-144	2.84E+02	5.27E-02	1.04E-02	1.88E-05	1.33E+05
Pm-146	2.02E+03	7.53E-01	1.33E-01	2.37E-04	7.77E+04
Nd-147	1.10E+01	1.40E-01	2.29E-02	4.44E-05	7.77E+03
Pm-147	9.58E+02	4.37E-06	2.56E-06	1.09E-08	1.85E+04
Sm-147	3.87E+13	0.00E+00	0.00E+00	0.00E+00	3.55E+07
Pm-148m	4.13E+01	1.99E+00	3.58E-01	6.27E-04	1.89E+04
Sm-151	3.29E+04	1.34E-05	1.34E-07	1.61E-09	1.48E+04
Eu-152	4.87E+03	1.14E+00	2.09E-01	3.52E-04	1.55E+05
Gd-153	2.42E+02	1.05E-01	1.37E-02	3.39E-05	7.77E+03
Eu-154	3.21E+03	1.22E+00	2.27E-01	3.80E-04	1.96E+05
Eu-155	1.81E+03	6.05E-02	9.21E-03	1.89E-05	2.55E+04
Eu-156	1.52E+01	1.31E+00	2.50E-01	3.93E-04	1.26E+04
Tb-160	7.23E+01	1.12E+00	2.05E-01	3.45E-04	2.59E+04
Ho-166m	4.38E+05	1.74E+00	3.13E-01	5.43E-04	4.44E+05
Tm-170	1.29E+02	5.46E-03	8.25E-04	1.89E-06	2.59E+04
Hf-175	7.00E+01	3.68E-01	6.25E-02	1.16E-04	4.44E+03
Hf-181	4.24E+01	5.55E-01	9.69E-02	1.75E-04	1.85E+04
W-181	1.21E+02	4.04E-02	5.18E-03	1.26E-05	2.81E+04
Ta-182	1.15E+02	1.29E+00	2.37E-01	3.93E-04	2.81E+04
W-185	7.51E+01	5.67E-05	1.99E-05	5.88E-08	4.44E+02
W-188	6.94E+01	1.90E-03	3.34E-04	6.14E-07	2.11E+03
Ir-192	7.40E+01	8.11E-01	1.45E-01	2.57E-04	1.92E+04
Tl-202	1.22E+01	4.67E-01	8.07E-02	1.47E-04	7.03E+02
Tl-204	1.38E+03	1.13E-03	2.07E-04	4.73E-07	1.44E+03
Bi-210	5.01E+00	0.00E+00	1.22E-04	3.36E-07	3.44E+05
Pb-210	8.14E+03	4.81E-03	2.09E-04	7.93E-07	4.07E+06
Po-210	1.38E+02	8.50E-06	1.54E-06	2.65E-09	1.22E+07
Pb-212	4.43E-01	1.48E-01	2.54E-02	4.57E-05	6.25E+05
Ra-223	1.14E+01	1.33E-01	2.25E-02	4.09E-05	2.74E+07
Ra-224	3.66E+00	9.89E-03	1.74E-03	3.06E-06	1.11E+07
Ac-225	1.00E+01	1.79E-02	2.67E-03	5.05E-06	2.74E+07
Ra-225	1.48E+01	1.37E-02	1.03E-03	4.25E-06	2.33E+07
Ra-226	5.84E+05	6.74E-03	1.17E-03	2.06E-06	1.30E+07
Ac-227	7.95E+03	2.31E-04	2.15E-05	5.02E-08	8.14E+08

Nuclide Name	Gonad Inhalation (rem-Ci)	Lung Inhalation (rem/Ci)	Marrow Inhalation (rem-Ci)	COMIDA Name	A1 Limit (Ci)	A2 Limit (Ci)
Ce-141	7.77E+01	8.88E+04	1.07E+03	Ce-141	270	13.5
Pr-143	2.78E+00	5.55E+04	4.44E+02	Pr-143	108	13.5
Ce-144	6.29E+03	6.66E+05	5.18E+04	Ce-144	5.41	5.41
Pm-146	6.29E+03	9.99E+04	1.92E+04	Pm-146	5	0.5
Nd-147	1.70E+01	5.55E+04	7.03E+02	Nd-147	108	13.5
Pm-147	1.48E+00	7.03E+04	4.81E+03	Pm-147	1080	24.3
Sm-147	1.18E+03	1.70E+07	4.07E+06	Sm-147	100000	100000
Pm-148m	4.81E+02	1.15E+05	7.40E+03	Pm-148m	13.5	13.5
Sm-151	5.18E-01	1.11E+04	1.81E+03	Sm-151	1080	108
Eu-152	1.37E+04	1.44E+05	2.59E+05	Eu-152	24.3	24.3
Gd-153	8.51E+01	4.07E+04	3.44E+03	Gd-153	270	135
Eu-154	1.22E+04	2.92E+05	3.70E+04	Eu-154	21.6	13.5
Eu-155	3.11E+02	6.66E+04	5.55E+03	Eu-155	541	54.1
Eu-156	1.59E+02	8.14E+04	2.33E+03	Eu-156	16.2	13.5
Tb-160	4.44E+02	1.67E+05	1.04E+04	Tb-160	24.3	13.5
Ho-166m	3.59E+04	2.07E+05	3.55E+04	Ho-166m	16.2	8.11
Tm-170	3.22E+02	1.78E+05	1.70E+04	Tm-170	108	13.5
Hf-175	1.70E+02	2.52E+04	2.59E+03	Hf-175	81.1	81.1
Hf-181	2.04E+02	1.37E+05	4.07E+03	Hf-181	54.1	24.3
W-181	1.18E+03	1.96E+05	5.18E+03	W-181	811	811
Ta-182	1.18E+03	1.96E+05	5.18E+03	Ta-182	21.6	13.5
W-185	9.25E+00	7.77E+01	1.63E+02	W-185	1080	24.3
W-188	2.96E+01	9.62E+01	1.07E+03	W-188	5.41	5.41
Ir-192	8.51E+02	1.33E+05	2.55E+03	Ir-192	27	13.5
Tl-202	3.70E+02	4.07E+02	4.44E+02	Tl-202	54.1	54.1
Tl-204	8.51E+02	9.25E+02	8.51E+02	Tl-204	108	13.5
Bi-210	1.74E+02	2.85E+06	1.70E+02	Bi-210	16.2	13.5
Pb-210	2.41E+05	1.81E+07	1.22E+06	Pb-210	16.2	0.243
Po-210	1.81E+05	9.62E+07	1.67E+06	Po-210	1080	0.541
Pb-212	1.92E+03	5.18E+06	6.29E+03	Pb-212	8.11	8.11
Ra-223	1.22E+04	2.29E+08	2.78E+05	Ra-223	16.2	0.811
Ra-224	9.25E+03	9.25E+07	1.48E+05	Ra-224	8.11	1.62
Ac-225	1.33E+05	2.26E+08	9.25E+05	Ac-225	16.2	0.27
Ra-225	5.55E+04	1.92E+08	7.40E+05	Ra-225	16.2	0.541
Ra-226	8.88E+04	9.99E+07	3.70E+05	Ra-226	8.11	0.541
Ac-227	2.89E+08	3.66E+08	5.55E+07	Ac-227	1080	0.000541

Nuclide Name	Half Life (days)	Photon Energy (MeV)	Cloudshine (rem-m^3/Ci-sec)	Groundshine (rem-m^2/μCi-day)	Effective Inhalation (rem/Ci)
Th-227	1.87E+01	1.06E-01	1.81E-02	3.32E-05	3.15E+07
Ra-228	2.10E+03	4.14E-09	0.00E+00	0.00E+00	9.62E+06
Th-228	6.98E+02	3.30E-03	3.40E-04	7.51E-07	1.18E+08
Th-229	2.68E+06	9.54E-02	1.42E-02	2.73E-05	4.07E+08
Th-230	2.81E+07	1.55E-03	6.44E-05	2.40E-07	1.59E+08
Pa-231	1.20E+07	4.76E-02	6.36E-03	1.30E-05	5.18E+08
Th-232	5.13E+12	1.33E-03	3.23E-05	1.76E-07	1.67E+08
U-232	2.63E+04	2.19E-03	5.25E-05	3.23E-07	2.89E+07
Pa-233	2.70E+01	2.03E-01	3.46E-02	6.23E-05	1.22E+04
U-233	5.79E+07	1.31E-03	6.03E-05	2.29E-07	1.33E+07
Th-234	2.41E+01	9.34E-03	1.25E-03	2.66E-06	2.44E+04
U-234	8.92E+07	1.73E-03	2.82E-05	2.39E-07	1.30E+07
Np-235	3.96E+02	7.09E-03	1.89E-04	1.17E-06	1.55E+03
U-235	2.57E+11	1.54E-01	2.66E-02	4.73E-05	1.15E+07
Np-236a	4.20E+07	1.36E-01	1.98E-02	3.84E-05	1.18E+07
Pu-236	1.04E+03	2.09E-03	2.35E-05	3.14E-07	7.40E+07
U-236	8.55E+09	1.57E-03	1.85E-05	2.08E-07	1.18E+07
Np-237	7.82E+08	3.43E-02	3.81E-03	9.17E-06	8.51E+07
Pu-237	4.53E+01	5.23E-02	7.47E-03	1.49E-05	1.30E+03
U-237	6.75E+00	1.42E-01	2.21E-02	4.25E-05	6.29E+03
Np-238	2.12E+00	5.50E-01	1.01E-01	1.69E-04	7.77E+03
Pu-238	3.20E+04	1.81E-03	1.81E-05	2.68E-07	1.70E+08
U-238	1.63E+12	1.36E-03	1.26E-05	1.76E-07	1.07E+07
Np-239	2.36E+00	1.72E-01	2.85E-02	5.21E-05	3.44E+03
Pu-239	8.78E+06	7.96E-04	1.57E-05	1.17E-07	1.85E+08
Pu-240	2.39E+06	1.73E-03	1.76E-05	2.57E-07	1.85E+08
Am-241	1.58E+05	3.24E-02	3.03E-03	8.79E-06	1.55E+08
Pu-241	5.26E+03	2.54E-06	2.68E-07	6.17E-10	3.33E+06
Am-242m	5.55E+04	5.11E-03	1.17E-04	9.65E-07	1.37E+08
Cm-242	1.63E+02	1.83E-03	2.11E-05	3.06E-07	1.92E+07
Pu-242	1.37E+08	1.44E-03	1.48E-05	2.13E-07	1.78E+08
Am-243	2.69E+06	5.59E-02	8.07E-03	1.71E-05	1.52E+08
Cm-243	1.04E+04	1.34E-01	2.18E-02	4.00E-05	1.15E+08
Cm-244	6.61E+03	1.70E-03	1.82E-05	2.81E-07	9.99E+07
Pu-244	3.01E+10	1.22E-03	1.10E-05	1.78E-07	1.74E+08
Cm-245	3.10E+06	9.55E-03	1.47E-02	2.78E-05	1.55E+08

Nuclide Name	Gonad Inhalation (rem-Ci)	Lung Inhalation (rem/Ci)	Marrow Inhalation (rem-Ci)	COMIDA Name	A1 Limit (Ci)	A2 Limit (Ci)
Th-227	1.04E+05	2.59E+08	1.22E+06	Th-227	243	0.27
Ra-228	1.85E+06	2.92E+07	1.92E+06	Ra-228	16.2	1.08
Th-228	1.30E+07	6.66E+08	3.29E+07	Th-228	8.11	0.0108
Th-229	1.22E+08	4.44E+08	2.78E+07	Th-229	8.11	0.000811
Th-230	7.03E+07	2.60E-05	1.41E+07	Th-230	54.1	0.00541
Pa-231	1.52E+04	1.07E+08	9.25E+06	Pa-231	16.2	0.00162
Th-232	7.77E+07	7.40E+07	1.18E+07	Th-232	100000	100000
U-232	4.81E+06	1.44E+08	2.29E+06	U-232	81.1	0.00811
Pa-233	3.40E+01	9.25E+04	1.37E+03	Pa-233	135	24.3
U-233	5.18E+05	9.99E+07	3.18E+05	U-233	270	0.027
Th-234	5.92E+02	1.70E+05	7.03E+03	Th-234	5.41	5.41
U-234	5.18E+05	9.62E+07	3.15E+05	U-234	270	0.027
Np-235	4.07E+02	5.92E+03	1.04E+03	Np-235	1080	1080
U-235	4.81E+05	8.51E+07	2.92E+05	U-235	100000	100000
Np-236a	8.88E+06	5.92E+05	1.67E+05	Np-236a	189	0.027
Pu-236	2.37E+07	1.33E+08	1.26E+07	Pu-236	189	0.0189
U-236	4.81E+05	8.88E+07	2.96E+05	U-236	270	0.027
Np-237	5.18E+07	9.99E+07	1.04E+07	Np-237	54.1	0.00541
Pu-237	6.29E+01	8.51E+03	4.81E+02	Pu-237	541	541
U-237	1.44E+01	4.44E+04	1.33E+02	U-237	5	0.5
Np-238	3.44E+03	1.96E+04	9.99E+02	Np-238	5	0.5
Pu-238	7.03E+07	1.26E+08	1.37E+07	Pu-238	54.1	0.00541
U-238	4.44E+05	8.14E+07	2.92E+05	U-238	100000	100000
Np-239	3.70E+01	2.33E+04	1.30E+02	Np-239	162	13.5
Pu-239	7.77E+07	1.11E+08	1.30E+07	Pu-239	54.1	0.00541
Pu-240	7.77E+07	1.11E+08	1.30E+07	Pu-240	54.1	0.00541
Am-241	1.22E+08	1.22E+08	8.14E+06	Am-241	54.1	0.00541
Pu-241	1.55E+06	2.85E+04	1.33E+04	Pu-241	1080	0.27
Am-242m	1.18E+08	1.96E+07	4.07E+06	Am-242m	54.1	0.00541
Cm-242	1.78E+06	1.30E+08	4.07E+06	Cm-242	1080	0.27
Pu-242	7.40E+07	1.04E+08	1.22E+07	Pu-242	54.1	0.00541
Am-243	1.22E+08	1.15E+08	7.77E+06	Am-243	54.1	0.00541
Cm-243	8.51E+07	1.37E+08	8.51E+06	Cm-243	81.1	0.00811
Cm-244	6.66E+07	1.37E+08	8.51E+06	Cm-244	108	0.0108
Pu-244	7.40E+07	9.62E+07	1.22E+07	Pu-244	8.11	0.00541
Cm-245	1.26E+08	1.18E+08	8.14E+06	Cm-245	54.1	0.00541

Nuclide Name	Half Life (days)	Photon Energy (MeV)	Cloudshine (rem-m^3/Ci-sec)	Groundshine (rem-m^2/μCi-day)	Effective Inhalation (rem/Ci)
Cm-246	1.73E+06	1.51E-03	1.65E-05	2.51E-07	1.55E+08
Cm-247	5.69E+09	3.14E-01	5.55E-02	9.91E-05	1.44E+08
Cm-248	1.24E+08	1.16E-03	1.25E-05	1.92E-07	5.55E+08
Cf-252	9.63E+02	1.20E-03	1.87E-05	2.31E-07	7.40E+07

Nuclide Name	Gonad Inhalation (rem-Ci)	Lung Inhalation (rem/Ci)	Marrow Inhalation (rem-Ci)	COMIDA Name	A1 Limit (Ci)	A2 Limit (Ci)
Cm-246	1.22E+08	1.18E+08	8.14E+06	Cm-246	54.1	0.00541
Cm-247	1.15E+08	1.04E+08	7.40E+06	Cm-247	54.1	0.00541
Cm-248	4.44E+08	2.33E+08	3.00E+07	Cm-248	1.08	0.00135
Cf-252	1.48E+07	1.92E+08	2.81E+07	Cf-252	2.7	0.027

APPENDIX C: COMIDA DATABASE

Due to the amount of information that is in the COMIDA database, this appendix will only provide the ingestion information for one radionuclide. If the entire database is needed please contact one of the following persons at Sandia National Laboratories:

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The ingestion doses used by RADTRAN are taken from the COMIDA2 ingestion code and summed over all crop types. The summed values are then averaged over the dates and divided by the initial ground concentration of $1.00x10^{12}$ Bq/m^2.

The backyard farmer dose is used to calculate a maximum individual dose with the assumption that a family of 5 is on a totally self-reliant subsistence farm of $5x10^4$ square meters (1 person per $1x10^4$ square meters).The individual backyard farmer dose is in units of (Sv/m^2) and the societal dose is in units of (person-Sv/m^2). The following tables list values taken directly from the COMIDA2 ingestion file for Na-22 radionuclide:

Julian	**Na-22**			**Effective Backyard Farmer Dose Values**					
Date	**CROP 1**	**CROP 2**	**CROP 3**	**CROP 4**	**CROP 5**	**CROP 6**	**CROP 7**	**CROP 8**	**CROP 9**
1	2.60E-01	3.10E-01	3.10E-01	4.50E-01	2.80E-01	1.30E+03	1.50E+03	3.30E-01	8.30E+00
61	4.70E-01	5.60E-01	5.60E-01	8.30E-01	5.10E-01	2.80E+03	3.40E+03	3.40E-01	8.30E+00
121	3.90E+02	4.20E+02	5.30E+02	7.80E+02	4.50E+02	1.00E+04	1.20E+04	1.70E+00	4.10E+01
151	4.80E+02	5.10E+02	6.30E+02	9.20E+02	5.30E+02	1.10E+04	1.30E+04	2.00E+00	4.90E+01
181	5.40E+02	6.10E+02	7.10E+02	1.00E+03	6.00E+02	1.00E+04	1.20E+04	2.30E+00	5.70E+01
201	5.80E+02	6.90E+02	7.70E+02	1.10E+03	6.50E+02	1.10E+04	1.30E+04	2.60E+00	6.30E+01
241	6.60E+02	1.10E+03	8.60E+02	1.30E+03	7.30E+02	1.00E+04	1.30E+04	3.90E+00	9.70E+01
271	7.20E+02	3.00E+03	9.50E+02	1.40E+03	8.00E+02	1.30E+04	1.60E+04	1.00E+01	2.50E+02
301	3.70E-02	4.40E-02	4.40E-02	6.40E-02	4.00E-02	7.90E+02	9.40E+02	3.30E-01	8.20E+00

Julian	**Na-22**			**Thyroid Backyard Farmer Dose Values**					
Date	**CROP 1**	**CROP 2**	**CROP 3**	**CROP 4**	**CROP 5**	**CROP 6**	**CROP 7**	**CROP 8**	**CROP 9**
1	2.10E-01	2.50E-01	2.50E-01	3.60E-01	2.30E-01	1.00E+03	1.20E+03	2.70E-01	6.70E+00
61	3.80E-01	4.60E-01	4.50E-01	6.70E-01	4.10E-01	2.30E+03	2.70E+03	2.70E-01	6.70E+00
121	3.10E+02	3.40E+02	4.30E+02	6.30E+02	3.60E+02	8.30E+03	9.90E+03	1.30E+00	3.30E+01
151	3.90E+02	4.10E+02	5.10E+02	7.40E+02	4.30E+02	9.00E+03	1.10E+04	1.60E+00	4.00E+01
181	4.40E+02	4.90E+02	5.70E+02	8.40E+02	4.90E+02	8.40E+03	1.00E+04	1.90E+00	4.60E+01
201	4.70E+02	5.60E+02	6.20E+02	9.10E+02	5.20E+02	8.80E+03	1.10E+04	2.10E+00	5.10E+01
241	5.30E+02	9.00E+02	7.00E+02	1.00E+03	5.90E+02	8.40E+03	1.00E+04	3.20E+00	7.80E+01
271	5.80E+02	2.40E+03	7.60E+02	1.10E+03	6.50E+02	1.10E+04	1.30E+04	8.10E+00	2.00E+02
301	3.00E-02	3.50E-02	3.50E-02	5.10E-02	3.20E-02	6.40E+02	7.60E+02	2.70E-01	6.60E+00

Julian Date	Na-22 CROP 1	Gonad Societal Dose Values CROP 2	CROP 3	CROP 4	CROP 5	CROP 6	CROP 7	CROP 8	CROP 9
1	3.80E-04	4.50E-04	4.50E-04	6.60E-04	4.10E-04	1.20E-01	1.40E-01	3.20E-05	7.80E-04
61	4.00E-04	4.80E-04	4.70E-04	7.00E-04	4.30E-04	2.60E-01	3.20E-01	3.20E-05	7.80E-04
121	6.20E-02	6.80E-02	8.40E-02	1.20E-01	7.10E-02	9.90E-01	1.20E+00	2.40E-04	6.00E-03
151	6.70E-02	7.20E-02	8.80E-02	1.30E-01	7.40E-02	1.10E+00	1.30E+00	2.60E-04	6.50E-03
181	6.80E-02	7.60E-02	8.90E-02	1.30E-01	7.50E-02	9.90E-01	1.20E+00	2.80E-04	6.80E-03
201	6.80E-02	8.10E-02	8.90E-02	1.30E-01	7.60E-02	1.00E+00	1.30E+00	2.90E-04	7.20E-03
241	6.80E-02	1.20E-01	8.90E-02	1.30E-01	7.60E-02	9.80E-01	1.20E+00	4.00E-04	9.90E-03
271	6.90E-02	2.80E-01	9.00E-02	1.30E-01	7.70E-02	1.20E+00	1.50E+00	9.50E-04	2.30E-02
301	3.60E-04	4.30E-04	4.30E-04	6.30E-04	3.90E-04	7.30E-02	8.80E-02	3.10E-05	7.80E-04

Julian Date	Na-22 CROP 1	Breast Societal Dose Values CROP 2	CROP 3	CROP 4	CROP 5	CROP 6	CROP 7	CROP 8	CROP 9
1	3.50E-04	4.20E-04	4.10E-04	6.10E-04	3.80E-04	1.10E-01	1.30E-01	2.90E-05	7.10E-04
61	3.70E-04	4.40E-04	4.40E-04	6.40E-04	4.00E-04	2.40E-01	2.90E-01	2.90E-05	7.20E-04
121	5.70E-02	6.20E-02	7.80E-02	1.10E-01	6.60E-02	9.10E-01	1.10E+00	2.20E-04	5.50E-03
151	6.10E-02	6.60E-02	8.00E-02	1.20E-01	6.80E-02	1.00E+00	1.20E+00	2.40E-04	5.90E-03
181	6.20E-02	7.00E-02	8.20E-02	1.20E-01	6.90E-02	9.10E-01	1.10E+00	2.50E-04	6.20E-03
201	6.30E-02	7.40E-02	8.20E-02	1.20E-01	6.90E-02	9.60E-01	1.20E+00	2.70E-04	6.60E-03
241	6.30E-02	1.10E-01	8.20E-02	1.20E-01	7.00E-02	9.00E-01	1.10E+00	3.70E-04	9.10E-03
271	6.30E-02	2.60E-01	8.30E-02	1.20E-01	7.00E-02	1.10E+00	1.40E+00	8.70E-04	2.20E-02
301	3.30E-04	3.90E-04	3.90E-04	5.80E-04	3.60E-04	6.70E-02	8.10E-02	2.90E-05	7.10E-04

Julian Date	Na-22 CROP 1	Lungs Societal Dose Values CROP 2	CROP 3	CROP 4	CROP 5	CROP 6	CROP 7	CROP 8	CROP 9
1	3.40E-04	4.00E-04	4.00E-04	5.90E-04	3.70E-04	1.10E-01	1.30E-01	2.80E-05	7.00E-04
61	3.60E-04	4.20E-04	4.20E-04	6.20E-04	3.90E-04	2.40E-01	2.80E-01	2.80E-05	7.00E-04
121	5.60E-02	6.00E-02	7.50E-02	1.10E-01	6.40E-02	8.90E-01	1.10E+00	2.20E-04	5.30E-03
151	6.00E-02	6.40E-02	7.80E-02	1.10E-01	6.60E-02	1.00E+00	1.20E+00	2.30E-04	5.80E-03
181	6.10E-02	6.80E-02	7.90E-02	1.20E-01	6.70E-02	8.90E-01	1.10E+00	2.50E-04	6.10E-03
201	6.10E-02	7.20E-02	8.00E-02	1.20E-01	6.80E-02	9.40E-01	1.10E+00	2.60E-04	6.40E-03
241	6.10E-02	1.00E-01	8.00E-02	1.20E-01	6.80E-02	8.80E-01	1.00E+00	3.60E-04	8.80E-03
271	6.20E-02	2.50E-01	8.00E-02	1.20E-01	6.80E-02	1.10E+00	1.30E+00	8.50E-04	2.10E-02
301	3.20E-04	3.80E-04	3.80E-04	5.60E-04	3.50E-04	6.50E-02	7.80E-02	2.80E-05	6.90E-04

Julian Date	Na-22 CROP 1	Red Marrow Societal Dose Values CROP 2	CROP 3	CROP 4	CROP 5	CROP 6	CROP 7	CROP 8	CROP 9
1	5.80E-04	6.90E-04	6.90E-04	1.00E-03	6.30E-04	1.80E-01	2.20E-01	4.80E-05	1.20E-03
61	6.10E-04	7.30E-04	7.30E-04	1.10E-03	6.60E-04	4.00E-01	4.80E-01	4.80E-05	1.20E-03
121	9.50E-02	1.00E-01	1.30E-01	1.90E-01	1.10E-01	1.50E+00	1.80E+00	3.70E-04	9.10E-03
151	1.00E-01	1.10E-01	1.30E-01	2.00E-01	1.10E-01	1.70E+00	2.00E+00	4.00E-04	9.90E-03
181	1.00E-01	1.20E-01	1.40E-01	2.00E-01	1.10E-01	1.50E+00	1.80E+00	4.20E-04	1.00E-02
201	1.00E-01	1.20E-01	1.40E-01	2.00E-01	1.20E-01	1.60E+00	1.90E+00	4.40E-04	1.10E-02
241	1.00E-01	1.80E-01	1.40E-01	2.00E-01	1.20E-01	1.50E+00	1.80E+00	6.10E-04	1.50E-02
271	1.10E-01	4.30E-01	1.40E-01	2.00E-01	1.20E-01	1.90E+00	2.30E+00	1.50E-03	3.60E-02
301	5.50E-04	6.50E-04	6.50E-04	9.60E-04	5.90E-04	1.10E-01	1.30E-01	4.80E-05	1.20E-03

Julian Date	Na-22 CROP 1	CROP 2	CROP 3	CROP 4	CROP 5	CROP 6	CROP 7	CROP 8	CROP 9
	Bone Surface Societal Dose Values								
1	7.50E-04	8.90E-04	8.90E-04	1.30E-03	8.10E-04	2.30E-01	2.80E-01	6.20E-05	1.50E-03
61	7.90E-04	9.40E-04	9.40E-04	1.40E-03	8.50E-04	5.20E-01	6.20E-01	6.20E-05	1.50E-03
121	1.20E-01	1.30E-01	1.70E-01	2.40E-01	1.40E-01	2.00E+00	2.30E+00	4.80E-04	1.20E-02
151	1.30E-01	1.40E-01	1.70E-01	2.50E-01	1.50E-01	2.20E+00	2.60E+00	5.20E-04	1.30E-02
181	1.30E-01	1.50E-01	1.80E-01	2.60E-01	1.50E-01	2.00E+00	2.30E+00	5.40E-04	1.30E-02
201	1.30E-01	1.60E-01	1.80E-01	2.60E-01	1.50E-01	2.10E+00	2.50E+00	5.70E-04	1.40E-02
241	1.30E-01	2.30E-01	1.80E-01	2.60E-01	1.50E-01	1.90E+00	2.30E+00	7.90E-04	1.90E-02
271	1.40E-01	5.60E-01	1.80E-01	2.60E-01	1.50E-01	2.40E+00	2.90E+00	1.90E-03	4.60E-02
301	7.10E-04	8.40E-04	8.40E-04	1.20E-03	7.70E-04	1.40E-01	1.70E-01	6.20E-05	1.50E-03

Julian Date	Na-22 CROP 1	CROP 2	CROP 3	CROP 4	CROP 5	CROP 6	CROP 7	CROP 8	CROP 9
	Thyroid Societal Dose Values								
1	3.40E-04	4.00E-04	4.00E-04	5.90E-04	3.70E-04	1.10E-01	1.30E-01	2.80E-05	6.90E-04
61	3.60E-04	4.20E-04	4.20E-04	6.20E-04	3.80E-04	2.40E-01	2.80E-01	2.80E-05	6.90E-04
121	5.50E-02	6.00E-02	7.50E-02	1.10E-01	6.40E-02	8.80E-01	1.10E+00	2.20E-04	5.30E-03
151	5.90E-02	6.40E-02	7.80E-02	1.10E-01	6.60E-02	1.00E+00	1.20E+00	2.30E-04	5.80E-03
181	6.00E-02	6.80E-02	7.90E-02	1.20E-01	6.70E-02	8.80E-01	1.10E+00	2.50E-04	6.10E-03
201	6.10E-02	7.20E-02	7.90E-02	1.20E-01	6.70E-02	9.30E-01	1.10E+00	2.60E-04	6.40E-03
241	6.10E-02	1.00E-01	7.90E-02	1.20E-01	6.70E-02	8.70E-01	1.00E+00	3.60E-04	8.80E-03
271	6.10E-02	2.50E-01	8.00E-02	1.20E-01	6.80E-02	1.10E+00	1.30E+00	8.50E-04	2.10E-02
301	3.20E-04	3.80E-04	3.80E-04	5.60E-04	3.50E-04	6.50E-02	7.80E-02	2.80E-05	6.90E-04

Julian Date	Na-22 CROP 1	CROP 2	CROP 3	CROP 4	CROP 5	CROP 6	CROP 7	CROP 8	CROP 9
	Remainder Societal Dose Values								
1	4.30E-04	5.10E-04	5.10E-04	7.50E-04	4.70E-04	1.30E-01	1.60E-01	3.60E-05	8.80E-04
61	4.50E-04	5.40E-04	5.40E-04	7.90E-04	4.90E-04	3.00E-01	3.60E-01	3.60E-05	8.80E-04
121	7.00E-02	7.70E-02	9.60E-02	1.40E-01	8.10E-02	1.10E+00	1.30E+00	2.70E-04	6.80E-03
151	7.60E-02	8.10E-02	9.90E-02	1.50E-01	8.40E-02	1.30E+00	1.50E+00	3.00E-04	7.30E-03
181	7.70E-02	8.60E-02	1.00E-01	1.50E-01	8.50E-02	1.10E+00	1.30E+00	3.10E-04	7.70E-03
201	7.70E-02	9.20E-02	1.00E-01	1.50E-01	8.60E-02	1.20E+00	1.40E+00	3.30E-04	8.10E-03
241	7.70E-02	1.30E-01	1.00E-01	1.50E-01	8.60E-02	1.10E+00	1.30E+00	4.50E-04	1.10E-02
271	7.80E-02	3.20E-01	1.00E-01	1.50E-01	8.70E-02	1.40E+00	1.70E+00	1.10E-03	2.70E-02
301	4.10E-04	4.80E-04	4.80E-04	7.10E-04	4.40E-04	8.30E-02	9.90E-02	3.60E-05	8.80E-04

Julian Date	Na-22 CROP 1	CROP 2	CROP 3	CROP 4	CROP 5	CROP 6	CROP 7	CROP 8	CROP 9
	Effective Societal Dose Values								
1	4.20E-04	5.00E-04	5.00E-04	7.30E-04	4.50E-04	1.30E-01	1.60E-01	3.50E-05	8.60E-04
61	4.40E-04	5.20E-04	5.20E-04	7.70E-04	4.80E-04	2.90E-01	3.50E-01	3.50E-05	8.60E-04
121	6.90E-02	7.50E-02	9.30E-02	1.40E-01	7.90E-02	1.10E+00	1.30E+00	2.70E-04	6.60E-03
151	7.40E-02	7.90E-02	9.70E-02	1.40E-01	8.20E-02	1.20E+00	1.50E+00	2.90E-04	7.10E-03
181	7.50E-02	8.40E-02	9.80E-02	1.40E-01	8.30E-02	1.10E+00	1.30E+00	3.00E-04	7.50E-03
201	7.50E-02	8.90E-02	9.90E-02	1.40E-01	8.30E-02	1.20E+00	1.40E+00	3.20E-04	7.90E-03
241	7.50E-02	1.30E-01	9.90E-02	1.40E-01	8.40E-02	1.10E+00	1.30E+00	4.40E-04	1.10E-02
271	7.60E-02	3.10E-01	9.90E-02	1.50E-01	8.40E-02	1.40E+00	1.60E+00	1.00E-03	2.60E-02
301	4.00E-04	4.70E-04	4.70E-04	6.90E-04	4.30E-04	8.10E-02	9.70E-02	3.50E-05	8.60E-04

Backyard Farmer Dose Example Calculation

An example of how to use the backyard farmer dose value charts is done with the following parameters:

Radionuclide:	Na-22
Number of Curies:	1.00 (Ci)
Release Fraction:	0.012
Aerosolized Fraction:	1.00
Deposition Velocity:	0.01 (m/sec)
Number of Packages:	1
Dispersion:	National Average Weather – 18 Isopleths

The following equation is used to determine the backyard farmer dose:

$$D = \frac{average\left[\sum_{i=1}^{9} \mathrm{Crop}_i\right]}{\mathrm{IG}} \cdot \mathrm{CF} \cdot \mathrm{GC}$$

where:

D	= The backyard farmer dose (Rem)
Crop_i	= The crop dose value for the i^{th} crop (Sv/m^2)
IG	= Initial ground concentration (Bq/m^2)
CF	= Conversion factor (3.7×10^6 Rem-Bq/Sv-µCi)
GC	= Ground contamination prior to clean-up (µCi)

Then for the example listed above:

Average crop dose value for the effective dose	= 19,972 Sv/m^2
Average crop dose value for the thyroid dose	= 16,396 Sv/m^2
Initial ground concentration	= 1.00×10^{12} Bq/m^2
Ground contamination prior to clean-up	= 0.41 µCi

- Severity Class 6
- 33 meters centerline downwind

The results are then the following for the backyard farmer dose:

	Hand Calculation	RADTRAN 5.5	Error
Effective:	3.03×10^{-2} Rem	3.07×10^{-2} Rem	-1.3%
Thyroid:	2.49×10^{-2} Rem	2.47×10^{-2} Rem	0.7%

Societal Ingestion Dose Example Calculation
With No Rainfall

An example of how to calculate the societal ingestion dose is done using the following input parameters:

Radionuclide:	Na-22
Number of Curies:	1.00 (Ci)
Probability of an Accident:	0.1
Release Fraction:	0.01
Aerosolized Fraction:	1.00
Accident Rate:	1.00 (accidents/km)
Distance Traveled:	1.00 (km)
Farm Fraction:	1.00
Deposition Velocity:	0.01 (m/sec)
Number of Shipments:	1
Number of Packages:	1
Rainfall:	0.00 mm/hr
Dispersion:	National Average Weather – 18 Isopleths

The following equation is used to determine the societal ingestion dose:

$$D = \frac{average\left[\sum_{k=1}^{9} \mathrm{Crop}_k\right]}{\mathrm{IG}} \cdot \mathrm{CF} \cdot \mathrm{FF} \cdot \mathrm{AR} \cdot \mathrm{NS} \cdot \mathrm{NP} \cdot \mathrm{DT} \cdot \sum_{a=1}^{z}\sum_{j=1}^{m}\sum_{i=1}^{n} \mathrm{AF}_a \cdot \mathrm{PA}_a \cdot \mathrm{RF}_a \cdot \mathrm{NC}_j \cdot \mathrm{CQ}_i \cdot \left(\mathrm{AD}_i - \mathrm{AD}_{(i-1)}\right) \cdot \mathrm{DV}$$

where:

D = The societal ingestion dose (Person-Rem)
Crop_k = The crop dose value for the k^{th} crop (Person-Sv/m^2)
IG = Initial ground concentration (Bq/m^2)
CF = Conversion factor (3.7×10^{12} Rem-Bq/Sv-Ci)
FF = Farm Fraction
AR = Accident rate (accident/km)
NS = Number of shipments
NP = Number of packages
DT = Distance traveled (km)
AF_a = Aerosolized fraction of the a^{th} severity category
PA_a = Probability of an accident for the a^{th} severity category
RF_a = Release fraction of the a^{th} severity category
NC_j = Number of curies for the j^{th} radionuclide (Ci)
CQ_i = The Chi/Q with deposition value for the i^{th} isopleth (s/m^3)
AD_i = Area of the i^{th} isopleth (m^2)
$\mathrm{AD}_{(i-1)}$ = Area of the $(i-1)^{th}$ isopleth (m^2)
DV = Deposition velocity (m/s)

This equation is only valid for scenarios in which there is no rainfall. For meteorological conditions which rainfall is present, there is another equation that must be used in order to determine the societal ingestion dose since the peak deposited concentration is not in the same isopleth as the peak air concentration.

This equation also assumes that only one physical/chemical group is used. If more than one physical/chemical group is used then using this equation and summing the results for each group will result in the societal ingestion dose.

Then for the example listed above:

Average crop dose value for the effective dose	= 2.203 Sv/m^2
Average crop dose value for the lung dose	= 1.779 Sv/m^2
Initial ground concentration	= 1.00 x 10^{12} Bq/m^2

The results are then the following for the societal ingestion dose:

	Hand Calculation	RADTRAN 5.5	Error
Effective:	4.67 x 10^{-3} Person-Rem	4.60 x 10^{-3} Person-Rem	1.4%
Lung:	3.77 x 10^{-3} Person-Rem	3.72 x 10^{-3} Person-Rem	1.3%

Societal Ingestion Dose Example Calculation With Rainfall

An example of how to calculate the societal ingestion dose is done using the following input parameters:

Radionuclide:	Na-22
Number of Curies:	1.00 (Ci)
Probability of an Accident:	0.1
Release Fraction:	0.01
Aerosolized Fraction:	1.00
Accident Rate:	1.00 (accidents/km)
Distance Traveled:	1.00 (km)
Farm Fraction:	1.00
Deposition Velocity:	0.01 (m/sec)
Number of Shipments:	1
Number of Packages:	1
Dispersion:	User Defined Model – 17 Isopleths
Release Height:	10.0 (meters)
Rainfall:	1.00 (mm/h)
Heat Release:	100,000 (cal/sec)
Cask Length:	3.45 (meters)

Cask Radius:	2.87 (meters)
Wind Speed:	4.00 (m/sec)
Anemometer Height:	10.0 (meters)
Ambient Temperature:	270.0 (K)
Atmospheric Mixing Height:	5,000 (meters)
Briggs:	Used the Briggs dispersion model with coefficients
Stability:	D
Rural:	Used the rural terrain coefficients

The following equation is used to determine the societal ingestion dose:

$$D = \frac{average\left[\sum_{k=1}^{9} Crop_k\right]}{IG} \cdot CF \cdot FF \cdot AR \cdot NS \cdot NP \cdot DT \cdot \sum_{a=1}^{z}\sum_{j=1}^{m}\sum_{i=1}^{n} AF_a \cdot PA_a \cdot RF_a \cdot NC_j \cdot CQ_i \cdot \left(AD_i - AD_{(i-1)}\right)$$

where:

D = The societal ingestion dose (Person-Rem)
$Crop_k$ = The crop dose value for the k^{th} crop (Person-Sv/m^2)
IG = Initial ground concentration (Bq/m^2)
CF = Conversion factor (3.7×10^{12} Rem-Bq/Sv-Ci)
FF = Farm Fraction
AR = Accident rate (accident/km)
NS = Number of shipments
NP = Number of packages
DT = Distance traveled (km)
AF_a = Aerosolized fraction of the a^{th} severity category
PA_a = Probability of an accident for the a^{th} severity category
RF_a = Release fraction of the a^{th} severity category
NC_j = Number of curies for the j^{th} radionuclide (Ci)
CQ_i = The Chi/Q deposited for the i^{th} isopleth (1/m^2)
AD_i = Area of the i^{th} isopleth (m^2)
$AD_{(i-1)}$ = Area of the $(i-1)^{th}$ isopleth (m^2)

This equation is only valid for scenarios in which there is rainfall. For meteorological conditions which no rainfall is present, there is another equation that must be used in order to determine the societal ingestion dose since the peak deposited concentration is in the same isopleth as the peak air concentration.

This equation also assumes that only one physical/chemical group is used. If more than one physical/chemical group is used then using this equation and summing the results for each group will result in the societal ingestion dose.

Then for the example listed above:

Average crop dose value for the effective dose	= 2.203 Sv/m^2
Average crop dose value for the lung dose	= 1.779 Sv/m^2
Initial ground concentration	= 1.00×10^{12} Bq/m^2

The results are then the following for the societal ingestion dose:

	Hand Calculation	RADTRAN 5.5	Error
Effective:	5.41×10^{-3} Person-Rem	5.46×10^{-3} Person-Rem	1.0%
Lung:	4.37×10^{-3} Person-Rem	4.42×10^{-3} Person-Rem	1.2%

APPENDIX D: HIGHWAY VEHICLE DENSITIES

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History

While the data contained in this report can be utilized to provide traffic density figures for any application where such values would be appropriate, they were gathered to aid users of RADTRAN. Historically, standard inputs for the vehicle densities on highways in the United States were the values shown in Table 1 below. The population density zone divisions are those employed by the routing software TRAGIS, which was developed by Oak Ridge National Laboratories (Johnson and Michelhaugh, 2000), and provide the mileage of each route that falls within each of these three zones. A 1975 traffic study (NRC, 1977) resulted in the traffic density values shown in the Table D-1; these values have been used in the RADTRAN program since 1977. Recognition that traffic densities have changed during the past 30 years warranted reinvestigation of those traffic density figures, resulting in this report.

Table D-1: Historical Values Used for Traffic Density in RADTRAN Calculations

Population Density Zone	Traffic Density
0 persons/km^2 – 54 persons/km^2: *Rural*	470 vehicles/hr
54 persons/km^2 – 1284 persons/km^2: *Suburban*	780 vehicles/hr
1284 persons/km^2 and up: *Urban*	2800 vehicles/hr

Approach

The present study was conducted by combining state traffic data (which provided average traffic counts) and U.S. Census 2000 data (which allowed the geographic correlation of the traffic counts with the three familiar population density zones). This process also allowed the division of traffic counts into those for two highway categories: U.S. highways and interstate highways. An additional benefit of this approach is that it provides the ability to define traffic densities for each state individually, or to combine the values for several states along a shipment route to determine an average traffic density along that route.

2000 U.S. Census Data

The U. S. Census (http://www.census.gov) divides the entire population of the country by state, subdivides it by county, further subdivides it into tracts, and finally includes individual census blocks as its smallest subdivision. The size of census blocks is roughly of inverse proportion to the number of inhabitants in each block; therefore, census blocks in less populated areas of the United States, such as the Mojave Desert, will often be several thousand times larger than census blocks in the middle of Manhattan where population is abundant. Within each census block the ethnicities, ages, and other identifying characteristics of inhabitants are compiled. A digital version of this census data for the 2000 Census was imported into the software program ArcView GIS, the geographic information system used in this analysis. Also used in the GIS program was a digital map of all of the U.S. and Interstate highways in the continental U.S.

The GIS program was configured to divide each highway into 1.6-kilometer-long pieces, and to calculate the number of persons within each 1.6-km-by-1.6-km square centered on the highway. Each of these numbers was compared to the limits of the three population density zones, and assigned a corresponding letter ("R" for rural zones, "S" for suburban zones, and "U" for urban zones).

Traffic Count Data

Most states, through their local departments of transportation, compile annual reports containing average traffic counts for their U.S., interstate, and state highways. The only highways considered for this analysis were U.S. and interstate highways, because these are the highways most frequented by radioactive material shipments. These counts are typically carried out using one of two types of equipment: a permanent collector, which is permanently located at the counting site, or a temporary counter, which can be moved frequently among several locations; most use optical or pressure sensing technology to obtain counts of passing vehicles.

This raw data is refined to obtain Average Annual Daily Traffic Counts (AADTs) for each considered public road. In the case of permanent counters, a yearly count total is simply divided by the number of days in the counting year to produce this value; for temporary counters, however, the process is more complicated. Because this type of counter is only present at the count location for a few hours or days during the count year, the raw count data that they produce are extrapolated using a variety of weighting algorithms, the contents of which are outside the scope of this report. The AADT for each considered road is then integrated into an annual report. This analysis used reports from the most recent count year, 2003.

While most states have a system in place similar to the one described above, some states do not currently have such a count report. These states have necessarily been unable to provide data for this traffic study and will not be included in this report. This is discussed in more detail in the next bolded section.

Data Synthesis

Once each highway is divided into rural, suburban, and urban portions via the GIS program, the traffic count data is similarly divided into 1.6-km-long portions and the average traffic density is calculated for each section. Every portion of the traffic data is then matched up with its corresponding population density zone designation. Finally, the traffic densities of all of the sections of the road that fall into each designation are averaged; thus, traffic densities divided into population density categories are calculated for each highway. These are compiled for each state, and then all of the traffic densities for each highway type within the state are distance averaged using Equation D-1. This is done to determine an average state-wide value for each highway type and population density zone.

$$TD_{i,j} = \frac{\sum_{k=1}^{N} TD_{i,j,k} \cdot L_{i,j,k}}{\sum_{k=1}^{N} L_{i,j,k}} \qquad \text{Equation D-1}$$

Where:

$TD_{i,j}$ ≡ State-Wide Average Traffic Density for the Current i,j Set
i ≡ Highway Type (U.S. or Interstate)
j ≡ Population Density Zone (Rural, Suburban, or Urban)
k ≡ Highway Index
N ≡ Number of Highways in the Current i,j Set
$TD_{i,j,k}$ ≡ Average Traffic Density for the Current i,j,k Set
$L_{i,j,k}$ ≡ Length for the Current i,j,k Set

This process was completed for each state included in the analysis, and the results are included in this report. Also included are the average traffic density values for each highway type divided into ten U.S. Environmental Protection Agency (EPA) regions, shown in Table 2. Finally, the data is also combined into a national average.

Limitations of Study

The U.S. Census only counts people where they reside; therefore, the data does not take into account the day-time influx of population into commercial and industrial centers. Also, only states whose traffic count data were readily available were considered for reporting. States that do not have the capability of developing or maintaining electronic traffic counts were automatically discounted, in addition to Hawaii and Alaska, which were considered to be relatively free of radiological shipments. In all, 21 states were included in this analysis; these states are shown in dark gray in Figure D-1. The figure also shows, in light gray, states whose data are available, but for which an analysis was not completed.

Table D-2: United States Divided into 10 EPA Regions

Region	States Included in Region
1	Connecticut, Massachusetts, Maine, New Hampshire, Rhode Island, Vermont
2	New Jersey, New York
3	Delaware. Maryland, Pennsylvania, Virginia, West Virginia
4	Alabama, Florida, Georgia, Kentucky, Mississippi, North Carolina, South Carolina, Tennessee
5	Illinois, Indiana, Michigan, Minnesota, Ohio, Wisconsin
6	Arkansas, Louisiana, New Mexico, Oklahoma, Texas
7	Iowa, Kansas, Missouri, Nebraska
8	Colorado, Montana, North Dakota, South Dakota, Utah
9	Arizona, California, Nevada
10	Idaho, Oregon , Washington

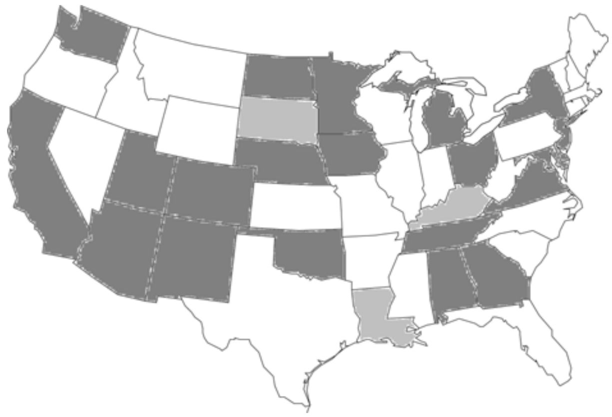

Figure D-1: States currently considered in this report (dark gray), and states whose data are available, but for which an analysis was not completed (light gray)

State-by-State Average Traffic Densities

Tables D-3 and D-4 on the following two pages list a state-by-state summary of the vehicle densities in each of the three population density zones. Each traffic density is compared to the historical values from Table D-1, and the total length of all of the sections of highway with each zone designation is given as the final column under each zone type.

Table D-3: State-by-State Traffic Densities Divided into Population Density Zones—Interstate Highways

Interstate Highways									
	Rural Zone			Suburban Zone			Urban Zone		
State	Traffic Density (vehicles/hr)	Departure from Historic Value (470 vehicles/hr)	Length (km)	Traffic Density (vehicles/hr)	Departure from Historic Value (780 vehicles/hr)	Length (km)	Traffic Density (vehicles/hr)	Departure from Historic Value (2800 vehicles/hr)	Length (km)
Alabama	1161	1477%	813	2138	174%	541	3784	35%	90
Arizona	825	76%	1401	2144	175%	288	4208	50%	145
California	1924	309%	1660	4509	478%	589	7914	183%	1205
Colorado	1248	166%	1036	2342	200%	338	4051	45%	127
Delaware	7187	1429%	3	3651	368%	19	3350	20%	34
Georgia	1537	227%	956	3286	321%	730	7340	162%	208
Iowa	992	111%	956	1588	104%	171	2157	-23%	80
Maryland	1953	315%	159	3656	369%	294	6100	118%	230
Michigan	1219	159%	827	2309	196%	792	4648	66%	360
Minnesota	738	57%	895	2296	194%	383	4376	56%	196
Nebraska	833	77%	677	1685	116%	50	3075	10%	40
New Jersey	2609	455%	105	3322	326%	277	4527	62%	225
New Mexico	654	39%	1195	1208	55%	349	3347	20%	58
New York	835	78%	927	1818	133%	1236	4002	43%	508
North Dakota	293	-38%	793	575	-26%	95	1063	-62%	29
Ohio	1824	288%	637	2655	240%	1002	4241	51%	476
Oklahoma	1175	150%	1046	1786	129%	352	2778	-1%	88
Tennessee	1570	234%	780	2735	251%	674	4121	47%	130
Utah	731	56%	1113	1958	151%	256	3940	41%	142
Vermont	439	-7%	259	726	-7%	230	2129	-24%	5
Washington	1123	139%	616	2670	242%	362	5624	101	206

Table D-4: State-by-State Traffic Densities Divided into Population Density Zones—U.S. Highways

U.S Highways									
	Rural Zone			Suburban Zone			Urban Zone		
State	Traffic Density (vehicles/hr)	Departure from Historic Value (470 vehicles/hr)	Length (km)	Traffic Density (vehicles/hr)	Departure from Historic Value (780 vehicles/hr)	Length (km)	Traffic Density (vehicles/hr)	Departure from Historic Value (2800 vehicles/hr)	Length (km)
Alabama	313	-33%	2888	607	-22%	2650	1077	-62%	230
Arizona	169	-64%	2296	364	-53%	348	2718	-3%	109
California	628	34%	1401	2231	186%	483	5771	106%	455
Colorado	320	-32%	4953	665	-15%	1250	1069	-62%	389
Delaware	800	70%	69	1134	45%	217	1712	-39%	63
Georgia*									
Iowa	280	-40%	3627	306	-61%	1073	481	-83%	262
Maryland	915	95%	302	1156	48%	365	1634	-42%	161
Michigan	471	0%	1911	786	1%	1268	1771	-37%	237
Minnesota	249	-47%	3768	523	-33%	1393	1323	-53%	296
Nebraska	161	-66%	4827	289	-63%	1014	857	-69%	177
New Jersey	916	95%	124	948	21%	656	1521	-46%	478
New Mexico	175	-63%	4693	450	-42%	759	563	-80%	93
New York	290	-38%	829	453	-42%	1022	887	-68%	296
North Dakota	129	-73%	2233	182	-77%	348	666	-76%	21
Ohio	363	-23%	2225	551	-29%	2029	816	-71%	774
Oklahoma	279	-41%	3911	354	-55%	1234	716	-74%	132
Tennessee*									
Utah	386	-18%	1585	509	-35%	328	1147	-59%	135
Vermont	288	-39%	467	377	-52%	451	422	-85%	66
Washington	322	-31%	1883	482	-38%	763	718	-74%	140

* These states only provided interstate highway data; U.S. highway data was not available.

Average Regional Traffic Densities

Tables D-5 and D-6 were constructed by taking existing data for all of the states within each region and distance-averaging them into the three familiar zone types. It is important to note that these values should be seen only as an approximation of the final traffic density values for each region; in Region 6, for example, Texas will eventually play a major role in defining the traffic densities of the region.

National Average Traffic Densities

Tables D-7 and D-8 display the results obtained when the state-wide data are distance-averaged over the entire country. These are the results that directly compare with the historical values found in Table D-1.

Table D-5: Average Regional Traffic Densities Divided into Population Density Zones—Interstate Highways

Interstate Highways									
	Rural Zone			Suburban Zone			Urban Zone		
Region	Traffic Density (vehicles/hr)	Departure from Historic Value (470 vehicles/hr)	Length (km)	Traffic Density (vehicles/hr)	Departure from Historic Value (780 vehicles/hr)	Length (km)	Traffic Density (vehicles/hr)	Departure from Historic Value (2800 vehicles/hr)	Length (km)
1	439	-7%	259	726	-7%	230	2129	-24%	5
2	1015	116%	1031	2094	168%	1512	4163	49%	734
3	2056	338%	163	3655	369%	314	5748	105%	264
4	1427	204%	2549	2776	256%	1945	5611	100%	428
5	1200	155%	2359	2466	216%	2177	4408	57%	1033
6	897	91%	2241	1498	92%	702	3003	7%	146
7	926	97%	1633	1610	106%	220	2463	-12%	121
8	795	69%	2943	1956	151%	689	3708	32%	298
9	1421	202%	3062	3732	379%	877	7517	168%	1350
10	1123	139%	616	2670	242%	362	5624	101%	206

Table D-6: Average Regional Traffic Densities Divided into Population Density Zones—U.S. Highways

U.S. Highways									
	Rural Zone			Suburban Zone			Urban Zone		
Region	Traffic Density (vehicles/hr)	Departure from Historic Value (470 vehicles/hr)	Length (km)	Traffic Density (vehicles/hr)	Departure from Historic Value (780 vehicles/hr)	Length (km)	Traffic Density (vehicles/hr)	Departure from Historic Value (2800 vehicles/hr)	Length (km)
1	288	-39%	467	377	-52%	451	422	-85%	66
2	371	-21%	953	647	-17%	1678	1278	-54%	774
3	894	90%	372	1148	47%	582	1656	-41%	224
4	313	-34%	2888	607	-22%	2650	1077	-62%	230
5	335	-29%	7905	606	-22%	4690	1104	-61%	1307
6	222	-53%	8605	391	-50%	1994	653	-77%	225
7	212	-55%	8454	298	-62%	2087	632	-77%	439
8	283	-40%	8771	551	-29%	1926	1072	-62%	545
9	343	-27%	3697	1449	86%	830	5180	85%	565
10	322	-31%	1883	482	-38%	763	718	-74%	140

TableD-7: National Average Traffic Densities Divided into Population Density Zones—Interstate Highways

Interstate Highways								
Rural Zone			Suburban Zone			Urban Zone		
Traffic Density (vehicles/hr)	Departure from Historic Value (470 vehicles/hr)	Length (km)	Traffic Density (vehicles/hr)	Departure from Historic Value (780 vehicles/hr)	Length (km)	Traffic Density (vehicles/hr)	Departure from Historic Value (2800 vehicles/hr)	Length (km)
1119	*138%*	16856	2463	*26%*	9028	5385	*93%*	4584

Table D-8: National Average Traffic Densities Divided into Population Density Zones—U.S. Highways

U.S. Highways								
Rural Zone			Suburban Zone			Urban Zone		
Traffic Density (vehicles/hr)	Departure from Historic Value (470 vehicles/hr)	Length (km)	Traffic Density (vehicles/hr)	Departure from Historic Value (780 vehicles/hr)	Length (km)	Traffic Density (vehicles/hr)	Departure from Historic Value (2800 vehicles/hr)	Length (km)
283	*-40%*	43993	590	*-24%*	28400	1575	*-44%*	4515

Results

This study reveals the importance of distinguishing between road types, which is captured in Figure D-2. The figure displays the departure of each traffic density in Tables D-7 and D-8 from the historical values found in Table D-1 (NRC, 1977). While traffic density on U.S. highways shows a decrease from the historically used values, interstate highways show a dramatic increase over those values.

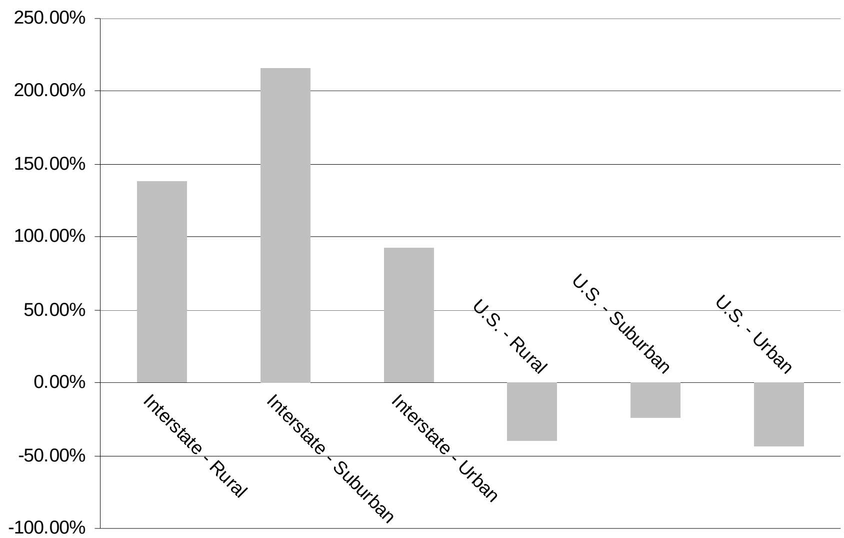

Figure D-2: Departure of National Average Traffic Densities from Historical Values

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