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RadCat 3.0 User Guide

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ABSTRACT

This document provides a detailed discussion and a guide for the use of the RadCat 3.0 Graphical User Interface input file generator for the RADTRAN code. RadCat 3.0 integrates the newest analysis capabilities of RADTRAN 6.0 which includes an economic model, updated loss-of-lead shielding model, and unit conversion. As of this writing, the RADTRAN version in use is RADTRAN 6.0.

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1. WELCOME TO RADTRAN/RADCAT

RADTRAN is an internationally accepted 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 statement on transportation of radioactive materials. RADTRAN and its associated software have undergone a number of improvements and advances consistent with improvements in both available data and computer technology.

The version of RADTRAN currently bundled with RadCat is RADTRAN 6.0.

2. DOWNLOADING AND CHECKING FOR THE LATEST VERSION

The RADTRAN/RadCat 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 your 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 click on [Launch the application to](#) download RadCat. 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. When you close RadCat3, a Java-type ("coffee-cup") icon labeled "RadCat3" will appear on the desktop.
- If you wish to put the Java Runtime Environment icon on your desktop, go to C:\Program Files\Java\jre1.6.0_07\bin, find the coffee cup javacpl.exe icon, and copy the icon to your desktop. To gain access from the Java Control Panel, click on "View" in the Temporary Internet Files section of the General tab.
- 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_02\bin, and click on the coffee cup javacpl.exe icon. The Java Control Panel dialog box will open. Click on “View” in the Temporary Internet Files section of the General tab. and the Java Cache Viewer will open and show your cached RadCats.

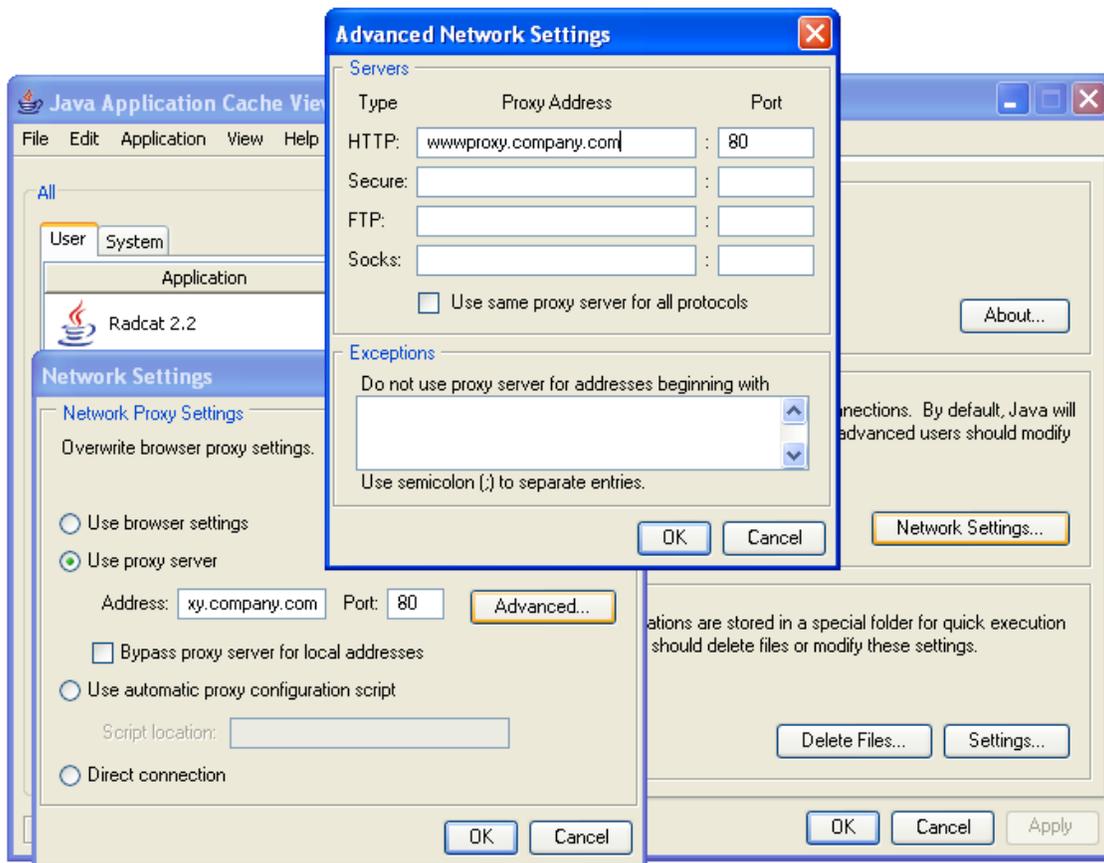


Figure 1: Proxy and Port Settings

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 the Java Control Panel (javacpl.exe), which will automatically update your version of RadCat. Major changes or additions to RadCat will be announced on the web site <https://radtran.sandia.gov>

3. RUNNING RADTRAN WITH RADCAT

RadCat will only **open** “*.rml” files. If you are using a “*.in5” or “.input” 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 can be seen in Figure 2. The directory will appear and you may 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 RADTRAN 5 FILES

RadCat has the ability to import old RADTRAN 5 input files and convert them to be run by RADTRAN version 6.0 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,” “*.dat,”** or **“.input”** file for RadCat to import and convert it properly.

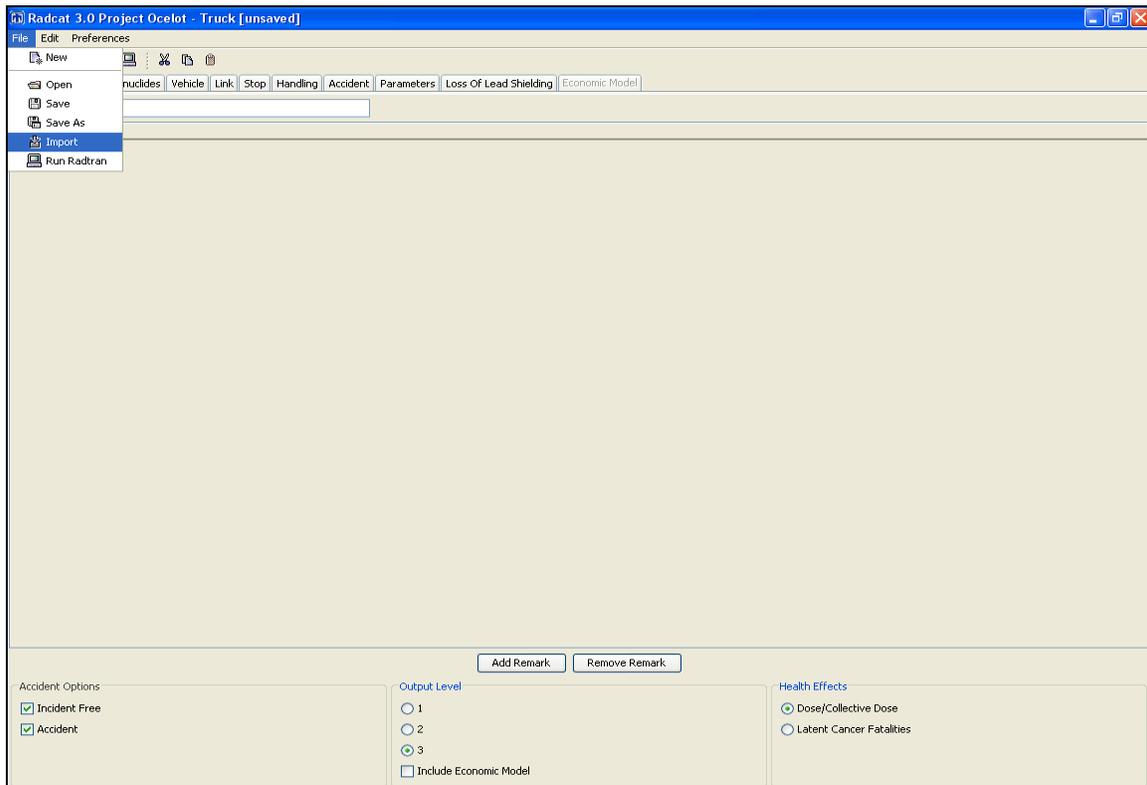


Figure 2: File Pull-down Menu

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. 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.INPUT*” file. A “*.INPUT” file can be imported into RadCat but cannot be opened in RadCat. The user can also go to the RadCat file folder and run the RADTRAN executable. The user must go to C:\Documents and Settings*username*\radcat to find the RADTRAN executable and input and output files. The user’s “*.INPUT” file must be copied and saved in RADTRAN.INPUT. Double click on the RADTRAN executable (rt6.exe) to run RADTRAN. To view the output, click on RADTRAN.OUTPUT. The output file RADTRAN.OUTPUT is overwritten every time RADTRAN is run, so it is important to save output files using another file name.

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 can be seen 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 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 change or otherwise affect any of the information in the first open file.

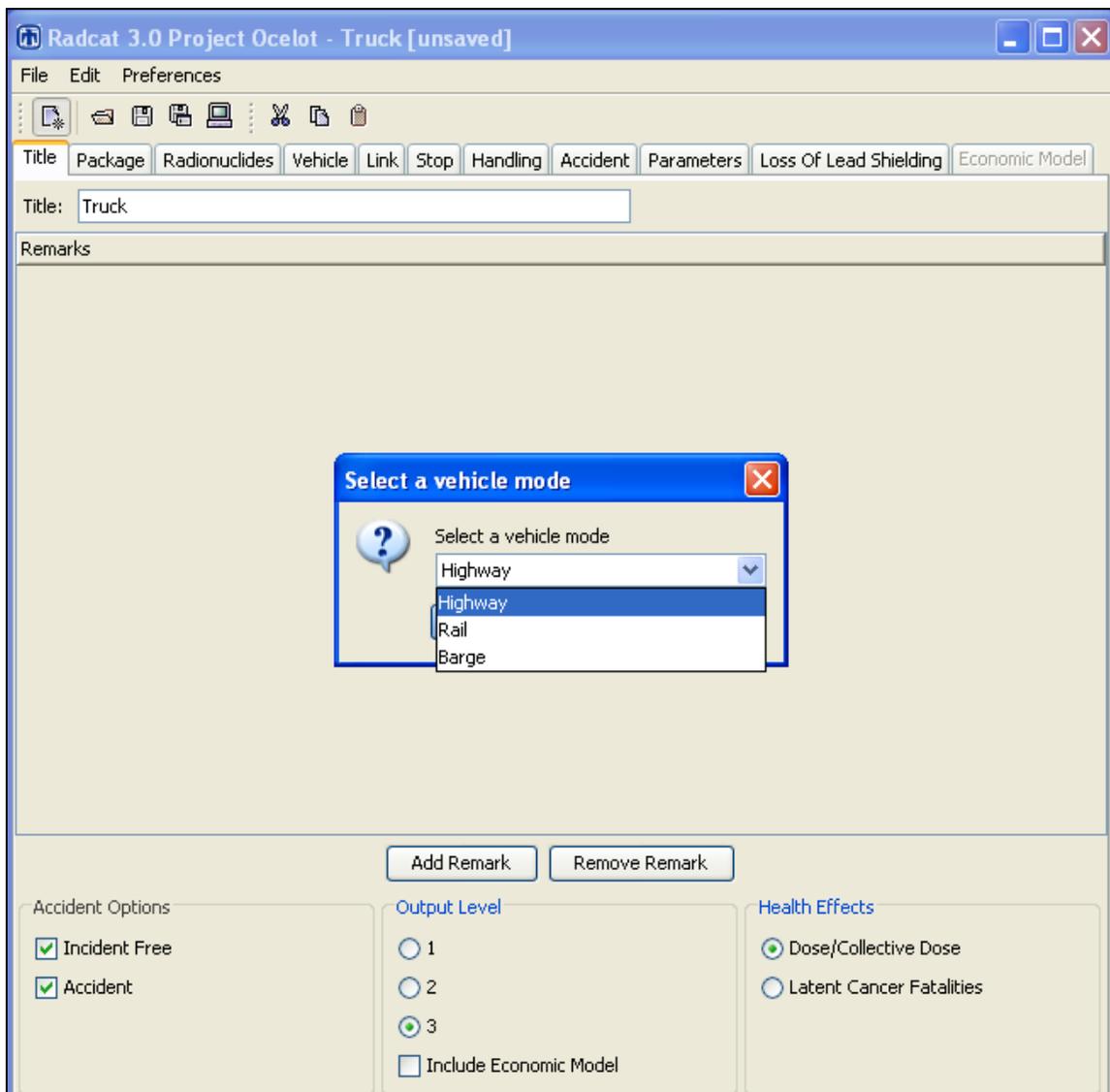


Figure 3: Mode Selection

Entering Data

Whenever an entry is made on a RadCat tab, you must hit ENTER (depress the ENTER key). Numbers can be entered into RadCat either in scientific notation (e.g. 3.0E-4) or as numbers (e.g. 0.00030). RadCat defaults to scientific notation (e.g. 3.00E-04) no matter how the number is entered.

Title

There is no default title in the **Title** box. Type a name for your file in the **Title** box and hit “ENTER” to give your file a title.. Your file must have a title. The **Title** box can be seen 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 be added for each line. Click on **Add Remark** to append additional remarks. **Remarks** can be seen in Figure 4.

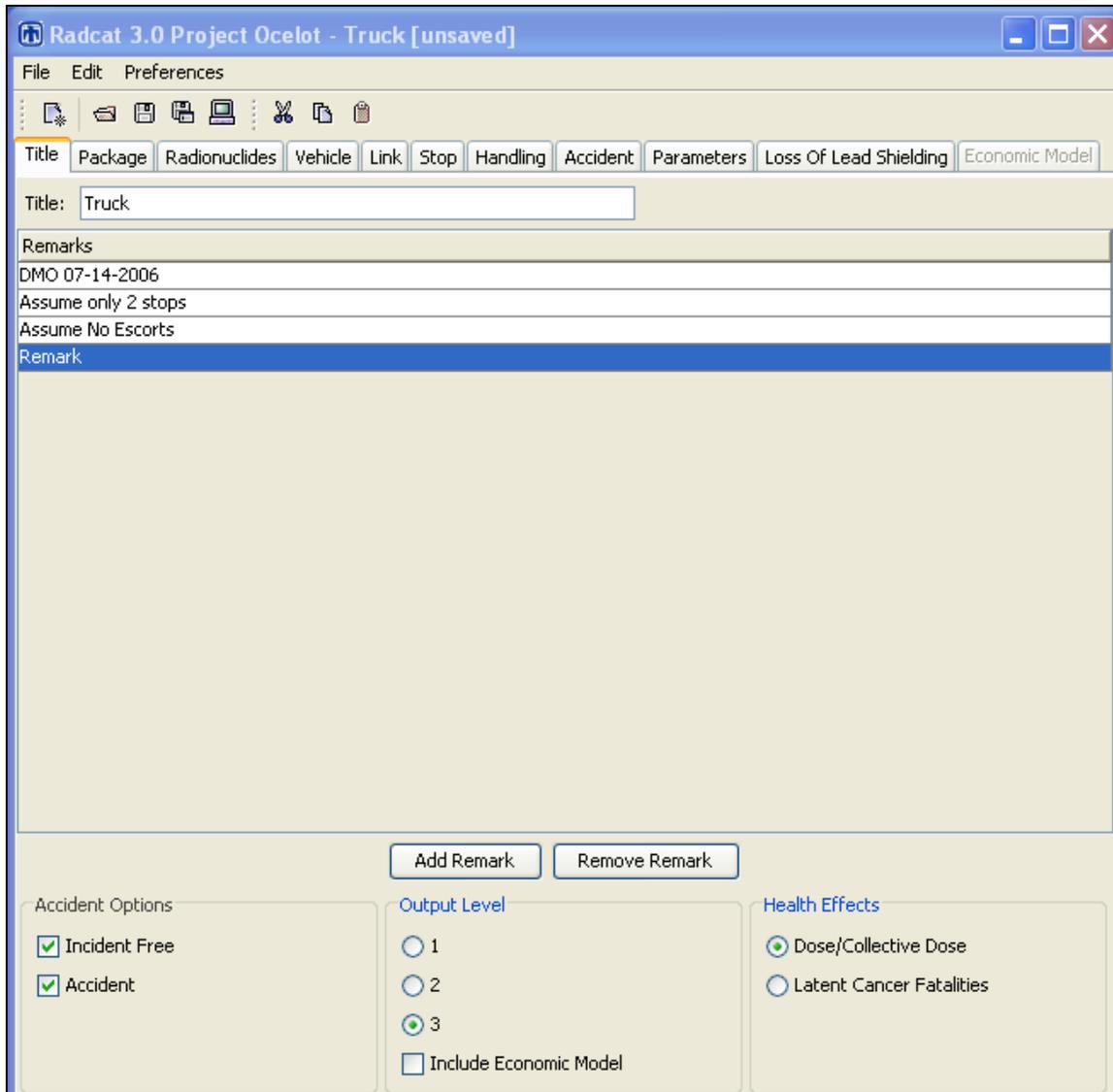


Figure 4: Title Tab

Accident Options

Checking the **Incident Free** box will result in analysis of routine, incident-free transportation only. 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. These options can be seen in Figure 4.

Output Level

Three 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. Full Output. Output for #2 plus consequence tables and sensitivity analysis. The output file is approximately 33 pages long.

This option can be seen in Figure 4. If you are importing a RADTRAN 5.6, RadCat 2.3 or older file which used the previous 4-level output structure, your output level will automatically be adjusted to match the new corresponding 3-level output structure.

A checkbox for the **Economic Model** is included on the Title Tab. When unchecked, the Economic Model Tab remains grayed out, and results from the Economic Model will not be included in the RADTRAN output. However, if the box is checked, the Economic Model Tab will become functional, allowing for default value editing and inclusion in the RADTRAN output.

Health Effects

Health 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 fatalities (LCF) by multiplying the dose in rem (or person-rem) by a linear conversion factor: 5×10^{-4} for public health effects and 4×10^{-4} for occupational health effects. 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.

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.

The Interagency Steering Committee on Radiation Standards conversion factor is 6.0E-04 LCF/rem (DOE 2002a, ISCORS 2002) 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

Preferences (Unit Conversion)

RadCat 3.0 automatically defaults to historical units, i.e. rem and curies. However, due to increased international use and the need for unit flexibility, RadCat 3.0 will accept for input either historical (rem/curie) or international (SI, sievert/becquerel) units, and will output either, at the user's discretion..

In the **Preferences** heading on the main toolbar, the user can select **Convert Units**. This will display a dialog box that will instruct the user to select **Convert to SI Mode and Change the Existing Values** or **Convert to SI mode without changing the Existing Values**. The first option automatically converts any historical numerical value already entered in RadCat 3.0 tabs. The latter is meant to allow for changing unit headings in the event the user accidentally entered values in SI units. Once in SI mode, the user can convert back to historical units by again selecting the **Preferences, Convert Units**.

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 can be seen 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.

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 can be seen in Figure 5. RadCat 3.0 includes some spreadsheet functionality: cells can be copied to a new location using the copy and paste icons at the top of the GUI, the pull-down "Edit" menu, or CTRL+C, and CTRL+V correspondingly. Field width can be adjusted. A line can be copied to another line, but cannot be copied where no line exists. Lines can be added or deleted only with the buttons at the bottom of each tab.

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, for historical reasons, this dimension is called the “critical dimension”, although it is not critical in the sense of nuclear criticality.

The long dimension of the package, the package dose rate, and the gamma and neutron fractions entered at this tab are used to calculate only the incident-free handler dose. However, these parameters must be entered because the radionuclide inventory of the package cannot be entered without them. The parameter values of the vehicle (Section 5.3) are used to calculate all other incident-free receptor doses.

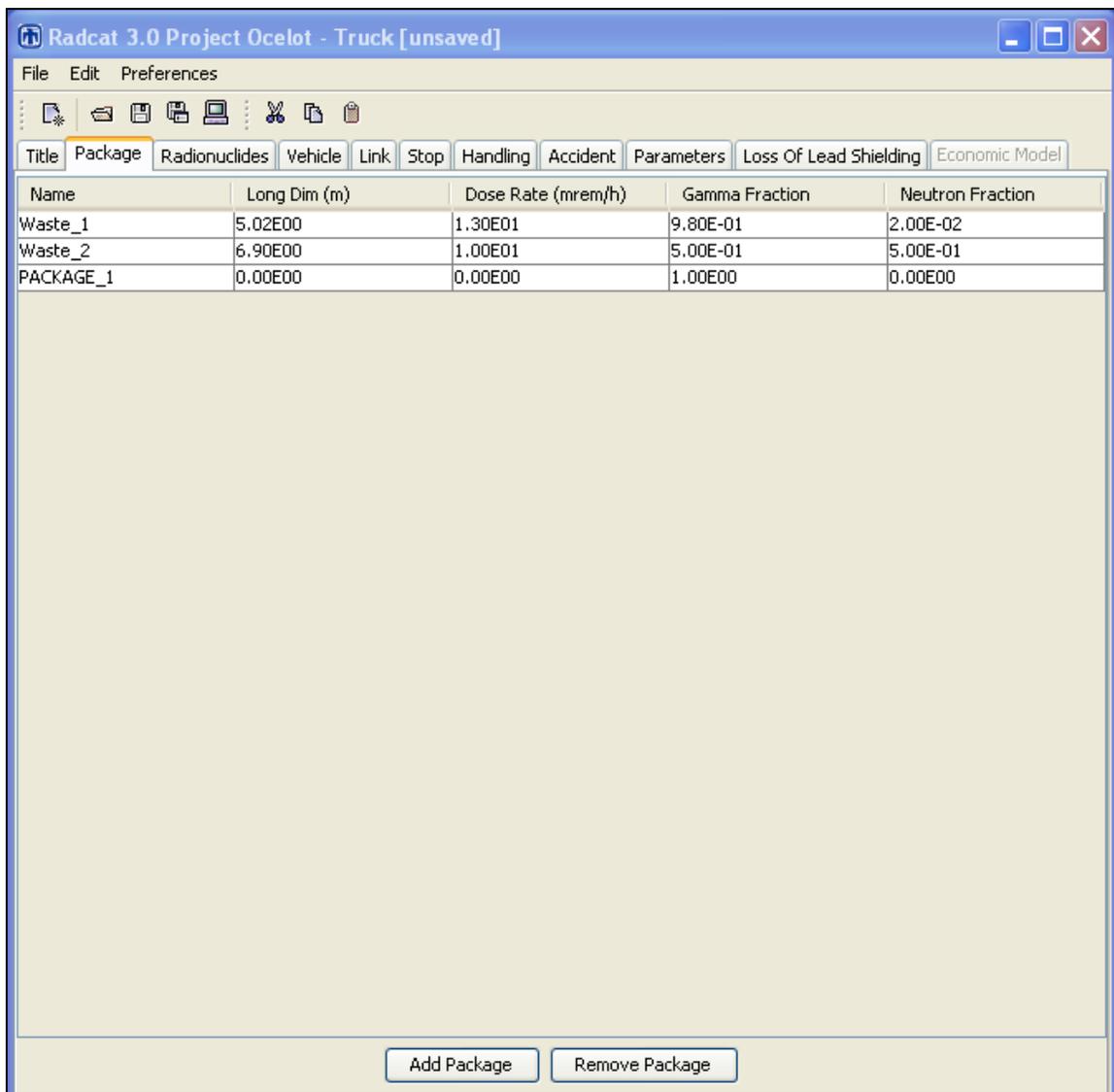


Figure 5: Package Tab

Dose Rate

Enter the external dose rate at one meter from the package surface, in units of mrem/hr. External dose rate can often be obtained by measurement, or can be estimated by calculating package shielding. 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 14 mrem/hr as the external dose rate at one meter, recognizing that either value is conservative. This can be seen in Figure 5.

The external dose rate is treated as a virtual point source at the center of the package, unless the distance between the receptor and the package is the same or less than the critical dimension. In that case the external dose rate is treated as a line source.

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 adjust the package length and dose rate internally 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 can be seen 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 can be seen in Figure 6.

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

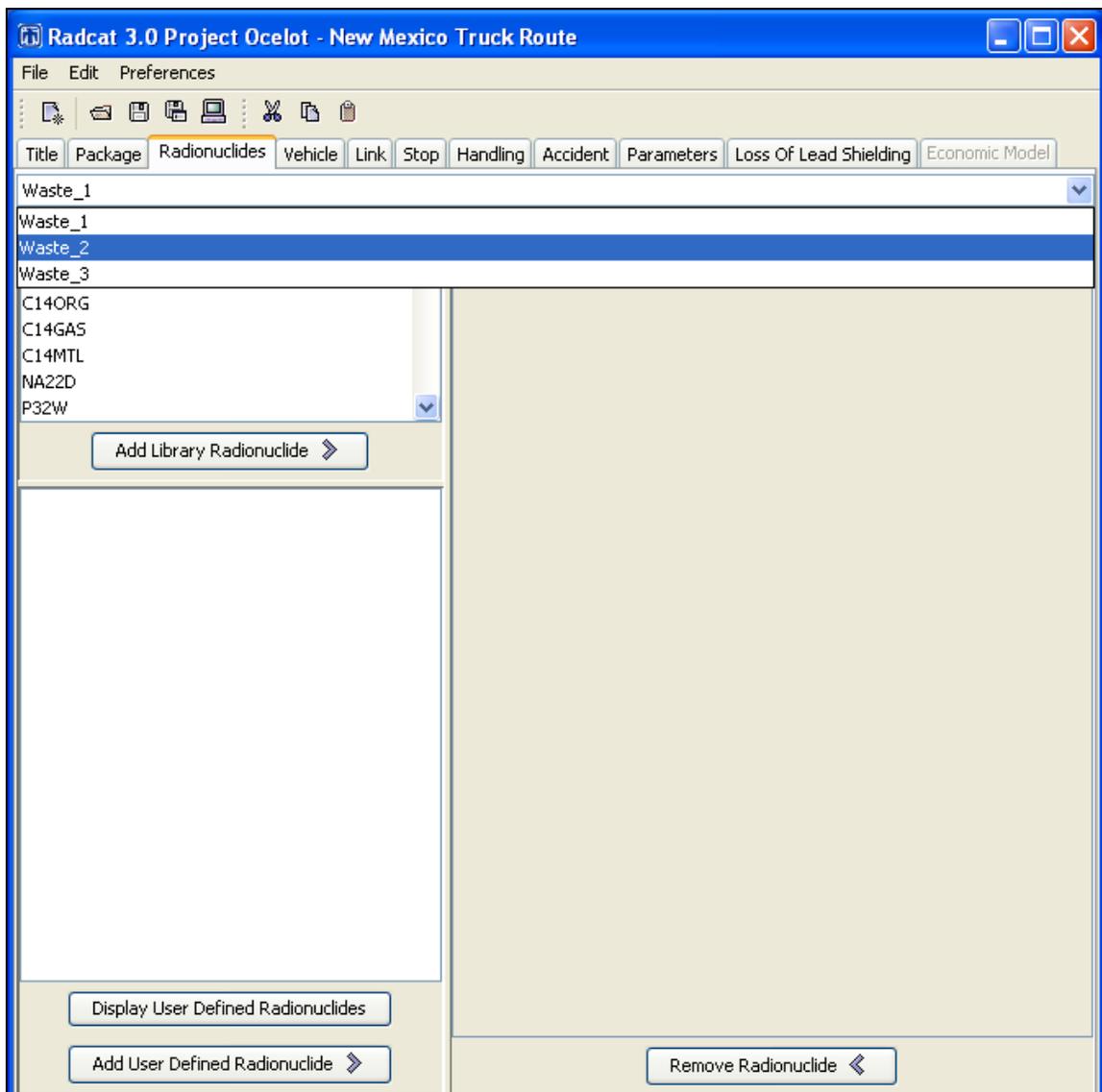


Figure 6: Radionuclides Tab with Package pull-down menu

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, as in Figure 7. 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 tab; they cannot be entered on any other tab. This can be seen in Figure 7.

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

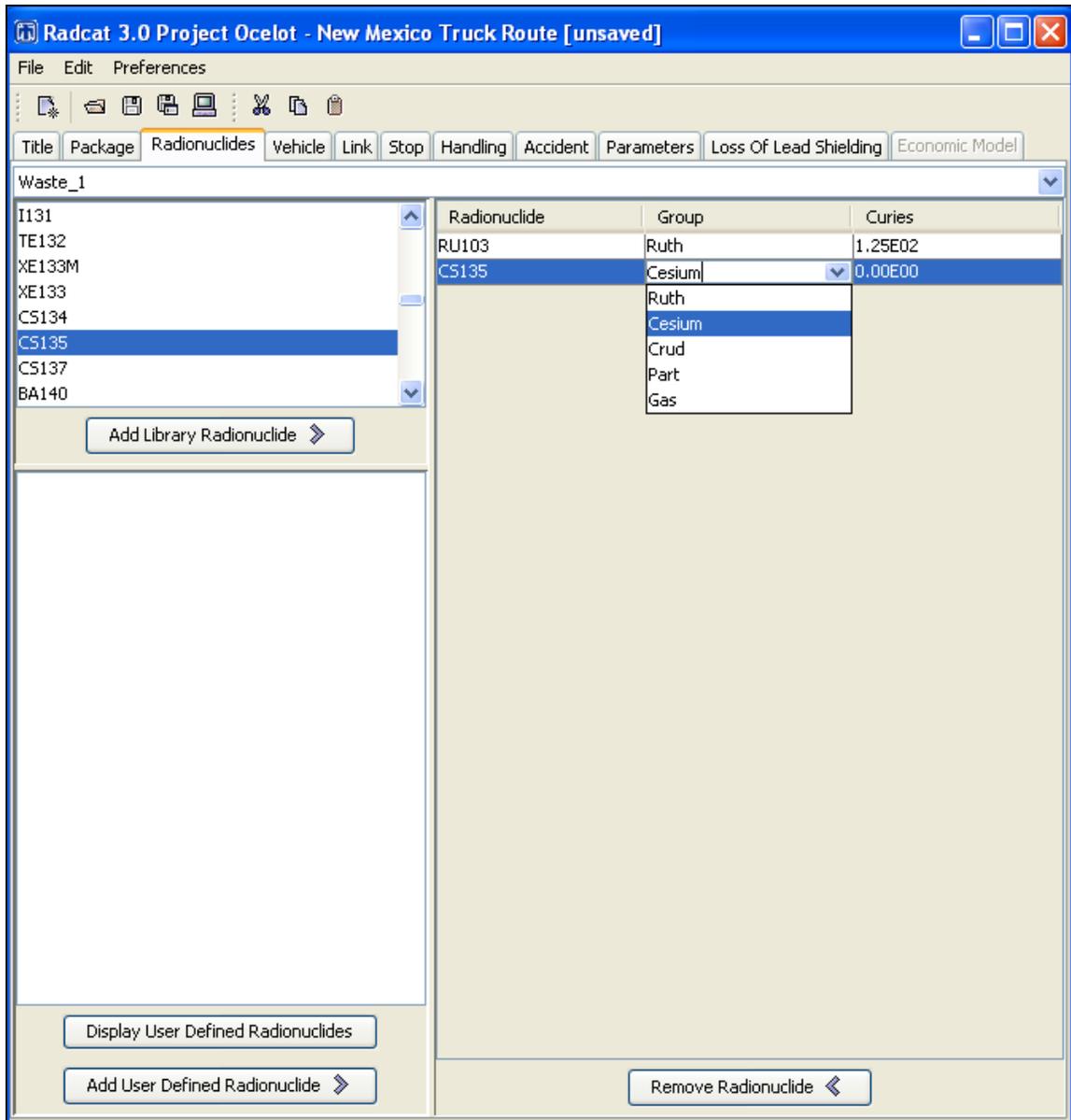


Figure 7: Radionuclides Tab with Physical / Chemical Group pull-down menu

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 **Display User-Defined Radionuclides** bar. The **User Defined Radionuclides** screen will open. In this tab, 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_1The name can be up to eight characters long and may not contain any spaces. This can be seen in Figure 8.

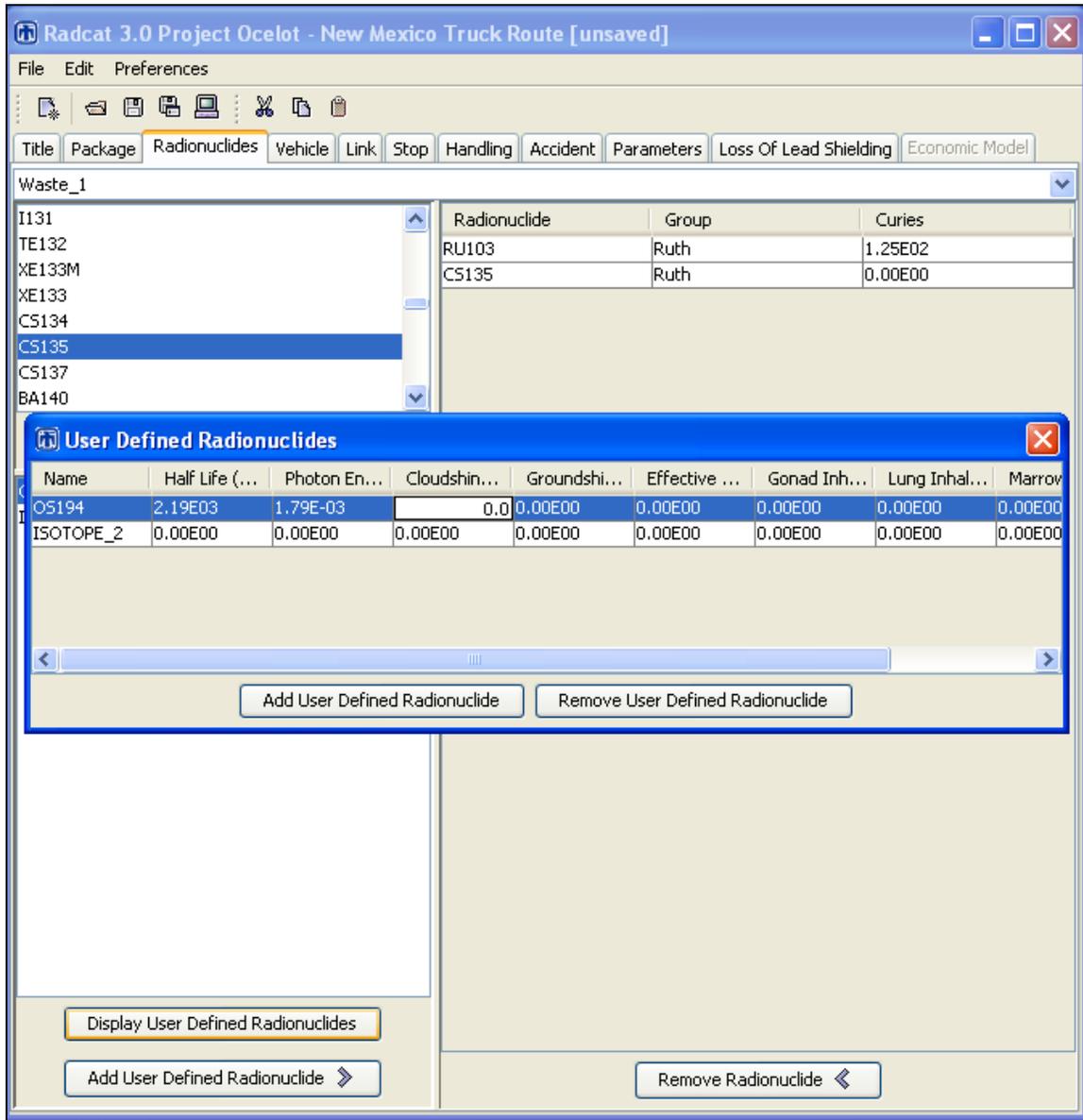


Figure 8: Radionuclides Tab with User Defined Radionuclides window

Half-lives may be found in the Chart of the Nuclides (KAPL, 2003) or the International Commission on Radiological Protection (ICRP) Publication 38 (ICRP, 1983), and dose conversion factors may be found in the Health Physics Handbook (Shleien et al, 1996), Federal Guidance report 12(Eckerman and Ryman, 1993), ICRP Publication 72 (ICRP, 1996), 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-m³/Ci-sec,**
- **Groundshine DCF in rem-m²/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., CO60CRUD, CO-60P for “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 package parameters are not used in this calculation). The analogous **Package** parameters determine doses to handlers. If there is only one package per vehicle, as for a spent fuel or UF₆ 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 can be seen 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 can be seen 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 can be seen 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.

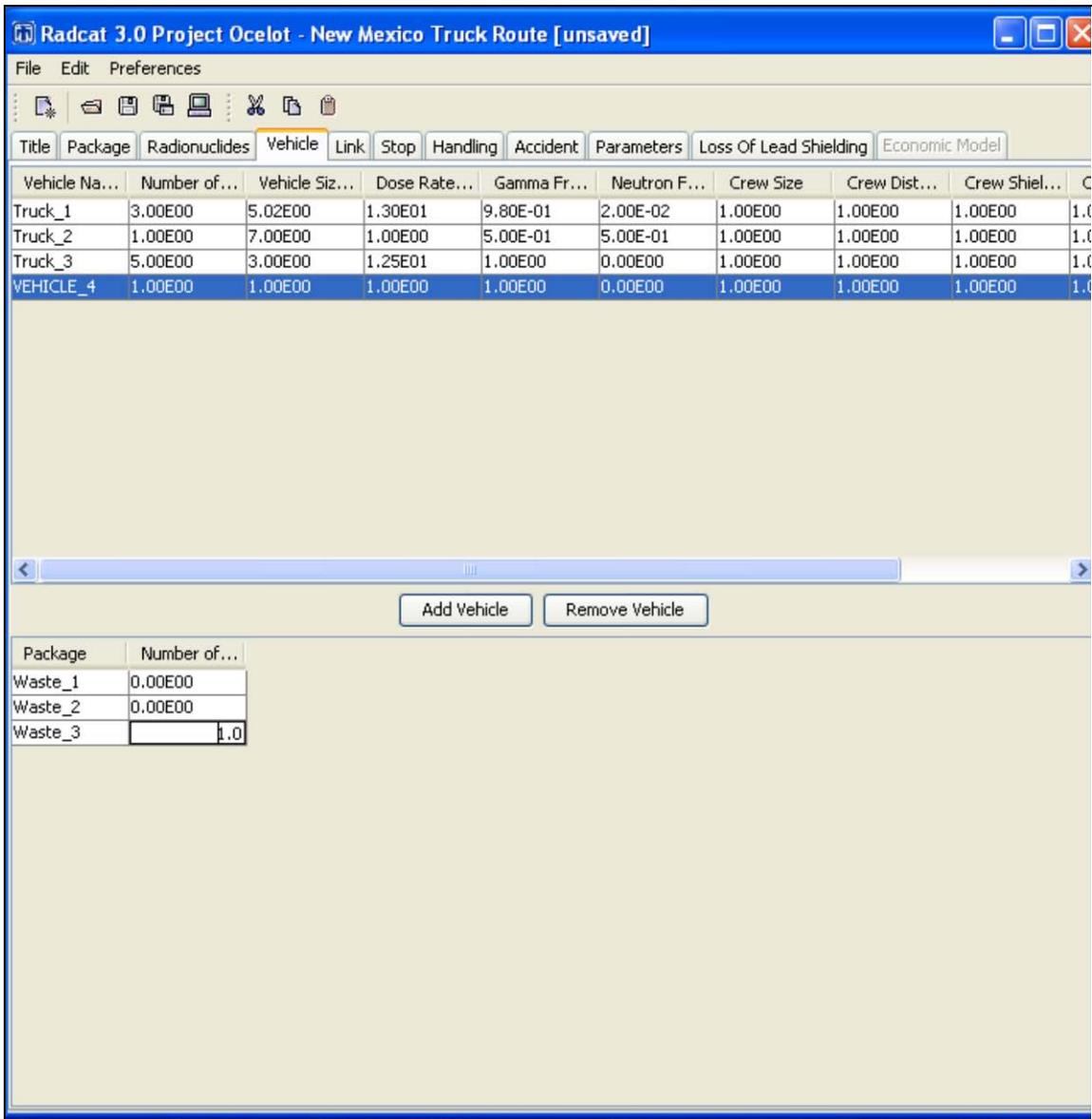


Figure 9: Vehicle Tab

Number of Shipments

Enter the number of shipments. This can be seen 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 largest 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 can be seen 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. This dose rate is independent of the package dose rate. 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, 14 mrem/hr, as the external dose rate, recognizing that this value is conservative. This can be seen 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 can be seen in Figure 9.

Crew Size

Enter the number of crew members that will be traveling on the vehicle. This can be seen in Figure 10.

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 can be seen in Figure 10. The crew on a train in transit is at least 150 m (several railcar lengths) from the radioactive cargo, and is shielded by intervening rail cars. “Crew” dose for rail shipments is the sum of the dose to the crew on the moving train and the dose sustained by rail yard workers at stops along the route. The dose to the train crew is usually insignificant compared to the dose to railyard workers. Railyard worker dose is calculated from parameters listed on the **Parameters** tab, which is discussed in Section 5.8.

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

Crew Shielding Factor

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 can be seen in Figure 10

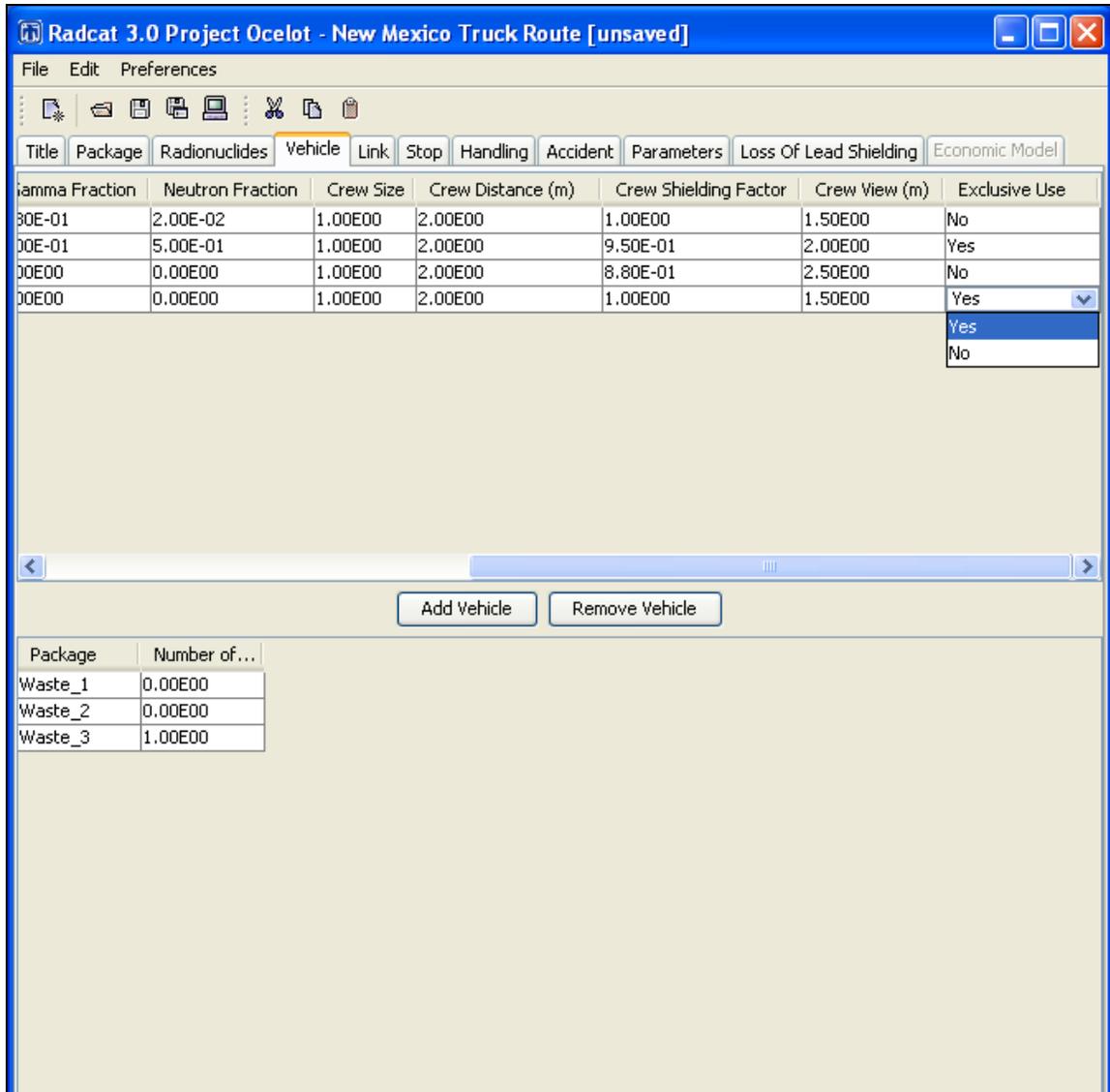


Figure 10: Vehicle Tab Continued

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 can be seen in Figure 10 in the **Crew View (m)** column.

Exclusive Use

A pull-down menu allows the user to indicate whether the vehicle is exclusive use or not. This can be seen 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 can be seen in Figure 11.

The parameter values on this tab can be provided by a routing code or a geographic information system (GIS). The routing code WebTRAGIS is available to U.S. citizens at: <https://tragis.ornl.gov/>. Data from WebTRAGIS can be imported to the LINKS tab electronically.

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.

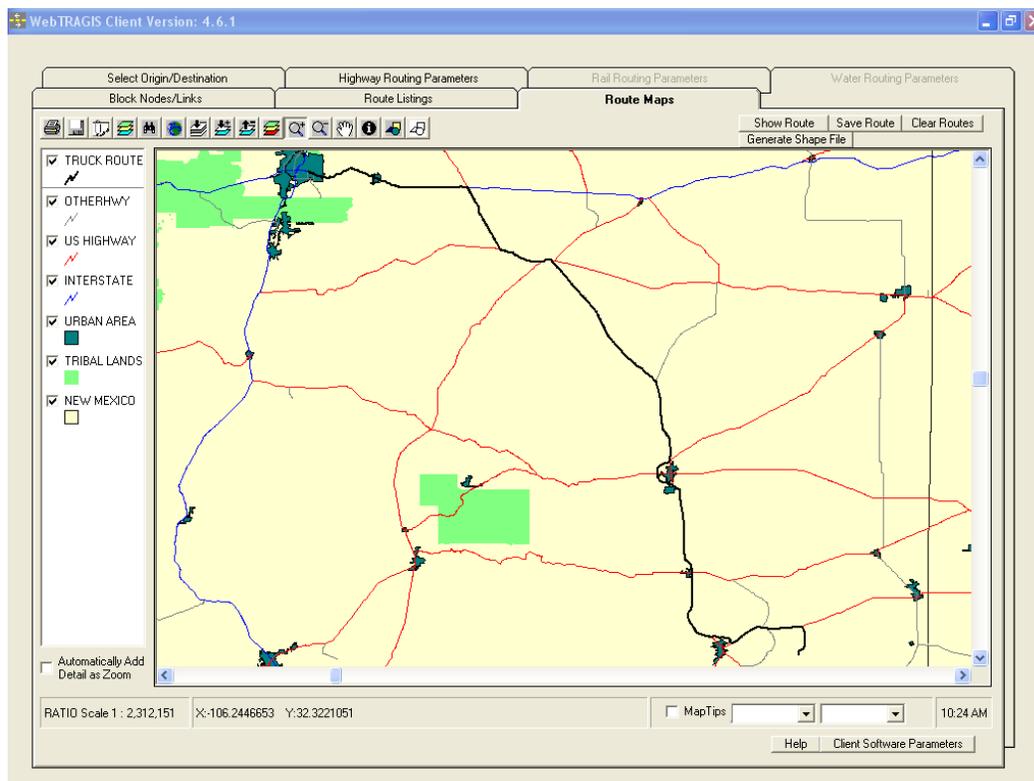


Figure 11: New Mexico Truck Route.

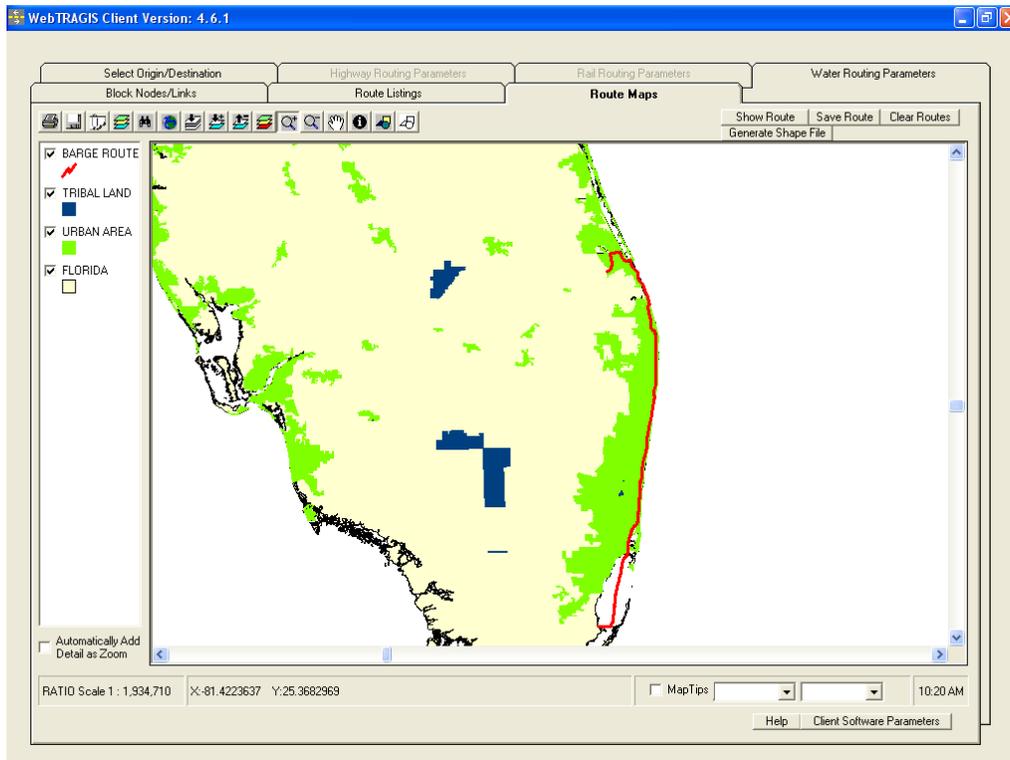


Figure 12: Florida Barge Route

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 can be seen in Figure 13 in the **Population Density (persons/km²)** 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 tab. This can be seen 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 5.4.1 of this Manual for Importing WebTRAGIS Data Listings). This can be seen in Figure 13 in the **Length (km)** column.

Useful conversion factors are:

1 km = 0.6217 mile

1 mile = 1.608 km.

$1 \text{ person/mi}^2 = (1 \text{ person/mi}^2) * (1 \text{ mi}/1.61 \text{ km})^2 = 1 \text{ person}/2.59 \text{ km}^2 = 0.387 \text{ persons/km}^2$

Speed

Enter the average speed of each vehicle on each link, in km/hr. This can be seen in Figure 13 in the **Speed (km/h)** column. You may use any speeds you choose. State highway speed limits as of 2005, in km/hour for various types of roads, are shown in Table 1. Suburban interstate highway speeds are usually the same as rural speeds.

Rail speed depends on the track class and type of cargo. Trains carrying hazardous materials are often limited to 50 mph (80 km/hr) in rural areas and 40 mph (64 km/hr) in urban areas. The U.S. Bureau of Transportation Statistics (www.bts.gov) is a good source of transportation information.

Table 1. State speed limits (from the Insurance Institute for Highway Safety).

State	Speed Limit (kilometers/hour)			
	Interstate		Other limited-access	Other roads
	Rural	Urban		
AL	113	105	105	105
AZ	121	88	88	88
AR	113, trucks 105	88	97	88
CA	113, trucks 88	105	113	105
CO	121	105	105	105
CT	105	88	105	88
DE	105	88	105	88
DC	NA	88	NA	40
FL	113	105	113	105
GA	113	105	105	105
ID	121, trucks 105	121	105	105
IL	105, trucks 88	88	105	88
IN	105, trucks 97	88	88	88
IA	105	88	105	88
KS	113	113	113	105
KY	105	105	105	88
LA	113	113	113	105
ME	105	105	105	97
MD	105	105	105	88
MA	105	105	105	88
MI	113, trucks 88	105	113	88
MN	113	105	105	88
MS	113	113	113	105
MO	113	97	113	105
MT	121, trucks 105	105	Day 113, night 105	Day 113, night 105
NE	121	105	105	97
NV	121	105	113	113
NH	105	105	88	88
NJ	105	88	105	88
NM	121	121	105	88
NY	105	105	105	88
NC	113	113	113	88
ND	121	121	113	105
OH	105, trucks 88	105	88	88
OK	121	113	113	113
OR	105, trucks 88	88	88	88

Table 1. State speed limits -- continued

State	Speed Limit (kilometers/hour)			
	Interstate		Other limited access	Other roads
	Rural	Urban		
PA	105	88	105	88
RI	105	88	88	88
SC	113	113	97	88
SD	121	121	105	105
TN	113	113	113	105
TX	121, Night/Truck 105	Day 113, Night 105	Day 121, Night/Truck 105	Day 97, Night 88
UT	121	105	121	105
VT	105	88	80	80
VA	105	105	105	88
WA	113. trucks 97	97	97	97
WV	113	88	105	88
WI	105	105	105	88
WY	121	97	105	105

Population Density

Enter the population density in persons/km², as obtained from WebTRAGIS (See Section 5.4.1 of this Manual for Importing WebTRAGIS Data Listings), the City/County data book, or some other GIS system or source. This can be seen 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/mi² (0 to 55 persons/km²)
- suburban: 139 to 3326 persons/mi² (55 to 1300 persons/km²)
- urban: more than 3326 persons/mi² (1300 persons/km²)

The historic RADTRAN classifications are:

- rural: 0 to 66 persons/km²
- suburban: 67 to 1670 persons/km²)
- urban: more than 1670 persons/km²)

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*.

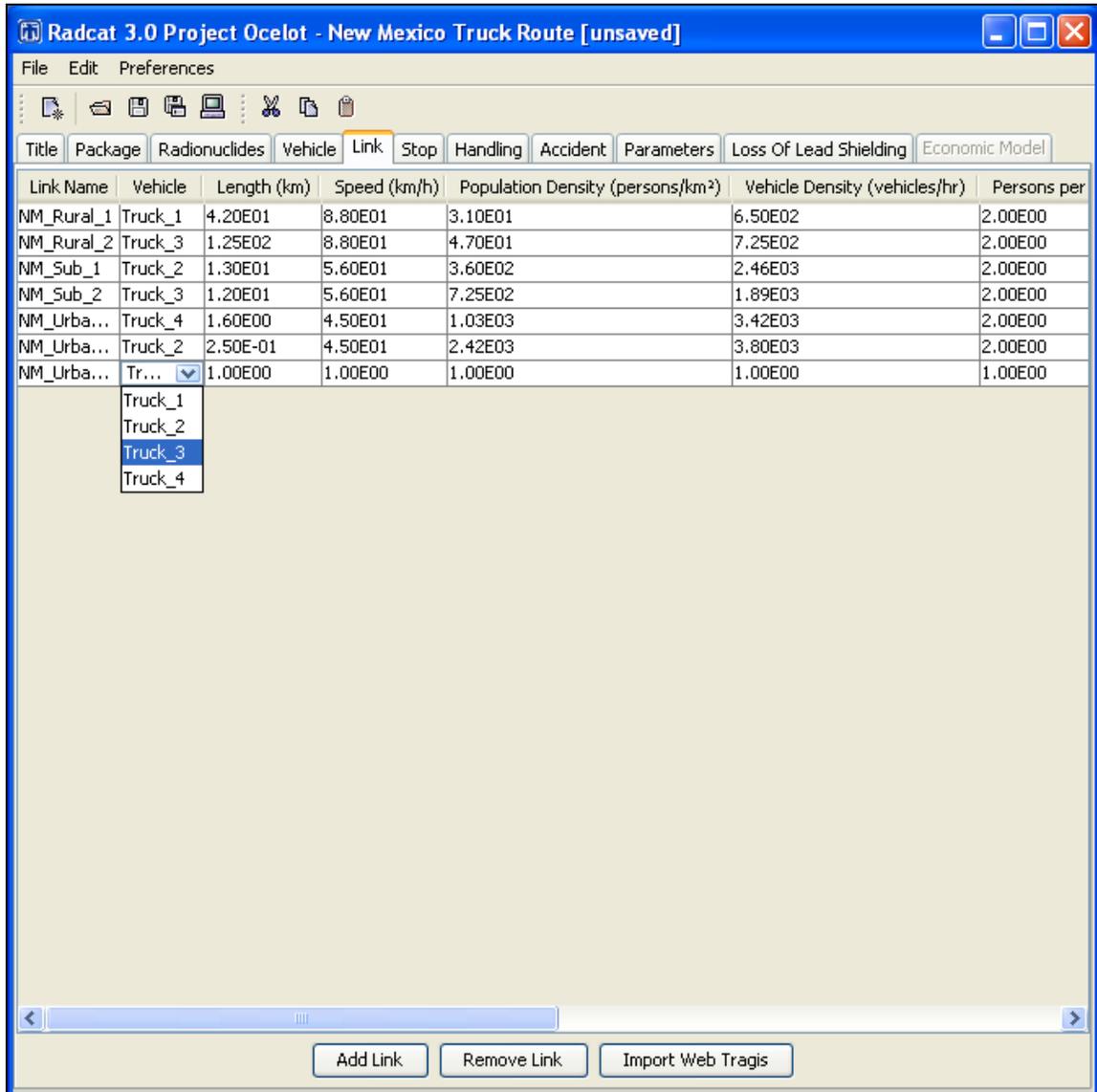


Figure 13: Link Tab

Vehicle Density

Enter the vehicle density – the vehicles that share the route with the radioactive cargo – in vehicles per hour. This can be seen in Figure 13 in the **Vehicle Density (vehicles/hr)** column National average vehicle densities from 2003 to 2005 are:

Interstate Highways

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

U.S. Highways

- * rural: 287 vehicles/hr
- * suburban: 618 vehicles/hr
- * urban: 1711 vehicles/hr

The study from which these numbers are extracted is provided in Appendix D, which 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.

Average rail densities, except for trains carrying passengers, are

Rail

- 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 can be seen 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 can be seen in Figure 14 in the **Accident Rate (accidents/veh-km)** column. Accident rates are usually reported by state and type of road or rail. A useful reference for accident rates is the Bureau of Transportation Statistics web site: <http://www.bts.gov>. Table 2 shows the data from that site.

Fatalities per Accident

Enter the number of fatalities per accident. This can be seen in Figure 14 and Table 2.. Fatality rates are usually reported by state and type of road or rail and can also be found at www.bts.gov.. Fatalities per accident in the U.S. are approximately 0.00353

Table 2. Highway accident and fatality rates ^a

State	accidents/vehicle mile	accidents/vehicle km
Alabama	5.54E-06	3.44E-06
Alaska	5.73E-06	3.57E-06
Arizona	5.68E-06	3.53E-06
Arkansas	6.30E-06	3.92E-06
California	3.55E-06	2.21E-06
Colorado	4.11E-06	2.55E-06
Connecticut	2.61E-06	1.62E-06
Delaware	4.08E-06	2.54E-06
District of Columbia	3.26E-06	2.02E-06
Florida	4.68E-06	2.91E-06
Georgia	4.11E-06	2.56E-06
Hawaii	4.14E-06	2.57E-06
Idaho	5.00E-06	3.11E-06
Illinois	3.52E-06	2.19E-06
Indiana	3.69E-06	2.29E-06
Iowa	3.50E-06	2.18E-06
Kansas	4.48E-06	2.78E-06
Kentucky	5.77E-06	3.59E-06
Louisiana	5.74E-06	3.57E-06
Maine	3.68E-06	2.29E-06
Maryland	3.30E-06	2.05E-06
Massachusetts	2.46E-06	1.53E-06
Michigan	3.18E-06	1.98E-06
Minnesota	2.84E-06	1.77E-06
Mississippi	6.47E-06	4.02E-06
Missouri	4.64E-06	2.88E-06
Montana	5.79E-06	3.60E-06
Nebraska	3.75E-06	2.33E-06
Nevada	5.78E-06	3.60E-06
New Hampshire	3.67E-06	2.28E-06
New Jersey	2.84E-06	1.77E-06
New Mexico	6.17E-06	3.83E-06
New York	3.07E-06	1.91E-06
North Carolina	4.60E-06	2.86E-06

Table 2. Highway accident and fatality rates -- continued

State	accidents/vehicle mile	accidents/vehicle km
North Dakota	3.73E-06	2.32E-06
Ohio	3.26E-06	2.03E-06
Oklahoma	4.72E-06	2.94E-06
Oregon	3.63E-06	2.26E-06
Pennsylvania	3.91E-06	2.43E-06
Rhode Island	2.78E-06	1.73E-06
South Carolina	5.98E-06	3.72E-06
South Dakota	6.35E-06	3.95E-06
Tennessee	5.14E-06	3.20E-06
Texas	4.39E-06	2.73E-06
Utah	3.40E-06	2.11E-06
Vermont	3.53E-06	2.20E-06
Virginia	3.32E-06	2.07E-06
Washington	2.87E-06	3.20E-06
West Virginia	5.74E-06	3.57E-06
Wisconsin	3.72E-06	2.31E-06
Wyoming	5.02E-06	3.12E-06
United States, total	4.3E-06	2.70E-06

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. For example, 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 can be seen in Figure 14 in the **Zone** column.

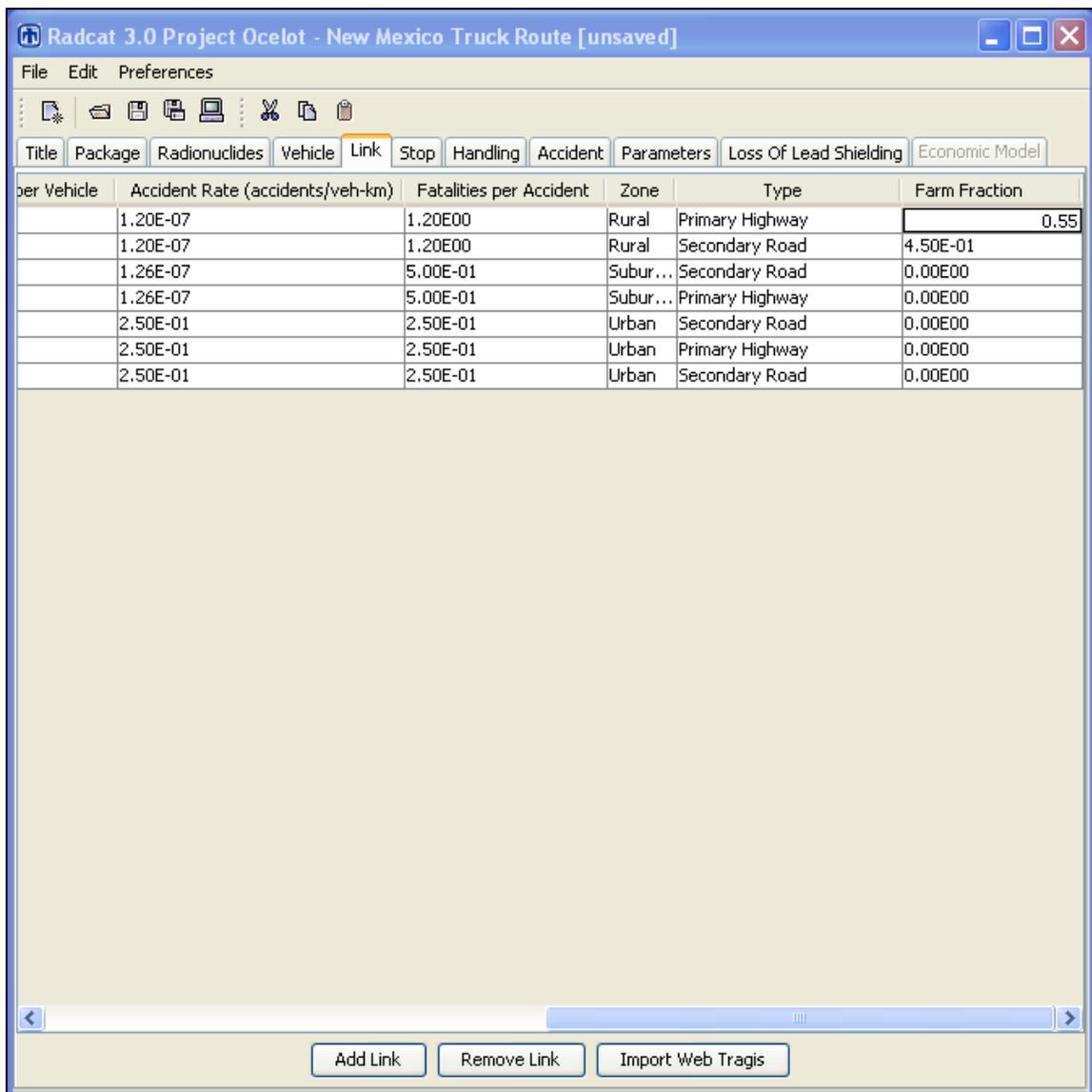


Figure 14: Link Tab Continued

Type

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

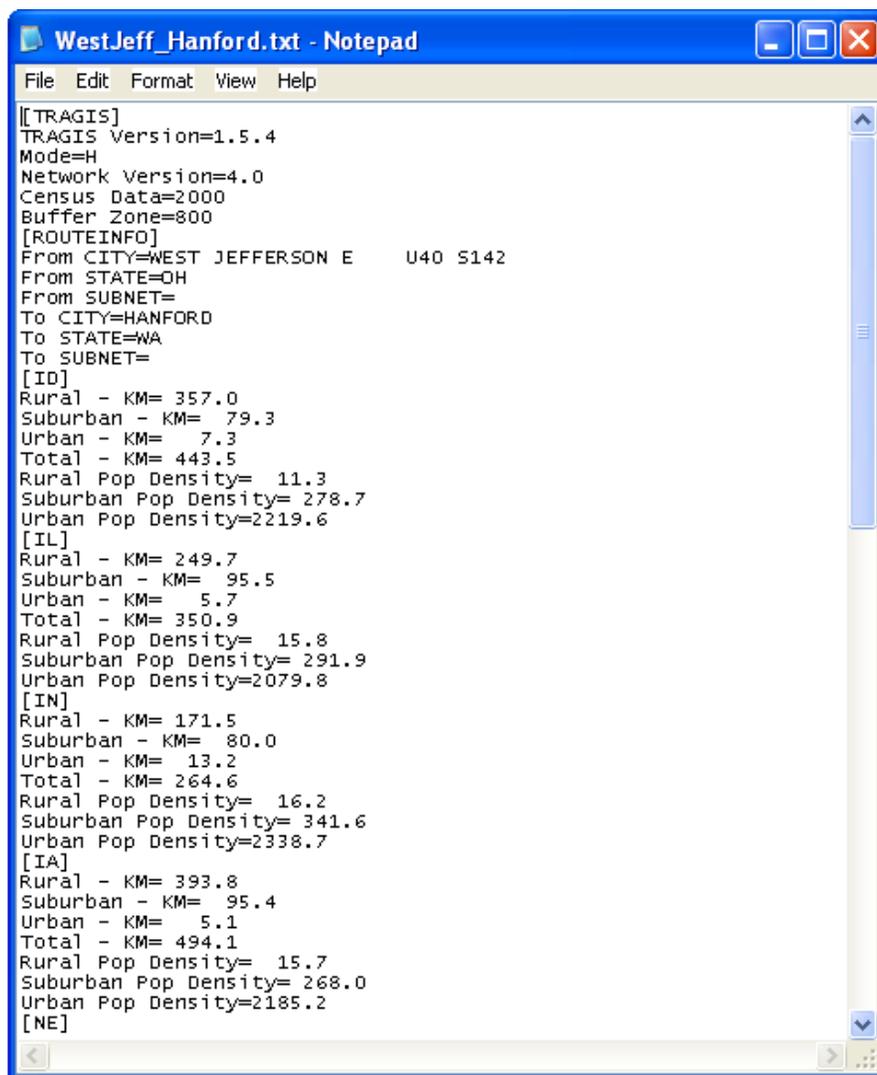
Farm Fraction

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, designate that link as rural. Farm fraction is shown in Figure 14 in the **Farm Fraction** column.

5.4.1 Importing WebTRAGIS

The current version of WebTRAGIS has a RADTRAN Data Listing feature. This feature reports population densities (persons/km²) 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

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

The screenshot shows the 'Radcat 3.0 Project Ocelot - New Mexico Truck Route' application window. The 'Link' tab is selected, displaying a table of imported data. The table has 10 columns: Link Name, Vehicle, Length (km), Speed (km/h), Population, Vehicle Density, Persons per Vehicle, Accident Rate, Fatalities, and Zone. The data is organized by state, with rows for each state (RURAL, SUBURBN, URBAN) and a 'VEHICLE_1' entry for each. The 'Zone' column indicates the link type (Rur., Sub, Urb.).

Link Name	Vehicle	Length (km)	Speed (km/h)	Population	Vehicle De...	Persons p...	Accident ...	Fatalities ...	Zo
RURAL_ID	VEHICLE_1	3.57E02	1.00E00	1.13E01	1.00E00	1.00E00	1.00E00	0.00E00	Rur.
SUBURBN_ID	VEHICLE_1	7.93E01	1.00E00	2.79E02	1.00E00	1.00E00	1.00E00	0.00E00	Sub
URBAN_ID	VEHICLE_1	7.30E00	1.00E00	2.22E03	1.00E00	1.00E00	1.00E00	0.00E00	Urb.
RURAL_IL	VEHICLE_1	2.46E02	1.00E00	1.58E01	1.00E00	1.00E00	1.00E00	0.00E00	Rur.
SUBURBN_IL	VEHICLE_1	9.17E01	1.00E00	2.98E02	1.00E00	1.00E00	1.00E00	0.00E00	Sub
URBAN_IL	VEHICLE_1	9.80E00	1.00E00	2.18E03	1.00E00	1.00E00	1.00E00	0.00E00	Urb.
RURAL_IN	VEHICLE_1	1.69E02	1.00E00	1.64E01	1.00E00	1.00E00	1.00E00	0.00E00	Rur.
SUBURBN_IN	VEHICLE_1	7.39E01	1.00E00	3.27E02	1.00E00	1.00E00	1.00E00	0.00E00	Sub
URBAN_IN	VEHICLE_1	1.50E01	1.00E00	2.47E03	1.00E00	1.00E00	1.00E00	0.00E00	Urb.
RURAL_IA	VEHICLE_1	3.78E02	1.00E00	1.64E01	1.00E00	1.00E00	1.00E00	0.00E00	Rur.
SUBURBN_IA	VEHICLE_1	1.08E02	1.00E00	2.73E02	1.00E00	1.00E00	1.00E00	0.00E00	Sub
URBAN_IA	VEHICLE_1	5.80E00	1.00E00	2.19E03	1.00E00	1.00E00	1.00E00	0.00E00	Urb.
RURAL_NE	VEHICLE_1	6.49E02	1.00E00	9.90E00	1.00E00	1.00E00	1.00E00	0.00E00	Rur.
SUBURBN_NE	VEHICLE_1	7.15E01	1.00E00	2.70E02	1.00E00	1.00E00	1.00E00	0.00E00	Sub
URBAN_NE	VEHICLE_1	8.00E00	1.00E00	2.41E03	1.00E00	1.00E00	1.00E00	0.00E00	Urb.
RURAL_OH	VEHICLE_1	7.76E01	1.00E00	2.04E01	1.00E00	1.00E00	1.00E00	0.00E00	Rur.
SUBURBN_OH	VEHICLE_1	5.87E01	1.00E00	2.82E02	1.00E00	1.00E00	1.00E00	0.00E00	Sub
URBAN_OH	VEHICLE_1	3.70E00	1.00E00	2.12E03	1.00E00	1.00E00	1.00E00	0.00E00	Urb.
RURAL_OR	VEHICLE_1	3.01E02	1.00E00	8.20E00	1.00E00	1.00E00	1.00E00	0.00E00	Rur.
SUBURBN_OR	VEHICLE_1	3.22E01	1.00E00	3.13E02	1.00E00	1.00E00	1.00E00	0.00E00	Sub
URBAN_OR	VEHICLE_1	2.30E00	1.00E00	1.98E03	1.00E00	1.00E00	1.00E00	0.00E00	Urb.
RURAL_UT	VEHICLE_1	1.87E02	1.00E00	9.70E00	1.00E00	1.00E00	1.00E00	0.00E00	Rur.
SUBURBN_UT	VEHICLE_1	5.16E01	1.00E00	2.58E02	1.00E00	1.00E00	1.00E00	0.00E00	Sub
URBAN_UT	VEHICLE_1	1.50E00	1.00E00	2.11E03	1.00E00	1.00E00	1.00E00	0.00E00	Urb.
RURAL_WA	VEHICLE_1	5.00E01	1.00E00	1.40E00	1.00E00	1.00E00	1.00E00	0.00E00	Rur.
SUBURBN_WA	VEHICLE_1	1.09E01	1.00E00	6.05E02	1.00E00	1.00E00	1.00E00	0.00E00	Sub
URBAN_WA	VEHICLE_1	6.80E00	1.00E00	2.26E03	1.00E00	1.00E00	1.00E00	0.00E00	Urb.
RURAL_WY	VEHICLE_1	6.07E02	1.00E00	4.90E00	1.00E00	1.00E00	1.00E00	0.00E00	Rur.
SUBURBN_WY	VEHICLE_1	3.39E01	1.00E00	3.99E02	1.00E00	1.00E00	1.00E00	0.00E00	Sub
URBAN_WY	VEHICLE_1	3.40E00	1.00E00	1.97E03	1.00E00	1.00E00	1.00E00	0.00E00	Urb.

Figure 17: Imported WebTRAGIS – RADTRAN Data Listing

5.5 STOPS

Select the **Stop** tab next 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 must 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 can be seen in Figure 18.

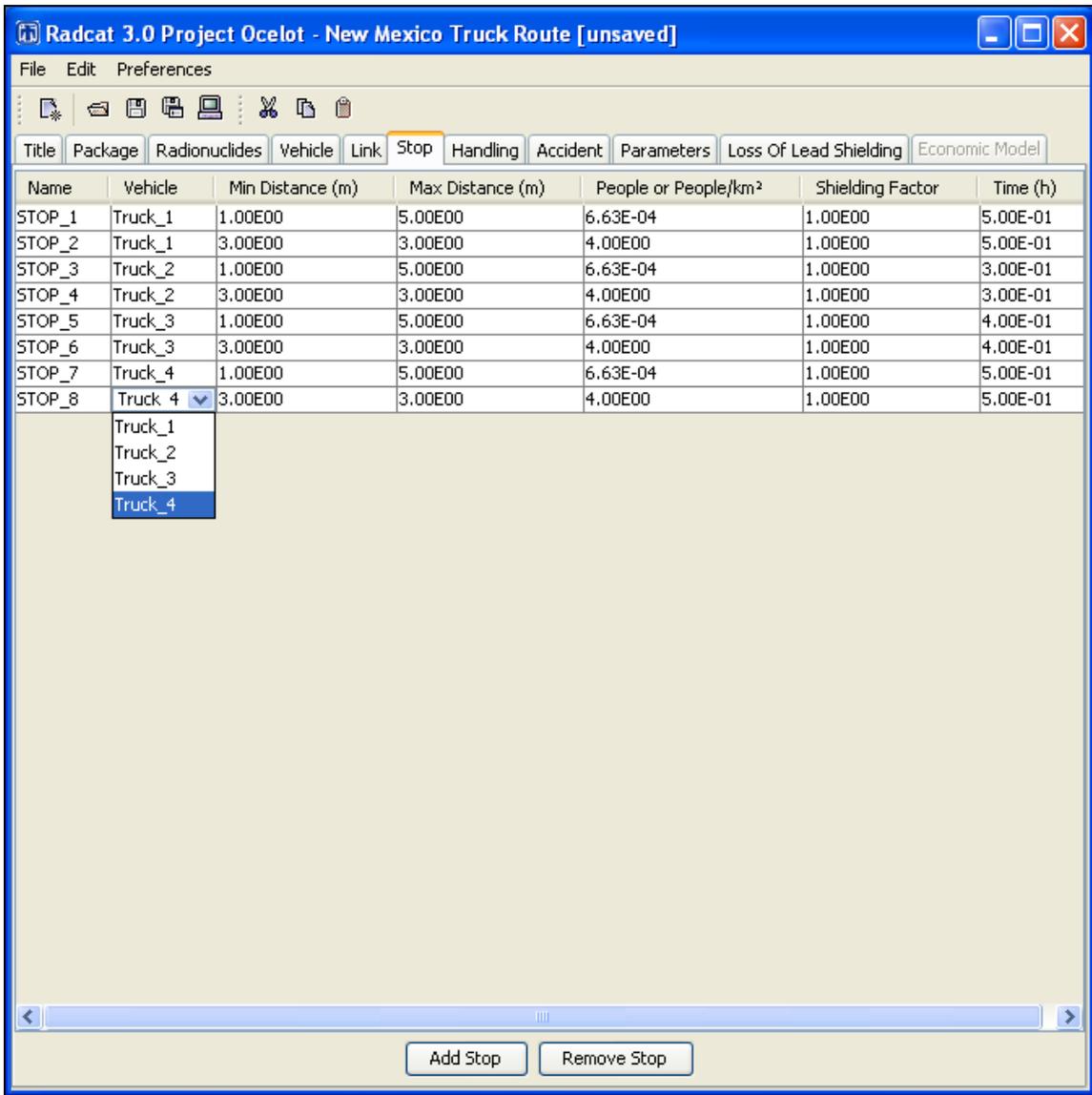


Figure 18: Stop Tab

Vehicle

Available vehicle names are on a pull-down menu in the **Vehicle** column. This can be seen 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 can be seen in Figure 18. The **Min(imum) Distance** 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 can be seen in Figure 18. The **Min(imum) Distance** and **Max(imum) Distance** define the area around the radioactive cargo in which there are receptors at that particular stop. The **Min(imum) Distance** and **Max(imum) Distance** may be the same or may be different (see **People or People/km²** below). The **Min(imum) Distance** can never be larger than the **Max(imum) Distance**.

People or People/km²

This parameter defines the number of radiation receptors at each particular stop, including crew. If the **Min(imum) Distance** 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; e.g., if there are 20 people all at 10 meters from the cargo, then enter 10 m for both **Min(imum) Distance** and **Max(imum) Distance**, and enter 20 for **People or People/km²**.

On the other hand, if the **Min(imum) Distance** and **Max(imum) Distance** are different, RADTRAN reads the number in this column as a population density: persons/km². This population density must be calculated off-line. For example, if there are 20 people around the cargo in an annular ring with a shortest distance to the cargo of 1 m and a longest distance of 10 m, the population density in this annular ring may be calculated as follows:

Inner radius = 1 meter.

Outer radius = 10 meters.

$$\text{Area of annulus} = \pi * [(10)^2 - (1)^2] = 99\pi = 311\text{m}^2 = 3.11 \times 10^{-4} \text{ km}^2$$

$$\text{Population density in the annulus} = 20 / (3.11 \times 10^{-4}) = 6.43 \times 10^4 \text{ people/ km}^2$$

Enter 1 meter for the **Min(imum) Distance**, 10 meters for the **Max(imum) Distance**, and then enter 6.43×10^4 for **People or People/km²**.

For areas surrounding the stop, for which the population density is given on the **Links** tab or is otherwise known, that population density may be entered directly into the stop model. RADTRAN reads total population when the **Min(imum) Distance** and **Max(imum) Distance** are the same, and reads population density when the **Min(imum) Distance** and **Max(imum) Distance** are different. This can be seen in Figure 18 in the **People or People/km²** 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 can be seen in Figure 18 in the **Shielding Factor** column.

Time

Enter the total time in hours for each type of stop. This is seen in Figure 18 in the **Time (h)** column.

5.5.1 A special case: 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 or 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 19 is a diagram of the situation you are modeling.

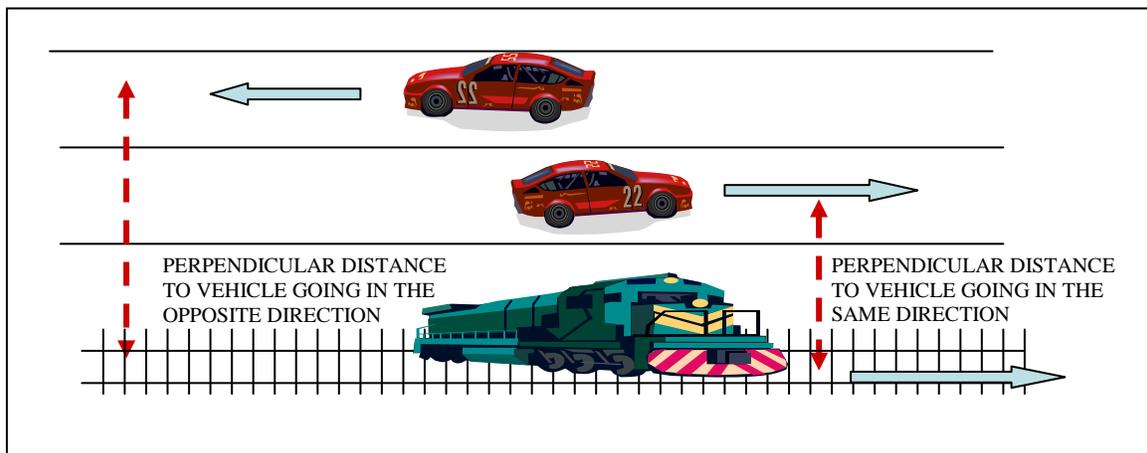


Figure 19: Diagram for the On-Link Dose on a Highway that Parallels a Rail Route

Structure your 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 tab, the Vehicle Speed will be the relative speed of the train (or barge) and the vehicles on the highway because you are calculating only the on-link dose.
 - “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.

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**.

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.

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 can be seen in Figure 19.

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 can be seen in Figure 19 in the **Name** column.

Vehicle

Available vehicle names are on a pull-down menu in the **Vehicle** column seen in Figure 19. 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 can be seen in Figure 19 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 can be seen in Figure 19 in the **Distance (m)** column.

Time

Enter the total time in hours that each group of handlers is handling the cargo. This can be seen in Figure 20 in the **Time (h)** column.

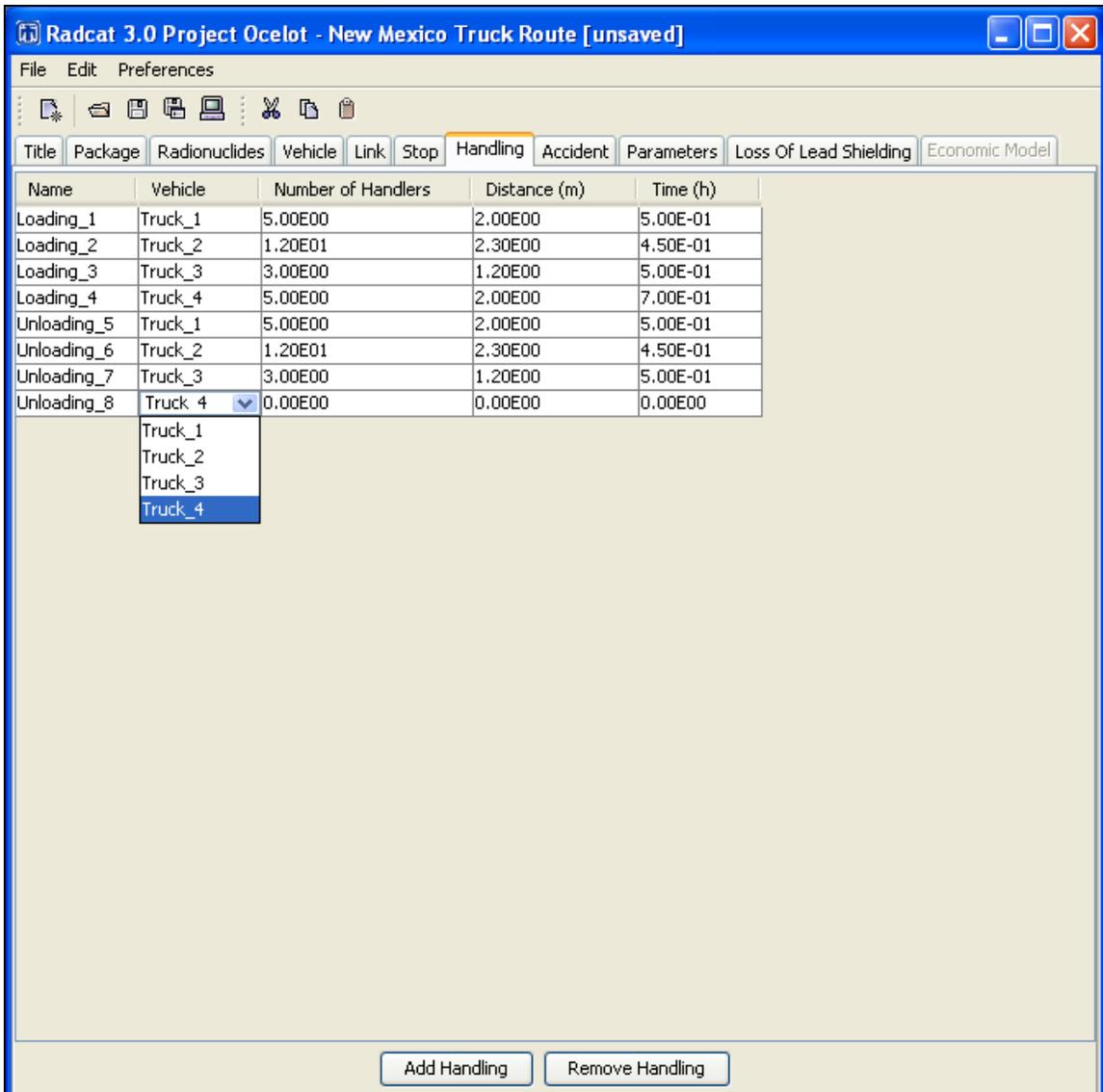


Figure 20: Handling Tab

5.7 ACCIDENTS

RADTRAN calculates both the risks and the consequences of accidents. Appendix E 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 have been 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** tab 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 can be seen in Figure 21. **Probability Fractions** may be obtained from studies of accidents as described in Sprung, J.L., et al. 2000, DOE (U.S. Department of Energy), 2002b, and Fischer, L.E., et al. 1987

Table 3, adapted from DOE (2002b) shows the relationship between the index, severity fractions (conditional probabilities) and release fractions.

Table 3. Severity and release fractions for truck-transported PWR spent fuel (adapted from DOE, 2002b) .

Severity Category	Severity Fraction	Gas	Volatiles	Particulates	CRUD
0	0.99993	0	0	0	0
1	6.06E-05	0.136	4.09E-09	1.02E-07	1.36E-03
2	5.86E-06	0.839	1.68E-05	6.71E-08	2.52E-03
3	4.95E-07	0.449	1.35E-08	3.37E-07	1.83E-03
4	7.49E-08	0.835	3.60E-05	3.77E-06	3.16E-03
5	3.00E-10	0.84	2.40E-05	5.01E-06	3.17E-03

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 tab. This can be seen in Figure 21.

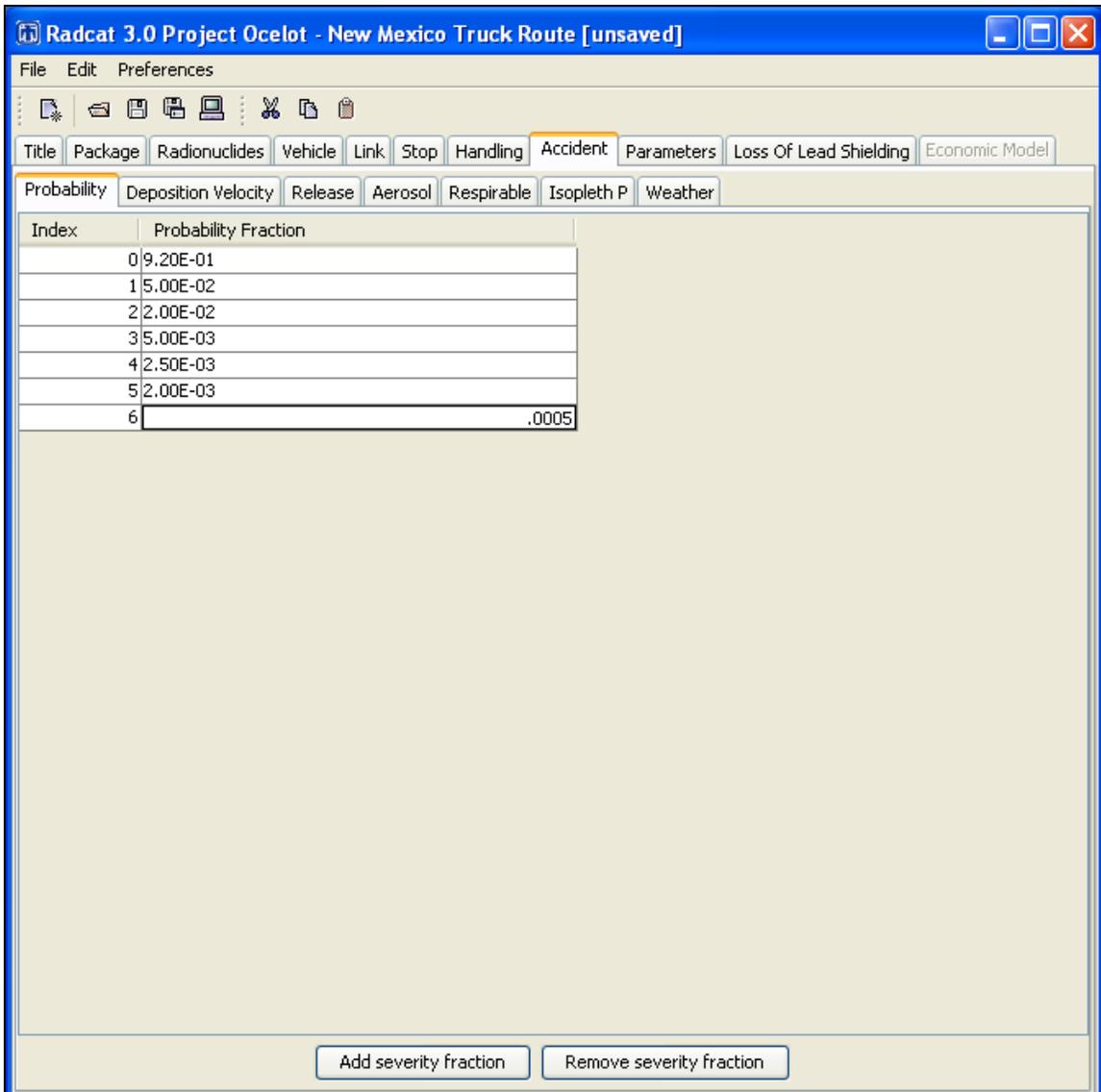


Figure 21: Accident / Probability Tab

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 tab. This can be seen in Figure 22.

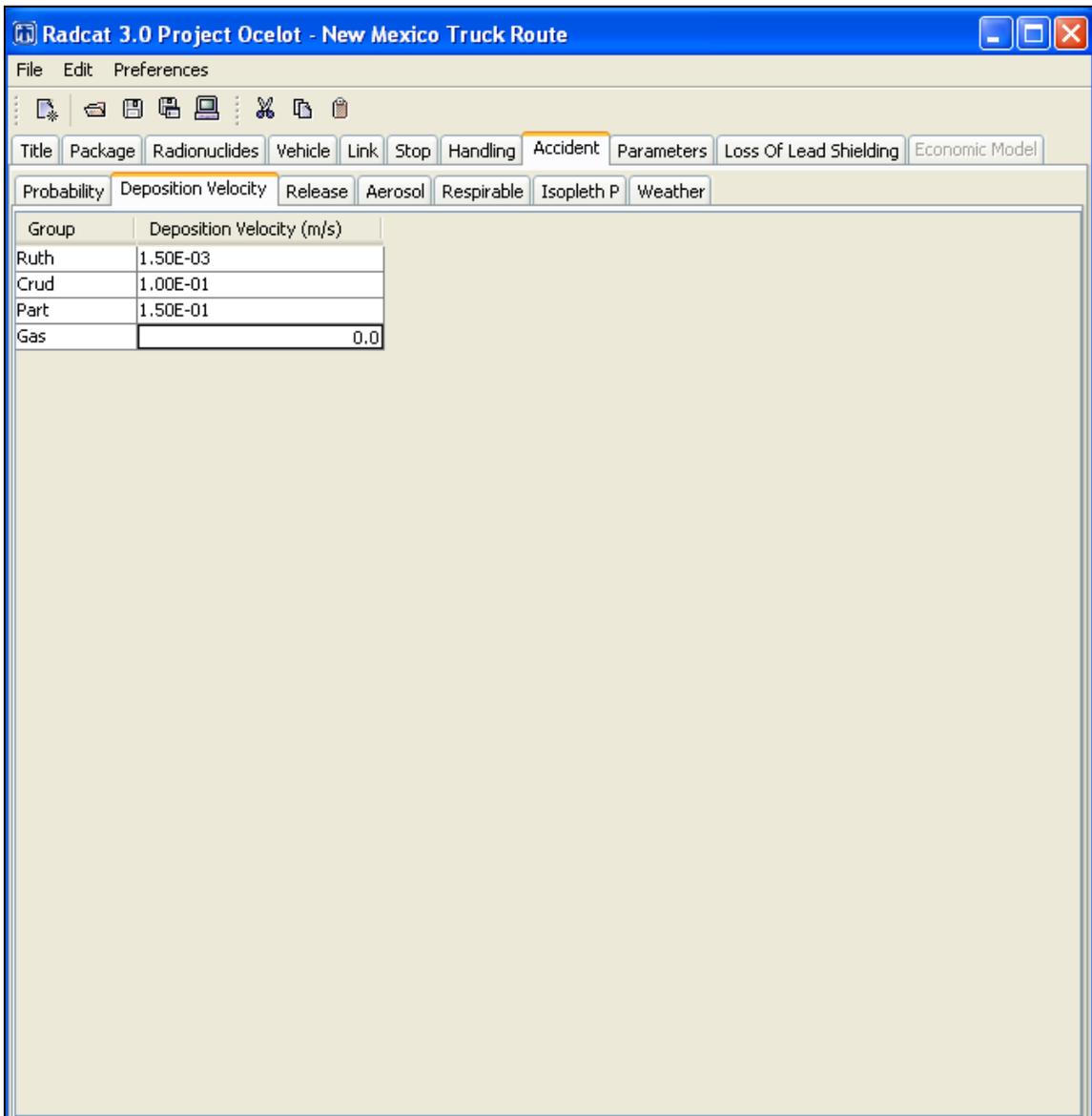


Figure 22: Accident / Deposition Velocity Tab

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 can be seen 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 tab.

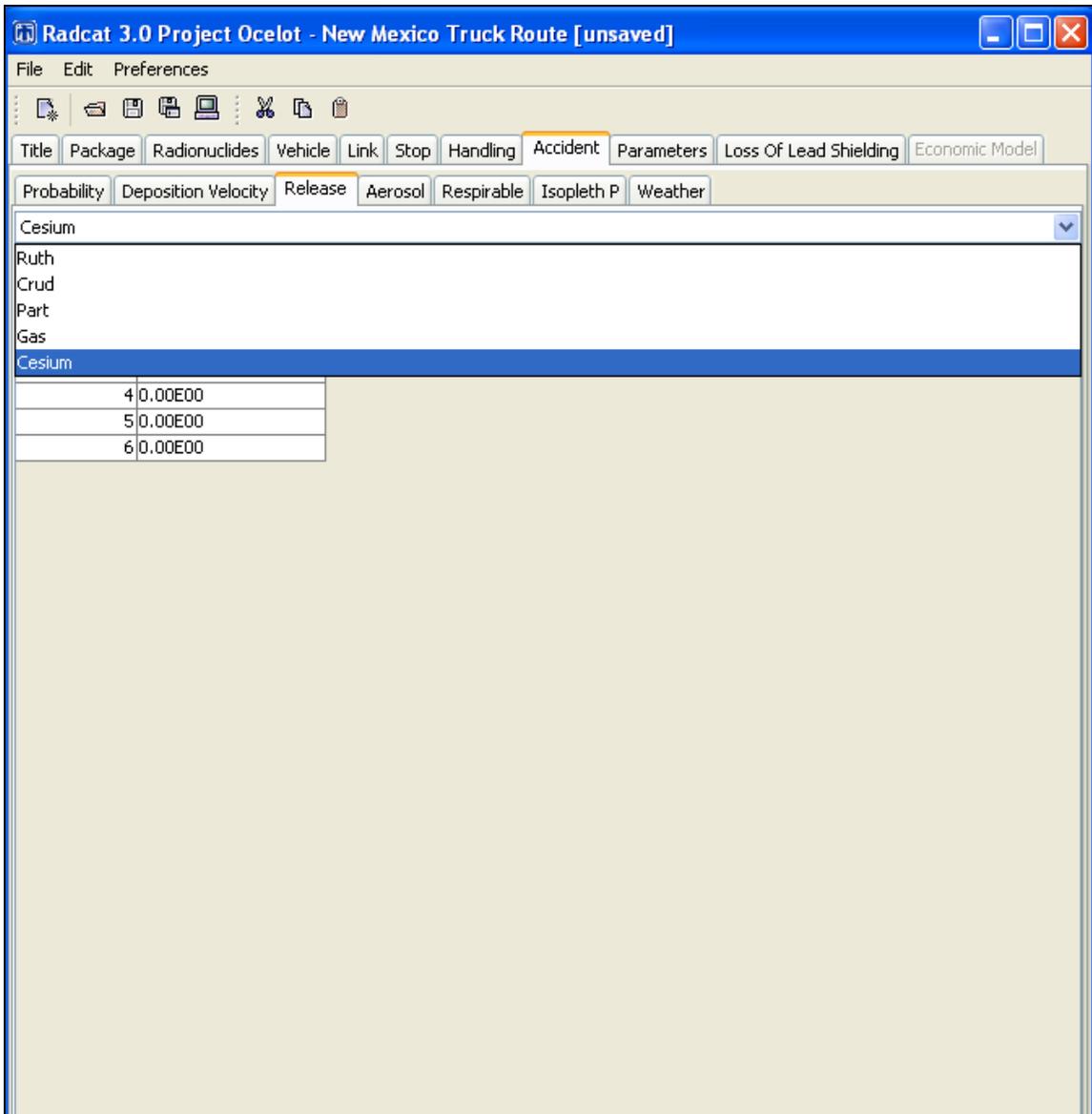


Figure 23: Accident / Release Tab

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 tab.

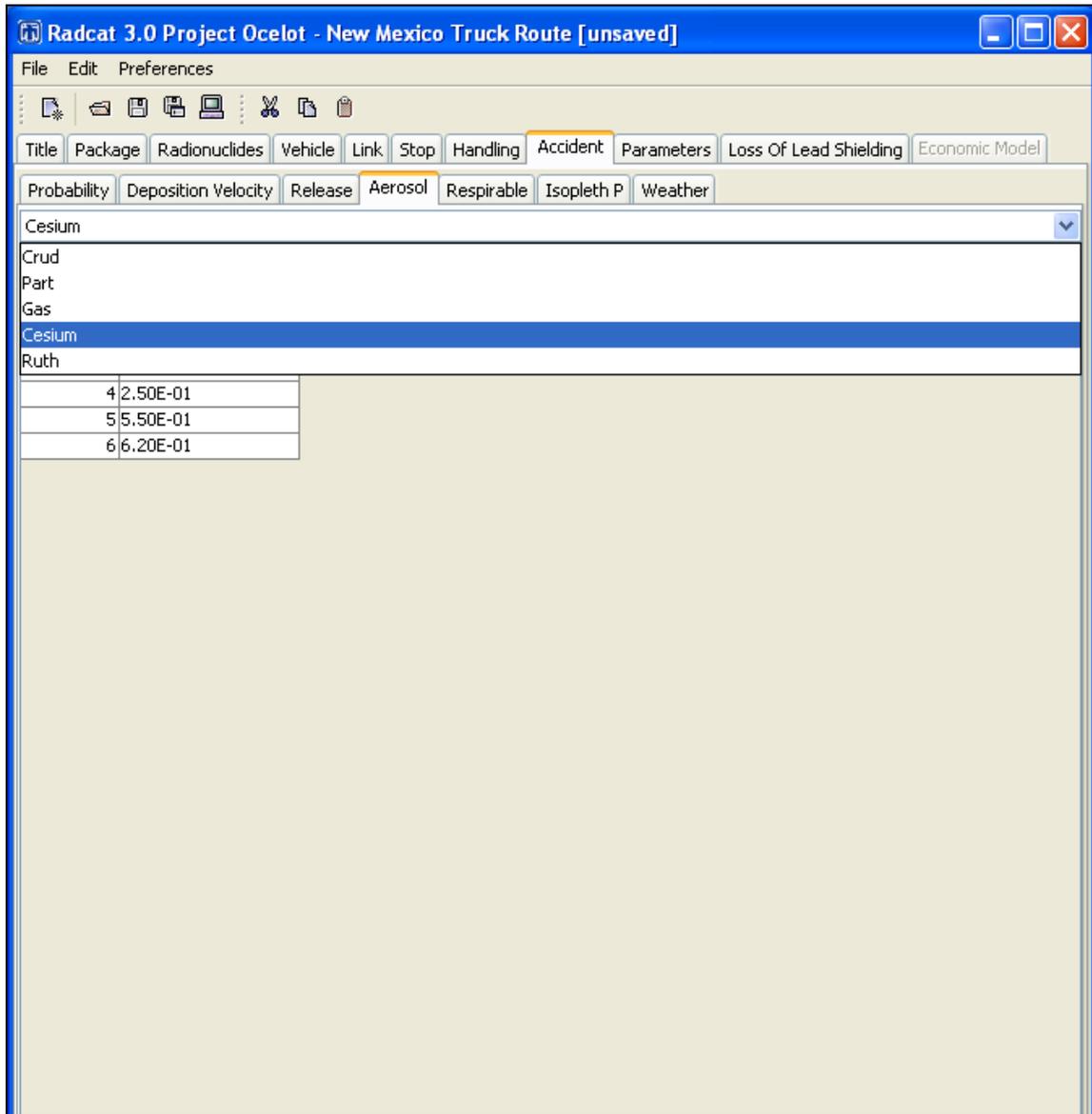


Figure 24: Accident / Aerosol Tab

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

² The inhalation dose conversion factors used in RADTRAN, which are from ICRP 72, include contributions from larger particles in the nasopharyngeal system

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 **Respirable Fraction** is usually between 0.05 and 0.1. Indices may not be added or deleted at this tab.

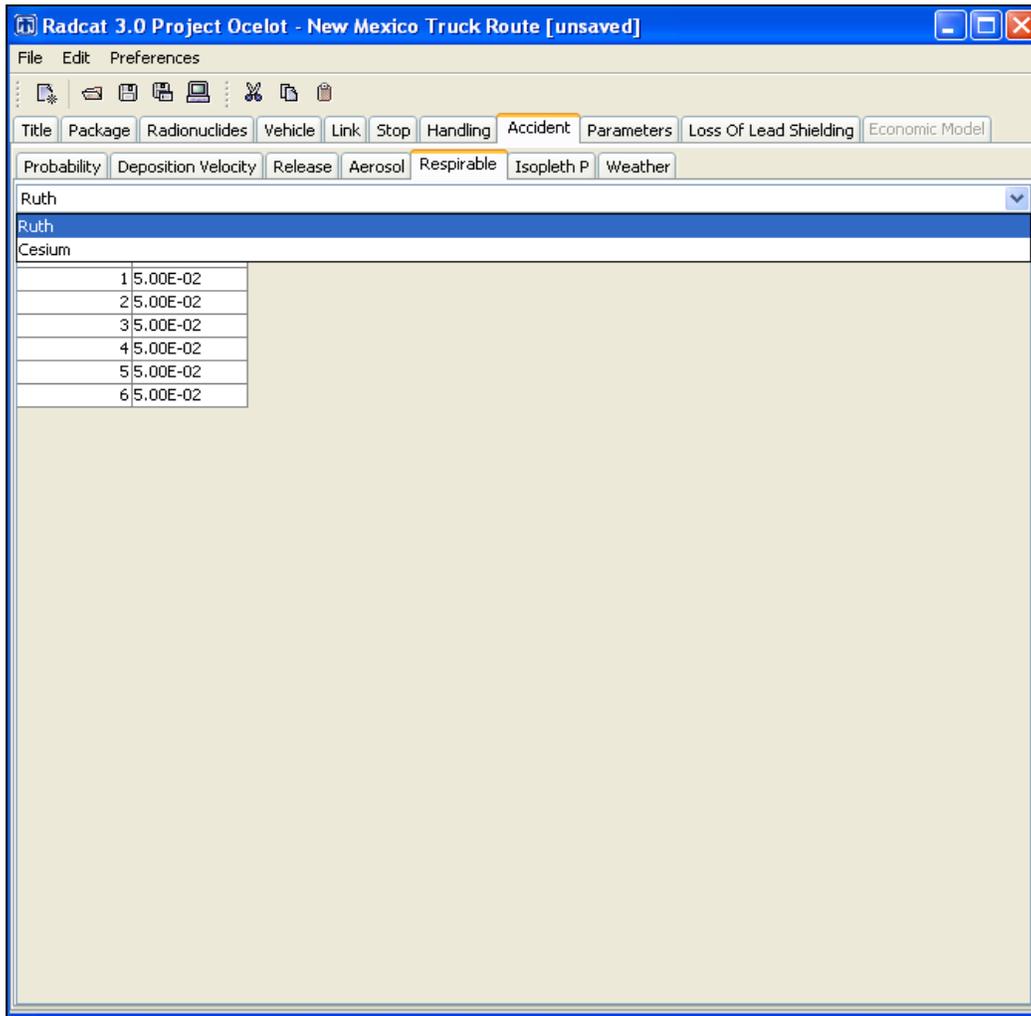


Figure 25: Accident / Respirable Tab

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. **Isopleth P** can be implemented only for the 18 isopleths on the **National Average**

Weather tab. 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 can be seen 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 tab. As RADTRAN is currently configured, the Isopleth P option can be used only with National Average weather (**Average Option** in the **Weather** tab).

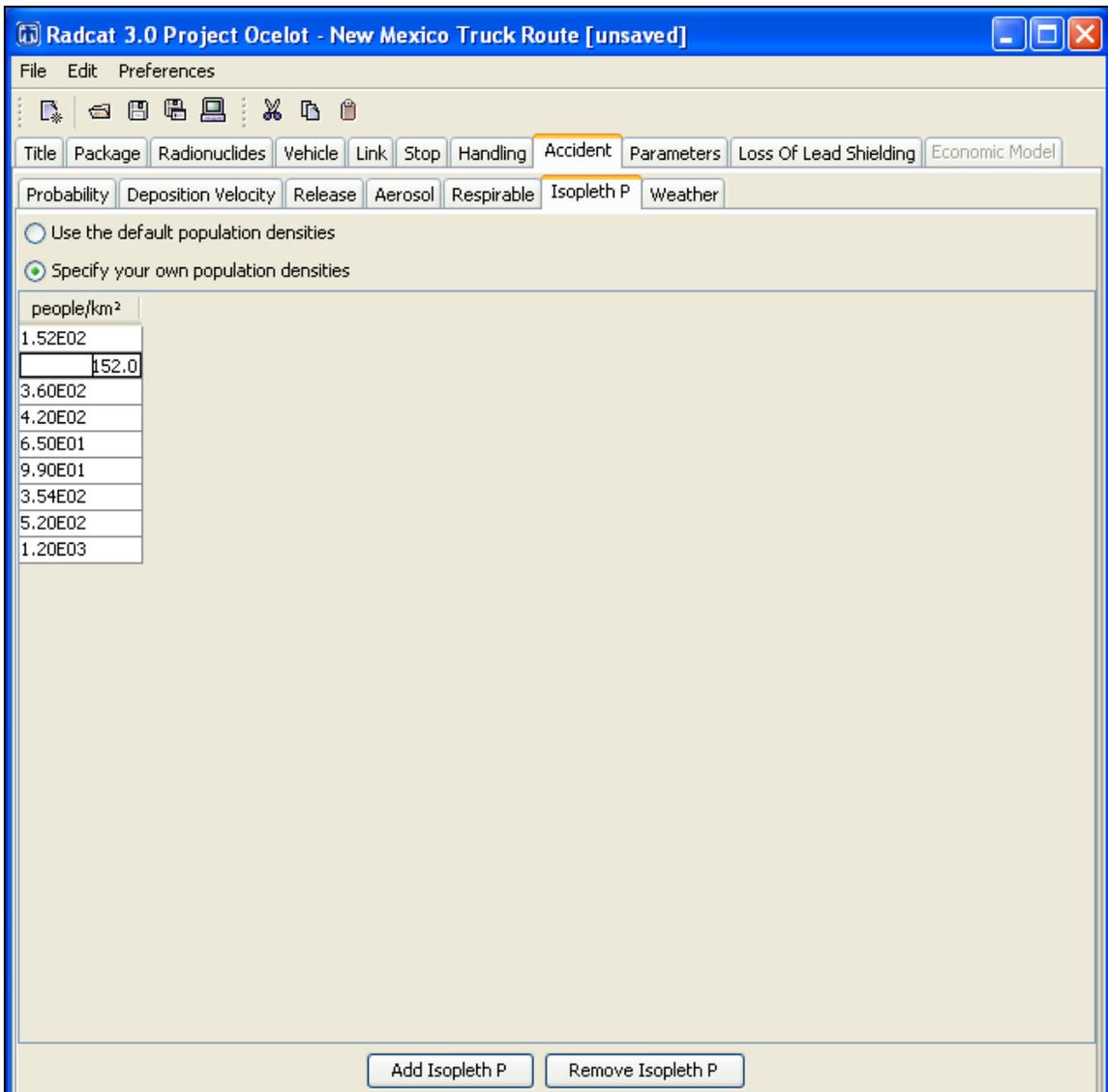


Figure 26: Accident / Isopleth P Tab

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 tab. This can be seen 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 tab. Note that you cannot add or delete population densities in this tab.

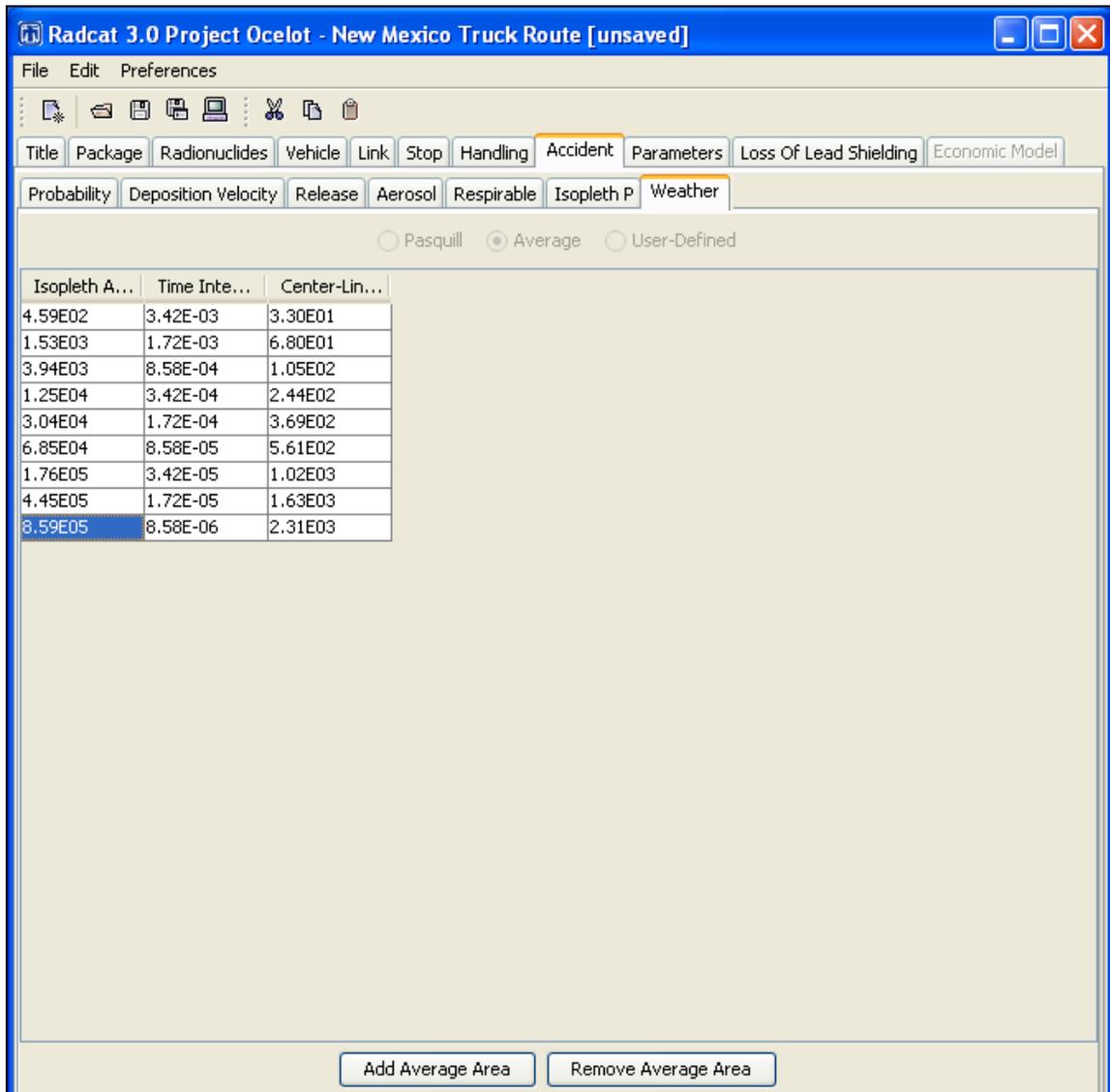


Figure 27: Accident / Weather Tab with User-Defined Dispersion Option

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 27, **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 can be seen in Figure 28. The number of areas may be added to or withdrawn using the bars at the bottom of the tab. RADTRAN cannot handle more than 18 isopleth areas in a single run.

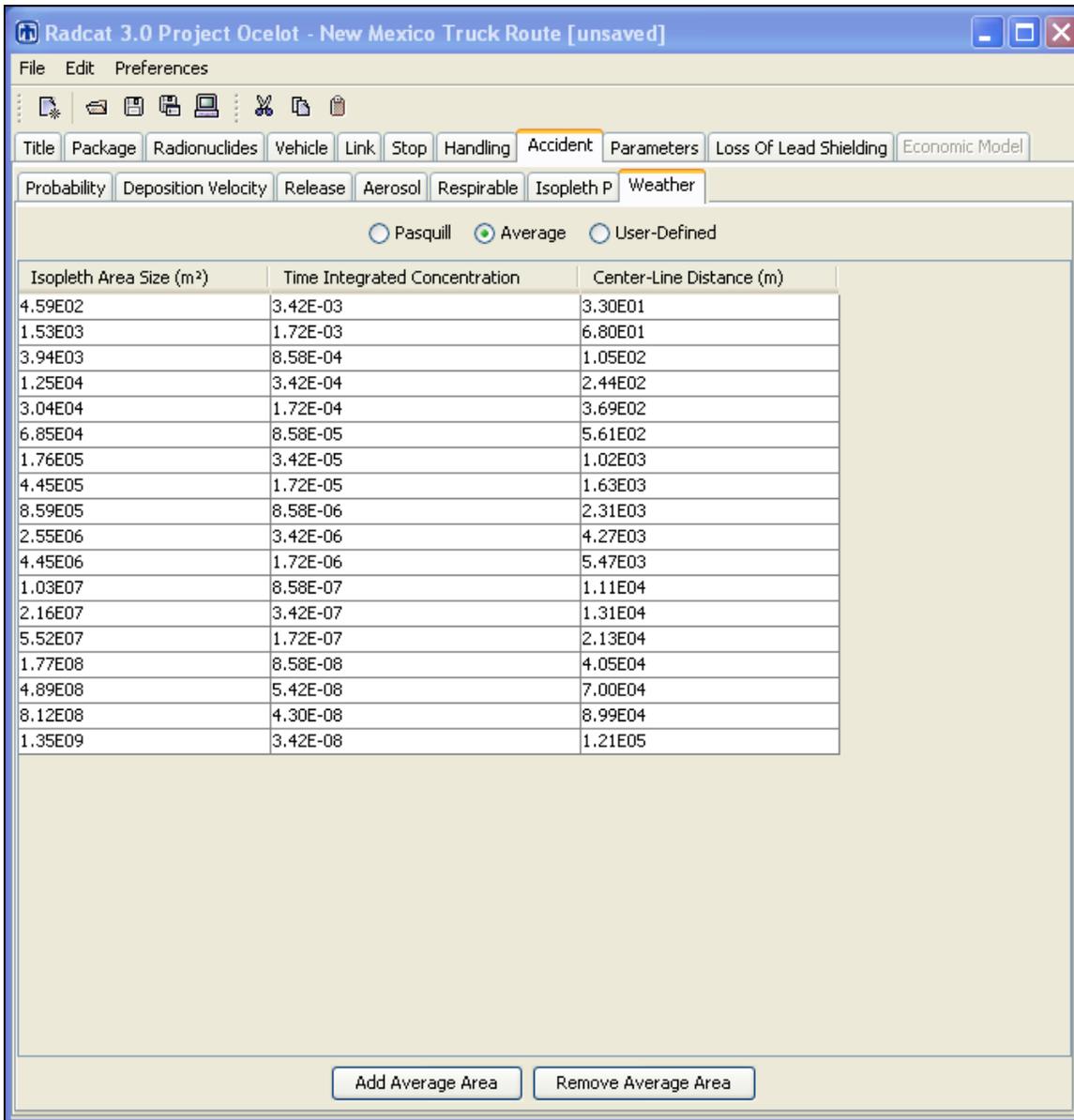


Figure 28: Accident / Weather Tab with National Average Weather Option

5.7.7.1.2 The Pasquill Option

Choosing the **Pasquill** option opens a tab 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 4.

Table 4: 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

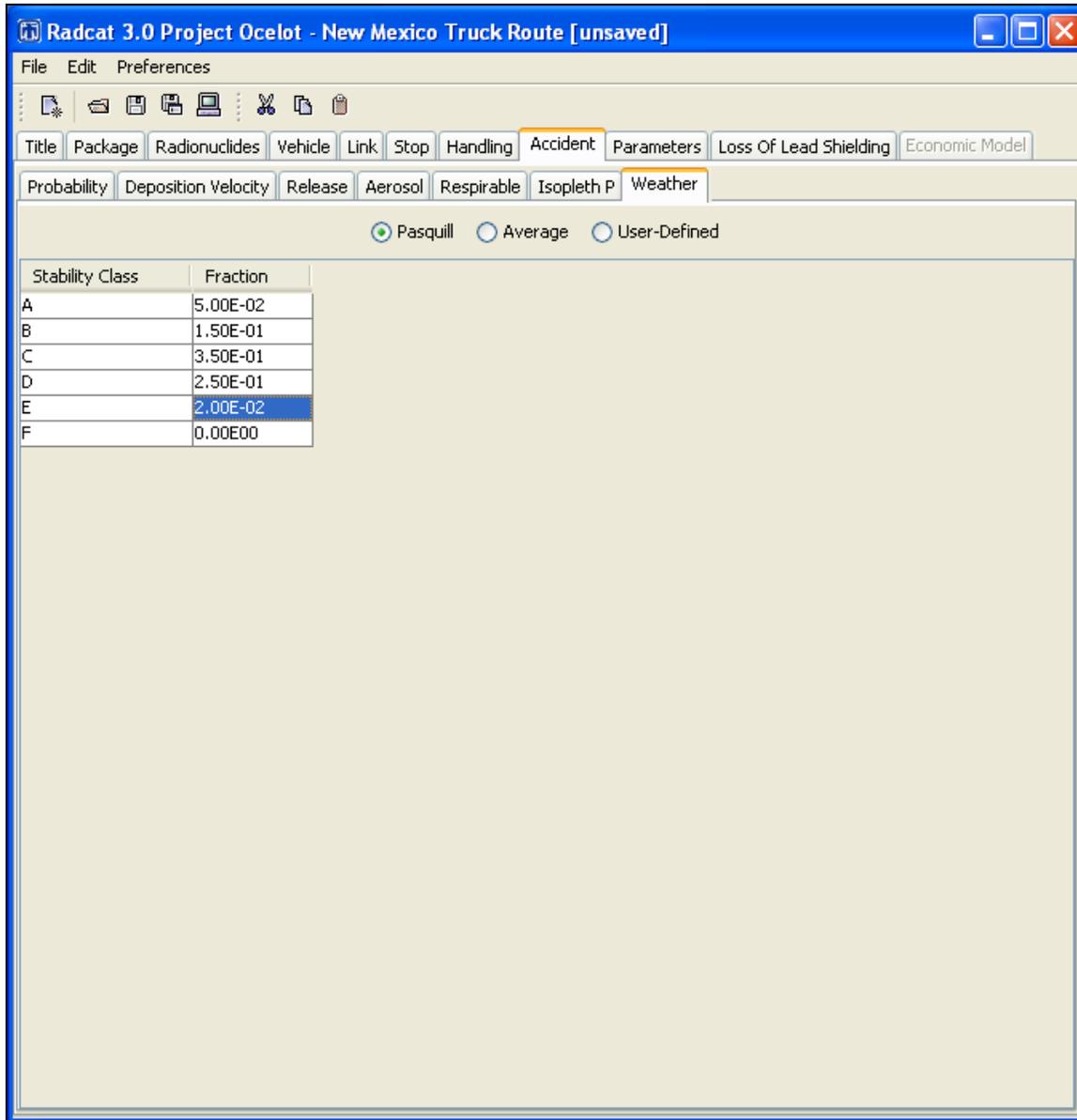


Figure 29: Accident / Weather Tab with Pasquill Option

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 tab 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** tab
4. **Cask Radius (m)** – This cask radius should be the same as indicated on the **Package** tab
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, °K)** – This parameter adjusts the plume rise accordingly to adiabatic and potential temperature lapse rates. $293\text{ °K} = 20\text{ °C} = 68\text{ °F}$; $273\text{ °K} = 0\text{ °C} = 32\text{ °F}$
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/beta/precip7.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.

Since this option provides different dispersion results, it should be used for Links that are either suburban/urban or rural only. If a combination of Links that are urban, suburban, and rural needs to be investigated, it is suggested that two different RADTRAN runs be conducted so as to reflect the dispersion models properly.

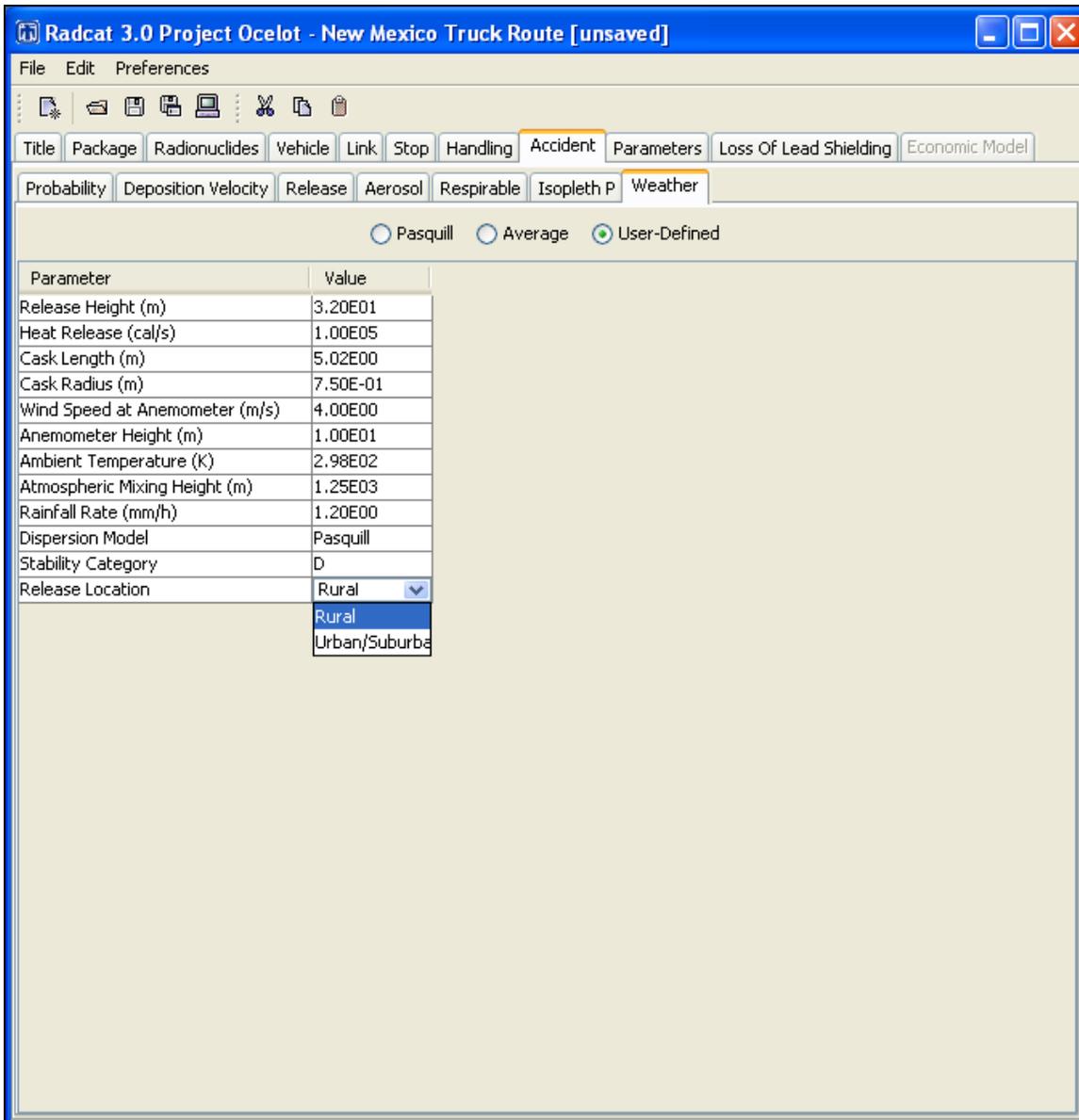


Figure 30: Accident / Weather Tab with User-Defined Option

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 the fraction of ionizing radiation to which residents along the route are exposed in their homes or other buildings. It is the inverse of the shielding fraction; i.e., a shielding factor of 1 indicates no shielding, and a shielding factor of zero

indicates 100% shielding. The shielding factor is different for rural, suburban, and urban zones because building materials differ. Figures 31, 32, and 33 show the default values for shielding factors: 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 is 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 default value of 0.05 represents a conservative average across a series of building types, including residential, office, and industrial structures (Engelmann, 1990).

Fraction of population occupying the sidewalk

This parameter specifies the fraction of population that is outdoors or the fraction of population that occupies sidewalks. The default value of 0.48 is taken from Finley et al. (1980). This value is suitable for large cities and conservative for smaller cities. This parameter and the **Fraction of urban population inside buildings** should add to 1.00.

Fraction of urban population inside buildings

This is equal to $1 - \text{Fraction of population occupying the sidewalk}$

Ratio of pedestrians/km² to residential population/km²

This ratio is used to calculate the exposure of unshielded persons on sidewalks and elsewhere in urban areas. 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 –the source of population densities used in RADTRAN -- includes only resident population. Workers in urban businesses are not counted in the census, but are shielded by being in buildings, and should therefore not be part of this ratio.

The default value is 6.0, which is based on empirical data from New York City (Finley et al., 1980).

Minimum small package dimension for handling

This parameter specifies the package size threshold, which determines whether the package is treated as a point source of radiation or as a line source. As a rule, if the distance between the package or vehicle and the receptor is the same or less than the critical dimension, the source is treated as a line source (see the section on dose rate in Section 5.1). However, if a package is designated as **small**, i.e., smaller than the default threshold, RADTRAN calculates the dose to the handler as if the source were a point source. If package dimensions exceed the threshold, RADTRAN calculates the handler

dose as originating in a line source, if the handler is close enough to the package, as in Section 5.1.. The default value of the minimum dimension is 0.5 (Javitz, 1985)

Distance from shipment for maximum exposure

This parameter is used to calculate the maximum individual off-link dose from incident-free transportation. It is the minimum distance, in meters, perpendicular to the route, from the shipment to an individual standing beside the route right-of-way while a shipment passes. The default value is 30 meters (NRC, 1977).

Vehicle speed for maximum exposure

This parameter is also used to calculate the maximum individual “in-transit” dose. It is the minimum speed of a shipment in km/hr. The default value is 24 km/hr (15 mph) (NRC, 1977), which is probably excessively conservative. Table 1 or the Bureau of Transportation Statistics (www.bts.gov) should be consulted for more realistic values for this parameter.

Imposed regulatory limit on vehicle external dose

The default setting is “**YES**” which causes a regulatory checks to be performed. If the dose at two meters from the vehicle exceeds the regulatory maximum of 10 mrem/hour, the critical dimension and dose rate are adjusted in RADTRAN so that this value is not exceeded. 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 intended to use.

Average breathing rate

This parameter is used to calculate inhalation doses. The default is 3.30×10^{-4} m³/sec. This breathing rate is that of the Reference Man (70-kg adult male at light work) in Shleien et al (1996; Table 12.6).

Cleanup Level

This parameter is the ground surface concentration, in microcuries/m², to which a contaminated surface is cleaned from contamination by a release of radioactive material.. It is the total activity of all deposited radionuclides after cleanup. The default value is the EPA guidance value of 0.2 μCi/m² (EPA, 1977).

Interdiction Threshold

This parameter specifies the threshold value for interdiction of contaminated land. The default value is 40, i.e., a value 40 times the **Cleanup Level** (NRC, 1977).

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/km ² to residential population/km ²	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 (m ³ /sec)	3.30E-04
Evacuation time for groundshine (days)	1.00E00
Survey interval for groundshine (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 pede...	3.00E01
Distance of freeway vehicle carrying radioactive cargo to right...	3.00E01
Distance of freeway vehicle carrying radioactive cargo to maxi...	8.00E02
Distance of non-freeway vehicle carrying radioactive cargo to p...	2.70E01
Distance of non-freeway vehicle carrying radioactive cargo to ri...	3.00E01
Distance of non-freeway vehicle carrying radioactive cargo to ...	8.00E02
Distance of city street vehicle carrying radioactive cargo to ped...	5.00E00
Distance of city street vehicle carrying radioactive cargo to righ...	8.00E00
Distance of city street vehicle carrying radioactive cargo to ma...	8.00E02
Perpendicular distance to freeway vehicle going in opposite dire...	1.50E01
Perpendicular distance to non-freeway vehicle going in opposit...	3.00E00
Perpendicular distance to city vehicle going in opposite direction...	3.00E00
Perpendicular distance to all vehicles going in same direction (m)	4.00E00

Figure 31: Parameters Tab for Highway Mode

Evacuation time for groundshine

This is the evacuation time in days following a dispersal accident, and is the time during which the residents of the area are exposed to groundshine from the dispersed and deposited radioactive material.. The default value is 1.0 day (24 hours). Mills et al. (1995) analyzed 66 verified hazardous materials accidents in which evacuations were carried out and found that the mean evacuation time was approximately one hour. This is also the time that the receptor is exposed to resuspended material.

Survey interval for groundshine

This parameter is the time (in days) required to survey contaminated land following a dispersal accident. None of the residents of the area are exposed to the released

radioactive material during the survey interval. The default value for the survey interval is 10 days (NRC, 1977).

Occupational latent cancer fatalities per person-rem

This parameter specifies the occupational Latent Cancer Fatality (LCF) risk; the units are LCF per rem. The default value for workers is 4.0E-04 LCF/rem, consistent with the recommendations of BEIR VII (NRC/NAS, 2005) and ICRP 60 (ICRP, 1991). The Interagency Steering Committee on Radiation Standards (DOE 2002a, ISCORS 2002) recommends 6.0E-04 LCF/rem.

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 default value for the public is 5.0E-04 LCF/rem. The Interagency Steering Committee on Radiation Standards (DOE 2002a, ISCORS 2002) recommends 6.0E-04 LCF/rem, as for Occupational dose..

The cancer risks discussed here are based on the linear non-threshold theory of radiation damage. 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 default value is 1.0E-04 genetic effects/rem. Although this value is consistent with the recommendations cited for occupational and public latent cancer fatality risk, it is questionable in light of the Tubiana and Aurengo (2005) paper. Moreover, BEIR V and ICRP 60 cite no evidence for this value.

Campaign

This is the duration of the shipping campaign in years, and is used to calculate the total number of off-link persons exposed, using the Census Bureau algorithm for the average length of residence in the U.S. The default value is 0.0833 years, an average month in an average year or 1/12th of a year. 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.

Rem per curie thyroid via inhalation

This is the one-year Committed Effective Dose Equivalent (CEDE) in rem per curie to the thyroid from inhalation of iodine isotopes to estimate early-mortality risk. The default values are 1.27×10^6 for Iodine-131, 5.77×10^6 for Iodine-129, and 9.25×10^5 for Iodine-125.

Distance of freeway vehicle carrying radioactive cargo to pedestrians

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

Distance of freeway vehicle carrying radioactive cargo to maximum exposure distance

Distance of non-freeway vehicle carrying radioactive cargo to pedestrians

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

Distance of non-freeway vehicle carrying radioactive cargo to pedestrians.

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

Distance of city street vehicle carrying radioactive cargo to pedestrians

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

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

These parameter values are self-explanatory. The incident-free collective dose is integrated from the smallest distance (default value usually 30 m.) to the largest distance (default value 800 m. except for city streets) between the vehicle and the receptor population.

Perpendicular distance to freeway vehicle going in the opposite direction

The default value is 15 meters and is taken from Madsen et al. (1986 p. 36-37). 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 radioactive materials shipment in the outside lane, oncoming traffic in the corresponding outside lane, and passing vehicles in the inner lanes.

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

The default value is 3 meters and is taken from Madsen et al. (1986 p. 36-37). 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.

Perpendicular distance to city vehicle going in the opposite direction

The default value is 3 meters and is taken from Madsen et al. (1986 p. 36-370). 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

Perpendicular distance of all vehicles going in the same direction

The default value is 4 meters and is taken from Madsen et al. (1986). This can be seen in Figure 30. 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 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 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 railyard worker groups, and is calculated primarily with a line-source model, though a point-source model is used when appropriate. The classification dose to railyard workers for both common carrier and dedicated rail (Wooden, 1987, as described in Appendix B of Neuhauser, et al, 2000). This can be seen in Figure 32.

Distance dependant 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 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.

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 default setting is **NO**. This can be seen 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).

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/km ² to residential population/km ²	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 (m ³ /sec)	3.30E-04
Evacuation time for groundshine (days)	1.00E00
Survey interval for groundshine (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 pedestrian...	3.00E01
Distance of rail vehicle carrying radioactive cargo to right-of-wa...	3.00E01
Distance of rail vehicle carrying radioactive cargo to maximum e...	8.00E02
Perpendicular distance to rail vehicle vehicle going in opposite di...	3.00E00

Figure 32: Parameters Tab with Rail Mode

Distance of railcar carrying radioactive cargo to pedestrians

Distance of railcar carrying radioactive cargo to right-of-way edge

Distance of rail car carrying radioactive cargo to maximum exposure distance

These parameter values are self-explanatory. The incident-free collective dose is integrated from the smallest distance (default value usually 30 m.) to the largest distance (default value 800 m.) between the vehicle and the receptor population

Perpendicular distance to rail car vehicle going in the opposite direction

The default value is 3 meters and is taken from Madsen et al. (1986 p. 36-37). 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.

Distance of waterway barge carrying radioactive cargo to pedestrians

The 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 can be seen in Figure 33.

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

The 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

Distance of waterway barge carrying radioactive cargo to maximum exposure distance

The 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.

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/km ² to residential population/km ²	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 (m ³ /sec)	3.30E-04
Evacuation time for groundshine (days)	1.00E00
Survey interval for groundshine (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 pede...	2.00E02
Distance of waterway barge carrying radioactive cargo to wate...	2.00E02
Distance of waterway barge carrying radioactive cargo to maxi...	8.00E02

Figure 33: Parameters Tab with Barge Mode

5.9 LOSS OF LEAD SHIELDING (LOS)

The **Loss of Lead Shielding** tab is currently only accessible in **Highway** mode (the tab is grayed out if **Rail** or **Barge** mode are selected), since loss of lead shielding in RADTRAN 6.0 has only been validated for highway transportation containers. Until **Loss of Lead Shielding** becomes available in **Rail** and **Barge** vehicle modes, it can be modeled for rail or barge by opening a new RadCat in **Highway** mode, modeling the package and vehicle using rail or barge package and vehicle parameters, respectively, and adjusting default parameters appropriately.

5.9.1 LOSS OF SHIELDING EVENT

Name

Give each **Loss of Shielding Event** a **Name** in the left-hand column. An event name must be a continuous text string and must not include any spaces. Different dose receptors (e.g., public near the event, emergency first responders) can be structured as different events. This difference is shown in Figure 34.

Vehicle

Available vehicle names are on a pull-down menu in the **Vehicle** column, as shown in Figure 34 in the **Vehicle** column. Vehicle names cannot be added or deleted at this tab.

Min Distance

Enter the shortest distance for the LOS event from the radioactive cargo to the receptor(s) whose dose will be calculated. The **Min(imum) Distance** cannot be less than 1.0 meters and must be less than or equal to the **Max(imum) Distance**. Realistic distances for this model are: 1, 2, 3, 4, 5, 10, 20, 50, and 100 meters.

Max Distance

Enter the longest distance for the LOS event from the radioactive cargo to the receptor(s) whose dose will be calculated. The **Max(imum) Distance** cannot be greater than 100.0 meters and must be greater than or equal to the **Min(imum) Distance**. Realistic distances for this model are: 1, 2, 3, 4, 5, 10, 20, 50, and 100 meters

People

This parameter defines the number of radiation receptors at each particular LOS Event as seen in Figure 34. If the **Min(imum)** and **Max(imum) Distance** are the same, RADTRAN will report the dose for the given number of receptors at only one distance. If the **Min(imum)** and **Max(imum) Distance** are different, RADTRAN will report the dose for the given number of receptors at distances between the minimum and maximum. RADTRAN 6.0 does not currently account for population density as described for the stop model in Section 5.5.

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 external to the package.. 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 can be seen in Figure 34 in the **Shielding Factor** column.

Time

Enter the total time in hours for each LOS event. The total time represents the duration of potential radiation exposure, and can be indicative of an emergency services first responder or the public awaiting evacuation. This is seen in Figure 34 in the **Time (h)** column.

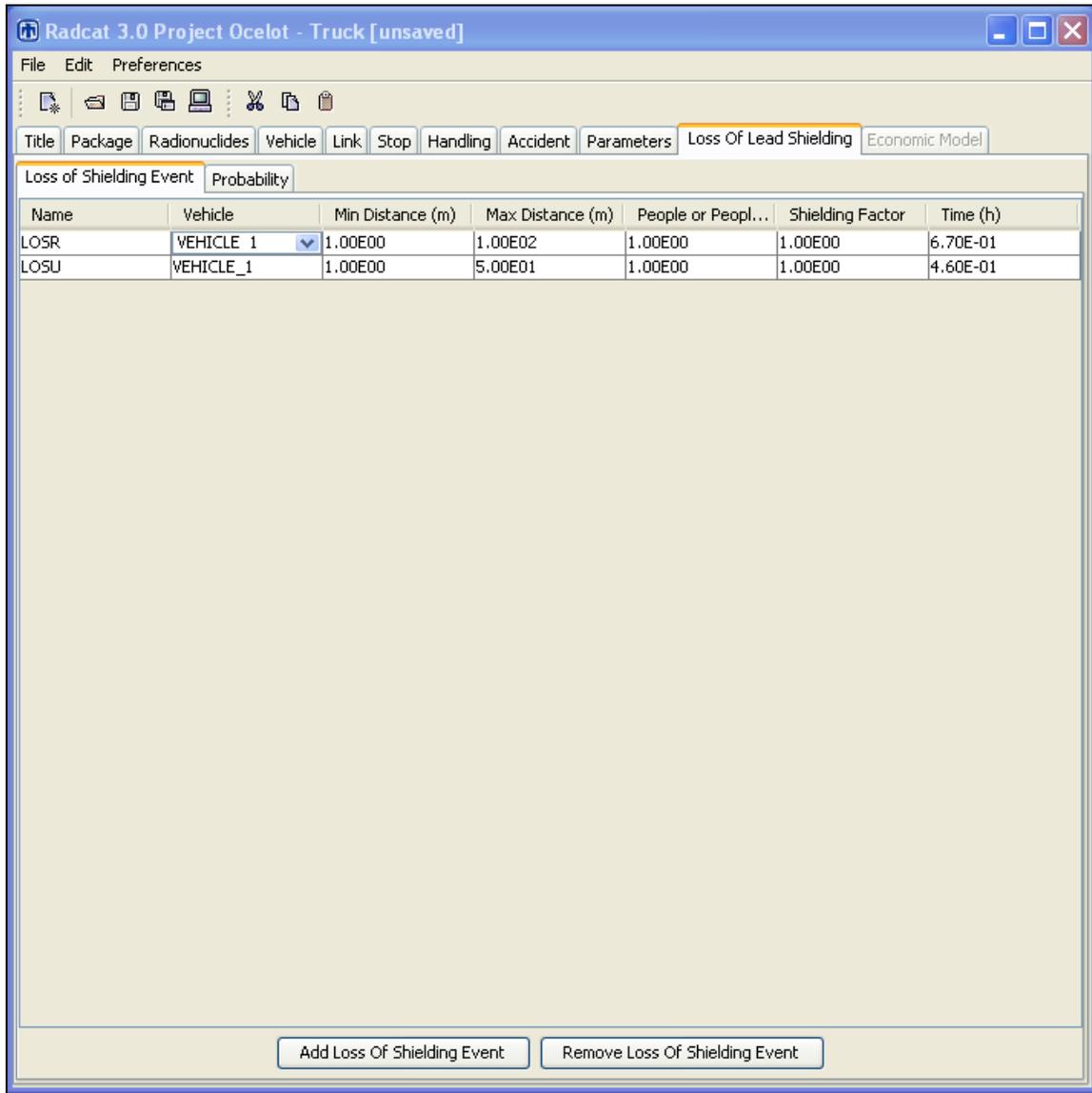


Figure 34: Loss of Lead Shielding Tab, LOS Event

5.9.2 LOS PROBABILITY

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 35.

Index and Probability Fraction

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 no loss of gamma shielding. The probability of this type of accident is usually more than 90%. **Probability Fractions** for LOS events may be obtained from studies of accidents as described in Sprung, et al (2000), DOE (2002b) and similar references: Table 5 (from DOE, 2002b, Table 5-52) shows some typical probability fractions for a Type B spent fuel cask. These are different from the parameter values shown in Figure 35.:

Table 5. Sample conditional probabilities of LOS (adapted from DOE 2002b, Table 5-52)

Severity category	Conditional probability of LOS severity category	Slump Fraction
0	0.9999	0.0
1	6.4E-06	0.10
2	4.9E-05	0.029
3	4.5E-07	0.17
4	2.4E-05	0.034
5	5.2E-09	0.34

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 appropriate column. Severity fractions may only be added and deleted on this tab. This can be seen in Figure 35.

Slump Fraction

RADTRAN can only model removal (loss) of gamma shielding, and therefore uses removal as a surrogate for thinning or other distortions of the gamma shield. The **Slump Fraction** represents the fractional portion of the lead gamma shielding that is removed during an LOS event. Therefore, if 50% of the lead shielding is lost for a corresponding probability fraction, then the **Slump Fraction** would be 0.5. Each index and probability fraction will have an associated slump fraction as shown in Table 5 and Figure 34.

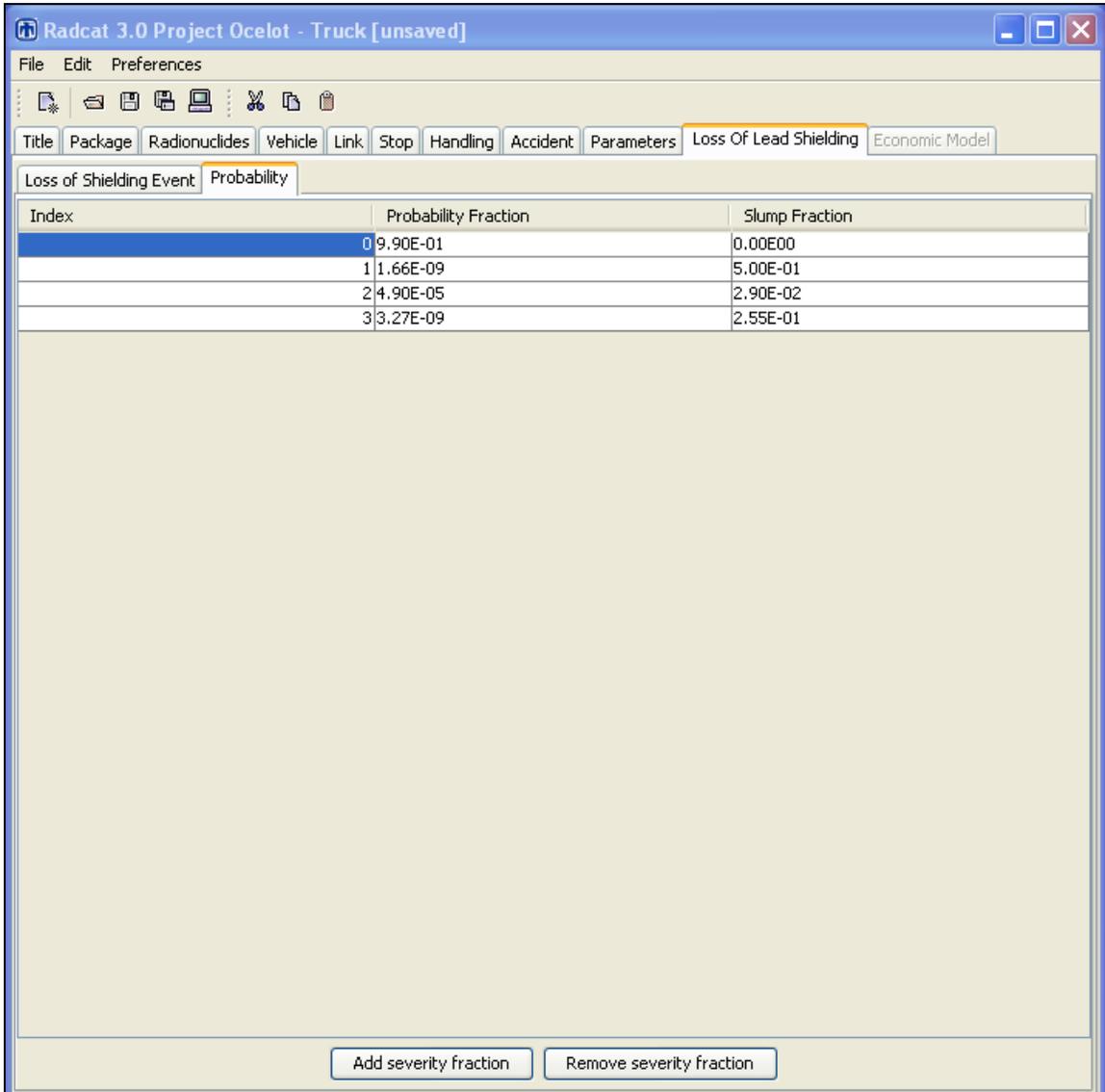


Figure 35: Loss of Lead Shielding Tab, Probability

5.10 ECONOMIC MODEL

An accidental release and dispersal of radioactive material during transportation could require evacuation of the population and decontamination of the affected area. The economic model in RADTRAN 6.0 estimates the cost of evacuation and decontamination.

A checkbox for the **Economic Model** is included on the Title Tab. When unchecked, the Economic Model Tab remains grayed out, and results from the Economic Model will not be included in the RADTRAN 6.0 output. However, if the box is checked, the Economic Model Tab will become functional, allowing for default value editing and inclusion in the RADTRAN 6.0 output. Figure 36 lists default values for the Economic Model. Any of these values can be overwritten by the user. A listing of economic model parameter names (specifically used for RADTRAN 6.0 text input), descriptions, average values and

units can be found in Appendix A, Table 5, “Economic Model Default Values”. Derivation of the economic model parameters is discussed in Osborn, et al (2007).

The screenshot shows the 'Economic Model' tab in the Radcat 3.0 software. The window title is 'Radcat 3.0 Project Ocelot - Truck [unsaved]'. The menu bar includes 'File', 'Edit', and 'Preferences'. The toolbar contains icons for file operations. The 'Economic Model' tab is active, displaying a table of parameters and their values.

Parameter	Value
Footprint of commercial buildings	3.37E02
Footprint of industrial buildings	6.62E03
Footprint of residential buildings	1.18E02
Area of commercial lots	9.30E02
Area of industrial lots	9.70E03
Area of residential lots	2.23E02
External dose rate per drum of resin	5.00E00
External dose rate for 1 Ci of Co-60 resin drum	2.70E02
Annual crop profit	1.30E-02
Cost of washing contaminated area	3.23E01
Rural evacuation cost	7.88E00
Suburban evacuation cost	1.36E01
Urban evacuation cost	1.36E01
Rural commercial land use fraction	1.00E-02
Suburban commercial land use fraction	1.40E-01
Urban commercial land use fraction	3.70E-01
Rural industrial land use fraction	1.00E-02
Suburban industrial land use fraction	9.00E-02
Urban industrial land use fraction	1.10E-01
Rural residential land use fraction	3.00E-02
Suburban residential land use fraction	2.80E-01
Urban residential land use fraction	2.40E-01
Rural soil land use fraction	9.50E-01
Suburban soil land use fraction	4.10E-01
Urban soil land use fraction	9.00E-02
Fraction of building surfaces contaminated	4.49E-01
Rural soil land use fraction for crops	2.00E-01
Rural soil land use fraction for livestock	2.80E-01
Average commercial building outside height	1.64E01
Average industrial building outside height	6.05E00
Average residential building outside height	5.32E00
Rural road density	5.97E-04
Suburban road density	8.11E-04
urban road density	8.06E-02
Resin density	1.28E00
Road width	8.84E00

Figure 36: Economic Model Default Values

7. RADTRAN Output

Once all the necessary input data has been entered to run RADTRAN, click on the computer icon (the “Run RADTRAN” icon), as shown in Figure 37. Once RADTRAN has run, a new Java window will open. If RADTRAN has run properly, SUCCESSFUL COMPLETION will be shown at the bottom of the Java window as shown in Figure 38.

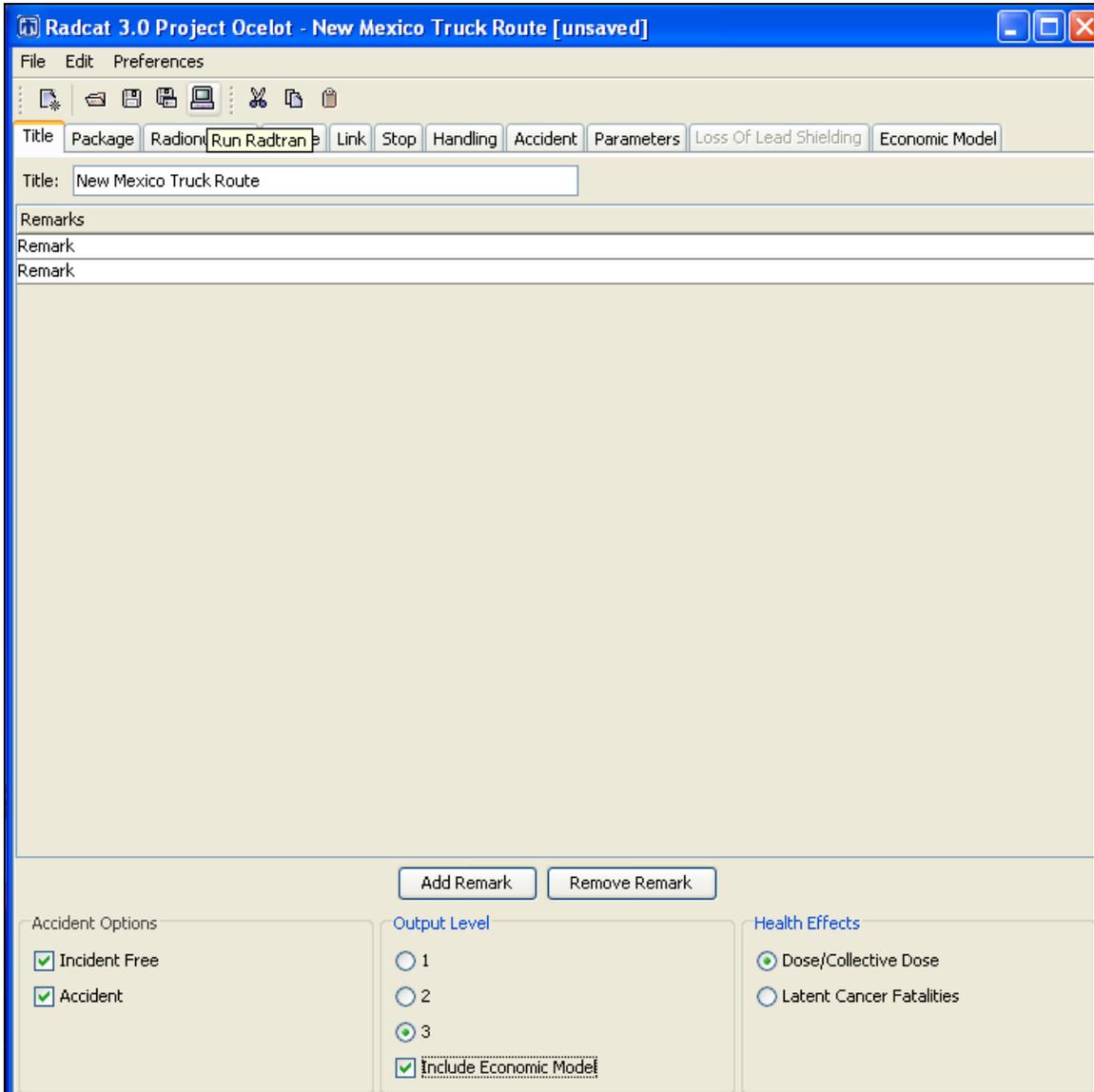


Figure 37: Run RADTRAN

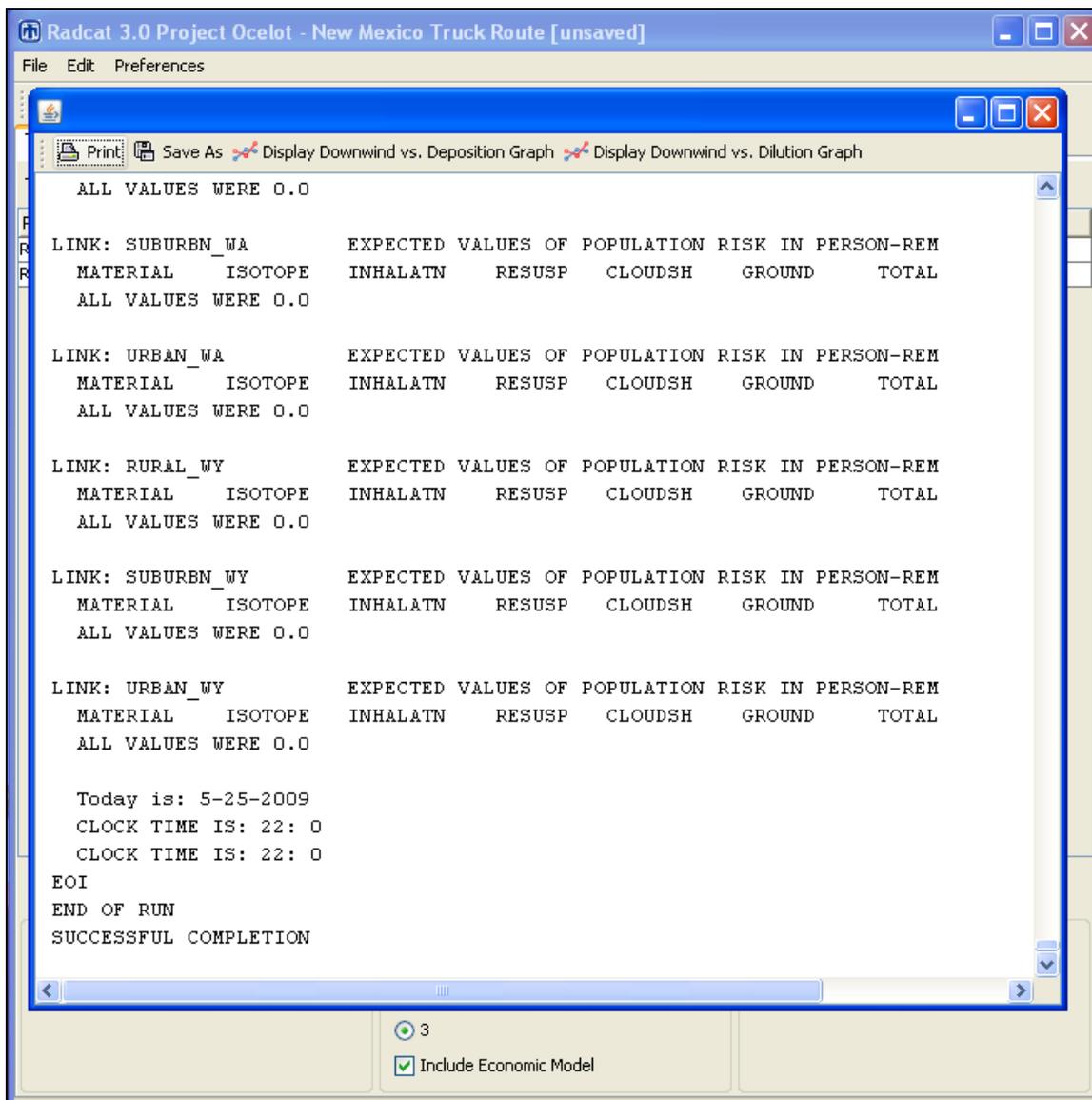


Figure 38: End of RADTRAN Output

The output is a text file that can be saved in text form. It can also be saved as, or imported into, an EXCEL spreadsheet so that the user can work with the numbers in the output.

On the bar at the top of the output screen is an icon titled “Display Downwind vs. Deposition Graph” as shown in Figure 38. These graphical displays plot the downwind distance vs. deposition and the downwind distance vs. dilution for National Average and User-defined weather only; results using the Pasquill option cannot be displayed as graphs. Figure 39 shows an example of a graphical output. The graphical outputs are made with every successful RADTRAN run.

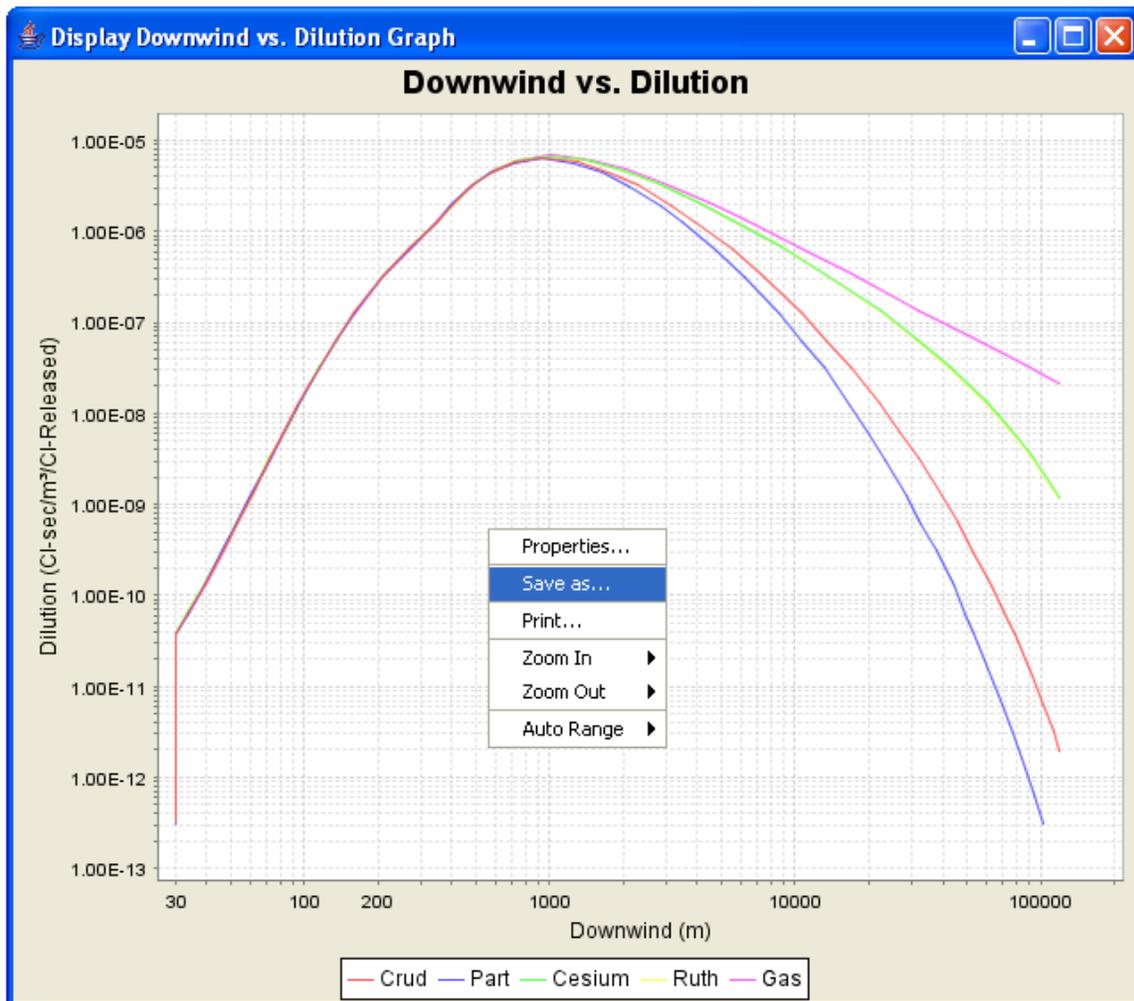


Figure 39: Graphical Output

The user has the ability to make changes and save graphical outputs. Left click over the graph window and select “Properties” or “Save as”, as shown in Figure 39. The graphical outputs can be saved as PNG Image Files. The properties that can be changed are:

- Title
- y-axis Name
- y-axis Range
- x-axis Name
- x-axis Range
- Background color

The legend and line colors cannot be changed. An example of these changes can be seen in Figure 40.

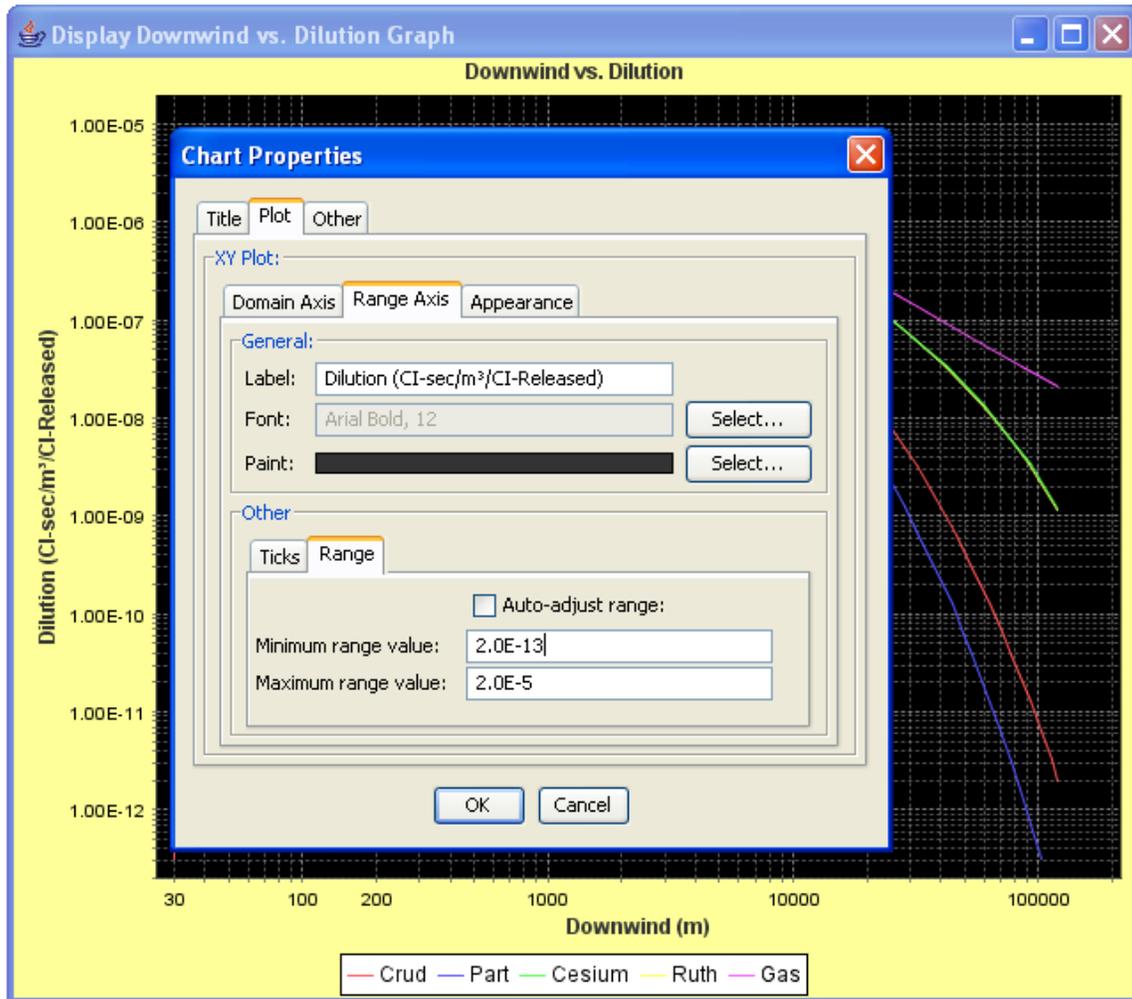


Figure 40: Graphical Output Property Changes

8. SAVING, RUNNING RADTRAN, EXITING

The input file can be saved with either the **Save** or the **Save As** icon See Section 4, above). Your file should 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 41. The file may be run in RADTRAN by clicking on the **Run RADTRAN** icon (the computer icon). A newly created or newly modified input file can be run even if it has not been saved.

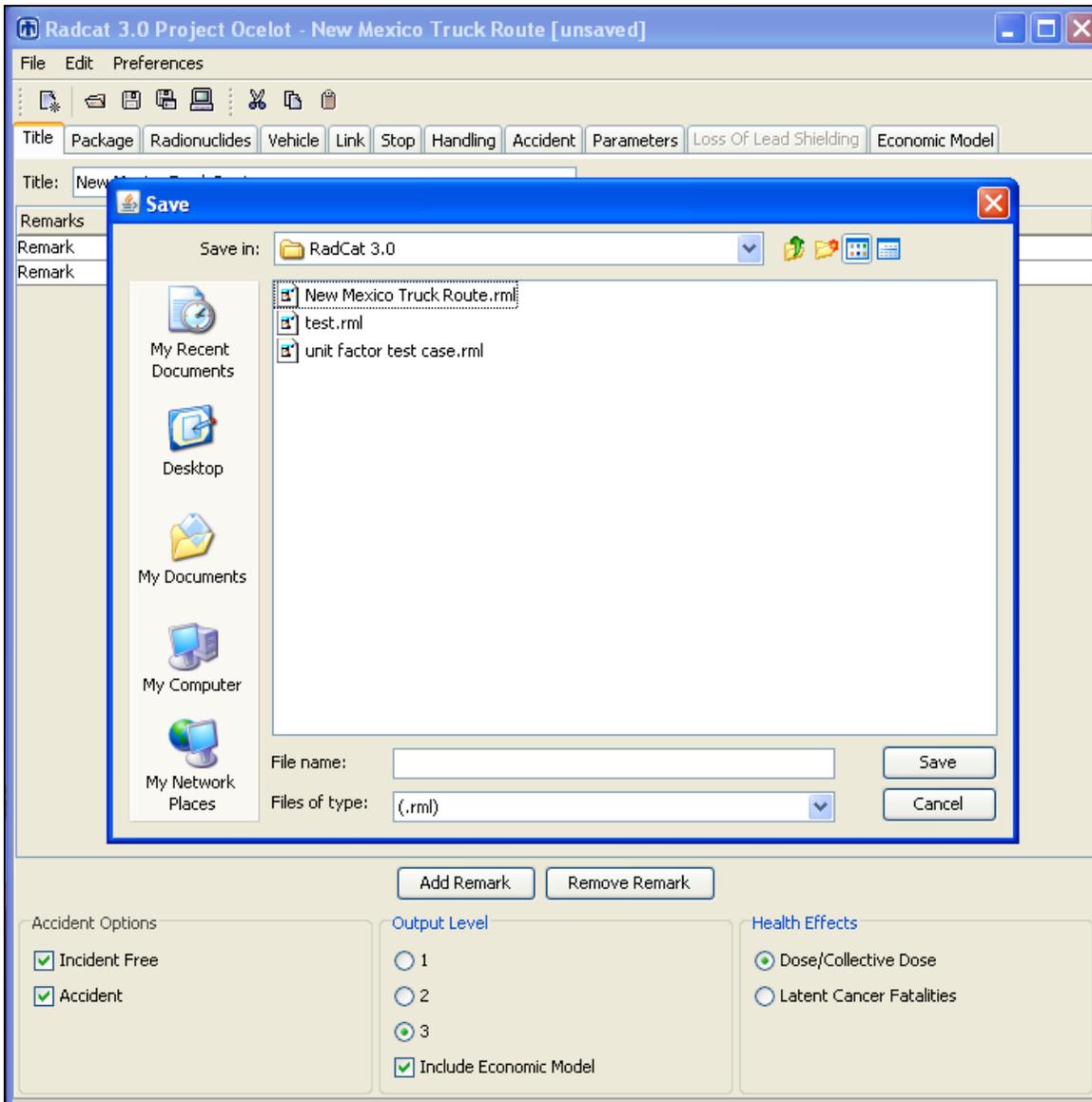


Figure 41: Saving a RadCat Input File

When RADTRAN is run, the output appears immediately on the screen, and may be printed and/or saved. The file that appears on the screen starts with an echo of the input file. The beginning of the output file is clearly marked. 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. Saving is necessary if anything is to be copied from the output file, since copying directly from the output file is not possible. An incomplete output file indicates some error in the input file that caused RADTRAN to abort. 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 42.

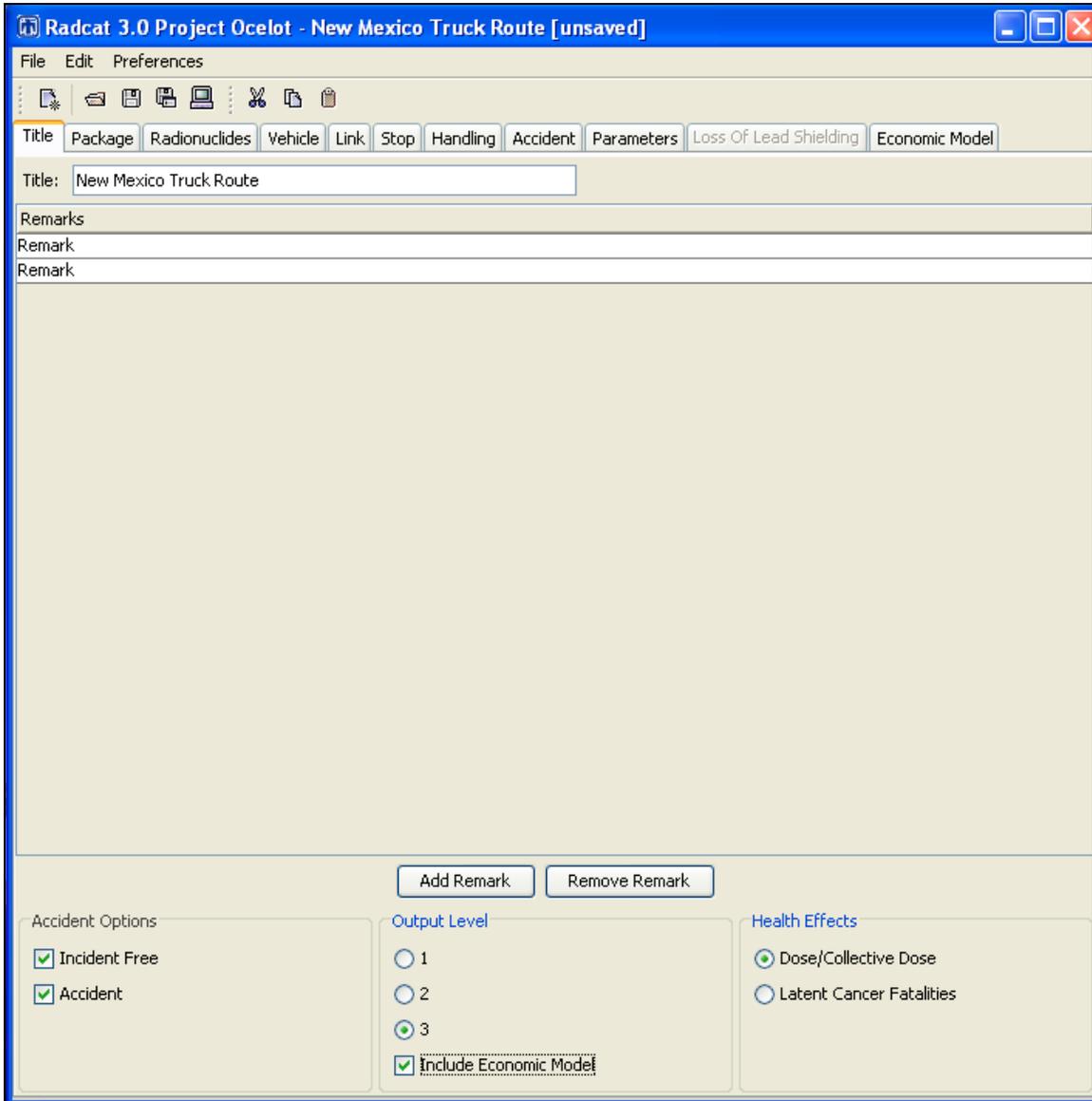


Figure 42: Closing RADTRAN / RadCat

9. REFERENCES

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APPENDIX A: RADTRAN 6.0 REFERENCE SHEET

Creating RADTRAN 6.0 Files with a Text Editor

Note: A text file must be saved with the “.INPUT” extension. The text “RADTRAN 6 March 2006” must be entered before the TITLE is entered..

Key:

[Brackets] indicate an optional statement

{Braces} indicate a required value

ALL CAPS indicates a keyword that must be entered

RADTRAN 6 March 2006

TITLE {**alphanumeric title**}

INPUT {**STANDARD (Default values) or ZERO**}

FORM {**UNIT for population dose or NONUNIT for health effects**}

DIMEN {**# of severity categories**} {**# of LOS severity categories**} {**# of isopleths for National Average Weather**}

PARAM {**0 no Econ model/1 Econ model**} {**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**}

[BQ_SV] (required for SI outputs)

[SI_INPUT 1] (required for SI inputs)

SEVERITY

NPOP = {**1 rural**}

NMODE = {**transport mode (see Mode Chart in Table 1)**}
{**Severity Fraction 1**} {**Severity Fraction 2**} {**Severity Fraction 3...**}

NPOP = {**2 suburban**}

NMODE = {**transport mode (see Mode Chart in Table 1)**}
{**Severity Fraction 1**} {**Severity Fraction 2**} {**Severity Fraction 3...**}

NPOP = {**3 urban**}

NMODE = {**transport mode (see Mode Chart in Table 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...**}

DEPVEL
Deposition Velocity of Group (m/s)

[GROUP=...]

[LOS_SHIELD]

[NPOP] = {**1 rural**}

[ACIDNT_PRB]
{**LOS Severity Fraction 1**} {**LOS Severity Fraction 2**} {**LOS Severity Fraction 3...**}

[FRAC_LOST]
{**Fraction of shielding lost 1**} {**Fraction of shielding lost 2**} {**Fraction of shielding lost 3...**}

[NPOP] = {**2 suburban**}

[ACIDNT_PRB]
{**LOS Severity Fraction 1**} {**LOS Severity Fraction 2**} {**LOS Severity Fraction 3...**}

[FRAC_LOST]
{**Fraction of shielding lost 1**} {**Fraction of shielding lost 2**} {**Fraction of shielding lost 3...**}

[NPOP] = {3 urban}
[ACIDNT_PRB]
{LOS Severity Fraction 1} {LOS Severity Fraction 2} {LOS Severity Fraction 3...}
[FRAC_LOST]
{Fraction of shielding lost 1} {Fraction of shielding lost 2} {Fraction of shielding lost 3...}

[ISOPLETHP]
[NPOP] = {1 rural}
{Rural population density of isopleth 1} {Rural population density of isopleth 2...}
[NPOP] = {2 suburban}
{Suburban population density of isopleth 1} {Suburban population density of isopleth 2...}
[NPOP] = {3 urban}
{Urban population density of isopleth 1} {Urban population density of isopleth 2...}
[AREADA]
{Area of Isopleth 1 (m²)} {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 in Table 4)

&& 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-m³/Ci-second)} {Groundshine dose factor (rem-m³/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)} {Class A waste concentration (Ci/m³)} {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

[PACKAGE] {alphanumeric identifier...}

[END]

VEHICLE {minus sign if shipment is exclusive} {transportation mode number (see Table 1 - ode chart)} {vehicle 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...}]

[VEHICLE {minus sign if shipment is exclusive...}]

[FLAGS]
 {see Flag Chart in Table 2}

[MODSTD]
 {see MODSTD Standard Values List in Table 3}

[ECONOMIC]
 {see Economic Model Default Values List in Table 5}

EOF

LINK {link identifier} {vehicle name} {segment length (km)} {velocity (kph)} {vehicle occupancy}
 {population density (persons/km²)} {vehicle density} {accident rate (acc/km)} {fatalities per
 accident} {R rural/S suburban/U urban} {1 interstate/2 non-interstate} {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
 (m)} {handling time per package (hr)}

[HANDLING] {handling identifier...}

[LOS_STOP] {LOS 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)}

[LOS_STOP] {LOS stop identifier...}

EOF
 EOF

Table 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 2: Flag Chart

Flag Name	<u>Flag Description</u>	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

Table 3: MODSTD Default VALUES LIST

MODSTD Name	<u>Description</u>	Default Value
BDF	<p>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 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.</p>	0.05
BRATE	<p>This factor represents breathing rate and is used for calculation of inhalation doses. The breathing rate (BRATE = 3.30E-04 m³/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 default value. The value in the cited table has been converted from liters per hour to m³/sec.</p>	3.30E-04
CULVL	<p>This factor describes Clean-Up Level, which is the required level to which contaminated surfaces must be cleaned up. The default value is the EPA guideline of 0.2 μCi/m² (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.</p>	0.2
EVACUATION	<p>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 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.</p>	1.0

MODSTD Name	<u>Description</u>	Default Value
GECON	<p>This parameter specifies the Genetic Effects Conversion Factor. The 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 F₁ 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).</p>	1.00E-04
INTERDICT	<p>This parameter specifies the threshold value for interdiction of contaminated land. The default value is 40, i.e., a value 40 times greater than CULVL, and it was taken from NUREG-0170 (NRC, 1977).</p>	40
LCFCON	<p>This parameter specifies the Latent Cancer Fatality (LCF) Conversion Factors; units are LCFs per rem. The 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 DRRF (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.</p>	5.0E-04 for the public 4.04E-04 for workers
LOS	<p>The parameter was used to analyze loss-of-shielding accidents. It is no longer used in RADTRAN analyses.</p>	
NE	<p>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.</p>	

MODSTD Name	<u>Description</u>	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 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 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 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

MODSTD Name	<u>Description</u>	Default Value
USWF	<p>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 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.</p>	0.1
ADJACENT	See DISTON	
CAMPAIGN	<p>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 default value is 0.0833 years. This is an average month in an average year, or 1/12th of a year.</p>	0.0833
DDRWEF	<p>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 default value of 0.0018 inspections/km is taken from Ostmeyer (1986).</p>	0.0018

MODSTD Name	<u>Description</u>	Default Value
	<p>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 default values, which are supplied for each link type, are from NUREG-0170 (NRC, 1977). The link types and values for each are:</p>	
DISTOFF	<p>FREEWAY Any limited-access divided highway. [30, 30, 800]</p>	30, 30, 800
	<p>SECONDARY Any non-limited-access highway that is not a city street (27, 30, 800)</p>	27, 30, 800
	<p>STREET Any city street. [5, 8, 800]</p>	5,8,800
	<p>RAIL Any rail right-of-way in the U.S. [30, 30, 800]</p>	30, 30, 800
	<p>WATER Any vessel. [200,200,800]</p>	200, 200, 1000
	<p>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.</p>	

MODSTD Name	<u>Description</u>	Default Value
	<p>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 <i>average</i> perpendicular distance between the shipment <i>centerline</i> and the <i>centerline</i> of oncoming traffic lanes(s). In the passing-vehicle case, DISTON represents the distance between the shipment <i>centerline</i> and the <i>centerline</i> of adjacent passing vehicles (HIGHWAY mode only). DISTON must be followed by a second keyword that specifies the link type. The default values in parentheses in the following list are taken from Madsen et al. (1986, p. 36-37).</p>	
DISTON	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
	<p>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.</p>	

MODSTD Name	<u>Description</u>	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 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 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 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 default value is 24.0 km/hr (15 mph) (NRC, 1977).	24
RAIL	See DISTOFF and DISTON	

MODSTD Name	<u>Description</u>	Default Value
RPD	<p>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 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.</p>	6.0
RR	<p>This parameter specifies the Rural Shielding Factor. The 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.</p>	1.0
RS	<p>This parameter specifies the Suburban Shielding Factor. The 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.</p>	0.87
RU	<p>This parameter specifies the Urban Shielding Factor. The 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.</p>	0.018

MODSTD Name	<u>Description</u>	Default Value
SECONDARY	See DISTOFF and DISTON	
SMALLPKG	<p>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 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.</p>	0.5
STREET	See DISTOFF and DISTON	

Table 4: Definitions for Input to the 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

Table 5: Economic Model Default Values

Parameter Name	Description	Average Value	Units
AF_C	Footprint of commercial buildings	337	m ²
AF_I	Footprint of industrial buildings	6620	m ²
AF_R	Footprint of residential buildings	118	m ²
ALOT_C	Area of commercial lots	930	m ²
ALOT_I	Area of industrial lots	9700	m ²
ALOT_R	Area of residential lots	223	m ²
BARL_DR_LM	External dose rate per barrel of resin	5.0	mrem/hour
CO_BARL_DR	External dose rate per 1 Ci of Co-60	269.7	mrem/hour
CROP_PROFT	Annual crop profit	0.01303	\$/m ²
C_WASH	Cost of washing contaminated area	32.29	\$/m ²
EVAC_CST_R	Rural evacuation cost	7.88	\$/person-km ²
EVAC_CST_S	Suburban evacuation cost	13.61	\$/person-km ²
EVAC_CST_U	Urban evacuation cost	13.61	\$/person-km ²
F_CR	Rural commercial land use fraction	0.01	
F_CS	Suburban commercial land use fraction	0.14	
F_CU	Urban commercial land use fraction	0.37	
F_IR	Rural industrial land use fraction	0.01	
F_IS	Suburban industrial land use fraction	0.09	
F_IU	Urban industrial land use fraction	0.11	
F_RR	Rural residential land use fraction	0.03	
F_RS	Suburban residential land use fraction	0.28	
F_RU	Urban residential land use fraction	0.24	
F_SR	Rural soil land use fraction	0.95	
F_SS	Suburban soil land use fraction	0.41	
F_SU	Urban soil land use fraction	0.09	
FBC	Fraction of building surfaces contaminated	0.449	
FR_C	Rural soil land use fraction for crops	0.20	
FR_L	Rural soil land use fraction for livestock	0.28	
OH_C	Average commercial building outside height	16.40	m
OH_I	Average industrial building outside height	6.05	m
OH_R	Average residential building outside height	5.32	m
RHO_RD_R	Rural road density	5.97E-04	m of road/m ² of land
RHO_RD_S	Suburban road density	8.11E-04	m of road/m ² of land
RHO_RD_U	urban road density	8.06E-02	m of road/m ² of land
RHO_RESIN	Resin density	1.28	g/cm ³
ROAD_W	Road width	8.84	m
SOIL_COST	Cost of soil removal	10	\$/m ³
SOIL_DPTH	Contaminated soil depth	0.03	m
STCK_PROFIT	Bi-annual profit from livestock	0.02499	\$/m ²
VOL_BARREL	Volume of waste container	0.2167	m ³

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 ($\text{rem}\cdot\text{m}^3/\text{Ci}\cdot\text{sec}$). Source: FGR 12 (multiply by 3.7×10^{12} to convert from SI units to historical units)
4. Groundshine Dose Factor ($\text{rem}\cdot\text{m}^2/\mu\text{Ci}\cdot\text{day}$). Source: FGR 12 (multiply by 3.197×10^{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 3.7×10^{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 3.7×10^{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 3.7×10^{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 3.7×10^{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-m³/Ci-sec)	Groundshine (rem-m²/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-m³/Ci-sec)	Groundshine (rem-m²/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-m³/Ci-sec)	Groundshine (rem-m²/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-m³/Ci-sec)	Groundshine (rem-m²/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-m³/Ci-sec)	Groundshine (rem-m²/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 1.00×10^{12} Bq/m².

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 5×10^4 square meters (1 person per 1×10^4 square meters).

The individual backyard farmer dose is in units of (Sv/m²) and the societal dose is in units of (person-Sv/m²). The following tables list values taken directly from the COMIDA2 ingestion file for Na-22 radionuclide:

Julian Date	Na-22 Effective Backyard Farmer Dose Values								
	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 Date	Na-22	Thyroid Backyard Farmer Dose Values							
	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	Gonad Societal Dose Values							
	CROP 1	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	Breast Societal Dose Values							
	CROP 1	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 Lungs Societal Dose Values								
	CROP 1	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 Red Marrow Societal Dose Values								
	CROP 1	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 Bone Surface Societal Dose Values								
	CROP 1	CROP 2	CROP 3	CROP 4	CROP 5	CROP 6	CROP 7	CROP 8	CROP 9
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	Thyroid Societal Dose Values								
	Na-22 CROP 1	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	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	Remainder Societal Dose Values								
	Na-22 CROP 1	CROP 2	CROP 3	CROP 4	CROP 5	CROP 6	CROP 7	CROP 8	CROP 9
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	Effective Societal Dose Values								
	Na-22 CROP 1	CROP 2	CROP 3	CROP 4	CROP 5	CROP 6	CROP 7	CROP 8	CROP 9
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:

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

where:

D = The backyard farmer dose (Rem)
 Crop_i = The crop dose value for the ith crop (Sv/m²)
 IG = Initial ground concentration (Bq/m²)
 CF = Conversion factor (3.7 x 10⁶ 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/m²
 Average crop dose value for the thyroid dose = 16,396 Sv/m²
 Initial ground concentration = 1.00 x 10¹² Bq/m²
 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:

	<u>Hand Calculation</u>	<u>RADTRAN 5.6</u>	<u>Error</u>
Effective:	3.03 x 10 ⁻² Rem	3.07 x 10 ⁻² Rem	-1.3%
Thyroid:	2.49 x 10 ⁻² Rem	2.47 x 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:

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

where:

- D = The societal ingestion dose (Person-Rem)
- Crop_k = The crop dose value for the kth crop (Person-Sv/m²)
- IG = Initial ground concentration (Bq/m²)
- CF = Conversion factor (3.7 x 10¹² 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 ath severity category
- PA_a = Probability of an accident for the ath severity category
- RF_a = Release fraction of the ath severity category
- NC_j = Number of curies for the jth radionuclide (Ci)
- CQ_i = The Chi/Q with deposition value for the ith isopleth (s/m³)
- AD_i = Area of the ith isopleth (m²)
- AD_(i-1) = Area of the (i-1)th isopleth (m²)
- 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/m²
Average crop dose value for the lung dose = 1.779 Sv/m²
Initial ground concentration = 1.00 x 10¹² Bq/m²

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

	<u>Hand Calculation</u>	<u>RADTRAN 5.6</u>	<u>Error</u>
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:

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

where:

- D = The societal ingestion dose (Person-Rem)
- Crop_k = The crop dose value for the kth crop (Person-Sv/m²)
- IG = Initial ground concentration (Bq/m²)
- CF = Conversion factor (3.7 x 10¹² 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 ath severity category

- PA_a = Probability of an accident for the ath severity category
- RF_a = Release fraction of the ath severity category
- NC_j = Number of curies for the jth radionuclide (Ci)
- CQ_i = The Chi/Q deposited for the ith isopleth (1/m²)
- AD_i = Area of the ith isopleth (m²)
- AD_(i-1) = Area of the (i-1)th isopleth (m²)

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/m²
- Average crop dose value for the lung dose = 1.779 Sv/m²
- Initial ground concentration = 1.00 x 10¹² Bq/m²

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

	<u>Hand Calculation</u>	<u>RADTRAN 5.6</u>	<u>Error</u>
Effective:	5.41 x 10 ⁻³ Person-Rem	5.46 x 10 ⁻³ Person-Rem	1.0%
Lung:	4.37 x 10 ⁻³ Person-Rem	4.42 x 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 : <i>Rural</i>	470 vehicles/hr
54 persons/km ² – 1284 persons/km ² : <i>Suburban</i>	780 vehicles/hr
1284 persons/km ² and up: <i>Urban</i>	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.

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

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

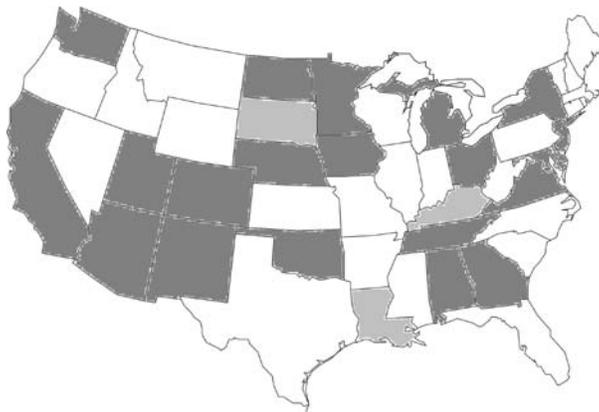


Figure D-1: States currently considered in this report (dark gray), and states whose data are available, but for which an analysis was not completed (light gray)

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									
Region	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)
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.

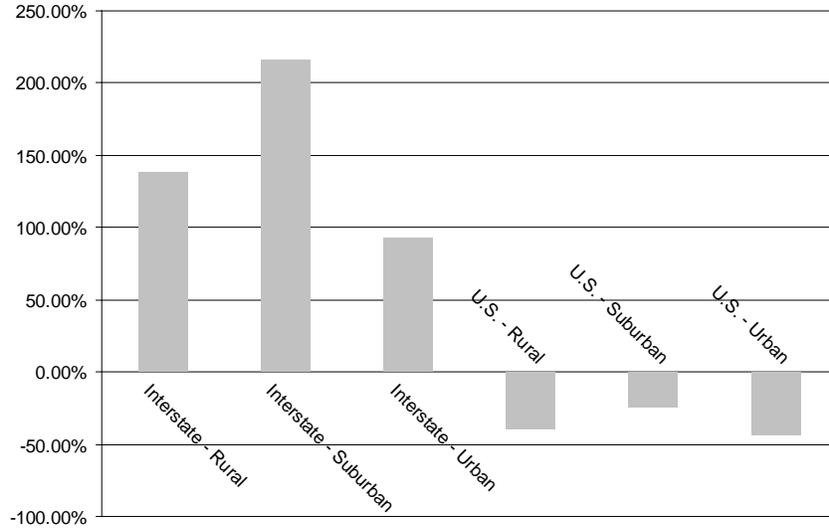


Figure D-2: Departure of National Average Traffic Densities from Historical Values

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