LLNL-TM-411345 Rev. 1

HotSpot

Health Physics Codes
Version 2.07.1
User's Guide

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1. Getting Started

About This Manual

The HotSpot Health Physics Codes, or HotSpot program, provides a first-order approximation of the radiation effects associated with the atmospheric release of radioactive materials. The HotSpot program was created to equip emergency response personnel and planners with a fast, field-portable set of software tools for evaluating incidents involving radioactive material. The software is also used for safety-analysis of facilities handling radioactive material. This program is designed for short-range (less than 10 km), and short-term (less than a few hours) predictions.

System Requirements

HotSpot requires the following:

- Windows® 95/98/2000/NT/XP/Vista/Windows 7 operating system
- 64 megabytes RAM
- 300 megabytes disk space
- Optional GPS device (NMEA 0183 output format)

Contacting NARAC for HotSpot Support

Lawrence Livermore National Laboratory's National Atmospheric Release Advisory Center (NARAC), provides HotSpot support.

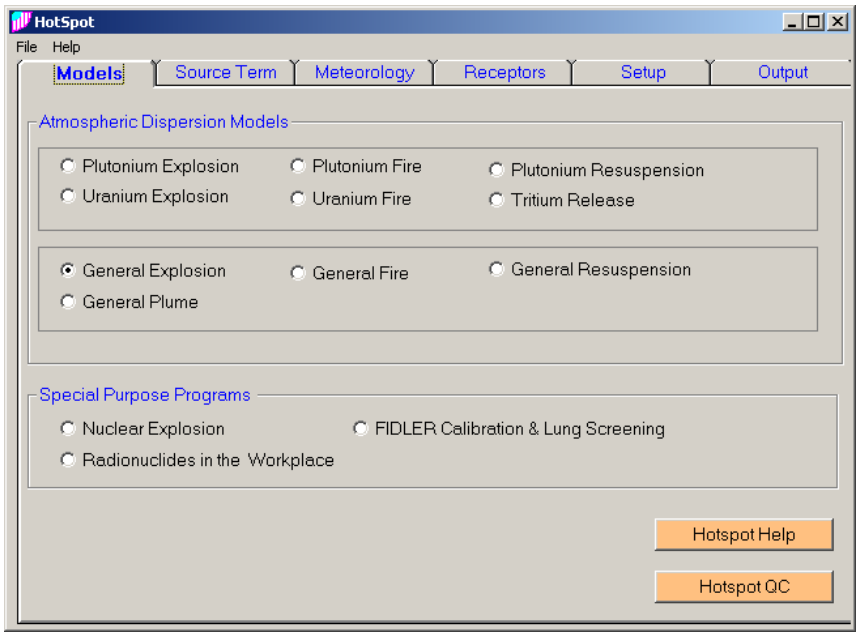
For software technical support, please contact:

NARAC Customer Support
Phone: (925) 422-9159
Hours: 7:30am – 4:15pm Pacific Time
Monday-Friday, except holidays

Web: http://narac.llnl.gov
Email: narac@llnl.gov

2. Introduction

The Department of Energy (DOE) funds ongoing maintenance and development of the HotSpot Health Physics Codes. The HotSpot program has been distributed worldwide since 1988. HotSpot codes are a conservative (estimated radiation dose data are usually greater) estimation of the radiation effects associated with the atmospheric release of radioactive materials. The main user interface screen for HotSpot is shown below.



Atmospheric Dispersion Models

To expedite the initial assessment of accidents involving nuclear weapons, HotSpot includes atmospheric dispersion models for a plutonium explosion (non-nuclear), fire, and resuspension; a uranium explosion (non-nuclear), and fire; and a tritium release. Additional "General" programs address the release of any radionuclide or mixture in the HotSpot library (ICRP 30, ICRP60+, and Acute). These models estimate the short-range (less than 10 km), downwind radiological impact following the release of radioactive material resulting from a short-term release (less than a few hours), explosive release, fuel fire, or an area contamination event.

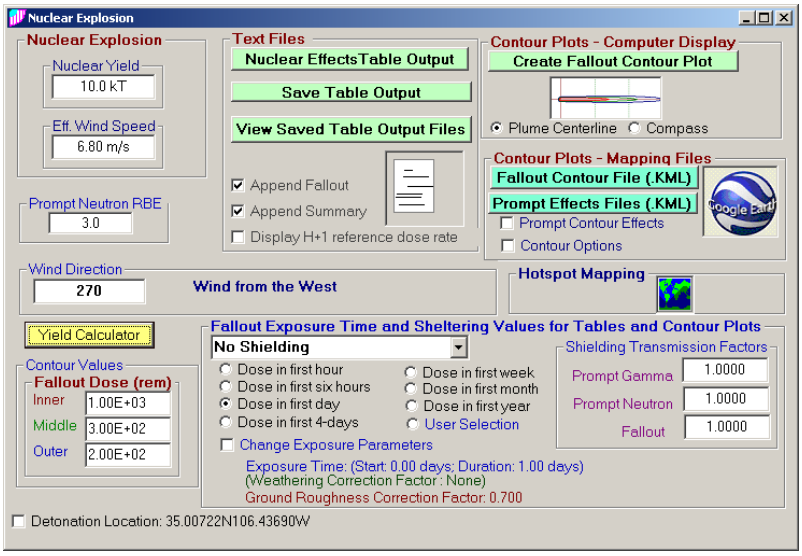
Example scenarios for each of the dispersion types are available under the program's File menu. In addition to providing example models, HotSpot allows the user to save a scenario; and create, edit, or add to a radionuclide mixture. Up to 50 radionuclides can be included to create a mixture.

Special Purpose Programs

In addition to the atmospheric dispersion models, four special purpose programs are also included in HotSpot: Nuclear Explosion (nuclear yield), FIDLER Calibration and Lung Screening, Radionuclides in the Workplace, and a module to calculate Percentile Dose using Historical Meteorological Data.

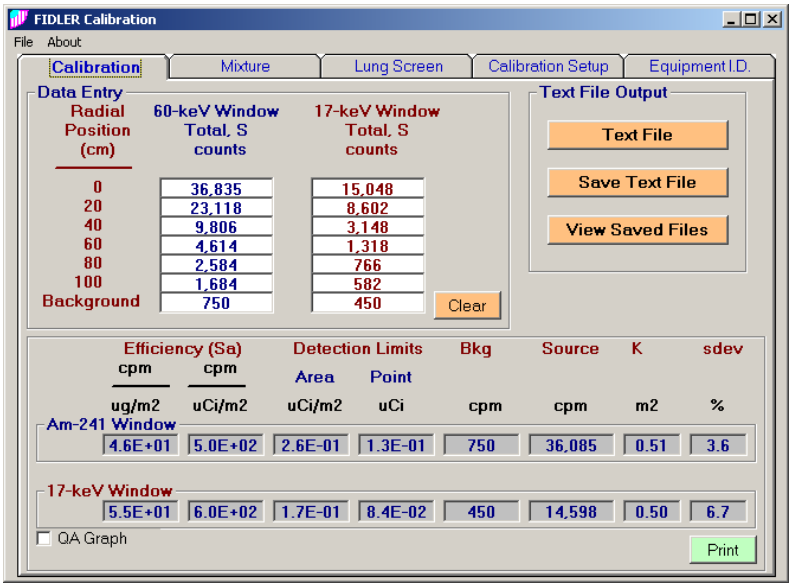
Nuclear Explosion

The Nuclear Explosion program estimates the effects of a surface-burst nuclear weapon. These include prompt effects (neutron and gamma, blast, and thermal), and fallout information. Fallout information includes fallout arrival time, dose rate at arrival time, and integrated dose contours for several time periods, for example, the first 6 hours, first day, first week, etc. Users can enter a specific start time and duration of exposure. The user interface screen for the Nuclear Explosion program is shown below.



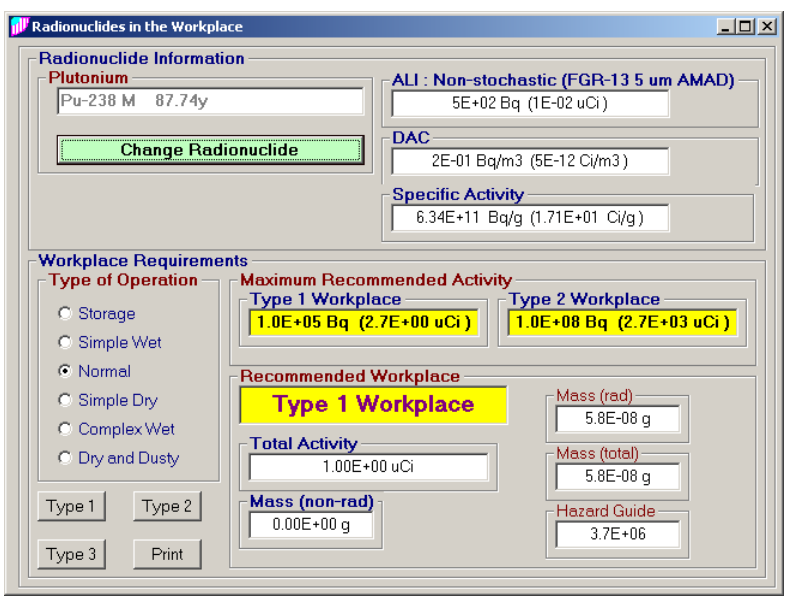
FIDLER Calibration and Lung Screening

The FIDLER (Field Instrument for the Detection of Low-Energy Radiation) program is a tool to calibrate instruments for ground-survey measurements of plutonium and provide initial screening for possible plutonium uptake in the lung. However, the FIDLER program can also be applied to any instrument suitable for measuring external radiation levels and non-plutonium mixtures. Current versions of the FIDLER instrument are coupled with a Multi Channel Analyzer (MCA). These advanced MCA instruments are referred to as the Violinist and more recently the Stradivarius.



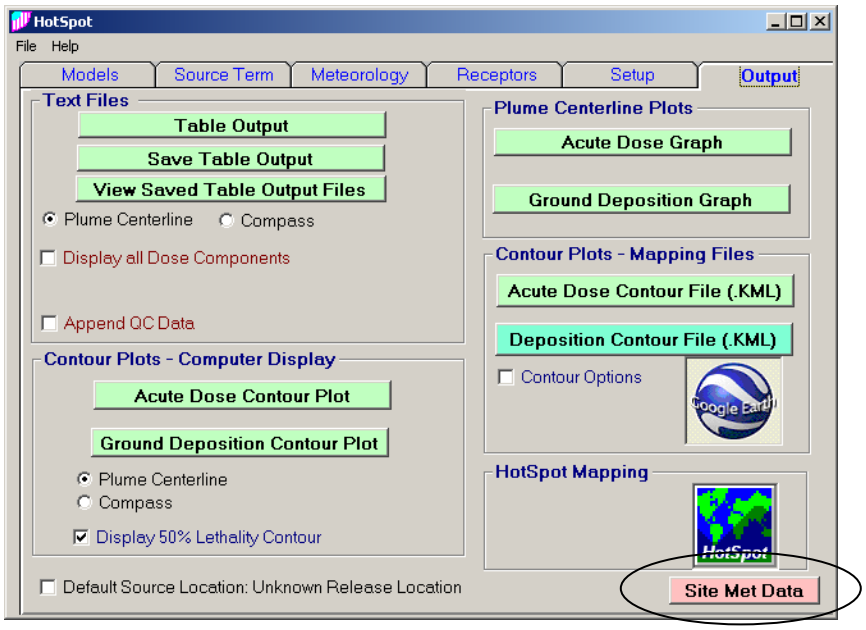
Radionuclides in the Workplace

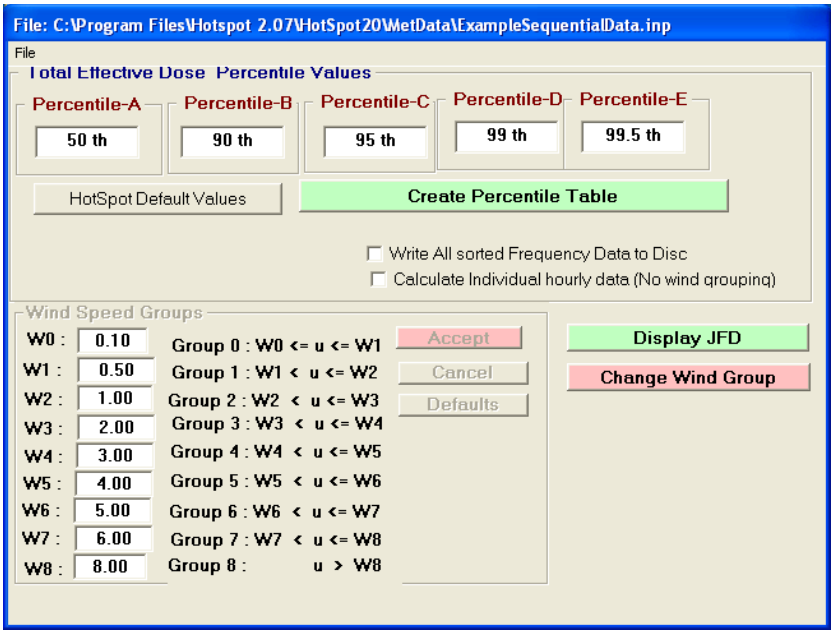
The Radionuclides in the Workplace program provides a guide for initial planning of experiments and workplace environments. The selection of a workplace is generally based on the relative hazard of an operation and on the quantity and radiotoxicity of the radionuclides involved. The relative hazard of an operation is determined by evaluating the type of radionuclide to be used, its chemical and physical form, the mass of the material containing the radionuclide, and the nature of the operation to be performed. Workplaces are divided into three classifications: Type 1, Type 2, and Type 3.



Percentile Dose using Historical Meteorological Data

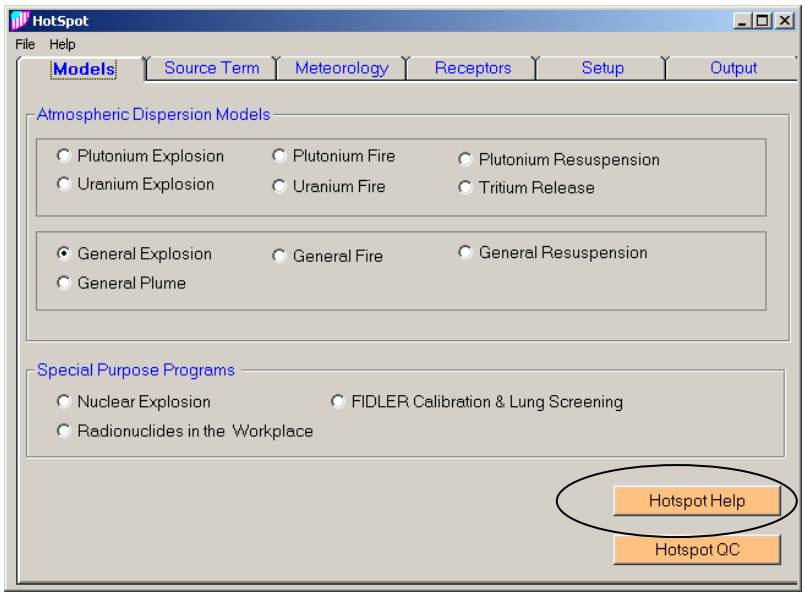
This module calculates the 95th percentile of the dose distribution for up to 20 radial centerline distances in each of 16 wind direction sectors (direction dependent), and all 16 sectors (direction independent). Default percentile values are 50th, 90th, 95th, 99th, and 99.5th. Users may select other percentile values as needed (50th – 100th). HotSpot inputs a sequential file of up to 5 years of hourly meteorological observations and either determines the percentile data via an intermediary Joint Frequency Distribution (JFD) or calculating the dose value for each hourly data set. The JFD method is much faster than the "brute force" individual dose calculations. The JFD uses 9 wind speed groups, and users can change the wind group values.



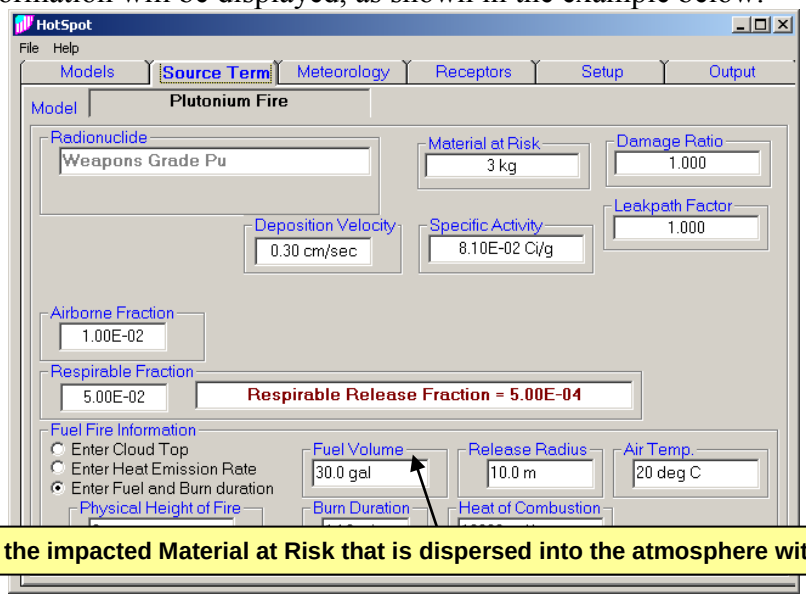


Additional Information and HotSpot Help

Clicking on the "HotSpot Help" button (circled below) will provide additional information.



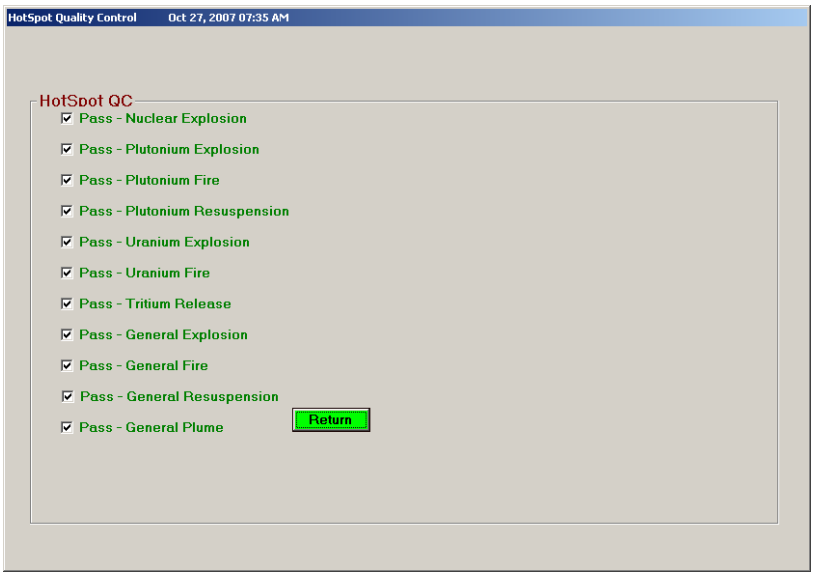
There are also hot buttons within the program. When scrolling over select fields, additional information will be displayed, as shown in the example below.



Fraction of the impacted Material at Risk that is dispersed into the atmosphere with an AMAD of 1 micrometer

HotSpot QC

The HotSpot program has been designed with a Quality Control (QC) feature that verifies that the codes are functioning properly. It is a good idea to run this check to confirm HotSpot has been installed correctly on your system. To do so, **CLICK HOTSPOT QC** located at the lower right of the opening screen. A checkmark and message indicating that all systems pass should appear in green. In the event a system is highlighted in red and indicates that it did not pass, contact NARAC at Lawrence Livermore National Laboratory.



Basis of the HotSpot Codes

The HotSpot Health Physics codes were created to provide emergency response personnel and emergency planners with a fast, field-portable set of software tools for evaluating incidents involving radioactive material. The software is also used for safety-analysis of facilities handling radioactive material. HotSpot atmospheric dispersion models codes are a first-order approximation of the radiation effects associated with the short-term (less than a few hours) atmospheric release of radioactive materials.

Verification

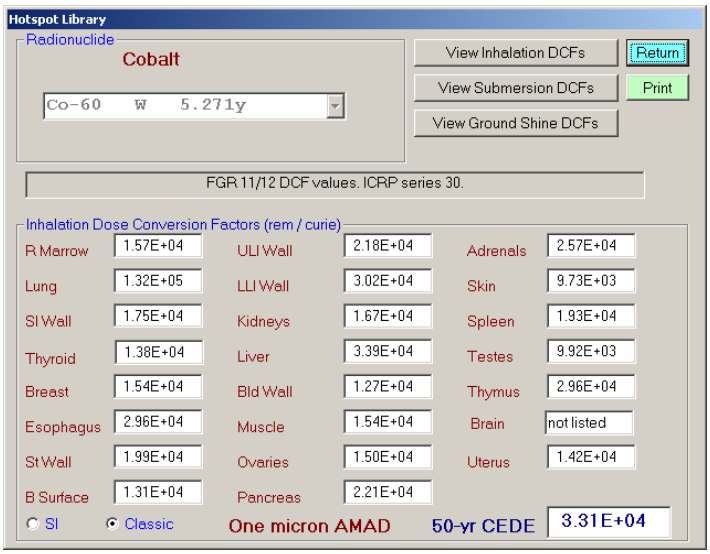
HotSpot codes involving the dispersal of radioactive material use the Gaussian model—the workhorse for atmospheric dispersion calculations that is used by most government agencies, including the Environmental Protection Agency in its document, "Technical Guidance for Hazards Analysis—Emergency Planning for Extremely Hazardous Substances," U.S. Environmental Protection Agency, Federal Emergency Management Agency, and U.S. Department of Transportation, December 1987. The adequacy of this model for making initial dispersion estimates or worst-case safety analyses has been tested and verified for many years (Handbook on Atmospheric Diffusion, DOE/TIC-

11223 (DE82002045), prepared for the Office of Health and Environmental Research, Office of Energy Research, U.S. Department of Energy, 1982).

To more accurately estimate the radiological effects in proximity of the release area, for example, 100 meters from the point of radioactive release, virtual source terms are used to model the initial atmospheric distribution of source material following an explosion, fire, or resuspension zone, or user-input geometry.

The HotSpot codes are continuously updated to incorporate the most current and approved radiological dose conversion data and methodologies. To ensure correct implementation of the HotSpot algorithms following software revisions, each HotSpot module is thoroughly tested against a library of case studies. HotSpot allows the user to run this automatic verification process. Each case study is executed with all parameters/defaults set to the exact case-study values stated in the HotSpot documentation. The resulting output is compared with the documented results. This ensures that the HotSpot program has been properly installed and all algorithms and assumptions are working correctly.

Radionuclide Library



HotSpot uses the radiation dosimetry methodologies recommended by the International Commission on Radiological Protection (ICRP). These methodologies are summarized in Federal Guidance Report No. 11 (FGR-11, 1988), Federal Guidance Report No. 12 (FGR-12, 1993), and Federal Guidance Report No. 13 (FGR-13). FGR-11 provides dose coefficients in the form of 50-year integrated dose equivalents for acute inhalation of radionuclides and is based on the biokinetic and dosimetric models of ICRP Publication 30 (1979, 1980, 1981, 1988). FGR-12 provides dose coefficients in the form of dose per unit time-integrated exposure for external exposure to radionuclides in air, water, or soil.

FGR-13 provides dose coefficients using the new ICRP-66 lung model and ICRP series 60/70 methodologies, Eckerman *et al* (2010).

In addition to the inhalation 50-year Committed Effective Dose Equivalent DCFs, acute DCFs are available for estimating deterministic effects. This acute mode can be used for estimating the immediate radiological impact associated with high acute radiation doses (applicable target organs are the lung, small intestine wall, bone marrow and thyroid), Eckerman *et al* (2010).

A one micron activity median aerodynamic diameter (1 AMAD) is assumed. HotSpot supports both classic units (rem, rad, curie) and SI (Sv, Gy, Bq) units. Users can add radionuclides and custom mixtures (up to 50 radionuclides per mixture).

Summary

HotSpot FGR-11 Option

- Old Lung Model (ICRP-30)
- ICRP Publication 26 (1977) Tissue Weighting Factors
- Absorption Types D, W, Y.

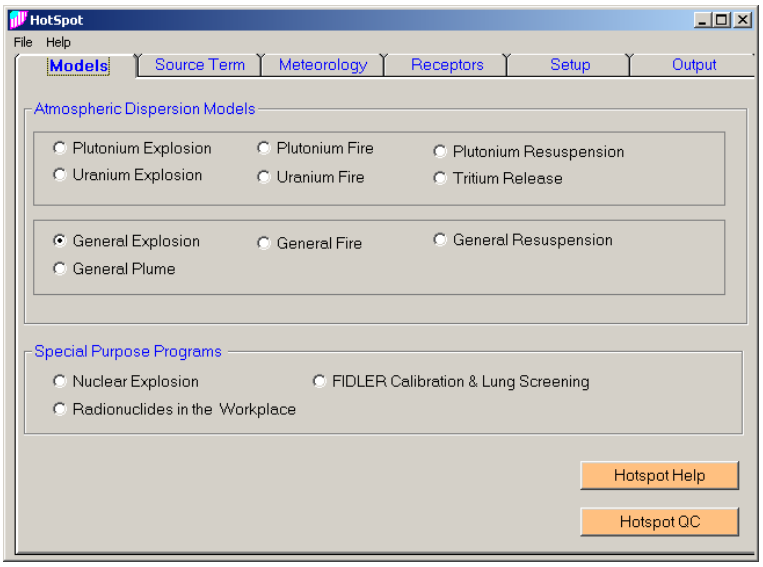
HotSpot FGR-13 Option

- New Lung Model (ICRP-66)
- ICRP Publication 60 (1991) Tissue Weighting Factors
- Absorption Types F, M, S.

Old ICRP 26/30 (HotSpot FGR-11 Option)	**New ICRP 60/66 (HotSpot FGR-13 Option)**
Committed effective dose equivalent	**Committed effective dose**
Committed dose equivalent	**Committed equivalent dose**
Cumulative total effective dose equivalent	**Cumulative total effective dose**
Dose equivalent	**Equivalent dose**
Effective dose equivalent	**Effective dose**
Quality factor	**Radiation weighting factor**
Weighting factor	**Tissue weighting factor**
Total effective dose equivalent	**Total effective dose**

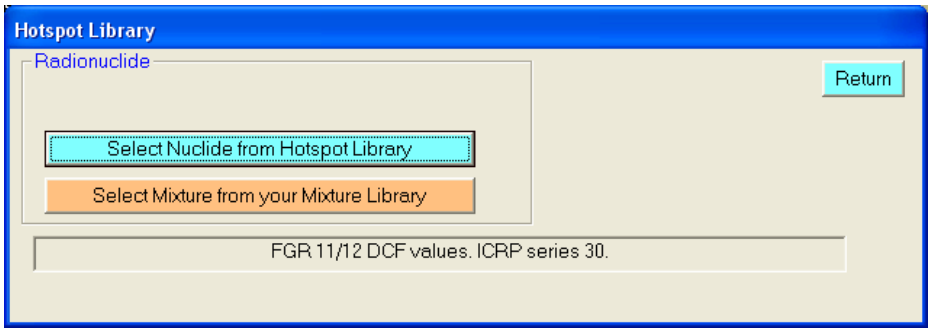
3. Using a HotSpot Program

This section steps through an example dispersion model to highlight some of the features of the HotSpot program.

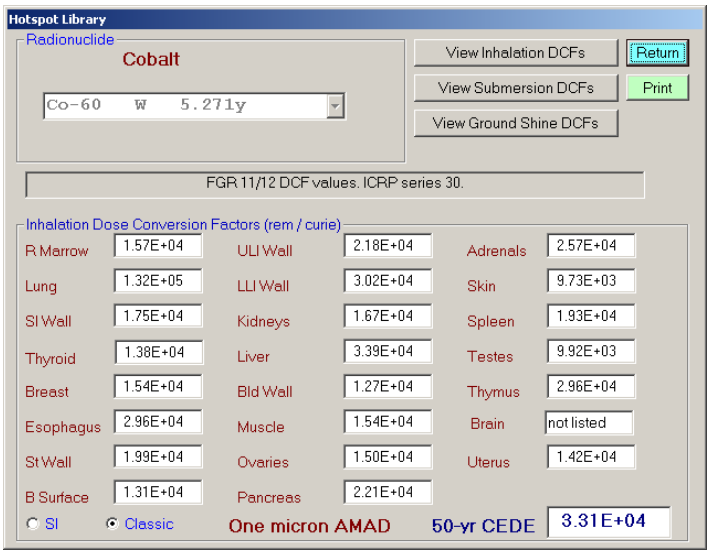


From the opening screen, select a dispersion model or scroll under the File menu to open a saved scenario or to create or edit a mixture. Then, navigate through each of the tabs: **Source Term**, **Meteorology, Receptors**, **Setup**, and **Output**, entering all criteria specific to the release. Default criteria based on typical data for each of the dispersion types are included in HotSpot. However, you may change these values.

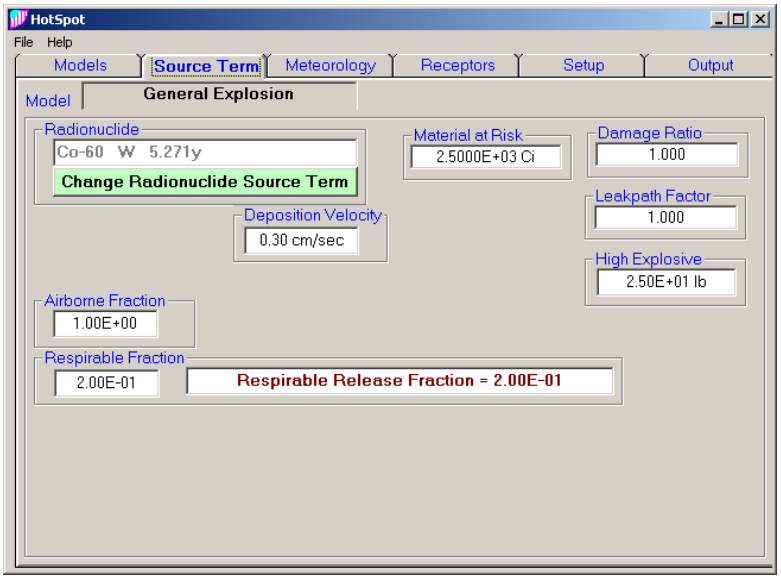
When one of the four general dispersion models (explosion, fire, resuspension, and plume) is chosen, a prompt will appear to select a radionuclide from the HotSpot Library or to select a mixture from your mixture library.



After selecting a radionuclide(s) involved in the general release, **CLICK OK** and a summary of dose conversion factors (DCFs) for various organs and areas of the body will be displayed. Inhalation, submersion, and ground-shine DCFs may be displayed as applicable.



CLICK RETURN to continue imputing data under the **Source Term** tab.



Material at Risk (MAR), is the total quantity of the radionuclide involved in the release scenario. ***Damage Ratio(DR),*** is the fraction of the MAR that is actually impacted in the release scenario. The ***Leakpath Factor (LPF)*** is the fraction of the MAR that passes through some confinement or filtration mechanism. For unmitigated release scenarios, the

Leakpath Factor is 1. ***Airborne Fraction (AF)*** is the fraction of the MAR that is aerosolized and released to the atmosphere. The ***Respirable Fraction (RF),*** is the fraction of aerosolized material that is respirable (Aerodynamic Diameter (AD), ≤ 10 microns). The ***Respirable Release Fraction*** is the fraction of the MAR that is dispersed into the atmosphere with an AD ≤ 10 microns. (Respirable release fraction = AF × RF). The ***Non-Respirable Release Fraction*** is the fraction of the MAR that is dispersed into the atmosphere with an AD in excess of 10 microns. (Non-respirable release fraction = AF × (1 – RF). The final HotSpot respirable airborne source term is,

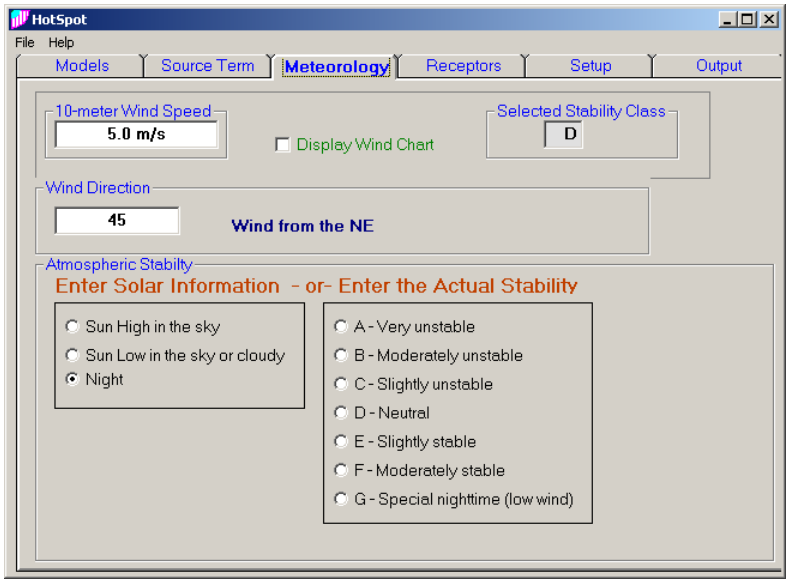
Respirable Source Term = MAR x DR x LPF x AF x RF

Non-respirable Source Term = MAR x DR x LPF x AF x (1-RF)

The ***Deposition Velocity*** is the ratio of the observed respirable deposition flux and the observed respirable air concentration near the ground surface. The total airborne source term may include both respirable and non-respirable release components. The respirable release component (the quantity of material that is respirable and available for dispersion in the atmosphere) has a separate respirable deposition velocity than the non-respirable release component (the quantity that is non-respirable and available for dispersion into the atmosphere). The Respirable Release component is the fraction of the total quantity of material involved in the fire, explosion, etc., that is respirable and available for dispersion into the atmosphere. This component has a separate respirable deposition velocity (default value of 0.3 cm/sec for non noble gases), and is used to determine the inhalation, groundshine, submersion doses, and plume depletion due to the respirable component of the source term.

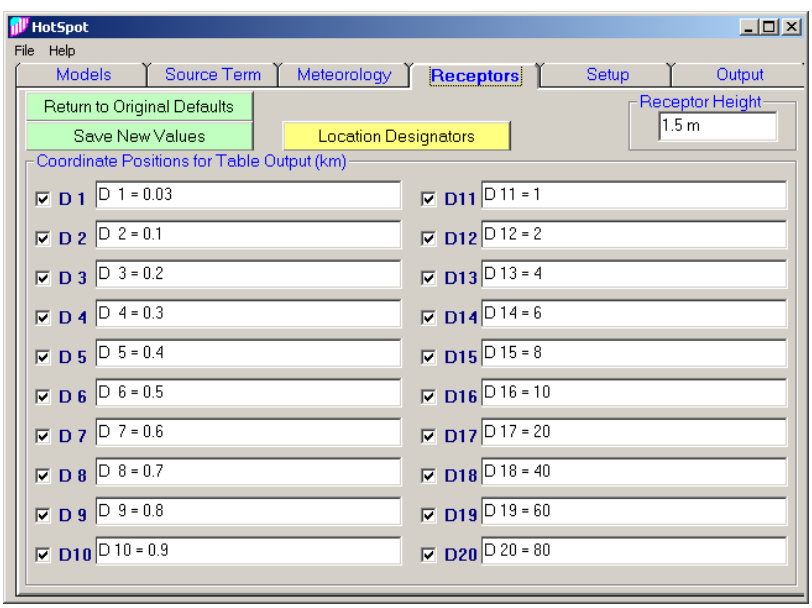
After entering information about the source of the release, go to the **Meteorology** tab and enter applicable wind and solar data. You may also select specific atmospheric stability classifications, such as A-G.

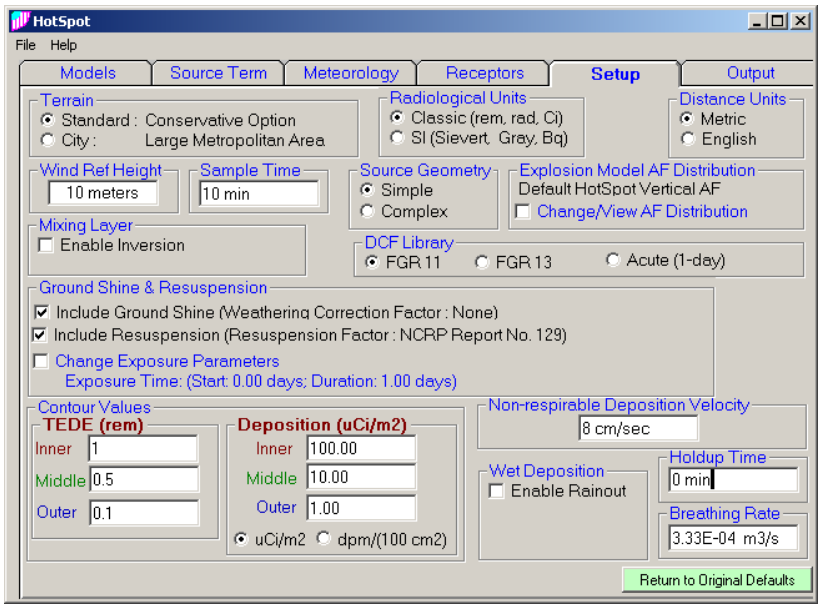
10-meter Wind Speed is the wind speed at a reference height of 10 meters. (Under the **Setup** tab, the default height can be changed to any value from 2 to 100 meters.) In the Selected ***Stability Class*** window, choose the atmospheric stability classification from among the descriptions provided. The azimuth of the ***Wind Direction*** (direction wind is coming <u>from</u>).is given in degrees: 0 = wind from the north, 90 = wind from the east, 180 = wind from the south, and 270 = wind from the west.



Next, go to the **Receptors** tab to select specific downwind locations for the HotSpot table output. Default coordinates will be provided for distances (in kilometers) from the source. Distance values can be changed. To enter an off-axis position, enter the *x*-distance and *y*-distance (in kilometers) separated by a semicolon. For example, 3.23; 0.22 is a location with an *x*-coordinate of 3.23 km and a *y*-coordinate of 0.22 km. To save these values in a file, **CLICK SAVE NEW VALUES**. The Location Designators button allows you to add names and distance values for a particular location, such as a local school, office building, or hospital.

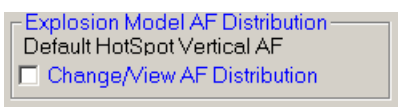
In the ***Receptor Height*** window, enter a range that is between 0 and 200 meters. The default value of 1.5 meters is typical for the breathing zone near the ground service.



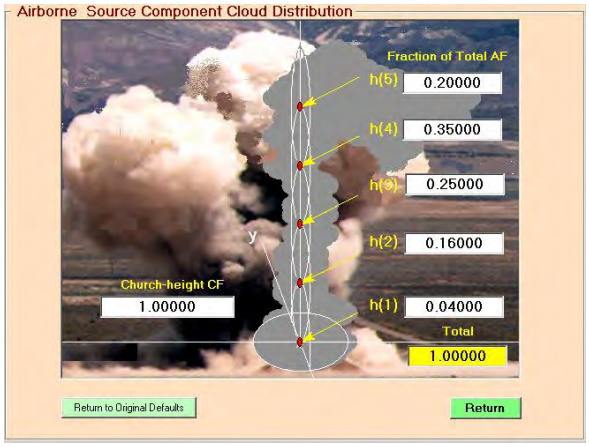


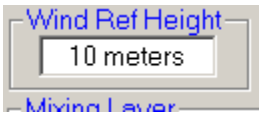
Under the **Setup** tab, replace any of the default values with those that are specific to the release.

Choosing ***City terrain*** will usually result in lower doses than those displayed for ***Standard***, due to the increased diffusion from the turbulence caused by larger building structures. Choosing ***Standard*** terrain will usually produce the most conservative estimates (higher potential doses).

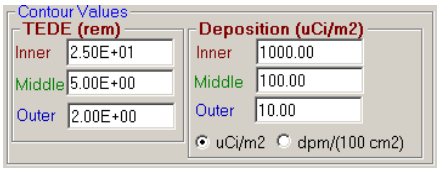


If a check is placed in front of ***Change/View Vertical AF Distribution***, you will be prompted to enter a custom vertical source distribution for the explosion release model. The default values are base on experiments involving 100+ pounds of high explosive. You also have the option of setting a "Church-height Correction Factor" to adjust the height of the stabilized plume.



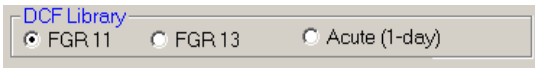


Wind Ref Height is the height at which the wind speed is referenced. Wind speed data are typically referenced to a height of 10 meters. The actual data might be measured at a different height (e.g., using data from a 61 meter meteorological tower and then these data are adjusted to a 10-meter reference height by the wind height power law.)

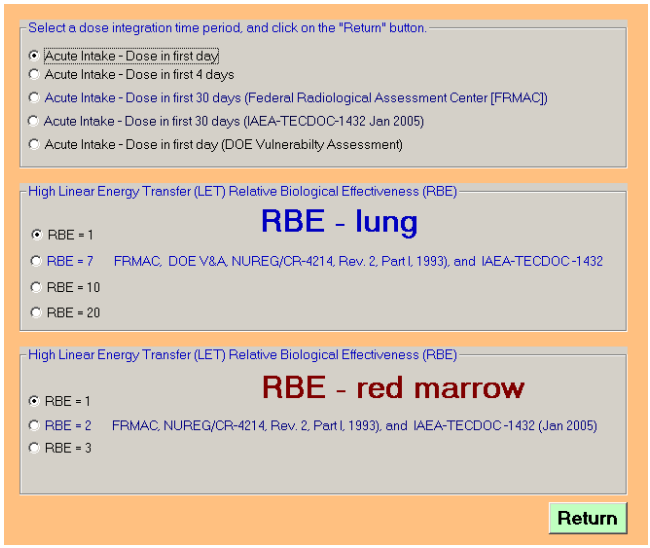


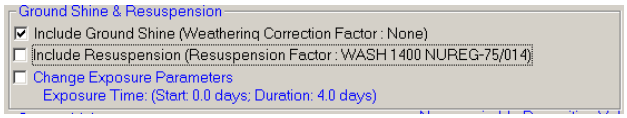
Contour Values are the TEDE and Deposition values used for the contour plots. TEDE and Deposition contour values must follow a progression. Specifically, the inner TEDE contour value must be greater than the middle value, which in turn, must be greater than the outer TEDE value. The same applies for Deposition contour values.

In the HotSpot program, the time over which the integrated concentration is averaged is referred to as the ***Sample Time***. The equations for the standard deviation of the Gaussian concentration distribution in the cross-axis direction (sigma-y) are representative of observing plume characteristics over a sample time of 10 minutes. Concentrations downwind from a source decrease with increasing sampling time primarily because of a larger sigma-y, which is due to increased meander of wind direction and increased horizontal diffusion.

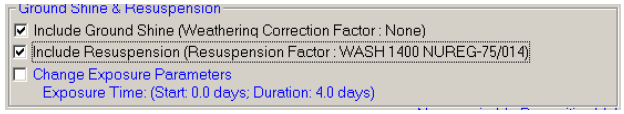


Under ***DCF Library***, select which library HotSpot is to use. ***FGR 11*** enables FGR 11/12 DCF values (ICRP series 30), ***FGR 13*** enables FGR 13/12 DCF values. (ICRP series 60 and 70 – New Lung Model). If Acute is selected, you will be prompted to select specific acute DCF values from the following menu.

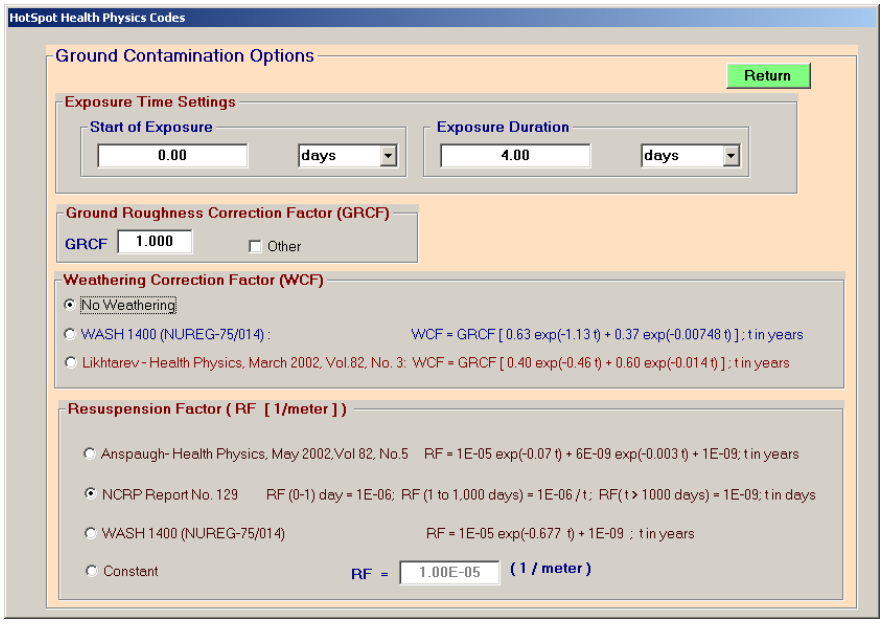




If a check is placed in front of ***Include ground shine,*** all output dose data will include ground shine for the indicated exposure time period (four days beginning at time zero). If a check is placed in front of ***Include Resuspension***, the inhalation dose from resuspended material will be included in all dose data. If either or both boxes are checked, the ***Change Exposure Parameters*** check box will appear.



If the ***Change Exposure Parameters*** box is checked, you will be prompted to enter the ground shine exposure time period, ground roughness factor, and specific weathering model to use from the following menu.



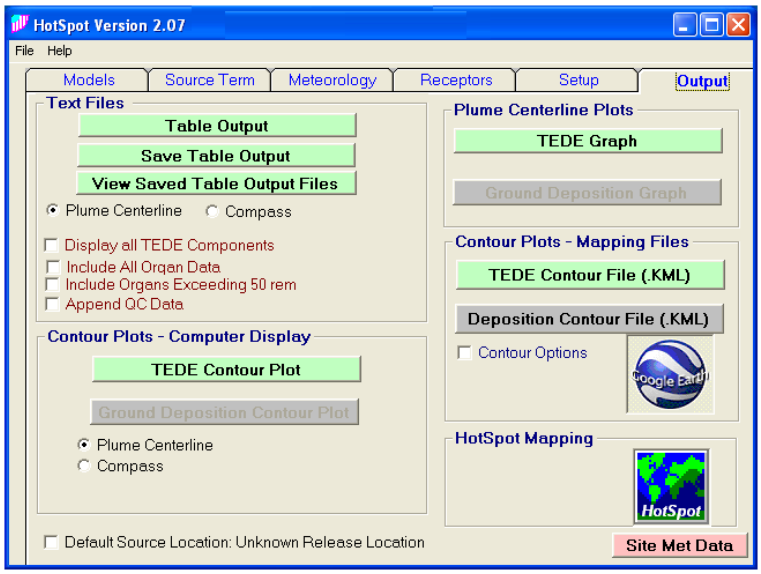
Note: The Total Effective Dose Equivalent (TEDE) values output in previous versions of HotSpot only included the inhalation and submersion component of the TEDE during plume passage. If applicable, the initial ground shine dose rate (rem/hr or Sv/hr) was also output. Starting with Version 2.07 both resuspension and ground shine, inclusive of weathering, are optionally included in the TEDE values. The duration of the exposure time period is now selectable by the user. When you first run HotSpot, the time period is from initial release plus 4 days (***Start of Exposure*** = 0 days, ***Exposure Duration*** = 4.0 days), and the ***Include Ground Ground Shine*** and ***Include Resuspension*** options are not checked. This results in calculated TEDE values identical with previous versions of HotSpot (TEDE due to plume passage only). If the ***Start of Exposure*** is any value greater than zero, the plume passage component (inhalation and submersion) is not included in the output TEDE values. For example, if the ***Start of Exposure*** is set to 0.1 days (or 0.1 hour, etc.) the plume-passage component of the TEDE will not be included. If the ***Include Ground Ground Shine*** and ***Include Resuspension*** options are not checked, the output TEDE values will all be zero since plume passage is not included. If the ***Include Ground Ground Shine*** and ***Include Resuspension*** options are checked, both ground shine and resuspension are included. If the ***Start of Exposure*** is set to 1 year and the ***Exposure Duration*** set to 1 year, the resuspension and ground shine TEDE from year 1 to year 2 will be output. The Plutonium Fire example demonstrates this feature.

Holdup Time is the duration that the released radionuclide(s) is contained prior to its release into the atmosphere.

Breathing Rate is the assumed breathing rate for individuals exposed to the radioactive plume (Default is 3.33 x 10^{-4} m^3/sec = 1.2 m^3/hr).

Non-respirable Deposition Velocity is the ratio of the measured non-respirable deposition flux and the measured non-respirable air concentration near the ground surface. The non-respirable release component is the fraction of the total quantity of material involved in the fire, explosion, etc., that is non-respirable and available for dispersion into the atmosphere. This component has a separate non-respirable deposition velocity (default value of 8 cm/sec), and is used to determine groundshine, submersion, and plume depletion.

Next, go to the **Output** tab. HotSpot provides several output options.



Selecting ***Table Output*** will produce a text summary of results for the radionuclide entered at the beginning of the session. This summary can be saved and viewed or compared with previously generated summaries.

If ***Plume Centerline*** is selected, all points will be converted to radial distances on the plume centerline. If ***Compass*** is selected instead, the table will contain actual *x,y* locations and HotSpot will use input wind directions.

Display all TEDE Components will include the individual components of the TEDE; Inhalation, Submersion, Ground Shine, and Resuspension as applicable.

Select ***Include All Organ Data*** or ***Include Organs Exceeding 50 rem*** to include the organ committed equivalent dose data for the selection.

Append QC Data will include all HotSpot variables in the output table. If a radiological mixture was used, all of the mixture data will be included.

Site Met Data (located in lower right corner), will launch the HotSpot module that inputs site-specific meteorological data to for calculation of percentile dose values.

Table Output Text Summary

HotSpot Table Output - Notepad

File Edit Format View Help

```
HotSpot  Version 2.07 General Explosion


Source Material            : Co-60   W   5.27ly
Material at Risk           : 2.5000E+03 Ci
Damage Ratio               : 1.000
Leakpath Factor            : 1.000
Airborne Fraction          : 1.000
Respirable Fraction        : 0.200
Respirable Release Fraction: 0.200
Wind Speed (h=10 m)        : 5.00 m/s
Wind Direction             : 45.0 degrees  Wind from the NE
Distance Coordinates       : All distances are on the Plume Centerline
High Explosive             : 25.00 Pounds of TNT
Debris Cloud Top           : 170 m

UNMITIGATED BLAST DAMAGE
IABTI safe distance                              : 274 m (900 ft)
Onset of shattered glass due to blast   (0.5 psi): 64 m - 82 m  (211 ft - 269 ft)
Eardrum ruptures and incapacitation     ( 5 psi) :  13 m - 20 m  (42 ft - 66 ft)
Lung damage and complete incapacitation (10 psi) :  8.8 m - 13 m  (29 ft - 44 ft)
Onset of lethality                      (25 psi) :  5.7 m - 8.8 m  (19 ft - 29 ft)
Fatalities in over 99% of population   (100 psi) :  3.1 m - 5.2 m  (10 ft - 17 ft)
Note: minimum range corresponds to side-on pressure and maximum range
      corresponds to reflected overpressure generated using
      Sandia National Laboratories BLAST model.

Stability Class            : D
Respirable Dep. Vel.       : 0.30 cm/s
Non-respirable Dep. Vel.   : 8.00 cm/s
Receptor Height            : 1.5 m
Inversion Layer Height     :  None
Sample Time                : 10.000 min
Breathing Rate             : 3.33E-04 m3/sec

Maximum Dose Distance      : 0.010 km
MAXIMUM TEDE               :   65 rem
Inner  Contour Dose        : 25 rem
Middle Contour Dose        : 5.0 rem
Outer  Contour Dose        : 2.0 rem
Exceeds Inner  Dose Out To : 0.069 km
Exceeds Middle Dose Out To : 0.27 km
Exceeds Outer  Dose Out To : 0.70 km

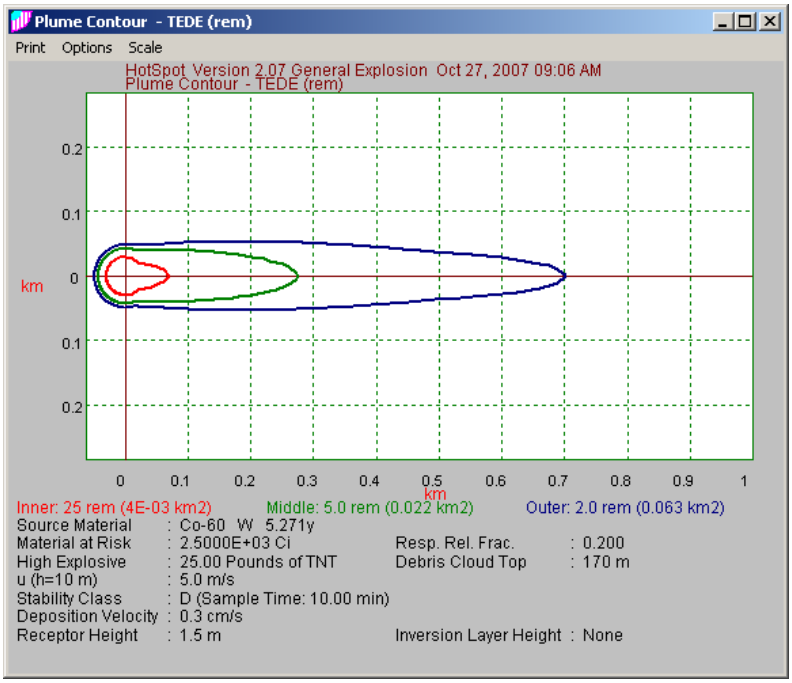
FGR-11 Dose Conversion Data - Total Effective Dose Equivalent (TEDE)

      Include Plume Passage Inhalation and Submersion
      Include Ground Shine (Weathering Correction Factor : None)
      Include Resuspension (Resuspension Factor : WASH 1400 NUREG-75/014)
      Exposure Window:(Start: 0.00 days; Duration: 4.00 days)  [100% stay time].
      Initial Deposition and Dose Rate shown
      Ground Roughness Correction Factor: 1.000
```

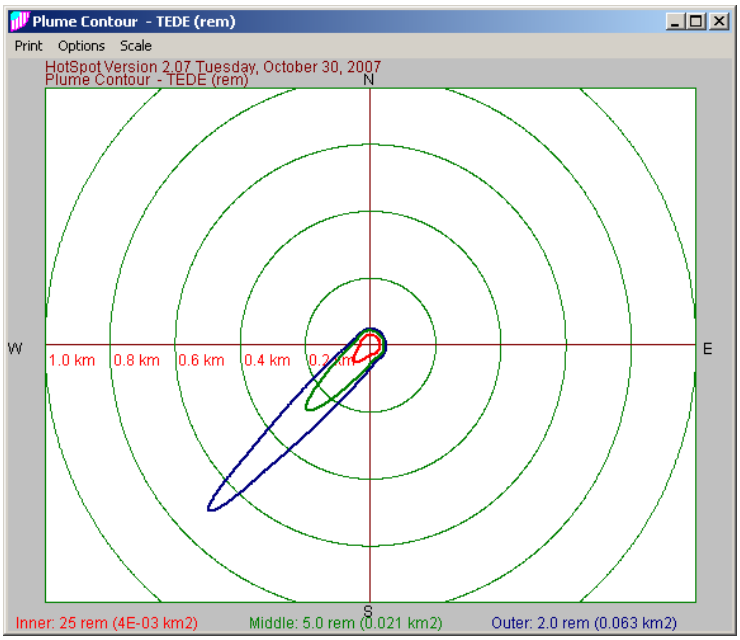
DISTANCE km	T E D E (rem)	RESPIRABLE TIME-INTEGRATED AIR CONCENTRATION (Ci-sec)/m3	GROUND SURFACE DEPOSITION (uCi/m2)	GROUND SHINE DOSE RATE (rem/hr)	ARRIVAL TIME (hour:min)
0.030	4.2E+01	8.6E-02	1.4E+04	4.3E-01	<00:01
0.100	1.8E+01	3.9E-02	5.8E+03	1.8E-01	<00:01
0.200	7.6E+00	1.7E-02	2.5E+03	7.8E-02	<00:01
0.300	4.4E+00	1.0E-02	1.4E+03	4.5E-02	<00:01
0.400	3.1E+00	7.1E-03	1.0E+03	3.1E-02	<00:01

Close the table to return to the **Output** screen.

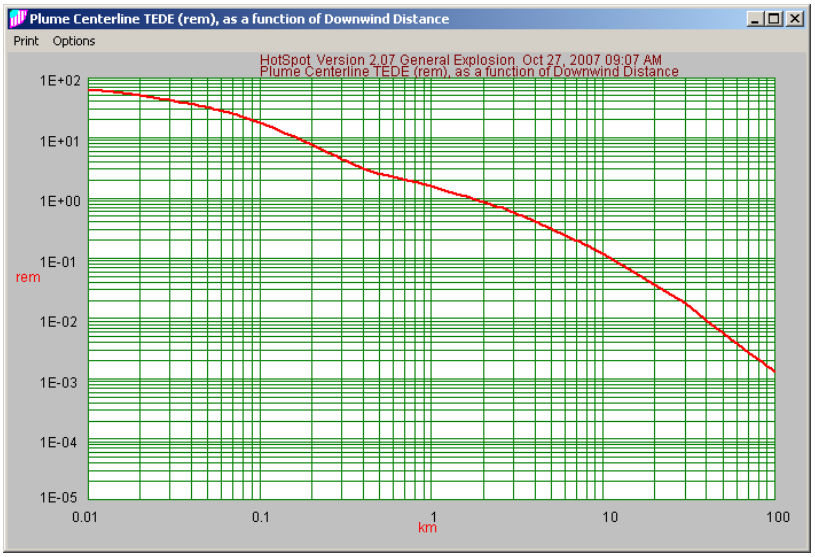
Under ***Contour Plots—Computer Display***, select ***TEDE Contour Plot*** to view the dose contour or ***Ground Deposition Contour Plot*** to view the ground deposition.



If the Compass option is selected, the actual plume direction is displayed.

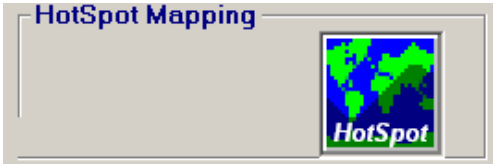


Under ***Plume Centerline Plots***, select ***TEDE Graph*** to produce a graph displaying dose as a function of plume centerline downwind distance.

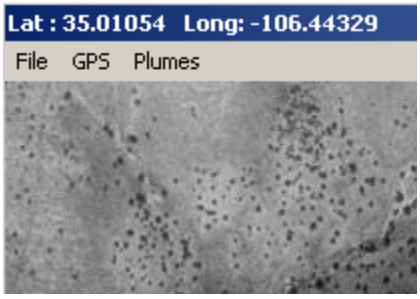


HotSpot also provides the option to produce a *TEDE Contour File*, which displays the dose contour files onto geographical maps, or a ***Deposition Contour File***, which displays ground deposition contours.

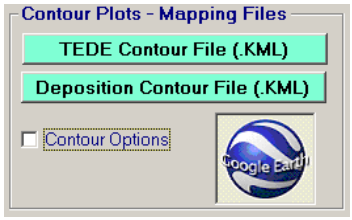
To display a geographical map with contours for either deposition or dose contours, click HotSpot Mapping icon.



When the map is displayed, the ***Plumes*** menu selection at the top left of the map display provides the option to display deposition contours or dose contours on the map.

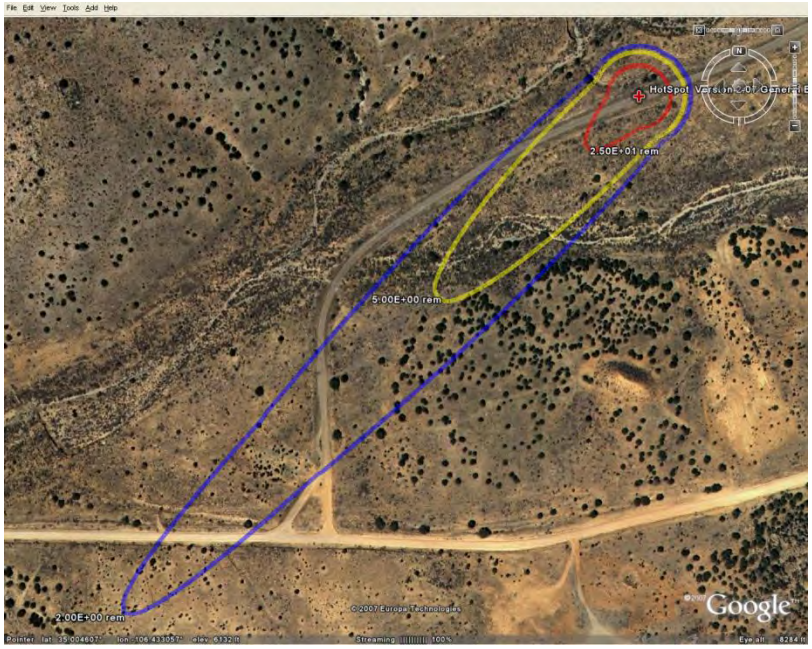


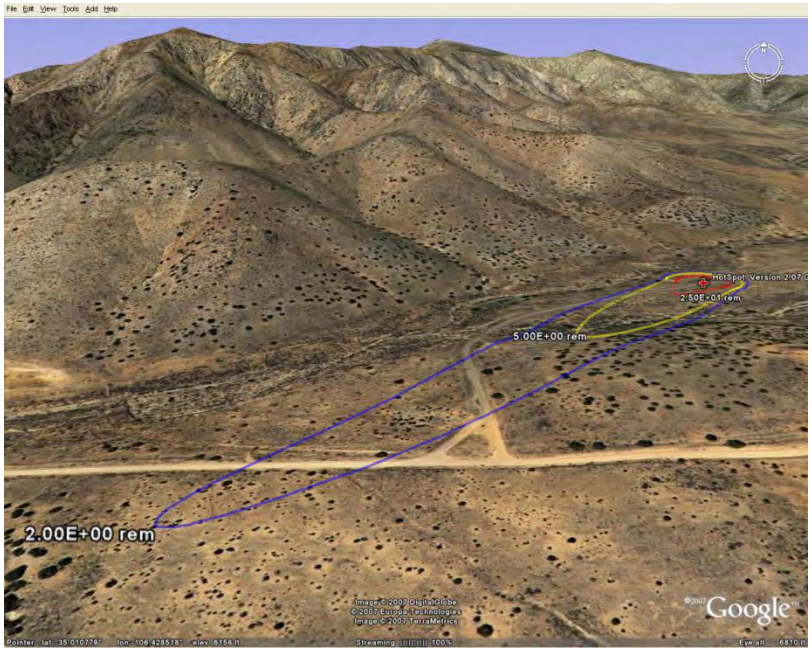
HotSpot Contour plots—Mapping files provides the option to produce a *TEDE Contour File* (.KLM) or Deposition ***Contour File (.KLM)***, which can be displayed in Google™ Earth.



To display contours for either deposition or dose contours in the Google Earth environment, click the Google Earth icon, and select the desired .KML file. If Google Earth is installed on your computer, HotSpot will automatically invoke Google Earth and display the selected contour at the HotSpot release location.

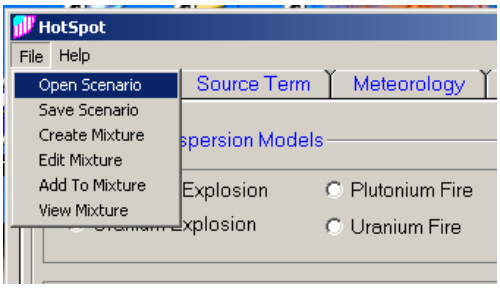
Click the "Contour Options" box to change displayed contour colors, line width, and labels. The following example displays contours in Google Earth.


2.50E+01 rem
5.00E+00 rem
2.00E+00 rem
Google


2.50E+01 rem
5.00E+00 rem
2.00E+00 rem
Google

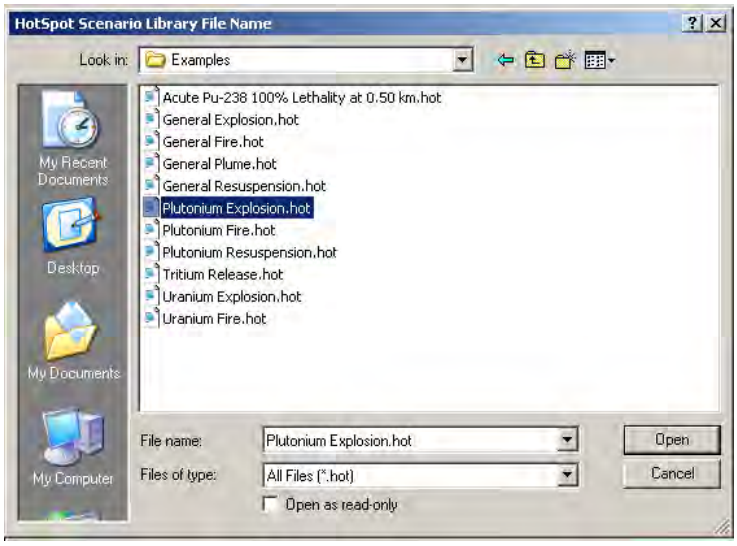
4. Atmospheric Dispersion Model Examples

This section contains examples for each of the HotSpot dispersion models: (1) a plutonium explosion (non-nuclear), fire, and resuspension; (2) a uranium explosion (non-nuclear), and fire; (3) a tritium release. You can enter the examples yourself, or simply load the scenarios from the HotSpot Scenario Library. To download the first Plutonium Explosion example, click the ***File*** option (upper left corner of HotSpot window), and select ***Open File***. Select ***Open Scenario*** to display scenario files. The file named ***current.hot*** is the currently loaded scenario. Whenever HotSpot is terminated; the current scenario and all parameters are saved in this file. *Current.hot* is automatically loaded when HotSpot is re-started, i.e., HotSpot resumes with the same scenario and parameters that were in effect when terminated.



Open the ***Examples*** folder and select the desired scenario.

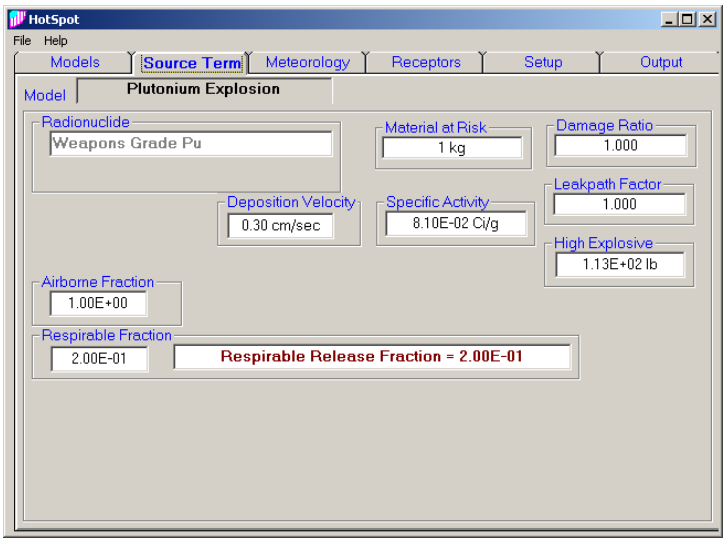
Next, open the *.hot* file of your choice.



Plutonium Explosion (non-nuclear) Example

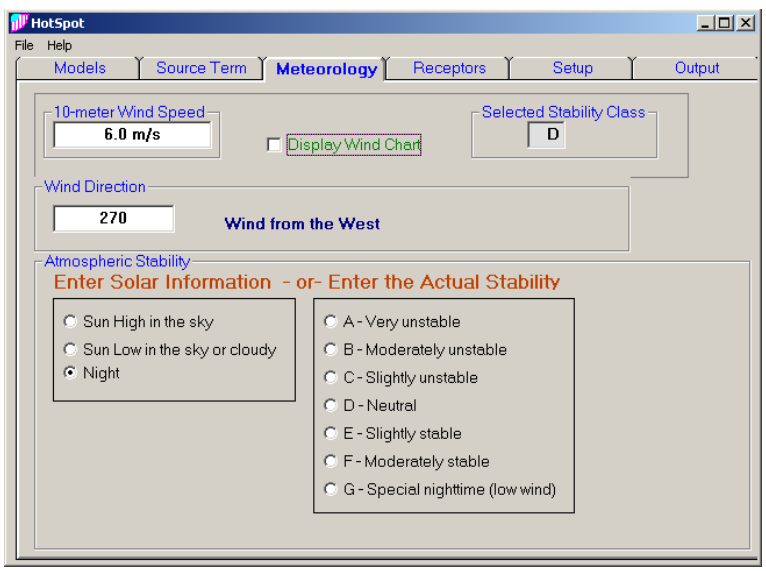
Background

In Operation Roller Coaster, a series of explosive-release mitigation studies was carried out at the Department of Energy's Nevada Test Site. One of the tests, named Double Tracks, involved the explosive (non-nuclear) release of plutonium (0.081 alpha curies/gram) using 113 lbs. of high explosive. The test was performed at 3 a.m., neutral "D" stability class, and the wind speed was 6 meters per second at a reference height of 10 meters. Compare the HotSpot estimates with the actual test measurements. The experimental results were normalized to a 1-kilogram initial mass of plutonium, of which 20% was determined to be respirable (Dewart, et al., 1982).



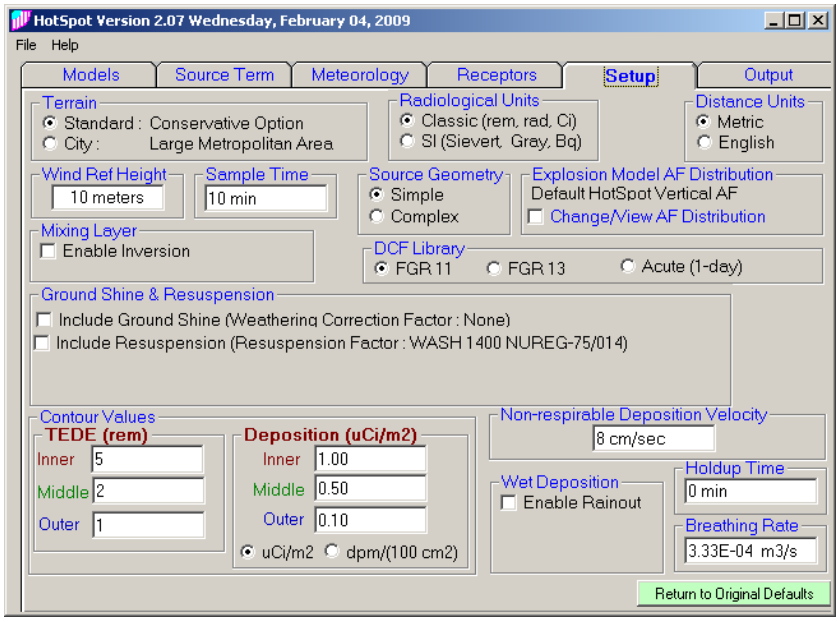
The following assumptions are used for this example:

Radionuclide: Weapons Grade Pu
Material at Risk:1 kg (normalized)
Damage Ratio: 1.000
Leakpath Factor: 1.000
Respirable Deposition Velocity: 0.30 cm/sec
Airborne Fraction: 1.000E + 00
Respirable Fraction: 0.200E-01
Respirable Release Fraction: 2.00E-01
Specific Activity: 8.10E-02 Ci/g
High Explosive: 113 lbs. TNT



10-meter Wind Speed: 6.0 m/s
Atmospheric Stability Class: D

The setup data for this example are as follows. Ground shine and resuspension were not checked, since the time-integrated air data only included measurements during plume passage.



The results for this example are as follows. The International Association of Bomb Technicians and Investigators (IABTI), blast safe distances are also output.

```
HotSpot  Version 2.07.1  Plutonium Explosion

Source Material            : Weapons Grade Pu
Material-at-Risk   (MAR)   : 1 kg
Damage Ratio        (DR)   : 1.000
Airborne Fraction  (ARF)   : 1.000
Respirable Fraction (RF)   : 0.200
Leakpath Factor    (LPF)   : 1.000
Respirable Source Term     : 1.62E+01 Ci
Non-respirable Source Term : 6.48E+01 Ci
Specific Activity          : 8.10E-02 Ci/g
Wind Speed (h=10 m)        : 6.00 m/s
Distance Coordinates       : All distances are on the Plume Centerline
High Explosive             : 113.00 Pounds of TNT
Debris Cloud Top           : 248 m

UNMITIGATED BLAST DAMAGE
IABTI safe distance                              : 431 m (1414 ft)
Onset of shattered glass due to blast   (0.5 psi): 106 m - 135 m  (349 ft - 444 ft)
Eardrum ruptures and incapacitation     ( 5 psi) :  21 m - 33 m  (69 ft - 110 ft)
Lung damage and complete incapacitation (10 psi) :  14 m - 22 m  (48 ft - 73 ft)
Onset of lethality                      (25 psi) :  9.4 m - 15 m  (31 ft - 48 ft)
Fatalities in over 99% of population   (100 psi) :  5.1 m - 8.7 m  (17 ft - 28 ft)
Note: minimum range corresponds to side-on pressure and maximum range
      corresponds to reflected overpressure generated using
      Sandia National Laboratories BLAST model.

Stability Class            : D
Respirable Dep. Vel.       : 0.30 cm/s
Non-respirable Dep. Vel.   : 8.00 cm/s
Receptor Height            : 1.5 m
Inversion Layer Height     :  None
Sample Time                : 10.000 min
Breathing Rate             : 3.33E-04 m3/sec

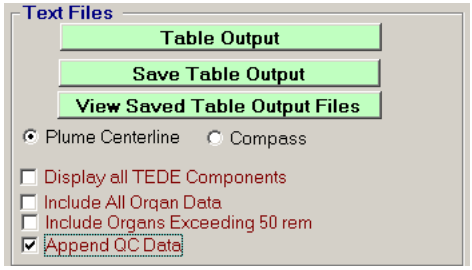
Maximum Dose Distance      : 0.010 km
```

```
MAXIMUM TEDE                :   64 rem
Inner Contour Dose         : 5.0 rem
Middle Contour Dose         : 2.0 rem
Outer  Contour Dose         : 1.0 rem
Exceeds Inner  Dose Out To : 0.48 km
Exceeds Middle Dose Out To : 1.82 km
Exceeds Outer  Dose Out To : 4.46 km

FGR-11 Dose Conversion Data - Total Effective Dose Equivalent (TEDE)
```

DISTANCE km	T E D E (rem)	RESPIRABLE TIME-INTEGRATED AIR CONCENTRATION (Ci-sec)/m3	GROUND SURFACE DEPOSITION (uCi/m2)	ARRIVAL TIME (hour:min)
0.030	5.3E+01	5.2E-04	1.7E+02	<00:01
0.100	2.9E+01	2.8E-04	8.8E+01	<00:01
0.200	1.4E+01	1.4E-04	4.1E+01	<00:01
0.300	8.6E+00	8.4E-05	2.4E+01	<00:01
0.400	6.1E+00	5.9E-05	1.7E+01	<00:01
0.500	4.8E+00	4.7E-05	1.3E+01	<00:01
0.600	4.1E+00	4.0E-05	1.1E+01	00:01
0.700	3.8E+00	3.7E-05	9.9E+00	00:01
0.800	3.5E+00	3.4E-05	9.2E+00	00:01
0.900	3.2E+00	3.1E-05	8.5E+00	00:01
1.000	3.0E+00	2.9E-05	8.0E+00	00:01
2.000	1.9E+00	1.8E-05	4.8E+00	00:03
4.000	1.1E+00	1.1E-05	2.7E+00	00:07
6.000	7.8E-01	7.6E-06	1.8E+00	00:10
8.000	6.0E-01	5.9E-06	1.3E+00	00:14
10.000	4.9E-01	4.8E-06	1.0E+00	00:17
20.000	2.5E-01	2.4E-06	3.9E-01	00:35
40.000	1.2E-01	1.2E-06	1.2E-01	01:10
60.000	8.0E-02	7.8E-07	5.5E-02	01:46
80.000	5.9E-02	5.8E-07	3.1E-02	02:21

As shown in Figures 1 and 2, the HotSpot estimates agree well with the measured integrated air concentration and ground deposition measurements. The time-integrated air concentration data were converted to (microgram-sec)/m^3 using a specific activity of 0.081 curies per gram (same as the value used in the source term). The non-respirable time-integrated air concentration is output in the table by checking the ***Append QC Data*** box.



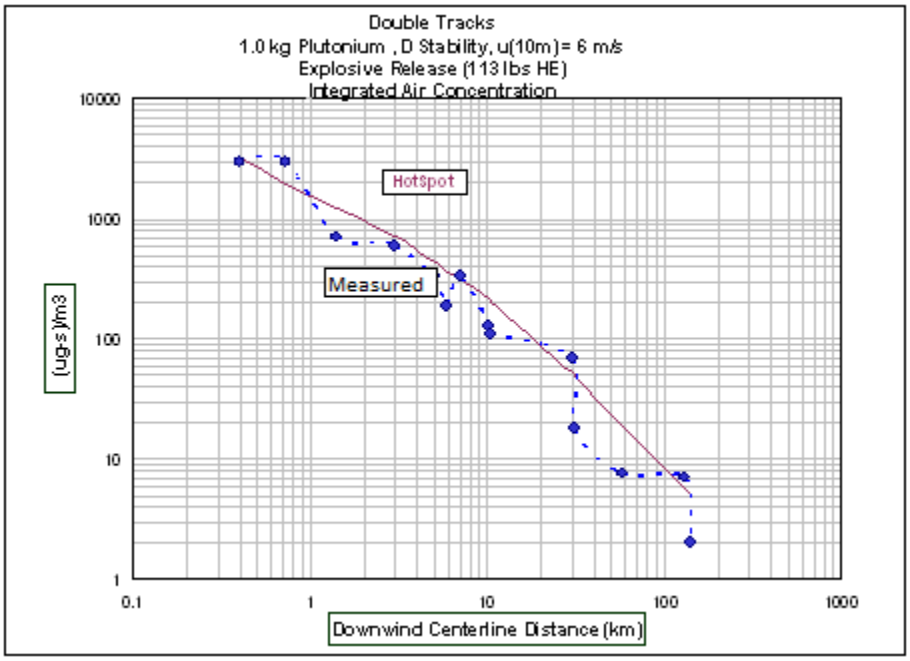


Figure 1. Double Tracks – air concentration (ug-sec per cubic meter; Total plutonium (respirable + non-respirable).

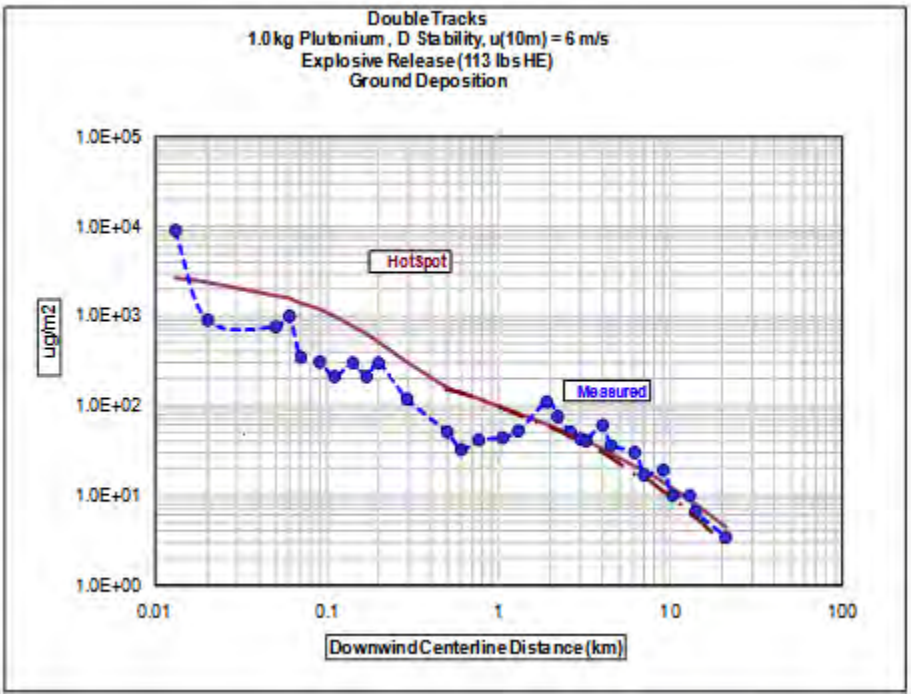


Figure 2. Double Tracks – ground deposition (micrograms per square meter)

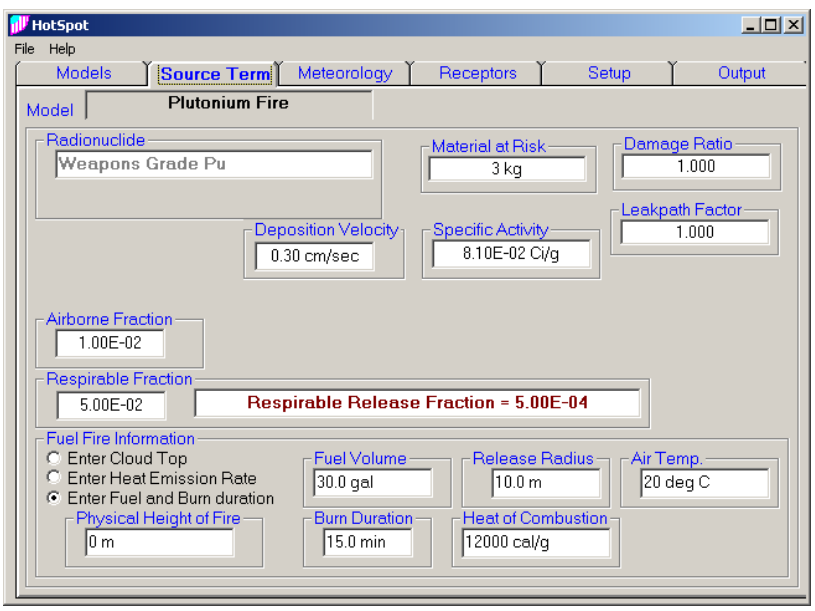
Plutonium Fire Example

A plutonium fire containing three kilograms of weapons-grade plutonium and 30 gallons of fuel has burned for a total of 15 minutes. The effective radius of the fire zone is 10 meters. The sun has set, the wind speed (at a reference height of 10-meters), is 5 m/sec, and the temperature is 20°C. Use an airborne fraction of 0.01 and a respirable fraction of 0.05 which results in a respirable release fraction of 5.0×10^{-4}.

1. Estimate the dose commitment to individuals remaining downwind throughout the entire fire due to passage of the plume.

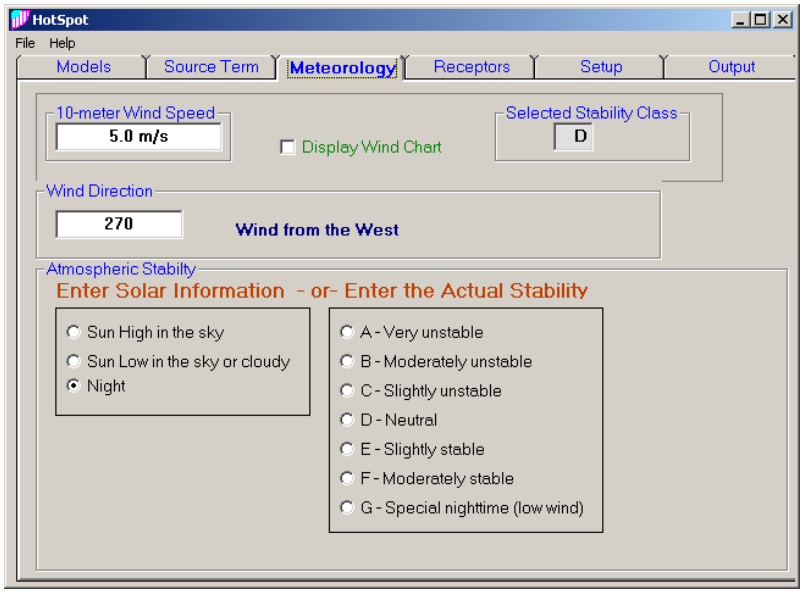
2. How far downwind does the 100 mrem TEDE contour extend?

3. What is the dose from resuspension of plutonium to individuals remaining in the deposition zone for 4 days following the initial plume passage (this is the "avoidable dose" via sheltering, evacuation, etc., <u>after</u> plume passage)?

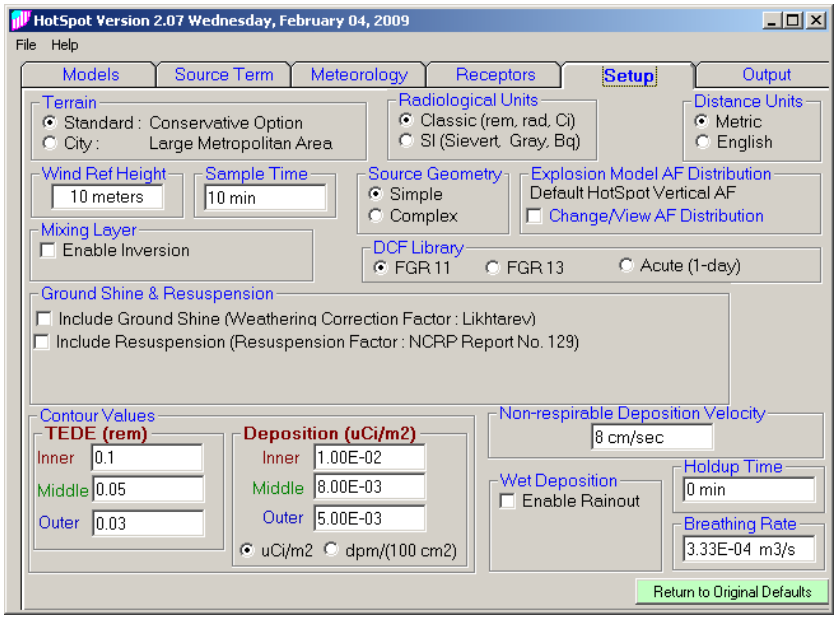


The following assumptions are used for this example:
Radionuclide: Weapons Grade Pu
Material at Risk: 3 kg
Damage Ratio: 1.000
Leakpath Factor: 1.000
Respirable DepositionVelocity: 0.30 cm/s
Airborne Fraction: 1.00E-02
Respirable Fraction: 5.00E-02
Respirable Release Fraction: 5.00E-04
Specific Activity: 8.10E-02 Ci/g
Fuel Volume: 30.0 gal

Fire (Burn) Duration: 15 min
Release Radius: 10.0 m
Physical Height of Fire: 0 m



10-meter height wind speed: 5.0 m/s
Solar Condition: Night (Stability Class D)



HotSpot Table Output - Notepad

File Edit Format View Help

```
HotSpot  Version 2.07.1  Plutonium Fire

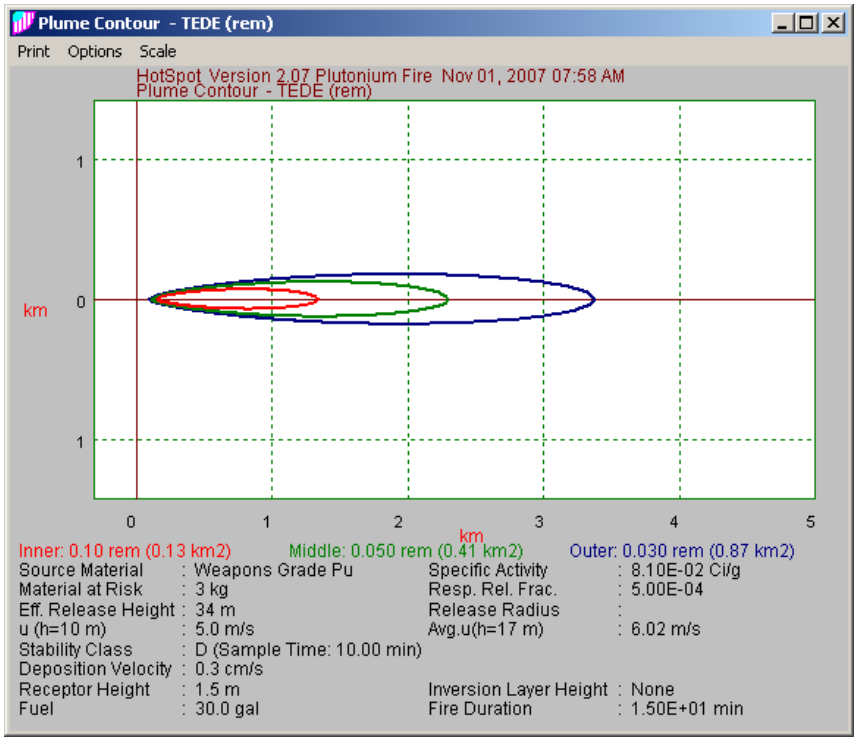
Source Material              : Weapons Grade Pu
Material-at-Risk    (MAR)    : 3 kg
Damage Ratio         (DR)    : 1.000
Airborne Fraction   (ARF)    : 1.00E-02
Respirable Fraction (RF)     : 5.00E-02
Leakpath Factor     (LPF)    : 1.000
Respirable Source Term       : 1.22E-01 Ci
Non-respirable Source Term   : 2.31E+00 Ci
Specific Activity            : 8.10E-02 Ci/g
Fuel                         : 30 gal
Fire Duration                : 15 min
Release Radius               : 10 m
Physical Height of Fire      : 0 m
Effective Release Height     : 34 m
Wind Speed (h=10 m)          : 5.00 m/s
Distance Coordinates         : All distances are on the Plume Centerline
Avg Wind Speed (h=H-eff)     : 6.02 m/s
Stability Class              : D
Respirable Dep. Vel.         : 0.30 cm/s
Non-respirable Dep. Vel.     : 8.00 cm/s
Receptor Height              : 1.5 m
Inversion Layer Height       : None
Sample Time                  : 10.000 min
Breathing Rate               : 3.33E-04 m3/sec

Maximum Dose Distance        : 0.39 km
MAXIMUM TEDE                 : 0.251 rem
Inner  Contour Dose          : 0.100 rem
Middle Contour Dose          : 0.050 rem
Outer  Contour Dose          : 0.030 rem
Exceeds Inner  Dose Out To   : 1.32 km
Exceeds Middle Dose Out To   : 2.29 km
Exceeds Outer  Dose Out To   : 3.34 km

FGR-11 Dose Conversion Data - Total Effective Dose Equivalent (TEDE)
```

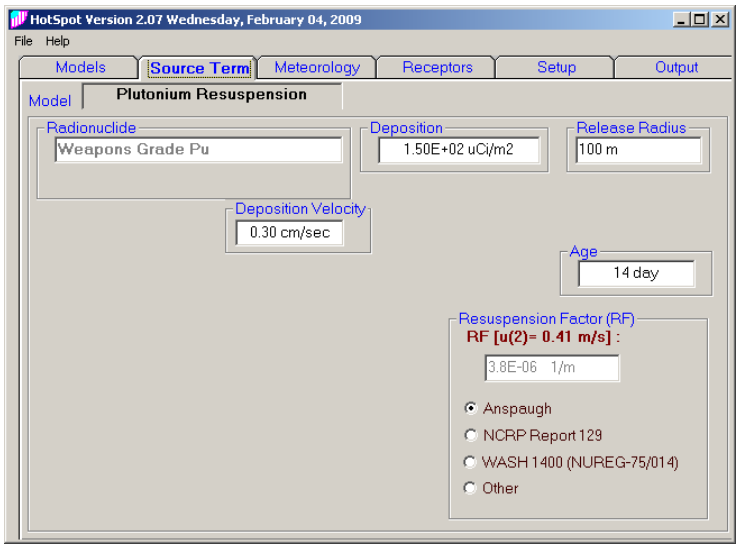
DISTANCE km	T E D E (rem)	RESPIRABLE TIME-INTEGRATED AIR CONCENTRATION (Ci-sec)/m3	GROUND SURFACE DEPOSITION (uCi/m2)	ARRIVAL TIME (hour:min)
0.030	2.0E-04	1.9E-09	2.0E-03	<00:01
0.100	2.6E-02	2.5E-07	3.5E-01	<00:01
0.200	1.5E-01	1.5E-06	2.2E+00	<00:01
0.300	2.3E-01	2.3E-06	3.4E+00	<00:01
0.400	2.5E-01	2.4E-06	3.6E+00	00:01
0.500	2.4E-01	2.3E-06	3.4E+00	00:01
0.600	2.2E-01	2.1E-06	3.0E+00	00:01
0.700	1.9E-01	1.9E-06	2.6E+00	00:01
0.800	1.7E-01	1.7E-06	2.3E+00	00:02
0.900	1.5E-01	1.5E-06	2.1E+00	00:02
1.000	1.4E-01	1.4E-06	1.8E+00	00:02
2.000	6.0E-02	5.8E-07	6.6E-01	00:05
4.000	2.4E-02	2.3E-07	2.1E-01	00:11
6.000	1.4E-02	1.4E-07	9.9E-02	00:16
8.000	9.6E-03	9.3E-08	5.9E-02	00:22

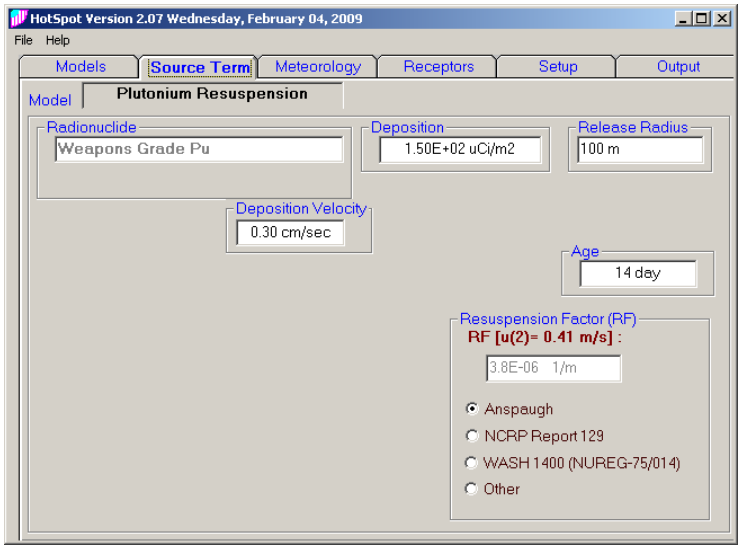
As shown in the above text output, the Inner Contour Dose value of 0.100 rem (100 mrem) extends out to a distance of 1.32 km. This is also shown in the following TEDE contour plot.

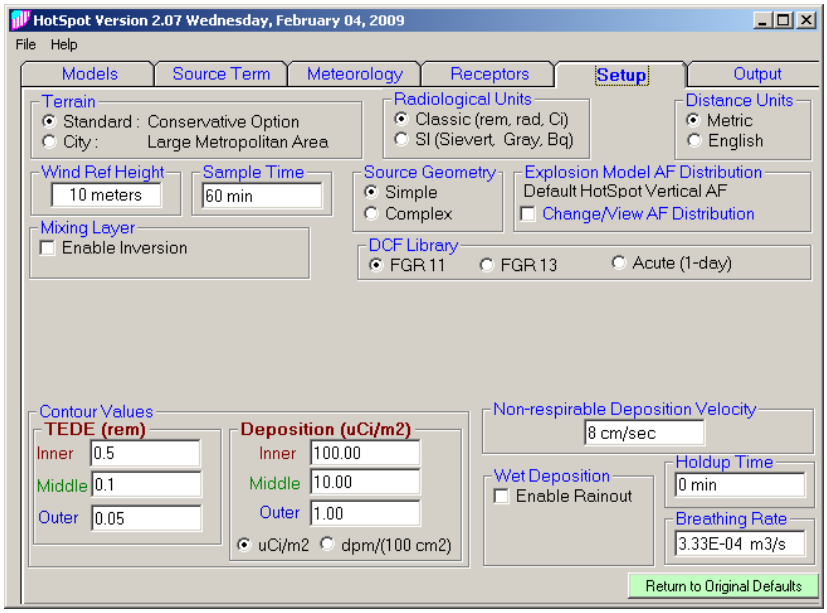

Plume Contour - TEDE (rem)
Print Options Scale
HotSpot Version 2.07 Plutonium Fire Nov 01, 2007 07:58 AM
Plume Contour - TEDE (rem)
km
1
0
1
0 1 2 3 4 5
km
Inner: 0.10 rem (0.13 km2)
Middle: 0.050 rem (0.41 km2)
Outer: 0.030 rem (0.87 km2)
Source Material : Weapons Grade Pu
Specific Activity : 8.10E-02 Ci/g
Material at Risk : 3 kg
Resp. Rel. Frac. : 5.00E-04
Eff. Release Height : 34 m
Release Radius :
u (h=10 m) : 5.0 m/s
Avg.u(h=17 m) : 6.02 m/s
Stability Class : D (Sample Time: 10.00 min)
Deposition Velocity : 0.3 cm/s
Receptor Height : 1.5 m
Inversion Layer Height : None
Fuel : 30.0 gal
Fire Duration : 1.50E+01 min

Plutonium Resuspension Example

Estimate the 50-year CEDE rates, i.e., dose commitment per hour of downwind exposure, to individuals downwind from a two-week-old plutonium contamination event. Most of the plutonium is contained in an area with an effective radius of 100 meters. The average contamination level is 150 uCi/m^2. it is nighttime and the wind speed is 1 m/sec (at 10-meter reference height).








```
HotSpot  Version 2.07.1 Plutonium Resuspension

(Resuspension Factor: Anspaugh 2002)

Source Material             : Weapons Grade Pu
Source Term                 : 1.50E+02 uCi/m2
Resuspension Factor         : 3.8E-06    1/m
Effective Release Radius    : 100 m
Effective Source Term       : 5.6E-07 Ci/s
Contamination Age           : 14 day
Wind Speed (h=10 m)         : 1.00 m/s
Distance Coordinates        : All distances are on the Plume Centerline
Stability Class             : F
Respirable Dep. Vel.        : 0.30 cm/s
Receptor Height             : 1.5 m
Inversion Layer Height      :  None
Sample Time                 : 60.000 min
Breathing Rate              : 3.33E-04 m3/sec

Maximum Dose Distance       : 0.010 km
MAXIMUM TEDE                :  0.141 rem
Inner  Contour Dose         : 0.500 rem
Middle Contour Dose         : 0.100 rem
Outer  Contour Dose         : 0.050 rem
Exceeds Inner  Dose Out To  : Not Exceeded
Exceeds Middle Dose Out To  : 0.025 km
Exceeds Outer  Dose Out To  : 0.12 km

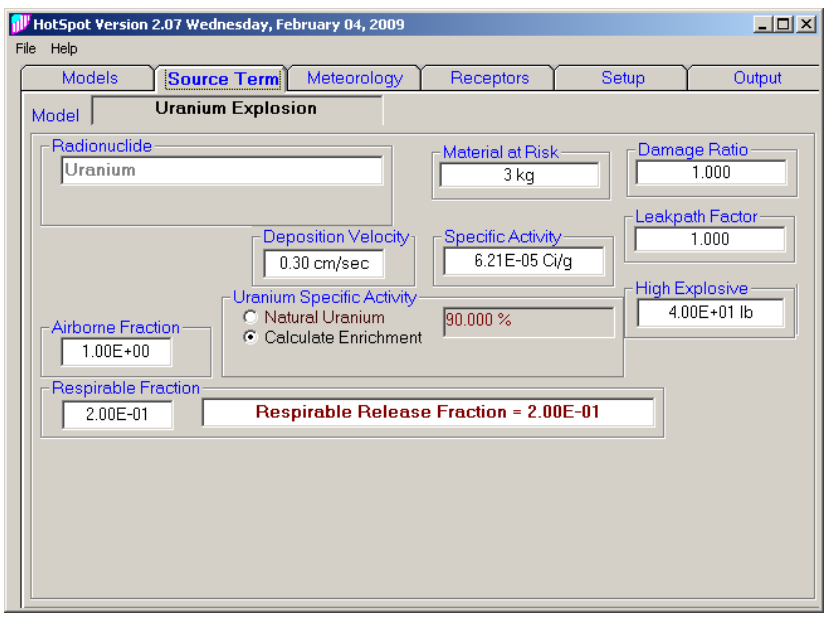
FGR-11 Dose Conversion Data - Total Effective Dose Equivalent (TEDE)

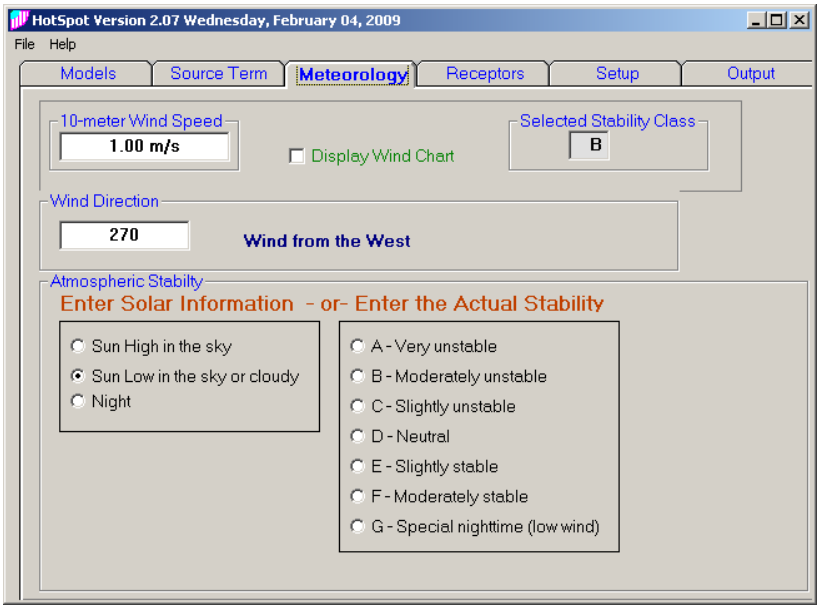
 DISTANCE          T E D E                  AVERAGE
            PER 1-HR EXPOSURE TIME     AIR CONCENTRATION
    km               (rem)                  (Ci/m3)
 ____________________________________________________
   0.030            9.3E-02                  2.5E-10
   0.100            5.6E-02                  1.5E-10
   0.200            3.9E-02                  1.0E-10
   0.300            3.0E-02                  8.2E-11
   0.400            2.4E-02                  6.6E-11
   0.500            2.0E-02                  5.5E-11
   0.600            1.7E-02                  4.7E-11
   0.700            1.5E-02                  4.1E-11
```

0.800	1.3E-02	3.6E-11
0.900	1.2E-02	3.2E-11
1.000	1.0E-02	2.8E-11
2.000	4.2E-03	1.1E-11
4.000	1.4E-03	3.9E-12
6.000	6.9E-04	1.9E-12
8.000	4.1E-04	1.1E-12
10.000	2.8E-04	7.6E-13
20.000	3.3E-05	8.8E-14
40.000	1.3E-06	3.5E-15
60.000	7.6E-08	2.1E-16
80.000	1.0E-08	2.8E-17

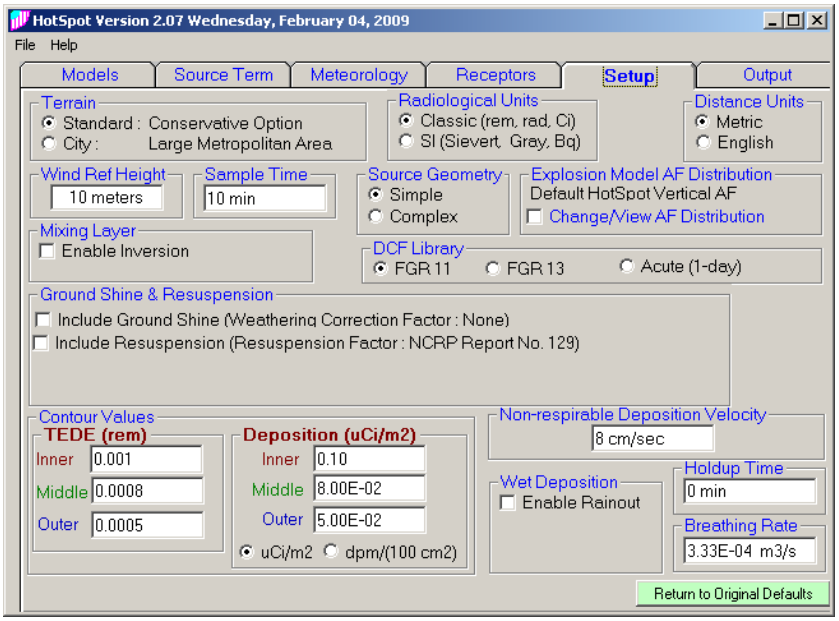
Uranium Explosion Example

Three kilograms of weapons-grade uranium (90% U-235, 10% U-238), are involved in a non-nuclear detonation of 40 lbs. of high explosive. The sun is low in the sky and the wind speed is 1 m/sec at a measurement height of 10 meters. Assume 100% of the uranium is aerosolized and 20% is respirable. Estimate the ground contamination and 50-year CEDEs as a function of downwind centerline distance. As is typical in an explosive release scenario, the Damage Ratio and Leakpath Factor are both 1.000. Since we are only interested in centerline dose and deposition estimates, the azimuth of the wind direction is not required.




HotSpot Version 2.07 Wednesday, February 04, 2009
File Help
Models
Source Term
Meteorology
Receptors
Setup
Output
10-meter Wind Speed
1.00 m/s
Display Wind Chart
Selected Stability Class
B
Wind Direction
270
Wind from the West
Atmospheric Stabilty
Enter Solar Information - or- Enter the Actual Stability
Sun High in the sky
Sun Low in the sky or cloudy
Night
A - Very unstable
B - Moderately unstable
C - Slightly unstable
D - Neutral
E - Slightly stable
F - Moderately stable
G - Special nighttime (low wind)

.


HotSpot Version 2.07 Wednesday, February 04, 2009
File Help
Models
Source Term
Meteorology
Receptors
Setup
Output
Terrain
Standard : Conservative Option
City : Large Metropolitan Area
Radiological Units
Classic (rem, rad, Ci)
SI (Sievert, Gray, Bq)
Distance Units
Metric
English
Wind Ref Height
10 meters
Sample Time
10 min
Source Geometry
Simple
Complex
Explosion Model AF Distribution
Default HotSpot Vertical AF
Change/View AF Distribution
Mixing Layer
Enable Inversion
DCF Library
FGR 11
FGR 13
Acute (1-day)
Ground Shine & Resuspension
Include Ground Shine (Weathering Correction Factor : None)
Include Resuspension (Resuspension Factor : NCRP Report No. 129)
Contour Values
TEDE (rem)
Inner 0.001
Middle 0.0008
Outer 0.0005
Deposition (uCi/m2)
Inner 0.10
Middle 8.00E-02
Outer 5.00E-02
uCi/m2
dpm/(100 cm2)
Non-respirable Deposition Velocity
8 cm/sec
Wet Deposition
Enable Rainout
Holdup Time
0 min
Breathing Rate
3.33E-04 m3/s
Return to Original Defaults

```
HotSpot  Version 2.07.1  Uranium Explosion

Source Material            : Uranium
Material-at-Risk   (MAR)   : 3 kg
Airborne Fraction  (ARF)   : 1.000
Respirable Fraction (RF)   : 0.200
Respirable Source Term     : 3.73E-02 Ci
Non-respirable Source Term : 1.49E-01 Ci
Specific Activity          : 6.21E-05 Ci/g  90.000 %
Wind Speed (h=10 m)        : 1.00 m/s
Distance Coordinates       : All distances are on the Plume Centerline
High Explosive             : 40.00 Pounds of TNT
Debris Cloud Top           : 191 m

UNMITIGATED BLAST DAMAGE
IABTI safe distance                              : 305 m (1000 ft)
Onset of shattered glass due to blast   (0.5 psi): 75 m - 96 m  (247 ft - 314 ft)
Eardrum ruptures and incapacitation     ( 5 psi) :  15 m - 24 m  (49 ft - 78 ft)
Lung damage and complete incapacitation (10 psi) :  10 m - 16 m  (34 ft - 51 ft)
Onset of lethality                      (25 psi) :  6.6 m - 10 m  (22 ft - 34 ft)
Fatalities in over 99% of population   (100 psi) :  3.6 m - 6.1 m  (12 ft - 20 ft)
Note: minimum range corresponds to side-on pressure and maximum range
      corresponds to reflected overpressure generated using
      Sandia National Laboratories BLAST model.

Stability Class            : B
Respirable Dep. Vel.       : 0.30 cm/s
Non-respirable Dep. Vel.   : 8.00 cm/s
Receptor Height            : 1.5 m
Inversion Layer Height     :  None
Sample Time                : 10.000 min
Breathing Rate             : 3.33E-04 m3/sec

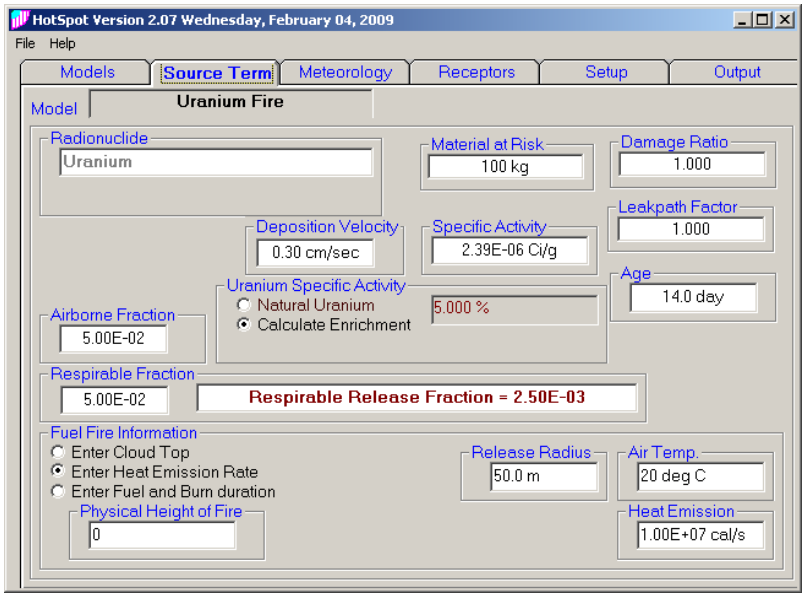
Maximum Dose Distance      : 0.010 km
MAXIMUM TEDE               :  0.451 rem
Inner  Contour Dose        : 1.00E-03 rem
Middle Contour Dose        : 8.00E-04 rem
Outer  Contour Dose        : 5.00E-04 rem
Exceeds Inner  Dose Out To : 4.68 km
Exceeds Middle Dose Out To : 5.33 km
Exceeds Outer  Dose Out To : 6.97 km

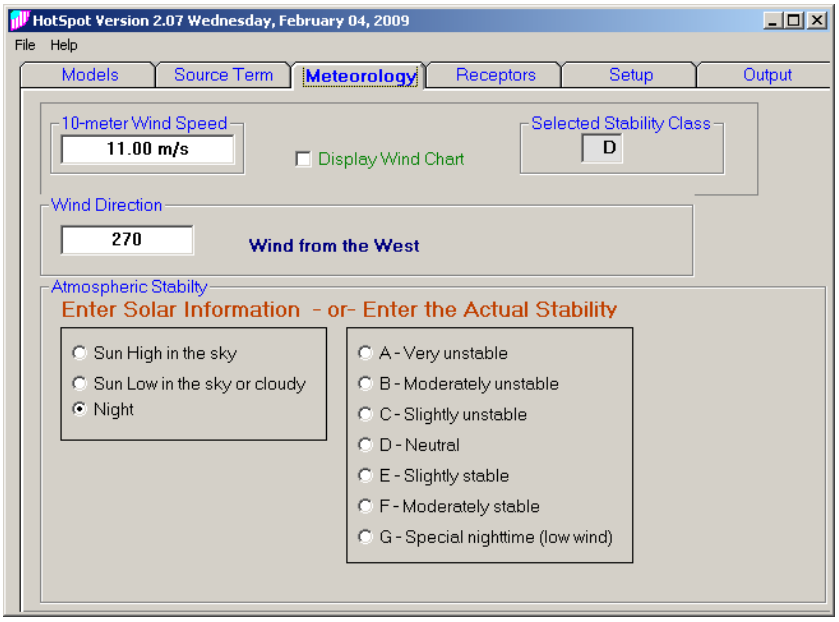
FGR-11 Dose Conversion Data - Total Effective Dose Equivalent (TEDE)
```

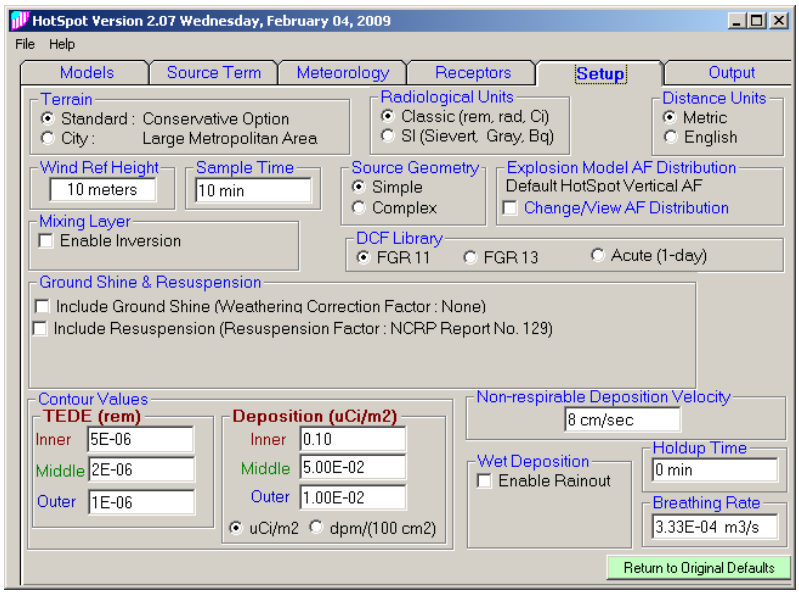
DISTANCE km	T E D E (rem)	RESPIRABLE TIME-INTEGRATED AIR CONCENTRATION (Ci-sec)/m3	GROUND SURFACE DEPOSITION (uCi/m2)	ARRIVAL TIME (hour:min)
0.030	2.2E-01	5.6E-06	2.1E+00	<00:01
0.100	6.7E-02	1.7E-06	4.9E-01	00:01
0.200	4.9E-02	1.2E-06	3.4E-01	00:02
0.300	3.9E-02	9.8E-07	2.7E-01	00:04
0.400	3.2E-02	8.0E-07	2.1E-01	00:05
0.500	2.6E-02	6.7E-07	1.7E-01	00:06
0.600	2.2E-02	5.6E-07	1.4E-01	00:08
0.700	1.9E-02	4.8E-07	1.2E-01	00:09
0.800	1.6E-02	4.1E-07	1.0E-01	00:11
0.900	1.4E-02	3.5E-07	8.5E-02	00:12
1.000	1.2E-02	3.1E-07	7.4E-02	00:13
2.000	4.3E-03	1.1E-07	2.0E-02	00:27
4.000	1.3E-03	3.4E-08	4.9E-03	00:55
6.000	6.6E-04	1.7E-08	2.0E-03	01:22
8.000	4.0E-04	1.0E-08	1.1E-03	01:50
10.000	2.7E-04	6.9E-09	6.8E-04	02:17
20.000	8.4E-05	2.1E-09	1.6E-04	04:35
40.000	2.7E-05	6.9E-10	3.8E-05	09:10
60.000	1.4E-05	3.6E-10	1.7E-05	13:46
80.000	9.0E-06	2.3E-10	9.6E-06	18:21

Uranium Fire Example

100 kilograms of LEU uranium (5% U-235, 95% U-238), used in an isotope-separation experiment is involved in a significant building fire (heat emission = 1 E+07 calories/sec, effective radius of building fire is 50 m). The sun has set, the wind speed is approximately 11 m/sec (at 10-meter reference height), and the ambient air temperature is 20°C. The nearest occupied location is at a downwind distance of 0.5 km. What is the maximum expected 50-year CEDE for this location? Since we are only interested in the centerline dose, the azimuth of the wind direction is not required.








```
HotSpot  Version 2.07.1  Uranium Fire

Source Material              : Uranium
Material-at-Risk    (MAR)    : 100 kg
Damage Ratio         (DR)    : 1.000
Airborne Fraction   (ARF)    : 5.00E-02
Respirable Fraction (RF)     : 5.00E-02
Leakpath Factor     (LPF)    : 1.000
Respirable Source Term       : 5.98E-04 Ci
Non-respirable Source Term   : 1.14E-02 Ci
Specific Activity            : 2.39E-06 Ci/g  5.000 %
Heat Emission                : 1.00E+07 cal/s
Release Radius               : 50.0 m
Physical Height of Fire      : 0 m
Effective Release Height     : 31 m
Wind Speed (h=10 m)          : 11.00 m/s
Distance Coordinates         : All distances are on the Plume Centerline
Avg Wind Speed (h=H-eff)     : 13.04 m/s
Stability Class              : D
Respirable Dep. Vel.         : 0.30 cm/s
Non-respirable Dep. Vel.     : 8.00 cm/s
Receptor Height              : 1.5 m
Inversion Layer Height       : None
Sample Time                  : 10.000 min
Breathing Rate               : 3.33E-04 m3/sec
Maximum Dose Distance        : 0.010 km
MAXIMUM TEDE                 :   4.14E-04 rem
Inner  Contour Dose          : 5.00E-06 rem
Middle Contour Dose          : 2.00E-06 rem
Outer  Contour Dose          : 1.00E-06 rem
Exceeds Inner  Dose Out To   : 11.82 km
Exceeds Middle Dose Out To   : 25.93 km
Exceeds Outer  Dose Out To   : 48.06 km
```

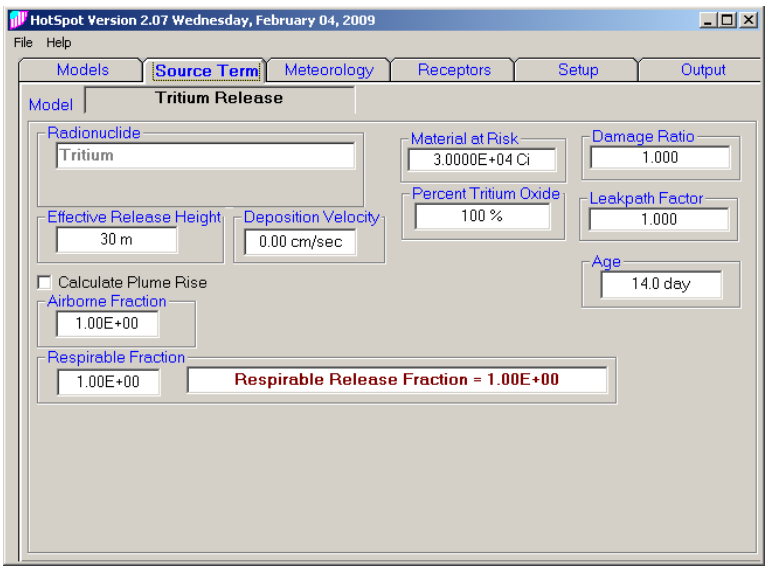
FGR-11 Dose Conversion Data - Total Effective Dose Equivalent (TEDE)

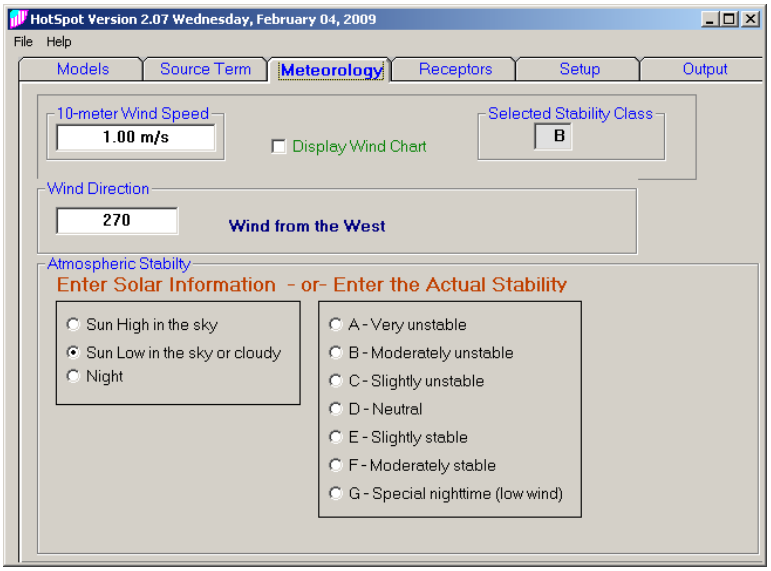
DISTANCE km	T E D E (rem)	RESPIRABLE TIME-INTEGRATED AIR CONCENTRATION (Ci-sec)/m3	GROUND SURFACE DEPOSITION (uCi/m2)	ARRIVAL TIME (hour:min)
0.030	4.0E-04	1.0E-08	1.5E-02	<00:01
0.100	3.4E-04	8.6E-09	1.3E-02	<00:01
0.200	2.8E-04	7.0E-09	1.1E-02	<00:01
0.300	2.3E-04	5.9E-09	8.9E-03	<00:01
0.400	2.0E-04	5.0E-09	7.5E-03	<00:01
0.500	1.7E-04	4.3E-09	6.3E-03	<00:01
0.600	1.5E-04	3.7E-09	5.5E-03	<00:01
0.700	1.3E-04	3.3E-09	4.8E-03	<00:01
0.800	1.2E-04	2.9E-09	4.2E-03	00:01
0.900	1.0E-04	2.6E-09	3.8E-03	00:01
1.000	9.4E-05	2.4E-09	3.4E-03	00:01
2.000	4.4E-05	1.1E-09	1.5E-03	00:02
4.000	1.9E-05	4.9E-10	5.7E-04	00:05
6.000	1.2E-05	2.9E-10	3.1E-04	00:07
8.000	8.1E-06	2.1E-10	2.1E-04	00:10
10.000	6.2E-06	1.6E-10	1.5E-04	00:12
20.000	2.7E-06	6.9E-11	4.9E-05	00:25
40.000	1.2E-06	3.1E-11	1.5E-05	00:51
60.000	7.9E-07	2.0E-11	7.4E-06	01:16

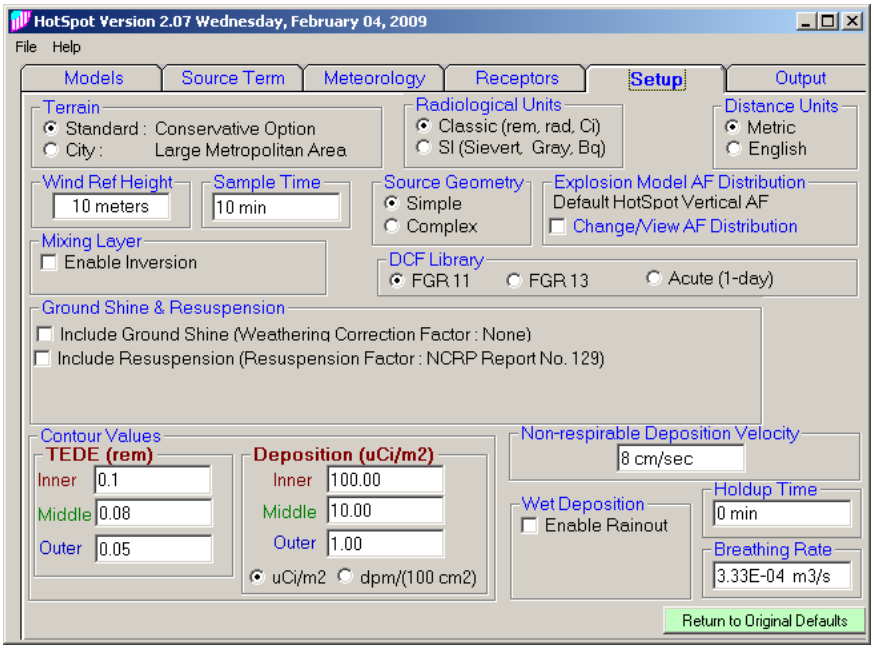
2

Tritium Release Example

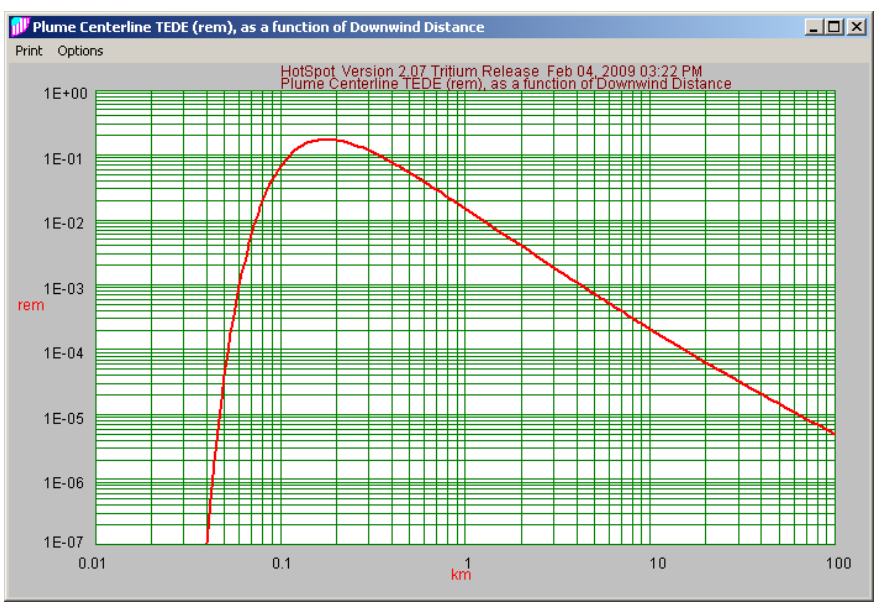
30,000 curies of tritium oxide (HTO), are released from a 30-meter stack. Use a deposition velocity of 0 cm/sec for the HTO. The wind speed is 1 m/sec (at 10-meter reference height). The sun is low in the sky. What distance is associated with the maximum 50-year CEDE to an individual remaining at this location throughout the release?







Plume Centerline (TEDE) rem as a Function of Downwind Distance



```
HotSpot  Version 2.07.1  Tritium Release

Source Material            : Tritium
Material-at-Risk   (MAR)   : 3.0000E+04 Ci  100 % Tritium Oxide
Damage Ratio        (DR)   : 1.000
Airborne Fraction  (ARF)   : 1.000
Respirable Fraction (RF)   : 1.000
Leakpath Factor    (LPF)   : 1.000
Respirable Source Term     : 3.00E+04 Ci
Non-respirable Source Term : 0.00E+00 Ci
Effective Release Height   : 30 m
Wind Speed (h=10 m)        : 1.00 m/s
Distance Coordinates       : All distances are on the Plume Centerline
Wind Speed (h=H-eff)       : 1.08 m/s
Stability Class            : B
Respirable Dep. Vel.       : 0.00 cm/s
Non-respirable Dep. Vel.   : 8.00 cm/s
Receptor Height            : 1.5 m
Inversion Layer Height     :  None
Sample Time                : 10.000 min
Breathing Rate             : 3.33E-04 m3/sec

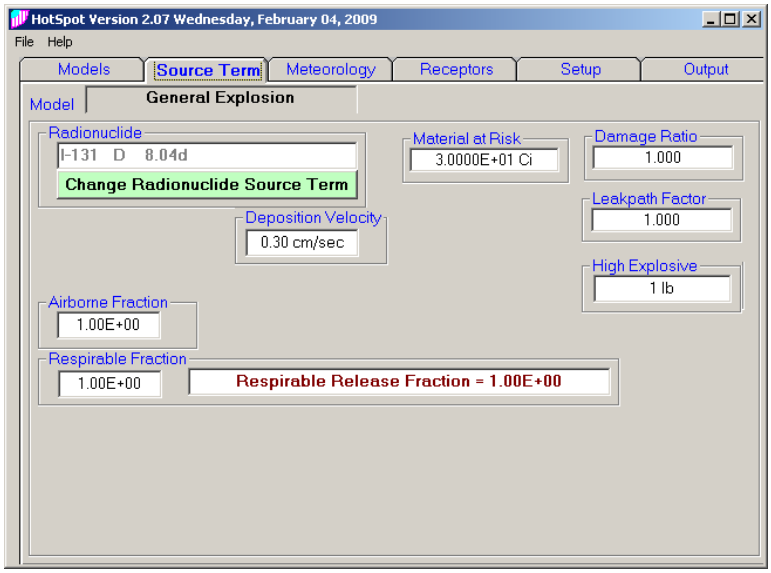
Maximum Dose Distance      : 0.18 km
MAXIMUM TEDE               : 0.176 rem
Inner  Contour Dose        : 0.100 rem
Middle Contour Dose        : 0.080 rem
Outer  Contour Dose        : 0.050 rem
Exceeds Inner  Dose Out To : 0.34 km
Exceeds Middle Dose Out To : 0.39 km
Exceeds Outer  Dose Out To : 0.51 km

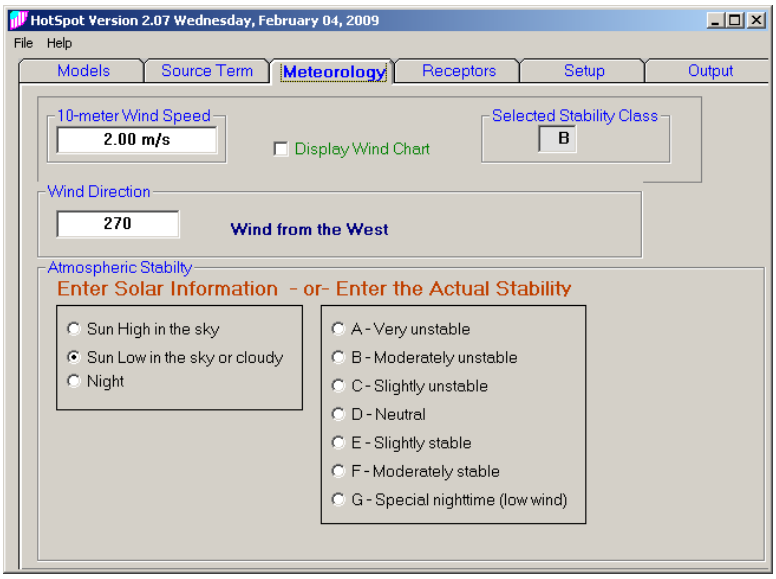
FGR-11 Dose Conversion Data - Total Effective Dose Equivalent (TEDE)
Note: Dose Results Include HTO Skin Absorption
```

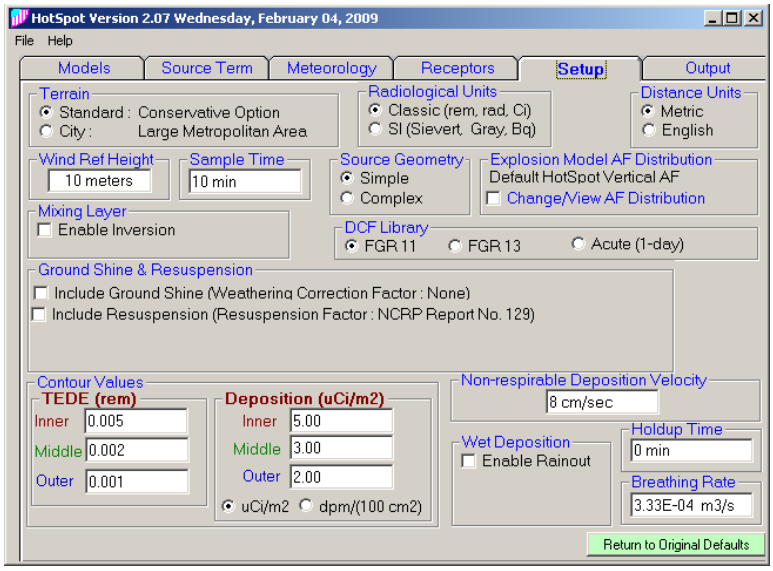
DISTANCE km	T E D E (rem)	RESPIRABLE TIME-INTEGRATED AIR CONCENTRATION (Ci-sec)/m3	ARRIVAL TIME (hour:min)
0.030	2.0E-13	6.3E-12	<00:01
0.100	6.8E-02	2.1E+00	00:01
0.200	1.7E-01	5.3E+00	00:03
0.300	1.2E-01	3.7E+00	00:04
0.400	7.7E-02	2.4E+00	00:06
0.500	5.3E-02	1.7E+00	00:07
0.600	3.9E-02	1.2E+00	00:09
0.700	2.9E-02	9.1E-01	00:10
0.800	2.3E-02	7.1E-01	00:12
0.900	1.8E-02	5.7E-01	00:13
1.000	1.5E-02	4.7E-01	00:15
2.000	4.0E-03	1.3E-01	00:30
4.000	1.1E-03	3.4E-02	01:01
6.000	5.2E-04	1.6E-02	01:32
8.000	3.1E-04	9.6E-03	02:03
10.000	2.1E-04	6.5E-03	02:34
20.000	6.4E-05	2.0E-03	05:08
40.000	2.1E-05	6.4E-04	10:17
60.000	1.1E-05	3.4E-04	15:25
80.000	6.9E-06	2.2E-04	20:34

General Explosion Example

A vehicle, transporting 30 curies of I-131, is involved in a severe accident that results in the detonation of the vehicle's gas tank. The wind is from the west at 2 meters per second (at a 10-meter reference height), on a cloudy day. Assume 100% of the I-131 becomes airborne, and that 100% of the airborne material is respirable. As is typical in an explosive release scenario, the Damage Ratio and Leakpath Factor are both 1.000. Estimate the 50-year CEDE as a function of downwind centerline distance from the accident scene. Note: a conservative estimate of the TNT equivalent of an exploding vehicle gas tank is 1 lb.








```
HotSpot  Version 2.07.1  General Explosion

Source Material            : I-131   D    8.04d
Material-at-Risk   (MAR)   : 3.0000E+01 Ci
Damage Ratio        (DR)   : 1.000
Airborne Fraction  (ARF)   : 1.000
Respirable Fraction (RF)   : 1.000
Leakpath Factor    (LPF)   : 1.000
Respirable Source Term     : 3.00E+01 Ci
Non-respirable Source Term : 0.00E+00 Ci
Wind Speed (h=10 m)        : 2.00 m/s
Distance Coordinates       : All distances are on the Plume Centerline
High Explosive             : 1.00 Pounds of TNT
Debris Cloud Top           : 76 m

UNMITIGATED BLAST DAMAGE
IABTI safe distance                              : 274 m (900 ft)
Onset of shattered glass due to blast   (0.5 psi): 22 m - 28 m  (72 ft - 92 ft)
Eardrum ruptures and incapacitation     ( 5 psi) :  4.4 m - 6.9 m  (14 ft - 23 ft)
Lung damage and complete incapacitation (10 psi) :  3.0 m - 4.6 m  (9.9 ft - 15 ft)
Onset of lethality                      (25 psi) :  1.9 m - 3.0 m  (6.4 ft - 9.9 ft)
Fatalities in over 99% of population   (100 psi) :  1.0 m - 1.8 m  (3.4 ft - 5.9 ft)
Note: minimum range corresponds to side-on pressure and maximum range
      corresponds to reflected overpressure generated using
      Sandia National Laboratories BLAST model.

Stability Class            : B
Respirable Dep. Vel.       : 0.30 cm/s
Non-respirable Dep. Vel.   : 8.00 cm/s
Receptor Height            : 1.5 m
Inversion Layer Height     :  None
Sample Time                : 10.000 min
Breathing Rate             : 3.33E-04 m3/sec
```

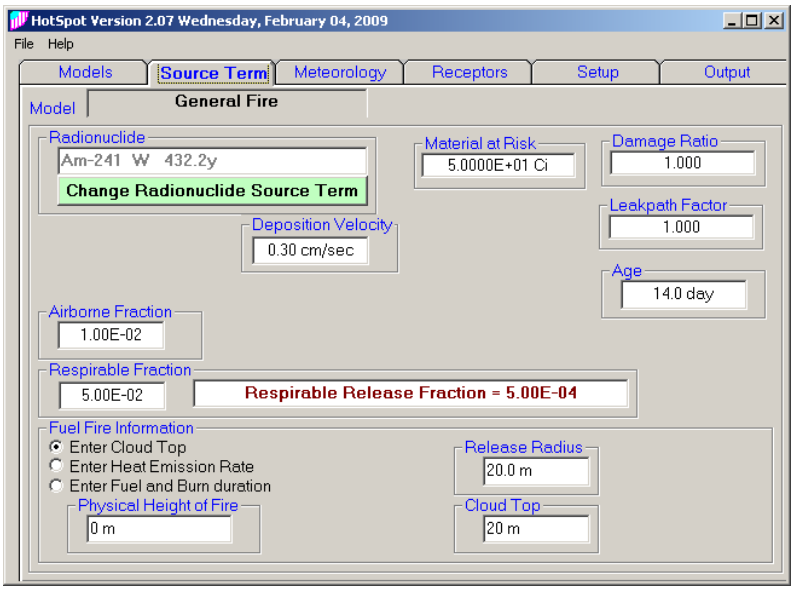
```
Maximum Dose Distance      : 0.010 km
MAXIMUM TEDE               :  0.333 rem
Inner  Contour Dose        : 5.00E-03 rem
Middle Contour Dose        : 2.00E-03 rem
Outer  Contour Dose        : 1.00E-03 rem
Exceeds Inner  Dose Out To : 0.59 km
Exceeds Middle Dose Out To : 1.03 km
Exceeds Outer  Dose Out To : 1.52 km
```

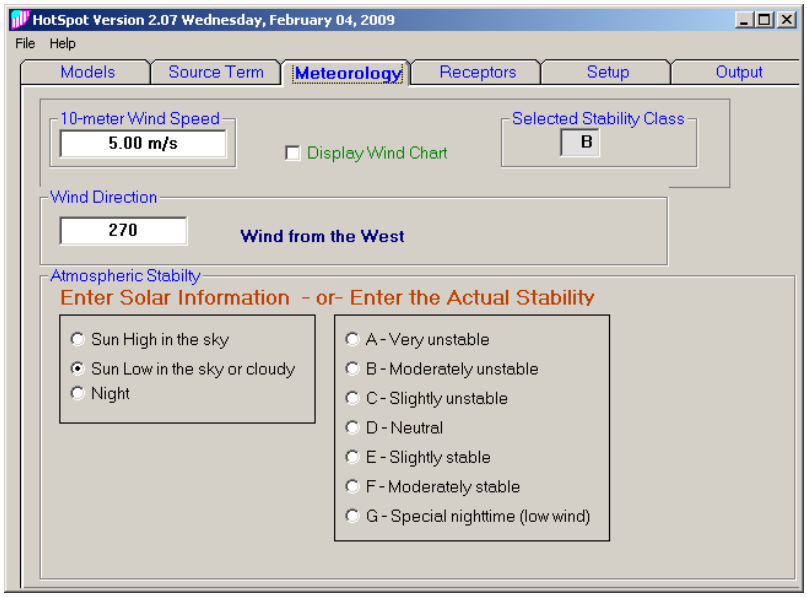
FGR-11 Dose Conversion Data - Total Effective Dose Equivalent (TEDE)

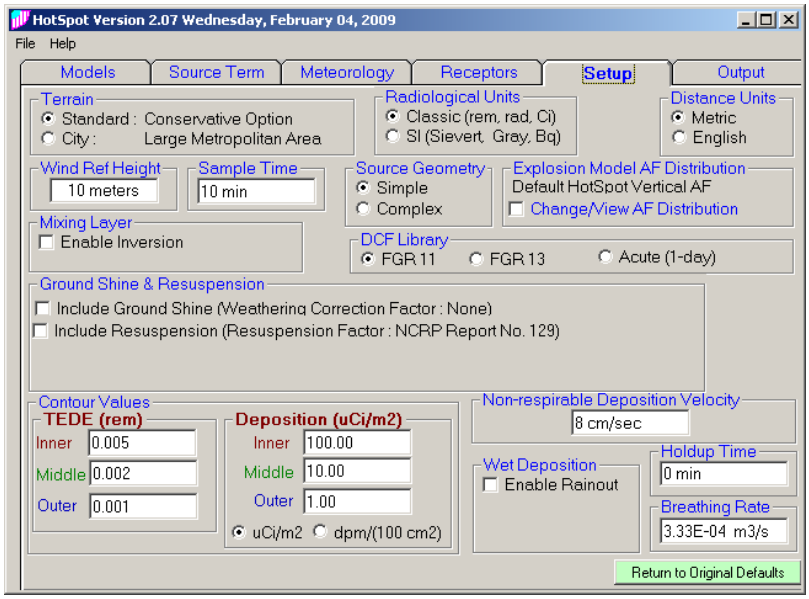
DISTANCE km	T E D E (rem)	RESPIRABLE TIME-INTEGRATED AIR CONCENTRATION (Ci-sec)/m3	GROUND SURFACE DEPOSITION (uCi/m2)	GROUND SHINE DOSE RATE (rem/hr)	ARRIVAL TIME (hour:min)
0.030	1.8E-01	1.6E-02	4.9E+01	2.5E-04	<00:01
0.100	4.7E-02	4.3E-03	1.3E+01	6.4E-05	<00:01
0.200	2.0E-02	1.8E-03	5.4E+00	2.7E-05	00:01
0.300	1.3E-02	1.2E-03	3.5E+00	1.7E-05	00:02
0.400	8.9E-03	8.1E-04	2.4E+00	1.2E-05	00:02
0.500	6.5E-03	5.9E-04	1.8E+00	8.9E-06	00:03
0.600	4.9E-03	4.5E-04	1.3E+00	6.7E-06	00:04
0.700	3.9E-03	3.5E-04	1.0E+00	5.3E-06	00:05
0.800	3.1E-03	2.8E-04	8.4E-01	4.2E-06	00:05
0.900	2.5E-03	2.3E-04	6.9E-01	3.5E-06	00:06
1.000	2.1E-03	1.9E-04	5.8E-01	2.9E-06	00:07
2.000	6.2E-04	5.6E-05	1.7E-01	8.4E-07	00:14
4.000	1.7E-04	1.6E-05	4.7E-02	2.4E-07	00:29
6.000	8.4E-05	7.6E-06	2.3E-02	1.1E-07	00:44
8.000	5.0E-05	4.6E-06	1.4E-02	6.8E-08	00:58
10.000	3.4E-05	3.1E-06	9.2E-03	4.6E-08	01:13
20.000	1.0E-05	9.5E-07	2.8E-03	1.4E-08	02:26
40.000	3.4E-06	3.0E-07	9.1E-04	4.6E-09	04:53
60.000	1.8E-06	1.6E-07	4.8E-04	2.4E-09	07:20

General Fire Example

Fifty curies of Am-241 are involved in a laboratory fire. Assume no containment and the Airborne and Respirable Fractions are 0.01and 0.05, respectively. The effective radius of the fire is 20 meters. The sun is low in the sky, and the wind speed (at a 10-meter reference height), is 4 meters per second. The observed cloud top of the plume is approximately 20 meters above the ground. Estimate the ground contamination and 50-year CEDEs as a function of downwind centerline distance.








```
HotSpot  Version 2.07.1  General Fire

Source Material              : Am-241  W   432.2y
Material-at-Risk    (MAR)    : 5.0000E+01 Ci
Damage Ratio         (DR)    : 1.000
Airborne Fraction   (ARF)    : 1.00E-02
Respirable Fraction (RF)     : 5.00E-02
Leakpath Factor     (LPF)    : 1.000
Respirable Source Term       : 2.50E-02 Ci
Non-respirable Source Term   : 4.75E-01 Ci
Release Radius               : 20.0 m
Cloud Top                    : 20 m
Physical Height of Fire      : 0 m
Effective Release Height     : 14 m
Wind Speed (h=10 m)          : 5.00 m/s
Distance Coordinates         : All distances are on the Plume Centerline
Avg Wind Speed (h=H-eff)     : 5.12 m/s
Stability Class              : B
Respirable Dep. Vel.         : 0.30 cm/s
Non-respirable Dep. Vel.     : 8.00 cm/s
Receptor Height              : 1.5 m
Inversion Layer Height       :  None
Sample Time                  : 10.000 min
Breathing Rate               : 3.33E-04 m3/sec

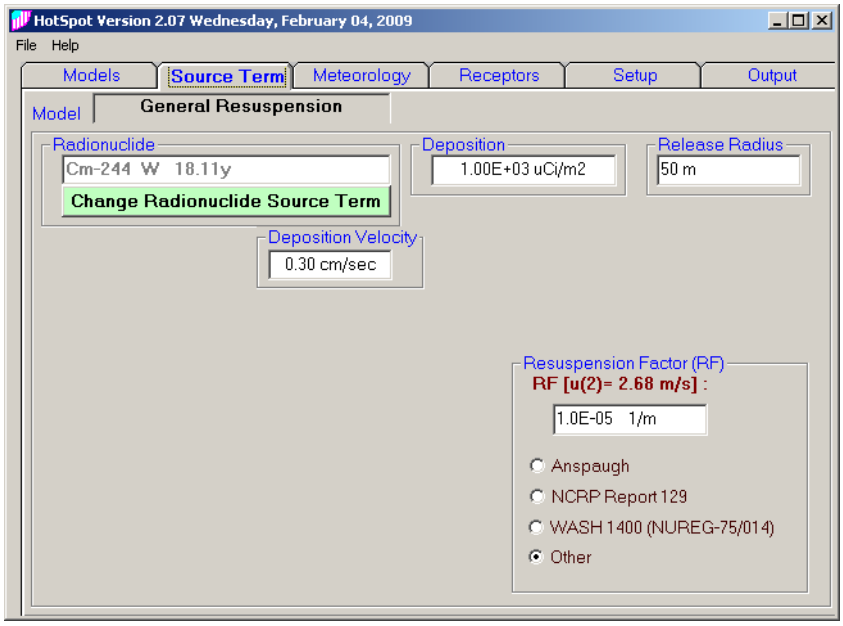
Maximum Dose Distance        : 0.010 km
MAXIMUM TEDE                 :  0.807 rem
Inner  Contour Dose          : 5.00E-03 rem
Middle Contour Dose          : 2.00E-03 rem
Outer  Contour Dose          : 1.00E-03 rem
Exceeds Inner  Dose Out To   : 1.51 km
Exceeds Middle Dose Out To   : 2.48 km
Exceeds Outer  Dose Out To   : 3.62 km
```

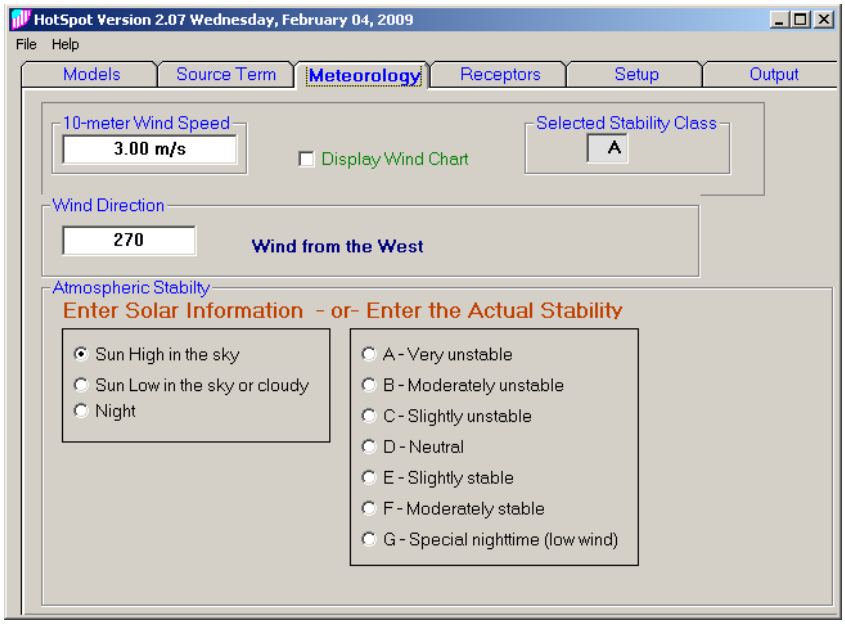
FGR-11 Dose Conversion Data

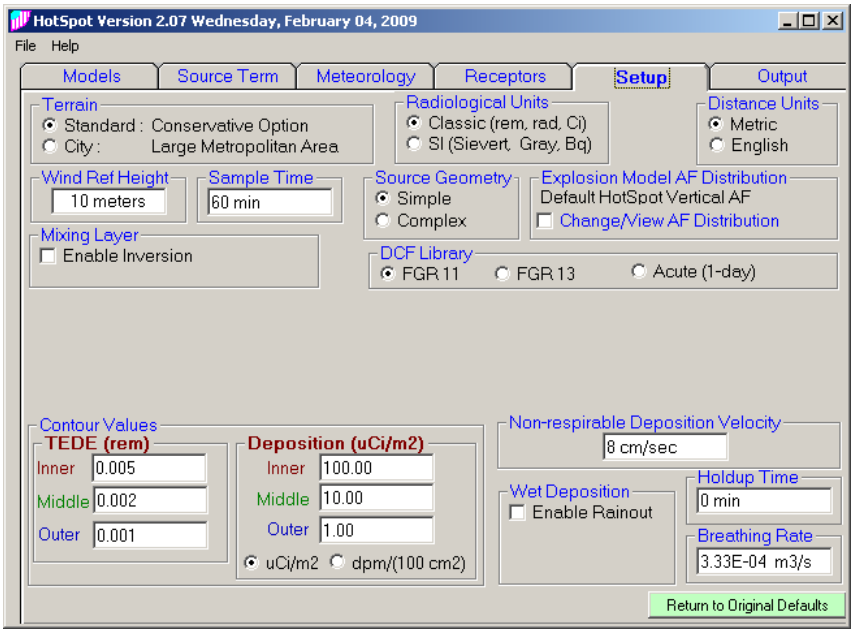
DISTANCE km	T E D E (rem)	RESPIRABLE TIME-INTEGRATED AIR CONCENTRATION (Ci-sec)/m3	GROUND SURFACE DEPOSITION (uCi/m2)	GROUND SHINE DOSE RATE (rem/hr)	ARRIVAL TIME (hour:min)
0.030	6.7E-01	4.5E-06	7.4E+00	2.7E-06	<00:01
0.100	3.3E-01	2.2E-06	3.3E+00	1.2E-06	<00:01
0.200	1.5E-01	1.0E-06	1.4E+00	5.2E-07	<00:01
0.300	8.3E-02	5.6E-07	7.7E-01	2.8E-07	<00:01
0.400	5.3E-02	3.6E-07	4.7E-01	1.7E-07	00:01
0.500	3.6E-02	2.5E-07	3.2E-01	1.2E-07	00:01
0.600	2.7E-02	1.8E-07	2.3E-01	8.5E-08	00:01
0.700	2.0E-02	1.4E-07	1.7E-01	6.4E-08	00:02
0.800	1.6E-02	1.1E-07	1.4E-01	5.0E-08	00:02
0.900	1.3E-02	8.8E-08	1.1E-01	4.0E-08	00:02
1.000	1.1E-02	7.3E-08	8.9E-02	3.3E-08	00:03
2.000	3.0E-03	2.0E-08	2.3E-02	8.5E-09	00:06
4.000	8.4E-04	5.7E-09	6.0E-03	2.2E-09	00:13
6.000	4.0E-04	2.7E-09	2.8E-03	1.0E-09	00:19
8.000	2.4E-04	1.6E-09	1.6E-03	5.9E-10	00:26
10.000	1.6E-04	1.1E-09	1.1E-03	3.9E-10	00:32
20.000	5.0E-05	3.4E-10	3.1E-04	1.1E-10	01:05
40.000	1.6E-05	1.1E-10	9.3E-05	3.4E-11	02:10
60.000	8.6E-06	5.8E-11	4.7E-05	1.7E-11	03:15
80.000	5.5E-06	3.7E-11	2.9E-05	1.1E-11	04:20

General Resuspension Example

Estimate the 50-year CEDE rates (i.e., dose commitment per hour of downwind exposure) to individuals downwind from a contamination event involving Cm-244. Most of the curium is contained in an area with an effective radius of 50 m. The average contamination level is 1,000 microcuries per square meter. Based on air sampling measurements, the Resuspension Factor (RF), is 1.0 E-05 1/m. The RF values are determined at a height near the ground surface (assumed to be a wind speed height of 2 meters). The sun is high in the sky on a cloudless day with a 3 m/s wind speed (measured at a 10-meter reference height, which results in a 2-meter height winds peed of 2.68 m/s).


HotSpot Version 2.07 Wednesday, February 04, 2009
File Help
Models
Source Term
Meteorology
Receptors
Setup
Output
Model
General Resuspension
Radionuclide
Cm-244 W 18.11y
Change Radionuclide Source Term
Deposition
1.00E+03 uCi/m2
Release Radius
50 m
Deposition Velocity
0.30 cm/sec
Resuspension Factor (RF)
RF [u(2)= 2.68 m/s] :
1.0E-05 1/m
Anspaugh
NCRP Report 129
WASH 1400 (NUREG-75/014)
Other


HotSpot Version 2.07 Wednesday, February 04, 2009
File Help
Models
Source Term
Meteorology
Receptors
Setup
Output
10-meter Wind Speed
3.00 m/s
Display Wind Chart
Selected Stability Class
A
Wind Direction
270
Wind from the West
Atmospheric Stabilty
Enter Solar Information - or- Enter the Actual Stability
Sun High in the sky
Sun Low in the sky or cloudy
Night
A - Very unstable
B - Moderately unstable
C - Slightly unstable
D - Neutral
E - Slightly stable
F - Moderately stable
G - Special nighttime (low wind)


HotSpot Version 2.07 Wednesday, February 04, 2009
File Help
Models
Source Term
Meteorology
Receptors
Setup
Output
Terrain
Standard : Conservative Option
City : Large Metropolitan Area
Radiological Units
Classic (rem, rad, Ci)
SI (Sievert, Gray, Bq)
Distance Units
Metric
English
Wind Ref Height
10 meters
Sample Time
60 min
Source Geometry
Simple
Complex
Explosion Model AF Distribution
Default HotSpot Vertical AF
Change/View AF Distribution
Mixing Layer
Enable Inversion
DCF Library
FGR 11
FGR 13
Acute (1-day)
Contour Values
TEDE (rem)
Inner 0.005
Middle 0.002
Outer 0.001
Deposition (uCi/m2)
Inner 100.00
Middle 10.00
Outer 1.00
uCi/m2
dpm/(100 cm2)
Non-respirable Deposition Velocity
8 cm/sec
Wet Deposition
Enable Rainout
Holdup Time
0 min
Breathing Rate
3.33E-04 m3/s
Return to Original Defaults

```
HotSpot  Version 2.07 General Resuspension
Feb 04, 2009 05:12 PM
(Resuspension Factor : User-input Value)

Source Material            : Cm-244  W   18.11y
Source Term                : 1.00E+03 uCi/m2
Resuspension Factor        : 1.0E-05    1/m
Effective Release Radius   : 50 m
Effective Source Term      : 4.8E-05 Ci/s
Wind Speed (h=10 m)        : 3.00 m/s
Distance Coordinates       : All distances are on the Plume Centerline
Stability Class            : A
Respirable Dep. Vel.       : 0.30 cm/s
Receptor Height            : 1.5 m
Inversion Layer Height     :  None
Sample Time                : 60.000 min
Breathing Rate             : 3.33E-04 m3/sec

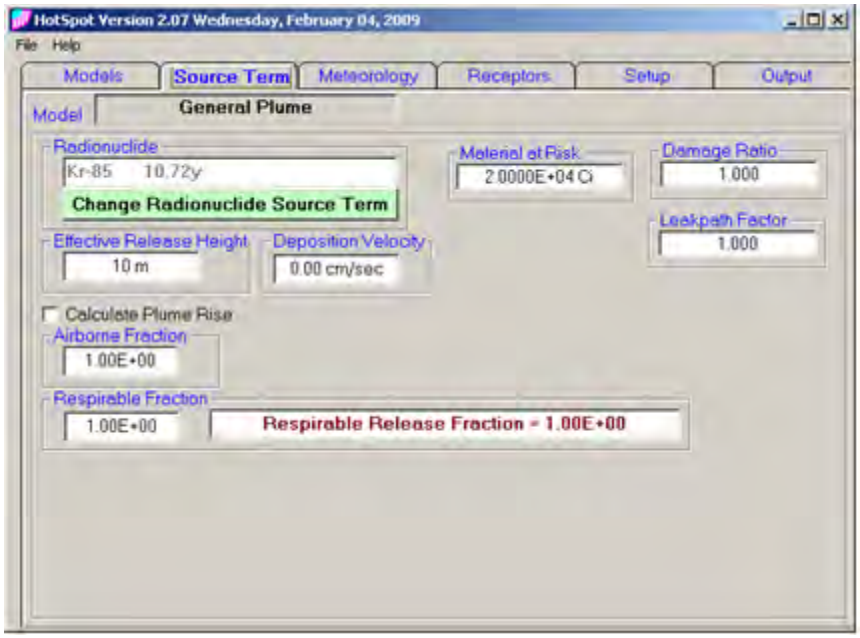
Maximum Dose Distance      : 0.010 km
MAXIMUM TEDE               :   1.8 rem
Inner  Contour Dose        : 5.00E-03 rem
Middle Contour Dose        : 2.00E-03 rem
Outer  Contour Dose        : 1.00E-03 rem
Exceeds Inner  Dose Out To : 2.29 km
Exceeds Middle Dose Out To : 3.80 km
Exceeds Outer  Dose Out To : 5.60 km

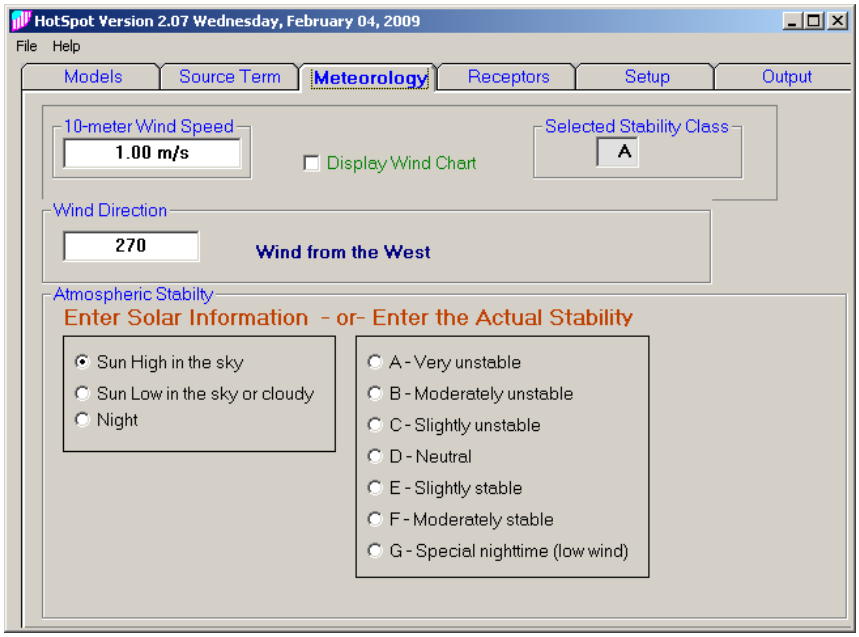
FGR-11 Dose Conversion Data - Total Effective Dose Equivalent (TEDE)
```

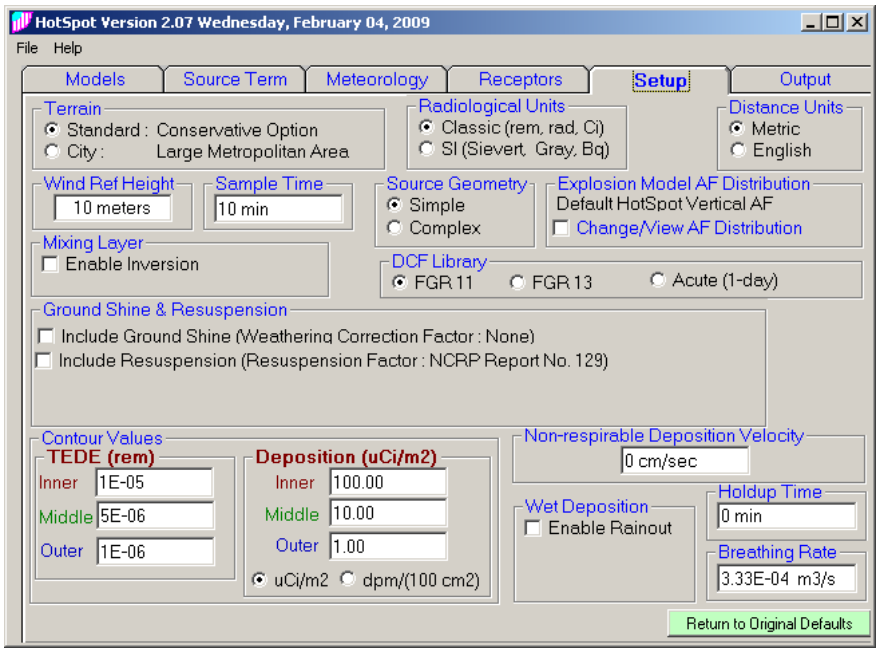
DISTANCE km	T E D E PER 1-HR EXPOSURE TIME (rem)	AVERAGE AIR CONCENTRATION (Ci/m3)
0.030	1.3E+00	4.4E-09
0.100	5.9E-01	2.0E-09
0.200	2.7E-01	9.2E-10
0.300	1.6E-01	5.3E-10
0.400	1.0E-01	3.5E-10
0.500	7.2E-02	2.4E-10
0.600	5.4E-02	1.8E-10
0.700	4.1E-02	1.4E-10
0.800	3.3E-02	1.1E-10
0.900	2.7E-02	9.1E-11
1.000	2.2E-02	7.5E-11
2.000	6.5E-03	2.2E-11
4.000	1.8E-03	6.2E-12
6.000	8.9E-04	3.0E-12
8.000	5.4E-04	1.8E-12
10.000	3.6E-04	1.2E-12
20.000	1.1E-04	3.8E-13
40.000	3.6E-05	1.2E-13
60.000	1.9E-05	6.4E-14
80.000	1.2E-05	4.1E-14

General Plume Example

Estimate the potential Total Effective Dose Equivalent (TEDE), due to a release of 20,000 curies of Kr-85 from a 10-meter stack. The wind is from the West at 1 meter/second (at a 10-meter reference height), on a sunny day. Since this is a noble gas, the Leakpath Factor Airborne Fraction, and Respirable Fraction are all 1.000.








```
HotSpot  Version 2.07.1  General Plume

Source Material              : Kr-85   1.0756E+01 y
Material-at-Risk    (MAR)    : 2.0000E+04 Ci
Damage Ratio         (DR)    : 1.000
Airborne Fraction   (ARF)    : 1.000
Respirable Fraction (RF)     : 1.000
Leakpath Factor     (LPF)    : 1.000
Respirable Source Term       : 2.00E+04 Ci
Non-respirable Source Term   : 0.00E+00 Ci
Effective Release Height     : 10 m
Wind Speed (h=10 m)          : 1.00 m/s
Distance Coordinates         : All distances are on the Plume Centerline
Wind Speed (h=H-eff)         : 1.00 m/s
Stability Class              : A
Respirable Dep. Vel.         : 0.00 cm/s
Distance Coordinates         : All distances are on the Plume Centerline
Wind Speed (h=H-eff)         : 1.00 m/s
Stability Class              : A
Respirable Dep. Vel.         : 0.00 cm/s
Non-respirable Dep. Vel.     : 0.00E+00 cm/s
Receptor Height              : 1.5 m
Inversion Layer Height       :  None
Sample Time                  : 10.000 min
Breathing Rate               : 3.33E-04 m3/sec

Maximum Dose Distance        : 0.034 km
MAXIMUM TEDE                 : 0.019 rem
Inner  Contour Dose          : 1.00E-05 rem
Middle Contour Dose          : 5.00E-06 rem
Outer  Contour Dose          : 1.00E-06 rem
Exceeds Inner  Dose Out To   : 2.66 km
Exceeds Middle Dose Out To   : 3.84 km
Exceeds Outer  Dose Out To   : 9.40 km
```

FGR-11 Dose Conversion Data - Total Effective Dose Equivalent (TEDE)

DISTANCE km	T E D E (rem)	RESPIRABLE TIME-INTEGRATED AIR CONCENTRATION (Ci-sec)/m3	ARRIVAL TIME (hour:min)
0.030	1.9E-02	4.2E+01	<00:01
0.100	5.6E-03	1.3E+01	00:01
0.200	1.6E-03	3.5E+00	00:03
0.300	7.1E-04	1.6E+00	00:05
0.400	4.0E-04	9.1E-01	00:06
0.500	2.6E-04	5.9E-01	00:08
0.600	1.8E-04	4.1E-01	00:10
0.700	1.3E-04	3.0E-01	00:11
0.800	1.0E-04	2.3E-01	00:13
0.900	8.2E-05	1.9E-01	00:15
1.000	6.7E-05	1.5E-01	00:16
2.000	1.7E-05	4.0E-02	00:33
4.000	4.7E-06	1.1E-02	01:06
6.000	2.2E-06	5.1E-03	01:40
8.000	1.3E-06	3.0E-03	02:13
10.000	9.0E-07	2.0E-03	02:46
20.000	2.8E-07	6.3E-04	05:33
40.000	8.9E-08	2.0E-04	11:06
60.000	4.7E-08	1.1E-04	16:40
80.000	3.0E-08	6.8E-05	22:13

5. Special Purpose Programs

In addition to the atmospheric dispersion and explosion models, four special purpose programs are also included in HotSpot: 1) Nuclear Explosion (nuclear yield), 2) Radionuclides in the Workplace, 3) FIDLER Calibration and Lung Screening, and a module to calculate 4) Percentile Dose using Historical Meteorological Data.

Nuclear Explosion

Background

HotSpot estimates the effects of a surface-burst nuclear weapon, based on the information in The Effects of Nuclear Weapons by Samuel Glasstone and Philip J. Dolan (3rd Edition, U.S. Department of Defense and the U.S. Department of Energy, 1977). The predominant initial ionizing radiation species are neutrons and gamma rays produced during the first minute of the nuclear explosion. This initial radiation is often referred to as prompt radiation. The total energy of the initial neutrons and gamma rays is only about 3 percent of the total explosive energy, compared with the 35 to 45 percent appearing as thermal radiation. However, it is this prompt ionizing radiation that causes a significant proportion of the casualties.

The effective wind speed and direction (wind shear), vary with the height of the top and bottom of the stabilized debris cloud. HotSpot fallout predictions assume a default effective wind speed of 15 miles per hour (6.8 meters per second) and a fixed wind shear of 15 degrees. The Glasstone idealized fallout dose calculations are assumed to be independent of the atmospheric stability classification (i.e., A – G). All dose data are midline tissue doses- the midline dose is assumed to be 70% of the "surface" absorbed dose (Glasstone, page 579, section 12.108). A fallout dose terrain reduction factor of 0.7 is assumed (Glasstone, page 428, section 9.95).

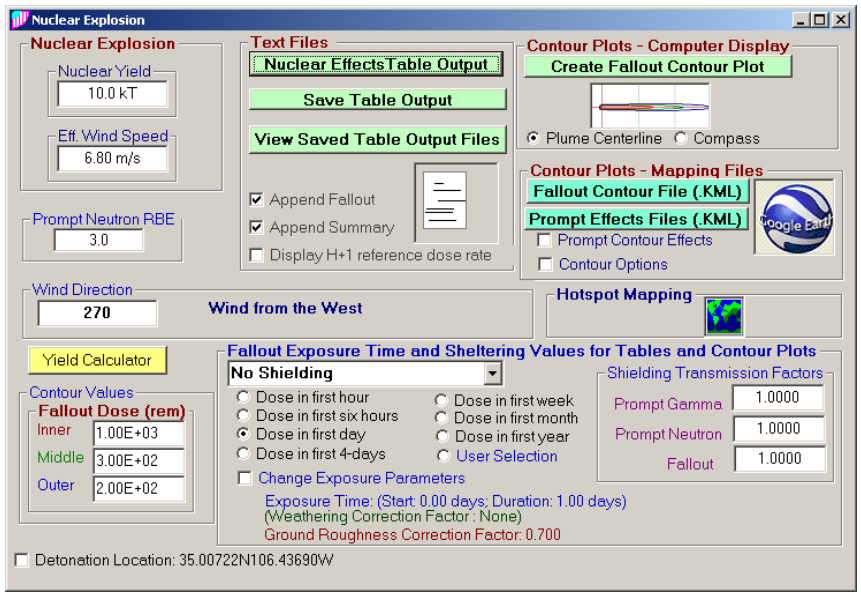
Shielding attenuation from fallout gamma radiation for various structures (home, apartment, earth, etc.), are selectable options for table output, fallout contour plots and contour files. Table 5.1 contains the dose transmission factors used in HotSpot for fallout gamma, prompt gamma, and prompt neutron radiation. (See Glasstone, page 441, Table 9.120 and section 9.118). All of the structures are assumed to be isolated, so that possible effects of adjacent structures have been neglected.

Shielding Structure	Dose Transmission Factor		
	Fallout Gamma	Prompt Gamma	Prompt Neutron
No Shielding	1.0	1.0	1.0
Vehicles (i.e., cars, trucks, buses)	0.5	1.0	1.0
Frame house	0.6	1.0	0.8
Basement	0.1	0.6	0.8
Multistory-lower floor	0.1	0.6	0.8
Concrete 9-inch walls	0.09	0.2	0.5
Concrete 12-inch walls	0.03	0.1	0.4
Multistory-upper floor	0.01	0.9	1.0
Concrete 24-inch walls	0.002	0.02	0.2
1 m (3 ft) underground	0.0002	0.004	0.01

Table 5.1 HotSpot Shielding structure dose transmission factors.

Nuclear Explosion Example

What would be the prompt effects from the surface detonation of a 10-kiloton fission device? Assume an effective windspeed of 6.8 m/s. Also include the estimated fallout external dose to individuals remaining in the open environment (i.e., no sheltering), at 1, 2, and 3 kilometers directly downwind of the nuclear detonation.



The following provides general information about nuclear explosions for this example:

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HotSpot Version 2.07 Nuclear Explosion
Feb 04, 2009 05:23 PM


Nuclear Explosion: 10.0 kT Surface Burst

Personnel exposed to a nuclear explosion may be killed or suffer injuries
of various types.  Casualties are primarily caused by blast, thermal
radiation, and ionizing radiation.  The distribution and severity of these
injuries depends on device yield, height of burst, atmospheric conditions,
body orientation, protection afforded by shelter, and the general nature
of the terrain.

The energy of a nuclear explosion is partitioned as follows,

50% Blast and ground shock
35% Thermal Radiation (Effective partition = 18% for surface burst)
15% Ionizing Radiation
   5%   Prompt  (first minute)
   10%  Delayed (minutes to years)

The 10.0 kT nuclear explosion produces a fireball of incandescent
gas and vapor. Initially, the fireball is many times more brilliant
than the sun at noon, but quickly decreases in brightness and continues to
expand. In about 1 second, the fireball will have reached its maximum diameter
of about 440 meters. After 1 minute, the fireball will have cooled
sufficiently so that it no longer glows.


BLAST

Blast casualties may occur due to the direct action of the pressure wave,
impact of missiles and fragments, and whole body translation and impact.
The destructiveness of the blast is a function of its peak overpressure
and duration of the positive pressure wave (or impulse). The 10.0 kT explosion
will produce in excess of the blast required to produce 100% Lethality
out to a distance of 0.27 km (0.17 miles)  Injuries associated with shattered
glass windows can occur out to a distance of  4.09 km (2.54 miles)

THERMAL RADIATION

Burn casualties may result from the absorption of thermal radiation energy
by the skin, heating or ignition of clothing, and fires started by the
thermal pulse or as side effects of the air blast or the ground shock.
Exposed eyes are at risk of permanent retinal burns and flash blindness out
to relatively large distances (especially at night when the diameter of the
pupil is maximum). Under daytime conditions,the 10.0 kT  explosion
could produce temporary flash blindness from scattered light out to a
distance of  22 km (14 miles). Individuals who directly view the initial
fireball could experience retinal burns out to a distance of 23 km (14 miles).
Unprotected individuals could receive in excess of the thermal radiation dose
required for third degree burns, out to a distance of 1.4 km (0.9 miles).


IONIZING RADIATION

Radiation casualties may be caused by prompt nuclear radiation or by
radioactive fallout. Prompt ionizing radiation consists of x rays, gamma
rays, and neutrons produced in the first minute following the nuclear
explosion. Unprotected individuals could receive in excess of the prompt
ionizing radiation dose required for 50% lethality (within weeks),
out to a distance of  1.4 km (0.89 miles)

The delayed ionizing radiation is produced by fission products and
neutron-induced radionuclides in surrounding materials (soil, air,
```

structures, nuclear device debris). These radioactive products will be dispersed downwind with the fireball/debris cloud. As the cloud travels downwind, the radioactive material that has fallen and settled on the ground creates a footprint of deposited material (fallout).

The exposure to the fallout is the dominant source of radiation exposure for locations beyond the prompt effects of the nuclear detonation. The dose received depends upon the time an individual remains in the contaminated area. Unprotected individuals remaining in the contamination zone for the first hour following the nuclear explosion could receive in excess of the fallout dose required for 50% lethality (within weeks), out to a distance of about 9 km (5 miles). The idealized maximum width of the fallout footprint (actual width could be larger or smaller) is about 0.40 km (0.25 miles). For individuals remaining in the contamination for the first 24 hours, the downwind extent of the 50% lethality contour increases to approximately 17 km (11 miles). The 50% lethality contour width increases to about to about 0.85 km (0.53 miles).

ELECTROMAGNETIC PULSE (EMP)

The EMP range for the 10.0 kT detonation is approximately 4 km (3 miles). This range is the outer extent that any EMP effects are expected to occur. Not all equipment within the EMP-effects circle will fail. The amount of failure will increase the closer to ground zero the equipment is located, the larger the equipment's effective receptor antenna, and the equipment's sensitivity to EMP effects. Solid state devices are more sensitive than vacuum tube devices. Least affected by EMP are electro-mechanical devices such as electric motors, lamps, heaters, etc. Cell phones and handheld radios have relatively small antennas and if they are not connected to electrical power supplies during the EMP pulse, will probably not be affected by the EMP.

The effects of EMP occur at the instant of the nuclear detonation and ends within a few seconds. Any equipment that will be damaged by EMP will be damaged within those seconds. Electronic equipment entering the area after the detonation will function normally as long as they do not rely on previously damaged equipment, e.g., repeaters, power supplies, etc.

```
Nuclear Yield        :      10.0 kT
Cloud Top            :      8200           m
Cloud Radius         :      2300           m
Cloud Bottom         :      5100           m
Stem Radius          :      780            m
Wind Direction       :      270            degrees       Wind from the West
Effective Wind Speed :      6.8            m/s

_____________________________________________________
Ionizing Radiation Shielding: No Shielding
     Prompt  Gamma   Transmission Factor: 1.0000
     Prompt  Neutron Transmission Factor: 1.0000
     Fallout Gamma   Transmission Factor: 1.0000
     (Weathering Correction Factor : None)
     (Ground Roughness Correction Factor : 0.700)
_____________________________________________________

Radial Distances for Prompt Effects (first minute following nuclear explosion)

Prompt Ionizing Radiation Effects : Whole-body Midline Dose
Includes Gamma and Neutron Radiation (Neutron RBE = 3.0)

10,000  rad-eq (cGy-eq)  [100% death, < 1 day]........  0.87 km (0.54 miles)
 1,000  rad-eq (cGy-eq)  [100% death, days]...........  1.23 km (0.76 miles)
   460  rad-eq (cGy-eq)  [95% death, weeks]...........  1.36 km (0.84 miles)
   400  rad-eq (cGy-eq)  [85% death, weeks]...........  1.38 km (0.86 miles)
   300  rad-eq (cGy-eq)  [50% death, weeks]...........  1.43 km (0.89 miles)
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```
   200  rad-eq (cGy-eq)  [15% death, years]..........  1.51 km (0.94 miles)
   140  rad-eq (cGy-eq)  [ 5% death, years]..........  1.57 km (0.98 miles)

Prompt Blast Effects : Lethality

 Threshold 30 psi (30-50)...............        0.40 km (0.25 miles)
 50  %     50 psi (50-75)...............        0.32 km (0.20 miles)
 100 %     75 psi (75-115)..............        0.27 km (0.17 miles)

Prompt Blast Effects : Lung Damage

 Threshold  8 psi (8-15)................        0.74 km (0.46 miles)
 Severe    20 psi (20-30)...............        0.48 km (0.30 miles)

Prompt Blast Effects : Eardrum rupture

 Threshold  5 psi.......................        0.96 km (0.60 miles)
 50 %      15 psi (15-20)...............        0.54 km (0.34 miles)

Prompt Blast Effects : Shattered window glass injury

 Threshold 0.5 psi......................        4.09 km (2.54 miles)

Prompt Thermal Effects : Skin burns and Eye Damage

Eye Damage
Day
 Flash Blindness  ......................        22   km (13.7   miles)
 Retinal Burns  ........................        23   km (14.4   miles)

Night
 Flash Blindness  ......................        73   km (45.3   miles)
 Retinal Burns  ........................        41   km (25.5   miles)

Visibility :    20 km (12 miles)
 50 % 1st Degree  (2.4    cal/cm2)......        2.00 km (1.24 miles)
 50 % 2nd Degree  (4.7    cal/cm2)......        1.50 km (0.93 miles)
 50 % 3rd Degree  (7.3    cal/cm2)......        1.25 km (0.78 miles)

Visibility :    40 km (25 miles)
 50 % 1st Degree  (2.4    cal/cm2)......        2.18 km (1.35 miles)
 50 % 2nd Degree  (4.7    cal/cm2)......        1.61 km (1.00 miles)
 50 % 3rd Degree  (7.3    cal/cm2)......        1.32 km (0.82 miles)

Visibility :    80 km (50 miles)
 50 % 1st Degree  (2.4    cal/cm2)......        2.35 km (1.46 miles)
 50 % 2nd Degree  (4.7    cal/cm2)......        1.70 km (1.06 miles)
 50 % 3rd Degree  (7.3    cal/cm2)......        1.38 km (0.86 miles)

Electromagnetic Pulse (EMP)
 Maximum extent of radial EMP effects...        4    km (3 miles).

_____________________________________________________________
Ionizing Radiation Shielding: No Shielding
     Prompt  Gamma   Transmission Factor: 1.0000
     Prompt  Neutron Transmission Factor: 1.0000
     Fallout Gamma   Transmission Factor: 1.0000
     (Weathering Correction Factor : None)
     (Ground Roughness Correction Factor : 0.700)
_____________________________________________________________
     Centerline Distance  1.000 km (  0.621 mi )

Blast (maximum overpressure)              4.6E+00 psi
Prompt Neutron                            2.8E+03 rad-eq
Prompt Gamma                              1.3E+03 rad
Total Prompt Ionizing Radiation           4.1E+03 rad-eq
Thermal @ Visibility = 20 km (12 miles):  1.2E+01 cal/cm2
Thermal @ Visibility = 40 km (25 miles):  1.3E+01 cal/cm2
Thermal @ Visibility = 80 km (50 miles):  1.4E+01 cal/cm2
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Fallout Information

Cloud Arrival Time (hr:min)                00:02
Actual Dose Rate @ Cloud Arrival Time      1.1E+05 rem/hr
External Dose in First Hour                1.1E+04 rem
External Dose in First 6-hours             1.5E+04 rem
External Dose in First Day                 1.7E+04 rem
External Dose in First 4-days              1.8E+04 rem
External Dose in First Week                1.9E+04 rem
External Dose in First Month               2.0E+04 rem
External Dose in First Year                2.1E+04 rem
External Dose in 50-years                  2.1E+04 rem
_____________________________________________________________
_____________________________________________________________
     Centerline Distance  2.000 km (  1.242 mi )

Blast (maximum overpressure)               1.4E+00 psi
Prompt Neutron                             6.2E+00 rad-eq
Prompt Gamma                               8.5E+00 rad
Total Prompt Ionizing Radiation            1.5E+01 rad-eq
Thermal @ Visibility = 20 km (12 miles):   2.4E+00 cal/cm2
Thermal @ Visibility = 40 km (25 miles):   2.9E+00 cal/cm2
Thermal @ Visibility = 80 km (50 miles):   3.4E+00 cal/cm2

Fallout Information

Cloud Arrival Time (hr:min)                00:04
Actual Dose Rate @ Cloud Arrival Time      4.9E+04 rem/hr
External Dose in First Hour                8.0E+03 rem
External Dose in First 6-hours             1.2E+04 rem
External Dose in First Day                 1.4E+04 rem
External Dose in First 4-days              1.5E+04 rem
External Dose in First Week                1.6E+04 rem
External Dose in First Month               1.7E+04 rem
External Dose in First Year                1.8E+04 rem
External Dose in 50-years                  1.8E+04 rem
_____________________________________________________________
_____________________________________________________________
     Centerline Distance  3.000 km (  1.863 mi )

Blast (maximum overpressure)               Minimal Blast
Prompt Neutron                             Minimal Neutron
Prompt Gamma                               1.3E-01 rad
Total Prompt Ionizing Radiation            1.7E-01 rad-eq
Thermal @ Visibility = 20 km (12 miles):   8.7E-01 cal/cm2
Thermal @ Visibility = 40 km (25 miles):   1.2E+00 cal/cm2
Thermal @ Visibility = 80 km (50 miles):   1.5E+00 cal/cm2

Fallout Information

Cloud Arrival Time (hr:min)                00:07
Actual Dose Rate @ Cloud Arrival Time      3.0E+04 rem/hr
External Dose in First Hour                6.4E+03 rem
External Dose in First 6-hours             1.0E+04 rem
External Dose in First Day                 1.2E+04 rem
External Dose in First 4-days              1.4E+04 rem
External Dose in First Week                1.4E+04 rem
External Dose in First Month               1.5E+04 rem
External Dose in First Year                1.7E+04 rem
External Dose in 50-years                  1.7E+04 rem
_____________________________________________________________
```

Radionuclides in the Workplace

Background

The HotSpot program provides a guide for initial planning of experiments and workplace selection. It cannot be treated as a precise hazard analysis for handling radioactive materials. Further considerations may be necessary depending on the material's physical form (i.e., solid, powder, etc.) volatility, pyrophoric properties, ability to penetrate the skin, radiation dose rate, and the experience of the experimenter and the health physicist. This workplace screening method can be used as a guide for the initial planning of operations involving radioactive material.

Operations involving radioactive material must be designed, equipped, and conducted to protect personnel as much as is practical against the hazards of ionizing radiation. The protective measures selected must take into account the nature of the operation, the radionuclides involved, and the quantities that will be used. These operations must only be conducted in approved workplaces. The selection of the workplace is based on the relative hazard of an operation and on the quantity and radiotoxicity of the radionuclides involved. Accordingly, the relative hazard of an operation is determined by evaluating the following factors for each radionuclide.

- Radionuclide to be used.
- Chemical and physical form of the radionuclide to be used.
- Quantity of the radionuclide to be used.
- Nature of the operation to be performed.
- Mass of the material in which the radioactivity is contained.

Workplaces are divided into three classifications: Type 1, Type 2, and Type 3. An operation that, according to this methodology, requires other than a Type 1 workplace should be referred to a health physicist for a final evaluation of the workplace requirements. The health physicist may increase or decrease the workplace criteria as appropriate for a particular operation.

Type 1 Workplaces

Type 1 workplaces are used only for low-hazard operations. The requirements for such workplaces include—

- Room ventilation is changed six times each hour at a minimum.
- Work surfaces are smooth and impermeable.
- Personnel wear aprons or laboratory coats.
- A periodic monitoring program is maintained to detect any contamination of surfaces.

Type 2 Workplaces

Type 2 workplaces are used for low- or moderate-hazard operations. The requirements for such workplaces include—

- Operations are carried out in chemical fume hoods or the equivalent having a minimum exhaust velocity of 0.75 linear m/s (150 ft/min) at any point of the hood opening.

- The walls and floors of the hood are smooth and protected with impermeable coverings.
- The coverings of work surfaces are either disposable or selected for ease of contamination cleanup.
- Personnel wear laboratory coats and gloves appropriate to the material handled.
- Radioactive materials are stored in a hood, a glove box, or other approved container.
- A monitoring program is maintained to detect external radiation, surface contamination, and airborne radioactivity.
- Special receptacles are provided for separate collection of solid and liquid radioactive or mixed waste generated in the workplace.

Type 3 Workplaces

Type 3 workplaces are used for operations classified as high hazard. These workplaces must be isolated from other working areas. The minimum requirements for such workplaces include—

- Operations are carried out in glove boxes equipped with negative-pressure ventilation and a high-efficiency filtration (e.g., HEPA) system. Other protective devices (e.g., shielding, remote handling devices, air locks, bag-out ports, etc.) commensurate with the degree of hazard associated with the operations are included.
- The coverings of work surfaces are impermeable and adapted to the type of operation to facilitate decontamination.
- The atmosphere in work rooms is maintained at negative pressure with respect to other parts of the building ventilation.
- Access to the workplace is limited to those persons actually needed to perform the operation.
- Protective clothing, such as lab coats, and gloves and protective equipment, such as respirators, are used as specified by the health physicist.
- Radioactive materials are stored in glove boxes, source pits, water pools, or other devices, commensurate with the degree of hazard and the nature of the material.
- A monitoring program is maintained to detect atmospheric contamination, external radiation, and surface contamination. Alarm devices are installed to warn personnel of external radiation or airborne contamination exceeding permissible levels.
- Special receptacles are provided for separate collection of solid and liquid residues generated during operations.

Guide for Selecting Workplaces

The following equation is used to define the relative hazard of the radionuclide operation.

$H = QTU/(m)^{1/2}$

where—

H = Hazard Guide Value (dimensionless);
Q = Quantity of radionuclide (uCi);
T = Toxicity factor (dimensionless);
U = Use factor (dimensionless);
m = Mass of total radioactive and non-radioactive material (g).

Note: If m <1 g, assume m = 1g.

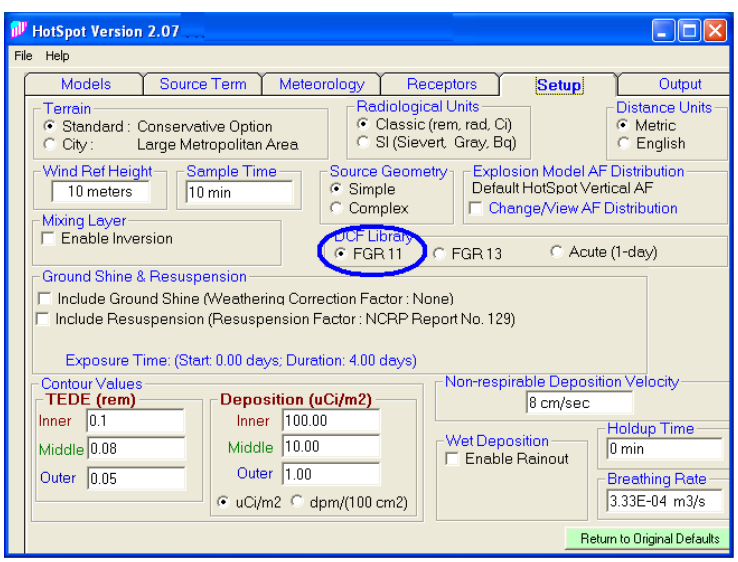
The Hazard Guide Values are based on the 50-year CEDE due to the accidental inhalation of a specific fraction of the radioactive material present at the work area. Once the Hazard Guide for a specific operation has been calculated, the recommended workplace type can be determined from the workplace requirements table. Select the factors necessary to calculate *H*.

Workplace requirements as a function of *H*.

Hazard Guide Value (*H*)	Required Workplace
H ≤ 1 E+07	Type 1
1 E+07 < H < 1 E+10	Type 2
H ≥ 1 E+10	Type 3

Toxicity Factor

The toxicity factor, *T*, accounts for the relative radiotoxicity of the subject material. The toxicity factor is the ratio of the Derived Air Concentration (DAC) of tritium oxide to the DAC of the specific radionuclide(s) in the material. If the "FGR 11" DCF Library Option (Main HotSpot "Setup" form) is selected, ICRP-30 DCFs are used for determination of the DAC and Annual Limit of Intake (ALI), (1 µm AMAD). If the "FGR 13" DCF Library Option is selected, the DAC and ALI values are determined using the new ICRP-60+ DCFs for occupational exposure (5 µm AMAD). The following screen shows that the FGR 11 Library has been selected.



T = DAC (HTO)/DAC (Radionuclide under consideration).

NOTE: Radionuclides labeled to molecules (i.e., amino acids, nucleosides, antibiotics, etc.) must be evaluated on an individual basis because they may represent a special hazard due to their distribution and concentration in the body.

Use Factor

The actual respirable fraction to calculate a specific Hazard Guide value depends on the type of operation performed in the work area (e.g., wet chemistry, grinding of dry material). The respirable fraction is defined as the fraction of the released material associated with an AMAD of 1 μm for the FGR 11 option or an AMAD of 5 μm for the FGR 13 option. For normal operations, as shown in the use factors table, the inhalation fraction is 1×10^{-4}. This inhalation fraction is based on actual incidents involving the inhalation of radioactive material and is conservative by factors of 10 to 1,000 with respect to actual observed values (Franke, 1966).

For other than normal operations the Hazard Guide equation incorporates a use factor, U, to account for the increase or decrease in the inhalation fraction associated with a specific operation (i.e., the inhalation fraction associated with material storage is smaller than the value associated with mixing dry material). The use factor for normal operations is 1.

Use factors as a function of operation

Type of Operation	**Use Factor *(U)***
Storage	**0.01**
Very simple, wet	
Diluting stock solutions	**0.1**
Washing precipitates	
Normal	
No production of dry material	
No vigorous chemical reactions	
Precipitation	
Filtration or centrifuging	**1**
Solvent extraction	
Chromatography	
Pipetting or titration	
Ambient temperatures	
Simple dry	
Fusion reactions	
Fluorination	**5**
Transfer of dry precipitates	

Complex wet	
Distillation	
Evaporation to dryness	**50**
Elevated temperatures	

Dry and dusty	
Machine or hand crushing	
Machining or sawing	**500**
Sieving	
Mixing	

Mass Factor

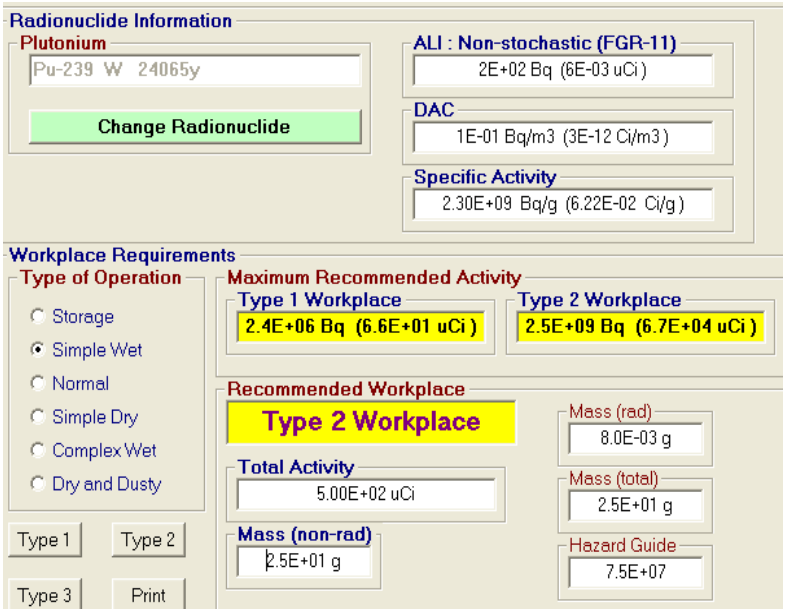
If the radionuclide concentration of the material is increased or decreased, the consequences of inhalation of a specific fraction of the material will also vary. The mass factor adjusts the Hazard Guide for this variation.

When the amount of material to be handled exceeds 10,000 g, the workplace requirement should be evaluated individually by a health physicist. This is necessary to take into account the special consideration of handling very large amounts of material. For example, large quantities can potentially pose a significant hazard outside of the immediate work area. In addition, quantities less than 0.1 g should be evaluated by a health physicist because they can potentially pose a greater inhalation risk if the radioactive material is contained in a relatively small number of respirable particles.

Radionuclides in the Workplace Example 1

Note: These examples use FGR-11 Dose Conversion Factors (DCF), for determination of the DAC and ALI (1 µm AMAD, ICRP-30). If you have selected FGR-13 mode, the DAC and ALI values are determined using the new ICRP-60+ DCFs for occupational exposure (5 µm AMAD). 60+).

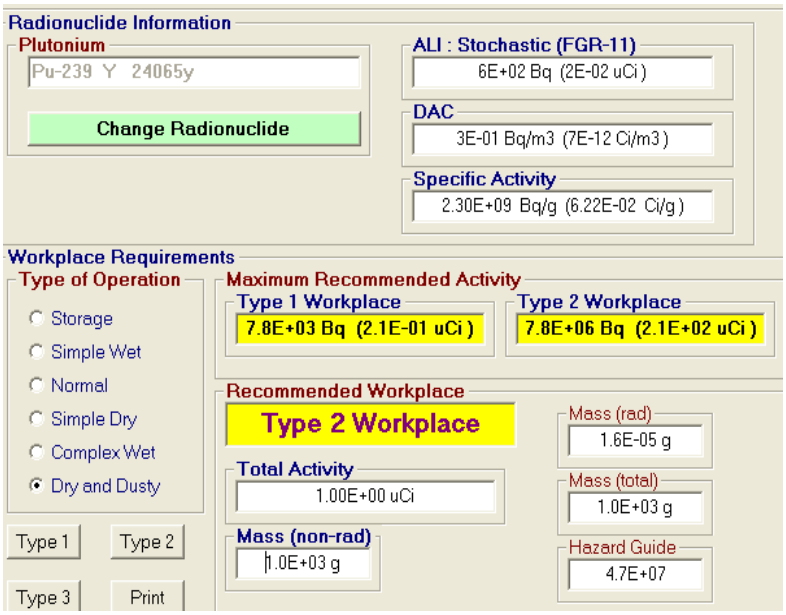
An experimenter wants to pipette a solution containing a total of 500 µCi of class W Pu-239. The activity concentration of the solution is 20 µCi/g, therefore total mass is 25 g. What type of workplace should be recommended for this operation?



Workplace Example 1

Radionuclides in the Workplace Example 2

You are responsible for preparing soil samples following a nuclear weapon accident involving plutonium. The operation will involve mixing soil samples to achieve a homogenous sample and repackaging of the soil for gamma spectroscopy. The highest activity soil samples will be taken in an area with maximum ground contamination on the order of 100 µCi/m^2 of weapons-grade plutonium. The radiotoxicity of weapons-grade plutonium oxide is well represented by assuming the radionuclide is Pu-239 (PuO_2 is usually assumed to be inhalation class Y). Each soil sample has a mass of approximately 100g and is representative of a ground area of 100 cm^2. Therefore, the total activity per sample is 1 µCi. A maximum of 10 soil samples will be processed at any one time. What type of work environment should you recommend for this operation?



Workplace Example 2

FIDLER Calibration

The FIDLER program is used to calibrate a FIDLER (Field Instrument for the Detection of Low-Energy Radiation) or Violinist (FIDLER combined with a multichannel analyzer), for measurement of plutonium contamination on the ground. However, the program can also be applied to any instrument suitable for measuring external radiation levels and non-plutonium mixtures, for example, using a Geiger-Mueller instrument for the measurement of Cs-137 ground contamination. Under the File menu, there are options to open or save a calibration, and to load a FIDLER example.

When measuring plutonium ground contamination, the FIDLER is typically calibrated for the 60-keV gamma ray from the Am-241 component of the mixture or the low-energy x rays centered around 17 keV. The Am-241component is typically on the order of thousands of parts per million by weight. It should be noted that measurements using x rays are very sensitive to overburden, for example, rain, contamination fixative, and dust, and therefore are generally not recommended. Measurements using the 60-keV gamma from Am-241 are much less sensitive to the overburden effects due to their higher energy. FIDLER assumes that contamination lies entirely on the surface of the soil, characteristic of newly-deposited activity. If significant weathering has occurred (e.g., measurements are months to years post deposition), a correction factor is required to account for the attenuation of the emitted photons as a function of soil depth. This correction factor should be based upon actual soil sample analyses.

The standard FIDLER consists of a 12.7-cm diameter by 0.16-cm thick NaI(Tl) crystal. The detector entrance window is typically 0.025-cm thick beryllium. The crystal is connected to a photomultiplier tube, and the output of the tube is connected to a hand-held rate meter, or scaler.

A radiation detector can be calibrated by several methods for measuring surface contamination. As shown in Figure 5.1, the most direct method is suspending the detector over a known area source. Here, every square meter of the source contains, for example, 1 μCi of Am-241, and the counts per minute (cpm) indicated on the instrument is, by definition, the areal counting efficiency for Am-241 (cpm/[μCi-m^2]). However, such a source is not practical in terms of size, cost, and transportability.

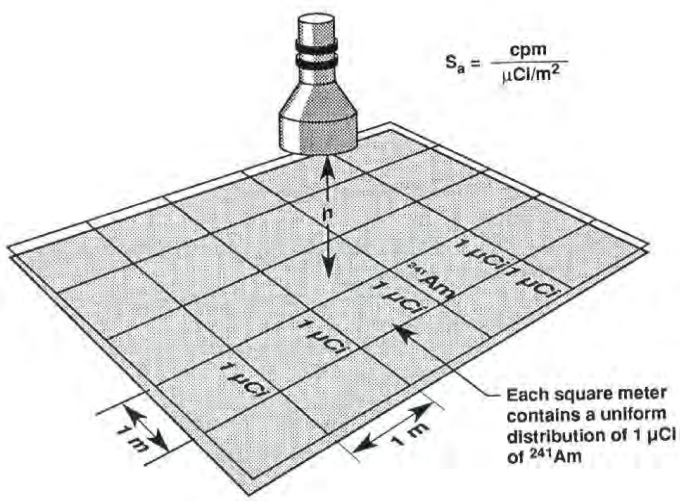


Figure 5.1. Semi-infinite plane Am-241 check source

The following procedure describes a method for calibrating a detector to measure surface contamination with a single-point check source. Figure 5.2 shows the six measurement positions required for this calibration procedure. The calibration method was originally intended for a standard FIDLER instrument, but the technique is applicable to any suitable detector and contamination, for example, a 2-inch-diameter by 2-inch-thick NaI(Tl) detection system for surveying Cs-137 ground contamination.

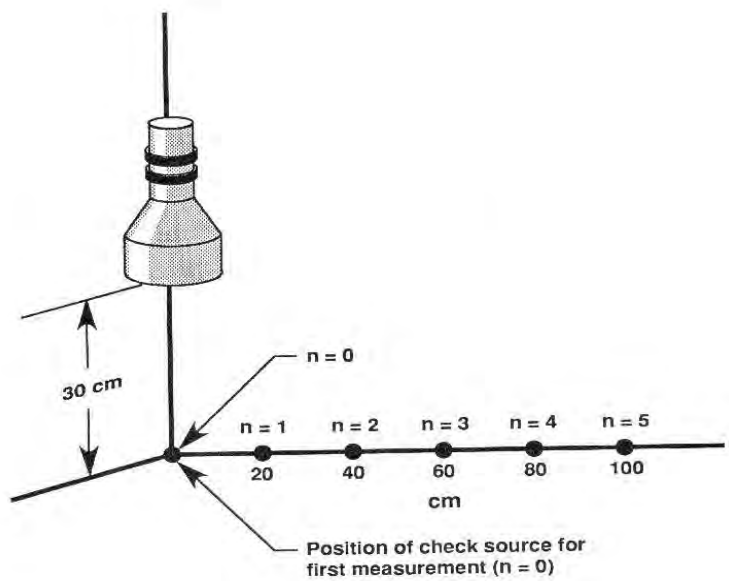


Figure 5.2. Radial check source position

The primary goal of the calibration procedure is to determine the instrument's counting efficiency for an assumed, uniform area contamination per square meter of surface. This parameter is referred to as the areal counting efficiency (*Sa*). This efficiency differs considerably from the simple point-source efficiency, which is commonly used to determine an instrument's sensitivity for locating small point sources. In this case we you need to account for the instrument's sensitivity for off-axis radiation sources and field of view.

Figure 5.3 shows the count rate for a typical FIDLER system as a function of radial position of a 5.9 µCi Am-241 check source.

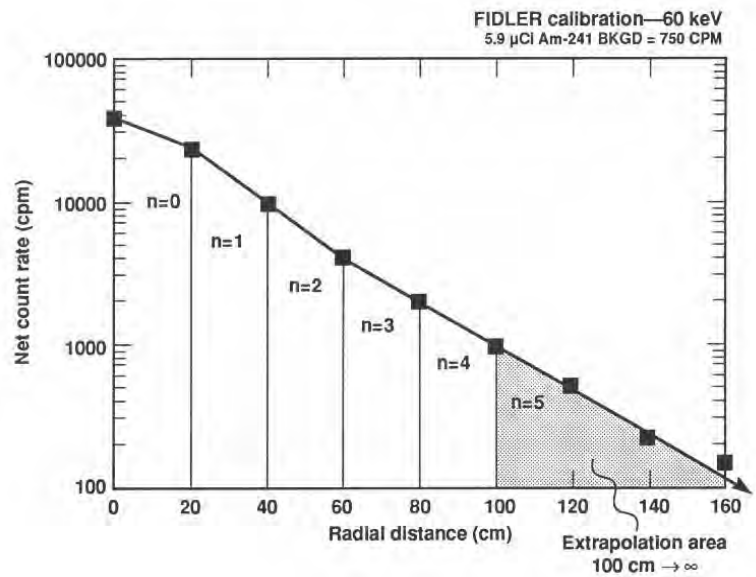


Figure 5.3. Typical FIDLER calibration data

Determination of the Areal Counting Efficiency (*Sa*)

The FIDLER is suspended at height (*h*) above the ground. The FIDLER's areal counting efficiency (*Sa*) for Am-241 (using the 60-keV gamma ray), from a uniform distribution over a circular area (*A*) of radius (*R*) is:

$$S_a = \frac{1}{q} \int C(r)\, dA$$

(Eq. 1)

where:

q = activity (µCi), in area, dA (m^2)
$C(r)$ = count rate (cpm), from activity (q) in area, dA,
Because $dA = r\, dr\, d\theta$.

$$S_a = \int_0^{2\pi} \frac{1}{q} \int_0^{R} C(r)\, r\, dr\, d\theta$$

(Eq. 2)

$$S_a = \frac{2\pi}{q}\int_0^R C(r)\, r\, dr$$

(Eq. 3)

The determination of the areal counting efficiency requires the evaluation of the integral in Equation 3. As shown in Figure 2, the FIDLER program requires check-source measurements at six locations (r0–r5), each location being radially offset by 20 cm.

The observed FIDLER count rate between any two adjacent calibration points, as a function of radial distance, is well represented by a simple exponential function of the form:

$$C(r) = ae^{br}$$

where:

a = Y-axis intercept,
b = slope,
r = radial distance

Letting $C(r) = ae^{br}$ in Equation 3,

$$S_a = \frac{2\pi}{q}\left[\sum_{n=0}^{4} a_n \int_{r_n}^{r_{n+1}} re^{b_n r}\, dr \;+\; a_4 \int_{r_5}^{\infty} re^{b_4 r}\, dr\right]$$

(Eq. 4)

$$S_a = \frac{2\pi}{q}\left[\sum_{n=0}^{4} \frac{a_n}{b_n^2}\left[e^{b_n r_{n+1}}(b_n r_{n+1} - 1) - e^{b_n r_n}(b_n r_n - 1)\right] - \frac{a_4}{b_4^2} e^{b_4 r_5}(b_4 r_5 - 1)\right]$$

(Eq. 5)

where:

$$\int re^{br}dr = \frac{e^{br}}{b^2}(br-1) \quad ,$$

$$b_n = \frac{\ln\left(\frac{C(r_n)}{C(r_{n+1})}\right)}{r_n - r_{n+1}} \quad , \quad \text{and}$$

$$a_n = C(r_n)e^{-b_n r_n} \quad .$$

This is the *Sa* value for a mixture consisting of 100% Am-241. Because we are interested in the *Sa* value for a plutonium mixture, we need to account for the activity fraction of Am-241 in our actual sample mixture.

$$S_{mix} = \frac{S_a}{f} \quad , \quad \frac{\text{counts - m}^2}{\text{min - }\mu\text{Ci}_{\text{mix}}}$$

(Eq. 6)

where:

f = the ratio of alpha µCi of mix to µCi of Am-241.

The *f* ratio is a function of the assumed mix and is automatically determined once you have either selected the default mix and age, default mix and user-input age, or input a specific mix and age. The value of *f* is always displayed with the final calibration data (computer display) and is stated as "*1 microcurie of Am-241 = 8.66E +00 alpha µCi of MIX.*"

In this example, *f* = 8.66. Note: If you were actually measuring a mix of 100% Am-241, the *f* ratio = 1, and no adjustment of the *Sa* value is required. If you are calibrating the FIDLER using the 17-keV window, the x-ray abundance ratio of the Am-241 check source to the plutonium mixture is automatically determined and used in calculating the 17-keV window efficiency. If you are measuring a specific nuclide, for example, Cs-137, it is assumed your calibration source is identical to the sample mix, and again the *f* ratio is 1.

Once the areal counting efficiency has been determined for an instrument, a simple spot- check calibration scheme based in the *K* ratio is possible. The *K* ratio is defined as the ratio (*K*) of the areal source counting efficiency (*Sa*) to the point source counting efficiency (*Sp*).

$$K = \frac{S_a}{S_p} \quad , \quad \text{m}^2$$

(Eq. 7)

where:

Sa = cpm per μCi/m^2,
Sp = cpm per μCi.

Once the *K* ratio has been determined for a particular geometry, the ratio will remain relatively constant. The electronics might drift (e.g., the PRM-5-3 window might shift away from the desired photopeak), but the system's *K* ratio will not be affected. In other words, the *Sa* and *Sp* can change, but their ratio will remain constant. The "quick" calibration consists of measuring the point source efficiency (*Sp*) with an Am-241 check source. The FIDLER's areal counting efficiency is then calculated by multiplying *Sp* by the *K* ratio. Any changes in the detection system will be accounted for by the current *Sp* measurement. This allows for a quick field-calibration scheme. For example, a monitoring team can measure the point efficiency before and after a series of field measurements to confirm the status of the areal counting efficiency (*K* x *Sp*). This provides an audit trail of the detector efficiency for post-survey data reduction and documentation.

The Limit of Sensitivity (LOS) is reported with a Type 1 and Type 2 error (alpha and beta) equal to 0.05. The following determines the LOS (Scale from Curie, 1975):

$$LOS = \frac{2.7 + 4.65\sqrt{r_b / t_s}}{S_a} \quad , \quad \mu\text{Ci}$$

(Eq. 8)

Rate meter:

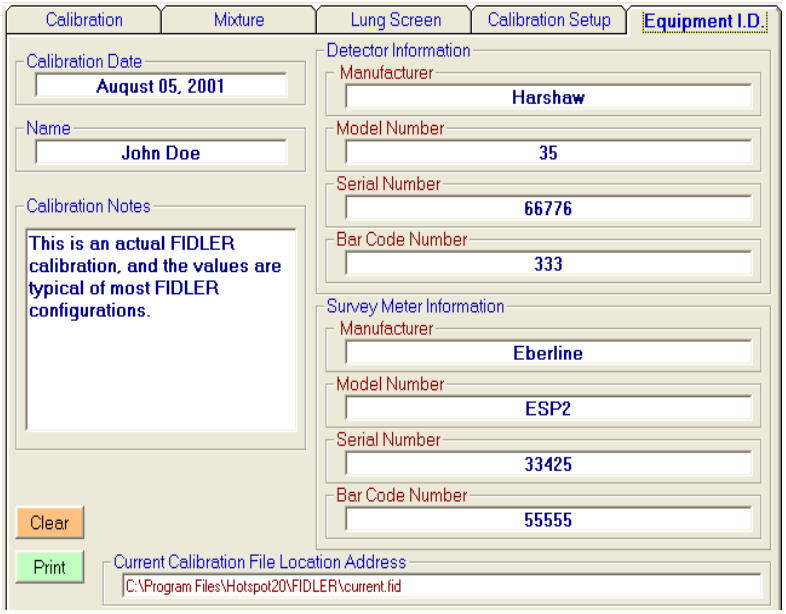
$$LOS = \frac{3.3\sqrt{r_b / 2RC}}{S_a} \quad , \quad \mu\text{Ci}$$

(Eq. 9)

where:

RC = rate meter time constant (min),
r_b = background count rate (cpm),
t_s = sample counting time (min),
S_a = areal counting efficiency (cpm/[μCi/m^2]).

The standard deviations of the areal counting efficiency and *K* factor are also output to the calibration information display. If you are using a weak check source, short integration time, etc., this will be reflected in a large standard deviation.

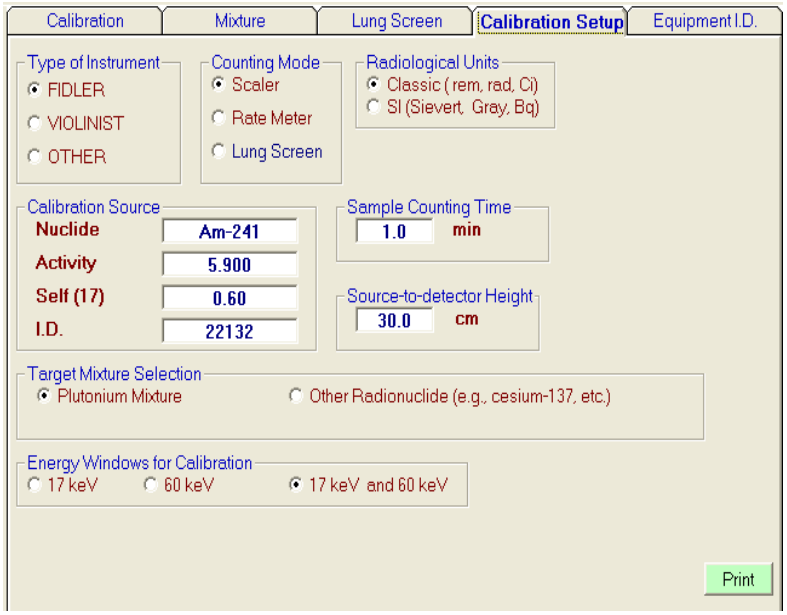


FIDLER Calibration Example

A FIDLER will be used to survey a contaminated area following a recent event involving weapons-grade plutonium. No information on the plutonium mixture is available, but it is known that the mixture is 30 years old (i.e., 30 years since it was processed). The following data were obtained using the FIDLER at a ground-to-detector distance of 30 cm. Determine the FIDLER calibration constants.

Calibration Data:

Radial Position (cm)	60-keV Window Total, S counts	17-keV Window Total, S counts
0	36835	15048
20	23118	8602
40	9806	3148
60	4614	1318
80	2584	766
100	1684	582
Background	750	450



First, calibrate the FIDLER using the 5.9-µCi Am-241 check source. It is important to confirm the self-absorption characteristics of the source (for example, a paper label covering the activity material). The 60-keV gamma rays will not be appreciably attenuated in most check sources, and the absorption factor is assumed to be 1.00, that is, SELF(60) = 1.00. However, the 17-keV x-ray absorption factor can be significant and is required information for the FIDLER calibration unless you are only interested in 60-keV measurements. If you do not know the SELF(17) factor, you can always update the calibration data at a later date. In this example, we will assume a 17-keV self-absorption factor of 60%, that is, SELF(17) = 0.60. In other words, 60% of the 17-keV x rays emitted and directed towards the FIDLER detector reach the detector. Therefore, 40% of the x rays are attenuated by the source itself. The FIDLER code assumes a constant thickness of "overburden" material associated with the check source and automatically adjusts the increase in self-absorption path length as the FIDLER is position at increasing radial distances during the calibration procedure.

After input of the above information, the calibration results are displayed as follows:

Calibration | Mixture | Lung Screen | Calibration Setup | Equipment I.D.

Data Entry

Radial Position (cm)	60-keV Window Total, S counts	17-keV Window Total, S counts
0	36835	15048
20	23118	8602
40	9806	3148
60	4614	1318
80	2584	766
100	1684	582
Background	750	450

Clear

Text File Output: Text File | Save Text File | View Saved Files

	Efficiency (Sa) cpm / ug/m2	Efficiency (Sa) cpm / uCi/m2	Detection Limits Area uCi/m2	Detection Limits Point uCi	Bkg cpm	Source cpm	K m2	sdev %
Am-241 Window	4.6E+01	5.0E+02	2.6E-01	1.3E-01	750	36,085	0.51	3.6
17-keV Window	5.5E+01	6.0E+02	1.7E-01	8.4E-02	450	14,598	0.50	6.7

QA Graph

Print

Calibration | Mixture | Lung Screen | Calibration Setup | Equipment I.D.

Plutonium Mixture

Isotope	Halflife (years)	Initial Mixture Age = 0 years (weight %)	Current Mixture Age = 30.00 years (weight %)
PU-238	87.74	0.0400	0.0316
PU-239	24065	93.3400	93.2594
PU-240	6537	6.0000	5.9809
PU-241	14.35	0.5800	0.1362
PU-242	376300	0.0400	0.0400
AM-241	432.2	0.0000	0.4309
		100.0000	

Mixture Age (years): 30.00

Current Mixture Specific Activity

ALPHA Curie: 0.0918 curie / gram

TOTAL Curie: 0.2320 curie / gram

1 alpha microcurie of Mix = 0.1609 microcurie of Am-241

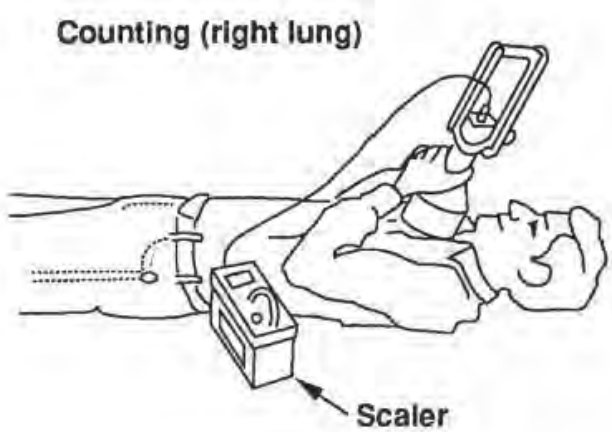
- or -

1 microcurie of Am-241 = 6.2137 alpha microcurie of Mix

Original Defaults | 100% Am-241 | Print

Lung Screening

HotSpot's Lung Screening program screens for plutonium uptake in the lung using a FIDLER or similar detector. The FIDLER must be positioned above the right lung (less photon attenuation near the heart). Body height and weight are used to estimate chest-wall thickness. The 60-keV gamma associated with the decay of Am-241 is used in determining the quantity of the plutonium mix in the lung. The limit of sensitivity is seldom below several lung burdens. However, this is more than adequate for emergency screening when low-level counting facilities are not available. For more information, see HotSpot's online help.



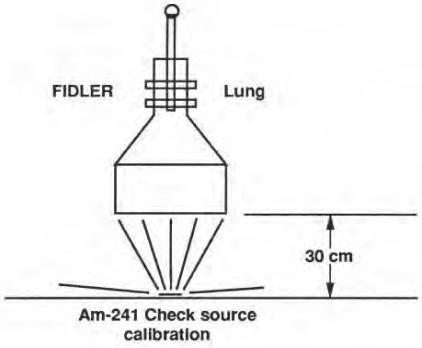


Figure 5.4. Lung screening using a FIDLER and calibration of a detector

The 60-keV gamma rays are attenuated by the chest wall. The chest-wall thickness is approximated using the following empirical equation (Kruchten, et al., 1990):

$$t = 0.110\frac{m}{h} - 2.00$$

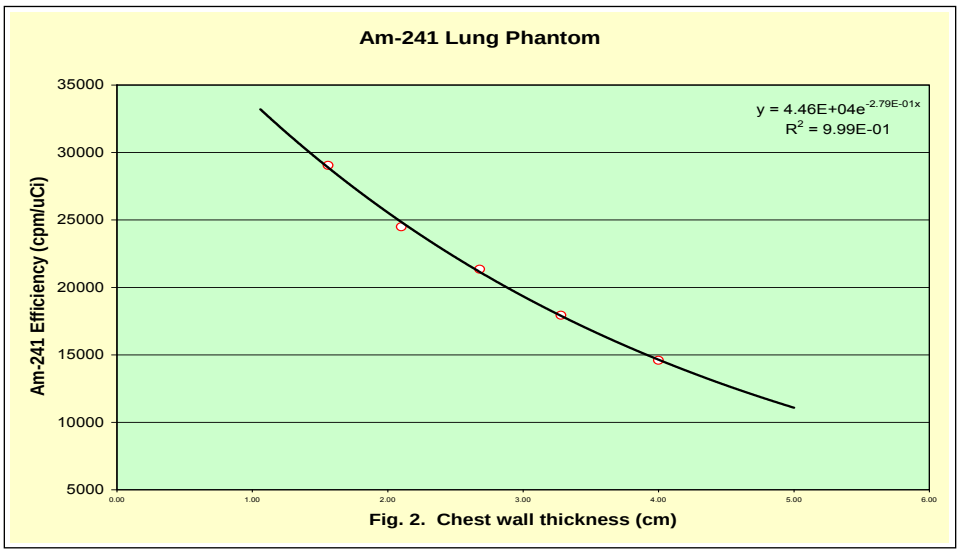
(Eq. 1)

where,

t = chest wall thickness (cm),
m = mass of person (kg),
h = height of person (m).

The standard deviation of the estimated chest-wall thickness is approximately 15% for values in the range of 2 to 4 centimeters. The standard deviation rapidly increases for thickness values outside this range. It is assumed that the chest wall is 100% muscle, which is conservative (more attenuation of 60-keV photons). For t<0.5 cm., the chest-wall thickness is assumed to be 0.5 cm.

The counting efficiency for Am-241 deposited in the lung was determined using a Humanoid Systems' Lawrence Livermore National Laboratory Realistic Lung Phantom with lungs containing a uniform distribution of Am-241 (available from Radiology Support Devices, Inc., Long Beach, California). Figure 2 shows the count rate as a function of the chest-wall thickness. The data are well represented by the following exponential equation:



The above efficiency (cpm per µCi of Am-241 deposited in the lung), is normalized to a simple one-point calibration using an Am-241 check source positioned 30 cm below the FIDLER as shown in Figure 1. This accounts for variations in different FIDLER configurations, that is, window thickness, electronic setup, etc. The 30-cm calibration count rate for the FIDLER used in the lung calibration was 8,700 cpm per µCi of Am-241. Therefore, the normalized equation for efficiency, e, is:

$$e = 4.46x10^4 \left(\frac{r_{check} - r_b}{8.70x10^3 \; A_{check}}\right) e^{-0.279t}$$

$$e = 5.13\left(\frac{r_{check} - r_b}{A_{check}}\right) e^{-0.279t}$$

(Eq. 2)

where,

r_{check} = count rate with Am-241 check source positioned at a detector distance of 30 cm (cpm),

r_b = background count rate (cpm),

A_{check} = activity of Am-241 check source (µCi),

t = chest-wall thickness (cm).

The Limit of Sensitivity (LOS) is reported with a Type 1 and Type 2 error (alpha and beta) equal to 0.05. The following determines the LOS (Scaler from Currie, 1975):

$$LOS = \frac{2.7 + 4.65\sqrt{r_b / t_s}}{S_a} \quad , \quad \mu\text{Ci}$$

(Eq. 3)

If the lung screen results exceed the LOS, the standard deviation of the results is:

$$sdev = \frac{100 \sqrt{r_b / t_s + r_b / t_b}}{r_s - r_b} \quad , \mu Ci$$

(Eq. 4)

where,

r_b = background count rate (cpm),
t_s = sample counting time (min),
e = counting efficiency (cpm/µCi $_{lung}$),
t_b = sample counting time (min).

Lung Screening Example

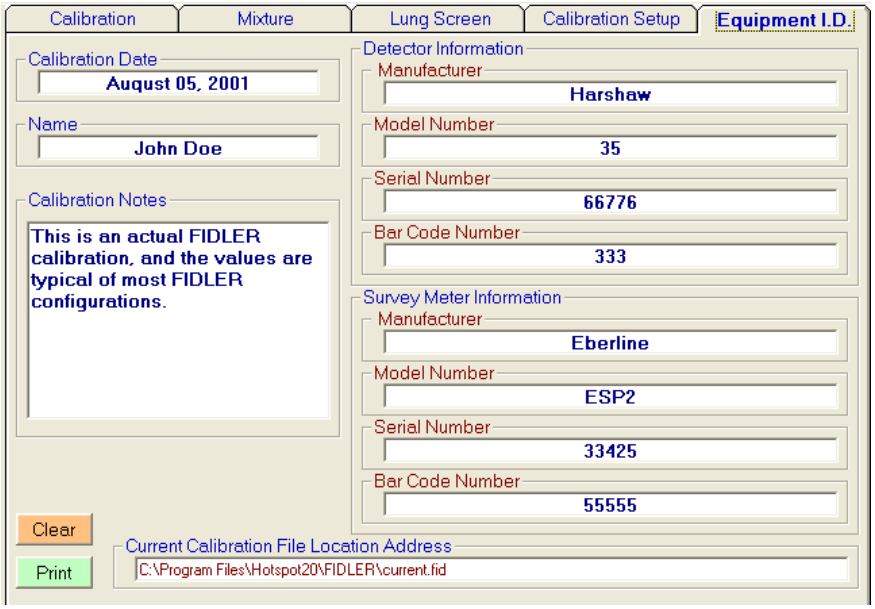
Three individuals were involved in an accident involving weapons-grade plutonium. No information on the plutonium mixture is available. However, the age of the mixture is known to be approximately 30 years. Using a FIDLER and a PS-1 RASCAL scaler, screen the three people for possible plutonium deposition in the lung.

Am-241 check source: counting time 1 minute, 36,835 counts
Background: counting time 5 minutes, 3,750 counts

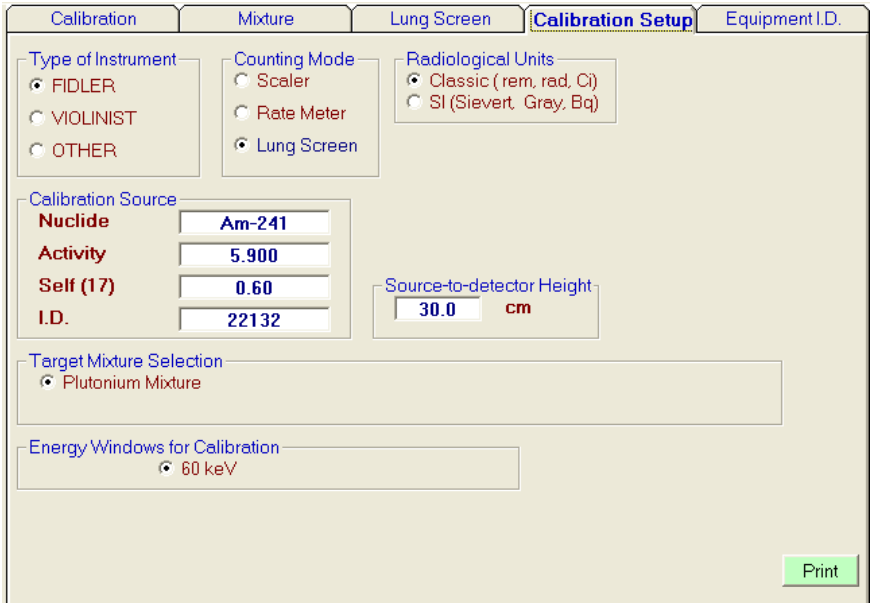
Subject	Counting time	Counts	Height	Weight
Roxanna Luna	5 minutes	4,500	5 ft. 8 in.	120 lbs.
Robert Wills	5 minutes	3,950	6 ft. 2 in.	165 lbs.
Jovian Callisto	5 minutes	3,800	5 ft. 8 in.	155 lbs.

From the main HotSpot menu, SELECT MODELS under Special Purpose Programs and click on the FIDLER Calibration & Lung Screening button.

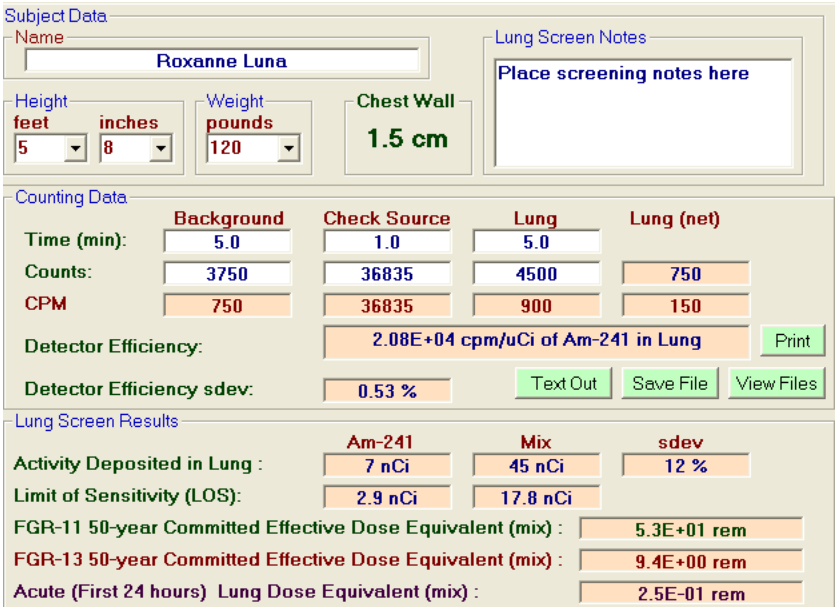
The following screen will appear. Note: The default FIDLER example will be displayed. However, because the last FIDLER calibration will always appear, the default example may not be displayed in your current configuration.



Under the **Calibration Setup** tab, SELECT LUNG SCREEN under the **Counting Mode** frame. The following screen will appear:



Click on the **Name** text box and type the subject's name. Notes can be added to the **Lung Screen Notes** box. Select the correct height and weight of the subject. You can either directly type the data or use the pull-down scroll boxes. Then click on the remaining white boxes and follow the data input prompts.



Lung Screen Information for Roxanne Luna
Subject Name: Roxanne Luna
Subject height: 5 ft. 8 inches
Subject mass: 120 lbs.
Lung screen notes: (Place screening notes here.)
Background counting time: 5 minutes
Background counts: 3,750
Check source counting time: 1 minute
Check source counts: 36,835
Lung counting time: 5 minutes
Lung counts: 4,500

Lung Screening Results
Detector efficiency (cpm/µCi of Am-241 in lung): 2.08E+04 cpm/µCi of Am-241 in lung
Detector efficiency (percent): 0.53%
Chest-wall thickness (centimeters): 1.5 cm
Net lung counts: 750
Am-241 activity deposited in lung (µCi): 7 µCi
Mixture activity deposited in lung (µCi): 45 µCi
Mixture activity deposited in lung sdev (percent): 12%
LOS Am-241 in lung (µCi): 2.9 µCi
LOS mixture in lung (µCi): 17.8 µCi
FGR-11 50-year CEDE-Mix (rem): 5.3E+01 rem
FGR-13 50-year CEDE-Mix (rem): 9.4E+00 trem
Acute lung dose equivalent-Mix (rem): 2.5E-01 rem

To output a text file containing all of the lung screening information, click the Text Out button. The following file information will appear:

Subject name	Roxanne Luna
Report date	January 20, 2005 09:50 AM
Calibration date	August 05, 2001
Target mix	Plutonium mixture
Radionuclide	Am-241
Detector barcode number	333
Meter barcode number	55555
Detector manufacturer	Harshaw
Detector model number	35
Detector serial number	66776
Meter Manufacturer	Eberline
Meter Model Number	ESP2
Meter Serial Number	33425
Check Source I.D.	22132
Calibration Date	August 05, 2001

Calibrated by	John Doe
Check Source Activity (uCi)	5.900E+00
Check Source 17-keV Self	6.000E-01
Lung Counting Time (min)	1.000E+00
Plutonium mixture initial (time:0) information: Mixture age (years)	0
Pu-238(%)	0.0400
Pu-239(%)	93.3400
Pu-240(%)	6.0000
Pu-241(%)	0.5800
Pu-242(%)	0.0400
Am-241(%)	0.0000
Instrument Type	FIDLER
Window option	Only 60 keV
Units	Classic

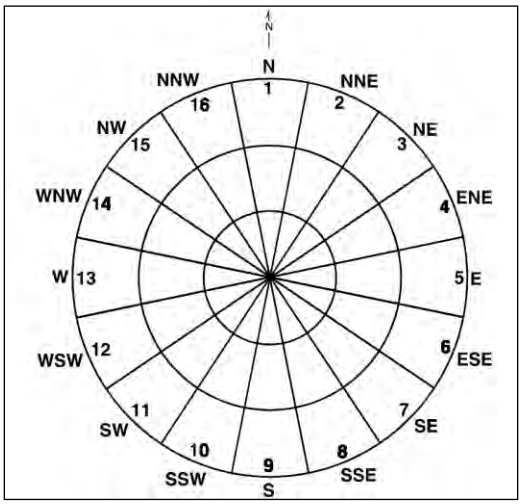
This is an actual FIDLER calibration, and the values are typical of most FIDLER configurations.

Detector Calibration Results

Plutonium Mixture Current Information: Mixture Age (years)	30.00
Pu-238(%)	0.0316
Pu-239(%)	93.2594
Pu-240(%)	5.9809
Pu-241(%)	0.1362
Pu-242(%)	0.0400
Am-241(%)	0.4309
Alpha Specific Activity (Ci/g)	0.0918 curie/g
Total Specific Activity (Ci/g)	0.2320 curie/g
60-keV Detector Efficiency (cpm/(µg/m^2))	4.6E+01
60-keV Detector Efficiency (cpm/(uCi/m2))	5.0E+02
60-keV Detector Areal LOS (µCi/m^2	1.3E-01
60-keV Detector Point LOS (µCi)	2.6E-01
60-keV Detector Background Rate (cpm)	750.000
60-keV Detector Check Source Rate (cpm)	36,085
60-keV Detector K-Factor (m^2)	0.51
60-keV Detector K-Factor sdev(%)	3.6

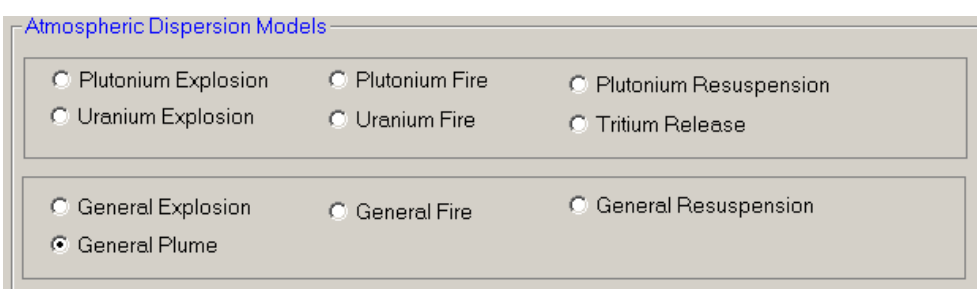
Percentile Dose Option Using Historical Meteorological Data

This module calculates the 95th percentile of the dose distribution for up to 20 radial centerline distances in each of 16 wind direction sectors (direction dependent), and all 16 sectors (direction independent). The wind direction sectors are each 22.5 degrees and the sector numbering scheme is shown in the following compass diagram.

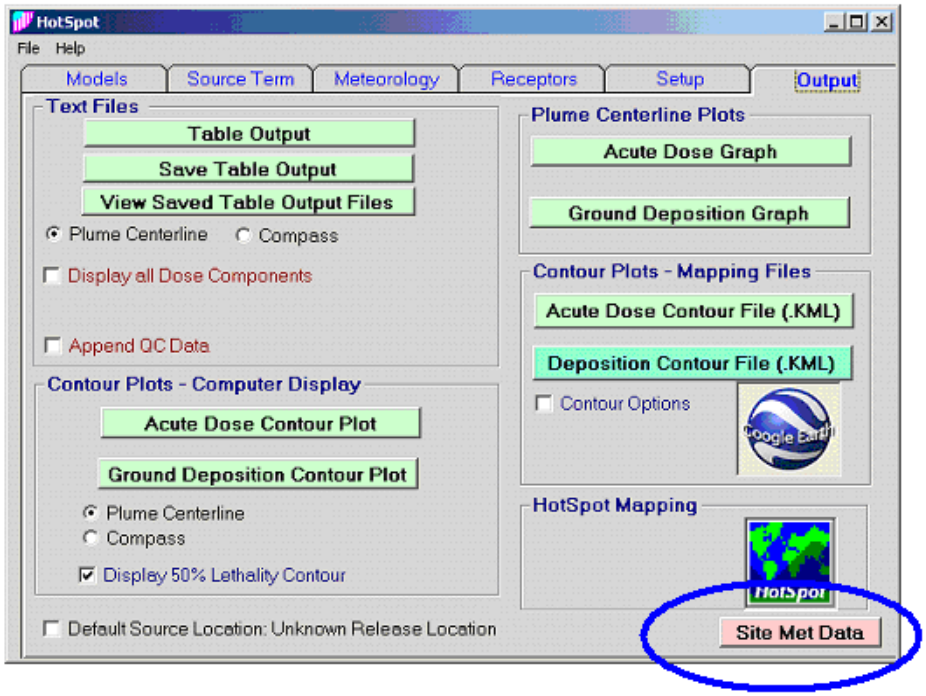


Default percentile values are 50th, 90th, 95th, 99th, and 99.5th. Users may select other percentile values as needed (50th – 100th). HotSpot inputs a sequential file of up to 5 years of hourly meteorological observations (wind speed, direction, stability classification), and either determines the percentile data using an intermediary Joint Frequency Distribution (JFD) or directly calculates the dose value for each hourly observation (EHO). The JFD methodology is much faster than the "brute force" EHO methodology. The JFD uses 9 wind speed groups, and users can change the wind group parameters.

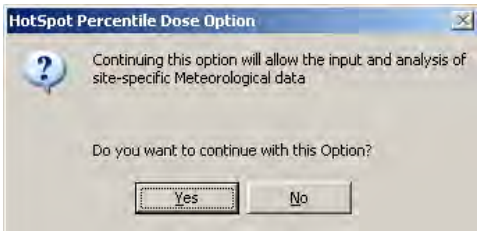
Any of the HotSpot atmospheric dispersion models can be used for determination of the percentile dose values. With the exception of wind speed, wind direction, and stability classification, all of the selected scenario parameters will be used in the calculation. The wind speed, wind direction, and stability will be input from the selected meteorological data file.



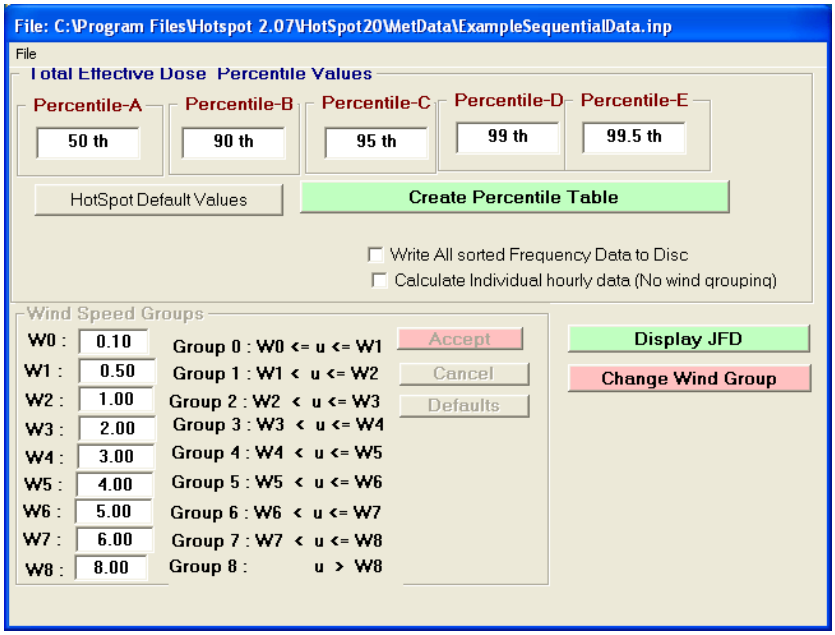
To start the Percentile Dose Option, click on the "Site Met Data" button on the lower right of the "Output" form.



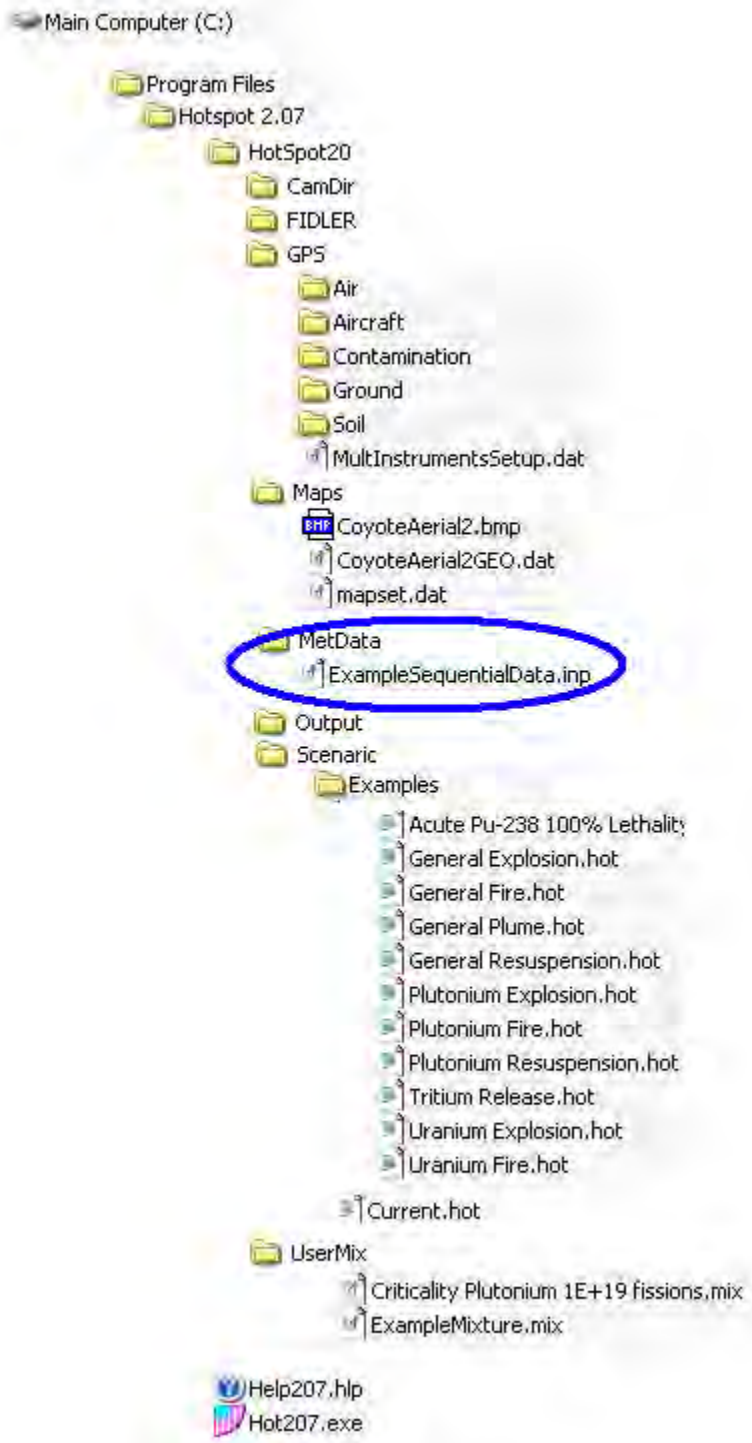
A confirmation box will appear. Select "Yes" to continue to open the Percentile Dose Option



The Percentile Dose Option form will be displayed with the current wind group parameters and percentile values. The currently selected meteorological file is displayed in the form header ("ExampleSequentialData.inp"), along with the file location.



When HotSpot is run for the first time, an example meteorological data file is automatically loaded. The file is actual hourly meteorological data for the year 2000 at the U. S. Department of Energy's Savannah River Site (SRS). To use other met data files, place them in the HotSpot sub folder "MetData." Note: the current version of HotSpot only inputs hourly sequential data in the format of the example file (maximum time period of 5 years). Future versions of HotSpot will incorporate additional formats.


Main Computer (C:)
Program Files
Hotspot 2.07
HotSpot20
CamDir
FIDLER
GPS
Air
Aircraft
Contamination
Ground
Soil
MultInstrumentsSetup.dat
Maps
CoyoteAerial2.bmp
CoyoteAerial2GEO.dat
mapset.dat
MetData
ExampleSequentialData.inp
Output
Scenaric
Examples
Acute Pu-238 100% Lethality
General Explosion.hot
General Fire.hot
General Plume.hot
General Resuspension.hot
Plutonium Explosion.hot
Plutonium Fire.hot
Plutonium Resuspension.hot
Tritium Release.hot
Uranium Explosion.hot
Uranium Fire.hot
Current.hot
UserMix
Criticality Plutonium 1E+19 fissions.mix
ExampleMixture.mix
Help207.hlp
Hot207.exe

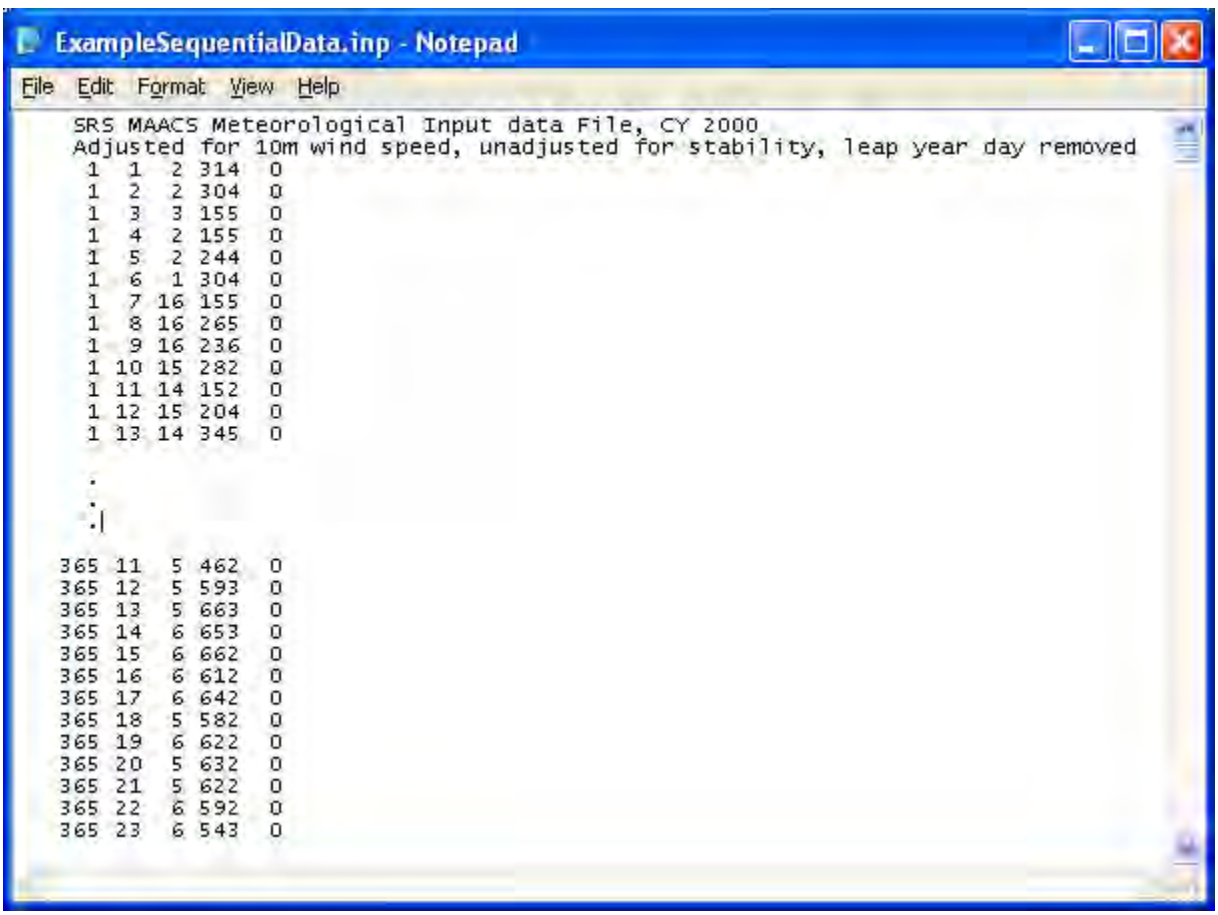
HotSpot Meteorological Input File Format

The meteorological data are in the following format:
Day, hour, wind sector (1-16), wind speed (tenths of 1 m/s), stability (1-7, A-G)), rainfall (mm/hr). One year of hourly data consist of 8,760 observations. For example, the last entry of the year is interpreted as follows.

```
365 24  6 603  0

Day:              365                          (columns 4, 5, 6)
Hour:             24                           (columns 8, 9)
Wind sector:      6 (wind coming from ESE)     (columns 11, 12)
Wind speed:       6.0 m/s                      (columns 13, 14, 15)
Stability:        3 (C)                        (column 16)
Rain:             0 mm/hr                      (columns 18, 19)
```

The data must be in the specific columns shown below. Note that there are no spaces separating wind speed and stability classification. Refer to the actual sample file in the ~~M~~etData folder.




```
SRS MAACS Meteorological Input data File, CY 2000
Adjusted for 10m wind speed, unadjusted for stability, leap year day removed
 1  1  2 314  0
 1  2  2 304  0
 1  3  3 155  0
 1  4  2 155  0
 1  5  2 244  0
 1  6  1 304  0
 1  7 16 155  0
 1  8 16 265  0
 1  9 16 236  0
 1 10 15 282  0
 1 11 14 152  0
 1 12 15 204  0
 1 13 14 345  0

 .
 .
 .

365 11  5 462  0
365 12  5 593  0
365 13  5 663  0
365 14  6 653  0
365 15  6 662  0
365 16  6 612  0
365 17  6 642  0
365 18  5 582  0
365 19  6 622  0
365 20  5 632  0
365 21  5 622  0
365 22  6 592  0
365 23  6 543  0
```

The HotSpot Joint Frequency Distribution (JFD) for this specific meteorological data file can be displayed by selecting the "Display JFD" button.

The 8,760 observations are displayed into the 9 wind speed groups (groups 0-8), 7 stability classes (A-G) for each of the 16 compass sectors (1-16). Each of the 1,008 table values represents the percentage of the total observations in the specified wind speed group, stability class and wind direction sector. For example, the high-lighted value below indicates that 0.034% of the 8,760 observations are in wind speed group 1 (greater than 0.5 m/s and less than or equal to 1.0 m/s), stability class A, and the wind direction values are coming <u>from</u> the 22.5 degree sector centered on the East (sector 5).

HotSpot JFD Format
HotSpot Version 2.07 General Plume
Feb 28, 2009 01:32 PM

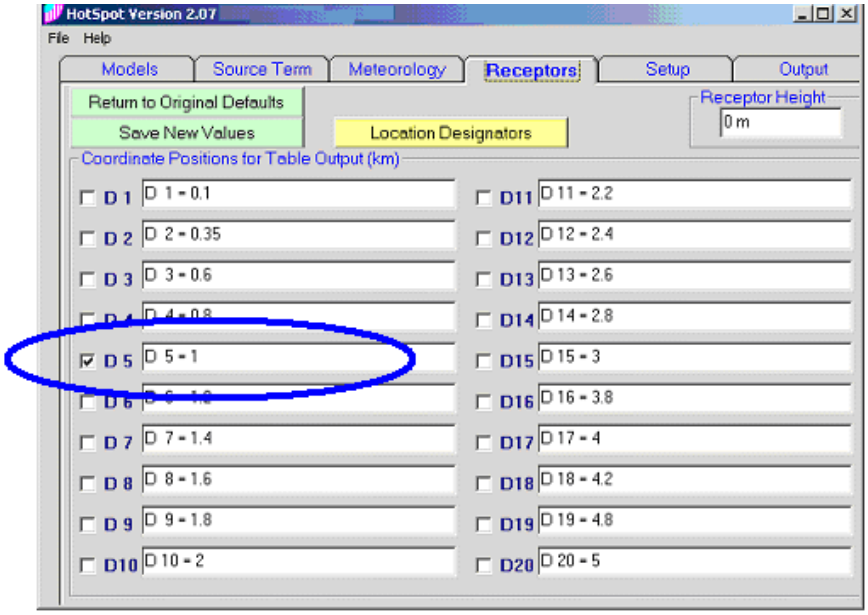
Wind Speed Groups	Group Frequency
Group 0: 0.10 <= u <= 0.50	0.26 %
Group 1: 0.50 < u <= 1.00	1.03 %
Group 2: 1.00 < u <= 2.00	15.58 %
Group 3: 2.00 < u <= 3.00	35.63 %
Group 4: 3.00 < u <= 4.00	28.65 %
Group 5: 4.00 < u <= 5.00	12.19 %
Group 6: 5.00 <= u <= 6.00	4.36 %
Group 7: 6.00 < u <= 8.00	2.03 %
Group 8: u > 8.00	0.26 %
Total Sum:	100.00 %

		Compass Direction the Wind is coming FROM																Row
G	SC	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW	Sum
0	A	0.000	0.000	0.000	0.000	0.023	0.023	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.011	0.057 %
0	B	0.000	0.000	0.000	0.000	0.000	0.011	0.000	0.000	0.000	0.011	0.000	0.000	0.000	0.000	0.000	0.000	0.023 %
0	C	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.091	0.011	0.000	0.000	0.000	0.000	0.000	0.103 %
0	D	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.057	0.023	0.000	0.000	0.000	0.000	0.000	0.080 %
0	E	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000 %
0	F	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000 %
0	G	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000 %
Col Sum		0.000	0.000	0.000	0.000	0.023	0.034	0.000	0.000	0.000	0.160	0.034	0.000	0.000	0.000	0.000	0.011	0.263 %
1	**A**	0.011	0.068	**0.023**	0.011	0.034	0.080	0.057	0.023	0.000	0.046	0.046	0.114	0.011	0.068	0.080	0.091	0.765 %
1	B	0.023	0.000	0.011	0.000	0.000	0.000	0.034	0.023	0.023	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.114 %
1	C	0.011	0.000	0.011	0.000	0.000	0.000	0.000	0.011	0.000	0.000	0.000	0.000	0.023	0.000	0.000	0.000	0.057 %
1	D	0.000	0.011	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.011	0.000	0.000	0.000	0.011	0.011	0.011	0.057 %
1	E	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.011	0.000	0.000	0.000	0.011	0.000	0.023 %
1	F	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.011	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.011 %
1	G	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000 %
Col Sum		0.046	0.080	0.046	0.011	0.034	0.080	0.091	0.068	0.023	0.057	0.057	0.114	0.034	0.080	0.103	0.103	1.027 %
2	A	0.400	0.388	0.502	0.537	0.731	0.616	0.502	0.582	0.457	0.502	0.434	0.502	0.559	0.331	0.468	0.400	7.911 %
2	B	0.068	0.011	0.126	0.103	0.148	0.046	0.046	0.046	0.194	0.160	0.126	0.091	0.034	0.057	0.103	0.103	1.461 %
2	C	0.068	0.068	0.137	0.046	0.103	0.114	0.080	0.103	0.103	0.114	0.080	0.046	0.080	0.046	0.080	0.057	1.324 %
2	D	0.103	0.068	0.057	0.080	0.103	0.068	0.137	0.068	0.034	0.034	0.126	0.034	0.046	0.023	0.034	0.126	1.142 %
2	E	0.217	0.388	0.205	0.205	0.160	0.114	0.194	0.194	0.011	0.103	0.217	0.103	0.126	0.194	0.274	0.274	2.979 %
2	F	0.034	0.034	0.068	0.068	0.034	0.034	0.046	0.046	0.000	0.126	0.057	0.000	0.046	0.068	0.057	0.046	0.765 %
2	G	0.000	0.000	0.000	0.023	0.000	0.000	0.034	0.011	0.023	0.000	0.000	0.000	0.000	0.023	0.034	0.000	0.148 %
Col Sum		0.890	0.959	1.096	1.062	1.279	0.993	1.039	1.050	0.822	1.039	1.039	0.776	0.890	0.742	1.050	1.005	15.73 %
3	A	0.457	0.571	0.708	0.947	0.925	0.925	0.502	0.377	0.616	0.674	0.651	0.731	0.559	0.491	0.377	0.388	9.897 %
3	B	0.240	0.194	0.263	0.365	0.228	0.171	0.080	0.171	0.377	0.331	0.217	0.365	0.263	0.080	0.160	0.171	3.676 %
3	C	0.308	0.342	0.365	0.388	0.274	0.354	0.148	0.091	0.400	0.320	0.662	0.616	0.251	0.183	0.365	0.114	5.183 %
3	D	0.662	0.628	0.582	0.388	0.457	0.525	0.411	0.263	0.126	0.365	0.788	0.354	0.377	0.342	0.320	0.388	6.975 %
3	E	0.947	0.845	1.062	0.674	0.388	0.331	0.240	0.160	0.068	0.616	0.457	0.388	0.274	0.400	0.377	0.616	7.842 %
3	F	0.160	0.183	0.126	0.160	0.080	0.080	0.137	0.057	0.080	0.297	0.091	0.057	0.057	0.183	0.034	0.126	1.906 %
3	G	0.000	0.000	0.000	0.011	0.000	0.000	0.011	0.000	0.011	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.034 %
Col Sum		2.774	2.763	3.105	2.934	2.352	2.386	1.530	1.119	1.678	2.603	2.865	2.511	1.781	1.678	1.632	1.804	35.51 %
4	A	0.274	0.377	0.365	0.605	0.616	0.651	0.171	0.240	0.285	0.365	0.365	0.377	0.228	0.285	0.183	0.057	5.445 %
4	B	0.114	0.274	0.285	0.468	0.468	0.342	0.160	0.057	0.422	0.228	0.331	0.320	0.228	0.114	0.091	0.057	3.961 %
4	C	0.240	0.342	0.434	0.559	0.491	0.400	0.183	0.137	0.297	0.422	1.107	0.594	0.365	0.183	0.274	0.171	6.199 %
4	D	1.187	1.107	0.868	0.856	0.662	0.525	0.308	0.126	0.103	0.457	1.039	0.502	0.422	0.400	0.457	0.742	9.760 %
4	E	0.388	0.365	0.342	0.331	0.194	0.160	0.080	0.046	0.011	0.240	0.171	0.114	0.183	0.148	0.137	0.263	3.174 %
4	F	0.011	0.023	0.000	0.000	0.023	0.011	0.000	0.000	0.000	0.000	0.011	0.000	0.000	0.000	0.000	0.000	0.080 %
4	G	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000 %
Col Sum		2.215	2.489	2.295	2.820	2.454	2.089	0.902	0.605	1.119	1.712	3.025	1.906	1.427	1.130	1.142	1.290	28.62 %
5	A	0.126	0.171	0.217	0.263	0.160	0.091	0.091	0.080	0.171	0.137	0.103	0.046	0.091	0.057	0.046	0.023	1.872 %
5	B	0.137	0.114	0.285	0.377	0.331	0.251	0.103	0.103	0.308	0.251	0.160	0.205	0.068	0.103	0.034	0.046	2.877 %
5	C	0.308	0.148	0.217	0.365	0.400	0.422	0.183	0.046	0.057	0.331	0.879	0.217	0.080	0.103	0.183	0.148	4.087 %
5	D	0.616	0.194	0.365	0.148	0.126	0.228	0.023	0.000	0.011	0.137	0.263	0.068	0.057	0.011	0.103	0.468	2.820 %
5	E	0.103	0.080	0.046	0.034	0.000	0.000	0.000	0.000	0.011	0.046	0.011	0.068	0.046	0.023	0.011	0.057	0.537 %
5	F	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000 %
5	G	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000 %
Col Sum		1.290	0.708	1.130	1.187	1.016	0.993	0.400	0.228	0.559	0.902	1.416	0.605	0.342	0.297	0.377	0.742	12.19 %

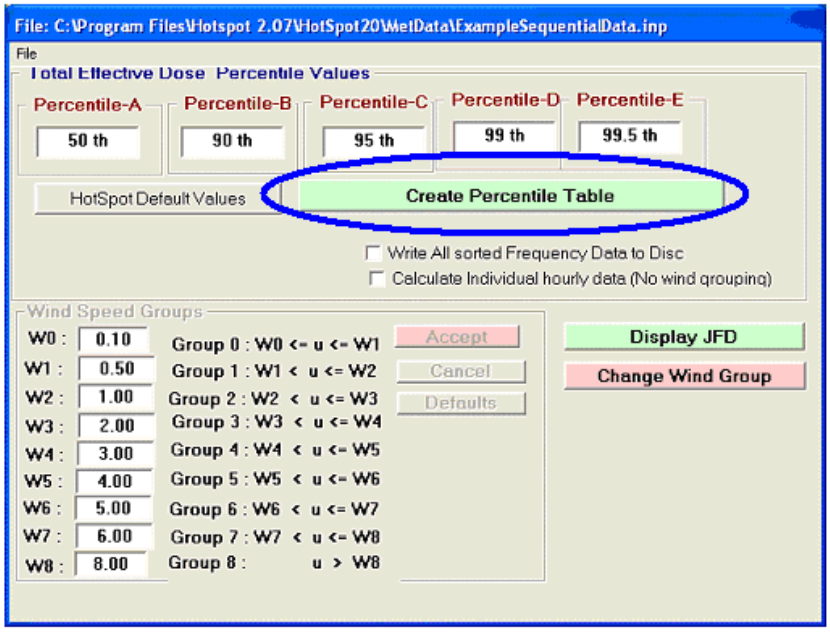
6 A	0.034	0.023	0.057	0.091	0.080	0.103	0.023	0.034	0.068	0.023	0.011	0.011	0.000	0.000	0.000	0.034	0.594 %
6 B	0.057	0.046	0.148	0.320	0.205	0.205	0.046	0.023	0.091	0.103	0.114	0.023	0.023	0.023	0.000	0.034	1.461 %
6 C	0.171	0.034	0.160	0.160	0.194	0.308	0.171	0.034	0.011	0.103	0.320	0.103	0.103	0.068	0.080	0.057	2.078 %
6 D	0.080	0.000	0.057	0.000	0.000	0.000	0.011	0.000	0.000	0.011	0.000	0.000	0.000	0.000	0.011	0.057	0.228 %
6 E	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000 %
6 F	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000 %
6 G	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000 %
Col Sum	0.342	0.103	0.422	0.571	0.479	0.616	0.251	0.091	0.171	0.240	0.445	0.137	0.126	0.091	0.091	0.183	4.361 %
7 A	0.011	0.023	0.011	0.023	0.011	0.023	0.000	0.011	0.023	0.000	0.000	0.011	0.000	0.000	0.000	0.000	0.148 %
7 B	0.034	0.023	0.080	0.171	0.263	0.194	0.000	0.011	0.000	0.000	0.011	0.000	0.000	0.000	0.000	0.011	0.799 %
7 C	0.091	0.057	0.091	0.114	0.137	0.320	0.046	0.023	0.000	0.011	0.023	0.011	0.011	0.034	0.023	0.023	1.016 %
7 D	0.046	0.011	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.011	0.068 %
7 E	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000 %
7 F	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000 %
7 G	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000 %
Col Sum	0.183	0.114	0.183	0.308	0.411	0.537	0.046	0.046	0.023	0.011	0.034	0.023	0.011	0.034	0.023	0.046	2.032 %
8 A	0.000	0.000	0.000	0.000	0.011	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.011 %
8 B	0.011	0.000	0.034	0.011	0.068	0.046	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.171 %
8 C	0.011	0.000	0.011	0.000	0.011	0.034	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.068 %
8 D	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.011	0.011 %
8 E	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000 %
8 F	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000 %
8 G	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000 %
Col Sum	0.023	0.000	0.046	0.011	0.091	0.080	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.011	0.263 %
Col Sum	7.763	7.215	8.322	8.904	8.139	7.808	4.258	3.208	4.395	6.724	8.916	6.073	4.612	4.053	4.418	5.194	100.00 %

The default HotSpot methodology first converts the hourly annual meteorological data (8,760 hourly observations), into a JFD and then uses the JFD to calculated the sorted cumulative frequency distribution and percentile values. To prevent a cumulative frequency distribution with 9 plateaus (for each of the 9 wind speed group), the group wind speed values used in the dose calculation are randomly generated within each wind speed group. The same initial random number seed is used so repeated analyses produce identical results.

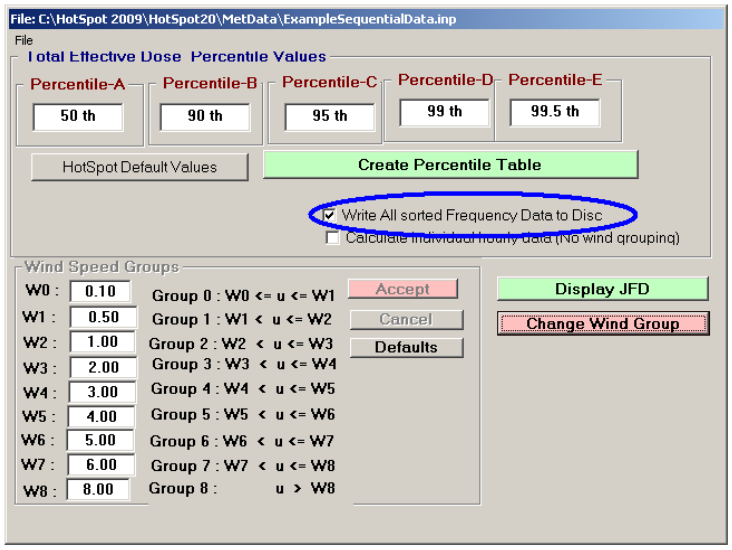
Since the JFD methodology uses 9 wind speed groups, 16 wind directions, and 7 stability classifications (A-G), the 8,760 observations are reduced to 1,008 grouped observations. This reduces the number of dose calculations and sorting time required for generating the cumulative frequency distribution and percentile dose data. The computer time saving is especially apparent if 5 years of hourly data are analyzed (43,800 observations). A comparison of the JFD and EHO methodologies is shown below for a radial distance of 1.0 km. If the JFD methodology is used, the output includes the wind speed groups and percentage values. Since the EHO methodology uses each actual observation, the wind speed group data are irrelevant. In this example, the JFD percentile values are all within 10 % of the EHO values. The JFD methodology can be used for initial scoping of a release scenario followed by yhe the more accurate EHO methodology. A ground-level plutonium-239 release was setup in HotSpot to demonstrate the JFD and EHO methodologies. This example release scenario will also be used to compare MACCS2 and HotSpot percentile calculations. As shown below, only the 1 km (D 5), is checked in the main HotSpot ―Receptor" form. Consequently only this distance will be used in this example calculation. All twenty distances can be selected.

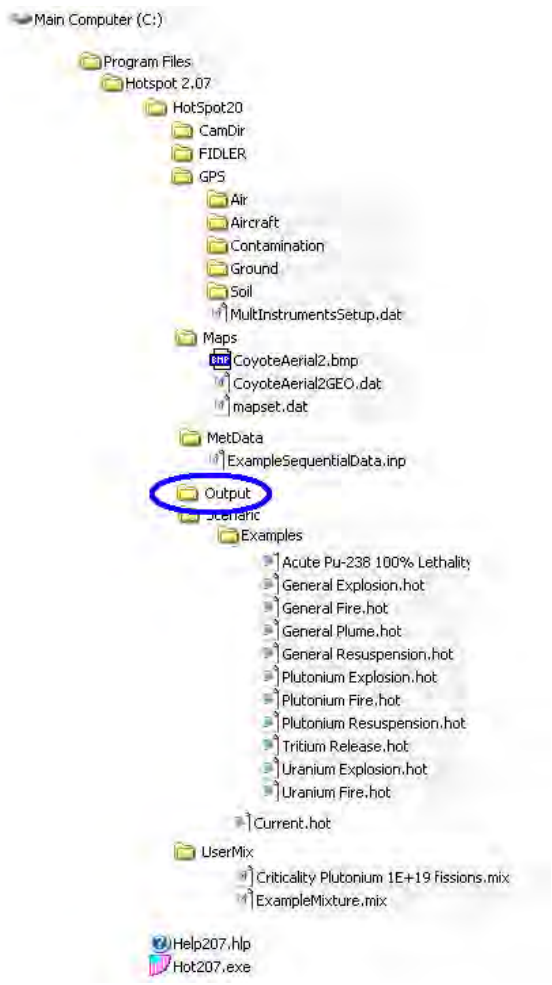


Click the "Create Percentile Table" button to generate the percentile information for a radial distance of 1 km.



If you would like individual tables of the sorted Total Effective Dose (TED), data for all sectors and radial distances, check the ―Write All sorted Frequency Data to Disc" check box prior to clicking the ―Create Percentile Table." All of the files are stored in the ―Output" folder.





When HotSpot completes the percentile calculations, the following table is displayed. The table includes a summary of the release scenario and wind speed groups and percentage of total observations within each group. The Total Effective Dose (TED) values for each of the 5 percentiles are displayed for each of the individual wind direction sectors (direction dependent values) and all sectors (direction independent). In this table, Compass Direction is the Direction the Wind/Plume is moving towards. For example, the 95th percentile TED for the 22.5 degree wind direction sector towards the North (sector 1), is 2.17 rem. In other words, the TED in sector 1 at a radial downwind distance of 1 km, would exceed 2.17 rem in only 5% of the hourly meteorological observations. The 95th percentile TED for all sectors (full 360 degree direction independent value) is 4.14 rem. Therefore, the TED in any compass direction at a radial downwind distance of 1 km, would exceed 4.14 rem in only 5% of the hourly meteorological observations.

JFD Methodology

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HotSpot  Version 2.07 General Plume


Source Material            : Pu-239  M    24065y
Material at Risk           : 1.0000E+00 Ci
Damage Ratio               : 1.000
Leakpath Factor            : 1.000
Airborne Fraction          : 1.000
Respirable Fraction        : 1.000
Respirable Release Fraction: 1.000
Wind Speed Ref. Height     : 2.0 m
Effective Release Height   : 0.00 m
Respirable Dep. Vel.       : 1.00 cm/s
Non-respirable Dep. Vel.   : 8.00 cm/s
Receptor Height            : 0.0 m
Inversion Layer Height     :  None
Sample Time                : 10.000 min
Breathing Rate             : 3.33E-04 m3/sec


FGR-13 Dose Conversion Data - Total Effective Dose (TED)

      Exposure Window:(Start: 0.00 days; Duration: 4.00 days)  [100% stay time].
      Initial Deposition and Dose Rate shown
      Ground Roughness Correction Factor: 1.000

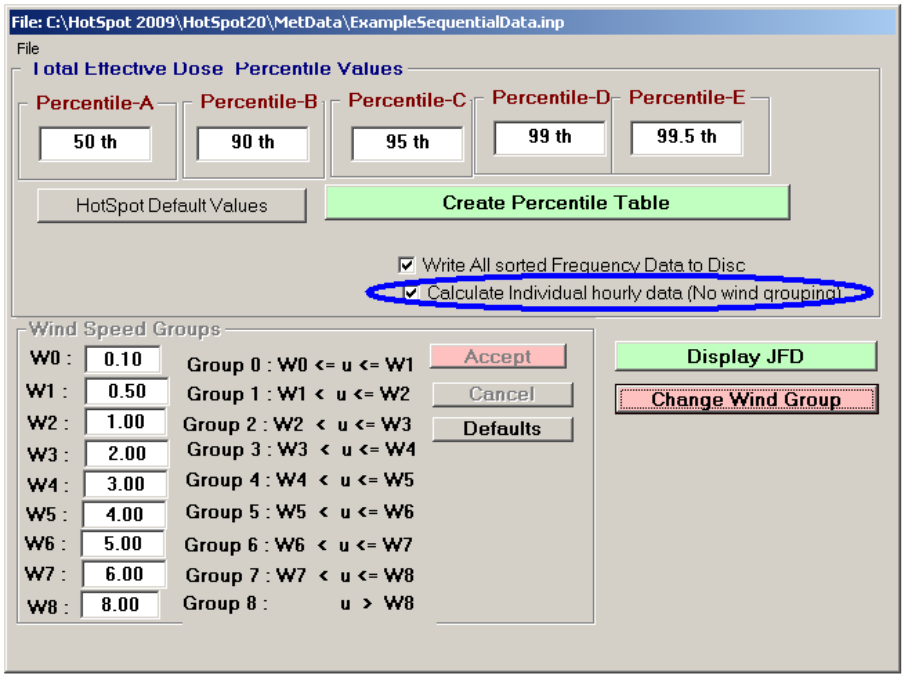
    Wind Speed Groups                      Group Frequency
Group 0: 0.10 <= u <= 0.50                     0.26 %
Group 1: 0.50 <  u <= 1.00                     1.03 %
Group 2: 1.00 <  u <= 2.00                    15.58 %
Group 3: 2.00 <  u <= 3.00                    35.63 %
Group 4: 3.00 <  u <= 4.00                    28.65 %
Group 5: 4.00 <  u <= 5.00                    12.19 %
Group 6: 5.00 <= u <= 6.00                     4.36 %
Group 7: 6.00 <  u <= 8.00                     2.03 %
Group 8:  u > 8.00                             0.26 %
                                             _______
                                  Total Sum: 100.00 %


Compass Direction is the Direction the Wind/Plume is Moving Towards

                              [Sector Centerline Distance of  1.000  km]
                           Total Effective Dose (TED) Percentiles
```

Compass Sector	Compass Direction	50.0 (rem)	90.0 (rem)	95.0 (rem)	99.0 (rem)	99.5 (rem)
1	N	3.41E-01	1.48E+00	2.17E+00	5.24E+00	5.81E+00
2	NNE	5.39E-01	3.40E+00	5.27E+00	6.15E+00	6.21E+00
3	NE	6.80E-01	3.10E+00	3.39E+00	6.22E+00	6.30E+00
4	ENE	5.48E-01	2.69E+00	3.32E+00	4.28E+00	5.26E+00
5	E	5.36E-01	2.89E+00	3.55E+00	5.36E+00	5.84E+00
6	ESE	7.02E-01	3.80E+00	5.60E+00	6.31E+00	6.33E+00
7	SE	7.90E-01	3.63E+00	3.83E+00	5.08E+00	5.62E+00
8	SSE	1.37E+00	3.28E+00	3.97E+00	5.72E+00	6.04E+00
9	S	1.31E+00	3.41E+00	3.71E+00	6.23E+00	6.24E+00
10	SSW	1.25E+00	3.28E+00	4.01E+00	6.27E+00	6.31E+00
11	SW	8.88E-01	3.24E+00	3.31E+00	6.20E+00	6.26E+00
12	WSW	4.43E-01	3.44E+00	3.93E+00	5.91E+00	6.10E+00
13	W	3.21E-01	2.87E+00	3.58E+00	5.87E+00	6.15E+00
14	WNW	3.53E-01	2.36E+00	3.27E+00	5.75E+00	6.02E+00
15	NW	5.29E-01	3.65E+00	4.18E+00	6.27E+00	6.31E+00
16	NNW	4.22E-01	3.67E+00	4.09E+00	5.80E+00	6.09E+00
1-16	ALL	6.42E-01	3.43E+00	4.14E+00	6.31E+00	6.35E+00

To calculate the percentile table using each hourly observation (EHO), check the –Calculate Individual hourly data (No wind grouping)" check box.



The EHO process requires more time, and after HotSpot completes the calculations, the following table is displayed. When using the HotSpot default wind speed groupings, the JFD results are all within 10% of the EHO values. The JFD methodology can be used for initial scoping of a release scenario followed by yhe the more accurate EHO methodology.

EHO Methodology

```
HotSpot  Version 2.07 General Plume


Source Material            : Pu-239  M    24065y
Material at Risk           : 1.0000E+00 Ci
Damage Ratio               : 1.000
Leakpath Factor            : 1.000
Airborne Fraction          : 1.000
Respirable Fraction        : 1.000
Respirable Release Fraction: 1.000
Wind Speed Ref. Height     : 2.0 m
Effective Release Height   : 0.00 m
Respirable Dep. Vel.       : 1.00 cm/s
Non-respirable Dep. Vel.   : 8.00 cm/s
Receptor Height            : 0.0 m
Inversion Layer Height     :  None
Sample Time                : 10.000 min
Breathing Rate             : 3.33E-04 m3/sec


FGR-13 Dose Conversion Data - Total Effective Dose (TED)

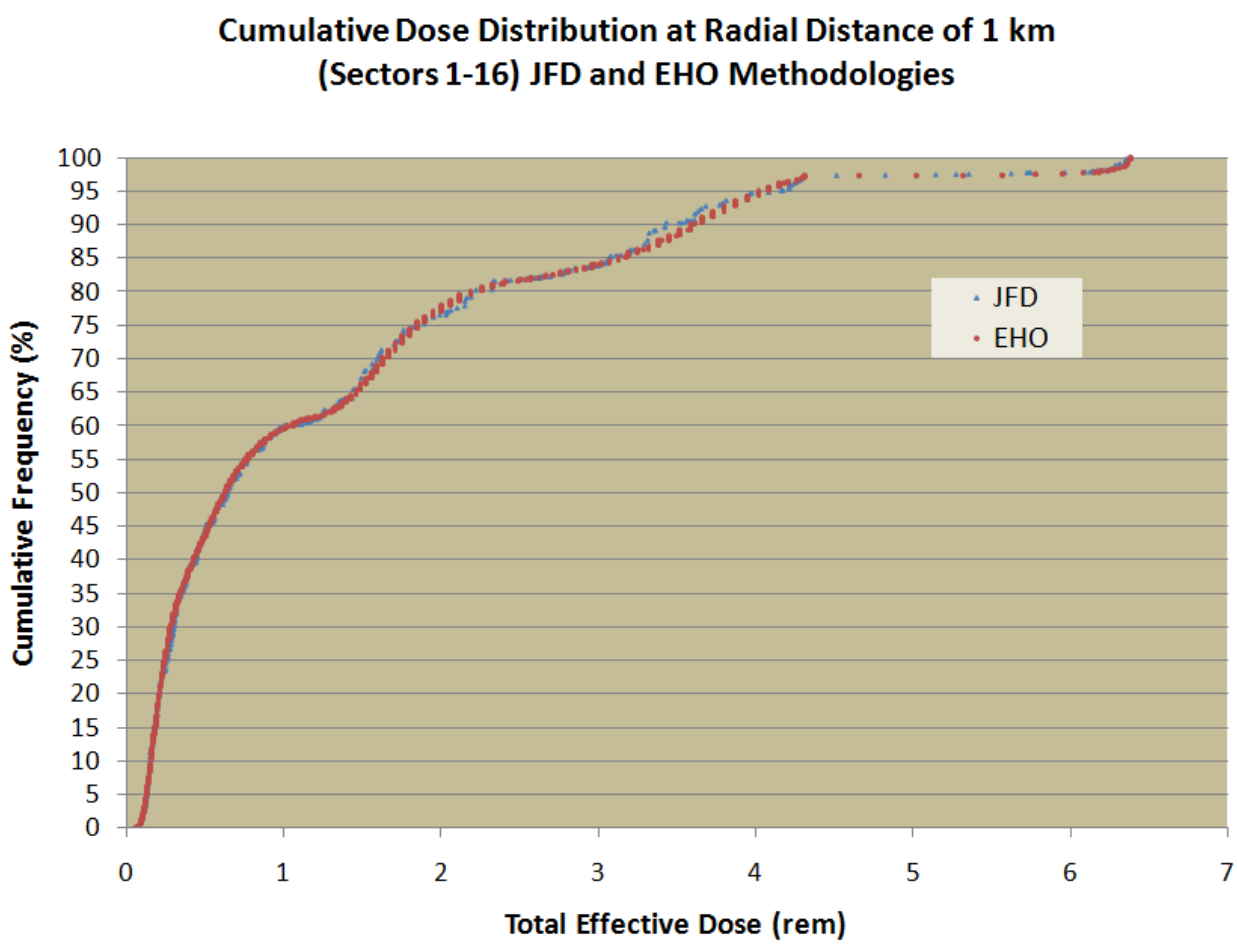
      Include Plume Passage Inhalation and Submersion
      Include Resuspension 0.35000
      Exposure Window:(Start: 0.00 days; Duration: 4.00 days)  [100% stay time].
      Initial Deposition and Dose Rate shown
      Ground Roughness Correction Factor: 1.000


Compass Direction is the Direction the Wind/Plume is Moving Towards

                              [Sector Centerline Distance of  1.000  km]
                           Total Effective Dose (TED) Percentiles
```

Compass Sector	Compass Direction	50.0 (rem)	90.0 (rem)	95.0 (rem)	99.0 (rem)	99.5 (rem)
1	N	3.06E-01	1.47E+00	2.33E+00	6.31E+00	6.36E+00
2	NNE	6.24E-01	3.73E+00	6.18E+00	6.37E+00	6.38E+00
3	NE	6.60E-01	3.25E+00	3.94E+00	6.24E+00	6.32E+00
4	ENE	5.73E-01	3.12E+00	3.68E+00	4.24E+00	6.35E+00
5	E	5.99E-01	3.35E+00	3.95E+00	6.31E+00	6.36E+00
6	ESE	7.67E-01	4.05E+00	5.98E+00	6.37E+00	6.38E+00
7	SE	8.02E-01	3.82E+00	4.15E+00	6.18E+00	6.35E+00
8	SSE	1.46E+00	3.87E+00	4.22E+00	6.37E+00	6.38E+00
9	S	1.43E+00	3.66E+00	4.02E+00	6.36E+00	6.37E+00
10	SSW	1.49E+00	3.87E+00	4.15E+00	6.36E+00	
11	SW	8.41E-01	3.66E+00	3.95E+00	6.31E+00	6.38E+00
12	WSW	4.69E-01	3.45E+00	3.95E+00	6.37E+00	
13	W	3.68E-01	3.07E+00	3.73E+00	6.23E+00	6.35E+00
14	WNW	4.09E-01	2.57E+00	3.73E+00	6.24E+00	6.33E+00
15	NW	5.53E-01	3.85E+00	4.29E+00	6.38E+00	
16	NNW	3.85E-01	3.80E+00	4.17E+00	6.32E+00	6.35E+00
1-16	ALL	6.28E-01	3.59E+00	4.02E+00	6.36E+00	6.37E+00

The following figure compares the cumulative frequency distribution for the 1,008 JFD grouped observations with the 8,760 EHO observations. Note, the data for these charts are from the tables created if the ―Write All sorted Frequency Data to Disc" check box is checked prior to clicking the ―Create Percentile Table" button. If copying into Microsoft Excel to display the data, you will need to remove the text lines from the table values. These lines appear whenever the cumulative dose values increase to the next order of magnitude e.g., 1.0E-03 rem to 1.0E-02 rem.



Example – Comparison of MACCS2 and HotSpot

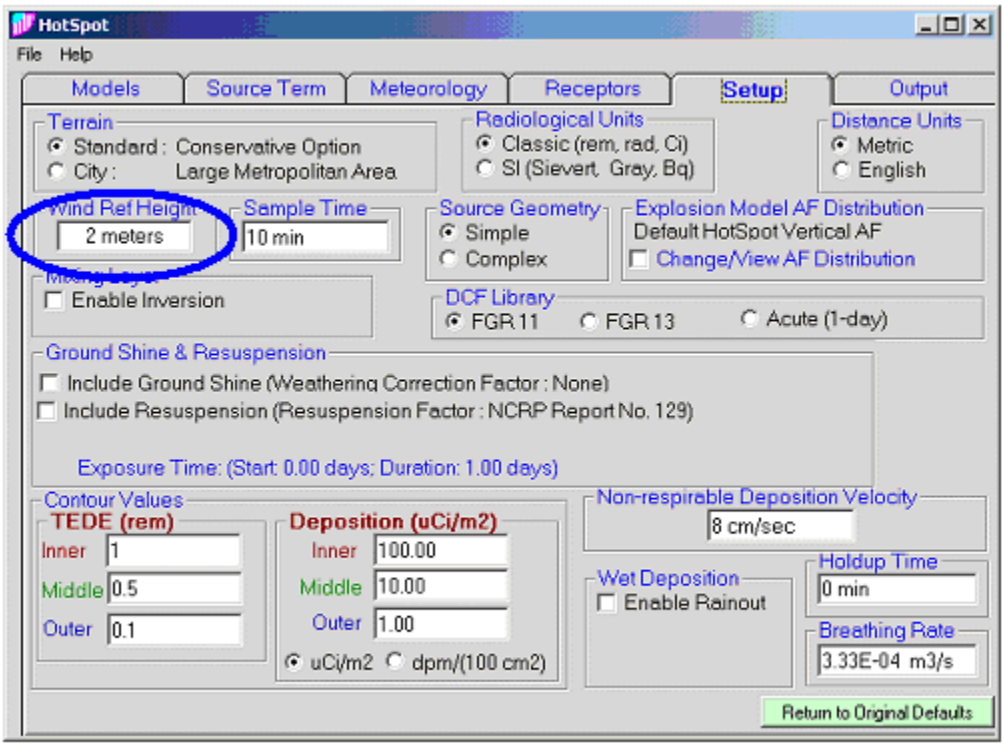
A comparison of MACCS2 Version 1.13.1 and HotSpot Version 2.07 was made using a ground-level release of plutonium-239. The 50th and 95th percentile dose values for dry deposition velocities of 0 cm/sec and 1 cm/sec were calculated. The agreement between the two models was very good.

HotSpot Version 2.07 General Plume

Source Material	: Pu-239 M 24065y
Material at Risk	: 1.0000E+00 Ci
Damage Ratio	: 1.000
Leakpath Factor	: 1.000
Airborne Fraction	: 1.000
Respirable Fraction	: 1.000
Respirable Release Fraction	: 1.000
Wind Speed Ref. Height	: 2.0 m
Effective Release Height	: 0.00 m
Respirable Dep. Vel.	: 0.0 cm/s And 1.0 cm/s
Non-respirable Dep. Vel.	: 8.00 cm/s
Receptor Height	: 0.0 m
Inversion Layer Height	: None
Sample Time	: 10.000 min
Breathing Rate	: 3.33E-04 m3/sec

FGR-13 Dose Conversion Data - Total Effective Dose (TED)

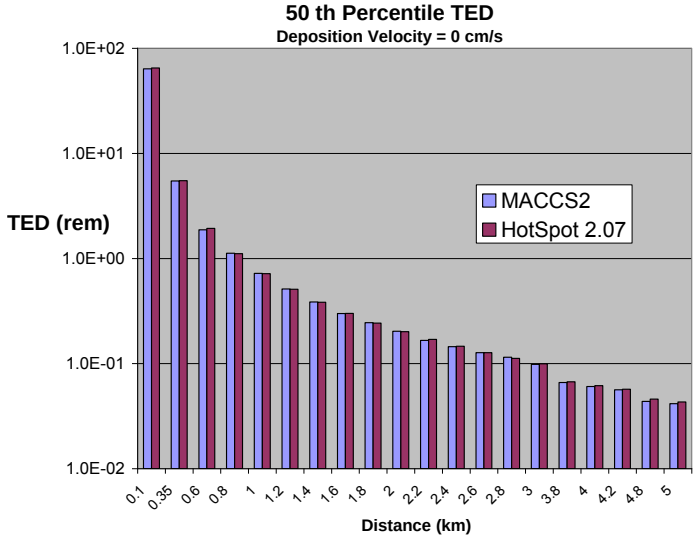
Note: Some dispersion models do not adjust the wind speed for release heights below a specific reference height. MACCS2 assumes the wind speed is equal to the 10-meter reference height value for release heights below 10 meters. Since the ^{239}Pu release scenario assumes a ground-level release (release height = 0 m), HotSpot will adjust the 10-meter wind speed data to a height of 2 meters (Wind speed at 2 meters is considered ―ground level" in HotSpot). To compare the two codes (using the same wind speed values in the Gaussian equation) the HotSpot wind speed height correction must be turned off. To use the wind speed data without height correction, the ―Wind Ref Height" in HotSpot must be set to 2 meters.


HotSpot
File Help
Models
Source Term
Meteorology
Receptors
Setup
Output
Terrain
Standard : Conservative Option
City : Large Metropolitan Area
Radiological Units
Classic (rem, rad, Ci)
SI (Sievert, Gray, Bq)
Distance Units
Metric
English
Wind Ref Height
2 meters
Sample Time
10 min
Source Geometry
Simple
Complex
Explosion Model AF Distribution
Default HotSpot Vertical AF
Change/View AF Distribution
Enable Inversion
DCF Library
FGR 11
FGR 13
Acute (1-day)
Ground Shine & Resuspension
Include Ground Shine (Weathering Correction Factor : None)
Include Resuspension (Resuspension Factor : NCRP Report No. 129)
Exposure Time: (Start: 0.00 days; Duration: 1.00 days)
Contour Values
TEDE (rem)
Inner 1
Middle 0.5
Outer 0.1
Deposition (uCi/m2)
Inner 100.00
Middle 10.00
Outer 1.00
uCi/m2
dpm/(100 cm2)
Non-respirable Deposition Velocity
8 cm/sec
Wet Deposition
Enable Rainout
Holdup Time
0 min
Breathing Rate
3.33E-04 m3/s
Return to Original Defaults

Comparison Results

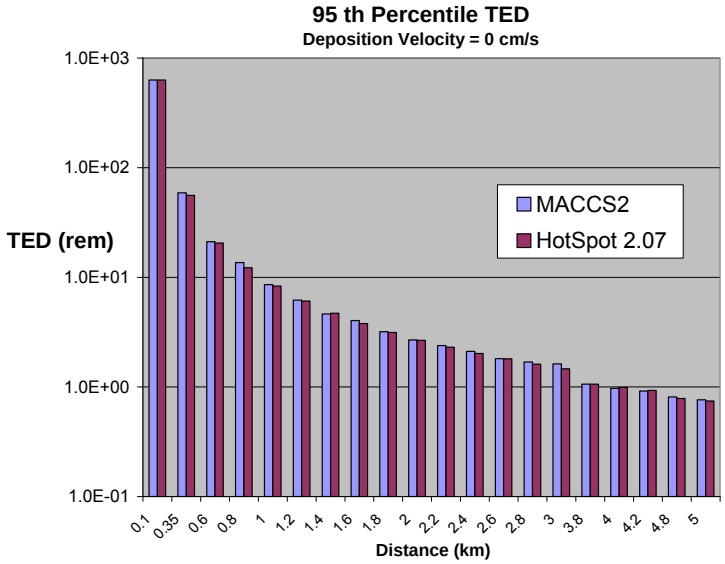
1 Ci Pu-239 Unfiltered Release
50th percentile TEDs
Deposition Velocity = 0 cm/s
EHO

Distances (km)	TED (rem) MACCS2	TED (rem) HotSpot 2.07	Delta (%)
0.1	6.38E+01	6.49E+01	1.7
0.35	5.47E+00	5.49E+00	0.4
0.6	1.87E+00	1.93E+00	3.2
0.8	1.12E+00	1.11E+00	-0.9
1	7.21E-01	7.17E-01	-0.6
1.2	5.12E-01	5.09E-01	-0.6
1.4	3.86E-01	3.83E-01	-0.8
1.6	2.99E-01	3.00E-01	0.3
1.8	2.45E-01	2.43E-01	-0.8
2	2.03E-01	2.01E-01	-1.0
2.2	1.66E-01	1.70E-01	2.4
2.4	1.45E-01	1.46E-01	0.7
2.6	1.27E-01	1.27E-01	0.0
2.8	1.15E-01	1.12E-01	-2.6
3	9.81E-02	9.96E-02	1.5
3.8	6.60E-02	6.71E-02	1.7
4	6.05E-02	6.17E-02	2.0
4.2	5.62E-02	5.69E-02	1.2
4.8	4.37E-02	4.59E-02	5.0
5	4.15E-02	4.31E-02	3.9



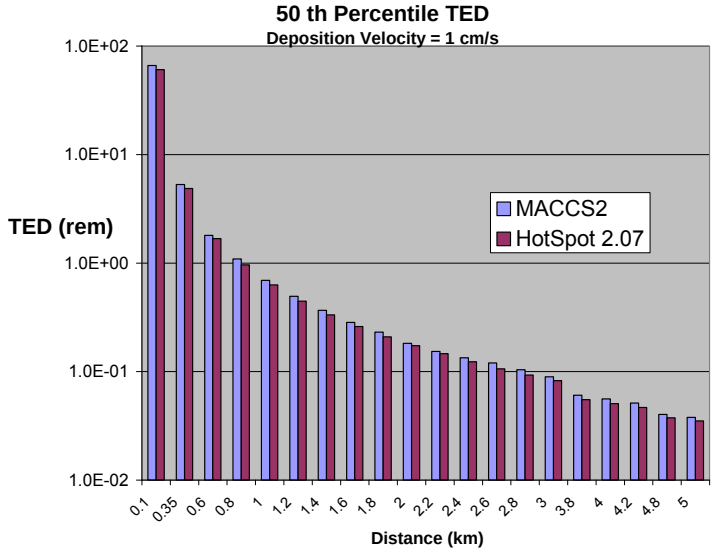
1 Ci Pu-239 Unfiltered Release
95th percentile TEDs
Deposition Velocity = 0 cm/s
EHO

Distances (km)	TED (rem) MACCS2	TED (rem) HotSpot 2.07	HotSpot Delta (%)
0.1	6.29E+02	6.29E+02	0.0
0.35	5.88E+01	5.58E+01	-5.1
0.6	2.11E+01	2.05E+01	-2.8
0.8	1.36E+01	1.22E+01	-10.3
1	8.57E+00	8.29E+00	-3.3
1.2	6.19E+00	6.07E+00	-1.9
1.4	4.63E+00	4.70E+00	1.5
1.6	4.03E+00	3.78E+00	-6.2
1.8	3.19E+00	3.14E+00	-1.6
2	2.68E+00	2.66E+00	-0.7
2.2	2.38E+00	2.30E+00	-3.4
2.4	2.11E+00	2.02E+00	-4.3
2.6	1.81E+00	1.80E+00	-0.6
2.8	1.69E+00	1.61E+00	-4.7
3	1.62E+00	1.46E+00	-9.9
3.8	1.06E+00	1.06E+00	0.0
4	9.71E-01	9.89E-01	1.9
4.2	9.17E-01	9.28E-01	1.2
4.8	8.08E-01	7.83E-01	-3.1
5	7.62E-01	7.44E-01	-2.4



1 Ci Pu-239 Unfiltered Release
50th percentile TEDs
Deposition Velocity = 1 cm/s
EHO

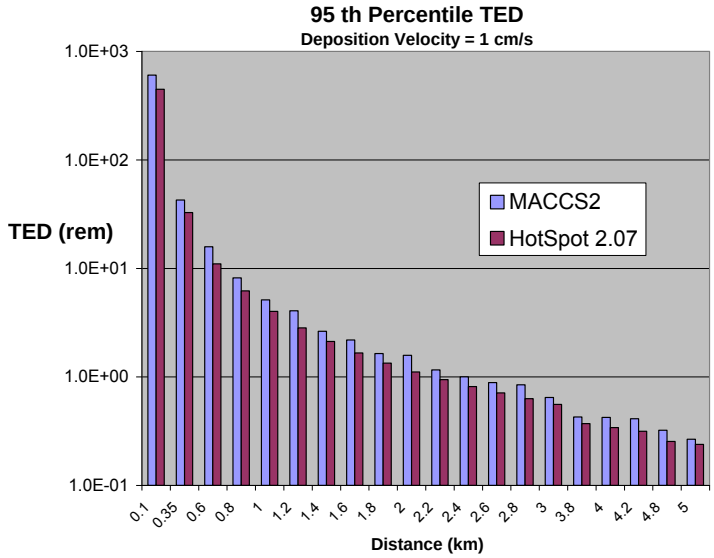
Distances (km)	TED (rem) MACCS2	TED (rem) HotSpot 2.07	Delta (%)
0.1	6.61E+01	6.07E+01	-8.2
0.35	5.30E+00	4.86E+00	-8.3
0.6	1.80E+00	1.68E+00	-6.7
0.8	1.09E+00	9.62E-01	-11.7
1	6.92E-01	6.28E-01	-9.2
1.2	4.94E-01	4.45E-01	-9.9
1.4	3.67E-01	3.33E-01	-9.3
1.6	2.84E-01	2.60E-01	-8.5
1.8	2.31E-01	2.09E-01	-9.5
2	1.82E-01	1.73E-01	-4.9
2.2	1.53E-01	1.46E-01	-4.6
2.4	1.34E-01	1.23E-01	-8.2
2.6	1.20E-01	1.06E-01	-11.7
2.8	1.04E-01	9.29E-02	-10.7
3	8.93E-02	8.24E-02	-7.7
3.8	6.04E-02	5.51E-02	-8.8
4	5.60E-02	5.06E-02	-9.6
4.2	5.12E-02	4.67E-02	-8.8
4.8	4.02E-02	3.75E-02	-6.7
5	3.78E-02	3.51E-02	-7.1



1 Ci Pu-239 Unfiltered Release
95th percentile TEDs
Deposition Velocity = 1 cm/s
EHO

HotSpot

Distances (km)	TED (rem) MACCS2	TED (rem) HotSpot 2.07	Delta (%)
0.1	6.05E+02	4.47E+02	-26
0.35	4.26E+01	3.27E+01	-23
0.6	1.58E+01	1.10E+01	-30
0.8	8.18E+00	6.21E+00	-24
1	5.12E+00	4.02E+00	-21
1.2	4.07E+00	2.83E+00	-30
1.4	2.63E+00	2.12E+00	-19
1.6	2.19E+00	1.66E+00	-24
1.8	1.64E+00	1.34E+00	-18
2	1.58E+00	1.11E+00	-30
2.2	1.16E+00	9.44E-01	-19
2.4	1.00E+00	8.14E-01	-19
2.6	8.86E-01	7.11E-01	-20
2.8	8.44E-01	6.29E-01	-25
3	6.46E-01	5.58E-01	-14
3.8	4.27E-01	3.71E-01	-13
4	4.23E-01	3.41E-01	-19
4.2	4.12E-01	3.15E-01	-24
4.8	3.22E-01	2.54E-01	-21
5	2.66E-01	2.39E-01	-10



6. HotSpot Version History and File Structure

HotSpot Version History

1985—HotSpot 1.0 Hewlett Packard HP-41CX system.

1990—1994 HotSpot 2.0–HotSpot 7.0 (IBM PC or compatible).

1995—HotSpot 8.0 (Urban diffusion coefficients, wet deposition, user's custom library, 50-nuclide mixture, GIS interface) Borland Turbo Pascal 7.0; HotSpot 8.02: Corrected Pentium II incompatibility with Borland Turbo Pascal.

1999—HotSpot 98 Version 1.04: Full 32-bit Windows 95/98/NT application; Microsoft Visual Basic 6.0 Professional; HotSpot 8.03 (DOS Version) Borland Turbo Pascal 7.0.

2000—HotSpot 98 Version 1.06: Full 32 bit Windows 95/98/00/NT application; Microsoft Visual Basic 6.0 Professional; New Module: *Radionuclides in the Workplace*; Corrected mixture error (submersion and ground dose were not included in the dose predictions if a mixture was used for the source term). Standard onboard library radionuclides were not affected; Added plutonium and uranium criticality mixtures.

2002—HotSpot 2.0: Full 32 bit Windows 95/98/00/XP/NT application; Microsoft Visual Basic 6.0 Professional; New Module: *FIDLER* Calibration and Lung Screening; Geographical Mapping capability; GPS Exercise Mode (Virtual plume/ instrument response); Plume bending (up to four bend points), for exercise simulation; FGR 13 Dose Conversion Library (FGR 11, FGR 13, and 24-hour Acute Dose Conversion Factors); Default receptor height changed from 0 meter to 1.5 meters; Addition of buoyant and momentum plume rise for stacks; Default respirable deposition velocity changed to 0.3 cm/sec for non noble gas radionuclides; Non-respirable deposition velocity remains at 8 cm/sec, but is now a variable in HotSpot Setup; HotSpot QC Check; Table output option to include the Committed Equivalent Dose for 23 individual organs (options for all organs or organs exceeding 50 rem (0.5 Sv).

2003—HotSpot 2.05: Full 32-bit Windows 95/98/00/XP/NT application; Microsoft Visual Basic 6.0 Professional; Explosive Release models (Plutonium Explosion, Uranium Explosion and General Explosion. Table output includes Unmitigated blast effect distances for eardrum rupture and incapacitation (5 psi), Lung damage and complete incapacitation (10 psi) and onset of lethality. In addition (25 psi) the International Association of Bomb Technicians and Investigators (IABTI) safe distance is output. (See Explosion.); Revised Fuel Fire model. Two upwind virtual-term point sources are used to model the initial distribution of material in the vertical and horizontal dimensions. The virtual-term point sources are positioned at an upwind distance resulting in a Sigma-y and Sigma-z, above the origin, equal to 50% of the input pool radius. In previous versions,

the largest of either 50% of the pool radius or 60% of the effective plume height was used. The 60% criterion is no longer used.

2005—HotSpot 2.06: Full 32-bit Windows 95/98/00/XP/NT application; Microsoft Visual Basic 6.0 Professional.

Table output for the nuclear explosion model now includes an optional nuclear explosion event summary. All dose data are midline tissue doses—the midline dose is assumed to be 70% of the surface absorbed dose (Glasstone, page 579, section 12.108). A fallout dose terrain reduction factor of 0.7 is assumed (Glasstone, page 428, section 9.95). Previous versions of HotSpot assumed these modifiers were 100% and 1.0, respectively. Users can now select shielding attenuation options for fallout dose data (Table and Plume Contours).

CEDE vs. TEDE. The HotSpot output dose values, due to plume passage, have always included the cloud submersion Effective Dose Equivalent (EDE), with the inhalation Committed Effective Dose Equivalent (CEDE). Beginning with this version, the label "CEDE" is replaced by "TEDE" to reflect the cloud submersion component. TEDE is the Total Effective Dose Equivalent, TEDE = CEDE (inhalation) + EDE (submersion)

If the "include 4-days of Ground Shine" check box is checked (Setup Page), the EDE from 4-days of ground shine will be included in the TEDE value, TEDE = CEDE (inhalation) + EDE (submersion) + EDE (ground shine)

Lung Screening module: Updated with improved lung phantom data

Regional and Language Options: Previous versions of HotSpot required the Regional and Language Options to be set to English (United States).

HotSpot 2.06 now operates regardless of the computer's Regional and Language Option settings. The language remains English, but time date and number formats are supported, e.g., 3.14159 versus 3,14159. 100,000,000 versus 100 000 000, etc.

2009—HotSpot 2.07: Full 32-bit Windows 95/98/00/XP/NT/Vista application; Microsoft Visual Basic 6.0 Professional.

Using new ORNL dose conversion factor data base: DCFPAK 1.6:

- ICRP26 or ICRP60 tissue weighting factors
- FGR11/ICRP30 or FGR13/ICRP66 biokinetic models
- 30-day acute committed inhalation dose
- External air immersion or ground exposure (FGR12)

Weathering correction factors for nuclear fallout and deposition of radionuclides. Two options:

- WASH 1400 (NUREG-75/014),

- Anspaugh (Health Physics, March 2002, Vol. 82) – newer, default option

Resuspension options:
- WASH-1400 (NUREG-75/014)
- NCRP Report 129 (Used by FRMAC) – newer, default option

Resuspension included with General model TEDE calculations
- Plume passage
  - Submersion
  - Inhalation
- Ground shine + weathering
- Resuspension

HotSpot plume files can be displayed on Google Earth global maps
HotSpot plume files (.KML) automatically invoke Google Earth and zoom to the user-input Lat/Long and display select contours
Contour options include
- General and Explosive release models
  - Dose
  - Deposition
- Nuclear explosion
  - Fallout dose and dose rate
  - Prompt nuclear effects
    - Blast
    - Thermal
    - Ionizing

Explosion model has improved deposition and ground shine estimates in proximity (within a few 100 m) of the detonation point

- Users can customize cloud parameters
  - Vertical source distribution
  - Scale cloud height calculated using Church formula

Expanded source term description
Controllable parameters:
- Material at Risk (MAR)
- Damage Ratio (DR)
- Leakpath Factor (LP)
- Airborne Fraction (AF)
- Respirable Fraction (RF)

Site-specific meteorological data can be input into HotSpot for calculation of percentile dose values

Input file format: Sequential hourly data (in MACCS2 code format) (1-5 years):

- Date/Time
- Wind speed
- Wind direction
- Stability Class (A-G)

Output options:

- 50th, 90th, 95th, 99th, and 99.5^{th} default percentile dose values for up to 20 locations within each of the 16 compass sectors. Users can also input other percentile values.
- Direction dependant percentile values (sectors 1-16)
- Direction independent percentile values (all sectors 1-16).
- Joint Frequency Distribution (JFD)
- Cumulative Frequency Distribution for each location within each sector and sum of sectors 1-16.

Avoidance Dose (Resuspension and/or Ground Shine) calculated using:

- Exposure Start Time
- Exposure Duration

The Total Effective Dose Equivalent (TEDE) values output in previous versions of HotSpot only included the inhalation and submersion component of the TEDE during plume passage. If applicable, the initial ground shine dose rate (rem/hr or Sv/hr) was also output. Starting with Version 2.07 both resuspension and ground shine, inclusive of weathering, are optionally included in the TEDE values. The duration of the exposure time period is now selectable by the user. When you first run HotSpot, the time period is from initial release plus 4 days (***Start of Exposure*** = 0 days, ***Exposure Duration*** = 4.0 days), and the ***Include Ground Ground Shine*** and ***Include Resuspension*** options are <u>not</u> checked. This results in calculated TEDE values identical with previous versions of HotSpot (TEDE due to plume passage only). If the ***Start of Exposure*** is <u>any</u> value greater than zero, the plume passage component (inhalation and submersion) is <u>not</u> included in the output TEDE values. For example, if the ***Start of Exposure*** is set to 0.1 days (0r 0.1 hours, etc.) the plume-passage component of the TEDE will not be included. If the ***Include Ground Ground Shine*** and ***Include Resuspension*** options are not checked, the output TEDE values will all be zero since plume passage is not included. If the ***Include Ground Ground Shine*** and ***Include Resuspension*** options are checked, both ground shine and resuspension are included. If the ***Start of Exposure*** is set to 1 year and the ***Exposure Duration*** set to 1 year, the resuspension and ground shine TEDE from year 1 to year 2 will be output.

March 2010—HotSpot 2.07.1: Full 32-bit Windows 95/98/00/XP/NT/Vista application; Microsoft Visual Basic 6.0 Professional.

Dose conversion factor database was updated to DCFPAK 2.2, Eckerman *et al* (2010).

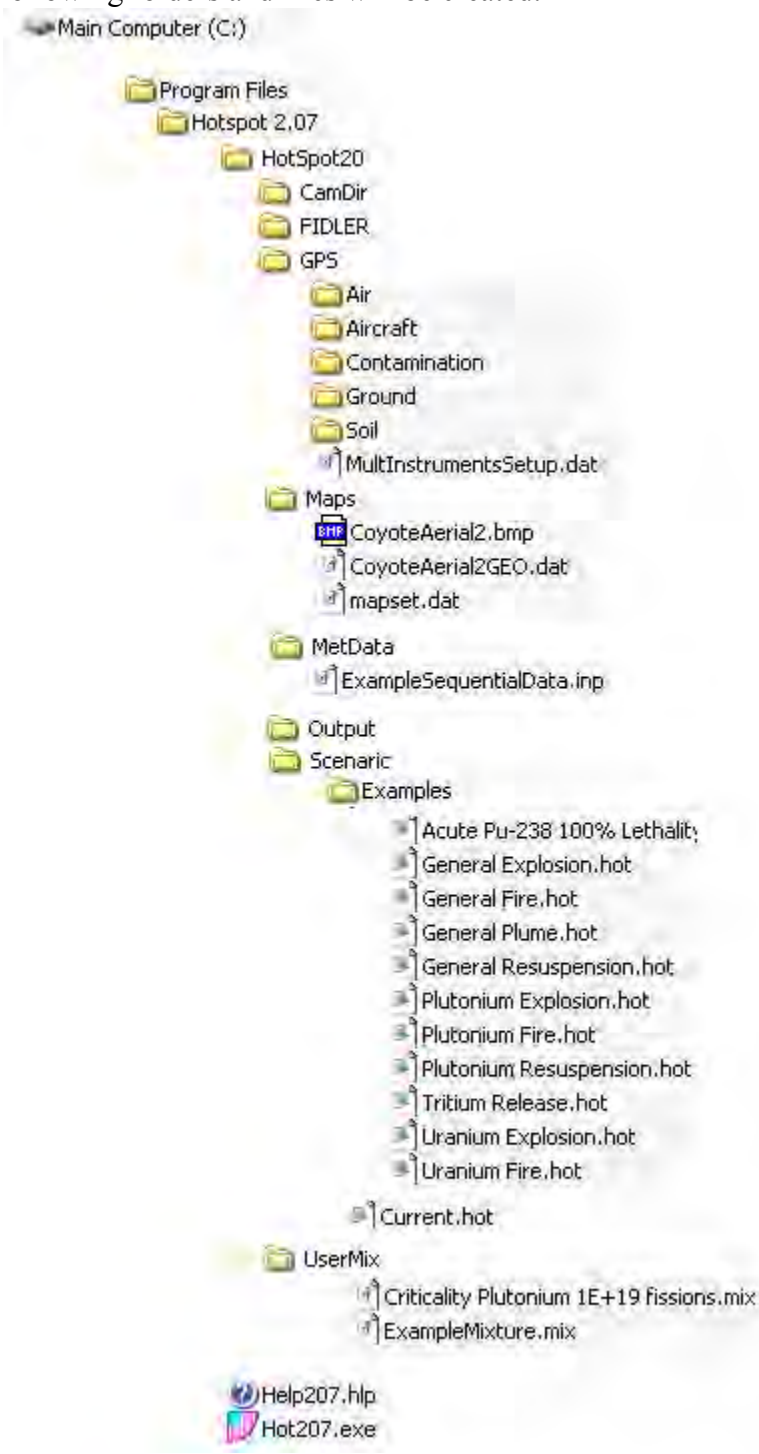
Additional test cases were developed for pre-release testing for more software components and databases, and for a range key input parameters, as described below:

- Scenario Library Validation – each dispersion model is exercised with the TEDE, integrated air concentration and deposition values calculated at three downwind distances.
- Explosive Release Validation – this component is exercised with three values for TNT quantity and, as with the scenario library validation, values for the three types of products are compared at three downwind distances.
- Fuel Fire Release Validation – this component is exercised with three values each for fuel quantities, fire radii, and fire time duration. Again the values for the three products are compared and three downwind distances.
- Library Validation – all ORNL DCFPAK 2.2 values are compared with an independent NARAC library.
- A variety of tests are performed on the test data set that contains one year of meteorological observations to verify proper handling of the data. These tests include corrupt and out-of-range values so the appropriate error handling can be verified.
- Sigma-y and Sigma-z Validation – these values are computed for the two terrain types at three downwind centerline distances for all stability classes. These are compared against analytic values.
- Wind Speed as a Function of Height Validation – for a reference wind speed, the calculated wind speeds are compared with analytic values for all terrain types, stability classes and three heights.
- Plume Depletion Validation – plume depletion factors are computed for all terrain and stability classes, three downwind centerline distances, three wind speeds and three release heights and compared with analytic values.

In addition a checklist has been generated that supports independent verification of HotSpot handling of incorrect inputs from the GUI that has been performed on HotSpot 2.07.1 and will be performed as part of acceptance testing for HotSpot releases.

HotSpot File Structure

The default installation location for HotSpot is the "HotSpot 2.07" folder located in the "Program Files" folder on the main drive. After HotSpot is run for the first time, the following folders and files will be created.



HotSpot 20

- Main folder containing all HotSpot sub folders and files

CamDir

- Folder used for interfacing to the Canberra Albuquerque, Inc. Environmental Continuous Air Monitor (ECAM). Contains ECAM alpha/beta air measurement data.

FIDLER (Field Instrument for the Detection of Low Energy Radiation)

- Contains all calibration files for FIDLER calibration and Lung measurement data

GPS

- Contains files supporting Hotpot Global Positioning Satellite (GPS), exercise mode.

Maps

- Location of .bmp maps and associated geo position data for each map. An example map and geo file for Coyote Hills in Albuquerque, New Mexico, are automatically loaded when HotSpot is initially run.

MetData

- Contains Site-specific meteorological data for HotSpot Percentile Dose Option. An example file is loaded when HotSpot is initially run.

Output

- Contains HotSpot output files, tables, plots, etc.

Scenario

- Contains Example release files and user-created files.

UserMix

- Contains user-created radionuclide mixtures and two example mixtures, ―Criticality Plutonium 1E+19 fissions.mx" and ―ExampleMixture.mix."

Help207.hlp

- HotSpot Help and Documentation program.

Hot207.exe

- HotSpot executable program.

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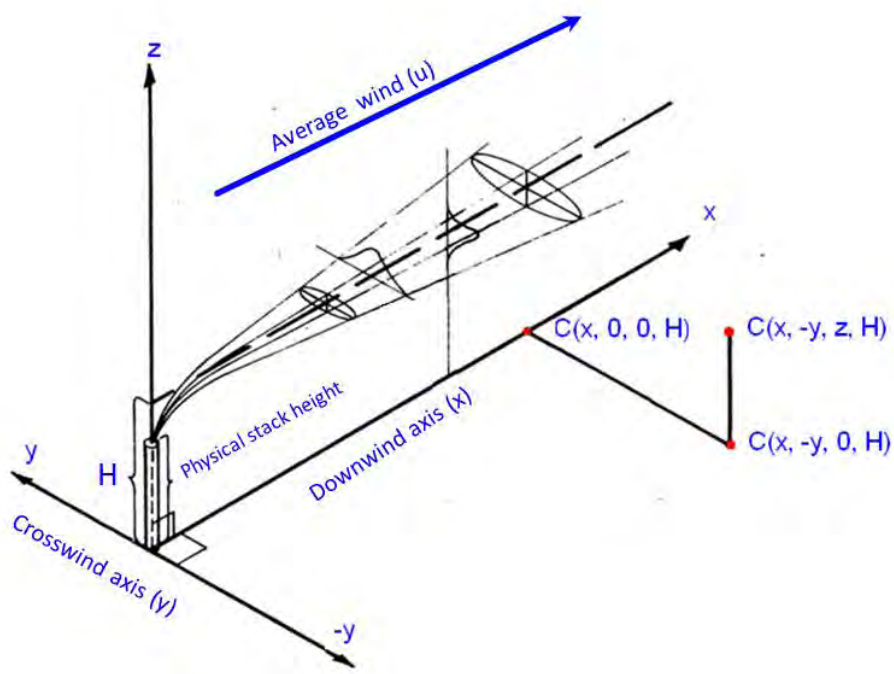
7. HotSpot Algorithms

There are many implementations of the Gaussian model, and so for completeness, the following summary is included. The Gaussian model has been widely used and verified in the scientific community and is still the basic workhorse for initial atmospheric dispersion calculations. The Gaussian model generally produces results that agree well with experimental data, and as a result, has found its way into most governmental guidebooks, and is also used and accepted by the Environmental Protection Agency (EPA, 1978). The origin of the Gaussian model is found in work by Sutton (1932), Pasquill (1961, 1974), and Gifford (1961, 1968). Additional background and supplemental information on the Gaussian model can be found in Turner (1969), Hanna, *et al* (1982, 1987, 1989), S. Pal Arya (1999).

Figure 7.1 HotSpot Coordinate System



In the HotSpot codes, the coordinate origin is located at ground level, beneath the point of radionuclide release *(x* = 0, *y* = 0, z = 0). The *x* axis is the **downwind** axis, extending horizontally with the ground in the average wind direction. The *y* axis is the **crosswind** axis, perpendicular to the downwind axis, also extending horizontally. The z axis extends vertically frpm the ground. A plume travels along, or parallel to, the downwind axis, and reelects off the ground surface when the plume touches down.

Gaussian Equation

The following Gaussian model equations determine the atmospheric concentration of a gas or an aerosol at any point in space:

$$C(x,y,z,H) = \frac{Q}{2\pi\sigma_y\sigma_z u}\exp\left[-\frac{1}{2}\left(\frac{y}{\sigma_y}\right)^2\right]\left\{\exp\left[-\frac{1}{2}\left(\frac{z-H}{\sigma_z}\right)^2\right]+\exp\left[-\frac{1}{2}\left(\frac{z+H}{\sigma_z}\right)^2\right]\right\}\exp\left[-\frac{\lambda x}{u}\right]DF$$

If the inversion layer option is in effect, and σ_z exceeds the inversion height (L), the following equation is used.

$$C(x,y,z,H) = \frac{Q}{\sqrt{2\pi}\sigma_y L u}\exp\left[-\frac{1}{2}\left(\frac{y}{\sigma_y}\right)^2\right]\exp\left[-\frac{\lambda x}{u}\right]DF$$

To avoid the sharp transition between the two above equations, the transition into the inversion layer equation begins when σ_z equals 70% of L, and is complete when σ_z equals L. Between these two values, the two equations are linearly interpolated.

Where:

C = Time-integrated atmospheric concentration (Ci-s)/(m^3).
Q = Source term (Ci).
H = Effective release height (m).
λ = Radioactive decay constant (s^{-1}).
x = Downwind distance (m).
y = Crosswind distance (m).
z = Vertical axis distance (m).
σ_y = Standard deviation of the integrated concentration distribution in the crosswind direction (m).
σ_z = Standard deviation of the integrated concentration distribution in the vertical direction (m).
u = Average wind speed at the effective release height (m/s).
L = Inversion layer height (m).

DF(x) = Plume Depletion factor

Atmospheric Stability Classification

Meteorologists distinguish general states of the atmospheric surface layer as to how they compare to the adiabatic lapse rate (unstable, neutral, and stable). These categories refer to how a parcel of air reacts when displaced adiabatically in the vertical direction. HotSpot allows you to select the atmospheric stability classification in two ways.

For those not familiar with the different stability classifications, HotSpot will select the appropriate stability classification based on user-input of direct observations. Or, users can directly select and force a particular stability classification. The simplified method requires selecting the solar insolation factor and the ground wind speed (2-m height). HotSpot automatically determines the atmospheric stability category from the matrix in the following table. This table contains criteria for the six stability classes, based on five categories of solar insolation. The scheme is widely used in meteorology and is accepted for stability class estimates.

Meteorological conditions used to define the Atmospheric Stability Categories, A-F, used in HotSpot.

Ground wind speed (m/s)	Sun high in sky	Sun low in sky or cloudy	Night time
< 2	A	B	F
2 - 3	A	C	E
3 - 4	B	C	D
4 - 6	C	D	D
> 6	C	D	D

Pasquill Stability Types:

A: Extremely Unstable	(σ_θ = 25 degrees)
B: Moderately Unstable	(σ_θ = 20 degrees)
C: Slightly Unstable	(σ_θ = 15 degrees)
D: Neutral	(σ_θ = 10 degrees)
E: Slightly Stable	(σ_θ = 5 degrees)
F: Moderately Stable	(σ_θ = 2.5degrees)

Worst-Case Stability

For an elevated release, the location of the maximum concentration depends on the stability class chosen. For materials with a deposition velocity of zero and a release point at or very near GROUND LEVEL, the maximum concentration is always associated with "F" stability. However, if the deposition velocity is greater than zero, the worst-case stability at large downwind distances is not always associated with "F" stability due to the effects of plume depletion, i.e., the concentration of the plume decreases at a faster rate with increasing stability class (A-F) and increasing deposition velocity. For example, at a specific location, "E" stability could result in a higher local concentration than "F" due to LESS plume depletion associated with "E" stability. This effect is minimal for deposition velocities less than 0.1 cm/sec.

Special G Stability

On occasion, it can be difficult to reconcile differences between various dispersion model results such as the National Atmospheric Release Advisory Center's (NARAC), LODI (Leone et al, 2001) model, and those of Gaussian plume models such as HotSpot. A significant difference may be caused by different model assumptions about atmospheric diffusion in night-time, stable conditions. For stable atmospheric condition of ―F" stability and 1 m/s wind speed (often used for conservative calculations for ground-level releases), a Gaussian Plume model may give a much more conservative result than NARAC due to the way a stable atmosphere is treated.

An atmospheric stability class of ―F" (moderately stable night time conditions) with a 10-meter height wind speed of 1 m/s (about 2 mph), is very close to ―calm" conditions. It is common for the wind direction to fluctuate significantly at such a low wind speed. However, Gaussian plume models typically assume minimal fluctuations in wind direction for F stability class. This results in narrower plumes and higher concentrations. This conservative methodology is assumed in HotSpot to be in concert with various government publications (e.g., EPA ―Green Book"). However, HotSpot also has a ―G" stability class option specifically for extremely stable low-wind speed conditions. This option uses a more-typical, larger fluctuation in the wind direction (standard deviation of 25 degrees is the default assumption), which produces a more rapid dilution of the plume and lower air concentrations. The G stability option agrees well with the NARAC model results for night time, stable conditions, under simple, homogenous meteorological conditions. Under more complex meteorological conditions NARAC model results may differ for other reasons, including detailed atmospheric flow, transport and deposition processes not included in simpler Gaussian plume models.

Diffusion experiments under clear, nearly calm nighttime conditions suggest that horizontal diffusion is actually greater (i.e., larger σ_y) than modeled with F stability due to increased plume meander. The standard deviation of the observed wind fluctuations in the horizontal direction, σ-theta, can be very large. The observed σ-theta values during G stability conditions correspond to anything between categories A–F, i.e., diffusion in terms of tabulated dispersion parameters is indeterminate during G stability conditions (Hanna, 1982). The diffusion can best be estimated using the actual measurement of σ-theta. If the G stability class is selected, the user is prompted for σ-theta, and the applicable stability class is used for the horizontal diffusion component. F stability is always assumed for the vertical component.

Determining σ_y and σ_z

Once the atmospheric stability category has been determined, HotSpot uses the equations given in Table 2 to estimate σ_y and σ_z for two terrain types-Standard and City. The City terrain factor accounts for the increased plume dispersion from crowded structures and the heat retention characteristics of urban surfaces, such as asphalt and concrete. The City terrain factor will estimate lower concentrations than the standard factor, due to the increased dispersion from large urban structures and materials.

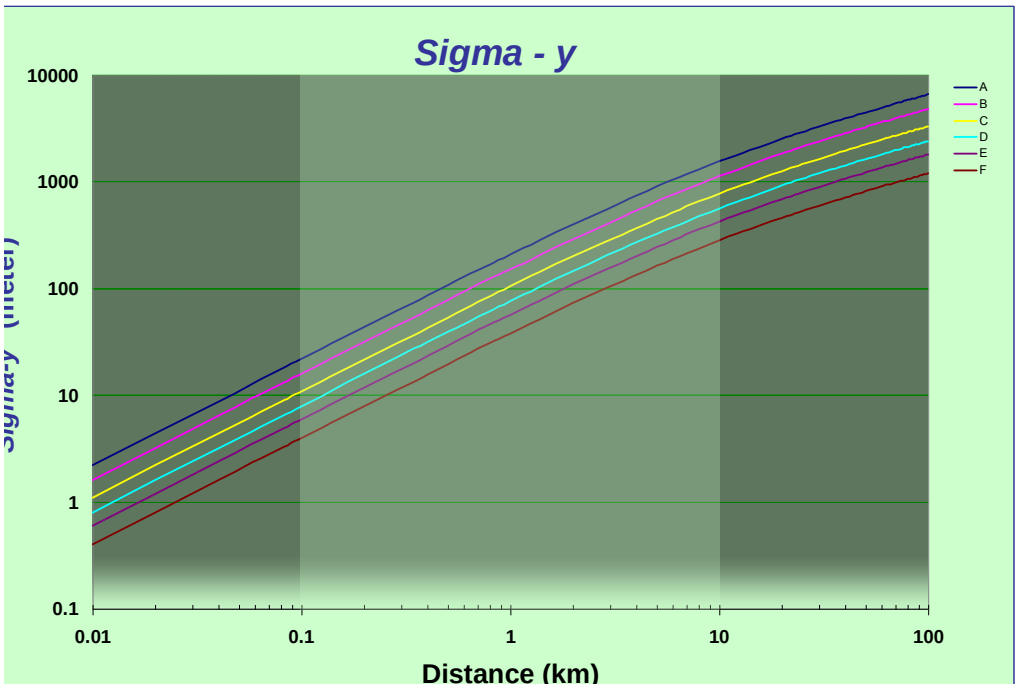
The most widely used scheme to estimate σ_y and σ_z was developed by Pasquill (1961). Briggs (1973) combined the Pasquill curves with curves derived from data observed at Brookhaven National Laboratory and the Tennessee Valley Authority, the latter including observations out to a downwind distance of 10 km. Briggs incorporated theoretical concepts regarding asymptotic limits of the formulas to produce a widely used set of equations for σ_y and σ_z. The equations are associated with dispersion experiments conducted over short grassy surfaces with roughness heights in the range from 0.01 meter to 0.1 meter (Note: the roughness height is approximately equal to the physical height divided by 10, e.g., a roughness height of 0.1 meter would be associated with a field of objects with an average physical height of 1 meter). Briggs' formulas are applicable from a distance of 0.1 km to approximately 10 km and are extendible to 20 or 30 km, although Briggs does not recommend this extension. However, for lack of any other validation schemes, these formulas are commonly used out to a distance of 100 km. HotSpot limits the maximum downwind distance to 200 km. U.S. Nuclear Regulatory Commission Regulatory Guide 1.194 (June 2003), does not recommend extrapolating the σ_y and σ_z. data below a distance of 10 meters. HotSpot limits the minimum downwind distance to this 10 meter value. As shown in the following figures, the values of σ_y and σ_z. are smooth functions of the downwind distance x. Consequently, HotSpot allows input of distances to within 10 meters (0.01 km) of the release point.

Equations used to determine σ_y and σ_z. This methodology is derived from Briggs, 1973.

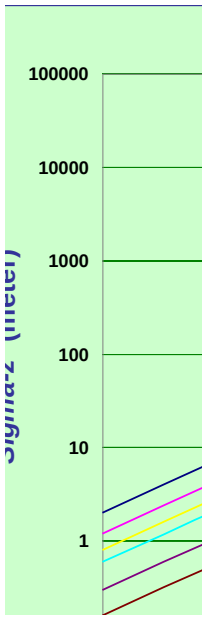
Standard Terrain

Pasquill Type	σ_y (meter)	σ_z (meter)
A	$\frac{0.22x}{\sqrt{1+0.0001x}}$	$0.20x$
B	$\frac{0.16x}{\sqrt{1+0.0001x}}$	$0.12x$
C	$\frac{0.11x}{\sqrt{1+0.0001x}}$	$\frac{0.080x}{\sqrt{1+0.0002x}}$
D	$\frac{0.08x}{\sqrt{1+0.0001x}}$	$\frac{0.060x}{\sqrt{1+0.0015x}}$
E	$\frac{0.06x}{\sqrt{1+0.0001x}}$	$\frac{0.030x}{1+0.0003x}$
F	$\frac{0.04x}{\sqrt{1+0.0001x}}$	$\frac{0.016x}{1+0.0003x}$

Graphical representation of the above equations for sigma-y (standard terrain) is shown below.



Graphical representation of the above equations for sigma-z (standard terrain) is shown below.



z

Equations used to determine σ_y and σ_z.

City Terrain

Pasquill Type	σ_y (meter)	σ_z (meter)
A-B	$\frac{0.32x}{\sqrt{1+0.0004x}}$	$0.24x\sqrt{1+0.001x}$
C	$\frac{0.22x}{\sqrt{1+0.0004x}}$	$0.20x$
D	$\frac{0.16x}{\sqrt{1+0.0004x}}$	$\frac{0.14x}{\sqrt{1+0.0003x}}$
E-F	$\frac{0.11x}{\sqrt{1+0.0004x}}$	$\frac{0.08x}{\sqrt{1+0.0015x}}$

x = downwind distance, meter.

Sample Time

The equations for the standard deviation of the Gaussian concentration distribution in cross-wind direction (σ_y) are representative of observing plume characteristics over a time period of 10 min. In the HotSpot codes, this averaging time is referred to as the sampling time. Concentrations downwind from a source decrease with increasing sampling time primarily because of a larger σ_y due to an increased meander of wind direction. The following photographs (Slade, 1968) demonstrate the effect of sampling time. In the first photograph, the camera exposure duration (sampling time) was 1/50 second, and the plume shows the ~~"i~~nstantaneous" cloud concentration (loops, etc.). The second exposure duration of 5 minutes results in a smoothed cloud concentration (and reduced average centerline concentration) due to averaging all of the ~~"i~~nstantaneous" values over the 5 minute sampling time.

Sample time = 1/50 sec

Sample time = 5 min

In the HotSpot codes, the default release duration of radioactive material is 10 minutes. If you are interested in a scenario with a release duration of 1 hour, you should change the sample time to 60 min. The sample time for the explosive-release programs is fixed at 10 min and cannot be altered. However, the sample time may be changed in non-explosive programs in the ―SETUP" menu. In HotSpot, the following equation adjusts for sampling times different than 10 min (Hanna, et al., 1982; Gifford, 1975)

$$\sigma'_y = \sigma_y \left[\frac{t}{10} \right]^{0.2} ,$$

where—

σ_y = 10-min standard deviation of the concentration distribution.

σ_y' = Standard deviation for averaging time, *t*.

Effective Release Height

The actual plume height may not be the physical stack height. Plume rise can occur because of the velocity of stack emission, and the temperature differential between the stack effluent and the surrounding air. The rise of the plume results in an increase in the release height.

This effective release height leads to lower integrated concentrations at ground level. If you cannot estimate or calculate the effective release height, the actual physical release height (height of the stack) or zero for ground-level release should be used. This will usually yield a conservative estimate, (i.e., larger radiation doses for all downwind receptors, etc). If you are using the HotSpot "General Plume" or "Tritium Release" models, an optional check box enables the Plume Rise Calculation.

Wind Speed Variation with Height

The Gaussian plume equation requires the wind speed at height H, the effective release height. Wind speed data are typically referenced to a height of 10 meters. The actual data might be measured at a different height, e.g., using data from a 61 meter meteorological tower and then these data are adjusted to a 10-meter reference height. HotSpot uses the following power-law formula to adjust the wind speed for all effective heights greater than 2 meters (if the release height is less than 2 meters, HotSpot will adjust the wind speed to a height of 2 meters).

$$u(H) = u(z) \left(\frac{H}{z} \right)^p$$

where—

$u(z)$ = Wind speed (m/s), at reference height z (m).
H = Effective release height (m).
P = Factor from the following table.

Exponential factor, *P*, used by HotSpot for calculating wind speed variation with height (from Irwin, 1979).

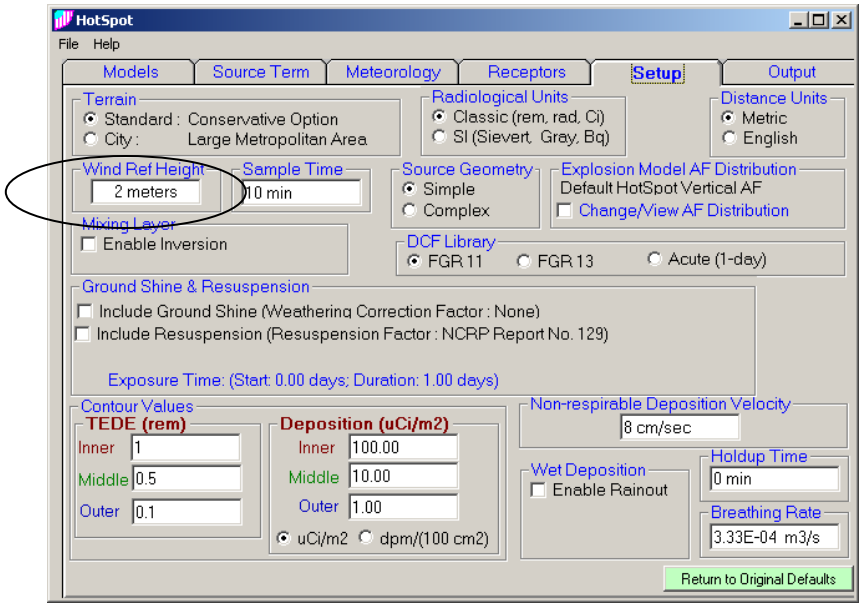
Standard Terrain

Stability Class					
A	B	C	D	E	F
0.07	0.07	0.10	0.15	0.35	0.55

City Terrain

Stability Class					
A	B	C	D	E	F
0.15	0.15	0.20	0.25	0.40	0.60

Note: Some dispersion models do not adjust the wind speed for release heights below a specific reference height. For example, for release heights below 10 meters, MACCS2 assumes the wind speed is equal to the 10-meter reference height value. Suppose you want to compare the results of HotSpot with MACCS2 using wind speed data referenced to a height of 10 meters. If the release scenario assumes a ground-level release (release height = 0), HotSpot will adjust the 10-meter wind speed data to a height of 2 meters (Wind speed at 2 meters is considered ―ground level"). To compare the two codes (use the same wind speed values in the Gaussian equation) the HotSpot wind speed height correction must be turned off. To use the wind speed data without height correction, the ―Wind Ref Height" in HotSpot must be set to 2 meters.



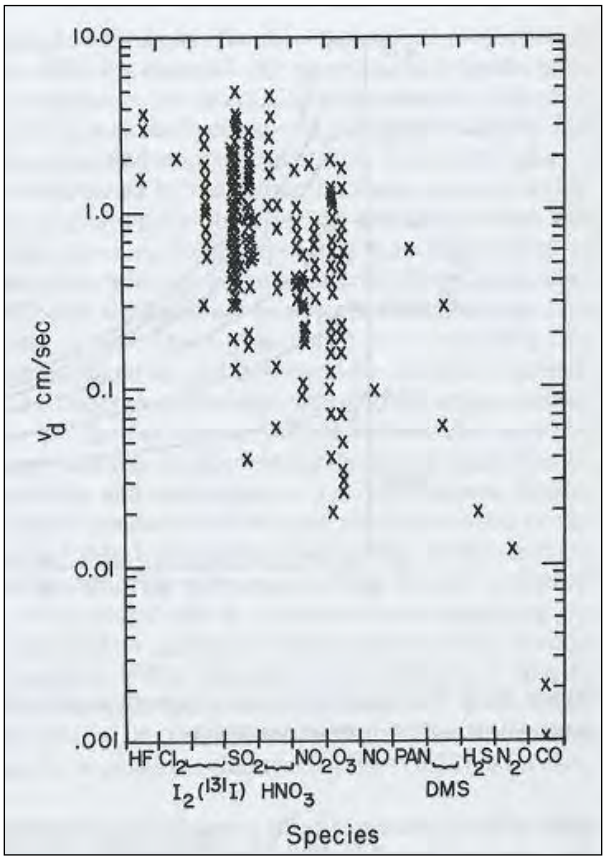
Plume Depletion

Dry deposition

Very small particles and gases or vapors are deposited on surfaces as a result of turbulent diffusion and Brownian motion. Chemical reactions, impaction, and other biological, chemical, and physical processes combine to keep the released substance at ground level. This process is called dry deposition, and the effective deposition velocity (e.g., in units of cm/s) is empirically defined as the ratio of the observed deposition flux (e.g., in units of uCi / (cm^2-s)) and the observed air concentration near the ground surface (uCi /cm^3). As this material is deposited on the ground, the plume above becomes depleted. HotSpot uses a source-depletion algorithm to adjust the air concentration in the plume to account for this removal of material.

For most materials, a dry deposition velocity of about 1 cm/s can be assumed and the dry deposition flux to the surface (e.g., uCi /cm^2), can be assumed to equal the dry deposition velocity times the concentration (Hanna and Britter, 2002). However, as shown in the figure below, the dry deposition velocity varies several orders of magnitude, depending on the chemical species of the source term. For perspective, the most extensively measured dry deposition velocities are for sulfur dioxide (SO_2) and iodine (I_2), with values for the former ranging from 0.04 cm/s to 7.5 cm/s, and those for iodine ranging from 0.02 cm/s to 26 cm/s, depending on the ground surface and micrometeorological conditions (S. Pal Arya 1999).

To be in concert with the NRC code "RASCAL" (USNRC, 2000)' and the Department of Energy's NARAC the default dry deposition velocity for the respirable component of the source term is 0.3 cm/s.



Experimental data on dry deposition velocities for various gases ranked in approximate order of chemical reactivity (S. Pal Arya, 1999).

HotSpot uses a dual-deposition velocity methodology. A separate deposition velocity is used for respirable particles (less than 10 micron aerodynamic diameter) and non-respirable particles (greater than 10 micron aerodynamic diameter) portions of the source term. The default values are:

Respirable Source Term Deposition Velocity = 0.3 cm/s

Non-respirable Source Term Deposition Velocity = 8 cm/s

(Based on empirical comparisons with NARAC deposition data)

These default values can be changed by the user if more applicable data are available (e.g., increased deposition due to chemical reactivity, etc.). The conservative assumption (greater concentration estimates), would be to assume that the deposition velocity is always zero. However, this is only true of noble gases such as krypton and xenon, and such an assumption would result in unrealistically large concentration estimates at large downwind distances.

The respirable and non-respirable source term components are defined as follows.

Material at Risk (MAR): The total quantity of the radionuclide involved in the release scenario.

Damage Ratio (DR): The fraction of the MAR that is actually impacted in the release scenario.

Leakpath Factor (LPF): The fraction of the MAR (modified by th DR), that passes through some confinement or filtration mechanism. For unmitigated release scenarios, the Leakpath Factor is 1.

Airborne Fraction (AF): The fraction of the material at risk that is aerosolized and released to the atmosphere.

Respirable Fraction (RF): The fraction of aerosolized material that is respirable (AMAD = 1 micron).

Respirable Release Fraction: The fraction of the MAR that is dispersed into the atmosphere with an AMAD of 1 micron; ***Respirable release fraction*** $= AF \times RF$.

Non-respirable Release Fraction: The fraction of the material at risk that is dispersed into the atmosphere with an aerodynamic diameter in excess of 10 microns; ***Non-respirable release fraction*** $= AF \times (1-RF)$. The final HotSpot respirable and non-respirable source terms are,

$$\textit{Respirable Source Term} = MAR \times DR \times LPF \times AF \times RF$$

$$\textit{Non-respirable Source Term} = MAR \times DR \times LPF \times AF \times (1-RF)$$

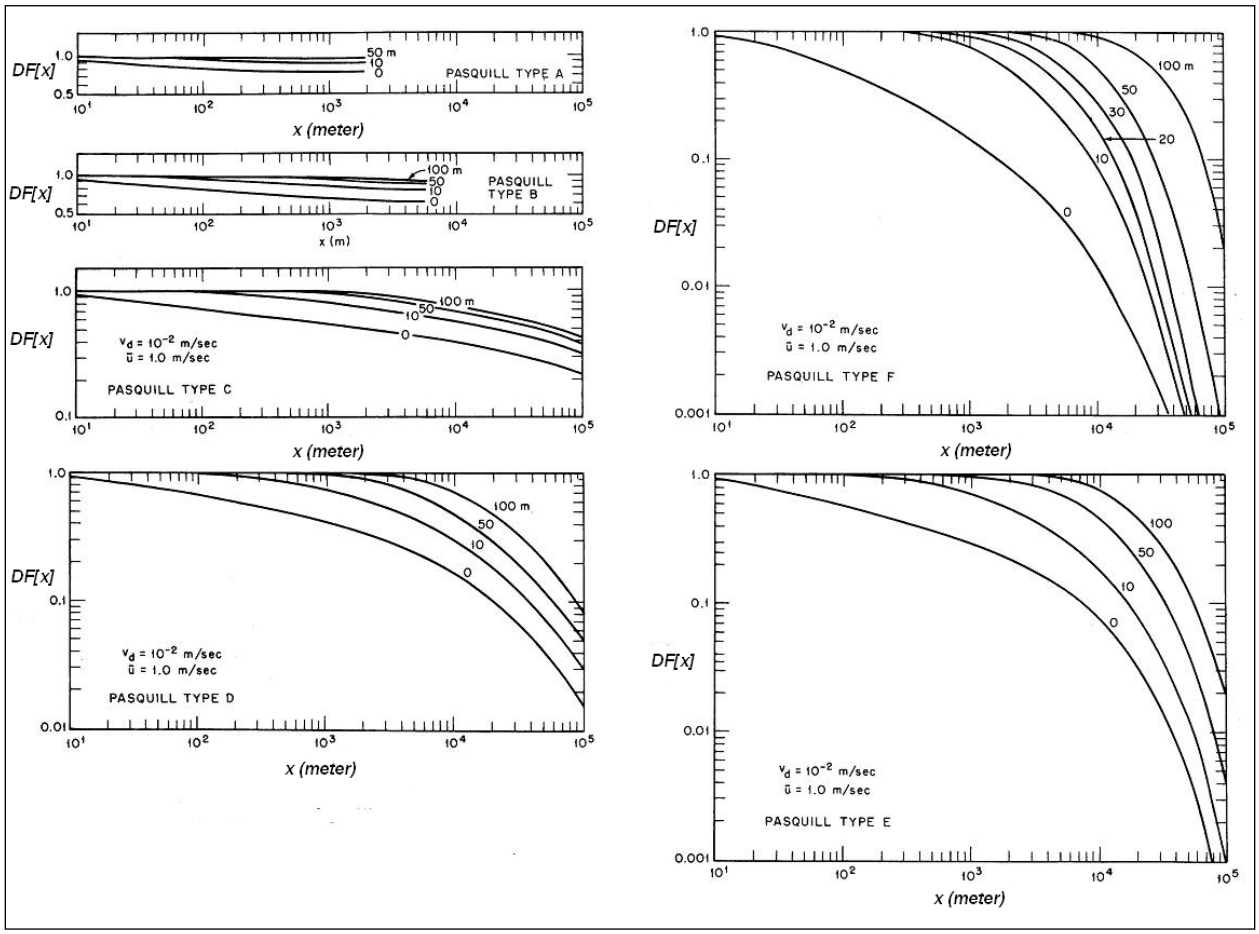
The source term in HotSpot is allowed to decrease with downwind distance. This plume depletion is accomplished by multiplying the original source term by a source-depletion factor [DF(x)]. The evaluation of this depletion factor has been described by Van der Hoven (1968).
The equation used in HotSpot is—

$$DF(x) = \left[\exp \int_0^x \frac{1}{\sigma_z(x) \exp\left[\frac{1}{2} \left(\frac{H}{\sigma_z(x)} \right)^2 \right]} dx \right]^{-\frac{v}{u}\sqrt{\frac{2}{\pi}}}$$

where:

DF(x)	= Depletion factor, (dimensionless)
x	= Downwind distance (m)
ν	= Deposition velocity (cm/s).
u	= Average wind speed at the effective release height (*H*), (m/s).
H	= Effective release height
$\sigma_z(x)$	= Standard deviation of the air concentration distribution in the vertical direction (z axis) for either Standard or City terrain, as applicable.

The following figure shows the Depletion Factor, (DF[x]), for a deposition velocity of 1 cm/s. Plume depletion is significant for stable conditions, and source release heights in proximity to the ground.



Plume Depletion Factor (DF[x]), for a wind speed of 1 m/s, a deposition velocity of 1 cm/s, for source heights from 0 to 100 meters above the ground for stability classes A-F, (Van der Hoven 1968).

Wet deposition

The theoretical treatment of wet deposition is often divided into rainout (scavenging within the rain cloud), and washout (scavenging below the rain cloud).In many practical applications and HotSpot, the two processes are simply combined and treated as a sinle removal process. If the wet deposition option is enabled in HotSpot, the effects of precipitation will be modeled by exponentially decreasing the radionuclide concentration as follows.

$$C'(x,y,z) = C(x,y,z)e^{-\Lambda x/u}$$

Where

C' = concentration (Ci/m^3)
Λ = washout coefficient (s^{-1})
u = mean wind speed (m/s)

Rain rate (mm/hr)	Rainout Coefficient (s^{-1})
0.5	0.0001
1	0.0002
5	0.0006
10	0.0010
15	0.0013
20	0.0017
25	0.0020

Typical Coefficient values

Ground Shine

Radioactive material deposited on the ground can continue to expose individuals via ground shine and/or resuspension. HotSpot dose conversion factors for ground shine assume a perfectly smooth plane.

Two optional Weathering Correction Factor (WCF) methodologies have been implemented in HotSpot.

1. WASH 1400 (NUREG-75/014)*

$$WCF = GRF\ [0.63\ e^{-(1.13\ t)} + 0.37\ e^{-(0.00748\ t)}]$$

Where

t = years post release
GRF = Ground roughness correction factor (default = 0.7)

Ref: WASH-1400, "Reactor Safety Guide," Appendix VI, "Calculation of Reactor Accident Consequences," (NRC 1975, p. 8-8, Equation VI 8-1 (also referred to as Equation VI E-1).

2. Likhtarev*

$$WCF = GRF\ [0.4\ e^{-(0.46\ t)} + 0.6\ e^{-(0.014\ t)}]$$

Where

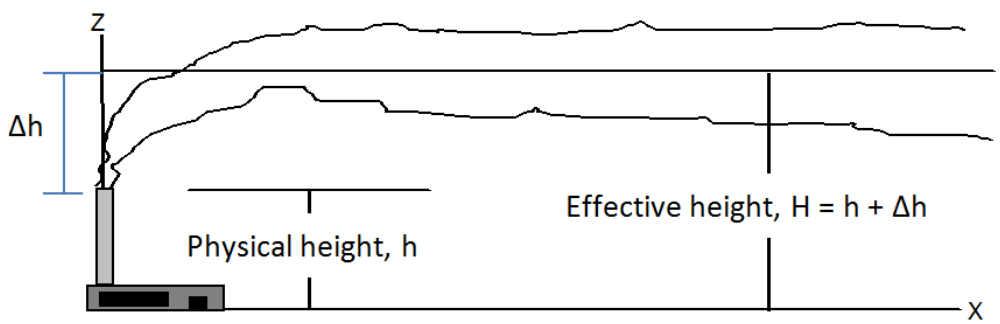
t = years after release
GRF = Ground roughness correction factor (dimensionless).

(default = 0.7)

Ref: Likhtarev I. A. et al., "Chernobyl Accident: Retrospective and Prospective Estimates of External Dose of the Population of Ukraine," Health Physics, March 2002, Volume 82, No. 3, pp. 290 -303, Equation 5.

*The Likhtarev weathering equation included a "hardwired" GRF value of 0.82. WASH-1400 did not include a GRF in the weathering factor, as it was a separate variable. In HotSpot, the GRF is a variable in both the WASH-1400 and Likhtarev implementations, with the default value being 0.7 for the "Nuclear Explosion" model. (Note, the default is 0.82 for non-fallout radionuclide ground shine). Users may change the GRF as needed.

Plume Rise



The actual plume height may not be the physical release height (e.g., the stack height). Plume rise can occur because of the velocity of the stack efflux, and the temperature differential between the stack effluent and the surrounding air. The rise of the plume results in an increase in the release height.

This effective increase in release height leads to lower concentrations at the ground level. If you cannot visually estimate or calculate the effective release height, we recommend you use the actual physical release height (the height of the stack) or use zero height for a ground-level release. This will almost always yield conservative estimates.

If the release is from a stack, and you know additional information on the stack discharge velocity, temperature, and stack diameter (e.g., if you are designing a new stack for a building), HotSpot can automatically calculate the effective release height.

HotSpot calculates both the momentum plume rise (Briggs, 1969) and the buoyant plume rise (Briggs, 1975) and chooses the greater of the two results. The recommended methodologies in the above two references are strictly followed.

Buoyant Plume Rise

The buoyancy flux, F, is:

$$F = r^2 g v \left(1 - \frac{T_a}{T_s}\right) \quad , (m^4 / s^3)$$

Where:

g	= gravitational acceleration (9.8 m/s^2)
v	= stack exit velocity (m/s)
r	= stack radius (m)
T_a	= ambient air temperature (deg K)
T_s	= stack effluent temperature (deg K)

The effective release height, H, due to buoyancy plume rise is determined as follows, (Briggs, 1975).

For atmospheric stability classifications A, B, C, and D, (Unstable to Neutral),

$$H = h + \frac{1.6\,(F)^{1/3}\,(X^*)^{2/3}}{u(H)}$$

Where:

h = physical stack height (m)
u(H) = wind speed at effective release height, (m/s)
X* = distance associated with final plume height ,(m)
(Munger, 1982)

$$X^* = 119\,F^{0.40} \qquad for\ F \geq 55$$

$$X^* = 49\,F^{0.625} \qquad for\ F < 55$$

For stability classifications E, F and G, (Stable),

and F,

for u(H) > 1.4 m/s

$$H = h + 2.6\left(\frac{F}{u(H)\,S}\right)^{1/3}$$

for u(H) ≤ 1.4 m/s

$$H = h + 5.0\,F^{1/4}\,S^{-3/8}$$

Where:

$S = 0.020\,g\,/\,T_a$ for stability class E

$S = 0.035\,g\,/\,T_a$ for stability class F

Momentum Plume Rise

The effective release height due to momentum plume rise is determined as follows, (Briggs, 1969).

For atmospheric stability classifications A, B, C and D, (Unstable to Neutral),

$$H = h + \frac{6\,v\,r}{u(h)}$$

Where:

v = stack exit velocity (m/s)

h = physical stack height (m)

r = stack radius (m)

$u(h)$ = wind speed at physical stack height, (m/s)

For stability classifications E and F,

$$H = h + 1.5\left(\frac{F}{u(H)}\right)^{1/3} S^{-1/6}$$

Where:

$$F = 0.25(2r\,v)^2 \quad , (m^4/s^2)$$

S = *0.000875* for stability class E
S = *0.00175* for stability class F

Fuel Fire Plume Rise

In the specific case of a fuel fire (e.g., an aircraft accident involving burning fuel), you have the option of having HotSpot calculate buoyant plume rise. The momentum plume rise for a fire in open terrain is minimal compared to the buoyancy rise and the former is assumed to be zero.
Two important parameters in the determination of plume rise are the heat emission rate (Q) and the buoyancy flux (F). For a fuel fire, the heat emission rate is,

$$Q = 3785\ V\ d\ H\ (1-f) / t$$

Where:
Q = heat emission rate (cal/s)
3785 = volume conversion factor (cm^3/gal)
V = volume of fuel (gallons) burned in time, Δt (s)
d = fuel density (g/cm^3)
H = heat of combustion (cal/g)
f = fraction of the heat of combustion that is radiated, (dimensionless)
t = duration of fuel fire (s)

Note: The volume of fuel consumed in time t determines the buoyant plume rise. Experiments have shown that burn rates, given in terms of pool depth rate, generally fall within the range of 1-5 mm per minute (Drysdale, 1985).

In HotSpot, it is assumed that 30% of the heat of combustion is radiated, fuel density is 0.81 gram/cm^3, and the default heat of combustion is 1.2E+04 cal/g. Therefore, the above equation becomes,

$$Q = 2.58E+07\ V / t$$

Given the heat emission rate, the buoyancy flux is,

$$F = a\,Q / \pi\, C\ \rho\, T \qquad ,(m^4 / s^3)$$

Where:

a	= gravitational acceleration (9.8 m/s^2)
C	= specific heat of effluent gases (0.24 cal/[g °K])
ρ	= density of air (1.29 E+03 g/m^3)
T	= ambient air temperature (°K)

Therefore,

$$F = 0.011\ Q / T$$

The effective release height due to buoyancy plume rise is determined as follows, (Briggs, 1975).

For atmospheric stability classifications A,B,C, and D,

$$H = 1.6\,(F)^{1/3}\ (X^*)^{2/3}\ /\ u(H/2)$$

Where:

H	= effective release height (m)
X*	= distance associated with final plume height ,(m) (Munger, 1982)
X*	= 119 $(F)^{0.40}$ for $F \geq 55$
X*	= 49 $(F)^{\wedge 0.625}$ for $F < 55$

For stability classifications E and F,

$$H = 2.6\,[F / u(2)\ S]^{1/3}$$

Where:

S	= 0.020 g / T_a	for stability class E
S	= 0.035 g / T_a	for stability class F

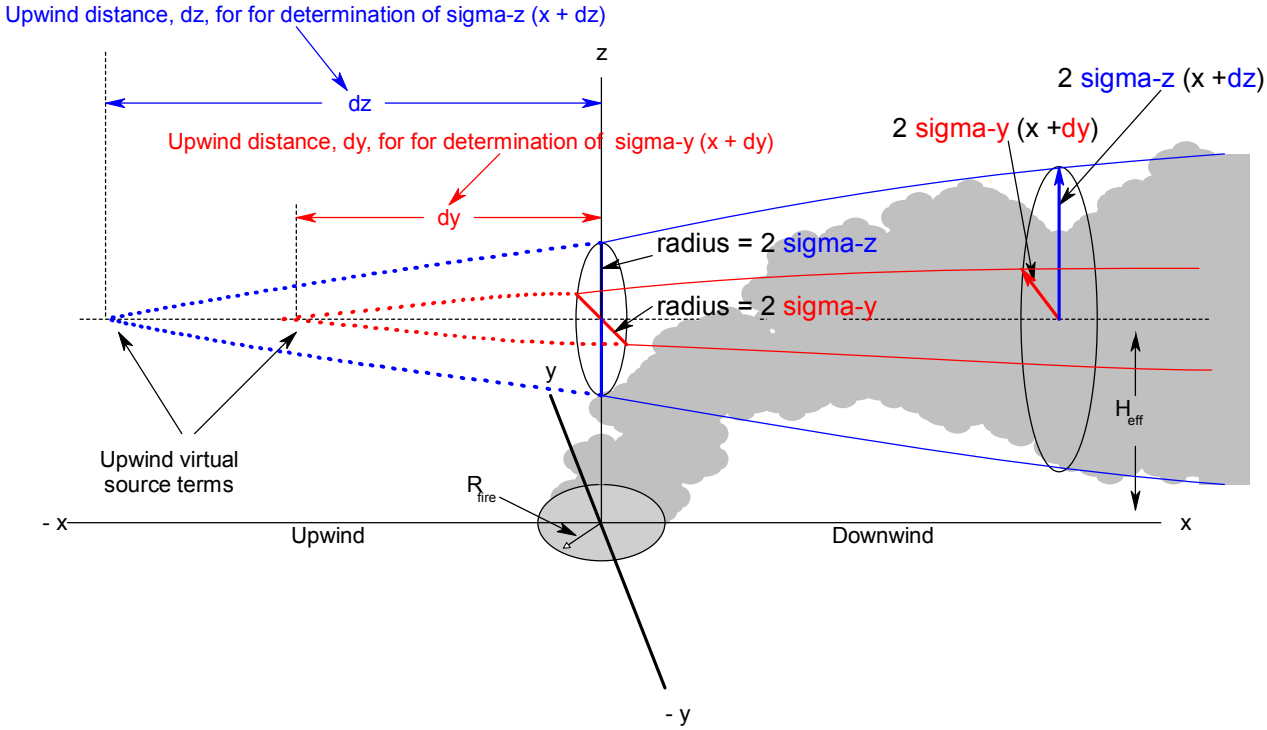
Briggs' plume rise equations for plume rise apply to the release from a stack with a negligible radius. The plume rise from a burning pool of fuel will be less than the Briggs value. For a burning pool of radius (R), the calculated plume rise is modified as follows, (Mills, 1987),

$$H = [\, H^3 + (R / \gamma)^3]^{1/3} - R / \gamma$$

Where:

H = Effective release height via the Briggs methodology, (m)
R = Radius of burning fuel pool, (m)
γ = entrainment coefficient for buoyant plume rise, 0.6, (dimensionless)

Two upwind virtual-term point sources are used to model the initial distribution of material in the vertical and horizontal dimensions. The virtual-term point sources are positioned at an upwind distance resulting in a sigma-y and sigma-z, above the origin, equal to 50% of the input pool radius.



sigma-*y* (*x*=0) = sigma-*z* (*x*=0) = 0.5 R

A single elevated area source models the initial distribution of material. This area source is represented by 2 separate upwind virtual source terms. Each of these two virtual source terms is associated with the horizontal (crosswind) and vertical components of the area source.

In the above figure, the two upwind virtual source terms for the area source are shown. The term "d_y" indicates the upwind "virtual" distance used for the horizontal (y), component, and the "d_z" is the upwind distance for the vertical (z), component. The virtual distances are determined by solving for the upwind distance that results in a σ_y or σ_z, directly over the fire. The applicable algorithms for σ_y and σ_z are used, where the value of σ_y and σ_z are defined below. This is an iterative process (see example below).

- σ_y directly above the fire equal to 50% of the fire radius. Note: 95% of the fire debris is contained within a radius equal to $2\sigma_y$, therefore σ_y = radius/2).
- σ_z directly above the fire equal to σ_y ,as defined above.
- A Sampling Time of 10 minutes is used for the determination of the upwind virtual source term distances (d_z and d_y).

Example of calculating an upwind virtual source distance, d_y

Determine the upwind distance (d_y), for a fire radius of 500 meters. The equation for σ_y is used to determine the upwind distance required to generate a σ_y equal to 50% of the fire radius (250 meters). This is an iterative process.

F stability
Radius = 500 meters
Standard Terrain

For "F" stability and "standard" terrain,

$$\sigma_y = \frac{0.04x}{\sqrt{1+0.0001x}} \qquad \text{Equation 1.}$$

where x = meters

We want to solve for x = d_y for σ_y = R/2 .
Letting σ_y = R/2 , and solving for d_y, in Equation 1,

$$d_y = \frac{(R/2)\sqrt{1+0.0001\,d_y}}{0.04}$$

Since d_Y is on both sides of the equation, HotSpot iterates until the difference in successive iterations is less than 0.1 %.

1st iteration, d_Y (1): note - The initial d_Y is 0 (zero).

$$d_y(1) = \frac{(500/2)\sqrt{1+0.0001\,(0)}}{0.04} = 6.25\times10^3 \quad meters$$

$$d_y(2) = \frac{(500/2)\sqrt{1+0.0001(6.25\times10^3)}}{0.04} = 7.97\times10^3 \quad meters$$

$$d_y(3) = \frac{(500/2)\sqrt{1+0.0001(7.97\times10^3)}}{0.04} = 8.38\times10^3 \quad meters$$

$$d_y(4) = \frac{(500/2)\sqrt{1+0.0001(8.38\times10^3)}}{0.04} = 8.47\times10^3 \quad meters$$

$$d_y(5) = \frac{(500/2)\sqrt{1+0.0001(8.47\times10^3)}}{0.04} = 8.49\times10^3 \quad meters$$

$$d_y(6) = \frac{(500/2)\sqrt{1+0.0001(8.49\times10^3)}}{0.04} = 8.50\times10^3 \quad meters$$

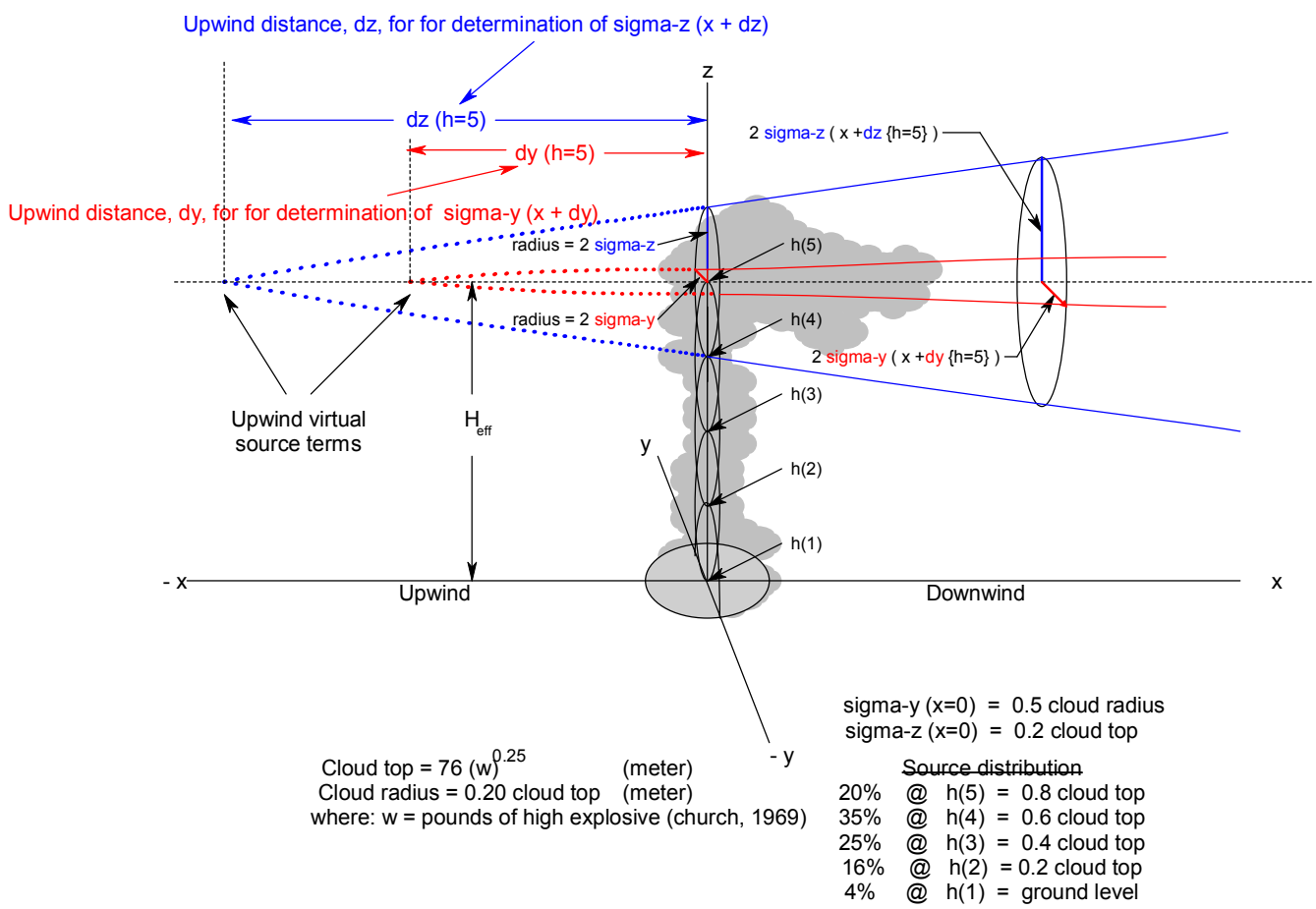
$$d_y(7) = \frac{(500/2)\sqrt{1+0.0001(8.50\times10^3)}}{0.04} = 8.50\times10^3 \quad meters$$

The new value is within 0.1 % of the previous value, so the iterative process is complete.

Therefore, the virtual upwind distance for the horizontal component of the area source *dy*, is 8.50×10^3 meters, or 8.50 km.

Explosion (Non-nuclear)

The release is partitioned as follows:



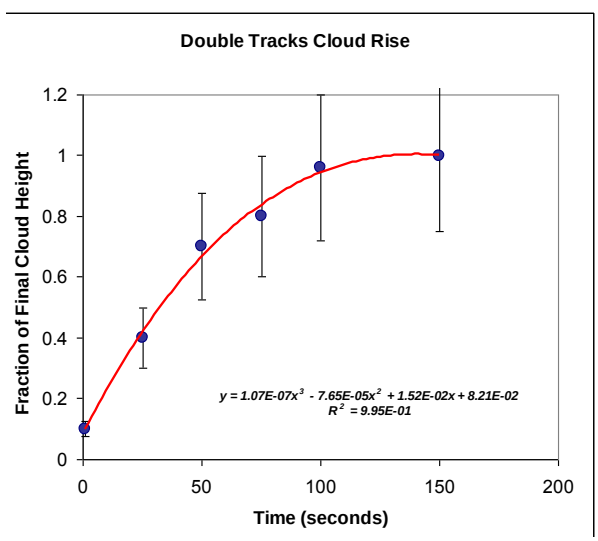
Five separate area sources model the initial distribution of material. Each of the 5 area sources [h(1) to h(5)] is represented by 2 separate upwind virtual source terms. These two virtual source terms are associated with either the horizontal (crosswind) or the vertical components of the area source.

In the above figure, the two upwind virtual source terms for the fifth [h(5)], area source are shown. The term "dy" indicates the upwind "virtual" distance used for the horizontal (y), component of h(5), and the "dz" is the upwind distance for the vertical (z), component of h(5). The virtual distances are determined by solving for the upwind distance that results in a σ_y or σ_z, over the point of explosion. The applicable algorithms for σ_y and σ_z are used (see atmospheric stability classification), where the

value of σ_y and σ_z are defined below. This is an iterative process (see Fuel Fire Example).

- σ_y over the explosion point equal to 50% of the cloud radius defined above component. (95% of the cloud debris is contained within a radius equal to $2\sigma_y$, therefore σ_y = radius/2).
- σ_z over the explosion point equal to 20% of the cloud top. If the equation for σ_z never approaches the 20% criterion (which is possible for very large explosions, and stability class E or F), the target σ_z value is forced to 20% of the cloud top.
- A Sampling Time of 10 minutes is used for the determination of the upwind virtual source term distances (d_z and d_y).

The initial explosive cloud top is based on the empirical correlation described by Church (1969). This correlation yields the stabilized cloud height based on the quantity of chemical explosive (TNT equivalent). The following figure shows the observed explosive cloud height as a function of time since detonation for the Double Tracks shot in the Roller Coaster series of experiments in 1963 at the Tonopah Test Range in Nevada (Foster et al., 1990). To better estimate the deposition and dose in proximity of the detonation, the virtual source term array height is reduced for plume arrival times less than the time required to attain a stabilized cloud height. In HotSpot, it is assumed that the cloud height requires 2 minutes to stabilize. For arrival times less than 120 seconds (arrival time [sec] = downwind distance [m] / surface wind speed [m/s]), the array height reduction factor is determined using the polynomial displayed in the figure below.

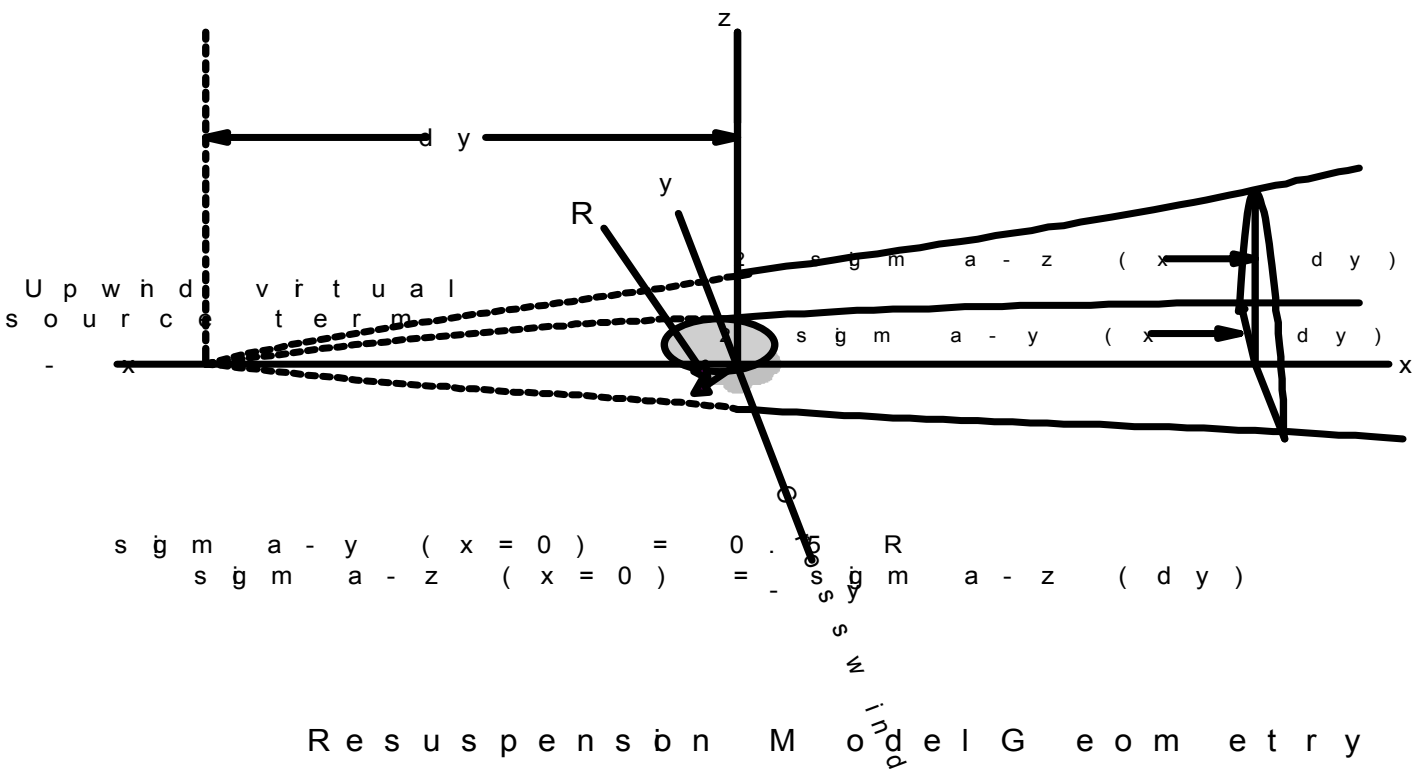


Explosive Release models (Plutonium Explosion, Uranium Explosion and General Explosion).

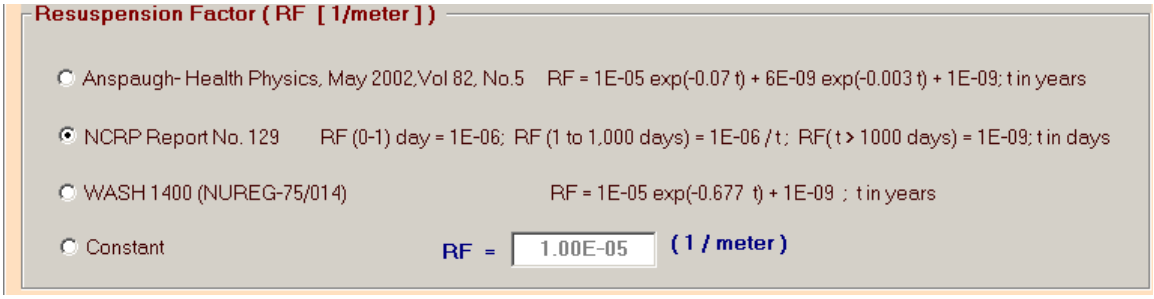
Table output includes Unmitigated blast effect distances for eardrum rupture and incapacitation (5 psi), Lung damage and complete incapacitation (10 psi) and onset of lethality. In addition (25 psi). the International Association of Bomb Technicians and Investigators (IABTI) safe distance is output.

Department of the Army Technical Manual TM-5-1300. (Also Department of the Navy Publication NAVFAC P-397, and Department of the Air Force Manual AFM 88-22). Structures to Resist the Effects of Accidental Explosions, June 1969.

Resuspension



An upwind virtual source term models the initial distribution of material. The virtual-term point source is positioned at an upwind distance that results in a σ_y, at the center of the contamination zone, equal to 50% of the input effective radius. The following four resuspension methodologies are available in the HotSpot resuspension model. The RF values are determined at a height in proximity to the ground surface (assumed to be a wind speed height of 2 meters).



For wind speeds in excess of 3 m/s, the RF is adjusted as follows,

$$RF(u) = RF \bullet (u/3)^2 \text{ ; for } u > 3 \text{ m/s}$$

Note: If the "Constant" RF option is selected, the wind speed is <u>not</u> adjusted.

The effective source term (Q_{eff}) associated with the observed ground contamination (G) is,

$$Q_{eff} = RF(u) \bullet G \bullet \pi \bullet \sigma_{y,\,origin} \bullet \sigma_{z,\,origin} \bullet u \quad , \quad (Ci/s)$$

where G = ground contamination (Ci/m^2).

The Gaussian standard deviations are evaluated at a distance equal to the distance from the origin to the upwind virtual source position. Q_{eff} can then be used in the Gaussian equation to estimate the radionuclide concentration downwind from the contamination.

Note: The resuspension factor is determined using measurements of the ground contamination (Ci/m^2), and the radionuclide air concentration (Ci/m^3) above the ground measurement location. The resuspension factor is then defined as the ratio of the air concentration to the ground concentration (1/m).

The 50-year committed effective dose equivalents are calculated per one-hour residence time. Therefore, an individual would be committed to the output dose for each one hour at the output location. The sampling time associated with resuspension is automatically changed from the normal 10-min values to 60-min values.

8. Ionizing Radiation Dose Terminology

Radiation Health Effects
People can receive radiation doses externally such as from an x-ray machine or internally through inhalation, ingestion, or by absorption through intact or broken skin, such as a wound.

The toxicity of a particular radioactive material and the associated internal organ doses are a function of:

- The radiation types and energies emitted by the radionuclide,
- The radiation types and energies emitted by any radioactive daughter products,
- The physical half-life of the radionuclide and any daughter radionuclides,
- The route of intake,
- The airborne particle size distribution and solubility of inhaled radionuclides, and
- The chemical and biokinetic characteristics of the element which determine the retention and distribution of the radionuclide within the body, and the rate and pathway(s) of excretion.

After radioactive materials are taken into the body, their subsequent distribution and retention depends upon the chemical nature of the material. Typically, some fraction of inhaled radioactive materials will be absorbed into the bloodstream and deposited in various organs. The degree of retention of radioactive materials also depends upon the chemical form of the material.

In radiation biology and radiation protection, the dose received from an intake of radioactive materials is a measure of the energy deposited per gram of tissue over a specified period of time. This dose (typically in units of rad or gray) can then be related to short-term biological damage, and longer-term risks of cancer induction.

When evaluating the potential for acute health effects from intakes of radioactive materials, it is important to appropriately define and understand the time pattern in which various organ systems receive the radiation doses. For acute health effects, the dose integration period of interest is likely to be relatively short, perhaps the first 30 to 60 days after intake.

In contrast, in occupational radiation protection, internal radiation doses are most commonly specified in terms of the total dose received over a 50-year period after intake. Thus, a committed organ dose-equivalent is the dose equivalent received by a specified organ over the entire 50-year period after intake. Also, because the occupational dose limits are based on limiting the overall risk of cancer, an effective dose (a sum of risk-weighted organ doses) is used as a regulatory limit.

Accordingly, it is generally *not* appropriate to use the commonly available 50-year committed effective dose equivalent dose conversion factors to predict acute health effects. In order to assess the likelihood and nature of acute health effects, dose conversion factors that represent the actual (cumulative) dose received as a function of the number of days after intake are needed.

Stochastic and Deterministic Effects

Health effects due to exposure to ionizing radiation are classified as either stochastic or deterministic (previously termed non-stochastic). Stochastic effects occur randomly and the probability of the effect occurring, rather than its severity, is assumed to be a linear function of dose without a threshold. Stochastic effects can result from injury to a single cell or small number of cells and the principal consequences are considered to be heritable effects and carcinogenic effects.

Deterministic effects result from the collective injury of substantial numbers of cells in affected tissues. The severity of the tissue injury is a function of the dose and it is assumed that a threshold dose, below which no injury occurs, exists. Deterministic effects were among the first observed biological effects of ionizing radiation and include cataract of the lens, non-malignant damage to the skin, cell depletion in the bone marrow causing hematological deficiencies, and gonadal cell damage leading to impairment of fertility. Deterministic effects may also be associated with damage to blood vessel or connective tissue elements. Protection limits for radiation workers are set at levels to prevent the occurrence of deterministic effects and to limit the stochastic effects to an acceptable level.

Acute Radiation Syndrome

Typically, the organ systems of interest for acute dose effects (for example, the various components of acute radiation sickness) are the red bone marrow, the small intestine, and the lungs. There is some uncertainty concerning what dose levels can be expected to cause acute health effects. However, in HotSpot, it is assumed that acute doses (for example, dose received in 1 day or less) of 300 rad, 1,500 rad, and 1,000 rad, to the red bone marrow, small-intestine wall, or lungs, respectively, will result in serious, and possibly lethal damage to those organ systems. For early doses (e.g., dose received in the first 30 days), the corresponding doses are of 600 rad, 1,500 rad, and 4,000 rad, to the red bone marrow, small-intestine wall, or lungs, respectively. The small-intestine wall value remains the same due to fast passage through the GI system. For more information, see Acute DCF.

Stochastic Health Effects (Cancer)

At lower doses, the health end-point of concern is the induction of cancer or leukemia. Estimates of cancer risks (morbidity and mortality) for internally deposited radionuclides are partly based on external exposures of human populations (for example, survivors of the Hiroshima and Nagasaki bombings), partly on animal studies, and to a lesser extent, on the very limited human experience with internal radiation doses (National Research Council, National Academy of Science, 1998).

Dose Rate

A dose of radiation can be delivered in a very short time period, for example, medical x rays in a fraction of a second, or over many months or years, such as exposure to natural background radiation. In addition, the dose may be received in a single exposure or may be fractionated into several exposure periods, such as in split-course cancer radiation therapy. Although there is no strict time boundary to distinguish between exposure time periods, HotSpot defines a total dose received in a time period of 30 days or less as an acute dose.

The early biological effects of acute, high-level doses appear within minutes to weeks, depending on the dose received and the fraction of the total body exposed to the radiation. An acute, high-level, localized dose can result in hair loss, skin burns, cataracts, and temporary or permanent sterility. An acute, high-level, whole-body dose (greater than 50 rad) can decrease the number of blood cells and cause diarrhea, vomiting, and fever. Very high doses (greater than 1,000 rad) can cause disorientation, coma, and death.

When evaluating the potential for acute health effects from intakes of radioactive materials, it is important to appropriately define the time pattern in which various organ systems receive the radiation doses. For acute health effects, the dose integration period of interest is likely to be relatively short, perhaps the first 30 to 60 days after intake. In HotSpot, we use the 30-day time integration period.

In contrast, in occupational radiation protection, internal radiation doses are most commonly specified in terms of the total dose received over a 50-year period after intake. Thus, a committed organ dose equivalent is the dose equivalent received by a specified organ over the entire 50-year period after intake. Also, since the occupational dose limits are based on limiting the overall risk of cancer, an effective dose (a sum of risk-weighted organ doses) is used as a regulatory limit.

Accordingly, it is generally *not* appropriate to use the commonly available 50-year committed effective dose equivalent dose conversion factors to predict acute health effects. In order to assess the likelihood and nature of short-term health effects, dose conversion factors that represent the actual (cumulative) dose received as a function of the number of days after intake are needed.

Doses that are delivered over an extended time period are likely to be less effective at causing damage. For example, an acute dose of 300 rads to the bone marrow would be much more likely to result in lethality than the same dose received over a period of several months. Similarly, a dose of 300 rads to the bone marrow received relatively uniformly over 50 years would not produce any acute health effects, in contrast to the same dose received within a period of 1 day.

Type of Radiation

It is well known that different types of radiation cause different amounts of biological damage per unit of absorbed dose. Types of radiation that directly or indirectly result in high rates of energy loss per unit path length of tissue are more effective in producing biological effects than radiation with lower rates of energy loss per path length. The quantity termed linear energy transfer (LET) is used to quantify this energy loss. For example, gamma and x rays have LET values of a few keV/um while alpha particles associated with the decay of Pu^{239} or Am^{241} have LET values of approximately 150 keV/um.

In order to calculate the equivalent biological response from various types of radiation, the concept of a dose equivalent (H), is used for radiation protection criteria (occupational dose limits, etc).

$$H = Q \cdot D$$

where:

H = dose equivalent, rem
D = absorbed dose, rad
Q = quality factor

The quality factor is an LET-dependent factor by which absorbed doses are multiplied to account for the varying effectiveness of different types of radiation. The Q values are used for radiation protection and derived primarily from relative biological effectiveness (RBE) data for carcinogenesis and mutagenesis. Q values are estimates of the probable effectiveness of the various types of radiation and are not experimentally determined. RBE values are experimentally derived values based on the specific biological system under study. The RBE is the ratio of an absorbed dose of radiation for a particular type of radiation to the absorbed dose of a reference radiation required to produce an identical biological effect in an organism or tissue. If a neutron dose of 100 rad produced the same effect as a 200 rad dose of 250 kVp x rays, the RBE of the neutrons would be 2.

The Q values do not apply to early radiation effects or late non-cancerous organ effects. HotSpot also addresses the early effects of acute radiation dose, and uses a similar unit of dose equivalent (rad-equivalent), to denote that the rad dose has been modified by an RBE value associated with acute/early deterministic effects.

$$Hr = RBE_d \cdot D$$

where:

Hr =	RBE-weighted absorbed dose, rad-equivalent
D =	absorbed dose, rad
RBE_d =	Deterministic Effects Relative Biological Effectiveness, dimensionless (described below)

The FRMAC, NARAC, and HotSpot use this dose equivalent methodology for determining the RBE-weighted absorbed dose to the lungs from inhalation of high-LET radiation, such as alpha particles associated with the decay of Pu-239 or Am-241). For example, the LD50/60 for humans for lung dose is 1000 rad of low LET radiation. If the lung dose was due to alpha particles (high LET), the LD50/60 would be 143 rad (1000 rad-equivalent dose) due to the increased effectiveness of the alpha particles in causing this particular acute exposure deterministic effect (assuming an RBE of 7). The rad-equivalent notation indicates that the dose has been modified by the RBE to account for the deterministic effects of high LET radiation. In HotSpot, the RBE for SI wall always remains 1.0 for the high LET component (selected RBE for High-LET radiation is applied to the Lung and Red marrow).

Deterministic Effect RBE_d Values for Internally Deposited Alpha Emitters and External Neutron Exposure

This section discusses the recommended Relative Biological Effectiveness (RBE_d) values for estimating the probability of acute and early deterministic health effects for the alpha dose component of inhaled or ingested radioactive material and external neutron exposure. The lung and red marrow represent the target organs for early fatality following uptake of radioactive material. The red marrow is the primary target for early fatality following external neutron exposure. These RBE_d values will be used by LLNL/NARAC (in the LODI, NUKE, and HotSpot codes; see http://narac.llnl.gov), and SNL (in the NUKE and Turbo FRMAC codes) for evaluation of deterministic health effects. .

Stochastic Effects Relative Biological Effectiveness, (RBE_s) and Quality Factor (Q)

Committed effective dose equivalent (CEDE) dose conversion factors (DCF) make use of quality factors or alternately the radiation weighting factors (w_R), and tissue weighting factors (w_T), to account for the higher effectiveness of certain forms of radiation and to account for the variable sensitivities of various tissues to cancer induction. The quality factor weights the absorbed dose for the RBE_s of the radiation producing the absorbed dose. The quality factor was chosen to encompass appropriate values of the RBE_s of the radiation, independent of the organ or tissue, or the biological endpoint under consideration (ref 1. ICRU, 1993). The quality factor applies primarily to low-dose radiation exposures and does not hold linearly with increasing levels of absorbed dose. Q values are chosen by committee and are associated with the linear energy transfer (LET), of the radiation in water.

The CEDE DCF values should not be used for estimating the probability of acute and early deterministic health effects, as these values include Q values specific to stochastic effects. The tissue weighting factors used in these DCFs reflect organ sensitivities to cancer induction, not specific deterministic effects. A Q of 20 Sv/Gy is normally used for the alpha component of the absorbed dose in the calculation of the CEDE for internal occupational exposure. The Q value for external exposure to neutrons depends on the neutron energy and has a range of 5 to 10 Sv/Gy.

Deterministic Effects Relative Biological Effectiveness, (RBE_d)

To evaluate possible deterministic effects, the RBE_d for the specific radiation type and target organ or tissue is required. In the particular case of internally deposited radioactive material, the principal high LET radiation is the alpha particle, and the RBE_d is required to evaluate deterministic health effects. For external neutron exposure, the RBE_d for the red marrow is required.

A review of current literature revealed that for acute and early effects, an RBE_d of 7 for the lung and an RBE_d of 2 for the red marrow are appropriate for high-LET radiation, such as alpha particles (ref 2. IAEA-TECDOC-1432, 2005, and ref 3. NUREG/CR-4214, 1993). The IAEA document also recommends an RBE_d of 3 for external neutron dose to the red marrow.

The following Table is from IAEA-TECDOC-1432, page 99, lists the recommended RBE_d values for the lung and red marrow.

Relative Biological Effectiveness of Radiation for Severe Deterministic Health Effects

Radiation	Lungs	Red marrow
Photons (gamma- and X-rays)	1	1
Electrons and positrons, including β^- and β^+ particles	1	1
Neutrons	3	3
Alpha particles	7	2

The following Figure is from NUREG/CR-4214 Fig. 2A.1, page 24, and also recommends the use of an RBE_d of 7 and 2, for deterministic effects in the lung and red marrow, respectively, for the alpha dose component due to inhaled or ingested radioactive material.

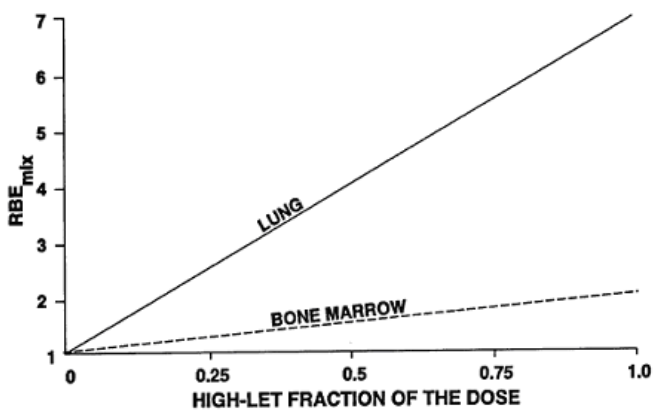


Figure 2A.1 Predicted linear relationships between RBE_{mix} for deterministic effects and the fractio of the total dose due to high-LET alpha radiation, for combined, high dose-rate exposu of the lung or bone marrow to alpha and low-LET beta and gamma radiations. It wa assumed that beta and gamma radiations were equally effective for the same pattern irradiation. The slope of the organ-specific curve is equal to one less than the RBE f the alpha radiation. For deterministic effects in lung, a value of 7 was used for RBE for bone marrow, a value of 2 was used.

K. F. Eckerman and R. W. Leggett (ref. 4, DCFPAK Version 2.2) of Oak Ridge National Laboratory provided the acute DCF values (Gy/Bq), used for evaluating deterministic effects. These DCF data contain the Gy/Bq for both high and low LET radiations for various target organs and tissue. At the present time, a 30-day time integration period is used by both the IAEA and NRC for estimating the probability of early deterministic effects. The unit of the 30-day committed RBE-weighted absorbed dose to the lung or red marrow is the Gy-equivalent (rad-equivalent, etc.). The RBE-weighted DCF is defined as follows,

$$\mathbf{DCF_{RBE}\ (Gy\text{-}equivalent\ /Bq) = DCF\ (low\ LET\text{-}Gy/Bq) + RBE_d * DCF\ (high\ LET\text{-}Gy/Bq)}$$

Based on the above recommendations, HotSpot will use an RBE_d of 7 for the lung and an RBE_d of 2 for the red marrow. These values will be applied to the high LET values for calculating early organ dose DCFs using ORNL's DCFPAK 2.2 data files. All other organs were assigned an RBE_d value of 1.

A default RBE_d of 3 will be used in HotSpot for calculation of the red marrow neutron dose from nuclear explosion prompt neutrons.

References

1). International Commission on Radiation Units Measurements, ―Quantities and Units in Radiation Protection Dosimetry." Bethesda MD, ICRU, Report Number 51, 1993.

2). International Atomic Energy Agency, ―Development of an extended framework for emergency response criteria." IAEA-TECDOC-1432, January 2005.

3). NUREG/CR-4214, Rev. 1, Part II, Addendum 2, LMF-136, ―Health Effects Models for Nuclear Power Plant Accident Consequence Analysis," May, 1993.

4). Eckerman, K. F., Leggett, R. W. Personal communication, DCFPAK 2.2: Updated Dose and Risk Coefficient Database for Rapid Assessment of Radiation Doses, 2010.

Dose Terminology

Radioactive materials emit one or more forms of energy that can have harmful effects on the human body. The degree of injury to the body is determined by the type, amount, and location of the absorbed energy. *Radiation dose* is a general term that can have different,

but related, definitions. Radiation dose can refer to the actual quantity of energy (independent of the form) that has been absorbed by some material, such as human tissue. However it can also refer to a quantity that accounts for the amount of biological damage caused by the particular kind of energy being absorbed. The distinction between these meanings is made by using one of the following terms:

Absorbed Dose: This is a quantity of energy that has actually been absorbed into the material. It is independent of the type of energy and does not reflect the biological effects on the material. The unit for the absorbed dose is the rad or gray (SI unit).

Dose Equivalent**:** Each type of ionizing radiation may have a different ability to cause biological damage. Therefore equal absorbed doses from two different types of radiation may produce very different affects on the organs of the human body. A "quality factor" (unique to each type of energy) is used to convert absorbed doses to a quantity, the dose equivalent, which can be directly compared with other converted absorbed doses (for the same organ), and whose magnitude is proportional to the amount of potential biological damage caused by the absorbed dose. Dose equivalents are measured with the unit of rem or sievert (SI unit), and apply to a specific organ or tissue of the body. There are a few additional terms that can modify this meaning of dose equivalent:

*Effective Dose Equivalent (EDE)***:** Dose equivalent to the individual organs can be combined (through the use of tissue weighting factors) to calculate the sum of the dose equivalents as applied over the entire body. When this is done the resulting dose is the effective dose equivalent.

Committed Dose Equivalent (CDE): Radioactive material that is retained by the body (through inhalation and retention in the lungs, for example) can continue to produce a significant dose over the remainder of the individual's life. Once the material is retained, or committed to the individual, there is little that can be done to avoid the future dose. The committed dose equivalent is the dose equivalent that will be delivered to a particular tissue or organ (lung, liver, thyroid, etc.) of the body over a specific time interval, for example, the next 50 years after intake of the material. In HotSpot, the 50-Year committed dose equivalent is output.

50-Year Committed Dose Equivalent: The *unweighted* 50-year committed dose equivalent (rem, Sv), received by an individual's target organ(s) due to remaining at the specified location throughout the entire radioactive material release The dose is calculated by multiplying the integrated air concentration by the dose conversion factor (DCF) contained in the HotSpot Library:

$$\text{50-year CDE (T)} = \text{Chi ([Ci-s]/[m}^3\text{])} \times \text{DCF(T) ([rem-m}^3\text{]/[Ci-s]), rem}$$

where:

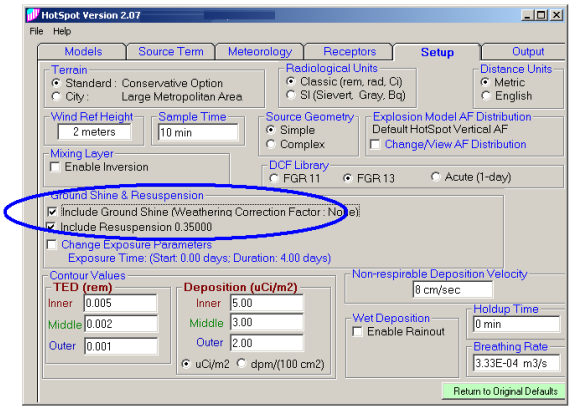
T is the applicable target organ (for example, lung, and *DCF*(*T*) is the dose conversion factor for the target organ).

Committed Effective Dose Equivalent: Sum of the CDE to the individual organs and tissues (using the appropriate weighting factors) to calculate a combined dose as applied over the entire body.

> 50-Year Committed Effective Dose Equivalent (CEDE): The 50-year committed effective dose equivalent (rem, Sv) received by an individual due to remaining at the specified location throughout the entire radioactive material release. This value is the sum of the 50-year committed dose equivalents to various tissues in the body, each multiplied by the appropriate weighting factor.

Total Effective Dose Equivalent (TEDE): The radioactive material producing the dose equivalent may be external to the body (for example when the material is on the ground or is in the air surrounding the individual), or internal (as when the individual has ingested, or inhaled and retained the material). The Total Effective Dose Equivalent (TEDE) is the sum of the EDE (caused by the external material) and the CEDE (caused by the internal material). The TEDE is the most complete expression of the combined dose from all applicable delivery pathways.

> CEDE vs. TEDE**.** The HotSpot output dose values, due to plume passage, have always included the cloud submersion effective dose equivalent (EDE) with the inhalation committed effective dose equivalent (CEDE). Starting with HotSpot version 2.06, the label, *CEDE* was replaced with *TEDE* (total effective dose equivalent) to reflect the cloud submersion component.
>
> *TEDE = CEDE (inhalation) + EDE (submersion)*
>
> If ***Include Ground Shine*** and/or ***Include Resuspension*** are checked under the Setup tab, the EDE from ground shine and/or resuspension will be included in the TEDE value.



TEDE = CEDE (inhalation) + EDE (submersion) + EDE (ground shine) + EDE (resuspension)

<u>RBE-weighted Absorbed Dose</u>**:** Each type of ionizing radiation may cause different types of biological damage. Therefore, equal absorbed doses from two different types of radiation may produce very different affects on body organs. The RBE-weighted

absorbed dose is the product of the absorbed dose in an organ or tissue and the relative biological effectiveness (RBE) of each radiation component. The RBE-weighted absorbed dose is intended to account for differences in RBE in producing deterministic effects associated with acute (dose received in the first day), or early (dose received in the first 30 days) exposure. The unit for the RBE-weighted absorbed dose is the rad-equivalent or gray-equivalent (SI unit).

Committed RBE-weighted Absorbed Dose**:** Radioactive material that is retained by the body (through inhalation and retention in the lungs, for example) can continue to produce a significant dose over the remainder of the individual's life. Once the material is retained, or committed to the individual, there is little that can be done to avoid the future dose. The Committed RBE-weighted Absorbed Dose is the RBE-weighted Absorbed Dose that will be delivered to a particular tissue or organ (lung, red marrow, SI wall, etc.) of the body over a specific time interval, e.g., the next 30-days after intake of the material.

*1-day Committed RBE-weighted Absorbed Dose***:** The 1-day committed RBE-weighted absorbed dose (rad-equivalent, Gy-equivalent) received by an individual's target organ(s) due to remaining at the specified location throughout the entire radioactive material release

4-day Committed RBE-weighted Absorbed Dose: The 4-day committed RBE-weighted absorbed dose (rad-equivalent,Gy-equivalent) received by an individual's target organ(s) due to remaining at the specified location throughout the entire radioactive material release

30-day Committed RBE-weighted Absorbed Dose: The 30-day committed RBE-weighted absorbed dose (rad-equivalent, Gy-equivalent), received by an individual's target organ(s) due to remaining at the specified location throughout the entire radioactive material release.

Total RBE-weighted Organ Dose (TOD): The radioactive material producing the total organ dose may be external to the body, such as when the material is on the ground or is in the air surrounding the individual, or internal, such as when the individual has ingested or inhaled and retained the material. The Total RBE-weighted organ dose is the sum of the organ dose (caused by the external material) and the 30-day committed RBE-weighted absorbed dose (caused by the internal material). The TOD is the most complete expression of the combined dose from all applicable delivery pathways to be used for assessing potential acute and early deterministic health effects:

TOD = Committed RBE-weighted Absorbed Dose (inhalation)
+ RBE-weighted Absorbed Dose (cloud shine)
+ RBE-weighted Absorbed Dose (ground shine)
+ RBE-weighted Absorbed Dose (resuspension)

The new terminology for ICRP60+ is shown in the following Table

Old ICRP 26/30 (HotSpot FGR-11 Option)	New ICRP 60/68 (HotSpot FGR-13 Option)
Committed effective dose equivalent	Committed effective dose
Committed dose equivalent	Committed equivalent dose
Cumulative total effective dose equivalent	Cumulative total effective dose
Dose equivalent	Equivalent dose
Effective dose equivalent	Effective dose
Quality factor	Radiation weighting factor
Weighting factor	Tissue weighting factor
Total effective dose equivalent	Total effective dose

Dose Conversion Factors

HotSpot uses the radiation dosimetry methodologies recommended by the International Commission on Radiological Protection (ICRP). These methodologies are summarized in Federal Guidance Report No. 11 (FGR-11), Federal Guidance Report No. 12 (FGR-12), and Federal Guidance Report No. 13 (FGR-13). FGR-11 provides dose coefficients in the form of 50-year integrated dose equivalents for acute inhalation of radionuclides and is based on the biokinetic and dosimetric models of ICRP Publication 30 (1979, 1980, 1981, 1988). FGR-12 provides dose coefficients in the form of dose per unit time-integrated exposure for external exposure to radionuclides in air, water, or soil. FGR-13 provides dose coefficients using the new ICRP-66 lung model and ICRP series 60/70 methodologies

Summary

HotSpot FGR-11 Option

- Old Lung Model (ICRP-30)
- ICRP Publication 26 (1977) Tissue Weighting Factors
- Absorption Types D, W, Y.

HotSpot FGR-13 Option

- New Lung Model (ICRP-66)
- ICRP Publication 60 (1991) Tissue Weighting Factors
- Absorption Types F, M, S.

9. Glossary

The following are brief descriptions for many of the terms used in the HotSpot program. More detailed definitions can be found in the program's online help.

Absorbed Dose—The amount of energy imparted by ionizing radiation to a unit mass of absorbing material. The SI unit is the centigray (Gy), and the English unit is the rad. (1 Gy = 100 rad; 1 cGy = 1 rad.; see Radiation Dose).

Acute Radiation Exposure—A dose of ionizing radiation delivered in a short period of time, from seconds to days.

Aerodynamic Diameter—The diameter of a unit density (1 g/cm3) sphere that has the same settling velocity as the actual particle.

Aerosol—System of colloidal (finely divided) particles dispersed in gas (for example, fog or smoke). Generally, aerosol refers to dispersed solid or liquid matter in a gaseous medium.

Airborne Fraction—The fraction of the total quantity of material involved in a fire, explosion, etc., that is released to the atmosphere.

Atmosphere—The gaseous envelope surrounding the earth. The chief constituents of the atmosphere are nitrogen and oxygen, which make up 75% and 23%, respectively, of its total mass. In addition, there are very small quantities of argon, neon, helium, and other inert gases, methane, nitrogen dioxide, and hydrogen, as well as small, variable amounts of water vapor, carbon dioxide, and, in the upper atmosphere, ozone.

Atmospheric Stability Classification—Meteorologists distinguish several states of the atmospheric surface layer—unstable, neutral, and stable. These categories refer to how a parcel of air reacts when displaced adiabatically in the vertical direction.

Chronic Radiation Exposure—A dose of ionizing radiation that is spread out over an extended period of time, usually months to years.

Committed Dose Equivalent— See Section 8.

Committed Effective Dose Equivalent (CEDE)—See Appendix C.

Compass Direction—The horizontal direction expressed as an angular distance measured clockwise from compass north.

Compass North—The uncorrected direction indicated by the north-seeking end of a compass needle. (See also Magnetic North.)

Contamination—The deposit and/or absorption of radioactive material or biological or chemical agents on and by structures, areas, personnel, or objects. (See also Induced Radiation; Residual Radiation.)

Coordinated Universal Time—Specifies that the associated time is equivalent to the mean solar time at the prime meridian (0 degrees longitude). Formally known as Greenwich Mean Time or GMT. Also referred to as Z or Zulu time.

Coordinates—Linear or angular quantities which designate the position that a point occupies in a given reference frame or system. Also used as a general term to designate the particular kind of reference frame or system such as plane rectangular coordinates or spherical co-ordinates. (See also Geographic Co-ordinates; GEOREF.)

Deposition Velocity—(cm/s). The ratio of the observed deposition flux (in units of uCi/(cm^2-s), for example) and the observed air concentration near the ground surface (uCi /cm^3).

Derived Intervention Level—Developed by the U.S. Food and Drug Administration (FDA 1998), these levels specify the concentration of radioactive materials in food that, if ingested in a manner consistent with a set of assumptions used by the FDA, will produce a committed dose equivalent (see Radiation Dose) to an individual that exceeds the ingestion Protective Action Guides.

Derived Response Level—Relates a Protection Action Guide (PAG) to a concentration of radioactive material at which the PAG will be exceeded, using a set of selected assumptions. DRLs are typically used when employing the PAGs for ingestion of contaminated foods in order to relate the Food and Drug Administration's Derived Intervention Levels to specific surface deposition concentrations for a particular radioactive material and ingestion pathway (see Protective Action Guides: Intermediate Phase PAGs: Ingestion PAGs).

Dose Equivalent—See Section 8.

Dose Rate Contour Line—A line on a map, diagram, or overlay joining all points at which the radiation dose rate at a given time is the same. Radiation dose levels within the contour are higher than the contour line value, and radiation dose levels outside the contour are lower than the contour value.

Effective Dose Equivalent (EDE)—See See Section 8.

EPA Action Guides—The Environmental Protection Agency (EPA) has established Protective Action Guides (PAGs) to guide actions (e.g., evacuation) in the event of an environmental accident.

FIDLER Calibration—The FIDLER program is used to calibrate a FIDLER (Field Instrument for the Detection of Low-Energy Radiation) for measurement of plutonium

contamination on the ground. However, the program can be applied to any instrument suitable for measuring external radiation levels and non-plutonium mixtures, e.g., using a Geiger-Mueller instrument for the measurement of 137Cs ground contamination.

Fireball—The luminous sphere of hot gases formed a few millionths of a second (micro-seconds), after detonation of a nuclear weapon.

Fission—The process whereby the nucleus of a heavy element splits into (generally) two nuclei of lighter elements, with the release of substantial amounts of energy.

Fission Products—A general term for the complex mixture of substances produced as a result of nuclear fission.

Flash-to-Bang Time—The time period that extends form the beginning of radiation light until the sound of the nuclear detonation. The measured flash-to-bang time is used in connection with the estimation of the yield that has been detonated.

Fusion—The process whereby the nuclei of light elements combines to form the nucleus of a heavier element, with the release of tremendous amounts of energy.

Geographic Coordinates—The quantities of latitude and longitude that define the position of a point on the surface of the earth with respect to the reference spheroid. (See also Coordinates.)

IMAAC— The National Response Framework designates the Interagency Modeling and Atmospheric Assessment Center (IMAAC) as the single Federal source of airborne hazards predictions during incidents requiring federal coordination. IMAAC is responsible for producing and disseminating predictions of the effects from hazardous chemical, biological, and radiological releases.

Induced Radiation—Radiation produced as a result of exposure to radioactive materials, particularly the capture of neutrons. (See also Contamination; Residual Radiation).

Inversion Layer Height (Mixing Layer Height)—Elevation at which the temperature gradient is inverted (temperature begins to increase with increasing altitude). The inversion layer acts like a blanket that limits the vertical mixing of the released radioactive material. The region below the inversion layer is also referred to as the mixing layer.

Ionizing Radiation—Electromagnetic radiation (gamma, x rays), or particulate radiation (alpha, beta, neutrons, etc.), capable of producing ions (directly or indirectly) as the radiation passes through matter.

Isodose Rate Line—See Dose Rate Contour Line.

Lethal Dose 50/60— The ionizing radiation dose to the whole body which would be fatal to 50 percent of the exposed personnel in a time period of 60 days.

Maximum Dose Distance—The location associated with the maximum dose received by an individual remaining at the stated location throughout the radioactive material release.

Military Grid—Two sets of parallel lines intersecting at right angles and forming squares; the grid is superimposed on maps, charts, and other similar representations of the surface of the earth in an accurate and consistent manner to permit identification of ground locations with respect to other locations and the computation of direction and distance to other points.

Military Grid Reference System (MGRS)—A system that uses a standard-scaled grid square, based on a point of origin on a map projection of the surface of the earth in an accurate and consistent manner to permit either position referencing or the computation of direction and distance between grid positions.

Mixing Layer Height—See Inversion Layer.

Mixture Library—A list of radionuclides available in HotSpot. A custom radionuclide mixture can be created for use with the general dispersion models in HotSpot (General Plume, General Fire, General Resuspension).

NARAC-- National Atmospheric Release Advisory Center . The National Atmospheric Release Advisory Center, NARAC, provides tools and services that map the probable spread of hazardous material accidentally or intentionally released into the atmosphere. NARAC provides atmospheric plume predictions in time for an emergency manager to decide if taking protective action is necessary to protect the health and safety of people in affected areas. For additional information,

Web: http://narac.llnl.gov

Natural Background Radiation—Ionizing radiation that comes primarily from cosmic rays, radioactive material in the earth (such as uranium md thorium), food (such as potassium-40), and radon gas. The average annual radiation dose from natural background sources is 0.3 rem or 3 mSv. Medical procedures such as x rays and diagnostic test using radioactive material contribute an additional radiation dose of approximately 0.06 rem per year (0.6 mSv).

Neutron Induced Activity—Radioactivity induced in the ground or an object as a result of direct irradiation by neutrons.

Non-ionizing Radiation—Non-ionizing radiation does not have enough energy to remove electrons from neighboring atoms. Examples of non-ionizing radiation are radio waves, lasers, microwaves, and visible light.

Nuclear Weapon—A complete assembly (i.e. implosion type, gun type or thermonuclear type) in its intended ultimate configuration which, upon completion of the prescribed arming, fusing and firing sequence, is capable of producing the intended nuclear reaction and release of energy.

Nuclear Yield—See Yield

Plutonium—A heavy metal such as lead or uranium. Plutonium is radioactive and emits primarily alpha radiation.

Prompt Thermal Radiation—The radiation emitted from the heated air of the fireball within the first minute (or less), following the nuclear detonation. For burst altitudes below approximately 100,000 feet, roughly 35 to 45 percent of the total energy yield of the explosion is emitted as prompt thermal radiation. The actual percent of the total energy that appears as prompt thermal radiation depends on the burst altitude, total yield, and specific characteristics of the nuclear device. In HotSpot, the effective thermal partition is 18% for a surface burst fission device. The energy of a nuclear explosion is partitioned as follows,

- 50% Blast and ground shock
- 35% Thermal Radiation (**Effective partition = 18% for surface burst**)
- 15% Ionizing Radiation
  - 5% Prompt (first minute)
  - 10% Delayed (minutes to years)

Protective Action Guides (PAGs)— The projected dose, from an accidental release of radioactive material, where specific actions to reduce or avoid dose are warranted.

Quality Factor (Q)— The principal modifying factor that represents the biological effectiveness of different radiation types with respect to induction of stochastic effects. It is used to calculate the dose equivalent from the absorbed dose. The absorbed dose, expressed in rad or Gy, is multiplied by the appropriate quality factor to obtain the dose equivalent

Radiation Dose—See Section 8..

Receptor Height—Height above the ground from which the output dose data are determined. HotSpot default value is 1.5 meter.

Relative Biological Effectiveness (RBE)-- The RBE of a given type of ionizing radiation is a factor used to compare the biological effectiveness of absorbed radiation doses (i.e., rads) due to one type of ionizing radiation with that of other types of ionizing radiation; more specifically, it is the experimentally determined ratio of an absorbed dose of a radiation in question to the absorbed dose of a reference radiation required to produce an identical biological effect in a particular experimental organism or tissue. (See section 8).

Residual Radiation—Nuclear radiation caused by fallout, radioactive material dispersed artificially, or irradiation which results from a nuclear explosion and persists longer than one minute after burst.

Respirable Fraction (RF)—The fraction of the airborne material that is respirable (less than 10 microns aerodynamic diameter. In HotSpot , the RF is assumed to have an Activity Median Aerodynamic Diameter (AMAD) of 1 micron.

Respirable Release Fraction—The fraction of the total quantity of material involved in the fire, explosion, etc., that is respirable and available for dispersion into the atmosphere. This component has a separate respirable deposition velocity (default value of 0.3 cm/sec for non noble gases), and is used to determine the inhalation, ground-shine, submersion , and resuspension doses due to the respirable component.

Resuspension Factor—The ratio of the air concentration to the ground concentration (1/m). In HotSpot, the resuspension factor is determined using measurements of the ground contamination (Ci/m2) and the radionuclide air concentration (Ci/m3) above the ground measurement location.

Sample Time— In the HotSpot codes, this averaging time is referred to as the sampling time. The equations for the standard deviation of the Gaussian concentration distribution in cross-axis direction (sigma-y) are representative of observing plume characteristics over a time period of 10 min. Concentrations downwind from a source decrease with increasing sampling time primarily because of a larger sy due to an increased meander of wind direction.

Stability Classification— Meteorologists distinguish several states of the atmospheric surface layer—unstable, neutral, and stable. These categories refer to how a parcel of air reacts when displaced adiabatically in the vertical direction.

Thermonuclear Weapon—A nuclear weapon in which very high temperature and pressure are used to bring about the fusion of light nuclei such as those of hydrogen isotopes (e.g. deuterium and tritium) with the accompanying release of energy. The high temperatures required are obtained by means of an initial fission device.

Time of Fall (Fallout)—The time required for the average size particle (25–75 microns) to fall from the cloud bottom to the ground.

TNT Equivalent—A measure of the energy released from the detonation of a nuclear weapon, or from the explosion of a given quantity of fissionable material, in terms of the amount of TNT (trinitrotoluene) that could release the same amount of energy when exploded.

Total Effective Dose Equivalent (TEDE)—See Section 8.

Universal Transverse Mercator Grid (UTM)—A grid coordinate system based on the transverse Mercator projection, applied to maps of the earth
's surface extending to 84 degrees N and 80 degrees S latitudes.

Universal Transverse Mercator (UTM)—A transverse Mercator projection is the ordinary Mercator projection turned through a 90 degree angle so that it is related to a central meridian the same way that an ordinary Mercator is related to the equator. Because the cylinder is tangent to the globe at a meridian, the scale is true along that meridian, which is called the central meridian, and is used as the origin of the map X coordinate. The origin of the map Y coordinate is the equator. UTM projection is in zones that are 6 degrees wide. The reference ellipsoid is Clarke 1866 in North America. The unit of measure is the meter. For the southern hemisphere, a false northing of, 10,000,000 meters is used. A false easting of 50,000 meters is used for the central meridian of each zone. The zones are numbered beginning with 1 for the zone between 180 degrees West and 174 degrees West and increasing to 60 for the zone between meridians 174 degrees East and 180 degrees East. The latitude for the system varies from 80 degrees North to 80 degrees South. For example, San Francisco is located in zone 10.

Uranium—A heavy metal, somewhat like lead. Uranium is a naturally occurring mineral that is mildly radioactive. In nature, uranium consists mostly of the isotope U-238, with small quantities of U-235 (about 0.7 % by mass), and extremely small quantities of U-234. Natural uranium is only mildly radioactive, emitting alpha and beta radiation, and low levels of gamma radiation. The half life of U-238, the major constituent of natural uranium, is 4.5 billion years. Uranium involved in a nuclear weapon is usually in the chemical form of uranium oxide.

Yield—The energy released in the detonation of a nuclear weapon, measured in terms of the kilotons or megatons of trinitrotoluene required to produce the same energy release.

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