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HOTSPOT

Health Physics Codes for the PC

Steven G. Homann

Hazards Control Department

and

**the Emergency Preparedness and
Response Program,
Nonproliferation, Arms Control, and
International Security Directorate**

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Lawrence Livermore National Laboratory
University of California, Livermore, California 94551

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HOTSPOT

Health Physics Codes for the PC

1. Introduction

The HOTSPOT Health Physics codes were created to provide Health Physics personnel with a fast, field-portable calculation tool for evaluating accidents involving radioactive materials. HOTSPOT codes are a first-order approximation of the radiation effects associated with the atmospheric release of radioactive materials. HOTSPOT programs are reasonably accurate for a timely initial assessment. More importantly, HOTSPOT codes produce a consistent output for the same input assumptions and minimize the probability of errors associated with reading a graph incorrectly or scaling a universal nomogram during an emergency. The HOTSPOT codes are designed for short-term (less than 24 hours) release durations. Users requiring radiological release consequences for release scenarios over a longer time period, e.g., annual wind-rose data, are directed to such long-term models as CAPP88-PC (Parks, 1992). Users requiring more sophisticated modeling capabilities, e.g., complex terrain; multi-location real-time wind field data; etc., are directed to such capabilities as the Department of Energy's ARAC computer codes (Sullivan, 1993).

Four general programs—**Plume, Explosion, Fire, and Resuspension**—calculate a downwind assessment following the release of radioactive material resulting from a continuous or puff release, explosive release, fuel fire, or an area contamination event. Other programs deal with the release of plutonium, uranium, and tritium to expedite an initial assessment of accidents involving nuclear weapons. Additional programs estimate the dose commitment from the inhalation of any one of the radionuclides listed in the database of radionuclides; calibrate a radiation survey instrument for ground-survey measurements; and screen plutonium uptake in the lung (see *FIDLER Calibration* and *LUNG Screening* sections).

About This Manual

The HOTSPOT manual is organized into several tabbed sections. This first section describes the program itself and the operating assumptions behind the HOTSPOT codes. The largest section covers examples of various scenarios with various problem sets and detailed examples. The four appendices include Gaussian algorithms and glossary definitions, as well as descriptions of the minimum requirements for the computer system and the Radionuclide Library.

Equipment

HOTSPOT will run on an IBM PC, XT, AT, or compatible, with a minimum of 512 kbytes of RAM and a single floppy-disk drive; however, the programs run more efficiently when they reside on a hard disk. HOTSPOT will also run on the HP 100LX Palmtop. The software supports either monochrome or color monitors (CGA, EGA, VGA, SVGA). The only operating system required is MS-DOS

version 3.0 or later. HOTSPOT also supports high-resolution (300-dpi) output to printers and also to graphics files (.PCX and .BMP Files). The latter allows HOTSPOT graphics to be incorporated into word-processing files. Appendix A describes how to use the HOTSPOT codes.

Basis of the HOTSPOT Codes

HOTSPOT uses the well-established Gaussian plume model, widely used for an initial emergency assessment or safety-analysis planning of a radionuclide release. Appendix B describes the HOTSPOT algorithms in detail. The dosimetric methods of ICRP Publication 30 were used throughout the HOTSPOT programs. Individual doses (unweighted) are produced, along with the 50-year Committed Effective Dose Equivalents (CEDEs). HOTSPOT supports both classic units (rem, rad, curie) and SI units. Appendix C is a glossary of the HOTSPOT output definitions. Appendix D contains the HOTSPOT Library of nuclides and 50-year CEDEs.

The HOTSPOT dose values are due solely to the inhalation of released material during passage of the plume. In the specific case of noble gases (e.g., ^{85}Kr) the submersion dose is output. The specific dose-conversion factors for all of the radionuclides in the HOTSPOT Library can be viewed in the **HOTSPOT Library** program (DOE, 1988). The ground-shine dose is not included because the CEDE (per hour of time in the contaminated area) due to ground shine is typically several orders of magnitude less than the CEDE due to plume passage. For alpha-emitting radionuclides (e.g., ^{239}Pu and ^{241}Am), the hourly ground-shine component is at least 7 orders of magnitude less than the inhalation component.

Emergency preparedness requires a fast and adequate means of generating an initial assessment of an actual or scheduled atmospheric release. Just as important is the need for consistency in the assessment methodology, e.g., well-documented, consistent output for a particular set of input assumptions, etc. Actual source terms, the substances involved, meteorological conditions, etc., are seldom accurately known. Overly sophisticated and data-intensive models seldom provide useful and timely information in emergencies involving the release or potential release of radioactive material into the atmosphere.

In the specific case of emergency planning and response, we are usually interested in *worst-case scenarios*, i.e., if the plume of radioactive material does reach a community, what are the projected committed effective dose equivalent values? Unless specific accident scenarios are accurately detailed and proven reliable, large modeling errors are possible. Such errors render large, complex, and time-consuming models no more accurate than a simple Gaussian model. The Gaussian model should be recognized as a starting place for analyses and, in many cases, the only tool necessary due to the large uncertainty associated with a release scenario.

Verification

HOTSPOT codes involving the dispersal of radioactive material use the Gaussian model. The Gaussian model is still the basic workhorse for atmospheric dispersion calculations and has found its way into most government guidebooks.

The Gaussian model has also been used and accepted by the Environmental Protection Agency (EPA, 1978). The adequacy of this model for making initial dispersion estimates or worst-case safety analyses has been tested and verified for many years.

HOTSPOT strictly follows the well-established Gaussian model. HOTSPOT uses no "black-box" techniques. All algorithms are presented and fully referenced in this document.

Accuracy

Large errors in concentration estimates can result when using a straight-line Gaussian model in situations involving a complex terrain and/or wind conditions. Should the plume abruptly change direction by 90°, because of a change in wind direction or terrain geometry, the straight-line model will predict a concentration at a specific downwind location that is offset to a new location. Even though the spatial information is now invalid, the concentration estimate is still valid, albeit offset to another location. So, what prevents the wind from abruptly changing direction once again, perhaps even returning to its original direction? Even in the case of a radioactive-material release monitored by a grid of meteorological towers and accurate terrain data, evacuation decisions do not typically depend on a predicted plume dogleg to circumvent a community. Rather, the potential concentration as a function of distance is considered, and the evacuation is a remote possibility for the targeted community. In fact, it is not uncommon to evacuate communities based on a 360° potential-hazard zone, effectively eliminating the wind-direction variability problem. This is particularly common at a low wind speeds (for example, <2 m/s) in which wind direction is frequently changing.

The many uncertainties associated with variables in the Gaussian model—fluctuations in the meteorological conditions or type of terrain—result in a degree of imprecision in calculated concentrations and radiation dose values. If inappropriate meteorological data, source-term assumptions, effective stack height, etc., are input into the programs, large errors are possible in the HOTSPOT estimates. Given accurate input assumptions, the standard deviation of the dose values as calculated in HOTSPOT is approximately a factor of 5 [some authors report a factor of 3 (Cember, 1985)]. Therefore, 68% of the time (i.e., the percentage of observations within 1 standard deviation, assuming a Gaussian distribution), the calculated dose values will be within a factor of 5.

Other percentages can be inferred from the Gaussian distribution. If D is the calculated radiation dose, then 50% of the time the true dose should lie between $D/3$ and $3D$; and 80% of the time between $D/8$ and $8D$. For example, if the calculated 50-year CEDE were 300 mrem, at least half of the time you would expect the true value to lie between 100 mrem and 900 mrem. This level of accuracy is more than acceptable for emergency response and planning and is almost always less than the error associated with estimating the actual source term, etc. More importantly, the Gaussian will usually be conservative, i.e., produce dose estimates greater than the actual observed values.

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2. Examples

Plutonium Explosion

Assumptions:

- The respirable fraction released of the total plutonium involved in the explosion is 0.20 (20%). The respirable fraction is defined as the fraction of the released material associated with an Activity Median Aerodynamic Diameter (AMAD) of 1 μm (see Appendix B). The default ICRP-30 internal dosimetry conversion factors also assume an AMAD particle-size distribution of 1 μm .
- Deposition velocity of the respirable fraction (AMAD = 1 μm) is 1 cm/sec.
- Deposition velocity of the non-respirable fraction (AMAD = 40 μm) is 8 cm/sec. The non-respirable fraction equals $1-f$, where f is the respirable fraction. The default value for f is 0.2 (20% of the material involved in the explosion has an AMAD of 1 μm). The non-respirable fraction is used for deposition estimates only and does not contribute to the inhalation dose values.
- Default alpha specific activity of weapons-grade plutonium is 0.081 Ci/g.
- Inhalation class is Y.
- Standard-person breathing rate is 1.2 m^3/hr .

Plutonium Explosion Example

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 release of plutonium using 113 lbs. of high explosive. The test was performed at 3 a.m. and the wind speed was 5 m/sec at a height of 2 m. Compare the HOTSPOT estimates with the actual test measurements. The experimental results were normalized to a 1-kg initial mass of plutonium, so use 1 kg as the total mass of plutonium involved in the explosion (Dewart, *et al.*, 1982). The HOTSPOT output agrees well with the measured air concentration and ground deposition data (Figs. 2-1 and 2-2).

18-S/1207-2-1

18-S/1207-2-2

HOTSPOT:		PLUTONIUM EXPLOSION	
RADIONUCLIDE :		PU-239 Inhalation Class Y	
HALFLIFE :		2.4E+04 Years	
SOURCE TERM :		1.0E+00kg	
RELEASE FRACTION :		2.0E-01	
HIGH EXPLOSIVE :		113.0 LBS	
CLOUD TOP :	248 m		
WINDSPEED (h=2m) :	5.0 m/s		
STABILITY CLASS :	D	DEPOSITION VELOCITY :	1.00 cm/s
RECEPTOR HEIGHT :	0.0 m	INVERSION LAYER HEIGHT :	5000.0 m
MAXIMUM DOSE DISTANCE :	< 0.10 km	MAXIMUM CEDE :	> 8.4 rem
Plume Centerline			

D = 0.10 km
 DEP = 2.4E+01 uCi/m²
 CHI = 7.7E-05 (Ci-s)/m³

50-YR DOSE COMMITMENT:

LUNG	3.1E+01 rem
SURFACE BONE	9.0E+01 rem
RED MARROW	7.2E+00 rem
LIVER	2.0E+01 rem
EFFECTIVE DOSE	
EQUIVALENT	8.4E+00 rem

D = 0.20 km
 DEP = 1.9E+01 uCi/m²
 CHI = 6.3E-05 (Ci-s)/m³

50-YR DOSE COMMITMENT:

LUNG	2.5E+01 rem
SURFACE BONE	7.3E+01 rem
RED MARROW	5.8E+00 rem
LIVER	1.6E+01 rem
EFFECTIVE DOSE	
EQUIVALENT	6.9E+00 rem

D = 0.50 km
 DEP = 1.2E+01 uCi/m²
 CHI = 4.1E-05 (Ci-s)/m³

50-YR DOSE COMMITMENT:

LUNG	1.6E+01 rem
SURFACE BONE	4.8E+01 rem
RED MARROW	3.8E+00 rem
LIVER	1.1E+01 rem
EFFECTIVE DOSE	
EQUIVALENT	4.5E+00 rem

D = 1.00 km
 DEP = 8.1E+01 uCi/m²
 CHI = 2.7E-05 (Ci-s)/m³

50-YR DOSE COMMITMENT:

LUNG	1.1E+01 rem
SURFACE BONE	3.2E+01 rem
RED MARROW	2.5E+00 rem
LIVER	7.0E+00 rem
EFFECTIVE DOSE	
EQUIVALENT	3.0E+00 rem

D = 2.00 km
 DEP = 4.8E+01 uCi/m²
 CHI = 1.7E-05 (Ci-s)/m³

50-YR DOSE COMMITMENT:

LUNG	6.7E+01 rem
SURFACE BONE	1.9E+01 rem
RED MARROW	1.6E+00 rem
LIVER	4.3E+00 rem
EFFECTIVE DOSE	
EQUIVALENT	1.8E+00 rem

D = 5.00 km
 DEP = 2.1E+00 uCi/m²
 CHI = 8.0E-06 (Ci-s)/m³

50-YR DOSE COMMITMENT:

LUNG	3.2E+01 rem
SURFACE BONE	9.3E+01 rem
RED MARROW	7.5E+00 rem
LIVER	2.1E+00 rem
EFFECTIVE DOSE	
EQUIVALENT	8.8E-01 rem

D = 10.00 km
 DEP = 1.0E+00 uCi/m²
 CHI = 4.2E-06 (Ci-s)/m³

50-YR DOSE COMMITMENT:

LUNG	1.7E+00 rem
SURFACE BONE	4.9E+00 rem
RED MARROW	3.9E-01 rem
LIVER	1.1E+00 rem
EFFECTIVE DOSE	
EQUIVALENT	4.6E-01 rem

D = 20.00 km
 DEP = 3.7E-01 uCi/m²
 CHI = 2.0E-06 (Ci-s)/m³

50-YR DOSE COMMITMENT:

LUNG	8.0E-01 rem
SURFACE BONE	2.3E+00 rem
RED MARROW	1.9E-01 rem
LIVER	5.2E-01 rem
EFFECTIVE DOSE	
EQUIVALENT	2.2E-01 rem

D = 50.00 km
 DEP = 7.1E-02 uCi/m²
 CHI = 6.9E-07 (Ci-s)/m³

50-YR DOSE COMMITMENT:

LUNG	2.7E-01 rem
SURFACE BONE	8.0E-01 rem
RED MARROW	6.4E-02 rem
LIVER	1.8E-01 rem
EFFECTIVE DOSE	
EQUIVALENT	7.5E-02 rem

18-S/1207-PE

Plutonium Fire

Assumptions:

- The respirable fraction released of the total plutonium involved in the fire is 5×10^{-4} (0.05%) [Stewart, 1959]. The respirable fraction is defined as the fraction of the released material associated with an Activity Median Aerodynamic Diameter (AMAD), of 1 mm (see Appendix B). The default ICRP-30 internal dosimetry conversion factors also assume a AMAD particle-size distribution of 1 mm.

The effective release height is determined using the methodology contained in the *Fuel Fire* section of Appendix B. Once the effective release height is determined, the radius of the final bent-over plume is set equal to 60% of the effective release height (Hanna, *et al.*, 1982). An upwind virtual point source, which results in an initial σ_y and σ_z equal to 50% of the plume radius at the origin (i.e., plume radius = 2), models the fire scenario.

- Deposition velocity is 1 cm/sec.
- Alpha specific activity of weapons-grade plutonium is 0.081 Ci/g.
- Inhalation class is Y.
- Standard-person breathing rate is 1.2 m³/hr.

Plutonium Fire Example

Three kilograms of weapons-grade plutonium are involved in a fire due to 30 gal of fuel burning for 14 min. The effective radius of the fire zone is 10 m. Use the default release fraction of 0.05%. The sun has set, the wind speed is 2 m/sec, and the temperature is 20°C. Estimate the 50-year CEDEs to individuals remaining downwind throughout the entire fire.

HOTSPOT:	PLUTONIUM FIRE		
RADIONUCLIDE :	PU-239 Inhalation Class: Y		
HALFLIFE :	2.4E+04 Years		
SOURCE TERM :	3.0E+00 kg		
RELEASE FRACTION:	5.0E-04		
FUEL :	3.0E+01 gal	FIRE DURATION :	14.0 min
EFFECTIVE RELEASE HEIGHT :	40.00 m	RELEASE RADIUS :	10 m
WIND SPEED (h=2m) :	2.0 m/s	DEPOSITION VELOCITY :	1.00 cm/s
WIND SPEED (h=H-eff) :	5.71 m/s	INVERSION LAYER HEIGHT :	5000.0 m
STABILITY CLASS :	E	MAXIMUM CEDE :	0.160 rem
RECEPTOR HEIGHT :	0.0 m		
SAMPLE TIME :	10.0 min		
MAXIMUM DOSE DISTANCE :	0.7 km		
Plume Centerline			

D = 0.10 km
 DEP = 3.7E-03 uCi/m²
 CHI = 3.7E-07 (Ci-s)/m³

50-YR DOSE COMMITMENT:

LUNG 1.5E-01 rem
 SURFACE BONE 4.3E-01 rem
 RED MARROW 3.4E-02 rem
 LIVER 9.6E-02 rem
 EFFECTIVE DOSE
 EQUIVALENT 4.1E-02 rem

D = 1.00 km
 DEP = 1.3E-02 uCi/m²
 CHI = 1.3E-06 (Ci-s)/m³

50-YR DOSE COMMITMENT:

LUNG 5.3E-01 rem
 SURFACE BONE 1.6E+00 rem
 RED MARROW 1.2E-01 rem
 LIVER 3.5E-01 rem
 EFFECTIVE DOSE
 EQUIVALENT 1.5E-01 rem

D = 0.20 km
 DEP = 7.3E-03 uCi/m²
 CHI = 7.3E-07 (Ci-s)/m³

50-YR DOSE COMMITMENT:

LUNG 2.9E-01 rem
 SURFACE BONE 8.5E-01 rem
 RED MARROW 6.8E-02 rem
 LIVER 1.9E-01 rem
 EFFECTIVE DOSE
 EQUIVALENT 8.0E-02 rem

D = 2.00 km
 DEP = 7.9E-03 uCi/m²
 CHI = 7.9E-07 (Ci-s)/m³

50-YR DOSE COMMITMENT:

LUNG 3.1E-01 rem
 SURFACE BONE 9.2E-01 rem
 RED MARROW 7.3E-02 rem
 LIVER 2.0E-01 rem
 EFFECTIVE DOSE
 EQUIVALENT 8.6E-02 rem

D = 0.50 km
 DEP = 1.4E-02 uCi/m²
 CHI = 1.4E-06 (Ci-s)/m³

50-YR DOSE COMMITMENT:

LUNG 5.6E-01 rem
 SURFACE BONE 1.6E+00 rem
 RED MARROW 1.3E-01 rem
 LIVER 2.5E-01 rem
 EFFECTIVE DOSE
 EQUIVALENT 1.5E-01 rem

D = 5.00 km
 DEP = 2.7E-03 uCi/m²
 CHI = 2.7E-07 (Ci-s)/m³

50-YR DOSE COMMITMENT:

LUNG 1.1E-01 rem
 SURFACE BONE 3.1E-01 rem
 RED MARROW 2.5E-02 rem
 LIVER 6.9E-02 rem
 EFFECTIVE DOSE
 EQUIVALENT 2.9E-02 rem

18-S/1207-PF

Plutonium Resuspension

Assumptions:

- Resuspension is modeled using the methodology in the *Resuspension* section of Appendix B.
- Inhalation class is Y.
- Standard-person breathing rate is $1.2 \text{ m}^3/\text{hr}$.

Plutonium Resuspension Example

Estimate the 50-year CEDE rates (i.e., dose commitment per hour of downwind exposure) to individuals downwind from a 2-week-old plutonium contamination event. Most of the plutonium is contained in an area with an effective radius of 100 m. The average contamination level is $150 \mu\text{Ci}/\text{m}^2$. Assume nighttime conditions with a wind speed of 1 m/sec.

HOTSPOT:	PLUTONIUM RESUSPENSION	
RADIONUCLIDE :	PU-239 Inhalation Class:Y	
HALFLIFE :	2.4E+04 Years	
RESUSPENSION FACTOR:	5.7E-05 1/m	
EFF. RADIUS :	100 m	
AVG. DEPOSITION :	1.5E+02 $\mu\text{Ci}/\text{m}^2$	
CONTAMINATION AGE:	14 days	
EFFECTIVE RELEASE HEIGHT :	0.00 m	
WIND SPEED (h=2m) :	1.0 m/s	
STABILITY CLASS :	F	DEPOSITION VELOCITY : 1.00 cm/s
RECEPTOR HEIGHT :	0.0 m	INVERSION LAYER HEIGHT : NONE
SAMPLE TIME :	60.0 min	
MAXIMUM DOSE DISTANCE :	< 0.10 km	MAXIMUM CEDE : > 0.651 rem
Plume Centerline		

D = 0.10 km
CHI = $1.6\text{E-}09 \text{ Ci}/\text{m}^3$

50-YR DOSE COMMITMENT: PER 1-HR EXPOSURE TIME

LUNG	2.4E+00 rem
SURFACE BONE	6.9E+00 rem
RED MARROW	5.5E-01 rem
LIVER	1.5E+00 rem
EFFECTIVE DOSE EQUIVALENT	6.5E-01 rem

D = 0.20 km
CHI = $1.0\text{E-}09 \text{ Ci}/\text{m}^3$

50-YR DOSE COMMITMENT: PER 1-HR EXPOSURE TIME

LUNG	1.5E+00 rem
SURFACE BONE	4.4E+00 rem
RED MARROW	3.5E-01 rem
LIVER	9.8E-01 rem
EFFECTIVE DOSE EQUIVALENT	4.1E-01 rem

D = 0.50 km
CHI = $4.8\text{E-}10 \text{ Ci}/\text{m}^3$

50-YR DOSE COMMITMENT: PER 1-HR EXPOSURE TIME

LUNG	6.9E-01 rem
SURFACE BONE	2.0E+00 rem
RED MARROW	1.6E-01 rem
LIVER	4.5E-01 rem
EFFECTIVE DOSE EQUIVALENT	1.9E-01 rem

D = 1.00 km
CHI = $2.2\text{E-}10 \text{ Ci}/\text{m}^3$

50-YR DOSE COMMITMENT: PER 1-HR EXPOSURE TIME

LUNG	3.2E-01 rem
SURFACE BONE	9.2E-01 rem
RED MARROW	7.4E-02 rem
LIVER	2.1E-01 rem
EFFECTIVE DOSE EQUIVALENT	8.7E-02 rem

D = 2.00 km
CHI = $7.7\text{E-}11 \text{ Ci}/\text{m}^3$

50-YR DOSE COMMITMENT: PER 1-HR EXPOSURE TIME

LUNG	1.1E-01 rem
SURFACE BONE	3.2E-01 rem
RED MARROW	2.6E-02 rem
LIVER	7.2E-02 rem
EFFECTIVE DOSE EQUIVALENT	3.0E-02 rem

D = 5.00 km
CHI = $1.3\text{E-}11 \text{ Ci}/\text{m}^3$

50-YR DOSE COMMITMENT: PER 1-HR EXPOSURE TIME

LUNG	1.9E-02 rem
SURFACE BONE	5.6E-02 rem
RED MARROW	4.5E-03 rem
LIVER	1.3E-02 rem
EFFECTIVE DOSE EQUIVALENT	5.3E-03 rem

18-S/1207-PR

Uranium Explosion

Assumptions:

- The default respirable fraction released of the total uranium involved in the explosion is 0.20 (20%). The respirable fraction is defined as the fraction of the released material associated with an Activity Median Aerodynamic Diameter (AMAD) of 1 μ m (see Appendix B). The default ICRP-30 internal dosimetry conversion factors also assume a AMAD particle-size distribution of 1 μ m.
- Deposition velocity of the respirable fraction (AMAD = 1 μ m) is 1 cm/sec.
- Deposition velocity of the non-respirable fraction (AMAD = 40 micron) is 8 cm/sec. The non-respirable fraction equals $1-f$, where f is the respirable fraction. The default value for f is 0.2 (20% of the material involved in the explosion has an AMAD of 1 μ m). The non-respirable fraction is used for deposition estimates only and does not contribute to the inhalation dose values.
- Specific activity, S (Ci/g), as a function of ^{235}U enrichment is (Alexander, 1974)—
$$S = (0.4 + 0.38E + 0.0034E^2)(10^{-6}) ,$$
where E = percent enrichment. This equation includes the contribution from ^{234}U .
- Inhalation class is Y.
- Standard-person breathing rate is 1.2 m³/hr.

Uranium Explosion Example

Three kilograms of weapons-grade uranium (90% ^{235}U , 10% ^{238}U) are involved in a non-nuclear detonation of a weapon containing 40 lbs. of high explosive. The sun is low in the sky and the wind speed is 1 m/sec. Estimate the ground contamination and 50-year CEDEs as a function of downwind centerline distance.

HOTSPOT:	URANIUM EXPLOSION		
RADIONUCLIDE:	URANIUM Inhalation Class: Y		
SPECIFIC ACTIVITY:	6.2E-05 Ci/g		
SOURCE TERM:	3.0E+00 KG		
RELEASE FRACTION:	2.0E-01		
HIGH EXPLOSIVE:	40.0 lbs		
CLOUD TOP:	191 m		
WIND SPEED (h=2m):	1.0 m/s		
STABILITY CLASS:	B	DEPOSITION VELOCITY:	1.00 cm/s
RECEPTOR HEIGHT:	0.0 m	INVERSION LAYER HEIGHT:	NONE
MAXIMUM DOSE DISTANCE:	< 0.1 km	MAXIMUM CEDE :	< 0.058 rem
Plume Centerline			

D = 0.10 km
 DEP = 4.4E-01 uCi/m²
 CHI = 1.4E-06 (Ci-s)/m³

50-YR DOSE COMMITMENT:

LUNG 4.8E-01 rem
 EFFECTIVE DOSE
 EQUIVALENT 5.8E-02 rem

D = 0.20 km
 DEP = 3.3E-01 uCi/m²
 CHI = 1.5E-06 (Ci-s)/m³

50-YR DOSE COMMITMENT:

LUNG 3.6E-01 rem
 EFFECTIVE DOSE
 EQUIVALENT 4.3E-02 rem

D = 0.50 km
 DEP = 1.7E-01 uCi/m²
 CHI = 5.8E-07 (Ci-s)/m³

50-YR DOSE COMMITMENT:

LUNG 1.9E-01 rem
 EFFECTIVE DOSE
 EQUIVALENT 2.3E-02 rem

D = 1.00 km
 DEP = 7.3E-02 uCi/m²
 CHI = 2.7E-06 (Ci-s)/m³

50-YR DOSE COMMITMENT:

LUNG 8.8E-02 rem
 EFFECTIVE DOSE
 EQUIVALENT 1.1E-02 rem

D = 2.00 km
 DEP = 2.2E-02 uCi/m²
 CHI = 9.2E-08 (Ci-s)/m³

50-YR DOSE COMMITMENT:

LUNG 3.0E-02 rem
 EFFECTIVE DOSE
 EQUIVALENT 3.7E-03 rem

D = 5.00 km
 DEP = 3.6E-03 uCi/m²
 CHI = 1.8E-08 (Ci-s)/m³

50-YR DOSE COMMITMENT:

LUNG 6.1E-03 rem
 EFFECTIVE DOSE
 EQUIVALENT 7.4E-04 rem

D = 10.00 km
 DEP = 8.8E-04 uCi/m²
 CHI = 5.4E-09 (Ci-s)/m³

50-YR DOSE COMMITMENT:

LUNG 1.8E-03 rem
 EFFECTIVE DOSE
 EQUIVALENT 2.1E-04 rem

D = 20.00 km
 DEP = 2.2E-04 uCi/m²
 CHI = 1.6E-09 (Ci-s)/m³

50-YR DOSE COMMITMENT:

LUNG 5.3E-04 rem
 EFFECTIVE DOSE
 EQUIVALENT 6.4E-05 rem

D = 50.00 km
 DEP = 3.8E-05 uCi/m²
 CHI = 3.5E-10 (Ci-s)/m³

50-YR DOSE COMMITMENT:

LUNG 1.1E-04 rem
 EFFECTIVE DOSE
 EQUIVALENT 1.4E-05 rem

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Uranium Fire

Assumptions:

- The default respirable fraction released of the total uranium involved in the fire is 5×10^{-4} (0.05%) [Stewart, 1959]. The respirable fraction is defined as the fraction of the released material associated with an Activity Median Aerodynamic Diameter (AMAD) of $1 \mu\text{m}$ (see Appendix B). The default ICRP-30 internal-dosimetry conversion factors also assume a AMAD particle-size distribution of $1 \mu\text{m}$.
- The effective release height is determined using the methodology contained in the *Fuel Fire* section of Appendix B. Once the effective release height is determined, the radius of the final bent-over plume is set equal to 60% of the effective release height (Hanna, 1982). An upwind virtual point source, resulting in an initial σ_y and σ_z equal to 50% of the plume radius at the origin (plume radius = 2σ), models the fire scenario.
- Deposition velocity is 1 cm/sec.
- Specific activity, S (Ci/g), as a function of ^{235}U enrichment is (Alexander, 1974)—
$$S = (0.4 + 0.38E + 0.0034E^2)(10^{-6}) ,$$
where E = percent enrichment. This equation includes the contribution from ^{234}U .
- Inhalation class is Y.
- Standard-person breathing rate is $1.2 \text{ m}^3/\text{hr}$.

Uranium Fire Example

One-hundred kilograms of uranium (95% ^{238}U , 5% ^{235}U) being used in an isotope-separation experiment are involved in a significant building fire (heat emission = 1×10^7 calories/sec, effective radius of building fire is 50 m). The sun has set and the wind speed is approximately 9 m/sec, 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?

HOTSPOT: URANIUM FIRE
RADIONUCLIDE : URANIUM

Inhalation Class: Y

SPECIFIC ACTIVITY : 2.38E-06 Ci/g

SOURCE TERM : 1.0E+02 kg

RELEASE FRACTION : 5.00E-04

HEAT EMISSION : 1.0E+07 cal/s

RELEASE RADIUS : 50.0 m

EFFECTIVE RELEASE HEIGHT : 28.22 m

WIND SPEED (h=2 m): 9.0 m/s

WIND SPEED (h=H-eff): 13.4 m/s

STABILITY CLASS : D

DEPOSITION VELOCITY : 1.00 cm/s

RECEPTOR HEIGHT : 0.0 m

INVERSION LAYER HEIGHT : 5000.0 m

SAMPLE TIME : 10.0 min

MAXIMUM DOSE DISTANCE : < 0.1 km MAXIMUM CEDE : > 7.5E-05 rem

D = 0.50 km

DEP = 8.8E-06 uCi/m²

CHI = 8.8E-10 (Ci-s)/m³

50-YR DOSE COMMITMENT:

LUNG 2.9E-04 rem

EFFECTIVE DOSE

EQUIVALENT 3.5E-05 rem

18-S/1207 UF

Tritium Release

Assumptions:

- 50-year CEDE (rem-m³)/(Ci-sec):

Tritiated Water:

- HOTSPOT assumes that two-thirds of the CEDE is due to inhalation and one-third is due to absorption through the intact skin (ICRP 30, Part 1, 1978, page 65).
- CEDE = 0.031 [0.021 due to inhalation + 0.010 due to absorption]

Elemental Tritium:

- CEDE: = 1.2×10^{-6} .
- LUNG: = 1.0×10^{-5} .

Tritium Release Example

Thirty-thousand curies of HTO are released from a 30-m stack. The wind speed is 1 m/sec; the sun is low in the sky. What distance is associated with the maximum 50-year CEDE (Fig. 2-3) to an individual remaining at this location throughout the release?

Maximum dose distance: 0.17 km
Maximum CEDE : 0.151 rem

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HOTSPOT:	TRITIUM RELEASE
TOTAL TRITIUM RELEASE:	3.0E+04 curies 100.000 % TRITIUM OXIDE
Dose Results Include Skin Absorption	
EFFECTIVE RELEASE HEIGHT :	30.00 m
WIND SPEED (h=2 m):	1.0m/s
WIND SPEED (h=H-eff):	1.2m/s
STABILITY CLASS :	B
DEPOSITION VELOCITY :	00E+00 cm/s
RECEPTOR HEIGHT :	0.0 m
INVERSION LAYER HEIGHT :	NONE
SAMPLE TIME :	10.0 min
MAXIMUM DOSE DISTANCE :	0.17 km
MAXIMUM CEDE :	0.151 rem
Plume Centerline	

D = 0.10 km
CHI = 1.8E+00 uCi/m³

D = 0.20 km
CHI = 4.8E+00 (Ci-s)/m³

D = 0.50 km
CHI = 1.5E-00 (Ci-s)/m³

50-YR DOSE COMMITMENT:

EFFECTIVE DOSE EQUIVALENT 5.6E-02 rem

50-YR DOSE COMMITMENT:

EFFECTIVE DOSE EQUIVALENT 1.5E-01 rem

50-YR DOSE COMMITMENT:

EFFECTIVE DOSE EQUIVALENT 4.6E-02 rem

D = 1.00 km
CHI = 4.2E-01 (Ci-s)/m³

D = 2.00 km
CHI = 1.1E-01 (Ci-s)/m³

D = 5.00 km
CHI = 2.0E-02 (Ci-s)/m³

50-YR DOSE COMMITMENT:

EFFECTIVE DOSE EQUIVALENT 1.3E-02 rem

50-YR DOSE COMMITMENT:

EFFECTIVE DOSE EQUIVALENT 3.5E-03 rem

50-YR DOSE COMMITMENT:

EFFECTIVE DOSE EQUIVALENT 6.2E-04 rem

18-S/1207-TR

Nuclear Explosion

Assumptions:

The Nuclear Explosion code 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. ed., U. S. Department of Defense and the U. S. Department of Energy, 1977). As Glasstone and Dolan state, the predictive data are not exact. Users are strongly urged to refer to the book for detailed discussions and limitations of the effects data (see following tables on blast effects).

The code estimates the maximum overpressure (psi), prompt neutron and gamma doses (rad), and the thermal radiation (cal/cm²), as a function of radial distance from the point of detonation. For distances greater than 1 km, the following fallout prediction data are generated:

- Arrival time of fallout.
- Reference dose rate at one hour post-detonation (H+1).
- Initial dose rate at actual cloud arrival time.
- Integral dose from *external* ionizing radiation in first hour, day, etc., since detonation. Therefore, if the fallout arrival time is greater than 1 hr, the dose in the first hour is zero.
- Fallout assumptions: default effective wind is 15 miles per hour with a wind shear of 15°.

Notes:

1. The RBE for neutrons varies with the energy and type of injury. For the neutron energy spectrum of nuclear weapons, the RBE for acute radiation injury is close to 1.0. However, the RBE is significantly larger (4-10) for the occurrence of opacities of the lens of the eye, leukemia, and genetic changes.

2. Approximate thermal exposure required to produce skin burns for yields ≤20 kT (Fig. 2-4).

- First degree 2 cal/cm².
- Second degree 4 cal/cm².
- Third degree 7 cal/cm².

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Tentative criteria for direct (primary) blast effects in people from fast-rising, long-duration pressure pulses.

Effect	Peak Pressure (psi)
Lung damage:	
Threshold	12 (8–15)
Severe	25 (20–30)
Lethality:	
Threshold	40 (30–50)
50 percent	62 (50–75)
100 percent	92 (75–115)
Eardrum rupture:	5
Threshold	15–20 (More than 20-years old)
50 percent	30–35 (Less than 20-years old)

Approximate radiant exposures for Ignition of various materials.

Material	Weight (oz/yd ²)	Color	Effect on material	Radiant Exposure (cal/cm ²)		
				35 kilotons	1.4 megatons	20 megatons
<u>Household Tinder Materials</u>						
Newspaper, shredded	2		Ignites	4	6	11
Newspaper, dark picture area	2		Ignites	5	7	12
Newspaper, printed text area	2		Ignites	6	8	15
Crepe paper	1	Green	Ignites	6	9	16
Kraft paper	3	Tan	Ignites	10	13	20
Bristol board, 3-ply	10	Dark	Ignites	16	20	40
Kraft paper carton, used (flat side)	16	Brown	Ignites	16	20	40
New bond typing paper	2	White	Ignites	24	30	50
Cotton rags		Black	Ignites	10	15	20
Rayon rags		Black	Ignites	9	14	21
Cotton string scrubbing mop (used)		Gray	Ignites	10	15	21
Cotton string scrubbing mop (weathered)		Cream	Ignites	10	19	26
Paper book matches, blue head exposed			Ignites	11	14	20
Excelsior, ponderosa pine		Light Yellow	Ignites		23	23
<u>Outdoor Tinder Materials</u>						
Dry rotted wood punk (fir)			Ignites	4	6	11
Deciduous leaves (beech)			Ignites	4	6	8
Fine grass (cheat)			Ignites	5	8	10
Coarse grass (sedge)			Ignites	6	9	11
Pine needles, brown (ponderosa)			Ignites	10	16	21
<u>Construction Materials</u>						
Roll roofing, mineral surface			Ignites		>34	>116
Roll roofing, smooth surface			Ignites		30	77
Plywood, douglas fir			Flaming during exposure	9	16	20
Rubber, pale latex			Ignites	50	80	110
Rubber, black			Ignites	10	20	25
<u>Other Materials</u>						
Aluminum aircraft skin (0.020 in. thick) coated with 0.002 in. of standard white aircraft paint			Blisters	15	30	40
Cotton canvas sandbags, dry-filled			Failure	10	18	32
Coral sand			Explodes (popcorning)	15	27	47
Siliceous sand			Explodes (popcorning)	11	19	35

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Conditions of failure of overpressure-sensitive elements.

Structural element	Failure	Peak overpressure (psi)
Glass windows, large and small	Shattering usually, occasional frame failure	0.5–1.0
Corrugated asbestos siding	Shattering	1.0–2.0
Corrugated steel or aluminum paneling	Connection failure followed by buckling	1.0–2.0
Brick wall panel, 8- or 12-in. thick (not reinforced)	Shearing and flexure failures	3.0–10.0
Wood siding panels, standard house construction	Usually failure occurs at the main connections allowing a whole panel to be blown in	1.0–2.0
Concrete or cinder-block wall panels, 8- or 12-in. thick (not reinforced)	Shattering of the wall	1.5–5.5

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Nuclear Explosion Example

What are the prompt radiation effects from the surface detonation of a 1-kt fission device? Assume the atmospheric visibility is 50 miles, and the effective wind speed is 15 mph.

SURFACE-BURST NUCLEAR DETONATION

YIELD : 1.00 kilotons
EFFECTIVE WIND SPEED : 15.00 mph
BLAST DATA ARE MAXIMUM OVERPRESSURE

NOTE: Temporary flash blindness can occur at 0.0001 cal/cm²
and retinal burns at 0.16 cal/cm²

D = 0.10 km		D = 0.20 km		D = 0.50 km	
BLAST	1.1E+02 psi	BLAST	2.3E+01 psi	BLAST	4.1E+00 psi
NEUTRON	1.2E+07 rad	NEUTRON	1.1E+05 rad	NEUTRON	1.8E+03 rad
GAMMA	1.7E+04 rad	GAMMA	9.1E+03 rad	GAMMA	1.3E+03 rad
TOTAL	1.2E+07 rad	TOTAL	1.2E+05 rad	TOTAL	3.1E+03 rad
THERMAL	3.2E+02 cal/cm2	THERMAL	7.9E+01 cal/cm2	THERMAL	1.3E+01 cal/cm2
D = 1.00 km		D = 2.00 km		D = 5.00 km	
BLAST	1.5E+00 psi	BLAST	6.3E-01 psi	MINIMAL BLAST and RAD	
NEUTRON	4.4E+01 rad	NEUTRON	1.1E-01 rad		
GAMMA	6.1E+01 rad	GAMMA	5.0E-01 rad		
TOTAL	1.0E+02 rad	TOTAL	6.1E-01 rad		
THERMAL	3.1E+00 cal/cm2	THERMAL	7.5E-01 cal/cm2	THERMAL	1.1E-01 cal/cm2
FALLOUT		***FALLOUT***		***FALLOUT***	
ARRIVES IN	0.04 Hour	ARRIVES IN	0.08 Hour	ARRIVES IN	0.21 Hour
H+1 :	6.6E+03 rem/hr	H+1 :	2.1E+03 rem/hr	H+1 :	4.5E+02 rem/hr
INITIAL EXTERNAL RATE		INITIAL EXTERNAL RATE		INITIAL EXTERNAL RATE	
AT CLOUD ARRIVAL TIME		AT CLOUD ARRIVAL TIME		AT CLOUD ARRIVAL TIME	
IS 3.0E+05 rem/hr		IS 4.2E+05 rem/hr		IS 3.0E+03 rem/hr	
DOSE IN FIRST:		DOSE IN FIRST:		DOSE IN FIRST:	
HOURL	3.0E+04 rem	HOURL	6.7E+03 rem	HOURL	8.4E+02 rem
DAY	4.5E+04 rem	DAY	1.2E+04 rem	DAY	1.9E+03 rem
WEEK	5.1E+04 rem	WEEK	1.3E+04 rem	WEEK	2.3E+03 rem
MONTH	5.4E+04 rem	MONTH	1.4E+04 rem	MONTH	2.5E+03 rem
YEAR	5.7E+04 rem	YEAR	1.5E+04 rem	YEAR	2.7E+03 rem
50-YEARS	6.0E+04 rem	50-YEARS	1.6E+04 rem	50-YEARS	2.9E+04 rem
D = 1.00 km		D = 2.00 km		D = 5.00 km	
MINIMAL BLAST and RAD		MINIMAL BLAST and RAD		MINIMAL BLAST and RAD	
THERMAL	2.4E-02 cal/cm2	THERMAL	4.4E-03 cal/cm2	THERMAL	2.8E-04 cal/cm2
FALLOUT		***FALLOUT***		***FALLOUT***	
ARRIVES IN	0.41 Hour	ARRIVES IN	0.83 Hour	ARRIVES IN	2.07 Hour
H+1 :	1.4E+02 rem/hr	H+1 :	4.5E+01 rem/hr	H+1 :	3.0E+00 rem/hr
INITIAL EXTERNAL RATE		INITIAL EXTERNAL RATE		INITIAL EXTERNAL RATE	
AT CLOUD ARRIVAL TIME		AT CLOUD ARRIVAL TIME		AT CLOUD ARRIVAL TIME	
IS 4.1E+02 rem/hr		IS 5.6E+01 rem/hr		IS 1.3E+00 rem/hr	
DOSE IN FIRST:		DOSE IN FIRST:		DOSE IN FIRST:	
HOURL	1.4E+02 rem	HOURL	8.6E+00 rem	HOURL	0.0E+00 rem
DAY	4.7E+02 rem	DAY	1.1E+02 rem	DAY	5.0E+00 rem
WEEK	5.9E+02 rem	WEEK	1.5E+02 rem	WEEK	7.6E+00 rem
MONTH	6.6E+02 rem	MONTH	1.7E+02 rem	MONTH	9.0E+00 rem
YEAR	7.3E+02 rem	YEAR	2.0E+02 rem	YEAR	1.1E+01 rem
50-YEARS	7.9E+02 rem	50-YEARS	2.2E+02 rem	50-YEARS	1.2E+01 rem

182-S/1207-SBND

General Plume

Assumptions:

- The default respirable fraction of the total material involved in the release is dependent upon the type of material input, e.g., 1.00 for noble gases, 0.0005 for plutonium, etc. For non-noble gas radionuclides, the respirable fraction is defined as the fraction of the released material associated with an Activity Median Aerodynamic Diameter (AMAD) of 1 mm (see Appendix B). The default ICRP-30 internal dosimetry conversion factors also assume a AMAD particle-size distribution of 1 μm .
- Standard-person breathing rate is 1.2 m³/hr.

General Plume Example

Estimate the dose commitments from a release of 20,000 Ci of ^{85}Kr from a 10-m stack. The wind is from the east at 1 m/sec on a sunny day.

HOTSPOT: GENERAL PLUME

RADIONUCLIDE : KR-85 Inhalation Class : N/A

HALFLIFE : 10.720 Years

SOURCE TERM : 2.0E+04Ci

RELEASE FRACTION : 1.00E+00

FILTER EFFICIENCY : 0.00000%

EFFECTIVE RELEASE HEIGHT: 10.00 m

WINDSPEED (h=2m): 1.0 m/s

WIND SPEED (h=H-eff): 1.1 m/s

STABILITY CLASS : A

RECEPTOR HEIGHT : 0.0 m

SAMPLE TIME : 10.000 min

MAXIMUM DOSE DISTANCE : < 0.1 km

Plume Centerline

DEPOSITION VELOCITY : 0.0E+00 cm/s

INVERSION LAYER HEIGHT : NONE

MAXIMUM CEDE : > 5.4E-03 rem

D = 0.10 km

CHI = 1.1E+01 (Ci-s)m³

50-YR DOSE COMMITMENT:

EFFECTIVE DOSE

EQUIVALENT 5.4E-03 rem

D = 0.20 km

CHI = 3.2E+00 (Ci-s)m³

50-YR DOSE COMMITMENT:

EFFECTIVE DOSE

EQUIVALENT 1.5E-03 rem

D = 0.50 km

CHI = 5.3E-01 (Ci-s)m³

50-YR DOSE COMMITMENT:

EFFECTIVE DOSE

EQUIVALENT 2.5E-04 rem

D = 1.00 km

CHI = 1.4E-01 (Ci-s)m³

50-YR DOSE COMMITMENT:

EFFECTIVE DOSE

EQUIVALENT 6.4E-05 rem

D = 2.00 km

CHI = 3.5E-02 (Ci-s)m³

50-YR DOSE COMMITMENT:

EFFECTIVE DOSE

EQUIVALENT 1.7E-05 rem

D = 5.00 km

CHI = 6.3E-03 (Ci-s)m³

50-YR DOSE COMMITMENT:

EFFECTIVE DOSE

EQUIVALENT 3.0E-06 rem

D = 10.00 km

CHI = 1.8E-03 (Ci-s)m³

50-YR DOSE COMMITMENT:

EFFECTIVE DOSE

EQUIVALENT 8.7E-07 rem

D = 20.00 km

CHI = 5.6E-04 (Ci-s)m³

50-YR DOSE COMMITMENT:

EFFECTIVE DOSE

EQUIVALENT 2.7E-07 rem

D = 50.00 km

CHI = 1.3E-04 (Ci-s)m³

50-YR DOSE COMMITMENT:

EFFECTIVE DOSE

EQUIVALENT 6.0E-08 rem

18-S/1207-GP

General Explosion

Assmptions:

- The default respirable fraction of the total material released from the explosion is dependent upon the type of material input, e.g., 1.00 for noble gases, 0.20 for plutonium, etc. For non-noble gases radionuclides, the respirable fraction is defined as the fraction of the released material associated with an Activity Median Aerodynamic Diameter (AMAD) of 1 mm (see Appendix B). The default ICRP-30 internal dosimetry conversion factors also assume a AMAD particle-size distribution of 1 μm .
- Standard-person breathing rate is 1.2 m³/hr.

General Explosion Example

A vehicle, transporting 30 Ci of ^{131}I , 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 m/sec on a cloudy day. Assuming the release fraction is 1.0, estimate the 50-year CEDE as a function of downwind distance from this accident scene. Note: a conservative estimate of the TNT equivalent of an exploding vehicle gas tank is 1 lb.

HOTSPOT:GENERAL EXPLOSION

RADIONUCLIDE : I-131 Inhalation Class: D

HALFLIFE : 8.045 days

SOURCE TERM : 3.0E+01 Ci

RELEASE FRACTION : 1.00E+00

HIGH EXPLOSIVE : 1.0 LBS

CLOUD TOP : 76 m

WINDSPEED (h=2m): 2.0 m/s

STABILITY CLASS : C

RECEPTOR HEIGHT : 0.0 m

MAXIMUM DOSE DISTANCE : < 0.0 km

Plume Centerline

DEPOSITION VELOCITY : 1.00 cm/s

INVERSION LAYER HEIGHT : 5000.0 m

MAXIMUM CEDE : > 0.031 rem

D = 0.10 km
DEP = 2.9E+01 uCi/m²
CHI = 2.9E-03 (Ci-s)m³

D = 0.20 km
DEP = 2.0E+01 uCi/m²
CHI = 2.0E-03 (Ci-s)m³

D = 0.50 km
DEP = 8.3E+00 uCi/m²
CHI = 8.3E-04 (Ci-s)m³

50-YR DOSE COMMITMENT:

THYROID 1.1E+00 rem
EFFECTIVE DOSE
EQUIVALENT 3.1E-02 rem

50-YR DOSE COMMITMENT:

THYROID 7.2E-01 rem
EFFECTIVE DOSE
EQUIVALENT 2.1E-02 rem

50-YR DOSE COMMITMENT:

THYROID 3.0E-01 rem
EFFECTIVE DOSE
EQUIVALENT 8.8E-03 rem

D = 1.00 km
DEP = 3.2E+00 uCi/m²
CHI = 3.2E-04 (Ci-s)m³

D = 2.00 km
DEP = 1.0E+00 uCi/m²
CHI = 1.0E-04 (Ci-s)m³

D = 5.00 km
DEP = 2.3E-01 uCi/m²
CHI = 2.3E-05 (Ci-s)m³

50-YR DOSE COMMITMENT:

THYROID 1.2E-01 rem
EFFECTIVE DOSE
EQUIVALENT 3.4E-03 rem

50-YR DOSE COMMITMENT:

THYROID 3.8E-02 rem
EFFECTIVE DOSE
EQUIVALENT 1.1E-03 rem

50-YR DOSE COMMITMENT:

THYROID 8.5E-03 rem
EFFECTIVE DOSE
EQUIVALENT 2.5E-04 rem

18-S/1207-GE

General Fire

Assmptions:

- The default respirable fraction of the total material released from the fire is dependent upon the type of material input, e.g., 1.00 for noble gases, 0.0005 for plutonium, etc. For non-noble-gas radionuclides, the respirable fraction is defined as the fraction of the released material associated with an Activity Median Aerodynamic Diameter (AMAD) of 1 mm (see Appendix B). The default ICRP-30 internal dosimetry conversion factors also assume a AMAD particle-size distribution of 1 μm .
- The effective release height is determined using the methodology contained in the *Fuel Fire* section of Appendix B. Once the effective release height is determined, the radius of the final bent-over plume is set equal to 60% of the effective release height (Hanna, 1982). An upwind virtual point source, resulting in an initial σ_y and σ_z equal to 50% of the plume radius at the origin (i.e., plume radius = 2σ), models the fire scenario.
- Standard-person breathing rate is 1.2 m^3/hr .

General Fire Example

Fifty curies of ^{241}Am are involved in a laboratory fire. The effective radius of the fire is 20 m. The sun is low in the sky, and the wind speed is approximately 4 m/sec. The observed cloud top of the plume is approximately 20 m above the ground. Estimate the ground contamination and 50-year CEDEs as a function of downwind centerline distance.

HOTSPOT:	GENERAL FIRE	
RADIONUCLIDE:	AM-241 Inhalation Class: W	HALFLIFE: 432.2 years
SOURCE TERM:	5.0E+01 Ci	
RELEASE FRACTION:	5.00E-04	RELEASE RADIUS: 20.0 m
EFFECTIVE RELEASE HEIGHT:	10.0 m	
WIND SPEED (h=2m):	4.0 m/s	
WIND SPEED (h=H-eff):	4.7 m/s	
STABILITY CLASS:	C	DEPOSITION VELOCITY : 1.00 cm/s
RECEPTOR HEIGHT:	0.0 m	INVERSION LAYER HEIGHT : 5000.0 m
SAMPLE TIME:	10.000 min	
MAXIMUM DOSE DISTANCE:	<0.1 km	MAXIMUM CEDE : >0.673 rem

D = 0.10 km
 DEP = 3.9E-02 uCi/m²
 CHI = 3.9E-06 (Ci-s)/m³

50-YR DOSE COMMITMENT:

SURFACE BONE	1.2E+01 rem
RED MARROW	9.6E-01 rem
LIVER	2.6E+00 rem
GONADS	1.6E-01 rem
EFFECTIVE DOSE	
EQUIVALENT	6.7E-01 rem

D = 0.20 km
 DEP = 1.9E-02 uCi/m²
 CHI = 1.9E-06 (Ci-s)/m³

50-YR DOSE COMMITMENT:

SURFACE BONE	6.0E+00 rem
RED MARROW	4.7E-01 rem
LIVER	1.3E+00 rem
GONADS	7.7E-02 rem
EFFECTIVE DOSE	
EQUIVALENT	3.3E-01 rem

D = 0.50 km
 DEP = 5.3E-03 uCi/m²
 CHI = 5.3E-07 (Ci-s)/m³

50-YR DOSE COMMITMENT:

SURFACE BONE	1.7E+00 rem
RED MARROW	1.3E-01 rem
LIVER	3.6E-01 rem
GONADS	2.1E-02 rem
EFFECTIVE DOSE	
EQUIVALENT	9.3E-02 rem

D = 1.00 km
 DEP = 1.7E-03 uCi/m²
 CHI = 1.7E-07 (Ci-s)/m³

50-YR DOSE COMMITMENT:

SURFACE BONE	5.3E-01 rem
RED MARROW	4.2E-02 rem
LIVER	1.1E-01 rem
GONADS	6.8E-03 rem
EFFECTIVE DOSE	
EQUIVALENT	3.0E-02 rem

D = 2.00 km
 DEP = 5.3E-04 uCi/m²
 CHI = 5.3E-08 (Ci-s)/m³

50-YR DOSE COMMITMENT:

SURFACE BONE	1.6E-01 rem
RED MARROW	1.3E-02 rem
LIVER	3.5E-02 rem
GONADS	2.1E-03 rem
EFFECTIVE DOSE	
EQUIVALENT	9.1E-03 rem

D = 5.00 km
 DEP = 1.2E-04 uCi/m²
 CHI = 1.2E-08 (Ci-s)/m³

50-YR DOSE COMMITMENT:

SURFACE BONE	3.6E-02 rem
RED MARROW	2.9E-03 rem
LIVER	7.7E-03 rem
GONADS	4.6E-04 rem
EFFECTIVE DOSE	
EQUIVALENT	2.0E-03 rem

18-S/1207-GF

General Resuspension

Assumptions:

- Resuspension is modeled using the methodology contained in the Resuspension section of Appendix B.
- Standard-person breathing rate is $1.2 \text{ m}^3/\text{hr}$.

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 ^{244}Cm . Most of the curium is contained in an area with an effective radius of 50 m. The average contamination level is $1,000 \mu\text{Ci}/\text{m}^2$. Assume the resuspension factor, for the 3 m/sec prevailing wind, is $1 \times 10^{-5} \text{ m}^{-1}$ for the curium. The sun is high in a cloudless sky.

HOTSPOT:	RESUSPENSION 4-14-1994 13:03	
RADIONUCLIDE:	CM-244 Inhalation Class: W	
HALFLIFE:	18.110 years	
RESUSPENSION FACTOR:	$1.0\text{E}-05 \text{ 1/m}$	
EFF. RADIUS:	50 m	
AVG. DEPOSITION:	$1.0\text{E}+03 \text{ uCi/m}^2$	
EFFECTIVE RELEASE HEIGHT:	0.00 m	
WIND SPEED (h=2 m):	3.0 m/s	
STABILITY CLASS:	A	DEPOSITION VELOCITY : 1.00 cm/s
RECEPTOR HEIGHT:	0.0 m	INVERSION LAYER HEIGHT : NONE
SAMPLE TIME:	60.000 min	
MAXIMUM DOSE DISTANCE:	< 0.1 km	MAXIMUM CEDE : > 0.627 rem
Plume Centerline		

D = 0.10 km
CHI = $1.9\text{E}-09 \text{ Ci/m}^3$

50-YR DOSE COMMITMENT:
PER 1-HR EXPOSURE TIME

SURFACE BONE	$1.1\text{E}+01 \text{ rem}$
RED MARROW	$8.6\text{E}-01 \text{ rem}$
LIVER	$2.6\text{E}+00 \text{ rem}$
GONADS	$1.4\text{E}-01 \text{ rem}$
EFFECTIVE DOSE	
EQUIVALENT	$6.3\text{E}-01 \text{ rem}$

D = 1.00 km
CHI = $7.2\text{E}-11 \text{ Ci/m}^3$

50-YR DOSE COMMITMENT:
PER 1-HR EXPOSURE TIME

SURFACE BONE	$4.2\text{E}-01 \text{ rem}$
RED MARROW	$3.2\text{E}-02 \text{ rem}$
LIVER	$9.6\text{E}-02 \text{ rem}$
GONADS	$5.1\text{E}-03 \text{ rem}$
EFFECTIVE DOSE	
EQUIVALENT	$2.3\text{E}-02 \text{ rem}$

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D = 0.20 km
CHI = $9.0\text{E}-10 \text{ Ci/m}^3$

50-YR DOSE COMMITMENT:
PER 1-HR EXPOSURE TIME

SURFACE BONE	$5.2\text{E}+00 \text{ rem}$
RED MARROW	$4.0\text{E}-01 \text{ rem}$
LIVER	$1.2\text{E}+00 \text{ rem}$
GONADS	$6.3\text{E}-02 \text{ rem}$
EFFECTIVE DOSE	
EQUIVALENT	$2.9\text{E}-01 \text{ rem}$

D = 2.00 km
CHI = $2.1\text{E}-11 \text{ Ci/m}^3$

50-YR DOSE COMMITMENT:
PER 1-HR EXPOSURE TIME

SURFACE BONE	$1.2\text{E}-01 \text{ rem}$
RED MARROW	$9.2\text{E}-03 \text{ rem}$
LIVER	$2.7\text{E}-02 \text{ rem}$
GONADS	$1.5\text{E}-03 \text{ rem}$
EFFECTIVE DOSE	
EQUIVALENT	$6.7\text{E}-03 \text{ rem}$

D = 0.50 km
CHI = $2.4\text{E}-10 \text{ Ci/m}^3$

50-YR DOSE COMMITMENT:
PER 1-HR EXPOSURE TIME

SURFACE BONE	$1.4\text{E}+00 \text{ rem}$
RED MARROW	$1.0\text{E}-01 \text{ rem}$
LIVER	$3.1\text{E}-01 \text{ rem}$
GONADS	$1.7\text{E}-02 \text{ rem}$
EFFECTIVE DOSE	
EQUIVALENT	$7.6\text{E}-02 \text{ rem}$

D = 5.00 km
CHI = $3.9\text{E}-12 \text{ Ci/m}^3$

50-YR DOSE COMMITMENT:
PER 1-HR EXPOSURE TIME

SURFACE BONE	$2.3\text{E}-02 \text{ rem}$
RED MARROW	$1.7\text{E}-03 \text{ rem}$
LIVER	$5.2\text{E}-03 \text{ rem}$
GONADS	$2.8\text{E}-04 \text{ rem}$
EFFECTIVE DOSE	
EQUIVALENT	$1.3\text{E}-03 \text{ rem}$

3. Radionuclides in the Workplace

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. 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.
- Quantity of the radionuclide to be used.
- Nature of the operation to be performed.
- Mass of the material in which the radioactivity is contained.

The following method, used at the Lawrence Livermore National Laboratory, guides the initial planning of operations involving radioactive material. *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 (solid, powder, etc.), volatility, pyrophoric properties, ability to penetrate skin, radiation dose rate, and the experience of the experimenter. However, it is a good starting point for planning work involving radioactive material and provides a consistent initial workplace recommendation.

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 waste generated in the workplace.

Type 3 Workplaces

Type 3 workplaces are used for operations classed 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 (HEPA) system. Other protective devices (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.
- 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 should be 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—

$$H = QTU/\sqrt{m} \quad , \quad (\text{Eq. 3-1})$$

where—

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

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

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
$\leq 10^7$	Type 1
$> 10^7$ and $< 10^{10}$	Type 2
$\geq 10^{10}$	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. ICRP Publication 30 lists the DAC for most radionuclides.

$$T = \text{DAC (HTO)} / \text{DAC (Radionuclide under consideration)}.$$

NOTE: Radionuclides labeled to molecules (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 or grinding of dry material). The respirable fraction is defined as the fraction of the released material associated with an Activity Median Aerodynamic Diameter (AMAD) of 1 μm (see Appendix B). The default ICRP-30 internal dosimetry conversion factors also assume an AMAD of 1 μm . 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 Washing precipitates	0.1
Normal No production of dry material No vigorous chemical reactions Precipitation Filtration or centrifuging Solvent extraction Chromatography Pipetting or titration Ambient temperatures	1

Use factors as a function of operation. (cont.)

Simple, dry	
Fusion reactions	
Fluorination	5
Transfer of dry precipitates	
<hr/>	
Complex, wet	
Distillation	
Evaporation to dryness	50
Elevated temperatures	
<hr/>	
Dry and dusty	
Machine or hand-crushing	
Machining or sawing	500
Sieving	
Mixing	
<hr/>	

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. Also, 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.

Example 1

An experimenter wants to pipette a solution containing a total of 500 μCi of class W ^{239}Pu (PU-239W). The activity concentration of the solution is 20 $\mu\text{Ci/g}$ (therefore total mass is 25 g). What type of workplace should be recommended for this *simple* operation?

HOTSPOT OUTPUT:**Radionuclide: PLUTONIUM 239****Inhalation Class: W****Half-life: 2.4E+04 Years****Type of Operation is Simple Wet****Quantity of material is 5.0E+02 microcurie****Hazard Guide Value: H = 1.0E+08****RECOMMENDED WORKPLACE: TYPE 2**

Example 2

You are responsible for preparing soil samples following a nuclear-weapons accident involving plutonium. The operation will involve mixing the 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 of the order of $100 \mu\text{Ci}/\text{m}^2$ of weapons-grade plutonium. The radiotoxicity of weapons-grade plutonium is well represented by assuming the radionuclide is ^{239}Pu (inhalation class Y). Each soil sample has a mass of approximately 100 g and is representative of a ground area of 100 cm^2 (therefore, the total activity per sample is $1 \mu\text{Ci}$). A maximum of 10 soil samples will be processed at any one time. What type of work environment should you recommend for this operation?

HOTSPOT OUTPUT:**Radionuclide: PLUTONIUM 239****Inhalation Class : Y****Half-life: 2.4E+04 Years****Type of Operation is Dry Dusty****Quantity of material is 1.0E+01 microcurie****Hazard Guide Value: H = 5.3E+08****RECOMMENDED WORKPLACE: TYPE 2**

What is the maximum quantity of plutonium recommended for a Type 2 workplace?

Radionuclide: PLUTONIUM 239**Inhalation Class : Y****Half-life: 2.4E+04 Years****Type of Operation is Dry Dusty****MAXIMUM ACTIVITY FOR A TYPE 1 WORKPLACE IS: 1.9E-01 microcuries****MASS OF RADIONUCLIDE : 3.0E-06 gram****MASS OF INERT MATERIAL : 1.0E+03 gram****TOTAL MASS (Radionuclide +
Inert material) : 1.0E+03 gram****MAXIMUM ACTIVITY FOR A TYPE 2 WORKPLACE IS: 1.9E+02 microcuries****MASS OF RADIONUCLIDE : 3.0E-03 gram****MASS OF INERT MATERIAL : 1.0E+03 gram****TOTAL MASS (Radionuclide +
Inert material) : 1.0E+03 gram**

4. FIDLER Calibration

This program calibrates a FIDLER (Field Instrument for the Detection of Low-Energy Radiation) to measure 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 ^{137}Cs ground contamination.

When measuring plutonium ground contamination, the FIDLER is typically calibrated for the 60-keV gamma ray from the ^{241}Am component of the mixture (typically of the order of 1000s of ppm by weight), or the low-energy x rays centered around 17 keV. Measurements using the x rays are very sensitive to overburden, e.g., rain, contamination fixative, dust, etc., and generally not recommended. Measurements using the 60-keV gamma from ^{241}Am 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, 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.

Calibration of the FIDLER Detector

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 4-1, the most obvious method is suspending the detector over a known area source. Here, every square meter of the source contains, for example, 1 μCi of ^{241}Am , and the counts per minute (cpm) indicated on the instrument is, by definition, the areal counting efficiency for ^{241}Am (cpm/ $[\mu\text{Ci}\cdot\text{m}^2]$). However, such a source is not practical in terms of size, cost, and transportability.

The following procedure describes a method for calibrating a detector to measure surface contamination with a single-point check source. Figure 4-2 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, e.g., a 2-in. diam. $\times$ 2-in.-thick NaI(Tl) detection system for surveying ^{137}Cs ground contamination.

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The primary goal of the calibration procedure is determining 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 (S_a). 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. Here, we must account for the instrument's sensitivity for off-axis radiation sources and field of view. Figure 4-3 shows the count rate for a typical FIDLER system as a function of radial position of a 5.9- μCi ^{241}Am check source.

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Determination of the Areal Counting Efficiency (S_a)

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

$$S_a = \frac{1}{q} \int C(r) dA \quad (\text{Eq. 4-1})$$

where—

q = Activity in area, dA (μCi).

$C(r)$ = Count rate from activity (q) in area, dA .

Because $dA = r dr d\theta$,

$$S_a = \int_0^{2\pi} \int_0^R \frac{1}{q} C(r) r dr d\theta \quad (\text{Eq. 4-2})$$

$$S_a = \frac{2\pi}{q} \int_0^R C(r) r dr, \quad \frac{\text{cpm} \cdot \text{m}^2}{\mu\text{Ci}} \quad (\text{Eq. 4-3})$$

The determination of the areal counting efficiency requires the evaluation of the integral in Eq. 4-3. As shown in Fig. 4-2, the FIDLER program requires check source measurements at 6 locations (r_0 - r_5), 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 Eq. 4-3,

$$S_a = \frac{2\pi}{q} \left[\sum_{n=0}^4 a_n \int_{r_n}^{r_{n+1}} re^{b_n r} dr + a_4 \int_{r_5}^{\infty} re^{b_4 r} dr \right] \quad (\text{Eq. 4-4})$$

$$S_a = \frac{2\pi}{q} \left[\sum_{n=0}^4 \frac{a_n}{b_n^2} \left[e^{b_n r_{n+1}} (b_n r_{n+1} - 1) - e^{b_n r_n} (b_n r_n - 1) \right] - \frac{a_4}{b_4^2} e^{b_4 r_5} (b_4 r_5 - 1) \right] \quad (\text{Eq. 4-5})$$

where—

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

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

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

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

$$S_{\text{mix}} = \frac{S_a}{f} , \quad \frac{\text{counts} - m^2}{\text{min} - \mu\text{Ci}_{\text{mix}}} \quad (\text{Eq. 4-6})$$

where f = the ratio of alpha μCi of mix to μCi of ^{241}Am .

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 follows:

"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% ^{241}Am , the f ratio = 1, and no adjustment of the S_a value is required. If you are calibrating the FIDLER using the 17-keV window, the x-ray abundance ratio of the ^{241}Am 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, e.g., ^{137}Cs , 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 on the K ratio is possible. The K ratio is defined as the ratio (K) of the areal source counting efficiency (S_a) to the point source counting efficiency (S_p).

$$K = \frac{S_a}{S_p}, \quad \text{m}^2 \quad (\text{Eq. 4-7})$$

where—

S_a = cpm per $\mu\text{Ci}/\text{m}^2$.

S_p = cpm per μCi .

Once the K ratio has been determined for a particular instrument geometry, the ratio will remain relatively constant. The electronics might drift (e.g., the PRM-5-3 window shift away from the desired photopeak), but the system's K ratio will not be affected. In other words, the S_a and S_p can change, but their ratio will remain constant. The "quick" calibration consists of measuring the point source efficiency (S_p) with an ^{241}Am check source. The FIDLER's areal counting efficiency is then calculated by multiplying S_p by the K ratio. Any changes in the detection system will be accounted for by the current S_p 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 ($K \times S_p$). 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.

Scaler: (from Currie, 1975)

$$\text{LOS} = \frac{2.7 + 4.65\sqrt{r_b/t_s}}{S_a}, \quad \mu\text{Ci} \quad (\text{Eq. 4-8})$$

Rate Meter:

$$LOS = \frac{3.3\sqrt{r_b/2RC}}{S_a} , \mu\text{Ci} \quad (\text{Eq. 4-9})$$

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/ $[\mu\text{Ci}/\text{m}^2]$).

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 Procedure

This procedure describes the six-point method of calibrating a FIDLER instrument with a single ^{241}Am check source. Calibrating the FIDLER to measure ^{238}Pu using a ^{238}Pu check source demonstrates a radionuclide-specific calibration.

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 (S_a). Additionally, the Limit of Sensitivity (LOS) for both a distributed area source and a single point source are determined.

To access the FIDLER program, type M at the HOTSPOT main menu. This takes you to the FIDLER main menu. Note: if you have insufficient memory, FIDLER will not load. In this case, you need to exit HOTSPOT and run the program named FIDLER directly (type "FIDLER" at the DOS prompt).

HOTSPOT HEALTH PHYSICS CODES FIDLER CALIBRATION	F: FIDLER SETUP
<div style="border: 1px solid black; padding: 2px; display: inline-block;"> Q:QUIT </div>	<p> C: CALIBRATE detector D: DISPLAY calibration data to screen S: SAVE calibration data to disc R: RETRIEVE calibration data from disc M: Current radionuclide MIXTURE data E: EDIT calibration data L: Detector calibration LIBRARY P: PLUTONIUM LUNG SCREENING </p>	

**** Enter Selection ****

18-S/1207-I-1

Place the FIDLER at a ground-to-detector-face distance equal to the height you will be using the instrument for your ground survey, preferably using a tripod stand, etc. The standard survey height is 30 cm.

²⁴¹Am Check Source Calibration

Use this method if you are using an ²⁴¹Am check source. If you are using a ²³⁸Pu check source, skip to the section titled *²³⁸Pu Check Source Calibration*, page 4-10.

The FIDLER Library contains several example calibration files using a plutonium mixture (Appendix D). The following procedure will retrieve this mixture for the current calibration. If you prefer to enter your own mix, proceed to the section titled *Saving Calibration Data to Disc*, page 4-13.

Retrieve A Previously Stored Plutonium Mix From Disc

Select "R" (Press the "R" key—no ENTER is required) to retrieve calibration data from the FIDLER Library. You will be prompted with—

DO YOU WISH TO BROWSE THE DETECTOR LIBRARY FIRST ? (Y/N)

Enter "Y" to review the current list of calibration files contained on your FIDLER disc. The first file contains a standard weapons-grade plutonium mixture.

Press ENTER to be prompted for a file number, enter the number "1," and press ENTER again. The displayed calibration chart, for calibration file number 1, contains the desired plutonium mixture.

Press ENTER to return to the main FIDLER menu. We are now ready to calibrate a new FIDLER instrument. Select the "C" option. The following prompt appears:

START OVER WITH NEW MIXTURE ? (Y/N)

We want to use the currently retrieved mixture, so enter "N." Again, the current calibration data appear for confirmation of the mixture. Push ENTER, and the following menu appears.

Enter a selection NUMBER

1: K factor known (or accept a default value)

2: Determine Sa, and K Factor (Full calibration)

Q:

18-S/1207-I-2

We will use the full six-point method, so enter "2," and follow the prompted instructions.

SCALER ? (Y/N)

If you are using a scaler (e.g., Eberline ESP-2), enter "Y." Otherwise, enter "N" [therefore a rate meter (e.g., PRM-5) is assumed]. If you selected the scaler option, you will be prompted for the "SAMPLE TIME." Enter the sample time, e.g., one min, and press ENTER. If you are using a rate meter, enter the appropriate RC time constant of your instrument (e.g., 0.2 min), and press ENTER.

The next series of prompts allows you to enter the detector's identification information (e.g., the FIDLER serial number, etc.). Your calibration data will be stored using this identification information. You can always use the FIDLER EDIT feature to change the information at a later time.

The next prompt is detector height. Enter the distance between the detector face and the check source, and press ENTER. This input is merely for documentation of the detector height used for your calibration and survey data. Make sure you calibrate the detector for the same height used in your survey.

After the detector height is input the following prompt appears:

Select Calibration Option
1: 60 keV region
2: 17 keV region
3: Both 60 keV and 17 keV regions

Enter selection

18-S/1207-I-3

In this example, we will calibrate the FIDLER for both the 17-keV x-ray window and the 60-keV window, so enter "3." You will then be prompted for ²⁴¹Am check source data. Enter the check source activity, and SELF(17) factor. Most "thin/massless" check sources have a SELF(17) of 1.0, i.e., 100% of the x rays are transmitted through the check source coating. After entering the SELF (17) factor, the following prompt appears:

BKGD (17 keV)?

Enter the background COUNT RATE (CPM) and press ENTER. Enter CPM, even if you determined the count rate via a 10-min count, etc. (e.g., CPM = TOTAL COUNTS/10). The reported Limit of Sensitivity (LOS) will be based on this background count rate and the sample time or RC time constant.

You will be prompted to confirm the background input. If the count rate is correct, enter "Y." If the count rate is not correct, enter "N," and you will recycle through the background input sequence.

Following the confirmation of the 17-keV window data, you will be prompted for 60-keV window data. The next series of prompts will sequentially ask for the 17-keV and 60-keV window count rates at the six radial positions, 0, 20, 40, 60, 80, and 100 cm.

Upon confirming the last input (100-cm distance), the final calibration data is displayed on the computer monitor. You can print these summary data to a printer using the "Prt Sc" (PRINT SCREEN) key on your computer.

Isotope	Halflife (years)	Initial (weight %)	@ Age = 20.0 YR (weight %)	Americium-241 Check Source Data 5.900 uCi SELF (17) = 1.000
PU-238	87.74	0.0400	0.0342	
PU-239	24065	93.3400	93.2862	
PU-240	6537	6.0000	5.9873	
PU-241	14.35	0.5800	0.2207	
PU-242	376300	0.0400	0.0400	
AM-241	432.2	0.0000	0.3527	

Source-To-Detector Height = 30 cm Sample-Time = 1.00 min

ALPHA Curie: 9.0E-02 curies/gram

1 microcurie of Am-241 = 7.41E+00 alpha microcurie of Mix

*** The following data are for uCi of MIX***

WINDOW	EFFICIENCY	(Sa)	DETECTION	LIMITS	BKGD	SOURCE	K	SDEV
(keV)	cpm	cpm	Area	Point	cpm	cpm	m^2	(%)
	ug/m^2	uCi/m^2	uCi/m^2	uCi	cpm	cpm		
17	2.0E+01	2.3E+02	4.5E-01	1.5E-01	450	15048	0.34	7
60	3.8E+01	4.2E+02	3.1E-01	1.6E-01	750	36835	0.51	4

Eberline 33425 66776 7-14-93 10:21

18-S/1207-I-4

²³⁸Pu Check Source Calibration

This is an example of calibrating the FIDLER using a check source identical to the contamination to be measured. This particular example assumes you will use a ²³⁸Pu source to calibrate the FIDLER for a ²³⁸Pu ground survey using the 17-keV window.

Select the "C" option. The following menu appears.

Enter a selection NUMBER

- 1: K factor known (or accept a default value)
- 2: Determine Sa, and K Factor (Full calibration)

Q: NO! Leave Calibration alone and RETURN to main menu

We will use the full six-point calibration method, so enter "2" and the following menu appears.

<p style="text-align: center;">Select Target Mixture</p> <p>P: PLUTONIUM MIXTURE O: OTHER (e.g., cesium-137, etc.)</p>

Enter Selection

18-S/1207-I-6

Select option "O," (Other), and the following prompt appears:

ENTER RADIONUCLIDE NAME (e.g., cesium-137, CS-137, etc.), and press "ENTER"

Enter "PU-238" and press ENTER. A confirmation display appears. Press ENTER again, and follow the prompted instructions.

If you are using a scaler (e.g., Eberline ESP-2), enter "Y." Otherwise, enter "N" [therefore a rate meter (e.g., PRM-5) is assumed]. If you selected the scaler option, you will be prompted for the "SAMPLE TIME." Enter the sample time (e.g., one min), and press ENTER. If you are using a rate meter, enter the appropriate RC time constant of your instrument (e.g., 0.2 min), and press ENTER.

The next series of prompts allows you to enter detector identification information (e.g., FIDLER serial number, etc.) Your calibration data will be stored using this identification information.

The next prompt is detector height. Enter the distance between the detector face and the check source, and press ENTER. This input merely documents the detector height used for your calibration and survey results. Make sure you calibrate the detector for the same height used in your survey.

Upon entering the detector height, and pressing ENTER, you will be prompted for the check source activity.

Enter the activity of the calibration source (μCi), and press ENTER. The following prompt appears:

BKGD ?

Enter the background COUNT RATE (CPM) and press ENTER. Enter CPM, even if you determined the count rate via a 10-min count, etc. (e.g., $\text{CPM} = \text{TOTAL COUNTS}/10$). The reported Limit of Sensitivity (LOS) will be based on this background count rate and the sample time or RC time constant. The next series of prompts will sequentially ask for the count rate at the six radial positions, 0, 20, 40, 60, 80, and 100 cm.

Upon confirming the last input (100-cm distance), the final calibration data will be displayed on the computer monitor. You can print this summary data to a printer using the "Prt Sc" (PRINT SCREEN) key on your computer, or use the FIDLER LIBRARY to print all of the calibration data.

Example of "PRINT SCREEN"

Radionuclide: PU-238						
SDEV	EFFICIENCY	(Sa)	DETECTION	LIMITS	BKGD	SOURCE K
(%)		cpm	Area	Point	cpm	m ²
		uCi/m ²	uCi/m ²	uCi		
5		9.1E+02	6.0E-02	2.5E-02	121	22400 0.41
Custom Inc. 3224 445 7-15-93 20:38						
Check Source: 10.100 microcuries of PU-238						
Source-To-Detector Height = 30 cm						
Sample-Time = 1.00 min						

Custom Inc. 3224 445 7-15-93 20:38

18-S/1207-I-7

Example of FIDLER Library "Look up a Detector in the Library (Printer)"

Custom Inc. 3224 445 7-15-93 20:38						
Detector Manufacturer :		Bicron	Detector Model:	4A-3	Detector S/N :	445
Meter Manufacturer :		Custom Inc.	Meter Model :	R-45	Meter S/N :	3224
Check Source I.D. : PU239-45						
Calibration Date : 7-15-93 20:38 Calibrated By: Galileo						
Source-To-Detector Height = 30 centimeters						
Sample-Time = 1.00 min						
PU-238						
Background		:	121 Counts per minute			
Check Source: 10.100 microcuries of Pu-238						
Source-To-Detector Height = 30 centimeters						
Radial Position (cm)		Window				
	TOTAL (cpm)	NET (cpm)				
0	22400	22279				
20	12600	12479				
40	4580	4459				
60	1920	1799				
80	929	808				
100	537	416				
EFFICIENCY (Sa)		DETECTION	LIMITS	BKGD	SOURCE	K
	cpm	Area	Point			
	$\frac{\mu\text{Ci}}{\text{m}^2}$	$\frac{\mu\text{Ci}}{\text{m}^2}$	$\frac{\mu\text{Ci}}{\text{m}^2}$	cpm	cpm	m^2
	9.1E+02	6.0E-02	2.5E-02	121	22400	0.41
SDEV: 5%						

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Press ENTER to return to the main FIDLER menu.

Saving Calibration Data to Disc

Enter "S" to permanently store the calibration data to disc. You will be prompted with the same detector identification information that you entered in an earlier step. If you want to change the information, enter "N." If the information is correct, enter "Y" and the calibration data will be permanently stored, and you will return to the main FIDLER menu. At this point, you have completed the calibration and saved the data to disc. You can use the "L" option (Library) to enter the FIDLER Library to review stored calibration data, print calibration data, etc.

You can also use the "E" option (Edit) to edit any of the detector files (e.g., change the calibration source activity, background, etc.). Some users prefer to edit an existing file with new calibration data, and then save the new data under a new detector identification.

Follow this procedure to input your own plutonium mixture data. At the main FIDLER menu, select option "C" (Calibrate), the following menu appears:

The diagram shows a detector positioned above a check source. A vertical double-headed arrow indicates the 'Source-to-Detector Height (normally 30 cm [12"])' and a horizontal double-headed arrow indicates the 'Radial Distance'.

Enter a selection NUMBER

1: K factor known (or accept a default value)
2: Determine Sa, and K Factor (Full calibration)
Q: <input type="text" value="NO! Leave Calibration alone and RETURN to main menu"/>

18-S/1207-I-9

We will use the full six-point calibration method, so enter "2" and following menu appears:

Select Target Mixture
P: PLUTONIUM MIXTURE
O: OTHER (e.g., cesium-137, etc.)

Enter Selection

18-S/1207-I-10

Select option "P" (Plutonium mixture), and the following prompt appears:

MIX KNOWN ? (Y/N)

Input "Y" and you will be sequentially prompted for the weight percent of the mixture radionuclides. If you enter "N," the following default mixture is assumed.

Nuclide	Initial (Time = 0) Weight %	Today (Time = 15 y) Weight %
PU-238	0.0400	0.0355
PU-239	93.3400	93.2997
PU-240	6.0000	5.9905
PU-241	0.5800	0.2810
PU-242	0.0400	0.0400
AM-241	0.0000	0.2950

Upon entering the last mixture data (Am-241), or accepting the default mixture by selecting "N," a display of the plutonium mixture data will appear (default age of 15 years). Press ENTER, and the following prompt appears:

MIX AGE ? (YR)

This allows you to decay the initial mixture to a future date. If you are interested in the initial mixture (i.e., no decay required), enter "0" (zero) and press ENTER. You will again see a display of the current plutonium mixture. Press ENTER to continue with the calibration procedure. At this point, you have entered the mix data and can return to the SCALER ? (Y/N) prompt.

Example of a Full Six-Point Calibration

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 21 years old (i.e., 21 years since processing). The following data were obtained using the FIDLER at a ground-to-detector distance of 30 cm. Determine the FIDLER calibration constants.

Calibrate the FIDLER using the above instructions and an ^{241}Am check source of known activity. In this example, a 5.9- μCi source is used. It is important to confirm the self-absorption characteristics of the source (e.g., due 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, i.e., $\text{SELF}(60) = 1.00$. 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 may EDIT the calibration data at a later date and automatically correct all of the calibration constants. In this example, we will assume a 17-keV self-absorption factor of 60%, i.e., SELF (17) = 0.60. In other words, 60% of the 17-keV x rays emitted and directed towards the FIDLER detector reach the detector (40% 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.

Eberline 33425 66776 7-14-93 10:21		
Detector Manufacturer : Harshaw Detector Model: 35 Detector S/N : 66776		
Meter Manufacturer : Eberline Meter Model : ESP2 Meter S/N : 33425		
Check Source I.D. : 22132		
Calibration Date : 7-16-93 9:42 Calibrated By: SGH		
Source-To-Detector Height = 30 centimeters		
Sample-Time = 1.00 min		
Plutonium Mixture : Am-241 Check Source : 5.900 microcuries		
Self (17) = 0.6000		
17-keV Window Background : 450 Counts per minute.		
60-keV Window Background : 750 Counts per minute.		
Radial Position (cm)	17-keV Window TOTAL (cpm)	60-keV Window TOTAL (cpm)
0	15048	36835
20	8602	23118
40	3148	9806
60	1318	4614
80	766	2584
100	582	1684

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After you have input the above information and counting data, the final calibration is displayed as follows:

Isotope	Half-life (years)	Initial (weight %)	@ Age = 20.0 YR (weight %)
PU-238	87.74	0.0400	0.0339
PU-239	24065	93.3400	93.2836
PU-240	6537	6.0000	5.9867
PU-241	14.35	0.5800	0.2103
PU-242	376300	0.0400	0.0400
AM-241	432.2	0.0000	0.3625

Americium-241
 Check Source Data
 5.900 uCi
 SELF (17) = 1.000

Source-To-Detector Height = 30 cm Sample-Time = 1.00 min
 ALPHA Curie: 9.0E-02 curies/gram
 1 microcurie of Am-241 = 7.41E+00 alpha microcurie of Mix
 *** The following data are for uCi of MIX***

WINDOW (keV)	EFFICIENCY cpm ug/m^2	(Sa) cpm uCi/m^2	DETECTION Area uCi/m^2	LIMITS Point uCi	BKGD cpm	SOURCE cpm	K m^2	SDEV (%)
17	5.1E+01	5.6E+02	1.8E-01	9.0E-02	450	15048	0.50	7
60	3.9E+01	4.3E+02	3.0E-01	1.5E-01	750	36835	0.51	4

Eberline 33425 66776 7-14-93 10:21

18-S/1207-I-12

5. LUNG Screening

This program screens for plutonium uptake in the lung using a FIDLER detector. The FIDLER must be positioned above the right lung. Body height and weight are used to estimate chest-wall thickness. The 60-keV gamma associated with the decay of ^{241}Am 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 (Fig. 5-1).

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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).

$$t = 0.110 \frac{m}{h} - 2.00, \quad (\text{Eq. 5-1})$$

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 ~15% for values in the range of 2 cm–4 cm. The SDEV rapidly increases for thickness values outside this range. It is assumed that the 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.

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 21 years. Using a FIDLER and a PS-1 RASCAL scaler, screen the two people for possible serious plutonium deposition in the lung.

Data.

Subject	Counting Time (minutes)	Counts	Height	Weight
Am-241 check source	1	36,835	—	—
Background (uncontaminated)	5	3,750	—	—
Roxanne Luna	5	4,500	5' 8"	120 lbs
Robert Wills	5	3,950	6' 2"	165 lbs
Kevin Anderson	5	3,800	5' 8"	155 lbs

* The data and names of the individuals are fictitious and are presented only for the example. The data on page 5-4 are also fictitious.

Isotope	Half-life (years)	Initial (weight %)	@ Age = 20.0 YR (weight %)	Americium-241 Check Source Data 5.900 uCi			
PU-238	87.74	0.0400	0.0339				
PU-239	24065	93.3400	93.2836				
PU-240	6537	6.0000	5.9867				
PU-241	14.35	0.5800	0.2103				
PU-242	376300	0.0400	0.0400				
AM-241	432.2	0.0000	0.3625				
ALPHA Curie: 8.99E-02 Ci/g 1 uCi of Am-241 = 7.23E+00 alpha uCi-mix							
Height: 5 ft 8 in Weight: 120 lbs Chest wall: 1.5 cm							
FIDLER EFFICIENCY: 3.3E+03 cpm/uCi of Am-241 in lung SDEV: 0.53 %							
MDA : Am-241 = 7.3 nCi Mix = 53 nCi							
	BACKGROUND	CHECK SOURCE	GROSS LUNG	NET LUNG			
TIME (min):	5.0	1.0	5.0	5.0	LUNG	SCREEN	RESULTS
COUNTS:	3750	36835	4500	750	Am-241	Mix	SDEV
RATE (cpm):	750	36835	900	150	(nCi)	(nCi)	(%)
Alpha Activity Deposited in Lung:					45	328	12
50-year Committed Effective Dose Equivalent (mix):					4.4E+02 rem		

LUNG SCREEN: Roxanne Luna FIDLER + PS-1 RASCAL 2344

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Isotope	Halflife (years)	Initial (weight %)	@ Age = 20.0 YR (weight %)	Americium-241 Check Source Data 5.900 uCi	
PU-238	87.74	0.0400	0.0339		
PU-239	24065	93.3400	93.2836		
PU-240	6537	6.0000	5.9867		
PU-241	14.35	0.5800	0.2103		
PU-242	376300	0.0400	0.0400		
AM-241	432.2	0.0000	0.3625		
ALPHA Curie: 8.99E-02 Ci/g 1 uCi of Am-241 = 7.23E+00 alpha uCi-mix					
Height: 6 ft 2 in Weight: 165 lbs Chest wall: 2.4 cm					
FIDLER EFFICIENCY: 2.4E+03 cpm/uCi of Am-241 in lung SDEV: 0.53%					
MDA : Am-241 = 9.9 nCi Mix = 72 nCi					
	BACKGROUND	CHECK SOURCE	GROSS LUNG	NET LUNG	
TIME (min):	5.0	1.0	5.0	5.0	
COUNTS:	3750	36835	3950	200	
RATE (cpm):	750	36835	790	40	
Alpha Activity Deposited in Lung:					LUNG
50-year Committed Effective Dose Equivalent (mix):					SCREEN
					RESULTS
					Am-241
					Mix
					(nCi)
					(nCi)
					(%)
					17
					120
					44
					1.6E+02 rem

LUNG SCREEN: Robert Wills FIDLER + PS-1 RASCAL 2344

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Isotope	Half-life (years)	Initial (weight %)	@ Age = 20.0 YR (weight %)	Americium-241 Check Source Data 5.900 uCi			
PU-238	87.74	0.0400	0.0339				
PU-239	24065	93.3400	93.2836				
PU-240	6537	6.0000	5.9867				
PU-241	14.35	0.5800	0.2103				
PU-242	376300	0.0400	0.0400				
AM-241	432.2	0.0000	0.3625				
ALPHA Curie: 8.99E-02 Ci/g 1 uCi of Am-241 = 7.23E+00 alpha uCi-mix							
Height: 5 ft 8 in Weight: 155 lbs Chest wall: 2.5 cm							
FIDLER EFFICIENCY: 2.3E+03 cpm/uCi of Am-241 in lung SDEV: 0.53%							
MDA : Am-241 = 10 nCi Mix = 74 nCi							
	BACKGROUND	CHECK SOURCE	GROSS LUNG	NET LUNG			
TIME (min):	5.0	1.0	5.0	5.0	LUNG	SCREEN	RESULTS
COUNTS:	3750	36835	3800	50	Am-241	Mix	SDEV
RATE (cpm):	750	36835	760	10	(nCi)	(nCi)	(%)
Alpha Activity Deposited in Lung :					<LOS	<LOS	

LUNG SCREEN: Kevin Anderson FIDLER + PS-1 RASCAL 2344

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6. Appendix A: Using the HOTSPOT Codes

Single-Disk-Drive System

To access HOTSPOT, first load the standard DOS operating system into your computer. The FIDLER code requires DOS version 3.0 or later.

Put the HOTSPOT disk in the 'A' drive. At the DOS prompt ("A>"), type HOTSPOT and press RETURN (ENTER on some computers). This takes you to the HOTSPOT main menu.

Loading HOTSPOT on a Hard-Disk System

HOTSPOT runs much faster if it resides on a hard disk. If you have a hard disk, you will probably want to copy all of the HOTSPOT files onto it.

The following instructions assume that you have DOS on your hard disk and that your hard disk is drive C.

- (1) At the DOS prompt (C>), type MD\HOTSPOT and hit RETURN. This creates a directory named HOTSPOT.
- (2) Type CD\HOTSPOT and hit RETURN. This makes HOTSPOT the current directory.
- (3) Place the HOTSPOT program disk into drive A.
- (4) Type COPY A:*. * and hit RETURN. DOS then copies all of the files from the HOTSPOT disk to your hard disk in the current directory, HOTSPOT.

Starting HOTSPOT from a Hard-Disk System

- (1) Make sure the default drive letter at the DOS prompt is for the hard disk prompt, C>. If not, at the DOS prompt, type the letter of the hard disk and a colon—C: and press RETURN.
- (2) If the current directory is HOTSPOT, proceed to step 3. Otherwise, you need to access the HOTSPOT directory. At the DOS prompt, type CD\HOTSPOT and press RETURN. This makes HOTSPOT the current directory.
- (3) Type HOTSPOT and press RETURN. The HOTSPOT main menu will appear.

A Note About Monitors

HOTSPOT will automatically adjust its output to most types of color or monochrome monitors, but some types of monochrome monitors require that you configure HOTSPOT differently. If the monochrome display is difficult to read, you will need to change the monitor setting using the SETUP program. This is a simple and straightforward process. At the HOTSPOT main menu, select "S" for SETUP, and follow the prompted instructions. The SETUP program can also be used to adjust the aspect ratio of your display, set your printer type and port, and either CLASSIC or SI units.

7. Appendix B: Gaussian Model 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).

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. A plume travels along, or parallel to, the DOWNWIND axis.

HOTSPOT coordinate system

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Gaussian Equation

The following Gaussian model equations determine the atmospheric concentration of a gas or an aerosol:

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

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

$$\sigma_z > L: \\ C(x, y, z, H) = \frac{Q}{\sqrt{2\pi}\sigma_y L u} \exp\left[-\frac{1}{2}\left(\frac{y}{\sigma_y}\right)^2\right] \exp\left[-\frac{\lambda x}{u}\right] \quad (\text{Eq. B-2})$$

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-sec)/(m³).
- 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 windspeed at the effective release height (H), (m/s).
- L = Inversion layer height (m).

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. 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 windspeed (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 that define Atmospheric Stability Categories, A-F, used in HOTSPOT.

Ground Speed (m/s)	Wind (High in sky)	Sun or cloudy)	Sun (Low in sky Nighttime)
<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 ($\sigma_\theta = 25$ deg)
- B: Moderately Unstable ($\sigma_\theta = 20$ deg)
- C: Slightly Unstable ($\sigma_\theta = 15$ deg)
- D: Neutral ($\sigma_\theta = 10$ deg)
- E: Slightly stable ($\sigma_\theta = 5$ deg)
- F: Moderately Stable ($\sigma_\theta = 2.5$ deg)

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

Diffusion experiments under clear, nearly calm nighttime conditions suggest that horizontal diffusion is actually greater than diffusion F stability (i.e., larger σ_y) due to increased plume meander. The standard deviation of the observed wind fluctuations in the horizontal direction, σ_θ , can be very large. The observed σ_θ 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_θ . If the G stability class is selected, the user is prompted for σ_θ , and the applicable stability class used for the horizontal diffusion component. F stability is assumed for the vertical component.

Determining σ_y and σ_z

The most widely used scheme to estimate σ_y and σ_z was developed by Pasquill (1961). Briggs (1975) 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 lengths in the range from 0.01 m to 0.1 m. Briggs' formulas are applicable from a distance of 0.1 km to ~10 km and can be extended 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.

Equations used to determine σ_y and σ_z . This methodology is derived from Briggs (1975).

Pasquill Type	σ_y (m)	σ_z (m)
A	$0.22x (1+0.0001x)^{-1/2}$	$0.20x$
B	$0.16x (1+0.0001x)^{-1/2}$	$0.12x$
C	$0.11x (1+0.0001x)^{-1/2}$	$0.080x (1+0.0002x)^{-1/2}$
D	$0.08x (1+0.0001x)^{-1/2}$	$0.060x (1+0.0015x)^{-1/2}$
E	$0.06x (1+0.0001x)^{-1/2}$	$0.030x (1+0.0003x)^{-1}$
F	$0.04x (1+0.0001x)^{-1/2}$	$0.016x (1+0.0003x)^{-1}$

Sample Time

The equations for the standard deviation of the Gaussian concentration distribution in cross-axis 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. In the HOTSPOT codes, the default release duration of radioactive material is 10 min. If you are interested in a scenario with a release duration of 1 hour, you need to 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 at the main HOTSPOT output menu using the "T: SAMPLE TIME" option. In HOTSPOT, the following equation adjusts for sampling times different than 10 min (Hanna, *et al.*, 1982; Gifford, 1975)—

$$\sigma'_y = \sigma_y \left[\frac{t}{10} \right]^{0.2}, \quad (\text{Eq. B-3})$$

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 always yield a conservative estimate, i.e., larger radiation doses, etc.

Wind Speed Variation with Height

The wind speed that users input is the estimate for a height of 2 m. However, the Gaussian plume equation requires the wind speed at H , the effective release height. HOTSPOT automatically uses the following power-law formula to determine the wind speed for all effective heights greater than 2 m.

$$u(H) = u(2) \left[\frac{H}{2} \right]^P, \quad (\text{Eq. B-4})$$

where—

$u(2)$ = Surface wind speed (m/s) at 2-m height.
 H_{eff} = Effective release height (m).
 P = Factor from the following table.

Exponential factor used by HOTSPOT for calculating wind speed variation with height (from Hanna, 1982).

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

Plume Depletion

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. 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.

The source term in HOTSPOT is allowed to decrease with downwind distance. The code accomplishes this 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 (in Slade, 1986).

The equation used in HOTSPOT is—

$$DF(x) = \left[\exp \int_0^x \frac{1}{\sigma_z(x) \exp \left[\frac{1}{2} \left(\frac{H_{eff}}{\sigma_z(x)} \right)^2 \right]} dx \right]^{-\frac{v}{u} \sqrt{\frac{2}{\pi}}} \quad (\text{Eq. B-5})$$

Plume Rise

The actual plume height may not be the physical release height (the stack height). Plume rise can occur because of the velocity of the 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, as shown in Fig. B-2.

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.

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In HOTSPOT, it is assumed that 30% of the heat of combustion is radiated, fuel density is 0.81 g/cm^3 , and the heat of combustion is $1.2 \times 10^4 \text{ cal/g}$. Therefore, Eq. B-6 becomes—

$$Q_H = 2.58 \times 10^7 V/t \quad (\text{Eq. B-7})$$

Given the heat emission rate, the buoyancy flux is—

$$F_B = g Q_H / \pi C_p \rho_a T_a \quad , \quad (\text{m}^4/\text{s}^3) \quad (\text{Eq. B-8})$$

where—

$$\begin{aligned} g &= \text{Gravitational acceleration (9.8 m/s}^2\text{).} \\ C_p &= \text{Specific heat of effluent gases (0.24 cal/[g}^\circ\text{K})}. \\ \rho_a &= \text{Density of air (1.29} \times 10^3 \text{ g/m}^3\text{).} \\ T_a &= \text{Ambient air temperature (}^\circ\text{K).} \end{aligned}$$

Therefore,

$$F_B = 1.1 \times 10^{-2} Q_H / T_a \quad .$$

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

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

$$H_{eff} = 1.6 (F_B)^{1/3} (X^*)^{2/3} / u (H_{eff}/2) \quad (\text{Eq. B-9})$$

where—

$$\begin{aligned} H_{eff} &= \text{Effective release height (m)} \\ X^* &= \text{Distance associated with final plume height (m) [Munger, 1982]} \\ X^* &= 119 (F_B)^{0.40} \text{ for } F_B \geq 55. \\ X^* &= 49 (F_B)^{0.625} \text{ for } F_B < 55. \end{aligned}$$

- For stability classifications E and F,

$$\text{for } u (H_{eff}/2) > 1.4 \text{ m/s,}$$

$$H_{eff} = 2.6 \left(\frac{F_B}{\mu(2) \times S} \right)^{1/3} ; \quad (\text{Eq. B-10})$$

$$\text{for } u (H_{eff}/2) \leq 1.4 \text{ m/s,}$$

$$H_{eff} = 5.0 (F_B)^{1/4} (S)^{-3/8} ; \quad (\text{Eq. B-11})$$

where—

$$\begin{aligned} S &= 0.020 \text{ g/T}_a \text{ for stability class E.} \\ S &= 0.035 \text{ g/T}_a \text{ for stability class F.} \end{aligned}$$

Briggs' plume-rise equations 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):

$$H_{eff} = \sqrt[3]{(H_B)^3 + \left(\frac{R}{\gamma}\right)^3} - \frac{R}{\gamma} \quad , \quad (\text{Eq. B-12})$$

where—

- H_B = Effective release height via the Briggs methodology (m).
- R = Radius of burning fuel pool (m).
- γ = Entrainment coefficient for buoyant plume rise, 0.6.

Once the effective release height is determined, the radius of the final bent-over plume is set equal to 60% of the effective release height (Hanna, *et al.* 1982). An upwind virtual-term point source is used to model the initial distribution of material. The virtual-term point source is positioned at an up-wind distance, resulting in a σ_y and σ_z , above the origin, equal to 50% of the final bent-over plume radius. If the input pool radius is larger than the calculated plume radius, the actual pool radius is used for the target σ_y and σ_z values.

Explosion

The release fraction is partitioned as follows (Fig. B-4, following page):

Five separate source terms model the above initial distribution of material. The sources are represented by separate elevated upwind virtual source terms in which each term results in:

- σ_y over the explosion point equal to 50% of the cloud radius defined above.
- σ_z over the explosion point equal to 20% of the cloud top.

Cloud top = $76 (w)^{0.25}$

Cloud radius = 0.2 cloud top

Where w = pounds of high explosives (Church, 1969)

$\sigma_y (x = 0) = 0.5$ Cloud radius

$\sigma_z (x = 0) = 0.2$ Cloud top

Source distribution

- 20% ($h_5 = 0.8$ cloud top)
- 35% ($h_4 = 0.6$ cloud top)
- 25% ($h_3 = 0.4$ cloud top)
- 16% ($h_2 = 0.2$ cloud top)
- 4% ($h_1 =$ ground level)

Explosion Model Geometry

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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 (Fig. B-5).

The resuspension factor (S) for windspeed (u) at or below 3 m/s (Anspaugh, 1975):

$$S = 10^{-4} e^{-0.15 \sqrt{t}} + 10^{-9} \quad \text{m}^{-1}, \quad (\text{Eq. B-13})$$

where t = time since contamination event (days).

$$\sigma_y(x=0) = 0.5 R_{\text{contamination}}$$

$$\sigma_z(x=0) = 0$$

Resuspension Model Geometry

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Resuspension as a factor of wind speed:

$$S(u) = S \times (u/3)^2 \quad \text{for } u > 3 \text{ m/s}$$

$$S(u) = S \quad \text{for } u \leq 3 \text{ m/s}$$
(Eq. B-14)

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

$$Q_{\text{eff}} = S(u) \times G \times \pi \times \sigma_{y,\text{origin}} \times \sigma_{z,\text{origin}} \times u \quad , \quad \text{Ci/sec}$$
(Eq. B-15)

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 (see Appendix B) to estimate the radionuclide concentration downwind from the contamination.

Notes: 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 (m^{-1}).

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. The calculated resuspension factor is based on experimental data associated with the Nevada Test Site, and are not necessarily applicable to wet regions, etc. However, the above equations will result in a conservative resuspension-factor estimate for an initial hazard evaluation. Once the resuspension factor is actually determined via air sampling, the new factor can update the original downwind predictions.

Particle-Size Distribution

The particle size of a monodisperse suspension of fine solid or liquid particles in the atmosphere is completely characterized by the particle diameter. However, most aerosols are polydisperse and the particle sizes range over many magnitudes. In the HOTSPOT dispersion models, we are specifically concerned with the particle-size distribution with respect to radioactivity. Just as a number distribution gives the fraction of the total number of particles in any size range, the activity distribution gives the fraction of the total activity associated with the particles in any size range.

In most polydisperse aerosols, the normal distribution function does a poor job of representing the particle-size distribution. However, the logarithm of the particle size is adequately represented by a normal distribution. Hence, the log normal distribution is commonly used to statistically describe polydisperse particle-size distributions. In the HOTSPOT programs, it is assumed that the activity median aerodynamic diameter (AMAD) is $1\text{ }\mu\text{m}$ (geometric standard deviation is 3). The following figure represents the cumulative activity distribution for a log normal distribution with an AMAD of $1\text{ }\mu\text{m}$. Note that 50% of the activity is associated with particles with an aerodynamic diameter less than $1\text{ }\mu\text{m}$, and essentially all of the "respirable" activity is below particles with an aerodynamic diameter of approximately $10\text{ }\mu\text{m}$. The default ICRP-30 internal dosimetry conversion factors also assume a $1\text{-}\mu\text{m}$ AMAD particle-size distribution. In many models and studies, the respirable fraction is commonly defined as "all the material with an aerodynamic diameter less than 10 micrometers." As shown in the following graph, the $1\text{-}\mu\text{m}$ AMAD agrees with this assumption (Fig. B-6).

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Stating the distribution in terms of aerodynamic diameter standardizes the distribution in both particle shape and density. The aerodynamic diameter is the diameter of a unit density (1 g/cm^3) sphere that has the same settling velocity as the actual particle. If a particle has an aerodynamic diameter of $1 \text{ }\mu\text{m}$, it behaves in an aerodynamic sense like a $1\text{-}\mu\text{m}$ water droplet regardless of the particle's shape, density, or physical size.

Appendix C: Glossary of HOTSPOT Output Definitions

Average Deposition (Avg. Deposition)

Average ground contamination level ($\mu\text{Ci}/\text{m}^2$) used in resuspension models.

Chi

Integrated air concentration $[(\text{Ci-s})/\text{m}^3]$. Chi only includes the *respirable* fraction of the air concentration. Respirable fraction is defined as the fraction of the released material associated with an Activity Median Aerodynamic Diameter (AMAD), of $1\ \mu\text{m}$ (see Appendix B). The default ICRP-30 internal dosimetry conversion factors also assume a AMAD particle-size distribution of $1\ \mu\text{m}$.

D

Downwind distance from the center of the radionuclide release point or center of contamination area.

Dep

Ground contamination estimate ($\mu\text{Ci}/\text{m}^2$). In HOTSPOT codes, the ground contamination is determined by multiplying the air concentration by the deposition velocity (see Deposition Velocity).

Deposition Velocity

The deposition velocity (m/s , cm/s , etc.), is empirically defined as the ratio of the observed deposition rate [$\mu\text{Ci}/(\text{m}^2\text{-s})$] and the observed air concentration near the ground surface ($\mu\text{Ci}/\text{m}^3$).

Effective Radius (Eff. Radius)

The radius of a circle that effectively encompasses a region of contamination, used in the fire and resuspension models.

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, use the actual physical release height (height of the stack) or use zero for a ground-level release. This will always yield conservative estimates, i.e., larger radiation doses, etc.

Fire Duration

The total time duration of a fire. In the fire models, the fire duration estimates the heat emission rate (cal/s) for calculation of the effective release height due to buoyant plume rise.

Fuel

Total quantity of flammable material consumed in the fire models. In HOTSPOT, it is assumed that 30% of the heat of combustion is radiated, fuel density is 0.81 g/cm^3 , and the heat of combustion is $1.2 \times 10^4 \text{ cal/g}$.

Half-Life

Radioactive half-life of released material.

Heat Emission

Heat emission rate (cal/s) for calculating the effective release height due to buoyant plume rise.

High Explosive

TNT-equivalent in explosive release models. For example, a conservative estimate of the TNT-equivalent of an exploding vehicle gas tank is 1 lb.

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 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. In HOTSPOT, the default value is 5,000 m, which effectively means "no mixing layer." The mixing layer height is typically 300 to 3,000 m and can significantly increase air-concentration values.

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. For noble gases, for example, ^{85}Kr , the dose is due to submersion in the radioactive plume during plume passage. For other radionuclides, the dose is due to inhalation of the material and resulting irradiation of the applicable organs over the next 50 years. The dose is calculated by multiplying the integrated air concentration by the dose conversion factors (DCF) contained in the HOTSPOT Library:

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

where T is the applicable target organ (e.g., lung, and DCF_T is the dose conversion factor for the target organ). You can view the specific DCFs by running the HOTSPOT Library program at the main HOTSPOT menu.

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 committed dose equivalents to various tissues in the body, each multiplied by the appropriate weighting factor.

Maximum CEDE

The highest 50-year committed effective dose equivalent (rem, Sv) received by an individual due to remaining at the specific location associated with the maximum integrated air concentration throughout the entire radioactive material release (see **Maximum Dose Distance**).

Maximum Dose Distance

The location associated with the maximum dose received by an individual remaining at the location throughout the radioactive material release. If the location is less than 0.1 km (100 m), the output will indicate "<0.1 km" and the output dose value will be ">xxx rem", where xxx is the dose at 0.1 km. For releases near ground level, the maximum distance will always be less than 0.1 km. However, as the release height increases, the location of the maximum dose moves out beyond 0.1 km, and the specific location depends on the effective release height, meteorological parameters, and deposition velocity.

Receptor Height

Height above the ground that receives the output dose and contamination values. The default value is ground level (0 m). However, if you are interested at the dose an individual would receive on a 30-m tower, you can change the receptor height to 30 m, etc.

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 respirable fraction is defined as the fraction of the release material associated with an Activity Median Aerodynamic Diameter (AMAD) of 1 μm (see Appendix B).

Resuspension Factor

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 (m^{-1}).

Sample Time

The equations for the standard deviation of the Gaussian concentration distribution in cross-axis 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 (see Appendix B for details).

Source Term

Total quantity of material involved in the fire, explosion, etc.

Stability Class

Meteorologists distinguish three states of the atmospheric surface layer: unstable, neutral, and stable. These categories refer to how a parcel of air would react when displaced adiabatically in the vertical direction (see Appendix B).

Wind Speed ($h = 2$ m)

Wind speed at a height of 2 m. The wind speed a user inputs is the estimate for a height of 2 m. However, the Gaussian plume equation requires the wind speed at height H , the effective release height. HOTSPOT uses a power-law formula to determine the wind speed for all effective heights greater than 2 m (see Appendix B).

Wind Speed ($h = H_{eff}$)

The wind speed a user inputs is the estimate for a height of 2 m. However, the Gaussian plume equation requires the wind speed at height H , the effective release height. HOTSPOT automatically uses a power-law formula to determine the wind speed for all effective heights greater than two meters. Wind Speed ($h = H_{eff}$) is the calculated wind speed used by HOTSPOT (see Appendix B).

NUCLIDE	HALF-LIFE (YR)	NUCLIDE	HALF-LIFE (YR)	NUCLIDE	HALF-LIFE (YR)
AG-106	4.5550E-05	CL-36	3.0100E+05	I-131	2.2027E-02
AM-241	4.3220E+02	CM-242	4.4603E-01	I-132	2.6256E-04
AM-243	7.3800E+03	CM-244	1.8110E+01	I-133	2.3744E-03
AR-41	2.0856E-04	CO-57	7.4219E-01	I-134	1.0008E-04
AS-76	3.0046E-03	CO-58	1.9397E-01	I-135	7.5457E-04
AU-198	2.8960E+00	CO-58W	1.9397E-01	IR-192	2.0279E-01
BA-133	1.0740E+01	CO-58Y	1.9397E-01	IR-192W	2.0279E-01
BA-140	3.4904E-02	CO-60	5.2710E+00	IR-192Y	2.0279E-01
BE-10	1.6000E+06	CO-60W	5.2710E+00	K-40	1.2800E+09
BE-7	1.4600E-01	CO-60Y	5.2710E+00	KR-83M	2.0534E-04
BI-207	3.8000E+01	CR-51	7.5901E-02	KR-85	1.0720E+01
BI-210	1.3720E-02	CS-134	2.0620E+00	KR-85M	5.1142E-04
C-14	5.7300E+03	CS-135	2.3000E+06	KR-87	1.4517E-04
C-14G	5.7300E+03	CS-136	3.5890E-02	KR-88	3.2420E-04
CA-45	4.4658E-01	CS-137	3.0000E+01	KR-89	6.0840E-06
CD-109	1.2712E+00	FE-55	2.7000E+00	LA-140	4.5973E-03
CE-144	7.7890E-01	FE-59	1.2200E-01	LA-140D	4.5973E-03
CE-144W	7.7890E-01	H-3	1.2350E+01	LA-140W	4.5973E-03
CE-144Y	7.7890E-01	I-125	1.6477E-01	MN-54	8.5616E-01
CF-252	2.6380E+00	I-129	1.5700E+07	MO-99	7.5342E-03
NUCLIDE	HALF-LIFE (YR)	NUCLIDE	HALF-LIFE (YR)	NUCLIDE	HALF-LIFE (YR)
NA-22	2.6020E+00	PU-237	1.2400E-01	RB-86	5.1123E-02
NA-24	1.7123E-03	PU-238	8.7740E+01	RU-103	1.0762E-01
NB-95	9.6301E-02	PU-238W	8.7740E+01	RU-106	1.0088E+00
NB-95W	9.6301E-02	PU-238Y	8.7740E+01	S-35	2.3956E-01
NB-95Y	9.6301E-02	PU-239	2.4065E+04	SE-75	3.2882E-01
NI-63	9.6000E+01	PU-239W	2.4065E+04	SR-89	1.3836E-01
NP-237	2.1400E+06	PU-239Y	2.4065E+04	SR-89D	1.3836E-01
NP-239	6.4521E-03	PU-240	6.5370E+03	SR-89Y	1.3836E-01
P-32	3.9151E-02	PU-240W	6.5370E+03	SR-90	2.9120E+01
P-32D	3.9151E-02	PU-240Y	6.5370E+03	SR-90D	2.9120E+01
P-32W	3.9151E-02	PU-241	1.4400E+01	SR-90Y	2.9120E+01
PB-205	1.4300E+07	PU-241W	1.4400E+01	TA-182	3.1507E-01
PB-209	3.7110E-04	PU-241Y	1.4400E+01	TC-99	2.1300E+05
PB-210	2.2300E+01	PU-242	3.7630E+05	TC-99M	6.8721E-04
PM-147	2.6234E+00	PU-242W	3.7630E+05	TE-132	8.9269E-03
PO-210	3.7912E-01	PU-242Y	3.7630E+05	TE-132D	8.9269E-03
PR-144	3.2877E-05	PU-243	5.6540E-04	TE-132W	8.9269E-03
PU-234	1.0039E-03	PU-244	8.2600E+07	TH-228	1.9131E+00
PU-235	4.8100E-05	PU-245	1.1980E-03	TH-230	7.7000E+04
PU-236	2.8510E+00	RA-226	1.6000E+03	TH-232	1.4050E+10
NUCLIDE	HALF-LIFE (YR)	NUCLIDE	HALF-LIFE (YR)		
TL-204	3.7790E+00	XE-133	1.4370E-03		
U-232	7.2000E+01	XE-133M	5.4757E-03		
U-233	1.5850E+05	XE-135	1.0377E-03		
U-234	2.4450E+05	XE-135M	1.0381E-03		
U-235	7.0380E+08	XE-137	7.2249E-06		
U-235W	7.0380E+08	XE-138	2.6998E-05		
U-235Y	7.0380E+08	Y-91	1.6030E-01		
U-236	2.3415E+07	Y-91W	1.6030E-01		
U-237	1.8493E-02	Y-91Y	1.6030E-01		
U-238	4.4680E+09	Y-91Y	1.6030E-01		
U-238D	4.4680E+09	ZN-65	6.6822E-01		
U-238W	4.4680E+09	ZR-95	1.7529E-01		
U-238Y	4.4680E+09	ZR-95D	6.3980E+01		
XE-131M	3.2580E-02	ZR-95W	1.7529E-01		

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