EMERGENCY DETERMINATION OF DOSE FROM AIRBORNE RADIOACTIVE EMISSIONS WITHOUT COMPUTER ASSISTANCE

Purpose

This Meteorology and Air Quality Group (MAQ) procedure describes a graphical and a numerical estimation process for determining the doses from airborne radioactive emissions during an emergency response when computing resources are not available, and a method for estimating meteorological conditions at the time of the release in order to assign an appropriate stability class (atmospheric turbulence class). This allows the determination of the distance at which the protective action guide (PAG) projected dose would be encountered. Refer to EPA 400-R-92-001 for further explanation of PAGs.

Scope

This procedure applies to the determination of doses from airborne radioactive emissions during an emergency drill, exercise, or an actual accidental release when computing resources are not available (e.g., Hotspot, MIDAS). The results are appropriate for classifying an incident during the first 15 minutes of the real or simulated emergency and for recommendation of PAGs.

In this Procedure

Signatures

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04/10/06

General information about this procedure

Attachments

This procedure has the following attachments:

Number	Attachment Title	No. of pages
1	Dose/PAG Distance Estimation Form	1
2	Tritium Oxide (HTO) Hotspot Downwind Distance vs. Dose	3
3	Tritium Gas (T_2) Hotspot Downwind Distance vs. Dose	3
4	Pu-239 Hotspot Downwind Distance vs. Dose	3
5	Pu-238 Hotspot Downwind Distance vs. Dose	3
6	U-238 Hotspot Downwind Distance vs. Dose	3
7	Cs-137 Hotspot Downwind Distance vs. Dose	3
8	Sr-90 Hotspot Downwind Distance vs. Dose	3
9	Co-60 Hotspot Downwind Distance vs. Dose	3
10	Ir-192 Hotspot Downwind Distance vs. Dose	3
11	Discussion of numerical estimation of PAG dose distance for transuranics and tritium oxide	2
12	Discussion of graphical estimation of PAG dose distance	1

History of revision

This table lists the revision history and effective dates of this procedure.

Revision	Date	Description Of Changes
0	04/12/06	New document.

Who requires training to this procedure?

The following personnel require training before implementing this procedure:

- ENV-MAQ Health Physicist(s)/Dose Assessor(s)
- ENV-MAQ Meteorologists
- Other ENV Division personnel assigned responsibilities at the EOC.

Annual retraining is required and will be by self-study ("reading") training.

Training method

The training method for this procedure is "**self-study**" (reading) and is documented in accordance with the procedure for training (MAQ-024).

General information, continued

Definitions specific to this procedure

Hotspot: A software code that provides a first-order approximation of the radiation effects associated with the atmospheric release of radioactive materials using atmospheric dispersion models and exposure effects calculations.

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

Insolation: The amount of solar radiation incident on the surface of the earth, i.e., the amount of heat per unit area of earth from "sunshine."

MIDAS: Meteorological Information and Dispersion Assessment System. A software code system used to collect and process meteorological and source term data, perform atmospheric dispersion calculations, estimate exposure to toxic materials (including radioactive materials), and display results of these calculations in a color graphics format.

Protective action guideline (PAG): A set of dose equivalent levels, developed by the U.S. Environmental Agency (EPA), at which specific protective or mitigating actions should be considered. These levels reflect the projected, or potential, dose levels that would be delivered to the general population in the absence of protective actions. They apply to any atmospheric release (other than nuclear war) that results in the exposure of the general public to radioactive materials. The PAGs are dose equivalent levels at which immediate health effects are unlikely. The rational for selecting these particular levels is given in EPA 400-R-92-001, and is principally based on an assessment of the risk to the exposed individuals of developing cancer during their life, or the risk of producing genetic disorders in subsequent generations. There are PAGs that address different phases of the response to a radiological release.

Stability class: A classification of the level of surface air atmospheric turbulence that in broad terms can be distinguished as being unstable, neutral, or stable. The classes are usually denoted as being classes A through F, with A being most unstable and F being most stable.

General information, continued

References

The following documents are referenced in this procedure:

- MAQ-024, "Personnel Training."
- EPA 400-R-92-001, Manual of Protective Action Guides and Protective Actions for Nuclear Incidents, October 1991.
- LANL Hazard Assessment.
- Hotspot documentation, version 2.06.
- EPA-454/R-99-005, EPA Meteorological Monitoring Guidance for Regulatory Modeling Applications, February 2000.

Note

Actions specified within this procedure, unless preceded with "should" or "may," are to be considered mandatory guidance (i.e., "shall").

Determining meteorological conditions

Wind speed estimation

Using the following chart (from Hotspot documentation), estimate the wind speed based on the "observable features" listed in the second column.

NAME OF WIND	OBSERVABLE FEATURES	MPH	M/S
calm	Smoke rises vertically	< 1	< 0.5
light air	Smoke drifts downward	1 - 3	0.5 - 1
light breeze	Wind felt on face; leaves rustle	3 - 7	1 - 3
gentle breeze	Leaves and twigs in constant motion	7 - 12	3 - 5
moderate breeze	Raises dust and loose paper	12 - 18	5 - 8
fresh breeze	Small trees begin to sway	18 - 24	8 - 11
strong breeze	Large branches in motion	24 - 31	11 - 14
moderate gale	Whole trees in motion	31 - 38	14 - 17
fresh gale	Twigs break off; walking impeded	38 - 46	17 - 21
strong gale	Slight structural damage occurs	46 - 54	21 - 24
whole gale	Trees uprooted; structural damage	54 - 63	24 - 28
storm	Very rare; widespread destruction	63 - 75	28 - 34
hurricane		> 75	> 34

Determining meteorological conditions, continued

Insolation determination

For daytime releases, estimate the amount of heating of the earth's surface by the sun (daytime insolation) using the following chart (Slade, 1968):

Daytime conditions	Daytime insolation
Sun high in the sky	"Strong"
Sun low in the sky	"Moderate"
Cloudy	"Slight"

For nighttime releases, estimate the level of cloud cover:

- Thinly overcast or ≥ 4/8 low cloud cover*
- ≤ 3/8 low cloud cover*

*Note: Degree of cloudiness defined as that fraction of the sky above the local apparent horizon which is covered by clouds

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Stability class (atmospheric turbulence) estimation

Based on the estimated wind speed and solar heating of the earth's surface as determined above for daytime or nighttime, as appropriate, select the most appropriate stability class (A through F) from the chart below (EPA-454/R-99-005). Where two adjacent stability classes are presented for a single set of meteorological conditions, selection of the more stable class will typically result in a more conservative estimate of the dose or PAG distance.

	Daytime insolation			Nighttime conditions	
Surface wind speed, m/s	Strong	Moderate	Slight	Thinly overcast or ≥ 4/8 low cloud	≤ 3/8 low cloud cover
< 2	A	A-B	B		
2-3	A-B	B	C	E	F
3-5	B	B-C	C	D	E
5-6	C	C-D	D	D	D
>6	C	D	D	D	D

The following is a description of each type of stability class:

A – Extremely unstable conditions
B – Moderately unstable conditions
C- Slightly unstable conditions
D – Neutral conditions*
E – Slightly stable conditions
F – Moderately stable conditions

*Use this stability class (D) for heavy overcast, either day or night.

Numerical estimation of PAG dose distance for transuranics and tritium oxide

Order of magnitude estimate

For transuranics (TRU), if the source term, *S*, equals 1 Curie (Ci), the dose at 1 kilometer (km), *H*, is approximately equal to 5 rem, the upper range protective action guide (PAG) for evacuation and sheltering (refer to Table 2-1 and associated text in EPA 400-R-92-001). This relationship particularly holds true if the TRU radionuclide is Pu-239, Pu-242, Pu-244, Am-241, Am-243, Cm-244, Cf-252, or Np-237.

For tritium oxide, if the source term, *S*, equals 1 MegaCurie (MCi), the dose at 1 km, *H*, is approximately equal to 1 rem, the lower range PAG for evacuation and sheltering.

For a different source term, *S*: the dose is directly proportional to *S*, i.e., if the actual source term is 10 times the default source term used above, multiply the dose by a factor of 10. If the release is elemental tritium gas rather than tritium oxide, it is possible to account for the lower radiological hazard of elemental tritium gas compared to tritium oxide by dividing *S* by 25,000.

Distance to 5 rem/1 rem PAG isodose contour line

For most conditions, if *S* is the source term, in Ci for TRU and in MCi for tritium oxide:

> The distance x in km to the 5 rem isodose contour line for transuranics or to the 1 rem isodose contour line for tritium oxide downwind from the source release point is approximately equal to $S^{2/3}$

This is most appropriate for stability classes B-D and ~3 m/s wind. The results compare well with the LANL Hazards Assessment for average conditions (2.5 m/s, class D).

Stability class correction

- If the atmospheric conditions are stable (class E or F), multiply x by 2.
- If the atmospheric conditions are very unstable (class A), divide x by 2.
- For stability classes B, C, or D, do not modify x.

Numerical estimation of PAG dose distance for transuranics and tritium oxide, continued

Wind speed correction

- If you can feel no wind (approximately 1 m/s or less), multiply x by 2.
- If it is very windy (approximately 10 m/s or greater), divide x by 2.
- For wind speeds greater than 1 m/s and less than 10 m/s, do not modify x.

Graphical estimation of PAG dose distance

How to use the graphs

Step	Action
1	Ascertain the radionuclide of concern and the amount released in Ci (note: 1 gram of tritium is approximately equal to 10,000 Curies, 1 gram of Pu-239 is approximately equal to 0.06 Ci) . If there is no graph for the radionuclide, use the following guidance: • If the radionuclide is a uranium isotope, use the U-238 graph • If the radionuclide is Pu-242, Pu-244, Am-241, Am-243, Cm-244, Cf-252, or Np-237, use the Pu-239 graph • If the radionuclide of concern is none of the above, multiply the source term in Ci by the ratio of dose conversion factor for the radionuclide of concern by the dose conversion factor for a radionuclide for which a graph has been generated.
2	Estimate the wind speed and stability class as described above for the weather conditions present in the area. The graphs only cover wind speeds of 1 m/s, 2 m/s, 4 m/s, 6 m/s, and 10 m/s. The 1 m/s wind speed represents the < 2 m/s surface wind speed selection above and the 10 m/s wind speed represents the > 6 m/s surface wind speed selection above.
3	Locate the graph for the radionuclide of concern and estimated wind speed in the appropriate appendix.
4	Find the curve on the graph for the estimated stability class.
5	Decide on the appropriate numerical protective action guide (PAG) for evacuation or sheltering during the early phase of a nuclear incident (5 rem for transuranics and 1 rem for all other radionuclides). Refer to Table 2-1 and associated text in EPA 400-R-92-001.
6	Divide the PAG dose selected in step 5 above by the number of Ci released (projected or actual) and locate that modified dose (*y* axis) in rem on the curve selected in step 4 above. Then read down from that point on the curve to the *x* axis to locate the distance in km where that PAG dose would be located downwind.
7	Alternatively, a downwind dose at a specific location downwind can be determined by reading up from the *x* axis to the appropriate curve and then read across to the *y* axis to locate the TEDE dose in rem for the 1 Ci release. Multiply that dose by the number of Ci that has been released or is projected to be released.

Records resulting from this procedure

Records

The following records generated as a result of this procedure are to be submitted **within 4 weeks** as records to the records coordinator:

- Dose/PAG Distance Estimation Form

DOSE/PAG DISTANCE ESTIMATION FORM

Meteorological Conditions

Wind speed: ☐ < 2 m/s ☐ 2 m/s ☐ 4 m/s ☐ 6 m/s ☐ > 6 m/s
Stability class: ☐ A ☐ B ☐ C ☐ D ☐ E ☐ F

Numerical estimation of PAG dose distance for transuranics and tritium oxide

Transuranics:
Quantity of transuranics released (S): Ci
$S^{2/3} = x$: km (distance downwind to 5 rem isodose contour line for stability classes B-D and ~3 m/s wind speed)
Stability classes E or F (stable) multiply x by 2: km
Stability class A (very unstable) divide x by 2): km
No wind ($\sim \leq 1$ m/s) multiply x by 2: km (x already adjusted for stability class)
Very windy ($\sim \geq 10$ m/s) divide x by 2: km (x already adjusted for stability class)
(Wind speeds > 1 m/s and < 10 m/s do not modify x)

Tritium oxide:
Quantity of tritium oxide released (S): MCi (megacuries)
$S^{2/3} = x$: km (distance downwind to 1 rem isodose contour line for stability classes B-D and ~3 m/s wind speed)
Stability classes E or F (stable) multiply x by 2: km
Stability class A (very unstable) divide x by 2): km
No wind ($\sim \leq 1$ m/s) multiply x by 2: km (x already adjusted for stability class)
Very windy ($\sim \geq 10$ m/s) divide x by 2: km (x already adjusted for stability class)
(Wind speeds > 1 m/s and < 10 m/s do not modify x)

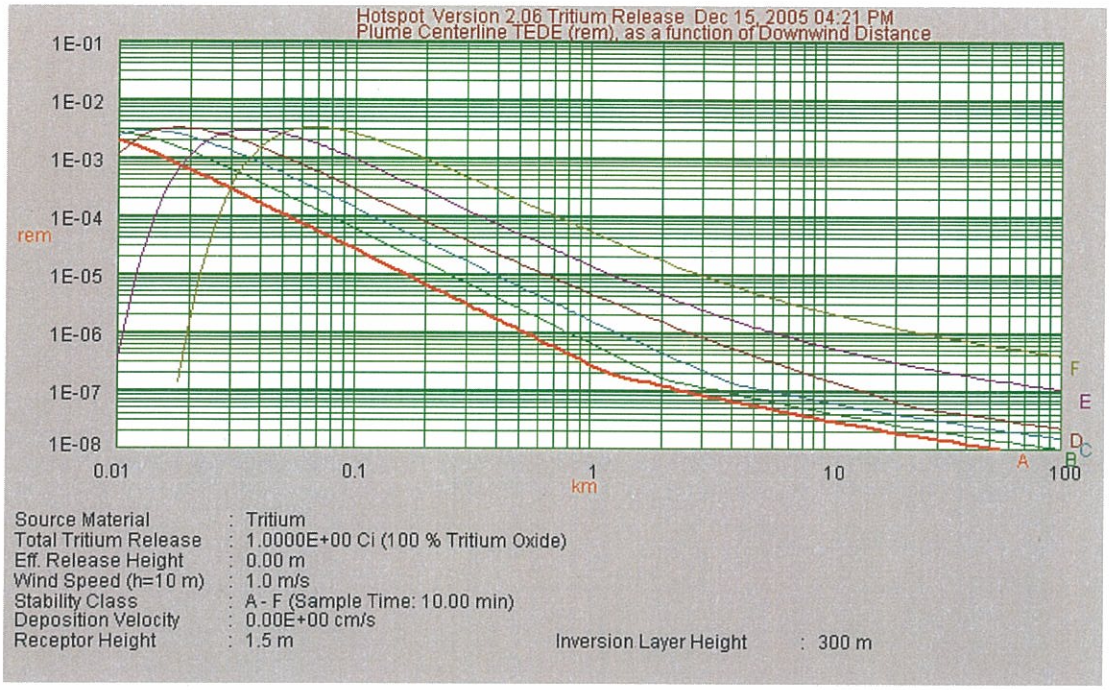
Graphical estimation of PAG dose distance

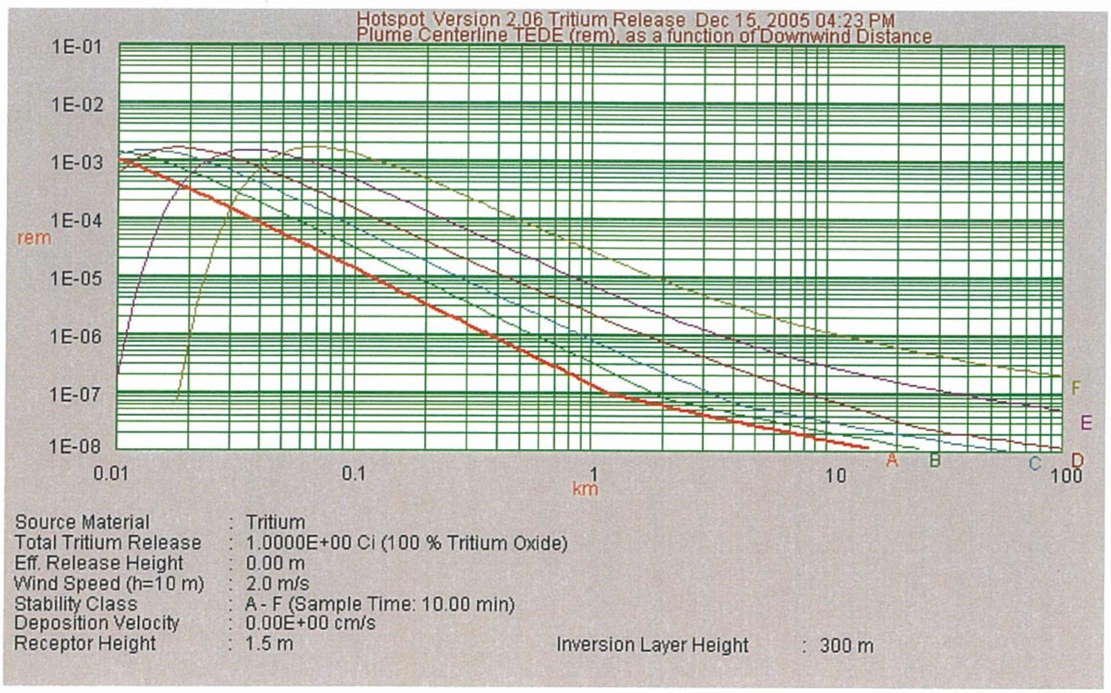
Radionuclide of concern:
Quantity of radionuclide: Ci
PAG dose: rem (5 rem for transuranics and 1 rem for all other radionuclides)
PAG dose in rem divided by number of Ci released: rem
Distance corresponding to PAG dose in rem multiplied by number of Ci released in rem on graph:
km (this is your PAG distance for evacuation or sheltering)

Estimate of dose at a specific distance downwind

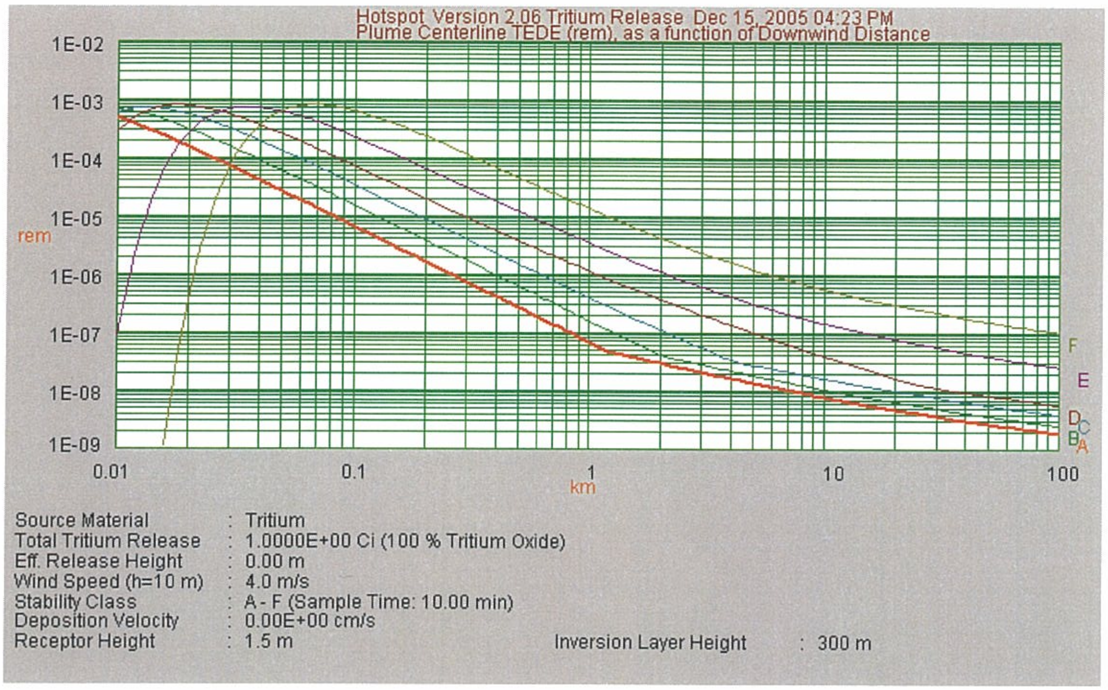
Radionuclide of concern:
Quantity of radionuclide: Ci (if unsure how to convert from units provided, e.g., grams to Ci, seek professional help)
Wind speed: ☐ < 2 m/s ☐ 2 m/s ☐ 4 m/s ☐ 6 m/s ☐ > 6 m/s
Stability class: ☐ A ☐ B ☐ C ☐ D ☐ E ☐ F
Downwind distance: km
TEDE dose for 1 Ci release: rem
TEDE dose for 1 Ci release in rem multiplied by quantity of radionuclide in Ci: rem

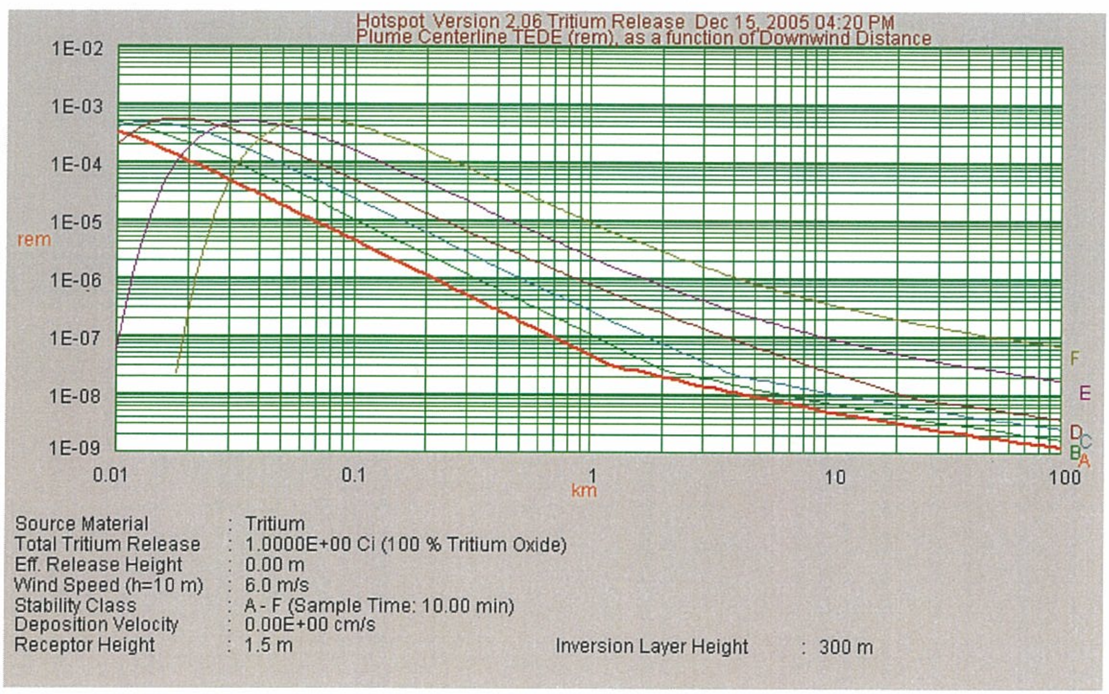
TRITIUM OXIDE (HTO) HOTSPOT DOWNWIND DISTANCE VS. DOSE





TRITIUM OXIDE (HTO) HOTSPOT DOWNWIND DISTANCE VS. DOSE (CONT'D)





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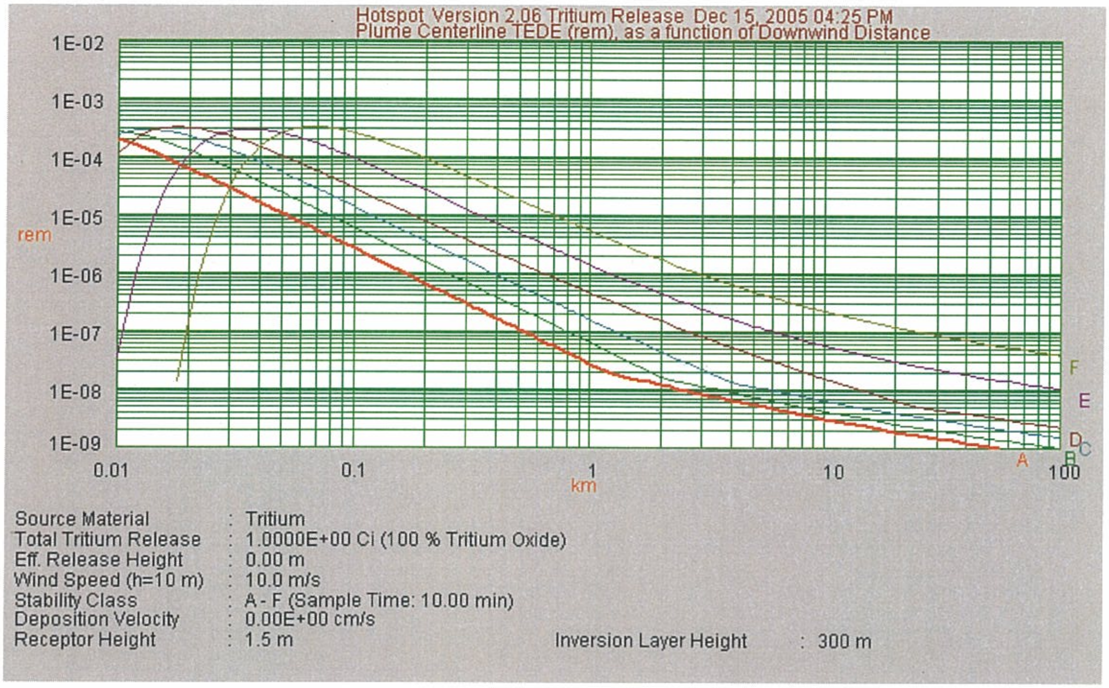
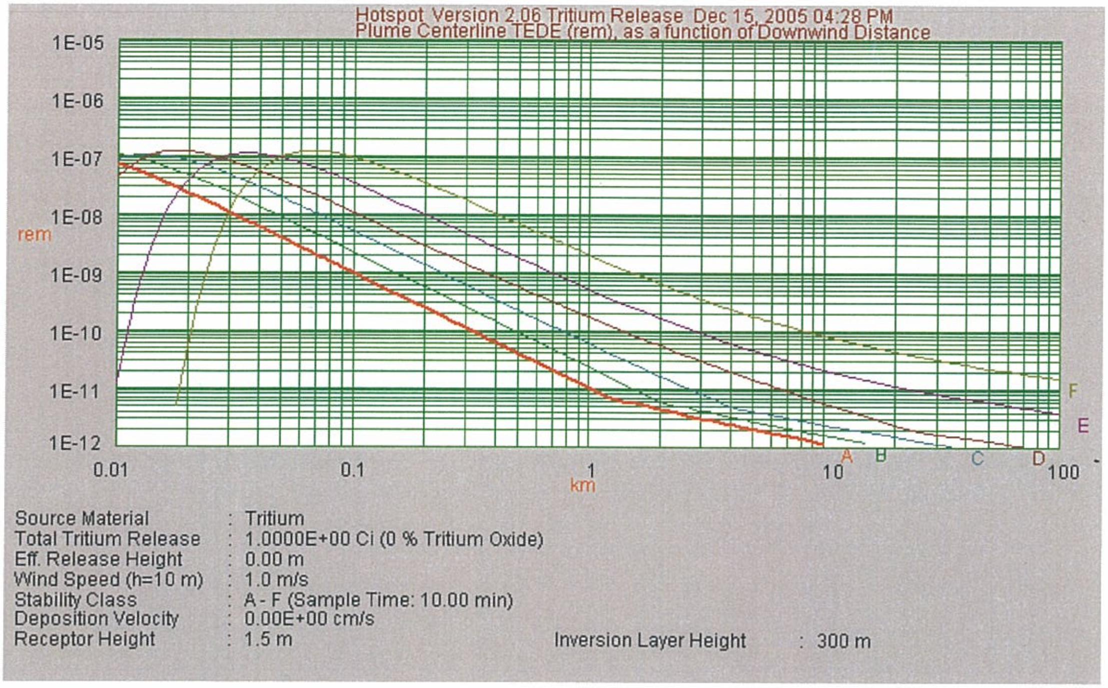
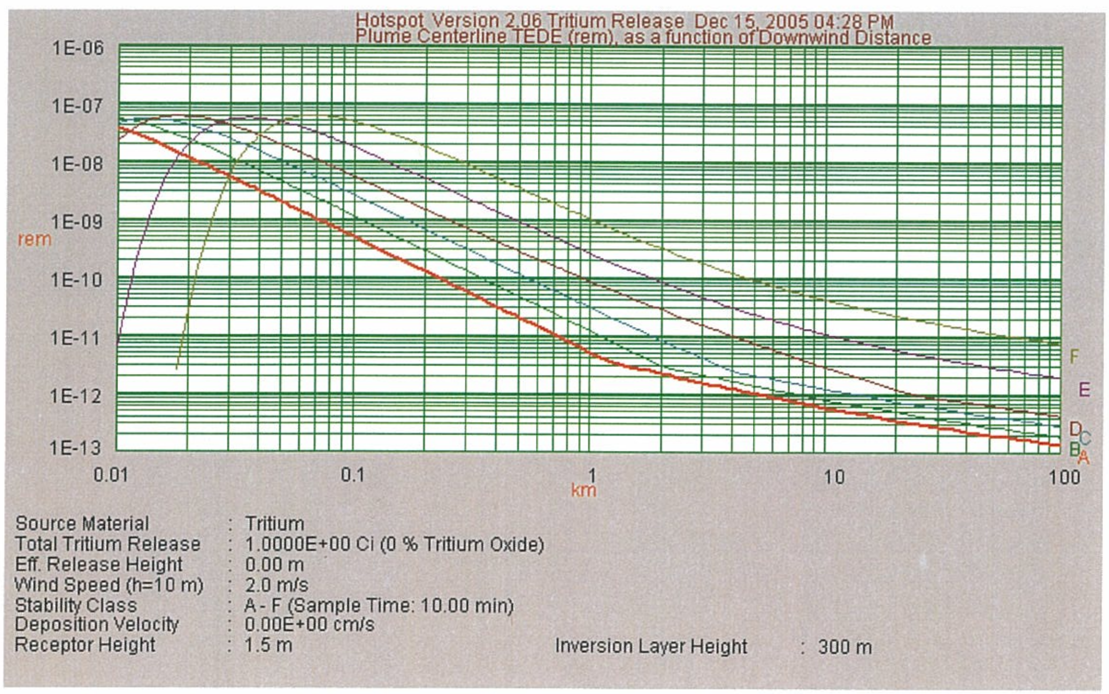
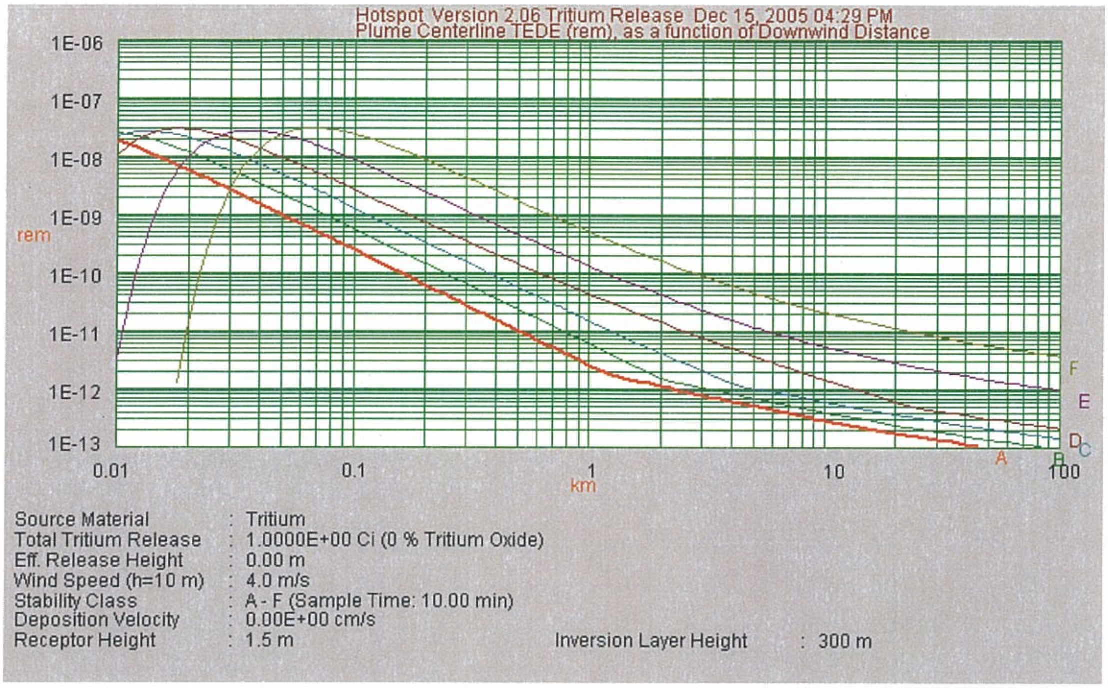


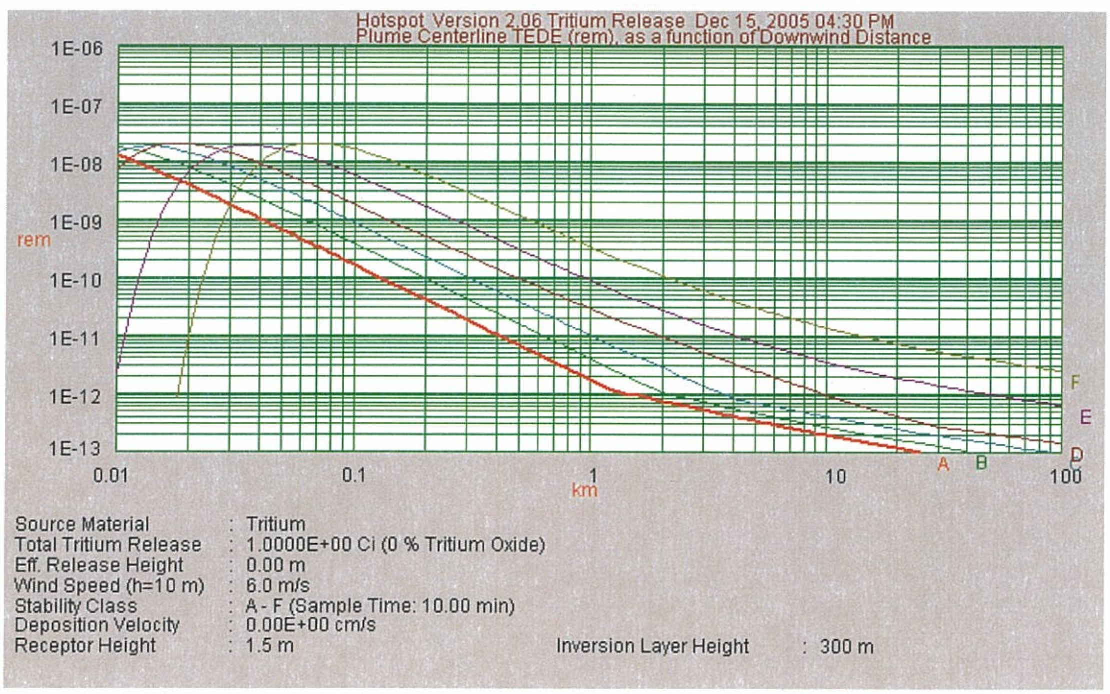
TRITIUM GAS (T_2) HOTSPOT DOWNWIND DISTANCE VS. DOSE





TRITIUM GAS (T_2) HOTSPOT DOWNWIND DISTANCE VS. DOSE (CONT'D)





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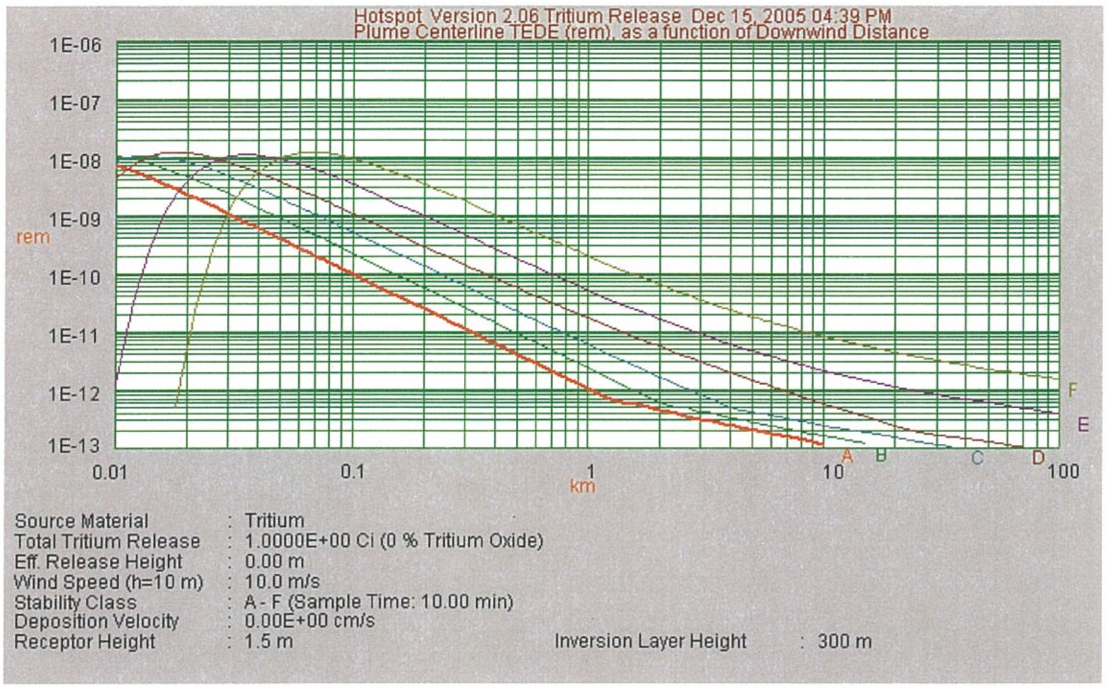
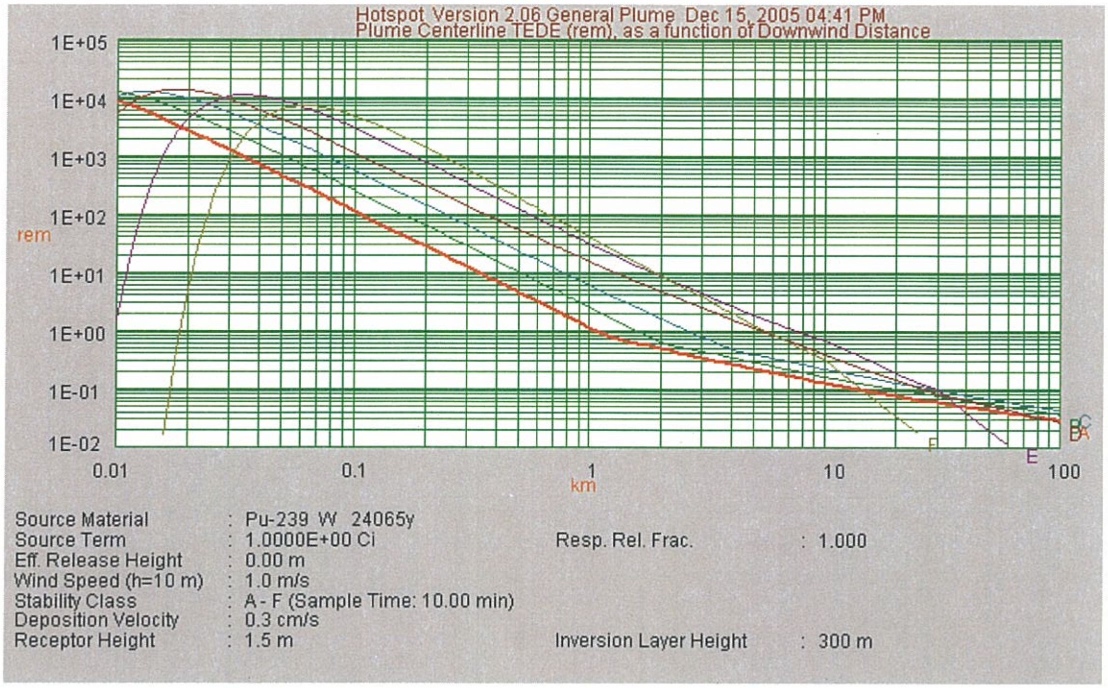
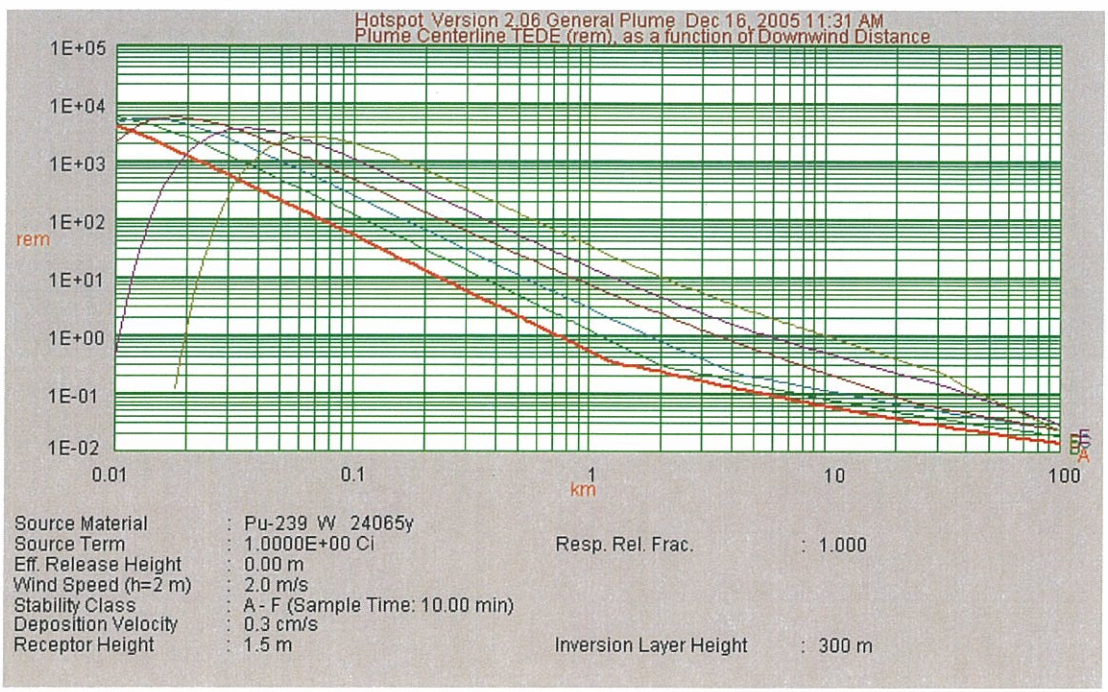
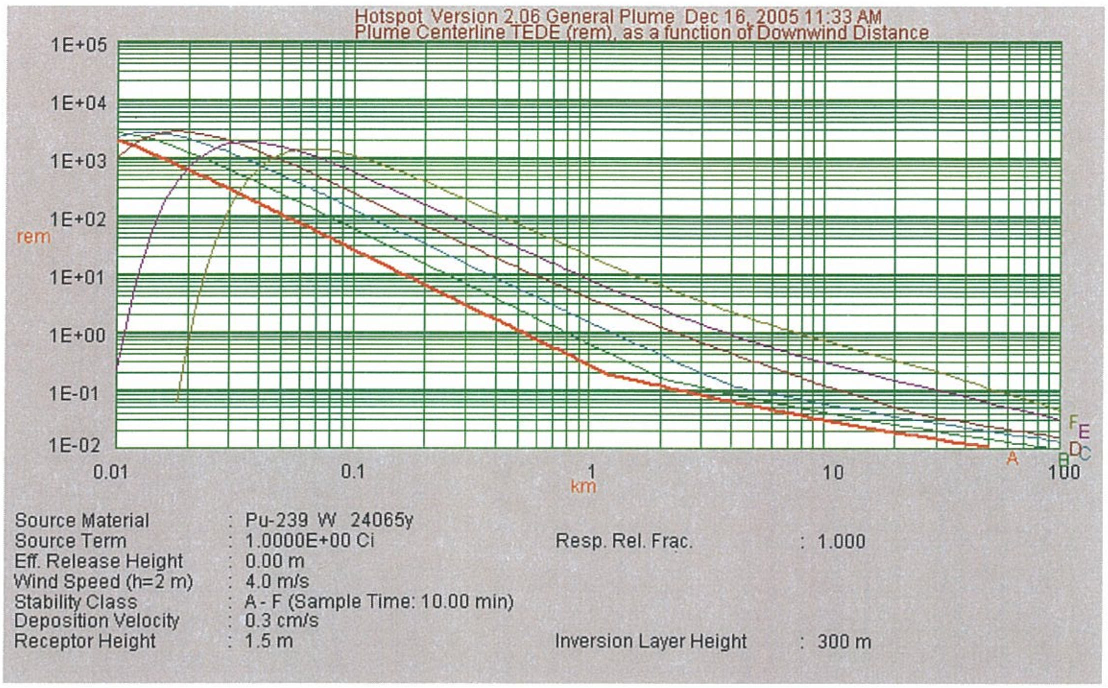


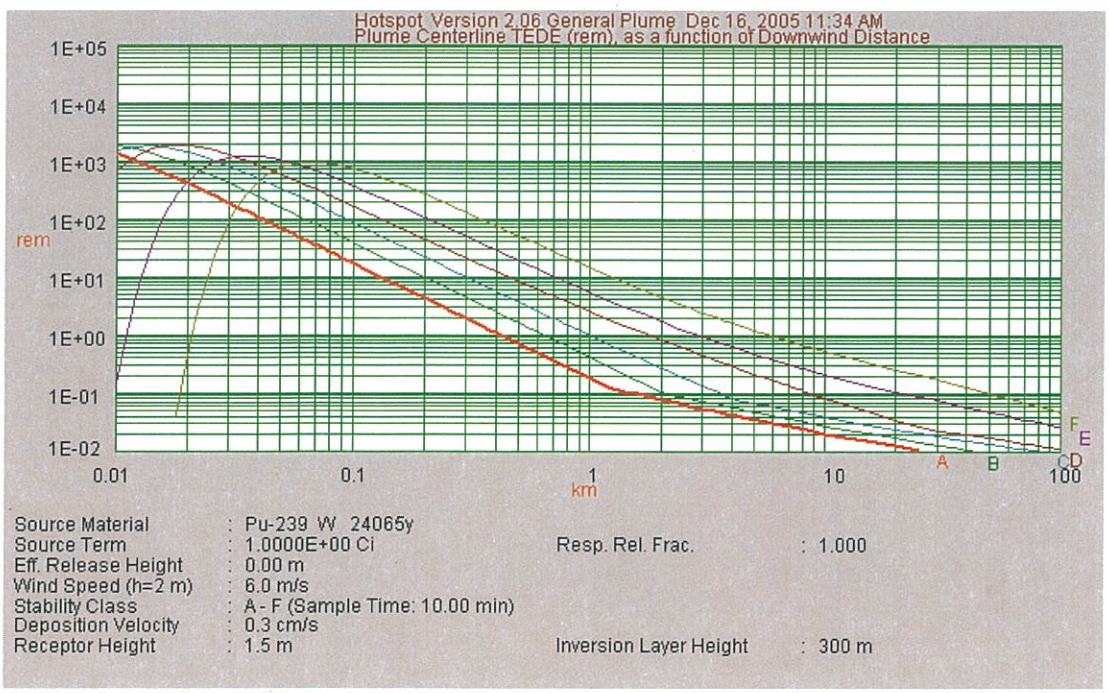
PU-239 HOTSPOT DOWNWIND DISTANCE VS. DOSE





PU-239 HOTSPOT DOWNWIND DISTANCE VS. DOSE (CONT'D)





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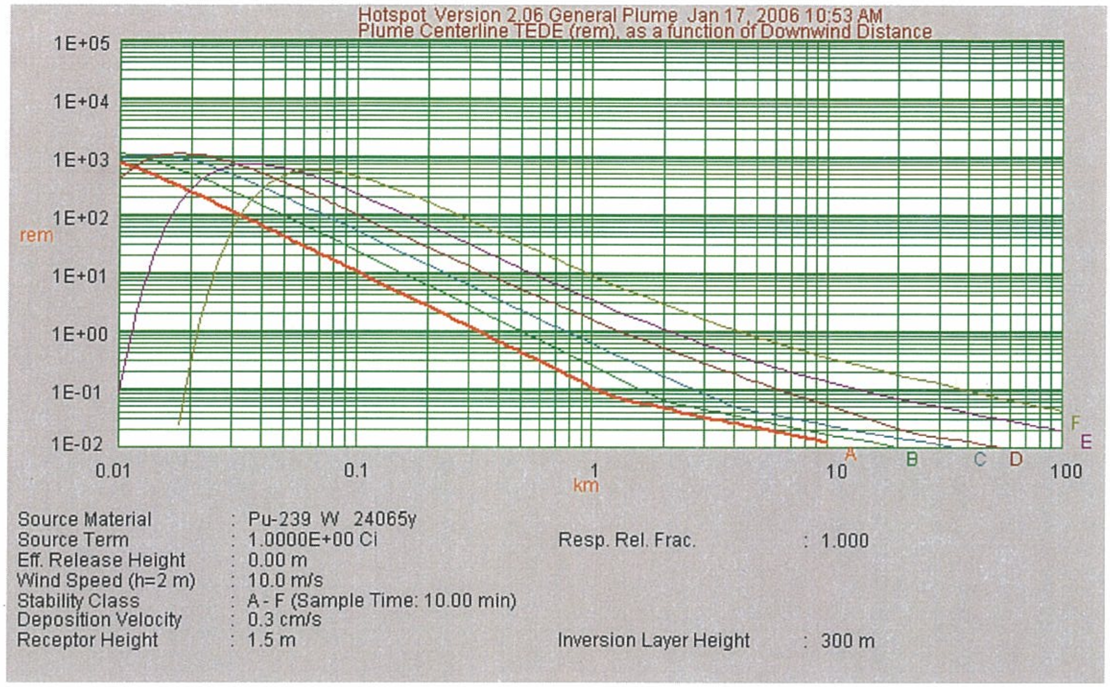
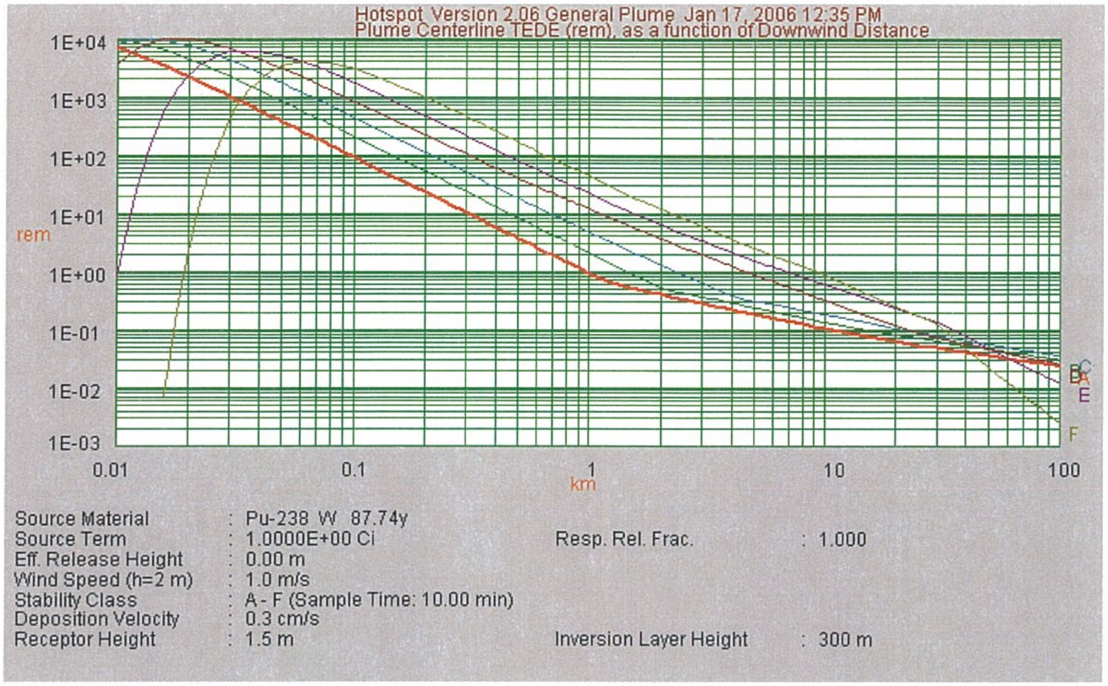
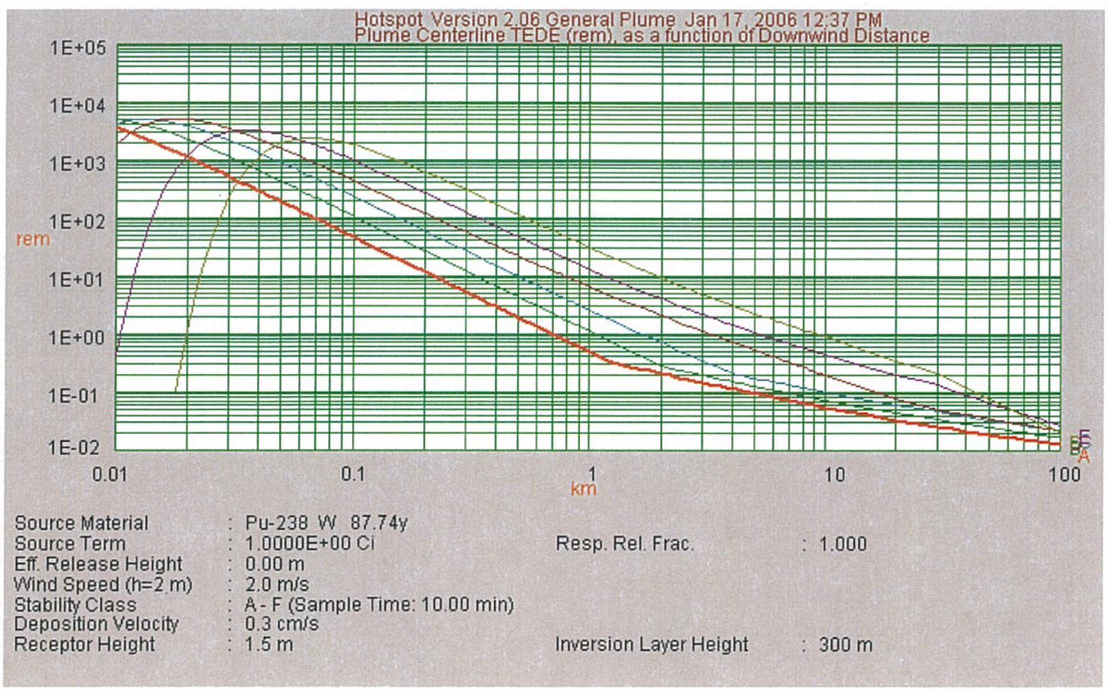


PU-238 HOTSPOT DOWNWIND DISTANCE VS. DOSE





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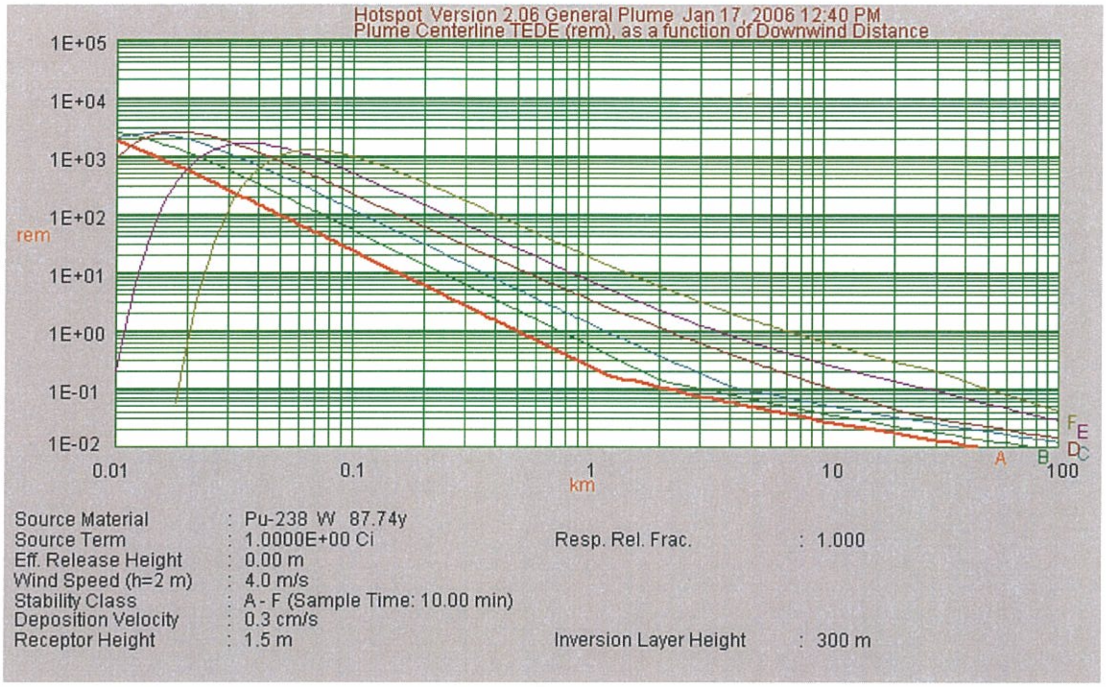
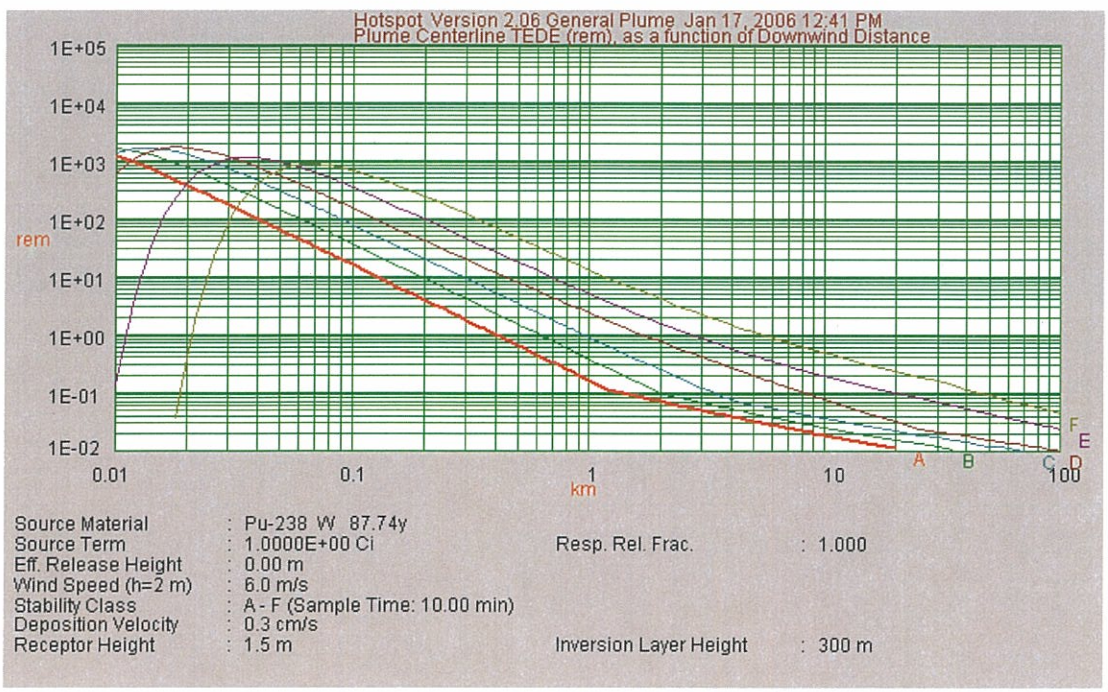
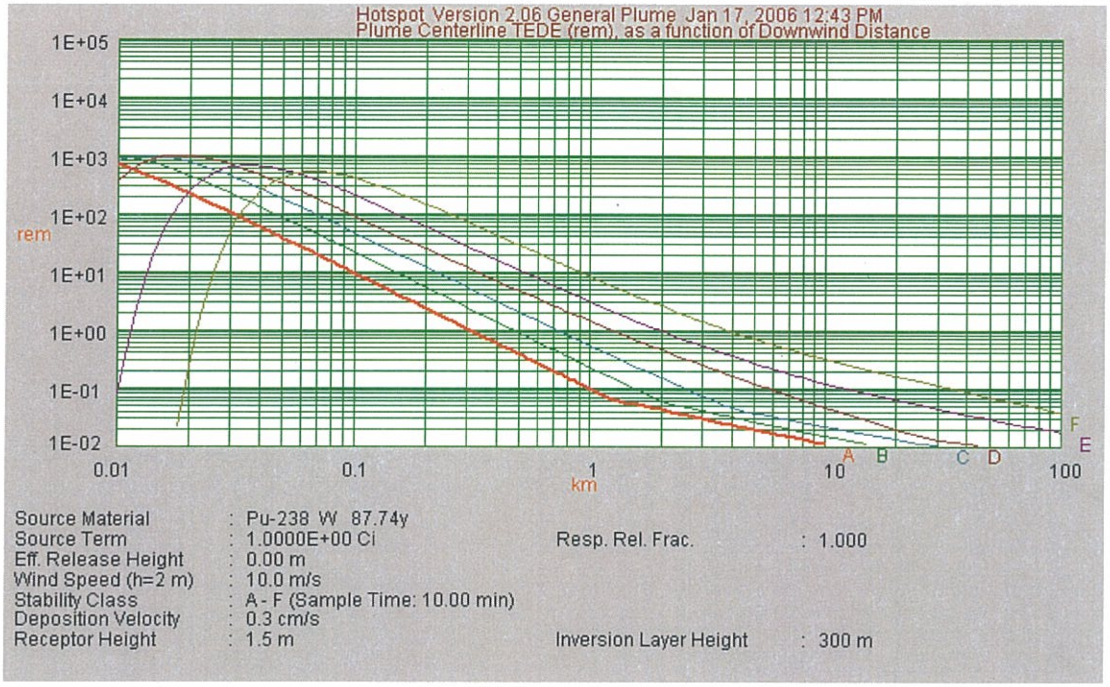
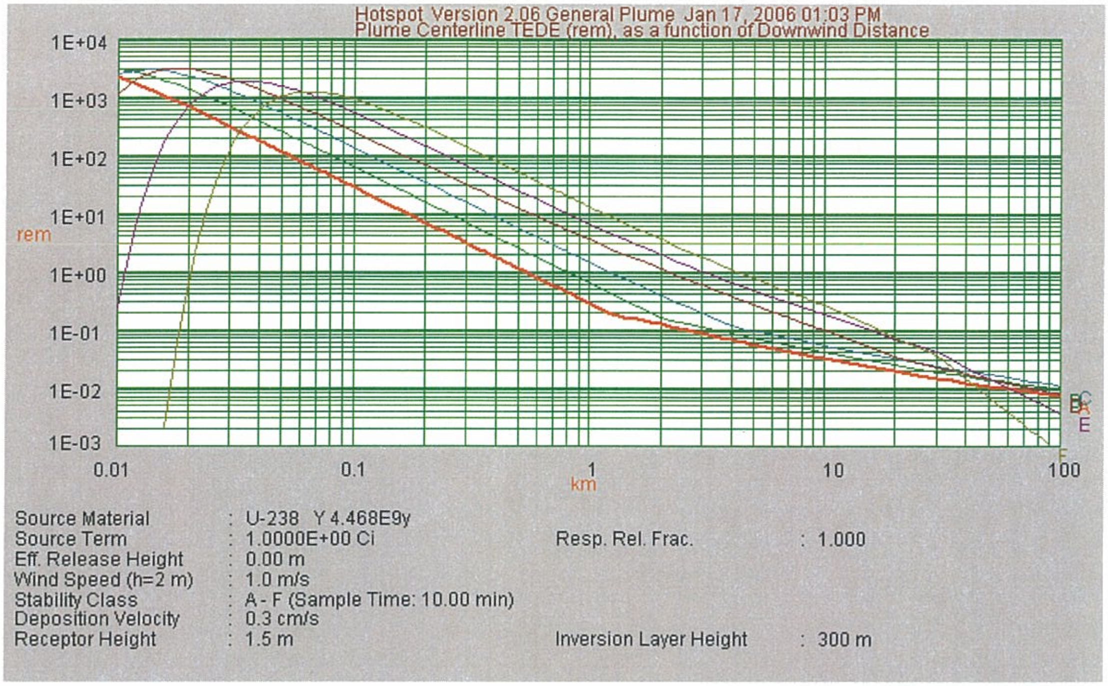


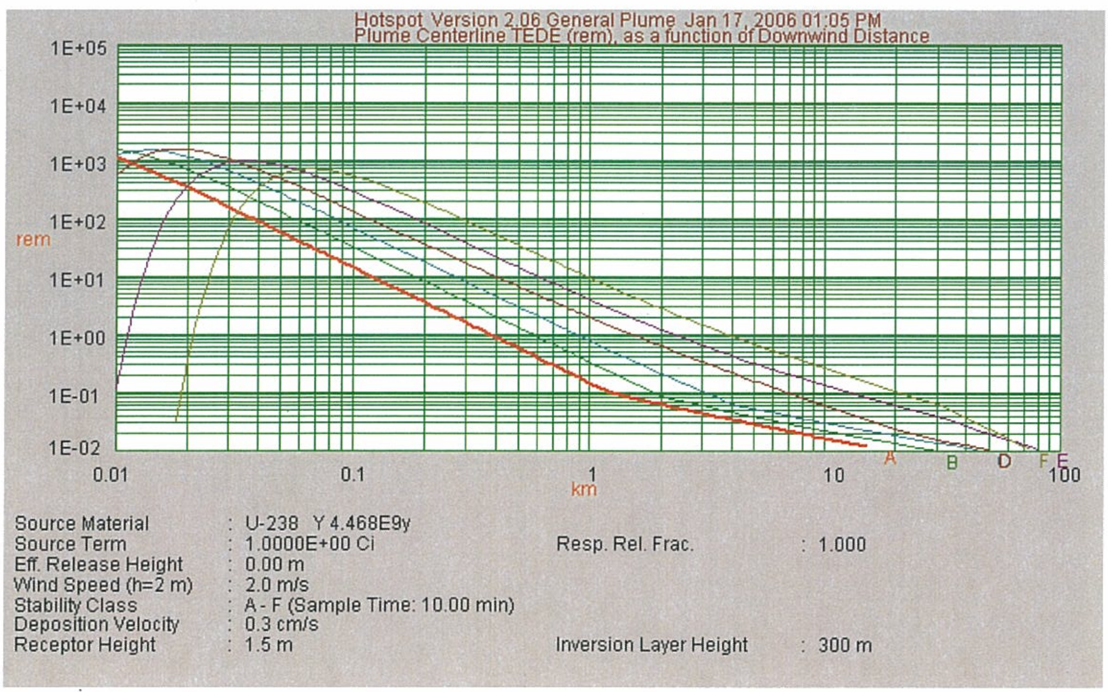


PU-238 HOTSPOT DOWNWIND DISTANCE VS. DOSE (CONT'D)

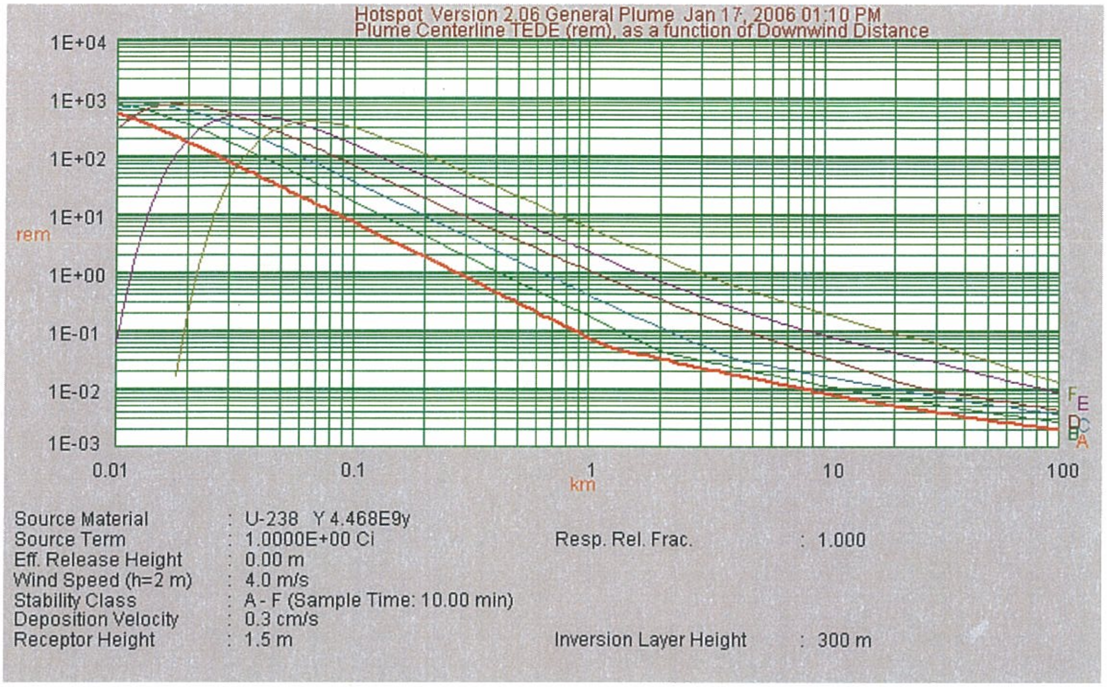


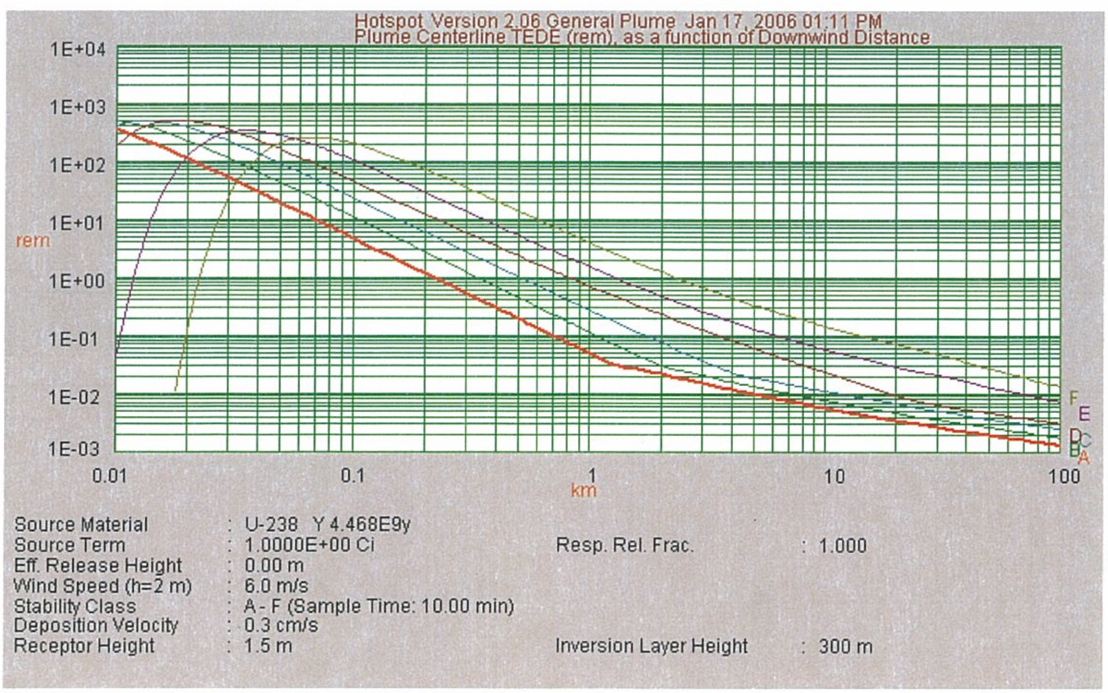
U-238 HOTSPOT DOWNWIND DISTANCE VS. DOSE



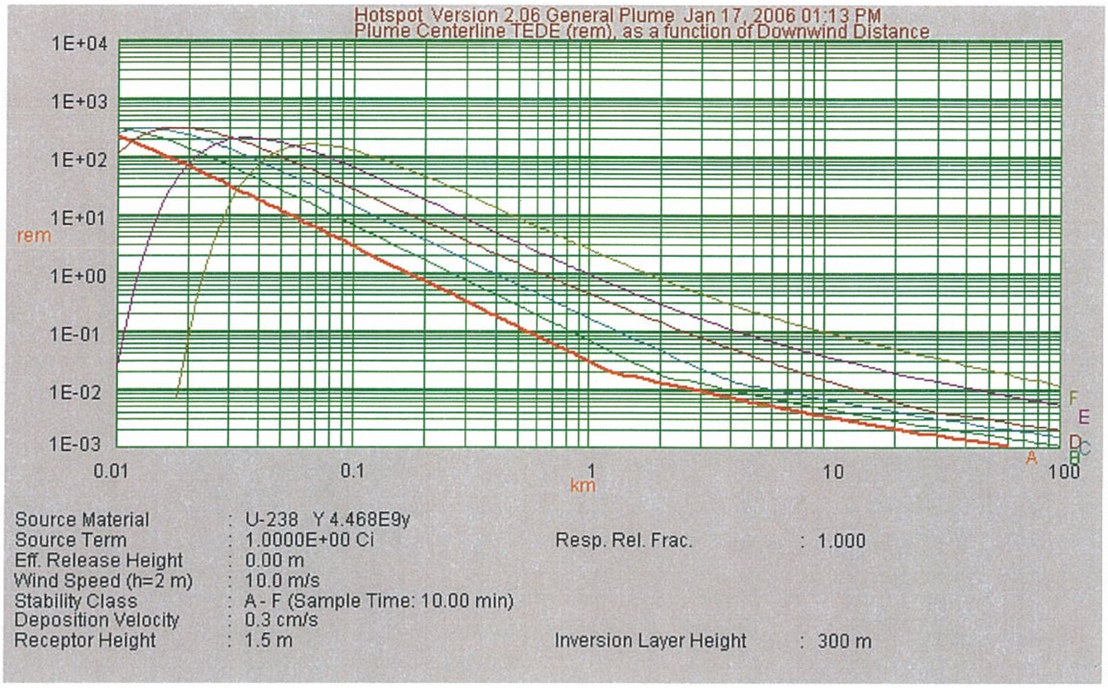


U-238 HOTSPOT DOWNWIND DISTANCE VS. DOSE (CONT'D)

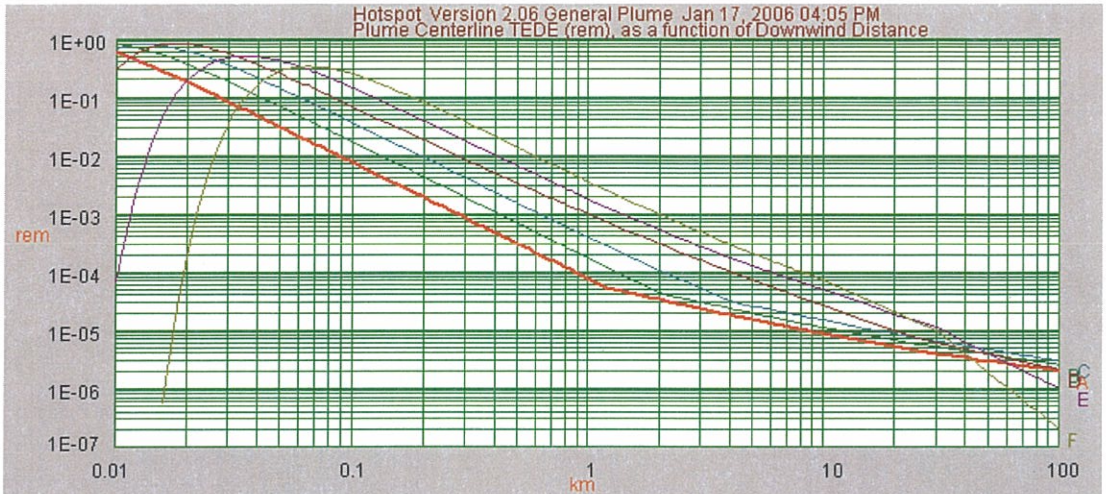




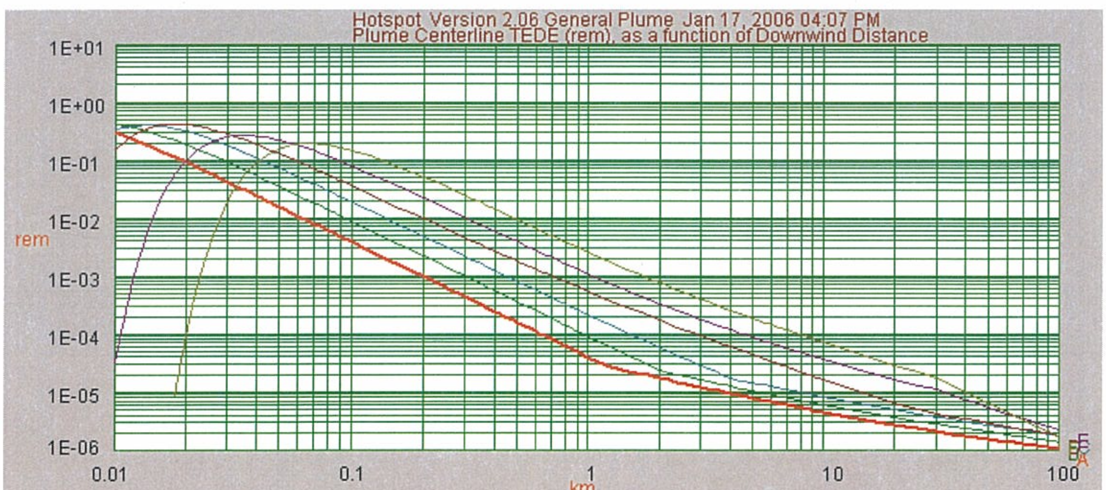
U-238 HOTSPOT DOWNWIND DISTANCE VS. DOSE (CONT'D)



CS-137 HOTSPOT DOWNWIND DISTANCE VS. DOSE

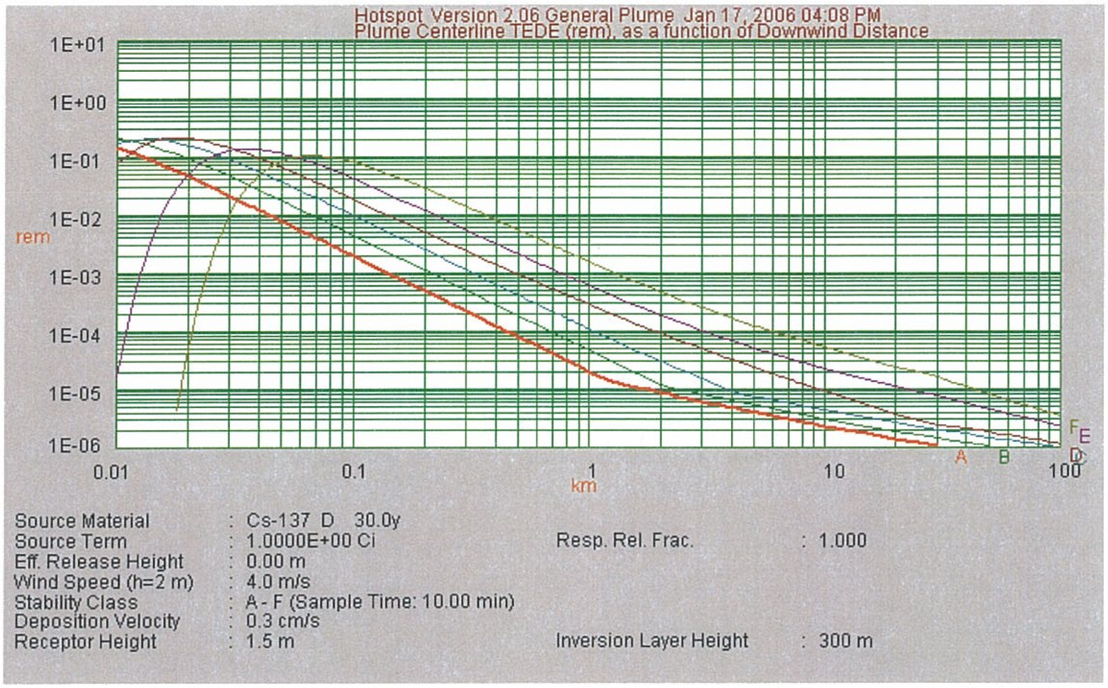


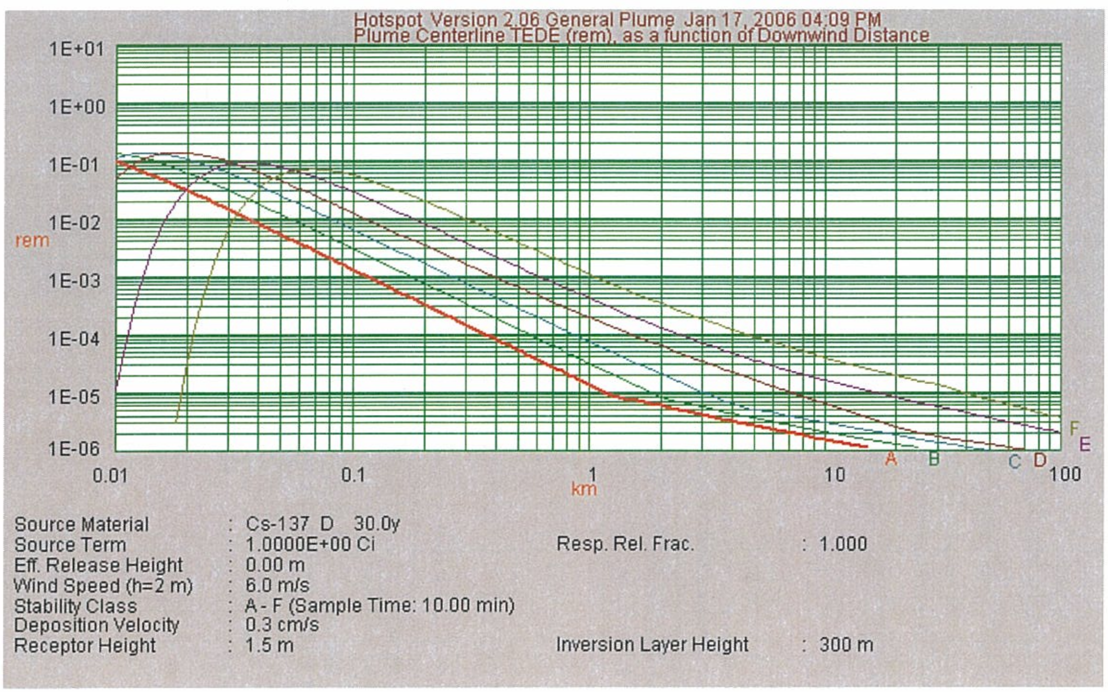
Source Material	: Cs-137 D 30.0y		
Source Term	: 1.0000E+00 Ci	Resp. Rel. Frac.	: 1.000
Eff. Release Height	: 0.00 m		
Wind Speed (h=2 m)	: 1.0 m/s		
Stability Class	: A - F (Sample Time: 10.00 min)		
Deposition Velocity	: 0.3 cm/s		
Receptor Height	: 1.5 m	Inversion Layer Height	: 300 m



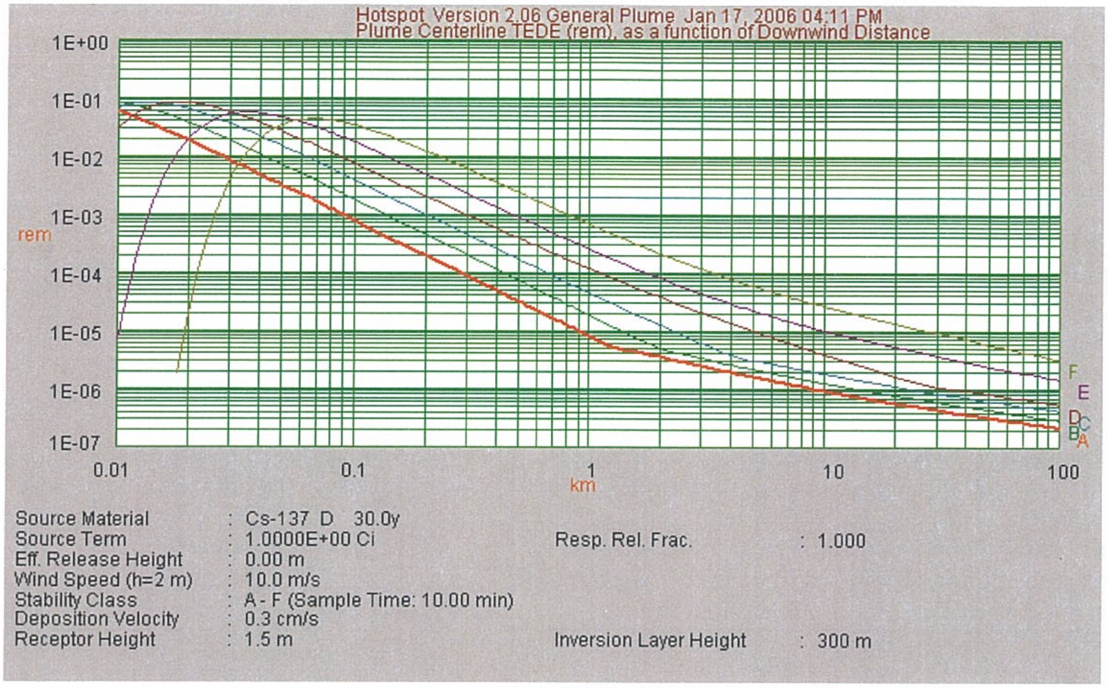
Source Material	: Cs-137 D 30.0y		
Source Term	: 1.0000E+00 Ci	Resp. Rel. Frac.	: 1.000
Eff. Release Height	: 0.00 m		
Wind Speed (h=2 m)	: 2.0 m/s		
Stability Class	: A - F (Sample Time: 10.00 min)		
Deposition Velocity	: 0.3 cm/s		
Receptor Height	: 1.5 m	Inversion Layer Height	: 300 m

CS-137 HOTSPOT DOWNWIND DISTANCE VS. DOSE (CONT'D)

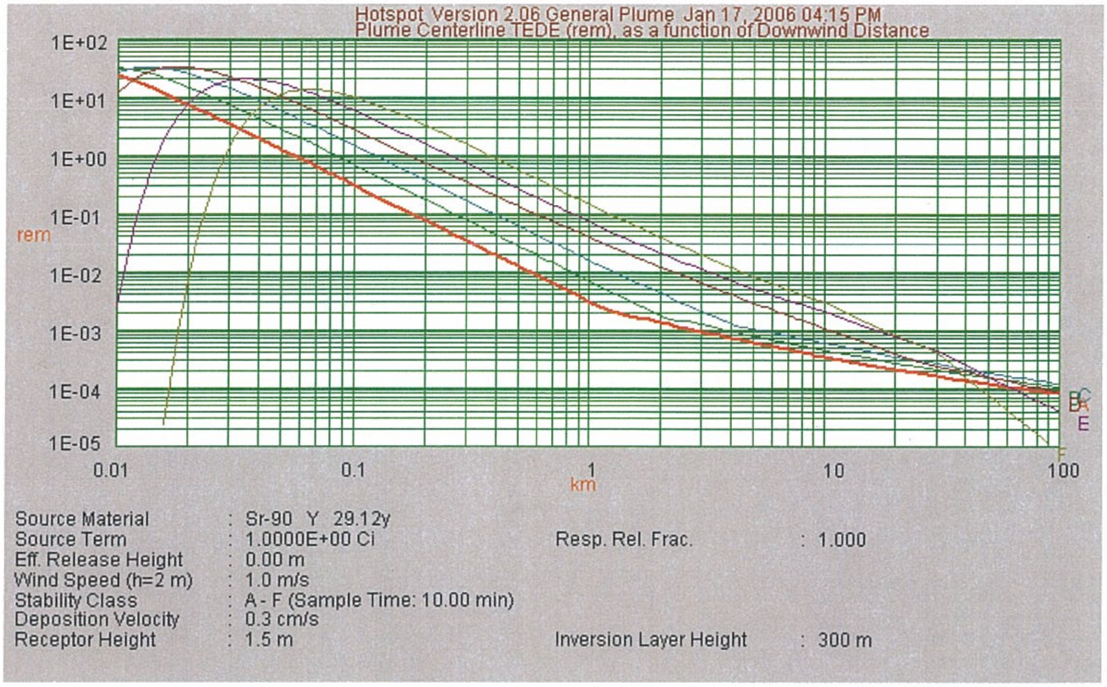


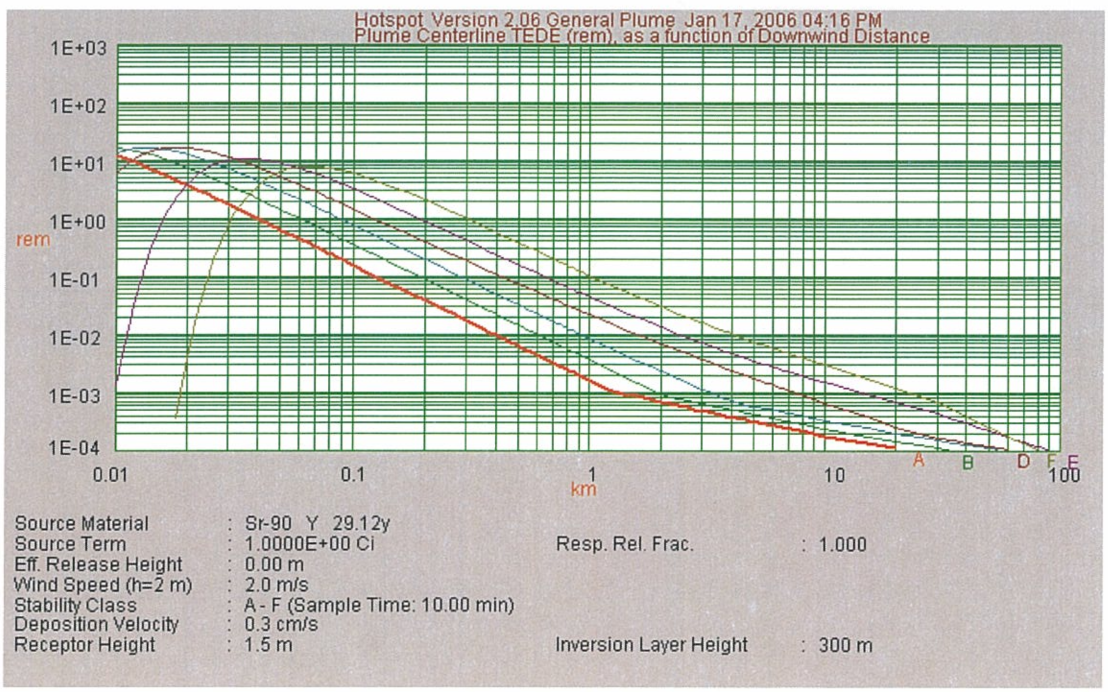


CS-137 HOTSPOT DOWNWIND DISTANCE VS. DOSE (CONT'D)

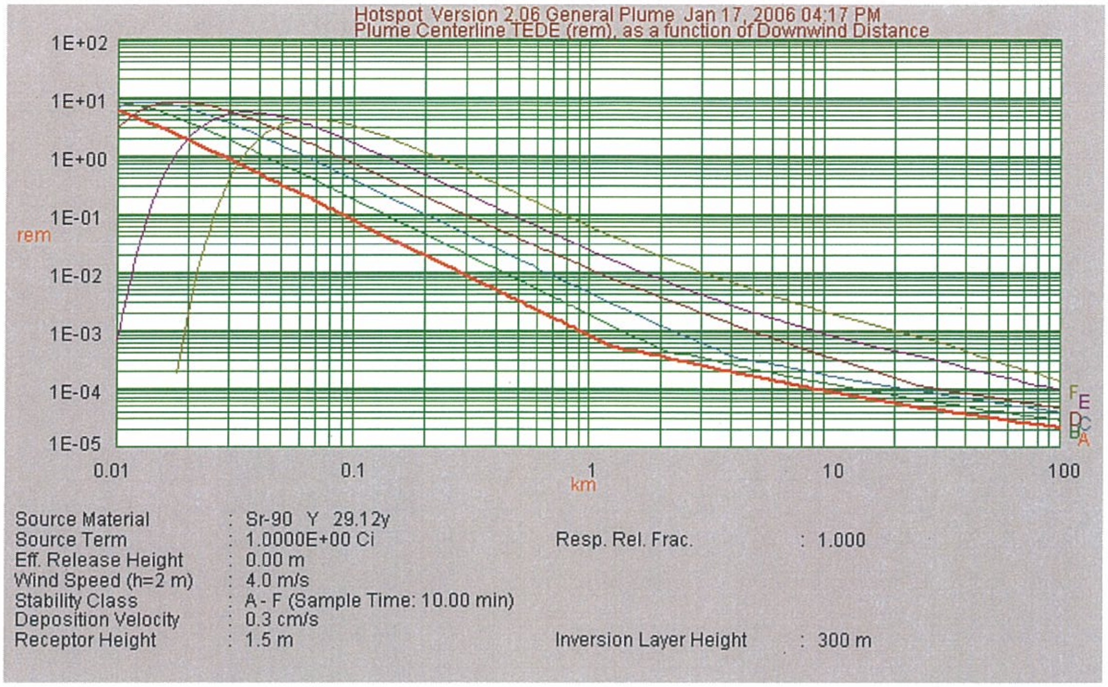


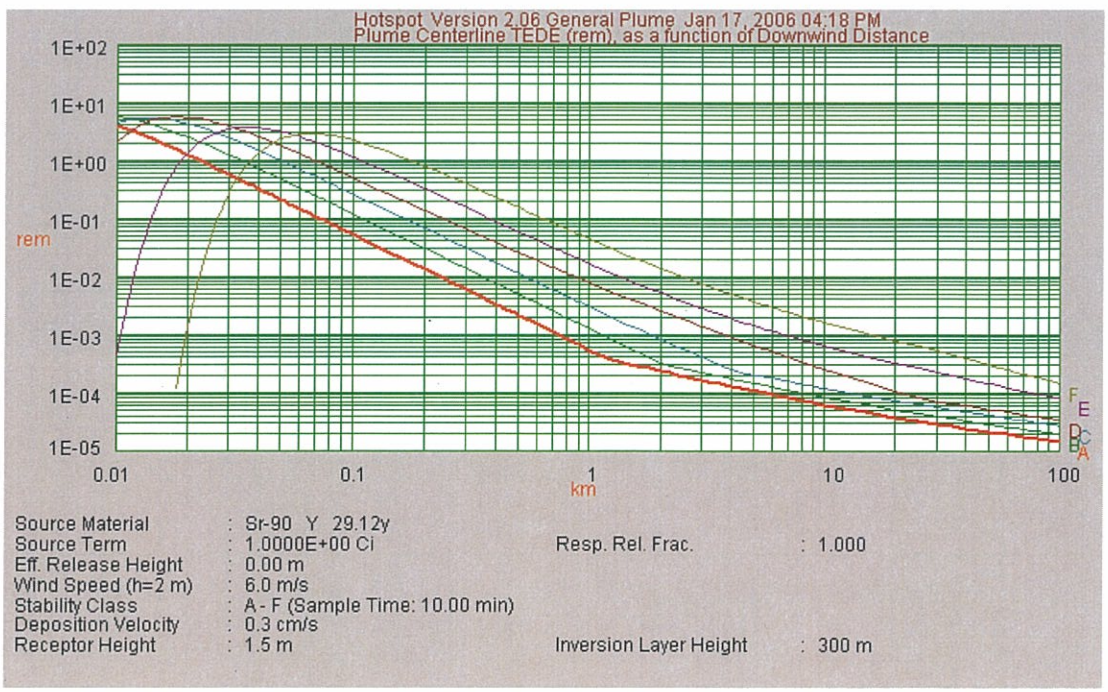
SR-90 HOTSPOT DOWNWIND DISTANCE VS. DOSE



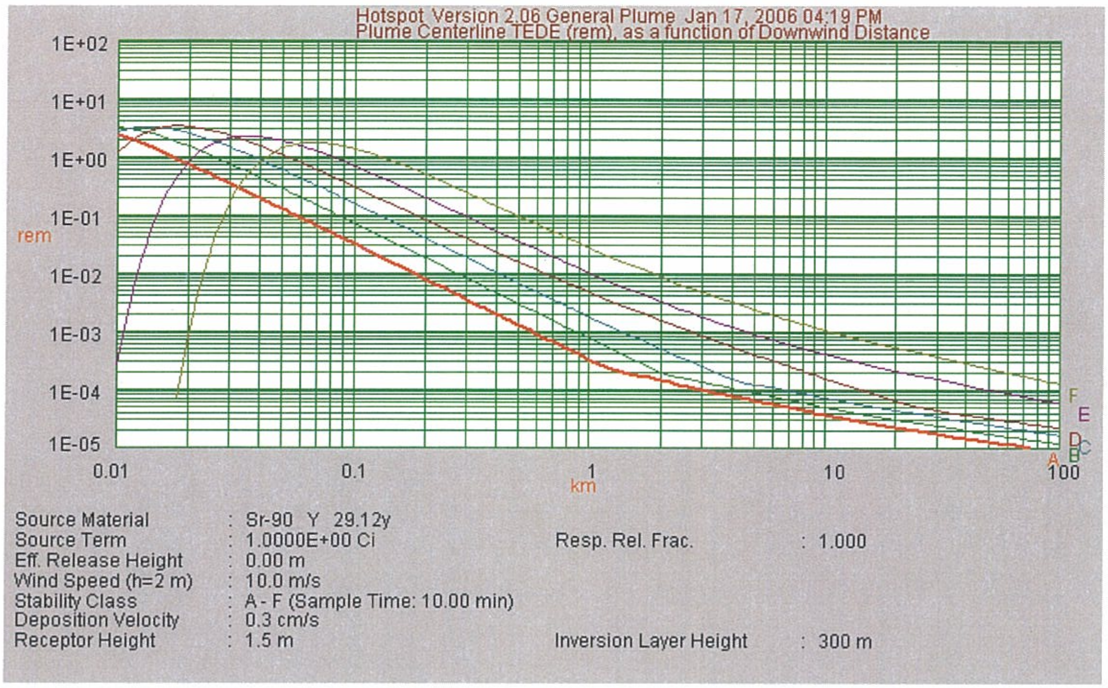


SR-90 HOTSPOT DOWNWIND DISTANCE VS. DOSE (CONT'D)

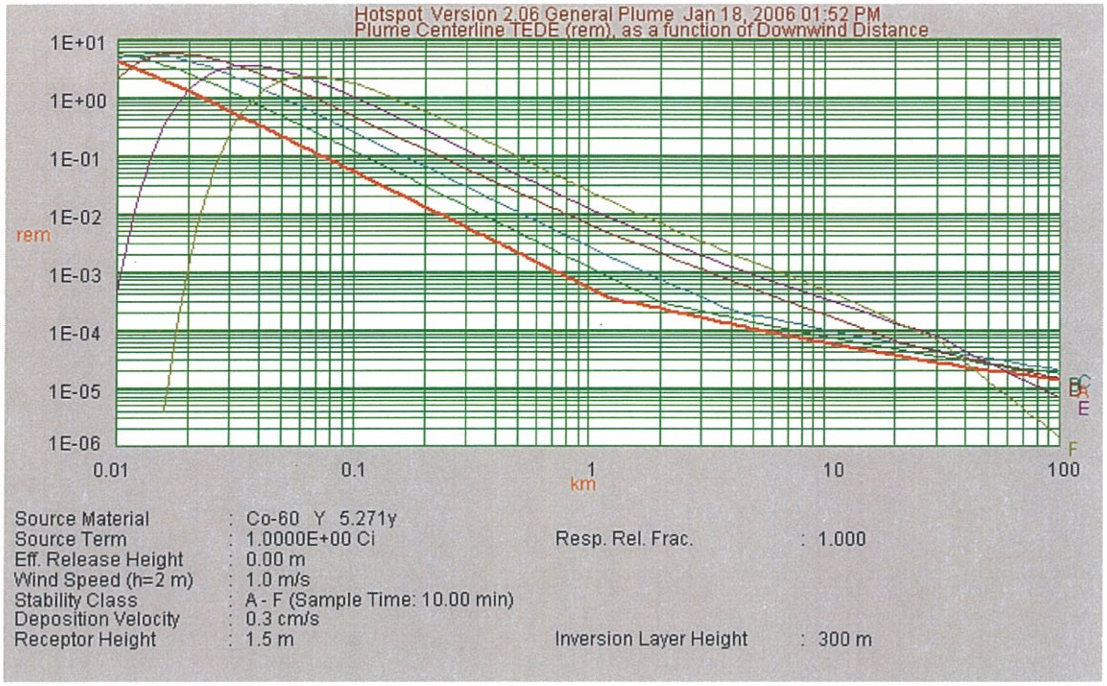


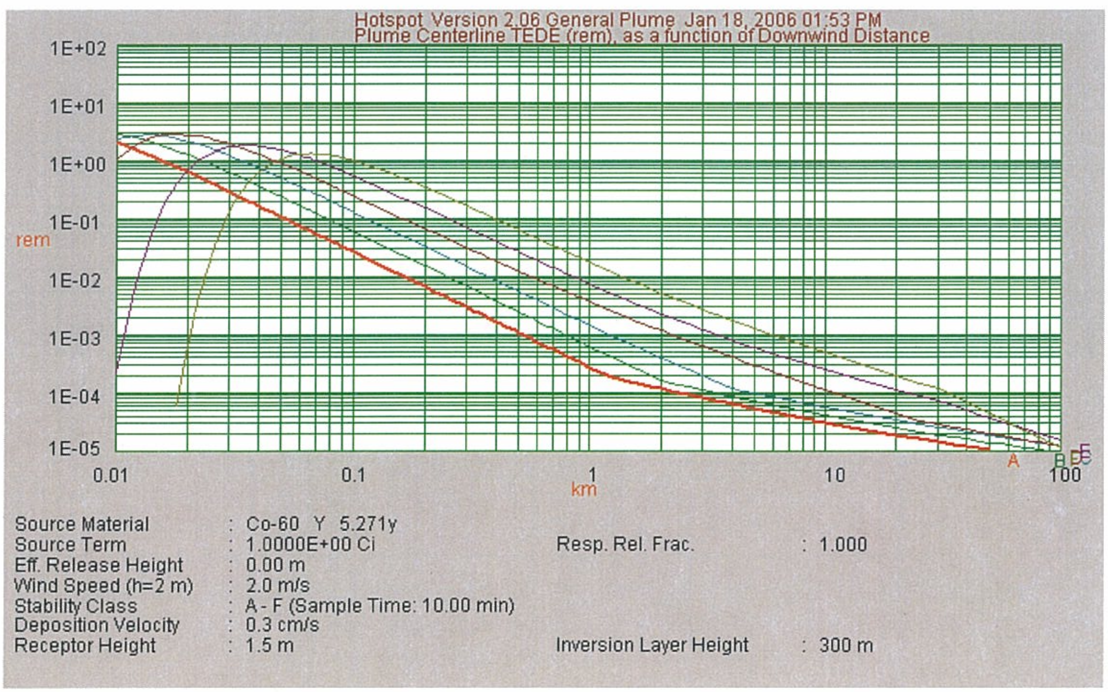


SR-90 HOTSPOT DOWNWIND DISTANCE VS. DOSE (CONT'D)

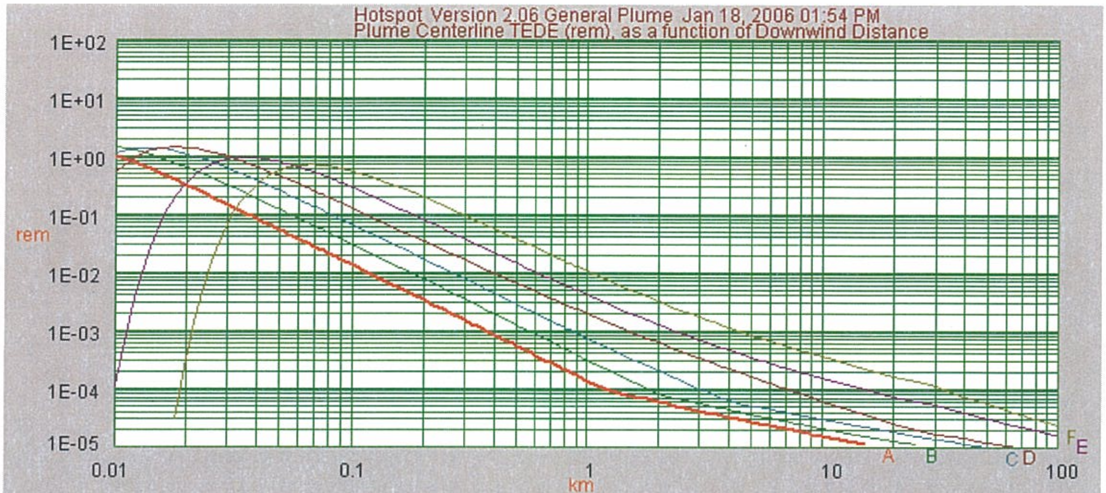


CO-60 HOTSPOT DOWNWIND DISTANCE VS. DOSE

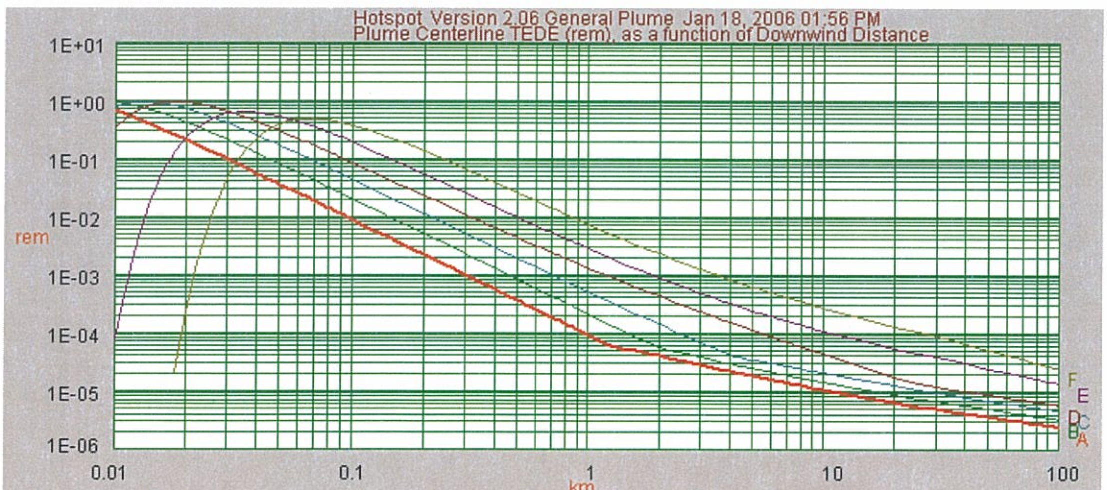




CO-60 HOTSPOT DOWNWIND DISTANCE VS. DOSE (CONT'D)

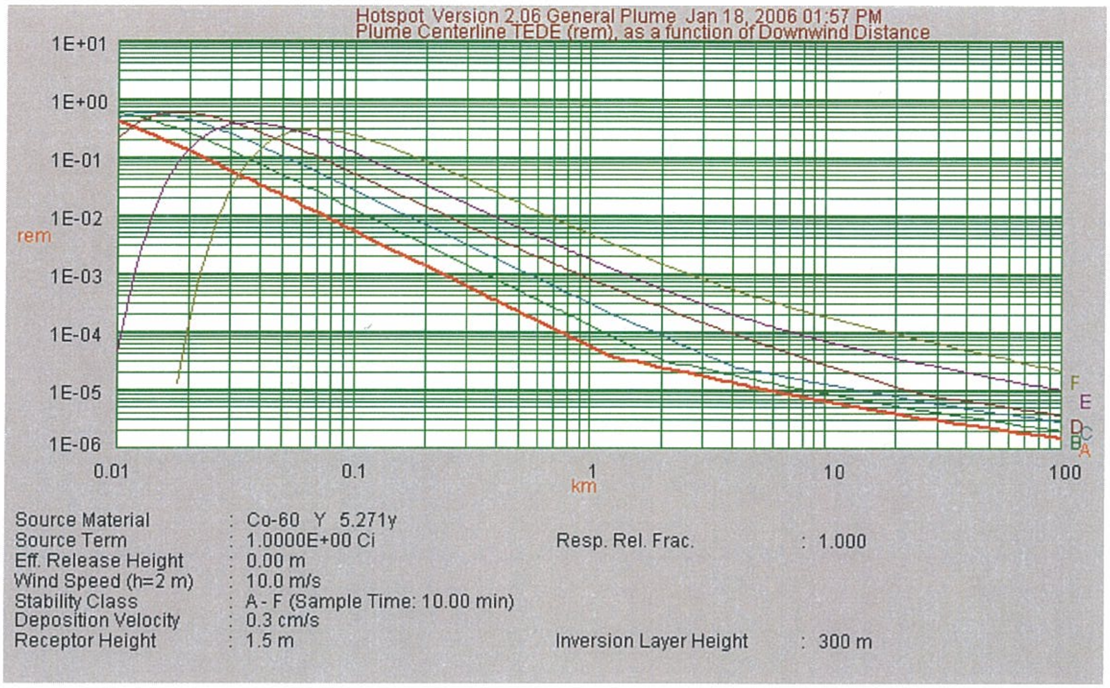


Source Material	: Co-60 Y 5.271y		
Source Term	: 1.0000E+00 Ci	Resp. Rel. Frac.	: 1.000
Eff. Release Height	: 0.00 m		
Wind Speed (h=2 m)	: 4.0 m/s		
Stability Class	: A - F (Sample Time: 10.00 min)		
Deposition Velocity	: 0.3 cm/s		
Receptor Height	: 1.5 m	Inversion Layer Height	: 300 m

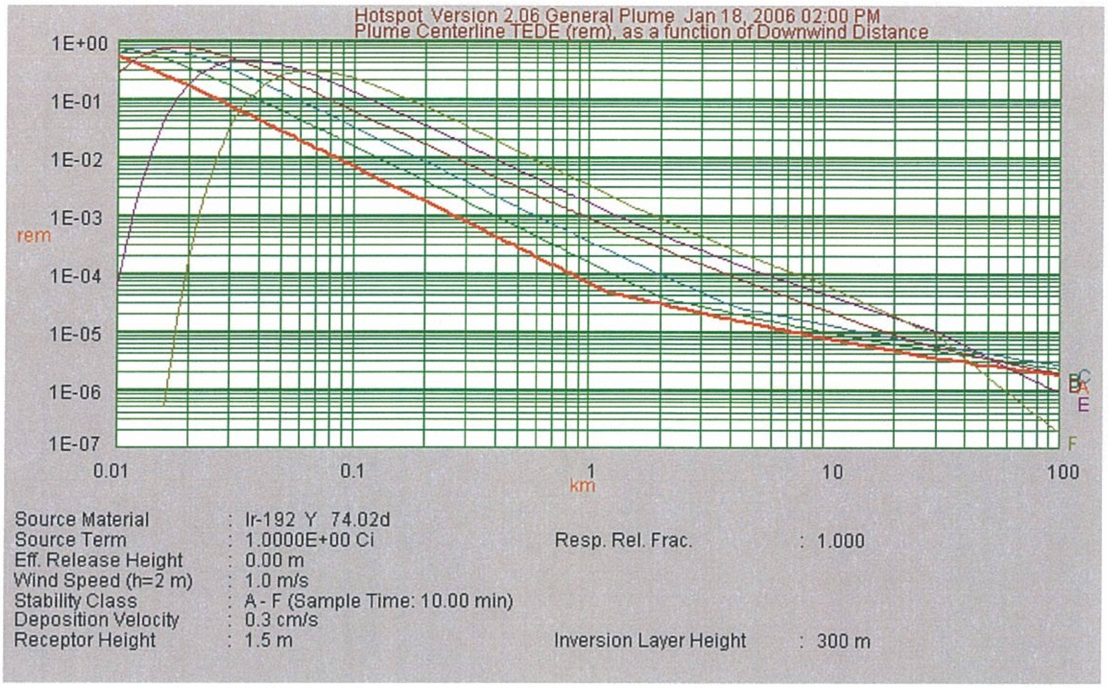


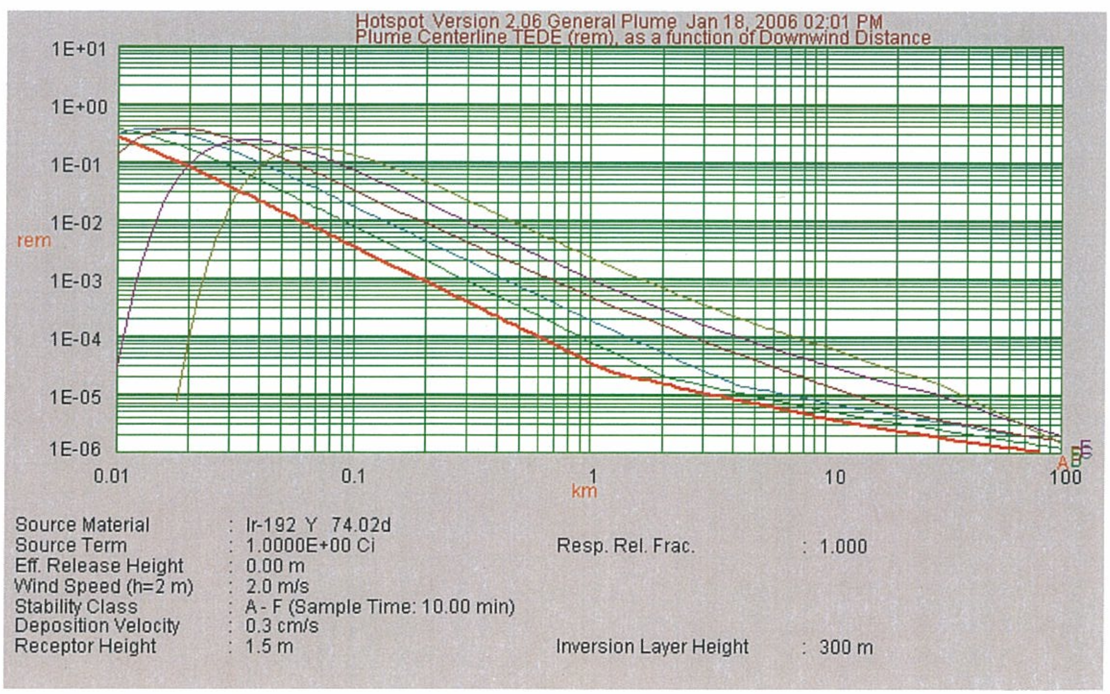
Source Material	: Co-60 Y 5.271y		
Source Term	: 1.0000E+00 Ci	Resp. Rel. Frac.	: 1.000
Eff. Release Height	: 0.00 m		
Wind Speed (h=2 m)	: 6.0 m/s		
Stability Class	: A - F (Sample Time: 10.00 min)		
Deposition Velocity	: 0.3 cm/s		
Receptor Height	: 1.5 m	Inversion Layer Height	: 300 m

CO-60 HOTSPOT DOWNWIND DISTANCE VS. DOSE (CONT'D)

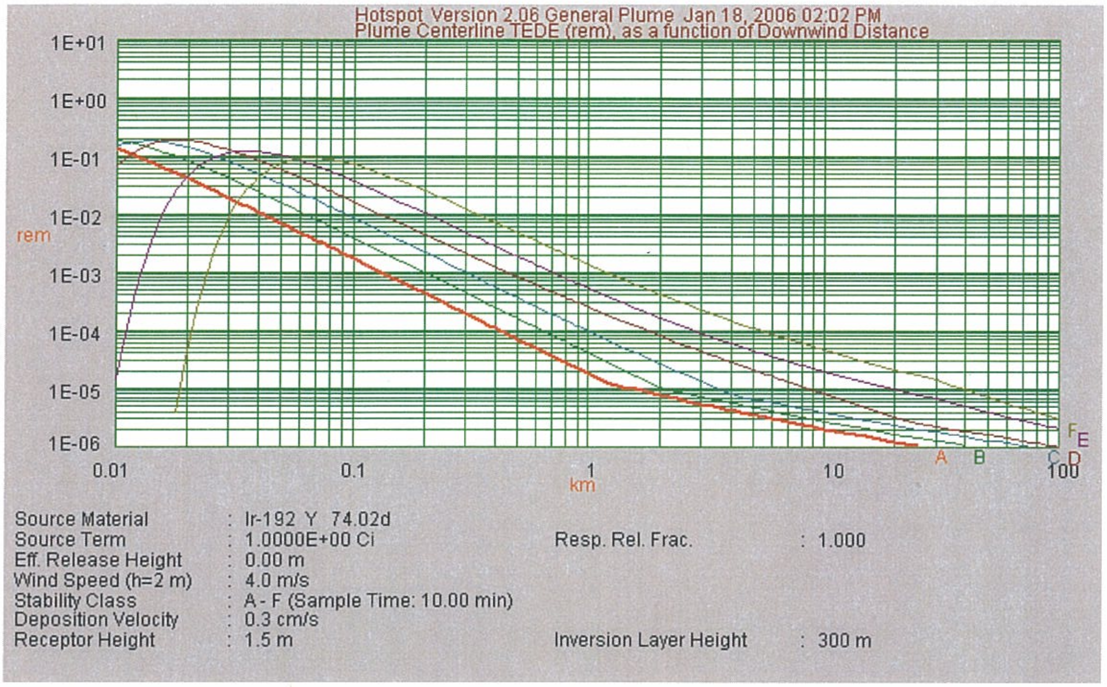


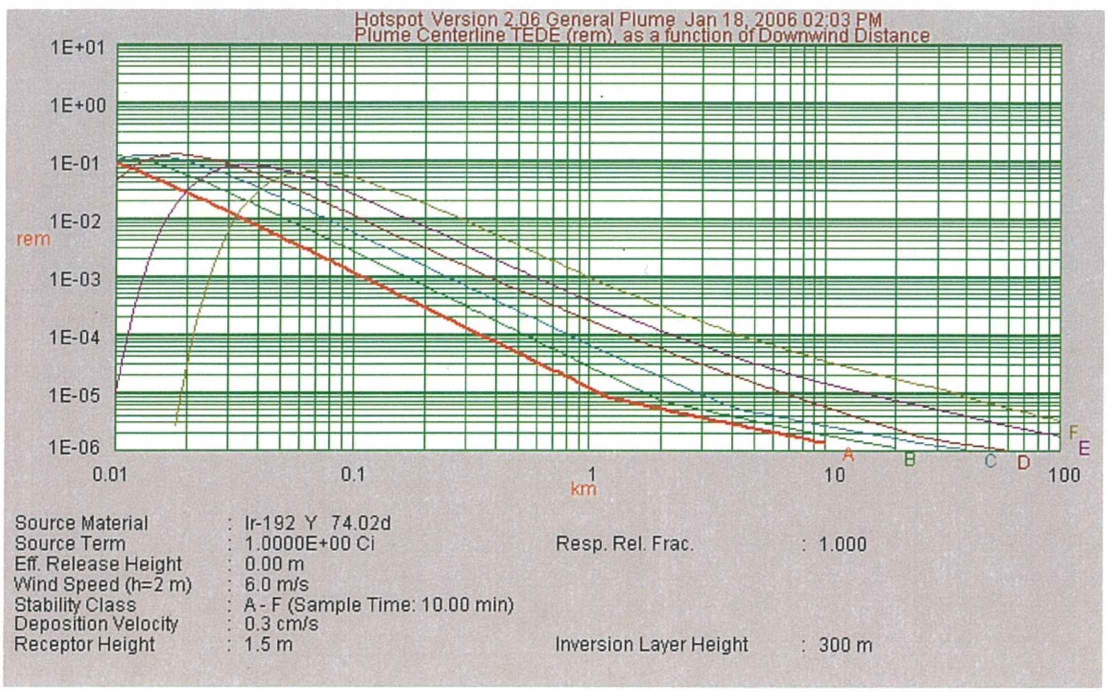
IR-192 HOTSPOT DOWNWIND DISTANCE VS. DOSE



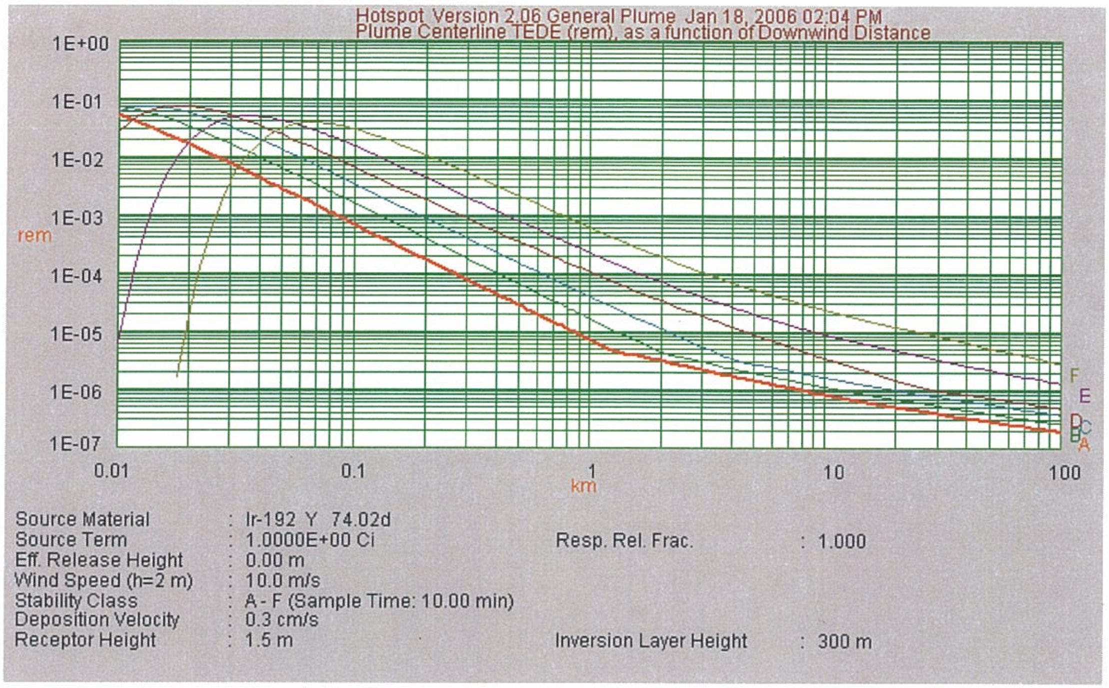


IR-192 HOTSPOT DOWNWIND DISTANCE VS. DOSE (CONT'D)





IR-192 HOTSPOT DOWNWIND DISTANCE VS. DOSE (CONT'D)



DISCUSSION OF NUMERICAL ESTIMATION OF PAG DOSE DISTANCE FOR TRANSURANICS AND TRITIUM OXIDE

Discussion of exponent, *b*

The dose, H is proportional to S/x^b, where the exponent b is usually between 1 and 2. Therefore, the distance to the 5 rem or 1 rem isodose curve, x, is proportional to $S^{1/b}$.

For atmospheric stability class A (unstable) the exponent $b \approx 2$ (inverse-square law.)
For stable conditions (class F) and at large distances (> 10 km), $b \approx 1$.
For most conditions, use $b = 3/2$ and $1/b = 2/3$.
It is most conservative to use $b = 1$ for $x > 1$ km and $b = 2$ for $x < 1$ km.

During an inversion with low wind speed, $b = 1$, so theoretically both H and x are inversely proportional to the wind speed. However, in such a case plutonium deposition is probably significant. Hotspot does not use wind speeds < 1 m/s.

Discussion of very large *x*

Simple calculations with Hotspot sometimes predict a very large isodose curve distance ($x > 10$ km) for very large source terms and stable conditions. In practice, the procedure described above is more conservative than all the Hotspot calculations in the LANL Hazards Assessment. The reasons are as follows.

For tritium oxide, the maximum LANL inventory, S is 20 MCi. Simple hotspot runs with $S = 20$ MCi of tritium oxide, stability classes E or F, and wind speed = 1 m/s, suggest the isodose curve distance x > 100 km; but this is for a ground-level release with no fire, in which case the source would be tritium gas, not oxide, and the dose would be 25,000 times smaller than the oxide case. In practice, the worst case in the LANL Hazards-Assessment document indicates $x = 10$ km for a release of $S = 19$ MCi in a fire. For comparison, the result of the procedure described above is: $x = 28$ km.

For plutonium, if you use the Hotspot default deposition velocity of 0.3 cm/s, the exponent, $b = 3/2$ is reasonably conservative, even at large distances. However, if deposition is small, for large distances and class E or F it would be more conservative to use $b = 1$.

Discussion of very small x

At very small distances ($x < 0.1$ km) from a ground-level release, it is more conservative to use the exponent b=2 (inverse-square) rather than b=3/2. In practice, the plume usually lofts over receptors closer than 0.1 km. There is only one case in the LANL Hazards Assessment for which the above procedure is not conservative: for a release of 0.0056 Ci of Pu at TA-50-69, the Hazards Assessment predicts $x = 0.055$ km, the above procedure with b=3/2 predicts $x = 0.032$ km, and b=2 (inverse-square) predicts $x = 0.075$ km.

Dose rate

Dose rate is proportional to release rate, and total dose is proportional to total released. If the release is spread over a time t then the dose will be received over the same time. For example, if *x* MCi of tritium are released over *t* hours and the total dose is *y* rem, the release rate is *x/t* MCi/h and the dose rate is *y/t* rem/h.

Simple math

To estimate $S^{2/3}$ within a factor of 2 without a calculator you may use the following.
$3^{2/3} \approx 2$
$10^{2/3} \approx 5$
$1000^{2/3} = 100$
Take products: e.g., $(300)^{2/3} = (3*10*10)^{2/3} \approx 2*5*5 = 50$.

DISCUSSION OF GRAPHICAL ESTIMATION OF PAG DOSE DISTANCE

Hotspot (version 2.06) general plume curves have been generated for specific radionuclides, wind speeds, and stability classes, and are located in Attachments 2 through 10. A single graph contains 6 curves representing stability classes A through F for a specific radionuclide and wind speed. The *x* (horizontal) axis of the graph represents the downwind distance in kilometers (km) from the source release point. The *y* (vertical) axis represents the plume centerline total effective dose equivalent (TEDE) in rem. It is the combination of the external and internal dose received by an individual located at that distance downwind for the entire passage of the plume. A single point on a specific curve represents the TEDE *y* for an individual at a specific downwind distance *x* for a 1 Curie (Ci) release for a specific radionuclide, stability class, and wind speed.

Certain assumptions were made to generate these curves:

- 1 Ci release from release point
- Most conservative (highest dose result) solubility class chosen for each radionuclide
- Ground-level release height
- Default particle deposition velocity of 0.3 cm/s
- Receptor height of 1.5 m, i.e., height of individual receiving dose
- Respiratory release fraction of 1.0
- Inversion layer at 300 m height

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