Method E.1
Estimation of Inhaled Soluble Uranium Intake and Hydrogen Fluoride Concentration After a Liquid UF_6 Release

Purpose

To estimate the soluble uranium uptake and the HF concentration at a given downwind distance from a liquid UF_6 release using default release and meteorological parameters.

Discussion

The estimations in this method are based on the following assumptions: average meteorological conditions [D stability, 4 mph (1.8 m/s) wind speed, and no rain]. Release of 1 kg of liquid UF_6 combining with 0.1 kg of water results in the release of 0.88 kg of UO_2F_2 (containing 0.68 kg of uranium) and 0.23 kg of HF (NUREG-1140, p. 28). Fifty percent of the released uranium is assumed to become airborne, producing a release fraction of 0.34 of the total liquid UF_6 release (NUREG-1140, p. 32). Fifty percent of the HF formed is assumed to become airborne, producing a release fraction of 0.12 of the total liquid UF_6 release. A release time of 15 min (NUREG-1140, p. 35) and breathing rate of 3.3×10^{-4} m^3/s, equivalent to adult light activity (EPA-520/1-88-020, p. 10) were used. A Gaussian plume model is assumed to approximate the distribution of the airborne fraction downwind.

Step 1

Estimate the amount of UF_6 released in metric tons (1 metric ton = 1000 kg). Obtain an estimate from the licensee or check the cylinder type in Table E-1.

Amount of UF_6 released or available for release _____ (metric ton)

Step 2

Estimate the amount of inhaled soluble uranium. Consult Fig. E-2 to estimate the intake of soluble uranium (IU_{sol}) in grams for the downwind distances of interest from a release of 1 metric ton of UF_6. Multiply the IU_{sol} value from the graph by the number of metric tons of UF_6 released.

_____ IU_{sol} × _____ *tons* UF_6 *released* = _____ g

Step 3

Estimate HF concentration, χ_{HF}. Use Fig. E-3 to estimate the concentration of HF (g/m^3) in the air downwind resulting from a release of 1 metric ton (1000 kg) of UF_6. Multiply the value from the graph by the number of metric tons of UF_6 released.

_____ χ_{HF} × _____ *tons* UF_6 *released* = _____ g/m^3

END

Method E.2
Calculation of Inhaled Soluble Uranium Intake and Hydrogen Fluoride Concentration After a UF_6 Release

Purpose

To project the soluble uranium uptake and the HF concentration at a given downwind distance from a UF_6 release using incident-specific parameters and meteorology.

Discussion

When specific information is known about the accident conditions, the soluble uranium uptake and HF concentration at a distance downwind can be calculated. A Gaussian plume model is assumed to approximate the distribution of the airborne fraction downwind. This method allows the values of parameters in the formula to be varied.

If gaseous UF_6 is released, then the assumption that 100% of the UF_6 becomes airborne and is incorporated in the plume is appropriate for the purposes of performing a rough bounding calculation. Under this assumption, the release fractions would be 0.68 for uranium and 0.23 for HF.

Calculation of inhaled soluble uranium is covered in Steps 3 and 4. Steps 5 and 6 deal with calculation of the HF air concentration.

Step 1

Estimate the amount of UF_6 released in grams (1 metric ton = 10^3 kg = 10^6 g). Obtain an estimate from the licensee or check the cylinder type in Table E-1.

Amount of UF_6 released or available for release (Q_{UF_6}) _____ g

Step 2

Determine the meteorological parameters. Dispersion close to the source ($\leq$0.25 mile) is dominated by building and source wake; the dilution factor is the same for all stability classes.

Stability class (see Table F-8 or F-9) _____
Wind speed ($\bar{U}$) _____ m/s
Distance downwind (d) _____ m
Dilution factor (see Table F-10) (DF_d) _____ m^{-2}

Step 3

Estimate the release fraction for soluble uranium ($RF_{U_{sol}}$). The release fraction is the fraction (by weight) of the uranium that is incorporated in the plume relative to the weight of the total UF_6 inventory available for release. Use licensee estimates if available or assume a release fraction of 0.34 for liquid UF_6 (see discussion in Method E.1) or 0.68 for UF_6 gas for bounding calculation.

Release fraction for soluble uranium ($RF_{U_{sol}}$) _____

Step 4

Calculate the amount of soluble uranium inhaled (IU_{sol}), over the entire duration of plume passage, at a given downwind distance.

$$IU_{sol} = \frac{Q_{UF_6} \times RF_{U_{sol}} \times DF_d \times BR}{\bar{U}}$$

$$(\quad g) = \frac{(\quad g) \times (\quad) \times (\quad m^{-2}) \times (\quad m^3/s)}{(\quad m/s)}$$

where

IU_{sol}	=	total integrated inhaled intake of soluble uranium (g)
Q_{UF6}	=	UF_6 inventory in process or container available for release (g)
$RF_{U_{sol}}$	=	uranium release fraction (default value 0.34 for liquid UF_6, 0.68 for gas)
DF_d	=	dilution factor (m^{-2}) at distance, *d*, from release for appropriate stability class (Table F-10)
BR	=	breathing rate (m^3/s) (default value 3.3×10^{-4} m^3/s from EPA-520/1-88-020, p. 10)
$\bar{U}$	=	average wind speed (m/s) (default value 4 mph = 1.8 m/s)

Step 5

Estimate the release fraction for HF. The release fraction is the fraction (by weight) of the total UF_6 inventory available for release that is released as HF. Use the licensee estimates if available or assume a release fraction of 0.12 for liquid UF_6 (see discussion in Method E.1) or 0.23 for gas for bounding calculation.

Release fraction for hydrogen fluoride (RF_{HF}) _____

Step 6

Calculate the HF concentration at this downwind distance.

$$\chi_{HF} = \frac{Q_{UF_6} \times RF_{HF} \times DF_d}{t_r \times \bar{U}}$$

$$(\quad g) = \frac{(\quad g) \times (\quad) \times (\quad m^{-2})}{(\quad s) \times (\quad m/s)}$$

where

χ_{HF}	=	HF concentration (g/m^3) at distance d from the release
Q_{UF6}	=	UF_6 inventory available for release (g)
RF_{HF}	=	HF release fraction (default value 0.12 for liquid UF_6, 0.23 for gas)
DF_d	=	dilution factor (m^{-2}) at distance, *d*, from release for appropriate stability class (Table F-10)
$\bar{U}$	=	average wind speed (m/s) (default value 1.8 m/s)
t_r	=	UF_6 release duration (s) [default value 900 s (15 min) from NUREG-1140, p. 35]

END

Method E.3
Estimation of Committed Effective Dose Equivalent Resulting From Inhaled Uranium After a Liquid UF_6 Release

Purpose

To estimate the radiological dose (committed effective dose equivalent) from inhaled uranium at a given distance downwind from a release of liquid UF_6 using default release and meteorological parameters.

Discussion

The calculations in this method assume the following: average meteorological conditions [D stability, 4 mph (1.8 m/s) wind speed, and no rain]. Release of 1 kg of UF_6 combining with 0.1 kg of water results in the release of 0.88 kg of UO_2F_2 (containing 0.68 kg of uranium) and 0.23 kg of HF (NUREG-1140, p. 28). Fifty percent of the released uranium is assumed to become airborne, producing a release fraction of 0.34 of the total UF_6 release. A release time of 15 min (NUREG-1140, p. 35) and breathing rate of 3.3×10^{-4} m^3/s, equivalent to adult light activity (EPA 520/1-88-020, p. 10) were used. A Gaussian plume model is assumed to approximate the distribution of the airborne fraction downwind.

Step 1

Estimate the amount of UF_6 released in metric tons (1 metric ton = 1000 kg). Gain information from the licensee or check the process inventory or cylinder type in Table E-1.

Amount of UF_6 released or available for release _____ (metric ton)

Step 2

Estimate the committed effective dose equivalent (CEDE). Consult Fig. E-4 to estimate the CEDE in rem for the downwind distances of interest from a release of 1 metric ton of liquid UF_6. The four curves correspond to different enrichment levels (the percentage by weight of the ^{235}U isotope). Multiply the value from the graph by the number of metric tons of UF_6 released.

_____ *CEDE* × _____ *tons* UF_6 *released* = _____ rem

END

Method E.4
Calculation of Committed Effective Dose Equivalent Resulting From Inhaled Uranium After a UF_6 Release

Purpose

To project the committed effective dose equivalent (CEDE) from the inhalation of uranium at a given distance downwind after a UF_6 (gas or liquid) release using incident-specific parameters and meteorology.

Discussion

A Gaussian plume model is assumed to approximate the distribution of the airborne fraction downwind. This method allows the values of parameters in the formula to be varied.

If gaseous UF_6 is released, then the assumption that 100% of the UF_6 becomes airborne and is incorporated in the plume is appropriate for the purposes of performing a rough bounding calculation. Under this assumption, the release fractions would be 0.68 for uranium and 0.23 for HF.

Step 1

If you used Method E.2 to calculate soluble uranium intake, refer to the values calculated in that method and skip to Step 5 (next page).

Estimate the amount of UF_6 released in grams (1 metric ton = 10^3 kg = 10^6 g).

Amount of UF_6 released or available for release (Q_{UF_6}) _____ g

Step 2

Determine the meteorological parameters. Dispersion close to the source ($\leq$0.25 mile) is dominated by building and source wake; the dilution factor is the same for all stability classes.

Stability class (see Table F-8 or F-9) _____
Wind speed ($\bar{U}$) _____ m/sec
Distance downwind (d) _____ m
Dilution factor (see Table F-10) (DF_d) _____ m^{-2}

Step 3

Estimate the release fraction for soluble uranium ($RF_{U_{sol}}$). The release fraction is the fraction (by weight) of the uranium that is incorporated in the plume relative to the weight of the total UF_6 inventory available for release. Use licensee estimates if available or assume a release fraction of 0.34 for soluble uranium from a liquid UF_6 release (see discussion in Method E.3) or 0.68 for release of UF_6 gas for bounding calculation.

Release fraction for soluble uranium ($RF_{U_{sol}}$) _____

Step 4

Calculate the amount of soluble uranium inhaled (IU_{sol}) at this downwind distance.

$$IU_{sol} = \frac{Q_{UF_6} \times RF_{U_{sol}} \times DF_d \times BR}{\bar{U}}$$

$$(\quad g) = \frac{(\quad g) \times (\quad) \times (\quad m^{-2}) \times (\quad m^3/s)}{(\quad m/s)}$$

where

IU_{sol}	=	total integrated inhaled intake of soluble uranium
Q_{UF6}	=	UF_6 inventory available for release in process or cylinder (grams)
$RF_{U_{sol}}$	=	uranium release fraction (default value 0.34 for liquid UF_6 release, 0.68 for gas)
DF_d	=	dilution factor (m^{-2}) at distance, *d*, from release for appropriate stability class (Table F-10)
BR	=	breathing rate (default value 3.3×10^{-4} m^3/s from EPA-520/1-88-020, p. 10)
$\bar{U}$	=	average wind speed (m/s) (default value 4 mph = 1.8 m/s)

Step 5

Determine the specific activity (*SpA*) of the uranium. Use licensee data or see Table E-4 for single isotopes or Table E-5 for different enrichment levels. ^{234}U is the major contributor to specific activity of enriched UF_6. If a specific activity cannot be

obtained, using the specific activity for ^{234}U (6.19×10^3 μCi/g) will provide an overestimate of CEDE.

$SpA_{U_{sol}}$ = _____ μCi/g

Step 6

Determine the dose conversion factor. Dose conversion factors, $DCF_{E,50}$, for the CEDE resulting from inhalation of soluble uranium isotopes are found in Table E-6. Use the dose conversion factor given for ^{234}U to approximate that for all isotopic mixes.

$DCF_{E,50}$ _____ rem/μCi

Step 7

Calculate the CEDE at this downwind distance.

$$H_{E,50} = I_{U_{sol}} \times SpA \times DCF_{E,50}$$

(rem) = (g) × (μCi/g) × (rem/μCi)

where

$H_{E,50}$	=	committed effective dose equivalent (CEDE) (rem)
IU_{sol}	=	total integrated inhaled intake of soluble uranium (g)
SpA	=	specific activity of uranium (Table E-4 or Table E-5).
$DCF_{E,50}$	=	dose conversion factor for CEDE resulting from inhalation of soluble ^{234}U (Table E-6).

END

Table E-1. UF_6 cylinder data

Cylinder model	Nominal diameter (in.)	Minimum wall thickness (in.)	Approximate tare weight without valve protector (lb)	Approximate tare weight without valve protector (metric ton[b])	Maximum enrichment (percent by weight ^{235}U)	Shipping limit[a] (maximum UF_6) (lb)	Shipping limit[a] (maximum UF_6) (metric ton[b])
1S	1.5	1/16	1.75	7.9E−04	100.0	1.0	4.5E−04
2S	3.5	1/16	4.2	1.9E−03	100.0	4.9	2.2E−03
5A, 5B	5	7/64	55	2.5E−02	100.0	55	2.5E−02
8A	8	1/8	120	5.4E−02	12.5	255	1.2E−01
12A, 12B	12	3/16	185	8.4E−02	5.0	460	2.1E−01
30B[c]	30	5/16	1,400	6.4E−01	5.0[d]	5,020	2.3E+00
48A, 48X[e]	48	1/2	4,500	2.0E+00	4.5[d,f]	21,030	9.5E+00
48F	48	1/2	5,200	2.4E+00	4.5[d]	27,030	1.2E+01
48G	48	1/4	2,600	1.2E+00	1.0[g]	26,840[h]	1.2E+01[h]
48Y[e]	48	1/2	5,200	2.4E+00	4.5[d]	27,560	1.3E+01
48H, 48HX	48	1/4	3,170	1.4E+00	1.0[g]	27,030	1.2E+01
48OM	48	1/4	3,050	1.4E+00	1.0[g]	27,030	1.2E+01

[a]Shipping limits are based on 250°F (121°C) maximum UF_6 temperature (203.3 lb UF_6/ft^3), certified minimum internal volumes for all cylinders, which provides a 5% ullage for safety. The operating limits apply to UF_6 with a minimum purity of 99.5%. More restrictive measures are required if additional impurities are present. The maximum UF_6 temperature must not be exceeded.

[b]1 metric ton = 1000 kg = 1.0E+06 g = 2205 lb.

[c]This cylinder replaces the Model 30A cylinder.

[d]Maximum enrichments indicated require moderation control equivalent to a UF_6 purity of 99.5%. Without moderation control, the maximum permissible enrichment is 1.0% by weight ^{235}U.

[e]Models 48X and 48Y replace Models 48A and 48F whose volumes have not been certified.

[f]In Model 48X, enrichment to 5.0% UF_6 by weight is safe with moderation control equivalent to UF_6 purity of 99.5%, but limited to 4.5% by weight ^{235}U for shipment.

[g]Enrichment to 4.5% by weight is safe with moderation control equivalent to a UF_6 purity of 99.5%, but limited to 1.0% by weight ^{235}U for shipment.

[h]For depleted uranium with UF_6 purity in excess of 99.5%, the shipping limit is 28,000 lb for cylinders with 8,800-lb water capacity or greater.

Source: Adapted from ORO-651, pp. 6, 25.

Table E-2. Health effects of uranium intake

Soluble uranium intake, IU_{sol} (g)	Health effect
<0.005	None
0.008	Threshold for transient renal damage
0.050	Threshold for permanent renal damage
0.230	50% will die

Source: Adapted from NUREG-1391, p. 3.

Table E-3. Health effects of hydrogen fluoride exposure

Airborne hydrogen fluoride concentration, χ_{HF} (g/m^3)[a]	Exposure time (min)	Health effect
0.0025	—	Detectable odor, but no health effect
0.004	60	Emergency Response Planning Guideline-1[b]
0.013	15	Irritation
0.016	60	Emergency Response Planning Guideline-2[c]
0.024	30	Immediately Dangerous to Life and Health[d]
0.408	60	Emergency Response Planning Guideline-3[e]
0.100	1	Unbearable for 1 min
3.500	15	Lethal

[a]g/m^3 = (ppm/1000) × (molecular weight/24.5).

[b]Emergency Response Planning Guideline (ERPG)-1 (5 ppm) is the maximum airborne concentration below which it is believed that nearly all individuals could be exposed for up to 1 h without experiencing other than mild, transient adverse health effects or without perceiving a clearly defined objectionable odor.

[c]ERPG-2 (20 ppm) is the maximum airborne concentration below which it is believed that nearly all individuals could be exposed for up to 1 h without experiencing or developing irreversible or other serious health effects or symptoms which could impair an individual's ability to take protective actions.

[d]The Immediately Dangerous to Life and Health (IDLH) (30 ppm) was developed for respirator use. It is the maximum concentration from which, in the event of respirator failure, one could escape within 30 min without a respirator and without experiencing any escape-impairing (e.g., severe eye irritation) or irreversible health effects.

[e]ERPG-3 (50 ppm) is the maximum airborne concentration below which it is believed that nearly all individuals could be exposed for up to 1 h without experiencing or developing life-threatening health effects.

Sources: Adapted from NUREG-1140, p. 39. IDLH value from NIOSH, p. 126. ERPG values from AIHA.

Table E-4. Radioactive half-life and specific activity for selected uranium isotopes

Isotope	Radioactive half-life (years)	Specific activity (μCi/g)
^{234}U	2.48E+5	6.19E+3
^{235}U	7.13E+8	2.14E+0
^{236}U	2.39E+7	6.34E+1
^{238}U	4.51E+9	3.33E−1

Table E-5. Isotopic abundance and specific activity for different enrichment levels

Enrichment (% ^{235}U by weight)	Specific activity[a] (μCi/g)	Percentage abundance			
		^{234}U	^{235}U	^{236}U	^{238}U
Depleted	0.4	0.0005	0.25		99.75
Natural	0.67	0.0006	0.72		99.27
4.0	2.4	0.032	4.0	0.025	95.94
20.0	9.4		20.0		
93.0	~110	>2.0	>93.0	<0.05	<5.0

[a]The specific activity of enriched uranium may depend somewhat on the history of the material and the method of enrichment. As material is enriched in ^{235}U by gaseous diffusion, the ^{234}U concentration increases faster than the ^{235}U concentration. ^{234}U is major contributor to the specific activity.

Sources: Sources of specific activities are EGG-2530, p. 2-8, for depleted; ORO-651, p. 31, for natural; and calculations from relative abundance and Table E-4 for 4%. Specific alpha activity for 20% enrichment was calculated using $SpA = 0.4 + 0.38\epsilon + 0.0034\epsilon^2$ (μCi/g), where ϵ is percentage ^{235}U by weight (equation from ORO-651, p. 31). Values given for 93% enrichment are noted in RTM-93 as measured. Relative isotopic abundance for depleted and natural uranium from EGG-2530, p. 2-2.

Table E-6. Adult dose conversion factors for committed effective dose equivalent from inhalation of soluble uranium isotopes

Isotope	Dose conversion factor for committed effective dose equivalent ($DCF_{E,50}$)[a,b]	
	(rem/μCi)	(Sv/Bq)
^{234}U	2.7	7.4E-7
^{235}U	2.3	6.8E-7
^{236}U	2.6	7.0E-7
^{237}U	2.4	6.6E-7

[a]Committed effective dose equivalent (CEDE or $H_{E,50}$) is the sum of the effective dose equivalent over a 50-year period following intake.
[b]Lung clearance class (solubility class) is D.

Source: EPA-520/1-88-020, pp. 150–151.

Fig. E-1
Distance downwind at which early health effects from HF exposure might occur or EPA PAGs could be exceeded.

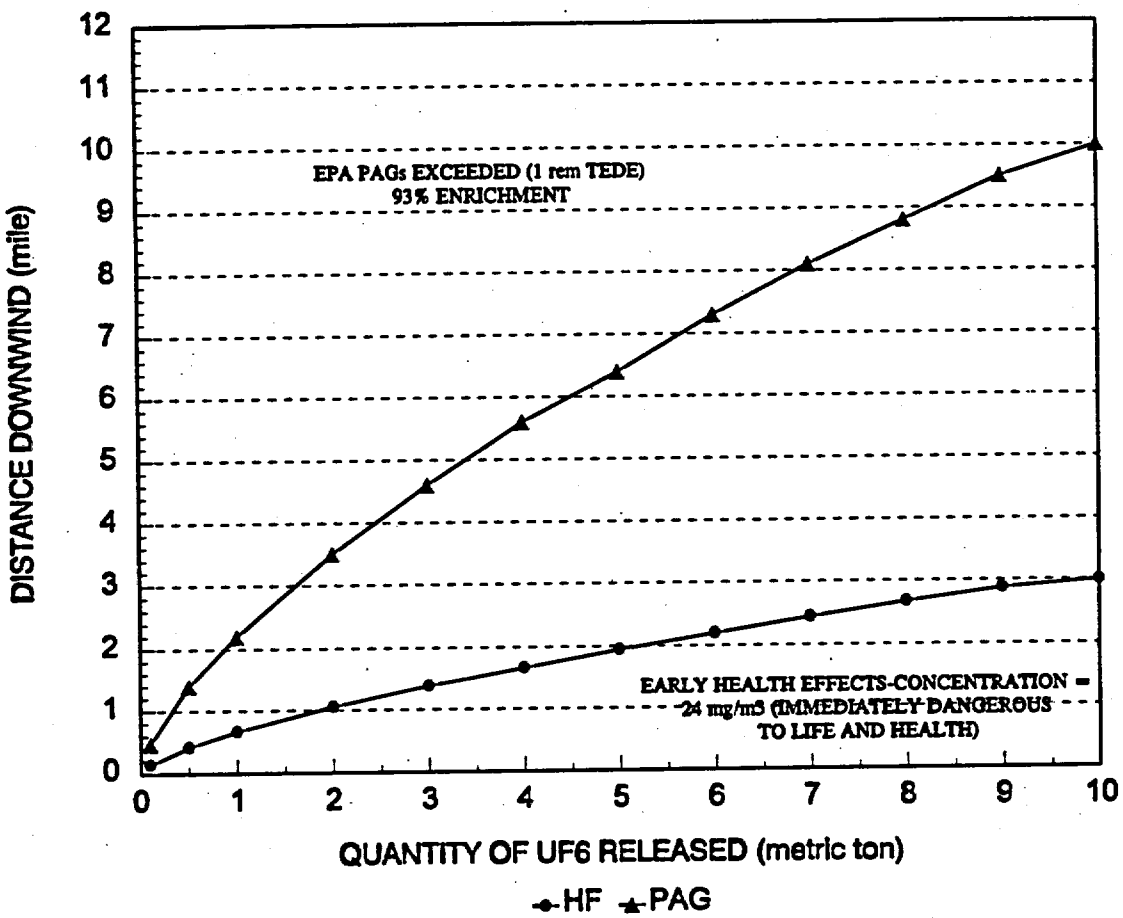
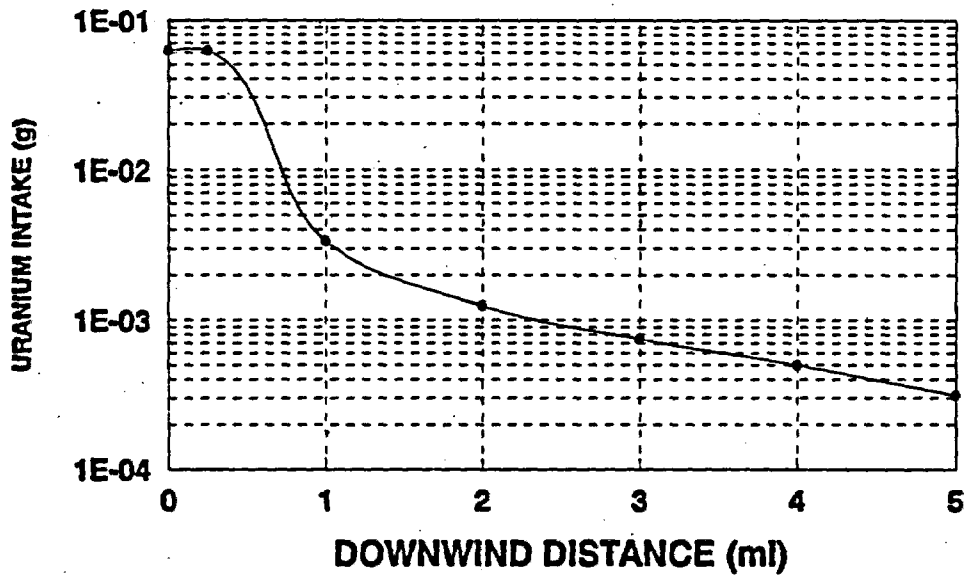
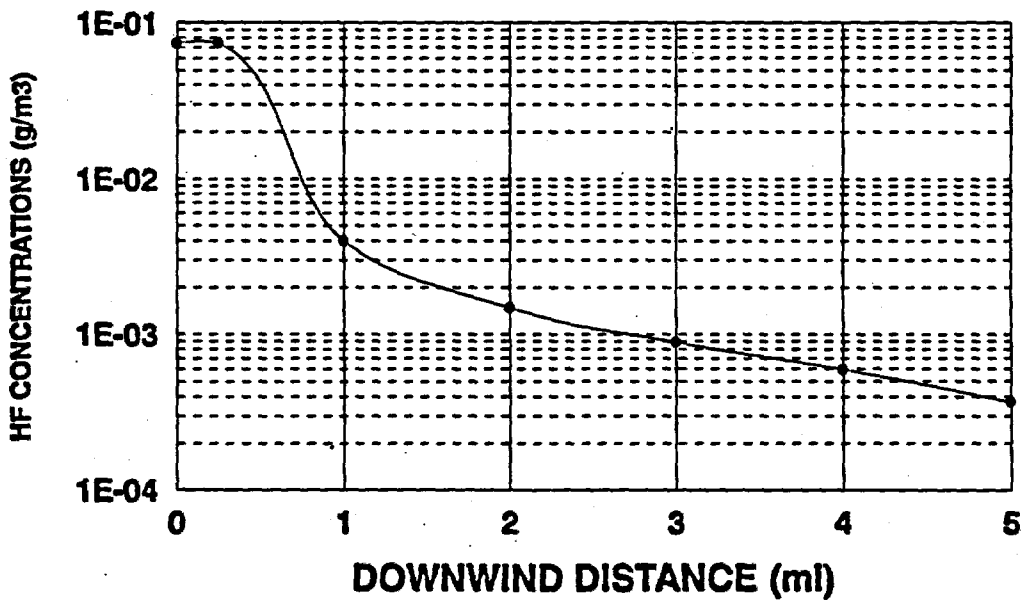


Fig. E-2
Adult uranium intake resulting from release of 1 metric ton of liquid UF_6.[a]



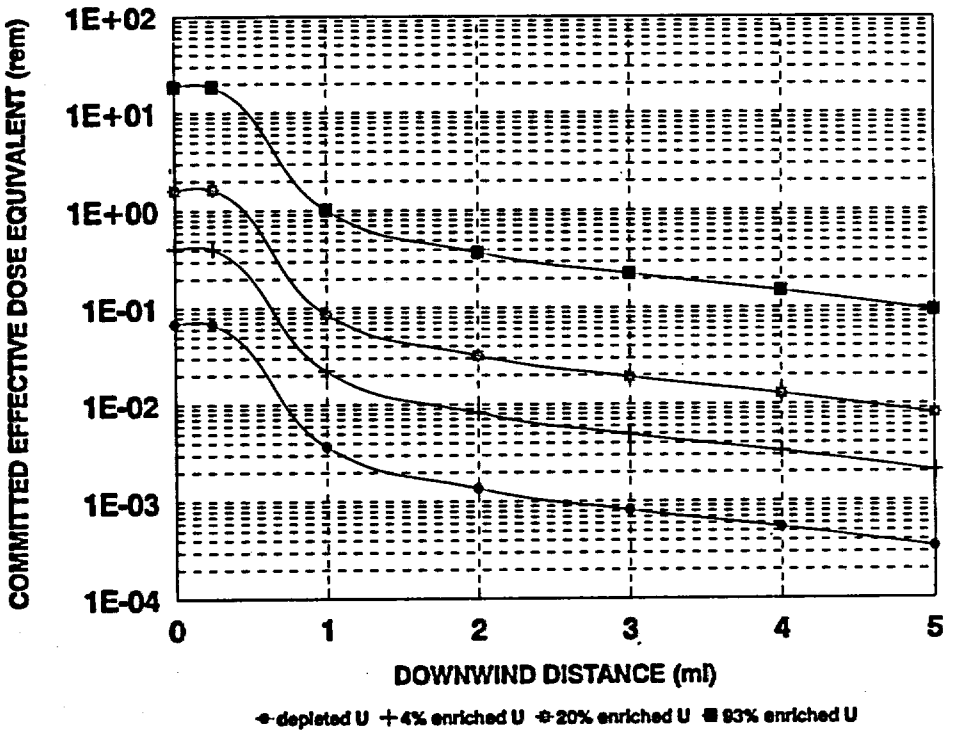
[a]Assumptions and default values are discussed in Method E.1.

Fig. E-3
Air concentrations of hydrogen fluoride from release of 1 metric ton of liquid UF_6.[a]



[a]Assumptions and default values are discussed in Method E.1.

Fig. E-4
Committed effective dose equivalent for adult downwind from release of 1 metric ton liquid UF_6.[a]



[a]Assumptions and default values are discussed in Method E.3.

F

SECTION F

EARLY PHASE DOSE PROJECTIONS

Section F
Quick Reference Guide

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Section F
Early Phase Dose Projections

Purpose

To provide methods to project the dose and assess the need to take urgent protective action during the early phase. Methods are provided to project doses and evaluate their potential for early health effects using (1) activity based on weight (mass), (2) releases from an accident (i.e., fire), (3) dose from point sources, and (4) doses for isotopic releases. Use Section E for assessment of a UF_6 release and Section C for assessment of LWR accidents.

Discussion

The early phase of an accident extends from the identification of a release threat until the release (or threat of the release) has ended and any areas of major contamination have been identified. The early phase normally includes up to 4 days (100 h) of exposure to deposition. To project the potential consequences from a radiological accident the following steps must be performed: (1) estimate the amount of activity released, (2) estimate the downwind dose from this material, and (3) determine the impact of this dose in terms of health effects and PAGs.

This section provides methods for performing these steps for accidents involving release of a simple isotopic mixture or exposure to a radioactive source. For complex mixtures (e.g., reactor accidents), other methods such as those in Section C or the RASCAL model (Section L) should be used. Remember that there are great uncertainties associated with these methods or any dose projection code.

This manual does not provide methods to assess environmental measurements; these methods can be found in the *FRMAC Assessment Manual*.

Step 1

Estimate the activity in a point source or the activity released or that may be released. The following methods may be useful:

- If one knows the mass of the radioactive material involved but not the activity, use Method F.1.
- To estimate the potential releases from isotopes involved in a fire (typically the worst case), use Method F.2.

Step 2

Estimate the dose from the source or release using one of the following:

- To project the dose 0.25 mile and 1 mile downwind based on the estimated activity released, use Method F.3.
- To estimate dose and exposure rates from a point source, use Method F.4.

Step 3

If needed, the dose at 1 mile can be adjusted for longer distances or to consider elevation or rain using Method F.5. Method F.6 can provide a quick estimate of the maximum air concentrations or ground deposition at much greater distances from the release.

Step 4

Assess the potential for early health effects and for projected doses exceeding early phase PAGs using Section G.

END

Method F.1
Calculation of Activity Based On Weight

Purpose

To determine the activity in microcuries of the radioactive material from the weight.

Discussion

The quantity of material involved in an accident may be specified by weight (mass). The activity (rate of radioactive disintegration) is needed for dose calculation. The total activity of an isotope is the product of the mass and the specific activity for that isotope. (Method F.3 can be used to estimate dose.)

Step 1

Calculate the activity using the following equation:

$$A_i = Wt \times SpA$$

$$(\quad \mu\text{Ci}) = (\quad \text{g}) \times (\quad \mu\text{Ci/g})$$

where

A_i	=	Activity (μCi) of isotope *i* available
Wt	=	Weight (g)
SpA	=	Specific activity (μCi/g) from Table F-1 or the formulas below

The specific activity is the defined as activity per unit mass (e.g., Ci/g, μCi/g) of material and can be calculated by one of the following equations depending on the units in which the radiological half-life ($T_{1/2}$) is given.

$$SpA\left(\frac{\mu\text{Ci}}{\text{g}}\right) = \frac{3.134 \times 10^{15}}{T_{1/2}(\text{h}) \times AMN}$$

or

$$SpA\left(\frac{\mu\text{Ci}}{\text{g}}\right) = \frac{1.306 \times 10^{14}}{T_{1/2}(\text{days}) \times AMN}$$

or

$$SpA\left(\frac{\mu Ci}{g}\right) = \frac{3.578 \times 10^{11}}{T_{1/2}(\text{years}) \times AMN}$$

where

AMN	=	Atomic mass number (the number of protons plus the number of neutrons in the isotope); for example, for ^{131}I, the AMN is 131.
$T_{½}$	=	radioactive half-life in hours, days or years, respectively

END

Source: PB-230 846, p. 103.

Method F.2
Estimation of the Activity Released by a Fire

Purpose

To estimate the quantity of radioactive material released from a fire and the rate of release when the total activity is known.

Discussion

Filtering, plateout, or other mechanisms that can reduce the release of non-nobles are not considered in this calculation. Therefore, this method should provide a reasonable upper bound for most accidents involving radioactive material. This method is *not* valid for reactor accidents. (To calculate the activity of the material from the weight, use Method F.1. Method F.3 can be used to estimate the dose.)

Step 1

Estimate the total activity or release rate using the following equations:

Total activity (μCi) released

$$Q_{Ti} = A_i \times FRF_i$$

$$(\qquad \mu\text{Ci}) = (\qquad \mu\text{Ci}) \times (\qquad)$$

Release rate (μCi/s)

$$Q_i = \frac{A_i \times FRF_i}{T_{rd}}$$

$$(\qquad \mu\text{Ci/s}) = \frac{(\qquad \mu\text{Ci}) \times (\qquad)}{(\qquad \text{s})}$$

where

A_i	=	Activity (μCi) of isotope i available (in fire)
FRF_i	=	Fire release fraction for isotope i, from Table F-2 if the compound form is known or Table F-3 if the compound form is unknown
T_{rd}	=	Release duration (s)
Q_i	=	Release rate (μCi/s) for isotope i
Q_{Ti}	=	Total activity (μCi) of isotope i released

END

Method F.3
Downwind Dose Projection Based on Estimated Activity Released

Purpose

To estimate doses from a release where the isotopic composition is known.

Discussion

Two alternative approaches to calculate the downwind components of the acute dose equivalent and total effective dose equivalent (TEDE) are provided: quick estimate or full calculation. The quick method is used to predict doses for ground-level releases under average or unknown meteorological conditions. The full calculation method is used when the meteorological conditions are fully understood or for isotopes not in the tables.

Once the dose components are calculated, they are summed to obtain the desired projected doses. These projected doses can then be compared to the thresholds for early health effects and to the early phase PAGs (Section G). For UF_6 accidents, chemical toxicity will dominate the risk; those accidents should be assessed using Section E.

Step 1

Quick estimate method

This method uses precalculated doses at 0.25 and 1 mile from a 1 μCi release. A ground-level release and average meteorological conditions (D stability, 4 mph wind speed, and no rain) were assumed in calculating these doses. The doses represent the maximum expected because the exposed individual is assumed to be at the centerline of the plume without protection for the entire release. Initial calculations can be adjusted to consider an elevated release and rain. The projections should be within a factor of 10 for a reasonable range of stability classes and wind speeds.

Calculate the following doses for isotopes in the release: organ dose from inhalation (D_T) (acute bone, acute lung, and thyroid); committed effective dose equivalent from inhalation (CEDE, $H_{e,50}$); effective dose equivalent from external radiation from immersion in plume (H_a); and early phase (4-day) dose equivalent from exposure to ground deposition (D_{EP_g}) using Worksheet F-1 and the following equations:

$$Dose_{ij} = Q_{Ti} \times RCF_{ij}$$

$$(\quad \text{mrem}) = (\quad \mu\text{Ci}) \times \left(\quad \frac{\text{mrem}}{\mu\text{Ci}} \right)$$

where

$Dose_{ij}$	=	Total dose equivalent (mrem) type j at specified distance from release of isotope i
Q_{Ti}	=	Total activity (μCi) of isotope i released
RCF_{ij}	=	Release conversion factor (mrem/μCi) from Table F-4 (0.25 mile) or Table F-5 (1 mile) for 1 μCi of isotope i and dose type j

Go to Step 2 to sum the dose components.

Full Calculation Method

Calculate the following doses for isotopes in the release: dose equivalent to organ from inhalation (D_T) (acute bone, acute lung, and thyroid); committed effective dose equivalent from inhalation (CEDE, $H_{e,50}$); effective dose equivalent from external radiation from immersion in plume (H_a); and early phase (4-day) dose equivalent from exposure to ground deposition (D_{EPg}) using Worksheet F-2 and the following equations:

Air immersion: H_{ai}

$$H_{ai} = \frac{Q_i \times DF \times DCF_{ai} \times T_{ed}}{\overline{U}}$$

$$(\quad \text{mrem}) = \frac{(\quad \mu\text{Ci/s}) \times (\quad \text{m}^{-2}) \times \left(\quad \frac{\text{mrem/h}}{\mu\text{Ci/m}^3} \right) \times (\quad \text{h})}{(\quad \text{m/s})}$$

Inhalation: CEDE ($H_{e,50i}$), organ dose (D_{Ti})—acute bone, acute lung, and thyroid

$$H_{e,50i} = \frac{Q_i \times DF \times DCF_{e,50i} \times T_{ed}}{\overline{U}}$$

$$D_{Ti} = \frac{Q_i \times DF \times DCF_{Ti} \times T_{ed}}{\overline{U}}$$

$$(\quad \text{mrem}) = \frac{(\quad \mu\text{Ci/s}) \times (\quad \text{m}^{-2}) \times \left(\quad \frac{\text{mrem/h}}{\mu\text{Ci/m}^3}\right) \times (\quad \text{h})}{(\quad \text{m/s})}$$

Early phase ground: D_{EPgi}, from groundshine and resuspension for 4 days exposure

$$D_{EPgi} = Q_{Ti} \times GCF \times DCF_{EPgi}$$

$$(\quad \text{mrem}) = (\quad \mu\text{Ci}) \times (\quad \text{m}^{-2}) \times \left(\quad \frac{\text{mrem}}{\mu\text{Ci/m}^2}\right)$$

where

DCF_{ai}	=	Effective air immersion dose conversion factor [(mrem/h)/(μCi/m^3)] from Table F-6
$DCF_{e,50i}$	=	CEDE dose conversion factor [(mrem/h)/(μCi/m^3)] for isotope *i* from Table F-7
DCF_{EPgi}	=	Dose conversion factor [(mrem)/(μCi/m^2)] for ground surface deposition during the early phase (4 days) including resuspension from Table F-6
DCF_{Ti}	=	Dose conversion factor [(mrem/h)/(μCi/m^3)] for inhalation dose for various organs (acute bone, acute lung, and thyroid) and commitment periods, from Table F-7
DF	=	Dilution factor (m^{-2}) from Table F-10 for projected distance from source (Table F-8 or F-9 can be used to determine the stability class)
GCF	=	Ground concentration factor from Table F-11
H_{ai}	=	Effective external dose (mrem) from isotope *i* from air immersion
Q_i	=	Release rate (source term) (μCi/s) of isotope *i*
Q_{Ti}	=	Total activity (μCi) of isotope *i* released
T_{ed}	=	Exposure duration (assume release duration)(h)
$\overline{U}$	=	Average wind speed (m/s)

Step 2

Calculate the total acute bone dose (TABD), total acute lung dose (TALD), and total effective dose equivalent (TEDE) by summing the contributing doses calculated with either of the methods in Step 1 and using Worksheet F-3 and the equations below. The acute thyroid dose is the committed dose equivalent to the thyroid from inhalation.

Total Acute Bone Dose (*TABD*)

$$TABD = \sum_{i}^{n} [H_{ai} + D_{EPgi} + D_{Ti}(bone)]$$

Total Acute Lung Dose (*TALD*)

$$TALD = \sum_{i}^{n} [H_{ai} + D_{EPgi} + D_{Ti}(lung)]$$

Total Effective Dose Equivalent (*TEDE*)

$$TEDE = \sum_{i}^{n} (H_{ai} + D_{EPgi} + H_{e,50i})$$

$$(\qquad \text{mrem}) = \sum_{i}^{n} [(\qquad \text{mrem}) + (\qquad \text{mrem}) + (\qquad \text{mrem})]$$

Acute Thyroid Dose [$D_{Ti}(thyroid)$]

$D_{Ti}(thyroid)$ = _____ mrem (from Step 1)

where

D_{EPgi}	=	Early phase dose equivalent from 4 days exposure to groundshine and resuspension of isotope *i* (calculated in Step 1)
$D_{Ti}(organ)$	=	Committed effective dose equivalent to organ (bone, lung, and thyroid) from inhalation of isotope *i* in plume (calculated in Step 1)
H_{ai}	=	Effective external dose equivalent (mrem) from isotope *i* due to air immersion (calculated in Step 1)

Step 3

Use Method F.5 to estimate the downwind dose or to consider rain or an elevated release.

Step 4

Determine consequences.

- Is the *projected* TABD or TALD greater than or equal to the thresholds in Table G-2? If yes, inform management immediately that early health effects are possible.

- Is either the *projected* committed dose equivalent to thyroid greater than or equal to early phase thyroid PAG or *projected* TEDE greater than or equal to the TEDE early phase PAG? If yes, inform management immediately that early phase PAGs may be exceeded. (See Table G-1 for EPA early phase PAGs. Some States may use State-specific PAGs; in these cases, use the State-specified values for comparison.)

END

Method F.4
Estimation of Dose and Exposure Rate from Point Source

Purpose

To estimate the exposure and dose from a point source.

Discussion

This method uses dose and exposure rates that have been precalculated at 1 m, assuming no shielding, to estimate the dose at various distances. It can be used to project doses to the public or emergency workers or to estimate instrument readings (e.g., when searching for a source). Shielding can be considered, but the calculation does not include build-up. Therefore if shielding is included, the result should be considered the *lower bound*.

Two equations are given. The first is used to estimate the dose for comparison to health effects thresholds and EPA PAGs. For contact dose (e.g., source in a pocket), assume a distance (*Dis*) from the source of 10^{-2} m (1 cm) (NUREG/BR-0024, p. 157). The second equation, for exposure intensity, can be used to estimate the instrument reading in a gamma field.

Step 1

Calculate the effective dose or exposure intensity using the following equations:

Effective Dose

$$H_p = \frac{A_i \times DCF_p \times T_{ed} \times (0.5^{\frac{ST}{HVL}})}{\left(\frac{Dis}{DCF\ Distance}\right)^2}$$

$$(\quad \text{mrem}) = \frac{(\quad \mu\text{Ci}) \times \left(\frac{\text{mrem/h}}{\mu\text{Ci}}\right) \times (\quad \text{h}) \times \left(0.5^{\frac{(\quad \text{cm})}{(\quad \text{cm})}}\right)}{\left(\frac{(\quad \text{m})}{1\ \text{m}}\right)^2}$$

where

A_i	=	Activity (μCi) of isotope i
DCF_p	=	Point source dose conversion factor (mrem/μCi) from Table F-12
Dis	=	Distance (m) from source
HVL	=	Half-value layer (cm) from Table F-13
H_p	=	Effective dose equivalent (mrem) from point source
T_{ed}	=	Exposure duration (h)
ST	=	Shielding thickness (cm)

Exposure Intensity

$$I = \frac{A_i \times ECF_p \times \left(0.5^{\frac{ST}{HVL}}\right)}{\left(\frac{Dis}{ECF\ distance}\right)^2}$$

$$(\qquad \text{mR/h}) = \frac{(\qquad \mu\text{Ci}) \times \left(\frac{\text{mrem/h}}{\mu\text{Ci}}\right) \times \left(0.5^{\frac{(\qquad \text{cm})}{(\qquad \text{cm})}}\right)}{\left(\frac{(\qquad \text{m})}{1\ \text{m}}\right)^2}$$

where

A_i	=	Activity (μCi) of isotope i
Dis	=	Distance (m) from source
ECF_p	=	Point source exposure conversion factor (mR/μCi) from Table F-12
HVL	=	Half-value layer (cm) from Table F-13
I	=	Exposure intensity (mR/μCi)
ST	=	Shielding thickness (cm)

Step 2

Determine consequences.

- Is the *projected* effective dose equivalent greater than or equal to the early effects thresholds in Table G-2? If yes, inform management immediately that early health effects are possible.

- Is the *projected* effective dose equivalent greater than or equal to State early phase PAGs? If yes, inform management immediately that early phase PAGs may be exceeded. (See Table G-1 for EPA early phase PAGs. Some States may use State-specific PAGs; in these cases, use the State-specified values for comparison.)

END

Method F.5
Adjusting 1-Mile Dose to Consider Distance, Elevation, and Rain

Purpose

To adjust the estimated total acute bone and thyroid dose for longer distances downwind and can also be used to determine the effect of rain and release elevation on the doses.

Discussion

This method requires an estimate of the dose at 1 mile from a ground-level release under average meteorological conditions (D stability, 4 mph wind speed, and no rain). Doses should be for the distances the plume has traveled, not the distance from the release source. The estimates assume a constant wind direction and should represent the maximum dose within a factor of 10 for a range of stability classes and wind speeds.

Estimates of the acute bone dose or thyroid dose at 1 mile from a ground-level release and no rain can be obtained using one of these suggested methods. The acute bone and inhalation doses (acute lung or thyroid dose) at 1 mile can be found for reactor accidents using the event trees in Section C, for spent fuel pool accidents using Section D, or for isotopic releases using Method F.3.

Acute bone doses used as input should represent dose equivalent from cloudshine and acute dose equivalent from inhalation and approximately 24 h of the resulting groundshine to an adult performing normal activities with no sheltering or protection (these are the assumptions used in Sections C and D and Method F.3). The thyroid dose should be from inhalation of the plume alone.

Assume a ground-level release unless the release is from an isolated stack more than 2.5 times higher than nearby structures or if observation indicates that it has an effective release height of 200 m or more. The elevated release height is assumed in this case to be 200 m. NOAA recommends that the maximum effective release height of a plume be assumed to be one-half of the mixing level. The assumed 200 m is one-half of the typical nighttime mixing level.

Step 1

Select the appropriate release conditions:

- ground-level release without rain
- ground-level release with rain
- elevated release without rain
- elevated release with rain

Step 2

Estimate the downwind acute bone and thyroid doses at 1, 2, 5, 10 and 25 miles using Worksheets F-4 and F-5, respectively. Each worksheet has conversion factors that represent each of the four release conditions shown above. Figures F-1 and F-2 show the dose conversion factors for different release conditions as a function of distance for acute bone marrow and thyroid doses, respectively.

END

Method F.6
Quick Long-Range Estimation

Purpose

To produce a quick estimate of the maximum ground-level air concentrations and deposition that can be expected for a given release amount at downwind distances after travel times of 1–5 days after release.

Discussion

Because dose is a function of air and ground concentration, these concentrations can also be used to estimate dose at great distances. The procedure used is a result of analytical and experimental studies which are summarized in a simple nomogram giving the normalized concentration as a function of travel time for a release within the atmospheric boundary layer and for a release above the boundary layer.

A long-range non-depositing tracer experiment conducted from January through March of 1987 showed that the maximum concentrations measured (Draxler et al. 1991, Fig. 10) during any 24 h sampling period followed the simple Gaussian model form for an instantaneous release (AP-26, Eq. 5.21),

$$\chi/Q = [0.5(2\pi)^{3/2}\sigma_x\sigma_y\sigma_z]^{-1}$$

where it is assumed that $\sigma_z = (2Kt)^{1/2}$ and that the vertical mixing coefficient K has an average value of 5 m^2/s in the atmospheric boundary layer (near the ground) and about 1 m^2/s in the upper regions of the atmosphere (Machta 1966). The along-wind and crosswind dispersion coefficients are assumed both to be equal to 0.5 times the downwind travel time in seconds (Heffter 1965). The equation in this form has each exponential term for the along-wind, crosswind, and vertical offset set to one to yield the maximum ground-level concentration.

If the release occurs above the boundary layer, a correction of the form

$$\exp[-0.5(H/\sigma_z)^{1/2}]$$

is applied to the normalized concentration to obtain an estimate of the ground-level concentration.

An estimate of the maximum deposition can be obtained from Fig. F-3 by multiplying the air concentration by the vertical dispersion parameter. This result would then assume that all the material in the air is removed at that time.

Step 1

Determine if the release is at ground level or elevated. An elevated release may occur when there is a large thermal source or explosion, resulting in most of the material being ejected above the boundary layer. The calculations in this method assume an average elevated release to be about 1500 m above ground. Normal stack emissions are to be considered as a ground-level release.

Step 2

Determine the time in days after the accidental release for which the estimate is desired. Assume 4-mph wind speed if the average wind speed is not known. Other analysis methods must be employed to determine the location of this estimate. For instance, a simple trajectory or projection based upon wind speed might be sufficient, depending upon the circumstances.

Step 3

Estimate air concentration and deposition based on total release

- Use Fig. F-3. Find the desired downwind travel time on the horizontal axis and read the normalized concentration from the appropriate release height curve. The concentration is in units of m^{-3}.

  Downwind travel time _____ days
  Normalized concentration (from Fig. F-3) _____ m^{-3}

- Determine the total amount of material emitted (in mass or activity units) and multiply this by the normalized concentration. Do not use a release rate (mass/time or activity/time) because the values in Fig. F-3 are based upon the total emission. If the total release was given in Ci, the result is now Ci/m^{-3}.

  peak air concentration = total release × normalized concentration

- The dashed line on Fig. F-3 gives an estimate of the deposition (use the same values on the vertical axis but units are m^{-2}). It is assumed that all the airborne material is available for ground deposit at each downwind time. Fractional removal requires subsequent deposition and air concentrations to be adjusted accordingly.

  Normalized maximum deposition (from Fig. F-3) _____ m^{-2}

  maximum deposition = total release × normalized maximum deposition

Estimate deposition or concentration based on near field measurements or model projections

- Find the downwind travel times on the horizontal axis of Fig. F-3 corresponding to the location of the near field and the long distance concentrations, depositions, or doses of interest. Read the normalized concentration from the appropriate release curve.

  Downwind travel time to near field point _____ days
  Normalized concentration at near field point, C_1 (from Fig. F-3) _____ m^{-3}
  Downwind travel time to distant point _____ days
  Normalized concentration at distant point, C_2 (from Fig. F-3) _____ m^{-3}

- To estimate the long distance dose or concentration (V_2), multiply the dose or concentration at the near field location by the ratio of the long distance to near field dose or concentrations.

  Measured or calculated near field value, V_1 _____ m^{-3}

$$V_2 = V_1 \times \frac{C_2}{C_1}$$

  Similar ratios can be used to estimate maximum deposition or dose (proportional to deposition or concentration) at longer travel times when a near field value is known.

Step 4

Ensure that the user understands the limitations of this method. It should be clear from Fig. F-3 that there can be large variations in the estimate if the height of release is incorrect. These calculations assume a non-depositing material. With a non-depositing material, ground-level estimates will always be the more conservative and should be used. It should be noted that elevated releases of depositing material can show much higher concentrations downwind than ground-level releases because of their initial lack of deposition.

The estimates from Fig. F-3 are much more appropriate at longer downwind distances, when the spreading of the material is comparable to the 24-h sampling time that was used to verify this approach. At travel times less than 1 day, the average dispersion parameters that were used are difficult to justify.

END

Table F-1. Specific activity

Isotope	Half-life, $T_{½}$ (h)	Specific activity, SpA[e] (μCi/g)
^{3}H	1.1E+05	9.7E+09
^{14}C	5.0E+07	4.5E+06
^{22}Na	2.3E+04	6.3E+09
^{24}Na	1.5E+01	8.7E+12
^{32}P	3.4E+02	2.9E+11
^{33}P	6.1E+02	1.6E+11
^{35}S	2.1E+03	4.3E+10
^{36}Cl	2.6E+09	3.3E+04
^{40}K	1.1E+13	7.0E+00
^{42}K	1.2E+01	6.0E+12
^{45}Ca	3.9E+03	1.8E+10
^{46}Sc	2.0E+03	3.4E+10
^{44}Ti	4.1E+05	1.7E+08
^{48}V	3.9E+02	1.7E+11
^{51}Cr	6.6E+02	9.2E+10
^{54}Mn	7.5E+03	7.7E+09
^{56}Mn	2.6E+00	2.2E+13
^{55}Fe	2.4E+04	2.4E+09
^{59}Fe	1.1E+03	5.0E+10
^{58}Co	1.7E+03	3.2E+10
^{60}Co	4.6E+04	1.1E+09
^{63}Ni	8.4E+05	5.9E+07
^{64}Cu	1.3E+01	3.9E+12
^{65}Zn	5.9E+03	8.2E+09
^{68}Ga	1.1E+00	4.1E+13
^{68}Ge	6.9E+03	6.7E+09
^{75}Se	2.9E+03	1.5E+10

Table F-1. Specific activity (continued)

Isotope	Half-life, $T_{½}$ (h)	Specific activity, SpA[a] (μCi/g)
^{85}Kr	9.4E+04	3.9E+08
^{85m}Kr	4.5E+00	8.2E+12
^{87}Kr	1.3E+00	2.8E+13
^{88}Kr	2.8E+00	1.3E+13
^{86}Rb	4.5E+02	8.1E+10
^{87}Rb	4.1E+14	8.7E−02
^{88}Rb	3.0E−01	1.2E+14
^{89}Sr	1.2E+03	2.9E+10
^{90}Sr	2.6E+05	1.4E+08
^{91}Sr	9.5E+00	3.6E+12
^{90}Y	6.4E+01	5.4E+11
^{91}Y	1.4E+03	2.5E+10
^{91m}Y	8.3E−01	4.2E+13
^{93}Zr	1.3E+10	2.5E+03
^{95}Zr	1.5E+03	2.1E+10
^{94}Nb	1.8E+08	1.9E+05
^{95}Nb	8.4E+02	3.9E+10
^{99}Mo	6.6E+01	4.8E+11
^{99}Tc	1.9E+09	1.7E+04
^{99m}Tc	6.0E+00	5.3E+12
^{103}Ru	9.4E+02	3.2E+10
^{105}Ru	4.4E+00	6.7E+12
^{106}Ru	8.8E+03	3.3E+09
^{106}Rh	8.3E−03	3.6E+15
^{109}Cd	1.1E+04	2.6E+09
^{113m}Cd	1.2E+05	2.3E+08
^{110m}Ag	6.0E+03	4.8E+09
^{114m}In	1.2E+03	2.3E+10
^{113}Sn	2.8E+03	1.0E+10
^{123}Sn	3.1E+03	8.2E+09
^{126}Sn	8.8E+08	2.8E+04

Table F-1. Specific activity (continued)

Isotope	Half-life, $T_{½}$ (h)	Specific activity, SpA[a] (μCi/g)
^{124}Sb	1.4E+03	1.7E+10
^{126}Sb	3.0E+02	8.4E+10
^{126m}Sb	3.2E−01	7.9E+13
^{127}Sb	9.2E+01	2.7E+11
^{129}Sb	4.3E+00	5.6E+12
^{127}Te	9.4E+00	2.6E+12
^{127m}Te	2.6E+03	9.4E+09
^{129}Te	1.2E+00	2.1E+13
^{129m}Te	8.1E+02	3.0E+10
^{131}Te	4.2E−01	5.7E+13
^{131m}Te	3.0E+01	8.0E+11
^{132}Te	7.8E+01	3.0E+11
^{125}I	1.4E+03	1.7E+10
^{129}I	1.4E+11	1.8E+02
^{131}I	1.9E+02	1.2E+11
^{132}I	2.3E+00	1.0E+13
^{133}I	2.1E+01	1.1E+12
^{134}I	8.8E−01	2.7E+13
^{135}I	6.6E+00	3.5E+12
^{131m}Xe	2.9E+02	8.4E+10
^{133}Xe	1.3E+02	1.9E+11
^{133m}Xe	5.3E+01	4.5E+11
^{135}Xe	9.1E+00	2.6E+12
^{135m}Xe	2.5E−01	9.1E+13
^{138}Xe	2.4E−01	9.6E+13
^{134}Cs	1.8E+04	1.3E+09
^{135}Cs	2.0E+10	1.2E+03
^{136}Cs	3.1E+02	7.3E+10
^{137}Cs	2.6E+05	8.7E+07
^{138}Cs	5.4E−01	4.2E+13
^{133}Ba	9.4E+04	2.5E+08
^{137m}Ba	4.3E−02	5.4E+14
^{140}Ba	3.1E+02	7.3E+10
^{140}La	4.0E+01	5.6E+11

Table F-1. Specific activity (continued)

Isotope	Half-life, $T_{½}$ (h)	Specific activity, SpA[a] (μCi/g)
^{141}Ce	7.8E+02	2.8E+10
^{144}Ce	6.8E+03	3.2E+09
^{144}Pr	2.9E−01	7.6E+13
^{144m}Pr	1.2E−01	1.8E+14
^{145}Pm	1.6E+05	1.4E+08
^{147}Pm	2.3E+04	9.3E+08
^{147}Sm	9.3E+14	2.3E−02
^{151}Sm	7.9E+05	2.6E+07
^{152}Eu	1.2E+05	1.8E+08
^{154}Eu	7.7E+04	2.6E+08
^{155}Eu	4.3E+04	4.7E+08
^{153}Gd	5.8E+03	3.5E+09
^{160}Tb	1.7E+03	1.1E+10
^{166m}Ho	1.1E+07	1.8E+06
^{170}Tm	3.1E+03	6.0E+09
^{169}Yb	7.7E+02	2.4E+10
^{172}Hf	1.6E+04	1.1E+09
^{181}Hf	1.0E+03	1.7E+10
^{182}Ta	2.8E+03	6.3E+09
^{187}W	2.4E+01	7.0E+11
^{192}Ir	1.8E+03	9.2E+09
^{198}Au	6.5E+01	2.4E+11
^{203}Hg	1.1E+03	1.4E+10
^{204}Tl	3.3E+04	4.6E+08
^{210}Pb	1.9E+05	7.7E+07
^{207}Bi	3.3E+05	4.5E+07
^{210}Bi	1.2E+02	1.2E+11

Table F-1. Specific activity (continued)

	Half-life, $T_{½}$ (h)	Specific activity, SpA[a] (μCi/g)
^{210}Po	3.3E+03	4.5E+09
^{226}Ra	1.4E+07	9.9E+05
^{227}Ac	1.9E+05	7.2E+07
^{228}Ac	6.1E+00	2.2E+12
^{227}Th	4.5E+02	3.1E+10
^{228}Th	1.7E+04	8.2E+08
^{230}Th	6.7E+08	2.0E+04
^{231}Th	2.6E+01	5.3E+11
^{232}Th	1.2E+14	1.1E−01
^{231}Pa	2.9E+08	4.7E+04
^{233}Pa	6.5E+02	2.1E+10
U-depleted[b]		3.6E+01[c]
U-natural[b]		6.8E+01[c]
U-enr (4% ^{235}U)[b]		2.4E+00[c]
U-enr (20% ^{235}U)[b]		9.4E+00[c]
U-enr (93% ^{235}U)[b]		1.1E+02[c]
^{232}U[b]	6.3E+05	2.1E+07
^{233}U[b]	1.4E+09	9.7E+03
^{234}U[b]	2.1E+09	6.3E+03
^{235}U[b]	6.2E+12	2.2E+00
^{236}U[b]	2.0E+11	6.5E+01
^{238}U[b]	3.9E+13	3.4E−01
^{237}Np	1.9E+10	7.1E+02
^{239}Np	5.7E+01	2.3E+11
^{236}Pu	2.5E+04	5.3E+08
^{238}Pu	7.7E+05	1.7E+07
^{239}Pu	2.1E+08	6.2E+04
^{240}Pu	5.7E+07	2.3E+05
^{241}Pu	1.3E+05	1.0E+08
^{242}Pu	3.3E+09	3.9E+03
^{241}Am	3.8E+06	3.4E+06
^{242m}Am	1.3E+06	9.7E+06
^{243}Am	6.5E+07	2.0E+05

Table F-1. Specific activity (continued)

	Half-life, $T_{½}$ (h)	Specific activity, SpA[a] (μCi/g)
^{242}Cm	3.9E+03	3.3E+09
^{243}Cm	2.5E+05	5.2E+07
^{244}Cm	1.6E+05	8.1E+07
^{245}Cm	7.4E+07	1.7E+05
^{252}Cf	2.3E+04	5.4E+08

[a]Except where noted SpA (μCi/g) = 3.134E+15/[$T_{½}$(h) × atomic mass number] from PB-230 846, p. 103.

[b]Caution: The chemical toxicity of uranium will be a problem before there are radiological concerns.

[c]The specific activity of natural and depleted uranium is based on 10 CFR 20 App. B, confirmed by calculations. For enriched uranium, SpA is dominated by the concentration of ^{234}U because the ^{234}U concentration increases with ^{235}U enrichment and ^{234}U has a relatively high SpA. The ^{234}U concentration relative to the ^{235}U enrichment is assumed to be 4% enrichment, 0.032% ^{234}U; 20% enrichment, 0.15% ^{234}U; and 93% enrichment, 2% ^{234}U.

Table F-2. Fire release fraction by compound form

Form of compound in fire[a]	Fire release fraction, *FRF*[b]
Noble gas	1.0
Very mobile form (i.e., particle attached to flammable trash in a fire)	1.0
Volatile and combustible compounds	0.5
Carbon	0.01
Semi-volatile compounds	0.01
Non-volatile compounds	0.001
Uranium and plutonium metal	0.001
Non-volatile in flammable liquids	0.005
Non-volatile in non-flammable liquids	0.001
Non-volatile solids	0.0001

[a]If the compound form is not known, use the fire release fractions in Table F-3.
[b]The fire release fraction is the fraction of the isotope released when the material is involved in a fire, FRF = [total activity released (μCi)]/[activity involved in fire (μCi)].

Source: NUREG-1140.

Table F-3. Fire release fraction by isotope

Isotope[a]	Fire release fraction, FRF[b]
^{3}H(gas)	5.00E−01
^{14}C	1.00E−02
^{22}Na	1.00E−02
^{24}Na	1.00E−02
^{32}P	5.00E−01
^{33}P	5.00E−01
^{35}S	5.00E−01
^{36}Cl	5.00E−01
^{40}K	5.00E−01
^{42}K	1.00E−02
^{45}Ca	1.00E−02
^{46}Sc	1.00E−02
^{44}Ti	1.00E−02
^{48}V	1.00E−02
^{51}Cr	1.00E−02
^{54}Mn	1.00E−02
^{56}Mn	1.00E−02
^{55}Fe	1.00E−02
^{59}Fe	1.00E−02
^{58}Co	1.00E−03
^{60}Co	1.00E−03
^{63}Ni	1.00E−02
^{64}Cu	1.00E−02
^{65}Zn	1.00E−02
^{68}Ga	NC
^{68}Ge	1.00E−02
^{75}Se	1.00E−02
^{85}Kr	1.00E+00
^{85m}Kr	1.00E+00
^{87}Kr	1.00E+00
^{88}Kr	1.00E+00

Table F-3. Fire release fraction by isotope (continued)

Isotope[a]	Fire release fraction, FRF[b]
^{86}Rb	1.00E−02
^{87}Rb	1.00E−02
^{88}Rb	1.00E−02
^{89}Sr	1.00E−02
^{90}Sr	1.00E−02
^{91}Sr	1.00E−02
^{90}Y	1.00E−02
^{91}Y	1.00E−02
^{91m}Y	1.00E−02
^{93}Zr	1.00E−02
^{95}Zr	1.00E−02
^{94}Nb	1.00E−02
^{95}Nb	1.00E−02
^{99}Mo	1.00E−02
^{99}Tc	1.00E−02
^{99m}Tc	1.00E−02
^{103}Ru	1.00E−02
^{105}Ru	1.00E−02
^{106}Ru	1.00E−02
^{106}Rh	1.00E−02
^{110m}Ag	1.00E−02
^{109}Cd	1.00E−02
^{113m}Cd	1.00E−02
^{114m}In	1.00E−02
^{113}Sn	1.00E−02
^{123}Sn	1.00E−02
^{126}Sn	1.00E−02
^{124}Sb	1.00E−02
^{126}Sb	1.00E−02
^{126m}Sb	1.00E−02
^{127}Sb	1.00E−02
^{129}Sb	1.00E−02

Table F-3. Fire release fraction by isotope (continued)

Isotope[a]	Fire release fraction, FRF[b]
^{127}Te	1.00E−02
^{127m}Te	1.00E−02
^{129}Te	1.00E−02
^{129m}Te	1.00E−02
^{131}Te	1.00E−02
^{131m}Te	1.00E−02
^{132}Te	1.00E−02
^{125}I	5.00E−01
^{129}I	5.00E−01
^{131}I	5.00E−01
^{132}I	5.00E−01
^{133}I	5.00E−01
^{134}I	5.00E−01
^{135}I	5.00E−01
^{131m}Xe	1.00E+00
^{133}Xe	1.00E+00
^{133m}Xe	1.00E+00
^{135}Xe	1.00E+00
^{135m}Xe	1.00E+00
^{138}Xe	1.00E+00
^{134}Cs	1.00E−02
^{135}Cs	1.00E−02
^{136}Cs	1.00E−02
^{137}Cs	1.00E−02
^{138}Cs	1.00E−02
^{133}Ba	1.00E−02
^{137m}Ba	1.00E−02
^{140}Ba	1.00E−02
^{140}La	1.00E−02
^{141}Ce	1.00E−02
^{144}Ce	1.00E−02
^{144}Pr	1.00E−02
^{144m}Pr	1.00E−02
^{145}Pm	1.00E−02
^{147}Pm	1.00E−02
^{147}Sm	1.00E−02
^{151}Sm	1.00E−02

Table F-3. Fire release fraction by isotope (continued)

Isotope[a]	Fire release fraction, FRF[b]
^{152}Eu	1.00E−02
^{154}Eu	1.00E−02
^{155}Eu	1.00E−02
^{153}Gd	1.00E−02
^{160}Tb	1.00E−02
^{166m}Ho	1.00E−02
^{170}Tm	1.00E−02
^{169}Yb	1.00E−02
^{172}Hf	1.00E−02
^{181}Hf	1.00E−02
^{182}Ta	1.00E−03
^{187}W	1.00E−02
^{192}Ir	1.00E−03
^{198}Au	1.00E−02
^{203}Hg	1.00E−02
^{204}Tl	1.00E−02
^{210}Pb	1.00E−02
^{207}Bi	1.00E−02
^{210}Bi	1.00E−02
^{210}Po	1.00E−02
^{226}Ra	1.00E−03
^{227}Ac	1.00E−03
^{228}Ac	1.00E−03
^{227}Th	1.00E−03
^{228}Th	1.00E−03
^{230}Th	1.00E−03
^{231}Th	1.00E−03
^{232}Th	1.00E−03
^{231}Pa	1.00E−03
^{233}Pa	1.00E−03

Table F-3. Fire release fraction by isotope (continued)

Isotope[a]	Fire release fraction, FRF[b]
^{232}U	1.00E−03
^{233}U	1.00E−03
^{234}U	1.00E−03
^{235}U	1.00E−03
^{236}U	1.00E−03
^{238}U	1.00E−03
^{237}Np	1.00E−03
^{239}Np	1.00E−03
^{236}Pu	1.00E−03
^{238}Pu	1.00E−03
^{239}Pu	1.00E−03
^{240}Pu	1.00E−03
^{241}Pu	1.00E−03
^{242}Pu	1.00E−03
^{241}Am	1.00E−03
^{242m}Am	1.00E−03
^{243}Am	1.00E−03

[a]If the specific compound form of the isotope is known, use Table F-2.

[b]The fire release fraction is the fraction of the isotope released when the material is involved in a fire, FRF = [total activity released (μCi)]/[activity involved in fire (μCi)].

Sources: NUREG-1140, relationship to isotopes not listed in NUREG-1140 from NUREG-1465, Table 3.7, p.12.

Table F-4. Release conversion factor, RCF, in mrem/μCi, ≤0.25 mile from source for 1-μCi release[a]

Isotope	Inhalation[b]				Air immersion[c]	Ground[d]
	Acute bone	Acute lung	Thyroid	CEDE		
^{3}H	1E−08	1E−08	NC	2E−08[e]	7E−13	6E−13
^{14}C	2E−07	2E−07	NC	4E−07	5E−13	1E−11
^{22}Na	NC	NC	NC	1E−06	2E−07	8E−08
^{24}Na	1E−07	8E−07	NC	2E−07	5E−07	3E−08
^{32}P	3E−06	2E−05	NC	3E−06	2E−10	2E−10
^{33}P	NC	NC	NC	4E−07	2E−12	1E−11
^{35}S	3E−08	2E−06	NC	5E−07	5E−13	1E−11
^{36}Cl	NC	NC	NC	4E−06	5E−11	1E−10
^{40}K	NC	NC	NC	2E−06	2E−08	5E−09
^{42}K	NC	NC	NC	3E−07	3E−08	2E−09
^{45}Ca	NC	NC	NC	1E−06	2E−12	3E−11
^{46}Sc	NC	NC	NC	6E−06	2E−07	7E−08
$^{44}Ti+^{44}Sc$	NC	NC	NC	2E−04	2E−07	8E−08
^{48}V	NC	NC	NC	2E−06	3E−07	9E−08
^{51}Cr	1E−08	2E−07	NC	6E−08	3E−09	1E−09
^{54}Mn	5E−07	2E−06	NC	1E−06	8E−08	3E−08
^{56}Mn	NC	NC	NC	7E−08	2E−07	2E−09
^{55}Fe	1E−08	2E−07	NC	5E−07	0	1E−11
^{59}Fe	8E−07	5E−06	NC	3E−06	1E−07	4E−08
^{58}Co	2E−07	3E−06	NC	2E−06	1E−07	3E−08
^{60}Co	6E−07	9E−06	NC	4E−05	3E−07	9E−08
^{63}Ni	2E−08	6E−07	NC	6E−07	0	1E−11
^{64}Cu	NC	NC	NC	5E−08	2E−08	1E−09
^{65}Zn	3E−07	2E−06	NC	4E−06	6E−08	2E−08
^{68}Ga	NC	1E−07	NC	3E−08	1E−07	6E−10
$^{68}Ge+^{68}Ga$	NC	1E−07	NC	1E−05	1E−07	3E−08
^{75}Se	4E−07	2E−06	NC	2E−06	4E−08	1E−08

Table F-4. Release conversion factor, RCF, in mrem/μCi, ≤0.25 mile from source for 1-μCi release (continued)

Isotope	Inhalation[b] Acute bone	Inhalation[b] Acute lung	Inhalation[b] Thyroid	Inhalation[b] CEDE	Air immersion[c]	Ground[d]
^{86}Rb	1E−06	2E−06	NC	1E−06	1E−08	3E−09
^{87}Rb	NC	NC	NC	6E−07	4E−12	2E−11
^{88}Rb	NC	NC	NC	2E−08	7E−08	9E−11
^{89}Sr	2E−06	2E−05	NC	8E−06	2E−10	3E−10
^{90}Sr	3E−06	4E−05	NC	2E−04	2E−11	6E−09
^{91}Sr	NC	NC	NC	3E−07	7E−08	3E−09
^{90}Y	2E−07	6E−06	NC	2E−06	4E−10	1E−10
^{91}Y	9E−07	2E−05	NC	9E−06	5E−10	4E−10
^{91m}Y	NC	NC	NC	7E−09	5E−08	2E−10
^{93}Zr	NC	NC	NC	6E−05	0	1E−09
^{95}Zr	2E−06	7E−06	NC	4E−06	7E−08	3E−08
^{94}Nb	NC	NC	NC	8E−05	2E−07	6E−08
^{95}Nb	3E−07	3E−06	NC	1E−06	8E−08	3E−08
^{99}Mo+^{99m}Tc	3E−07	3E−06	NC	7E−07	3E−08	6E−09
^{99}Tc	3E−08	4E−06	NC	2E−06	3E−12	4E−11
^{99m}Tc	2E−09	2E−08	NC	6E−09	1E−08	4E−10
^{103}Ru	3E−07	5E−06	NC	2E−06	5E−08	2E−08
^{105}Ru	NC	NC	NC	9E−08	8E−08	2E−09
^{106}Ru+^{106}Rh	2E−06	6E−05	NC	9E−05	2E−08	1E−08
^{106}Rh	NC	NC	NC	NC	2E−08	9E−13
^{110m}Ag	1E−06	9E−06	NC	2E−05	3E−07	1E−07
^{109}Cd+^{109m}Ag	NC	NC	NC	2E−05	1E−09	2E−09
^{113m}Cd	NC	NC	NC	3E−04	1E−11	7E−09
^{114m}In	NC	NC	NC	2E−05	9E−09	4E−09
^{113}Sn+^{113m}In	NC	NC	NC	2E−06	3E−08	1E−08
^{123}Sn	NC	NC	NC	6E−06	8E−10	5E−10
^{126}Sn+^{126m}Sb	NC	NC	NC	2E−05	6E−09	5E−08
^{124}Sb	9E−07	2E−05	NC	5E−06	2E−07	6E−08
^{126}Sb	NC	NC	NC	2E−06	3E−07	9E−08
^{126m}Sb	NC	NC	NC	6E−09	2E−07	3E−10
^{127}Sb	NC	NC	NC	1E−06	7E−08	2E−08
^{129}Sb	NC	NC	NC	1E−07	1E−07	3E−09

Table F-4. Release conversion factor, RCF, in mrem/μCi, ≤0.25 mile from source for 1-μCi release (continued)

Isotope	Inhalation[b]				Air immersion[c]	Ground[d]
	Acute bone	Acute lung	Thyroid	CEDE		
^{127}Te	NC	NC	NC	6E−08	5E−10	3E−11
^{127m}Te	2E−06	1E−05	NC	4E−06	3E−10	5E−10
^{129}Te	NC	NC	NC	2E−08	6E−09	4E−11
^{129m}Te	3E−06	2E−05	NC	4E−06	3E−09	1E−09
^{131}Te	NC	NC	2E−06	9E−08	4E−08	9E−11
^{131m}Te	2E−07	2E−06	3E−05	1E−06	1E−07	2E−08
^{132}Te	2E−07	1E−06	4E−05	2E−06	2E−08	6E−09
^{125}I	1E−08	2E−07	1E−04	5E−06	1E−09	2E−09
^{129}I	1E−08	2E−07	1E−03	3E−05	8E−10	2E−09
^{131}I	4E−08	5E−07	2E−04	6E−06	4E−08	1E−08
^{132}I	1E−08	2E−07	1E−06	7E−08	2E−07	3E−09
^{133}I	2E−08	6E−07	3E−05	1E−06	6E−08	6E−09
^{134}I	4E−09	1E−07	2E−07	2E−08	3E−07	1E−09
^{135}I+^{135m}Xe	2E−08	3E−07	6E−06	2E−07	2E−08	5E−09
^{131m}Xe	NC	NC	NC	NC	8E−10	7E−10
^{133}Xe	NC	NC	NC	NC	3E−09	1E−09
^{133m}Xe	NC	NC	NC	NC	3E−09	8E−10
^{135}Xe	NC	NC	NC	NC	2E−08	1E−09
^{135m}Xe	NC	NC	NC	NC	4E−08	6E−11
^{138}Xe	NC	NC	NC	NC	1E−07	1E−10
^{134}Cs	2E−06	2E−06	NC	9E−06	2E−07	6E−08
^{135}Cs	1E−07	3E−07	NC	9E−07	1E−12	2E−11
^{136}Cs	1E−06	1E−06	NC	1E−06	2E−07	7E−08
^{137}Cs+^{137m}Ba	1E−06	2E−06	NC	6E−06	6E−08	2E−08
^{138}Cs	NC	NC	NC	2E−08	3E−07	6E−10
^{133}Ba	NC	NC	NC	1E−06	4E−08	1E−08
^{137m}Ba	NC	NC	NC	NC	6E−08	1E−11
^{140}Ba	7E−07	1E−06	NC	7E−07	2E−08	6E−09
^{140}La	3E−07	3E−06	NC	9E−07	2E−07	4E−08
^{141}Ce	1E−07	6E−06	NC	2E−06	7E−09	3E−09
^{144}Ce+^{144m}Pr	1E−06	6E−05	NC	7E−05	2E−09	4E−09
^{144}Pr	NC	NC	NC	8E−09	4E−09	6E−12
^{144m}Pr	NC	NC	NC	NC	6E−10	8E−13
^{145}Pm	NC	NC	NC	6E−06	1E−09	1E−09
^{147}Pm	1E−07	3E−06	NC	7E−06	1E−12	2E−10

Table F-4. Release conversion factor, RCF, in mrem/μCi, ≤0.25 mile from source for 1-μCi release (continued)

Isotope	Inhalation[b] Acute bone	Inhalation[b] Acute lung	Inhalation[b] Thyroid	Inhalation[b] CEDE	Air immersion[c]	Ground[d]
^{147}Sm	NC	NC	NC	1E−02	0	3E−07
^{151}Sm	3E−08	8E−07	NC	6E−06	8E−14	1E−10
^{152}Eu	6E−07	8E−06	NC	4E−05	1E−07	4E−08
^{154}Eu	8E−07	1E−05	NC	5E−05	1E−07	4E−08
^{155}Eu	1E−07	3E−06	NC	8E−06	5E−09	2E−09
^{153}Gd	NC	NC	NC	4E−06	8E−09	4E−09
^{160}Tb	NC	NC	NC	5E−06	1E−07	4E−08
^{166m}Ho	NC	NC	NC	1E−04	2E−07	7E−08
^{170}Tm	NC	NC	NC	5E−06	5e-10	3E−10
^{169}Yb	3E−07	5E−06	NC	2E−06	3E−08	1E−08
^{172}Hf	NC	NC	NC	6E−05	8E−09	6E−09
^{181}Hf	NC	NC	NC	3E−06	5E−08	2E−08
^{182}Ta	NC	NC	NC	8E−06	1E−07	4E−08
^{187}W	NC	NC	NC	1E−07	5E−08	6E−09
^{192}Ir	6E−07	1E−05	NC	5E−06	8E−08	3E−08
^{198}Au	NC	NC	NC	6E−07	4E−08	9E−09
^{203}Hg	NC	NC	NC	1E−06	2E−08	8E−09
^{204}Tl	NC	NC	NC	5E−07	1E−10	6E−11
^{210}Pb	2E−06	7E−07	NC	3E−03	1E−10	6E−08
^{207}Bi	NC	NC	NC	4E−06	2E−07	5E−08
^{210}Bi	NC	NC	NC	4E−05	7E−11	7E−10
^{210}Po	6E−05	2E−03	NC	2E−03	9E−13	4E−08
^{226}Ra	7E−06	2E−03	NC	2E−03	7E−10	4E−08
^{227}Ac	NC	NC	NC	1E+00	1E−11	3E−05
^{228}Ac	NC	NC	NC	6E−05	1E−07	3E−09

Table F-4. Release conversion factor, RCF, in mrem/μCi, ≤0.25 mile from source for 1-μCi release (continued)

Isotope	Inhalation[b] Acute bone	Acute lung	Thyroid	CEDE	Air immersion[c]	Ground[d]
^{227}Th	3E−04	6E−03	NC	3E−03	1E−08	7E−08
^{228}Th	7E−04	1E−02	NC	6E−02	2E−10	2E−06
^{230}Th	1E−04	2E−03	NC	6E−02	4E−11	2E−06
^{231}Th	NC	NC	NC	2E−07	1E−09	2E−10
^{232}Th	1E−04	2E−03	NC	3E−01	2E−11	8E−06
^{231}Pa	8E−05	2E−03	NC	2E−01	4E−09	6E−06
^{233}Pa	NC	NC	NC	2E−06	2E−08	7E−09
U-dep&nat[f,g]	1E−05	2E−03	NC	2E−02	7E−12	6E−07
U-enric[f,g]	1E−05	2E−03	NC	2E−02	2E−11	6E−07
U-soluble[f,g,h] (UF_6)	1E−05	1E−04	NC	5E−04	2E−11	1E−08
^{232}U[g]	1E-05	2E-03	NC	1E-01	3E-11	3E-06
^{233}U[g]	NC	NC	NC	3E−02	3E−11	6E−07
^{234}U[g]	1E−05	2E−03	NC	2E−02	2E−11	6E−07
^{235}U[g]	1E−05	2E−03	NC	2E−02	1E−08	6E−07
^{236}U[g]	1E−05	2E−03	NC	2E−02	1E−11	6E−07
^{238}U[g]	1E−05	2E−03	NC	2E−02	7E−12	6E−07
^{237}Np	8E−05	2E−03	NC	1E−01	2E−09	3E−06
^{239}Np	6E−08	2E−06	NC	5E−07	2E−08	3E−09
^{236}Pu	NC	NC	NC	3E−02	1E−11	7E−07
^{238}Pu	9E−05	2E−03	NC	7E−02	1E−11	2E−06
^{239}Pu	8E−05	2E−03	NC	8E−02	9E−12	2E−06
^{240}Pu	8E−05	2E−03	NC	8E−02	1E−11	2E−06
^{241}Pu	2E−08	4E−07	NC	2E−03	2E−13	4E−08
^{242}Pu	8E−05	2E−03	NC	8E−02	8E−12	2E−06
^{241}Am	9E−05	2E−03	NC	8E−02	2E−09	2E−06
^{242m}Am	NC	NC	NC	8E−02	7E−11	2E−06
^{243}Am	9E−05	2E−03	NC	8E−02	5E−09	2E−06
^{242}Cm	1E−04	2E−03	NC	3E−03	1E−11	8E−08
^{243}Cm	1E−04	2E−03	NC	6E−02	1E−08	1E−06
^{244}Cm	1E−04	2E−03	NC	5E−02	1E−11	1E−06
^{245}Cm	NC	NC	NC	9E−02	8E−09	2E−06
^{252}Cf	NC	NC	NC	3E−02	1E−11	7E−07

[a]Release conversion factors (RCFs), when multiplied by the activity released (μCi), will give a dose estimate for a ground-level release with no rain close to the source (<0.25 mile). The RCFs assume that the exposed individual is at the center of the plume for the entire duration of the release. The daughters are included in all the inhalation doses and in the external doses where noted (e.g., ^{44}Ti+^{44}Sc). These RCFs should provide an upper bound of the dose from ground-level releases *not* involving rain and a range of stability classes and wind speeds. (The derivation of the RCFs is shown below.)

[b]Inhalation doses include daughters and are, as recommended by EPA, for an adult performing light activity. The RCFs given are the (1) organ dose [(D_T) for bone, lung, and thyroid] and (2) CEDE ($H_{E,50}$) from inhalation. Entries marked "NC" were not calculated.

[c]The air immersion dose equivalent is for a semi-infinite plume, thus maximizing the dose from cloudshine.

[d]The ground exposure is for the early phase and includes external dose equivalent from groundshine and CEDE from resuspension (non-arid area, R_s = 1E−6) from remaining on contaminated ground for 4 days. The groundshine doses were corrected for ground roughness.

[e]CEDE from inhalation was doubled to account for skin absorption.

[f]For natural and depleted uranium, it is assumed all the release is ^{238}U, and for enriched uranium it is assumed all of the release is ^{234}U. The specific activity of natural and depleted uranium is dominated by the concentration of ^{238}U, and enriched uranium is dominated by the concentration of ^{234}U (because of its high specific activity). While releases of natural and enriched uranium will be composed principally of a mixture of ^{234}U, ^{235}U, and ^{238}U, the dose factors for ^{234}U, ^{235}U, and ^{238}U are within 10%, so it is reasonable to use a single dose factor.

[g]Caution: For uranium, the chemical toxicity is always more important than the radiation dose.

[h]Inhalation dose for the soluble form of ^{234}U, which is the likely form in UF_6.

Calculation of Release Conversion Factors

RCF for acute bone marrow dose: $RCF\ (bone) = DCF_{ab} \times CF$

RCF for acute lung dose: $RCF\ (lung) = DCF_{al} \times CF$

RCF for thyroid dose: $RCF\ (thyroid) = DCF_{thy} \times CF$

RCF for CEDE dose: $RCF\ (CEDE) = DCF_{E,50} \times CF$

RCF for air immersion dose: $RCF\ (air) = DCF_{a} \times CF$

RCF for ground exposure dose for early phase:

$$RCF\ (early\ phase\ ground) = DCF_{EPg} \times GCF \times T_{ed}$$

where

CF	=	Conversion factor = 1.56E−7 from $CF = (Q \times DF \times T_{rd})/\bar{U}$, based on Method F.3
DCF	=	Dose conversion factors from Tables F-6 and F-7
DF	=	Dilution factor = 1E−3 m^{-2} for 0.25 mile from Table F-10
GCF	=	Ground concentration factor = 3.9E−8 for 0.25 mile from Table F-11
Q	=	Release rate = 2.8E−4 μCi/s (1 μCi/h)
T_{ed}	=	Exposure duration = 100 h (4 days) for D_{EPg}
T_{rd}	=	Release duration = 1 h
$\bar{U}$	=	Average wind speed = 1.8 m/s (4 mph)

Table F-5. Release conversion factor, RCF, in mrem/μCi, at 1 mile downwind for 1-μCi release[a]

Isotope	Inhalation[b] Acute bone	Inhalation[b] Acute lung	Inhalation[b] Thyroid	Inhalation[b] CEDE	Air immersion[c]	Ground[d]
^{3}H	6E−10	6E−10	NC	1E−09[e]	4E−14	3E−13
^{14}C	9E−09	9E−09	NC	2E−08	3E−14	6E−12
^{22}Na	NC	NC	NC	8E−08	1E−08	4E−08
^{24}Na	8E−09	4E−08	NC	1E−08	2E−08	2E−08
^{32}P	2E−07	8E−07	NC	2E−07	1E−11	9E−11
^{33}P	NC	NC	NC	2E−08	9E−14	6E−12
^{35}S	1E−09	9E−08	NC	2E−08	3E−14	6E−12
^{36}Cl	NC	NC	NC	2E−07	2E−12	7E−11
^{40}K	NC	NC	NC	1E−07	9E−10	3E−09
^{42}K	NC	NC	NC	1E−08	2E−09	9E−10
^{45}Ca	NC	NC	NC	7E−08	1E−13	2E−11
^{46}Sc	NC	NC	NC	3E−07	1E−08	4E−08
$^{44}Ti+^{44}Sc$	NC	NC	NC	1E−05	1E−08	5E−08
^{48}V	NC	NC	NC	1E−07	2E−08	5E−08
^{51}Cr	7E−10	1E−08	NC	3E−09	2E−10	6E−10
^{54}Mn	3E−08	9E−08	NC	7E−08	5E−09	2E−08
^{56}Mn	NC	NC	NC	4E−09	1E−08	1E−09
^{55}Fe	6E−10	1E−08	NC	3E−08	0	7E−12
^{59}Fe	4E−08	3E−07	NC	1E−07	7E−09	2E−08
^{58}Co	1E−08	2E−07	NC	1E−07	5E−09	2E−08
^{60}Co	3E−08	5E−07	NC	2E−06	1E−08	5E−08
^{63}Ni	1E−09	3E−08	NC	3E−08	0	8E−12
^{64}Cu	NC	NC	NC	3E−09	1E−09	7E−10
^{65}Zn	2E−08	9E−08	NC	2E−07	3E−09	1E−08
^{68}Ga	NC	8E−09	NC	1E−09	5E−09	3E−10
$^{68}Ge+^{68}Ga$	NC	8E−09	NC	5E−07	5E−09	2E−08
^{75}Se	2E−08	8E−08	NC	9E−08	2E−09	7E−09

Table F-5. Release conversion factor, RCF, in mrem/μCi, at 1 mile downwind for 1-μCi release (continued)

Isotope	Inhalation[b] Acute bone	Acute lung	Thyroid	CEDE	Air immersion[c]	Ground[d]
^{85}Kr	NC	NC	NC	NC	1E−11	5E−11
^{85m}Kr	NC	NC	NC	NC	8E−10	2E−10
^{87}Kr	NC	NC	NC	NC	5E−09	3E−10
^{88}Kr+^{88}Rb	NC	NC	NC	NC	2E−08	2E−09
^{86}Rb	7E−08	1E−07	NC	7E−08	5E−10	2E−09
^{87}Rb	NC	NC	NC	3E−08	2E−13	1E−11
^{88}Rb	NC	NC	NC	8E−10	4E−09	5E−11
^{89}Sr	9E−08	1E−06	NC	4E−07	9E−12	1E−10
^{90}Sr	2E−07	2E−06	NC	1E−05	8E−13	3E−09
^{91}Sr	NC	NC	NC	2E−08	4E−09	2E−09
^{90}Y	1E−08	3E−07	NC	9E−08	2E−11	8E−11
^{91}Y	5E−08	1E−06	NC	5E−07	3E−11	2E−10
^{91m}Y	NC	NC	NC	4E−10	3E−09	1E−10
^{93}Zr	NC	NC	NC	3E−06	0	8E−10
^{95}Zr	1E−07	4E−07	NC	2E−07	4E−09	1E−08
^{94}Nb	NC	NC	NC	4E−06	9E−09	3E−08
^{95}Nb	1E−08	1E−07	NC	6E−08	4E−09	1E−08
^{99}Mo+^{99m}Tc	1E−08	2E−07	NC	4E−08	1E−09	3E−09
^{99}Tc	1E−09	2E−07	NC	8E−08	2E−13	2E−11
^{99m}Tc	1E−10	1E−09	NC	3E−10	7E−10	2E−10
^{103}Ru	1E−08	3E−07	NC	9E−08	3E−09	9E−09
^{105}Ru	NC	NC	NC	5E−09	4E−09	1E−09
^{106}Ru+^{106}Rh	9E−08	3E−06	NC	5E−06	1E−09	5E−09
^{106}Rh	NC	NC	NC	NC	1E−09	5E−13
^{110m}Ag	6E−08	5E−07	NC	8E−07	2E−08	5E−08
^{109}Cd+^{109m}Ag	NC	NC	NC	1E−06	5E−11	9E−10
^{113m}Cd	NC	NC	NC	2E−05	8E−13	4E−09
^{114m}In	NC	NC	NC	9E−07	5E−10	2E−09
^{113}Sn+^{113m}In	NC	NC	NC	1E−07	1E−09	5E−09
^{123}Sn	NC	NC	NC	3E−07	5E−11	2E−10
^{126}Sn+^{126m}Sb	NC	NC	NC	1E−06	3E−10	3E−08

Table F-5. Release conversion factor, RCF, in mrem/μCi, at 1 mile downwind for 1-μCi release (continued)

Isotope	Inhalation[b] Acute bone	Inhalation[b] Acute lung	Inhalation[b] Thyroid	Inhalation[b] CEDE	Air immersion[c]	Ground[d]
^{124}Sb	5E−08	8E−07	NC	3E−07	1E−08	3E−08
^{126}Sb	NC	NC	NC	1E−07	2E−08	5E−08
^{126m}Sb	NC	NC	NC	3E−10	8E−09	1E−10
^{127}Sb	NC	NC	NC	6E−08	4E−09	9E−09
^{129}Sb	NC	NC	NC	6E−09	8E−09	2E−09
^{127}Te	NC	NC	NC	3E−09	3E−11	1E−11
^{127m}Te	9E−08	6E−07	NC	2E−07	2E−11	3E−10
^{129}Te	NC	NC	NC	9E−10	3E−10	2E−11
^{129m}Te	2E−07	1E−06	NC	2E−07	2E−10	8E−10
^{131}Te	NC	NC	1E−07	5E−09	2E−09	5E−11
^{131m}Te	9E−09	8E−08	1E−06	6E−08	8E−09	1E−08
^{132}Te	1E−08	5E−08	2E−06	1E−07	1E−09	3E−09
^{125}I	6E−10	8E−09	8E−06	2E−07	6E−11	9E−10
^{129}I	7E−10	8E−09	6E−05	2E−06	4E−11	9E−10
^{131}I	2E−09	2E−08	1E−05	3E−07	2E−09	6E−09
^{132}I	5E−10	1E−08	6E−08	4E−09	1E−08	1E−09
^{133}I	1E−09	3E−08	2E−06	6E−08	3E−09	3E−09
^{134}I	2E−10	5E−09	1E−08	1E−09	1E−08	6E−10
$^{135}I+^{135m}Xe$	8E−10	2E−08	3E−07	1E−08	1E−09	3E−09
^{131m}Xe	NC	NC	NC	NC	4E−11	4E−10
^{133}Xe	NC	NC	NC	NC	2E−10	7E−10
^{133m}Xe	NC	NC	NC	NC	2E−10	4E−10
^{135}Xe	NC	NC	NC	NC	1E−09	6E−10
^{135m}Xe	NC	NC	NC	NC	2E−09	3E−11
^{138}Xe	NC	NC	NC	NC	6E−09	7E−11
^{134}Cs	9E−08	1E−07	NC	5E−07	8E−09	3E−08
^{135}Cs	8E−09	2E−08	NC	5E−08	6E−14	1E−11
^{136}Cs	6E−08	7E−08	NC	7E−08	1E−08	4E−08
$^{137}Cs+^{137m}Ba$	5E−08	8E−08	NC	3E−07	3E−09	1E−08
^{138}Cs	NC	NC	NC	1E−09	1E−08	3E−10
^{133}Ba	NC	NC	NC	8E−08	2E−09	8E−09
^{137m}Ba	NC	NC	NC	NC	3E−09	7E−12
^{140}Ba	4E−08	6E−08	NC	4E−08	1E−09	3E−09
^{140}La	2E−08	2E−07	NC	5E−08	1E−08	2E−08
^{141}Ce	7E−09	3E−07	NC	9E−08	4E−10	1E−09
$^{144}Ce+^{144m}Pr$	5E−08	3E−06	NC	4E−06	1E−10	2E−09

Table F-5. Release conversion factor, RCF, in mrem/μCi, at 1 mile downwind for 1-μCi release (continued)

Isotope	Inhalation[b] Acute bone	Acute lung	Thyroid	CEDE	Air immersion[c]	Ground[d]
^{144}Pr	NC	NC	NC	4E−10	2E−10	3E−12
^{144m}Pr	NC	NC	NC	NC	3E−11	4E−13
^{145}Pm	NC	NC	NC	3E−07	8E−11	7E−10
^{147}Pm	6E−09	1E−07	NC	4E−07	8E−14	1E−10
^{147}Sm	NC	NC	NC	8E−04	0	2E−07
^{151}Sm	2E−09	4E−08	NC	3E−07	4E−15	8E−11
^{152}Eu	3E−08	4E−07	NC	2E−06	6E−09	2E−08
^{154}Eu	4E−08	7E−07	NC	3E−06	7E−09	2E−08
^{155}Eu	8E−09	1E−07	NC	4E−07	3E−10	1E−09
^{153}Gd	NC	NC	NC	2E−07	4E−10	2E−09
^{160}Tb	NC	NC	NC	3E−07	6E−09	2E−08
^{166m}Ho	NC	NC	NC	8E−06	9E−09	4E−08
^{170}Tm	NC	NC	NC	3E−07	2E−11	2E−10
^{169}Yb	2E−08	3E−07	NC	8E−08	1E−09	6E−09
^{172}Hf	NC	NC	NC	3E−06	5E−10	3E−09
^{181}Hf	NC	NC	NC	2E−07	3E−09	1E−08
^{182}Ta	NC	NC	NC	5E−07	7E−09	2E−08
^{187}W	NC	NC	NC	6E−09	3E−09	3E−09
^{192}Ir	3E−08	6E−07	NC	3E−07	4E−09	2E−08
^{198}Au	NC	NC	NC	3E−08	2E−09	5E−09
^{203}Hg	NC	NC	NC	7E−08	1E−09	4E−09
^{204}Tl	NC	NC	NC	2E−08	6E−12	3E−11
^{210}Pb	1E−07	4E−08	NC	1E−04	6E−12	3E−08
^{207}Bi	NC	NC	NC	2E−07	8E−09	3E−08
^{210}Bi	NC	NC	NC	2E−06	4E−12	4E−10
^{210}Po	3E−06	1E−04	NC	9E−05	5E−14	2E−08
^{226}Ra	4E−07	1E−04	NC	9E−05	4E−11	2E−08
^{227}Ac	NC	NC	NC	7E−02	7E−13	2E−05
^{228}Ac	NC	NC	NC	3E−06	5E−09	2E−09

Table F-5. Release conversion factor, RCF, in mrem/μCi, at 1 mile downwind for 1-μCi release (continued)

Isotope	Inhalation[b] Acute bone	Inhalation[b] Acute lung	Inhalation[b] Thyroid	Inhalation[b] CEDE	Air immersion[c]	Ground[d]
^{227}Th	2E−05	3E−04	NC	2E−04	5E−10	4E−08
^{228}Th	4E−05	6E−04	NC	3E−03	1E−11	9E−07
^{230}Th	6E−06	1E−04	NC	3E−03	2E−12	8E−07
^{231}Th	NC	NC	NC	9E−09	6E−11	1E−10
^{232}Th	6E−06	1E−04	NC	2E−02	1E−12	4E−06
^{231}Pa	4E−06	1E−04	NC	1E−02	2E−10	3E−06
^{233}Pa	NC	NC	NC	1E−07	1E−09	4E−09
U-dep&nat[f,g]	NC	1E−04	NC	1E−03	4E−13	3E−07
U-enric[f,g]	6E−07	1E−04	NC	1E−03	9E−13	3E−07
U-sol/UF_6[f,g,h]	6E−07	6E−06	NC	3E−05	9E−13	7E−09
^{232}U[g]	7E−07	1E−04	NC	7E−03	2E−12	2E−06
^{233}U[g]	NC	NC	NC	1E−03	2E−12	3E−07
^{234}U[g]	6E−07	1E−04	NC	1E−03	9E−13	3E−07
^{235}U[g]	5E−07	1E−04	NC	1E−03	8E−10	3E−07
^{236}U[g]	6E−07	1E−04	NC	1E−03	6E−13	3E−07
^{238}U[g]	5E−07	1E−04	NC	1E−03	4E−13	3E−07
^{237}Np	4E−06	1E−04	NC	5E−03	1E−10	1E−06
^{239}Np	3E−09	9E−08	NC	3E−08	9E−10	2E−09
^{236}Pu	NC	NC	NC	1E−03	7E−13	4E−07
^{238}Pu	5E−06	1E−04	NC	4E−03	5E−13	1E−06
^{239}Pu	4E−06	1E−04	NC	4E−03	5E−13	1E−06
^{240}Pu	4E−06	1E−04	NC	4E−03	5E−13	1E−06
^{241}Pu	9E−10	2E−08	NC	8E−05	8E−15	2E−08
^{242}Pu	4E−06	1E−04	NC	4E−03	4E−13	1E−06
^{241}Am	5E−06	1E−04	NC	4E−03	9E−11	1E−06
^{242m}Am	NC	NC	NC	4E−03	4E−12	1E−06
^{243}Am	5E−06	1E−04	NC	4E−03	2E−10	1E−06
^{242}Cm	5E−06	1E−04	NC	2E−04	6E−13	4E−08
^{243}Cm	5E−06	1E−04	NC	3E−03	7E−10	8E−07
^{244}Cm	5E−06	1E−04	NC	2E−03	5E−13	6E−07
^{245}Cm	NC	NC	NC	5E−03	4E−10	1E−06
^{252}Cf	NC	NC	NC	2E−03	6E−13	4E−07

[a]Release conversion factors (RCFs), when multiplied by the activity released (μCi), will give a dose estimate for a ground-level release with no rain at 1 mile downwind from the source. The RCFs assume that the exposed individual is at the center of the plume for the entire duration of the release. The daughters are included in all the inhalation doses and in the external doses where noted (e.g., ^{44}Ti+^{44}Sc). These RCFs should provide a upper bound of the dose from ground-level releases *not* involving rain and a range of stability classes and wind speeds. (The derivation of the RCFs is shown below.)

[b]Inhalation doses include daughters and are, as recommended by EPA, for an adult performing light activity. The RCFs are for the (1) organ dose [(D_T) for bone, lung, and thyroid] and (2) CEDE ($H_{E,50}$) from inhalation. Entries marked "NC" were not calculated.

[c]The air immersion dose equivalent is for a semi-infinite plume, thus maximizing the dose from cloudshine.

[d]The ground exposure is for the early phase and includes external dose equivalent from groundshine and CEDE from resuspension (non-arid area, R_s = 1E−6) from remaining on contaminated ground for 4 days. The groundshine doses were corrected for ground roughness.

[e]CEDE from inhalation was doubled to account for skin absorption.

[f]For natural and depleted uranium, it is assumed all the release is ^{238}U, and for enriched uranium it is assumed all of the release is ^{234}U. The specific activity of natural and depleted uranium is dominated by the concentration of ^{238}U, and enriched uranium is dominated by the concentration of ^{234}U (because of its high specific activity). While releases of natural and enriched uranium will be composed principally of a mixture of ^{234}U, ^{235}U, and ^{238}U, the dose factors for ^{234}U, ^{235}U, and ^{238}U are within 10%, so it is reasonable to use a single dose factor.

[g]Caution: For uranium, the chemical toxicity is always more important than the radiation dose.

[h]Inhalation dose for the soluble form of ^{234}U, which is the likely form in UF_6.

Calculation of Release Conversion Factors

RCF for acute bone marrow dose: $RCF\ (bone) = DCF_{ab} \times CF$

RCF for acute lung dose: $RCF\ (lung) = DCF_{al} \times CF$

RCF for thyroid dose: $RCF\ (thyroid) = DCF_{thy} \times CF$

RCF for CEDE dose: $RCF\ (CEDE) = DCF_{E,50} \times CF$

RCF for air immersion dose: $RCF\ (air) = DCF_{a} \times CF$

RCF for ground exposure dose for early phase:

$$RCF\ (early\ phase\ ground) = DCF_{epg} \times GCF \times T_{ed}$$

where

CF	=	Conversion factor = 1.56E−7 from $CF = (Q \times DF \times T_{rd})/\hat{U}$, based on Method F.3
DCF	=	Dose conversion factors from Tables F-6 and F-7
DF	=	Dilution factor = 5.4E−5 m^{-2} for 1 mile from Table F-11
GCF	=	Ground concentration factor = 2.1E−8 for 1 mile from Table F-11
Q	=	Release rate = 2.8E−4 μCi/s (1 μCi/h)
T_{ed}	=	Exposure duration = 100 h (4 days) for D_{EPg}
T_{rd}	=	Release duration = 1 h
$\hat{U}$	=	Average wind speed = 1.8 m/s (4 mph)

Table F-6. Early phase deposition and air immersion dose conversion factors

Isotope	External exposure rate from deposition[b,c], ECF_{gi} $\left(\frac{mR/h}{\mu Ci/m^2}\right)$	External EDE rate from deposition[b,d], DCF_{gi} $\left(\frac{mrem/h}{\mu Ci/m^2}\right)$	4-day EDE from deposition[a,b], DCF_{EPgi} Non-arid resuspension (R_s = 1E−6) $\left(\frac{mrem}{\mu Ci/m^2}\right)$	4-day EDE from deposition[a,b], DCF_{EPgi} Arid resuspension (R_s = 1E−4) $\left(\frac{mrem}{\mu Ci/m^2}\right)$	External EDE rate from air immersion[b,e], DCF_{ai} $\left(\frac{mrem/h}{\mu Ci/m^3}\right)$
^{3}H	0	0	1.5E−05	1.5E−03	4.4E−06
^{14}C	2.1E−07	1.5E−07	2.6E−04	2.5E−02	3.0E−06
^{22}Na	2.7E−02	2.0E−02	1.9E+00	2.0E+00	1.4E+00
^{24}Na	4.7E−02	3.4E−02	7.2E−01	7.2E−01	2.9E+00
^{32}P	3.8E−05	2.7E−05	4.1E−03	1.7E−01	1.3E−03
^{33}P	5.8E−07	4.2E−07	3.0E−04	2.6E−02	1.1E−05
^{35}S	2.2E−07	1.6E−07	3.1E−04	2.9E−02	3.2E−06
^{36}Cl	8.8E−06	6.3E−06	3.3E−03	2.6E−01	3.0E−04
^{40}K	1.9E−03	1.4E−03	1.4E−01	2.8E−01	1.1E−01
^{42}K	3.5E−03	2.5E−03	4.4E−02	4.7E−02	1.9E−01
^{45}Ca	6.0E−07	4.3E−07	8.3E−04	7.9E−02	1.1E−05
^{46}Sc	2.5E−02	1.8E−02	1.8E+00	2.1E+00	1.3E+00
$^{44}Ti+^{44}Sc$	2.9E−02	2.1E−02	2.2E+00	1.4E+01	1.5E+00
^{48}V	3.6E−02	2.6E−02	2.4E+00	2.5E+00	1.9E+00
^{51}Cr	4.0E−04	2.9E−04	2.7E−02	3.1E−02	2.0E−02
^{54}Mn	1.1E−02	7.6E−03	7.5E−01	8.3E−01	5.4E−01
^{56}Mn	2.1E−02	1.5E−02	5.5E−02	5.5E−02	1.1E+00
^{55}Fe	0	0	3.2E−04	3.2E−02	0
^{59}Fe	1.5E−02	1.0E−02	1.0E+00	1.2E+00	7.9E−01
^{58}Co	1.2E−02	8.9E−03	8.7E−01	9.9E−01	6.3E−01
^{60}Co	3.1E−02	2.2E−02	2.2E+00	4.8E+00	1.7E+00
^{63}Ni	0	0	3.7E−04	3.7E−02	0
^{64}Cu	2.4E−03	1.7E−03	3.2E−02	3.2E−02	1.2E−01
^{65}Zn	7.2E−03	5.2E−03	5.1E−01	7.5E−01	3.9E−01
^{68}Ga	1.2E−02	8.8E−03	1.4E−02	1.4E−02	6.1E−01
$^{68}Ge+^{68}Ga$	1.2E−02	8.8E−03	8.8E−01	1.5E+00	6.1E−01
^{75}Se	4.9E−03	3.5E−03	3.5E−01	4.5E−01	2.5E−01
^{85}Kr	3.4E−05	2.5E−05	2.5E−03	2.5E−03	1.6E−03
^{85m}Kr	2.0E−03	1.4E−03	9.1E−03	9.1E−03	9.9E−02
^{87}Kr	9.6E−03	6.8E−03	1.2E−02	1.2E−02	5.5E−01
$^{88}Kr+^{88}Rb$	3.0E−02	2.2E−02	8.9E−02	8.9E−02	1.8E+00
^{86}Rb	1.2E−03	8.7E−04	8.1E−02	1.5E−01	6.4E−02
^{87}Rb	1.1E−06	8.2E−07	4.7E−04	3.9E−02	2.4E−05
^{88}Rb	7.8E−03	5.5E−03	2.4E−03	2.4E−03	4.5E−01

Table F-6. Early phase deposition and air immersion dose conversion factors (continued)

Isotope	External exposure rate from deposition[b,c], ECF_{gi} $\left(\frac{mR/h}{\mu Ci/m^2}\right)$	External EDE rate from deposition[b,d], DCF_{gi} $\left(\frac{mrem/h}{\mu Ci/m^2}\right)$	4-day EDE from deposition[a,b], DCF_{EPgi} Non-arid resuspension (R_s = 1E−6) $\left(\frac{mrem}{\mu Ci/m^2}\right)$	4-day EDE from deposition[a,b], DCF_{EPgi} Arid resuspension (R_s = 1E−4) $\left(\frac{mrem}{\mu Ci/m^2}\right)$	External EDE rate from air immersion[b,e], DCF_{ai} $\left(\frac{mrem/h}{\mu Ci/m^3}\right)$
^{89}Sr	3.0E−05	2.1E−05	6.9E−03	4.8E−01	1.0E−03
^{90}Sr	3.7E−06	2.6E−06	1.6E−01	1.6E+01	1.0E−04
^{91}Sr	8.8E−03	6.3E−03	1.3E-01	1.3E−01	4.6E−01
^{90}Y	6.9E−05	5.0E−05	3.6E−03	6.5E−02	2.5E−03
^{91}Y	7.5E−05	5.4E−05	1.1E−02	5.8E−01	3.5E−03
^{91m}Y	6.8E−03	4.9E−03	5.8E−03	5.8E−03	3.4E−01
^{93}Zr	0	0	3.8E−02	3.8E+00	0
^{95}Zr	9.4E−03	6.7E−03	6.6E−01	9.3E−01	4.8E−01
^{94}Nb	2.0E−02	1.4E−02	1.5E+00	6.4E+00	1.0E+00
^{95}Nb	9.8E−03	7.0E−03	6.7E−01	7.4E−01	5.0E−01
$^{99}Mo+^{99m}Tc$	3.5E−03	2.5E−03	1.6E−01	1.8E−01	1.8E−01
^{99}Tc	1.0E−06	7.3E−07	1.1E−03	1.0E−01	2.2E−05
^{99m}Tc	1.6E−03	1.1E−03	9.8E−03	9.8E−03	7.8E−02
^{103}Ru	6.0E−03	4.3E−03	4.2E−01	5.2E−01	3.0E−01
^{105}Ru	1.0E−02	7.2E−03	4.6E−02	4.6E−02	5.1E−01
$^{106}Ru+^{106}Rh$	2.8E−03	2.0E−03	2.5E−01	5.9E+00	1.4E−01
^{106}Rh	2.8E−03	2.0E−03	2.4E−05	2.4E−05	1.4E−01
^{110m}Ag	3.5E−02	2.5E−02	2.5E+00	3.4E+00	1.8E+00
$^{109}Cd+^{109m}Ag$	4.2E−04	3.0E−04	4.4E−02	1.4E+00	6.5E−03
^{113m}Cd	3.4E−06	2.5E−06	1.8E−01	1.8E+01	9.2E−05
^{114m}In	1.2E−03	8.5E−04	9.3E−02	1.1E+00	5.6E−02
$^{113}Sn+^{113m}In$	3.7E−03	2.6E−03	2.6E−01	3.8E−01	1.7E−01
^{123}Sn	1.1E−04	7.8E−05	1.2E−02	3.9E−01	5.4E−03
$^{126}Sn+^{126m}Sb$	2.0E−02	4.1E−02	1.4E+00	2.6E+00	2.9E+00
^{124}Sb	2.2E−02	1.6E−02	1.6E+00	1.8E+00	1.2E+00
^{126}Sb	3.6E−02	2.6E−02	2.3E+00	2.4E+00	1.8E+00
^{126m}Sb	2.0E−02	1.4E−02	6.5E−03	6.5E−03	1.0E+00
^{127}Sb	8.8E−03	6.3E−03	4.4E−01	4.9E−01	4.4E−01
^{129}Sb	1.8E−02	1.3E−02	8.5E−02	8.5E−02	9.5E−01
^{127}Te	6.8E−05	4.8E−05	6.6E−04	1.2E−03	3.2E−03
^{127m}Te	1.5E−04	1.1E−04	1.3E−02	2.6E−01	2.0E−03
^{129}Te	7.8E−04	5.6E−04	9.4E−04	9.5E−04	3.7E−02
^{129m}Te	4.9E−04	9.1E−04	6.7E−02	3.3E−01	5.8E−02
^{131}Te	5.4E−03	3.8E−03	2.3E−03	2.3E−03	2.7E−01
^{131m}Te	1.8E−02	1.3E−02	5.5E−01	5.9E−01	9.3E−01
^{132}Te	3.0E−03	2.1E−03	1.4E+00	1.5E+00	1.4E−01

Table F-6. Early phase deposition and air immersion dose conversion factors (continued)

Isotope	External exposure rate from deposition[b,c], ECF_{gi} $\left(\frac{mR/h}{\mu Ci/m^2}\right)$	External EDE rate from deposition[b,d], DCF_{gi} $\left(\frac{mrem/h}{\mu Ci/m^2}\right)$	4-day EDE from deposition[a,b], DCF_{EPgi} Non-arid resuspension (R_s = 1E−6) $\left(\frac{mrem}{\mu Ci/m^2}\right)$	4-day EDE from deposition[a,b], DCF_{EPgi} Arid resuspension (R_s = 1E−4) $\left(\frac{mrem}{\mu Ci/m^2}\right)$	External EDE rate from air immersion[b,e], DCF_{ai} $\left(\frac{mrem/h}{\mu Ci/m^3}\right)$
^{125}I	5.6E−04	4.0E−04	4.2E−02	3.2E−01	6.9E−03
^{129}I	3.4E−04	2.4E−04	4.5E−02	2.1E+00	5.1E−03
^{131}I	4.9E−03	3.5E−03	3.0E−01	6.2E−01	2.4E−01
^{132}I	2.9E−02	2.1E−02	6.8E−02	6.8E−02	1.5E+00
^{133}I	7.8E−03	5.6E−03	1.6E−01	1.8E−01	3.9E−01
^{134}I	3.3E−02	2.4E−02	3.0E−02	3.0E−02	1.7E+00
$^{135}I+^{135m}Xe$	2.0E−02	1.4E−02	1.4E−01	1.4E−01	1.1E+00
^{131m}Xe	2.7E−04	1.9E−04	1.7E−02	1.7E−02	5.2E−03
^{133}Xe	6.0E−04	4.3E−04	3.3E−02	3.3E−02	2.1E−02
^{133m}Xe	5.3E−04	3.8E−04	2.1E−02	2.1E−02	1.8E−02
^{135}Xe	3.2E−03	2.3E−03	3.0E−02	3.0E−02	1.6E−01
^{135m}Xe	5.5E−03	4.0E−03	1.5E−03	1.5E−03	2.7E−01
^{138}Xe	1.3E−02	9.6E−03	3.3E−03	3.3E−03	7.7E−01
^{134}Cs	2.0E−02	1.4E−02	1.4E+00	2.0E+00	1.0E+00
^{135}Cs	4.3E−07	3.1E−07	5.8E−04	5.5E−02	7.5E−06
^{136}Cs	2.7E−02	1.9E−02	1.7E+00	1.8E+00	1.4E+00
$^{137}Cs+^{137m}Ba$	7.6E−03	5.5E−03	5.5E−01	9.3E−01	3.8E−01
^{138}Cs	2.9E−02	2.0E−02	1.6E−02	1.6E−02	1.6E+00
^{133}Ba	5.2E−03	3.7E−03	3.7E−01	4.6E−01	2.4E−01
^{137m}Ba	7.6E−03	5.5E−03	3.3E−04	3.3E−04	3.8E−01
^{140}Ba	2.3E−03	1.7E−03	1.1E+00	1.1E+00	1.1E−01
^{140}La	2.8E−02	2.0E−02	9.6E−01	9.9E−01	1.6E+00
^{141}Ce	9.6E−04	6.9E−04	6.7E−02	1.7E−01	4.6E−02
$^{144}Ce+^{144}Pr$	7.4E−04	6.7E−04	9.7E−02	4.5E+00	4.1E−02
^{144}Pr	4.9E−04	3.5E−04	1.5E−04	1.5E−04	2.6E−02
^{144m}Pr	1.7E−04	1.2E−04	2.1E−05	2.1E−05	3.7E−03
^{145}Pm	4.3E−04	3.0E−04	3.4E−02	3.9E−01	9.4E−03
^{147}Pm	4.4E−07	3.2E−07	4.7E−03	4.7E−01	9.2E−06
^{147}Sm	0	0	9.0E+00	9.0E+02	0
^{151}Sm	6.6E−08	4.7E−08	3.6E−03	3.6E−01	4.8E−07
^{152}Eu	1.4E−02	1.0E−02	1.0E+00	3.7E+00	7.5E−01
^{154}Eu	1.6E−02	1.1E−02	1.1E+00	4.5E+00	8.2E−01
^{155}Eu	7.7E−04	5.5E−04	6.0E−02	5.5E−01	3.3E−02
^{153}Gd	1.4E−03	9.9E−04	1.0E−01	3.8E−01	4.9E−02
^{160}Tb	1.4E−02	1.0E−02	9.9E−01	1.3E+00	7.4E−01
^{166m}Ho	2.2E−02	1.6E−02	1.7E+00	1.1E+01	1.1E+00

Table F-6. Early phase deposition and air immersion dose conversion factors (continued)

Isotope	External exposure rate from deposition[b,c], ECF_{gi} $\left(\frac{mR/h}{\mu Ci/m^2}\right)$	External EDE rate from deposition[b,d], DCF_{gi} $\left(\frac{mrem/h}{\mu Ci/m^2}\right)$	4-day EDE from deposition[a,b], DCF_{EPgi} Non-arid resuspension (R_s = 1E−6) $\left(\frac{mrem}{\mu Ci/m^2}\right)$	4-day EDE from deposition[a,b], DCF_{EPgi} Arid resuspension (R_s = 1E−4) $\left(\frac{mrem}{\mu Ci/m^2}\right)$	External EDE rate from air immersion[b,e], DCF_{ai} $\left(\frac{mrem/h}{\mu Ci/m^3}\right)$
^{170}Tm	7.7E−05	5.5E−05	8.6E−03	3.2E−01	3.0E−03
^{169}Yb	4.0E−03	2.8E−03	2.7E−01	3.6E−01	1.7E−01
^{172}Hf	1.5E−03	1.1E−03	1.4E−01	3.9E+00	5.4E−02
^{181}Hf	7.1E−03	5.1E−03	4.9E−01	6.7E−01	3.5E−01
^{182}Ta	1.6E−02	1.1E−02	1.1E+00	1.7E+00	8.5E−01
^{187}W	6.1E−03	4.4E−03	1.4E−01	1.4E−01	3.0E−01
^{192}Ir	1.0E−02	7.5E−03	7.4E−01	1.1E+00	5.2E−01
^{198}Au	5.2E−03	3.7E−03	2.3E−01	2.5E−01	2.6E−01
^{203}Hg	3.0E−03	2.2E−03	2.1E−01	2.9E−01	1.5E−01
^{204}Tl	1.9E−05	1.4E−05	1.7E−03	3.0E−02	7.4E−04
^{210}Pb	3.2E−05	2.3E−05	1.6E+00	1.6E+02	7.5E−04
^{207}Bi	1.9E−02	1.4E−02	1.4E+00	1.6E+00	1.0E+00
^{210}Bi	1.4E−05	9.8E−06	1.9E−02	1.8E+00	4.4E−04
^{210}Po	1.1E−07	7.7E−08	1.1E+00	1.1E+02	5.5E−06
^{226}Ra	8.4E−05	6.0E−05	1.4E+00	1.0E+02	4.2E−03
^{227}Ac	2.0E−06	1.5E−06	8.0E+02	8.0E+04	7.7E−05
^{228}Ac	1.2E−02	8.7E−03	8.0E−02	4.0E−01	6.4E−01
^{227}Th	1.4E−03	9.7E−04	1.9E+00	1.8E+02	6.5E−02
^{228}Th	3.1E−05	2.2E−05	4.1E+01	4.1E+03	1.2E−03
^{230}Th	9.8E−06	7.0E−06	3.9E+01	3.9E+03	2.3E−04
^{231}Th	2.4E−04	1.7E−04	6.0E−03	9.5E−03	6.9E−03
^{232}Th	7.2E−06	5.1E−06	2.0E+02	2.0E+04	1.2E−04
^{231}Pa	5.3E−04	3.8E−04	1.5E+02	1.5E+04	2.3E−02
^{233}Pa	2.5E−03	1.8E−03	1.7E−01	2.8E−01	1.2E−01
^{232}U[f]	1.3E−05	9.4E−06	7.9E+01	7.9E+03	1.9E−04
^{233}U[f]	9.3E−06	6.7E−06	1.6E+01	1.6E+03	2.2E−04
^{234}U[f]	9.8E−06	7.0E−06	1.6E+01	1.6E+03	1.0E−04
^{235}U[f]	1.9E−03	1.4E−03	1.5E+01	1.5E+03	9.6E−02
^{236}U[f]	8.5E−06	6.1E−06	1.5E+01	1.5E+03	6.7E−05
^{238}U[f]	7.2E−06	5.1E−06	1.4E+01	1.4E+03	4.5E−05
U-dep&nat[f,g]	7.2E−06	5.1E−06	1.4E+01	1.4E+03	4.5E−05
U-enrich[f,g]	9.8E−06	7.0E−06	1.6E+01	1.6E+03	1.0E−04
^{234}U-sol/UF_6[f,g,h]	9.8E−06	7.0E−06	3.2E−01	3.2E+01	1.0E−04

Table F-6. Early phase deposition and air immersion dose conversion factors (continued)

Isotope	External exposure rate from deposition[b,c], ECF_{gi} $\left(\frac{mR/h}{\mu Ci/m^2}\right)$	External EDE rate from deposition[b,d], DCF_{gi} $\left(\frac{mrem/h}{\mu Ci/m^2}\right)$	4-day EDE from deposition[a,b], DCF_{EPgi} Non-arid resuspension (R_s = 1E−6) $\left(\frac{mrem}{\mu Ci/m^2}\right)$	4-day EDE from deposition[a,b], DCF_{EPgi} Arid resuspension (R_s = 1E−4) $\left(\frac{mrem}{\mu Ci/m^2}\right)$	External EDE rate from air immersion[b,e], DCF_{ai} $\left(\frac{mrem/h}{\mu Ci/m^3}\right)$
^{237}Np	3.7E−04	2.7E−04	6.5E+01	6.5E+03	1.4E−02
^{239}Np	2.1E−03	1.5E−03	8.8E−02	1.0E−01	1.0E−01
^{236}Pu	1.3E−05	9.1E−06	1.7E+01	1.7E+03	8.4E−05
^{238}Pu	1.1E−05	7.8E−06	4.7E+01	4.7E+03	6.5E−05
^{239}Pu	4.8E−06	3.4E−06	5.1E+01	5.1E+03	5.6E−05
^{240}Pu	1.0E−05	7.5E−06	5.1E+01	5.1E+03	6.3E−05
^{241}Pu	2.5E−08	1.8E−08	9.9E−01	9.9E+01	9.6E−07
^{242}Pu	8.7E−06	6.2E−06	4.9E+01	4.9E+03	5.3E−05
^{241}Am	3.6E−04	2.6E−04	5.3E+01	5.3E+03	1.1E−02
^{242m}Am	3.9E−05	2.8E−05	5.1E+01	5.1E+03	4.2E−04
^{243}Am	7.0E−04	5.0E−04	5.3E+01	5.3E+03	2.9E−02
^{242}Cm	1.2E−05	8.9E−06	2.1E+00	2.1E+02	7.6E−05
^{243}Cm	1.6E−03	1.2E−03	3.7E+01	3.7E+03	7.8E−02
^{244}Cm	1.1E−05	8.2E−06	3.0E+01	3.0E+03	6.5E−05
^{245}Cm	1.1E−03	8.1E−04	5.5E+01	5.5E+03	5.3E−02
^{252}Cf	9.4E−06	6.7E−06	1.9E+01	1.9E+03	6.7E−05

[a]External dose equivalent from deposition and CEDE from inhaled resuspension from remaining on contaminated ground for 4 days. The dose is calculated for two different resuspension factors. Daughters are included in inhalation doses and in external doses as indicated.

[b]External doses from deposition are corrected by a factor of 0.7 for ground roughness. Contribution of daughters is included in external doses where noted (e.g., ^{44}Ti + ^{44}Sc).

[c]Exposure rate at 1 m above ground from a 1-$\mu Ci/m^2$ deposition of given isotope.

[d]Effective dose equivalent rate at 1 m above ground level from a 1-$\mu Ci/m^2$ deposition of given isotope.

[e]Effective dose equivalent from immersion in a semi-infinite cloud of uniform given isotope concentration. Contribution of daughters included where indicated.

[f]Caution: The chemical toxicity of uranium is more important in producing early health effects than radiation dose.

[g]For natural and depleted uranium it is assumed all the release is ^{238}U, and for enriched uranium it is assumed all of the release is ^{234}U. The activity of enriched uranium is dominated by the concentration of ^{234}U (because of its high SpA). While releases of natural and enriched uranium will be composed principally of a mixture of ^{234}U, ^{235}U, and ^{238}U, the dose factors are all within 10% so it is reasonable to use a single factor.

[h]The D (day) lung clearance class was used in estimating early phase inhalation dose because the uranium in UF_6 is in a soluble form.

Calculation of Exposure and Dose Conversion Factors

Exposure conversion factor from groundshine:

$$ECF_g = DCECSD \times SiCF \times GRCF \times 1.4$$

(EDE is multiplied by 1.4 to estimate external exposure rate as recommended by EPA 400-R-92-001. Early phase assessment methods in the *FRMAC Assessment Manual* can be used to calculate ECF_g for other isotopes or for different assumptions.)

Dose conversion factor from groundshine: $DCF_g = DCECGS \times SiCF \times GRCF$

(Early phase assessment methods in the *FRMAC Assessment Manual* can be used to calculate DCF_g for other isotopes or for different assumptions.)

Dose conversion factor for early phase (4 days) from deposition:

$$DCF_{EPg} = DCF_g + CEDE \text{ (from resuspension)}$$

The *FRMAC Assessment Manual* contains a full description of how DCF_{EPg} is calculated and early phase assessment methods to calculate DCF_{EPg} for other isotopes or other resuspension factors.)

Dose conversion factor air: $DCF_a = DCAS \times SiCF$

(Early phase assessment methods in the *FRMAC Assessment Manual* can be used calculate DCF_a for isotopes not listed or for different assumptions.)

where

DCAS	=	dose coefficients for air immersion from EPA-402-R-93-081, Table III.1, pp. 51-73
DCECGS	=	dose conversion for exposure to contaminated ground surface factor from EPA-402-R-93-081, Table III.3, pp. 93-109
GRCF	=	ground roughness correction factor, 0.7
SiCF	=	conversion factor from SI units, see below

$$SiCF = \frac{\text{Sv/s}}{\text{Bq/m}^2} \times \frac{3.6 \times 10^5 \text{ s}}{\text{h}} \times \frac{10^5 \text{ mrem}}{\text{Sv}} \times \frac{\text{Bq}}{2.7 \times 10^{-5} \ \mu\text{Ci}} = \frac{1.33 \times 10^{13} \text{ mrem}}{\mu\text{Ci/m}^2}$$

Table F-7. Early phase inhalation dose conversion factors in (mrem/h)/(μCi/m³)[a]

Isotope	$DCF_{e,Soi}$[b]	DCF_{Ti}		
		Acute bone[c]	Acute lung[c]	Thyroid CDE[d]
^{3}H	1.53E−01[e]	7.10E−02	7.10E−02	NC[f]
^{14}C	2.50E+00	1.02E+00	1.02E+00	NC
^{22}Na	9.19E+00	NC	NC	NC
^{24}Na	1.45E+00	9.32E−01	5.33E+00	NC
^{32}P	1.86E+01	2.04E+01	9.77E+01	NC
^{33}P	2.78E+00	NC	NC	NC
^{35}S	2.97E+00	1.78E−01	1.07E+01	NC
^{36}Cl	2.63E+01	NC	NC	NC
^{40}K	1.48E+01	NC	NC	NC
^{42}K	1.63E+00	NC	NC	NC
^{45}Ca	7.95E+00	NC	NC	NC
^{46}Sc	3.56E+01	NC	NC	NC
^{44}Ti	1.22E+03	NC	NC	NC
^{48}V	1.23E+01	NC	NC	NC
^{51}Cr	4.01E−01	7.99E−02	1.33E+00	NC
^{54}Mn	8.04E+00	3.42E+00	1.07E+01	NC
^{56}Mn	4.53E−01	NC	NC	NC
^{55}Fe	3.22E+00	7.10E−02	1.33E+00	NC
^{59}Fe	1.78E+01	5.33E+00	3.51E+01	NC
^{58}Co	1.31E+01	1.51E+00	2.00E+01	NC
^{60}Co	2.62E+02	3.91E+00	5.77E+01	NC
^{63}Ni	3.73E+00	1.38E−01	4.13E+00	NC
^{64}Cu	3.32E−01	NC	NC	NC
^{65}Zn	2.45E+01	2.09E+00	1.07E+01	NC
^{68}Ga	1.66E−01	NC	9.32E−01	NC
^{68}Ge	6.22E+01	NC	9.32E−01	NC
^{75}Se	1.02E+01	2.26E+00	9.77E+00	NC

Table F-7. Early phase inhalation dose conversion factors in (mrem/h)/(μCi/m³) (continued)

Isotope	$DCF_{e,50i}$[b]	DCF_{Ti}		
		Acute bone[c]	Acute lung[c]	Thyroid CDE[d]
^{85}Kr	7.32E−04	7.32E−04	NC	NC
^{85m}Kr	4.68E−04	4.68E−04	NC	NC
^{87}Kr	1.56E−03	1.56E−03	NC	NC
^{88}Kr	3.72E−03	3.72E−03	NC	NC
^{86}Rb	7.95E+00	7.99E+00	1.33E+01	NC
^{87}Rb	3.88E+00	NC	NC	NC
^{88}Rb	1.00E−01	NC	NC	NC
^{89}Sr	4.97E+01	1.02E+01	1.38E+02	NC
^{90}Sr	1.56E+03	2.09E+01	2.80E+02	NC
^{91}Sr	1.99E+00	2.76E−01	NC	NC
^{90}Y	1.01E+01	1.25E+00	4.13E+01	NC
^{91}Y	5.86E+01	5.77E+00	1.47E+02	NC
^{91m}Y	4.36E−02	NC	NC	NC
^{93}Zr	3.85E+02	NC	NC	NC
^{95}Zr	2.80E+01	1.20E+01	4.17E+01	NC
^{94}Nb	4.97E+02	NC	NC	NC
^{95}Nb	6.97E+00	1.78E+00	1.78E+01	NC
^{99}Mo	4.75E+00	1.69E+00	1.91E+01	NC
^{99}Tc	9.99E+00	1.73E−01	2.44E+01	NC
^{99m}Tc	3.91E−02	1.38E−02	1.38E−01	NC
^{103}Ru	1.07E+01	1.78E+00	3.06E+01	NC
^{105}Ru	5.46E−01	NC	NC	NC
^{106}Rh	NC	NC	NC	NC
^{106}Ru	5.73E+02	1.02E+01	3.95E+02	NC
^{110m}Ag	9.63E+01	7.10E+00	5.77E+01	NC
^{109}Cd	1.37E+02	NC	NC	NC
^{113m}Cd	1.83E+03	NC	NC	NC
^{114m}In	1.07E+02	NC	NC	NC
^{113}Sn	1.28E+01	NC	NC	NC
^{123}Sn	3.90E+01	NC	NC	NC
^{126}Sn	1.19E+02	NC	NC	NC

Table F-7. Early phase inhalation dose conversion factors in (mrem/h)/(μCi/m³) (continued)

Isotope	$DCF_{e,50i}$[b]	DCF_{TI} Acute bone[c]	Acute lung[c]	Thyroid CDE[d]
^{124}Sb	3.02E+01	5.77E+00	9.77E+01	NC
^{126}Sb	1.41E+01	NC	NC	NC
^{126m}Sb	4.07E−02	NC	NC	NC
^{127}Sb	7.24E+00	3.96E−01	NC	NC
^{129}Sb	7.73E−01	5.52E−02	NC	NC
^{127}Te	3.82E−01	4.68E−03	NC	NC
^{127m}Te	2.58E+01	1.07E+01	6.66E+01	NC
^{129}Te	1.07E−01	1.33E−02	NC	NC
^{129m}Te	2.87E+01	1.82E+01	1.15E+02	NC
^{131}Te	5.73E−01	NC	NC	1.17E+01
^{131m}Te	7.68E+00	1.02E+00	9.77E+00	1.60E+02
^{132}Te	1.13E+01	1.24E+00	6.22E+00	2.79E+02
^{125}I	2.90E+01	7.55E−02	4.44E−01	9.59E+02
^{129}I	2.08E+02	8.44E−02	9.77E−01	6.93E+03
^{131}I	3.95E+01	2.40E−01	2.89E+00	1.30E+03
^{132}I	4.57E−01	6.22E−02	1.20E+00	7.73E+00
^{133}I	7.02E+00	1.20E−01	3.64E+00	2.16E+02
^{134}I	1.58E−01	2.71E−02	6.22E−01	1.28E+00
^{135}I	1.47E+00	9.77E−02	1.95E+00	3.76E+01
^{131m}Xe	NC	NC	NC	NC
^{133}Xe	1.92E−03	1.92E−03	NC	NC
^{133m}Xe	NC	NC	NC	NC
^{135}Xe	2.52E−03	2.52E−03	NC	NC
^{135m}Xe	NC	NC	NC	NC
^{138}Xe	NC	NC	NC	NC
^{134}Cs	5.55E+01	1.02E+01	1.24E+01	NC
^{135}Cs	5.46E+00	9.32E−01	1.82E+00	NC
^{136}Cs	8.79E+00	6.66E+00	8.88E+00	NC
^{137}Cs	3.83E+01	6.22E+00	9.77E+00	NC
^{138}Cs	1.22E−01	NC	NC	NC
^{133}Ba	9.37E+00	NC	NC	NC
^{137m}Ba	NC	NC	NC	NC
^{140}Ba	4.48E+00	4.44E+00	7.10E+00	NC
^{140}La	5.82E+00	2.04E+00	1.86E+01	NC
^{141}Ce	1.07E+01	8.44E−01	3.73E+01	NC
^{144}Ce	4.48E+02	6.22E+00	3.60E+02	NC

Table F-7. Early phase inhalation dose conversion factors in (mrem/h)/(μCi/m³) (continued)

Isotope	$DCF_{e,50i}$[b]	DCF_{Ti}		
		Acute bone[c]	Acute lung[c]	Thyroid CDE[d]
^{144}Pr	5.19E−02	NC	NC	NC
^{144m}Pr	NC	NC	NC	NC
^{145}Pm	3.65E+01	NC	NC	NC
^{147}Pm	4.71E+01	6.66E−01	1.73E+01	NC
^{147}Sm	8.97E+04	NC	NC	NC
^{151}Sm	3.60E+01	2.09E−01	4.88E+00	NC
^{152}Eu	2.65E+02	4.04E+00	4.88E+01	NC
^{154}Eu	3.43E+02	5.33E+00	8.44E+01	NC
^{155}Eu	4.97E+01	9.32E−01	1.64E+01	NC
^{153}Gd	2.85E+01	NC	NC	NC
^{160}Tb	3.00E+01	NC	NC	NC
^{166m}Ho	9.28E+02	NC	NC	NC
^{170}Tm	3.16E+01	NC	NC	NC
^{169}Yb	9.68E+00	2.22E+00	3.11E+01	NC
^{172}Hf	3.82E+02	NC	NC	NC
^{181}Hf	1.85E+01	NC	NC	NC
^{182}Ta	5.37E+01	NC	NC	NC
^{187}W	7.41E−01	NC	NC	NC
^{192}Ir	3.38E+01	3.64E+00	6.66E+01	NC
^{198}Au	3.94E+00	NC	NC	NC
^{203}Hg	8.79E+00	NC	NC	NC
^{204}Tl	2.89E+00	NC	NC	NC
^{210}Pb	1.63E+04	1.33E+01	4.80E+00	NC
^{207}Bi	2.40E+01	NC	NC	NC
^{210}Bi	2.35E+02	NC	NC	NC
^{210}Po	1.13E+04	3.77E+02	1.20E+04	NC
^{226}Ra	1.03E+04	4.44E+01	1.15E+04	NC
^{227}Ac	8.04E+06	NC	NC	NC
^{228}Ac	3.70E+02	NC	NC	NC

Table F-7. Early phase inhalation dose conversion factors in (mrem/h)/(μCi/m³) (continued)

Isotope	$DCF_{e,50i}$[b]	DCF_{Ti}		
		Acute bone[c]	Acute lung[c]	Thyroid CDE[d]
^{227}Th	1.94E+04	2.23E+03	3.70E+04	NC
^{228}Th	4.10E+05	4.45E+03	7.57E+04	NC
^{230}Th	3.91E+05	7.55E+02	1.33E+04	NC
^{231}Th	1.05E+00	NC	NC	NC
^{232}Th	1.97E+06	6.66E+02	1.15E+04	NC
^{231}Pa	1.54E+06	4.89E+02	1.42E+04	NC
^{233}Pa	1.15E+01	NC	NC	NC
^{232}U[g]	7.90E+05	8.01E+01	1.60E+04	NC
^{233}U[g]	1.63E+05	NC	NC	NC
^{234}U[g]	1.59E+05	7.11E+01	1.33E+04	NC
^{235}U[g]	1.47E+05	6.41E+01	1.25E+04	NC
^{236}U[g]	1.51E+05	6.67E+01	1.29E+04	NC
^{238}U[g]	1.42E+05	6.39E+01	1.21E+04	NC
U dep & nat[g,h]	1.42E+05	6.39E+01	1.21E+04	NC
U enrich[g,h]	1.59E+05	7.11E+01	1.33E+04	NC
^{234}U sol (UF_6)[g,h,i]	3.20E+03	7.11E+01	6.7E+02	NC
^{237}Np	6.48E+05	4.90E+02	1.16E+04	NC
^{239}Np	3.01E+00	4.00E−01	1.07E+01	NC
^{236}Pu	1.74E+05	NC	NC	NC
^{238}Pu	4.71E+05	5.77E+02	1.55E+04	NC
^{239}Pu	5.15E+05	5.33E+02	1.47E+04	NC
^{240}Pu	5.15E+05	5.33E+02	1.47E+04	NC
^{241}Pu	9.90E+03	1.07E−01	2.84E+00	NC
^{242}Pu	4.93E+05	5.33E+02	1.38E+04	NC
^{241}Am	5.33E+05	5.78E+02	1.33E+04	NC
^{242m}Am	5.11E+05	NC	NC	NC
^{243}Am	5.28E+05	5.81E+02	1.29E+04	NC
^{242}Cm	2.07E+04	6.22E+02	1.38E+04	NC
^{243}Cm	3.69E+05	6.24E+02	1.42E+04	NC
^{244}Cm	2.97E+05	6.22E+02	1.42E+04	NC
^{245}Cm	5.46E+05	NC	NC	NC
^{252}Cf	1.88E+05	1.15E+04	NC	NC

[a]Dose conversion factors are provided in terms of mrem acquired in 1 h breathing an air concentration of $1 \mu Ci/m^3$. To arrive at these DCFs, the breathing rate of an adult performing light activity ($1.2\ m^3/h$) was assumed. Contribution from daughters is included in all the inhalation doses. The lung class giving the highest dose was assumed except for UF_6.

[b]Committed effective dose equivalent (CEDE) dose factor, $DCF_{e,50}$, is the committed dose equivalent for 50 years.

[c]Absorbed dose for 30 days after the isotope has been inhaled.

[d]Committed dose equivalent to thyroid from radioiodine.

[e]CEDE dose factor from inhalation was doubled to account for skin absorption.

[f]Not calculated.

[g]Caution: For uranium, chemical toxicity is always more important than the dose for early health effects.

[h]For natural and depleted uranium it is assumed all the release is ^{238}U, and for enriched uranium it is assumed all of the release is ^{234}U. The specific activity of enriched uranium is dominated by the concentration of ^{234}U (because of its high SpA). While releases of natural and enriched uranium will be composed principally of a mixture of ^{234}U, ^{235}U, and ^{238}U, the dose factors are all within 10% so it is reasonable to use a single factor.

[i]The day lung clearance class (soluble) was assumed because the uranium in UF_6 is in a soluble form.

Calculation of Dose Conversion Factors

Committed dose equivalent conversion factor: $DCF_{e,50} = EDCF_{e,50} \times BR \times CF$

Acute bone marrow dose conversion factor:

$$DCF_T(bone) = [ABM\text{-}AD_{(H)} \times QF + ABM\text{-}AD_{(L)}] \times BR \times CF$$

Acute lung dose conversion factor:

$$DCF_T(lung) = [AL\text{-}AD_{(H)} \times QF + AL\text{-}AD_{(L)}] \times BR \times CF$$

Thyroid committed dose equivalent: $DCF_T(thyroid) = EDCF_T \times BR \times CF$

where

ABM-AD	=	Acute bone marrow absorbed dose (high or low LET) in Gy/Bq (adult, 30 day) from NRPB-R162, Table A:4, p. 40. Most conservative lung clearance class was used.
AL-AD	=	Acute lung absorbed dose (high or low LET) in Gy/Bq (adult, 30 day) from NRPB-R162, Table A:5, p. 43. Most conservative lung clearance class was used.
BR	=	Breathing rate for an adult performing light activity, 0.020 m^3/min × 60 min/h = 1.2 m^3/h, from EPA 520/1-88-020, p. 10. This breathing rate overestimates the average daily rate (see Table 3.10).
$EDCF_{e,50}$	=	Exposure to committed effective dose equivalent conversion factor, from EPA-520/1-88-020, Table 2.1, "effective" column, pp. 121–153.
$EDCF_T$	=	Exposure to committed dose equivalent conversion factor for thyroid, from EPA-520/1-88-020, Table 2.1, "thyroid" column, pp. 121–153.
QF	=	Quality factor. The dose equivalent was computed using a quality factor of 10 to better represent the acute dose.
CF	=	Conversion factor for units, given below.

$$\frac{Sv}{Bq} \times \frac{10^5\ mrem}{Sv} \times \frac{Bq}{2.7 \times 10^{-5}\ \mu Ci} = \frac{3.7 \times 10^9\ mrem}{\mu Ci/m^2}$$

Early phase assessment methods in the *FRMAC Assessment Manual* can be used to calculate DCFs for isotopes not listed or for different assumptions.

Table F-8. Stability class description and relationship to standard deviation of wind direction and lapse rate

Class[a]	Description	Standard deviation of horizontal wind direction, σ_θ, at 10 m	Lapse rate, Δt $\left(\frac{°C}{100\ m}\right)$
A	Extremely unstable conditions	25°	< −0.19
B	Moderately unstable conditions	20°	−1.9 to −1.7
C	Slightly unstable conditions	15°	−1.7 to −1.5
D	Neutral conditions	10°	−1.5 to −0.5
E	Slightly stable conditions	5°	−0.5 to 1.5
F	Moderately stable conditions	2.5°	1.5 to 4.0

[a]Pasquill turbulence types.

Source: DOE/TIC-27601, p. 591.

Table F-9. Relationship of stability class to weather conditions

Surface wind speed (m/s)	Daytime insolation (solar radiation)			Nighttime conditions[a]		Day or night
	Strong	Moderate	Slight	Thin overcast or >4/8 cloudiness	≤3/8 cloudiness	Heavy overcast
<2	A	A-B	B	—	—	D
2	A-B	B	C	E	F	D
4	B	B-C	C	D	E	D
6	C	C-D	D	D	D	D
>6	C	D	D	D	D	D

[a]The degree of cloudiness is defined as that fraction of the sky above the local apparent horizon that is covered by clouds.

Source: DOE/TIC-27601, p. 591.

Table F-10. Dilution factors, $(\chi\bar{U})/Q$, in m^{-2}

Distance[b] (mile)	Stability class[a]					
	A	B	C	D	E	F
≤0.25[c]	1.0E−3	1.0E−3	1.0E−3	1.0E−3	1.0E−3	1.0E−3
1	1.0E−6	6.0E−6	1.7E−5	5.4E−5	1.1E−4	2.5E−4
2	7.0E−7	1.5E−6	5.0E−6	2.0E−5	4.0E−5	1.0E−4
3	4.5E−7	6.5E−7	2.2E−6	1.2E−5	2.5E−5	6.0E−5
4	3.5E−7	4.5E−7	1.2E−6	8.0E−6	1.6E−5	4.0E−5
5	3.0E−7	4.0E−7	9.5E−7	5.0E−6	1.1E−5	3.0E−5
10	1.7E−7	2.2E−7	3.0E−7	2.0E−6	5.0E−6	1.2E−5
15	1.2E−7	1.5E−7	2.0E−7	1.0E−6	2.6E−6	7.0E−6
20	9.5E−8	1.1E−7	1.7E−7	7.0E−7	2.0E−6	5.0E−6
25	8.0E−8	9.0E−8	1.3E−7	4.5E−7	1.4E−6	4.0E−6

[a]Pasquill turbulence types. Dilution factors are for center line of ground-level release at a vertical dispersion limit of 1000 m.

[b]Distance downwind of source on center line of plume.

[c]These factors are dominated by building wake; in this table they are assumed to be constant and independent of stability class.

Sources: Values for 0.25 mi are based on interpretation of NUREG/CR-5055, Figs. 5-7, pp. 25-27; others, AP-26, Figs. 3-5a-3-5f.

Table F-11. Ground concentration factors

Distance (mile)	Ground concentration factor[a], *GCF* (m^{-2})
0.25[b]	3.9E−08
1.0	2.1E−08
2.0	1.4E−08
5.0	6.3E−09
10.0	2.8E−09

[a]GCFs provide an estimate of the activity deposited as a function of distance from a ground-level release ($\mu Ci/m^2$ per μCi released). Factors were based on RASCAL calculations and consider building wake effects. Average meteorological conditions (D stability) were assumed. The deposition velocity assumed was 0.3 cm/s. This is considered reasonable for dry deposition for most depositing isotopes. A higher deposition velocity is often assumed for iodine, but for most accidents the majority of the iodine is assumed to be bound to a particle so the 0.3-cm/s deposition velocity should provide a reasonable estimate for iodine also.

[b]GCF (0.25 mile) = GCF (1 mile) × [DF(0.25 mile)/DF(1 mile)] where DF is dilution factor from Table F-10.

Table F-12. Point source dose rate and exposure rate factors at 1 m from source

Isotope	Exposure conversion rate factor, ECF_p $\left(\frac{mR/h}{\mu Ci}\right)$	Effective dose equiv. rate conversion factor, DCF_p $\left(\frac{mrem/h}{\mu Ci}\right)$	Bone dose equiv. rate conversion factor, DCF_{pab} $\left(\frac{mrem/h}{\mu Ci}\right)$
^{3}H	0	0	0
^{14}C	0	0	0
^{22}Na	1E−03	8E−04	7E−04
^{24}Na	2E−03	1E−03	1E−03
^{32}P	0	0	0
^{33}P	0	0	0
^{35}S	0	0	0
^{36}Cl	8E−08	1E−09	2E−11
^{40}K	8E−05	6E−05	5E−05
^{42}K	1E−04	1E−04	9E−05
^{45}Ca	2E−11	3E−13	6E−15
^{46}Sc	1E−03	8E−04	7E−04
^{44}Ti	1E−04	4E−05	2E−05
^{48}V	2E−03	1E−03	1E−03
^{51}Cr	7E−05	1E−05	1E−05
^{54}Mn	6E−04	3E−04	3E−04
^{56}Mn	9E−04	6E−04	6E−04
^{55}Fe	8E−05	1E−06	2E−08
^{59}Fe	7E−04	4E−04	4E−04
^{58}Co	6E−04	4E−04	3E−04
^{60}Co	1E−03	9E−04	8E−04
^{63}Ni	0	0	0
^{64}Cu	2E−04	7E−05	6E−05
^{65}Zn	5E−04	2E−04	2E−04
^{68}Ga	6E−04	4E−04	3E−04

Table F-12. Point source dose rate and exposure rate factors at 1 m from source (continued)

Isotope	Exposure conversion rate factor, ECF_p $\left(\frac{mR/h}{\mu Ci}\right)$	Effective dose equiv. rate conversion factor, DCF_p $\left(\frac{mrem/h}{\mu Ci}\right)$	Bone dose equiv. rate conversion factor, DCF_{pab} $\left(\frac{mrem/h}{\mu Ci}\right)$
$^{68}Ge+^{68}Ga$	8E−04	4E−04	3E−04
^{75}Se	5E−04	1E−04	1E−04
^{85}Kr	1E−06	8E−07	8E−07
^{85m}Kr	1E−04	6E−05	4E−05
^{87}Kr	4E−04	3E−04	3E−04
$^{88}Kr+^{88}Rb$	1E−03	9E−04	7E−04
^{86}Rb	5E−05	4E−05	3E−05
^{87}Rb	0	0	0
^{88}Rb	2E−04	2E−04	2E−04
^{89}Sr	8E−08	5E−08	5E−08
^{90}Sr	0	0	0
^{91}Sr	4E−04	3E−04	2E−04
^{90}Y	0	0	0
^{91}Y	2E−06	1E−06	1E−06
^{91m}Y	3E−04	2E−04	2E−04
^{93}Zr	0	0	0
^{95}Zr	4E−04	3E−04	3E−04
^{94}Nb	9E−04	6E−04	5E−04
^{95}Nb	4E−04	3E−04	3E−04
^{99}Mo	1E−04	6E−05	5E−05
^{99}Tc	2E−10	2E−10	9E−11
^{99m}Tc	8E−05	4E−05	3E−05
^{103}Rh	1E−04	8E−05	7E−05
^{103}Ru	3E−04	2E−04	2E−04
^{105}Ru	5E−04	3E−04	3E−04
^{106}Ru	3E−05	5E−06	1E−06
$^{106}Ru+^{106}Rh$	3E−05	5E−06	1E−06
^{110m}Ag	2E−03	1E−03	9E−04

Table F-12. Point source dose rate and exposure rate factors at 1 m from source (continued)

Isotope	Exposure conversion rate factor, ECF_p $\left(\frac{mR/h}{\mu Ci}\right)$	Effective dose equiv. rate conversion factor, DCF_p $\left(\frac{mrem/h}{\mu Ci}\right)$	Bone dose equiv. rate conversion factor, DCF_{pob} $\left(\frac{mrem/h}{\mu Ci}\right)$
$^{109}Cd+^{109m}Ag$	1E−03	6E−04	5E−04
^{113m}Cd	0	0	0
^{114m}In	1E−04	4E−05	3E−05
^{113}Sn	2E−04	1E−05	3E−06
^{123}Sn	4E−06	3E−06	2E−06
$^{126}Sn+^{126m}Sb$	8E−05	2E−05	1E−05
^{124}Sb	1E−03	7E−04	6E−04
^{126}Sb	2E−03	1E−03	9E−04
^{126m}Sb	3E−06	2E−06	2E−06
^{127}Sb	4E−04	3E−04	2E−04
^{129}Sb	8E−04	5E−04	5E−04
^{127}Te	4E−05	2E−05	2E−05
^{127m}Te	4E−05	6E−06	1E−06
^{129}Te	2E−04	2E−04	1E−04
$^{129m}Te+^{129}Te$	3E−04	2E−04	1E−04
^{131}Te	3E−04	2E−04	1E−04
^{131m}Te	8E−04	5E−04	5E−04
^{132}Te	2E−04	8E−05	6E−05
^{125}I	1E−04	2E−05	4E−06
^{129}I	8E−05	1E−05	2E−06
^{131}I	2E−04	1E−04	1E−04
^{132}I	1E−03	9E−04	8E−04
^{133}I	4E−04	2E−04	2E−04
^{134}I	2E−03	1E−03	9E−04
$^{135}I+^{135}Xe$	2E−03	1E−03	1E−03
^{131m}Xe	6E−05	1E−05	2E−06
^{133}Xe	7E−05	2E−05	6E−06
^{133m}Xe	8E−05	2E−05	9E−06
^{135}Xe	1E−04	9E−05	7E−05
^{138}Xe	6E−04	4E−04	4E−04

Table F-12. Point source dose rate and exposure rate factors at 1 m from source (continued)

Isotope	Exposure conversion rate factor, ECF_p $\left(\frac{mR/h}{\mu Ci}\right)$	Effective dose equiv. rate conversion factor, DCF_p $\left(\frac{mrem/h}{\mu Ci}\right)$	Bone dose equiv. rate conversion factor, DCF_{pab} $\left(\frac{mrem/h}{\mu Ci}\right)$
^{134}Cs	9E−04	6E−04	5E−04
^{136}Cs	1E−03	8E−04	7E−04
$^{137}Cs+^{137m}Ba$	4E−04	2E−04	2E−04
^{138}Cs	2E−05	1E−05	1E−05
^{133}Ba	3E−04	2E−04	1E−04
^{137m}Ba	4E−04	2E−04	2E−04
^{140}Ba	2E−04	7E−05	6E−05
^{140}La	1E−03	9E−04	8E−04
^{141}Ce	5E−05	3E−05	2E−05
$^{144}Ce+^{144}Pr$	4E−05	1E−05	6E−06
^{144m}Pr	1E−04	1E−05	3E−06
^{144}Pr	2E−05	5E−06	1E−06
^{145}Pm	7E−05	1E−05	3E−06
^{147}Pm	2E−09	1E−09	7E−10
^{151}Sm	4E−07	8E−09	4E−10
^{152}Eu	7E−04	4E−04	4E−04
^{154}Eu	7E−04	5E−04	4E−04
^{155}Eu	6E−05	2E−05	1E−05
^{153}Gd	2E−04	4E−05	2E−05
^{160}Tb	7E−04	4E−04	4E−04
^{166m}Ho	1E−03	6E−04	5E−04
^{170}Tm	2E−05	2E−06	7E−07
^{169}Yb	4E−04	1E−04	7E−05
^{172}Hf	2E−04	8E−05	7E−05
^{181}Hf	4E−04	2E−04	2E−04
^{182}Ta	8E−04	5E−04	4E−04
^{187}W	3E−04	2E−04	2E−04
^{192}Ir	5E−04	3E−04	3E−04

Table F-12. Point source dose rate and exposure rate factors at 1 m from source (continued)

Isotope	Exposure conversion rate factor, ECF_p $\left(\frac{mR/h}{\mu Ci}\right)$	Effective dose equiv. rate conversion factor, DCF_p $\left(\frac{mrem/h}{\mu Ci}\right)$	Bone dose equiv. rate conversion factor, DCF_{pab} $\left(\frac{mrem/h}{\mu Ci}\right)$
^{198}Au	2E−04	2E−04	1E−04
^{203}Hg	2E−04	8E−05	7E−05
^{204}Ti	4E−06	4E−07	2E−07
^{210}Pb	1E−04	3E−06	3E−07
^{207}Bi	1E−03	6E−04	5E−04
^{210}Bi	0	0	0
^{210}Po	5E−09	3E−09	3E−09
^{226}Ra	8E−06	2E−06	2E−06
^{227}Ac	8E−06	1E−07	2E−08
^{228}Ac	8E−04	4E−04	3E−04
^{227}Th	3E−04	4E−05	3E−05
^{228}Th	6E−05	1E−06	4E−07
^{230}Th	5E−05	9E−07	8E−08
^{231}Th	3E−05	9E−07	6E−08
^{232}Th	5E−05	8E−07	4E−08
^{231}Pa	3E−04	2E−05	9E−06
^{233}Pa	2E−04	6E−05	5E−05
U-dep & nat[a]	6E−05	8E−07	2E−08
U-enrich[a]	7E−05	1E−06	4E−08
^{232}U	8E−05	1E−06	6E−08
^{233}U	3E−05	4E−07	5E−08
^{234}U	7E−05	1E−06	4E−08
^{235}U	3E−04	5E−05	4E−05
^{236}U	0	0	0
^{238}U	6E−05	8E−07	2E−08
^{237}Np	2E−04	1E−05	5E−06
^{239}Np	0	0	0

Table F-12. Point source dose rate and exposure rate factors at 1 m from source (continued)

Isotope	Exposure conversion rate factor, ECF_p $\left(\frac{mR/h}{\mu Ci}\right)$	Effective dose equiv. rate conversion factor, DCF_p $\left(\frac{mrem/h}{\mu Ci}\right)$	Bone dose equiv. rate conversion factor, DCF_{pab} $\left(\frac{mrem/h}{\mu Ci}\right)$
^{236}Pu	4E−05	1E−06	7E−08
^{238}Pu	3E−05	1E−06	6E−08
^{239}Pu	1E−05	4E−07	3E−08
^{240}Pu	3E−05	1E−06	6E−08
^{241}Pu	0	0	0
^{242}Pu	3E−05	9E−07	5E−08
^{241}Am	1E−04	1E−05	3E−06
^{242}Am	9E−05	3E−06	2E−07
^{243}Am	1E−04	2E−05	8E−06
^{242}Cm	3E−05	1E−06	6E−08
^{243}Cm	2E−04	5E−05	3E−05
^{244}Cm	3E−05	1E−06	5E−08

[a]For natural and depleted uranium it is assumed all the material is ^{238}U, and for enriched uranium it is assumed all of the material is ^{234}U. The specific activity of enriched uranium is dominated by the concentration of ^{234}U (because of its high SpA). While releases from natural and enriched uranium will be composed principally of a mixture of ^{234}U, ^{235}U, and ^{238}U, the dose factors are all within 10% so it is reasonable to use a single factor.

Source: Calculated using CONDOS II program at 1 m with no shielding.

Table F-13. Half-value layer for selected materials

Isotope	Half-value layer[a], HVL (cm)					
	Lead[b]	Iron[b]	Aluminum[b]	Water[b]	Air[c]	Concrete[b]
^{3}H	0	0	0	0	0	0
^{14}C	0	0	0	0	0	0
^{22}Na	0.67	1.38	3.85	9.4	7,940	4.35
^{24}Na	1.32	2.14	6.22	14.75	12,678	6.88
^{32}P	0	0	0	0	0	0
^{33}P	0	0	0	0	0	0
^{35}S	0	0	0	0	0	0
^{36}Cl	0	0.01	0.02	0.04	39	0.02
^{40}K	1.15	1.8	4.99	11.97	10,192	5.63
^{42}K	1.18	1.84	5.1	12.21	10,414	5.75
^{45}Ca	0.01	0.03	0.1	0.24	212	0.11
^{46}Sc	0.82	1.48	4.2	9.84	8,472	4.66
^{44}Ti	0.04	0.21	0.6	1.41	1,247	0.67
^{48}V	0.8	1.48	4.18	9.95	8,503	4.67
^{51}Cr	0.17	0.82	2.38	5.69	4,980	2.68
^{54}Mn	0.68	1.33	3.8	9	7,703	4.22
^{56}Mn	0.94	1.65	4.78	11.13	9,664	5.27
^{55}Fe	0	0.02	0.05	0.12	102	0.05
^{59}Fe	0.94	1.59	4.51	10.58	9,097	5.02
^{60}Co	1	1.66	4.65	10.99	9,421	5.2
^{63}Ni	0	0	0	0	0	0
^{64}Cu	0.41	1.08	3.01	7.61	6,320	3.43
^{65}Zn	0.87	1.53	4.34	10.15	8,740	4.81
^{68}Ga	0.42	1.09	3.04	7.67	6,376	3.47
$^{68}Ge+^{68}Ga$[d]	0.42	1.09	3.04	7.67	6,376	3.47
^{68}Ge	0.01	0.03	0.08	0.18	160	0.09
^{75}Se	0.12	0.62	1.79	4.26	3,742	2.01

Table F-13. Half-value layer for selected materials (continued)

Isotope	Half-value layer[a], HVL (cm)					
	Lead[b]	Iron[b]	Al[b]	Water[b]	Air[c]	Concrete[b]
^{85}Kr	0.41	1.07	3	7.59	6,305	3.43
^{85m}Kr	0.1	0.5	1.46	3.46	3,046	1.64
^{87}Kr	0.83	1.67	4.84	11.46	9,922	5.36
$^{88}Kr+^{88}Rb$[d]	1.17	1.89	5.51	12.74	11,132	6.05
^{88}Kr	1.20	1.95	5.71	13.2	11,575	6.25
^{86}Rb	0.87	1.53	4.35	10.13	8,741	4.81
^{88}Rb	1.17	1.89	5.51	12.74	11,132	6.05
^{89}Sr	0.74	1.4	4	9.35	8,050	4.42
^{90}Sr	0	0	0	0	0	0
^{91}Sr	0.71	1.38	3.94	9.31	7,980	4.38
^{91}Y	0.96	1.62	4.57	10.74	9,226	5.09
^{93}Zr	0	0	0	0	0	0
^{95}Zr	0.6	1.26	3.58	8.61	7,314	4
^{94}Nb	0.64	1.30	3.70	8.84	7,538	4.13
^{95}Nb	0.62	1.28	3.63	8.72	7,416	4.06
$^{99}Mo+^{99m}Tc$[d]	0.49	1.11	3.16	7.6	6,483	3.54
^{99}Mo	0.49	1.11	3.16	7.6	6,483	3.54
^{99}Tc	0.05	0.25	0.73	1.73	1,529	0.82
^{99m}Tc	0.07	0.39	1.13	2.68	2,367	1.27
^{103}Ru	0.4	1.06	2.97	7.53	6,253	3.4
^{105}Ru	0.48	1.16	3.28	7.98	6,774	3.69
^{106}Ru	0	0	0	0	0	0
$^{106}Ru+^{106}Rh$[d]	0.49	1.17	3.29	8.16	6,837	3.73
^{106}Rh	0.49	1.17	3.29	8.16	6,837	3.73
^{110m}Ag	0.71	1.38	3.91	9.36	7,979	4.38
^{109}Cd	0.01	0.06	0.18	0.43	380	0.2
^{113m}Cd	0	0	0	0	0	0
^{114m}In	0.23	0.75	2.14	5.18	4,447	2.41

Table F-13. Half-value layer for selected materials (continued)

Isotope	Half-value layer[a], HVL (cm)					
	Lead[b]	Iron[b]	Al[b]	Water[b]	Air[c]	Concrete[b]
^{113}Sn	0.02	0.09	0.27	0.65	571	0.31
^{123}Sn	0.88	1.53	4.36	10.16	8,767	4.83
$^{126}Sn+^{126m}Sb$[d]	0.48	1.15	3.27	7.99	6,755	3.68
^{126}Sn	0.04	0.19	0.55	1.3	1,148	0.62
^{124}Sb	0.83	1.55	4.39	10.49	8,979	4.9
^{126}Sb	0.52	1.19	3.37	8.21	6,951	3.79
^{126m}Sb	0.48	1.15	3.27	7.99	6,755	3.68
^{127}Sb	0.47	1.14	3.24	7.92	6,695	3.65
^{129}Sb	0.72	1.4	3.98	9.45	8,092	4.43
^{127m}Te	0.01	0.08	0.23	0.54	476	0.26
^{129}Te	0.33	0.93	2.63	6.53	5,504	2.99
^{129m}Te	0.38	0.82	2.33	5.65	4,785	2.61
^{131m}Te	0.65	1.31	3.74	8.88	7,612	4.17
^{132}Te	0.1	0.53	1.5	3.66	3,223	1.73
^{125}I	0.01	0.08	0.23	0.54	477	0.26
^{129}I	0.02	0.09	0.25	0.6	526	0.28
^{131}I	0.25	0.93	2.67	6.5	5,587	3.02
^{132}I	0.63	1.31	3.7	8.91	7,574	4.14
^{133}I	0.47	1.15	3.23	8.05	6,735	3.67
^{134}I	0.72	1.4	3.98	9.43	8,081	4.43
^{135}I	0.98	1.66	4.7	11.06	9,526	5.23
$^{135}I+^{135m}Xe$[d]	0.98	1.66	4.7	11.06	9,526	5.23
^{131m}Xe	0.02	0.1	0.29	0.7	616	0.33
^{133}Xe	0.03	0.16	0.47	1.11	980	0.53
^{133m}Xe	0.05	0.25	0.73	1.72	1,519	0.82
^{135}Xe	0.14	0.72	2.1	4.99	4,380	2.36
^{135m}Xe	0.41	1.07	2.99	7.54	6,271	3.41
^{138}Xe	0.9	1.64	4.79	11.09	9,723	5.26
^{134}Cs	0.57	1.24	3.5	8.5	7,186	3.93
^{136}Cs	0.65	1.32	3.76	8.86	7,623	4.18
^{137}Cs	0	0	0	0	0	0
$^{137}Cs+^{137m}Ba$[d]	0.53	1.19	3.35	8.2	6,916	3.77

Table F-13. Half-value layer for selected materials (continued)

Isotope	Half-value layer[a], HVL (cm)					
	Lead[b]	Iron[b]	Al[b]	Water[b]	Air[c]	Concrete[b]
^{133}Ba	0.16	0.67	1.92	4.63	4,023	2.17
^{137m}Ba	0.53	1.19	3.35	8.2	6,916	3.77
^{140}Ba	0.33	0.96	2.69	6.72	5,645	3.06
^{140}La	0.93	1.64	4.63	11.04	9,468	5.19
^{141}Ce	0.07	0.37	1.07	2.52	2,225	1.2
$^{144}Ce+^{144m}Pr$[d]	0.05	0.28	0.82	1.95	1,722	0.93
^{144}Pr						
^{144m}Pr	0.02	0.1	0.28	0.67	588	0.32
^{145}Pm	0.02	0.11	0.31	0.74	656	0.35
^{147}Pm	0.06	0.34	0.99	2.35	2,075	1.12
^{147}Sm						
^{151}Sm	0.01	0.03	0.09	0.21	182	0.1
^{152}Eu	0.66	1.32	3.73	8.84	7,592	4.17
^{154}Eu	0.74	1.38	3.91	9.24	7,924	4.35
^{155}Eu	0.04	0.23	0.66	1.56	1,373	0.74
^{153}Gd	0.03	0.18	0.51	1.21	1,065	0.57
^{160}Tb	0.68	1.35	3.84	9.01	7,770	4.26
^{166m}Ho	0.45	1.09	3.1	7.46	6,374	3.48
^{170}Tm	0.03	0.18	0.51	1.21	1,064	0.57
^{169}Yb	0.06	0.3	0.87	2.05	1,808	0.97
^{181}Hf	0.27	0.86	2.41	6.02	5,074	2.75
^{182}Ta	0.8	1.39	3.94	9.26	7,972	4.39
^{187}W	0.43	1.03	2.91	7.17	6,038	3.29
^{192}Ir	0.24	0.92	2.64	6.42	5,521	2.98
^{198}Au	0.29	0.97	2.74	6.77	5,746	3.11
^{203}Hg	0.14	0.73	2.13	5.04	4,443	2.39

Table F-13. Half-value layer for selected materials (continued)

Isotope	Half-value layer[a], HVL (cm)					
	Lead[b]	Iron[b]	Al[b]	Water[b]	Air[c]	Concrete[b]
^{204}Tl	0.03	0.18	0.53	1.27	1,117	0.6
^{210}Pb	0.01	0.05	0.15	0.35	311	0.17
^{207}Bi	0.65	1.3	3.68	8.79	7,503	4.11
^{210}Bi	0	0	0	0	0	0
^{210}Po	0.65	1.31	3.73	8.88	7,581	4.15
^{226}Ra	0.09	0.48	1.4	3.32	2,930	1.58
^{227}Ac	0.01	0.08	0.22	0.52	457	0.25
^{228}Ac	0.67	1.35	3.84	9.05	7,786	4.27
^{227}Th	0.11	0.58	1.69	4.01	3,525	1.9
^{228}Th	0.02	0.13	0.37	0.88	773	0.42
^{230}Th	0.01	0.05	0.14	0.34	302	0.16
^{232}Th	0.01	0.04	0.12	0.28	248	0.13
^{231}Pa	0.09	0.46	1.35	3.2	2,816	1.51
^{232}U	0.01	0.04	0.12	0.29	259	0.14
^{233}U	0.01	0.06	0.16	0.39	344	0.18
^{234}U	0.01	0.04	0.12	0.28	242	0.13
^{235}U	0.09	0.46	1.35	3.19	2,814	1.51
^{238}U	0.01	0.04	0.11	0.27	236	0.13
^{237}Np	0.03	0.12	0.41	0.98	862	0.46
^{236}Pu	0.01	0.04	0.11	0.27	239	0.13
^{238}Pu	0.01	0.04	0.11	0.27	237	0.13
^{239}Pu	0.01	0.04	0.12	0.29	258	0.14
^{240}Pu	0.01	0.04	0.11	0.27	237	0.13
^{241}Pu	0	0	0	0	0	0
^{242}Pu	0.01	0.04	0.11	0.27	237	0.13
^{241}Am	0.02	0.12	0.35	0.82	727	0.39
^{242m}Am	0.01	0.04	0.13	0.3	267	0.14
^{243}Am	0.03	0.18	0.52	1.24	1,090	0.59

Table F-13. Half-value layer for selected materials (continued)

Isotope	Half-value layer[a], HVL (cm)					
	Lead[b]	Iron[b]	Al[b]	Water[b]	Air[c]	Concrete[b]
^{242}Cm	0.01	0.04	0.12	0.28	248	0.13
^{243}Cm	0.08	0.43	1.26	2.98	2,626	1.41
^{244}Cm	0.01	0.04	0.12	0.28	247	0.13
^{245}Cm	0.05	0.27	0.79	1.86	1,643	0.88
^{252}Cf	0.01	0.04	0.12	0.3	261	0.14

[a]The HVL is the thickness of a substance, which when introduced in the path of a beam of radiation, reduces the exposure rate by one-half. Values are given for "good geometry" where build-up of secondary radiation is not important.

[b]Values less than 0.01 were set equal to zero.

[c]Values less than 0.99 were set equal to zero.

[d]Values given are the higher of the two.

Source: Values calculated with CONDOS II with no build-up.

Fig. F-1
Conversion factors needed to adjust total acute bone dose (TABD) or total effective dose equivalent (TEDE) at 1 mile for other distances and other release conditions.

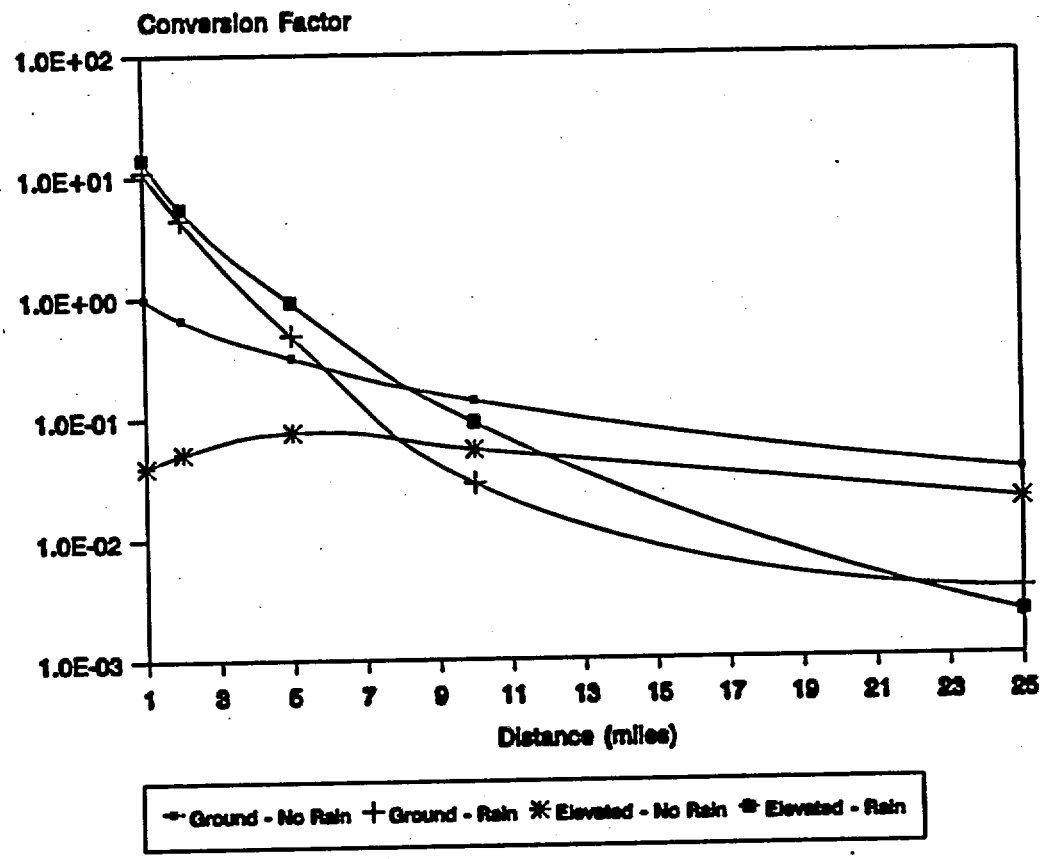


Fig. F-2
Conversion factors needed to adjust thyroid dose at 1 mile resulting from inhalation of plume for other distances and other release conditions.

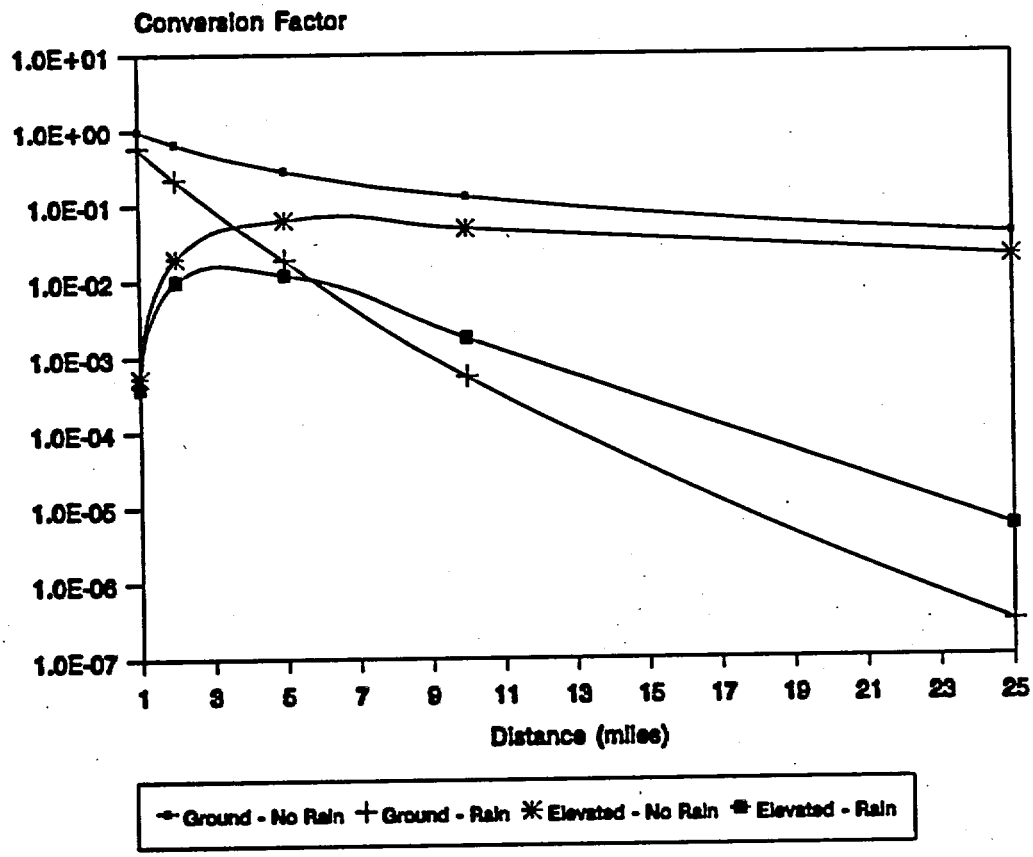
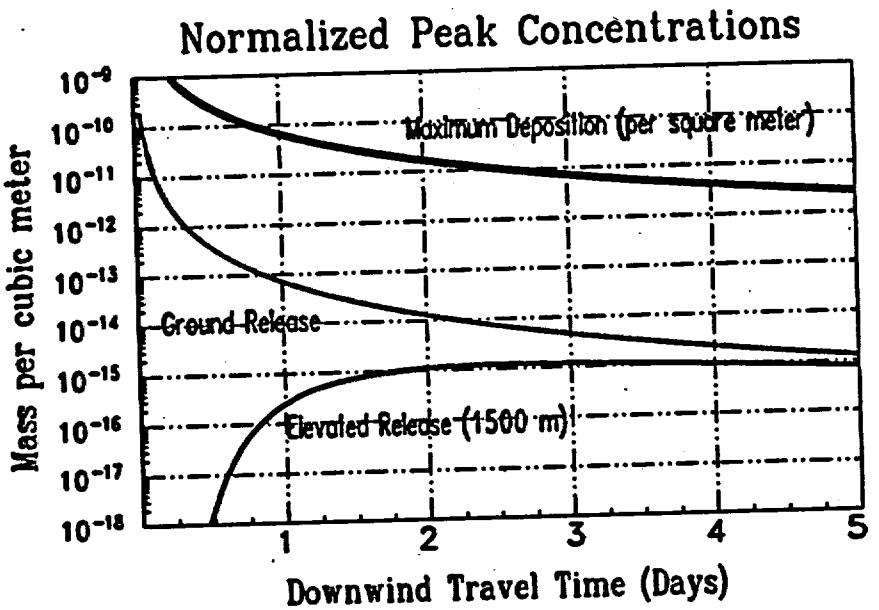


Fig. F-3
Normalized peak concentrations as a function of downwind travel time for a near-ground and elevated release.



Worksheet F-1. Isotopic contributions to dose components (Method F.3, Step 1, quick estimate method).

Number: _____ Date: _____ Time _____

Analyst: _____ Sample location: _____

Step 1

Isotope i	*Column A* Q_{Ti} (μCi)		*Column B* RCF_{ij} (mrem/μCi)		*Column D* Dose (mrem)
		×		=	
		×		=	
		×		=	
		×		=	
		×		=	
		×		=	
		×		=	
		×		=	
		×		=	
		×		=	
		×		=	
			Column C (sum)		

Notes:

Worksheet F-2. Isotopic contributions to dose components (Method F.3, Step 1, full calculation method).

Number:_____ Analyst:_____ Date:_____ Time:_____ Sample location:_____	Isotope i: _____

Air Immersion H_{ai}

$$H_{ai} = \frac{Q_i \times DF \times DCF_{ai} \times T_{ed}}{\overline{U}}$$

$$(\qquad \text{mrem}) = \frac{\left(\qquad \frac{\mu\text{Ci}}{\text{s}}\right) \times (\qquad \text{m}^{-2}) \times \left(\qquad \frac{\text{mrem/h}}{\mu\text{Ci/m}^3}\right) \times (\qquad \text{h})}{\left(\qquad \frac{\text{m}}{\text{s}}\right)}$$

Inhalation D_{Ti} or $H_{e,50i}$

$$H_{e,50i} = \frac{Q_i \times DF \times DCF_{e,50i} \times T_{ed}}{\overline{U}}$$

$$D_{Ti} = \frac{Q_i \times DF \times DCF_{Ti} \times T_{ed}}{\overline{U}}$$

$$(\qquad \text{mrem}) = \frac{\left(\qquad \frac{\mu\text{Ci}}{\text{s}}\right) \times (\qquad \text{m}^{-2}) \times \left(\qquad \frac{\text{mrem/h}}{\mu\text{Ci/m}^3}\right) \times (\qquad \text{h})}{\left(\qquad \frac{\text{m}}{\text{s}}\right)}$$

Ground D_{EPgi}

$$D_{EPgi} = Q_{Ti} \times GCF \times DCF_{EPgi}$$

$$(\qquad \text{mrem}) = (\qquad \mu\text{Ci}) \times \left(\qquad \frac{\mu\text{Ci/m}^2}{\mu\text{Ci}}\right) \times \left(\qquad \frac{\text{mrem}}{\mu\text{Ci/m}^2}\right)$$

Worksheet F-3. Summation of dose components (Method F.3, Step 2).

Number: _____ Date: _____ Time _____

Analyst: _____ Sample location: _____

Step 2

Isotope *i*	*Column A* H_{ai} (rem)		*Column B* D_{Ti}(*bone*) *or* D_{Ti}(*lung*) *or* $H_{e,50i}$ (rem)		*Column C* D_{EPgi} (rem)		*Column D* *TABD* *or* *TALD* *or* *TEDE* (rem)
		+		+		=	
		+		+		=	
		+		+		=	
		+		+		=	
		+		+		=	
		+		+		=	
		+		+		=	
		+		+		=	
		+		+		=	
		+		+		=	
		+		+		=	
					Column C (sum)		

Notes:

Worksheet F-4. Adjusting TABD for distance, elevation, and rain (Method F.5, Step 2).

Ground-level release without rain

Dose at 1 mile		Conversion factor		Doses at...
	×	1.0E+00	=	1 mile
	×	6.7E−01	=	2 miles
	×	3.2E−01	=	5 miles
	×	1.4E−01	=	10 miles
	×	3.5E−02	=	25 miles

Ground-level release with rain

Dose at 1 mile		Conversion factor		Doses at...
	×	1.1E+01	=	1 mile
	×	4.5E+00	=	2 miles
	×	4.9E−01	=	5 miles
	×	2.9E−02	=	10 miles
	×	3.6E−03	=	25 miles

Elevated release without rain

Dose at 1 mile		Conversion factor		Doses at...
	×	4.0E−02	=	1 mile
	×	5.2E−02	=	2 miles
	×	7.7E−02	=	5 miles
	×	5.5E−02	=	10 miles
	×	2.0E−02	=	25 miles

Elevated release with rain

Dose at 1 mile		Conversion factor		Doses at...
	×	1.4E+01	=	1 mile
	×	5.5E+00	=	2 miles
	×	9.2E−01	=	5 miles
	×	9.2E−02	=	10 miles
	×	2.3E−03	=	25 miles

Worksheet F-5. Adjusting thyroid dose for distance, elevation, and rain (Method F.5, Step 2).

Ground-level release without rain

Dose at 1 mile		Conversion factor		Doses at...
	×	1.0E+00	=	1 mile
	×	6.6E−01	=	2 miles
	×	2.9E−01	=	5 miles
	×	1.3E−01	=	10 miles
	×	4.0E−02	=	25 miles

Ground-level release with rain

Dose at 1 mile		Conversion factor		Doses at...
	×	5.8E+01	=	1 mile
	×	2.2E−01	=	2 miles
	×	1.9E−02	=	5 miles
	×	5.5E−04	=	10 miles
	×	2.9E−07	=	25 miles

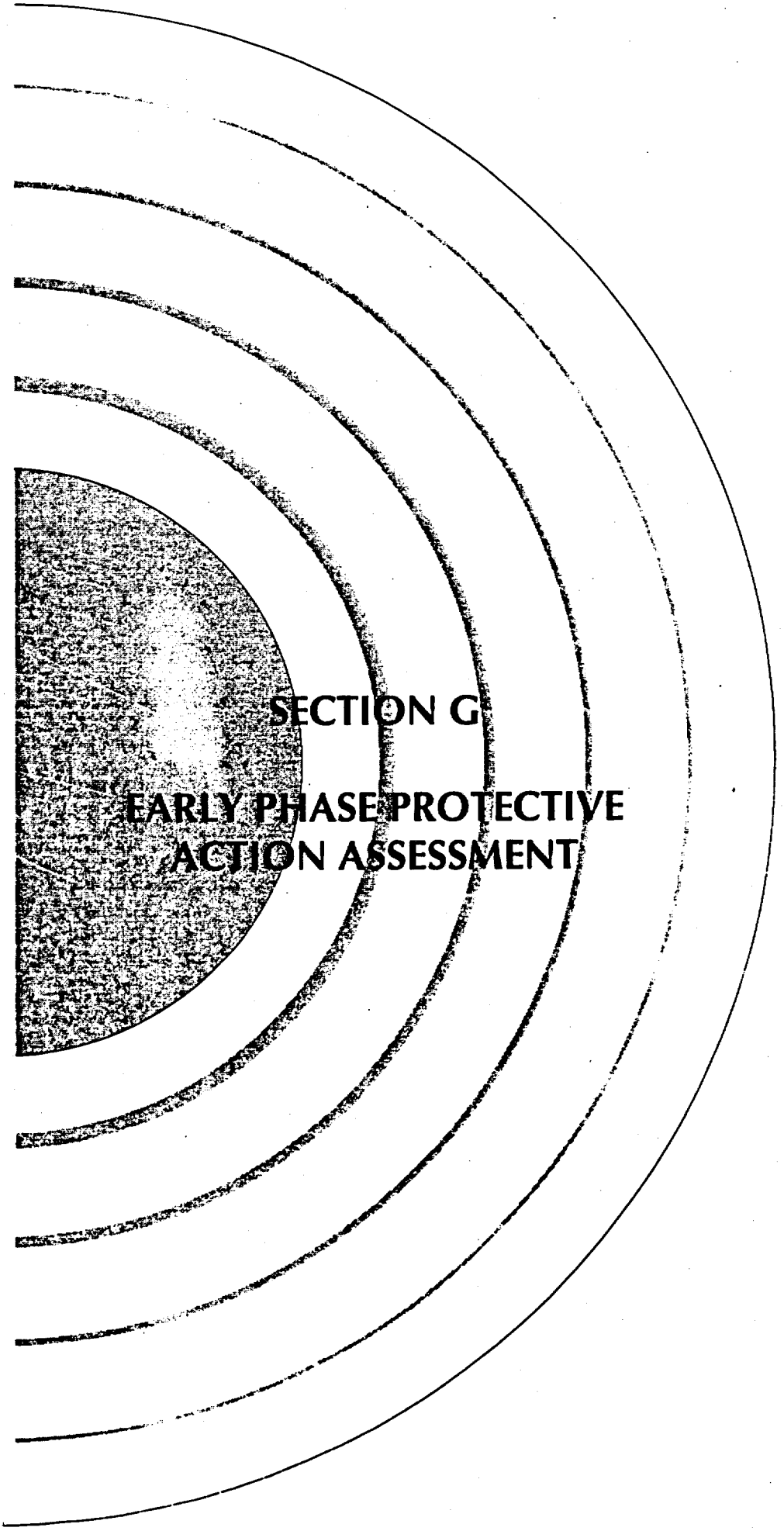
Elevated release without rain

Dose at 1 mile		Conversion factor		Doses at...
	×	5.4E−04	=	1 mile
	×	2.0E−02	=	2 miles
	×	6.4E−02	=	5 miles
	×	4.9E−02	=	10 miles
	×	2.0E−02	=	25 miles

Elevated release with rain

Dose at 1 mile		Conversion factor		Doses at...
	×	3.9E−04	=	1 mile
	×	1.0E−02	=	2 miles
	×	1.2E−02	=	5 miles
	×	1.8E−03	=	10 miles
	×	5.3E−06	=	25 miles

G



SECTION G

EARLY PHASE PROTECTIVE ACTION ASSESSMENT

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Section G
Early Phase Protective Action Assessment

Purpose

To assess public (offsite) protective actions in support of the State.

Discussion

The early phase is the period at the beginning of a nuclear incident when immediate decisions for effective use of protective actions are required and must therefore usually be based primarily on the status of the nuclear facility (or other incident site) and the prognosis for worsening conditions. This phase may last from hours to days. For the purpose of dose projection, it is assumed to last for 4 days. Radiation doses may accrue from both airborne and deposited materials. Early phase dose calculations normally include the dose from any airborne plume and up to 4 days (~100 h) of exposure to deposited radioactive material.

Protective actions must be taken during the early phase of an emergency to

- prevent early health effects (deaths and injuries) by keeping the short-term external dose equivalent below 50 rem and keeping the acute inhalation dose equivalent below the early health effects thresholds for the thyroid, lung, and bone marrow and

- reduce the risk of delayed health effects (primarily cancer and genetic effects)

by implementing protective actions in accordance with EPA Protective Action Guides (PAGs).

For reactor accidents it may be necessary to take actions based on plant conditions before or shortly after a release to meet these goals. Meeting these protective action goals during or after a major release may require prompt field monitoring to identify areas of high exposure rates and sources of high inhalation dose. For some accidents (e.g., dispersion of plutonium), it may be very difficult to measure the inhalation dose promptly. In these cases, estimates of the isotopic mix should be used to relate the field measurements to the inhalation dose. Methods for assessing environmental measurements can be found in the *FRMAC Assessment Manual*.

Federal recommendations should be made *only* if there is a major concern or if the State has requested Federal assistance. Do not allow offsite officials to wait for a Federal assessment before taking action. Do not do anything to interfere with ongoing

implementation of protective actions. In commercial reactor accidents, licensees recommend actions and the offsite officials make decisions based on these recommendations. Mechanisms are already in place for prompt decision making and for warning the public 24 h per day. Revising the preplanned actions may delay the response. Federal recommendations to extend the area for protective actions can be made after the initial protective actions have been started. (The emergency plans at most fuel conversion/fabrication facilities consider the need for protective actions, but they do not specify predetermined protective actions.)

Step 1

Review the protective action criteria in the licensee and State or local emergency plans and procedures.

Step 2

Assess the protective actions based on the accident type. Consult with representatives from HHS, USDA, and EPA, if possible.

- **Severe LWR core damage or loss of control of plant.** If the event is a reactor accident involving severe core damage or loss of control, use Fig. G-1 to make the initial assessment.

- **Release of radioactive material or after the initial assessment of protective actions for an LWR accident.** If the event involves release of radiological material, use the EPA early phase PAGs in Table G-1. Give priority to areas where early health effects are possible (Table G-2). (For most reactor accidents, the distance to which PAGs are exceeded will be determined by the thyroid dose.)

  Note that some States may use their own PAGs. If this is the case, the State PAGs should be considered in the assessment.

- **Uranium hexafluoride (UF_6) release.** Use Section E, Uranium Hexafluoride Release Assessment. Evaluate the chemical hazards of uranium hexafluoride before estimating the effects of exposure to the radioactive uranium in the uranium hexafluoride.

Step 3

If your assessment agrees with the licensee's recommendations and the State and local actions, go to Step 5. If there is disagreement, continue with Step 4.

Step 4

Discuss assessment differences with licensee and/or offsite technical contacts and determine the basis for their protective action recommendations. Do not do anything to interfere with ongoing implementation of protective actions. If offsite technical contacts cannot be contacted within a reasonable period of time, move on to Step 5.

Step 5

Prepare a briefing for the Executive Team (ET) or Director of Site Operations (DSO) using the following checklist:

_____ A comparison of the recommendations or actions of the licensee, offsite officials and your assessment.

_____ The results of your discussions with licensee and offsite officials (or the fact that these parties could not be contacted).

_____ The title, name, and phone number of the licensee and offsite protective action decision-makers.

_____ The existing emergency plan predetermined protective action decision-making criteria.

_____ The offsite radiological conditions, if known.

_____ Any local conditions that affected decisions (i.e., local weather or impediments on evacuation routes).

_____ Any consultation with the Advisory Team for Environment, Food, and Health (Advisory Team) during assessment. (Advisory Team members include EPA, HHS/FDA, and USDA, at a minimum).

Step 6

Provide verbal assessment to the ET Director and DSO immediately. Follow with a written assessment.

Step 7

Consult with and brief the representatives of other appropriate Federal agencies, such as DOE and FEMA, as time permits.

Step 8

Continue to reassess plant and radiological conditions until the situation stabilizes. If there has been a release, consider the need for intermediate phase protective actions (Section H) or protective measures for the ingestion pathway (Section I).

The magnitude of protective actions and the geographic areas affected can always be expanded and/or adjusted. Do not recommend that protective actions be relaxed until the threat of a release is over and any ground contamination has been characterized and thoroughly discussed with State officials.

END

Source: EPA 400-R-92-001.

Table G-1. Early phase Protective Action Guides (PAGs)

Protective action	PAG (projected dose)	Comments
Evacuation (or sheltering)[a]	1–5 rem[b]	Evacuation (or for some situations, sheltering)[a] should normally be initiated at 1 rem.
Administration of stable iodine	25 rem thyroid[c]	Requires approval of State medical officials.

[a]Sheltering may be the preferred protective action when it will provide protection equal to or greater than evacuation, based on consideration of factors such as source term characteristics, and temporal or other site-specific conditions. For further guidance, see EPA 400-92-001, Sect. 2.3.1.

[b]The sum of the effective dose equivalent (EDE) resulting from exposure to external sources and the committed effective dose equivalent (CEDE) incurred from all significant inhalation pathways during the early phase. Committed dose equivalents to the thyroid and to the skin may be 5 and 50 times larger, respectively.

[c]Committed dose equivalent (CDE) to the thyroid from radioiodine.

Source: Adapted from EPA 400-R-92-001, p. 2-6.

Table G-2. Early health effects of exposure to radiation

Organ[a]	Dose rate (rad/h)	Dose[b] (rad)	Acute health effects[c]	Onset[d]
Whole body (external effective dose)	>6	50	Threshold for vomiting and diarrhea	3 h (100–200 rem) 2 h (200–600 rem)
	>6	200	50% have vomiting and diarrhea	1 h (600-1000 rem)
Thyroid		20,000	Threshold for acute radiation thyroiditis	Within 2 weeks
		120,000	50% have acute radiation thyroiditis	
Lung	1000	700	Threshold for deaths[e]	
	100	2000	Threshold for deaths	
	50	4000	Threshold for deaths	
Marrow (WB)	≥1000	150 (230)[f]	Threshold for deaths[g]	Within 2 months (200–1000 rem)
	5	220 (330)	Threshold for deaths	Within 2 weeks
	5	440 (660)	50% deaths	(1000–5000 rem)
	1	500 (750)	Threshold for deaths	
Skin	>6	300[h]	Threshold for erythema	Erythema in 2–6 days (2000–3000 rad, single dose); in 12–17 days (1000–2000 rad, single dose, or 2000–4000 rad @200 rad/day).
	>6	1000	Threshold for transepithelial injury or moist desquamation[i]	Moist desquamation that heals in 30–50 days (2000–2400 rad, single dose, or 4500–5000 rad @200 rad/day).

[a]Effective dose equivalent from external sources (cloud and ground shine) is approximately equal to bone marrow and whole body (WB) dose.

[b]Thyroid doses are due to ^{131}I. Others are external doses.

[c]A threshold is the lowest dose at which an effect might occur. Occurrences at this level are unlikely. Thresholds are dose-rate dependent.

[d]Onsets are generally dose and dose rate dependent. (One rem dose equivalent corresponds to a 1 rad absorbed dose for β and γ radiation.)

[e]Deaths due to pulmonary syndrome.

[f]The first values represent minimal treatment (first aid in a clean environment). The second values are appropriate when there is supportive medical treatment (normal hospital care without heroic treatment, such as bone marrow transplants or use of colony stimulating factors).

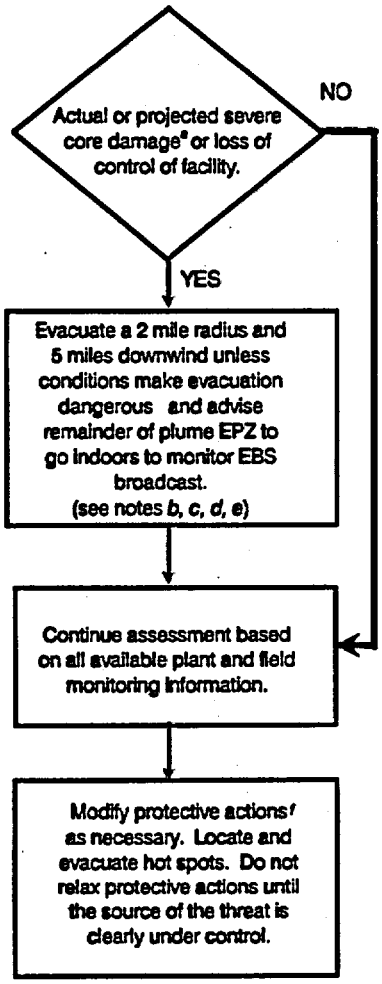
[g]Deaths due to marrow syndrome.

[h]Low LET irradiation of 50–100 cm^2 area.

[i]Moist shedding of outer layers of skin in scales or small sheets equivalent to second degree thermal burn in which blisters form in the epidermis.

Sources: NUREG/CR-4214, Rev. 1, Part II (external effective, p. II-21; thyroid, p. II-61; lung, p. 55; marrow, pp. II-38, II-39; skin, pp. II-67, II-68); IAEA Tech. Rep. #152 (onset of vomiting and diarrhea and onset of deaths from whole body exposure, p. 45).

Fig. G-1
Protective actions in the event of severe core damage or loss of control of facility.



[a]Severe core damage is indicated by (1) loss of critical functions required for core protection (e.g., loss of injection combined with loss of cooling accident); (2) high core temperatures (PWR) or partially uncovered core (BWR); or (3) very high radiation levels in area or process monitors.

[b]Distances are approximate—actual distances will be determined by the size of the preplanned sub-areas, which are based on geopolitical boundaries.

[c]If there are very dangerous travel conditions, initially shelter rather than evacuate the population until conditions improve.

[d]Transit-dependent persons should be advised to remain indoors until transportation resources arrive, if possible.

[e]Shelter may be the appropriate action for controlled releases of radioactive material from the containment if there is assurance that the release is short term (puff release) and the area near the plant cannot evacuated before plume arrives.

[f]Consider EPA PAGs (Table G-1) in modifying initial protective actions.

Source: NUREG-0654, Suppl. 3.

H

SECTION H

INTERMEDIATE PHASE PROTECTIVE ACTION ASSESSMENT

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Section H
Intermediate Phase Protective Action Assessment

Purpose

To provide guidance on the assessment of intermediate phase protective actions.

Discussion

The intermediate phase is the period beginning after the incident source and releases have been brought under control and reliable environmental measurements are available for use as a basis for decisions on additional protective actions and extending until these protective actions are terminated. This phase may overlap the early and late phases and may last from weeks to many months. For the purpose of dose projection, the intermediate phase is assumed to last for 1 year. In some accidents (e.g., a reactor core damage accident) there may be ongoing small releases even after the threat of a major release has passed. These small releases should not delay the intermediate phase assessments.

Two radiation exposure pathways are of primary concern during the intermediate phase: (1) exposure to deposited material (direct exposure and inhalation of resuspended material) and (2) ingestion. The evaluation of the ingestion pathway is discussed in Section I.

EPA has published PAGs for relocation of the general population to avoid exposure to deposited material. Areas where projected doses are equal to or greater than the intermediate (relocation) PAGs are called restricted zones. There are two aspects to intermediate phase assessment: (1) relocation PAGs for the first year (Table H-1) and (2) long-term dose objectives (Table H-2).

Identification of areas where the PAGs may be exceeded can be difficult. Field and aerial radiation measurements can help identify such areas (see the *FRMAC Assessment Manual*), but resuspension and drifting of radioactive material, complex deposition patterns, and unidentified hot spots may produce higher radiation levels in small portions of the surrounding area. The restricted area identified should be expanded to include a buffer zone until the radiological situation is evaluated and confirmed. The relocation zone may also be adjusted by State or local officials so that local terrain features and landmarks define the area to be investigated.

The EPA PAG manual recommends unrestricted return of evacuees when external radiation levels do not exceed twice background, but areas meeting this criterion may be hard to identify. If, however, the inhalation dose from resuspension is not the

principal exposure pathway, as is likely the case for reactor accidents, a 0.1-mR/h exposure rate will result in less than one-half of the relocation PAG (2 rem the first year), even if no decay or weathering is assumed. An exposure rate of less than 0.1 mR/h is recommended as an area suitable for "low background" screening of evacuees. Persons working in areas inside the restricted zone should operate under the controlled conditions normally established for occupational exposure.

If there is a shortage of food or water and contaminated food and/or water cannot be completely eliminated from the diet, the committed effective dose equivalent from ingestion of this food and water should be added to the projected dose from other exposure pathways for decisions on relocation.

Step 1

Evaluate whether the intermediate phase has begun by determining if a subsequent major release is possible. Consider the following:

- Is there radioactive material inventory capable of being released and causing offsite consequences?
- Are the barriers to a release threatened by
  - — fire,
  - — facility under control of others,
  - — hydrogen or other explosive gas,
  - — reactor core melt with possible containment failure at the time the vessel melts through,
  - — pressure build-up (loss of decay heat removal), or
  - — isolation failure.
- Is the reactor shutdown (subcritical) and can it go critical?
- Is the reactor core being cooled? Is decay heat removal threatened?

If the threat of a major release has passed, continue with the intermediate phase assessment.

Step 2

Determine the exposure rate at 3 ft (1 m) above ground level, the isotopic mixture (relative abundance) of the ground surface deposition, and air concentrations.

Step 3

Using the intermediate phase assessment methods in the *FRMAC Assessment Manual* or similar methods, identify the areas where the relocation PAGs may be exceeded (restricted zone). Recommend relocation of population in the restricted zone, with priority given to those in the areas with the highest exposure rates. Access to the restricted zone should be controlled. Monitoring and decontamination stations should be established at the boundaries of the zone to check any people, material, or agricultural products coming out of the restricted zone.

Step 4

In general, after reactor accidents, people who were initially evacuated may be able to return if exposure rates are less than 0.1 mR/h. However, if inhalation of resuspended activity is important or deposited material could drift into reoccupied or still-occupied areas, occupancy should be restricted until the situation is analyzed and dose projections are confirmed.

Step 5

Evaluate the second-year and 50-year dose (use the intermediate phase methods in the *FRMAC Assessment Manual* or RASCAL "Field Measurements to Dose" option). Evaluate the effectiveness of simple decontamination techniques and of sheltering (due to partial occupancy of residences and work places) in reducing the expected dose. Persons evacuated from higher dose rate areas may return once field measurements confirm that the objectives of the intermediate phase PAGs will be met. If it is impractical to meet the long-term objectives of the Intermediate PAG (Table H-2) through decontamination, consideration should be given to relocation at a lower projected first-year dose than that specified by the intermediate (relocation) PAG.

Step 6

Data should be gathered to establish long-term radiation protection criteria for recovery and to determine the effectiveness of various decontamination or other recovery techniques. Operations to recover contaminated property in the restricted zone should begin. Contamination screening levels are listed in Tables H-3 and H-4.

END

Source: EPA 400-R-92-001.

Table H-1. Relocation Protective Action Guides (PAGs)[a]

Protective action	Protective Action Guide (projected first-year dose)[b]	Comments
Relocate the general population.[c]	≥2,000 mrem	Beta dose to skin may be up to 50 times higher.
Apply simple dose reduction techniques.[d]	<2,000 mrem	These protective actions should be taken to reduce doses to as low as practicable levels.

[a]PAGs for exposure to deposited radioactivity during the intermediate phase of a nuclear incident.

[b]The projected sum of effective dose equivalent from external gamma radiation and committed effective dose equivalent from inhalation of resuspended materials, from exposure or intake during the first year. Projected dose refers to the dose that would be received in the absence of shielding from structures or the application of dose reduction techniques. These PAGs may not provide adequate protection from some long-lived radionuclides; see Table H-2 or EPA 400-R-92-001, Sect. 4.2.1, for further restrictions.

[c]Persons previously evacuated from areas outside the relocation zone defined by this PAG may return to occupy their residences. Cases involving relocation of persons at high risk from such action (e.g., patients under intensive care) should be evaluated individually.

[d]Simple dose reduction techniques include scrubbing and/or flushing hard surfaces, soaking or plowing soil, minor removal of soil from spots where radioactive materials have concentrated, and spending more time than usual indoors or in other low exposure rate areas.

Source: Adapted from EPA 400-R-92-001, Table 4.1, p. 4-4.

Table H-2. Long term objectives for intermediate phase[a]

Time period	Objective[b]
Second year (or any succeeding year)	≤500 mrem
50 years	≤5000 mrem

[a]For reactor incidents, if the PAG of 2,000 mrem is met in the first year, the long-term objectives should be met through radioactive decay, weathering, and normal part-time occupancy of structures. If the release consists primarily of long-lived radionuclides, decontamination may be required during the first year in areas *outside* the restricted area. If decontamination is not practical in these situations, relocation at a lower first-year projected dose than 2,000 mrem should be considered.

[b]The projected sum of effective dose equivalent from external gamma radiation and committed effective dose equivalent from inhalation of resuspended materials, from exposure or intake during the indicated time period.

Source: EPA 400-R-92-001, p. 4-4.

Table H-3. Recommended surface contamination screening levels for emergency screening of persons and other surfaces at screening or monitoring stations in high background radiation areas (0.1–5 mR/h)[a]

Condition	Geiger-counter shielded-window reading	Recommended action
Before decontamination	• <2× background *and* <0.5 mR/h above background	Unconditional release.
	• >2× background *or* >0.5 mR/h above background	Decontaminate. Equipment may be stored or disposed of as appropriate.
After decontamination	• <2× background *and* <0.5 mR/h above background	Unconditional release.
	• >2× background *or* >0.5 mR/h above background	Continue to decontaminate or refer to low background monitoring and decontamination station. Equipment may also be stored for decay or disposed of as appropriate.

[a]Monitoring stations in these high exposure rate areas are for use only during the early phase of an incident involving major atmospheric releases of particulates. In other cases, use Table H-4.

Source: Adapted from EPA 400-R-92-001, Table 7-6, p. 7-23.

Table H-4. Recommended surface contamination screening levels for persons and other surfaces at monitoring stations in low background radiation areas (< 0.1 mR/h)

Condition	Geiger counter thin-window[a] reading	Recommended action
Before decontamination	• <2× background • >2× background	Unconditional release. Decontaminate.
After simple decontamination[b] effort	• <2× background • >2× background	Unconditional release. Full decontamination[c]
After full decontamination[c] effort	• <2× background • >2× background • <0.5 mR/h[d]	Unconditional release. Continue to decontaminate persons. Release animals and equipment.
After additional full decontamination effort	• <2× background • >2× background • <0.5 mR/h[d] • >0.5 mR/h[d]	Unconditional full release. Send persons for special evaluation. Release animals and equipment. Refer, or use informed judgement on further control of animals and equipment.

[a]Window thickness of approximately 30 mg/cm^2 is acceptable. Recommended limits for open window readings are expressed as twice the existing background (including background) in the area where measurements are being made. Corresponding levels, expressed in units related to instrument designations, may be adopted for convenience. Levels higher than twice background (not to exceed the meter reading corresponding to 0.1 mR/h) may be used to speed the monitoring of evacuees in very low background areas.

[b]Flushing with water and wiping is an example of a simple decontamination effort.

[c]Washing or scrubbing with soap or solvent followed by flushing is an example of a full decontamination effort.

[d]Closed shield reading including background.

Source: Adapted from EPA-400-R-92-001, Table 7-7, p. 7-24.

SECTION I

INGESTION PATHWAY PROTECTIVE ACTION ASSESSMENT

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Section I
Ingestion Pathway Protective Action Assessment

Purpose

To assess ingestion pathway protective actions.

Discussion

This section is used only to determine if protective actions are warranted to protect the public from ingestion of food, milk, and water that have been contaminated as a result of an accident. This procedure should be performed by the Advisory Team for Environment, Food, and Health (composed of EPA, HHS, and USDA, at a minimum) in support of the State.

The assessments are based on the HHS guidance for ingestion in EPA 400-R-92-001. Two levels of PAGs are provided: emergency and preventive (Table I-1). Recommended protective actions for each PAG level are shown in Table I-2. For large reactor releases involving core damage, milk-producing animals within 10 miles should immediately be sheltered, if possible, and placed on stored feed and protected water.

The PAGs apply only to *short-term* exposure from consumption of contaminated food and milk. They do not apply to the consumption of water; however, because guidance for water is still under development, the HHS PAGs are also being used for water.

The ingestion PAGs are intended to assess concentrations measured in food. However, it will be virtually impossible to analyze all potentially contaminated food. The goal, therefore, is to identify an *area* where the levels of radioactivity in food could exceed HHS PAGs. This identification must be made on the basis of readily measured quantities (e.g., exposure rate or surface deposition). Analysis of food samples will be used to confirm the areas of concern. The *FRMAC Assessment Manual* provides methods for evaluating environmental data to identify where the ingestion PAGs may be exceeded and for analyzing food, water, and milk samples.

Step 1

Using the methods in the *FRMAC Assessment Manual* or similar methods, determine the area where HHS ingestion PAGs may be exceeded based on either (1) gross gamma measurements (for a reactor accident before the isotopic contamination mixture is known) or (2) ground surface deposition.

Step 2

Obtain the analyses of food, water, and milk samples from the area where results from Step 1 indicate that the ingestion PAGs may be exceeded. Other areas of suspected contamination should also be sampled.

Step 3

Recommend protective actions in accordance with State or Federal guidance. (Federal guidance is summarized in Tables I-1 and I-2.) Results from samples taken around the perimeter of the identified areas may indicate whether the area of analysis needs to be expanded, reduced, or shifted.

Step 4

Coordinate a working group to develop guidance and a program for long-term ingestion controls to protect the public from ingestion of contaminated foods.

END

Source: EPA 400-R-92-001.

Table I-1. Ingestion Protective Action Guides

Protective action	Organ of interest	Projected dose commitment (mrem)
Preventive[a] (Lower impact)	• Whole body, bone marrow, or any other organ	500
	• Thyroid	1,500
Emergency[b]	• Whole body, bone marrow, or any other organ	5,000
	• Thyroid	15,000

[a]Preventive PAGs are applicable to situations where protective actions causing minimal impact on the food supply are appropriate. A preventive PAG establishes a level at which responsible officials should take protective actions having minimal impact to prevent or reduce the concentration of radioactivity in food or animal feed.

[b]Emergency PAGs are applicable to incidents where protective actions of great impact on the food supply are justified because of the projected health hazards. An emergency PAG establishes a level at which responsible officials should isolate food containing radioactivity to prevent its introduction into commerce, and at which the responsible officials must determine whether condemnation or another disposition is appropriate.

Source: 47 FR 47073, p. 47081, as incorporated into EPA 400-R-92-001, Chapter 3.

Table I-2. Ingestion pathway protective actions[a]

Contaminated item	Protective action
	At preventive PAG
Pasture	• Remove lactating (milk-producing) dairy animals from pasture and substitute uncontaminated feed. • Substitute uncontaminated water.
Milk	• Withhold contaminated milk from market to allow decay of short-lived radionuclides. • Divert fluid milk to production of dry whole milk, non-fat dry milk, butter, cheese or evaporated milk.
Fruits and vegetables	• Wash, brush, scrub, or peel to remove surface contamination. • Preserve by canning, freezing, dehydration, or storage to permit decay of short-lived radionuclides.
Grains	• Mill • Polish
Other foods	• Process to remove surface contamination.
	At emergency PAG
All food	• Isolate food to prevent introduction into commerce and determine whether condemnation or other disposition is appropriate.
Before taking action consider the following:	• Availability of other possible protective actions. • Relative proportion of contaminated food in total diet by weight. • Importance of the food in nutrition and availability of uncontaminated substitutes. • Contribution of other foods and other radioisotopes to total projected dose. • Time and effort required to implement corrective action. • Exposure of food processing workers.

[a]HHS has published guidance on the protective actions that should be considered if the ingestion of contaminated food may produce doses that exceed the PAGs. This guidance is summarized here.

Source: 47 FR 47073, p. 47083, as incorporated into EPA 400-R-92-001, Chapter 3.

SECTION J

USE OF POTASSIUM IODIDE AND THYROID MONITORING

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Section J
Use of Potassium Iodide and Thyroid Monitoring

Purpose

To provide information on the use of potassium iodide (KI) to protect the thyroid from radioactive iodine intake.

Discussion

KI, administered orally, can be used effectively as a thyroid blocking agent to reduce the accumulation of radioiodine in the thyroid gland. The radioiodine enters the body through inhalation or ingestion. KI is not an adequate substitute for prompt evacuation or sheltering of the general population near a plant for a severe reactor accident. The decision to use KI to protect the public rests with the State and local health authorities. EPA early phase PAGs recommend evacuation or sheltering to avoid a total effective dose equivalent of 1–5 rem and administration of KI to avoid a committed dose equivalent from radioiodine to the adult thyroid of 25 rem (Table G-1).

Step 1

Consult with the representatives of involved State(s) and other Federal agencies (FEMA, HHS, EPA) before making any recommendations.

Step 2

Refer to the following information to answer questions:

Federal Position. The Food and Drug Administration (FDA) has evaluated the medical and radiological risks of administering KI for thyroid blocking under nuclear emergency conditions. FDA guidance states that risks from the short-term use of relatively low doses of KI for thyroid blocking in a radiation emergency are lower than the risk of radioiodine-induced thyroid nodules or cancer at a projected committed dose equivalent to the thyroid gland of 25 rem or more. FDA has approved the over-the-counter sale of the drug for this purpose.

Federal policy recommends the stockpiling or distribution of KI during emergencies for emergency workers and institutionalized persons but does not recommend requiring predistribution or stockpiling for the general public.

Effectiveness. The effectiveness of KI in blocking uptake of radioiodine by the thyroid depends strongly on the timing of the dose of KI relative to the exposure to radioactive iodine. KI is most effective when taken just before or within 1–2 h after exposure to radioiodine. Taking the recommended dosages of KI just before or at the time of exposure can provide greater than 90% blocking of radioactive iodine uptake by the thyroid (Fig. J-1). If KI is taken approximately 3–4 h after acute exposure, about 50% blocking could still occur. Once radioactive iodine has concentrated in the thyroid, KI is not effective at removing it.

Dosage. The FDA recommended dosage of KI is 130 mg/day for adults and children above 1 year, and 65 mg/day for children below 1 year of age (130 mg of KI contains 100 mg of stable iodine) given shortly before or just after the intake of radioactive iodine. KI should be administered for at least 3 days after an acute exposure because it takes approximately 48 h for most of the radioiodine to be excreted in the urine.

Thyroid Monitoring. Thyroid dose resulting from ^{131}I can be estimated by taking a measurement with a gamma radiation detector held horizontally next to the thyroid (immediately below the Adam's apple). From the count rate, an approximation of the thyroid uptake can be obtained. Several detectors have been evaluated using this technique; the average count rate per μCi of ^{131}I in the thyroid is given in Table J-1. The projected dose to the thyroid (in rem) is found by multiplying the estimated ^{131}I uptake in μCi by the appropriate dose conversion factor: adult (6.50 rem/μCi), 5-year-old child (19.1 rem/μCi), or 2-year-old child (36.0 rem/μCi).

The minimum detectable thyroid dose commitment, assuming all the radioiodine has reached the thyroid, ranges from 0.01 rem (adult thyroid, scintillation counter) to 4.3 rem (2-year-old child thyroid, GM detector). This thyroid screening procedure is recommended only for emergency personnel at completion of their final mission involving direct exposure to a plume or for evacuees who were exposed to the plume for a significant time before evacuation. If this procedure suggests a projected thyroid dose greater than 10 rem, the individual should be sent to a hospital or laboratory for a more accurate determination of radioiodine uptake.

END

Sources: 50 FR 30258; 47 FR 28158; FDA 83-8211; (dose estimation) FEMA-REP-2, Sect. 5.6.

Table J-1. Approximate response to radioiodine in the thyroid for different detectors

Thyroid model	Detector response[a] (net cpm per μCi ^{131}I in thyroid)							
	D-103[b] #1	D-103 #2	6306[c] #1	6306 #2	489-4[d]	489-55[e]	SPA-3[f]	RD-22[g]
ANSI standard adult	152 ±33	151 ±26	1,149 ±77	1,232 ±159	258 ±117	75,780 ±6,244	53,570 ±2,950	54,970 ±1,324
Adult	124 ±23	123 ±14	668 ±51	682 ±110	149 ±31	45,840 ±2,056	32,490 ±173	30,270 ±996
5-year-old child	224 ±52	231 ±20	1,390 ±61	1,580 ±53	321 ±79	18,140 ±3,060	58,100 ±4,917	56,830 ±2,521
2-year-old child	227 ±53	274 ±46	1,640 ±234	1,910 ±115	381 ±79	102,120 ±5,428	72,980 ±3,791	73,020 ±3,830

[a]The first number for each instrument is the average of a series of 10 tests; the second is the standard deviation.

[b]Civil defense model OCD-D-103 GM detector.

[c]Victoreen model 6306 GM detector (organic quench gas, bismuth cathode, and special lead and copper shield).

[d]Victoreen model 489-4 GM detector (organically quenched).

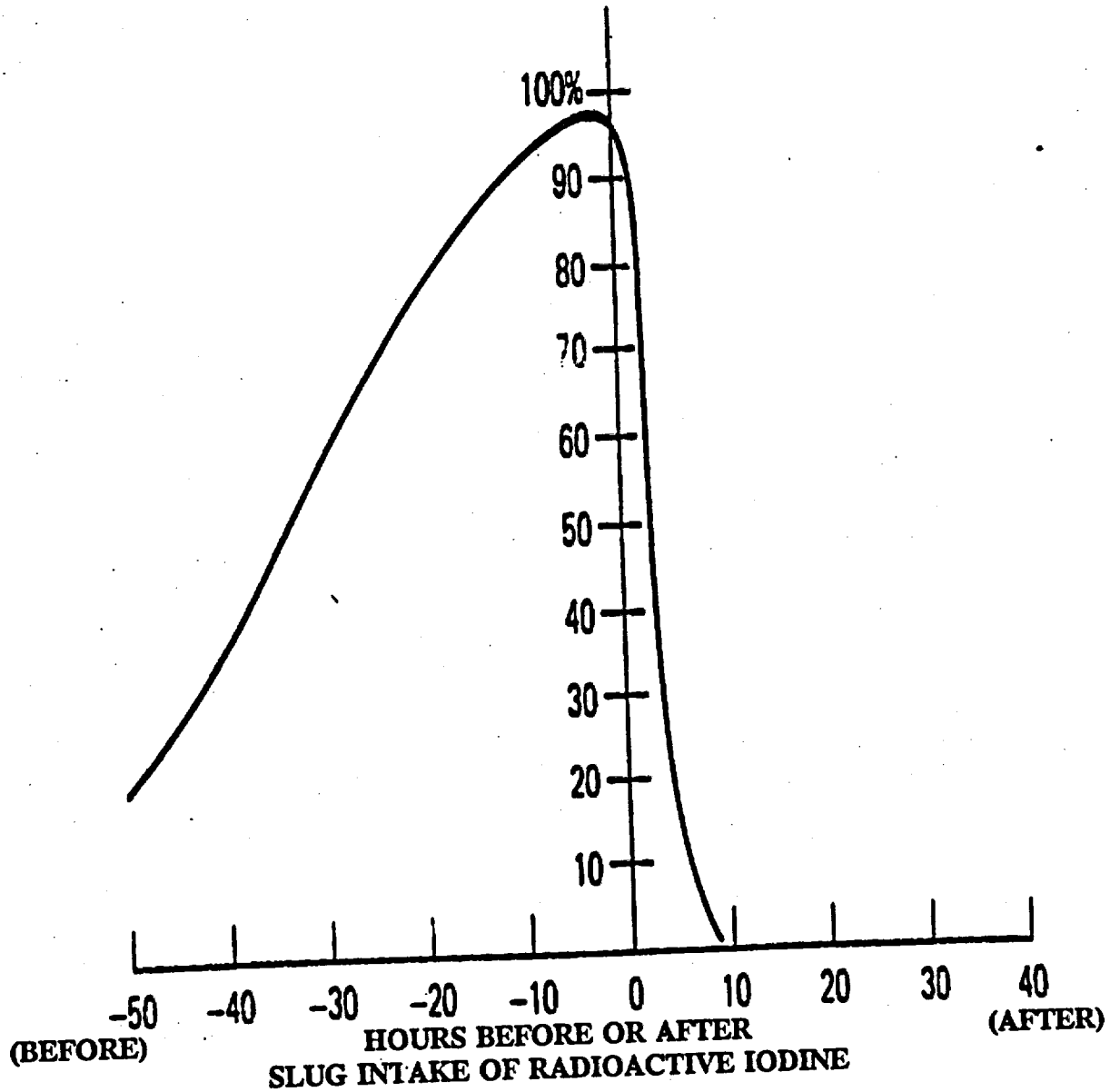
[e]Victoreen model 489-55, 3.2 × 3.8 cm NaI(Tl) crystal.

[f]Eberline model SPA-3, 5 × 5 cm NaI(Tl) crystal.

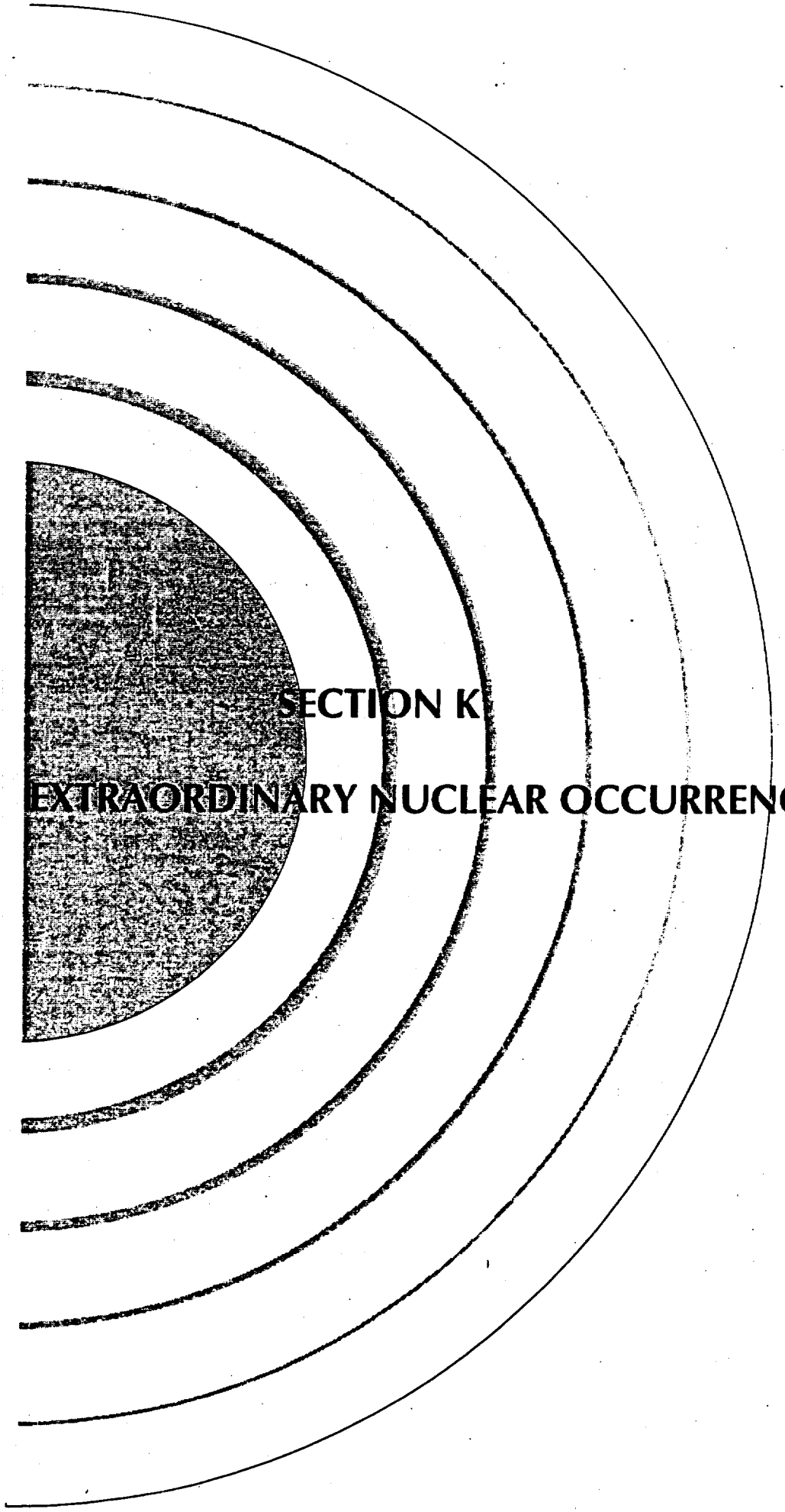
[g]Eberline model RD-22, 5 × 5 cm NaI(Tl) crystal (with ^{241}Am check source for use with stabilized assay meter).

Source: FEMA-REP-2, p. 5-16.

Fig. J-1
Percentage of thyroid blocking by 130 mg of KI.



Source: AEC-tr-7536, p. 224.



SECTION K

EXTRAORDINARY NUCLEAR OCCURRENCE

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Section K
Extraordinary Nuclear Occurrence

Purpose

To provide the Commission with an assessment of whether an event is an extraordinary nuclear occurrence in accordance with 10 CFR 140.81–140.85.

Discussion

An extraordinary nuclear occurrence determination does not mean that a particular claimant will recover on a claim. If there has been an extraordinary nuclear occurrence determination, the claimant must still proceed (in the absence of settlement) with a tort action, but the claimant's burden is substantially eased.

Any affected person, licensee, person with whom an indemnity agreement is executed, or a person providing financial protection may petition the Commission for a determination for whether or not there has been an extraordinary nuclear occurrence. If within 7 days of the event's occurrence the Commission does not have enough information to make a determination, it will publish a *Federal Register* notice requesting persons to submit information concerning the event. If the Commission publishes a notice in the *Federal Register* and does not make a determination within 90 days, the alleged event will not be deemed an extraordinary event.

Step 1

Determine if there has been a substantial release of radioactive material and/or substantial radiation levels offsite. There has been a substantial release if, as a result of an event of one or more related happenings, radioactive material is released from its intended place of confinement or radiation levels occur offsite *and* either criterion A *or* B are met:

A. One or more persons offsite were, could have been, or might be exposed to radiation or to radioactive material resulting in a dose or a projected dose exceeding one of the levels in Table K-1.

B. Surface contamination of at least a total of any 100 m^2 of offsite property has occurred as the result of a release of radioactive material from a production or utilization facility in levels exceeding one of the values in Column 1 or Column 2 of Table K-2.

or

Surface contamination of any offsite property has occurred as the result of a release of radioactive material in the course of transportation in levels exceeding one of the values in Column 2 of Table K-2.

Step 2

If the conditions in Step 1 are not met, no extraordinary nuclear occurrence has occurred; go to Step 3. If the conditions in Step 1 were met, continue with Step 2.

Determine if the event has resulted or will probably result in substantial damages to persons offsite or property offsite. This is indicated if either criterion C *or* D below is met.

C. Death or hospitalization, within 30 days of the event, of five or more people located offsite showing objective clinical evidence of physical injury from exposure to the radioactive, toxic, explosive, or other hazardous properties of source, special nuclear, or byproduct material.

D. Any of the following offsite damages has been or will probably be sustained:

1. $2,500,000 or more by any one person;
2. $5 million or more in the aggregate; or
3. $5,000 or more by each of 50 or more persons, resulting in $1 million or more in the aggregate.

Damages shall be based upon estimates of the following: (1) total cost to put affected property back into use; (2) loss of use of affected property; (3) value of affected property where not practical to restore to use; (4) financial loss resulting from protective action appropriate to reduce or avoid exposure to radiation or radioactive materials.

Step 3

Prepare a report for the Commission based on your findings in Steps 1 and 2. The Commission can find that an extraordinary nuclear occurrence exists if the criteria in Step 1 *and* Step 2 are met.

END

Source: 10 CFR 140.81–140.85.

Table K-1. Total projected radiation doses for extraordinary nuclear occurrence

Critical organ	Dose[a] (rems)
Thyroid	30
Whole body	20
Bone marrow	20
Skin	60
Other organs or tissues	30

[a]Doses from the following types of radiation sources are included: (1) radiation sources external to the body and (2) radioactive material that may be taken into the body through its occurrence in air, water, or food or on terrestrial surfaces.

Source: 10 CFR 140.84.

Table K-2. Total surface contamination levels for extraordinary nuclear occurrence[a]

Type of emitter	Column 1[b]	Column 2[c]
Alpha emission from transuranic isotopes	3.5 μCi/m^2	0.35 μCi/m^2
Alpha emission from isotopes other than transuranic isotopes	35 μCi/m^2	3.4 μCi/m^2
Beta or gamma emission	40 mrad/h at 1 cm[d]	4 mrad/h at 1 cm[d]

[a]The maximum levels (above background), observed or projected, 8 h or more after initial deposition.

[b]Offsite property, contiguous to site, owned or leased by person with whom an indemnity agreement is executed.

[c]Other offsite property.

[d]Measured through not more than 7 mg/cm^2 of total absorber.

Source: 10 CFR 140.84.

SECTION L

USE OF RASCAL

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