DEFENSE THREAT REDUCTION AGENCY

NUCLEAR TEST PERSONNEL REVIEW PROGRAM

RADIATION DOSE ASSESSMENT

STANDARD METHOD

ID01 – Doses to Organs from Intake of Radioactive Materials

Revision 2.0

Cleared for Release

Key to SOP ID Codes

RA (Radiation Assessment - SOP)
ED (External Dose - Standard Methods)
ID (Internal Dose - Standard Methods)
UA (Uncertainty Analysis - Standard Methods)

Revision Control

Revision	Revision Description	Revision Date	Authorization Official
1.0	Original	10/31/2007	Paul K. Blake
1.1	- Section 5.2.1: Added a paragraph on the treatment of mission badges and related uncertainty. - Section 5.3.2: Added a discussion about the daily rate of incidental ingestion of soil and dust. - Attachment 1: Added a new table for resuspension factors as Table 2 (Resuspension factors for typical participant activities in contaminated areas). - Attachment 1: Added the time-variable resuspension factor function for land-based exposures and related references. - Attachment 2: The "List of Surrogate Organs" is moved to this SM from RA01 and RA02.	03/31/2008	Paul K. Blake
1.2	Editorial revisions to improve clarity of presentation.	10/31/2008	Paul K. Blake
1.3	- Section 5.2.1: Expanded section on resuspension factors to include probabilistic models. - Section 5.2.2: Added section on blast-driven resuspension of fallout. - Section 5.2.3: Expanded section on descending fallout to include probabilistic methods. - Section 5.2.4: Expanded section on neutron activation products. - Attachment 1: Added table on model parameters, default values and distributions. - Renamed Attachments 1 and 2 to Attachments 2 and 3. - Updated References and made other editorial changes.	01/31/2010	Paul K. Blake
1.3a	- Added the list of standard NTPR organs and tissues - Moved Attachment 3 to Attachment 1.	03/31/2010	Paul K. Blake
2.0	- Added text in Section 5.2.1 explicitly stating the duration of exposure limit of 100 hours from inhalation of resuspended fallout deposited on the desk of ships and small boats. - Added new Section 5.2.1.1 and Table 2 to define, describe and provide values for GSMF. - Revised Section 5.2.1.4 to clarify use of film badge readings to reconstruct internal doses for long-term exposures. - Revised Section 5.2.2 to clarify that deterministic blast wave resuspension factors are upper bounds. - Modified Section 5.2.3 to provide a discussion of inhalation of descending fallout for land-based and shipboard personnel and clarified use of a simplified deterministic equation. - Revised Section 5.3.1 to clarify food ingestion scenarios impacted by descending fallout. - Added resuspension factors to Attachment 3 for troops in helicopters, armored vehicles, and tank movements, personnel involved in decontaminating aircraft, and separate resuspension factors for support and target ships. - Updated Attachment 1 for consistency with RA02. - Updated Table A3-1 in Attachment 3 and added small transport boats. - Updated references and made other editorial changes as needed.	04/30/2021	James D. Franks

Table of Contents

List of Tables

Standard Method

ID01 – Doses to Organs from Intake of Radioactive Materials

1. Purpose/Summary

Standard Method (SM) ID01, *Doses to Organs from Intake of Radioactive Materials*, provides general technical and computational methods for assessing dose to internal organs and tissues from the ingestion and inhalation of radioactive materials (principally fallout) by nuclear test participants for the Nuclear Test Personnel Review (NTPR) Program. This standard method is used in support of the procedures specified in SOP RA01.

2. Scope

This standard method provides technical guidance for reconstructing internal organ doses due to alpha, beta, and gamma ionizing radiation as a result of the ingestion or inhalation of radioactive material produced during nuclear testing. This standard method is not to be used to estimate any external radiation doses such as to the skin or lens of the eye because those dose assessments are addressed in other standard methods of this SOP Manual. This standard method is used in conjunction with other standard methods for assessing radiation doses to organs and tissues from internally-deposited radionuclides in accordance with the requirements described in DoD (2020).

3. Responsibilities

Qualified radiation dose analysis staff members use the methods described below for assessing the radiation doses for exposed individuals. If situations arise where these methods and techniques are inadequate to address a specific exposure scenario, it is the responsibility of the analyst encountering this deficiency to bring it to the attention of the RDA SOP Task Manager so that the methodology can be extended as required to provide adequate estimates of organ doses. It is the responsibility of the analyst executing and implementing this extension to document such extension in a revision to this standard method.

4. Definitions

Aerodynamic diameter: The diameter of a sphere of density 1 g cm^{-3} that exhibits the same settling velocity as the particle in question.

Committed Equivalent Dose (50-year CED): The time integral of the equivalent dose rate over the time in years following the intake. The implied value for adults is 50 years, from age 20 to 70 years. (ICRP, 1990)

Dose Conversion Factor (DCF): The ratio of 50-year CED to a tissue or organ to a unit film badge equivalent dose (rem) or curie intake of radioactive material given by the computer code FIIDOS (Fallout Inhalation and Ingestion Dose to Organs) and calculated using published specific dose coefficients for each radionuclide in the assumed inventory (Raine et al., 2007).

Equivalent Dose: The product of the absorbed dose in an organ or tissue and a radiation weighting factor that accounts for the variation in the biological damage of the various types of radiation.

Internal Dose: In the NTPR program, "internal dose" means 50-year CED.

5. Method Description

5.1 Introduction

NTPR participants, whether at the Nevada Test Site (NTS), the Pacific Proving Ground (PPG) or in Japan, could have accrued internal doses as a result of intakes of radionuclides by inhalation, ingestion, or absorption through the skin or open wounds. Intakes by inhalation are the most common pathway for the majority of participants in atmospheric nuclear tests. Most exposure scenarios involve inhalation of descending fallout or fallout that was deposited on the ground or other surfaces and subsequently resuspended into the air. Additional pathways of internal exposure involve the consumption of food or water that has been contaminated by fallout and the incidental ingestion of contaminated soil and dust. Absorption of radionuclides through the skin or an open wound is uncommon in exposures of atomic veterans and is not considered here.

Unlike external doses, internal doses cannot be measured directly but must be estimated based on other available data and models. Because no relevant air monitoring data and very little bioassay data are available for atmospheric nuclear test participants, dose estimates are performed with indirect methods using internal dose models for 23 standard organs and tissues listed in Table 1 (Raine et al., 2007). These models use available data such as gamma intensity measurements in conjunction with various assumptions. For organs or tissues not listed, a surrogate organ or tissue should be selected from Table 1 using the guidelines provided in Attachment 1 (DNA, 1986).

The values of the input parameters for the deterministic models and parameter distributions used in the probabilistically-based analyses are given in Attachment 2.

5.2 Inhalation Intakes

There are four basic pathways for the inhalation of radioactive material by nuclear test participants: 1) inhalation of fallout particles deposited on the ground or other surfaces and resuspended by mechanical or natural disturbances, 2) inhalation of radioactive material contained in descending fallout, 3) inhalation of neutron-induced radioactive material in the soil (or other material) lofted into the air by mechanical or natural

disturbances, and 4) inhalation of radioactive material in an atmospheric cloud (DNA, 1986).

Table 1. NTPR Standard Organs and Tissues used in Internal Dose Models

Organ Name		
Adrenals	Kidneys	Skin*
Bone Surfaces	Liver	Spleen
Brain	Extra-Thoracic Region	Testes
Breast	Lung	Thymus
Stomach Wall	Muscle	Thyroid
Small Intestine Wall	Ovaries	Uterus
Upper Large Intestine Wall	Pancreas	Urinary Bladder Wall
Lower Large Intestine Wall	Red Marrow	

* Skin cancers are presumptive per SOP RA02.

Estimates of dose from an inhalation of the combined radionuclides in a mixture produced by alpha particles and by beta particles plus gamma rays are based on the following equation:

$$\delta D(t) = AA(t)\, BR\, DCF(t)\, \delta t \qquad (1)$$

where

$\delta D(t)$	=	Increment in 50-year CED at time t to the organ or tissue (rem)
$AA(t)$	=	Time-dependent airborne activity concentration of radioactive material (Ci m^{-3})
BR	=	Breathing rate (m^3 h^{-1})
δt	=	Duration of exposure (h)
$DCF(t)$	=	Time-dependent inhalation dose conversion factors for the composite radionuclides for the organ or tissue of interest (rem Ci^{-1})

Equation 1 gives the dose from inhalation of airborne radionuclides. Because most inhalation exposure scenarios associated with nuclear testing involve intakes of mixtures of radionuclides, the dose to an organ or tissue of concern is the sum of the doses from intakes of all of the radionuclides. Composite dose conversion factors (DCF) that apply to mixtures of radionuclides are used in most assessments. The radionuclide composition of

the mixture is based on shot-specific radiochemistry data. The concentration of radionuclides in fallout on the ground and in air and the associated DCFs are time-dependent due to radioactive decay and in-growth. Operation-, shot-, and unit-specific assumptions, parameters, dose tables, and other relevant data for the calculation of internal doses are found in SOP Appendices A–C, and H.

There is little history of respiratory protection being used during nuclear tests at either the Nevada Test Site or the Pacific Proving Grounds. However, there is some indication that respiratory protection was used during cloud sampling operations (Martin and Rowland, 1982) and during Task Force RAZOR maneuver operations (Ponton et al., 1981).

5.2.1. Inhalation of Fallout Resuspended from Surfaces

Equation 2 is a generalized expression for the calculation of organ doses from the inhalation of resuspended fallout (DNA, 1986).

$$D_{inh} = GSMF \int_{t_{start}}^{t_{end}} I(t)\, FR(t)\, K(t')\, BR\, DCF_{inh}(t)\, dt \qquad (2)$$

where

D_{inh}	=	50-year CED to an organ from inhalation (rem)
$GSMF$	=	Gamma source modification factor[1] (See details in Section 5.2.1.1)
t_{start}	=	Time after detonation that veteran's exposure started (h)
t_{end}	=	Time after detonation that veteran's exposure ended (h)
$I(t)$	=	Time-dependent gamma radiation intensity measured or estimated (R h^{-1})
$FR(t)$	=	Time-dependent, shot-specific ratio of surface activity density to radiation intensity ("FIIDOS Ratio") for an infinite plane estimated using FIIDOS; historically designated *SA/I* (t) (Ci m^{-2} per R h^{-1})
$K(t')$	=	Resuspension factor (m^{-1})
t'	=	Time after end of fallout deposition event (h)
BR	=	Breathing rate (m^3 h^{-1})
$DCF_{inh}(t)$	=	Time-dependent, shot-specific inhalation DCF for an organ for the mixture of radionuclides in the fallout estimated using FIIDOS (rem Ci^{-1})

[1] The GSMF corrects the conversion ratios between the exposure rate and surface activity for contaminated surfaces that cannot be assumed infinite in spatial extent (see details in Section 5.2.1.1).

The values of the input parameters for the deterministic models and parameter distributions used in the probabilistically-based analyses are given in Attachment 2. When dose factors are not available for an affected organ or tissue, a surrogate organ or tissue is selected from the list provided in Attachment 1.

The $FR(t)$ and $DCF_{inh}(t)$ are calculated using the FIIDOS computer code for shot-specific radionuclides inventories. The DCFs are discussed in further detail in Section 5.4.

The duration of exposure, $t_{end} - t_{start}$, is based on the individual's exposure scenario. Typically, the veteran's external and internal doses are integrated over the period of exposure and are modified to account for shielding factors, e.g., when below deck on a ship or when indoors inside a tent or a building. It is also assumed that inhalation of resuspended contaminants only occurred when the participant was outdoors on land or topside on a ship. For inhalation of fallout resuspended from the deck of a ship or small boat, in addition to accounting for the fraction of time spent topside, t_{end} is set to 100 hours after the end of deposition; this is because any resuspendable fallout would have been washed out within 4 days of deposition (Goetz et al, 1991).

In practice, the veteran's inhalation dose from resuspended fallout is calculated using a modified version of Equation 2, with the $DCF_{inh}(t)$ replaced with values of $DCF'_{inh}(t)$ calculated using FIIDOS, that are specific to the shot(s) and organ(s) of interest, and that are normalized to 1 rem of dose to the whole body from a film badge reading or film-badge equivalent calculation. For use in assessments of inhalation of resuspended fallout, $DCF_{inh}(t)$ and $DCF'_{inh}(t)$ are related by the following equation:

$$DCF'_{inh}(t) = \frac{BR_0\, FR_0\, K_0}{F_B}\, DCF_{inh}(t) \qquad (3)$$

where

$DCF'_{inh}(t)$	=	Time-dependent, shot-specific inhalation dose conversion factor (rem CED rem^{-1} i.e., CED in rem to organ of interest per rem of dose to the whole body from a film badge reading)
BR_0	=	Default breathing rate of 1.2 $m^3\ h^{-1}$ used in FIIDOS to generate $DCF'_{inh}(t)$
FR_0	=	Shot-independent constant value of the ratio of surface activity density to radiation intensity for an infinite plane (0.16 Ci m^{-2} per R h^{-1}), derived in DNA (1986) and used in the development of FIIDOS *DCF*s
K_0	=	Default resuspension factor used in FIIDOS to generate $DCF'_{inh}(t)$, and equals $10^{-4}\ m^{-1}$

F_B = Film badge conversion factor[2] (rem R^{-1})

Combining Equation 2 and Equation 3 yields the following equation, which is typically used to calculate inhalation doses from resuspended fallout:

$$D_{inh} = \frac{GSMF\, BR\, F_B}{K_0\, BR_0} \int_{t_{start}}^{t_{end}} I(t)\, K(t')\, DCF'_{inh}(t)\, dt \qquad (4)$$

5.2.1.1 Gamma Source Modification Factor (GSMF)

To calculate internal doses at a location where no exposure rate data are available, use the value of GSMF that is applicable for the location where the measurement was taken with consideration of superstructure in the case of ships (Weitz, 2010a). It is incorrect to use the GSMF for the location where exposure occurred. Use of surrogate data from a nearby location is based on the assumption of similarity of the surface activity density at the location of the measurement and the location where a dose needs to be assessed. The exposure rates at the two locations should not be assumed to be similar. For example, the reconstructed internal dose for a destroyer that uses exposure rate measurements from a nearby aircraft carrier should be based on the GSMF for the aircraft carrier, not the destroyer. Similarly, the reconstructed internal dose for a ship that uses measurements of exposure rates at a nearby island should be based on the GSMF of an island rather than that of the ship. The mean values of GSMF for the deterministic models for various types of ships are given in (Weitz, 2010a, Table 2).

5.2.1.2 Resuspension Factor

The resuspension factor, $K(t')$, adopted for use in deterministic land-based calculations is given by the time-dependent expression (Till and Meyer, 1983):

$$K(t') = 10^{-5}\, e^{-0.01\frac{t'}{24}} + 10^{-9} \qquad (5)$$

The $K(t')$ adopted for central estimates in probabilistically-based analyses for land-based calculations is given by the time-dependent expression (Anspaugh et al., 2002):

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[2] The film badge conversion factor (F_B) is the ratio of dose recorded on a properly worn film badge to free-in-air integrated intensity. This factor, which accounts for body shielding of the film badge to gamma radiation, has been assigned the deterministic values of 0.7 for the standing position in a planar fallout field and 1.0 for one facing the source of radiation (e.g. a contaminated aircraft during engine maintenance).

$$K(t') = 10^{-5}\, e^{-0.07\frac{t'}{24}} + 6\cdot 10^{-9}\, e^{-0.003\frac{t'}{24}} + 10^{-9} \qquad (6)$$

In addition, resuspension factors for specific short duration activities of test participants, such as troop maneuvers involving helicopter operations in contaminated areas, aircraft decontamination, trucking, digging trenches, etc., are provided in Attachment 3. These resuspension factors should be used in lieu of Equations 5 and 6 for the periods of time relevant to those specific activities.

Table 2. Average *GSMF* for Various Ship Types

Ship Type	**Designation**	**Example**	***Length*** **(m)**	***Width*** **(m)**	**Super-Structure Fraction (SS)**	**Average *GSMF* w/SS**
Aircraft Carrier, ASW	CVS	USS BOXER	271	45	0*	1.6
Aircraft Carrier, Escort	CVE	USS BAIROKO	203	32	0*	1.7
Amphibious Force Flagship	AGC	USS ESTES	140	19	0.40	3.0
Attack Transport	APA	USS GENEVA	139	19	0.50	3.2
Battleship	BB	USS NEW YORK	175	29	0.50	2.6
Cruiser	CA	USS PENSACOLA	179	20	0.50	3.0
Destroyer	DD	USS MANSFIELD	115	12	0.50	4.0
Destroyer Escort	DE	USS SILVERSTEIN	93	11	0.50	4.3
Dock Landing Ship	LSD	USS BELLE GROVE	140	22	0.40	2.8
Fleet Oiler	AO	USS CACAPON	169	23	0.30	2.6
Fleet Tug	ATF	USS TAKELMA	62	12	0.35	3.8
Infantry Landing Craft	LCI	LCI-327	48	7	0.30	5.0
Salvage Ship	ARS	USS BOLSTER	65	12	0.50	4.2
Store Ship	AF	USS MERAPI	103	15	0.30	3.2
Submarine Rescue Ship	ASR	USS CHANTICLEER	77	13	0.60	4.4
Tank Landing Craft	LCT	LCT-1013	36	10	0†	2.8
Tank Landing Ship	LST	USS LAWRENCE CO.	100	15	0.30	3.2

* As a first approximation, the superstructure of an aircraft carrier was neglected in this assessment because it is located on the extreme starboard side of the flight deck and therefore provides little shielding to those crewmembers who worked on the flight deck.

† LCT has a nearly rectangular deck with modest superstructure at far aft end.

5.2.1.3 Breathing Rate

The deterministic default breathing rate value is 1.2 $m^3\ h^{-1}$ and applies to an adult male performing light activity comparable to walking at a rate of 3 miles per hour on a flat firm surface (ICRP, 1975).

For the probabilistic method, a triangular probability distribution function is used to characterize the variability of breathing rates for each activity level. The lower limit, mean, and upper limit of breathing rate distributions for each activity level are shown in Table 3. They are used as the minimum, mode, and maximum values, respectively, for the triangular probability distribution function corresponding to each activity level. Samples for the triangular distributions are then multiplied by the average activity level fractions for each level of activity (Weitz et al., 2009). The fractions of time performing at each activity level can be adjusted based upon the veteran specific scenario and must sum to 1.

Table 3. Breathing Rate Distributions by Activity Level for NTPR Test Participants

Activity Level	Fraction of Time for each Level of Activity*	Breathing Rate Distributions ($m^3\ h^{-1}$)		
		Low	Mean	High
Rest	0.25	0.1	0.7	1.1
Light	0.60	0.2	1.4	2.7
Moderate	0.08	0.9	2.5	4.7
Heavy	0.07	1.4	3.3	7.6

* Example that should be changed as needed for other specific exposure scenarios.

5.2.1.4 Use of Film Badge Doses for Internal Dose Estimation

The internal dose commitment to an organ or tissue can be related to an external film badge dose or to a measured radiation intensity specific to a veteran's location and exposure conditions. Use of film badge readings for internal dose reconstruction is subdivided into short-term exposures and long-term exposures. Short-term exposures are those for which the duration is short enough to justify use of an average value for the radiation intensity over the period of exposure. Long-term exposures are those for which variations in radiation intensity are such that an average value cannot be justified. For all uses of a film badge reading for calculation of internal dose due to inhalation of resuspended fallout, the film badge reading must be due primarily to the ground-deposited fallout.

5.2.1.4.1 Short-Term Exposures

For short-term exposures, the reported dose for a film badge or badges worn by an individual can be used to estimate an average radiation intensity ($I_{average}$) via Equation 7, which can be substituted for *I(t)* and taken out of the integral in Equation 2 or 4 to estimate the inhalation dose, D_{inh}, accrued concurrently with the external gamma exposure recorded by the film badge(s).

$$I_{average} = \frac{D_{FB}}{F_B \, \Delta t} \tag{7}$$

where

D_{FB}	=	Film badge dose (rem)
F_B	=	Film badge conversion factor (rem R^{-1})
Δt	=	Time period of exposure corresponding to film badge (h)

5.2.1.4.2 Long-Term Exposures

For long-term exposures, Equation 2 or 4 can be used to estimate an inhalation dose, D_{inh}. However, the result should be multiplied by the ratio of the total film badge dose (see SM ED01) to the corresponding reconstructed whole body external dose estimated using a generic scenario of activities of the veteran's unit, if available. However, to be conservative, the ratio should not be used if less than 1, i.e., when the total film badge dose is lower than the reconstructed external dose.

5.2.1.4.3 Period of Coverage of Film Badge Readings

For badge readings from continuous exposure over the period of coverage, e.g., permanent film badge or cohort film badge, the period of time integration used in Equation 2 or 4 to estimate an inhalation dose is defined by the issue and return dates of the badge. For mission film badges, the integration period is assumed to be 8 hours on the day of issue or as specified from scenario information. For mission film badges that exceed 1 day, an additional uncertainty due to the lack of knowledge of when the exposure occurred in this case is discussed in SM UA01.

5.2.2. Inhalation of Blast-Driven Resuspended Fallout from Previous Depositions

In response to the findings of a National Research Council review of the NTPR Program (NRC, 2003), a special study was undertaken to characterize potential internal dose accrual to NTS participants from blast wave-driven resuspension of fallout deposited from previous detonations. A total of 16 exposure scenarios for which previously deposited fallout had the potential to contribute to internal doses of Exercise Desert Rock (EDR) participants were identified for the period 1952 to 1955. The 16 scenarios, the approach and methodologies employed, and the internal dose estimates are discussed in Dancz (2006). Internal dose estimates for the 16 specific scenarios during Operations TUMBLER-SNAPPER (1952), UPSHOT-KNOTHOLE (1953), and TEAPOT (1955) are included in SOP Appendices C-4 through C-6. For non-EDR scenarios, and scenarios after 1955, refer to the general methodology described below. The doses resulting from the use of the deterministic resuspension factors in Attachment 2 for the inhalation of blast wave-driven resuspended fallout are upper bounds.

Resuspension of previously deposited fallout by a nuclear detonation can occur in two regions near ground zero (GZ): the thermal-pulse (previously precursor) region and the blast-wave region (Kocher et al., 2009). The thermal-pulse region extends from GZ outward to the distance at which the peak overpressure at ground level associated with the blast wave is 6 pounds per square inch (psi) (Glasstone and Dolan, 1977). The blast-wave region extends from the outer limits of the thermal-pulse region to the distance at which the peak overpressure at ground level associated with the blast wave is 2 psi. The method for determining the distances from GZ of the thermal-pulse region and the blast-wave region is based upon yield and height of burst of a detonation and is given in Kocher et al. (2009).

For deterministic analyses of blast-driven resuspension scenarios, the inhalation dose in each region is given by the following general equations:

$$D_{inh,tp} = BR \int_{t_{start_{tp}}}^{t_{end_{tp}}} I(t)\ FR(t)\ K_{tp}\ DCF_{inh}(t)\ dt \tag{8}$$

$$D_{inh,bw} = BR \int_{t_{start_{bw}}}^{t_{end_{bw}}} I(t)\ FR(t)\ K_{bw}\ DCF_{inh}(t)\ dt \tag{9}$$

where

$D_{inh,tp}$	=	50-year CED to the organ from inhalation of blast-driven, resuspended fallout in the thermal-pulse region (rem)
$t_{start_{tp}}$	=	Start time of veteran's exposure in the thermal-pulse region (h after shot H+0 that is the source of previously deposited fallout)
$t_{end_{tp}}$	=	End time of veteran's exposure in the thermal-pulse region (h after shot H+0 that is the source of previously deposited fallout)
K_{tp}	=	Resuspension factor for the thermal-pulse region (m^{-1})
$D_{inh,bw}$	=	50-year CED to the organ from inhalation of blast-driven, resuspended fallout in the blast-wave region (rem)
$t_{start_{bw}}$	=	Start time of veteran's exposure in the blast-wave region (h after shot H+0 that is the source of previously deposited fallout)
$t_{end_{bw}}$	=	End time of veteran's exposure in the blast-wave region (h after shot H+0 that is the source of previously deposited fallout)
K_{bw}	=	Resuspension factor for the blast-wave region (m^{-1})

Other variables as defined above, with $I(t)$, $FR(t)$, and $DCF_{inh}(t)$ specific to the shot that is the source of the previously deposited fallout. Similar to Equations 2–4 used for fallout resuspended by typical mechanical disturbances, the general equations shown above for

blast-driven resuspension can be modified to include $DCF'_{inh}(t)$. The resulting sum of the organ doses from each region are to be treated as both the best estimates and as the upper-bound doses (Kocher et al., 2009). The resuspension factors for blast-driven resuspension are listed in Attachment 2. These resuspension factors are to be applied for the 24 hours post detonation for resuspension in the thermal-pulse region and for 5 hours post detonation in the blast-wave region (Kocher et al., 2009).

For probabilistic analyses of blast-driven resuspension scenarios, resuspension factors for respirable and non-respirable fractions of resuspended fallout are available, as shown in Attachment 2 (Kocher et al., 2009). These resuspension factors are used as shown in the following equations:

$$D_{inh,tp} = BR\left[\begin{array}{l} K_{R_{tp}} \int_{t_{start_{tp}}}^{t_{end_{tp}}} I(t)\, FR(t)\, DCF_{inh}(t)\, dt \\ + K_{NR_{tp}} \int_{t_{start_{tp}}}^{t_{end_{tp}}} I(t)\, FR(t)\, DCF_{ing}(t)\, dt \end{array}\right] \quad (10)$$

$$D_{inh,bw} = BR\left[\begin{array}{l} K_{R_{bw}} \int_{t_{start_{bw}}}^{t_{end_{bw}}} I(t)\, FR(t)\, DCF_{inh}(t)\, dt \\ + K_{NR_{bw}} \int_{t_{start_{bw}}}^{t_{end_{bw}}} I(t)\, FR(t)\, DCF_{ing}(t)\, dt \end{array}\right] \quad (11)$$

where

$K_{R_{tp}}$	=	Resuspension factor for respirable particles (<10 μm) in the thermal-pulse region (m^{-1})
$K_{NR_{tp}}$	=	Resuspension factor for non-respirable particles (10–100 μm) in the thermal-pulse region (m^{-1})
$K_{R_{bw}}$	=	Resuspension factor for respirable particles (<10 μm) in the blast-wave region (m^{-1})
$K_{NR_{bw}}$	=	Resuspension factor for non-respirable particles (10–100 μm) in the blast-wave region (m^{-1})
$DCF_{ing}(t)$	=	Time-dependent shot-specific ingestion DCF for an organ for the mixture of radionuclides in the fallout estimated using FIIDOS (rem Ci^{-1})

Other variables are defined above as $I(t)$, $FR(t)$, $DCF_{inh}(t)$ and $DCF_{ing}(t)$ specific to the shot that is the source of the previously deposited fallout. The resuspension factors for blast-driven resuspension of fallout are listed in Attachment 2. Similar to the

deterministic assessment of blast-driven resuspended fallout, the equations above can be modified to use $DCF'_{inh}(t)$, and the pathway should be assessed for the time periods indicated for the deterministic analysis. When using the above equations for inhalation of blast-driven resuspended fallout, it must be recognized that only a fraction of the non-respirable taken in by inhalation are swallowed and cleared directly to the gastro-intestinal (GI) tract. This fraction is currently under study, which is expected to produce an additional factor of about 0.3. Until this factor is included, doses will be overestimated.

5.2.3. Inhalation of Descending Fallout

The inhalation of descending fallout is a pathway for internal dose to a test participant who was outside (for land-based personnel) or topside (for shipboard personnel) during a fallout event. The fraction of time spent outside during descending fallout events is assumed to be 100 percent for land-based exposures regardless of the time during the day of fallout events. This is based on documented statements that additional precautions were not taken during fallout episodes on residence islands as described, for example, in the white book for CASTLE Naval Personnel (Thomas et al., 1984). For ship-based personnel, it is assumed that participants were inside/below deck during periods of descending fallout unless they had specific topside duties such as deck decontamination or operation of washdown systems (for example Thomas et al., 1984; Martin and Rowland, 1982).

Conceptually, the fallout particles that descended at a participant's location can be sorted into n particle size classes (denoted by index $i = 1,\ldots, n$) according to their aerodynamic diameters. The most general equation for the internal dose accrued through this route of entry is then given by:

$$D_{inh} = \sum_{i=1}^{n} \int_{t_{start}}^{t_{end}} AA_i(t)\, BR(t)\, DCF_{inh,i}(t)\, dt \qquad (12)$$

where the summation is over the particle size classes and

D_{inh}	=	50-year CED to an organ from inhalation (rem)
t_{start}	=	Time from detonation to start of fallout (h)
t_{end}	=	Time from detonation to end of fallout (h)
$AA_i(t)$	=	Airborne activity density of particles in the i^{th} size class at time t (Ci m^{-3})
$BR(t)$	=	Breathing rate at time t (m^3 h^{-1})
$DCF_{inh,i}(t)$	=	Shot-specific dose conversion factor at t for CED to the organ of interest from inhalation of particles in the i^{th} size class (rem Ci^{-1})

The following assumptions are typically applied in deterministic assessments.

1. All fallout particles have aerodynamic diameters in the range of 1–10 μm.
2. The dose conversion factor $DCF_{inh}(t)$ is calculated with the computer code FIIDOS using the maximum of the values of the dose coefficients for particles with activity median aerodynamic diameters (AMADs) of 1, 3, 5, and 10 μm tabulated in ICRP (1996).
3. The duration of fallout deposition at the site of interest is much smaller than the time (after detonation) at which it occurred, that is, $t_e - t_s \ll t_s$.
4. The time of the peak intensity, t_p, coincides with the end of fallout, t_e.
5. The deposition velocity is equal to the height of the stabilized cloud, $H_0 = 10^4$ m, divided by t_p.
6. The breathing rate $BR(t)$ is constant with a default value (BR_0) of 1.2 $m^3\ h^{-1}$.
7. The ratio of surface activity density to radiation intensity [$(FR(t)$], generated via the FIIDOS code and generally shot- and time-dependent, has a shot-independent, constant value of $FR_0 = 0.16$ Ci m^{-2} per R h^{-1}, which was derived in DNA (1986) and used in the development of the DCF.

Given these assumptions, Equation 12 reduces to the form used in deterministic assessments:

$$D_{inh} = GSMF\ F_B \frac{BR}{BR_0} t_p\ I(t_p)\ DCF'_{inh}(t_p) \tag{13}$$

where, in addition to the parameters defined above,

$GSMF$	=	Gamma source modification factor (See details in Section 5.2.1.1)
F_B	=	Film badge conversion factor (0.7 or 1.0 rem R^{-1}, see Section 5.2.1)
BR	=	Constant breathing rate appropriate for the exposure scenario ($m^3\ h^{-1}$)
$I(t_p)$	=	Peak gamma radiation intensity from the fallout (R h^{-1})
$DCF'_{inh}(t_p)$	=	Shot-specific inhalation dose conversion factor at t_p with units rem CED rem^{-1} i.e., CED (rem) to organ of interest per rem of dose to the whole body from a film badge reading

As used in assessments of descending fallout, $DCF'_{inh}(t_p)$ and $DCF_{inh}(t_p)$ are related by

$$DCF'_{inh}(t_p)\,[rem\,rem^{-1}] = \frac{BR_0\ FR_0}{F_B\ H_0}\,DCF_{inh}(t_p)\,[rem\,Ci^{-1}]\cdot \tag{14}$$

The values of the input parameters for the deterministic calculations are given in Attachment 2.

If Assumption 3 above is not valid, i.e., the duration of fallout deposition at the site of interest is not much smaller than the time (after detonation) at which it occurred, the simplified deterministic model represented by Equation (13) above for inhalation doses from descending fallout should not be used. Instead, use the following equation (Weitz, 2010b):

$$D = \frac{GSMF \cdot BR}{H_o} \cdot \int_{t_s}^{t_e} \Lambda(t) \cdot t \cdot \frac{d}{dt}\left[\frac{I(t) \cdot FR(t)}{\Lambda(t)}\right] \cdot DCF_{inh_1}(t) \cdot dt \tag{15}$$

where $\Lambda(t)$ is a dimensionless function that represents the time dependence of $FR(t)$ due to radioactive decay of fallout already deposited on the ground, and other variables are defined previously. The function $\Lambda(t)$ can be derived empirically with the FIIDOS code (Raine et al., 2007) as the time scaling factors, or more generally approximated as $(t/t_o)^{-1.2}$, t_o being a reference time usually 1. It is implicitly assumed in Equation 15 that there is no fractionation of fallout material with particle size, for otherwise $\Lambda(t)$ must be indexed according to size bin. While some fractionation is likely, its inclusion is beyond the scope of the present analysis. Also, $DCF_{inh1}(t)$ is the shot-specific DCF at time t in the 1-10 μm (i = 1) size class.

The decay factor for the integral of the derivative descending fallout model is assumed to be 1.2 (2.2 after six months) as indicated in Weitz (2010b) unless there are specific decay factors such as those for Shots BRAVO and ROMEO during Operation CASTLE.

A more general formulation was developed for probabilistic applications (Weitz, 2010b). Assumption 1 above was removed through the use of three particle size classes and associated activity fractions and internal deposition fractions. Class 1 consists of particles with aerodynamic diameters between 1 and 10 μm, Class 2 between 10 and 20 μm, and Class 3 between 20 and 100 μm; particles larger than 100 μm are considered non-inhalable and therefore do not contribute to internal dose through the inhalation route of entry. The high-sided bias introduced by Assumption 2 was removed through the use of a bias factor as discussed in Section 5.4 (McKenzie-Carter and Stiver, 2009a), and Assumption 5 was mitigated through more rigorous modeling of the fallout deposition process (Weitz, 2009).

To develop the probabilistic formulation, the fraction of total activity carried by all particles with aerodynamic diameters less than 100 μm is first calculated. Then the activity fractions AF_1, AF_2, and AF_3 are calculated for the aerodynamic diameter ranges 1–10 μm (Class 1), 10–20 μm (Class 2), and 20–100 μm (Class 3), respectively. These particle size class activity fractions are calculated using the following equations:

$$\begin{aligned} AF_1 &= f_1 AF_{100} \\ AF_2 &= f_2 AF_{100} \\ AF_3 &= (1 - f_1 - f_2) AF_{100} \end{aligned} \tag{16}$$

where

AF_1	=	Activity fraction for size Class 1 particles (1–10 μm)
f_1	=	Fraction of AF_{100} that is attributable to particles in size Class 1
AF_{100}	=	Fraction of total activity carried by all particles with diameters less than 100 μm
AF_2	=	Activity fraction for size Class 2 particles (10–20 μm)
f_2	=	Fraction of AF_{100} that is attributable to particles in size Class 2
AF_3	=	Activity fraction for size Class 3 particles (20–100 μm)

For a given fallout event, values of these parameters AF_{100}, f_1, and f_2 are randomly sampled from their assigned triangular distributions.

Settling velocities for particles of each size class are estimated as described in Weitz (2009). Log-triangular distributions are estimated for the velocity of descending fallout particles in each size class in the breathing zone, defined as the 1.6 m layer of air immediately above the Earth's surface.

Respiratory tract deposition fractions are then defined for each particle size class as the fractions of inhaled particles in a given size class that deposit in a defined portion of the human respiratory tract. For use in the NTPR probabilistic methodology, deposition fractions for two regions are defined, the posterior extra-thoracic (ET_2) region and thoracic (TH) airway (bronchial, bronchiolar, and alveolar-interstitial regions). Fractions that deposit in the ET_2 region are treated as an ingestion intake. All activity associated with particles of size Class 1 (1–10 μm) has deposition fractions as defined in the underlying ICRP 66 human respiratory tract model. Lognormal distributions of deposition fractions for size Classes 2 (10–20 μm) and 3 (20–100 μm) are derived in McKenzie-Carter and Stiver (2009b). The values and distributions of these deposition fractions, designated by their Mathcad representations R_1, R_2 and R_3 for the respective deposition of size Classes 1, 2 and 3 in the TH airway, and by NR_1, NR_2 and NR_3 for the respective particle-size class deposition in ET_2 region, are provided in Attachment 2.

The equation used for probabilistic assessments of internal dose from the inhalation of descending fallout is given by:

$$D_{inh} = GSMF\ I(t_p) \left[\begin{array}{l} F_B\, H_0\, \dfrac{BR}{BR_0} \left(\displaystyle\sum_{i=1}^{3} \dfrac{AF_i}{V_i} \dfrac{R_i}{R_1} \right) \dfrac{DCF'_{inh}(t_p)}{BF} \\ + BR \left(\displaystyle\sum_{i=1}^{3} \dfrac{AF_i}{V_i} \left[NR_i - NR_1 \dfrac{R_i}{R_1} \right] \right) FR(t_p)\ DCF_{ing}(t_p) \end{array} \right] \tag{17}$$

where

R_i	=	Fraction of i^{th} size class particles depositing in the thoracic airways of the respiratory tract (bronchial, bronchiolar, and alveolar-interstitial regions).
R_1	=	Fraction of particles in the 1–10 μm (i = 1) size class depositing in the thoracic airways of the respiratory tract
NR_i	=	Fraction of i^{th} size class particles depositing in the posterior extra-thoracic (ET_2) region of the respiratory tract and cleared to the GI tract
NR_1	=	Fraction of particles in the 1–10 μm (i = 1) size class depositing in the ET_2 region of the respiratory tract and cleared to the gastro-intestinal tract
V_i	=	Deposition velocity (m h^{-1}), or average velocity of descent in the breathing zone (nominally up to 1.6 meters above the surface) for i^{th}-sized particles
H_0	=	The height of the stabilized cloud (10^4 m)
BF	=	Bias factor, to remove the bias introduced by Assumption 2 above (also see Section 5.4, Table 6).
$FR(t_p)$	=	FIIDOS-generated time-and shot-dependent ratio of surface activity density to intensity at time t_p, referred to as the "FIIDOS ratio" (Ci m^{-2} per R h^{-1})

The input parameter value distributions used in the probabilistic methods of analysis are given in Attachment 2.

5.2.4. Inhalation of Suspended Soil Activation Products

The method for estimating airborne concentrations of radionuclides due to suspension of radioactive material produced by neutron activation in soil at the NTS is similar to the method used in Section 5.2.1 involving resuspension of deposited fallout. However, FIIDOS DCFs are not used. See SOP Appendix A-1 for methodologies to be used for locations in Japan.

Relative activities of activation products in soil are estimated on the basis of the following inputs:

- Field radiation measurements from known activation products
- Known elemental compositions of soil
- Neutron transport in air and soil
- Neutron capture in nuclei of stable elements in soil
- Known decay characteristics of the activation product radioisotopes.

Activities of radionuclides per unit volume of soil (Ci m^{-3}) are then estimated by scaling the estimated relative activities to a calculated photon exposure in air above ground or exposure rate at a particular time that matches available measurements with film badges or field instruments, taking radioactive decay into account. The intensity $I_{Na}(t)$ due to Na-24 is estimated as a percentage of the total exposure rate by using the table of fractions listed in Table 4 for the appropriate location. The intensity from Na-24 at time equals zero $I_{Na}(0)$ is then calculated using the half-life of Na-24. The activities per square meter of the radionuclides of interest are then calculated using the appropriate conversion factor in Table 5 (Goetz, et al., 1981). Radionuclide activities per unit volume of surface soil are converted to equivalent surface activity concentrations (Ci m^{-2}) by assuming the top 1 cm of soil can be suspended in the air and contains the total activity in the soil profile. Finally, a resuspension factor is applied to the estimated surface activity concentrations of radionuclides in surface soil to obtain an estimate of the concentrations in air.

Resuspension factors applied to activation products in surface soil are the same as those applied to deposited fallout (see Section 5.2.1). As with resuspension of deposited fallout, an important condition in using this method is that the film badge or instrument readings must be due primarily to activation products in soil (DNA, 1986; NRC, 2003).

Table 4. Ratio of Intensity Due to Na-24 to Intensity Due to all Neutron Activation Products [$IR_{,Na}(t_m)$]

Time after Shot (h)	Area 7 NTS	Frenchman Flat NTS
0	0.002	0.001
1	0.323	0.196
2	0.374	0.233
3	0.426	0.273
4	0.481	0.317
5	0.535	0.364
6	0.589	0.414
7	0.640	0.464
8	0.688	0.514
9	0.732	0.562
10	0.772	0.608
11	0.806	0.651
12	0.837	0.690
13	0.862	0.725
14	0.884	0.755
15	0.903	0.782
16	0.918	0.805
17	0.931	0.824
18	0.941	0.840
19	0.950	0.854
20	0.957	0.865
21	0.962	0.874
22	0.967	0.882
23	0.971	0.889
24	0.974	0.894

Table 5. Relative Surface Radioactivity of Neutron Activation Products to Na-24 Intensity, [$SA_i(0)$]

Radioisotope	$SA_i(0)^*$	Half Life of Radioisotope
Na-24	1.7×10^{-3}	15.0 hours
P-32	4.0×10^{-7}	14.3 days
K-40	3.5×10^{-4}	12.4 hours
Ca-45	5.5×10^{-7}	163 days
Mn-56	3.7×10^{-3}	2.58 hours

* The surface density of radioactivity (Ci m^{-2}) per R h^{-1} of radiation intensity from Na-24 at time $t = 0$.

Based on the previous discussion, the inhalation dose from activation products in suspended soil is estimated using the following equations:

$$D_{inh} = I_{Na}(0) BR \sum_i SA_i(0)\, DF_i \int_{t_{start}}^{t_{end}} K(t)\, e^{-\frac{0.693\, t}{HL_i}}\, dt \tag{18}$$

$$I_{Na}(0) = I(t_m)\, IR_{Na}(t_m)\, e^{\frac{0.693\, t_m}{HL_{Na}}} \tag{19}$$

where

D_{inh}	=	50-year CED to an organ from activation products in suspended soil (rem)
$I_{Na}(0)$	=	Intensity due to Na-24 at time equal zero (R h^{-1})
t_m	=	Time of intensity measurement after detonation (h)
$I(t_m)$	=	Measured intensity at time t_m (R h^{-1})
$IR_{,Na}(t_m)$	=	Ratio of intensity due to Na-24 to total measured intensity at time t_m
$SA_i(0)$	=	Ratio of surface activity for the i^{th} isotope to intensity due to Na-24 at time equals zero (Ci m^{-2} per R h^{-1})
DF_i	=	Inhalation dose coefficient for the organ of interest from ICRP-72 (ICRP, 1996) for the i^{th} isotope (rem Ci^{-1}).
HL_i	=	Half-life of the i^{th} neutron activation product (h)
HL_{Na}	=	Half-life of Na-24 (h)

The time-dependent ratios of intensity due to Na-24 to total measured intensity $IR_{Na}(t_m)$ at time t_m are included in Table 4. Table 5 lists the intensity to surface activity conversion factors ($SA_i(0)$) for neutron-activated products at NTS at time equals zero for neutron-induced radioactivity that can lead to significant internal doses. Values of other input parameters for the deterministic models and parameter distributions used in the probabilistically-based analyses are given in Attachment 2.

5.2.5. Inhalation in an Atmospheric Cloud

The scenario involving inhalation of radionuclides in an atmospheric cloud is applied only for individuals who flew through nuclear cloud debris in an airplane or helicopter. For this scenario, the inhalation dose is calculated as follows:

$$D = \frac{1}{RPF} \int_{t_{start}}^{t_{end}} I(t) \left(\frac{AA}{I}\ (t) \right) BR\ DCF_{inh}\ (t)\ dt \tag{20}$$

where

$\frac{AA}{I}(t)$	=	Time-dependent, shot-specific airborne activity concentration–to–intensity ratio estimated using FIIDOS (Ci m^{-3} per R h^{-1})
RPF	=	Respiratory Protection Factor from any respiratory protection used during the flight (USNRC, 1999) (dimensionless)

Values of $\frac{AA}{I}(t)$ are shot-specific and are included in SOP Appendix H. They are calculated using FIIDOS based on an assumption that the atmospheric cloud is uniformly contaminated and infinite in extent since the aircraft were submerged in the radioactive cloud. The quantities, $I(t)$, $\frac{AA}{I}(t)$, and $DCF_{inh}(t)$ are time-dependent, and $\frac{AA}{I}(t)$ and $DCF_{inh}(t)$ are based on an assumed mixture of radionuclides in air (DNA, 1986; NRC, 2003).

For the inadvertent exposure of a person in an aircraft to a radioactive cloud, it is assumed that no respiratory protection was used. However, in cases of expected exposure, such as during cloud sampling, it is assumed that respiratory protection was used and that the equipment provided complete protection against inhalation of airborne contamination unless otherwise indicated in historical documents and reports. Thus, the inhalation dose in cases of expected exposures is typically zero (NRC, 2003).

5.3 Ingestion Intakes

Two principal models are employed for the evaluation of internal dose to nuclear test participants from the ingestion of radioactive contamination:

- Direct deposition of contaminants on consumed food and beverages during fallout events, and
- Incidental ingestion of contaminated soil and dust during routine daily activities.

The direct deposition model requires the characterization of the radiation environment and the participant's activities therein, and is described in Section 5.3.1. Because data for such characterization are not generally available, the direct deposition model requires that the analyst assume scenario elements and parameter values, most of which are based on experience and consensus judgment among radiation assessment analysts rather than published, peer-reviewed data. The incidental daily ingestion model (Section 5.3.2) requires fewer assumed parameter estimates, no assumptions regarding the mode of intake, and ingestion rates that are based on published technical guidance from the U.S. Environmental Protection Agency (USEPA) and the U.S. Army Center for Health Promotion and Preventive Medicine (USACHPPM). Because the incidental daily

ingestion model uses the highest estimated intake rate for an adult carrying out strenuous activities for the entire period of presence in a soil/dust-contaminated environment, resultant doses are credible estimates of upper bound doses for the deterministic method.

5.3.1. Ingestion of Fallout Deposited on Food

The ingestion of descending fallout deposited on consumed food will be included as an internal dose pathway only if after a careful review of the Scenario of Participation and Radiation Exposure (SPARE) and other relevant information in the case file or historical documents, the analyst concludes that the participant could have been exposed to descending fallout while eating a meal outdoors or topside on a ship. This determination should be based on statements made by the participant and contemporaneous records and reports.

The model is based on the amount of fallout that would have fallen on the participant's food during the meal at the average rate of deposition as determined from intensity buildup data and the geometric properties (size and shape) of the food consumed. The model for estimating internal dose from the ingestion of food contaminated by descending fallout requires the following types of information:

- A set of well-characterized measurements of intensity buildup during the period of deposition, typically at least three or more time-intensity data pairs
- A description of the veteran's activities and conditions of exposure during fallout deposition, including:
  - Periods of fallout occurring when meals would have been consumed
  - Participant involvement in activities that would have precluded the consumption of food during the period of deposition; e.g., topside decontamination crew
  - If the participant was in a ship during fallout deposition, whether the ventilation system was opened or closed.
- A description of the type of food consumed, its geometric properties (size, shape), and those of the plate or tray, if used
  - Lacking such information, a 15-minute deposition on a 9-inch diameter plate at the average rate of deposition is assumed. A period of 15 minutes (0.25 hours) is based on the approximate time needed to consume a meal.

If data are not sufficient to characterize the potential intake as described above, in land-based scenarios the incidental ingestion of soil and dust model described in Section 5.3.2 should be used.

Since sealed food stores prevent primary contamination of foodstuff, such contamination is not considered a viable route of entry of fallout material into the body. Additionally, routine mess hall cleaning precludes repeated exposures at the initial level.

Contamination deposited on surfaces such as the ground is ingested only if it enters the food chain. Since routine meals were prepared from imported foodstuff and drinking water, ground contamination is not considered to be a significant source of internal dose from ingestion (NRC, 2003).

5.3.2. Incidental Ingestion of Contaminated Soil and Dust

Based on past studies and guidelines of the USEPA and USACHPPM, routine daily activities by nuclear test participants may have involved the inadvertent ingestion of small quantities of soil and dust particles that adhered to food, beverages, cigarettes, or hands (USEPA, 1996, 1997 and 2002; USACHPPM, 2003). Therefore, nuclear test participants at land locations had the potential for the incidental ingestion of contaminated soil and dust in the course of their regular daily activities. NTS participants were principally involved in routine activities at their temporary-duty stations in the vicinity of the NTS, mainly Camp Desert Rock (CDR), Camp Mercury and Indian Springs Air Force Base (ISAFB). PPG participants were primarily land-based garrison force personnel and others stationed at residence islands for extended periods as well as ship-board personnel. The incidental ingestion of soil and dust is not a potential pathway for ship-based personnel, except for extended periods of time spent on ashore; this does not apply for time spent on liberty ashore for recreation.

The incidental ingestion pathway is a chronic type of exposure that involves the daily intake of relatively small quantities of contaminated soil and dust. The source of the ingested contamination includes direct contact and airborne soil and dust due to walking, vehicular traffic, and wind-driven lofting of contaminated particles in areas where military personnel were stationed during nuclear testing operations.

The ingestion dose for the incidental intake of soil and dust is calculated as follows (Chehata and Stiver, 2009):

$$D_{ing} = GSMF \frac{q_{ing}}{b_{soil}\,\rho_{soil}} \int_{t_{start}}^{t_{end}} I(t)\, FR(t)\, DCF_{ing}(t)\, dt \qquad (21)$$

where

D_{ing}	=	50-y CED to an organ due to ingestion of radioactive materials (rem)
ρ_{soil}	=	Bulk density of soil (g m^{-3})
q_{ing}	=	Average incidental ingestion rate (g h^{-1})
$DCF_{ing}(t)$	=	Time-dependent activity-weighted average (composite) ingestion *DCF* (rem Ci^{-1})
b_{soil}	=	Thickness of soil layer available for intake, generally assumed to be 1 centimeter (0.01 meter)

The values of the input parameters for the deterministic models and parameter distributions used in the probabilistically-based analyses are given in Attachment 2.

This pathway is applicable only to land-based personnel. The *GSMF* is equal to 1 if *I*(t) are land-based intensity measurements, and is equal to a value applicable to a nearby ship if the *I*(t) measurement was made on that ship.

Further information concerning the calculation and application of the average *GSMF* is found in Section 5.2.1.1. Average *GSMF*s for various ship types are provided in Table 2.

Given the considerations detailed in Chehata and Stiver (2009), it was recommended that the NTPR adopt an incidental ingestion model using a soil/dust ingestion rate of 500 mg day^{-1} as an upper-bound value for the entire period of residence. This upper-bound rate should be used for personnel who were stationed at NTS facilities while carrying out routine daily activities at CDR, Camp Mercury, ISAFB, and other similar locations, where dusty conditions were prevalent. The incidental ingestion model is also applicable to personnel located on shore at the PPG. The upper-bound rate is consistent with the highest value recommended in USEPA screening level guidance and USACHPPM exposure guidance for deployed military personnel (USEPA, 1996, 1997 and 2002; USACHPPM, 2003).

For the probabilistically-based approach, several types of distributions have been utilized in past studies or cited as examples in USEPA guidance (e.g., USEPA, 2001). However, due to the limited information on this parameter, a skewed triangular distribution is recommended unless better data are available. Ranges of the parameters of the triangular distribution are given in Attachment 2 and are based on the data compilation cited above.

The estimation of internal doses using measurements of activity on the ground requires knowledge of the bulk density of soil. At NTS, surface soils are characterized as being moderately- to poorly-sorted sand to silty loam. These soils have a bulk density that ranges from 1.3 to 1.6 g cm^{-3} with an average of 1.45 g cm^{-3} (Hillel, 1980). A symmetrical triangular or a uniform probability distribution can be used unless site-specific data supports another type of distribution (Chehata and Stiver, 2009). Soil density at the PPG residence islands would be slightly higher but within a similar range. For the deterministic model, the lower value of 1.3 g cm^{-3} leads to the more conservative result in the dose (See Equation 21). Distributions and deterministic (high-sided) parameter values are given in Attachment 2.

As with resuspension of deposited fallout, an important condition in using the incidental ingestion model is that the film badge or instrument readings must be due primarily to ground-deposited fallout.

The method described here does not apply to the assessment of doses in acute exposure situations such as event-driven ingestion of descending fallout deposited on food (see Section 5.3.1), when parameters, such as time and deposited quantities, are well-known or can be estimated with a relatively higher degree of confidence.

5.4 Use of FIIDOS in Dose Reconstructions

FIIDOS is a computer code developed for internal dose calculations that is used to generate *DCFs* for the calculation of internal dose from intakes of radioactive materials. For most radiation dose assessments involving inhalation, FIIDOS has been used to generate shot-specific, time-dependent *DCF* tables (Raine et al., 2007; ICRP, 1994 and 1995). The analyst should be aware of three aspects of the methodology that impose limitations on the application of FIIDOS. All three relate to the use of a radiological measurement to characterize a radiological environment. (Raine et al., 2007)

- First, the radiological measurement represents the radioactive contamination at a specific location only. The radiological environment that FIIDOS calculates is referenced to that same location. FIIDOS does not provide a mechanism for translating a radiological measurement at one location to another location.
- Second, when a radiological measurement made at one time is used to determine the radiological environment at a different time, the only effect that FIIDOS considers is radioactive decay. Decontamination and other effects that alter the distribution of the radioactive material, such as wind and rain, are not included in the FIIDOS methodology.
- Third, the association of the radiological hazard with the radiological measurement is valid only as long as the fallout debris emits sufficient gamma-ray radiation to give meaningful measurements. This condition exists in a fresh fallout field and can continue for several years; however, after some time, the fallout radiation level will become indistinguishable from the prevailing background radiation level. At these late times, the fallout material could still contain some radionuclides, such as certain actinides that contribute significantly to an internal dose, even though the gamma-ray radiation emission rate from the fallout material is low.

Separate sets of tables are generated for $DCF_{inh}(t)$ and $DCF'_{inh}(t)$ as follows:

- Tabulated values for $DCF_{inh}(t)$ are calculated to produce the CED to an organ, in rem, from the intake of 1 curie of a mixture of fallout radioactivity calculated by FIIDOS (rem CED Ci^{-1}).
- Tabulated values for $DCF'_{inh}(t)$ are calculated to produce the CED to an organ, in rem, per rem of dose to the whole body from a film badge reading (rem CED rem^{-1}). $DCF'_{inh}(t)$ uses reference values for the resuspension factor and the breathing rate as follows:
  - The reference resuspension factor used is $K_0 = 10^{-4}\ m^{-1}$
  - The reference breathing rate used is $BR_0 = 1.2\ m^3\ h^{-1}$
- In deterministic (high-sided) models, maximum inhalation *DCF*s are selected from those calculated for particle size distributions of 1, 3, 5, and 10 μm AMAD using the

ICRP 72 dose coefficients for the recommended absorption type of the oxide form of each radioactive material.

For both inhalation and ingestion, separate *DCF* tables have been generated for the calculation of doses from alpha particles, and from beta particles and gamma rays combined for each organ at various times following a detonation. For inhalation intakes, separate tables are provided for both radiation types for the doses normalized to 1 rem film badge equivalent dose ($DCF'_{inh}(t)$) and also to 1 curie of total radioactivity inhaled ($DCF_{inh}(t)$). For ingestion intakes, tables are provided for both radiation types only for doses normalized to 1 curie of total radioactivity ingested ($DCF_{ing}(t)$). SOP Appendix H contains the tables for each shot for each test series for which radiochemistry data are available.

To use the deterministic inhalation *DCF*s in a probabilistically-based analysis, bias factors, *BF* (Table 6), are used to estimate adjusted central values of the inhalation *DCF*s (McKenzie-Carter and Stiver, 2009a). Incorporating the bias factor into a probabilistically-based analysis is accomplished as follows:

$$DCF_{adj} = \frac{DCF}{BF} \tag{22}$$

where

DCF_{adj} = Adjusted (unbiased) shot-specific, time-dependent inhalation *DCF* (rem CED per rem film badge dose, or rem CED Ci^{-1})
BF = Organ-specific bias adjustment factor for inhalation DCFs (Also see BF definition following Equation (17))

Table 6. Organ-Specific Inhalation *DCF* Bias Adjustment Factors, *BF*

Organ(s)	Alpha Radiation	Beta-plus-Gamma Radiation
Lung, breast, thymus, adrenals, spleen, liver, and pancreas	1.3	1.35
Extra-thoracic region	1.15	1.2
All FIIDOS organs not listed elsewhere in table	1.3	1.2

6. Data and Input

Operation- and shot-specific data are compiled in SOP Appendices A–C). The values of the input parameters for both the deterministic and probabilistic models are given in Attachment 2. Values for the time-dependent surface activity–intensity ratio, $FR(t)$, $\frac{AA}{I}(t)$, $DCF_{inh}(t)$, $DCF'_{inh}(t)$ and $DCF_{ing}(t)$ are provided in SOP Appendix H.

7. Referenced SOPs and Standard Methods from this Manual

(1) SOP RA01 - Radiation Dose Assessment for Cases Requiring Detailed Analysis

(2) SOP RA02 - Expedited Processing of Radiation Dose Assessments for Atmospheric Nuclear Weapons Testing Veterans

(3) SM ED01 - Film Badge Dose Assessment

(4) SM UA01 - Dose Uncertainty and Upper-Bound Dose Determinations

8. References

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Attachment 1.

Cross Reference of Organs, Tissues, and Diseases for Internal Dose Assessment

This attachment consists of Table A1-1 that lists potentially diseased organs and tissues, cross referenced to NTPR Standard Organs[3] for use in NTPR internal dose calculations. Some of the organs and tissues listed in the first column of the table correspond directly to NTPR standard organs (e.g., adrenal glands), for which FIIDOS DCFs are available. For other organs and tissues or diseases (e.g., arthritic tissue), FIIDOS DCFs are not available and surrogate organs have been determined. The surrogate organs or tissues were determined based on similarity to the anatomy, physiology, and biokinetics of the organs, tissues, and diseases for which there are no NTPR standard organs. Entries in the "NTPR Standard Organ Type" column of the table indicate whether the assignment in the NTPR Standard Organ column is an actual NTPR Standard Organ used in FIIDOS calculations ("**FIIDOS**"), or if it is an NTPR Standard Organ selected as a surrogate for the diseased organ ("Surrogate"). When conducting a dose assessment for an organ, tissue or disease listed in the first column, the DCFs for the identified NTPR standard organ should be used. More detailed rationale describing the technical association between the individual organs or diseases and the surrogate organs will be documented elsewhere in the future.

[3] A complete list of NTPR Standard Organs is listed in Table 1 of this SM.

Table A1-1. Cross Reference of Diseased Organs, Tissues and Diseases and Corresponding NTPR Standard Organs[*]

Organ, Tissue, or Disease	NTPR Standard Organ	NTPR Standard Organ Type[†]
Acute lymphocytic leukemia (ALL)	Red Marrow	Surrogate
Acute myeloid leukemia (AML)	Red Marrow	Surrogate
Adrenal glands	Adrenals	**FIIDOS**
Arthritic Tissue	Bone Surface	Surrogate
Bladder	Urinary Bladder Wall	**FIIDOS**
Blood, **bone marrow**, **red marrow**, yellow marrow, leukemia (excluding ALL, AML, CLL, and CML)[‡]	Red Marrow	**FIIDOS**, Surrogate
Bone, **bone surface**, endosteum, joints, and all other **bones** (e.g., ankle, **elbow**, **femur**, hand, jaw, **pelvis**, shoulder, spine, vertebrae)	Bone Surface	**FIIDOS**, Surrogate
Brain, anterior commissure, brain stem, cranial nerve	Brain	**FIIDOS**, Surrogate
Breast	Breast	**FIIDOS**
Cervix	Uterus	Surrogate
Chronic lymphocytic leukemia (CLL)	Spleen	Surrogate
Chronic myeloid leukemia (CML)	Red Marrow	Surrogate
Connective tissue	Muscle	Surrogate
Endocrine glands (endocrine glands not included elsewhere)	Specific diseased organ must be known.	Surrogate
Esophagus	ET Region[‡]	**FIIDOS**
Eye, choroid, retina	Brain	Surrogate
Gallbladder, bile duct	Liver	Surrogate
Heart, aorta, atrial sarcoma	Muscle	Surrogate
Kidney	Kidney	**FIIDOS**
Larynx, including glottis, vocal cords	ET Region[‡]	Surrogate
Lipoma	Muscle	Surrogate
Liver	Liver	**FIIDOS**
Lower large intestine, colon, **large intestine**	LLI Wall[‡]	**FIIDOS**, Surrogate
Lung, trachea	Lung	**FIIDOS**, Surrogate

Table A1-1. Cross Reference of Diseased Organs, Tissues and Diseases and Corresponding NTPR Standard Organs[*] (cont.)

Organ, Tissue, or Disease	**NTPR Standard Organ**	**NTPR Standard Organ Type[†]**
Lymph system, including lymph glands, lymph nodes, lymphatic tissue, lymphoma	Thymus (If this is primary disease)	Surrogate
Middle ear	Brain	Surrogate
Muscle, including, **thigh muscle**, eye muscle, eyelid muscle, neuro-muscular	Muscle	**FIIDOS**, Surrogate
Nasal cavities, including sinus (maxillary), sinus (nasal), nasal tip	ET Region[‡]	Surrogate
Nervous system, spinal cord, spine nerves	Brain	Surrogate
Neuroendocrine system, including hypothalamus, pituitary gland, pineal gland	Brain	Surrogate
Oral cavity and pharynx, including epiglottis, gum, hypopharynx, lip, mouth, nasopharynx, oropharynx, palate, parotid gland, pharynx, salivary gland, throat, tongue, tonsil, uvula, and nasolabial fold (specific disease needed if not skin cancer)	ET Region[‡]	Surrogate
Ovary	Ovary	**FIIDOS**
Pancreas	Pancreas	**FIIDOS**
Parathyroid	Thyroid	Surrogate
Peritoneum, peritoneal cavity muscle	Muscle	Surrogate
Pleura	Lung	Surrogate
Rectum, anus, anal canal	LLI Wall[‡]	Surrogate
Respiratory other than Lung	ET Region[‡]	Surrogate
Small intestine, duodenum	SI Wall[‡]	**FIIDOS**, Surrogate
Soft tissue, e.g., hip, shoulder, thigh, upper arm	Muscle	Surrogate
Spleen	Spleen (Use only if solid cancer of spleen is the primary disease)	**FIIDOS**
Stomach	Stomach Wall	**FIIDOS**
Testes and other male genitalia, including penis prostate, scrotum	Testes	**FIIDOS**, Surrogate

Table A1-1. Cross Reference of Diseased Organs, Tissues and Diseases and Corresponding NTPR Standard Organs[*] (cont.)

Organ, Tissue, or Disease	NTPR Standard Organ	NTPR Standard Organ Type[†]
Thymus	Thymus	**FIIDOS**
Thyroid	Thyroid	**FIIDOS**
Upper large intestine, including appendix, cecum	ULI Wall[‡]	**FIIDOS**, Surrogate
Urinary tract, urethra, ureter	Urinary Bladder Wall	Surrogate

[*] Based on Table Att 2-1 of SOP RA02.

[†] FIIDOS (in bold) means there are FIIDOS dose conversion factors (DCFs) for the organ(s) in bold. Surrogate means that DCFs for the NTPR Standard Organ are used for the non-bolded diseased organ(s).

[‡] ET=extra-thoracic, ALL = Acute lymphocytic leukemia, AML = Acute myeloid leukemia, CLL=chronic lymphocytic leukemia, CML = chronic myeloid leukemia, LLI=lower large intestine, SI=small intestine, ULI = upper large intestine.

Attachment 2.

Distributions and Deterministic Values of Model Parameters for Internal Dose Assessments

The values of input parameters to the internal dose models provided in Table A2-1 of this attachment are default numbers that are applicable in most cases. They should be adjusted or replaced for cases where veteran-specific data is available. These default parameter values were estimated or derived in Weitz et al. (2009) and other technical basis documents listed in the references section of that document.

The column labeled "Nominal Value for Central Estimation" contains model input values that can be used to calculate the central (best) estimate of a dose. These values are usually based on documented observed data or best estimates, and were used in building the statistical distributions for each uncertain parameter. For numerically-generated distributions, such as *GSMF*, *BR*, f_1, f_2, AF_{100}, etc., nominal values are the central estimates of those distributions, which are based on physical and mathematical models that characterize input parameters and their uncertainty and variability. Calculations of nominal doses provide point estimates using a dose reconstruction model with nominal values for all of its input parameters. In addition, nominal values are used as input parameters for model sensitivity analyses (Weitz et al., 2009).

Table A2-1. Distributions and Deterministic Values for Model Parameters for Internal Dose Assessments

Parameter	Definition	Distribution for Probabilistic Analysis	Nominal Value for Central Estimation	Deterministic*
SCENARIO PARAMETERS				
Dates and Times of Arrival and Departure from Assigned Location				
$Date_{Arrived}$	Start date[time]	Triangular Example min = Jun 19 [0000] mode = Jun 19 [1200] max = Jun 19 [2400]	Jun 19 [1200]	Jun 19 [0800]
$Date_{Departed}$	End date[time]	Triangular Example min = Jul 5 [0000] mode = Jul 5 [1200] max = Jul 5 [2400]	Jul 5 [1200]	Jul 5 [2400]
INTERNAL DOSE (GENERAL)				
Biasα	Bias factors to adjust high-sided inhalation DCF values	Assigned Constant (see Weitz et al. [2009] Table 14) ET region = 1.15 All other organs = 1.3	Assigned Constant (see Weitz et al. [2009] Table 14) ET region = 1.15 All other organs = 1.3	1.0
Biasβγ	Bias factors to adjust high-sided inhalation DCF values	Assigned Constant (see Weitz et al. [2009] Table 14) 1.35 for lung, breast, thymus, adrenals, spleen, liver, and pancreas 1.2 for all other organs	Assigned Constant (see Weitz et al. [2009] Table 14) 1.35 for lung, breast, thymus, adrenals, spleen, liver, and pancreas 1.2 for all other organs	1.0
BR	Breathing rate	Triangular distribution derived from USEPA (1997) data (see Weitz et al. [2009]) min = 0.33 $m^3\ h^{-1}$ mode = 1.53 $m^3\ h^{-1}$ max = 2.79 $m^3\ h^{-1}$	Mean of Distribution ~1.5 $m^3\ h^{-1}$	1.2 $m^3\ h^{-1}$
DCFInhα *DCFIngα*	Uncertainty in inhalation and ingestion dose conversion factors for fallout α emitters	*DCF*s calculated with FIIDOS multiplied by Lognormal GM = 1.0 [Weitz et al. (2009)] GSD = 7.91 (Kocher et al., [2009])	*DCF*s calculated with FIIDOS (see Weitz et al. [2009])	DCFs calculated with FIIDOS (see Weitz et al. [2009])

Table A2-1. Distributions and Deterministic Values for Model Parameters for Internal Dose Assessments (cont.)

Parameter	Definition	Distribution for Probabilistic Analysis	Nominal Value for Central Estimation	Deterministic*
DCFInhβγ *DCFIngβγ*	Uncertainty in inhalation and ingestion dose conversion factors for fallout β+γ radiation	*DCF*s calculated with FIIDOS multiplied by Lognormal GM = 1.0 (Weitz et al. [2009]) GSD = 4.05 (Kocher et al., [2009])	*DCF*s calculated with FIIDOS (see Weitz et al. [2009])	DCFs calculated with FIIDOS (see Weitz et al. [2009])
F_B	Film Badge Conversion Factor	n/a	0.7 for planar source 1.0 for facing a source	0.7 for planar source 1.0 for facing a source
INHALATION DOSE ABOARD SHIP				
GSMF	Topside-averaged gamma source modification factor to adjust radiation intensity for sources that are not infinite planes	Calculated distribution based on ship type and dimensions. (See Weitz [2010b])	Mode of Distribution from probabilistic analysis	2
DESCENDING INHALATION DOSE†				
AF_{100}	Fraction of total airborne activity in fallout for particles less than 100 µm aerodynamic diameter	Triangular (min, mode, max) Calculate for Series and Shot (See Weitz [2009])	Mode of Distribution from probabilistic analysis	1.0
f_1	Faction of AF_{100} in Class 1 sized (1–10 µm) particles	Triangular min = 0 mode = 0.00136 max = 0.01	Mode of Distribution 0.00136	n/a
f_2	Faction of AF_{100} in Class 2 sized (10–20 µm) particles	Triangular min = 0 mode = 0.025 max = 0.1	Mode of Distribution 0.025	n/a
f_3	Faction of AF_{100} in Class 3 sized (20–100 µm) particles	$1-(f_1+f_2)$	$1-(f_1+f_2)$	n/a
NR_1	Fraction of Class 1 sized (1–10 µm) particles deposited in Region ET2 and cleared to digestive tract	n/a	0.4	n/a
NR_2	Fraction of Class 2 sized (10–20 µm) particles deposited in Region ET2 and cleared to digestive tract	Lognormal GM = 0.363 GSD = 1.106	Geometric Mean 0.363	n/a
NR_3	Fraction of Class 3 sized (20–100 µm) particles deposited in Region ET2 and cleared to digestive tract	Lognormal GM = 0.285 GSD = 1.139	Geometric Mean 0.285	n/a

Table A2-1. Distributions and Deterministic Values for Model Parameters for Internal Dose Assessments (cont.)

Parameter	Definition	Distribution for Probabilistic Analysis	Nominal Value for Central Estimation	Deterministic*
R_1	Fraction of Class 1 sized (1–10 µm) particles deposited in Regions BB, bb and AI	n/a	0.1	n/a
R_2	Fraction of Class 2 sized (10–20 µm) particles deposited in Regions BB, bb and AI	Lognormal GM = 0.0056 GSD = 1.744	Geometric Mean 0.0056	n/a
R_3	Fraction of Class 3 sized (20–100 µm) particles deposited in Regions BB, bb and AI	Lognormal GM = 0.001 GSD = 1.754	Geometric Mean 0.001	n/a
H_0	Bottom of fallout cloud	n/a	10,000 m	10,000 m
V_1	Settling velocities for Class 1 sized (1–10 µm) particles	Logtriangular min = 3.96 m h^{-1} mode = 7.92 m h^{-1} max = 1000 m h^{-1}	7.92 m h^{-1}	H_0/time of arrival (m h^{-1})
V_2	Settling velocities for Class 2 sized (10–20 µm) particles	Logtriangular min = 14.94 m h^{-1} mode = 29.88 m h^{-1} max = 1000 m h^{-11}	29.88 m h^{-1}	H_0/time of arrival (m h^{-1})
V_3	Settling velocities for Class 3 sized (20–100 µm) particles	Logtriangular min = 234 m h^{-1} mode = 468 m h^{-1} max = 1000 m h^{-1}	468 m h^{-1}	H_0/time of arrival (m h^{-1})
RESUSPENDED INHALATION DOSE (LAND-BASED PERSONNEL)				
F_{os}	Fraction of time spent outside	Triangular min = 5/24 mode = 12/24 max = 18/24	0.5 (or 12/24)	0.6 (or 14.4/24)
I_i	Relative intensity distribution of fallout while outdoors (i = 1) and indoors (i = 2) normalized to average intensity at the location	Log-normal GM = 1.0 GSD = 1.5 (used with F_{os})	1.0	1.0
K(t)	Time-dependent resuspension factor	Lognormal multiplier of Equation 6 GM = 1 GSD = 4.05	Equation 6, or see Attachment 3 for values for surface activities	Equation 5, or see Attachment 3 for values for specific activities

Table A2-1. Distributions and Deterministic Values for Model Parameters for Internal Dose Assessments (cont.)

Parameter	Definition	Distribution for Probabilistic Analysis	Nominal Value for Central Estimation	Deterministic*
K_{bw}	Resuspension factor for fallout in blast wave region due to detonation effects	Log-normal Respirable: GM = 1.4×10^{-8} GSD = 25.6 Non-Respirable: GM = 6.3×10^{-8} GSD = 21.7	Respirable: $K_{bw} = 1.4 \times 10^{-8}$ Non-Respirable: $K_{bw} = 6.3 \times 10^{-8}$	Respirable & Non-Respirable: $K_{bw} = 1 \times 10^{-4}$
K_{tp}	Resuspension factor for fallout in thermal-pulse region due to detonation effects	Log-normal Respirable: GM = 1.6×10^{-6} GSD = 9.23 Non-Respirable: GM = 7.8×10^{-6} GSD = 7.22	Respirable: $K_{tp} = 1.6 \times 10^{-6}$ Non-Respirable: $K_{tp} = 7.8 \times 10^{-6}$	Respirable & Non-Respirable: $K_{tp} = 1 \times 10^{-3}$
INCIDENTAL INGESTION DOSE (LAND-BASED PERSONNEL)				
q_{ing}	Soil ingestion rate	Triangular min = 0 to 10 mg d^{-1} mode = 50 to 100 mg d^{-1} Max = 400–500 mg d^{-1}	100 mg d^{-1}	500 mg d^{-1}
ρ_{soil}	Soil bulk density	Triangular min = 1.3 g cm^{-3} mode = 1.45 g cm^{-3} max = 1.6 g cm^{-3}	1.45 g cm^{-3}	1.3 g cm^{-3}

* For deterministic dose models, high-sided (conservative) parameter values are selected to obtain upper-bound doses at least equal to the 95th percentile of a probability distribution.

† AMAD particle size classes: Class 1 = 1–10 μm, Class 2 = 10–20 μm, Class 3 = 20–100 μm.

Attachment 3.

Resuspension Factors for Typical Participant Activities in Contaminated Areas

Table A3-1 of this attachment provides specific resuspension factors as a function of work activity used by NTPR for NTS- and PPG-based activities. These activity-specific resuspension factors are adapted from the Reactor Safety Study (USNRC, 1975) and listed in DNA (1986, Table 5).

Table A3-1. Resuspension Factors for Typical Participant Activities in Contaminated Areas

Participant Category	Activity	Resuspension Factor (m^{-1})
Observers & Maneuver Troops	Touring display area after shot (on foot, or inside vehicle)	10^{-5}
Troops involved in Helicopter, Armored Vehicles, and Tank Maneuvers and Operations in Contaminated Areas	Assaults or marches involving armored vehicles, including tank occupants.	10^{-3}
Maneuver Troops Involving Helicopter Operations	Maneuvers involving helicopter landings/take off	10^{-3}
	Assaults or marches involving armored vehicles, including tank occupants	10^{-3}
	Crawl through open terrain	10^{-4}
	Dig foxholes, etc.	10^{-4}
	Ground assaults (no vehicle)	10^{-5}
	Trucking	10^{-5}
Project Troops	Dig out buried instrumentation/ equipment	10^{-4}
	Equipment/data recovery	10^{-4} –10^{-5}
	Decontamination projects (Bulldozing, etc.)	10^{-4}
	Visit project area (on foot or vehicle)	10^{-5}
Support Troops		
- Engineers/Ordinance	Dig trenches, install/dismantle displays	10^{-4}
- Communications	Lay wire (communications network)	10^{-4}
- Decontamination	Equipment/personnel decontamination	10^{-4}
- Transportation	Trucking	10^{-5}
- MP’s	Traffic control, security sweep	10^{-5}
- Rad-Safe	Survey area on foot or from vehicle	10^{-5}
Support Ships Small Transport Boats	Normal operations for the first 100 hours following the end of fallout deposition	10^{-5}
	Decontamination (SOP Appendix B-5 and Case Number 341533)	10^{-4}
CROSSROADS target ships	Decontamination; disposal	10^{-5}
Aircraft decontamination personnel	Decontamination of active operations; aircraft returning from cloud sampling and tracking; and other aircraft decontamination	10^{-4}