APPENDIX F - Intake Calculational Methodology, Dose of DU Calculational Methodology and Risk Characterization Methodology

F.1 Introduction

Material may enter the body through inhalation, ingestion, absorption through a wound in the skin, and fragment impaction (injection). Inhalation and ingestion are important routes of exposure for intake of DU on the battlefield. The contamination of wounds by DU is also important on the battlefield.

When the CEDE is calculated, W_T (see Appendix G) and radiation quality or weighting factors (see Appendix H) are used to convert the CDE to CEDE. To determine the resulting intake by inhalation, the following must first be calculated—

- Either direct measurement of the airborne concentration (C) or the average airborne C.
- Surface contamination activity (A) in units of area (A/m^2), which is a function of a resuspension factor.

The intake and dose calculational methodologies are discussed and examples are provided in this Appendix. The risk characterization methodology is also discussed in this Appendix.

F.2 Airborne Concentration of Material Released from an Enclosed Space or During Cleanup

The airborne C of material released from an enclosed space or during cleanup is calculated by the following equations. Appendix E discusses the source term which is the amount or quantity of material released as a result of hard target perforation or fire involving DU munitions.

$$Q = MAR * ARF$$

Where:

- Q = The amount of material (μCi or mg) released at time zero (t = 0).
- MAR = Total amount of material (μCi or mg) available for release.
- ARF = Airborne release fraction (see Appendix E).

In the case of a fire, the ARF is assumed to be 0.1 percent (or 0.001) for most materials; however, for solid materials in a protective device or enclosure, a value of 0.01 percent (or 0.0001) is assumed.

The airborne C ($\mu Ci/m^3$ or mg/m^3) of material that is instantaneously released into the air is given by the following equation.

$$C = \frac{Q}{V * k * t}\left(1 - e^{-kt}\right)$$

Where:

- C = The average airborne concentration ($\mu Ci/m^3$ or mg/m^3)
- Q = Amount of material (μCi or mg) released at t = 0
- k = Ventilation rate (1/hr)
- t = Time of exposure or the time over which C is averaged (hr)
- V = Volume of air into which the material is dispersed (m^3)

For cleanup following a fire or other surface-contaminating event, the average airborne C ($\mu Ci/m^3$ or mg/m^3) is given by the following equation.

$$C = K_t * S$$

Where:

- C = Airborne concentration ($\mu Ci/m^3$ or mg/m^3)
- K_t = Resuspension factor (1/meter)
- S = Surface contamination per unit area ($\mu Ci/m^2$ or mg/m^2)

For resuspension factors see Part III, Section 3.3.1 and Appendix I.

When the contaminant is uniformly mixed within the top 1 cm of soil or more, the mass-loading model is preferrred[9]. In the mass-loading model, the amount of material that is resuspended in the air is estimated by measuring the concentration of the contaminant in the soil (µg of DU/µg of soil or pCi of DU/µg of soil)[9] and a concentration in air (pCi/m or µg/m). Hence, the airborne C of the contaminant of interest, C, is given by:

$$C = C_m * C_p$$

Where:

C	=	Airborne concentration ($\mu g/m^3$ or pCi/m^3)
C_m	=	Concentration of contaminant in µg per µg of soil ($\mu g/\mu g$ or $pCi/\mu g$)
C_p	=	Concentration of contaminant in air ($\mu g/m^3$ or pCi/m^3)

This mass-loading model cannot be used unless the amount of contaminant in the soil and the amount of contaminant in the air are known. This model is not applicable for estimating resuspension outside a vehicle or structure, because the contamination is not uniformly distributed on the battlefield. Typically, "hot spots" or areas of elevated measurements will be found on the battlefield.

Values for C_p range from 9 $\mu g/m^3$ to 79 $\mu g/m^3$. However, 100 $\mu g/m^3$ has been recommended as a general value for predictive purposes[18].

See Appendix I for other resuspension calculational models.

F.3 Dose Calculational Methodology

Because the airborne C changes very fast due to gravitational settling and mixing, use of an average value is more appropriate.

- The factors involved in calculating the CEDE resulting from inhalation are described by the following two equations:

For Exposure Mode (1) -

$H_{E,50}$ = [Exposure Duration (hr)]
* [Airborne C ($\mu g/m^3$ or pCi/m^3]
* [Volumetric BR (m^3/hr)]
* [Inhalation DCF]
* [Unit Conversion Factors]
* [Organ or Tissue Weighting Factor]
* [RF]

For Exposure Modes (2) and (3) -

$H_{E,50}$ = [Exposure Duration (hr)]

* [Average Surface Contamination A per Unit Area (A/m^2)]

* [Resuspension Factor for Surfaces (1/meter)]

* [Volumetric BR (m^3/hr)]

* [Inhalation DCF]

* [Unit Conversion Factors]

* [Organ or Tissue Weighting Factor]

* [RF]

- The factors involved in calculating the CEDE from secondary or inadvertent ingestion (hand-to-mouth), from surface contamination, are described by the following equation:

$H_{E,50}$ = [Exposure Duration (hr)]

*[Average Surface Contamination A per Unit Area (A/m^2)]

*[Effective Transfer Rate for Hand-to-Mouth Ingestion (m^2/hr)]

*[Ingestion DCF]

*[Unit Conversion Factors]

*[Organ or Tissue weighting factor]

*[GI Transfer Coefficient]

F.4 Secondary Ingestion (Hand-to-Mouth) Calculational Methodology for OSAGWI Level I Scenarios

The assumption made is that "if the contaminant got on his hands, he ate it." The exposure duration would be the amount of time that he spent in a vehicle. The area of both hands is 0.084 m^{2} [10, 42]. However, it is also assumed that only the palms of the hands (0.042 m^2) were contaminated and that from 0 to 100 percent of the DU contaminant was transferred from hands-to-mouth. The assumed secondary ingestion effective transfer rate for loose or removable DU surface contamination is 1 x 10^{-4} m^2/hr of exposure; however, this value may not be appropriate for an acute contamination event. Therefore, this ingestion transfer rate was not used in the calculation of the intake for the Level I Scenarios. The average value of the surface-contamination levels was used in estimating the intake of DU.

Since secondary ingestion intake is via mouth to GI tract, the GI transfer coefficient for uranium or DU is employed to calculate the uptake to blood. The GI transfer coefficients for soluble uranium or DU of Class D and W (or Type F and M) is 2 percent. For insoluble Class Y (or Type S), the GI transfer coefficient is 0.20 percent. The approach, as used in this report, is consistent with Federal Guidance Report No. 11 and International Atomic Energy Agency (IAEA) Safety Series 115. It is also recognized that the ICRP in ICRP-72 does not differentiate between the GI transfer coefficient for ingestion because of the solubility of the various forms of uranium or DU. ICRP-72 states that the GI transfer coefficient for ingestion is 2 percent for the various forms of uranium or DU.

Removable surface-contamination data generated from the Fliszar et al., (1989) Test 5A were used to estimate the hand-to-mouth transfer for secondary ingestion. The greatest removable radioactivity found on the vehicle surface after Test 5A was used.

- **Assumptions:**

  - 100 percent of the DU contamination of the hands was transferred (upper bound).
  - 50 percent of the DU contamination on the hands was transferred (lower bound).
  - Removable activity of 4,815 dpm/100 cm^2, Fliszar et al., (1989).
  - Only the underside or palm of the hand was considered, which is equivalent to 0.042 m^2 (or 420 cm^2).
  - 83 percent of the DU oxide is insoluble (Class Y or Type S).
  - 17 percent of the DU oxide is soluble (Class W or Type M).

Because data from a DU-on-DU test are used to estimate hand-to-mouth transfer, it is believed that the approach used is very conservative. Another conservative approach is that all DU on the hands (both hands - palm side) was transferred via hand-to-mouth. With these assumptions, an upper-bound value for secondary ingestion (hand-to-mouth) was calculated.

The upper-bound calculation to determine the intake of DU via hand-to-mouth transfer from secondary ingestion is as follows:

$$\left(\frac{4815 dpm}{100 cm^2}\right) * \left(0.042 m^2\right) * \left(\frac{10{,}000 cm^2}{1 m^2}\right) * \left(\frac{1 \min}{60 \sec}\right) * \left(\frac{1 Bq}{1 dps}\right) = 337 Bq$$

$$\left(337 Bq\right) * \left(\frac{27 pCi}{Bq}\right) * \left(\frac{1 mg}{0.38 pCi}\right) = 2.4 \; x \, 10^4 \, mg \cong 24 mg$$

Where:

- dpm – disintegrations per minute
- dps – disintegrations per second
- cm^2 – square centimeters
- m^2 - square meters
- min – minutes
- sec – seconds
- mg - milligrams
- µg - micrograms
- pCi – picocuries
- Bq - bequerels

Total: (24 mg)

Insoluble: (0.83) * *24 mg) = 20 mg

Soluble: (0.17) * (24 mg) = 4 mg

For the lower-bound estimate of secondary ingestion (hand-to-mouth), approximately 50 percent of the DU contamination on the hand was assumed to be transferred (12 mg).

Total: (12 mg)

Insoluble: (0.83) * (12 mg) = 10 mg

Soluble: (0.17) * (12 mg) = 2 mg

F.5 Secondary Ingestion (Hand-to-Mouth) Calculational Methodology for OSAGWI Levels II and III Exposure Scenarios

For Levels II and III individuals, it is assumed that any exposure to DU may have constituted an intermittent rather than an acute exposure. Therefore, the secondary ingestion effective transfer rate for loose removable DU-surface contamination was applied (1×10^{-4} m^2/hr of exposure). The exposure duration would be the amount of time spent in a vehicle. The area of both hands is 0.084 m^2. However, it was assumed that only the palms of the hands (0.042 m^2) were contaminated.

Since secondary ingestion is via hand-to-mouth to GI tract, the GI transfer coefficient for uranium or DU is used to calculate the uptake to blood. The GI transfer coefficients for soluble uranium or DU or of Class D and W (or Type F and M) is 2 percent. For insoluble Class Y (or Type S), the GI transfer coefficient is 0.20 percent. The approach, as used in this report, is consistent with Federal Guidance Report No. 11 and IAEA Safety Series 115. It is also

recognized that the ICRP in ICRP-72 does not differentiate between the GI transfer coefficient for ingestion because of the solubility of the various forms of uranium or DU. ICRP-72 states that the GI transfer coefficient for ingestion is 2 percent for the various forms of uranium or DU.

Removable surface-contamination data generated from Fliszar et al., (1989) Test 5A were used to estimate the hand-to-mouth transfer for secondary ingestion. Data for the greatest removable radioactive contamination found on the vehicle surface after Test 5A were used.

- **Assumptions:**

  - Effective transfer rate for loose removable contamination (1×10^{-4} m^2/hr of exposure).
  - Removable activity (upper bound) 4,815 dpm/100 cm^2, Fliszar et al., (1989).
  - Only the underside or palm of the hand was considered, which is equivalent to 0.042 m^2.
  - Both hands were considered.
  - 83 percent of the DU oxide is insoluble (Class Y or Type S).
  - 17 percent of the DU oxide is soluble (Class W or Type M).

Because data from a DU-on-DU test are used to estimate hand-to-mouth transfer, it is believed that the approach is very conservative.

Depleted uranium munitions involved in fires tend to produce more insoluble oxides as opposed to hard target impacts resulting in no fire (93 percent insoluble and 7 percent soluble versus 83 percent insoluble and 17 percent soluble). Secondary ingestion entails direct contact with a contaminated surface and the removal of the material by the hand(s) and consequent transfer to the mouth. Entry into damaged vehicles would have occurred at some time after the vehicle was impacted and stopped burning. Because it is not known exactly how long after impact and/or fire did entry occur, it was assumed that weathering of the oxide may have taken place. The scientific literature indicates that weathering or corrosion of DU oxides may increase the solubility. Also, it is not known to what extent the fire damage was to vehicles and to which damaged vehicles were entered (more the case for the Level III personnel). In considering these unknowns, the DU-oxide mixture used for secondary ingestion was chosen to be 83 percent insoluble and 17 percent soluble. From a radiation dose standpoint, the secondary ingestion dose from 93 percent and 83 percent insoluble DU oxide does not vary greatly. From a chemical toxicity standpoint involving secondary ingestion of DU oxides, the difference in the kidney concentration is greater, from 7 percent to 17 percent.

To adjust for contamination on the palm of the hands, the surface removable contamination per 100 cm^2 was normalized to the area of the hand that was contaminated:

$$\frac{4815\,\text{dpm}}{100\,\text{cm}^2} * (420\ \text{cm}^2) = 20{,}223\ \text{dpm}$$

Therefore, the upper-bound calculation to determine the intake of DU via hand-to-mouth transfer from secondary ingestion is as follows:

$$\left(\frac{20223\text{dpm}}{0.042\text{m}^2}\right)*\left(\frac{1\text{min}}{60\,\text{sec}}\right)*\left(\frac{1\text{Bq}}{1\text{dps}}\right)*\left(\frac{1\text{E}-4\text{m}^2}{\text{hr}}\right)*(1\text{hr})=0.8\text{Bq}$$

$$(0.8Bq)*\left(\frac{27\,pCi}{Bq}\right)*\left(\frac{1mg}{0.38\,pCi}\right)\cong 0.057mg$$

Where:

- dpm – disintegrations per minute
- dps – disintegrations per second
- cm^2 – square centimeters
- m^2 – square meters
- min – minutes
- sec – seconds
- mg – milligrams
- µg – micrograms
- pCi – picocuries
- Bq – bequerels

Total: (0.057 mg)

Insoluble: $(0.057 \text{ mg})(0.83) \cong 0.047 \text{ mg}$

Soluble: $(0.057 \text{ mg})(0.17) \cong 0.01 \text{ mg}$

The upper-bound dose estimate for a secondary ingestion intake of 0.057 mg (83 percent insoluble and 17 percent soluble) of DU is calculated as follows:

$$(1.61 \times 10^{-5} \text{ rem/mg} * 0.047 \text{ mg}) + (1.24 \times 10^{-4} \text{ rem/mg} * 0.01 \text{ mg}) =$$

$$2 \times 10^{-6} \text{ rem or } 0.000002 \text{ rem}$$

For the lower-bound estimate of secondary ingestion (hand-to-mouth), approximately 50 percent of the DU contamination on the hand was assumed to be transferred (0.025 mg).

To adjust for contamination on the palm of the hands, the surface removable contamination per 100 cm^2 was normalized to the area of the hand that was contaminated:

$$\frac{2408\,\text{dpm}}{100\,\text{cm}^2} * \left(420\,\text{cm}^2\right) = 10112\,\text{dpm}$$

Therefore, the lower-bound calculation to determine the intake of DU via hand-to-mouth transfer from secondary ingestion is as follows:

$$\frac{10112\,\text{dpm}}{0.042\,\text{m}^2} * \frac{1\,\text{min}}{60\,\text{sec}} * \frac{1\,\text{Bq}}{1\,\text{dps}} * \frac{1\text{E}\quad 4\,\text{m}^2}{\text{hr}} * (1\,\text{hr}) = 0.4\,\text{Bq}$$

$$(0.4\ \text{Bq}) * \frac{27\,\text{pCi}}{\text{Bq}} * \frac{1\mu\text{g}}{0.38\,\text{pCi}} \cong 0.028\ \text{mg}$$

Where:

- dpm – disintegrations per minute
- dps – disintegrations per second
- cm^2 – square centimeters
- m^2 – square meters
- min – minutes
- sec – seconds
- mg – milligrams
- µg – micrograms
- pCi – picocuries
- Bq – bequerels

Total: (0.028 mg)

Insoluble: (0.028 mg)(0.83) ≅ 0.023 mg

Soluble: (0.028 mg)(0.17) ≅ 0.005 mg

The lower-bound dose estimate for a secondary ingestion intake of 0.028 mg (83 percent insoluble and 17 percent soluble) of DU is calculated as follows:

$$(1.61 \times 10^{-5} \text{ rem/mg} * 0.023 \text{ mg}) + (1.24 \times 10^{-4} \text{ rem/mg} * 0.005 \text{ mg}) =$$

$$1 \times 10^{-6} \text{ rem or } 0.000001 \text{ rem}$$

F.6 Direct Ingestion Intake and CEDE from the Intake of DU-Contaminated Soil for OSAGWI Exposure Scenarios

The intake of DU via the direct ingestion of contaminated foodstuffs, water, and soil may result in a small dose from the intake of DU residue on the battlefield. The total soil ingestion rate is assumed to be equal to that which would occur in a construction site. The NCRP in NCRP Report 129 has suggested an ingestion intake rate of 100 mg of soil per day for an adult. A lognormal distribution is assumed to represent a range of possible alternative values, with a σ_g of 3.2 for an adult. This degree of uncertainty in the upper 95th percentile would result in an ingestion intake rate of 1,024 mg/d (100 mg $*$ 3.2^2). The average concentration (or volume activity or mass) of DU in the top 5 cm of soil must be determined. If the average workday were assumed to be 10 hr/d, then the ingestion intake rate would be about 10 mg/hr to 100 mg/hr. This exposure assessment does not address direct ingestion of foodstuffs, soil, or water that may have been contaminated with DU, because data were not available to estimate the intake.

However, an example of an intake and the CEDE is provided for the ingestion of soil. The calculation of the direct ingestion dose is described by the following equation:

$H_{E,50}$ = [Exposure Duration (hr)]

*[Effective Ingestion Transfer Rate (μg/hr, L/d or g/d, or mg/hr)]

*[Ingestion DCF]

*[Mean Volume Activity (or Mass) (pCi/g or μg/g and pCi/L or μg/L)]

*[Unit Conversion Factors]

*[Organ or Tissue Weighting Factor]

*[GI Transfer Coefficient]

As an example, the intake and radiation dose that an individual would receive due to ingestion of soil from working in a contaminated area for 100 hrs would be as follows:

- **Assumptions:**

  - DCF = 1.61×10^{-5} rem/mg (insoluble) (See Appendix J.)
  - DCF = 1.24×10^{-4} rem/mg (soluble) (See Appendix J.)
  - Soil Concentration = 0.1 mg of DU/mg of soil
  - Effective Soil Ingestion Rate = 10 mg/hr
  - Exposure Time = 10 hr/d
  - Exposure Duration = 100 hrs
  - Percent Insoluble = 83% (or 0.83)
  - Percent Soluble = 17% (or 0.17)

- GI Tract Transfer Factor for Soluble DU = 0.02
- GI Tract Transfer Factor for Insoluble DU = 0.002

The CEDE due to ingestion of contaminated soil is calculated according to the following equation:

$$D = (DCF * SC * SIR * ET * ED * SF) + (DCF * SC * SIR * ET * ED * SF)$$

Where:

- D = CEDE (rem) (or $H_{E,50}$)
- DCF = Ingestion dose conversion factor (rem/mg DU) based on solubility
- SC = Soil mass concentration (mg DU/mg soil)
- SIR = Soil ingestion rate (100 mg/d to 1,020 mg/d)
- ET = Exposure time (hr/d)
- ED = Exposure duration (hr)
- SF = Solubility fraction

The CEDE for the parameters above is—

D = $[(1.61 \times 10^{-5}$ rem/mg) ∗ (0.1 mg DU/mg soil) ∗ (10 mg/hr) ∗ (100 hrs) ∗ (0.83)] + $[(1.24 \times 10^{-4}$ rem/mg) ∗ (0.1 mg DU/mg soil) ∗ (10 mg/hr) ∗ (100 hrs) ∗ (0.17)]

= $(1.34 \times 10^{-3}$ rem) + $(2.11 \times 10^{-3}$ rem)

= 3.45×10^{-3} rem (or 0.00345 rem)

For an intake of 100 mg (0.1 ∗ 10 ∗ 100) the CEDE would be 0.00344 rem (100 mg ∗ 3.44×10^{-5} rem/mg).

As a first approximation, the intake by direct ingestion (μCi or mg) is estimated to be 1×10^{-4} * A, where A is the total amount (μCi or mg) of available MAR.

See Appendix J for the derivation of the ingestion DCFs.

- The factors involved in calculating a CEDE resulting from wound contamination (except for embedded DU fragments) are described by the following equation:

$H_{E,50}$ = [Exposure Duration (hr)]

*[Average Activity in the Wound per Unit Area (A/cm^2)]

*[Ingestion DCF]

*[Area of the Wound (cm^2)]

*[Unit Conversion Factors]

*[Organ or Tissue Weighting Factor]

- The factors involved in calculating the TEDE, which is the sum of the contributions from all exposure pathways, are shown in the following equation:

TEDE = [H_d, the External Deep Dose]

+ [$H_{E,50}$ for Inhalation]

+ [$H_{E,50}$ for Ingestion]

+ [$H_{E,50}$ for Wound Contamination Excluding Fragment Impaction]

+ [$H_{E,50}$ from Embedded Fragments Impaction]

F.7 Wound Assessment

Because of differences in the route of exposure, commonly tabulated values of inhalation or ingestion limits on intake cannot be applied to DU intake via a wound. A wound as used herein means trauma/injury to any of the tissues of the body, especially the skin. A wound may be a cut, puncture, perforation, or abrasion that does not involve embedded DU metal fragments. A

wound must be treated as a unique situation, and the dose assessed must be based on wound-site in vivo measurements and follow-up bioassay measurements, which are appropriate for the radionuclide. For dose calculations, it is assumed that 10 percent of the activity deposited in a wound is transmitted/translocated to the general circulation system; the remainder will be in the wound compartment. This value is conservative and the uncertainty associated with it is unknown.

Wounds should be modeled as an initial wound-site deposition in one or more compartments, each having a clearance half time, generally to the transfer compartment. Wound measurements made over several days following the injury can be used to establish the initial clearance rate and to identify the appearance of long-term compartments. In many cases wounds are treated by extensive flushing and, on occasion, minor surgical debridement. Using the follow-up wound measurement data to extrapolate back to the initial deposition at the time of the injury can result in underestimating the intake, owing to the fact that a very rapid uptake component might be missed. Additional in vivo and excreta bioassay measurements appropriate for the radionuclide should be obtained to fully evaluate this possibility.

If the wound(s) were contaminated with DUO_2 or DU_3O_8, both of which are considered relatively insoluble in tissue fluid, it is likely that continued measurements would show a long-term residual contamination at the wound site. As such, the contaminant may be bound-up in scar tissue. It should be noted that relatively small particles of insoluble material could translocate through the lymphatic system to regional lymph nodes. Skin contamination and the

translocation of material to the lymph nodes may reduce the capability of in vivo bioassay to measure the inhalation intakes because of the potential interference.

The wound DCFs listed below for Pu, uranium, and other radionuclides are based on the assumption that all of the activity deposited in a wound goes directly and immediately into the blood, where it then becomes distributed as specified in the biokinetic models in ICRP-30. Tables F-1, F-2, and F-3 provide dose conversion uptake factors for radionuclides found in the DU exposure scenarios. The radionuclides other than uranium or DU are for the trace contaminants in the DU metal. However, these trace contaminants do not contribute more than 1.0 percent to the dose from DU.

Table F-1. DCFs for Wound Uptakes of Pu

Radionuclide	rem/μCi Uptake (CEDE)
Pu-238	3,470
Pu-239	3,470
Pu-240	3,500
Pu-241	70
Pu-242	3,300
Am-241	3,600

Table F-2. DCFs for Wound Uptakes of Radionuclides

Radionuclide	rem/μCi Uptake (CEDE)
Np-237	4,070
Tc-99	1.46

Table F-3. DCFs for Wound Uptakes of Uranium

Radionuclide	rem/μCi Uptake (CEDE)
U-234	5.2
U-235	4.8
U-236	4.8
U-238	4.7
U_{nat}	4.7
DU	4.7

F.8 Intake of DU Calculational Methodology for USACHPPM Interim DU Exposure and Health Risk Characterization

The USACHPPM Interim Health Risk Assessment, 3 August 1998, stated that an individual in an OSAGWI Level I Exposure Scenario would have an inhalation intake of 26 mg of DU over a 15-minute period. This estimated intake of 26 mg was derived from the Fliszar et al., (1989) report, according to the following process:

- When assessing the intake data (Commander-21,000 μg, Gunner-26,000 μg, and Driver-19,000 μg) in Table C-5 of Fliszar et al., (1989) report and Table 20, Part IV of this report, the values are essentially the same order of magnitude. If the three values are added together and averaged, the resultant intake value is 22,000 μg. This average value agrees well with the 19,000 μg intake calculated by Fliszar et al., (1989) for the Driver's Compartment where the air sampler ran for 2 minutes. The standard deviation of the three intakes is rounded to ± 4,000 μg. Adding one standard deviation (+ 4,000 μg) to the average value (of the three samples) 22,000 μg gives an estimated intake value of 26,000 μg or 26 mg.

- This estimated intake of 26 mg is considered to be the best value for both the Driver and Crewmembers. The value of 26 mg for the Gunner's position, the highest value reported, is not the only value used. The small interior air volume (~ 7.6 m^3), the operation of the NBC System, the equilibrium of the DU air concentration in the vehicle, and the reasonable circulation of the air throughout the two compartments were all considerations in using an average inhalation intake value of 26 mg. All data points were averaged, rather than using only one data point, to provide a better estimation of the amount of DU that may have been internalized. This is a bounding estimate for risk assessment and not a dose reconstruction for the individuals in the tank.
- In considering the air sampler times and the review of the Fliszar et al., (1989) data, the best estimate of the air samplers' run-time or duration, which may or may not have been recorded, is two minutes or less for all three air-sampler positions for Test 5A. Once the air samplers shut off, there would be a minimum collection of the contaminant on the air filter because of the residual vacuum on the pump. There is no way to speculate how high the values for filter amounts could have been if the air samplers had continued running for the exposure duration. Therefore, a reasonable estimate of the DU intake value, used in USACHPPM's August 1998 Interim Report is the 26 mg, because the exact location of the Crewmembers in the vehicle at time of perforation is unknown except for the Driver.
- The estimated intake values of a contaminant can be calculated by dividing the average BR (or ventilation rate) by the air sampler average FR and multiplying that value by the quantity of DU measured on the air sampler filter after correcting for FCE. The air sampler time duration is not a factor in this equation; however, the exposure time and the sampling time must be the

same. It is important to note that there is a decrease in the air concentration through time due to gravitational settling and mixing of the DU particles, based on particle size. During the first minute or two after perforation, the hot gases and DU particles burn out and cool, getting larger in size as they coagulate and agglomerate, resulting in a reasonable gravitational settling and mixing of the DU particles in the first several minutes.

- The use of a 15-minute exposure duration may be too long for individuals exiting an impacted Abrams tank. Two minutes is a more reasonable time period. The 15-minute period was chosen as an upper bound for an injured crewmember that could not rapidly exit the vehicle and First Responders who came to their assistance.

The following contribute to the uncertainties associated with the use of the Fliszar et al., (1989) published Test 5A data in estimating the intake of DU for the Level I scenarios (see Table 20 and Table 21, Part IV of this report).

- Actual run-time of the air samplers? Unknown. Some data not recorded.
- Actual air sampling rate? Post-run calibration was not performed. Reported values were used.
- Had peak concentration of DU in the Crew Compartment been attained prior to the air samplers shut off? Unknown.
- Orientation of the air sampler heads during perforation? Unknown.

- What would have been the DU-airborne C in the Driver's and Crew Compartments if the NBC System had not been in operation during Test 5A? Unknown.
- Conditions of air sampler equipment after Test 5A?

    - Leaking tube connection at cassette bottom (Commander's air sampler).
    - Tubing collapsed and burned (Loader's area air sampler).
    - Waxy coating and burned or flame-damaged filters (Loader's air sampler).
    - Air sampler filter for the Loader's position was not analyzed.

F.7 Radiation Risk Characterization Methodology

Calculating the risk from material released into the environment involves several components of a generic equation that must be known or assumed. The degree of uncertainty for calculating a risk will increase as the number of assumptions that are factored into the equation increases. The generic equation employed to calculate risk is[43]:

$$\text{Risk} = (S * T * U * E * D * R)_{uvcpm}$$

Where:

- S = Source term (characterization of the type, quantity, and temporal distribution of the material released)

- T = Environmental transport and fate of contaminants
- U = Usage factors
- E = Exposure duration
- D = Conversion to dose
- R = Conversion of dose to risk
- u = Uncertainty and sensitivity analysis
- v = Validation
- c = Communication of results
- p = Public participation
- m = Management and decision making

The source term (S) is the key to an HRA and is typically derived from as many independent directions as possible. Therefore, the existence of quality data that adheres to the requirements for determining the source term in calculating risk is crucial.

The environmental transport and fate of contaminants (T) is the mechanism by which materials are transported and usually determines the ultimate fate of the material in the environment. Atmospheric, surface water, ground water, and the food chain are mechanisms in which materials are transported.

Usage factors (U) involve the characteristics of the individuals exposed. Examples of these characteristics are age group, BR (or ventilation rate) of individuals, and SIR. The usage factors may be site and time specific.

Exposure duration (E) is the total exposure time and the frequency of exposures.

Dose conversion (D) utilizes the DCFs for the contaminant in question. The USEPA has published DCFs for external exposure to radionuclides as well as DCFs for inhalation, submersion, and ingestion of radionuclides in Federal Guidance Report No. 11. The USEPA has calculated slope factors to be used to estimate risk from exposure to chemicals and radioactive materials. (See Appendix J for the calculation of DCFs.)

Conversion to risk (R) utilizes risk factors based upon the amount of exposure the individual has received from both the internal and external contribution of dose. There are several risk models that are used. These risk models vary slightly in the assumptions and parameters employed in associating a risk from exposure to ionizing radiation. (See Appendix G for a discussion of risk coefficients.)

Uncertainty (u) and sensitivity analysis identifies the importance of changes in the parameters and values used to estimate confidence intervals in the overall exposure assessment. (See Appendix O for a discussion of selected inputs to the uncertainty and sensitivity analysis for OSAGWI Level I scenarios.)

Validation (v) utilizes measured or recorded data to confirm or complement results that are based on a variety of assumptions utilized in a mathematical equation. This is especially true when computer models are employed. It is important that computer models also be verified by hand calculations. Measured or experimental data as well as other default parameters are usually used to accomplish this.

Communication of results (c) is a qualitative measure by which the end result is presented to interested parties. When communicating results ("Risk Communication"), it is important to consider the audience of interest. Results should be conveyed on a level such that the audience can understand and relate.

Public participation (p) is a qualitative measure that can enhance the audience's understanding of the process by which a dose and risk are assessed. Public participation can lead to a greater degree of credibility of the end results or product. Public participation at the beginning of the project is more desirable when considering credibility. The OSAGWI continues to meet with representatives of various Veterans' Service Organizations to apprise them of the progress regarding OSAGWI's projects, including issues with DU.

Management and decision making (m) is a qualitative measure by which the results are presented to management. After considering all the input into the risk equation, a decision is made by the responsible individual. (See FM-100-14.)

It should be noted that because of the uncertainties associated with battlefield conditions only a health risk characterization could be performed. This will include upper and lower bounds for the radiological and chemical hazards from exposure and intake of DU residue.