APPENDIX Q - Summary of Sensitive Parameters Used in Depleted Uranium Assessment of OSAGWI Level I Scenarios

Q.1 Introduction

The sensitive parameters used in the exposure assessment to estimate exposure intake and characterize risks from possible DU exposures in the Gulf War have been categorized into three primary groups: (1) Source Term Parameters, (2) Physiological Parameters, and (3) General Parameters.

Q.1.1 Source Term Parameters

Source term parameters are those that pertain to the initial quantity of DU available for an exposure and the physical and chemical processes involved in DU residues being produced as a result of a fratricide incident. Seven sensitive source term parameters have been identified as follows:

- Type of DU munition (mass)
- Isotopic and elemental composition of DU and residue
- DU armor
- Airborne Release Fraction
- Respirable Fraction
- Chemical form
- Particle size

Q.1.2 Physiological Parameters

Physiological parameters are those that pertain to biological factors associated with internalizing DU in an individual. Twelve sensitive parameters have been identified as follows:

- Reference Man
- BR or ventilation rate (type of exercise or exertion)
- Type (or route) of breathing (nose or mouth)
- Exposure duration
- Frequency of exposure
- Particle size distribution
- Solubility of DU in lung fluid (chemical form)
- ICRP respiratory tract model(s)
- ICRP biokinetic model(s)
- Intake
- Weighting Factors (organ and radiation)
- Radiation internal dose (first year and fifty-year)

Q.1.3 General Parameters

- EC/NBC System
- Fire suppression system
- Vehicle integrity

Q.2 Assessment of Parameters

Q.2.1 Source Term Parameters

- **<u>Type of DU munition</u>**

  - Several DU munitions were fielded at the time of the Gulf War. The DU munition that was used in the USACHPPM exposure assessment was the 120mm DU penetrator fired from the Abrams tank platform.
  - The 120mm DU munition had an average mass of 4.7 kg of DU as compared with the other DU munitions expended in Southwest Asia. In addition, all of the fratricide incidents during the Gulf War involved the 120mm DU munitions, OSAGWI, (1998).
  - Developer test data from a 120mm DU munition were used in the exposure assessment. Therefore, it is more accurate to use the 120mm DU munition to assess exposure and characterize risk to individuals involved in fratricide incidents.

- **<u>Isotopic and Elemental Composition of Uranium and Other Isotopes in DU and DU Residue</u>**

  - Depleted uranium is a byproduct of the uranium enrichment process. During the enrichment process, the uranium isotopes in U_{Nat}, which are useful for fissionable applications, are removed. The result is a byproduct referred to as DU.

- The isotopic composition of DOD DU munitions is based on an analysis performed on a DU penetrator by ORNL (99.8 percent U-238, 0.2 percent U-235, 0.0006 percent of U-234 and 0.0003 percent of U-236).
- There may be other contaminants in DU that are the result of reprocessing nuclear fuel. These contaminants are present in trace quantities based on current data. These contaminants (Pu-238, Pu-239, Pu-240, Am-241, Np-237, and Tc-99) will add less than 1 percent to the dose and are inconsequential from a chemical toxicity standpoint. (See Memorandum For Record, 7 August 2000.)
- The elemental composition of aerosols from hard-target DU perforations frequently contain iron, aluminum, silicon, Ca, magnesium, potassium, and tungsten as a result of contamination during impaction or perforation. The contaminants are inconsequential from a dose or chemical toxicity standpoint, but they may influence the solubility of the DU compounds.
- The rate and conditions of DU oxidation influence both the particle size distribution and the solubility of the DU oxide in interstitial lung fluid. At ambient temperatures, the rate of oxidation is slow and non-linear. The initial layer of the oxide that is formed on the DU metal is the rate of oxygen diffusion to the metal-oxide interface. The DUO_2 is subsequently oxidized to non-adherent DU_3O_8 that can be detached from the surface of the DU metal. The DU_3O_8 can be oxidized to thermodynamically stable DUO_3. The presence of water vapor is postulated to form -OH and H_2 at the DU oxide–atmosphere interface. The –OH will penetrate through the DU oxide layer and the –H reacts with the DU metal. The DUH_2 formed is oxidized by the –O releasing the H_2 for further penetration and reaction. The slower the oxidation (or corrosion), the finer or the smaller the particle size distribution.

Oxidation at temperatures that are higher than ambient may generate a coarser or larger particle size distribution and less soluble DU oxides.

- **Armor Package**

- Fratricide incidents during the Gulf War involved the Abrams tank and the BFV.
- The BFV is less armored than the Abrams. Interviews of individuals and battle damage assessments regarding fratricide incidents with these armored vehicles vary.
- The Abrams tank offers more resistance to anti-tank munitions than the BFV does. This aspect leads researchers to believe that a greater amount of aerosolized DU particles are generated when a 120mm DU munition penetrates an Abrams tank. There have been no perforation tests involving the BFV and DU munitions. There has been one hard target perforation test involving DU munition(s) against an Abrams Heavy (with DU armor) tank.
- The exposure assessment utilizes data from a test involving a 120mm DU munition against an Abrams Heavy tank. To date, this represents the most appropriate set of data to model a fratricide incident involving DU munitions.
- Using the data generated from a 120mm DU munition against an Abrams Heavy tank is a conservative approach (DU on DU).

- **Airborne Release Fraction (ARF)**

- The ARF refers to the portion of the DU penetrator that becomes aerosolized.

- In reviewing the test data for hard-target perforations involving DU munitions, a range of 10 percent to37 percent aerosolized DU was reported.
- Researchers have also determined that fires involving uploaded DU munitions produce a different ARF than hard-target perforations involving DU munitions.
- Although ARF is a key parameter in determining the intake of aerosolized DU, its reported range of values (10 percent to 37 percent) leads to a tremendous amount of uncertainty. However, if airborne concentrations of DU are measured and if estimated intake values are based on air sampling data, then the dose modeling should focus on using the airborne concentration and exposure duration.
- The exposure assessment did consider the ARF but utilized airborne concentration and inhalation intake data generated by hard-target testing with DU munitions [data from the tests involving DU munitions and rolled homogeneous-armor targets postulated that 18 percent of the penetrator aerosolized (Jette, et al., 1990; as reported in Parkhurst, et al., 1995b)]. This helped to narrow the range of uncertainty.

- **<u>Respirable Fraction</u>**

  - When a DU munition perforates a hard target, aerosolized DU is produced. In a fratricide incident, excluding individuals injured by embedded fragments, the inhalation and indirect ingestion pathways are considered the primary routes of exposure.
  - The RF generally refers to particulate matter (particles) that is less than 10 µm AED and can be deposited into the lower regions of the respiratory tract. According to research, approximately 60 percent to 96 percent of the aerosolized DU generated by a hard-target

perforation is within the respirable range (< 10 μm AED). For conservatism, the exposure assessment considered an RF of 96 percent. (See Appendix D and Appendix J.)

- Researchers have also determined that fires involving uploaded DU munitions produce different RFs than hard-target perforations involving DU munitions.

- **<u>Particle Size Distribution</u>**

- The aerosolized fraction that is produced when a DU penetrator strikes a hard target will produce particles of various sizes. Generally, particles less than 100 μm in AED can be inhaled. Respirable particles are those that are less than 10 μm AED. (See Appendix D.)
- Particle size is particularly important because it determines many of the particle's characteristics. In general, particle size establishes the transport and inhalation potential of the aerosol. Specifically, the volume varies as the cube of the size, specific surface varies inversely with size, settling velocity varies with the square of the size, and diffusivity varies inversely with the n^{th} power of size where $1 \leq n \leq 2$. Unfortunately, most particles encountered in actual measurements are irregular in shape and size; therefore, determining the various physical properties is extremely difficult.
- Particle size will affect the initial suspendability of the oxidized material, aerosol deposition, and the fraction deposited in the different regions of the respiratory tract.
- Immediately following a perforation, the DU aerosol puff will be a mixture of dusts and hot vapors. As the puff cools, the DU will agglomerate into particles with sizes ranging from very small to very large. Because of this evolution, particle sizes are difficult to predict. However, most of the data accumulated in field tests show that a portion of the oxide

produced falls within the respirable size range. Particle size ranges from 0.2 μm to 1.1 μm AED.

- The exposure assessment utilizes a 5 μm AMAD aerosol in this dose assessment. The ICRP-66 recommends the use of a 5 μm AMAD aerosol for adult workers. A more thorough explanation will be provided in the physiological parameter section of this summary. (See Appendix J.)

- **<u>Chemical Form</u>**

- Research from the testing and evaluation of DU munitions indicates that hard-target perforations, fires and explosions involving DU munitions produce DUO_2 and DU_3O_8. As DU oxides weather in the environment, DUO_3 may be formed. Therefore, the chemical forms most likely to be encountered in battlefield situations are DU_3O_8, DUO_2 and DUO_3.
- Based on the various and different fratricide incidents and the complexity of uranium or DU chemistry, the exact composition of the oxide may be uncertain. Oxides of DU will change their chemical form over time as weathering takes place.
- Finely divided DU metal is reactive (sometimes called pyrophoric) and oxidizes to DU_3O_8 in air. The chemical form of pure DU oxide is DUO_3 when formed at 1 atmosphere O_2 pressure and below 500°C; DU_3O_8 is the stable phase when formed above 500°C. In limited oxygen environments or as an intermediate form, DUO_2 is formed.
- Fires involving DU munitions tend primarily to produce DUO_2 and a trace of DUO_3. Hard-target perforations involving DU munitions tend to produce two DU compounds:

DUO_2 and DU_3O_8. The DUO_2 is formed within about one minute following perforation and then DU_3O_8.

- Data that have been reviewed indicate that DU oxides produced as a result of testing, as part of the life cycle of DU munitions and of hard-target perforations, span a considerable range. Because the test data indicate that a range of DU oxides are produced in hard-target perforations, the exposure assessment utilizes the most conservative chemical forms in addressing chemical and radiological toxicity for an acute exposure.

Q.2.2 Physiological Parameters

- **<u>Reference Man</u>**

  - Reference Man is a shortened term for "Reference Man for Purposes of Radiation Protection". The current version is a classic 1975 publication, published by the ICRP as ICRP-23. This publication addresses human characteristics that relate directly or indirectly to the intake, metabolism, distribution, and retention of selected radionuclides in the human body.
  - ICRP-23 contains a wealth of information useful for radiation dosimetry, including anatomical and physiological data, including the gross and elemental composition of the human body, its organs and its tissues. The anatomical data provide specific reference values for an adult male and an adult female. Other reference values primarily pertain to the adult male. ICRP-23 has been updated in ICRP-66 and ICRP-70. Currently, there is an ICRP task group working on revising selected parts of the Reference Man publication.

- The models used to assess exposure and characterize risk from potential DU exposures in the Gulf War incorporate Reference Man values. Also, standard parameters outlined in the Reference Man document are consistent with values utilized in risk characterization.

- **<u>Breathing Rate (or Ventilation Rate) and Type of Exercise or Exertion</u>**

  - Breathing rate (or ventilation rate) pertains to the amount of air breathed in by an individual per unit time. The type of exercise an individual exerts dictates the BR (or ventilation rate). The types of exercise are sleeping, sitting, light work, and heavy work.
  - The models that were used have default BRs (or ventilation rates) based on the type of exercise an individual is performing.
  - The BR (or ventilation rate) of an individual involved in a fratricide incident, as well as the BR (or ventilation rate) for First Responders, was assumed to be very conservative as a result of the scenario. The BR (or ventilation rate) is factored into the ICRP-66 respiratory tract model used in the exposure assessment.
  - Breathing rate (or ventilation rate) also dictates deposition of particles in the respiratory tract (that is, the greater the BR (or ventilation rate), the greater the deposition). The exposure assessment assumes a BR (or ventilation rate) of 3 m^3/hr, for individuals inside armored vehicles at time of perforation and for First Responders. This BR (or ventilation rate) corresponds to a BR (or ventilation rate) typical of firefighters who are attempting to suppress fire conditions. Therefore, a BR (or ventilation rate) of 3 m^3/hr for individuals involved in a fratricide incident is conservative, if not at least practical.

- **Type (or Route) of Breathing**

  - The type (or route) of breathing is another parameter that also affects deposition of respirable particles in the respiratory tract. There are two basic types of breathing, nose and mouth. Breathing through the mouth results in a different deposition profile in the respiratory tract when compared to that of nose breathing.
  - Individuals involved in fratricide incidents were assumed to be breathing through the mouth. This assumption was based on the situations surrounding the fratricide incidents. A mouth breather takes approximately 60 percent of the inspired air through the mouth at a BR (or ventilation rate of 1.2 m^3/hr).
  - A BR (or ventilation rate) of 3 m^3/hr (heavy exercise), in conjunction with mouth breathing, will consistently result in a greater amount of deposited material in the respiratory tract when compared with the lower BRs (or ventilation rates) of nose breathing. A mouth breather with this BR (or ventilation rate) inspires approximately 70 percent of air through the mouth.
  - The exposure assessment utilizes a mouth breather and a BR (or ventilation rate) of 3 m^3/hr. (See Appendix J for a discussion of the respiratory tract models, computer models, and uranium transport through the kidney.)

- **<u>Exposure Duration</u>**

  - The exposure duration pertains to the time in which an individual is exposed to DU. It is assumed the primary routes of exposure, excluding embedded fragment casualties, is via inhalation, indirect ingestion, and secondary ingestion (hand-to-mouth).
  - The exposure duration for individuals, involved in a fratricide incident and remaining in an atmosphere containing a concentration of aerosolized DU, is at least a practical parameter.
  - This exposure assessment utilized a 2-min exposure duration for individuals involved in fratricide incidents. This assessment also utilized DU test data generated from exposure times consistent with sampling periods.
  - Exposure duration is also linked to the airborne concentration and particle size. Over time, after perforation of a vehicle by a DU munition, the airborne concentration, inside the vehicle, is diminished due to gravitational settling and mixing. Additionally, aerosolized particles of DU will agglomerate to form larger particles that become unavailable for exposed individuals to breath into their respiratory tract. The exposure duration and frequency of exposure are key parameters, which require assessment in conjunction with the DU airborne concentration, particle size and how these parameters change over an integrated time period.
  - Very little information is available to address this issue; therefore, exposure duration is a parameter that is assumed to have an uncertainty.

- **<u>Frequency of Exposure</u>**

  - In addition to exposure duration, the frequency of exposure of an individual is important. For example, some soldiers may have been exposed twice when two DU penetrators perforated their vehicle. In addition, soldiers may have been exposed to DU from fires and surface contamination.
  - Data are not available to model more than a single perforation; therefore, the "worst case" may not be simply doubling the values for two round perforation because the following must be considered:
    - Resuspension of DU inside the vehicle
    - The time between perforations
    - The types of munitions
    - The type of vehicle
    - The thickness and type of armor perforated
    - Where the perforations took place
    - Angle of the perforations
  - Based on professional judgment, the intake via inhalation and indirect ingestion of DU and the resulting CEDE for two perforations could be 1.5 to 3 times greater than that for a single perforation. The BFV will offer less resistance to a DU penetrator than a tank (hard target); therefore, less aerosolation of the DU penetrator will occur. Some of the vehicles in the Gulf War may have received two perforations.

- Some of the individuals in the Gulf War may have also been exposed to DU in the Level II or Level III scenarios. No attempt has been made to consider multiple exposures of an individual, other than for the number of penetrators that perforated their vehicle.

- **<u>Particle Size Distribution</u>**

- Particle size distribution refers to the size of aerosolized particles, in this case DU that is available for intake into the human body via inhalation or ingestion. (See Appendix D.)
- Particles that are less than 100 μm AED are considered available for inhalation. In dealing with oxides of DU, the particle size ranges that are of most concern are those less than 10 μm AED. Such particles are considered respirable, (that is, they are retained in the lower regions of the respiratory tract and are not cleared by physical process).
- Particles that range from 10 μm to 100 μm AED enter the upper regions of the respiratory tract but are cleared via the mucocilliary escalator (mucus and cilia) and are either coughed out and/or consequently swallowed. (See Appendix D and Appendix J.)
- Particles of DU oxide(s) swallowed and ingested enter the GI tract. The fraction of ingested DU, in the form of the identified oxides absorbed into the body fluids, is minimal. The ingestion pathway contributes very little from either a chemical toxicity or an internal radiation dose standpoint.
- Specifically, the exposure was assessed using 5 μm AMAD aerosols. The ICRP recommends that the 5 μm AMAD aerosol be utilized for worker exposures. Some DU munition test reports include a range of respirable particle sizes. A discussion on intake and

dose as it relates to the range of these particle sizes is discussed in the exposure assessment. (See Appendix J.)

- **<u>Solubility of DU in Simulated Lung Fluid (Chemical Form)</u>**

- Solubility pertains to the chemical reactivity and absorption rate of particles that are internalized into the human body.
- The chemical form of the DU particles internalized dictates the reactivity and absorption rate into the bloodstream. The three DU oxides (DUO_2, DUO_3 and DU_3O_8) that have been identified in the exposure assessment exhibit different rates of absorption into the bloodstream as indicated by the ICRP. (See Appendix J.) The manner in which DU oxides are formed may influence solubility.
- The absorption process involves particles that are dissociated into material that can be absorbed into the body fluids. However, absorption into the body fluids is time dependent, and the ICRP has identified three different absorption rates that can be applied to the DU oxides. The rate at which a compound is absorbed into body fluids determines the region in the body most likely to be affected by the transfer. (See Appendix J.)
- The ICRP has recently published a new respiratory tract model (ICRP-66) somewhat different to the previous respiratory tract model (ICRP-30), but the absorption rates for the most part are the same. (See Appendix J.)

  - ICRP has identified DUO_2 as being Class Y (or Type S) (exhibiting slow absorption into the bloodstream), DU_3O_8 as Class Y (or Type S) (exhibiting slow absorption into the bloodstream), and DUO_3 as being Class D/W (or Type F/M) (exhibiting fast to moderate absorption into body fluids).

- DU oxides that exhibit fast or Class D (or Type F) characteristics tend to concentrate in the kidney at a much faster rate than DU oxides exhibiting Class Y (or Type S) or slow absorption characteristics. However, DUO_3 is not formed during hard-target perforation or fires.
- DU oxides exhibiting fast absorption rates would pose more of a chemical toxicity concern, and DU oxides exhibiting moderate and slow absorption rates would pose more of an internal radiation dose concern.

- In reviewing the DU test reports, a wide range of absorption characteristics were identified for hard-target perforations. The exposure assessment focused on bounding this parameter from a standpoint of both chemical toxicity and internal radiation dose. For fratricide incidents, the upper-bound value for considering chemical toxicity assumed 43 percent of the aerosolized fraction that is internalized as being Class D (or Type F) material (exhibiting fast absorption). The solubility of the DU oxides depends on the manner in which they are formed (that is, whether formed from hard-target impacts or as a result of a fire). For hard-target impacts, the percent of Class D (or Type F) material is greater than for soft-target impacts or fires. In addition, the upper-bound value for considering internal radiation dose assumed 83 percent of the aerosolized fraction that is internalized as Class Y (or Type S) (exhibiting slow absorption). These two values for (43 percent and 83 percent) cannot be summed, because their sum would be greater than 100 percent.

- **<u>ICRP Respiratory Tract Model(s)</u>**

  - The ICRP recently adopted a new respiratory tract dosimetric model of the human respiratory tract. This model is discussed in ICRP-66 and ICRP-71. The ICRP-66 updates the previous respiratory tract model described in ICRP-30. (See Appendix J.)
  - The new respiratory tract model is broader in scope. It has been designed not only to evaluate secondary limits on intake of radionuclides by inhalation for Reference Man but also to provide a more realistic framework for modeling respiratory tract retention and excretion characteristics in individual cases.
  - The new respiratory tract model also calculates biologically meaningful doses in a manner that is consistent with the morphological, physiological, and radiobiological characteristics of the various tissues of the respiratory tract.
  - The two factors that influence the degree of hazard from the inhalation of DU particles are (1) the amount and site of particle deposition in the respiratory tract, and (2) the fate of the DU particles within the respiratory tract.
  - The computer software LUDEP, which incorporates the newer ICRP respiratory tract model, was used in this exposure and dose assessment. (See Appendix J.)

- **<u>ICRP Biokinetic Model(s)</u>**

  - The ICRP has also recently revised the biokinetic model described in ICRP-30. The new biokinetic model (ICRP-69, ICRP-71, and ICRP-78) considers additional and modified transport mechanisms of radioactive material in the human body.

- The version of the LUDEP software used in these calculations incorporates the ICRP-30 biokinetic model with the ICRP-66 respiratory tract model.
- There is a version of LUDEP, not yet available for distribution at this time that incorporates the new biokinetic model in ICRP-69 and ICRP-78. However, one of the authors of the LUDEP software calculated internal radiation doses using USACHPPM data and the version of the LUDEP software that incorporates the respiratory tract model, the ICRP-69 biokinetic model, and ICRP-78 transfer rates; the results of that exercise indicated close agreement (within 1 percent) in using either the ICRP-30 or the ICRP-69, ICRP-71 and ICRP-78 biokinetic model with the ICRP-66 respiratory tract model. The newer biokinetic models (ICRP-69, ICRP-71, and ICRP-78) will result in about a 1 percent increase in the CEDE.
- For DU oxides that enter the GI tract, the fraction that goes to blood is termed the GI transfer coefficient. This depends on the solubility of the oxide. For Class D (or Type F) and Class W (or Type M) DU compounds, the value is 0.02 or 2 percent. For Class Y DU compounds, the value is 0.002 or 0.2 percent. For example, for an intake of 10 mg of a Class Y (or Type S) oxide, the transfer from the GI tract to blood would be 0.02 mg. Therefore, only 0.02 mg would enter the bloodstream and pass through the kidney. The remainder, 9.98 mg would then be excreted in the feces.
- Urinary excretion of DU is assumed to arise from the DU moving directly from plasma to the urinary bladder. Approximately 50 to 60 percent of the DU leaves the blood directly to the bladder and another 12 percent is stored temporarily in the renal tubes prior to excretion. (See Appendix J for a discussion of uranium transport through the kidneys and the removal rate.)

- **Intake**

  - Intake is defined as the amount of material that is internalized into the human body. The intake of an airborne contaminant via inhalation is calculated as follows:

$$I = A * \frac{BR}{SR} * \frac{1}{FCE} * (RF * t)$$

Where:

I	=	Intake (µg, mg or µCi)
A	=	Amount of contaminant collected on filter media (µg, mg or µCi)
BR	=	Breathing Rate (L/min or m^3/hr)
SR	=	Sampling Rate (L/min or m^3/hr)
FCE	=	Filter Collection Efficiency
RF	=	Respirable fraction
t	=	Exposure duration (minute or hour)

  - If the sampling time and exposure time are the same, then the exposure duration drops from the equation.
  - The amount of material that is absorbed into the body fluids is referred to as an uptake. The ICRP models utilized in the exposure assessment take into consideration the uptake of the material internalized or the intake into the body.

- Intake is usually a function of the BR (or ventilation rate), type (or route) of breathing, airborne concentration, particle size, exposure duration, and exposure frequency.
- The uptake of material is usually a function of the chemical and physical form and the solubility of the material in body fluids (either in the GI or respiratory tract).

- Intake values used in the exposure assessment were calculated from DU test reports involving hard-target perforations by DU munitions.
- These intake values were entered into the LUDEP software, along with parameter values for BR (or ventilation rate), particle size, and density of the DU oxide, to calculate an internal dose. In addition, the calculated internal doses for all of the uranium or DU isotopes and their progeny that are in equilibrium comprise DU (using the weight percentage of the uranium isotopes in DU).
- The inhalation and ingestion (indirect, direct and secondary) intake values used include upper- and lower-bound values of intakes calculated from data reported in the DU test reports reviewed. (See Appendix F.)
- DU removable surface contamination available for exposure by secondary ingestion (hand-to-mouth) depends on the following: (See Appendix F for the methodology used for calculating secondary ingestion.)

    - Removable DU contamination may possibly be found on all interior and exterior surfaces of vehicles and equipment damaged by DU perforation or from DU smoke.

- The limited space within an armored vehicle when occupied by individuals can result in body contact with the interior surfaces of the vehicles. Entry into and access to areas inside the armored vehicles can also result in body contact with exterior surfaces as well.
- This body contact with interior and exterior surfaces can increase the possibility of ingestion of DU particles by way of hand-to-mouth transfer.
- Any activity causing movement within the armored vehicle by crewmembers increases the airborne concentration of DU by resuspension, therefore, increasing possible DU intake by inhalation.

The following assumptions have been made to estimate the dose from hand-to-mouth transfer of DU contamination:

- The secondary ingestion effective transfer rate for loose/transferable surface contamination associated with a contaminating event (transfer from contaminated surface to palm of hand range from 0 to 100 percent, transfer from hand-to-mouth range from 0 to 100 percent).
- The hands were uniformly contaminated. No credit is taken for personal hygiene on the battlefield.
- All the contaminant on the surface was transferred to the palm of the hand(s) (0 to 100 percent transfer).
- Only the contamination on the palm(s) of the hand(s) was transferred from hand-to mouth (0 to 100 percent transfer).
- To estimate the lower-bound value, an approximate 50 percent transfer was assumed.

See Appendix F for calculation of intake via secondary ingestion.

- **Weighting Factors (Organ and Radiation)**

  - The organ or tissue weighting factor is the proportion of the risk of stochastic effects resulting from irradiation of that organ or tissue to the total risk of stochastic effects when the whole body is uniformly irradiated.

    - A stochastic effect is a health effect that occurs randomly and for which the probability of the effect occurring, rather than its severity, is assumed to be a linear function of dose without threshold. Hereditary effects and cancer incidence are examples of stochastic effects.
    - Organ and tissue weighting factors are applied because the radiation-absorbed dose is insufficient by itself to predict either the severity or the probability of the deleterious effects on health resulting from irradiation under unspecified conditions. (See Appendix G.)

  - The radiation Q or radiation W_R allows for radiation effects upon the detriment of the microscopic distribution of the absorbed energy.

    - When the distribution of radiation is not known at all points in the volume of interest, ICRP recommends that the same values of Q or W_R be used for both external and internal radiation. (See Appendix G.)

- The ICRP has established the radiation Q in ICRP-26 and the radiation W_R in ICRP-60. (See Appendix H.)

- The exposure assessment utilizes the organ or tissue weighting factors and the radiation Q described in ICRP-26. (See Appendix G and Appendix H, respectively.)

- **Radiation Internal Dose**

  - The CEDE was calculated for the first year and for fifty years after exposure and reported in the exposure assessment for the lower and upper bounds of the DU intake. For a single perforation, the CEDE would be less than 2 rem; for two perforations, the CEDE would be less than 5 rem.
  - Based on the parameters used to calculate the doses, the first year dose constitutes greater than 75 percent of the 50-year dose CEDE for 5 μm AMAD aerosol.

Q.2.3 General Parameters

- **Environmental Control/Nuclear Biological Chemical System**

  - The Abrams tank and the BFV are equipped with an EC/NBC System. When in operation, the EC/NBC System functions to filter out radioactive, biological, and chemical products in the incoming air, not the air already inside the vehicle, for individuals inside the armored vehicle and provides an overpressure in the “buttoned-up” tank. Due to this filtering of incoming air, the possibility that the airborne concentration of DU will be reduced is great.

- Very little data exist with regard to the function of the EC/NBC System and its effect on the aerosolized DU interior airborne concentration in the vehicle.
- The exposure assessment utilized data from a hard-target perforation by a DU munition of an Abrams Heavy tank. In that test, the EC/NBC System was actuated. Although 70 percent of the air inside the armored vehicle is exchanged within the first minute, it is difficult to predict how this system’s operation would affect aerosolized DU particles and airborne concentration in an interior compartment of a damaged armored vehicle. The effect of the EC/NBC System on particle size distribution and airborne concentration in the vehicle was considered but was not factored into the exposure assessment, because no data are available.

- **<u>Fire Suppression</u>**

  - Both the Abrams tank and the BFV contain a halon fire suppression system on board that can be operated automatically and/or manually.
  - There does not appear to be any data concerning how effective the halon fire suppression system is in influencing the airborne concentration of aerosolized DU after the armored vehicle is penetrated by a DU munition.
  - The effects of the fire suppression system were considered, but with no data to support any theory, they were not factored into the exposure assessment.

- **Vehicle Integrity**

The integrity of the vehicle may have been compromised through open hatches, leaking seals, blown turrets, and/or operation of NBC System. Any or all of these could affect the levels of DU oxides available for resuspension in the vehicle. The effects of vehicle integrity were considered in the exposure assessment, but no data are available.

Q-3. Uncertainty and Sensitivity Analysis

Appendix O provides a discussion of the uncertainty and sensitivity of parameters required to estimate the exposures, intakes, and doses (upper and lower bounds) for individuals in the OSAGWI Level I Scenarios.

Q-4. Summary of Sensitive Parameters

A listing of the sensitive parameters used in this DU exposure and dose assessment for OSAGWI Level I is provided in Table Q-1.

Table Q-1. Sensitive Parameters Used in DU Assessment OSAGWI Level I Scenarios

PARAMETER	RANGE	SELECTED VALUE	COMMENT
Source Term			
Type of DU Munition	200 grams – 4.7 kg	4.7 kg	All fratricide incidents involved the 120mm DU penetrators
Isotopic Composition of DU	99.8% U-238 0.2% U-235 0.0006% U-234 0.0003% U-236	99.8% U-238 0.2% U-235 0.0006% U-234 0.0003% U-236	Based on analysis by ORNL
DU Armor	BFV & Abrams	Abrams Heavy Tank	No available test data for BFV
Airborne Release Fraction	10% – 37%	18%	Based on rolled homogenous-armor perforation tests
Respirable Fraction	60% - 96%	96%	Conservative parameter
Chemical Form	DUO_2, DU_3O_8, DUO_3	DUO_2, DU_3O_8, DUO_3	DUO_2 and DU_3O_8 considered for fires and hard-target perforation; DUO_3 considered for environmental evaluation
Physiological			
Reference Man	70 kg/man	70 kg/man	Standard weight used in HRAs
Breathing Rate (or Ventilation Rate)	1.2 m^3/hr – 3.0 m^3/hr	3.0 m^3/hr	Conservative
Type of Exercise	Sleep, sitting, light, heavy	100% heavy exercise	Conservative
Type (or Route) of Breathing	Nose or Mouth	Mouth	Conservative
Exposure Duration	1 min – 5 min	2 min	Most realistic
Frequency of Exposure	1 – 2	1 and 2	Several vehicles were penetrated twice
Particle Size	1 µm – 10 µm	5 µm	5 µm used for soldiers
Solubility in Lung Fluid	1%-83% Y Class 1%-20% W Class 1%-43% D Class	83% Y Class 17% W Class	Upper-bound values for chemical toxicity and radiation dose
ICRP Respiratory tract Model	ICRP-30 ICRP-66	ICRP-66	Better flexibility and used in LUDEP
ICRP Biokinetic Model	ICRP-30 ICRP-78	ICRP-30	ICRP-78 not incorporated into LUDEP as of yet
Intake via Inhalation and Indirect Ingestion for a Single Perforation	9 mg - 79 mg DU	9 mg and 79 mg DU	Largest intake estimate from hard-target perforation corrected for BR, type (or route) of breathing, and exposure duration
Intake via Inhalation and Indirect Ingestion for Two Perforations	118.5 mg - 237 mg	118.5 mg DU - 237 mg of DU	Largest intake estimate from hard-target perforation corrected for BR, type (or route) of breathing, and exposure duration (1.5 - 3 times a single perforation)
Weighting Factors	ICRP-26 ICRP-60	ICRP-26	Consistent with NRC
Dose	1st year 50 years	1st year 50 years	Most of the dose is received in 1st year
General			
EC/NBC System	On or off	On	High uncertainty
Fire suppression	Actuated or not	Not	High uncertainty