APPENDIX K - Exposure Limits For Uranium

K.1 Introduction

The terminology used to describe the controls for inhalation exposures of workers to contaminants varies among countries and even between standard-making bodies or regulatory agencies in the same country.

Uranium and DU may present a radiological as well as a chemical hazard if internalized. The hazards are dependent on the amount of DU that is internalized, route of intake, and the chemical and physical form of the uranium or DU. The percent of enrichment is important in industry; however, not with the military DU used during the Gulf War, because such DU is all the same in terms of enrichment. Appendix J discusses the intake of uranium or DU and its fate in the human body.

The exposure limits discussed in this Appendix have been established by several U.S. agencies. The NRC[10] follows the guidance recommended in ICRP-30, which established the ALI and DAC based on the respiratory tract model for a 1 μm AMAD aerosol, a GI tract model, and a biokinetic model to control the exposure of individuals. (See Appendix J.) The OSHA has established long- and short-term PELs to control the exposure of individuals. The DOE, ACGIH, and American Industrial Hygiene Association (AIHA) have also published guidelines to control exposure of individuals. These exposure limits and guidelines have been established to control the exposure of individuals in industrial uranium processing facilities.

K.2 NRC Limits for Exposure to Airborne Uranium

The NRC[10] has established standards for protection of the worker and members of the public in 10 CFR 20, and licensing of uranium and DU in 10 CFR 40. The airborne pathway is of primary interest (inhalation and indirect ingestion) for scenarios involving DU exposure. The NRC[10] guidance for occupational workers' surveillance programs has an inhalation classification based on the solubility of inhaled materials as it affects the rates and pathway of clearance through various compartments of the respiratory tract. Three clearance classifications describe this system: Y(year), W(week), and D(day)[6]. The risk received from exposure to a 1 μm AMAD aerosol is the basis for the ALI of uranium compounds. For particles where the AMAD differs from 1 μm, adjustment of the ALI and DAC must be made. For a 5 μm AMAD particle for Class D DU compound, the ALI or DAC is multiplied by 0.88. For Classes W and Y, the ALI or DAC is increased by a factor of 2.8 (see Appendix D).

The NRC[10] has ALIs and DACs for uranium that are promulgated in 10 CFR 20.1001-20.2401, Appendix B. The DACs for uranium in air that, if inhaled by Reference Man for 2,000 working hours per year [that is, 8 hr/day x 40 hr/wk x 50 wk/yr at a BR (or ventilation rate) of 1.2 m^3/hr] as a nose breather, would result in 2,400 m^3 of air being inhaled per year. Both the inhalation ALI and DAC are established based on ICRP-30 respiratory tract clearance Classes D, W, and Y and ICRP-30 biokinetic model. Table K-1 summarizes the NRC inhalation ALI and DAC for radioisotopes of uranium found in DU munitions based on 1 μm AMAD aerosol.

Table K-1. NRC ALIs and DACs for Isotopes of Uranium

Radioisotope	Class	Inhalation		
		ALI (μCi)	DAC ($\mu Ci/cm^3$)	DAC mg/m^3
U-234	D	1E+0	5E-10	8.0E-5
	W	7E-1	3E-10	4.8E-5
	Y	4E-2	2E-11	3.2E-6
U-235	D	1E+0	6E-10	2.8E-1
	W	8E-1	3E-10	1.4E-1
	Y	4E-2	2E-10	9.3E-2
U-236	D	1E+0	5E-10	7.7E-3
	W	8E-1	3E-10	4.6E-3
	Y	4E-2	2E-11	3.1E-4
U-238	D	1E+0	6E-10	1.8E+0
	W	8E-1	3E-10	9.0E-1
	Y	4E-2	2E-11	6.0E-2
U_{Nat}	D	1E+0	5E-10	7.4E-1
	W	8E-1	3E-10	4.4E-1
	Y	5E-2	2E-11	3.0E-2

Reference: 10 CFR 20.1001 – 20.2401, Appendix B.

See Appendix D for the method used to adjust the ALI and DAC for particle size distribution.

The conversion of an airborne activity concentration ($\mu Ci/cm^3$) to an airborne mass concentration (mg/m^3) for DU munition is—

$$mg/m^3 \text{ DU} = (\mu Ci/cm^3) * (2.632 \times 10^9)$$

Table K-2 summarizes the ALIs for the various inhalation classes of 1 µm AMAD aerosol and ingestion of DU oxides[10].

Table K-2. NRC ALIs for DU

Inhalation Class	DU Oxide	ALI	
		Activity (µCi)	Mass (mg)
D	DUO_3	1	3,225
W	DUO_3	0.8	2,580
Y	DUO_2, DU_3O_8	0.04	121,125
Ingestion		10	32,250

Reference: 10 CFR 20.1001 – 20.2401, Appendix B.

The NRC has also established in 10 CFR 20.1201(e) a limit of 10 mg/wk of soluble uranium (Class D) intake by inhalation in addition to the annual dose limits[10].

K.3 OSHA Limits for Exposure to Airborne Uranium

The OSHA has established an inhalation PEL to protect the worker. The PEL is an 8-hour TWA concentration. The PEL is promulgated in 29 CFR 1910.1000, Subpart Z. Table K-3 summarizes the OSHA inhalation PELs for uranium.

Table K-3. OSHA PELs for Inhaled Uranium

Uranium Form	Concentration (mg/m^3)
Soluble Compounds	0.05
Insoluble Compounds	0.25

The particle size is not specified; therefore, a 1 µm AMAD aerosol is assumed for these calculations.

The following assumptions are made to calculate the CEDE from inhalation of U_{Nat} at the OSHA PELs.

- **Assumptions:**

  - Contaminant is U_{Nat}
  - Airborne concentration is 0.0254 Bq/µg
  - BR (or ventilation rate) is 1.2 m^3/hr
  - Nose breather
  - Average DCF[44] is 3.4×10^{-5} Sievert (Sv)/Bq for insoluble (Class Y)
  - Average DCF[44] is 6.96×10^{-7} Sv/Bq for soluble (Class D)
  - Working year is 2,000 hours
  - 1 Sv = 100 rem
  - PELs from Table K-3

Based on the above assumptions, the following CEDEs have been calculated:

- Insoluble (Class Y):

  - (250 $\mu g/m^3$) * (0.0254 Bq/μg) * (1.2 m^3/hr) * (2000 hr/yr) * (3.4 x 10^{-5} Sv/Bq) * (100 rem/Sv) ≈ **50 rem/yr**

- Soluble (Class D):

  - (50 $\mu g/m^3$) * (0.0254 Bq/μg) * (1.2 m^3/hr) * (2000 hr/yr) * (6.96 x 10^{-7} Sv/Bq) * (100 rem/Sv) ≈ **0.2 rem/yr**

K.4 ACGIH Limits for Exposure to Airborne Uranium

The most widely recognized inhalation exposure limit is that recommended by ACGIH[39]. The TLVs, as issued by ACGIH, are recommendations and should be used as guidelines for good practice. Two categories of TLVs have been established for uranium.

- TLV–TWA is a time-weighted average concentration for a conventional 8-hour workday and a 40-hour workweek, to which it is believed that nearly all workers may be repeatedly, exposed, day after day, without adverse effect, ACGIH, (2000).
- TLV-STEL is defined as a 15-minute TWA exposure that should not be exceeded at any time during a workday even if the 8-hour TWA is within the TLV-TWA. Exposures above the TLV-TWA up to the STEL should not be longer than 15 minutes and should not occur more than four (4) times per an 8-hour day. At least 60 minutes should exist between successive exposures

in this range. An average period other than 15 minutes may be recommended when warranted by observed biological effects, ACGIH, (2000). The TLV-Ceiling (TLV-C) is the concentration that should not be exceeded during any part of the working exposure, ACGIH, (2000).

Table K-4 summarizes the ACGIH TLVs for airborne concentrations of uranium[44].

Table K-4. ACGIH TLVs for Airborne Uranium

Substance	TLV-TWA (mg/m^3)	TLV-STEL and TLV-C (mg/m^3)
Soluble & Insoluble Compounds	0.2	0.6

The particle size is not specified; therefore, a 1 μm AMAD aerosol was assumed for these calculations.

The SpA for U_{Nat} is 0.68 μCi/g. The airborne concentration ($\mu Ci/cm^3$) of U_{Nat} can be converted to mg/m^3 by multiplying $\mu Ci/cm^3$ by 1.47×10^9. The SpA for DU munitions is 0.38 μCi/g as used in this report. Therefore, DU is about 40 percent less radioactive than U_{Nat}. The airborne concentration ($\mu Ci/cm^3$) of DU can be converted to mg/m^3 by multiplying $\mu Ci/cm^3$ by 2.632×10^9.

The following assumptions are made to calculate the CEDE from inhalation of U_{Nat} at ACGIH TLV-TWA.

- **Assumptions:**

  - Contaminant is U_{Nat}
  - Airborne concentration is 0.0254 Bq/µg
  - BR (or ventilation rate) is 1.2 m^3/hr
  - Nose breather
  - Average DCF[44] is 3.4×10^{-5} Sv/Bq for insoluble (Class Y)
  - Average DCF[44] is 6.96×10^{-7} Sv/Bq for soluble (Class D)
  - Working year is 2,000 hours
  - 1 Sv = 100 rem
  - TLVs from Table K-4

Based on the above assumptions, the following CEDEs have been calculated:

- Insoluble (Class Y):

  - (200 µg/m^3) * (0.0254 Bq/µg) * (1.2 m^3/hr) * (2,000 hr/yr) * (3.4×10^{-5} Sv/Bq) * (100 rem/Sv) ≈ **40 rem/yr.**

- Soluble (Class D):

  - (200 µg/m^3) * (0.0254 Bq/µg) * (1.2 m^3/hr) * (2,000 hr/yr) * (6.96×10^{-7}Sv/Bq) * (100 rem/Sv) ≈ **0.85 rem/yr.**

The above regulatory or recommended limits, which are protective, are based on continuous or chronic (2,000-hour work year) inhalation exposure to a contaminant. Therefore, they are inappropriate for evaluating acute exposure to uranium or DU aerosols on a battlefield.

K.5 Health Physics Society Limits for Acute Inhalation Intakes of Uranium

The HPS (ANSI/HPS-N13.22 – 1995)[29] postulates that an acute inhalation intake of 8 mg of soluble [Class D (or Type F)] uranium is a threshold for transient renal injury in a 70-kg person. An acute inhalation intake of 40 mg of soluble [(Class D (or Type F)] uranium has been postulated as the threshold for permanent renal damage to a 70-kg person.

K.6 DOE Limits for Exposure to Airborne Uranium

The TEELs developed by DOE are for acute inhalation exposure to uranium or DU[45]. Federal regulations and internal DOE guidance require the use of ERPG (and particularly ERPG-2) for emergency planning. Recognizing that ERPGs exist for a limited number of chemicals (none exist for insoluble or moderately soluble uranium), the DOE SCAPA developed TEELs so that DOE facilities could do complete hazard analysis and consequence assessments, even for chemicals lacking ERPGs. The TEELs are derived using a hierarchy or occupational exposure limits (such as PELs, TLVs) and toxicity-based data (for example, TD_{LO}, TC_{LO}, LD_{50}, LC_{50}, LD_{LO}, and LC_{LO}). The TEELs exist for insoluble and soluble forms of uranium.

Definitions for the different TEEL levels are based on those for ERPGs as follows:

- ERPG-1 - The maximum concentration in air below which it is believed nearly all individuals could be exposed for up to one hour without experiencing other than mild transient adverse health effects or perceiving a clearly defined objectionable odor.
- ERPG-2 - The maximum concentration in air below which it is believed nearly all individuals could be exposed for up to one hour without experiencing or developing irreversible or other serious health effects or symptoms that could impair the ability to take protective action.
- ERPG-3 - The maximum concentration in air below which it is believed nearly all individuals could be exposed for up to one hour without experiencing or developing life-threatening health effects.

K.7 TEELs for Exposure to Uranium or Depleted Uranium

The TEELs are for acute inhalation exposure for uranium or DU. The TEEL levels are defined as follows:

- TEEL-0 - The threshold concentration in air below which it is believed most people will experience no appreciable risk of health effects.
- TEEL-1 - The maximum concentration in air below which it is believed nearly all individuals could be exposed without experiencing other than mild transient adverse health effects or

perceiving a clearly defined objectionable odor. The values are consistent with the ACGIH TLV-STEL.

- TEEL-2 - The maximum concentration in air below which it is believed nearly all individuals could be exposed without experiencing or developing irreversible or other serious health effects or symptoms that could impair the ability to take protective action.
- TEEL-3 - The maximum concentration in air below which it is believed nearly all individuals could be exposed without experiencing or developing life-threatening health effects.

For the application of TEELs, the airborne concentration at the receptor point of interest should be calculated as the peak 15-minute TWA concentration. The TEELs are default values only.

Table K-5 summarizes the DOE TEELs for insoluble and soluble forms of airborne uranium or DU. The TEELs were derived from the TLV-TWA, the STEL, and the IDLH, Douglas Craig, personal communication, (2000).

Table K-5. DOE TEELs for Airborne Uranium

	TEEL-0 (mg/m^3)	TEEL-1 (mg/m^3)	TEEL-2 (mg/m^3)	TEEL-3 (mg/m^3)
Soluble	0.05	0.6	1.0	10.0
Insoluble	0.05	0.6	1.0	10.0

The particle size is not specified; therefore, a 1 µm AMAD aerosol was assumed.

The kidney is the primary target organ in the case of an acute inhalation intake of soluble [Class D (or Type F)] or moderately soluble [Class W (or Type M)] uranium or DU. Appendix J provides an evaluation of the transport of uranium or DU through the kidney. The lung is the primary target organ in the case of an acute intake of insoluble [(Class Y (or Type S)] uranium or DU [3].

Based on findings on the chemical toxicity of uranium, a guideline of 3 μg of uranium per gram of kidney was adopted in 1959 by the ICRP, based on data from ICRP-2, Spoor and Hursh, (1973). Data that have become available since this guideline was adopted suggest that it may need to be reassessed (Leggett, 1989; Zhao and Zhao, 1990).