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Biological Effects of Depleted Uranium (DU)

Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company,
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Topics

- Chemical Hazards
- Radiological Hazards
- Exposure Pathways
- Dose Calculations
- Risks in Perspective

Chemical Hazards of DU

- DU is a heavy metal similar to tungsten, lead, and cadmium
- Occurs in soils at an average concentration of 3 parts per million
- Average daily intake 1.9 microgram from food and water; 0.007 microgram from inhalation
- Biological effects depend on particle size and solubility
- Solubility depends on chemical from (composition) and the solvent (bodily fluid)

Chemical Hazards of DU

- References to "soluble" and "insoluble" forms of depleted uranium are relative generalizations about depleted uranium's overall solubility
- Uranium oxides of primary concern (UO_3, UO_2, and U_3O_8) all tend to dissolve slowly in bodily fluids
  - Days for UO_3
  - Years for UO_2 and U_3O_8
- Dissolved U in body may react with biological molecules and, in the form of the uranyl ion, may exert its toxic effects
  - Cellular necrosis (death of cells) in the kidney
  - Atrophy in the tubular walls of the kidney

Chemical Hazards of DU

- 90% of dissolved DU in body will be excreted by the kidneys in urine within 24 - 48 hours
- 10% of DU in blood that is not excreted is retained by the body, and can deposit in bones, lungs, liver, kidney, fat and muscle
- Insoluble uranium oxides, if inhaled, can remain in the lungs for years, where they are slowly taken into the blood and then excreted in urine
- Uranyl-carbonate complexes decompose in the acidic urine in the kidney
- Effects on kidneys resemble the toxic effects caused by other heavy metals, such as lead or cadmium

OSHA DU Inhalation Standard for Workers

- Inhalation standards for workers based on the chemical toxicity to kidney
  - 0.05 mg/m^3 for Soluble Compounds
  - 0.25 mg/m^3 for Insoluble Compounds
  - For general comparison of the relative toxicity of the various metals
- There is evidence that repeated exposures cause less damage after the first exposure
  - The estimated threshold concentration of uranium for kidney damage ranges from less than 1 to 3 micrograms per gram of kidney mass

As with all chemicals, the hazard depends mainly upon the amount taken into the body.

Chemical Hazards of DU

- DU does not remain fixed in the kidneys, but is eliminated at a rate of about half every two weeks
- Moderately severe damage to the kidneys as a result of acute exposure is repairable, and a return toward normal kidney function may occur even during continued exposure

Chemical Hazards of DU

- For an acute ingestion intake of soluble uranium, the LD_{50} from kidney damage is estimated to be greater than about 1 to 3 milligrams per kilogram of body mass
  - Usually a lag period of 6 hours to several days followed by chemical necrosis
  - Even after levels that cause necrosis, the kidneys show evidence of regeneration within 2 to 3 days, depending on the severity of the initial exposure

Chemical Hazards - Acute Intakes

Acute Uranium Intakes *

- 3 µg/g kidneys tissue guideline (310 g ref. man)
- < 25 mg kidney repairs itself after intake stops
- 25 to 40 mg protein & dead cells detected
- 50 to 150 mg acute kidney failure
- LD_{50} is ~1 g inhalation exposure
- LD_{50} is ~5 g ingestion exposure (increases for lesser solubility)

* Heavy metal toxicity

Radiological Hazards of DU

Isotope	Percent of Total Uranium in Crustal Rock: by weight	Percent of Total Uranium in Crustal Rock: by radioactivity	Alpha energies, MeV (abundance)	Half-life (years)
^{234}U	0.0055	48.9	4.776 (72.5%) 4.723 (27.5%)	2.45×10^{5}
^{235}U	0.720	2.2	4.597 (5%) 4.395 (55%) 4.370 (6%) 4.364 (11%) 4.216 (5.7%) Others (17.3%)	7.04×10^{8}
^{238}U	99.2745	48.9	4.196 (77%) 4.147 (23%)	4.46×10^{9}

- DU and its decay products emit alpha, beta, and gamma radiation
- Radiation dose from DU dependent upon the amount and composition of DU
  - Solubility
  - Retention time in body – biological half-life

Radiological Hazards of DU

- Maximum radiation dose rates from DU armor and DU munitions in a fully loaded Mark 1 Abrams battle tank are estimated to be 0.0001 - 0.0002 mSv/h (for the tank commander, gunner and/or loader)
- Driver of the tank may receive a slightly higher dose (0.00013 – 0.0003 mSv/h)
- Skin dose rate associated with handling a bare penetrator is estimated to be < 2 mSv/h

Armor piercing rounds

Reference: Report by WHO (WHO/SDE/PHE/01.1, April 2001)

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Radiological Hazards of DU

- Penetrators, bullets, and armor are contained in a protective coating, and adsorption through the skin can therefore be considered to be negligible
- Potential external dose received in the vicinity of a target following attack with DU munitions has been theoretically estimated to be ~ 0.004 mSv/yr (based upon gamma ray exposure)
- Such doses are small when compared to the recommended guidelines for occupational exposure to ionizing radiation (20 mSv/yr for whole-body, or 500 mSv/year for skin]

Reference: Report by WHO (WHO/SDE/PHE/01.1, April 2001)

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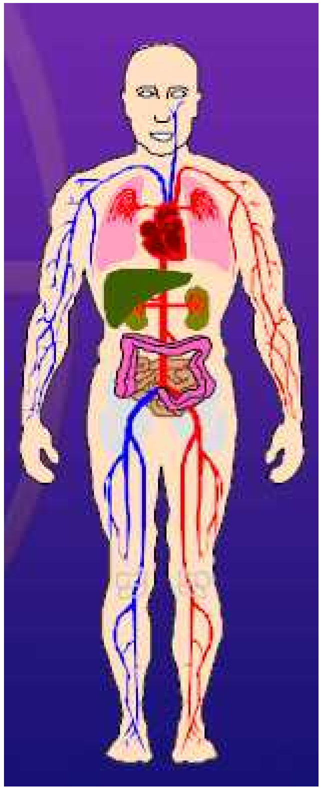
Exposure Pathways

Major Exposure Pathways:

- External
  - Skin – Dermal
- Internal
  - Inhalation
  - Ingestion
  - Injury
    - Cuts, wounds, implanted shrapnel



Exposure Pathways

Major Exposure Pathways:

- External
  - Alpha radiation not an external radiation concern (8 alphas)
  - Very low external dose from betas (6 betas)
- Internal
  - Inhalation – particle size dependent
  - Ingestion
  - Injury – cuts, wounds, implanted shrapnel

URANIUM 238 (U238) RADIOACTIVE DECAY

type of radiation	nuclide	half-life
	uranium—238	4.5×10^{9} years
α		
	thorium—234	24.5 days
β		
	protactinium—234	1.14 minutes
β		
	uranium—234	2.33×10^{5} years
α		
	thorium—230	8.3×10^{4} years
α		
	radium—226	1590 years
α		
	radon—222	3.825 days
α		
	polonium—218	3.05 minutes
α		
	lead—214	26.8 minutes
β		
	bismuth—214	19.7 minutes
β		
	polonium—214	1.5×10^{-4} seconds
α		
	lead—210	22 years
β		
	bismuth—210	5 days
β		
	polonium—210	140 days
α		
	lead—206	stable

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Dose Calculations

External Radiation Doses to Tank Personnel:

- Inside tank: ~ 0.0001 - 0.0002 mSv/h
  - Tank driver may receive 0.0003 mSv/h (gun pointed forward) and 0.0013 mSv/h (bustle fully loaded with DU ammunition pointed forward)
  - Above doses are much lower than the **annual occupational limit of 20 mSv/yr** (0.01 mSv/h; 0.4 mSv/wk at 50 week/yr)
- Outside a fully loaded tank, the maximum dose rate is 0.003 mSv/h – much less than the occupational limit

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Dose Calculations

Contact Radiation Doses from DU:

- Contact skin dose rate: ~ 2 mSv/h (mainly beta radiation from U daughters)
  - Armors and penetrators use DU from enrichment process where the daughters are not in equilibrium yet
  - DU in armor and penetrators are coated with a thin layer of material which drastically reduces the beta dose and completely eliminates any alpha dose
- Shallow skin dose limit for occupational worker is 500 mSv/yr to depth of 7 mg/cm^2
  - Requires beta energy greater than 70 keV or maximum beta energy of greater than 210 keV to penetrate

Dose Calculations

- In fires and during impact, DU forms both soluble and insoluble oxides
- Inhalation of the insoluble oxides presents an internal hazard from radiation if they are retained in the lungs
- Sustained exposure to the alpha and beta radiation from the material could damage lung tissue
- Examination of soldiers suspected of exposure to DU from fire showed less than one-fifth the annual occupational limit

Dose Calculations

- DU intakes of 26 mg, 12 mg, and 0.042 mg (total DU oxide) are estimated for cases when DU penetrators enter the crew compartment of a tank
- Using the Lung Dose Evaluation Program (LUDEP), [a lung dosimetry computer modeling program], the resulting doses were estimated to be:
  - 4.8 mSv (maximum), and 2.3 mSv (average) when the penetrator entered the crew compartment
  - 0.005 mSv when there was no entry into the crew compartment
  - For two hits, the intakes double to 52 mg, 24 mg, and 0.084 mg, respectively, which were estimated to produce radiation doses of 9.6 mSv, 4.6 mSv, and 0.01 mSv

Dose Calculations

For a single DU penetrator that enters a tank crew compartment:

- The total DU oxide can be divided between soluble and insoluble components. Tests showed:
  - 83% insoluble and 17% soluble
- Estimate of the DU oxide intake for a single DU penetrator hit (three cases were analyzed):
  - 22 mg insoluble / 4 mg soluble
  - 10 mg insoluble / 2 mg soluble, and
  - 0.035 mg insoluble / 0.007 mg soluble
- Conclusion: Results vary widely in every case – difficult to develop a generic model

Dose Calculations

- Understanding the battlefield scenarios and doses to soldiers will help in understanding the potential impact on the environment and doses to the public
- Studies on medical effects from DU exposure are continuing
- Cancer and genetic effects are a major part of these studies
- Current estimated risk for these effects are believed to be about 7.3×10^{-5} per mSv

Note: Recall that the estimated internal dose for most are less than 5 mSv → the risk for such case is less than 4 in 10,000

Risks in Perspective

- External exposure for all plausible and practical cases is very low if:
  - Follow ALARA Concept
  - Seek expert advise before handling DU
- Internal exposure could result in higher doses, depending upon:
  - Chemical form of DU – solubility
  - Amount of intake
- Chemical risk (heavy metal toxicity) exceeds radiological risk

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Risks in Perspective

DU is a heavy metal

- Chemical toxicity similar to other heavy metals such as lead, tungsten, and cadmium
- Chemical form of DU and solubility impact the biological effects
- Limits on intake based on mass of kidney and individual's weight
- Approximately 90% of DU intake is excreted through feces and urine within 24 - 48 hours from intake
- Proper training and awareness for public safety professionals and the public will greatly reduce the risk from potential DU exposure