Estimate of Radiation Dose From a Depleted Uranium Oxide Particle

dr. Len A. Dietz

(Radiation dose, Alpha particles, erg. rad, RBE, rem, MeV, electron Volt, Ev, g-mole, rads/yr)

http://www.xs4all.nl/~stgvisie/VISIE/ud_main.html

(Derived from Uranium Battlefielts Home & Abroad: Depleted Uranium Use by the U.S. Department of Defense 1993)

ESTIMATE OF RADIATION DOSE FROM A DEPLETED URANIUM OXIDE PARTICLE

References: 1. Radiation and Human Health, J. W. Gofman, Sierra Club Books, San Francisco (1981).
2. Nuclear Physics, I. Kaplan, Addison-Wesley Publ. Co., Inc., Reading, Mass. (1955).
3. Handbook of Chemistry and Physics, 50th Edition, Chemical Rubber Co., Cleveland, Ohio (1969).
4. The Radiation Controversy, R. E. Lapp, Reddy Communications, Inc., Greenwich, Conn. (1979).

Definitions: 1. A dose of 1 rad = 100 ergs of energy absorbed in each gram of material.
2. RBE (relative biological effectiveness) = 10 is assumed for alpha particles (Ref. 1, p. 430).
3. Dose in rem = dose in rad x RBE.
4. Electron volt is eV; million electron volts is MeV; g is grams; g-mole is gram-mole; 1 micron = 1 micrometer.

Assume: A spherical particle of depleted UO_2, 0.0001 in. dia. (2.5 micrometers dia). This size is within the range of dangerous particle sizes that can become trapped permanently in the lung. According to Gofman (Ref. 1, p. 489), "Particles in the general range of less than 5 microns in diameter are considered respirable, meaning they will pass the upper respiratory airway and may be deposited in segmental bronchi, bronchioles, and alveolar tissues."

Constants: 1. Density of UO_2 = 11 g/cm^3 (Ref. 3).
2. 1 eV = 1.602×10^{-12} erg (Ref. 2. p. 596).
3. Mean Range in air of U-238 alpha particles = 2.70 ± 0.02 cm (Ref.2, p. 265).
4. Density of dry air at 15°C and 76 cm Hg = 0.001226 g/cm^3 (Ref. 3).
5. Avagadro's Number = 6.023×10^{23} atoms/ g-mole (Ref. 3).

Table I. Depleted Uranium data.

	U-234	U-235	U-236	U-238
Abundance (atom %)	0.0008	0.2015	0.0030	99.7947
Half Life (yr.)	2.47×10^5	7.1×10^8	2.39×10^7	4.51×10^9
Decay Constant (yr.$^{-1}$)	2.81×10^{-6}	9.8×10^{-10}	2.90×10^{-8}	1.54×10^{-10}
Alpha Energy (MeV)	4.9	4.4	4.5	4.2

ESTIMATE OF RADIATION DOSE FROM A DEPLETED URANIUM OXIDE PARTICLE

CALCULATIONS

Using the data given above, we first calculate the number of atoms of U-238 in the oxide particle as follows:

$$\text{Atoms} = (4\pi/3)(1 \times 10^{-4} \text{ in.} \times 2.54 \text{ (cm/in.)}/2)^3 \times 11 \text{ g/cm}^3 \times 238/(238+32) \times (238 \text{ g/g-mole})^{-1} \times 6.023 \times 10^{23} \text{ atoms/g-mole} \times 0.99747 = 2.10 \times 10^{11}$$

The alpha activity from U-238 equals decay constant x total number of atoms.

$$\text{Alpha Activity} = 1.54 \times 10^{-10} \text{ yr} \quad \times 2.10 \times 10^{11} \text{ atoms} = 32.3 \text{ alphas/yr}$$

Similarly, we calculate that U-234, U-235 and U-236 combined emit 5.3 alphas/yr, for a total of approximately 38 alphas/yr from the uranium particle.

Next, we estimate the range of U-238 alpha particles in tissue, the volume of tissue affected and the radiation dose received by the tissue in 1 year.

The mean range of alpha particles from U-238 is 2.70 ± 0.02 cm in air (Ref. 2, p. 265). The thickness of material, in mass/unit area, that is equivalent in stopping power to 2.70 cm of air is given by

$$\text{Equivalent thickness} = 2.70 \text{ cm} \times 0.001226 \text{ g/cm}^3 = 0.00331 \text{ g/cm}^2$$

Assuming that lung tissue has approximately the same density as water (1 g/cm^3), then the thickness of 1 cm^2 of lung tissue that will stop an alpha particle emitted from U-238 is equal to the equivalent thickness calculated above, divided by the density of the stopping material, 1 g/cm^3. The result is 0.00331 cm. Therefore, within a radius of 0.00331 cm, all the alpha particles from the depleted uranium oxide particle will be stopped by lung tissue. The volume of this sphere is

$$\text{Volume} = (4\pi/3)(0.00331 \text{ cm})^3 = 1.519 \times 10^{-7} \text{ cm}^3$$

and its weight is 1.519 x 10^{-7} g, because its density is 1 g/cm^3.

The dose rate in rads/yr is

$$\text{Dose Rate} = 38 \text{ alphas/yr} \times 4.2 \times 10^6 \text{ eV/alpha} \times 1.602 \times 10^{-12} \text{ erg/eV} \times (100 \text{ ergs/g rad})^{-1} \times (1.519 \times 10^{-7} \text{ g})^{-1} = \underline{17 \text{ rads/yr}}.$$

ESTIMATE OF RADIATION DOSE FROM A DEPLETED URANIUM OXIDE PARTICLE

From the definitions, the dose rate in rem/yr is

$$\text{Dose Rate} = \text{dose in rads/yr} \times \text{RBE} = 17 \text{ rads/yr} \times 10 = \underline{170 \text{ rem/yr}}.$$

We should note that radioactive decay itself is a random process, whose statistics are described by the Poisson distribution; therefore, there will be a fluctuation in the number of alpha particles emitted per year. An estimate of this fluctuation (at one standard deviation error) is given by the square root of the average number expected to be emitted. For the U-238 particle size assumed here, it is $(38)^{1/2} = \pm 6.2$. Thus, the number of alpha particles expected in the first year is 38 ± 6; after 10 years it is 380 ± 20, etc.

The Code of Federal Regulations dealing with energy specifies permissible radiation doses. Occupational doses (for radiation workers) shall not exceed 5 rem/yr, except in unusual circumstances. For the general population, the annual limit is 170 millirem (0.17 rem) and a specific limit of 500 millirem (0.5 rem) for any individual in the general population (Ref. 4, p. 51).

If the above estimate of radiation dose (170 rem/yr) received by lung tissue surrounding the depleted uranium oxide particle is correct, then it is 34 times the maximum dose that radiation workers are permitted to receive and 100 times higher than the maximum acceptable dose for the general population. For a 5 micrometer dia. depleted uranium oxide particle (8 times the volume), the estimated dose is 1,360 rem, or 272 times the maximum permissible dose to a radiation worker. Until these doses can be related to a cancer risk factor, they must be viewed as qualitative indicators of danger, as red flags.

Discussion

These calculations show that particles of depleted uranium oxide can cause very high radiation doses. According to Gofman (Ref. 1, p. 430), the RBE for alpha particles depends on the biological effect. He states that a reasonable value is 10 but has a large uncertainty. I have assumed that lung tissue is in close contact with the uranium oxide particle as it emits alpha particles through a solid angle of 4π. If the particle is attached to the inside surface of an alveolus (air cell) or bronchial passageway of the lung, the effective geometry will be somewhat less than 4π but still greater than 2π. Some of the alpha particle energy may be deposited in mucus between the particle and lung tissue. All alpha paricles emitted from trapped uranium particles will irradiate lung tissue, even if part of their path in the lung is through air. Lastly, it should be noted that the younger the person exposed to alpha particle radiation, the greater the risk that cancer will develop.

L. A. Dietz, January 10, 1991

[Issues on the Use and Effects of Depleted Uranium]

[DU's global spread spurs debate over effect on humans]

DU's global spread spurs debate over effect on humans

By SCOTT PETERSON*

BAGHDAD, IRAQ (29 April 1999) -- AT LEAST 17 countries already have in their arsenals bullets made from depleted uranium (DU). Many -- such as Israel, Turkey, Saudi Arabia, Kuwait, Taiwan -- get them from the United States. England and France buy DU wholesale from the US. Russia now sells DU rounds on the open market.

Such proliferation has raised unanswered questions about the long-term health effects of the hard-hitting and controversial ordnance.

Is there a continuing health risk from DU fragments and particles for civilians in Iraq and Kuwait? And if the degree of danger to human health can't be nailed down, how should future use of DU be dealt with?

Several official bodies already take serious precautions. The United States Nuclear Regulatory Commission (NRC), for example, requires a license to handle or test-fire DU munitions. The US Army has 14 separate NRC licenses related to the substance. The Navy and Air Force each have one NRC "master materials" license.

Workers handling DU in the US must treat it as low-level radioactive waste. Disposal typically means the substance is locked into a 30-gallon canister, sealed with plastic, then sealed again inside a 55-gallon drum and, by law, buried in licensed underground dumps. Fine particles are mixed into concrete and locked into drums.

Definitive statements about DU's health risks to humans are not easy to make, scientists say.

"We don't know everything we'd like to know," says Ron Kathren, a physics professor and director of the US Transuranium and Uranium Registries in Richland, Wash. Attached to Washington State University, the registry has studied uranium and its effect on industry workers for 30 years.

"The reason people get panicky is because DU is radioactive, but [the battlefield dose] is so small that it never approaches chemical hazard," says Mr. Kathren.

Part of the problem with DU is public misperception, says John Russell, the associate director of the registries: "You say 'uranium,' and people think of the bomb. That's not the case here."

At the heart of the health debate is this question: Do small DU particles trapped in the body emit enough radiation over time -- in the form of alpha particles -- to cause physical harm?

Most of the concern is focused on dust particles left after a bullet is incinerated upon impact.

Carried aloft by the wind, the small particles can work their way into the human body, where the emission of alpha particles can be extremely damaging to cells, says Douglas Collins, a health physicist for 20 years and an NRC division director of nuclear material safety in Atlanta.

A 1990 study commissioned by the Army links DU with cancer and states that "no dose is so low that the probability of effect is zero." Dr. Asaf Durakovic, who was chief of nuclear medicine at the US Department of Veterans Affairs' medical center in Wilmington, Del., from 1989 until 1997, takes that a step further. Even the smallest internal alpha dose, he says, "is a high radioactive risk."

One safety memo, written by the US Army in 1991, says a single charred DU bullet found by US forces was emitting 260 to 270 millirads of radiation per hour. (A rad is a measurement of ionizing radiation absorbed into material.)

"The current [NRC] limit for non-radiation workers is 100 millirads per year," it noted. The limit for radiation workers would be some 30 times more.

DU's critics cite incidents to bolster their case against its use.

In 1992, for instance, a German scientist found a spent DU bullet in the Iraqi desert and was later arrested and fined by a Berlin court for "releasing ionizing radiation upon the public" when he brought it home.

"You're not playing with anything innocuous," says Leonard Dietz, a nuclear scientist who worked for 28 years at the Knolls Atomic Power Laboratory in New York.

In 1979, DU particles escaped from the National Lead Industries factory near Albany, N.Y., which manufactured DU penetrators. The particles traveled 26 miles and were noticed in a laboratory filter by Mr. Dietz. The factory was shut down in 1980 for releasing more than 0.85 pounds of DU dust into the atmosphere every month -- a fraction of the 320 tons fired during the Gulf War.

"It's still hot forever," says Doug Rokke, a Pentagon DU expert until last year. "It doesn't go away, it only disperses and blows around in the wind."

The British Atomic Energy Agency, at the behest of the Ministry of Defense in 1991, tried to quantify the risk. Based on an early estimate of just 40 tons of DU used during the Gulf War, it said that that amount could cause "500,000 potential deaths."

Recently declassified, its report says this purely theoretical calculation is "obviously n ot realistic" because it would require every single person to inhale similar quantities. But the sheer volume does "indicate a significant problem."

The Pentagon rejects that. "The problem is that all of that stuff has to be put into people. It physically can't happen," says Col. Eric Daxon, the radiological staff officer for the Armed Forces Radiobiology Research Institute. The possibility of DU causing serious health problems in Iraq, he says, is "exceptionally small, to the point where it should be absolutely at the bottom of the list."

Bernard Rostker, the Pentagon's special assistant for Gulf War illness, also sounds an all-clear. The Gulf War "is not an extraordinary nuclear event," he said. "This area [where DU was used], we would say, is free for any agricultural, industrial use, any personal use."

But Dr. Durakovic says those areas are still dangerous. Widespread use of DU, he told Congress in 1997, means that "the battlefields of the future will be unlike any ... in history."

The result is that "injury and death will remain lingering threats to 'survivors' of the battle for years and decades into the future," he testified. "The battlefield will remain a killing zone long after the cessation of hostilities."

*Christian Science Monitor