"Errare humanum est"
"To err is human"

May 2000

Background Information on a Current Topic

Depleted Uranium

1. Introduction

A quotation from the alternative press:

"Iraq-Balkans: The Apocalypse Caused by Man!"

Recently, such and other horrific statements have been more frequently read and heard. They speak about the alleged "uncontrollable, irrevocable, and annihilating" consequences of the use of a new type of ammunition by the US and Great Britain in Iraq and the Balkans. It is claimed that this ammunition consists of a "highly poisonous and radioactive" material, called **depleted uranium** (DU).

Are these terrifying statements and frightening pictures - such as the "unstoppable" increase in cases of cancer or pictures of birth defects in newborns in the afflicted population of these former battlefields - based on facts or are they simply a journalistic exaggeration or possibly even state propaganda?

Are the peace-keeping troops in Kosovo - who also include our Swiss soldiers - exposed to the danger of "radiating" uranium lying around everywhere?

The following background information from AC-Laboratorium Spiez investigates these questions from a **scientific perspective** and tries to summarize the current state of knowledge about the use of ammunition containing depleted uranium and about the possible consequences for man and environment.

2. Uranium, the stuff

What is uranium?

Uranium (U) is the chemical element with atomic number 92. It is a silver-gray metal with an average occurrence in the earth's crust of 4 grams per metric ton. It is more abundant than elements such as mercury, silver, or gold. Uranium-containing rock is also found in Switzerland. **Natural uranium** consists of three different **isotopes:** 99.2836% ^{238}U, 0.7110% ^{235}U, and 0.0054% ^{234}U. Isotopes are chemically barely distinguishable atoms of one and the same element, having the same number of protons in the nucleus of the atom. However, the isotopes differ in the number of neutrons and correspondingly, their mass and nuclear properties. Isotopes are either stable or unstable. Unstable isotopes are called radioactive.

Uranium has a few **special properties**:

Uranium has a very high density of 19.07 g/cm³, only slightly lower than tungsten (19.3 g/cm³) and somewhat higher than lead (11.35 g/cm³.) Metallic uranium is chemically very reactive. In powdered form, it can ignite spontaneously. All uranium isotopes are **radioactive**, which means that their nuclei are unstable.

What is depleted uranium?

Uranium has achieved its eminent significance in civil and military nuclear technology (nuclear power plants for the production of electricity, nuclear weapons) through its **isotope ^{235}U**, being a so-called **fissile material**, allowing a self-sustained chain reaction.

For most applications in nuclear technology, the comparatively small fraction of 0.711% ^{235}U in natural uranium is not sufficient and must be increased. This process is called **enrichment**: The atoms of natural uranium are separated into a mixture containing more ^{235}U, and one with less ^{235}U. The part with more than 0.711% ^{235}U is called **enriched**, the other one **depleted**. Usually, natural uranium is depleted to a remaining content of approximately 0.2 - 0.3% ^{235}U.

Summary:	Depleted uranium is simply a ***waste product*** from the production of fuel rods for nuclear power plants and nuclear powered ships, as well as from the production of highly enriched uranium for nuclear weapons.

How radioactive is depleted uranium?

Radioactive nuclei transform spontaneously into nuclei of another element. Usually this process is accompanied by the emission of radiation. The unit of measurement for radioactivity is the Becquerel (Bq). An activity of 1 Bq means that one decay takes place per second. Different types of atomic decay can be distinguished. In an **Alpha-decay**, the nucleus emits an α-particle, consisting of two protons and two neutrons. In a **Beta-decay**, the nucleus emits an electron, a so-called β-particle. Alpha-, as well as Beta-decay, can be accompanied by **gamma radiation**, a high energy electromagnetic radiation.

All three uranium isotopes discussed here emit **α-particles.** The α-activity of natural uranium amounts to about 25'000 Bq per gram; that of DU amounts to about 15'000 Bq per gram. Thus, the α-activity of DU is about 40% less than that of natural uranium.

The newly formed nuclei resulting from the α-decay of uranium - called daughter products - are not stable, but continue to decay, mostly by emitting β-particles. The activity of its daughter products must be added to that of uranium. The **β-radiation** of the **daughter products** of natural uranium and DU have practically the same intensity, amounting to about **25'000** Bq/g.

Together with its daughter products, depleted uranium has an activity of approximately 40'000 Bq per gram. This means that about **40'000** decays take place per gram and per second. Only about 100 of these are accompanied by high energy gamma radiation.

A comparison of the activities of a few radioactive materials:

iodine 131	4'598'000'000'000'000 Bq/g
cesium137	3'206'000'000'000 Bq/g
plutonium 239	2'298'000'000 Bq/g
natural uranium with its daughter products	ca. 50'000 Bq/g
depleted uranium with its daughter products	ca. 40'000 Bq/g

Summary:	In comparison to other radioactive materials, neither natural uranium nor depleted uranium are particularly highly radioactive.

How much depleted uranium is there?

In June 1998, the US Department of Energy (DoE) stored 734'000 metric tons of uranium-hexafluoride. Two thirds of it - about 500'000 metric tons - are depleted uranium; the rest is fluorine. Figures for the "stockpiles" in other countries with enrichment facilities are not published. Together they certainly store at least again as much DU. In 1995 as well as in 1996, about 35'000 metric tons of uranium were mined worldwide. From this fact, it can be estimated, that yearly an additional 30'000 metric tons can be added onto this already huge supply of DU.

How can the existence of depleted uranium be detected?

With an usual hand monitor for the detection of radioactivity, a DU metallic fragment can be detected from a distance of some 10 cm without any problem.

Since the alpha and beta radiation in the air have a very limited range and only a small amount of gamma radiation is present, it is very difficult to detect remains of DU ammunition from a distance of one meter or more.

Therefore, an efficient and extensive search for DU fragments is practically impossible. A determination of the DU content in a soil sample or in the dust of an air filter with the help of gamma detectors is barely possible or even impossible. This makes it extremely difficult to establish a reliable geographical distribution of the DU contamination on the former battlefields in Iraq or Kosovo.

Reliable, **quantitative** information on DU contamination of the air or the ground must be determined in specially equipped laboratories. A special laboratory, such as AC-Laboratorium Spiez, can analyze between 10 and 100 samples per week, depending on the method of measurement.

What are possible applications of depleted uranium?

Many **civil** applications of DU stem from its high specific weight and its low price. Therefore, depleted uranium is used where maximum mass in a limited volume is required, such as in counterweights in control surfaces of wide-bodied aircraft. Also, because of its excellent shielding properties for gamma radiation, it can be used in containers for spent fuel rods from nuclear power plants.

In the **military** field, DU is used in armor and anti-armor ammunition. Incidentally, the use of **depleted** uranium has nothing to do with the use of uranium in its **highly enriched form** in atomic bombs!

3. Why is DU used in ammunition and armor?

Alloyed with 2% molybdenum or 0.75% titanium and after a special thermal treatment, uranium is as hard as hardened tool steel. Combined with its high density, it is a material well-suited for armor-piercing ammunition.

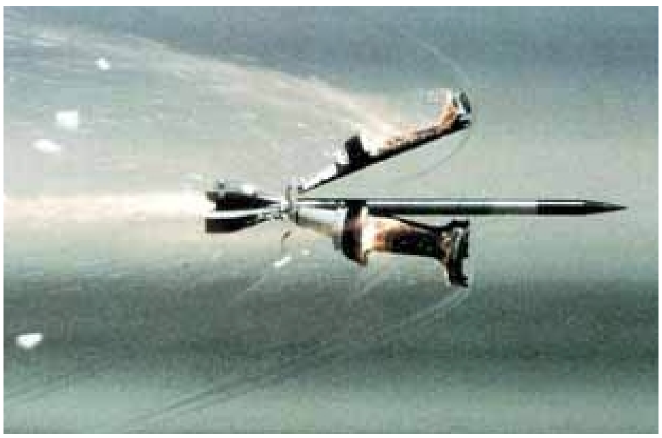

Figure 1: Armor-piercing ammunition shortly after being fired, at the moment of release from its sabot.

According to the US technical literature, upon impact on armor a projectile made from DU keeps its form better than one made of tungsten or steel; the penetrator "sharpens" itself on impact, in contrast to the more expensive tungsten projectiles, which tend to mushroom. After penetrating the armor and as soon as the DU projectile again comes into contact with air, the part of DU, which is now in the form of a liquid or powder starts burning, thereby increasing its destructive effects. Often, this leads to setting the fuel tank on fire and/or detonating the ammunition stored in the tank.

In battle tanks, such as in the new version of the US Abrams, DU plates are built in to improve the protective properties of the conventional steel plate armor.

Because of the superiority of this type of ammunition, it has already been introduced by the military forces of several countries. The impressive results in the Gulf War may encourage more countries to procure DU-armor and -ammunition. By the way, Switzerland gave up the development of anti-armor ammunition containing radioactive material twenty years ago.

4. Pathways of depleted uranium into the environment and man

Depending on the use of DU, there are various ways that DU can enter the environment and man, where it can possibly produce damaging effects. One main exposure pathway is based on the fact that uranium is radioactive and acts as a long-lasting source of radioactivity, irradiating man from outside (**external)** the body. Depending on the uptake into the body through the lungs (inhalation), with water and food through the digestive tract (ingestion), or through wounds (inoculation), it will affect the body from the inside **(internal).**

During normal operations in the **industrial processing** of DU, as well as in accidents, the formation and emission of fine dust particles (aerosols) are of immediate importance.

In **fires**, such as in DU ammunition storage facilities, DU burns into a poorly soluble DU oxide powder. This contaminates the burning site itself and is also partly carried into the air as a fine aerosol.

In the **penetration through armor** of high-speed ammunition, people can be injured by flying DU fragments. Depending on the material and thickness of the armor that is struck, a small portion of the DU is transformed into a fine aerosol, typically about 10% in the case of hard armor. The DU aerosol predominantly burns into poorly soluble uranium oxides, which can remain in the air at relatively high concentrations in closed spaces (tanks, bunkers) for quite some time. The portion that reaches the outside is quickly diluted, transported, and eventually deposited. The rest of the DU-projectiles, as well as those bullets that missed their targets, remain in the tank or in the nearby surroundings in the form of larger or smaller metal fragments.

5. The effects of chemically toxic substances and ionizing radiation [1)]

In general, the **chemical toxicity** of a substance in the human body is defined by a threshold concentration, below which no damage can be observed.

The damaging effect of **ionizing radiation** is essentially a result of the energy absorption by the body tissues, called radiation dose. The unit of measurement for radiation doses is the Sievert (Sv), or the millisievert (1 Sv = 1000 mSv). In order to relate the activity of a radioactive material (in Bq) to the radiation dose it produces (in Sv), it must be known if the body is irradiated internally or externally, which type of radiation it is (alpha, beta, or gamma), and what energy the radiation has. The ICRP [2)] and other organizations have published corresponding conversion factors for internal and external irradiation of man.

As in the case of chemical toxicity, a threshold dose also exists for ionizing radiation, below which no **acute** radiation damage can be observed. It is still unknown whether or not there is a threshold dose for the occurrence of late-time damages from radiation in the form of an increased probability of cancer. In order to avoid acute radiation damage and to limit late-time damages to a very low level, international recommendations and national laws for dose limits, as well as threshold values for the concentrations of artificial radioactive materials in the environment, air and food were established.

6. How does depleted uranium affect man ?

The damaging effect of DU, or otherwise expressed, its dangerousness for man, is based on two of its properties:

- Uranium is chemically toxic, like other heavy metals such as lead and mercury.
- All uranium isotopes are radioactive, i.e. they emit ionizing radiation.

Outside the body, DU only acts through irradiation. After incorporation, chemical as well as radiological effects must be simultaneously taken into consideration. The following review focuses on the situation on the former battlefields of Iraq and the Balkans.

Summary: In the former battlefields, DU makes only a tiny contribution towards the already present external radiation from natural sources. However, long-lasting direct skin contact with DU ammunition fragments should be avoided.

External irradiation by DU

DU outside the body acts exclusively via the emitted gamma and beta radiation, since the alpha-radiation is absorbed by the outermost layers of the skin and therefore does not affect the living tissue.

The dose-rate from external radiation **in the vicinity of DU** is very low. One kg DU at a distance of 1 m produces a dose of less than 1 mSv per year. In comparison, an average person in Switzerland accumulates about 3 mSv per year from natural radiation sources.

According to some American publications, if a DU surface is touched by the bare skin, a localized dermal dose of about 2 mSv per hour results. The very improbable case of a direct contact for several days with the same part of the skin would lead to a considerable dermal dose.

Radiation doses of millisieverts per year do not cause acute radiation damage; the only consequence would be a barely quantifiable increase in the risk of cancer.

Internal contamination through inhalation of aerosols

Uranium in the form of fine particulate dust - such as that produced in the uranium industry by mining uranium ore, or from the impact of high-speed projectiles on armor, or from the burning of uranium - can enter the lungs through inhalation. However, only about 25% of the particles with a diameter smaller than 10 µm are deposited in the lungs.

The decisive factor for the effect is the **solubility** of the inhaled DU in the body fluids. American investigations have shown that after the impact of DU projectiles on heavy armor, about 17% of the DU aerosol produced, is found in an easily soluble form. In contrast, when DU burns in open fires, practically no soluble uranium oxide is produced.

If uranium is in a **chemically soluble** form, the main part is relatively quickly eliminated - within days - through the bloodstream and the kidneys . At the same time, the kidneys are the target organ for the chemically-toxic effects of uranium, which can lead to impaired function or even total organ failure. A single inhalation of 8 mg uranium in soluble form is the threshold value for the occurrence of temporary kidney damage; while a level of 40 mg uranium in soluble form can lead to permanent kidney damage.

1) alpha, beta- and gamma radiation produce ions, i.e. positive or negative charged atoms and molecules as they interact with matter.

2) ICRP: abbreviation for International Commission on Radiological Protection

If the uranium is in a **poorly soluble form**, it can remain in the lungs for a long time (years). The kidneys are hardly affected, since the mobilized quantity of uranium is very small. In contrast, the radioactivity of DU produces radiation doses in the lungs and bronchi. The ICRP calculates a dose factor of 0.1 mSv/mg for the inhalation of poorly soluble ^{238}U. Therefore, except in extremely high uranium concentrations, acute radiation damage is not expected.

An inhaled quantity of, e.g. 100 mg DU, would lead to permanent kidney damage if in soluble form; if in insoluble form, it would lead to a slight increase in the risk of cancer, about 0.04% in the worst case. Supported by experiments in the US, it was calculated that the crew of a tank that has been hit by DU-projectiles, could inhale up to 50 mg uranium aerosol. This quantity could possibly lead to slight, reversible, toxicity-induced damage to the kidneys, as well as to an internal radiation dose, roughly equivalent to less than that of the yearly dose allowed for people professionally involved in nuclear activities.

For people in open areas near destroyed tanks or near burning DU, the aerosol dose is considerably less. For people who entered the tanks or the vicinity of the former fire sites after the aerosol had settled, the internal contamination is also much much smaller. At the most, a smaller portion of the aerosol is resuspended and could be inhaled. Over time this danger is further reduced by climatic influences, such as rain or snow.

Summary: In former battlefields, the inhalation of DU aerosols is the critical pathway for human exposure. An acute health risk is practically only to be feared from the chemical toxicity of uranium.

Internal Contamination from Ingestion of DU

Only about 2 to 5 % of uranium in easily soluble form is taken up into the bloodstream from the digestive tract. Thus, the threshold value for the occurrence of reversible or permanent kidney damage after a single exposure, is comparable to the one for the inhalation pathway. Uranium in the form of uraniumoxide, which is poorly soluble in the body, is practically not taken up by the digestive tract, and therefore, even in gram quantities, has no chemically toxic effect.

Since the DU radiation dose through ingestion is orders of magnitude less than that through the inhalation pathway, it is practically negligible.

Summary: The ingestion of DU poses practically no danger to the population in the former theatres of war.

Internal Contamination through Uptake of DU by Wounds

When DU is brought directly into the body through wounds, the toxicological effect is also determined by the solubility of DU. Soluble uranium is eliminated by the kidneys and can damage them when the threshold dose is exceeded. Insoluble DU remains in the tissues for a long time, causing a relatively high, locally limited radiation dose, leading to a slight increase in the long-term risk of cancer. In the US, there is a group of about 30 Gulf War veterans, victims of so-called "friendly fire incidents" (Fig. 2), who live with DU fragments embedded in their body. "Friendly fire" means they were mistakenly fired upon by their own troops.

Summary: For the population in the former theatres of war, wound contamination by DU has no significance.

Fig 2: American M1A1 tank having been hit by its own troops ("friendly fire incident")

7. Consequences of the use of Depleted Uranium in Iraq and the Balkans

How much DU was used?

In Iraq, about 300 metric tons of DU ammunition were fired by American and British troops. Recently, NATO confirmed the use of DU ammunition in Kosovo battlefields, where approximately 10 metric tons of DU were used.

The often-heard claim that this use of DU was a cheap way to "solve" a waste problem, is certainly not true. The total quantity of DU in ammunition that was used in Iraq and Kosovo corresponds to barely four days of DU production worldwide.

Effect on Soldiers

Before the introduction of DU weapons in the US, estimates and calculations led to the judgement that the occupants of tanks which have been hit by DU projectiles and who survived these hits without great injury, may be affected, at the most, by reversible, short-term effects on the kidneys, as well as by an irradiation below the legal yearly limit. These risks, in comparison to the other much greater risks during battle, were considered to be acceptable. These estimates are rather conservative and appear to be plausible. Medical examinations of a group of about 100 soldiers exposed to DU aerosols in their own tanks from friendly fire incidents during the Gulf War, have not discovered any health damages so far, that could be attributed to DU. Somewhat less certain is the long-term prognosis of adverse health effects for those injured by DU fragments. Up to now, in this whole group of approximately 30 people, there has also been no evidence of negative effects.

Additional and much larger groups of Gulf War veterans stayed in the vicinity of the destroyed tanks and ammunition fires or entered such places afterwards. In these cases, at the most, only rough estimates can be made, since neither measurement data on DU emissions or dose calculations have yet been published. One can estimate that the DU uptake by these groups of people was far less than by those who were directly exposed. The well-known health problems that were later observed in many Gulf War veterans, called "Gulf War Syndrome" [3] cannot be explained by exposure to uranium, and therefore, must be attributed to other causes.

Consequences for the Civil Population and the Evironment

Information on the occurrence of DU contamination during and after the fighting is available neither for the Gulf Region nor the former Yugoslavia. In the best case, a judgement can only be made in very broad terms.

In the **vicinity** of the impact point of DU ammunitions, it is not excluded that individuals unaware of the contamination (e.g. children playing with pieces of ammunition or in tank wrecks) and who stayed there for an extended period of time, could have accumulated radiation doses and/or could have incorporated uranium quantities exceeding the internationally recognized limits. However, the probability that these quantities and doses were so high that they led to acute illnesses, is very slim. Overlaying the relatively high rate of naturally-occurring cancer, the additional risk of cancer resulting from this radiation dose would be very small and hardly detectable.

In all other places **further away from the immediate battlefield** it is extremely improbable that people living there were afflicted by health-threatening quantities of DU, through one of the contamination pathways. In particular, the ingestion pathway is even less dangerous, since uranium is only poorly transferred into the biological cycle "soil - plants – animals – man". Evidence of damage to the genetic material with an increase in abnormalities in newborns is not to be expected from such very small DU doses.

The problem with the use of DU ammunition probably lies mainly in the fact that after the fighting, in the more highly contaminated places, the remaining local **environmental contamination by uranium and its radiation exceeds the internationally recommended standards**. However, one cannot directly conclude that there is a health risk for the people living there. Detectable extensive damage to the **biosphere** through DU contamination is very improbable, because the estimated concentrations are much too small.

3) **See:** "Das Golfkriegssyndrom – was steckt dahinter?"
Background Information from AC-Laboratorium Spiez on NBC-Weapons

8. Conclusions

"Depleted uranium - the apocalypse?" was the first question asked in the introduction. Based on the above presentation and the analysis of possible consequences on man and environment, the answer is as follows:

An apocalypse caused by man as a result of the use of DU ammunition in Iraq and the Balkans is **not worthy of discussion**!

Are there "irradiated Swiss soldiers in Kosovo?"

The answer to this second question is:

If certain minimal precautions are taken - i.e. **no trespassing on tank wrecks and no long-term contact with remaining DU ammunition fragments** - the health risks of a time-limited stay in a DU-contaminated area are shown to be **negligibly small**, especially in comparison to other risks such as mine fields, duds, snipers, etc.

Should military applications of depleted uranium be internationally banned?

Military considerations

Up to now, the new ammunition and armor made from depleted uranium have proven to be superior to previous systems. Thus, it would be difficult for the military to abandon them. Furthermore, it is also clear that the highly-praised superiority of these weapons will only last as long as the opponent does not have them available too.

Views and Arguments of the Opponents

Various activist groups, especially in the US, Great Britain, and Holland, are trying to involve international organizations in bringing about a ban on DU ammunition. They are organizing information campaigns and symposiums promoting their viewpoint that these weapons are "inhuman", comparable to biological and chemical weapons.
Their few objective justifications for such a ban are derived from the fact that the resident population has to continue to live on the former battlefields, which according to valid radiation protection norms, are at least locally radioactively contaminated; and from the fact that the long-term effects of depleted uranium on man and the environment are not entirely clarified.

View of the authors of this background information

Generally it is left to the reader to weigh and interpret this technical "Background Information" and the above summarized viewpoints. Clearly, this kind of ammunition leaves behind a long-lasting contamination on the battlefields, which **is not compatible with civil radiation protection norms**. This argument holds independently whether or not - objectively - there is a danger to man and the environment.

9. Further Sources of Information

The Internet has proven to be a most extensive source of information. A keyword search for "depleted uranium" produces about 10'000 citations on this topic. Among these are very good scientific papers on the associated hazards and risks of depleted uranium, as well as on the consequences of the use of DU ammunition in the Gulf War and Kosovo. Below are some sources of information which the authors consider reliable.

http://www.rand.org/publications/MR/MR1018.7/MR1018.7.html
http://www.gulflink.osd.mil/du/
http://www.antenna.nl/wise/uranium/

Furthermore, the website of AC-Laboratorium Spiez, **http://www.vbs.admin.ch/acls**, contains a more comprehensive German version of this background information on DU, that can be downloaded by a "click" as a Word Document.

The authors: E. Schmid, Ch. Wirz

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