Depleted Uranium (DU) – Chemo- and Radiotoxicity

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Abstract. DU metal used for civil or military purpose reacts with water, undergoes radiolysis, dissolves and contaminates soil and ground water. DU is pyrophoric and burns on impact (3000ºC). DU oxide particles (mainly U^{6+}!) have a diameter of about 1.5 µm to 10 Å; 10 Å particles behave like a gas, carried by the air and travel long distances before they come down. DU is taken up by living organisms. Its α-radiation causes chromosome brakes (CB). A pilot study performed with Gulf War Veterans, originated by one of the authors (AS), did find 5.2 times more CBs on the average, with a maximum of 14 times higher. DU reaches all parts of an organism and leads to chemical and radiological damage.

Introduction

First of all I have to thank the organisers of this International Meeting, especially Prof. Dr. B. J. Merkel, to have given us the opportunity to participate and to make a contribution.

To introduce myself: I am a chemist. I am Founder and Head of the World Depleted Uranium Centre, WODUC e.V., based in Berlin. WODUC is an outcome of the Antidiscrimination Network MSD e.V. headed by me. We are a strictly independent scientific NGO. We work on the consequences of the civil and military use of Depleted Uranium (DU). DU is the byproduct – 4 million metric tons world wide – of 235 U enrichment of natural uranium: DU is 99,8% 238U, it still

contains 0,2 % 235 U. DU shells sometimes contain 236 U from recycled fuel cells from atomic power plants accompanied by small amounts of plutonium.

We work on the following subjects:

1. Remediation of DU contaminated soil and water.
2. Chemical, physical and biological analysis of water, soil, plants and animals.
3. Diagnosis of DU poisoning of civilians and war veterans. Urine/Uranium test, Chromosome-Aberration Analysis, analysis of biopsy and autopsy materials.
4. Development of health treatment procedures.
5. Documentation
6. Information of the general public: DU brochure, lectures, articles, independent inquiries (Lloyd-Inquiry London 2004) etc.
7. Resolution on the Banning of DU (April 2000).
8. Sometimes we do what others talk about. We do what has to be done for humanitarian and scientific reasons irrespective of any political constellations.

Why do I attend this meeting? Your experiences can be helpful for us and vice versa. The uranium mining waste is recycled to a large extent. In nearly all countries you find DU contaminated soil from civilian and military use. In Germany about 18 sites are known, worldwide over 600. Procedures to remediate environment especially agricultural soil have to be developed. Only the very first steps in this direction have been carried out.

I want to sensibilise you to this new uranium waste problem, to draw your attention to this subject. DU remediation is not only a great scientific challenge but it is also a great market in future. Our goal is constructive cooperation.

Basics on DU

Toxicologically, uranium is a multi-talent! What are the atomic and molecular mechanisms of this dangerous talent?

Three basic aspects of this toxicity:

1. It is chemically poisonous, a characteristic of its atomic shell.
2. It is radiologically poisonous as an alpha-emitter. The spontaneous decay is a characteristic of the atomic nucleus.
3. We have to consider the experimental observation that **mutuality can strengthen chemical and radiological toxicity**, in particular at low uranium concentrations (Miller et al. 2002, 2002). A new and basic understanding of heavy metal toxicity mechanisms is being developed in keen and ingenious steps.

Chemo- and Radiotoxicity

General Remarks

DU metal reacts with water, undergoes radiolysis, dissolves and contaminates soil and groundwater. DU is very pyrophoric and burns on impact (3000°C). DU oxide particles consist of water soluble U^{6+} (in addition to ceramic DU). Uranium minerals mainly consist of water insoluble U^{4+}.

The chemo-toxicities of natural and depleted uranium are the same of course. The uranium isotopes are α-emitters. Only the decay rates differ. The α-toxic potential depends on the decay rate **and** the concentration of the uranium isotope. This fact sometimes is not mentioned, so the DU concentration is a basic parameter differentiated by the speciation (see below).

The DU oxide particles have a diameter of about 1.5 μm to 0.001μm (10 Angstrom). 10 Angstrom particles behave like a gas, enter the atmosphere, are carried by the wind and travel long distances before they come down.

Particle filters for this size particle do not exist. DU is taken up by plants, animals and humans. Inhalation of DU dust plays a major role in this contamination. DU reaches all parts/organs of an organism. It passes the blood-brain barrier and the placental barrier.

DU is chemically very toxic (T+). As α-emitter it leads to chromosome breaks (CB). I (AS) am originator of the first peer reviewed pilot study with British Gulf War Veterans. Their lymphocytes had five times more CBs than a comparative population, and fourteen times more maximum.

Uranium Speciation

Chemically malicious is uranium always, radiologically malicious only once: at the moment of its decay. Afterwards however its chemotoxic and radiotoxic decay products continue to be effective. The chemical characteristics, thus the toxicity, are a result of the electronic structure, the importance of the external electron shells. We compare sodium and uranium.

Singly ionized sodium has a noble gas configuration. Only Na^+ is present in the organism.

With uranium the behaviour is completely different. Several electron shells are only partly filled! Only after loss of six electrons does uranium achieve a stable noble gas configuration and becomes thereby U^{6+}, the most stable form in the organism. However by loss of 2, 3, 4 or 5 electrons, i.e. on the way to the most stable form, U^{2+}, U^{3+}, U^{4+} are formed, which are also stable, and U^{5+}. All these oxidation states are well-known. They could all be involved in metabolic processes.

Table 1.

Atomic Nr.	Element	Electronic shell							
		K	L	M	N	O	P	Q	
		1.	2.	3.	4.	5.	6.	7.	
10	Ne	2	8						
11	**Na**	**2**	**8**	**1**					-1e~Na^{+} („Neon“)
86	Rn	2	8	18	32	18	8		
92	**U**	**2**	**8**	**18**	**32**	**21**	**9**	**2**	-2e~U^{2+}
									-3e~U^{3+}
									-4e~U^{4+}
									-5e~U^{5+}
									-6e~U^{6+} („Radon“)

We now consider U^{6+}. t can be present in two forms – as the uranyl cation UO_2^{2+} or as the uranat anion UO_4^{2-}. The characteristics of the uranium molecule are strongly pH dependent.

The variety of the molecular forms in which uranium can be present extends again by the ability of the uranium atom to form complex connections. Uranium in the uranyl form can be absorbed in the organism for example with phosphate or carbonate complex connections. Here we refer to the fundamental work of Professor Bernhard and his co workers (Guenther 2004).

All these different forms have different biological activities and thus also different toxicities. Hereby it is clear that the toxicity can be directly set by the uranium ionization; this is not the case with lead, which has been claimed.

Toxicity develops on the level of molecular mechanisms, in particular the intermediary metabolism, diaphragm transportation, genetic, and in particular reproductive procedures. Here uranium intervenes.

Redox procedures play thereby a substantial role. Think for example of the mitochondrial energy metabolism. By its ability to take on different oxidation levels, uranium could intervene also in this connection on molecular level in metabolism.

The elucidation of the functions of uranium, the way uranium intervenes in life procedures, is a crucial step for treatment and eventual therapy of uranium intoxication with humans and animals, but the same holds for the bioremediation and biogeochemistry of the uranium.

Depleted Uranium (DU) and Natural Uranium (NU)

As mentioned the chemical toxicities of NU and DU are basically the same. What are the differences? What would be possible guidelines? A main point is the origin of the uranium. As long as we deal with uranium minerals we in most cases have to do with U^{4+}-based compounds. They are not water-soluble and their toxicity depends on the chemical “assimilation” they undergo in an organism, that means the oxidation/solubilisation etc.

The toxicity, i.e. the damage to the molecular mechanisms of intermediary metabolism depends on the uranium speciation, on the building of chemical complexes, on the redox-state of the molecular reaction mechanisms, on the pH value of the system. This is an extremely complex situation.

DU in contrast to NU is found in the environment in metallic form. 99% of the machine gun bullets fail their target and penetrate the ground. Technical machinery using DU for example as counterweights or as radiation protection goes to the trash when they are no longer used. This metallic uranium undergoes radiolysis and results in U^{6+}.

On impact, pyrophoric DU shells burn at about 3000°C forming uranium oxide (U^{6+}). The higher the burning temperature, the less water-soluble oxide is formed. This also depends on the conditions of impact resulting in varying percentages of soluble and water-insoluble "ceramic" DU oxide (with a particle size from 10 Å to 1,5 μm). This mixture enters the atmosphere and reaches the ground water. Possible proliferation is discussed below.

Uranium is taken up by plants. The mechanisms are not fully understood. It interferes with plant metabolism. Basic research in this field has been done by Guenther (2003) and Kothe (2005, in press) and Merten (2004).

The DU dust is inhaled by animals and humans. The water soluble DU oxide immediately enters metabolism, the ceramic DU is stored mainly in lymph nodes and released over years.

The mainly affected organs are: blood, kidney, lung tissue, CNS, liver, reproductive system, muscle and bone marrow. Every organ has his specific metabolism and in consequence develops specific toxicity.

Technical Aspects of Uranium Contamination

I go now to the technical aspects of uranium contamination. Some mechanisms are known already. There is immense need of basic and applied research in this area.

Which are the different sources of uranium contamination above natural levels in the environment? The most important source is the uranium mining industry, refining uranium ore up to the stage of yellow cake (including fine dust formation, also from the slag). Sources not related to the uranium industry include mining of phosphate minerals including the production and processing of the phosphate fertilizers. In this way infiltration takes place into the food chain. The burning of coal also leads to uranium in the environment. Most importantly, the production of reactor core fuel elements, atom bombs, mini atom bombs and DU weapons as well as civilian DU products leads additionally to uranium contamination. Here also testing and accidents must be considered, in particular in the military range.

Clinical Aspects of Uranium Intoxication

Uranium enters the organism by respiration, through the food chain and through injuries. It arrives at every part of the body. The particles, down to 10 Å in size,

dissolve and reach all, we emphasize all organs of the body, even those normally protected. Brain and placental blood barriers are penetrated. During pregnancy, the foetus will be contaminated. Presumably, this is also true for the blood testicle barrier. Insoluble, ceramic DU is stored in lymph nodes of the lung and transferred over time to the whole organism.

In the course of evolution many toxic heavy metals have found entrance into metabolism in the form of trace elements, usually as active substances. In the case of uranium to my knowledge no such example has been found.

Uranium compounds have different valences and can be deposited preferentially on blood proteins or to diaphragm proteins of blood cells (Erythrocytes and Leukocytes). This also ensures its complete distribution in organisms.

Irradiation by uranium alpha-radiation can be demonstrated and reliably quantified by measuring the chromosome breaks in the Lymphocytes. A pilot study with 16 British Gulf War veterans demonstrated an average 5-fold increase of Chromosome breaks, with a maximum of 14-fold increase (Schroeder 2003).

A substantial part of our toxicological knowledge is due to systematic toxicological research as well as laboratory and industrial accidents connected with the development and building of the atom bomb. (Voegtlin, Hodge 1949, Toxicological Profile for Uranium 1990, Toxicological Profile for Uranium (Update) 1999) Unfortunately many documents and research results have never been made public.

Kidney damage has been demonstrated from experiments on animals. The classical way to produce kidney damage for the examination and testing of medical treatment procedures is by administrating Uranylacetat. This leads to a reduction of the glomerular ultrafiltration coefficient Kf. Electron microscopic studies have shown a decrease in the density and diameter of the endothelial window, which leads to a decrease in K_f and the glomerular filtration rate GFR because of a decrease in the filter area Here as well there is evidence of the formation of complexes of uranyl with phosphoryl- carboxyl- and sulfhydryl-groups on the surface of the cell membrane. Since the proximal tubulus of the kidney is very much dependent on the oxidative generation of high-energy phosphate, ATP, an effect from uranium is to be examined here too.

In the uranium mining industry, illnesses of the gastrointestinal tracts have led to an increase in deaths. Haematological effects, in particular a decrease of the haemoglobin concentration, have been observed. An increase in lymphatic leukaemia has also been observed. Reproductive effects: because the y-y-chromosome (few genes) is more resistant to radiation than the x-x-chromosome, an increase in the ratio in births of boys to girls was found. Gene-toxic effects: With mountain workers an increased number of chromosome breaks was determined.

Migration Paths of the Depleted Uranium (DU) and their Research in Iraq

During the Gulf wars of 1991 and 2003, the southern and central regions of Iraq were affected by the use of armour- and bunker-piercing weapons containing DU. The amount of the released DU is estimated as probably 340 metric tons in 1991 and probably 1200 metric tons in 2003. Two migration paths with different extents must be discussed: **water / soil** and **wind**.

Migration Path Water / Soil

The majority of the fired ammunation (more than 90%) missed their targets (tanks, fighting vehicles, buildings, bunker etc.) and finished in the ground penetrating to different depths. Consequently the solid DU- rounds are affected by percolating water. There is the chance of contacts with the ground water in the area of the alluvial plain of the Euphrates and Tigris. The United Nations Enviromental Program (UNEP) has determined that DU-penetrators buried near the ground surface in Bosnia Herzegovina had decreased in mass by approximately 25% over 7 years (UNEP 2003).

The oxidation and corrosion depend on the rainfall. The dry southern and middle regions of Iraq have low annual precipitation, not more than 200 mm (Baghdad: 154 mm, Basra: 172 mm). Nevertheless, short and havy thundery shower sometimes occur and thus the annual rainfall varies.

The DU ammunation in the ground are often surrounded by a salty milieu, especialy in irrigated fields of the Euphrates and Tigris lowland plain. The Food and Agriculture Organisation (FAO) estimated in 1998 that 5.5 million out of a total of 11.48 million hectare are agriculturally useless because of salination and the trade embargo imposed during that period. The highest water-bearing aquifers can have a content of salt of 5000 ppm – 60000 ppm (DIA 1991) classified as brackish or saline.

Migration Path Wind

When a DU-containing shell impacts a target DU-dust is produced (size of the particles vary between 1.5 µm to 10 Å) and will be transported by the wind. The wind direction, its strength and frequency fluctuate seasonally and regionally (Wilkerson 1991).

The main wind is the summer “shamal” from June to September: the wind of the 120 days, coming out of the south and southeast, with average speeds up to 50 KmH and dust plumes and walls up to some thousands meter high. It meets a dry ground nearly free of vegetation. The thermal radiation at night (loss of temperature) and the violent heating during the day lead to horizontal air movements and turbulences over the ground as well. The velocity of the winds and of the tur-

bulences is sufficient to carry the dust over longer distances. Decreased speeds lead to a fall-out over a larger area and wind-protected sites will receive a local sedimentation.

Research

Here we make some recommendations for investigations which will be brought under discussion. A multistage approach which takes into account the current security situation would be favourable. For a successful implementation, the Iraqi administration and companies would have to be more and more involved and under better security conditions.

The first step would not include field work. The affected sites, the battle areas and the areas of DU use will be registered by date including details. Necessary data for follow-up investigations will also be collected and a first risk assessment will be undertaken.

The second step, based on the first one and branching out into local, regional and national research, corresponds to determining the extent of the two migration paths.

For a start, remote sensing can be used to determine the main investigation sites for follow-up geoscientific studies (including geophysical, geochemical, hydrological, geological, meteorological and other methods). Remote sensing allows a carefully targeted and cost cutting project.

Step 1: Acquiring Data and Registering Sites

1. Collecting situation and battle reports (Pentagon, Department of Defense, internet, privat reports) and registration of the sites of battles and use of DU.
2. Acquiring data concerning the sites:
   - Data from satellites (ASTER, IKONOS, OrbView, Quickbird etc.) and aerial photos.
   - Geological, hydrogeological, geochemical, geophysical and other data, information on restricted zones.
   - Meteorological data for the whole of Iraq and Kuwait.
3. Establishing a registry of battle sites and sites where DU was used.
4. Assessment of the length of potential migration paths of DU- particles, first assessment of risk

Step 2: Local, Regional and National Investigation by Integrated Methods

1. Local investigation using remote sensing:
   - Detailed mapping of battle sites and sites of use of DU: emplacement, tanks, military vehicles, impacts of duds, damaged buildings and grounds etc.
   - Establishing of Digital Elevation Models (DEM).
   - Fixing of wind-protected sites as potential accumulation sites.

- Recommendations for geoscientific site investigations

2. Local geoscientific integrated investigation of selected pilot sites:
   - Geophysical survey: radiometry, electromagnetic, magnetic, conductivity.
   - Search for munitions and shells in the ground.
   - Analyses of wind-protected sites.
   - Analyses of the soil and the ground water system.
   - Modelling of ground water flow.
   - Modelling of the spreading of the DU-dust by the wind.
   - Forecast of the risks involved.
3. Regional and national investigations:
   - Setting up of a stationary air measurement system (air samplers) for Iraq and Kuwait.
   - Analyses of agricultural areas und standing water.
   - Analyses of agricultural products and drinking water.
   - Analyses of humans and animals.

Techniques for DU Remediation

In 1996 a patent was obtained on DU remediation (Ma 1996). It is based on the classical leaching procedures combined with mechanical separation steps. Bioremediation procedures are developed by Guenther (2003), Kothe (2005 in press) and Merten (2004).

With respect to the current situation this contribution shows different aspects of DU toxicity. We just seek one thing: constructive cooperation.

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