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The Effects of Depleted Uranium Weapons on Humans and the relevant Environment

A Master's Thesis submitted for the degree of
"Master of Science"

supervised by
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Vienna, 01 June 2017

Affidavit

I, THOMAS TILLER, hereby declare

1. that I am the sole author of the present Master's Thesis ," THE EFFECTS OF DEPLETED URANIUM WEAPONS ON HUMANS AND THE RELEVANT ENVIRONMENT". 69 pages, bound, that I have not used any source or tool other than those referenced or any other illicit aid or tool, and
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Abstract

Ammunition containing depleted uranium (DU) has been used in armed conflicts since the First Gulf War in 1991. This type of ammunition is used in certain weapons, such as tank rounds, 30mm guns and cruise missiles. Depleted uranium munition has such a high density that it can pierce armor. Consequently, it is used to penetrate hard targets, such as armored vehicles and tanks. Depleted uranium is a byproduct of the enrichment process in nuclear power production and thus radioactive. It is abundantly available and very cheap.

There are more than a dozen states who have DU-munition and it has been mainly used by the USA. There are major concerns about its long-term effects. DU-munition is said to cause various types of cancer and severe reproductivity problems for both men and women. The most discussed and controversial adverse effect is the cause of congenital malformations on newborns. Numerous studies by miscellaneous groups and scholars have been conducted on the alleged health effects. The results differ considerably until today. The major reasons are that studies are either conducted too early after exposure (i.e. during the incubation periods of illnesses) or they only scrutinize the radiological toxicity and disregard the neurological effects. Today it is known that the main problem is not the DU-munition per se but the aerosols containing DU which are created after a DU-round has hit a hard target. DU has a high chemical toxicity and it is mutagenic.

This master thesis reviews the studies about the health effects of DU-weapons on humans and the relevant environment and analyzes why the outcomes differ frequently.

Additionally, it compares the hazards of DU-munition to other types of uranium like nuclear energy, uranium mining, the natural exposure to uranium and nuclear weapons. The outcome is displayed in a Severity Impact Assessment Scale which provides an overview about the health consequences of the various uranium types.

Eventually, the legal situation of DU-weapons is examined. It is described how the problem has been addressed so far in the international community and what needs to be done to curb the use of DU-weapons in the future.

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List of Abbreviations

µg	Microgram
µm	Micrometre
AEPI	Army Environmental Policy Institute
AFFRI	Armed Forces Radiobiology Research Institute
Bq	Becquerel
DU	Depleted Uranium
e.g.	Exempli gratia
et. al.	Et alia
etc.	Et cetera
EU	European Union
Gy	Gray
IAEA	International Atomic Energy Agency
ICBUW	International Coalition to Ban Uranium Weapons
ICC	International Criminal Court
ICJ	International Court of Justice
ICRC	International Committee of the Red Cross
ISIL	Islamic State of Iraq and the Levant
KFOR	Kosovo Force
kg	Kilogram
mg	Milligram
mBq	Millibecquerel
mSv	Millisievert
NATO	North Atlantic Treaty Organization
NGO	Non-Governmental Organization
ppm	Parts per million
RERF	Radiation Effects Research Foundation
SIAS	Severity Impact Assessment Scale
Sv	Sievert
TNT	Trinitrotoluene

UN	United Nations
UNEP BTF	United Nations Environmental Programme Balkans Task Force
UNSC	United Nations Security Council
UNSCEAR	United Nations Scientific Committee on the Effects of Atomic Radiation
UXO	Unexploded ordnance
WHO	World Health Organization

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1. Introduction

1.1 Outline of the theme

The element uranium is used in numerous ways. There are several civil and military applications. For the latter, the most known purpose is its use in nuclear bombs. However, uranium is also used in a depleted form in tanks as armour and in ammunition. While nuclear bombs are only considered as an ultima ratio due to its devastating effects, ammunition consisting of depleted uranium (DU) is commonly used in warfare. It has a very high penetration force and thus increases the wanted effect of ammunition significantly. Weapons where DU-ammunition is used, are often referred to as DU-weapons. They are majorily used by the USA but also by more than a dozen other states.

Since its first use in Gulf War I there are major concerns about its long-term effects. DU-munition is said to cause leukaemia, cancer and severe reproductivity problems for both men and women. The most discussed and controversial adverse effect is the cause of congenital malformations on newborns. Babies are born without eyes or limbs and their organs are placed outside. This is a perception of many veterans and in particular of the civilian population where the DU-munition has been fired. All these claims have come up by people who were exposed to DU-munition at some place. Many doctors observed an increase in the above mentioned diseases too and linked it to DU. Consequently, this topic gained a lot of attention from the media and raised the concerns of scientists. Numerous studies by miscellaneous groups and scholars have been conducted on the alleged health effects. The results differ greatly until today. They range from denying any harmful effects on people to the accusations of a deliberate attempt of insidious genocide. Today it is known that the main problem is not the DU-munition per se but the aerosols containing DU which are created after a DU-round has hit a hard target. The detrimental health effects are due to the alpha particles of DU, which ionize strongly and cause 20 times more cell damage than Beta or Gamma particles if they are inhaled or ingested. DU has a high chemical toxicity and it is mutagenic.

1.2 Objectives of research

The author of the master thesis pursues three objectives.

First Objective

At the beginning the author analyzes the different studies which scrutinize the impacts of DU-munition on humans and the relevant environment. Studies from all examined conflicts are considered. This means that the Gulf War of 1991, the war in Bosnia and Herzegovina between 1992 and 1995, the Kosovo War of 1999 and the Iraq War of 2003 and the following years are included in the analysis. Additionally to these conflict areas, the results of tests with DU-munition conducted in the USA and the UK are included in the examination. Here, the focus lies on the effects on the environment.

DU-weapons have also been used in Afghanistan, Libya and Syria, but due to the fact that no studies have been conducted there, these three war zones cannot be included in the analysis of the health effects. Thus, the use of DU-munition in these areas is outlined. Besides, the conflict zones Yemen and Gaza are mentioned where an alleged use of DU-munition has occurred.

The outcome of the first objective shall be the clarification whether the studies are conclusive and if there is clear evidence about the long-term effects on humans.

Second Objective

The second goal of the thesis is to compare the hazards of DU-munition with other types of uranium. In the first step it shall be explained whether peaceful uses of uranium are significantly less harmful to people and the environment than the use of DU-weapons. Therefore, nuclear energy, the exposure of uranium in mining and the natural exposure of humans to uranium shall be considered. In the next step, the impact of DU-weapons shall be compared to those of nuclear weapons. The whole topic shall be seen from an unbiased and new angle by introducing a scale of danger of the different uranium types.

Third Objective

After having assessed the dangers of the different types of uranium, it is possible to make a conclusion if DU-weapons cause such devastating consequences that their use should be banned as several countries demand. Consequently, the legal situation is addressed and it shall be found out if they should be categorized as a weapon of mass destruction and how a possible ban can be implemented in the future.

1.3 Structure of the thesis

The topics of the thesis are divided into four chapters.

1) The properties of uranium are explained and its fields of application are presented. Moreover, the types of exposure and their health risks are described.
2) Then, the different studies about DU-munition are reviewed. It is analyzed why the outcomes differ considerably in some cases. This could be due to the different methodology, sampling, location and the interpretation of results.
3) The exposure to all other relevant uranium types is briefly examined with the focus on nuclear weapons. The different types are compared and subsequently categorized according to their threats by using a severity impact assessment scale to humans and the environment.
4) The author dedicates to the legal aspects and assesses if the use of DU-munition infringes any existing laws or principles. Moreover, it is described how the topic is addressed in the international community. Based on the health effects of DU-weapons and the legal situation a recommendation regarding the implementation of a possible ban is made.

Finally, a conclusion is drawn of the findings the author has made and the results of the three objectives are presented in a concise manner.

2. Properties, use and exposure of depleted uranium

2.1 Uranium

Uranium is an element with the atomic number 92. It is a dense heavy metal which can be found in all types of rocks, soils and waters. It is ductile and malleable and appears throughout the earth's crust at an average concentration of two to four mg per kg (Fathi et al. 2013). It occurs in solid, liquid and gaseous forms. The formation of uranium compounds depends on the amount of oxygen, the surrounding acidity and moisture, the other metals in the compound and the temperature (AEPI 1995). There exist three isotopes of it whose features are shown in table 1.

Table 1: Uranium isotopes

Isotope	**U-234**	**U-235**	**U-238**
Half-life in years	246,000	700mn	4,470mn
Relative mass in natural uranium	0.006%	0.72%	99.3%
Bq/g	$231x10^{6}$	80,01	12,45

Since all isotopes are very unstable it emits only little radioactivity. It decays very slowly as can be seen according to the long half-lives. The decay process of a radioactive element is referred to as half-live and it means that after the denoted time half of the initial radioactivity is gone. The radioactive decay products emit alpha, beta and gamma radiation. Alpha particles cannot even penetrate a piece of paper but still can be harmful if ingested or inhaled. Beta rays can penetrate human tissue up to two centimetre. Gamma rays consist of highly energetic photons and shielding requires big amounts of mass.

In figure 1 the nuclear fuel cycle is depicted. Uranium is the required element for nuclear energy production, nuclear weapons and DU-munition.

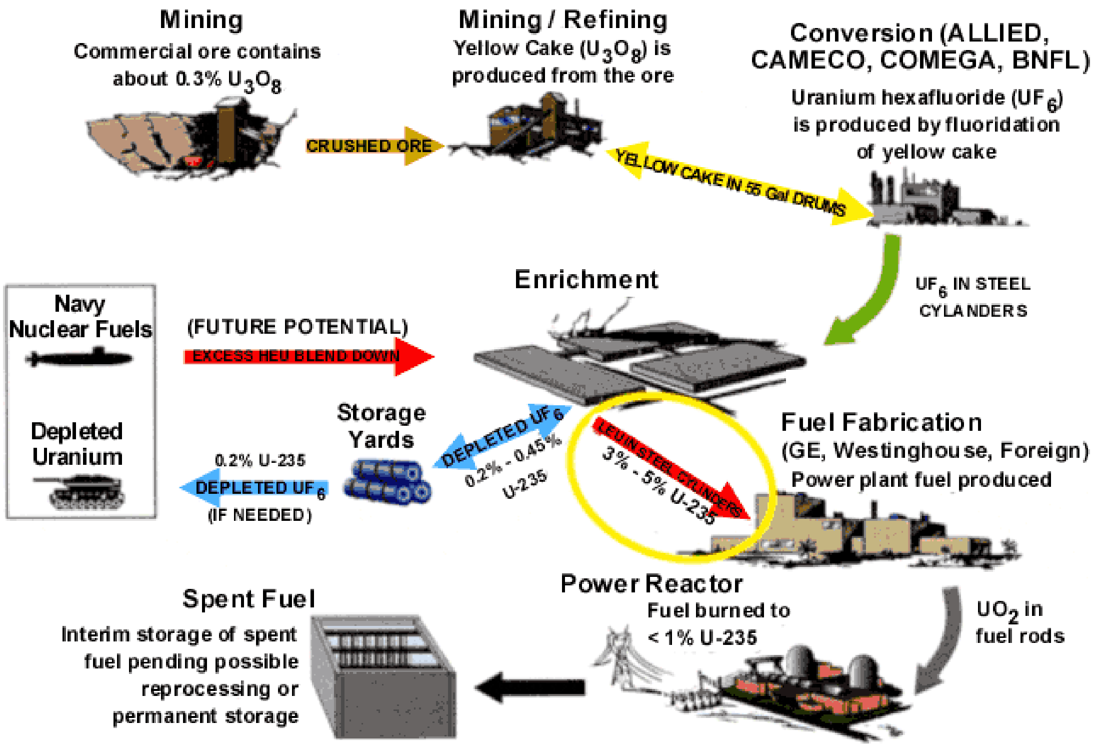

Figure 1: The nuclear fuel cycle (Office of Nuclear Energy 2017)

For the production of nuclear energy and nuclear weapons it is necessary to increase the share of U-235 from the naturally given 0.72% to 4% or 90%, respectively. This phase is called enrichment process. Uranium was first enriched in the 1940s by the USA and the USSR in their endeavour to produce nuclear weapons. It is a sophisticated and energy intense process. The rationale why U-235 must be increased is to start and maintain a nuclear chain reaction. This fission reaction releases tremendous amounts of energy. The crucial difference in enriching U-235 for nuclear power plants and nuclear bombs is that for the latter U-235 must be enriched to a proportion of 90%.

2.2 Sources of DU

Depleted uranium is produced as a by-product from the enrichment process during the nuclear fuel cycle. This leftover amounts to 96% of the mass converted during the enrichment phase (Chitumbo, 2016). Since U-235 and U-234 are increased during the enrichment process it is clear that the by-product called DU contains much less of these isotopes. The content of U-234 and U-235 is about one third of the original values (Bleise, Danesi, and Burkart 2003). Thus, also the radioactivity is significantly less in DU than in natural uranium with 14,80 Bq/g compared to 25.28Bq/g (Ibid).

Types of DU

There are three types of DU:

1. Regular depleted uranium, which are the leftovers of the U-235 enrichment process (Hamilton 2001).
2. Unprocessed depleted uranium in spent fuel, which is very radioactive and undoubtedly hazardous for the environment. This hot DU can be found after nuclear accidents or near nuclear reprocessing plants (Ibid).
3. Reprocessed depleted uranium, which is used after the spent fuel of a nuclear reactor is removed. (Ibid).

Hence, there are two forms of deliberately produced DU, namely the regular depleted uranium and the reprocessed depleted uranium.

DU inventories

Around 95% of DU is stored in the form of uranium hexafluoride (UF6) in steel cylinders (Zucchetti 2009). In the USA it is estimated that there are more than 57,000 such cylinders of which most of them are stored in the proximity of enrichment plants (Ibid).

The largest stock holders of DU are the USA and Russia with almost 500,000 tons (Wikipedia, 2017). France and the UK have the highest stocks in Europe (Ibid). There is a report from the Nuclear Energy Agency of the OECD from 2001 which quotes the countries' inventories of DU. This, however, does not say anything about the use of DU-ammunition and the stocks.

Table 2: Depleted Uranium Inventory (OECD NEA, 2001)

Nation	**DU stocks in tons**
USA	686,000*
Russia	460,000
France	190,000
UK	30,000
Netherlands	16,000
Germany	16,000
Japan	10,000
China	2,000
South Korea	200
South Africa	73

*as of 2008 (Zucchetti 2009)

Table 2 shall merely give a rough overview of the stocks held by several countries. It is likely that these figures have markedly changed during the past 16 years.

2.3 Radiological and chemical properties of DU

It must be distinguished between the radiological and the chemical effects. The difference is that the chemical characteristics of an element remain the same regardless of its isotopic form. The radiological effects, on the other hand, differ according to the isotopic form.

Radiation from ultraviolet rays, X-rays and Gamma rays are a common cause of cancer. Since DU has such a low specific activity it is widely agreed upon that its radioactivity is not the cause for any diseases such as cancer. Even through inhaling relatively large amounts of DU aerosols a harmful radiation dose can virtually not be reached (Fetter and von Hippel 2000).

The chemical toxicity of DU, however, is of big concern. The kidney is most susceptible for the uptake of uranium. Its acid environment dissolves the uranium. It then induces cell death in the kidney tissue from a concentration of 3 ppm onwards (Ibid). This would be equivalent to around 1 mg of uranium in a human kidney.

The biggest problem is that DU is mutagenic because it alters cells to a tumorigenic type (McClain et al. 2001). It is known that the uranyl ion reacts biochemically and forms complexes which can damage the DNA. It is also neurotoxic and changes the hippocampus in the brain (Ibid). These neurological effects can already occur at rates five to ten times smaller than those which cause kidney damage (Fetter and von Hippel 2000). Furthermore, it crosses the placental barrier and enters fetal tissue (McClain et al. 2001). In general, there is a big concern about the reproductive effects of DU. These include:

- Structural effects: damaging the reproductive system like the germ lines
- Genotoxic effects: altering the DNA which would be passed to offspring and result in fetal demise (i.e. miscarriage or stillbirths) or birth defects
- Developmental effects: damaging the fetus

Miscarriage usually refers to fetal death within the first 24 weeks of pregnancy and stillbirth to fetal death after the 24th week. The crucial distinction is that in the latter case, a baby is born but dies shortly afterwards.

For other metals like lead, chromium and cadmium, these genotoxic effects are already known for a few decades (Arfsten, Still, and Ritchie 2001).

2.4. Civil use of uranium and DU

Mining of uranium has already been conducted in the Middle Ages (World Health Organization 2001a). The main peaceful use of uranium, of course, is for power generation in nuclear power plants. DU was also used in power production. There it was majorily used as a cladding material in so called fast-breeder reactors. The DU produced additional reactor fuel there (Priest 2001).

Besides, until the middle of the 20^{th} century uranium has been used for the colouring of glassware and ceramics. Until the 1980s it has been used as an additive in porcelain crowns for teeth to obtain a natural colour and fluorescence. A further medical application of the past was as a pharmaceutical to treat diabetes (Priest 2001). Another historical use was as a catalyst in specialized chemical reactions and photography (World Health Organization 2001a).

A current use of DU is in radiation shielding. Due to the high density DU can shield gamma radiation. Consequently, it is used in tele-therapy units which are used in cancer treatment and as radiation shielding for radioactive transports (World Health Organization 2001a).

Furthermore, DU plays an important role in the following areas thanks to its high density: as counterweight in aircrafts to stabilize the wings, to add weight to big fork lifts and the keel of yachts can be made up of DU too. For instance, it is used in the Boeing 747 fleet where it adds more than one ton of counterweight in order to enable better flight control (Ibid).

2.5 Military use of DU

On the one hand, DU is applied to enhance the armour of vehicles and on the other hand in ammunition because it is armour-piercing.

2.5.1 Armour

DU is commonly used in tanks to amplify the armour. Due to its high density, namely 1,7 times higher than lead, it is hard to be penetrated. Its density is $19g/cm^3$ compared to $11.3g/cm^3$ in lead (McClain et al. 2001). It is usually used in between the steel layers of a tank. Examples are the main battle tanks of the US Army, the “M1 Abrams”, and of the Israeli forces, the “Merkava”.

2.5.2 DU-munition

Why is DU-ammunition used in the military? There are several attributes which make the use of DU attractive.

- It has a high density.
- It is pyrophoric, which means that it ignites spontaneously at temperatures below 55°C.
- Its melting point is high at 1132°C and its tensile strength is similar to steel (Bleise, Danesi, and Burkart 2003).
- It is abundantly available and cheap.

Since DU is a radioactive waste product and thus costly to dispose, it is delivered to the armament industry at very low cost or for free (White 2008).

When was DU introduced in armed forces? In the UK test firings of DU bullets have begun in the 1960s and the USA followed around 10 years later (Handley-Sidhu et al. 2010). When the research began in the USA, tungsten and DU were tested because both materials have a very high density (Bleise, Danesi, and Burkart 2003). However, since tungsten lacks pyrophoricity it is much less effective than DU. Additionally, DU is more abundantly available and cheaper, because it is a waste product in the nuclear energy industry. Hence, it does not have to be produced for any applications because it is already there. Since the disposal of nuclear waste is very costly it is economical to use it than to store it.

Who uses DU-ammunition and for which weapons? In general, each nation is reluctant to reveal sensitive military data. Thus, it is quite difficult to get reliable information about countries who use DU-ammunition and how much they possess. From some countries it is known that they use it due to official statements or sufficient evidence. These are the USA, UK, France, Saudi Arabia, Russia, Israel, Pakistan, Thailand and Turkey (Harley et al. 1999).

Some countries, however, admit the use of this type of ammunition. These are the USA and the UK for instance. It is preferably used in tank ammunition and in the 30mm calibre Gatling gun. The tank rounds are of 105 and 120mm calibre and contain 4 and 5kg of DU respectively (Fetter and von Hippel 2000). The Gatling gun is used in the standard fighter jet, the “Thunderbolt” (Fairchild-Republic A-10), and in the “Apache” Attack Helicopter. One round contains 0.3kg of DU (Ibid).

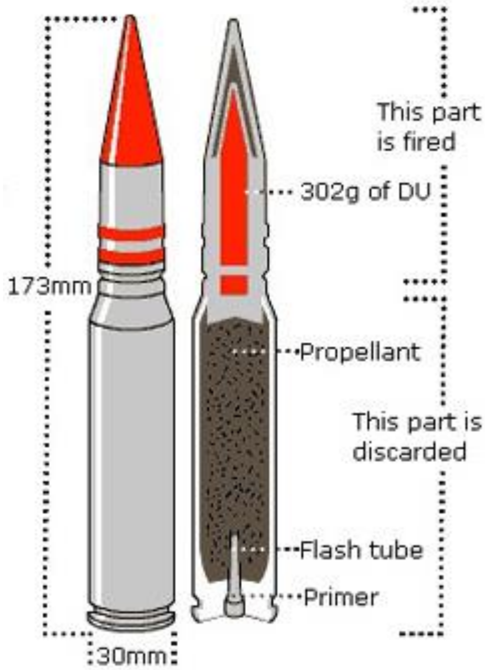

Figure 2: Sketch of a 30mm round (Hunter E., 2011)

The Gatling gun of the Thunderbolt aircraft can fire 3900 rounds per minute and DU ammunition makes up around 75% of all bullets (Bleise, Danesi, and Burkart 2003). Further applications of DU-munition are in 20 and 25mm rounds which are fired from machine cannons. These weapons are mounted on the “Bell AH-1 Cobra” attack helicopter and the “AV-8B Harrier” ground-attack aircraft and contain 180 and 200g of DU, respectively (Zucchetti 2009).

It could be that the US Navy and Royal Navy of the UK use DU too in some Tomahawk cruise missiles. These are long-range land-attack missiles which are fired from ships. They are around six meters long and frequently used when military action is taken. There are critics like the Italian professor Massimo Zucchetti who is convinced to have profound indications about the existence of DU in the ammunition. He estimates the DU in the warheads to be anything between three and 400 kilos (Zucchetti 2009). The problem with the Tomahawk missiles is that it is not officially confirmed by the states that they use them with DU. The US Navy admitted that they tested Tomahawk missiles containing DU in April 1999 on the Vieques training site (Physicians for Social Responsibility, 1999). Uses in armed conflicts have always been denied. Officially, the US-Navy stopped in 1993 to use DU-munition and changed to use tungsten for armor-piercing purposes.

The Russian Army is believed to have used DU-munition since the end of the 1970s in their main battle tanks (Zucchetti 2009). The French Army uses DU-rounds in their main battle tanks “AMX-30” and “Leclerc” (Borrmann 2010)

As it has been shown in chapter 2.2 there are two options for the production of DU. Whether the DU is used immediately after the conversion process for the production of ammunition and armour or as reprocessed DU differs among the countries. In the UK, for instance, reprocessed DU is used to produce ammunition for the British Army. It is the Starmet Corporation which is responsible for the chemical processing and provision of DU munitions to the army (Hamilton 2001).

The composition of DU ammunition is shown in table 3.

Table 3: Composition of DU tank ammunition in the UK (Hamilton 2001)

Radionuclide	**Half-life in years**	**Mass in g**
Uranium 238	4.51×10^{9}	0.9979
Uranium 235	7.1×10^{8}	0.00199
Uranium 234	2.47×10^{5}	0.00001
Uranium 236	2.39×10^{7}	0.0000003
Neptunium 237	2.44×10^{6}	2.2×10^{-7}
Plutonium 239	244,000	1.2×10^{-10}
Plutonium 240	6,500	2.26×10^{-10}
Americium 243	7,950	1×10^{-9}
Plutonium 238	86	5.2×10^{-12}

As it can be seen in table 3 the DU consists of more or less only Uranium 238. From the composition of DU-munition depicted in table 3 it can be inferred the UK-Army uses reprocessed DU. This type of DU is more dangerous than the regular type, because it contains plutonium and americium.

2.6 Exposure to DU

The types of exposure to DU are shown in exhibit 3:

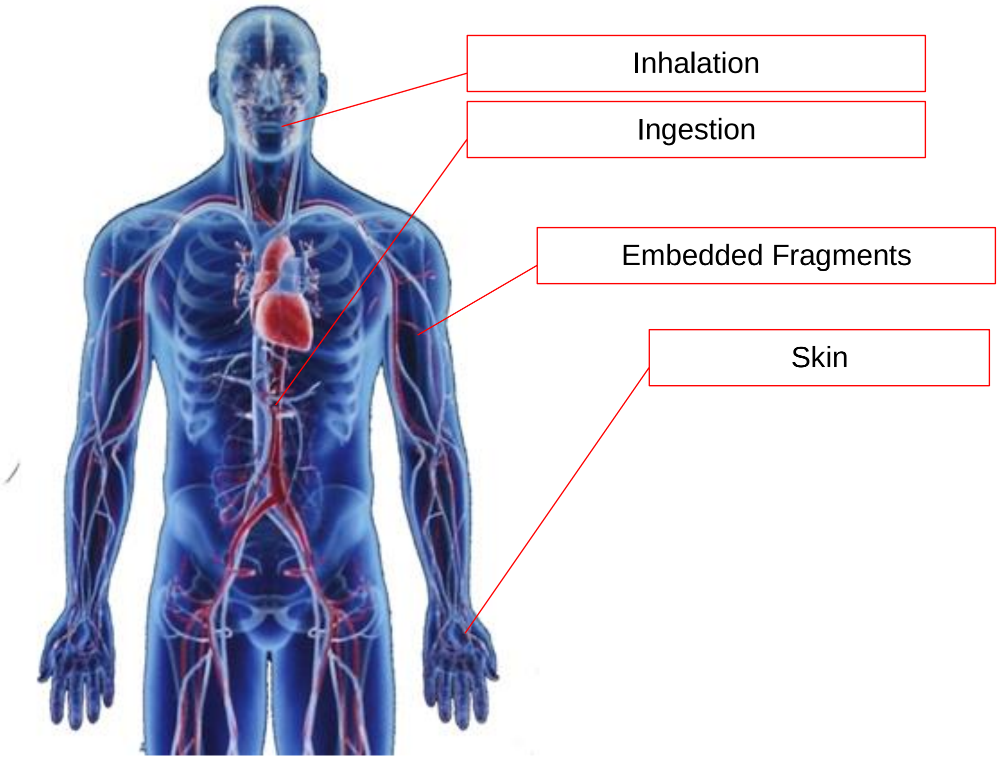

Figure 3: Pathways of DU to into the human body

2.6.1 External exposure

The only form of external exposure to DU is given when DU objects are touched. Then, the DU is absorbed via the skin through beta particles. The dose of a pure DU piece is around 2mSv/h (Bleise, Danesi, and Burkart 2003). The annual harmful limit for skin is 500mSv. Thus, one would have to touch such an object 250 hours until hazardous levels are reached. Thus, Bleise et al. come to the conclusion that *“no visible health effects are expected from external radiation caused by DU left in the field.”* (Bleise, Danesi, and Burkart 2003, p. 104)

2.6.2 Embedded fragments

Embedded fragments are DU shrapnel which is in human bodies because they have been shot with it. If the wounds were not life threatening they mostly were not removed from the body. There are only studies available which examine the effects of DU shrapnel on American veterans during Gulf War I but none which take into consideration the wounded inhabitants of the conflict zones. Thus, the number of examined people is very limited because it only includes soldiers who have been hit by friendly fire (since the opposing forces have never used DU-munition). The results will be shown in chapter 3.2.

2.6.3 Ingestion

Humans have around 56 µg of uranium in the body, while more than half of it is in the skeleton and around 35% can be found in muscle tissue and fat (Bleise, Danesi, and Burkart 2003). The rest is in blood, lung, liver and kidneys. For the sake of completion it must be mentioned that these values differ from source to source. The WHO, for instance, states that the human body consists of around 90 µg of uranium and that the proportion in the skeleton and the liver is markedly higher than mentioned before (World Health Organization 2001a).

An adult with a regular diet consumes about 1.5 µg uranium per day. The daily tolerable threshold is around 48 µg (Hamilton 2001). The United Nations Scientific Committee of the Effects of Atomic Radiation set a limit of 100 µg per litre in potable water (J. L. Domingo 2001). This level is based on the chemical toxicity for the kidney. The uptake of DU via ingestion refers to contaminated food and water. DU dust can settle on agricultural ground and could leach into potable water. It also can be taken up via the food chain when exposed animals are eaten by humans. Until the beginning of the 2000s no study has ever proven a significant negative effect of DU via ingestion pathways. The current status of knowledge, however, is that despite of the low radioactivity level, DU poses a threat if ingested (Briner 2010).

2.6.4 Inhalation

Creation of DU dust

Aerosols containing DU pose the biggest threat to humans which is the reason why this master thesis emphasizes the analysis of DU dust. As long as DU is part of armour or an unfired bullet it is not harmful. It only unfolds its toxicity when it hits other objects at high speed. It ignites on impact, which means that the outer layer of the projectile catches fire. Tank-fired rounds have a muzzle velocity of 1,500 meter per second (Fetter and von Hippel 2000). The kinetic energy of a 120mm fired round equals 1.4 kg of the highly explosive TNT (Ibid). The harder the hit object is, for instance another tank or vehicle, the higher is the temperature. Most of the kinetic energy is converted into heat. The uranium subsequently melts. Due to DU's pyrophoric property small fragments can burn and thereby generate DU-oxide aerosols. The predominantly formed oxide is depleted triuranium octaoxide (U_3O_8) (Harley et al. 1999). Uranium can also oxidize to form uranium dioxide (UO_2) and uranium trioxide (UO_3). Thus, due to this impact DU dust is created. The harder a target is the more particles are formed.

Another form of creation of DU dust is via corrosion over the course of time. Findings of DU penetrators by UNEP in Bosnia and Herzegovina conducted seven years after the war showed a decrease in mass by one fourth (UNEP 2003). The corrosive process creates uranium oxides and a DU round can be completely oxidized after around 30 years. Here it must me remarked that this applies to DU-ammunition lying a bit beneath the ground surface and that objects on the surface corrode slower (Ibid).

Inhalation of DU aerosols

These aerosols can be inhaled and unfold their detrimental effects in the human body. What does the pathway of the particles look like in the body? In order to understand the ongoing processes better it is necessary to know the respiratory system. Exhibit 4 shows the respiratory regions of a human.

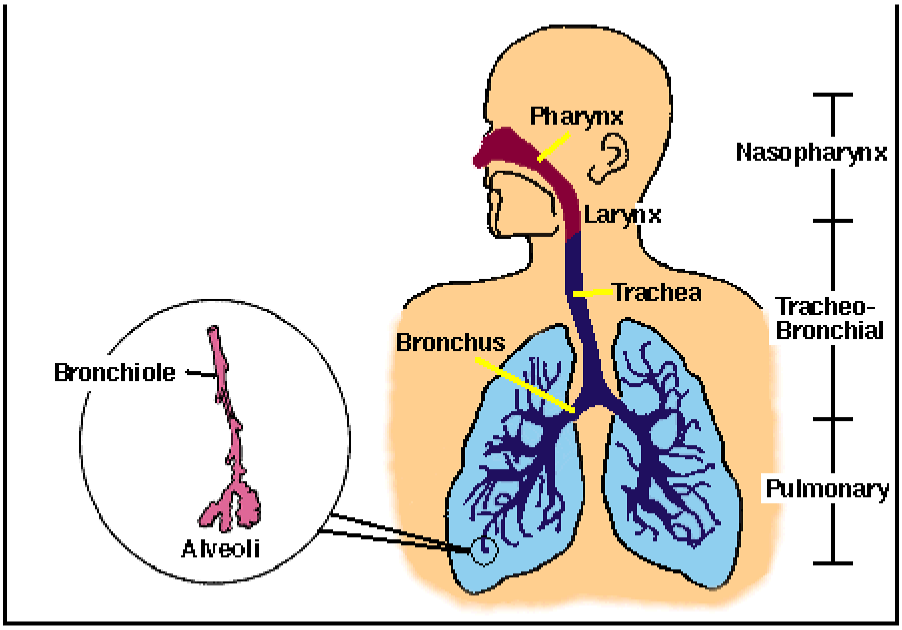

Figure 4: The human respiratory system

As it can be seen in the graphic there are three compartments: the head section on top with the nose and the throat, then the wind pipe and the bronchia and then the pulmonary area. Virtually all particles between 10 and 100 µm in aerodynamic diameter are cleared by the nasopharyngeal section (Puxbaum, 2016). Respirable particles which are a bit larger than 10 µm deposit in the tracheobronchial section. A big proportion of this particulate matter is cleared to the pharynx by the mucociliary clearance mechanism which means that they are either swallowed or excreted via the nose. The problem with DU particles is that (under the common circumstances which will be explained in chapter 3.1.2) most of them have a size of less than 10 µm in aerodynamic diameter (Harley et al. 1999). This makes it difficult for the respiratory system to cope with. The smaller the particulates are the more deposit in the alveoli of the lung. Thus, one major factor of how much the DU dust deposits in the body is the particle size. A further distinctive factor for the uptake into the bloodstream is the solubility. The solubility depends on the particular compound and the solvent. Body fluids can dissolve such uranium compounds. Thus, the solubility refers to the rate at which DU is absorbed into the bloodstream. If a component is soluble the body absorbs it quickly from the lung which means a few days (Bleise, Danesi, and Burkart 2003). A particle is referred to as insoluble when this process takes months to years (Ibid). Soluble aerosols are more harmful than insoluble particles because due to the faster uptake the risk of chemical toxicity is higher. The difference between the effects of these two types of aerosols is tremendous. A hazardous concentration of 1 ppm in the kidney (i.e. around 3mg) would result after inhaling 15 to 18 mg of soluble uranium aerosols while as 900 to 4200 mg of insoluble aerosols would be needed (Fetter and von Hippel 2000). As mentioned in chapter 2.2 the neurotoxic effects are likely to occur at a concentration of five to ten times lower. The maximum amount inhaled when standing next to a 120-mm DU round fired from a tank would be 0.3 mg (Ibid). The same value is also reached after firing 40 to 500 30-mm DU bullets, depending again very much on the soluble proportion (Ibid). If the DU aerosols unfold their neurotoxic effects depends of course on the duration of the exposure.

95% of the large inhaled particles deposit in the bronchioles, After DU has entered the bloodstream the human body excretes 90% of it via urine within 24 hours (Priest 2001). The remnants are deposited in the bones and to a smaller extent in the kidneys and other organs.

Monitoring of DU aerosols

Most of the time the DU particles are smaller than 5 µm (Bleise, Danesi, and Burkart 2003). This means that they can be borne for a long time and a long distance in the atmosphere. They could be carried up to a hundred kilometres before deposition (Fetter and von Hippel 2000). This depends on wind velocity, precipitation, topography and size and height of the initial cloud which contains the DU aerosols. A large part of the deposited particles from the plume can be kicked up by winds because they initially form just a thin layer of DU dust on the ground. This phenomenon is called resuspension. Only after some years the aerosols finally settle into the soil (Ibid).

How can these particles be monitored? There are two ways to do so: first, to check the levels in humans and second, to monitor the environment. Regarding the first method, the following options exist: gauging the DU amount in the kidneys, the bones, blood, urine and the lungs. As far as the measurements in the lung are concerned, there are tremendous restrictions because only a minor fraction stays there after inhalation (Bleise, Danesi, and Burkart 2003). The WHO recommends for the assessments of exposures which took place more than year ago that DU in urine should be measured (World Health Organization 2001a).

Environmental monitoring can be implemented via air filters, air pollution biomonitors or via remote sensing. As far as the latter are concerned there are radars which can sense buried materials. The air-filters can be stationary which collect particulate matter or low-flying aircrafts which have such air-filters installed. Suitable biomonitors are lichen and mosses because they nourish themselves from the atmosphere, do not alter their morphology during the seasons and have a high capacity to accumulate atmospheric particles (Ibid).

3. Literature review of studies examining the health effects of DU-munition

The radiological and chemical toxicities have been quite abundantly studied and the first are negligible while the latter pose a threat to human health in high doses. Thus, the chemical toxicities are mentioned here but in a compressed way. Hence, this chapter focuses on the neurotoxic effects of DU.

A common argument which can be heard from deniers of the harmful effects of DU is that such effects are difficult to prove. The explanation often is that the large number of hazardous substances scattered in the environment make it impossible to prove that DU causes adverse health effects. Another supposed reason is that a major cause for the health consequences are the bad sanitation levels. This certainly could be true but it should not be used as a general argument to refute the plausibility of studies which attribute adverse health effects to DU.

The critics of DU-munition are convinced that it induces all types of cancer. Here it must be said that it requires several years to prove the effects because the median-latency period for solid cancers is 16 to 24 years (Bleise, Danesi, and Burkart 2003).

3.1 Tests

The first scientific research about the health effects of uranium has been published as early as 1949 (World Health Organization 2001a). Several studies were published back then by scientists Spiegel, Dygert, Roberts, Rothstein, Maynard & Hodge and Tannenbaum who all analyzed the toxicity of uranium, in particular in rodents but also in humans.

3.1.1 Animal Tests and in-vitro studies

Already in the end of the 1940s the effects of inhalation of uranium compounds was thoroughly studied. The studies used guinea pigs, mice, rats, cats, rabbits and dogs and ranged from short-term to long-term studies. It was found out that pulmonary toxicity depends on the chemical form of the uranium compound and that mortality at high concentrations of uranium hexafluoride is due to "*irritative damage to the respiratory tract*" (World Health Organization 2001a). This is not caused by the uranium compound itself but by hydrofluoric acid which is a product of the hydrolysis of uranium hexafluoride (Spiegel 1949).

The main affected organ of uranium exposure is, regardless of the type of exposure, the kidney (World Health Organization 2001a). This means that not only the oral uptake of uranium but also the inhalation of uranium compounds causes severe renal effects.

What was found out about the relation of uranium and cancer? When the animals took up the uranium compounds orally no carcinogenic effects were observed (Wrenn, Lipsztein, and Bertelli 1989). Still, it was pointed out that any radioactive material in the body increases the risk of cancer.

Regarding the mutagenic effects it is noteworthy that there are miscellaneous studies available which prove that uranium has negative effects on reproductivity and developmental processes. In all the animal tests the uranium compounds uranyl nitrate hexahydrate or uranyl acetate dihydrate were added to the diet of mice and rats. First findings have already been made by Maynard et al. in 1953 and Malenchenko et al. in 1978 when degeneration and lesions of the testicles of male rates as well as depletion of germ cells were observed. These results mentioned above are true for chronic uranium exposure too (J. L. Domingo 2001). The reproduction of male mammals was examined. Male mice were mated with untreated females and the pregnancy rate was only 25-35% while as the control group consisting of untreated males showed a pregnancy rate of 81% (Ibid).

In the studies which examined the reproductive and developmental toxicity of natural and depleted uranium the following consequences were discovered (J. Domingo et al. 1989):

- fetotoxicity
- reduced fetal body weights and reduced fertility
- increased incidence of developmental alternations
- external and internal malformations

Such mutagenic and tumorigenic effects were also identified in in-vitro studies. There is indication that human osteoblast cells can be transformed to a tumorigenic phenotype which means that they change their morphology and induct tumors when they are implanted into mice (World Health Organization 2001a). It is clearly stated that this transformation is due to chemical rather than radiological effects.

Tests in hamster ovary cells showed that uranyl nitrate is cytotoxic and genotoxic. It reduces the viability of the cells and the cell cycle kinetics and induces chromosomal aberrations (Lin et al. 1993). More recent tests confirm these results. Due to the increasing concerns about the genotoxic and carcinogenic effects of DU-dust, more studies have been conducted in this field in the past years. Human bronchial cells were tested how they develop after treatment with DU particulates. The compounds uranium trioxide and uranyl acetate were used and the results clearly showed that UO_3 is cytotoxic and clastogenic (Wise et al. 2007). The latter means that they are capable of changing chromosomes (i.e. either deleting, gaining or rearranging the chromosomes).

Embedded DU fragments

The Armed Forces Radiobiology Research Institute (AFFRI) is an American institution which conducted studies on the biological effects of embedded DU in rodents. Their study lasted 18 months and they injected DU pellets of 2mm size in their calf. In 2000 they came to the following results. After a few days the uranium moved to the bones, kidney, liver and muscle tissue (McClain et al. 2001). Most of the uranium was excreted via urine during the entire study. Two staggering findings were made: First, the uranium dose in the kidney was clearly nephrotoxic but at least in the short term the rodents' bodies adapted to the high levels. Second, DU has neurotoxic features as it accumulated in the brain and changed the hippocampus (Ibid). The hippocampus plays a very important role in the brain because it is the learning and memory centre and is also responsible for spatial orientations.

Pellmar et al. found out the same results like the AFFRI when they implanted DU alloy into rats. They put in DU pellets at low, medium and high dose levels and observed the health effects over a period of 18 months (Pellmar et al. 1999). Uranium deposited basically across the whole body. The concentrations were high in the kidney, bones (the skull and the shin were examined), muscle tissue, liver, heart, lymph nodes, lung, testicles and the brain (Ibid). While the kidney and the bones were identified as the main target reservoirs for uranium, the strongly elevated levels in the reproductive organs and the brain are of particular interest. Already at moderate doses (4 DU = low dose and 8 DU = medium dose), the uranium impaired the so called population synaptic potentials which was found out when electrophysiological responses were measured (Ibid). The authors concluded that "*The accumulations in brain, lymph nodes, and testicles suggest the potential for unanticipated physiological consequences of exposure to uranium through this route."* (Ibid)

Later research has confirmed that DU crosses the blood brain barrier and preferably accumulates in the forebrain and the hippocampus (Briner 2010). Besides depositing in the central nervous system it also triggers physiologic activities there (Ibid).

Regarding the carcinogenic properties of implanted DU alloy in rats there are also studies available which confirm this effect (Arfsten, Still, and Ritchie 2001).

3.1.2 Test sites – environmental studies

Jefferson Proving Ground

At the Jefferson Proving Ground in the state of Indiana more than 90 tons of DU-munition was tested between 1984 and 1994 (AEPI 1995). The ammunition was tested mostly against soft targets. Soil samples from the test site were taken before the implementation of the tests and from then on twice a year (Ibid). The average DU concentration in soil was 318 Bq/kg (Giannardi and Dominici 2003). This value does not pose a radiological risk to humans. For instance, the maximum radioactive level for milk products in the EU is 370 Bq/kg. Nevertheless, also much higher concentrations were measured ranging from 592 Bq/kg to a staggering 13,690 Bq/kg (Ibid).

The removal of the UXOs is very costly. In order to decontaminate the area around one meter of soil has to be stripped (AEPI 1995).

Yuma Proving Ground

At this test site in Arizona more than 38 tons of DU-munition was fired from 1982 till 1992 (AEPI 1995). The test site is still used. Like in Jefferson Proving Ground, the environmental impact was assessed and regular samples were taken. The pathways of DU were evaluated and an environmental monitoring plan was elaborated.

Army Research Laboratory

In Watertown military applications of DU was researched and alloys were developed. The facility was closed in the late 1980s and from then on decommission and decontamination began. The DU-containing soil was treated and stored as radioactive waste.

In Aberdeen the US Army already started to conduct experiments with DU-munition in the 1950s (AEPI 1995). Rounds of miscellaneous calibres were fired against hard targets. Additionally, armour consisting of DU was developed for the “Bradley” Infantry Fighting Vehicle and the “Abrams” Main Battle Tank (Ibid). In 1979 the open-air firing was curbed. Hard target testing continues with the goal of measuring the time that people can be exposed to it without any adverse health effects.

Vieques

Vieques is a small island which belongs to Puerto Rico. It was a military training range of the US Navy from 1941 till 2003 and it was closed due to fierce local protests. The US Navy admitted that they used DU-munition on the training site in 1999 but they are accused by many local inhabitants of using it for more than a decade (Eglund, 2001). Besides, they also conducted tests with other toxic materials like agent orange, white phosphorus and even one nuclear bomb test in the 1950s and 60s. The statistics of Puerto Rico show that the cancer rates of breast, cervix and uterus have risen between 1980 and 2000 by 300% (Ibid). Most of the inhabitants of Vieques have come together to take legal action against the USA but the case has still not been heard by the Supreme Court due to legal difficulties such as the sovereign immunity of the USA. In regards of the link between the high cancer rates and the use of DU-munition it must be said that many scientists are still struggling to prove any connection. This is because so many toxic substances have been used on the island over the course of time which makes it almost impossible to establish a direct link.

Besides the above mentioned test sites there are other facilities too where DU-munition is tested today. One of them is the Armament Research Development and engineering Center which conducts hard-impact indoor tests with the currently used DU-munition. It also produces DU-munition (Ibid). Another institution which deals with DU-munition is the Armament, Munitions and Chemical Command which is authorized to ship, store and receive DU munition (Ibid). Moreover, there is the Tank Automotive Command which is allowed to transport, store and receive all the DU-ammunition for tanks (Ibid). A crucial DU test firing range is the Nellis Air Force Base which is still used and almost 30 tons of DU have been fired there.

An evaluation of the health status of former workers at the test sites in the USA has not shown any increased rates of kidney problems or any other disease commonly associated with DU (Harley et al. 1999).

Test results about the creation of DU dust

Due to congressional requests the Army Environmental Policy Institute (AEPI) and and the Department of Defense (DoD) have conducted studies about the health and environmental consequences of DU-munition. Besides, the US Army has conducted several tests to find out more about the creation of DU dust. As mentioned in chapter 2.5.4 the creation of dust depends strongly on the hardness of the hit target. Other influencing factors are the velocity at impact and the pathway through the target object. Results at test sites in the USA showed that up to 70% of the DU contained in a round can form aerosols (Harley et al. 1999). Usually, the value ranges between 10 and 35% (Ibid). When a soft target like soil is hit, the aerosolized fraction is negligible. It must be said that most of the fired rounds in combat miss their target and thus hit soil. Estimates are difficult to make and some go up to 90% (Bem and Bou-Rabee 2004). In case that a hard target (which usually is another tank or a building made of concrete, steel or bricks) is hit, the size of the created particles must be analyzed. The particles pose problems for the respiratory tract when they have an aerodynamic diameter of less than 10 µm. This applies to virtually all DU aerosols after a hard target has been hit. When particles are generated by fire, the size of them are mostly bigger than 10 µm and can thus be cleared by the nasopharyngeal section (Harley et al. 1999).

After taking into account all influencing factors it was eventually estimated that around 20% of the DU mass hitting a hard target is converted into respirable aerosols (Fetter and von Hippel 2000).

3.2 Iraq

This section reviews the epidemiological studies about DU-munition of both Gulf Wars, the first one in 1991 and the armed conflict from 2003 onwards. Much more research has been carried out concerning the First Gulf War. This is regrettable insofar as the second conflict lasted much longer (one month versus eight and a half years) and much more DU-munition has been fired. Another unfortunate aspect is that there has been done more research on veterans of the NATO troops than on the mainly affected group, namely the civilian population of Iraq.

First Gulf War

The goal of the military operation of the USA and the UK was to repel and push back the Iraqi troops from Kuwait. Therefore, the first US troops were deployed to the Persian Gulf area in August 1990 for the first phase called Operation Desert Shield. The armed conflict (i.e. Operation Desert Storm) started in January 1991 and lasted only five weeks. In total, there served 697,000 US troops in the Persian Gulf during the military campaign (Kang et al. 2001). Additionally, there were 53,000 UK troops deployed in the conflict area during the same period (Doyle et al. 2004). The First Gulf War marked an unprecedented military success for the USA and its allies with less than 200 casualties. However, many of the personnel were exposed to multiple (environmental) hazards such as DU, smoke from burning oil wells, (anthrax) vaccination and of course psychological stress.

Gulf War Syndrome

Since the number of veterans who claim to suffer from various symptoms due to their deployment in the First Gulf War is so high it became known as an own disease, namely the Gulf War Syndrome or Gulf War Illness. The symptoms include fatigue, cognitive disorders, muscle pain, rashes and diarrhea. There are around 250,000 veterans who report that they have these symptoms due to their deployment (National Academies of Sciences 2016). In the end it is a poorly understood illness and there are many theories about its causes and the biological mechanisms which lead to the diseased state. There is abundant literature available regarding this phenomenon which is not of concern for this master thesis. The question is whether these ailments are also a cause of DU. This can be virtually excluded because the mentioned symptoms of the Gulf War Syndrome are not a consequence of exposure to DU. Such a direct link is also ruled out in the comprehensive 465-page report of the Research Advisory Committee on Gulf War Veterans' Illnesses:

"… exposure to DU munitions is not likely a primary cause of Gulf War illness. Questions remain about long-term health effects of higher dose exposures to DU, however, particularly in relation to other health outcomes." (Binns et al. 2008, p. 8).

Interestingly, following the Second Gulf War, no such complaints have been made by veterans in significant numbers.

Second Gulf War

The second armed conflict between the coalition forces under the leadership of the USA and Iraq is also referred to as the "2003 Invasion of Iraq" or "Iraq War 2003". The mission was to depose Saddam Hussein and his Baath Party. The military operation was dubbed "Operation Iraqi Freedom" and was a tremendous military success like the intervention 12 years earlier. The mission was accomplished again after five weeks and with less than 200 casualties but this time the invading troops stayed in the country until the end of 2011. Since fightings went on after the fall of Saddam Hussein and reached their peak in the civil war three years later, the coalition forces continued to use DU-munition. Afterwards, DU-weapons were used too, but to a significant less extent.

Depleted Uranium use in the Gulf Wars

The ministry of defense of the USA disclosed in the 1990s how much ammunition they used in the military operation Desert Storm in 1991. Thus, the volume of DU amounts to 300 to 320 tons, varying from source to source. In total, this amounts to

4,000 tank rounds and 800,000 bullets from the Gatling-gun according to official statements released by the Pentagon (Fetter and von Hippel 2000). In the Second Gulf War around 1000 tons of DU-munition was fired (Zucchetti 2009).

Soil samples across the country show high concentrations of uranium in the upper layer (Fathi et al. 2013). Of particular concern are the densely populated areas like Mosul, Baghdad, Bosra and Falluja where a lot of DU-munition was fired.

The follow-up questions are how many of this ammunition has hit hard targets, how much DU converted into soluble particles and how long and to which concentrations were the soldiers and the civilian population exposed to DU aerosols? The following map shows the DU-contaminated areas in Iraq.

Figure 5: DU-contaminated sites in Iraq (Al-Ansari, Pusch, and Knutsson 2013)

3.2.1 Health effects of DU on exposed Gulf War veterans

The health effects of DU on Gulf War veterans can be assessed for those soldiers who either were near strikings, whose vehicles were hit by DU-munition or who have DU-shrapnel in their body. In total there were 15 Bradley Infantry Fighting Vehicles and nine main battle tanks Abrams which were struck mistakenly by DU-munition from the own forces during the First Gulf War (Melissa A McDiarmid et al. 2000). Fetter and von Hippel concentrated in their analysis on the acute exposure and short-term effects of DU-munition. They show with calculations that it can be excluded that a soldier has inhaled a dangerous amount of DU dust when he stood outside of a hit vehicle or building. Therefore, the released respirable DU-aerosols are too little to cause any immediate harm (Fetter and von Hippel 2000). Those particles which are released appear to stay quite long in the lung. Obviously, the inhaled DU has a pulmonary half-life of about 4 years (Briner 2010). At least this value was derived from examinations of Gulf War veterans.

The situation is completely different in regards of inside struck vehicles. The uranium concentration in the urine was gauged of 14 soldiers who were in struck vehicles. The estimated inhalation was derived from these values and amounted to 25 mg of DU (Ibid). As it has been explained in chapter 2.5.4 this acute exposure has immediate nephrotoxic effects. Fetter and von Hippel did not study the neurotoxic consequences. There are two more frequent cases when soldiers spent time inside struck vehicles. First, many soldiers entered shelled Iraqi vehicles to gather souvenirs. Second, clean-up operations were conducted. It was calculated that around 150 mg of DU was inhaled per hour. Given that 17 to 43 percent of this amount are soluble the nephrotoxic threshold of 40 mg of soluble uranium compounds would be exceeded after one hour (Ibid).

It is striking that some DU-exposed veterans without metal fragments had markedly higher urinary uranium levels than non-exposed people six years after the exposure (Melissa A McDiarmid et al. 2000).

As it could be seen a lot of research has been done on the Gulf War veterans of the NATO troops. On the other side, there is hardly any study about the Iraqi veterans available. One of these checked the medical status of 14,000 Iraqi soldiers who were deployed in the area of Basra. This city in the southeast of Iraq was heavily shelled by DU-munition. During the period of 1991 to 1996 there was a 10-fold increase in lymphomas and 40-fold increase in brain cancer of the people examined (Arbuthnot 1999).

Reproductive and neurological effects

There was one big American study in 1993 which included the hospital records of 75,000 children of Gulf War veterans and non-Gulf War veterans. It did not reveal any adverse reproductive effects of soldiers who had been deployed to the Persian Gulf. This is probably the case because the study was conducted too early after the deployment and the negative developmental effects have a markedly longer latency period.

One of the first studies which focused on the developmental effects of DU-munition and was conducted on a big scale was led by Kang et al.. The goal was to "compare rates of reported spontaneous abortions, stillbirths, pre-term births, birth defects, and infant mortality between Gulf veterans and non-Gulf veterans" (Kang et al. 2001). The study encompassed 15,000 people of each group. Data was collected via a questionnaire on the participants' health status, reproductive outcomes and possible risk factors (Ibid). Those who experienced a pregnancy (either on their own or as a partner) were asked to provide information about it (i.e. livebirth, stillbirth, miscarriage, birth defects). All data was self-reported and not cross-checked with medical records. Eventually, almost 21,000 veterans took part in the study. 29% or 6,043 persons indicated index pregnancies (Ibid). Both miscarriages and stillbirths were reported more often by Gulf War veterans. A statistically significant difference occurred only for miscarriages. Moreover, infants with birth defects were double the rate from Gulf veterans. For female Gulf veterans this rate was even three times higher than in the control group. Obviously, the transfer of toxic agents to the mother is possible. A strength of the study is the big number of participants and the thorough adjustment of the odds ratio. This means that factors like history of smoking, history of prior pregnancy, age and ground vs. non-ground troops were taken into account in order to avoid distortions of the study outcome. Furthermore, possible reporting bias could be excluded by making some sample cross-checks. All in all the above mentioned results are very strong and meaningful.

Do studies of British Gulf War veterans come to other conclusions than the US-led research when reproductive effects are analyzed? Between 1998 and 2001, a survey was conducted, which asked 106,000 British soldiers about any developmental effects (Doyle et al. 2004). Half of the group were veterans of the First Gulf War and the other half were demographically similar soldiers who had not been deployed to the Persian Gulf (Ibid). In total, more than 28,000 pregnancies were reported. The result showed that there was a 40% higher risk of miscarriage and a even a 50% higher risk of congenital malformations reported by male Gulf War veterans (Ibid). Only the rates in stillbirths were not substantially different. However, this strong outcome was relativized by the authors of the study because "these findings need to be interpreted with caution as such outcomes are susceptible to recall bias." (Doyle et al. 2004, p. 1)

Embedded DU fragments

Since the Iraqi Armed Forces did not use DU-ammunition the veterans who have DU fragments in their bodies are the consequence of friendly fire incidents. The effects of the embedded DU particles on American Gulf War veterans are much alike those on rodents. The high uranium levels in urine were maintained even seven years after the first exposure (Bleise, Danesi, and Burkart 2003). The levels were up to 25 times higher than on non-exposed Gulf War veterans (Ibid). In total 68 American soldiers underwent medical evaluation of which 29 were exposed to DU-munition and 38 were not. Since the study did not emphasize the outcomes of embedded fragments, it must be mentioned that not all of the exposed veterans were wounded with DU shrapnel but most of them. The people were examined two years after the First Gulf War and again in 1997 (Melissa A McDiarmid et al. 2000). A psychiatric assessment, neurocognitive evaluation and genotoxicity studies were done. It was one of the first studies which proved the adverse neurocognitive effects of DU-munition on humans. All soldiers had to do traditional (with paper and pencil) and automated neurocognitive tests. In total there were 13 tests from reading, arithmetic and digit symbol subtests to a nonverbal selective reminding test. There was a significant relationship between high uranium levels in urine and weak performance on automated tests. In light of the findings that DU crosses the blood-brain barrier the authors of the study recommended further observations. Furthermore, it is concluded that the first target systems are the brain and the reproduction and not the kidney as it is commonly quoted.

In the following years further medical tests were conducted with the same Gulf War veterans by the Department of Veterans Affairs Medical Center (McDiarmid et al. 2007). The extremely high uranium concentration in urine remained but no adverse renal effects were observed. Mutations in peripheral blood lymphocytes were 2-fold compared to the control group which confirmed the earlier results of DU's genotoxic nature (Ibid).

3.2.2 Health effects of DU on the population

Unfortunately, there are much less studies available on the possible health effects of DU-ammunition on the local inhabitants. This is in particular regrettable because this thesis focuses on the long-term effects of DU dust and its potential link to cancer, congenital malformations and birth defects.

Cancer

A look at the statistics show an appalling increase of cancer rates and birth defects in Iraq since 1991. In 1991, the rate of cancer incidence was 31 per 100,000 inhabitants compared to 45 per 100,000 in 2008 (Husain and Al-Alawachi 2016). Admittedly, this rate is still significantly below average rates in affluent countries where the incidence rates are between 250 and 330 (World Cancer Research Fund International, 2017). The common explanation for the difference in cancer rates between countries is the average age of population, because older people have a much higher risk to get any type of cancer. The cancer incidence rates of children (i.e. persons under the age of 15) has literally exploded in Iraq since 1990. The value has risen from 3.98 per 100,000 to 22.4 per 100,000 in 2012 (Fathi et al. 2013). This is a value which is higher by a factor of ten than in industrialised countries (Ibid). As of 2004, more than half of all cancer patients were children below five years compared to 13% some 15 years earlier (Ibid). Various types of cancer have increased sharply in Basra. Between 1990 and 1997 leukaemia rose by 60%, breast cancer by 102%, thyroid cancer by 143% and uterine cancer by 160% (Ibid). These values are similar in the most populous regions like Baghdad and Mosul (Ibid). Overall, breast cancer incidence has risen even more than any other types since DU-munition had been fired, namely by a factor of three until 2008 (AL-Dujaily et al. 2008).

Developmental effects

A limitation in the analysis of the rates of spontaneous abortions, stillbirths and congenital malformations is the inaccurate data about it. Many births do not take place in hospitals. Moreover, rural medical facilities often do not administer medical statistics (Ibid). This implies that the actual rates are higher than the official records.

What do studies reveal about congenital malformations in Iraq? Therefore, we first have to take a look at the toughest battlegrounds where most of the ammunition was used. Falluja had long been a stronghold of insurgents against the American troops and in particular in 2004 there were two fierce battles. First, during the “Operation Vigilant Resolve” in spring where the coalition forces withdrew after one month and second, in autumn, when the US troops could take the city after almost two months of intense fighting. What is the current situation in Falluja regarding birth defects? Since 2003, the congenital malformations have risen to 15% of all births in that city (Alaani et al. 2010). This is a devastating value.

The city of Basra in the southeast of the country is known in particular for the high DU-contamination. In this region, most of the DU was fired (Fathi et al. 2013). Congenital malformations increased by a factor of three between 1990 and 1998 (Ibid).

Patently, there were also negative developmental effects in Bahrain after the First Gulf War. This is remarkable insofar as this small emirate is located more than 600 kilometres away from the southern Iraqi border. Three doctors of the Salmaniya Medical Complex compared the incidence rates of spontaneous abortions five years before and after the First Gulf War. Taking the records of this medical institution provides a sound basis for the whole country because more than 80% of all abortions are treated there (Rajab, Mohammad, and Mustafa 2000). The result of the study was that in the years 1987 till 1991 there were 6402 abortions compared to 9226 abortions in the period between 1992 and 1996 (Ibid). Total pregnancies differed only a little and thus the abortion rate was 11.4% before the First Gulf War and 15.5% afterwards (Ibid). Other distortion factors such as the median age of pregnant women and the socioeconomic conditions in Bahrain were cleared. Hence, there undoubtedly was a staggering increase in abortions. The reasons therefore are, however, very unclear. The authors of the study suppose that the change was due to environmental pollution which occurred during the armed conflict. The burning oil wells and ignited refineries in Kuwait caused massive smoke plumes and subsequent air and sea pollution which reached Bahrain.

Apart from the Bahrain case, the statistics show a clear correlation between the DU-contamination and the occurrence of DU related illnesses. It can also be seen that the civilian population is much more affected than the veterans from which a direct correlation between duration of exposure and DU related diseases can be inferred.

All in all it can be said that there is irrefutable and tremendous evidence available in Iraq about the multiple devastating effects of DU-munition on humans and the environment. Many studies are very comprehensive with a big sampling and sufficient information about the long-term effects on the target group, which is the civilian population, is available as well. The studies often examine only a specific group (veterans, children, local population) or effect (mutagenic effects, cancer rates, radiological emissions, birth defects, etc.) and thus vary in their outcome. In terms of what they analyzed they are mostly conclusive.

3.3 Kosovo

During the Kosovo War in 1999 the NATO troops used DU ammunition mainly in Kosovo and to some extent in South Serbia. The troops conducted 112 attacks between April and June 1999 (WHO, 2001b). Since some targets were attacked several times there are 84 geographically different locations which are affected (Ibid). The munition was fired from the Thunderbolt aircrafts and amounted to around 10 tons of DU (Bleise, Danesi, and Burkart 2003). In total, these are around 31,000 rounds (Durante and Pugliese 2003). Around one third of it detonated over today's Serbian territory (Handley-Sidhu et al. 2010). No clean-up mission was conducted to clear the sites from the DU rounds. According to KFOR 80% of the rounds lie within 100 meters of the target (WHO, 2001b). More than two thirds of the rounds which hit soft soil are assumed to be buried up to 3 meters beneath the surface and thus pose a minor hazard.

The UNEP BTF identified the sites where DU-munition had been fired at.

Figure 6: Sites where DU-munition had been fired in Kosovo (UNEP 2001)

UNEP BTF

In 2000 and thus very shortly after the NATO intervention, the Balkans Task Force of the UNEP examined all 11 of the 112 sites where DU-munition had been used (UNEP 2001). Their mission was to collect samples of soil, water, vegetation and milk. Soil samples showed extremely high concentrations of DU two years after its use (several hundred thousand DU particles in a few mg of soil) (Schroeder et al. 2003). Most of them were smaller than 5 µm and more than a half were even smaller than 1,5 µm in aerodynamic diameter (Ibid). The size distribution showed that the smaller the particles are the more of them are there. This can be seen in exhibit 7, which illustrates two soil samples taken by the UNEP BTF.

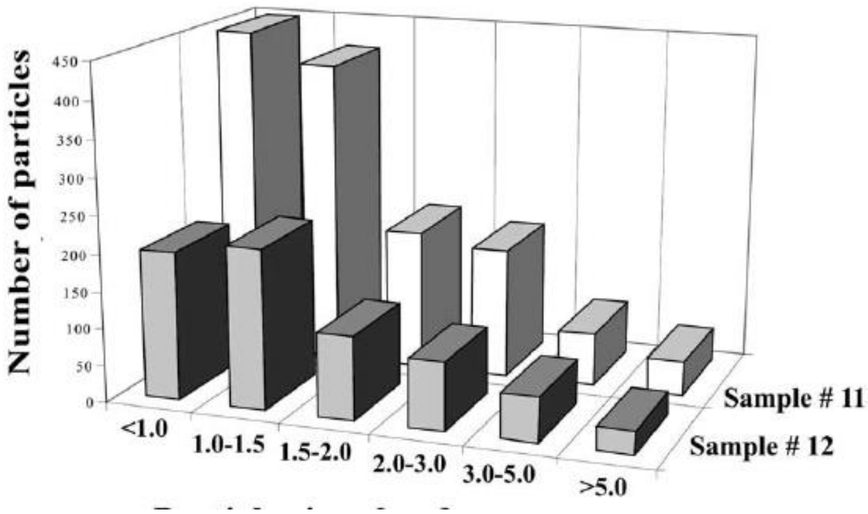

Figure 7: Size distribution of soil samples in Kosovo (Danesi et al. 2003)

Due to the analysis of the isotopic composition it was confirmed that the uranium in the soil came from DU-munition (Ibid). In particular the small sized matter can resuspend easily and thus stay in the atmosphere very long. How long DU dust can be transported is shown with the following example: DU aerosols were found in the air in Hungary which apparently moved from the Balkans a few hundred kilometres north (Schroeder et al. 2003).

The soil samples of the UNEP BTF were analyzed in miscellaneous laboratories and showed low levels of radioactivity (UNEP 2001). Nevertheless, the chief of the UNEP mission clearly stated that *“major scientific uncertainties persist over the long-term environmental impacts of DU.”* (UNEP 2001, p. 4) and *“…UNEP calls for precaution. There is very clear need for action to be undertaken on the clean-up and decontamination of the polluted sites”* (Ibid).

3.3.1 Health effects of DU on the exposed soldiers and peacekeepers

Similar to the Gulf War Syndrome many returning veterans of the missions in Bosnia-Herzegovina and Kosovo claimed to suffer from the same symptoms. Subsequently, it was dubbed “Balkans Syndrome”. The likelihood that the medical complaints are due to DU-ammunition is certainly negligible, in particular when considering the much lower rate of affected people and the substantially lower exposure to DU in the Kosovo region.

Due to concerns about adverse health effects on international soldiers who served in Kosovo, more than 700 German veterans have been checked. The uranium concentration in their urine was examined not longer than one year after their deployment had ended (Oeh et al. 2007). Uranium excretion was not elevated and thus it was concluded that the peacekeepers had not been exposed to mentionable DU amounts (Ibid).

Mutagenic effects

More extensive physical examinations were carried out with Italian soldiers who had served in the Balkan military campaigns because there were much stronger indicators that the people were afflicted with diseases due to their deployment. Subsequently, two uranium investigation commissions were installed upon request of the Italian Parliament. The mortality rate due to Hodgkin and Non-Hodgkin Lymphoma of Italian veterans of the Balkan missions was three and a half times higher than average (Zucchetti 2009). Hodgkin and Non-Hodgkin Lymphoma are types of cancer which alter white blood cells. The question is why Italian soldiers clearly were affected from their deployment and Germans not. Taking a look at the map where DU-munition was used and where the troops were deployed delivers an unsatisfactory answer. The Italians have ever since been responsible for the west of Kosovo where most of the DU-munition had been used but to a big extent this also true for the German sector. One simple answer is that in Germany no long term studies have been conducted and therefore the effects on their veterans is not known.

In regards of the mutagenic effects there was also one study conducted with British soldiers who served in Kosovo, Bosnia and Herzegovina and/or Iraq. It analyzed the dicentric and ring chromosome aberration in peripheral lymphocytes of the test persons. The results were that every veteran had some chromosomal aberrations (Schroeder et al. 2003). Compared to the non-exposed group the average aberration increase was 5.2-fold (Ibid). The authors write that dicentric chromosomes are reliable indicators for ionizing radiation. The chromosome aberrations are an interesting result in light of the fact that virtually all scientific papers from international organizations such as the IAEA and the WHO as well as from national institutions (AFFRI, AEPI, Department of Defense, etc.) attribute very little radiological toxicity to DU.

3.3.2 Health effects of DU on the population

Very much like in Iraq, claims of the local population about the adverse health effects and in particular about congenital malformations and lung cancer increased in the years after the NATO intervention. A big problem for a sound verification of these anecdotal reports is that data on cancer rates was incomplete before and shortly after the war. A reason therefore is that many ethnic Kosovo Albanians went to Macedonia or Albania for treatment (WHO, 2001b). Data about congenital malformations was not systematically collected at all (Ibid). The same applies to miscarriages (Ibid).

Another problem is that long-term studies about the health effects of DU-munition are missing on the Balkans. Thus, the WHO commission, which wrote the Kosovo Report, concluded in 2001: "*No convincing evidence is available to indicate any health impacts to the Kosovo population associated with the use of depleted uranium.*" (WHO 2001b, p. 26). The reasons therefore are also mentioned: "*The health and population information systems presently available in Kosovo do not permit the reliable identification of any changes in disease frequency in the population*" (Ibid, p. 26) and *"Several years are needed between exposure to ionizing radiation and development of cancers. As barely two years have elapsed since the conflict in Kosovo, it is not biologically plausible to expect any increase in cancers at this stage, even if there were high doses of radiation."* (Ibid, p. 27)

The WHO mission to Kosovo identified the picking up of DU-munition as the major source of exposure of civilians to DU in Kosovo (WHO 2001b). It is true that gathering DU contaminated war souvenirs poses a bigger problem than in Iraq or Afghanistan because in Kosovo the targeted sites were located more often in urban areas. However, the hazard of DU dust should not be underestimated there either and it was strongly recommended to carry out clean up operations.

Durante and Pugliese used the gathered UNEP data and conducted an assessment of the radiological risk. As expected, it is negligible and only a small radiological risk from the contamination of groundwater was established (Durante and Pugliese 2003). The same conclusion is drawn by the WHO. It states that the radiation exposure in conflict zones which is due to the inhalation and ingestion of DU dust amounts to less than 10 mSv (WHO 2001b). This is half of the yearly radiation limit for workers.

A study measured the uranium levels in urine of 25 local residents who lived in regions where DU-munition had been fired. Since the uranium levels were not above average it was inferred that no negative health effects from the DU-munition are expected (Oeh et al. 2007).

The overall assessment of the health effects of DU-weapons in Kosovo is that some mutagenic effects in NATO veterans were proved although they likely did not lead to any detrimental health conditions. For the civilian population there cannot be drawn any serious conclusions because of a lack of investigations and a lack of comparable statistical data from pre-war periods.

3.4 Bosnia-Herzegovina

The NATO conducted airstrikes against Bosnian Serbs in the Republika Srpska in 1995 during the Operation Deliberate Force. Around three tons of DU were fired (Bleise, Danesi, and Burkart 2003). Some estimates speak about only one ton which was used (Handley-Sidhu et al. 2010).

Upon request of the Bosnian authorities a task force of the UNEP was sent to Bosnia and Herzegovina in 2002 to measure uranium levels. They investigated fourteen sites where DU-munition had reportedly been fired (UNEP 2003). Three of these places contained elevated uranium concentrations (Ibid). None of them was widespread which means that the contamination was within a couple of hundred meters. DU contaminations in the water were found in one well but the elevation was insignificant for adverse health effects (Ibid). Elevated levels of uranium in air was found at two sites (Ibid). One was a tank repair facility and the other one an artillery barracks. The uranium concentration was, however, so little that no hazardous ramifications were expected, neither from radiological nor chemical processes.

The claims of rising cancer rates by some medical personnel could not be verified by the incomplete available statistical data (Ibid). Overall, it can be concluded that due to the low exposure to DU in Bosnia and Herzegovina, no DU-related diseases have occurred.

3.5 Afghanistan, Libya, Syria, Yemen

All the locations described in this chapter have in common that:

- The use of DU-munition has allegedly happened but in many cases is not confirmed by officials
- No studies about the claimed health effects have been carried out

Because of the absence of any fact-finding missions on the spot and the unverified use of DU-munition a serious assessment of the possible health effects is impossible. Nevertheless, the available information shall not be withheld from the reader. All the data about the number of Tomahawk cruise missiles fired are retrieved from official news releases of the US Central Command and this information is commonly spread by various news stations such as CNN, FOX News and so on. Thus, this is verified information, the question just remains whether the missiles contain DU.

In response to 9/11 the USA started with some coalition forces the “Operation Enduring Freedom in Afghanistan in October 2001. The mission was to overthrow the Taliban regime and to capture Osama Bin Laden. The mission in Afghanistan ended by the end of 2014. DU-munition was probably used at the beginning when Tomahawk cruise missiles were fired and during the entire operation in the attack helicopters.

The military intervention of the NATO in Libya was carried in 2011 and lasted seven months. DU-munition was most likely used in the 124 Tomahawk cruise missiles which were fired and for sure in the A-10 aircraft.

In Yemen, the USA have launched several attacks with the Tomahawk cruise missiles against Al-Qaeda in the past years.

In Syria, the US Navy reported that they fired 47 Tomahawk missiles against ISIL in 2014. On 06 April 2017 they launched 59 such missiles and attacked an airbase of the Syrian Arab Armed Forces near Homs. In October 2016, Major Jacques, who is the spokesperson of the US Central Command, confirmed that more than 5,000 30mm DU-rounds were fired in November 2015 in attacks flown against ISIL convoys in north-eastern Syria (Oakford, 2017). This marked a U-turn in the communication policy of the USA because until then they had always denied the use of DU-munition in their fight against ISIL. The rationale for refraining from the use of this armor-piercing ammunition had been that there was no need since ISIL had no tanks.

Finally, there have been numerous allegations for many years that Israel used DU-ammunition in their military operations in Gaza and Lebanon too. The Arab League requested the UN several times to investigate the claims. Since there is not sufficient evidence at the moment and no scientific reports about its use or health effects, this issue is not further elaborated here.

4. Comparative assessment of the health effects of uranium types

In order to be able to compare the different potential dangers of uranium types with each other, the sources of exposure other than from DU-munition shall be analyzed.

4.1. Natural Exposure

Radiation exposure

Uranium is one of multiple radiation sources which exist on earth. These sources are shown in figure 8.

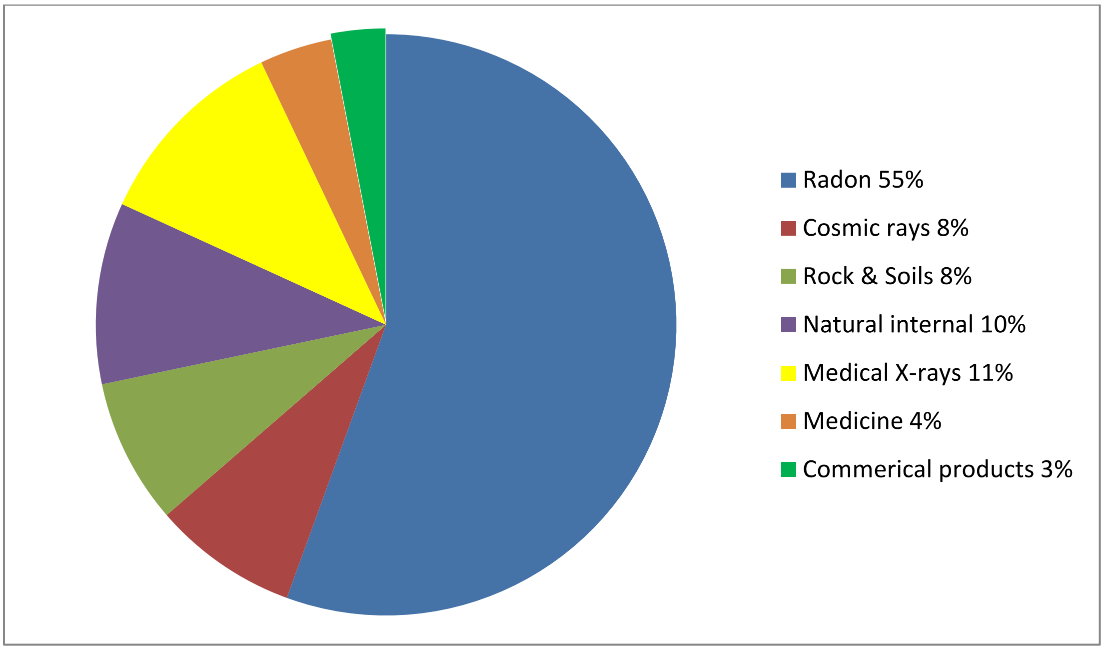

Figure 8: Radiation Sources on Earth (Harley et al. 1999)

The average dose rate of uranium to humans in the USA is 3 Sv per year (Fetter and von Hippel 2000).

For the sake of scientific completion it must be said that there is only one element, namely radon, which has a relevant radioactivity to humans. It easily escapes from soil or rock. Some old watches still contain it. DU is three million times less radioactive than radon (Bleise, Danesi, and Burkart 2003).

As it can be seen in exhibit 9, radon is a decay product of Uranium 238.

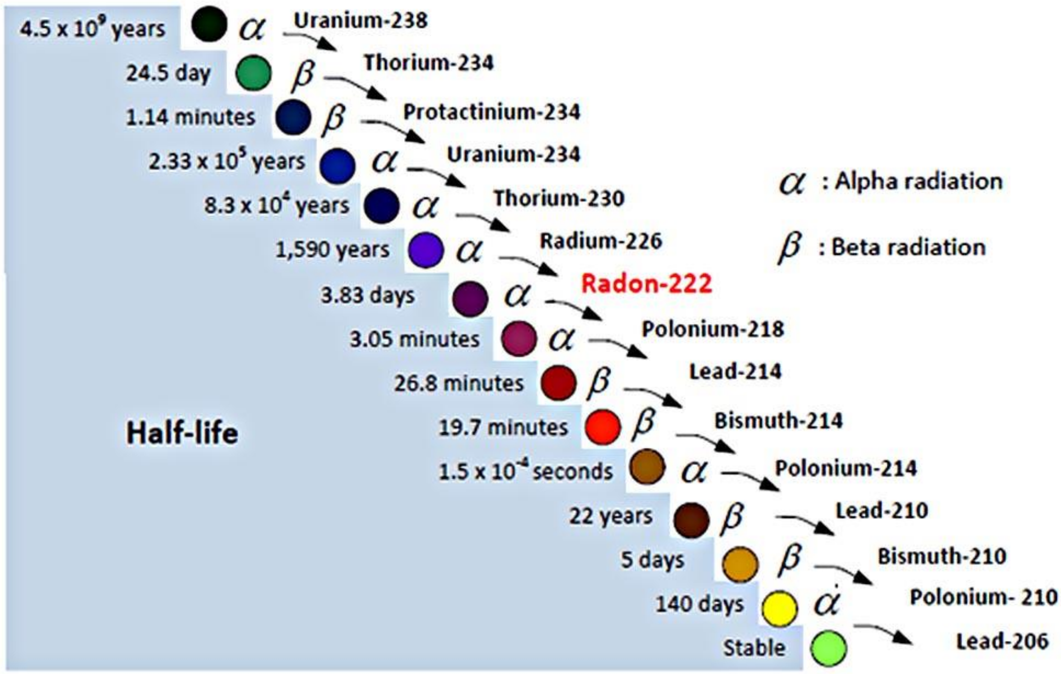

Figure 9: Decay Chain of Uranium 238 (Socratic 2017)

There are radiation dose limits to protect humans from excessive radiation. The thresholds are set by the WHO and vary because they are different for the general public and for occupational exposure. In the vocational sphere the limits are 20 mSv per year over a period of five years or 50 mSv in a single year (World Health Organization 2001a). For the skin the maximum dose limit is 500 mSv per year (Ibid). The general public shall not be exposed to annual radiation higher than 1 mSv per year or 5 mSv under some circumstances (Ibid). The skin exposure shall not exceed 50 mSv per anno (Ibid).

Inhalation and Ingestion

As far as the inhalation of natural uranium is concerned the values are around 15 mBq per year (Harley et al. 1999). Most of the inhaled natural uranium is exhaled again and just one quarter stays in the lungs (Ibid). 80% of the uranium in the lungs is cleared by the bronchial tract which means that it is digested. Of this share, most of the uranium is excreted and only a minor part enters the bloodstream (Ibid).

The uranium concentrations in water differ greatly. In the USA, for instance, the Environmental Protection Agency set a maximum limit of 30µg per litre (Bleise, Danesi, and Burkart 2003). In Northern Europe, however, the natural concentration of uranium in water is often even higher (Ibid). There is no evidence whatsoever that this has any harmful effects of the population.

4.2 Mining, Refining, Conversion

The major health threat in mining is that the uranium particles are inhaled over a long period. The insoluble particulates stay in the lung and can cause lung cancer.

In the USA, the permissible exposure levels for soluble uranium aerosols are 0.05 mg/m^3 and for insoluble compounds 0.25 mg/m^3 (Fetter and von Hippel 2000). These are continuous occupational exposure limits which means that an exposure of 40 hours per week during 50 weeks per year would lead to a continuous uranium dose of 1 ppm in the kidney (Ibid). Hence, the limits are based on the nephrotoxicity of uranium but it disregards the potential reproductive and developmental toxic effects.

The highest exposures of uranium workers has probably been during the 1940s and 50s when there were considerably less safety requirements in place. Moreover, less tests about the exposure to environmental hazards were carried out.

Studies about cancer rates and renal effects

The largest American study ever conducted on the health effects of uranium to uranium workers comprised 18,869 people (Priest 2001). The study observed the people between 1943 and 1974 (Ibid). The persons were exposed to high average concentrations of uranium aerosols. The findings were that lung cancer was above average. However, other diseases commonly related to DU such as leukaemia or bone cancer were not higher than average. A weakness of the study is that it did not take into account the offspring of the workers.

The largest study ever conducted in the UK included 19,454 workers between 1946 and 1995 (Ibid). In this study, no excess mortality from whatever cause was proven.

Other epidemiological studies which analyzed the lung cancer incidence rates did not find evidence about uranium as a likely cause either (World Health Organization 2001). It must be said that the authors admitted that the statistical power of the studies was low (Ibid). In Namibia, on the other hand, recent statistics show that uranium miners are three times more likely affected by cancer than non-exposed persons (Zaire et al. 1997).

In a uranium processing plant, 2,514 workers were observed who had worked there between 1942 and 1966 (Dupree-Ellis et al. 2000). The goal of the study was to find out whether there was an association between ionizing radiation and cancer. The results were that the mortality rate due to chronic nephritis was elevated but not statistically significant (Ibid). All in all, epidemiological studies of workers in uranium processing show that risk for lung cancer is not elevated (WHO 2001b).

Studies which focused on the renal effects of workers in uranium mines did not show any increased mortality rates due to nephrotoxicity (World Health Organization 2001).

A study examined the kidneys of uranium mill workers and found that they were damaged due to the chronical exposure to uranium dioxide (World Health Organization 2001). The results showed that there was a correlation between the occurrence of renal tubular dysfunctions and the duration of exposure to the place where the yellowcake was dried and packaged (Ibid).

After an accident in an uranium enrichment plant 24 workers had been observed for two years but no nephrotoxic effects occurred.

Studies about mutagenic effects

There were more than two dozen a uranium mines in the Navajo Indian Reservation in the state of New Mexico which were operational for more than three decades until the 1970s (Shields et al. 1992). Many houses were located near the mines or tailings. Alpha radiation was extraordinarily high and the permissible levels of uranium aerosols was exceeded in the first two decades by a hundred times (Ibid). First of all, a link was proven between the alpha radiation and lung cancer of the uranium miners (Ibid). Second, a study by Shields et al. analyzed the association between congenital effects and the high exposure to uranium dust. This was done as reports of the local population accumulated that spontaneous abortions and malformations of newborns have increased drastically. Subsequently, the adverse pregnancy outcomes including birth defects and stillbirths of 13,32 9 inhabitants of the Navajo region were examined. The births of people from Navajo between 1964 and 1981 were evaluated. There was one significant result. The birth defects were higher when the mother lived near tailings or mine dumps. The conclusion of the study is that the association between adverse pregnancy outcomes and the exposure to uranium radiation are weak (Ibid).

In Namibian uranium miners chromosomal instabilities and changes of hormone levels were observed (Zaire et al. 1997). 75 miners were compared to 31 non uranium exposed persons (Ibid). The chromosomal aberrations of the uranium miners were three times higher than in the control group (Ibid).

On top of these studies there are scientists who generally advise against using studies of uranium miners for the assessment of health effects of DU because radon poses a much bigger health threat (Bleise, Danesi, and Burkart 2003). A reason therefore is that the carcinogenic substances are not the uranium ores but the gaseous decay products of radon (Harley et al. 1999). There are two decay products of radon which form in air and emit much alpha radiation. It was proven that they deposit easily in the pulmonary tract (Ibid).

All in all it can be said with sufficient evidence that lung cancer rates rise due to high alpha radiation in uranium mines but it is more likely that gaseous decay compounds of radon are the main contributor. Besides, there is evidence that genotoxic effects also occur to uranium miners but to a considerably less extent than after exposure to DU-munition.

4.3 Nuclear Power Plants

4.3.1 Exposure during operation

In history, there were only three major accidents in nuclear reactors, namely Three Mile Island in 1979, Chernobyl in 1986 and Fukushima-Daiichi in 2011. These and other accidents in nuclear power plants have received massive media and scientific coverage. In this chapter, the exposure to hazardous compounds after an accident are excluded because this thesis focuses on the regular exposures to the miscellaneous types of uranium. Besides, an elaboration of the health consequences of the accidents would be beyond the scope of this academic work. Thus, the question is how big the exposure to uranium is during regular operation.

Basically, no one outside the plant can be exposed to radioactive materials. The workers in the reactor are required to wear adequate protective clothes. There are numerous safety requirements (such as mandatory containment buildings) and control systems to ensure that no negative environmental impact occurs. Most of the power plants release very little radiological effluents, which are a byproduct of the Chemical Volume Control System. The concentrations are so little that they do not affect the environment. The whole process is monitored and recorded. Additionally, samples of the surrounding waters, soil and air are taken in order to ensure conformity with the regulations.

There are studies which indicate higher cancer risk of nuclear power plant workers and also of children living in the vicinity of nuclear power plants (Kaatsch et al. 2008). Most of the studies are inconsistent and controversial and overall it can be said that under today's stringent regulations the exposure to uranium in a nuclear power plant is low.

4.3.2 Exposure during decommissioning and waste disposal

It is clear that for a comprehensive approach the environmental costs for the disposal of nuclear waste should be taken into account. Radioactive waste is divided into three categories: low-level, intermediate-level and high-level radioactive waste. Really problematic is only the handling of high-level radioactive waste because it is so radioactive that it is lethal. The nuclear fuel of the reactor vessel accounts for virtually all high-level radioactive waste. It makes up 95% of the radioactivity generated in the past 50 years, including the radioactivity from nuclear weapons production (Chitumbo 2016). The reactor fuel changes its composition over time and increases its radioactivity as it can be seen in the following figure.

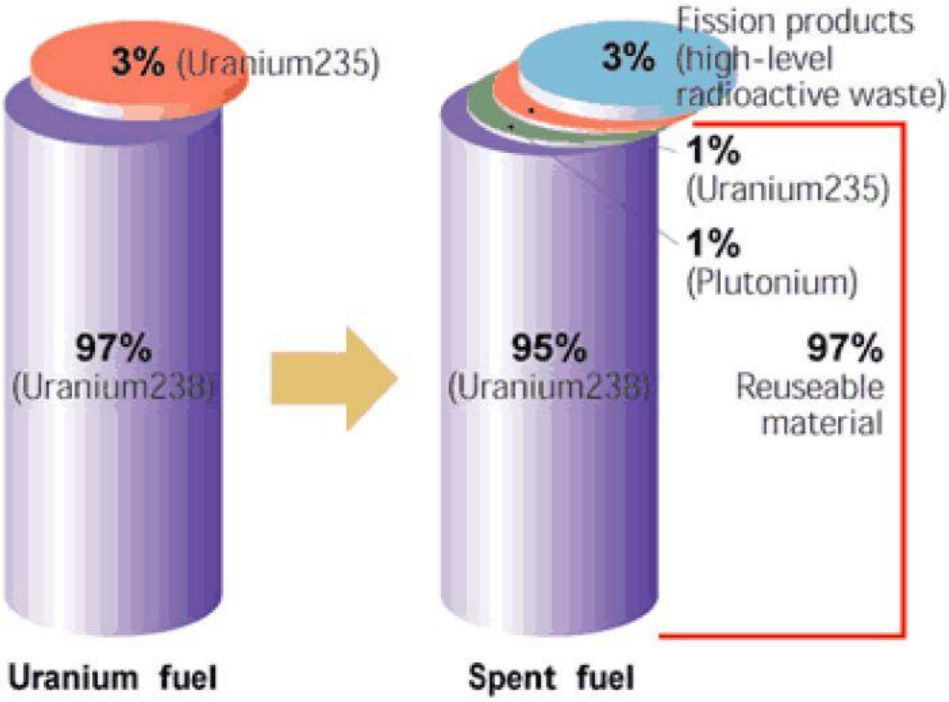

Figure 10: Change of composition of nuclear fuel (Nuclear Energy Information 2010)

The reactor fuel can be either reprocessed or directly disposed. Most of the countries dispose it directly. Before this can be done the spent fuel must be stored at the reactor site for several years to cool down. This is done in so called spent fuel pools which are water basins designed for the cooling of the fuel rods. Afterwards they are moved to a dry interim storage site where the fuel is stored in specifically designed containers which provide sufficient radiation shielding. These are commonly stainless steel cylinders and the fuel rods are surrounded by inert gas.

These casks must withstand severe impacts and heat in case of an accident. Only then the high-level radioactive waste can be transported to the reprocessing plant or to the disposal site. This is done in specialized vessels, airplanes, trains and lorries under stringent safety requirements. Nevertheless, accidents during transportation of high-level radioactive waste occur from time to time and alone in the USA there have been seven accidents between 1971 and 1991 (Cashwell and McClure 1990). In none of them the casks were severely damaged and thus no radioactive waste leaked outside (Ibid). For the disposal of radioactive waste there are various options but only one is legal and economically and technologically feasible, namely the deep underground burial. Here, the casks are buried several hundred meters below the surface. This is said to be a safe option, because the casks hardly corrode and the geological formations do not allow the uranium compounds to migrate significantly (Chitumbo 2016). Sometimes, however, nuclear waste accidents in underground storage sites occur. In February 2016, for instance, a 210 litre drum exploded in a radioactive waste site in New Mexico which was stored 700 metres below the surface (Vartabedian 2014). 21 workers were exposed to low-level radiation and the site was shut down for several months (Ibid).

All in all it can be summarized that there are no adverse health effects due to uranium exposure if radioactive waste management is properly done.

4.4 Nuclear bombs

The decisive difference between nuclear bombs and all other types of uranium sources is that in the first there is a short-term and high-dose radiation exposure while in the latter there is a long-term and low-dose exposure. (An exception is the exposure to DU-weapons when standing next to a hit hard target or inside a struck vehicle.)

First, what are nuclear weapons? They are referred to as weapons where the explosion (which is one form of energy release) is a result of nuclear fission or nuclear fusion (Nuclear Weapon 2016). The first is called atomic bomb and the latter is called hydrogen bomb. The energy release during the detonation of a nuclear bomb is so incredibly high because the entire chain reaction occurs in a few milliseconds. It is uncontrolled as opposed to nuclear power plants where the chain reaction is carefully controlled.

There have been conducted more than 2,000 tests of nuclear weapons since the first use on July 16, 1945 (Yang 2000). Such tests can be executed in the exosphere, the atmosphere, underwater or underground. Since all types of tests other than underground were banned from 1963 onwards by the Limited Test Ban Treaty, the overall majority of nuclear tests took place under the earth's surface. It is known that eight countries have tested nuclear weapons while almost half of all tests have been carried out by the USA (Ibid). As this master thesis focuses on the health effects on humans, atomic tests are not considered in this paper.

It happened twice in history that nuclear weapons were used in combat. This was on 06th August 1945 when the USA dropped one atom bomb on the Japanese city of Hiroshima and on 09th August 1945 when they hit Nagasaki with one nuclear warhead.

4.4.1 Immediate effects

The immediate effects refer to the a period of up to four months after the attacks. The data about the causalities which the two bombs caused in that time span is rather consistent. Six weeks after the bombings several research parties and a joint commission was sent by the Americans to the hit sites to investigate what had happened.

Hiroshima was a city with a population of about 325,000 people at the time of the attack (Atomic Heritage Foundation 2014). The casualties amounted to 90,000 to 146,000 people within the first four months in Hiroshima (Ibid). The atomic bomb contained around 64kg of Uranium 235 and it detonated at a height of 580m above the centre of the city in order to maximize the destruction (Nuclear Weapon 2016). The total destruction was within a radius of around 1,6km and the fires spread across 11km^2 (Atomic Heritage Foundation 2014). The devastating effects can be seen in figure 11.

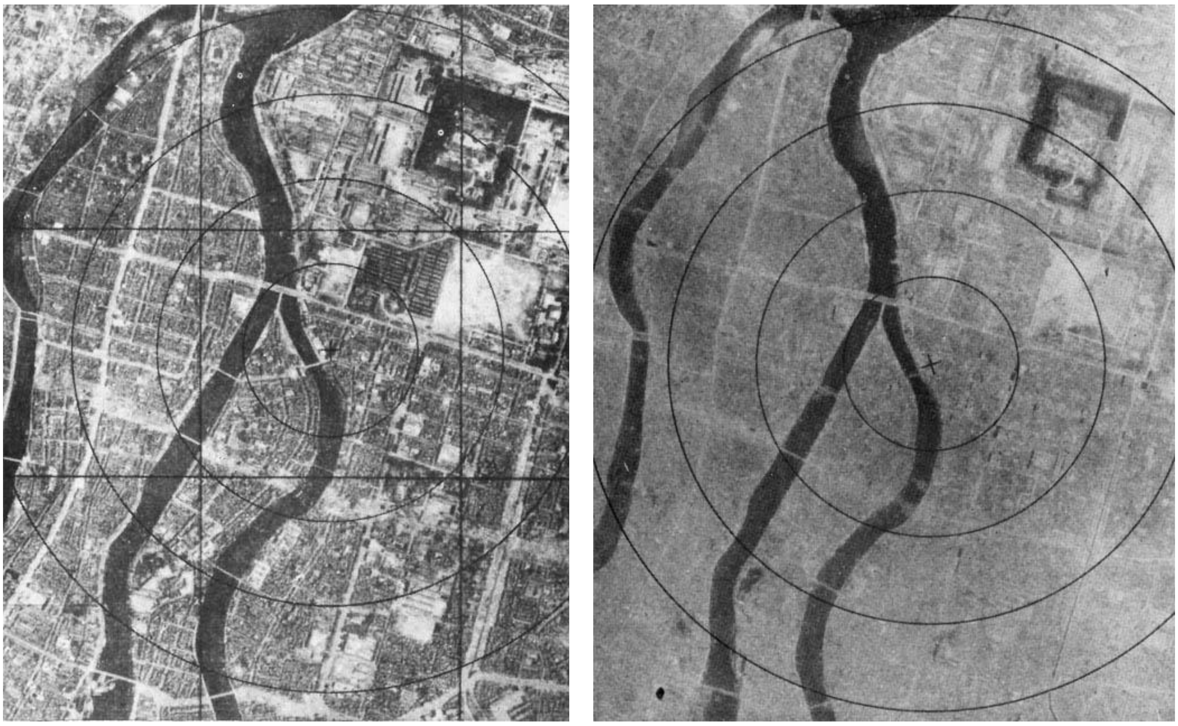

Figure 11: Hiroshima before and after the bombing (Sim 2016)

In Nagasaki there lived around 260,000 people when the atomic bomb was dropped. The acute effects amount to a death toll of 39,000 to 80,000 persons (Ibid). This time, the bomb contained plutonium (around 6.4kg) and again was triggered half a kilometre up in the air above the city centre.

Around half of the people who are accounted to the immediate casualties died on the first day. It goes without saying that it is very hard to understand how so many people can die due to one bomb. The simple physical explanation is that a tremendous amount of energy is released after the explosion of a nuclear bomb. The causes of death are listed in table 4.

Table 4: Energies and effects of the atomic bombs in Japan (Liebow, Warren, and DeCoursey 1949)

Energy	Injury	Type of injury
Mechanical	Trauma	Blast
		Falling debris
Thermal Radiation	Burns	Flash burns
		Indirect
Ionizing Radiation	Radiation effect	Skin
		Gastro-intestinal tract
		Gonads
		Lymphoid tissue
		Marrow
		Other tissues

Most of the people died because of the tremendous blast and the heat (Liebow, Warren, and DeCoursey 1949). The fireball was almost 4,000° Celsius hot and the winds were stronger than 1000km/h. The death rate within 1,1km was 95% because of the massive blast and the subsequent firestorm (Ibid). Those who died within the first two weeks died either of the severity of the burnings and injuries or due to a lethal overdose of the short-wave gamma radiation (Ibid). This overdose was later called radiation sickness.

4.4.2 Long-term effects

Numerous studies about the long-term health effects on the survivors of the nuclear bombings on Nagasaki and Hiroshima have been carried out. A brief summary shall be given in this chapter.

Cancer

After ten years of the bombings a big increase of a wide range of types of cancers was observed. Even before, the high incidence rate of leukaemia became apparent (Little 2009). Thus, in 1948, a leukaemia registry was established and two years later a life span study cohort was introduced (Ibid). The goal was to observe the long-term effects of the survivors of the bombings. Responsible for the periodically physical examinations and their evaluation was the Atomic Bomb Casualty Commission and its successor, the Radiation Effects Research Foundation. The most important findings are presented in this chapter. First of all, the correlation between cancer and high radiation exposure is linear (Ibid). Second, there was an excess mortality due to leukaemia. Third, the older people were at the time of the bombings, the smaller was the risk for developing a type of cancer due to the radiation (Ibid). A study about the radiation-induced risk of thyroid cancer, for instance, showed that those people who had been 20 years or older at the time of the bombings only had a minor excessive relative risk (Furukawa et al. 2013). By contrast, children are particularly vulnerable to ionizing radiation. Additionally, embryos and fetuses developed an excess risk of cancer which is comparable to young children and babies (Liebow, Warren, and DeCoursey 1949).

Besides the known malignant diseases a significant increase in non-malignant diseases occurred. These were in particular cardiovascular, respiratory and digestive illnesses (Ibid). Cardiovascular diseases have been developed by many survivors who were exposed to low radiation (Ibid).

Generally speaking, people who received low radiation doses also had a higher cancer risk which is also confirmed by the UNSCEAR and the International Commission on Radiological Protection (Ibid).

It is quite striking that 55 years after the bombings 45% of the examined cohort of survivors were still alive (Ibid). However, as we have seen before, many of the Japanese atomic bomb survivors had developed some type of cancer or other diseases which are related to the bombings.

Developmental and mutagenic effects

Another important question is whether the nuclear bombs have adverse health effects on generations to come. This means if they caused congenital or developmental health effects? Interestingly, after reviewing various papers covering this topic, the author realized that the same controversies existed like in the studies about DU-weapons. Although the cohort included in the life span study consisted of more than 100,000 people who were regularly examined, many authors stress that many difficulties and uncertainties exist in obtaining valid results. Often, they relativize the long-term effects on the offspring. As the American National Defense Research Institute summarizes succinctly: "*The average exposure to the follow-up population of 40,000 persons was 0.30 Sv. No statistically significant effects of parental exposure have been found."* (Harley et al. 1999, p.64). Between 1948 and 1954, the RERF examined more than 76,000 newborns of Japanese parents in that period (National Research Council 1991). More than 90% of all pregnancies are believed to be accounted for during that period because of a supplementary ration programme for pregnant Japanese women (Ibid). It is assumed that virtually all eligible women registered for the programme. Subsequently, the birth outcomes of these women were medically checked. The RERF analyzed the ratio of stillbirths, malformations and neonatal deaths within two weeks after birth for both the mothers and the fathers. They categorized them into low/middle dose exposure and high dose exposure during the nuclear attack. The control group were non-exposed Japanese mothers. The stunning result is that the birth outcomes were not significantly related to parental radiation doses. This is depicted in table 5.

Table 5: Stillbirths, malformations and neonatal deaths of atomic bomb survivors between 1948 and 1953 (National Research Council 1991)

Mother's weighted dose (Gy)	**Father's weighted dose (Gy)**		
	<0.01	0.01 – 0.49	>0.50
<0.01	**5%**	**5%**	**5.7%**
0.01 – 0.49	**4.8%**	**4.6%**	**4.5%**
>0.50	**6.1%**	**4.1%**	**8%**

Overall, it can be said that the immediate effects of an atomic bomb are absolutely disastrous and unparalleled to any other weapon. The consequences are appalling and in light of the huge number of casualties and the massive collateral damage (i.e. particularly civilians are victims) any discussion about the morality and legality of such use becomes obsolete.

The long-term effects are dreadful too, because cancer incidence rates are highly elevated. On the other hand, obviously the high-radiation dose in a short-term does not cause significant adverse developmental effects.

4.5 Severity Impact Assessment Scale

There has not been yet a scientific paper which compared the different types of uranium with each other. The author thinks that putting the hazards of DU-weapons in relation to other uranium types is a suitable and innovative way to display the actual dangers.

As a result of the literature study about the health effects of the uranium types and a comparative assessment, the following scale of danger was created.

Table 6: Scale of danger of uranium types

Uranium type	Environmental effects (no. of people affected)	Description of impacts (severity)	Unintended impacts	Threat level	Examples
Nuclear bombs	Hundreds of thousands	Mostly lethal, immediately	Cancer, cardiovascular, respiratory and digestive diseases	Extremely high	Nuclear attack at Hiroshima and Nagasaki by the USA
DU-weapons	Up to hundreds of thousands	To a significant extent lethal after several years	Cancer, numerous developmental effects, neurological effects	High	Approximately 1300t of DU-ammunition fired in both Gulf Wars by the USA
Mining, Refining, Conversion	(Nowadays) only few workers	Sometimes lethal after several years	Some increases in cancer rates	Medium	Uranium mines in Navajo Indian Reservoir
Nuclear Power Plants (incl. decommissioning & nuclear fuel disposal)	Virtually zero	Negligible	Sometimes low radiation exposure	Very low	Any nuclear power plant
Natural Exposure	Virtually zero	Negligible	Virtually zero	Very low	Radiation from rock & soil

Explanation of the scale of danger

The five investigated **uranium types** are compared and put together in one table.

As a representative factor of the environmental effects the impact on the number of humans was chosen.

There are five **threat levels** which are: very low, low, medium, high and extremely high. They are ranked from 1 (i.e. very low) to 5 (i.e. extremely high).

The **severity of the impact** denotes whether the uranium source has deadly consequences, and if yes, to which extent. “To a significant extent” means that there is a substantial risk to die from the impact of the uranium type. In the case of DU-weapons this means that it is likely to die from the DU-ammunition when it is fired, regardless of somebody being a direct target or being exposed to high amounts of DU dust over a longer period. “Mostly lethal” refers to the circumstance that most of the people who are within a few kilometres vicinity of the bomb’s detonation will die. “Sometimes lethal” refers to the fact that elevated cancer incidence rates occurred sometimes to uranium miners which were the cause of death.

The **unintended impacts** refer to those effects which are not the goal when of the uranium sources is applied. For the two mentioned weapon systems this means the following: A weapons or weapons system is applied because a specific goal shall be reached. In a military sense this is mostly the destruction of objects like critical infrastructure (power plants, bridges, roads, railroads, enemy buildings, enemy military facilities, vehicles, etc.). Another goal can be persons if they are combatants. Unfortunately, the reality shows that till today the majority of casualties in armed conflicts are civilians, regardless of the supposed highly technological and “precise” weapon systems. This unintended but accepted effect is commonly and ruthlessly referred to as collateral damage. The unintended effects in the scale of danger, however, refer to the long-term consequences of the affected people. They are unintended because they do not facilitate reaching a military goal. Clearly, above military goals stand political objectives. If the long-term effects are deliberately accepted or not by political decision makers is not examined in this chapter.

The scale of danger (table 6) can be transformed into a Severity Impact Assessment Scale. It has the shape of a reversed pyramid showing the highest threat level on the top. It displays the consequences for each threat level.

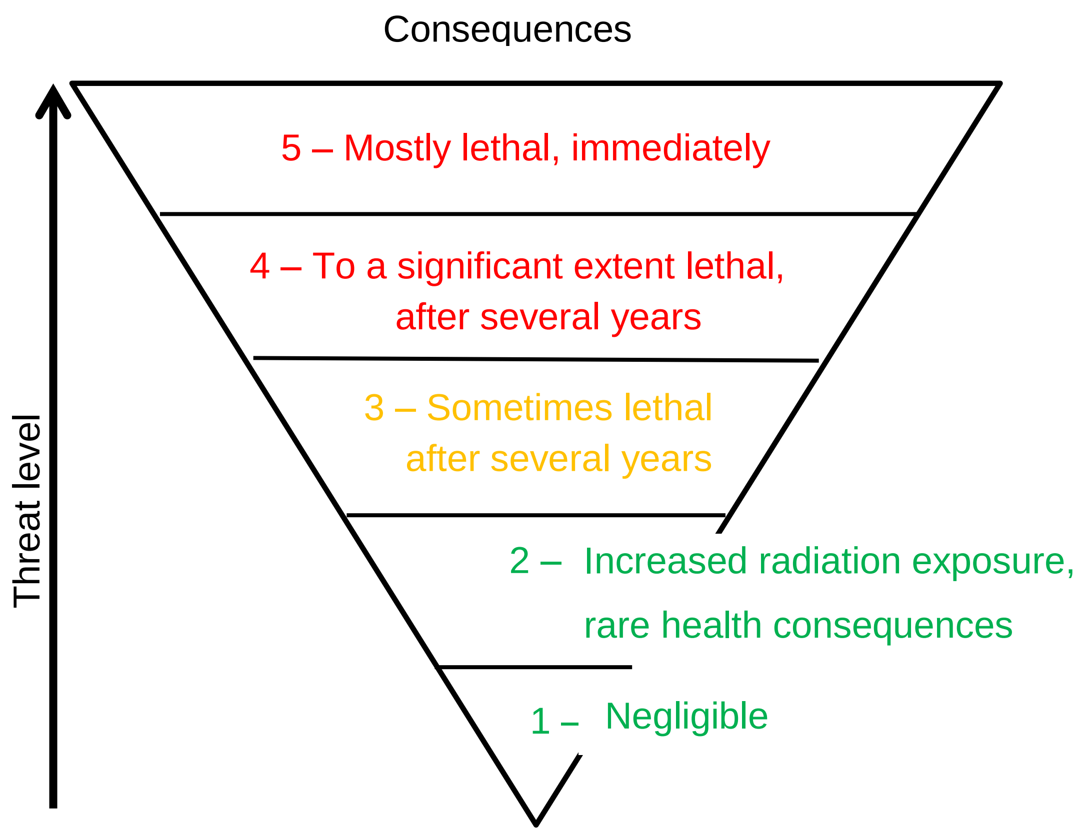

Figure 12: Severity Impact Assessment Scale

5. Implementation of a prohibition of DU-weapons

5.1 Current legal status of DU-ammunition

Currently, there is no treaty which explicitly prohibits the use of DU-weapons. The other question is whether the use of DU-ammunition can be considered illegal under some existing treaties. Therefore, an overview of the legal situation must be given and some terms must be clarified.

5.1.1 Overview of the relevant treaties and terms

There are numerous laws of war which entered into force and many provisions are seen today as customary international law. The most important treaties in the context of DU-weapons are the

- Geneva Protocol of 1925 (Prohibition of use in war of asphyxiating, poisonous or other gases, and of bacteriological methods of warfare)
- Geneva Protocol I & II of 1977 (Protection of victims of international or non-international armed conflicts)
- United Nations Convention on Prohibitions or Restrictions on the Use of Certain Conventional Weapons Which May be Deemed to be Excessively Injurious or to Have Indiscriminate Effects of 1980
- Chemical Weapons Convention of 1997

5.1.2 Weapons of Mass Destruction

Next, we want to know which types of weapons exist in legal terms and what can DU-weapons be assigned to? There are conventional weapons and weapons of mass destruction (WMD). Now, what are WMDs and can DU-weapons be classified as such? Although there is no universal definition of the term WMD there is a common understanding of its inherent properties. These are, regardless of where it is defined:

- nuclear, biological and chemical weapons AND
- they have the potential to kill a very large number of people and massively jeopardize the environment

Sometimes, also radiological weapons are explicitly included. If we applied such a wider definition then DU-ammunition would definitely be a WMD. Nevertheless, there is no treaty, which prohibits the use of WMDs.

Nuclear Weapons

There is no treaty which explicitly prohibits the use of nuclear weapons. However, Article 6 of the Non Proliferation Treaty says that all parties pursue measures to complete disarmamanet of nuclear weapons. Moreover, the ICJ infers from their potentially devastating effects that its use would infringe the principles of international humanitarian law. This is the content of the "Advisory Opinion of the ICJ on the Legality of the Threat or Use of Nuclear Weapons" from 1996.

Besides, there is a large number of treaties which regulates the testing and armament of such weapons. Examples are shown in table 7:

Table 7: Exemplary list of nuclear weapons treaties

Name	Date of entry into force	Number of Signatory States
Non Proliferation Treaty	1970	190
Antarctic Treaty	1961	12
Comprehensive Nuclear Test Ban Treaty	Not effective	183
Partial Test Ban Treaty	1963	104
START I	Not effective anymore	2
START II	Not effective	2
New START	2011	2

The listed treaties in table 7 could be extended by several regional nuclear treaties which are still in force today.

The follow-up question is if DU-weapons are nuclear weapons. The answer is no because their destructive power is not due to the process of fission or fusion of nuclei (see the definition of nuclear weapons in chapter 4.4). Additionally, it is not the purpose to use its radioactivity to kill other people and the immediate effects of DU-weapons are much less.

Biological Weapons

What is the situation regarding biological and chemical weapons? It is illegal to develop, produce, stockpile and use biological and chemical weapons. Biological weapons are prohibited since the Biological Weapons Convention entered into force in 1975. Yet, DU-weapons are not biological weapons because they are neither microbial nor biological agents or toxins as it is defined in the Biological Weapons Convention. Biological agents are commonly understood as living organisms (Kleffner et al. 2008). Yet, are DU-weapons chemical weapons?

Chemical Weapons

Article 2 of the Chemical Weapons Convention defines what these weapons are. In paragraph 1. (b) it says:

“Munitions and devices, specifically designed to cause death or other harm through the toxic properties of those toxic chemicals specified in subparagraph (a), which would be released as a result of the employment of such munitions and devices;”

Since DU-ammunition is not specifically designed to cause death through its chemical toxicity but to penetrate hard objects, the scope of the Chemical Weapons Convention does not apply to DU- weapons.

The same is true for the applicability of the “Protocol for the prohibition of use in war of asphyxiating, poisonous or other gases, and of bacteriological methods of warfare”, because the poisoning effects of DU-weapons are an unintended side effect.

5.1.3 Conventional Weapons

Since DU-weapons cannot be categorized as any form of WMDs, they are conventional weapons. This is true regardless of the fact that they are not addressed specifically in any convention. In the Conventional Weapons Conventions and its additional protocols several types of weapons are regulated. One of them are incendiary weapons. As DU-ammunition is pyrophoric the question emerges whether they can be classified as incendiary weapons. Protocol III to the Certain Conventional Weapons Convention states in Article 1 that incendiary weapons *“means any weapon or munition which is primarily designed to set fire to objects”* and do not include *“Munitions designed to combine penetration, blast or fragmentation effects with an additional incendiary effect, such as armour-piercing projectiles,”* …*” in which the incendiary effect is not specifically designed to cause burn injury to persons, but to be used against military objectives, such as armoured vehicles, aircraft and installations or facilities.”*

All in all, it is a matter of fact that DU-munition is currently not addressed in any arms control law.

5.1.4 Protocol I to the Geneva Convention

The "Protocol Additional to the Geneva Conventions of 12 August 1949 , and relating to the Protection of Victims of International Armed Conflicts (Protocol I), 8 June 1977" is ratified by 174 states but important military powers such as the United States, Israel, Iran, Turkey, India and Pakistan have not done so (although the USA, Pakistan and Turkey initially signed it in 1977). Nevertheless, it is customary law and thus binding on all states regardless whether they signed the protocol or not (ICRC 1987).

The Protocol I is the legal foundation for regulating warfare. It contains several crucial principles, which are presented in the following paragraphs and put into the context of DU-weapons.

Part III - Methods and Means of Warfare - Basic Rules

In part III of the Protocol I the methods and means of warfare are codified. Article 35 defines the basic rules:

"1. In any armed conflict, the right of the Parties to the conflict to choose methods or means of warfare is not unlimited.

2. It is prohibited to employ weapons, projectiles and material and methods of warfare of a nature to cause superfluous injury or unnecessary suffering.

3. It is prohibited to employ methods or means of warfare which are intended, or may be expected, to cause widespread, long-term and severe damage to the natural environment."

This principle of superfluous injury or unnecessary suffering has already existed in the 19th century when it was written down in the St. Petersburg Declaration .The question is whether DU-weapons cause superfluous injury or unnecessary suffering and if it causes widespread, long-term and severe damage to the natural environment. The ICJ describes "unnecessary suffering" as a harm greater than that unavoidable to achieve legitimate military objectives (ICJ 1996). Examples are projectiles filled with glass or the barrel bombs, which are currently used in Syria. How can "superfluous injury" be described? A typical case is when combatants are killed or injured where it is not necessary to reach the military goal (Kleffner et al. 2008). This case must be distinguished from war crimes or torture where people are deliberately injured or killed without pursuing a military objective.

Given the effects of DU-weapons in the long-term and the availability of alternative armor-piercing rounds like those filled with tungsten, it most likely infringes the provisions of Article 35.

An argument against the applicability of Article 35 on DU-weapons is that DU-munition is mainly used against armored target and thus objects. Therefore, it is an anti-material weapon and not an anti-personnel weapon like assault rifles and machine guns (Borrmann 2010). The author of this thesis does not find this argument to be sound because the Geneva Conventions and its protocols do not distinguish between anti-personnel and anti-material weapons.

What about the influence of DU-weapons on the environment as it is mentioned in paragraph 3 of Article 35? The provisions “widespread, long-term and severe” set a high limit for fulfilment because of its cumulative nature. The effects are certainly widespread, because DU-dust can be transported a few hundred kilometres. However, they are probably not long-term, because at latest after a couple of years the DU-aerosols are suspended on the ground.

Part IV - Protection of Civilians

Part IV of the Protocol I provides for the protection of civilians. In Article 48 we can find the principle of distinction:

“In order to ensure respect for and protection of the civilian population and civilian objects, the Parties to the conflict shall at all times distinguish between the civilian population and combatants and between civilian objects and military objectives and accordingly shall direct their operations only against military objectives.”

This principle to distinguish at all times between combatants and civilians is related to Article 51 (4), which defines indiscriminate attacks:

“4. Indiscriminate attacks are prohibited. Indiscriminate attacks are:

(a) those which are not directed at a specific military objective;

(b) those which employ a method or means of combat which cannot be directed at a specific military objective; or

(c) those which employ a method or means of combat the effects of which cannot be limited as required by this Protocol; and consequently, in each such case, are of a nature to strike military objectives and civilians or civilian objects without distinction.”

Can the use of DU-weapons considered to be an indiscriminate attack per se even if only a military target is hit? Subparagraph “(a)” describes a general rule regardless of the type of weapon. Subparagraph “(b)” refers to the precision of a weapon. Since all types where DU-ammunition is used (or allegedly used as in the Tomahawk cruise missiles) are precise, this provision cannot include DU-weapons. Typical examples of imprecise weapons are big bombs like the “mother of all bombs” which has been fired by the USA on Afghan territory in April 2017.

Subparagraph “(c)”, however, could be applicable to DU-weapons because DU-dust is inevitably spread to areas where civilians live. This means that the effects cannot be limited in such a way that the principle of distinction is complied with.

Next, there is the principle of proportionality, which is explained in the section about indiscriminate attacks. It is defined in Article 51 (5):

“(b) an attack which may be expected to cause incidental loss of civilian life, injury to civilians, damage to civilian objects, or a combination thereof, which would be excessive in relation to the concrete and direct military advantage anticipated.”

Do DU-weapons cause damage to civilians excessive compared to the direct military advantage? This is a further delicate question which has to be assessed and it probably sounds macabre to make a calculation how many civilians are accepted to perish. Without going into any detail here, at the first glance it seems that the military advantage of being able to penetrate the enemy’s armor is relatively small compared to the large number of civilians who get sick and die.

Precautionary principle

The section about indiscriminate attacks establishes a direct link to another serious principle of the Protocol I. It is the precautionary principle, which is stipulated in Article 57:

“1. In the conduct of military operations, constant care shall be taken to spare the civilian population, civilians and civilian objects.”

and in paragraph 2 (a) (ii):

“take all feasible precautions in the choice of means and methods of attack with a view to avoiding, and in any event to minimizing, incidental loss of civilian life, injury to civilians and damage to civilian objects;”

The first paragraph is very broadly formulated and therefore is a general rule in armed conflicts. The second paragraph, on the other hand, clearly states the obligation to choose a weapon system, which causes the least possible civilian casualties. Therefore, it is indispensable to have profound information about the military targets before a strike is executed. A constant evaluation about the potential civilian victims is the responsibility of the commander in charge, regardless of the echelon. Probably, the application of DU-weapons in remote areas where no civilians live, is in line with the precautionary principle. An example is the “highway of death” in the Iraqi desert leading from the southern border to Baghdad. There, the NATO forces destroyed hundreds of Iraqi tanks in the First Gulf War. A more recent example are strikes against ISIS positions in the Syrian desert.

Apart from these evaluations there is the general question whether the use of DU-ammunition is the only available means to pierce armor. This is apparently not the case in light of the availability of non-radioactive tungsten as substitute material.

Another notable aspect of the precautionary principle is that it outlaws DU-weapons even if it is argued that the adverse health effects of them are not proven. This is because means and methods of attacks of which there is uncertainty about their effects trigger the applicability of the precautionary principle (Borrmann 2010).

5.1.5 DU-weapons and international criminal law

Considering the infringements of Protocol I to the Geneva Convention the question arises if the use of DU-weapons constitutes a crime prosecuted by the International Criminal Court. The Rome Statute of the International Criminal Court covers the prosecution of individuals for war crimes, genocide, crime of aggression and crimes against humanity.

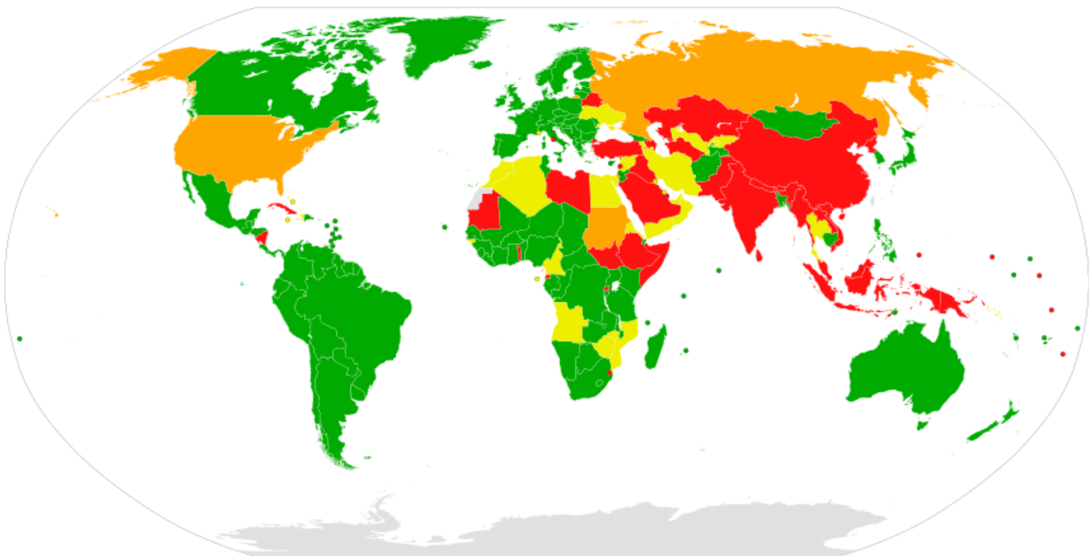

Figure 13: Members of the Rome Statute (States parties to the Rome Statute of the International Criminal Court, 2017)

The green countries are parties to the treaty, yellow means that they have not ratified it yet, orange means that they signed it but notified the UN not wanting to ratify it, and in red are non-signatory states.

As it can be seen in the figure, those countries who majorily use DU-weapons are not parties with only France and the UK being an exception. Hence, a prosecution of

US citizens by the ICC is not possible because the USA are not a party to the statute. In 2000, they signed the Rome Statute but two years later they informed the UN that they did not intend to ratify it anymore.

Regardless of the regrettable fact that the main users are not parties, it is doubtful whether the use of DU-weapons constitutes a crime according to the Rome Statute. Rob White, an Australian criminologist is of the opinion that it is a war crime and crime against humanity if the alleged effects are true and were known in advance (White 2008). Other authors, like Karen Parker, an American delegate to the UN Commission on Human Rights, also says that it constitutes a war crime and crime against humanity (Parker 2003). According to her, the reasons are that

- DU-weapons continue to act after the cessation of hostilities
- They are unduly inhumane
- They have an unduly negative effect on the environment
- They are indiscriminate

The director of the revealing documentary “Deadly Dust”, Frieder Wagner, even argues that it is a form of genocide (Wagner, 2007).

Other scholars have a different opinion about DU-munitions’ illegality under international criminal law. Robin Borrmann from the ICRC, for instance, points out that not every violation of the law of war is a war crime and that it is difficult to prove that the use of DU-weapons are a systemic attack against the civil population (Borrmann 2010). It goes without saying that the official representatives of the user states do not even consider the question of breaching the Rome Statute, because they are either not parties to the treaty or deny the harmful effects anyways.

All in all it can be said that it is very unlikely that the ICC will deal with this topic in the upcoming years, if so at all.

5.2 Requests for a ban of DU-weapons

As early as 1996 a sub-commission of the United Nations Human Rights Commission, namely the Commission for the Prevention of Discrimination and Protection of Minorities, included DU-ammunition in a list of proposed weapons to ban (Zucchetti 2009). The sub-commission requested to cover the issue in a UN working paper. This had been done by 2002 and the outcome was that DU-weapons (alongside other means of warfare which were listed) could breach the Universal Declaration of Human Rights, the UN Charter, the Genocide Convention, the

Geneva Conventions, the Convention on Conventional Weapons and the Chemical Weapons Convention (Ibid).

In 2001, the chief prosecutor for the International Criminal Tribunal for the Former Yugoslavia stated that the use of DU-munition could be a war crime because it infringes some general principles of laws of war (Zucchetti 2009).

Additionally, the problems of DU-weapons and a possible moratorium was discussed in the Council of Europe (Zucchetti 2009).

In 2003 a NGO was founded which stands up against the use of DU-weapons. It is called the International Coalition to Ban Uranium Weapons (ICBUW) and is the largest and most prominent platform today. It operates out of Great Britain. Their main objective is to set up a treaty which bans the use of uranium in all conventional weapons. Additionally, they want to achieve the provision of health care, compensation and environmental remediation for all affected people (ICBUW 2017). The organisation advises policy makers in international organizations and national governments and claims to represent more than 160 organizations (Ibid). The ICBUW has a special consultative status in the United Nations Economic and Social Council.

European Union

In the EU, the European Parliament has passed a resolution against DU-weapons by a staggering majority. 491 members of the European Parliament were in favor of the resolution and only 12 were against it. It contained, among others, the following requests (European Parliament 2008):

- To commission and fund scientific studies into the use of D- weapons
- No use of DU-weapons in European Security and Defense Policy operations
- No deployment of European civilian or military personnel to areas where DU has been used
- Asking all NATO members to curb the use of DU-weapons

In the preamble of the resolution it is stated that *“depleted uranium in warfare runs counter to the basic rules and principles enshrined in written and customary international, humanitarian and environmental law”* (European Parliament 2008).

The only two countries who are constantly against a ban are the only ones who use it, namely France and Great Britain. In the UNO they are the only European states who reject any resolutions nowadays.

UN General Assembly

The “Effects of the use of armaments and ammunitions containing depleted uranium” has already been six times on the agenda of the UN General Assembly. In 2007, the consequences of DU-weapons were discussed for the first time. The only opposing EU-states were France, Great Britain, the Czech Republic and the Netherlands. The resolution was adopted.

In September 2008, 15 states and the UNEP, WHO and IAEA proclaimed their stance towards the effects of DU-weapons. The opinion hardly differed from previous statements which means that a lack of evidence about the threats is claimed.

In the 63rd session of the General Assembly held in October 2008, 141 states were in favor of a resolution which envisaged that the UNEP, WHO and IAEA update their findings on the effects of uranium containing weapons. This time, the only EU-states who voted against it were Great Britain and France. Since then the use of DU weapons was on the General Assembly’s agenda every other year and each time the resolutions where passed by an overwhelming majority. By 2017 these are the resolutions number 62/30, 63/54, 65/55, 67/36, 69/57 and 71/70.

In the 69th session of the General Assembly in October 2014 a resolution was passed with 143 member states voting in favor and only four against and 26 abstaining (UN General Assembly 2014). The resolution requests:

- that all member states shall undertake greater effort to identify and manage contaminated areas
- that further research on the health risks and environmental impact of the use of DU arms shall be done
- that the Secretary-General should request the relevant international organizations to update and complete their studies on the effects of the DU-weapons

In December 2016, the resolution was passed with 151 votes in favor and only four votes against it. The content of the resolution remained the same (UN General Assembly 2016). The voting statistic is shown in figure 13:

Figure 14: Voting statistic of the 71st UN General Assembly (ICBUW 2016)

The fact that all resolutions about DU have been passed by more than two thirds majority shows and only those countries who use this type of ammunition voted against it or abstained, shows the tremendous awareness and conviction of the international community in this matter.

So why do the USA, France, Great Britain and Israel still reject any proposals to ban the use of DU-weapons? Their official rationale is that there is not sufficient scientific evidence about the harmful effects of DU-munition. When confronted with the obvious ramifications of its use, they commonly refer to international organizations which often do not acknowledge the findings of other studies.

How long it sometimes takes that a clear stance towards the topic is formulated by official authorities can be seen in the case of Italy. Soon after the deployment of Italian soldiers to the Balkan missions concerns about the health condition of the returning troops rose (as described in chapter 3.3.1). Scientific research on this matter had started as early as 1998 by an activist group (Zuccetti 2009). At the beginning the chief military command and government denied the exposure of Italian soldiers to DU (Ibid). Then, it was admitted that they were exposed to it but denied any adverse effects of it. Only after increasing public pressure a commission to investigate the claims was formed. This Italian Commission on the effects of DU on the Italian peacekeepers in the Balkan recommended to stop the use of DU-munition after the correlation between DU and strongly increased cancer rates became evident (Ibid).

In the international community it is even more laborious and cumbersome to reach common ground. The current status in the international arena is that most of the countries want to limit or ban the use of DU-weapons but its main users are against that proposition.

5.3 Recommendations for the control of DU-ammunition

5.3.1 Necessary legislative steps

As it was shown, for other types of weapons the international community reached some good agreements to ban them. Regrettably, the situation concerning DU-weapons is substantially different to that of WMDs or cluster munitions. As opposed to those types of arms, the main challenge in the case of DU-weapons is to reach a consent about the long-term effects. If the countries agreed to that, it would make any ban obsolete. The reason therefore is because it would be illegal under several provisions of Protocol I of the Geneva Convention as it was explained in the previous chapter. Moreover, according to the principle of nullem crime sine lege, establishing a ban implicates that the use of DU-weapons is currently legal. Illegality can solely be created by state consent (Beckett 2004). Still, some people would be in favor of establishing a convention, because by specifically addressing DU-weapons any tricky legal interpretations of existing conventions could be avoided (Borrmann 2010).

The ICBUW has drafted a convention for a ban. It follows the structure and approach of the Cluster Munitions Convention, which entered into force in 2010. It envisages the prohibition of stockpiling, use and transfer of DU-munition.

The deniers of the appalling effects keep referring to the lack of evidence provided in reports by international organizations such as the WHO, IAEA and UNEP. However, the next step to resolve the current deadlock in multilateral negotiations would be that these organizations provide irrefutable evidence. Let us recall that this evidence already exists to a decent extent and that the further research, which has been called for in the UN resolutions must deliver more profound results. This process is more or less analogous to the climate change debate where those states who were the biggest polluters denied its existence for the longest time. Only after the anthropogenic influence was indisputable countries like the USA started to tackle the problem. Still, there are global warming deniers and there will always be.

The same will be true for the case of DU-weapons. Nevertheless, this does not impede that the problem will be solved.

So what would be consequence if the user states, of which four happen to be permanent members in the UN Security Council, continued to refuse the existence of the long-term effects and thus will not sign a DU-weapons convention?

Basically, a DU convention would not be meaningless because most of the treaties in international law are not ratified by all states on earth. For instance, the USA did not ratify the Additional Protocols I and II of the Geneva Convention nor the ICC Charter nor the Cluster Munitions Convention. Yet, the applicability of those laws is not questioned. It goes without saying that it always is a major deficiency when big powers do not act responsibly in foreign policy because they can easily destabilize the fragile framework of international law.

In any case, the combined efforts of all countries who are already against the use of DU-weapons result into an overall limitation of DU-weapons, regardless of the involvement of big powers.

5.3.2 Assessment of the likelihood of practical realization of a ban

As we have seen, it is difficult to implement a ban on the use of DU-weapons through the legislative and diplomatic channels of the UNO. Are there other possibilities that the countries stop using it?

As it has been shown, the basic problem is the easy availability of DU. Since it is a radioactive by-product it comes in handy for nuclear power plant operators to provide it to the military industry at no cost or very little cost. Of course, the ammunition manufacturers appreciate the free delivery of it. The armed forces benefit from it too because they can procure armor-piercing ammunition at low prices. All in all, it is much easier and cheaper to use DU instead of disposing it and extracting a substitute material like tungsten. Hence, what are the prospects for the production levels of DU? The ulterior motive is whether the market for DU vanishes if the user states reduced nuclear energy production? The answer is that the demand for nuclear energy is rising markedly worldwide. The user states of DU-munition like Russia and the USA increase their nuclear energy production. Currently, nuclear power plants are under construction in 13 countries and in total 30 countries are considering to introduce nuclear power (Chitumbo 2016). Consequently, even more DU will be available and thus more countries will have an easy opportunity to implement DU-weapons in their arsenal.

Fortunately, considering the clear trend in the international community to request a ban of DU-munitions, it is rather unlikely that any countries will introduce them. The number of studies delivering strong evidence rises and the devastating long-term effects become more and more apparent. Subsequently, it is likely that the international and national pressure on the user states will increase and that they will eventually turn away from this type of ammunition.

The strongest argument that the user states will abandon DU-weapons is that there are substitute materials available at moderate costs, which are not radioactive. It is known that the properties of tungsten are not substantially worse. By contrast to DU it is not pyrophoric but this is not a crucial property. It was mentioned in chapter 2.5.2 that the US Navy officially replaced DU-rounds by tungsten in 1993. The reason for this decision is not known. It is likely that the commanders realized that it is a dirty weapon and causes unnecessary suffering or at least uncertain side effects which have nothing to do with the military purpose. In any case, this example shows that there is also the option for a voluntary renouncement from DU-weapons. Whether the motive to stop it is to protect the own troops or the civilian population does not matter as long as the DU-munition is removed from the weapon arsenals.

Apart from states it is likely that NGOs raise more awareness for this topic in the future by informing a broader public about the disastrous effects of DU-weapons. As a result of increased public pressure on the user states their political decision makers could decide to abandon DU-weapons.

5.3.3 Recommendations

After having assessed the threats of DU-weapons and the legal and political situation concerning the topic, the following recommendations can be made:

1) It is indispensable that the International Organizations carry out further research on the health effects of DU-munition and update their studies. Thus, they finally must include the long-term effects and cooperate closer with authors of the existing studies.
2) Parameters for studies should be developed in order to achieve more transparent and comparable results about the health effects. In general, the focus shall be directed at the analysis of DU dust and its effects on the local population which is exposed to it permanently.
3) There is already a lot of information available about the multiple effects of DU-weapons. This information should be shared in a common international database, which is administered by an international body like the WHO.

4) The awareness about the properties and consequences of DU-weapons must be raised. This applies to all kinds of groups such as the civilian population and military personnel alike. Notably, the political leaders and military commanders must be informed about the appalling long-term impact. The SIAS could help to raise the awareness and thus should be adopted.

6. Conclusion

Regarding the first objective of the master thesis – the study review about the health effects of DU-weapons – several conclusions can be drawn. DU-munition entails multiple lethal diseases if there is a chronic exposure at already low dosages. The target group is the local population which inhales the DU dust continuously, faces water contamination and the external exposure.

The reasons why the outcomes of many studies differ greatly are the following: First and foremost, the majority of the studies, in particular those until the beginning of the 2000s, only examine the radiological and chemical toxicities but disregard the neurological and mutagenic effects. It is a matter of fact, however, that the alleged diseases which originate from DU exposure are due to its neurotoxic properties. It seems that the "bystander effect" is either not considered or in general strongly underestimated. This effect occurs at low doses over a long exposure period. Unirradiated cells close to irradiated cells can alter genetically due to alpha radiation (Zucchetti 2009). Second, many studies are obsolete because they were carried out too early after an exposure and thus at the beginning of the incubation period of some diseases. Last but not least, comprehensive research has been carried out on the ramifications of acute exposure to DU under special consideration of veterans from the First Gulf War. This, however, is not of particular relevance, because the chronic exposure (i.e. over several years) causes totally different results and affects considerably more people. The main affected group is the civilian population which lives in the contaminated areas. The disastrous effects such as reproductivity problems and cancer unfold to the full extent only after long-term exposure.

It is very interesting that the results of studies are frequently relativized by the own authors when they show the various harmful effects of DU-weapons. It is then said that the conducted study is not very revealing because the sample groups were either too small or too heterogenic. At the same time, the control groups are said to be inappropriate. A further argument to question or moderate the own results is to refer to recall bias in surveys. Admittedly, all of this may be true but it does not change that the results are there.

All in all, it is a matter of fact that leukaemia, cancer, reproductive problems and birth defects significantly increased in areas where DU-munition was used. If this is the main cause is very hard to prove because of:

- Long incubation periods (cancer, leukaemia)
- Neurological studies have mostly been conducted on animals, not on humans
- Multiple possible influencing factors

Nevertheless, the health effects of DU-weapons, be it in the short or long term are well understood today. The reason why DU-munition is still used instead of tungsten is that it is so cheap because it is already available after the enrichment process in the nuclear fuel cycle. Additionally, the nuclear energy sector benefits from it as well because the costly and complicated disposal of DU can be omitted.

The second goal of this master thesis – the comparative threat assessment of DU-weapons compared to other sources of uranium – was achieved by introducing a scale of danger which summarizes the effects on humans. It can be clearly seen that the weapon systems (i.e. the atomic bomb and the DU-weapons) are by far the most dangerous sources of uranium. The immediate consequences of a nuclear bomb are incomparably worse than DU-weapons which is due to the different intended effects. The intriguing finding of the comparative assessment is, however, that the long-term effects of DU-ammunition can be even worse than that of an atomic bomb because the long-term exposure to DU-dust causes all types of developmental and neurological diseases which a nuclear bomb does not.

The third objective of the thesis was to evaluate if the use of DU-weapons should be banned or limited, and if yes, how this could be implemented. The conclusion after reviewing the studies about the health effects of DU-weapons and displaying the threat level compared to other uranium sources, is that they certainly should be banned. There is enough evidence available about the hazardous long-term effects. A responsible political leader should not ignore the awful long-term health effects as described in this thesis. Two reasons therefore are that the number of innocent casualties stands in no relation to the achieved goal and other means, which cause less agony, are available to achieve such goals. Taking into account existing treaties regulating the use of weapons it can be said that DU-weapons do not comply with some basic rules of warfare. They cause superfluous and unnecessary suffering and their effects can probably not be limited to military objectives. It was shown in the previous chapter that even if countries refer to the uncertainties about the effects of

DU-weapons, it can be argued that it is outlawed because it infringes the precautionary principle stated in Protocol I of the Geneva Convention.

Thanks to the rising awareness about the consequences of DU-ammunition pressure on the user states has increased significantly during the past two decades. Every other year it is an integral part of the agenda of the UN general assembly. There remain only four countries who are not willing to discuss the topic and continue to deny their responsibility, notably the USA. It is likely that the major reason for this strategy is to avoid any possible costs for the clean-up and compensatory damages. A prosecution under international criminal law is virtually impossible. Besides, the main actor, the USA, do not fall under this jurisdiction. Since the user states will not admit an infringement of laws of war and it is very difficult to prove that they knew about the effects of DU-munition it is unlikely that they will make any efforts to compensate the affected population.

It can be concluded that an implementation of a ban of DU-weapons including the main user states as signatory parties is unrealistic at the moment. A more likely scenario seems to be that the USA, Israel, France and UK will continue to use DU-munition and will only substitute it when domestic public pressure increases significantly.

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