Review

Depleted uranium: an overview of its properties and health effects

S. Shawky[1]

SUMMARY There has been much debate about the use of depleted uranium in the Gulf War and its health effects on United States and European war veterans. However, studies on the impact of this radioactive substance on the residents of the surrounding Gulf region are far from adequate. Depleted uranium introduces large quantities of radioactive material that is hazardous to biological organisms, continues to decay for millennia and is able to travel tens of kilometres in air. If depleted uranium were used in the Gulf War, its impact on the health of people in the area would have been considerable. This review of depleted uranium — its origin, properties, uses and effects on the human environment and health — aims to trigger further research on this subject.

Introduction

Many debates about the use of depleted uranium in the Gulf War have been held in industrialized countries. Some claim that depleted uranium was used extensively in place of tungsten for ordnance by the United States (US) and United Kingdom (UK) forces [*1,2*]. It has been suggested that at least 320 tons of depleted uranium were used during the war and much of that was converted at high temperatures into an aerosol of minute insoluble particles of uranium oxide [*1*]. The fact that depleted uranium was detected in the urine of Gulf War veterans seven to eight years after the war is substantial evidence of long-term internal contamination and tissue storage of this substance [*1,3,4*].

For some years after the Gulf War, many US and European veterans deployed in the region during the war complained of vague incapacitating symptoms that have been termed 'Gulf War syndrome' [*5,6*]. The US Department of Defense treated this illness as 'post-traumatic stress disorder' and advised military doctors to treat it with muscle relaxants and sleeping pills while ordering a mental illness assessment [*1*]. Arguments about the issue have continued for years, some authors describing it as a myth invented by the media [7], others documenting the symptoms reported by the veterans. These symptoms were multiple, consisting mainly of chronic fatigue, headache, muscle and joint pain, sleep disturbances, bladder dysfunction, sweating disturbances, skin manifestations, menstrual disorders, as well as neurological, psychological, respiratory, gastrointestinal and cardiac symptoms [*5,6,8*]. Over time, the focus shifted to more serious health risks and a number of dangerous conditions became linked to depleted uranium exposure. These included cancers of different types, renal diseases, as well as con-

[1]*Department of Community Medicine and Primary Health Care, College of Medicine and Allied Health Sciences, King Abdulaziz University, Jeddah, Saudi Arabia.*
Received: 26/06/01; accepted: 11/11/01

genital anomalies and perinatal deaths among the neonates of veterans [*3,9–14*]. These health concerns triggered an explosion of interest in the subject as the affected veterans started to campaign for more information about the relationship between their illnesses and exposure to depleted uranium.

If the Gulf War veterans who were temporarily stationed in the region were indeed victims of depleted uranium, what could have been the impact of this substance on the health of the residents of the region and surrounding countries? Most studies from Iraq have concentrated on the impact of the United Nations' sanctions against Iraq on nutritional deficiencies and on children's health. A few studies in the Gulf countries have noted an increased incidence of abortion and perinatal and infant mortality since the Gulf War [*15–17*], but no adequate in-depth research has been performed on the link between the war and serious health conditions. Many issues concerning the effect of depleted uranium on the health of the residents of the war countries and the surrounding regions remain unexplored.

This review of depleted uranium—its origin, properties, uses and impact on the human environment and health—aims to trigger further research on the subject. Internet and MEDLINE searches were performed to extract information on depleted uranium and its health effects. Information was mainly taken from published research on depleted uranium in general and from the Gulf War in particular.

Origin of depleted uranium [*1,18,19*]

Natural uranium is the heaviest naturally occurring element on earth. It is widely distributed in the earth's crust but is concentrated in certain rock formations. Natural uranium has both radioactive and fissive properties and is known to be the deadliest metal on earth.

Radioactivity is caused by unstable atoms exploding microscopically to form a series of new substances called 'decay products', emitting energy in the form of alpha and beta particles and gamma rays. The fission process requires highly sophisticated technology to bombard uranium atoms with neutrons, splitting them into two or three pieces and releasing a high degree of energy and more neutrons with great force. This splits more atoms and starts a chain reaction, producing substances called 'fission products'. Radioactivity and fissionability are two completely different processes and release different products. Radioactivity is not triggered and so cannot be controlled, whereas fission can be started, stopped, slowed or speeded. It is fission that allows uranium to be used in nuclear electricity generation and in nuclear weapons.

Natural uranium occurs in soil at about 1 to 3 parts per million whereas in uranium ore it is about 1000 times more concentrated, reaching about 0.05% to 0.20% of the total weight. Natural uranium is a blend of uranium-235 (U-235) and uranium-238 (U-238). The U-235 is the fissionable part and can be used directly but it is rare and constitutes only 1% of natural uranium. Thus at a uranium enrichment plant, the concentration of U-235 is increased by discarding some U-238. This cast-off uranium, which is almost 100% uranium (mainly U-238), is called depleted uranium.

Radioactive decay products of depleted uranium [*1,18,20*]

Depleted uranium is thus a nuclear waste by-product of uranium enrichment and has the same properties as metallic natural ura-

nium. As the concentration of uranium in depleted uranium is much higher than in its natural state, depleted uranium is more radioactive than natural uranium. Figure 1 shows the radioactive decay products of depleted uranium, their half-lives and the type of energy emitted (alpha or beta particles or gamma rays). It can be seen that radium is one of the decay products of U-238. Radium disintegrates into radon gas that in turn decays into the extremely dangerous 'radon daughters' or 'radon progeny', of which there are about half a dozen radioactive materials including polonium, the most toxic of all radon daughters. Finally, this progression ends with lead, which is a stable highly toxic substance. Figure 2 shows the radioactive decay products of the radon progeny. The very long half-life of U-238 means that depleted uranium remains radioactive for billions of years and over these periods will continue to produce radioactive decay products. Thus, depleted uranium becomes more radioactive over the centuries and millennia because the decay products accumulate.

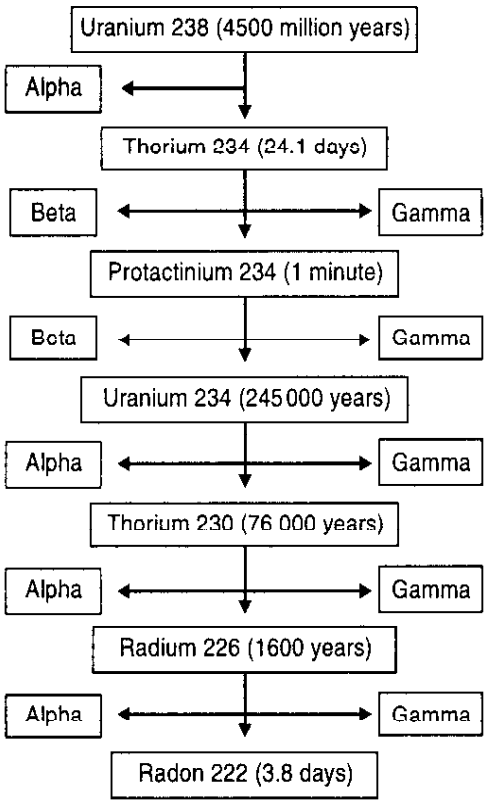

Figure 1 **Radioactive decay products of depleted uranium, their half lives (shown in brackets) and type of energy emitted: alpha or beta particles or gamma rays**

Uses of depleted uranium [*1,19,20*]

Depleted uranium has several military and peacetime uses. In military settings it can be used to breed plutonium, a powerful nuclear explosive; to double the explosive power of a hydrogen bomb; to coat conventional bullets and shells to improve their armour-piercing capabilities; and to provide armour-plating to tanks and other vehicles. The peacetime uses include: counterweights in aeroplanes; shields against radiation in medical radiotherapy units; and transport of radioactive isotopes.

Environmental pollution with depleted uranium [*1,20,21*]

Depleted uranium ignites at high temperatures, producing uranium oxide particles (UO_2 and UO_3) that are insoluble in water. The particles resist gravity and are able to travel tens of kilometres in air. Once on the ground, they can be resuspended and continue travelling when the soil or sand is dis-

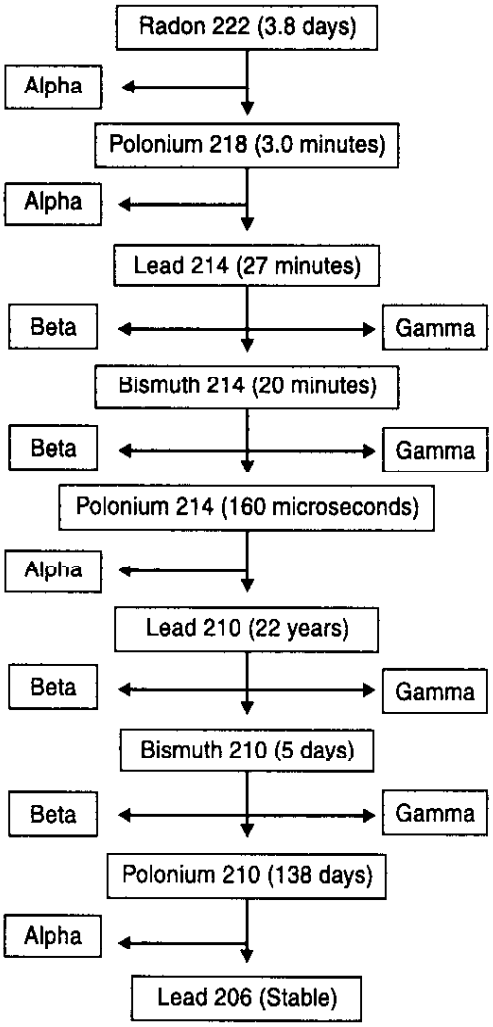

Figure 2 **Radioactive decay products of the radon progeny, their half lives (shown in brackets) and type of energy emitted: alpha or beta particles or gamma rays**

turbed by motion or wind. They contaminate the soil, ground water and river systems. Radioactive materials can also be carried long distances in the bodies of animals, fish, birds and insects. Thus, depleted uranium seeps into water, food and air and introduces into the human environment very large quantities of long-lasting radioactive materials, all of which are hazardous to biological organisms.

Human exposure to depleted uranium [*18–20*]

Human exposure to depleted uranium can be external or internal. External exposure occurs through proximity to depleted uranium metal or through contact with dust or shrapnel following an explosion or impact. Internal exposure occurs by ingestion of food and water contaminated with depleted uranium, as well as inhalation of depleted uranium that has been deposited in the environment or resuspended in the atmosphere by wind or other disturbances. In the military environment, humans can be exposed to radiation through wounds, if these are caused by the impact of depleted uranium projectiles or armour.

Health hazards of depleted uranium [*1,17–20*]

Depleted uranium and its decay products are extremely dangerous and remain radioactive even inside the human body. During the radioactive decay, tiny electrically charged alpha and beta particles and gamma rays are emitted that travel very fast. Some radioactive materials are alpha emitters and others are beta emitters. An alpha particle is made up of two protons and two neutrons whereas a beta particle is made up of a single electron. The gamma rays are not material particles but a form of pure energy travelling at the speed of light.

Gamma rays penetrate very fast through the soft tissues. Beta particles have

less penetrating power, travelling less than two centimetres in soft tissue. Alpha particles are the weakest, travelling just a few microns in soft tissue (equivalent to a few cell diameters). Thus, outside the body, alpha emitters are the least harmful because alpha particles are hardly able to penetrate the outer layer of the epidermis. Beta particles are able to penetrate the outer layers of the skin and reach the basal layer, giving a localized dose to the skin when contact is high. Gamma emitters are the most dangerous as gamma radiation can penetrate into internal organs, depending on the energy of the gamma radiation. However, although alpha particles cannot penetrate the epidermis, they are extremely hazardous when taken into the body. Alpha particles that are emitted within the body deposit energy more densely than either beta particles or gamma radiation and are consequently more destructive.

Cycle of depleted uranium inside the human body [*10,18,21*]

Internal contamination with depleted uranium occurs through inhalation or ingestion of depleted uranium particles. Once inhaled, very small insoluble particles of uranium oxide (2.5 mm or less in diameter) can reside in the lungs for years, slowly passing through the lung tissue into the blood. As a result of coughing and other involuntary mechanisms by which the body keeps large particles out of the lungs, the larger particles pass through the gastrointestinal tract. Around 0.2% of insoluble depleted uranium and 2.0% of the soluble depleted uranium taken in food and water are absorbed by the gut. Over 95% of the depleted uranium entering the body is not absorbed but is eliminated via the faeces. Of the depleted uranium that is absorbed into the blood, approximately 67% will be filtered by the kidneys and be excreted in the urine within 24 hours, increasing to 90% within a few days. The unexcreted depleted uranium is distributed around the body and stored in bones, kidneys, liver and other tissues.

Health effects of depleted uranium [*17–26*]

The human body has no way of protecting itself from depleted uranium in water, food or air. External exposure to depleted uranium leads to radiological toxicity, while the effects of internal contamination with depleted uranium are complex, caused by both chemical and radiological mechanisms. The detailed mechanism of radiation toxicity is a subject of continuing research. However, it is thought that one of the ways in which the deposited energy may damage cells is by causing changes in deoxyribonucleic acid (DNA), a biologically important molecule that controls all aspects of structure and function and which is mainly found in cell nuclei. Two types of health effects have been demonstrated: deterministic and stochastic.

The deterministic effects depend on the dose of radiation. Massive exposure can lead to death within a few days or weeks. Lower doses cause burns, erythema, loss of hair or other effects on the skin.

The primary stochastic effect associated with radiation exposure is cancer. Radiation causes direct damage to cell DNA. The damaged cells that die, as long as they are not too many, are not a real problem, but the damaged cells that survive may reproduce in an abnormal and uncontrolled fashion, becoming cancer cells. As the cancer spreads, it destroys the healthy tissue and

unless treated it eventually kills the host. Cancers of all kinds can result from internal radiation exposure, depending on the organ affected. In the case of inhalation of insoluble depleted uranium particles, the upper aerodigestive tract and the lungs are the first target organs, in which case tissue damage and an increased probability of cancers is these areas would be expected. The bone is one of the main places where depleted uranium is stored, leading to uncontrolled production of white blood cells to the detriment of other cells, ultimately leading to leukaemia. It takes many years for a cancer caused by contaminated air, food or water to grow, so the effect is not apparent immediately.

Exposure to radiation can also affect the reproductive system, causing infertility or damage to the father's sperm or mother's egg. Genetic damage is possible, leading to spontaneous abortion, premature death or congenital anomalies. Some forms of genetic damage are not seen in the first or second generations but only later after several generations have passed.

Another danger of exposure to low-dose radiation is biological damage in the form of monocyte depletion, leading to iron deficiency anaemia and a depressed cellular immune system. Radiation also deforms red blood cells, inhibiting their passage into the tiny capillaries and depriving the muscles and brain of adequate oxygen and nutrients. This can lead to impairment of many organs especially the kidneys, liver, lungs and cardiovascular and haematopoietic systems.

Radiation can cause disorders of protein and carbohydrate metabolism, leading to symptoms ranging from severe headache to brain dysfunction. Mental retardation owing to brain damage of the fetus has also been described as a result of radiation exposure in the womb during the critical period when the child's brain is being formed.

The chemical toxicity of depleted uranium results from its interaction with the biochemical processes of the human body. Chemically, depleted uranium damages kidney function in humans. The proximal tubules are the main site of potential damage. The types of damage that have been observed are nodular changes to the surface of the kidney, lesions to the tubular epithelium and increased levels of glucose and protein in the urine.

Conclusion

If depleted uranium were indeed used in the Gulf War, it will certainly have constituted an enormous health hazard not only to the US and European veterans deployed in the region during the war but also to the residents of the war countries and surrounding areas. The extent of the region affected has not been determined and the long-term dangers remain unidentified. Many issues concerning this subject need to be resolved through extensive public health action and intense epidemiological research.

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