Journal of Environmental Radioactivity 172 (2017) 207–217

Contents lists available at ScienceDirect

Journal of Environmental Radioactivity

journal homepage: www.elsevier.com/locate/jenvrad

# Meta-analysis of depleted uranium levels in the Balkan region

Larisa Besic [a], Imer Muhovic [a], Adna Asic [a], Amina Kurtovic-Kozaric [a, b, c, *]

[a] Department of Genetics and Bioengineering, International Burch University, Francuske revolucije bb, 71 000 Sarajevo, Bosnia and Herzegovina
[b] Department of Pathology, Cytology and Human Genetics, Clinical Center of the University of Sarajevo, Bolnička 25, 71 000 Sarajevo, Bosnia and Herzegovina
[c] Department of Biology, University of Sarajevo, Zmaja od Bosne 33-35, 71 000 Sarajevo, Bosnia and Herzegovina

A R T I C L E I N F O

*Article history:*
Received 22 August 2016
Received in revised form
22 February 2017
Accepted 10 March 2017

*Keywords:*
Depleted uranium
Toxicity
Radiation damage
Balkan conflicts
Environmental damage
Health effects

A B S T R A C T

In recent years, contradicting data has been published on the connection between the presence of depleted uranium and an increased cancer incidence among military personnel deployed in the Balkans during the 1992–1999 wars. This has led to numerous research articles investigating possible depleted uranium contamination of the afflicted regions of the Balkan Peninsula, namely Bosnia & Herzegovina, Serbia, Kosovo and Montenegro. The aim of this study was to collect data from previously published reports investigating the levels of depleted uranium in the Balkans and to present the data in the form of a meta-analysis. This would provide a clear image of the extent of depleted uranium contamination after the Balkan conflict. In addition, we tested the hypothesis that there is a correlation between the levels of depleted uranium and the assumed depleted uranium-related health effects. Our results suggest that the majority of the examined sites contain natural uranium, while the area of Kosovo appears to be most heavily afflicted by depleted uranium pollution, followed by Bosnia & Herzegovina. Furthermore, the results indicate that it is not possible to make a valid correlation between the health effects and depleted uranium-contaminated areas. We therefore suggest a structured collaborative plan of action where long-term monitoring of the residents of depleted uranium-afflicted areas would be performed. In conclusion, while the possibility of depleted uranium toxicity in post–conflict regions appears to exist, there currently exists no definitive proof of such effects, due to insufficient studies of potentially afflicted populations, in addition to the lack of a common epidemiological approach in the reviewed literature.



## 1. Introduction

In the last 70 years, several radioactivity release events have led to the accumulation of hazardous radionuclides in the environment. The first of such events was the atomic bombing of Hiroshima and Nagasaki in 1945, followed by atmospheric nuclear weapons testing during the 1950s and 1960s, and the 1986 Chernobyl nuclear reaction accident. More recently, several depleted uranium (DU) release events occurred in Iraq and Kuwait in 1991, the Balkan wars during 1995–1999, Afghanistan in 2002, and the Gulf war in Iraq in 2003 (Gustavsson *et al.*, 2004; Jia *et al.*, 2004, 2005; Žunić *et al.*, 2011).

Uranium is a heavy metal from the actinide series that is both chemically toxic and radioactive (Craft *et al.*, 2004; Dewar *et al.*, 2013; Domingo, 2001). This naturally abundant element, found in air, soil, water and rocks (HPS, 2010) possesses a half-life of 4.5 billion years, causing the level of radiation not to decrease significantly over time (UNEP, 2003). Uranium is considered radioactive since it emits $\alpha$-particles and is, in addition, capable of emitting $\beta$-particles and $\gamma$-rays (Dewar *et al.*, 2013; Miller, 2006). Natural uranium consists of three isotopes, $U^{238}$ (99.28%), $U^{235}$ (0.72%) and $U^{234}$ (0.0055%). Enriched uranium, which is necessary for the production of nuclear energy, contains higher amounts of the $U^{235}$ isotope (in the range from 1.5 to 4.6%). While in the past depletion was conducted by reducing the $U^{235}$ isotope from 0.72% to approximately 0.2%, the more economical way to deplete uranium in the recent period is by reducing its content to 0.3%. However, it is important to note that for military purposes, the $U^{235}$ percentage concentration by mass is usually still around 0.2% (Miller, 2006). Depleted uranium is mainly produced as a by-product of uranium enrichment, and this remaining residue is around 40% less

* Corresponding author. Laboratory of Human Genetics, Department of Clinical Pathology, Cytology and Human Genetics, Clinical Center of the University of Sarajevo, Sarajevo, Bosnia and Herzegovina.
*E-mail addresses:* amina.kozaric@kcus.ba, amina.kurtovic@gmail.com (A. Kurtovic-Kozaric).

http://dx.doi.org/10.1016/j.jenvrad.2017.03.013
0265-931X/

radioactive than naturally occurring uranium and contains the abovementioned isotopes in the following ratio: 99.8% $U^{238}$, 0.2% $U^{235}$ and 0.001% $U^{234}$ (Craft *et al.*, 2004; Miller, 2006; HPS, 2010). The activity ratios of the isotopes are lower in depleted uranium, with the $U^{235}/U^{238}$ ratio being 0.013 in DU, compared to 0.046 in natural uranium, and $U^{234}/U^{238}$ being 0.18, compared to a ratio of 0.8–1.2 in naturally occurring uranium (Saleh and Abdel-Halim, 2016).

DU is mainly used for the production of armor-penetrating bullets. It can also be used for civil purposes, for example, for the production of shields for the protection from irradiation in hospitals and containers for the transport of radioactive materials (Islamović and Selimović, 2008).

Despite being less radioactive than natural uranium, DU possesses high toxicity levels because of its high linear-energetic transfer irradiation, tissue deposition, as well as elimination time (Milačić *et al.*, 2004). Cancer types most commonly associated with the exposure to DU are leukemias, lymphomas, kidney and lung cancers (Berradi *et al.*, 2008; Capocaccia *et al.*, 2015). In cases of low-level exposure to DU, there appear to be no disease threats. However, one must take into account that 5–10% of the world population is naturally radio-sensitive, enabling even slightly elevated levels of radioactivity to cause biological effects (Milačić *et al.*, 2004).

### *1.1. Depleted uranium exposure pathways*

Inhalation is the likeliest route of DU intake, and it may occur via resuspension in the atmosphere through wind or dust disturbances, as well as a consequence of fire in a DU storage facility, aircraft crashes, armor-piercing weapons manufacturing processes, as well as decontamination of contaminated objects. Ingestion can occur in a large population if drinking water or food supplies become contaminated with DU. In addition, soil ingestion by children is considered a potentially significant pathway. Dermal contact is not considered a significant exposure type, as no significant DU transfer can occur through the skin, however DU can still enter the bloodstream through open wounds (Littleton, 2006).

When incorporated into the body, the highest concentrations of uranium will occur in the kidneys, liver tissues and skeletal structures. The primary sources of exposure to uranium are food and water, annually accounting to an intake of about 350 pCi. There are approximately 90 μg of uranium in the human body, of which about 66% resides in the skeleton, 16% in the liver, 8% in the kidneys, and 10% in other tissues. The lungs, kidneys and bones receive the highest annual doses of radiation which are estimated at 1.1, 0.93, and 0.64 mrem, respectively. The blood absorption levels are dependent on the exposure pathways, particle size and solubility. The three uranium oxides of primary concern ($UO^2$, $UO^3$, and $U^3O^8$) are relatively insoluble, and thus are believed to have little potential to cause renal toxicity, but are capable of causing pulmonary toxicity via inhalation exposure (Littleton, 2006).

While decaying, DU and its decay products emit alpha, beta and gamma radiation which is capable of resulting in external and internal exposure to those who handle or encounter DU-contaminated material. Based on the zero-threshold linear dose response model, any dose of uranium that is absorbed by the body can be assumed to increase the risk of cancer. Since uranium tends to concentrate in specific locations in the body, the risk of bone, liver and blood cancers may be increased. Inhalation of DU particles that reside in the lungs for longer time periods can damage lung cells and increase the possibility of lung cancer after many years. The air's uranium content is very small and considered insignificant for remedial operations. People who live in the vicinity of facilities that work or have worked on the production or testing of nuclear weapons, uranium ore processing, or uranium enrichment may experience increased exposure to uranium, due to particle release from the facility (Littleton, 2006).

### *1.2. Depleted uranium release events in the Balkan Peninsula*

Approximately 320 tons of DU ammunition have been used in the first Gulf War, while around three tons were discharged on Bosnia & Herzegovina (B&H) in the period between 1994 and 1995, one ton in Serbia and Montenegro, and 11 tons in Kosovo in 1999. The second Gulf war resulted in around 430 tons of DU released in Iraq in 2003 (Ough *et al.*, 2002; Jia *et al.*, 2005).

In 1995, the regions of B&H that were targeted with DU projectiles were Hadzici, Lukavica and Han Pijesak. It is assumed that over 10,800 bullets were discharged at these locations, corresponding to 3.3 tons of DU (Žunić *et al.*, 2011; Nuhanović *et al.*, 2015; Vidić *et al.*, 2013). In 1999, NATO has released 11 tons of DU ammunition during 98 air strikes on a total of 112 locations, the targets being predominantly Kosovo[1] (86 different targets), followed by the south of Serbia, and one location in Montenegro (Milačić *et al.*, 2004; Strand *et al.*, 2014; Di Lella *et al.*, 2003). It has been reported that over 30,000 rounds of DU were used in these military actions (Loppi *et al.*, 2003).

The majority of the DU ammunition penetrates the ground, potentially leading to airborne or groundwater contamination, as well as food contamination (Nuhanović *et al.*, 2015; Loppi *et al.*, 2003). Therefore, the United Nations Environment Programme (UNEP, 2001, 2002, 2003) has examined the areas afflicted by DU, in addition to various research articles expanding this database.

The aim of this study was to collect data from previously published reports investigating the levels of depleted uranium in affected regions of the Balkan Peninsula and to present the data in the form of a meta-analysis that would provide a clear image of the extent of DU contamination after the Balkan conflict. In addition, the authors aimed to test the hypothesis that there is a correlation between the levels of DU and the assumed DU-related health effects with the goal of providing a backbone for future research.

## 2. Methods

In order to perform the meta-analysis, original research papers that were published in peer-reviewed journals were collected through the search of relevant databases. Keywords consisting of country name (Bosnia & Herzegovina, Kosovo, Serbia, Montenegro) and the terms “depleted uranium” and “health effects” were searched through PubMed, ScienceDirect, Academia and ResearchGate.

Data were collected from studies performed in the countries of the Balkan Peninsula that were affected during the Balkan conflict, namely Bosnia and Herzegovina (B&H), Kosovo, Montenegro and Serbia. For the first part of this paper (DU levels in the Balkan Peninsula), studies were selected based on the following parameters: locations and sampling sites at which research was performed were clearly stated and DU levels were clearly defined. According to these criteria, five papers investigating DU levels in B&H were selected (Carvalho and Oliveira, 2010; Jia *et al.*, 2006; Vidić *et al.*, 2013; Žunić *et al.*, 2008, 2011), six for Kosovo (Carvalho and Oliveira, 2010; Danesi *et al.*, 2003a,b; Di Lella *et al.*, 2003; Sansone *et al.*, 2001; Žunić *et al.*, 2008), two for Serbia (Jia *et al.*, 2005; Žunić *et al.*, 2008) and one for Montenegro (Jia *et al.*, 2005). For the second part (DU-related health effects in the Balkan

[1] This designation is without prejudice to positions on status, and is in line with UNSC 1244 and the ICJ Opinion on the Kosovo Declaration of Independence.