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Meta-analysis of depleted uranium levels in the Middle East region

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ABSTRACT

Since the first widespread use of depleted uranium in military in the 1991 Gulf War, the so-called "Gulf War Syndrome" has been a topic of ongoing debate. However, a low number of reliable scientific papers demonstrating the extent of possible contamination as well as its connection to the health status of residents and deployed veterans has been published. The authors of this study have therefore aimed to make a selection of data based on strict inclusion and exclusion criteria. With the goal of clarifying the extent of DU contamination after the Gulf Wars, previously published data regarding the levels of DU in the Middle East region were analyzed and presented in the form of a meta-analysis. In addition, the authors attempted to make a correlation between the DU levels and their possible effects on afflicted populations.

According to results observed by comparing $^{234}U/^{238}U$ and $^{235}U/^{238}U$ isotopic activity ratios, as well as $^{235}U/^{238}U$ mass ratios in air, water, soil and food samples among the countries in the Middle East region, areas indicating contamination with DU were Al Doha, Manageesh and Um Al Kwaty in Kuwait, Al-Salman, Al-Nukhaib and Karbala in Iraq, Beirut in Lebanon and Sinai in Egypt. According to these data, no DU contamination was observed in Algeria, Israel, Afghanistan, Oman, Qatar, Iran, and Yemen.

Due to the limited number of reliable data on the health status of afflicted populations, it was not possible to make a correlation between DU levels and health effects in the Middle East region.

1. Introduction

Uranium is a naturally occurring radionuclide, used in the production of nuclear power (Craft et al., 2004). This heavy metal possesses both chemical and radiological toxicity (Domingo, 2001). Natural uranium represents an isotopic mixture of three radioactive isotopes: ^{238}U (99.27%), ^{235}U (0.72%) and ^{234}U (0.0055%), with half-lives of 5.6×10^9, 7.1×10^8 and 2.5×10^5, respectively (Gombeau et al., 2016). For the production of nuclear power, natural uranium is converted to enriched uranium. During the enrichment process, a by-product called depleted uranium (DU) is produced by the removal of the majority of the ^{235}U isotope from natural uranium. The leftover product, DU, is 40% less radioactive with the following isotopic ratio: ^{238}U (99.8%), ^{235}U (0.2%) and ^{234}U (0.001%; Asic et al., 2017; Hao et al., 2013). DU has specific properties such as low radioactivity, high density and a high penetrating power, which make it suitable for military usage for the generation of powerful projectiles, such as bullets or missile nose cones, as well as protective armor for tanks (Al-Kinani et al., 2005; Craft et al., 2004; Uddin et al., 2015). Despite its reduced radioactivity, DU is a highly toxic heavy metal, and its behavior in the human body corresponds to that of naturally occurring uranium, possibly leading to deleterious effects to human health (Besic et al., 2017; Milačić et al., 2004).

The first widespread use of depleted uranium in military was in the First Gulf War in 1991, whereby military forces discharged 320 tons of DU ammunition in aircraft rounds and tank-fired shells in Kuwait and southern Iraq over an area of around 20,000 km^2. In the period between 1995 and 1999, approximately 14 tons were used during the Balkan conflict in Bosnia and Herzegovina (B&H), Serbia, Montenegro and Kosovo. During the Second Gulf War, around 430 tons of DU were released in Iraq in 2003, while 465 kg of uranium oxides aerosol were released in Doha, Qatar as a result of fire destruction of tanks containing uranium munition (Bem and Bou-Rabee, 2004; Besic et al., 2017; McDiarmid et al., 2004; Danesi and Telleria, 2010). Data

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regarding the amount of DU used in Afghanistan in 2002 is not available (Briner, 2006).

There are three major pathways of DU exposure, namely ingestion, inhalation and external exposure through embedded fragments or wound contamination (Bem and Bou-Rabee, 2004; Papastefanou, 2002). When uranium is inhaled, 75% is exhaled and only 25% remains in the lungs out of which less than 1% eventually makes its way to the kidney where it might affect renal function. In a military environment, 95% of the larger particles are settled in the upper respiratory tract after inhalation and cleared to the pharynx or swallowed and blown out of the nose, while only the smaller particles represent a potential health hazard since they can reach the alveoli from where they can be transported to the lymph tissues. Due to its slow to medium solubility *in vivo*, gastrointestinal absorption of DU is not the main route of uranium exposure. No significant transfer of DU can occur through the skin, however open wounds may enable DU to enter into the bloodstream (Harley et al., 1999). Within the human body, the highest concentration of uranium would be found in the kidneys, liver tissues and skeletal structure. In addition, the lungs, kidneys and bones are hot spots as they receive the highest annual dose of radiation (Littleton, 2006).

The goal of this study was to analyze previously published data regarding the levels of DU in the Middle East region and present it in the form of meta-analysis which would help clarify the extent of DU contamination after the Gulf War. Furthermore, the authors aimed to provide a backbone for future research by hypothesizing the correlation among the levels of DU and the expected DU-related health effects.

2. Methods

2.1. Data collection and information sources

The meta-analysis was performed using original research papers that were published in peer-reviewed journals and were collected through the search of relevant databases. Keywords consisting of country name (Afghanistan, Algeria, Bahrain, Cyprus, Egypt, Iran, Iraq, Israel Kuwait, Jordan Lebanon, Oman, Palestine, Qatar, Saudi Arabia, Syria, Turkey, the United Arab Emirates and Yemen) 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 Middle East region, namely Afghanistan, Algeria, Iraq, Iran, Israel, Kuwait, Lebanon, Oman, Qatar, and Yemen. Data collection was done in duplicate by two independent researchers.

2.2. Data selection

For the analysis of DU levels in the Middle East region, studies were selected based on the following inclusion criteria: 1) locations and sampling sites at which research was performed were clearly stated and 2) DU levels were clearly defined. Exclusion criteria were defined as follows: 1) sampling sites were not clearly defined and 2) DU levels were not measured. According to these criteria, 29 studies were rejected and the following studies were included in the analysis: one study from Afghanistan (Durakovic, 2005), one study from Algeria (Elliot et al., 2014), seven studies from Egypt (Agha et al., 2011; Ebaid et al., 2000; El-Aassy et al., 2015; Higgy, 2000; Ibrahim et al., 2016; Khater et al., 2001; Khattab, 2016), one study from Iran (Yousefi and Najafi, 2013), two in Iraq (Al-Kinani, 2006; Al-Kinani et al., 2005), one from Israel (Rogojin et al., 1997); one from Kuwait (Luckett, 2006), four from Lebanon (Busby and Williams, 2006a, 2006b, 2007; El Samad et al., 2007), one from Oman and Yemen (Fleitmann et al., 2007) and one from Qatar (Al-Saad et al., 2010).

For the analysis of DU-related health effects in the Middle East region, studies were selected based on the following inclusion criteria: 1) subjects tested were human individuals temporarily (military personnel) or permanently (residents) inhabiting the afflicted regions and 2) results of the studies contained defined study groups with clearly defined values. Exclusion criteria were defined as follows: 1) subjects were not human, 2) research results were not presented as values, 3) research methodology was not sound, 4) subject groups were not properly defined. Based on these criteria, 11 papers were excluded from the analysis and seven papers investigating health effects on Gulf War military personnel were used (Hooper et al., 1999; McDiarmid et al, 2000, 2001a, 2001b, 2015, 2017; Squibb et al., 2005), one paper investigating health effects in Iraq was used (Al-Dujaily et al., 2008), and one investigating health effects in Afghanistan (Durakovic, 2005).

Differentiation between detected DU levels from different sampling sites within the same area is also provided in this study. Comparative analysis was done to correlate data from the Middle East countries and the results are presented in graphical form. A comprehensive list containing DU activity data from all sampling sites was collected, and all sites that contained a $^{235}U/^{238}U$ activity ratio lower than 0.026 were marked as DU contaminated, in order to account for the relatively high standard deviations of certain samples. Sites with $^{234}U/^{238}U$ activity ratios below 0.036 were also included as that is an additional indicator of DU presence (UNEP, 2003), as well as sites with $^{235}U/^{238}U$ mass ratios below 0.004 (Saleh and Abdel-Halim, 2016).

2.3. Statistical analysis

Data analysis and graphing were performed using R, and the geographical plotting of the sites was performed using the ggmap and rworldmap package (Team, 2013; Kahle and Wickham, 2013; South, 2011). All non-geographical plots use the base 10 logarithm of the plotted activities in order to account for the relatively wide range of values used in the dataset and improve readability.

3. Results and discussion

3.1. DU levels in the Middle East

The analysis included studies from the following countries: Algeria (n = 1), Egypt (n = 7), Lebanon (n = 4), Israel (n = 1), Iraq (n = 2), Iran (n = 1), Afghanistan (n = 1), Kuwait (n = 1), Qatar (n = 1), Yemen (n = 1), and Oman (n = 1; Fig. 1). The geographical representation of all investigated sites (circles) along with those exhibiting isotopic ratios indicating contamination with DU (squares) is presented in Fig. 2. The highest number of samples have been examined in Kuwait, more specifically in locations Al Abdali (n = 68), Al Wafrah (n = 58), Manageesh (n = 57) and Al Doha (n = 50; Luckett, 2006). The lowest number of samples was analyzed in studies from Afghanistan (n = 8) and Yemen (n = 9).

The prevalence of $^{234}U/^{238}U$ and $^{235}U/^{238}U$ activity ratios, as well as the $^{235}U/^{238}U$ mass isotopic ratio across the Middle East region, regardless of the sample type, is represented in Fig. 3. Analysis included soil, air, water and food samples. In the analyzed studies, the presence of DU contamination was defined as low levels of uranium isotopic activity ratios $^{234}U/^{238}U$ (values below 0.18) and $^{235}U/^{238}U$ (values below 0.013) because the proportion of ^{234}U and ^{235}U isotopes is reduced compared to the ^{238}U isotope during the production of depleted uranium. In addition, DU contamination was defined as mass $^{235}U/^{238}U$ ratio values less than 0.002 (Saleh and Abdel-Halim, 2016). For the purposes of our meta-analysis, DU contamination was defined as $^{234}U/^{238}U$ activity ratio values below 0.36, $^{235}U/^{238}U$ activity ratio values below 0.026, and $^{235}U/^{238}U$ mass ratios below 0.004. The reason for the shifted cut-off values was due to the high standard deviations in the analyzed studies.

The lowest $^{234}U/^{238}U$ isotopic activity ratio (indicating DU contamination) was observed in an underground water sample recovered from Sinai in Egypt ($^{234}U/^{238}U$: 0.03; El-Aassy et al., 2015), compared to the highest value found in a surface soil sample in Al Jahra in Kuwait ($^{234}U/^{238}U$: 11.8; Elliot et al., 2014). The lowest $^{235}U/^{238}U$ isotopic