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Toxic Metals through the Prism of World Warfares

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Abstract- The study of effects from environmental pollution by toxic substances due to warfare is not a new subject, although it remains poorly explored in many criteria. More and more scientific data shows that armed conflicts and military actions significantly contribute to pollution of the environment with toxic substances, and heavy metals in particular. Lately, Ukraine has been facing that problem in acute form.

The aim of the study is to provide an analytical overview of the current state of environmental pollution by toxic metals and organic substances released due to the armed conflicts, exercises and protracted wars in the world and to show the possible risks for the human health and for the environment.

Keywords: *toxic metals, warfare, environment, hazards for humans.*

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Toxic Metals through the Prism of World Warfares

Andrusyshyna I. M.

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The aim of the study is to provide an analytical overview of the current state of environmental pollution by toxic metals and organic substances released due to the armed conflicts, exercises and protracted wars in the world and to show the possible risks for the human health and for the environment.

Significant accumulation of metals was observed in the battle fields, small arms shooting ranges, artillery, mortar and jetranges, as well as grenade launching grounds during exercises. Weaponry residue left in the fields during warfare, combustion products from ballistic missiles and products of destroyed infrastructure (metallurgical combines, oil depots etc.) pose a threat due to their long-term impact on the current and descendant population. Metal emissions linked to military actions can play a significant role in the health hazard of both civillian population and military personnel that live in the area affected by pollution. Military action leads to soil pollution with Pb, Cu and other metals, that include Cd, Sb, Cr, Ni, Zn with their further leaching into groundwater, resulting in the increased risk of human exposure, as a consequence.

More than ever, today Ukraine needs legislative regulations of this impact on the environment and the population of the country, improvement on systems of monitoring and biomonitoring for pollution and assessment of risks for the impact of toxic substances on the environment and humans.

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I. Introduction

Population growth all over the World and huge production of wastes contribute to the aggravation of environmental problems and climate change. Of all human activities, war has the worst impact on the environment: on the one hand, hostilities have a negative impact on human health, and on the other hand, war resources could be better spent for the nature preservation and development of new safety technologies.The last 30 years have been marked by the emergence of local military conflicts, such as the military attacks in Iraq (1990-1991), the Israeli operations in Palestine (2008-2009), the war in Yugoslavia (1991-2001), Afghanistan (1979-1989, 2001-2022), the war in Syria (2012-2021)and Georgia (August 2008). New is the situation that has been taking place in Ukraine in recent years (operation OOS-2014-2022, and the active phase of the war, which begins on February 24, 2022). Evidently, the armed conflict and military activities pollute significantly the atmosphere with toxic substances. Along with emission of organic pollutants including polyaromatic hydrocarbons (PAH), polychlorinated biphenyls (PCB), as well as hexa chlorocyclohexane (HCH), dichlorodiphenyltrichloroe-thane(DDT), and hexachlorobenzene (HCB), military activity is associated with environment contamination by chromium, copper, zinc, lead, and cadmium to name a few (Hopke, 2009, A. Skalny et al, 2012,2021).

During an explosion, all substances undergo complete oxidation, and the products of the chemical reaction are released into the atmosphere. The main ones - carbon dioxide and water vapor - are not toxic, but harmful in the context of climate change, as both are greenhouse gases (Wingfors et al., 2014; Aurell et al., 2019). In the atmosphere, oxides of sulfur and nitrogen can cause acid rain, which changes soil pH and causes burns. Acid rain is known to have a negative impacton the human body and other mammals and birds, affecting the condition of mucous membranes and respiratory organs.

In Ukraine, there were numerous recent cases when ballistic missileshit the tank farms. Explosions leaded to the emission of number of toxic gases and solid particles (IFs) into the atmosphere. Significant soil and watercontamination is also possibleand around these areas. It should be noted that petroleum products have additional side effects. Their hydrocarbons are able to interact with a number of other environmental pollutants, such as pesticides, toxic metals, which together with petroleum products are concentrated in the near-surface layer of soils and water bodies.

Metal fragments of shells produced by military activity also pollute environment. They contain sulfur and copper, and a number of other toxic metals.Metallised incendiary mixtures, which include petroleum products with the addition of magnesium or aluminium shavings, oxidizers, liquid asphalt and heavy oils are used to equip tanks, mechanised and knapsack flamethrowers, aircraft

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bombs, as well as fire explosives of various types, can also be additional sources of pollution.

In addition, it has been shown that metal emissions depend on the type of ammunition. Specifically, firing with NM229 containing a steel core results in significant emission of Cu and Zn, whereas SS109 with soft lead core produces high number of Pb particles (Mariussen et al., 2021).In turn, firing lead-free small-caliber ammunition results in a significant emission of particulate matter consisting predominantly of Cu, Zn, and Fe, as well as soot originating from incomplete combustion (Wingfors et al., 2014).The content of Pb, Cu, Ni and Zn was found to be related to specific substances in air, with size of 1.95 μm, 0.01 μm, 1.22μm, 8.10 μm, respectively (Orru et al., 2018). In addition, the emissions of metals due to the application of firearms are is very different for pistols, rifles and shotguns. Therefore,the analyze of the air composition is needed to detect the content of metal nanoparticles (Charles et al.,2020). There is every reason to believe that much of the particles may easily penetrates the alveolar region of the lungs due to their size distribution. Some of them, which are considered more toxic to humans - are the endocrine disruptors.

In general, according to our information search, the number of toxicologically and hygienically important chemicals and their metabolites to be determined reaches at least a few hundred. Given the duration of hostilities in Ukraine, it would be important to assess the possible pollution effects of modern weapons.

The aim of the study is to provide an analytical overview of the current state of environmental pollution by toxic metals and organic substances released due to the armed conflicts, exercises and protracted wars in the world and to show the possible risks for human health and for the environment.

a) *Weapon residues as sources of metal emission- the impact of weapons remnants and emissions on the environment*

Specifically, significant accumulation of metals has been observed in areas of battle fields, small-arm shooting ranges, artillery, mortar and rocket ranges, and grenade courts (Barker et al., 2021). Military-related metal emissions with their potential subsequent overexposures may therefore play a significant role in health hazards to military personnel (Kalinich and Kasper, 2016).

Environmental monitoring studies demonstrated significant soil contamination resulting from military activities (Broomandi et al., 2020). Specifically, analysis of soils from military shooting ranges demonstrated significant contamination with Pb, Cu, Cd, Sb, Cr, Ni, and Zn (Etim and Onianwa, 2012; Islam et al., 2016). Consistent with these observations, a meta-assessment of soil metal levels revealed a significant increase in soil Pb, Cu, Hg, Sb, Ni, and Cr content in different shooting ranges, whereas elevated soil Pb could be considered as the most significant health hazard (Bai and Zhao, 2020). Moreover, Pb bioavailability from army shooting range soils was found to be 42% thus possessing significant hazards for biota (Islam et al., 2016). In contrast to Pb, soil Cr and Ni levels were found to be slightly affected by shooting activity (Etim and Onianwa, 2012).In another study demonstrated that soil mercury (Hg) content in the area of active gun use was nearly 10-fold higher as compared to the reference soils (Gębka et al., 2016). Similarly, an indoor firing range dust analysis revealed high levels of Pb and Cu, but the increase in Ni, Cd, Cr and Zn content was moderate-to-significant (Clarke et al., 2020). It is also noteworthy that other military facilities are characterized by soil metal pollution along with shooting ranges. In particular, soil Cd and Pb levels were found to be significantly increased at a former military airport, with the highest levels in the proximity of fuel bunkers (Skalny 2021).

Emission of metals into the environment upon military activity occurs from gunshot residues containing high levels of metal-containing particles (Charles et al., 2020), as well as from use of artillery, grenades, and rockets (Barker et al., 2021). An earlier study demonstrated various sources of metals in gunshot residues including primers (lead (Pb), antimony (Sb), barium (Ba)), metal jacket bullets (Cu, Zn), and gun barrels (Fe) (Brazeau and Wong, 1997). In indoor shooting ranges, Pb, Cu, Ni and Zn contents were found to be associated with different fractions of airborne particular matter, namely 1.95 μm, 0.01 μm, 1.22 μm, 8.10 μm, respectively (Orru et al., 2018). In addition, emission of metals with gunshot residues were shown to be quite different for pistols, shotguns, and rifles (Bailey et al., 2009), thus being indicative of the usefulness of gunshot residue analysis in forensic science (Charles et al., 2020).

In war areas people are exposed to it via contaminated air, food and water, due to the modern weaponry and absorption in the soil. The hexavalent chromium can cause various health effects, ranging from rashes, allergic reactions and respiratory problems to immune system impairments, organ damages and cancers (Sharma et al., 2012). Adverse impact of war is not limited to those who experience it directly, but is passed on to future generations through multiple mechanisms. International organizations are obliged to protect parents and infants from the modern weaponry in wars(M.Vänskäa, S.Y. Diabb 2019).

Metal emissions were shown to be dependent on the type of ammunition. Specifically, firing with NM229 containing a steel core results in significant emission of Cu and Zn, whereas SS109 with soft lead core produces high number of Pb particles (Mariussen et al., 2021). In turn, firing lead-free small-caliber ammunition results in a significant emission of particulate matter consisting predominantly of Cu, Zn, and Fe, as well as soot originating from incomplete combustion (Wingfors et al., 2014). Explosives also play a significant role in metal emissions into environment. Particles emitted from artillery backblasts were found to contain high levels of Pb and Cu that may originate from artillery shells, gun barrels, or deposited dust (Gillies et al., 2007). Flash bang grenades were also considered as a significant source of high concentrations of Pb (Weber et al., 2020).Depleted uranium (DU) has been used in widely used in military industry and especially projectile production. Correspondingly, DU-containing penetrators were shown to release DU particles during abrasion, combustion, and corrosion was reported in the review(Skalnyet al., 2021)

Thus, one can speak not only about the complex pollution of air, soil and water, but also, what is important, about the exposure of metals in the form of nanoparticles. As you know, nanoparticles penetrate into the lungs with inhaled air faster and better penetrate into the blood, that is, even small doses can act as strong toxicants.

b) Metal exposure in humans involved in military activity

Embedded fragments resulting from shrapnel wounds possess a significantsource of metal exposure in military personnel and retiredveterans, although the particular patterns of metal accumulation arestrongly dependent on metal contents of the ammunition. A detailedanalysis of the embedded components in injured military personneldemonstrated that the most common metal constituents were Fe, Cu,and Al, whereas Pb, Sb, Ti, and U were detected at trace levels (Centeno et al., 2014).

Exposure to other metals originating from military activity was alsoshown to result in a broad spectrum of adverse health effects. Specifically,it has been demonstrated that metal constituents of PM2.5 namelyNi and vanadium (V) are considered as survival predictors in a cohort ofU.S. military veterans (Lipfert et al., 2006). Military personnel with retained fragments after battlefield injury are also characterized byimpaired immune function characterized by increased lymphocytestimulation index, elevated IgE levels in parallel with a decrease in IgA,IgG, IgM levels (Samelko et al., 2020). Metal exposure may also underlie increased risk of amyotrophic lateral sclerosis (McKay et al., 2021) andototoxicity (Hammill et al., 2019) in military personnel. Finally, it is hypothesized that toxic metal accumulation may induce antimicrobial resistance in *Acinetobacter baumannii*(Bazzi et al., 2020)Legionnaires' disease, which is associated not only with bacterial exposure, but also with increased levels of Co in the body (Gold, 2007).

In 2003, the Norwegian armed forces changed their primary assault rifle to the HK416 (Heckler & Koch, Germany). Shortly after the new weapon was put into service, flu like symptoms after training sessions at firing ranges were reported. It became evident that the symptoms were due to exposure to gunshot fumes. The symptoms were similar to what previously have been observed among welders. The symptoms were attributed to the newly introduced ammunition with a steel core instead of a lead (Pb) core, and further use of this ammunition type was temporarily prohibited (Mariussen, 2021).

The rationale for replacing the traditional lead core bullets with the steel core bullets by the Norwegian armed forces in 2003, was to reduce both the environmental load of Pb contamination and the shooters exposure to Pb. Several studies have shown that exposure to Pb during training increases the level of Pb in the blood. In addition to exposure from training at firing ranges, there are also raised concerns about long-term effects of Pb exposure from consumption of game (Mariussen et al.,2021).

In a study by Voie et al. (2014), volunteers were exposed to gunshot fumes from the two ammunition types with steel core, NM229 and NM255, in addition to the leaded SS109 in order to compare health effects induced by gunshot firing. The main findings showed that all three ammunition types induced temporarily, but prominent health effects such as fever, coughing, increased C-reactive protein (CRP) in blood and reduced lung function, similar to the symptoms from metal fever. In addition, carbon monoxide (CO) in the fumes led to increased levels of carboxy hemoglobin in the blood of the exposed shooters. CO-poisoning may lead to headaches and seriously decrease judgment and performance (Mariussen, et al., 2021).

Along with military personnel, trainees, shooting range shooters, as well as civilian subjects living on the living in territories of armed conflicts or near military training grounds could be considered at high risk of military-related metal exposure.(Skalny et al.,2021).

c) Possible negative consequences and risks for public health

Exposure to toxic metals have been shown to cause adverse health effects associated with cardiovascular, metabolic, neurological and kidney disease, as well as cancer (Skalny et al., 2021).

A number of studies demonstrated the potential contribution of metal overload to adverse health effects in children living on the territories affected by military activity. In particular, military attacks were found to be associated with in utero metal exposure with the most prominent increase in As, Ba, and molybdenum (Mo), that could be potentially linked to underweight and stunting in children (Baraquoni et al., 2020). Moreover, a recent study demonstrated increased exposure of women to weapon-related heavy metals including Ba, As, Co, Cd, Cr, V and U in Gaza District (Palestine) that is associated with the number of preterm births and higher prevalence of birth defects (Manduca et al., 2020).

Military attacks are a source of heavy metal exposure among people living in war zones, as various heavy metals are used in new generation weapons. As an example, the waste of nuclear industry is re-used in depleted uranium weapons, which poses both radiological and chemical toxicity in humans (Hon, Österreicher, & Navrátil, 2015; Ifesinachi, 2014). In addition, weapons can be "enhanced" by the utilization of heavy metals as augmenters or as primary effective agents, and some new weapons are able to produce a 'molecular sieve' of toxic metal powder that can severely affect the human body. Analyses of wound tissues of war injuries provide evidence of civilian contamination to metals with toxicant, teratogen and carcinogen effects on human body (Skaik et al., 2010). Importantly, in addition to the risks posed by acute exposure, the persistence of heavy metals in post war environments can cause prolonged exposure, leading to accumulation of metals in compartments of the body (M. Vänskäa, S.Y. Diabb 2019).

Women and children are highly vulnerable during periods of war and military attacks, as well as in the aftermath of war, because of the possibility of the longterm effects of war related environmental changes on reproductive and infant health. Accumulation in human bodies of toxicants and heavy metal teratogens found in the remnants of war occurs, that, coupled with their long persistence in the environment, suggests a considerable risk for health. The effects of toxicants, teratogens and carcinogens related to heavy metals have been found in embryos at concentrations lower than in adults. During the first trimester of pregnancy, major morphogenetic events occur, and is the period of highest sensitivity of the embryo to external effectors. Apart from the mutational risks posed by some of the heavy metals, there is compelling evidence of their prevalent epigenetic mechanisms of action.(Ivanicoli et al 2009). Heavy metals act as endocrine disruptors, and their interference with gene expression causes disturbances in various metabolic and hormonal pathways (Manduca et al.,2017).

The prevalence of birth defects increased in areas heavilyexposed to military attacks in Iraq, and in Gaza afterthe Israeli military operation of Cast Lead in 2008–2009and since the implementation of air delivered weaponsin attacks. Previous research in Gaza also showed thatwomen's exposure to military attacks (courtesy of thedatabase of the United Nations' mine action team)correlated with a higher incidence of progeny with birth defects(Alaani S,2012; Abed Y,2014).We found a positive correlation between a high load of toxicants (Ba,Al, V, Sr and Cr), a teratogen (W) and a carcinogen (As)in women's hair and their proximity to military attacks in 2014. We also found that there was a higher load in the entire cross sectional convenience sample of Gaza women in comparison with the hair samples from individuals in areas unaffected by war (RHS), regardless of their recent exposure to attacks. The high load was for heavy metalsal ready detected as war remnants from previous attacks in2009 (toxicants such as Al, Fe, Ba, Mn, Cr, Ni, Pb, Sr and V; teratogens such as U and W; and carcinogens such as As, Cd and Co).(Manduca et al., 2017)

The heavy metal load in newborns was higher than that of normal newborn babies for teratogens (mercury and selenium) in babies with birth defects and for toxicants (barium and tin) in premature babies. Together, the data show an association of the damage to newborn health with maternal exposure to attacks, and the trans-placental passage of wartime heavy metal remnants from exposed mothers to their progeny in utero (Naim A,2012; 2013).

The participants were 502 palestinian mothers, pregnant in their first trimester during the 2014 War on Gaza. The mothers were recruited at their delivery (T1) and followed at the infants' age of 6–7 months (T2; N=392). The load of five weapon-related heavy metals (chromium, mercury, vanadium, strontium, and uranium) was analysed by Inductively Coupled Plasma Mass Spectrometry (ICP/MS) from mothers' hair samples at childbirth. In the whole sample and ineach subgroup, the load of toxicants (Al, Fe, Ba, Mn, Ni, Pb, Sr and V), teratogens (Hg, U and W), carcinogens (As,Cd and Co), and of Mg and Zn was significantly higher in the hair of women in all groups of the Gazacross sectional convenience sample than in the reference group. The load of Cs, Cu, Mo, SE, Sn and Ti did not significantly differ from what was found in the reference group.

Besides the identification of a high load of heavy metals, which we specifically traced to exposure to the military attacks in 2014, we found that all the participants had levels significantly higher than controls from outside are as affected by war (RHS) of other war remnant heavy metals, such as U, Hg, Cd, Co, Fe, Ni, Pb, V, Mn, Cd andCo. Previous reports had shown their delivery in Gaza by weaponry; teratogens Hg and Cd and toxicants Pb andFe were delivered by weapons in the 2008–2009 war.Ahigh load of Hg was reported in newborns of mothers exposed at that time to bombing and to attacks with white phosphorus ammunitions (Alaani S, 2011; Abed, 2014; Naim A, 2013, 2012) High loads of Al, Fe, Cd, Hg and U were detected in the hair of children tested 1 year after the 2008–2009 attacks (Manduca et al. 2017).

d) Toxicity of weapon emissions in model studies

The gunshot fumes consist of complicated mixtures of PM, gases, and aerosols of different chemical origin. The PM contains metals orginating from the bullet and the primer, such as Zn, Cu, Pb and iron (Fe). There will be formed combustion products from the gunpowder, such as soot and trace amounts of poly

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aromatic hydrocarbons (PAHs), in addition to gases such as CO, CO_2, H_2O, CO, HCN, NH_3, NOx, SO_2 and HCl (Wingfors et al., 2014; Aurell et al., 2019). It has been shown that more than 90% of the total amount of particles produced have diameters less than 30 nm (Wingfors et al., 2014; Aurell et al., 2019). A major concern is if repeated exposure to gunshot fumes may lead to harmful effects in the long term. These effects may include chronic pulmonary effects and even cancer, which may be induced by DNA-toxic substances such as PAHs. A study by Palmer et al. (1994) showed that emissions from the M16 rifle were mutagenic in the Salmonella/Ames test. The effect was associated with the nanosized particles. (Mariussen et al., 2021).

The cytotoxic effect of the smoke was tested to compare the general toxicity of the different ammunition types (from thethree ammunitions, NM255, NM229 and SS109). The generated gunshot fumes were subjected to physical and chemical characterization with respect to particle mass- and number-size distribution. Collected PM were analysed for Cu, Zn and Pb. In addition, the gasses CO2, CO, NH3, HCN and NOx. were measured by Fourier transform infrared spectroscopy (FTIR) (Mariussen et al., ,2021). Genotoxicity was elucidated by the comet assay, which is a widely used method to detect DNA breaks *in vitro* as well as *in vivo* (Collins et al., 2008). A modified version of the comet assay using the lesion-specific enzyme form amidopyrimidine DNA glycosylase (Fpg) was used to detect oxidized purines, which is an indicator of oxidative stress induced DNA lesions (Collins et al., 1996).

In conclusion, the emitted fumes from gunshots consist of complicatedmixtures of PM and gases, which can be harmful to exposedpersonnel. Most of the generated PM has, on a number basis, a sizedistribution of less than 100 nm. The smallest particles will rapidlyagglomerate into larger particles, but even several minutes after thefiring, there is reason to believe that a substantial portion of the particleshave a size distribution that will easily penetrate into the alveolar regionof the lungs. The use of the ALI approach is a promising tool to addressmore realistically potentially toxic effects on the lungs (Upadhyay and Palmberg, 2018). This experiment indicates that the gunshot fumes arecytotoxic to lung cells, and at high concentrations may induce genotoxity.The effects on the lung cells were related to the generated particlesfrom. As an additive to metals and gases, which are less likely to occur in this experiment, fire fumes can also be controlled by soot and trace PAHs (Wingfors et al., 2014; Aurell et al., 2019), which can contribute to toxicity (Mariussen et al., 2021).

War in the Balkans has prompted the investigation and use of other materials including heavymetal tungsten alloys (HMTAs) as nontoxic alternatives. Interest in the health effects of HMTAs has peakedsince the recent discovery that rats intramuscularly implanted with pellets containing 91.1% tungsten/6%nickel/2.9% cobalt rapidly developed aggressive metastatic tumors at the implantation site. Discovery of the superior mechanical properties obtained from the W–Ni–Co and W–Ni–Fe alloy systems has led to their recent use and development for fragmentation warheads and kinetic energy penetrators for defeating heavy armor (Gold et al., 2007; van der Voet et al., 2007).The in vivo carcinogenic potential of HMTAs containing W, Ni, and Co is supported by in vitro studies which demonstrated that exposure to military-relevant mixtures of W, Ni, and Co (WNiCo) induced malignant transformation, generation of reactive oxygen species (ROS), oxidative DNA damage, and expression of several stress genes in various cultured cell types, suggesting a synergistic effect that exceeded the effects of the metals individually (Harris et al., 2011; Miller et al., 2002, 2004). Although military-relevant mixtures of W, Ni, and Fe (WNiFe) also induced genotoxic effects and induced cell transformation in vitro (Miller et al., 2001), other studies found that WNiFe was less toxic than WNiCo and did not induce tumors in rats (Harris et al., 2011;Kalinich et al., 2005).

In another study shows (Roedel et al, 2012) that the intratrachealinstillation of WNiCo and WNiFe causes lung's rat injury by inducing pulmonary inflammation and the generation of toxic oxygen radicals. We propose that the rapid intracellular ROS/RNS formation inducedby WNiCo, and to a lesser extent,WNiFe,may also lead to a gradual depletionof energy stores and subsequent diminished oxidative burst response and phagocytosis capability of lung macrophages, there by compromising their defensive role. The *in vivo* carcinogenic potential of HMTAs containing W, Ni, and Co is supported by in vitro studies which demonstrated that exposure to military-relevant mixtures of W, Ni, and Co (WNiCo) induced malignant transformation, generation of reactive oxygen species (ROS), oxidative DNA damage, and expression of several stress genes in various cultured cell types, suggesting a synergistic effect that exceeded the effects of the metals individually (Harris et al., 2011; Miller et al., 2002, 2004). Although military-relevant mixtures of W, Ni, and Fe (WNiFe) also induced genotoxic effects and induced cell transformation in vitro (Miller et al., 2001), other studies found that WNiFe was less toxic than WNiCo and did not induce tumors in rats (Harris et al., 2011; Kalinich et al., 2005; Roedel, 2019).

By the way in the same study(Roedel,2019) were used military-relevant metal powder mixtures consisting of 92% tungsten/5% nickel/3% cobalt (WNiCo) and92% tungsten/5% nickel/3% iron (WNiFe), pure metals, or vehicle (saline) were instilled intratracheally in rats.Pulmonary toxicity was assessed by cytologic analysis, lactate dehydrogenase activity, albumin content, andinflammatory cytokine levels in bronchoalveolar lavage fluid 24 h after instillation. The expression of 84stress and toxicity-related genes was profiled in lung tissue and bronchoalveolar lavage cells using realtimequantitative PCR arrays, and in vitro assays were performed to measure the oxidative burst responseand phagocytosis by lung macrophages. Results from this study determined that exposure to WNiCo andWNiFe induces pulmonary inflammation and altered expression of genes associated with oxidative andmetabolic stress and toxicity (Roedel et al, 2012). Inhalation exposure to both HMTAs likely causes lung injury by inducingmacrophage activation, neutrophilia, and the generation of toxic oxygen radicals macrophage activation, neutrophilia, and the generation of toxic oxygen radicalscompromising their defensive role.

Result of this study determined that the intratrachealinstillation of WNiCo and WNiFe causes lung injury by inducingpulmonary inflammation and the generation of toxic oxygen radicals (Roedel et al, 2012).We propose that the rapid intracellular ROS/RNS formation inducedby WNiCo, and to a lesser extent, WNiFe, may also lead to a gradual depletionof energy stores and subsequent diminished oxidative burst responseand phagocytosis capability of lung macrophages, thereby.The obtained results emphasize thatinvestigation of additional metal combinations used in HMTA development is warranted.

However, there is a large difference between the concentrations required to achieve an in vitro effect compared to real-life exposure, which is a problem in risk assessment (Ryu et al 2007, Lipfert F. W. (2017). Developing an acceptable in vitro methodology that can more accurately mimic chronic exposure, for example through more sensitive endpoints, will reduce this gap in the future.

II. Conclutions

Measures developed for the prevention of overexposure ~~of~~ to military-related metals should include legislative regulation concerning impact of military activities on the environment, rehabilitation of metal-contaminated surroundings, improvement of the pollution monitoring and biomonitoring, assessment of the risks on human health related to the exposure to toxic elements.

In particular, the toxic effects depend on a variety of factors, including armortype, chemical constituents of the ammunition, routes of exposure, environment characteristics, to name a few. Moreover, combined metalexposure that occurs due to the use of alloys may potentiate metal induced toxicity. Interactive effects of toxic metal and persistent organic pollutant exposure should be also taken into account.

It is hypothesized that due to the accumulation of metals in the organism, the increased metal body burden may mediate latent and persistent health effects, some of which may not be unmasked for decades after exposure. However, estimation of the particular contribution of metal toxicity may be limited due to a variety of hazardous factors persisting during military activities and especially armed conflicts.

Therefore, monitoring programs are needed for further epidemiological, biomonitoring and laboratory studies to identify the impact of military metals (including their nanoforms) and to establish the main mechanisms of their adverse toxic effects.

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