Some Aspects of Environmental Interactions Related to UXO

Volodymyr Kuznyetsov

Abstract This chapter gives an overview of the current developments in the field of Unexploded Ordnance (UXO) management, detection and mitigation both in Ukraine and other countries. UXO and land mines are among the most terrifying legacies of war. The problem of their clean-up remains insoluble. The main focus of this chapter is a discussion of issues dealing with environmental impacts of UXO detection and disposal and the costs of environmental rehabilitation of UXO-affected sites. Also touched upon is the issue of depleted uranium (DU) contained in modern ordnance (like bombs). We also examine how environmental conditions influence the efficiency of UXO and mine detection. This influence very often hinders UXO detection and search operations, which results in considerable economic and social losses. We show that improvement of UXO detection efficiency and the appropriate mitigation of hazards posed by UXO yields huge economic benefits to society by avoiding unnecessary loss of life, property and natural resources. Analysis of available information shows that the impact of UXO on natural resources is wide-scale, poorly controlled, often neglected and in practice very difficult to control and avoid. Political, regulatory and budgetary concerns force development of better UXO detection and destruction technologies, to better protect human life, property and the natural environment. The technologies currently available to detect and/or discriminate buried UXO from natural or other man-made objects generally do not meet practical requirements, especially in large areas or difficult terrain. Also, unfortunately, there is no "magic bullet" in the foreseeable future that will solve the UXO detection, site characterization and remediation problem. Therefore, a multi-tiered approach to improve the current state of UXO detection and mitigation technology is required.

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1 Introduction

UXO and land mines are among the most terrifying legacies of war. When the battles have ended they remain active, causing a threat to innocent civilians that once again visit these grounds. Estimates on the number of UXO and land mines scattered around the world vary up to 100 million. Irrespective of this number, on the worldwide scale about $10,000$ people are killed and aboubt $30,000$ are injured each year in mine and UXO related accidents. Even assuming no further planting, the worldwide cost of landmine clearance and (UXO) removal using current technologies is estimated by the UN at approximately 30 billion dollars and hundreds of years of work. At the same time, large portions of agricultural land become abandoned, causing economic difficulties and loss of food stocks which tend to become global issues. Unfortunately, UXO spreading and landmine installation still surpassed UXO and landmine removal by a $30:1$ ratio in the mid-1990s [19].

2 Situation in Ukraine

Currently in the Ukraine there are about 2.5 million tons of explosive ordnance stored, of which nearly 1.5 million tons are ready to be disposed of. They are stored at 184 storage facilities, which are poorly managed, staffed and financed. Storage capacity is often exceeded by more than 50%. Ukraine remains affected by mines and unexploded ordnance (UXO) from World War II. Up to 10% of the bombs that fell on this country during WWII failed to function. Only a fraction have so far been found and disposed of [10].

In addition, many ammunition depots are overstocked and are located in immediate proximity to densely populated areas. On 6 May 2004 a munitions depot caught fire at Novobohdanovka in the Zaporizhya region, causing $92,000$ tons of munitions to explode. The explosions sprayed debris and shells up to $10-40$ kilometers away from the depot, destroying more than 300 homes and buildings in six villages within 40 kilometers of the explosion site. About $7,000$ people were evacuated to safer places from 11 nearby villages [10].

There is no formal UXO and mine action program in Ukraine. Clearance of World War II mines and ordnance is carried out by demining specialists from the Ministry of Defense, Ministry of Emergency Situations and the Bomb Disposal Service of the Ministry of Internal Affairs, on request from the population or on demand from developers at the areas where there is a fear of UXO or mines. After the May 2004 Novobohdanovka explosion, the Ministry of Defense explosive ordnance disposal (EOD) operations cleared more than $220,000$ UXO from the area. Following the May 2005 explosion in Cvetoha, the Ministry of Defense cleared 38,000 UXO by July 2005.

2.1 UXO/Landmine Casualties in Ukraine

In 2001 and 2002 21 people in the Ukraine were killed by exploded UXO. In 2004, UMACC recorded 20 new UXO casualties: 13 people were killed and seven injured. This represents a significant increase from the four new mine and UXO casualties reported in 2003; two people were killed and two injured. Casualties continued to be reported in 2005 with three people killed and 11 injured in UXO incidents to 27 May, including nine military personnel injured in an explosion at ammunition depots in Cvetoha, Khmelnitskiy oblast on 6 May. The total number of mine casualties in Ukraine is not known, although estimates range as high as 80,000 mine survivors among 300,000 disabled war veterans. Between 2000 and 2003, Landmine Monitor recorded 59 mine/UXO casualties: 25 people killed and 34 injured. The majority of casualties appear to be due to UXO [12].

2.2 UXO Detection and Disposal in Ukraine

During the period 1992 – 2003 Ukrainian deminers found more than 386 thousand UXO and mines (mainly from World War II) while clearing 270,000 ha. In 2002 1,270 accidents were reported and 17,000 mines and UXO were deactivated. For the purpose of UXO and mine detection and demolishing activities Ukraine is divided into 497 demining districts, of which 442 are managed by Ministry of Defense and 55 by the Ministry of Emergencies. By law, on-site disposal of mines and UXO is generally prohibited. An interesting development of the post-perestroika years was an attempt by criminal elements in the country to use UXO for criminal purposes. In 2001 the police registered 57 such cases leading to the death of 14 people, according to official statistics. The actual, unreported number might be considerably higher [13].

3 Sites with Particular Risk for UXO

UXO is often found in land previously used by the military for training (wartime requisition), ranges and sea dumping, including:

- land previously used by manufacturing facilities,
- areas of recent international and ethnic conflicts (e.g., Afghanistan, Iraq, Kosovo),
- areas that were subjected to WWI and WWII bombing activity.

A major problem with unexploded ordnance is that over the years the detonator and main charge deteriorate, frequently making them more sensitive to disturbance, and therefore more dangerous to handle.

A current UXO problem results from military training at firing ranges. Ukraine was lucky not to have any significant armed conflicts in recent decades. Internationally, the efficiency of UXO production has increased. For example, NATO air-strike missions dropped over 15,000 bombs and rockets on Yugoslavia. More than 2,000 cluster bombs were also dropped, resulting in the spreading of 380,000 bombs. Considering that the minimum dud rate is about 5% these bombing raids generated at least 20,000 UXO [16]. Modern armies pride themselves on the low dud rates of its munitions. However, all explosive ordnance has the potential to become UXO. The actual hazard area produced by UXO depends on the type and density. Again, as an example, a fire mission of 36 Multiple Launch Rocket System rockets could produce 1,159 UXO hazards in the target area and a B-52 bomber dropping a full load of 45 cluster bomb units (CBUs) 1,462 UXO hazards, both assuming a 5% dud rate.

4 Detection of UXO

Once an armed conflict has been resolved, the daunting task of reclaiming the land used as battlegrounds begins. The recognition of a UXO hazard is the initial and most important step. The problem in this task is that most of these battlegrounds are littered with unexploded ordinance, booby traps, improvised explosive devises and, more importantly, land mines. Prevailing current methods for detecting these battle spoils involve prodding the ground with long metal rods or scanning the field on foot with the help of metal detectors [7]. Due to the overwhelming quantity of land to be cleared, the speed at which they function and the risk deminers take in order to implement them, current UXO searching and demining techniques are far from satisfactory. Detection of UXO is not only a technical, logistic and research problem. Wide area detection of UXO is difficult to achieve. Most techniques for UXO detection depend on the slow and laborious probing of small areas, which is time-consuming and expensive. Current technologies have only limited ability to identify the material that is contained within the munitions, for example, inert fill, conventional explosives, chemical warfare materiel, smoke, etc. As a result, all munitions detected by geophysical methods must be considered to be “live” until proven otherwise, even though many are eventually determined to be inert [4].

4.1 Political Aspects of the UXO Detection Problem

The detection problem can be made easier to solve by the adoption of, and strict adherence to and enforcement of institutional, legal and organizational measures. In this respect, the recently adopted Protocol on Explosive Remnants of War (Geneva, 28.XI.2003) provides such a tool. Under this Protocol envisaged are measures to be taken by the states in relation to recording, storage and release of information for UXO and Abandoned Explosive Ordnance (AXO). They envisage recording of information regarding any explosive ordnance which may have become UXO, including data on the general location of known and probable UXO; types and approximate number of explosive ordnance used in the targeted areas; method of identifying the explosive ordnance including color, size and shape and other relevant markings; method for safe disposal of the explosive ordnance. However, much of the UXO problems are caused by non-governmental military organizations, for which international agreements have small impact. These groups are less organized and the lack of discipline makes it almost impossible, even after a peaceful agreement has been closed, to obtain reliable maps and information on where the explosive ordnance stocks have been buried. Locating buried UXO and land mines is a significant challenge to science and technology. Technology development efforts are under way to use chemical sensors that can discriminate inert ordnance and clutter from live munitions that continue to be a threat [15].

4.2 Some New Detection Techniques and Approaches

Modern techniques can combine geophysical and survey methods with modern electromagnetic and magnetic detectors. This provides digital mapping of UXO contamination with the aim to better target subsequent excavations, reducing the cost of digging on every metallic contact and speeding the clearance process. Magnetometer probes can detect UXO and provide geotechnical data before drilling or piling is carried out. Research is ongoing into not only the detection, but also discrimination of UXO from scrap metal. Much of the cost of UXO removal comes from removing non-explosive items that the metal-detectors identified, so improved discrimination is critical. New techniques such as shape reconstruction from magnetic data and better denoising techniques (to name two) will prove invaluable to reducing cleanup costs and enhancing recovery. In addition to traditional, standard methods, various "unconventional approaches" are being tested. In Africa (Sudan) rats (Cricetomys gambianu) are being trained to detect mines as they have an even more sensitive nose than dogs. A trained rat can sniff mines at the rate of $100m^2$ per hour [18]. The same applies to foraging bees, which are being tested in the US. Also pigs are considered to be better "sniffers" than dogs and are considered for mine detection. Tests are also conducted with genetically engineered bacteria or even cress. Besides these "natural approaches", intensive research is being carried out in the field of multi-technology systems. These techniques include - among others - laser, infrared, satellite, and remote robot systems. However, all of these unconventional approaches are in the testing stage and none of these methods will be available shortly. Future success of these techniques is uncertain.

4.3 Factors Impeding Detection Efficiency

Technology development efforts are under way to use chemical sensors that can discriminate inert ordnance and clutter from live munitions that continue to be a threat. However, the efficiency of UXO and mine detection is affected by multiple environmental phenomena that can enhance or reduce ability to detect UXO by, for example, affecting distribution of the chemical signature of a UXO explosive substance in the environment. Understanding of the environmental conditions that affect detection efficiency is needed to describe the favorable and unfavorable conditions for UXO detection efforts in order to minimize the consequences of obtaining a false negative. Among the environmental and natural conditions reducing the efficiency of UXO detection may are:

- Metal debris which makes distinguishing live UXO very difficult. Trying to increase UXO detection efficiency by increasing the sensitivity of mine detectors to metal only aggravates this situation.
- The covering of UXO by shifting sand and sediments, especially in river valleys.
- Rain events and dew.
- Fallen tree leaves or branches.
- Seasonal freeze-thaw cycles can cause buried UXO to migrate to the surface. UXO may also be covered by vegetation, snow, or other matter which also lowers the speed and efficiency of detection [1].
- Adverse weather conditions such as strong winds and rain impede the capability of mine-sniffing dogs to detect the smell of explosive substances.
- Sensors for landmine detection are often affected by soil water content, temperature, electrical conductivity, and/or dielectric constant. The most important of these is water content at the UXO site. Soil water content regimes around UXO sites are strongly affected by the interaction between climate, soil type, and landmine geometry. The occasional short-term accumulation or loss of soil water around UXO depends greatly on weather conditions and soil types.

The ability to recognize UXO is the most important step in reducing risks. Munitions come in all shapes, sizes, and colors. They are color-coded during manufacture to make them easy to identify; however, reliance on color alone for identification is unwise. Exposure to the weather can alter or remove these markings. Instead, physical features to identify UXO outside its normal environment should be used. Long-term exxposure of UXO to an adverse environment (rain, snow, wind and sun action) causes its rusting and physical disintegration, which affects the safety of its individual components. All bombs and sub-munitions have magnetic/seismic or anti-disturbance fusing. Small arms and ammunition are inherently dangerous. Mishandled or mismanaged, they represent grave danger, especially if they are located in overgrown vegetation or poorly accessible sites such as ravines, ditches or ruins. There are dangers in dealing with ammunition and explosives which became unstable due to the adverse impact of natural factors mentioned above and which result in leaking explosive content, degradation of fuse safety systems or in the degradation of propellant stabilizer leading to autocatalytic ignition and spontaneous combustion.

5 Impacts of UXO

There are numerous negative consequences of UXO upon population, infrastructure, natural resources and environment. Some of the most relevant and important are discussed below.

5.1 Socio-economic Impacts

The socio-economic costs of UXO and especially landmines can be divided into three broad categories:

- loss of life, health, human production potential, and human welfare resulting from mine accidents;
- denial of access to mine-infested land and loss of associated production or consumption benefits from the land concerned; and
- distortion of behavior due to the existence of mines with consequent socio-economic losses resulting from longer travel distances, journeys not undertaken due to greater distance and difficulty, and other distortions in behavior.

UXO poses a significant hazard to civilians and the infrastructure within the area of operations. Because most civilians are not familiar with military ordnance, they are largely unaware of the extreme hazard that UXO presents. Due to this unfamiliarity, civilians, often curious children, will pick up and handle UXO items with devastating effects. Civilians have also been killed or injured by buried UXO while performing routine tasks, such as walking or digging. The SEIS (Socio-Economic Impact Study of Landmines and Mine Action Operations in Afghanistan) estimated that the total number of landmine victims amounted to $90,000-104,000$ by the end of 1997. In Afghanistan it appears that the vast majority (96%) of civilian mine and UXO casualties are male. Men may be more exposed than women to mines in their daily activities. It might also be the case that female casualties are significantly underreported, and that women are less likely than men to present themselves for treatment at hospitals [2]. The death rate among the reported casualties is about 30%, and a further 40% have to undergo amputation. In an effort to reclaim homes and reestablish lives during post-conflict operations, local civilians often collect and return hazardous UXO items to the military for further disposal, often with great risk to their life. Unfortunately, UXOs will continue to be a deadly hazard to unwary indigenous personnel after cessation of military operations. The effects of UXO on the civil population and infrastructure can create significant, and often very undesirable, diplomatic, economic, and information impacts [17].

5.2 Impact on Military Operations

UXO pose a threat to mobility, personnel, equipment, and facilities. UXO concerns all ground, air, and maritime forces because all forces operating in areas with UXO hazards are at risk. UXO affects operational and tactical planning and execution of operations. The presence of UXO in operational areas can add considerable time to any operation. The presence of UXO on military bases and military training lands, as well as former and active combat zones, has significant impact on military readiness. The inability to effectively, safely, and cost-effectively identify, characterize, and remediate UXO in both peacetime and combat situations also has a potential adverse impact on health and safety of military and nonmilitary personnel.

5.3 UXO Impacts on Environment

The impact of military operations in general and resulting UXO on natural resources is wide-scale, poorly controlled, often neglected and in practice very difficult to control and avoid. War poses unavoidable danger to natural resources and the environment. Among environmental impacts directly related to UXO are:

- UXO poses an imminent and substantial environmental risk and could require the largest environmental cleanup at a huge cost (up to $ 14 billion for the USA alone). In addition to the obvious danger of explosion, buried UXO also entails the risk of environmental contamination through, for example, leakage of explosive substances into aquifers or their evaporation into the air [6].
- In some heavily-used military training areas, munitions-related chemicals such as explosives and perchlorate (a component of pyrotechnics and rocket fuel) can enter soil and groundwater. A prominent example could be ranges for artillery training which often contaminate water sources used for drinking water supply. The threat from UXO ground, water and air contamination is a huge problem for all affected areas and countries but is poorly studied [6].
- Search for UXO and mines very often is accompanied by burning vegetation cover of the area of possible UXO location which causes damage to vegetation and plant community and habitat. Kerosene is often used, with the addition of solidifying agents of the $M1$ and $M2$ type (forming a kind of napalm), which leads to ground contamination and leakage of polluting substances to aquifers. This procedure was incorporated into SOP (Standard Operative Procedure), at least as applied in Bosnia, because of its cheapness and great facilitation of mine detection.
- There is often a need to remove plant cover before starting UXO and mine search operations and use a mine detector or other equipment because dense and high vegetation and plants hinder efficiency of mine detection. Mine-detectors are typically designed to detect a mine or UXO at a depth to $5-10$ cm. This is especially

true for forest, mountain or rural areas. Such operations cause damage to trees, plants and wildlife.

- Treatment of the area of possible location of UXO or mines by the California Cf-252 isotope (the so-called TNA method) may lead to radioactive pollution of the area.
- Use of vehicle-born mine detection equipment and mechanical demining causes extensive soil erosion.
- Transportation of discovered UXO to disposal sites or facilities endangers road network, creates noise and endangers public safety.
- Transpiration of TNT through the roots and stems of plants causes its higher concentration in the leaves, making them dangerous to grazing animals.

6 Depleted Uranium

Radioactive contamination of the environment caused by the spreading of depleted uranium (DU) contained in shells and bombs also has considerable impact on public health and the environment. DU presence in and contamination of drinking water and air as for the first time detected by UNEP experts during an assessment in the Balkans. Surface soil samples revealed levels of localized ground contamination with DU. Most local ground contamination could be detected around contamination points at distances up to 200 meters, but usually much closer. Most of the DU fragments that impact on soft ground (e.g. sand or clay) will probably penetrate intact more than 50 cm into the ground and remain there for a long time. Second, fragments of DU (penetrators) buried near the ground surface and recovered a few years later tend to have their mass decreased by approximately 25% over 7 years. Based on this finding, correlated with those penetrators studied in other earlier studies, a DU penetrator can be fully oxidized to corrosion products (e.g. uranium oxides and carbonates) in 25 to 35 years after impact. Due to the fluctuating chemical properties of different soils and rocks, the fate of DU in the environment varies. Penetrators that are buried in clay will remain intact and will not affect the surrounding soil and groundwater. If penetrators are buried in quartz sand, they will weather relatively fast and may migrate to nearby groundwater. Weathering of penetrators buried in residual soils depends on the type of bedrock. If the soil consists of weathered granite or acid volcanic rock, the environment will be acidic and the weathering will be fast. Acid rain will accelerate the weathering, since uranium is acid soluble [15].

It was demonstrated in Iraq that workers and civilians, as well as military and mine clearance personnel with access to sites where DU presence was confirmed, often are unaware of or misunderstand the risks and issues surrounding DU-containing munitions and UXO. Awareness raising activities should be considered, including information about DU in general, associated risks, handling and storage and contact information for relevant authorities. The U-235 content in DU used in DU ammunition in the Balkans was found to be 0.2 per cent (UNEP 2001; UNEP 2002) as opposed to its natural content of 0.7%. Still the risk to health and environment can be considerable [9].

7 UXO-Related Environmental Impacts of Existing Military Facilities

During the last several years an increasing number of issues have arisen relative to UXO, hazardous contaminants, and military ranges cleanup both in Ukraine and in other countries. These include firing ranges.

Military range investigations often lack sufficient site-specific information. The standards and procedures for assessment and cleanup of lands used by the military are often not fully enforced. There is an increasing tendency for UXO investigations to use statistical grid sampling methods but extrapolation of their results often lead to inappropriate decisions. This method is only appropriate for a relatively uniform distribution of UXO, which is not the case at military ranges. In order to achieve protection of human health and the environment, UXO investigations should be based on a combination of information such as historical data (e.g., archives, photos, interviews), range use information, visual site inspections, previous detection surveys, previous Explosives and Ordnance Demolition (EOD) Unit response actions, and the resultant knowledge of impact zones and "hot spots" [15]. All areas at closed, transferred, and transferring bases with known or suspected UXO are areas of concern and need to be evaluated from the point of view of UXO availability at their territory. A shift to address ranges through a "risk management" strategy focusing on both range assessment and remediation for UXO and other constituents is required. In many areas where UXO clearance is not performed to the frost line or sufficient depth, additional UXO is likely to surface via frost heaving or erosion processes. The military generally do not apply the best available technologies to assess and remediate UXO. In most cases, there appears to be a standard approach to default to the traditional methods known as "mag and flag". In those cases where UXO investigations at ranges (or UXO sites) have been performed, they embrace known UXO sites only [8]. But investigations should not be limited to within the "fence line", especially when information suggests that UXO problems are more extensive. A good example is recent explosions at the Novobogdanovka storage facility, when shells and remnants of ordnance were found at a distance more then 10 km from the event site. Standards for depth of clearance generally are not being followed. The rule specifies that default depths of clearance should be 10 feet unless an alternative is justified and approved. Many UXO-contaminated areas at closed, transferred, or transferring military ranges are: 1) not being investigated, or 2) when discovered, are not being addressed consistent with human health, environmental, or explosives safety regulations. Information provided by the military on the scope, nature, and extent of UXO response measures is not always comprehensive and sufficient [11].

8 Selection of UXO Remedial Actions

Often the military use time-critical/emergency responses as the sole response paradigm which, however, should not be a default approach. There is a general overreliance on institutional controls as the principal remedy component or as the only remedy to ensure protection. Where employed, the institutional controls may not be adequately defined, roles and responsibilities are left unclear and ultimately they may not prevent future incidents where UXO is encountered. The military does not always implement adequate access controls (e.g., fencing, posting of guards, patrols, etc.) where needed. In addition, periodic inspections need to be performed at many locations where UXO has been identified, is suspected, or may have surfaced via erosion or frost heaving at previously cleared areas. Effective regulatory and departmental oversight is an important aspect of UXO remedy implementation. When it is not implemented, the risk of incidents increase and leads to such situations when UXO cleanup materials are mistakenly taken as clean scrap and transported to a scrap yard for recycling. There is a wide-spread opinion that the military should retain ownership and/or control of UXO areas that are not yet assessed and/or cleaned up, as determined according to the existing regulations. Present land transfer practices by military establishments show that UXO contaminated lands continue to be transferred to civilian usage despite the fact that such lands have not been adequately assessed and UXO contamination not yet addressed. In some cases, the military perform only a cursory investigation. Based upon limited information, property has been and is being transferred. Rather than sufficiently assessing sites and making the property safe for use or transfer, the military appear to be transferring the land and then waiting for others to identify problems for them to respond on request. Though, as a rule, the military accepts their responsibility if a UXO is found at the transferred land. Their responses tend to be limited to the newly found UXO. Generally no further investigation is carried out by the military to determine the nature and extent of any additional UXO. Such a "house call" type follow-up cannot be considered as a proper substitute for adequate investigations of the lands to be transferred.

9 Conclusions

A mixture of political, regulatory, and budgetary drivers forces development of better UXO detection and destruction technologies, the use of which is aimed at better protection of human life, property and the natural environment. The technologies currently available to detect and/or discriminate buried UXO from natural or man-made clutter fall significantly short of the user's minimum requirements. Also, unfortunately, there is no "magic bullet" in the foreseeable future that will solve the UXO detection, site characterization and remediation problem. Therefore, a multi-tiered approach to improve the current state of UXO detection and mitigation technology is required. A search for more reliable and cost effective solutions to the

UXO management problem is needed. Special attention must be paid to the need to improve our ability to reach proper environmental rehabilitation and restoration of UXO-contaminated sites in order to reduce their negative environmental foot print. Current UXO remediation efforts are based on decades-old technology and use several procedures that are inefficient, labor- intensive and costly. Because the suspect sites have not been surveyed, there is great uncertainty about the actual size of the UXO problem [14]. However, even if only 5% of suspect acreage needs cleanup, remediation costs will still be high (possibly exceeding 15 billion dollars for the USA alone) and will take a long time (possibly exceeding several decades to complete) using current technologies.

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