EFFECTS OF THE USE OF WEAPONS AND AMMUNITION CONTAINING DEPLETED URANIUM

INTRODUCTION

During the NATO bombing of the Federal Republic of Yugoslavia in 1999, the Military Technical Institute (VTI/MTI) gained certain experience regarding the effects of depleted uranium (DU) ammunition on its territory. VTI experts engaged in quantitative laboratory analyses, qualitative (field) analyses and construction of air sampling devices, in order to identify the presence of DU particles at locations in the zone of action.

The VTI has carried out research in the field of remediation of the consequences of the use of depleted uranium weapons and the transport of uranium oxides between ecosystem elements (between land and plants). The experience gained in this way has contributed to the establishment of certain positions regarding the problems caused by the use of ammunition containing DU, which are presented in this paper.

During the operations, in addition to other ordnance, NATO also used missiles based on DU.

The efficiency of the use of missiles containing DU needs to be observed from several aspects, namely:

- In the context of improving the penetration and armour-piercing characteristics of weapons;
- In economic terms, as depleted uranium is a material that is less expensive than alloys based on tungsten, titanium, etc., and is available in warehouses as low-level radioactive nuclear waste. In this way, the producer country disposes of significant amounts of waste, which requires allocating significant financial resources for the purpose of storage;
- In terms of the environment - by using depleted uranium to make ammunition, the producer country disposes of its radioactive waste in an efficient way while preserving its environment. On the other hand, the use of such ammunition carries out ecological aggression at the location of its application, with the consequences of long-term environmental damage; and
- In terms of psychological pressure, such ammunition is very effective, because there is always a fear of radiation and it is very easy to manipulate the public opinion of the victim country.

1. CONTAMINATION WITH DEPLETED URANIUM

Operations performed using ammunition which contains DU contaminate manpower, technical means and the environment. During the collision of a projectile made of DU with a solid base (e.g. metal shield), part of its kinetic energy is converted into heat and due to pyrophoricity uranium oxides are formed, primarily U3O8, then UO2 and UO3.

Depending on the material of the target, the kinetic energy of the projectile, the direction of penetration, etc. 10-70% of the total mass of DU is forming micrometer particles of uranium oxide with a size of 0.5-10 μm.

With the reduction of the diameter of microparticles, their rate of fall decreases significantly, and with the help of suitable air currents, these microparticles can be transported over much greater distances than would be expected given the density of uranium oxide. So far, uranium oxide microparticles have been registered at a distance of 42 km and more, which leads us to the conclusion that when using DU ammunition, aerosol particles will be transported over distances of as far as tens of kilometres.

2. DEPLETED URANIUM AND ITS OXIDES AS A CAUSE OF RADIOLOGICAL AND TOXICOLOGICAL RISK

Depleted uranium and its oxides pose a danger to human health primarily due to internal contamination, and to a much lesser extent due to radiation. In the zones of action where DU ammunition was used, the greatest danger is posed by finely dispersed aerosol particles of uranium oxides. Aerosol particles can enter the body by ingestion and inhalation, and also through open wounds that are a result of injuries on the battlefield.

The risk to human health from contamination with depleted uranium and its oxides exists due to the radiological and chemical toxicity of these compounds.

Radiological risk: Uranium isotopes are α emitters and α particles penetrate 30 μm into soft tissue, but do not penetrate dead skin layers, so they pose a danger after ingestion. β particles, emitted by uranium progeny, have the ability to penetrate the skin and are also dangerous when ingested. Gamma radiation, as an accompanying radiation in α and β decay, has the highest penetration power.

The energy carried by ionizing radiation through biological material is dissipated in organs and in various molecular interactions, including genetic material.

Ingestion and inhalation of DU particles causes nausea, vomiting, weakness and diarrhea in a short period of time. Years after exposure, health problems occur, such as liver and kidney damage, lung, bone and other organs cancer, chromosome damage, reproductive problems and breathing problems.

Chemical toxicity: Uranium is a heavy metal similar to lead and cadmium. These metals are usually highly reactive in a solution and can cause many cytotoxic effects. Heavy metals, as well as uranium, have a high affinity for biological molecules that contain phosphate residues, such as glucose phosphate, phospholipids, and nucleic acids; or sulfhydride groups, including cysteine, a large number of proteins, and oxygen anions. Due to their high affinity for biological molecules, heavy metals do not exist as free in biological systems.

For uranium toxicity, the most important oxyanions in biological systems are the carbonate and bicarbonate components. Almost half of the concentration of the hexavalent uranium ion, U^{6+}, circulating in the blood in the inorganic fraction is in the form $[UO_2 (C0_3)_2]^{2+}$. This component is stable in a neutral environment (blood pH) and in that form does not react further with biological molecules. In an acidic environment, in urine, uranyl ion is freer and more reactive.

The amount of excreted uranium, which originates from a natural source, is 50-500 ng/day. Residual uranium that is not excreted is distributed in the bones and soft tissues, including the kidneys, liver, lungs, fat, muscles and other organs. The main uranium reservoir is the skeleton, and the attacked organs are the kidneys. The biological half-life of uranium is 1-500 days, depending on the chemical form in which the uranium is found.

According to the recommendations of the International Radiation Protection Agency, uranium concentration limits in air of 50 μg/m³ for soluble uranium and 250 μg/m³ for insoluble uranium are noted. To reach an annual dose of 1 mSv, from uranium alone, the upper concentration in air is 0.18 μg/m³. For air that is considered clean, the aerosol concentration is 10 μg/m³, where the uranium concentration is at 2 μg/g of aerosol.

3. RISK MANAGEMENT OF DEPLETED URANIUM CONTAMINATION LOSSES

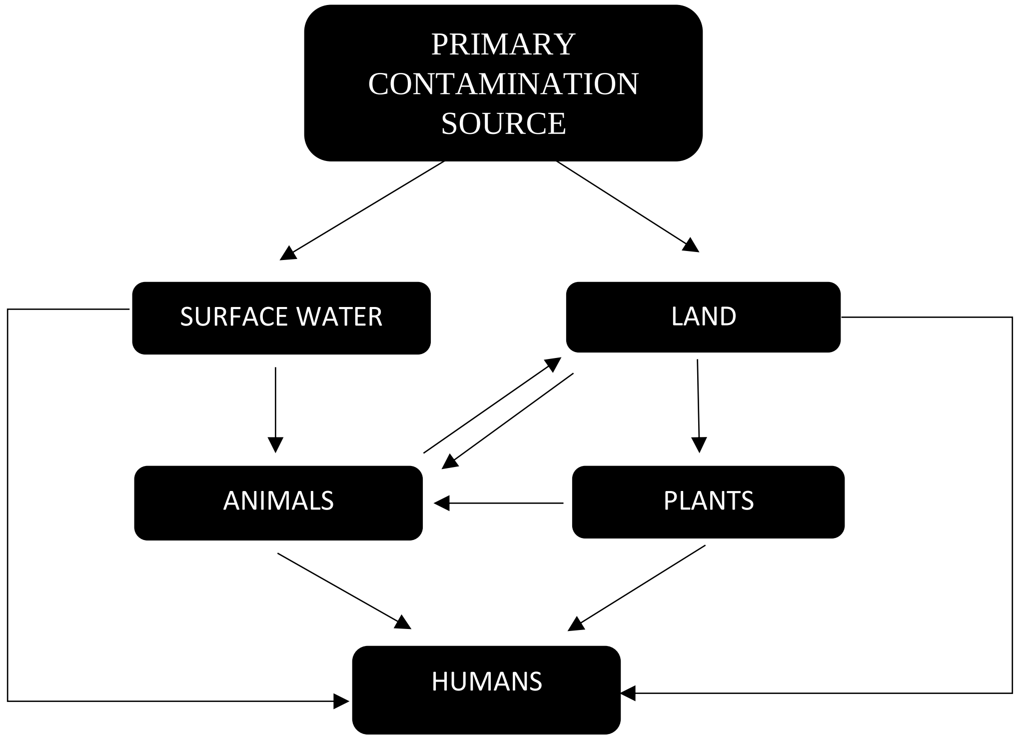
Contamination of people with depleted uranium can occur directly, indirectly and subsequently. Figure 1 illustrates these three cases.

Primary contamination source > People

a) Direct contamination of humans. It occurs when people, without protection, are exposed to an aerosol cloud of depleted uranium oxide particles, created by the use of ammunition and/or depleted uranium rockets.

Primary contamination source > Secondary source > People

b) Indirect contamination of humans. It occurs when people, without protection, come into contact with equipment and weapons that are contaminated.



c) One model of subsequent human contamination. It occurs through the food chain.

In all three described cases, there is a certain risk - the probability of loss, which means human losses, immaterial and material losses due to fatal and non-fatal health problems in humans and damage (changes) in their genetic material. Immaterial and material losses include those losses that have occurred as a result of non-execution or failure to achieve the set goal due to illness or death. The existence and urgency of the problem calls for the need to manage this risk. Therefore, it is necessary to first quantitatively assess the risk of losses due to the resulting or possible situation, compare it with the acceptable risk and, if necessary, take measures to reduce the risk.

The risk of direct contamination depends primarily on the amount of depleted uranium ammunition used during the combat operation, the existing protective equipment of soldiers as well as the manner of its use.

The risk of indirect contamination predominantly depends on the implementation and organization of the decontamination process.

Analysis of the risk of subsequent contamination indicates that the level of this risk also depends on the features of the area that is contaminated. Knowing the level of this risk can also be important when planning the deployment and combat operations of armored mechanized units.

Hazard risk management is a process that consists of the following activities:

1. Identification of contamination

2. Determining the characteristics of contamination

3. Assessment of the risk of losses due to contamination, and

4. Application of protection measures and procedures for risk reduction (bringing it to an acceptable level)

The course of activities is shown schematically in Figure 2.

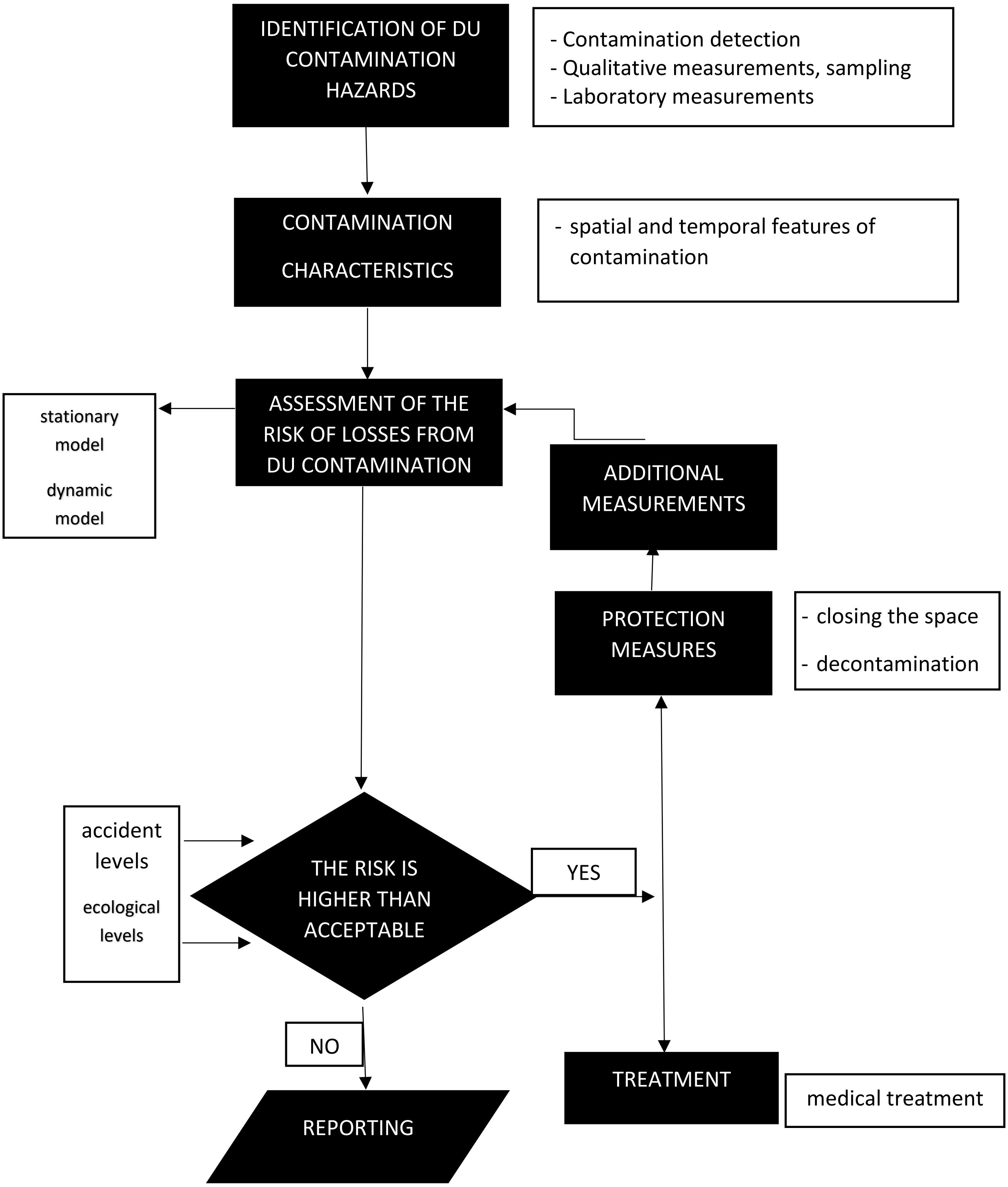


Figure 2. Risk management of losses due to the use of depleted uranium weapons

3.1 Identification of contamination

Identification of contamination in this case from depleted uranium oxide particles includes their detection and the necessary qualitative and quantitative measurements. Due to the features of DU, the detection and qualitative measurements serve for better sampling, and only laboratory quantitative methods can identify depleted uranium and determine its concentration.

The use of weapons with depleted uranium contaminates the air, land, technical material means, buildings and thus the manpower, i.e. the population in the immediate vicinity of the operations.

3.1.1 Detection of contamination

Detection is performed on and around the projectile crash site of contamination from depleted uranium and then quantitative identification of uranium content, i.e. the degree of contamination.

Detection requires scintillation detectors that are sensitive to detect alpha contamination. Detection of projectiles or parts of projectiles is also possible with radiological detectors for measuring the gamma radiation dose rate. However, in the detection of contamination with aerosol DU particles, the gamma dose strength is low due to the dispersion of particles over a large area, so that the detection of low gamma radiation of uranium isotopes is practically impossible. Detection with scintillation detectors for measuring alpha radiation should be performed at penetration spots, because the highest content of contaminants is expected there.

3.1.2 Sampling and sample preparation for contamination measurement

As previously mentioned, finely dispersed uranium oxide particles are found as aerosols in the air at the site of the projectile's fall immediately after the action, i.e. on the remains of the target and on the soil surface after deposition. Having in mind the particle deposition rate, air sampling should be performed immediately after the projectile falls (up to 10 hours), and sampling of soil and affected objects can be performed later if there is no precipitation.

Air sampling is performed by sieving large amounts of air (300 m^3 and more) through filters that retain particles the size of a part of a micron up to several tens of microns. After removing the filter from the sieving device, the further treatment of the deposited DU oxide particles depends on the method by which the uranium content will be quantified. For gamma-spectrometric measurement, the filter is measured directly, in which case a calibration with the standard of the same geometry had been performed, for other quantitative methods, it is necessary to burn the filter and dissolve the dry residue. By knowing the volume of compressed air, it is possible to calculate the level of contamination in $\mu g/m^3$.

Soil sampling is performed on the basis of previous dosimetric measurements and assessment of critical points. Critical points are places where it is assumed that the content of contaminants is higher and they are not available for measurement.

Sampling to determine the degree of soil contamination is the most efficient when done by vacuuming dust using appropriate devices. Sampling of contaminated soil is also done by removing surface layers. The sample is then dried, homogenized and, depending on the method used to analyze the uranium content, further treated. Samples are taken at the places where the projectile passes or falls. If the target of the projectile is a building or a construction means, the sample is taken at the points of penetration, because the highest content of contaminants is expected there. Sampling is performed by removing the surface layer or collecting solid, porous materials and exploded parts of the projectile. The quantity of the sample must be at least 0.5 l, and preferably 2-3 l. The samples should be properly packed and marked.

3.1.3 Determining the level of contamination with depleted uranium

The uranium content in air (μg/m³), solid samples (μg/kg), as well as the isotopic ratio U-235 /U-238 is calculated on the basis of data obtained from the analysis of samples by quantitative methods.

3.2 Contamination characteristics

Determining the characteristics of contamination implies defining the spatial-temporal distribution of the DU concentration. Based on detection and quantitative measurements, the level of environmental contamination is determined, which determines further procedures in order to perform risk management (schematic in Figure 2).

3.3 Assessment of the risk of losses due to contamination

The risk assessment of losses consists of assessing the likelihood of health problems and losses that may be caused by them as a result of contamination.

Mathematical models (irradiation models) play an important role in assessing the probability of health problems, which describe the means and ways of interaction of the DU with the elements of the ecosystem and through them with people

Given the half-life of uranium as well as rapid changes in its concentration in the air, there are models of irradiation that analyze the steady state and dynamic state. In stationary models, the interactions of DU with the elements of the ecosystem are time-independent, and in dynamic models they depend on the elapsed time. The models have a probabilistic character and give different values for different event scenarios. The scenario is a description of the ways in which the organism for which the risk is calculated interacts with elements of the ecosystem that are relevant. The model can follow one or more paths of interaction of DU with the elements of the ecosystem.

Input parameters for given models are the measured DU concentrations in a certain area, soil characteristics, files with radionuclide characteristics, etc. For each of the parameters, the probability distribution is given according to their probabilistic character. The Monte Carlo method is used for their numerical assessment. With the help of these models, the concentrations of DU in plants and meat of animals used as food for humans can be obtained.

Effective doses are calculated for different tissues irradiated with depleted uranium (kidneys, bone surfaces and digestive organs).

Risk assessment of depleted uranium exposure in humans was obtained from the dose rates of the previous models and by using the ICRP manual (ICRP, 1990).

Examples of implemented numerical risk assessment programs that use stationary models of different levels are NCRP (1984) and RESRAD (1990-1996). Both programs assume that the values of depleted uranium concentration are uniform over the entire contaminated area. The programs were implemented for the purpose of assessing the risk of losses on military training grounds in the USA, where depleted uranium ammunition and missiles are used.

4. RADIOLOGICAL DECONTAMINATION OF HUMANS, TECHNICAL MEANS AND LAND CONTAMINATED WITH DEPLETED URANIUM

Decontamination of people, weapons, technical means, facilities and land after the use of depleted uranium ammunition should prevent the spread of contamination, and where it has occurred, reduce it to the permitted level.

In deciding on the means and methods to be used in decontamination procedures, it is important to determine the level of contamination and define the physicochemical form of the contaminant and the contaminated area. As a contaminant in this case, aerosol particles of uranium oxides appear, the so-called ceramic aerosols: UO_2 and U_3O_8 (insoluble in aqueous phase) and UO_3 (soluble in aqueous phase). According to data from the literature, 17-48% of aerosol particles formed during a projectile explosion are soluble in water. These particles are bound to the contaminated surface by physical forces.

In the first phase, immediately after the armed actions, people, clothes, personal weapons and shelters are decontaminated. In the second (later) phase, decontamination of heavy weapons and decontamination of buildings and lands that were in the zone of action are performed. The problem of reclamation of contaminated land is a long-term procedure and practically represents a special phase.

When carrying out decontamination procedures the problem experienced is the detection of low concentrations of uranium and the verification of bringing the concentration of contaminants to the permitted level, i.e. determining the effectiveness of decontamination.

4.1 External decontamination of people

External contamination is removed by standard R-decontamination methods. Decontamination of people is done before cleaning the contaminated area.

4.2 Decontamination of clothes and equipment

When decontaminating clothes and equipment, the standard procedure for decontamination of fission products can be applied, which includes the procedures of vacuuming, wiping with a damp cloth, washing; decontamination by shaking and brushing should be avoided.

4.3 Decontamination of technical means

Contamination of technical means occurs by being directly hit with ammunition with depleted uranium and by movement on contaminated terrain. Contaminated technical means outside the contaminated terrain represent a new source of contamination and a danger to human health, so it is necessary not to move the contaminated means until decontamination is performed. The only effective way to clean the means contaminated with DU dust is to collect the dust, put it in containers, and store it using a low-level radioactive waste method.

4.4 Decontamination of soil

In the first phase, the decontamination of the land on which DU ammunition was used implies the collection of unexploded projectiles or projectile parts and their disposal according to the procedure for low-level radioactive waste. The choice of method for further decontamination depends on the level of contamination, its scope, vegetation present, geological characteristics of the soil, physicochemical form of the contaminant. Standard methods of decontamination include removing the contaminated layer of soil, plowing, covering with a layer of uncontaminated soil, etc. If there is contamination of large amounts of agricultural land, serious remediation programs are needed for its reclamation. On the contaminated agricultural land, in order to remove contamination and later revive the land for use, various agro-technical measures are used such as:

- removal of crops and the rest of the harvest (treated as radioactive waste);
- more frequent mowing of meadow areas;
- removal of the surface layer of soil (5 cm);
- deep plowing of radioactively contaminated soil (10 cm, 20 cm and 30 cm), whereby plants with shallow, deep and very deep root system can be planted on such soil, in consultation with agrotechnical experts;
- change of crop type;
- other possibilities.

Experiences that exist in our country on the rehabilitation and reclamation of large areas contaminated with heavy metals, such as lead, show that these are multi-year interventions that are usually implemented in 3 phases:

- Laboratory in-vitro tests;
- Testing in greenhouses and on experimental plots;
- Reclamation of contaminated surface;

In order to reduce the high level of uranium in the soil, it is important to know its global cycle in nature. This knowledge makes it possible to predict with certainty the processes that affect its transport and fixation, and thus develop models of environmental protection.

Figure 3 shows the global uranium cycle.

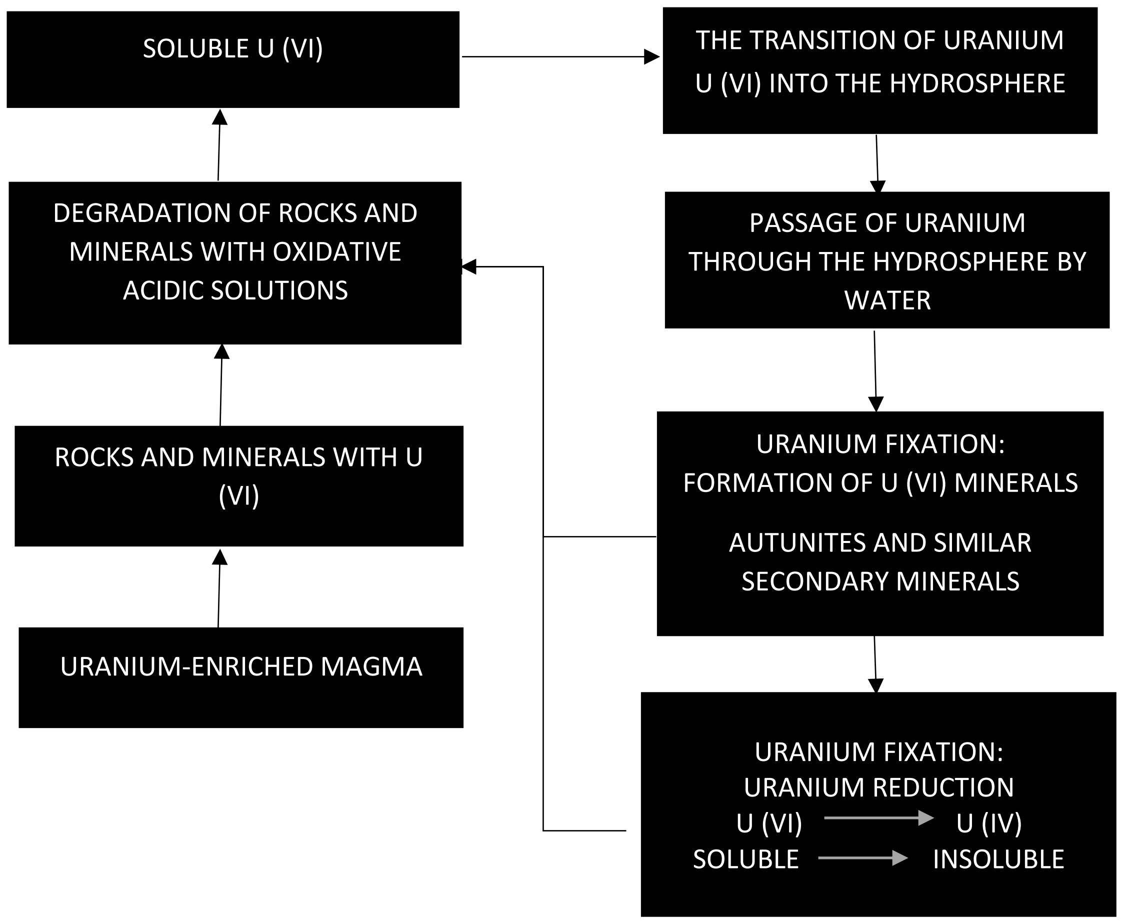


Figure 3. Global cycle of uranium in nature

The analysis of parameters that affect the transport of uranium in nature allows the consideration of the necessary preliminary tests in order to collect data on the basis of which it is possible to choose an appropriate method for reducing its content in the soil. Analyses that would precede the choice of fixation method are: determination of uranium content and chemical form, standard analyses to determine agrochemical character of soil, and surface and groundwater. After choosing the method of rehabilitation, it is necessary to perform testing on experimental plots, and then to proceed to carry out the rehabilitation.

5. CONCLUSION

The use of depleted uranium ammunition leads to severe and far-reaching consequences for the health of humans contaminated with aerosol particles of uranium oxides, long-term contamination of the land on which the actions were performed, as well as contamination of technical means directly involved in operations.

Prevention or reduction of the risk of human contamination is carried out by applying appropriate radiological protection measures - the use of protective suits and respirators to block submicron and micron particles.

Decontamination of weapons and military equipment needs to be performed before leaving the contaminated zone because they are a secondary source of contamination and radiation.

The environment contaminated with long-lived uranium isotopes is a danger due to the subsequent ingestion of contaminants into the body through the food chain. Assessing the risk of losses due to the use of DU is an important element in the management of this risk in a rational way. Its importance is reflected both in the analysis of possible situations and in the process of taking rehabilitation measures.