

Integrated approach to the remediation of complexly contaminated soils in military areas: Development of innovative technology for the removal of explosives, heavy metals and metal fragments

Co-funded by the Slovenian Research Agency and the Ministry of Defence, this 200,000 EUR project (2025–2027) addresses soil contamination from long-term military activities. Decades of training and open detonation of ammunition, mines and unexploded ordnance have led to the accumulation of heavy metals and organic pollutants. Common explosives such as 2,4,6-trinitrotoluene (TNT), hexahydro-1,3,5-trinitro-1,3,5-triazine (RDX), and octahydro-1,3,5,7-tetranitro-1,3,5,7-tetrazocine (HMX) persist in the environment, contaminating soil and water and posing risks to human health.

Soil contamination from military activities is a global issue. While the use of explosives and weaponry is unavoidable, sustainable remediation is essential to protect ecosystems. Traditional approaches, such as dig-and-dump, soil replacement, stabilization, and disposal of contaminated soil fractions, are financially and environmentally unsustainable.

Most research has focused on individual pollutants. Bioremediation using naturally occurring microorganisms can degrade explosives, but it is slow. Adding nutrients can stimulate microbial activity and accelerate degradation. Chemical methods using zero-valent iron, surfactants or oxidants have also shown promise. However, these technologies are mostly limited to laboratory-scale applications and cannot remove heavy metals or metal fragments.

Research on heavy metal contamination is mostly focused on shooting ranges. Common methods include soil replacement, mechanical screening, solidification/stabilization and acid soil washing. These approaches are not sustainable. Therefore, developing cost-effective and environmentally friendly remediation technologies is essential for the Slovenian Army and beyond. Soil contamination challenges extend globally, affecting not only military training areas but also conflict zones.

The objectives of this project are:

- C1) characterization of soil contamination in the area of open detonation;
- C2) investigation of the possibilities for removing explosives, heavy metals, and metal fragments from the soil in a laboratory scale;
- C3) removal of explosives, heavy metals, and metal fragments at a pilot scale – demonstration of the technology's functionality; and
- C4) assessment of the feasibility of the integrated remediation technology for removing explosives, heavy metals, and metal fragments, revitalization of the cleaned soil, and preparation of a proposal for the revitalization of the contaminated area.

The project aims to integrate the patented ReSoil® technology for sustainable removal of heavy metals, metalloids and metal fragments with biological and chemical methods for the degradation of explosives. This innovative approach combines multiple remediation technologies within ReSoil® to ensure efficient



removal of explosives and other pollutants. The main goal is to develop and demonstrate a sustainable process that not only removes contaminants but also enables the revitalization of degraded areas.



Figure 1. Area of open detonation on a military range



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