ELSEVIER

Chemosphere 60 (2005) 1246–1252

CHEMOSPHERE

www.elsevier.com/locate/chemosphere

Chemical and mineralogical transformations caused by weathering in anti-tank DU penetrators ("the silver bullets") discharged during the Kosovo war

Marcello Mellini [a], Francesco Riccobono [b,*]

[a] *Dipartimento di Scienze della Terra, University of Siena, Italy*
[b] *Dipartimento di Scienze Ambientali, University of Siena, Via Laterino 8, Siena I-53100, Italy*

Received 2 February 2004; received in revised form 27 January 2005; accepted 1 February 2005
Available online 21 March 2005

Abstract

A depleted-uranium penetrator, shot in 1999 at Djakovica, Western Kosovo, and there collected in June 2001, shows evident alteration processes, perceivable as black and yellow coatings. XRD indicates that the black coating mostly consists of uraninite, UO_2, with possible presence of other more oxidized uranium forms, such as U_3O_8. The yellow material is mostly amorphous, with variable weak diffraction lines, due to minor embedded uraninite grains, or possibly to schoepite, $UO_3 \times 2H_2O$.

SEM-EDS reveals only uranium. Whereas uraninite does not show any crystal shape, the yellow material recrystallizes to flattened pseudo-hexagonal prisms, approximately 2–10 μm wide and 1–4 μm long. Raman spectra of the yellow material have peaks at 3474 and 3222 cm^{-1}, indicative for OH groups, plus at 812 and 744 cm^{-1}, indicative for UO_2^{2+} uranyl ions.

Based on the different data, the yellow material covering the depleted-uranium dart is an oxidized corrosion product, containing uranyl ions and hydroxyls and/or water molecules, akin to schoepite. Therefore, the Djakovica dart shows evident oxidation and leaching processes, progressively releasing mobile uranium forms. As uranium will be progressively dispersed far from the impact sites, at a rate controlled by the presence of effective fixing mechanisms, we feel necessary to maintain long term geochemical control of water pollution within the battlefield surroundings.

Keywords: Kosovo; Depleted uranium; Bullet weathering; Pollution; Groundwaters

1. Introduction

The use of depleted uranium (DU) anti-tank ammunitions by NATO forces to strike Serbian armoured troops, during the 1999 Kosovo conflict, raised many polemics, especially over the public opinion of countries sending soldiers to the Balkans (e.g., Murray et al., 2002). Even the idea to employ depleted uranium to construct tips able to pierce the armor of battle tanks was criticized, since other materials (i.e., tungsten) might be used to produce very high density penetrators having good ballistic properties.

Actually, until 1970 piercing tips of anti-armor ammunition were commonly made by tungsten.

* Corresponding author. Fax: +39 577 233945.
E-mail address: riccobono@unisi.it (F. Riccobono).

0045-6535/$ - see front matter © 2005 Elsevier Ltd. All rights reserved.
doi:10.1016/j.chemosphere.2005.02.005

However, at that time NATO was decidedly troubled by the overwhelming number of tanks of the Warsaw Pact (3–1 ratio was estimated), as well as by their continuously improving performance. To maintain the traditional deterrence strategy, NATO was constrained to provide the best anti-armor ammunition, able to deal effectively with the Warsaw Pact tanks. From the strictly militar point of view, the use of anti-tank ammunitions equipped with DU penetrators (actually, a uranium alloy named "staballoy", containing 0.75 wt.% titanium) was appropriate. Huge quantities of DU were available at low cost and DU penetrators revealed to be incomparably better than any other material. For instance, whereas the tungsten penetrators acquire a mushroom-shaped head on impact, the DU penetrators display a "self-sharpening" aptitude. In other words, the "silver bullets" slice through tanks like a hot knife through butter.

Another crucial quality of DU ammunitions is offered by their pyrophoric behaviour, making them decidedly lethal against armored targets. While penetrating through the armor, the DU dart becomes overheated and burns, violently reacting with atmospheric oxygen. This triggers either fuel combustion and shot-magazine explosion which completely destroy the tank (Fig. 1).

Following a request by the United Nations General Secretary, NATO informed that approximately 30 000 DU rounds were shot by the A-10 anti-tank aircrafts in Spring 1999 in Kosovo. As they weigh 300 g each, a total of nine uranium tons were added to the natural uranium content of the hit areas (UNEP, 2001). NATO estimated that 70–90% of the shot rounds missed the target and penetrated into the ground, at a depth depending from the substratum nature. This fact raised some worries because of possible uranium transfer to the food chain and groundwater pollution. In fact, although the radioactivity levels proved to be generally not significant (e.g., UNEP, 2001), uranium is a toxic heavy element with adverse effects upon kidneys and, possibly, lungs. Incidentally, we observe that the Kosovo uranium waste is a small percentage with respect to the 320 uranium tons (or more) deposited on the Iraqi soil in 1991, and, most probably, with respect to the still larger amount there discharged in 2003.

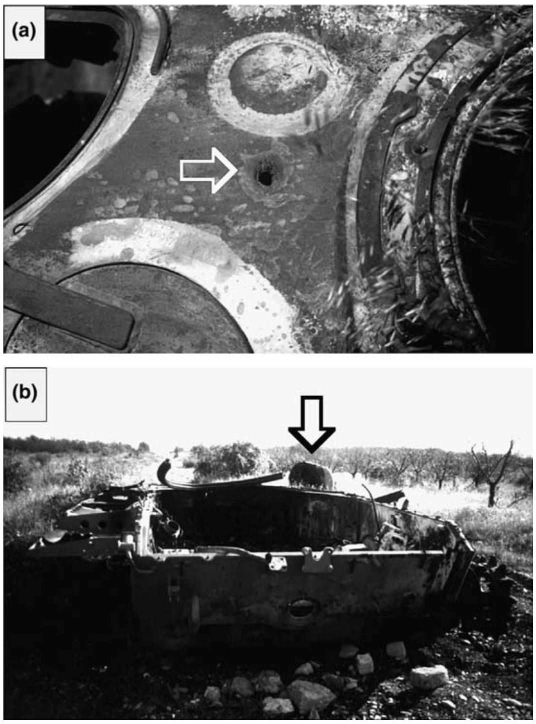

Fig. 1. (a) Hole in the armor of a Serbian tank made by a DU dart. (b) The dramatic effect of the DU dart on the same tank.

Because of the thermodynamic instability of metallic uranium with respect to oxidized forms, weathering processes may progressively corrode the DU metal pieces. New U-rich mineral phases may form at the reactive surface, while some uranium may be lost in solution as very mobile UO_2^{2+} uranyls and reach groundwater. Alteration rate and equilibrium stability of newly-formed assemblages will ultimately control uranium spreading in the environment. As contamination levels in food and drinking water could rise after some years, they should be monitored when there is a reasonable possibility of significant quantities of DU entering the ground water or food chain (WHO, 2001a,b).

During a sampling survey in Western Kosovo (June 2001), done to assess the environmental impact of DU discharged in heavily hit areas, we found a DU penetrator implanted into a concrete platform in front of a Serbian garrison, near Djakovica. The DU surface clearly showed intense alteration processes, perceivable even by naked eye as variously coloured spots and coatings. In what follows, we describe the chemical and mineralogical details of transformations occurred after two years permanence at the finding place. Although we presently deal with a Kosovo DU penetrator, we recall the even larger quantities of DU ammunition used elsewhere (i.e., the Gulf Wars). In the latter case, DU has been questioned to contribute to the increased occurrence of cancer, renal disease and congenital malformations, possibly together with other causes that led to an "epidemiological nightmare" (Abbott, 2001).

2. Sampling and methods

As previously stated, the DU penetrator studied was found driven deep into a 30 cm thick concrete platform at a garrison of the former Yugoslavian Army (VJ) in Djakovica. The garrison, used for armored vehicles storage and as ammunition repository, has an area of