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## **Disposal of ammunition from World War One (1914 -1918) on the western front by Open-Burning. The fingerprint of 100-year old forgotten contaminations.**

« *There is no proper method to eliminate ammunition*<sup>1</sup> » Francis Norman PICKETT

« *The war of 1914-18 was an artillery war. Artillery was the battle winner [...]* »<sup>2</sup>. During World War One, ammunition was used on an unprecedented scale. When hostilities ceased, huge dumps of unused ammunition and large numbers of fired unexploded ordnances remained. Accumulation of excess, obsolete, unserviceable, explosive- and also chemical-loaded projectiles has posed dangers in times of peace. After unfired shells ran out their service lifetimes, their susceptibility to shock, chemical action and heat increased greatly due to the formation of unstable chemical substances within the casings. There was an urgent need to dispose of 2.5 to 3 million tons of hazardous ammunition to reduce the threat of explosion and fire at depots and storage sites during the interwar period. More than 200 old ammunition disposal sites, mainly Open-Detonation (OD) demolition pits operated in the 20s, have been identified in France, some of them had dismantled from 11,000 tons to over 110,000 tons each.

New methods for safely breaking down projectiles, including Open-Burning (OB), were subsequently developed and operated to dispose projectiles and to recover valuable material (metals, ammonium nitrate, explosives) contained in ammunition. However ammunition clearance caused severe contaminations of topsoil and likely contributed to the contamination of groundwater by perchlorate ( $\text{ClO}_4^-$ ) and nitroaromatics compounds (NAC), mainly dinitrotoluene, aminodinitrotoluene, and dinitrobenzene isomers, on a regional scale in northeast of France. However, few studies (often fragmentary) are available on this topic. The ammunition destruction sites of the interwar period and the contamination resulting from them are nowadays absent from collective memory.

Original recent research was carried out on nine abandoned ammunition Burning-Grounds (BG) in France and Belgium to fingerprint the contamination and assess risks to land and groundwater use. Five of the BG are located in forest and four are in agricultural areas. BG sites typically have one or more parallel burning trenches that are 5 to 10 m long, and 50 to 80 cm deep and these are now filled with OB residues, remained unchanged or mixed with soil material. Because of the possible presence of dangerous warfare material and extremely high concentrations of hazardous compounds, special methods have been developed with the collaboration of EOD (Explosive Ordnances Disposal) experts to safely sample OB residues and soils

First, detailed historical research was needed and conducted to define (i) the compositions of ammunition types used by all the belligerents on the western front during WWI, (ii) the OB practices and (iii) the panel of compounds to analyze (when technically possible) for the characterization of OB residues and related contaminations. Metals and metalloids (Cd, Zn, Cu, Al from fuses, Hg from mercury fulminate primers, Pb from the casing of chemical shells, As, Sn from chemical warfare agents and smoke producing agents), NACs (of WWI high explosives and theirs environmental transformation by-products), chemical warfare agents and theirs environmental and thermal decomposition by-products, chlorinated and brominated dioxins (PCDD/F, PBDD/F, PCB-Dioxin like), and typical compounds from sulfur mustard (dichlorodiethyl sulfide) (chlorobenzene, thianes) and brominated compounds (from chemical shells) were analyzed by specialized laboratories in France and Germany. Parts of munitions

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<sup>1</sup> *The National Archives, Kew Gardens, LONDON. Mayfair « FN PICKETT et Fils. Démonteur de Munitions Toxiques et Explosives »*. Vol. 26, n°329, september 1921.

<sup>2</sup> JOHN TERRAINE. *White Heat*, p. 95.

have also been collected to be characterized by EOD experts to define what kind of ammunition has been burned at each burning grounds.



*“Place à Gaz” chemical ammunition BG near VERDUN. Cross section made by excavation showing a 40 cm thick black layer of OB residue. 200,000 chemical “Blue-Cross” shells have been burned on this spot around 1926 by the company FN PICKETT & Fils.*



*The largest BG of FN PICKETT & Fils’s “C-Factory” at LIESSIE near the Belgium / France boundary showing blackened OB residues and the total lack of vegetation.*

No vegetation grows at some OB locations due to phytotoxicity induced by extreme contamination levels by heavy metals (Zn: 10 to 100 g /kg DM, As: 2 to 110 g/kg DM) and PCDD/F (1,000 to 4,000,000 ng/kg DM). The highest Pb concentrations (> 50 g/kg DM) have been measured where bromid and brominated organic compounds (xylyle and benzyl-bromid, PBDD/F) occur. The Pb / Br-compounds contamination is the result of the OB of lachrymatory chemical shells. The presence in the OB residues of thianes (1,4-dithiane, 1,2,5-trithiepane, 1,4-oxathiane and 1-oxa-4,5-dithiepane) and chlorobenzene reveals historical OB of German “Yellow-Cross” mustard gas shells whereas high concentrations of inorganic arsenical compounds (mainly arsenates), associated with organic As by-products (triphenylarsine, (biphényl-4-yl)diphenylarsine, diphenylarsinic acid, As-PAHs (mainly 9-phenylfluoren)) give evidence of the OB of German arsenical “Blue-Cross” shells loaded with the sternutator diphenylchlorarsine (Clark 1). [Cd] and [Zn] are correlated with the relation  $[Zn] = 1,000 [Cd]$  in the OB residues where German artillery typical fuses from the last year of WWI have been open-burned. NACs having the composition of WWI high explosives, when detected, had experienced biotransformation and occur at low concentrations (mainly < 1 mg/kg DM), indicating that the NACs have been mainly destroyed by smoldering during OB operations.

Isomer distribution patterns indicate that PCDF (especially tetrachlorodibenzofurans) were the preferred products of burning when the primary precursors were chlorinated diphenylarsenical compounds, while  $\sum[PCDF] \text{ equal } \sum[PCDD]$  when monoaromatic compounds and/or sulfur mustard was decomposed. There are some historical (OB operation description in archive records) and geoscientific evidences (e.g. occurrence of extremely high concentration of PCDD/F, discovery of totally melted glass phials of arsenical “Blue-Cross” chemical shells) that the fires were out of control with temperature ranging from ca. 300 °C to up to 1,500 °C, over PCDD/F pyrolysis temperature. PCDD/F formation in OB fires may have drastically increased when temperature decreased in the presence of precursor mass excess.

This research indicates that BG sites have specific chemical patterns depending on the types of ammunition burned at each site. The fingerprint of contamination is linked to the composition of the ammunition being destroyed, and the manner in which the BG was operated, giving (i) valuable historical information that is missing in archive records, and (ii) data that are crucial for management of OB sites in order to protect public health and environment.