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Detection and Identification of Unexploded Ordnance (UXO) by Neutron Interrogation

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The detection of buried landmines is clearly a difficult and dangerous process. This contribution reviews the principle, of operation and unexploded ordnance (UXO) signatures of the PINS Chemical Assay System[1], a prompt-gamma-ray neutron activation analysis (PGNAA) for the identification of *recovered* UXO, so designers of countermine technologies right profit from our experience. We also suggest two related low-cost methods for buried landmine detection that might warrant further research.

PINS was initially developed for chemical warfare treaty verification. In 1992, the US Army began using PINS to determine the contents of suspect chemical warfare monitors recovered from firing ranges and former defense sites. Most of these range-recovered munitions have been exposed to the elements for years, and they have lost all of their identifying marks from corrosion.

PINS, as a field NAA technique, employs neutrons from a radioisotopic californium-252 source to interrogate the contents of a munition. The neutron passes through the munition's steel casing, scatters, slows down, and is captured by the nuclear of one of the chemical elements within the munition. The capturing nucleus then emits one or more gamma-rays. Additional gamma rays can be produced by inelastic scattering reactions. These energetic gamma rays can also penetrate steel easily, and they escape the munition and are recorded by a gamma-ray detector.

Nearly all chemical elements have a unique and well-known neutron-induced gamma-ray spectra signature. Because of their intimate connection with basic and applied nuclear physics, detailed tables of nuclear energy levels[2] and gamma-ray spectra catalogs and tables[3] have been compiled, peer-reviewed, and frequently updated by physicists. PINS decisions are based on intensities and ratios of intensities from the elements As, B, C, Ca, Cl, Fe, H, K, Na, P, S, Ti, and Zn.

As an example, consider a neutron interaction inside a high explosive-filled munition. Explosive compounds are rich in nitrogen-14 (^{14}N), the predominant stable nitrogen isotope. When a thermal neutron is captured by a nucleus, the following reactions occur:

$$n + {}^{14}N \rightarrow {}^{15}N^* \rightarrow {}^{15}N + \gamma.$$

A nitrogen-15 nucleus is produced in an excited state, denoted by the star; in less than a picosecond it de-excites to its ground state by emission of one or more gamma rays, of energies up to 10,829 kilo-electron volts (keV). All military explosive compounds are rich in the element nitrogen, and one would observe nitrogen capture gamma rays from explosive-filled items.

Similarly, the organophosphorus nerve agents are identified by detection of hydrogen and phosphorus gamma rays in the appropriate ratios. Blister agents, such as mustard gas, are identified by the observation of chlorine, hydrogen, and either sulfur, nitrogen, or arsenic gamma rays, again in distinctive intensity ratios.

Of strong relevance to the development of low-cost methods for explosive detection, PINS employs a five-microgram californium-252 source, chosen over accelerator-type neutron generators for economy and reliability. It produces ten million neutrons per second. The source is doubly encapsulated, and it is certified as 'special form' in accordance with the regulation of the International Atomic Energy Agency (IAEA), permitting its shipment worldwide by common carrier.

The *detection* of buried landmines appears to be a far more difficult problem than the identification of their contents once located[4]. We propose two nuclear techniques that might assist the search process. Both involve neutrons interacting in hydrogen.

The thermal neutron capture cross-section in nitrogen is about 80 millibarns. The hydrogen cross-section is four times larger, and the capture reaction rate is almost 400 times larger for hydrogen than for nitrogen. Since all military explosives contain 2-3% by weight hydrogen, it seems this element might provide a signature sufficiently intense for mine searches.

One search method would simply scan a PINS - like device over the ground, measuring the ratio of the hydrogen peak to the silicon peak. We recently tried this at INEEL, and obtained the following results. A simulated Russian PMN anti-personnel mine was constructed and filled with fertilizer as an explosive simulant. Two measurements were conducted: one with the PINS detection directly over the simulated landmine, another, 30 cm away from the center at the mine. The simulated mine itself was buried in crushed rocks; the top of the mine was level with the rock surface.

distance (cm)	Count rate (Hz)		Si/H ratio
	Si 1779	H 2223	
0	7.82 (0.55)	7.80 (0.51)	1.0 (0.1)
30	9.17 (0.58)	5.24 (0.43)	1.7 (0.3)

As shown in the table above, the hydrogen signal increases and the silicon falls when the instrument was directly over the simulated mine, as expected. A mine-search instrument could be designated on this method using scintillating gamma-ray detectors for economy and greater detection efficiency.

Another possible mine search method exploits the kinematics of neutron scattering in hydrogen. An unmoderated Cf-252 source and a thermal neutron detector, such as helium-3 tube, would scan the ground. An increased counting rate signals the presence of hydrogen. This simple technique is widely used in industry to measure bulk hydrogen, and recently Schänzler and colleagues have demonstrated its application to munition fill identification. Because thermal neutron detectors are inexpensive, and the read-out electronics simple, this approach is well suited to the construction of inexpensive arrays for imaging-buried landmines.

The principal technical challenge in humanitarian landmine clearance is the *detection* of landmines. Simple nuclear methods may compliment existing search techniques to improve the overall probability of detection and to reduce the false positive rate of other technologies.

In addition, nuclear methods are a proven method for identification of UXO such as landmines.

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