Evaluation of PELAN as a Confirmation Sensor for Landmines and Explosives

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PELAN (the initials of Pulsed Elemental Analysis with Neutrons) is a device that has been developed to identify a landmine through the elemental constituents of its explosive. PELAN uses neutrons as the probing particles. The incident neutrons interact with the nuclei of the various chemical elements in the mine or other explosive, emitting characteristic gamma rays that act as the fingerprints of the various chemical elements. PELAN is capable of identifying with the same probability of detection all types of high explosives (TNT, RDX etc.) either in plastic or metal encased landmines. Results of its evaluation with blind tests in Croatia and the US using anti-personnel and anti-tank landmines will be presented, as well as results from using PELAN for identifying the fill of suspect munitions.

I. INTRODUCTION

High explosives (TNT, RDX etc.) are composed primarily of the chemical elements hydrogen, carbon, nitrogen, and oxygen. Many innocuous organic materials are also composed of these same elements. The elemental ratios (e.g., C/O, O/N) and concentrations of these elements however, are different in explosives than in most of the innocuous materials. It is thus possible to identify and differentiate e.g., TNT from a tree root. The problem of identifying explosives is thus reduced to the problem of elemental identification.

Nuclear techniques show a number of advantages for non-destructive elemental characterization. These include the ability to examine bulk quantities with speed, high elemental specificity, and no memory effects from the previously measured object. In particular, neutrons have been utilized for several decades to measure the above mentioned elements. Neutrons have high penetrability and easily traverse the overburden under which a mine might be buried (Fig. 1). The incident neutrons interact with the nuclei of the various chemical elements in the mine, emitting characteristic γ rays which act as the fingerprints of the various chemical elements. The γ rays are detected by appropriate detector(s), capable of differentiating the γ rays according to their energy and their quantity.

The chemical elements of interest for the detection of explosives require different neutron energies in order to be observed. Elements such as H, Cl, and Fe are best observed through nuclear reactions initiated from very low energy neutrons. Other elements such as C, N, and O require neutron energies of several MeV to be observed at all. To satisfy this, a neutron source is required that can produce the high energy neutrons for measurement of elements such as C, N, and O, and low energy neutrons (energy ~ 0.025 eV) for elements such as H, Cl, and Fe. Such a task can be accomplished with the use of a pulsed (D,T) neutron generator.

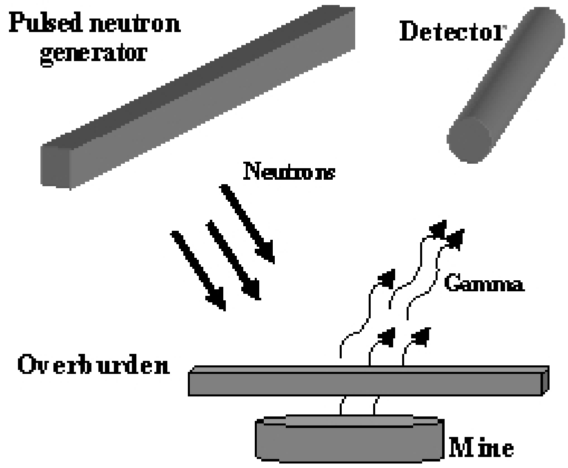

FIG. 1: Pictorial presentation of the PELAN principle.

II. TECHNOLOGY DESCRIPTION

The PELAN system [1] (the initials of **P**ulsed **El**emental **A**nalysis with **N**eutrons) consists of an electronically controlled pulsed neutron generator (the upper cylindrical part in Fig. 2) that creates neutrons through a deuterium-tritium reaction, after the deuterium ions are accelerated onto a tritium target. This exothermic fusion reaction releases a charged alpha particle and a 14.1 MeV fast neutron. The alpha particle does not travel far before being stopped within the generator's enclosure and the neutrons are emitted isotropically and penetrate deep into the object of interest causing secondary reactions that result in the emission of gamma rays. As mentioned previously, the gamma rays are generated with specific energies characteristic of the target nuclei. These gamma rays are collected by an inorganic scintillator (located in the bottom part of the rectangular PELAN component in Fig. 2) coupled to a photomultiplier tube (PMT) that converts the incident gamma rays to electrical signals. These electrical signals are analyzed by a multichannel analyzer (MCA) and a histogram of

FIG. 2: PELAN System.

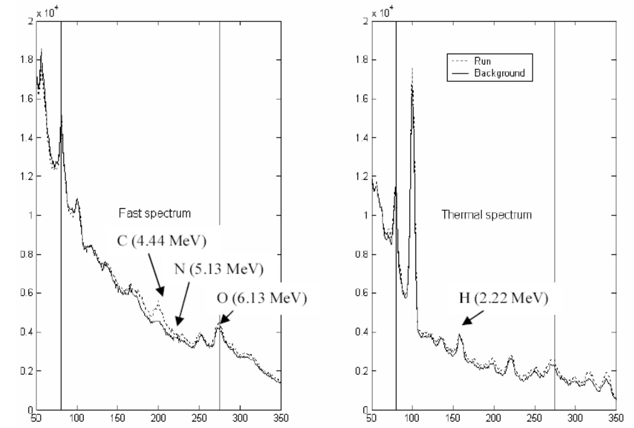

FIG. 3: Example of fast and thermal spectra measured with PELAN.

the number of recorded gamma rays vs. their energy is created. The scintillator is protected from direct fast neutron bombardment by the use of a shielding stack between the detector and the source of radiation. The purpose of the shielding stack is to minimize the number of neutron interactions within the detector, leading to a lower background (noise).

The D-T neutron generator provides a beam of pulsed 14 MeV neutrons. During the neutron pulse, the gamma-ray spectrum is primarily composed of gamma rays from nuclear reactions on elements such as C, N, and O, and is stored at a particular memory location within the data acquisition system. Between pulses, some of the fast neutrons that are still within the interrogated object lose energy by collisions with light chemical elements. When the neutrons have energy less than 1 eV, they are captured by such elements as H, N, and Fe and result in emitting characteristic gamma rays. The gamma rays from this set of reactions are detected by the same detector but stored at a different memory address within the data acquisition system. Figure 3 shows a gamma-ray spectrum produced from fast neutron reactions (left spectrum) and a spectrum produced from thermal neutron reactions (right spectrum).

PELAN is a man-portable unit weighing under 84 lbs (38 kg), and is easy to deploy, breaking into two components, the neutron generator and the electronics base. Other PELAN features include:

- Five minute data acquisition and analysis.
- No radiation is emitted with neutron generator OFF.
- Can be operated wireless or with a cable from a distance of 45 meters.
- Immune to ambient temperature changes.
- Can operate with its internal battery for up to 6 hours.

Regarding radiation safety, a 8 meters exclusion zone is required around PELAN during the 5 minute measuring time. Redundant hardware and software controls instantaneously interrupt the operation of PELAN if a person inadvertently enters into the exclusion zone. Such hardware controls are beam interrupt or motion sensors, commercially available.

III. PELAN EVALUATION TESTS

A. Landmine Confirmation

1. *Croatia*

The International Atomic Energy Agency (IAEA) evaluated PELAN as a mine confirmation sensor in November 2002 near Zagreb, Croatia, at a test minefield of the Croatian Mine Action Center. The evaluation included one type of anti-tank (AT) mine, and three types of anti-personnel (AP) mines. Their types and characteristics are shown in Table I. These are typical mines, found in many mine fields in Croatia. The AP mines were buried at depths up to 15 cm, and the AT mine up to a depth of 20 cm. The soil moisture varied between 25% and 29% (weight). PELAN was operated with its lap top computer through a hard-wired connection from a distance of at least 20 meters. PELAN was asked to check 127 "flagged" positions that could contain one of the above mines.

The analysis of the 2002 Croatian blind tests gave

- **P**robability of Detection: $P_d = 0.85$.
- **P**robability of False Alarm: $P_{fa} = 0.23$.

As stated in the report to IAEA by the test supervising team [2]:

> Although the time was inadequate for systematic testing, we can say that with control of system drifts, PELAN should have no problems with recognizing antitank mines

> buried under 15 cm of soil. In that case also recognition of small antipersonnel mines such as PMA-3 under 5 to 10 cm of soil will be quite probable. Multi-elemental analysis is a strong point of PFTNA analysis, as was demonstrated in the case of TMM-1 and PMA-1 mines. Although we stress the need to improve the reproducibility of data, we believe that this test has demonstrated great potential of PELAN for humanitarian demining.

2. *Yuma Proving Ground (Arizona)*

In 2003, a series of blind tests of PELAN as a landmine confirmation sensor were performed by the US Department of Defense at Yuma Proving Ground (YPG-see Fig. 4. Several types of AT mines were buried at various depths and with different types of overburden. Both types (plastic or metal casing) of mines were used. For the blind tests, a total of 100 "flagged" ground positions were interrogated. Prior to the blind tests, a total of 13 ground locations either containing calibration AT mines or no mines were interrogated. Based on the calibration results, a standard PELAN decision tree was modified to fit the calibration data. Following the calibration, 100 locations were interrogated. At the end of each 5-minute measurement cycle, this decision tree was used to identify each location as either containing a mine or not. The report to the US Dept of Defense by the independent evaluators of the PELAN data states [3]:

> IDA used the contractor's mine/clear designations on the 100 spots to obtain Pd and Pfa results. In most cases only a single measurement was taken at a spot; in some cases more than one measurement was made to gauge the repeatability of the measurements (in some of these the background spectrum was updated).

The P_d, P_{fa} results for the full blind test data set follows:

- The overall detection probability was measured to be $P_d = 0.90$, with a 90% confidence level (CL) statistical spread of $0.96 - 0.80$.

TABLE I: Characteristics of landmines used in the PELAN evaluation in Croatia.

Mine type	Explosive mass (g)	Total mass (g)	Explosive	Casing
TMM-1	5600		TNT + tetryl booster	metal
PMA-2	100	135	TNT + RDX booster	plastic
PMA-3	35	183	TNT	plastic
PMA-1	200	400	TNT	plastic

FIG. 4: PELAN on a cart used for the blind tests at Yuma Proving Ground.

- The false alarm probability was measured to be $P_{fa} = 0.14$, with a 90% CL statistical spread of $0.24 - 0.07$.

After the completion of the tests at Yuma, the collected data were also analyzed using the Generalized Likelihood Ratio Test (GLRT). Figure 5 shows the ROC curve obtained with the GLRT method. One can see that the curve has a very sharp rise, reaching about 0.94 detection probability at about 0.06 false alarm rate. This high quality result is due to a combination of having good experimental results, a representative training sample, and using an efficient statistical analysis method. Figure 5 also shows the point obtained from the Boolean Decision Tree.

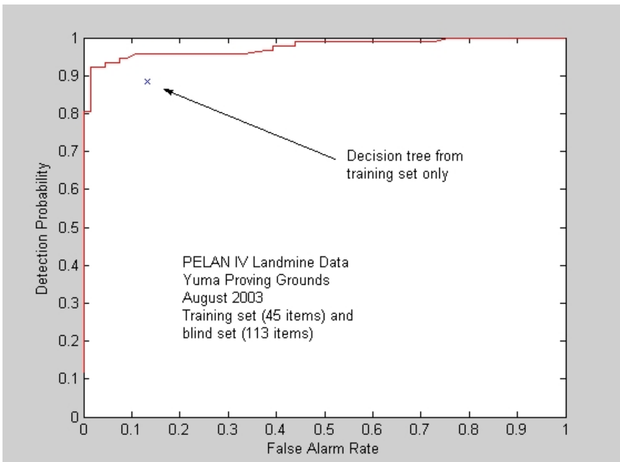

FIG. 5: ROC curve for the YPG data. The x point on the curve is the one obtained from the Boolean Decision Tree.

FIG. 6: PELAN interrogating an MK83 bomb at the White Oak Laboratory.

B. Explosives- Determining the fill of unexploded ordnance

PELAN was employed by the US Naval Explosive Ordnance Disposal Technology Division (NAVEODTECH) to aid in the cleanup of the US Navy's White Oak Laboratory, located in White Oak, MD [4]. Over the course of several investigations and remediation actions at this facility, several thousand ordnance items were recovered. Although the fill of most of them could be identified by visual inspection, there remained approximately 130 000 kg of ordnance items that could not be identified because they were sealed and could not be properly inspected. These ordnance were thought to be inert but were not documented as such. PELAN was used by the US Navy to interrogate 646 ordnance items (see Fig. 6) ranging in size from an 81 mm shell (approximate fill 1 kg) to an Mk 84 bomb (approximate fill 500 kg). The interrogation of the items by PELAN found that all 646 items contained inert fills. After the PELAN interrogation was completed an independent contractor responsible with the disposal of the items confirmed that all 646 items were indeed inert.

IV. CONCLUSIONS

The use of pulsed neutrons in PELAN has been shown to be an effective method for the detection of explosives. PELAN's strength lies in its quantitative multi-elemental analysis, which allows it to distinguish explosives from other substances that contain mostly the same chemical elements. For landmines, its current role is that of a confirmation sensor. For recovered ordnance, PELAN can differentiate between an explosive or inert fill, and in many cases can identify the fill. The mine casing does not present a hindrance to PELAN's ability, indeed PELAN can tell with a very high probability of detection whether the detected mine is plastic or metal encased. The current PELAN configuration allows its operation from a distance as large as 45 meters. It can be mounted to a robot and guided to within a few inches/centimeters from a "flagged" position.

Based on the results of the above blind test results, major performance characteristics that differentiate PELAN from other non-nuclear methodologies used for landmine confirmation and filler identification in shells are:

- Capable of detecting and differentiating plastic from metal landmines
- No soil dependence
- Not affected by soil temperature
- Not affected by variable elements (wind, rain)
- Not affected by mud on sensor
- Not affected by the time of day
- Not affected by dielectric properties of soil
- Not affected from up to 2.5 cm of standing water over the interrogation area

[1] G. Vourvopoulos, P. C. Womble, "Pulsed Fast/Thermal Neutron Analysis: A Technique for Explosives Detection", TALANTA **54** (2001) 459-468.

[2] V. Knapp, "Neutron explosive detector and its perspective in humanitarian demining", International Symposium Humanitarian Demining 2004, Sibenik, Croatia, April 21-23. PELANs-ibenik-publication

[3] F. Rotondo and S. Briglin, Results of the PELAN Confirmation System Test at YPG, Institute for Defense Analyses Science and Technology Division, Nov. 2003 (unpublished).

[4] S. Steward and D. Forsht, "Use of Nuclear Techniques to Determine the Fill of Found Unexploded Ordnance", Applied Radiation and Isotopes **63** (2005) 795-797.