DETECTION OF LAND MINES USING FAST AND THERMAL NEUTRON ANALYSIS

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ABSTRACT

The detection of land mines is made possible by using nuclear sensor based on neutron interrogation. Neutron interrogation allows to detect the sensitive elements (C, H, 0, N) of the explosives in land mines or in unexploded shells : the evaluation of characteristic ratio N/O and C/O in a volume element gives a signature of high explosives. Fast neutron interrogation has been qualified in our laboratories as a powerful close distance method for identifying the presence of a mine or explosive. This method could be implemented together with a multisensor detection system - for instance IR or microwave - to reduce the false alarm rate by addressing the suspected area.

Principle of operation is based on the measurement of gamma rays induced by neutron interaction with irradiated nuclei from the soil and from a possible mine. Specific energy of these gamma rays allows to recognise the elements at the origin of neutron interaction. Several detection methods can be used, depending on nuclei to be identified. Analysis of physical data, computations by simulation codes, and experimentations performed in our laboratory have shown the interest of Fast Neutron Analysis (FNA) combined with Thermal Neutron Analysis (TNA) techniques, especially for detection of nitrogen ^{14}N, carbon ^{12}C and oxygen ^{16}O. The FNA technique can be implemented using a 14 MeV sealed neutron tube, and a set of detectors.

The mines detection has been demonstrated from our investigations, using a low power neutron generator working in the 10^8 n/s range, which is reasonable when considering safety rules. A fieldable demonstrator would be made with a detection head including tube and detectors, and with remote electronics, power supplies and computer installed in a vehicle.

INTRODUCTION

Industrial neutronics department at SODERN includes development and manufacturing of industrial sealed neutron tubes and industrial neutron generators, characterized by :
- safety in use : no emission in "off" state, very low quantity of radioactive material in a sealed envelope,
- a capability to be operated in continuous or in pulsed mode,
- a very high energy of emitted neutrons, in a nearly monoenergetic form (at 14 MeV or 2.5 MeV),
- the larger tube lifetime on the market, giving a lower cost per emitted neutron,
- a large range of fully automatic and safe generators, one of them is transportable and cheap (the GENIE 16), and one of them is the most powerful sealed tube neutron generator on the market (the GENIE 46).

Starting from these generators, SODERN is developing different applications, either alone or in collaboration with other industrial partners :
- explosives and drug detection in parcels, explosives detection in landmines,
- nuclear waste inspection,
- bulk materials analysis using prompt neutron excitation and gamma rays detection,
- chemical weapons inspection,
- neutron radiography for non destructive testing of sub-assemblies (plane wings, pyrotechnic devices, turbine blades, ...).

The ongoing interest in nuclear techniques for mine detection is related to their capability to detect in depth, and their capability to recognize the common element in all mines, the explosives. Thermal neutron analysis (TNA), or a combination of fast and thermal neutron interrogation analysis (FNA and TNA), are the only effective methods to detect explosives hidden in the soil. These methods have been qualified in our laboratories as powerful close distance methods for identifying the presence of an explosive, from all of its sensitive elements : carbon, nitrogen, oxygen, hydrogen Nevertheless, the time to detect an explosive is quite high, and this concept is only valid for confirmation of a threat.

SODERN has started the study of a FNA/TNA mines detection system some years ago, and has developed the different pieces of technology for this use. A fieldable demonstrator could be designed in a multisensor concept and installed on a vehicle. The alarm would be given by observation in visible and infrared range, and by metal detectors and ground penetrating radars. The confirmation of the alarm would be given by a mine detection system using a FNA/TNA detection system.

DETERMINATION OF A SUITABLE METHOD

The principle of nuclear methods is to irradiate the soil with possible mines by an energetic radiation, and to detect the response of the atoms which are characteristics of explosives. In order to detect mines in depth, an energetic radiation is required for interrogation such as 14 MeV neutrons from sealed tubes. Compared to 14 MeV neutrons, neutrons from isotopic sources are less energetic, and emission cannot be interrupted after use. In addition, detection of all elements from mines is only possible using neutrons at energies higher than 9 MeV. Table A shows the interest of such high energy neutrons in FNA mode. The 14 MeV neutrons can be emitted in pulsed mode, allowing to separate the different interactions by the time at the microsecond scale. The practical interest of this principle is connected to the low cost of the neutron source, to the very low tritium quantity inside the neutron tube, for a safe use

even in hostile environment, and to its capability to work simultaneously in FNA and TNA modes.

Other nuclear methods were considered in the literature since 10 years. A survey of these methods is described in one of our papers (ref. 1) published at Edinburgh Conference for Detection of Abandoned Landmines, in October 1996. Nevertheless, no equipment was developed, because of too much complexity, too much volume or weight, or too much cost. Only one equipment was manufactured by Gozani and al. (2, 3), in a TNA form using a 252 Californium neutron source, but the only detection of nitrogen of explosives and the non interruptible source are strong limitations to its use.

In order to take advantage of pulsed 14 MeV neutrons emitted from sealed tubes, SODERN's team has selected the two possible principles :
- either to design a pulsed TNA equipment, for detection of H, N, and some elements of the soil,
- or better to design a pulsed FNA/TNA equipment, for detection of all elements in the mines and in the soil.

DESCRIPTION OF THE FNA/TNA MINES DETECTION SYSTEM

Neutrons at 14 MeV are emitted from a small neutron tube in any direction (4). Neutrons are scattered and captured by atoms from the soil and the possible mines, as well as from the shielding of the equipment (see fig. 1). Emission of energetic gamma rays between 1 and 12 MeV is the, collected by a set of collimated detectors. Each of these detectors delivers pulses, the height of which is proportional to the gamma ray energy. Using a fast counting electronics for each detectors, and using a gate supplying the suitable time windows, some spectra (see fig. 2) are obtained in the following way :

1. During the pulses, typ. 10 to 50 µs, only gamma rays from inelastic scattering of 14 MeV neutrons are collected, giving a quite pure FNA spectra,

2. After the pulses, typ. 50 to 300 µs, nearly only gamma rays from thermal neutron capture are collected, giving a quite pure TNA spectra,

3. After a pulse train, typ. 50 ms, the tube is turned off : gamma rays from delayed fast (FNAA) and thermal (TNAA) neutron activation are detected, delivering additional useful signals as well as delivering the residual activation noise to subtract to measurements obtained in FNA and TNA.

The FNA/TNA detection system is composed by the following sub-assemblies :
- an irradiation/detection head (see fig. 1) including the neutron emission module with its small tube, the set of detectors, the shielding between tube and detectors, the collimators for neutrons and for gamma rays, and the minimum shielding for operators safety when not used in a tele-operation mode. This head is placed in front of the vehicle.

- an electronics including neutron tube power supplies, measurement electronics for detectors, and computers. These elements are located inside the vehicle in a local operation mode and connected to a transmission equipment in a tele-operated mode.
- the cables between these elements.

Experimentation of a mock-up for such a system was made, using a neutron tube emitting 10^8 n/s at 14 MeV, and a BGO detector. This tube was used in continuous mode and in pulsed mode. Pulsed mode is more interesting : during neutron pulses (FNA), inelastic scattering of neutrons induces characteristic gamma rays of carbon, oxygen, nitrogen, silicon, aluminium, ... and after neutron pulses (TNA), neutron capture induces characteristic gamma rays of hydrogen, nitrogen, calcium, ... By splitting detection time windows in two classes, gamma ray pulses detected during FNA periods were directed to a multichannel analyser section A (FNA window), and those detected during TNA periods were directed to the multichannel analyser section B (TNA window). A careful comparison of obtained spectra in each window, with respect to preceding spectra in memory and to stored spectra from a data base, allows to detect the N/O, C/O, H/O ratios and to compare them with stored values. An example of inelastic scattering spectra (FNA window) is shown on figure 2. Neutron pulses duration was 3 µs, repetition rate being 1 kHz. Contributions of oxygen at 6.13 MeV, carbon at 4.14 MeV and silicon from the soil at 1.78 MeV are easy to detect after a small computation time. The observed maximum depth is 20 to 30 cm, depending on hardware materials and on allocated time for detection.

PERSPECTIVES

The FNA/TNA mines detection system seems to be very interesting for confirmation of an alarm :
- the main sub-assemblies are now available at relatively low cost : the GENIE 16 neutron generator with its SODITRON tube, the detectors, the specially designed fast electronics, the deconvolution softwares in reference conditions,
- in case of an accidental explosion, only a low quantity of tritium (120 GBq, or 3.3 Ci) may be released, compared to the risk of using a Californium permanent neutron source,
- the tube is turned off after operation : no more neutrons are emitted, and the residual activation of the neutron probe is very low,
- if more neutrons are required for a specific operation, then the tube may be operated up to 2.5 times emission.

We are now working on data handling and computation algorithms, in order to deliver a simple information after comparison of results with data stored in the computer : "mine detected, either small and on top or large and in depth, with x % confidence level".

We hope to be supported in our work, and to develop a fieldable demonstrator in a multisensor concept, installed on a vehicle. The FNA/TNA mines detection system would then confirm the alarms delivered by the other sensors.

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TABLE 1 -Some NAA measurement methods for explosives detection

Neutron energy Neutron sources examples	14 MeV D-T tubes	1 to 8 MeV D-D tubes (2,5 MeV) Sources 252Cf (2,4 MeV) Sources Am/Be	<1keV and thermal neutrons All kind of neutron sources + moderator
Detection modes: 1- Prompt modes —>physical interaction	FNA (Fast Neutron Analysis): Elastic or inelastic scattering <13 MeV Nuclear reaction with threshold < 13 MeV Neutron capture after slowing down	FNA (Fast Neutron Analysis): Elastic or inelastic scattering <some MeV Nuclear reaction with threshold < some MeV Neutron capture after slowing down	TNA (Thermal Neutron Analysis): Thermal neutron capture
2- Delayed modes —>physical interaction	FNAA (Fast Neutron Activation Analysis) High, medium, and low energy activation	FNAA (Fast Neutron Activation Analysis) Medium and low energy activation	TNAA (Thermal Neutron Activation Analysis) Low energy activation
Detected explosives elements C, H, O, N, +.....	C, H, O, N, Cl, P,Al ...	H, N, Cl, P,Al... C: hardly or not detected O: not detected	H, N,Cl... C: not detected O: not detected
Neutron collimation —>directed beam capability	yes	yes	no
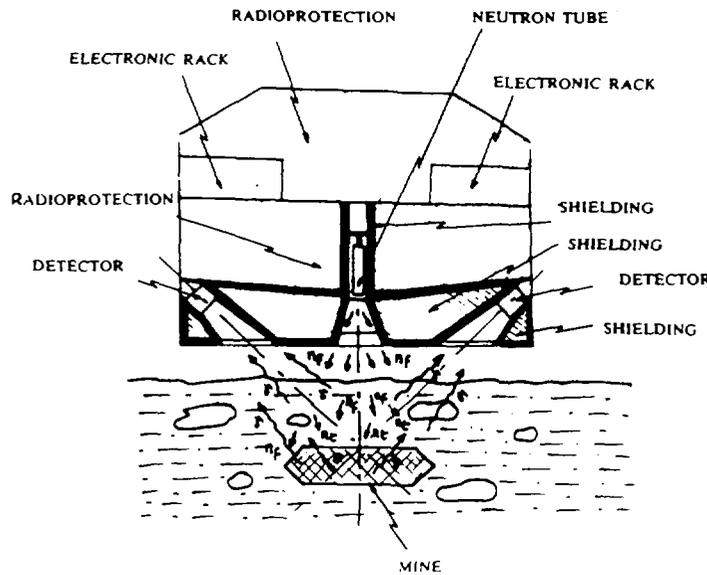
Fig.1:FNA/TNA mine detector: schematics of the irradiation/detection head
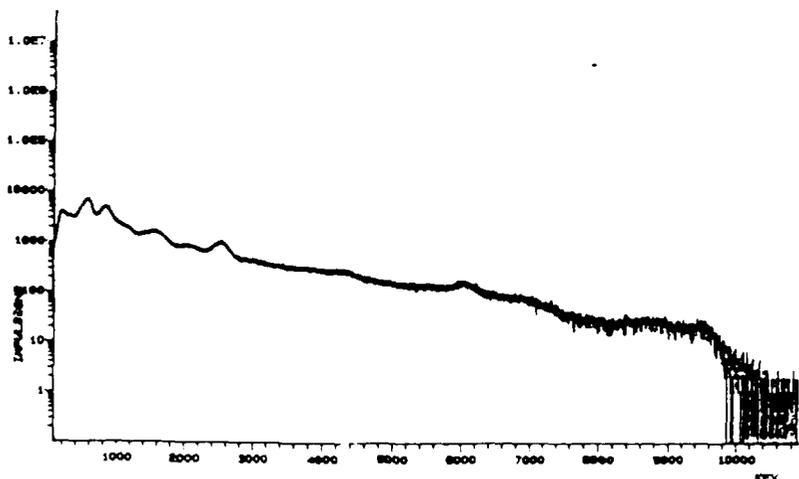
Fig.2: Example of an inelastic scattering spectra, from a mine simulant in the soil

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