Landmine Detection by Associated Particle Imaging Neutron Technique:
Lab and Field Results

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EADS SODERN specializes in Neutron Instrumentation since 1962. Its first Associated Sealed Tube Neutron Generator (APSTNG) was designed and manufactured in 2003 for the purpose of new concepts assessment in neutron analysis. Then, in the scope of a project with the French Délegation Générale à l’Armement (DGA), a study of the land mine detection problem was done and led to the realization of a field demonstrator based on Associated Particle Imaging (API) technique. Preliminary results of such study are presented.

1. Introduction

A first generation demonstrator has been used and assessed for anti tank mines detection in the field (a military test area) in November 2004. A second demonstrator has been designed in 2005 and delivered in October 2006 to the German and French project called MMSR Sydera. The aim of this project is the development of a full system for mine detection and neutralization based on several vehicles with several embedded sensors.

2. Story of Landmine Detection at SODERN

The idea of detecting buried land mines (and explosives generally speaking) with neutron interrogation exists since physicists found out that neutron can help analyze material. More advanced ideas arrived when it became possible to envision that neutron instrumentation components as neutron generators, gamma detectors and electronics could be enough integrated and ruggedized to leave the lab and go to the field.

First studies with SODERN neutron generators were made in 1990 and 1991. The goal of these studies was only an assessment of the capabilities of the neutron technique to solve the problem of mine detection and not to build any specific equipment like a demonstrator. At that time the conclusion was that a signal to detect explosives in the soil exists and could be measured but the noise would be extremely high and we didn’t see, at that time, a way to build an operational system with the existing components. Associated Particle technique was evoked but too many things were to be developed and tested to build a system rapidly.

The following years saw the development of neutron analysis tools like portable and improved neutron generators and data acquisition electronics and further the development of a raw material neutron analyzer designed first for the cement industry. Such industrial analyzers are now in a regular production phase.

In 2002 a new study on landmine detection was launched with the idea of using Associated Particle Imaging and the goal of going on the field with a demonstrator. The specifications were to develop a landmine detector for military purpose (anti tank mines) able to confirm the presence or the absence of a mine in a given location (confirmation sensor) in a reasonable time. These tests were eventually done in November 2004.

3. Main Components

The Associated Particle Tube has been developed with two kinds of alpha detector:

- silicon detectors
- scintillator detectors

The tubes with silicon detectors had two or three silicon diodes fixed inside the tube in front of the target. These alpha detectors were made by Canberra at Olen (Belgium). The diameter
was about 20 mm and the diodes were at 50 mm from the center of the target which had an angle of 45° with respect to the ion beam. The read out electronics was SODERN made.

The tubes with scintillator used YAP (Ce) crystals. The first one was made with the collaboration of INFN Padova who designed the alpha detection tube sub-assembly. We used commercially available PMTs and we designed the specific read out electronics and software. The location of the alpha particle hitting the detector is calculated thanks to a principle of barycentric algorithm.

These Associated Particle Tube work with a voltage between 70 kV and 110 kV and a beam current between few microamps to 100 µA roughly. They are able to emit up to $10^8$ n/s. Their life time has not been experimentally measured but according to their design (VHV structure and target technology) we assume it could be much more than 10000 hours at this output level.

For the gamma acquisition we have used both BGO detectors and NaI detectors. It is difficult to say which of them is the best choice economically and technically speaking. One can conclude that the NaI presents the best quality over cost ratio as BGO is the best technical choice if one prefers better spectra unfolding than time information.

Data acquisition electronics were developed by SODERN on the basis of electronics already developed for analyzers on which a Time-of-Flight functionality was added in order to acquire time coincidence events. The coincidence resolution we obtained is in the range of 5 ns. We consider this a domain where improvements can take place.

4. Principles of Design and Operation

The two landmine detection demonstrators are made of four main components: a detection head comprising the tube and gamma detectors, a set of cables, an electronic cabinet, a command-control PC.

The second demonstrator (see Fig. 1) has only few electronics boards in an external cabinet, all the main supplies having been installed in the head of detection. Its weight is about 300 kilograms and it has to be manipulated by a crane which has to control its relative position from the soil and the point to be checked. For the future version it can be chosen to put everything in the detection head (advantage: compactness, no external cables).

The first demonstrator used 4 BGO detectors (diameter 5" by thickness 3") and a tube with silicon diode alpha detector whereas the second used 6 NaI (4" × 4" × thickness 5") and a tube with YAP alpha detector. The imaging capabilities (thanks to alpha position sensitive measurement and Time-of-Flight measurement that allow knowing the location in the soil where the gamma comes from) are much higher for the second demonstrator than for the first.

Both demonstrators work on confirmation

<table>
<thead>
<tr>
<th>Soil Depth [cm]</th>
<th>Mine weight [kg]</th>
<th>Acquisition time [s]</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>5</td>
<td>15 s, 30 s</td>
</tr>
<tr>
<td>15</td>
<td>120 s</td>
<td>&gt; 120 s</td>
</tr>
</tbody>
</table>

Figure 1: The second demonstrator.
mode. They have to be put above the point to check at a distance (height) between 5 and 15 cm. After an acquisition time of 2 minutes, the operator gets on the PC the “advice” of the equipment on the presence or not of a mine. This information is given according to the measurement of the relative density in the soil of carbon (see Fig. 2 showing that particular case), oxygen and nitrogen. In the second demonstrator these density can be displayed on the operator screen: these images are made with 14 by 14 pixels and 4 images corresponding to 4 layers (first: 0 to −10 cm; second: −10 to −20 cm; third: −20 to −30 cm; fourth: beyond −30 cm) of soil are given.

5. Field and Lab Tests

The main results obtained in 2004 with the first demonstrator are given in Tables 1 and 2. The first results obtained with the second demonstrator in SODERN lab are given in Tables 3 and 4. More field tests are scheduled in 2007.
Table 3: Detection probability in various conditions.

<table>
<thead>
<tr>
<th>Mine Type &amp; Weight</th>
<th>Soil Type</th>
<th>Depth [cm]</th>
<th>Detection Probability</th>
</tr>
</thead>
<tbody>
<tr>
<td>AP 310 g</td>
<td>Sand</td>
<td>0</td>
<td>3 / 3</td>
</tr>
<tr>
<td>AC 7 kg</td>
<td>Sand</td>
<td>20</td>
<td>4 / 4</td>
</tr>
<tr>
<td>AC 7 kg</td>
<td>Sand</td>
<td>30</td>
<td>1 / 2</td>
</tr>
<tr>
<td>AC 5.6 kg</td>
<td>Gravel</td>
<td>10</td>
<td>1 / 1</td>
</tr>
<tr>
<td>AC 5.6 kg</td>
<td>Gravel</td>
<td>20</td>
<td>1 / 3</td>
</tr>
</tbody>
</table>

6. Perspectives and Conclusions

The results we have obtained are encouraging and show the good potential of neutron technology. It has been demonstrated, for the first time — as far as we know — that this complicated technology (neutron generator, gamma detectors, time of flight measurements) can go to the field (nevertheless it is not the final goal, the goal is to make something serving people). They encourage also to be and to stay modest: probably we will be able in the near future to have good results with antitank mines but antipersonnel mines will remain difficult to detect. Also our equipment will be heavy and cumbersome, not adapted to all possible situations.

Nevertheless the lessons learned by these two experiences are good and numerous and can help design a new generation with higher capabilities. These lessons concern mainly the signal acquisition (alpha detectors, gamma detectors, acquisition electronics) and its processing (software for unfolding spectra, software for 3D imaging, software for decision making). Good compromises on alpha position resolution, time resolution and alpha count rate have to be taken to obtain the best information for the decision making. These compromises could be not the same with those giving the best imaging capabilities (which are amazing). On a second time efforts could be done obviously to reduce the weight and the volume of the equipment.

As a result also these experiments give some ideas and also directly some tools to be tested on other applications (IEDs, Object screening).

Table 4: False alarm rate with 120 s acquisition time. The alarm rate represents the number of alarm set off versus number of test on soil without mine. Probability are given in the following row.

<table>
<thead>
<tr>
<th>Soil Type</th>
<th>Sandy Soil Alarm Rate</th>
<th>Average Soil Alarm Rate</th>
<th>Gravel Soil Alarm Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alarm Rate</td>
<td>0 / 7 (0%)</td>
<td>0 / 5 (0%)</td>
<td>0 / 12 (0%)</td>
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</tbody>
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