ULIS :
A Portable Device for Chemical and Explosive Detection

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Abstract - We are developing a new device for explosive and chemical detection using the Associated Particle Imaging (API) technology and based on a new Associated Particle Sealed Tube Neutron Generator (APSTNG) which specifications comply with one of the basic requirements of a portable device: it must be light. Our objective is to have a total weight lower than 25 kilos. This includes the neutron generator, its VHV supply, the detectors, the data acquisition system and all the electronics. Everything is in a suitcase that can be put near an object the contents of which one wants to know. Few minutes are enough to identify what is inside and to detect illicit materials as explosives or chemicals. The device will be globally described and the first laboratory results will be presented.

1. Context

For years the growth and marketing of neutron technology in the industry was to satisfy the need for material analysis. This marketing success is due primarily to the unique capacities of the neutron to provoke reactions with the atoms which allows the identification of these atoms by the gamma radiation emission which are created and secondly in the capacities of the technology and the industry to conceive and to realize instruments able to fulfil the safety regulations and industrial constraints.

The application of neutron technology in the field of Homeland Security (detection of illicit or dangerous materials, explosives, drugs, chemical weapons, nuclear materials or CRNE) are coming late with regard to the purely industrial applications (identified as "mining applications" in the broad sense) such as the on-line analysis of cement raw mix, coal, nickel, copper ore, and oil logging. There are now several hundred commercial neutron analysers installed throughout the world.

This development schedule is due to three major reasons:

1 – The need for detection of illicit materials is recent due to Homeland Security evolving requirements and threats. We can consider 9/11/2001 as a starting date, even if the subject was previously touched upon, in particular with FAA flight safety standards. The associated developments are also relatively recent.

2 - The technical objectives are much more difficult to achieve. Broadly speaking, the major difference is that in mining applications the customer desires to know the average composition of a sample of several kilograms, or even several tons in the conveyor belt analyzers, whereas in the Homeland Security applications the need is to identify the presence of a few hundreds of grams of a particular material in several kilograms (the weight of a piece of luggage) or in several tons (a maritime container for instance). In short, one asks in the first case what the object, in a whole, is composed from whereas in the second case one asks what

is the composition of each sub part of an object, with a given precision. The size of the subparts must be coherent with the nature of the threat which we wish to counter. And the common sense tells us that if we want to measure with the same relative precision the atomic composition of 500 grams and that of 50 kilograms, we need the same quantity of information in both cases. We shall thus need roughly 100 times more signal, for instance 100 times more detectors all things being equal in a typical application for Homeland Security than in a "mining" application.

3 - The context of safety and radioprotection is much more stringent because we generally have to operate in public areas (control of suitcase, container). Furthermore, while the public is familiar with X-rays, the same cannot be said with neutrons. And fears are strengthened by the lack of specific standards applying to new neutron instruments.

2. ULIS Introduction

Having developed a line of products for on-line analysis of raw materials (coal [1], cement [2], [3], [4], copper, nickel…), Sodern approached the detection of explosives with the realization of prototypes for the checked baggage and the control of containers within the framework of the European project Euritrack [5]. Today, Sodern proposes a portable system (ULIS) for the inspection of suspicious parcels (figure 1) or of abandoned luggage, capable of detecting explosives, chemical materials, radiological materials and, after an additional development, nuclear materials. This system is mainly dedicated to the table of equipment for bomb squads, but could also be part of the table of equipment (TOE) of Coast Guards, looking for illicit materials behind bulkheads or false walls.

The ULIS system (Unattended Luggage Inspection System) is the product of 6 years of research & development on the technology of associated particles (first tube with associated particles [APT] in 2003) and operates a new generation tube, which is lightweight and smaller than previous models, compatible with the requirements of portability. To achieve the best final performances, ULIS employs the best gamma scintillator detectors commercially available, based on lanthane bromide (LaBr3). In terms of safety to the operators and the public, ULIS will be compatible with the requirements of usual national regulations. A standard exclusion zone will be implemented around the instrument, and this exclusion zone will be smaller than that the zone imposed by the risk of detonation.

Figure 1

3. Physical and technological presentation

The ULIS system is a portable system appearing boxlike and a detection head which also has the shape of a carry-on sized suitcase. The detection head weighs approximately 30 kilograms. It must be placed by the operator beside the object to be inspected (see figure 1). It is powered by an internal battery with an average life of 4 hours, and connected by an Ethernet cable to a PC/laptop which constitutes the control unit of the system.

TABLE 1

TPA17 data sheet

Neutron energy : 14 MeV
Neutron flux : 10^8 n/s
Tritium content : 720 GBq
Maximum voltage (X or n) : 100 kV
Maximum current (X or n) : 150 µA
Ion source voltage : 0.5 to 2.5 kV
Alpha detection angle : 60°
Pulsed capability
Length : 280 mm
Weight : 900 grams

The detection head includes a neutron emission subassembly made of the APT17 neutron tube , the power supply, and the neutron tube associated electronics. The characteristics of the tube are described in the adjoining table. The neutron tube uses the fusion reaction deuterium-tritium, producing neutrons of 14 MeV, and is equipped with a scintillator-based alpha detector, integrated near the target. This alpha detector is intended for the detection of the alpha particle created with each neutron. This tube also has the capability to emit X-rays: the very high voltage is then used to accelerate electrons produced near the target towards the source of ions where their bremsstrahlung produces X-rays. By mechanical design (figure 2) the axes of main X-Ray emission and of main neutron emission are parallel so that the X-rays allow the creation of images of the object being analyzed by the neutron interrogation. This offers information of very high quality for the final decision-making process. The two features, X-ray and neutron emission, are performed one after the other.

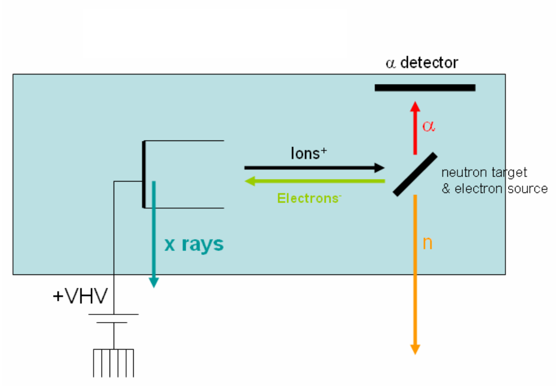

Figure 2 : Xn tube principle

The detection of alpha particles (figure 3) is made by a scintillator associated with a multi-channel photomultiplier. A barycenter calculation allows the computation of the localization of the interaction of the particle with the scintillator, with millimeter precision. The size of the scintillator is about 50 mm in diameter.

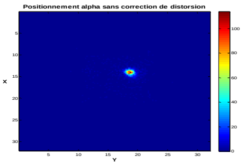

Image des alpha coïncidant avec des neutrons reçus par un détecteur neutron de 2 cm placé à 50 cm devant le tube.

Figure 3

The detection head includes a gamma detection subassembly made of gamma detectors and electronics for polarization and acquisition. The detection of the gamma rays emitted by the object being bombarded by neutrons is done by 2 LaBr3 gamma scintillator detectors located approximately 30 centimeters away from the target of the tube. These detectors, supplied by Saint-Gobain Crystals, have qualities of resolution in energy and time superior to those of all the commercially available crystals (some are better with respect to time resolution because of short constants of time of glow but have the handicap of bad resolutions in energy). The electronics for digital acquisition has been developed by Sodern. The time of the alpha and gamma events are compared with a precision of the order of 1 nanosecond, thus allowing the ability to sort out coinciding events.

It is worthwhile to note that the detection capability can be used independently of the neutron emission capability so that an active radiation source present in a suspicious object can also be detected.

The detection head includes a video camera which allows the operator to see the object in the same field of view as the neutron interrogation image. It also includes a processor unit to control the operation of the instrument. The acquired data (list of coincidences alpha gamma and energy) are first computed to locate the events in three dimensional space x, y & z. This space is divided into 16 x 16 x16 cubic elements (voxel) of 5 x 5 x 5 cm3 representing a maximum interrogation volume of 80 x 80 x 80 cubic centimeters(cm^3). In fact, considering the physics of the system (point-like target associated with a round-shaped alpha detector), the true volume of interrogation is a cone of 60° summit angle crossing the 3D matrix. The localization of events in this 3D space leads to the capture of the gamma spectrum of the simultaneous events for each of the elementary volumes (voxels) of the suspicious object. Every voxel is characterized by a gamma spectrum, emitted by the reaction of inelastic scattering of the neutrons. These gamma spectrum lead to the determination of the chemical composition of each voxel. Indeed, the vast majority of the Mendeleiev table elements deliver a specific signature, the only notable exception being hydrogen whose elementary nuclear structure (a proton) is not affected by the shock of a fast neutron.

After a preliminary calibration (the coefficients of which being constant for the life time of the instrument), it becomes possible to convert the intensity of the answer of an element in a mass expressed in grams. Complicated and iterative calculations allow to take into account and to correct the absorption of neutrons and gammas in the next voxels. This allows a fairly good evaluation of masses (or of densities because we are dealing with known volumes of 125 cm^3). From the knowledge of densities, we have access to the identification of materials or at least to a classification of the present materials. The capability to detect explosives by neutron interrogation relies on the capability to measure correctly the densities of every element which they are composed of. These elements are mainly carbon, oxygen, and nitrogen.

The absence of the hydrogen data is not important, because the densities of this element in the benign and dangerous materials are of the same order of magnitude. The decision algorithm uses and compares the data gained by acquisition and processing, with the data stored in an on-board material classification library. At the ultimate stage it states the opinion of the machine about the presence or absence of illicit or dangerous materials. This opinion in made on the basis of a likelihood calculation and of a comparison of the results with pre-established thresholds.

These results and calculations, as well as the various images: visible (coming from the camera), obtained with the X-rays (coming from the tube and detected by a digital plate detector to be placed behind the inspected object), and the neutron images are available on the screen of the PC which operates and controls the ULIS, connected with the detection head by a 30 meter long Ethernet cable. The " neutronic images " are not conventional images but in fact are 3D mappings filtered by element.

4. Concept of use and features

This instrument is intended for intervention teams to handle the alerts on suspect parcels or abandoned luggage. It helps them perform threat identification and resolution.

Considering the emission of neutrons, it is necessary to define around the equipment a safety exclusion zone. The safety distance will depend on national or specific regulations of the application but should be between 10m and 50m. Yet in the case of interventions implying a pyrotechnic risk, the distance of safety is typically bigger, generally 100 meters.

The idea is to take benefit of the inevitable existence of this explosion risk pyrotechnic exclusion zone by being inside as displayed by the figure 4. The dose rate during operation is very weak. Supposing that an acquisition is made in 5 minutes and supposing that the operator is at least at 11 meters from the equipment, he can make approximately 500 operations per year before reaching an accumulated equivalent dose to the one that he receives from the radioactivity of its own body (Source: NRC data) (figure 5).

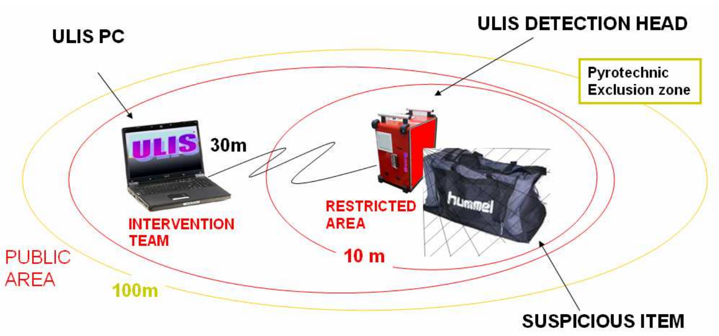

Figure 4

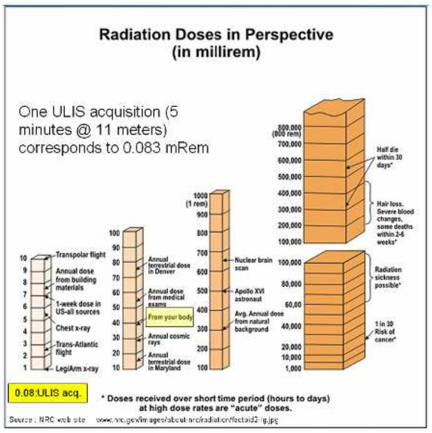

Figure 5

A typical operation consists of putting the detection head near the suspect object (figure 1) for evaluation. Once the detection head is next to the suspect object, the Ethernet cable is attached to both the detection head and the companion computer. The automated inspection sequence is then initiated by the operator. The first step of the interrogation process will be the verification or absence of radioactive sources in the object. This time can also be used for the implementation of barriers to create the exclusion zone. These barriers can be possibly linked with an optional safety interlock system. After few seconds or minutes, the operators can start the active interrogation and follow on the real-time progress of the interrogation operation.

The screen of the PC (figure 6) collects all the accessible information which permits the management of inspection and the analysis of the object.

Formula : C1 N2.1 O1.9
Density : 1.6 g/cm3
Mass : 1.2 kg

Explosive detected
Type : RDX

Acquisition 0
Progress 0 s
Operator SODERN
Status Idle
04/24/2009 14:13:08

Figure 6

The main feature of the ULIS device is the recognition of illicit materials contained in the internal software database. The operator has access to this information but also to the details which led the machine to the displayed results. These detailed results are established by the mapping in three dimensions of the inspected object for each of 14 elements analyzed by the equipment. These elements are, by increasing atomic number: Carbon (6), Nitrogen (7), Oxygen (8), Fluorine (9), Sodium (11), Aluminium (13), Silicon (14), Phosphor (15), Sulfur (16), Chlorine (17), Potassium (19), Calcium (20), Iron (26), Arsenic (33). They have been chosen because they mainly constitute either the environment of the illicit item (organic matters, mineral or metallic structures) or the illicit material (explosives: C N O, Chemical: F, P, Cl, K, …).

5. Performances

The measured and tested performances of ULIS will soon be establised in the field with real materials (including explosive materials). The detection goals are repeated in the table 2.

TABLE 2

Naked explosives 1 kg in 30s (PoD 95%, FAR 10%)
Naked chemicals / drugs 1 kg in 30s (POD 95%, FAR 10%)
In 10 kgs of benign material :
Explosives 1 kg in 2 mins (PoD 95%, FAR 10%)
Chemicals 1 kg in 2 mins (PoD 95%, FAR 10%)

The performances in terms of X-ray imaging are illustrated by the aside images (figure 7) that represent a fake Improvised Explosives Device - IED (left image) in a parcel and a block of TNT placed in a suitcase of clothes (right image).

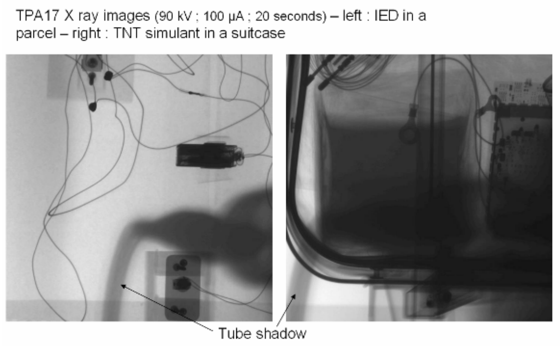

Figure 7

An example of acquisition is illustrated by the figure 8. It was realized in the laboratory of Sodern and shows the elementary results (results before processing segmentation and decision algorithms) obtained with three simple objects of 1 kg each respectively made up of oxide of arsenic, carbon and water. The figure represents in each pixel the spectral intensity of the elements arsenic, carbon, oxygen in the ninth layer - situated at a distance of 35 to 40 cm from the instrument for 4 increasing times of acquisition of 1, 3, 5 and 10 minutes. We notice the excellent answer (usual and well known) of carbon. We have the (unjustified) impression that the increase of time does not bring an important increase of the quality of the result for this element. The oxygen appears in 2 objects (oxide of arsenic and water) with a coherent different intensity according to the actual densities (oxygen density in the water being superior to oxygen density in the oxide of powder arsenic). The arsenic element that we can find in chemical weapons (lewisite), is more discreet than the two other elements but the suspicion of its presence is very real after one minute and the confirmation of this presence is then obtained quickly.

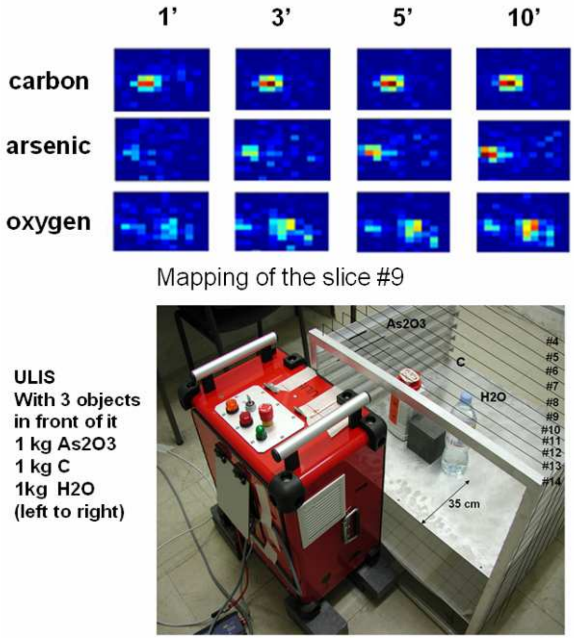

Figure 8

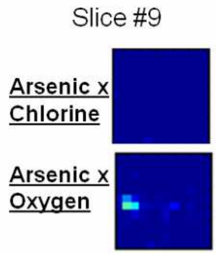

Figure 9

An interesting illustration of the potential of the data processing is brought by the figure 9 which presents the image of the algebraic product of the elementary spectral intensities of the arsenic and the oxygen in a case and the arsenic and the chlorine in the other case. This product shows quickly if a voxel contains two (or more) critical elements appearing in the composition of an unknown item: for example, in the case of the arsenic , it is interesting to verify that it is not associated with some chlorine, the risk of having lewisite then being high. Indeed if one of the elements misses in the voxel then the product has a low value, while if they are all present the product has a possibly important value. The figure shows us clearly that we are dealing with oxide of arsenic rather than with lewisite.

The figure 10 presents the specter obtained in one of the voxels where the presence of arsenic is indicated. The peaks of low energy signify the presence of arsenic. This specter corresponds to 10 minutes of acquisition with the reduced neutron emission of 3.107 n/s for a mass of arsenic of 75 g placed at approximately 40 cm from the target of the tube.

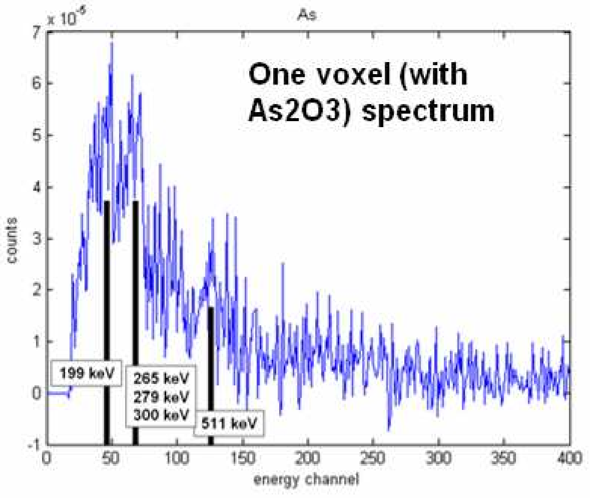

Figure 10

6. Perspectives

We intend to measure the actual performances of ULIS in operational configuration on the field with real explosive materials.

Version 1.0 of ULIS will offer automatic detection and identification of explosives and chemicals. Version 2.0 will add detection capability of nuclear materials by adding neutron detectors and by adapting the tube to create intense neutron pulses.

7. Conclusion

Sodern is a leader in the research and development of commercial industrial neutron analyzers for various industries. With the introduction of ULIS, Sodern is now completing the development of its first product for Homeland Security. This small man-portable system offers the benefit of modern technology in physics, electronics and algorithm science to provide unmatched performances in detecting explosives and chemicals. This equipment will also demonstrate the relevance & benefit of using neutrons (generally speaking) for Homeland security threats.

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