ADVANCED NUCLEAR TECHNIQUES FOR HUMANITARIAN DEMINING

G. Nebbia, G. Viesti, M. Cinausero, N. Cufaro-Petroni, G .D'Erasmo, D. Fabris, E. Fioretto, R. Fonte, M. Lunardon, I. Lazzizzera, G. Nardelli, G. Nardulli, M. Palomba, A. Pantaleo, L. Pappalardo, S. Pesente, P. Prati, G. Prete, S. Reito, A. Sartori, G. Tecchiolli, S. Zavatarelli, V.Filippini

Istituto Nazionale di Fisica Nucleare, Italy

INTRODUCTION

The global problem of many countries infested with landmines demands new technical solutions in the localization and identification of hidden explosives, expecially of anti-personnel landmines (APM).
It is believed that only a combination of different sensor systems can fulfill the requirements of humanitarian demining activities (1).
In this respect, nuclear techniques employing neutrons have proved to be a useful tool in the identification of commonly used explosives (2) which present an elevated concentration of nitrogen.
Characteristic γ-rays emitted in the thermal neutron capture reaction or in the fast neutron inelastic excitation of nitrogen nuclei have been proposed as the signature to identify hidden explosives (3). Compared to the other proposed non-nuclear techniques, the nuclear sensor is the only one allowing to discriminate mines from other underground objects.
The present challenge is to conceive a cost-effective,mobile detection system based on nuclear techniques which can be operated, in connection with other non-nuclear sensors, by non-specifically trained personnel in field conditions.
To this end one has to consider a number of specific requirements set by the United Nations to tailor the objectives of all R&D initiatives, such requirements can be summarized as follows.
The probability to localize anti-personnel mines without metal parts must be 99.9 %. It must be possible to locate small anti-personnel mines down to a size of 4 cm, buried in soil or grass at a depth of 10-20 cm. All mine localization equipment, apart from being used on-site, must also be serviced on-site. The use of the systems must be simple and the provided information clear. The actual cost of demining operations with the present techniques is about US$ 0.3-0.5 per square meter. As a result of R&D initiatives United Nations asked for a 10-fold reduction of these costs with a target of a 50-fold reduction by the year 2000.

The research program EXPLODET (EXPLOsive DETection) of the Istituto Nazionale di Fisica Nucleare is aimed at defining a conceptual design of such system. The EXPLODET program (1998-2000) will take advantage of modern technologies originating directly from basic nuclear research,including advanced detectors, high performance low-cost electronics andautomatic recognition algorithms.

An indoor test site equipped with ^{252}Cf source (10^6 neutrons/s)is operational at the Physics Department of the Bari University. A second site at the Laboratori Nazionali di Legnaro will host a 10^7 neutrons/s ^{252}Cf source.
Finally, a third test site located at the LENA facility of the Pavia University will host a portable electronic neutron source.
All these sites will be equipped with test benches made of soil, gravel, sand and other materials in order to reproduce at best the field operating conditions.
Preliminary R&D activities have already started at the Laboratori Nazionali di Legnaro using existing sources (10^4 neutrons/s) and the 7 MV VdG accelerator. Results are reported in the following.

TEST AT THE VDG ACCELERATOR

The γ-ray at E_γ = 10.8 MeV emitted in thermal neutron capture reactions on nitrogen nuclei has been proposed to identify hidden explosives (1). The cross section of the capture reaction is σ =75 mb at thermal neutron energy and the probability of the emission is 14 % per capture event. The energy of this γ-ray is relatively high with respect to the majority of the γ-ray emitted from the irradiation of common materials with thermal neutrons, making possible the identification of such events using low resolution scintillator detectors.
In beam tests have been performed using the CN VdG accelerator at LNL as a neutron source. The source reaction ^{9}Be(d,n) on a thick target was used, employing 1 MeV d beam of I=0.5 μA intensity. In those conditions about 10^7 neutron/s are produced with an average energy of 1.5 MeV. Primary neutrons are then thermalized in a moderator consisting of an inner shell of lead followed by high density poliethylene and by an outer shell of cadmium. The samples were placed at ϕ_{lab} = 0 deg. with respect to the beam direction at a distance of about 20 cm. The detectors were positioned also at about 20 cm from the sample position at an angle of 90 deg. with respect to the beam direction and shielded with poliethylene and lead.
The γ-rays produced in the irradiation of different samples have been first detected by using HPGe detectors in order to optimize the signal to noise ratio. Then NaI(Tl) (10cm x 10cm) scintillators were used.In Fig.1 we report the spectra relative to the irradiation of a

800 g Melamine ($C_3H_6N_6$) sample simulating the explosive and to a soil sample with the same geometry. In the energy range 9-11 MeV the spectrum shows structures only in the case of the Melamine irradiation.
In Fig.2 we show the spectrum obtained by subtracting from the Melamine spectrum the corresponding one relative to the soil sample. This difference spectrum shows very clearly peaks at 10.8 MeV (full energy) and 10.3 MeV (first escape) due to the neutron capture events in nitrogen. The lineshape of the structure is very well accounted for by calculation of the response function of our detector performed with the computer code GEANT (4).
The results reported in Figs.1 and 2 have been used to get a first insight on the measure time in field conditions, in the case of a nuclear sensor employing a ^{252}Cf source emitting about 10^7 neutron/second and 4 γ-ray detectors having efficiency comparable to that of the NaI(Tl) scintillator used here.
The actual estimate is that we should be able to reproduce the results in Fig.2 in less than 1 minute irradiation which opens the possibility of detecting small quantities of explosive in a reasonable time.

SCINTILLATION DETECTORS TEST

In the design of a landmine nuclear sensor, a detailed understanding of the sources of background in the gamma-ray energy region E_γ = 9-12 MeV is needed. An important contribution to the background will derive from capture reactions in the moderator, in the structural material and in the detector itself. Furthermore, when a ^{252}Cf source is used, the direct emission of prompt energetic γ-rays and neutrons in the fission process might contribute also to the γ-ray spectrum in the region of interest.
Measurements have been performed to determine the different sources of background at E_γ = 9-12 MeV by using a low activity ^{252}Cf source (about 10^4 fissions/s). The fission source was placed at the center of a barrel made by six BaF_2 sintillation detectors having exhagonal shape 48 cm^2 surface, 12 cm thick.
Standard scintillation detectors, already available in the laboratory, have been placed at about 80 cm from the fission source.The time difference between the detector and the (delayed) BaF_2 signals was used to discriminate prompt gamma-rays from fast neutrons and other delayed events. Furthermore, inclusive energy spectra were measured using the ^{252}Cf source with and without the lead-plastic-cadmium moderator.

We have studied 10cm x 10cm NaI(Tl) and BGO detectors and an exagonal BaF_2 scintillator (48 cm^2 surface, 12 cm thick).The obtained results can be summarized as follows:

1) The emission of prompt energetic γ-rays from the fission source is characterized by a well known exponential shape. The probability of having events in the E_γ = 9-12 MeV region is of the order of 10^5 10^6 of the total yield, in agreement with results from ref.5.

2) Fast neutrons are detected in the scintillators mainly via (n,n'γ) reactions (6). The cross section for (n,p) and (n,α) reactions on light nuclei (Na,F,O) seems to be non negligible. Nevertheless, the amplitude of the signal due to the scintillation light produced in such reactions is far lower than the region of interest. We found that the pulse height spectrum due to fast neutrons shows an endpoint close to 8-10 MeV, due to the tail of high energy neutrons emitted in the fission process. Considering the "inclusive" measurements, it is found that the event rate in the NaI(Tl) and BaF_2 in the energy range E_γ = 9-12 is scarcely affected by the moderated ^{252}Cf source being of the order of 0.1-0.2 events/s, practically equivalent to the rate due only to cosmic-rays and natural radioactivity.
On the contrary, the BGO scintillator shows a very large increase (1.7 events/s with respect to 0.1 events/s) when irradiated with the moderated fission source. This is due to the capture reaction in Ge isotopes which is known to produce gamma-rays with energy E_γ = 10.2 MeV (7). These results rule out the possibility of using BGO counters for this application.

CONCLUSIONS

We have started a detailed study to conceive a mobile system to detect small quantities of hidden explosives using modern technology in order to improve the overall effectiveness from the point of view of efficiency, costs and transportability.
To this end we are proceeding to test a number of Csi(Tl) scintillators assembled with a photodiode read-out and dedicated surface mounted fast front-end electronics. We are testing neural-network based decision algorithms for online analysis of the signals. Finally we are planning to test a mixed (thermal and fast neutron) technique in order to reduce both the scannning time and the false alarm rates.

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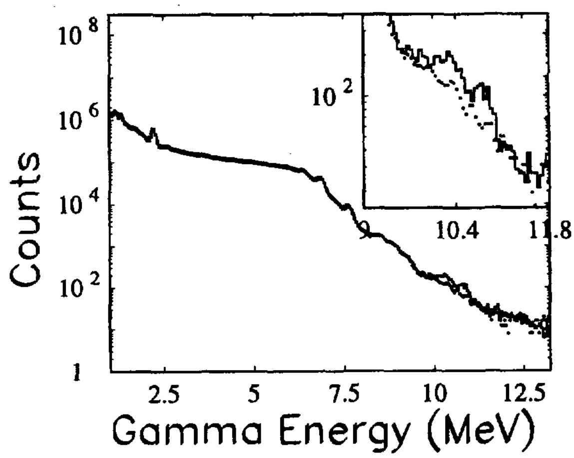

Figure 1: Gamma-ray spectra from the irradiation of a Melamine (line) and a Soil (dots) samples with neutrons

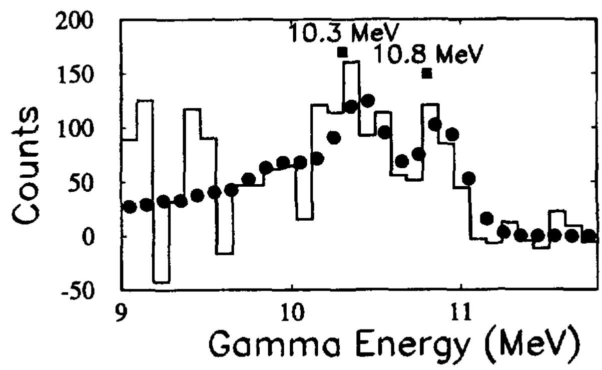

Figure 2: Difference (Melamine - Soil) gamma-ray spectrum. The prediction from a GEANT simulation (dots) is also shown.