Military versus humanitarian de-mining

Military De-mining:

Clearing corridors in minefield for combat use.

Requirements:

1) High probability of detection and low false alarm rate;
2) Operate in all weather conditions
3) Up to 20% casualties are tolerable.

Humanitarian De-mining

Complete clearing of the suspected areas.

Requirements:

1) UN sets a figure of 99.5% detection probability.
2) Operation with good and light weather conditions.
3) Slow rate search and large false alarm rate are tolerable.

Esempio di mina AP a basso contenuto metallico utilizzata Nella ex-Jugoslavia

Figure 1: A typical low metal AP mine (Type 72)

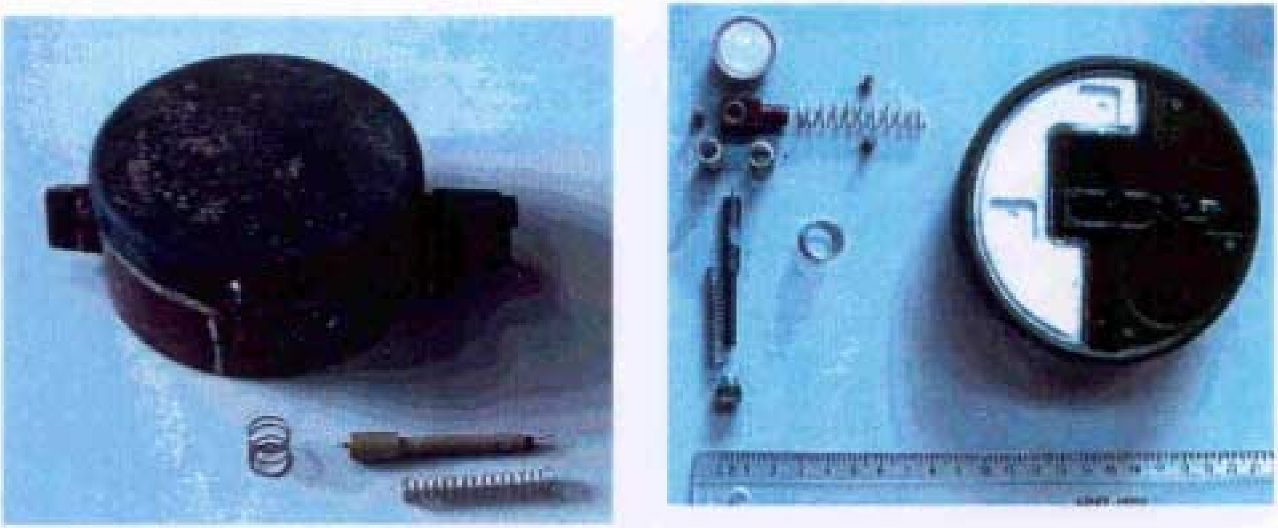


Figure 2: Metallic content of a PMN AP (left) and a PMN2 AP (right)

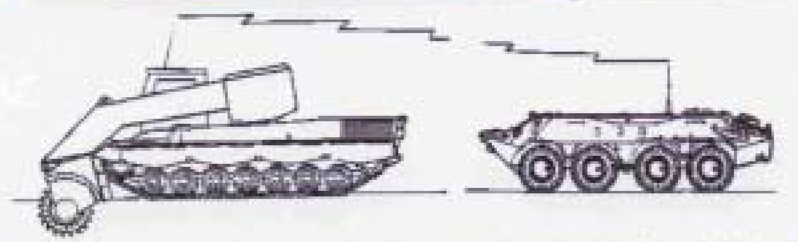
Tipici mezzi meccanici utilizzati
Per lo smiamento tattico.

TACTICAL DEMINING

Plough in front of a tank (courtesy of Dr Ken Fyfe, Univ. of Alberta).

See his comprehensive description of mechanical means (http://faramir.mece.ualberta.ca/landmine.html).

Leopard tank in action.



See the enlarged 80 kB figure on Bofors' Web page (http://www.bofors.se/minr.htm).

The Spitfire demining concept is proposed by Caterpillar and has been developed by BOA Sweden: the patented "rotator-tool" is covered with rotating heads adequate for rock-crushing. Since the upper soil is completely mixed, there is a good hope that all the mines are destroyed. The device is claimed to withstand impacts of up to 12 kg of TNT.

Humanitarian Demining

HOME | WHAT'S NEW | SEARCH | SITE TREE

1 January 1996

Cambodia : Photo gallery on mines

Rather unusually, the mine-clearance experts from the Mines Advisory Group (MAG) in B
women. Most of them are widows, and some are amputees, whilst others have lost a close
because of the mines. (Ref.KH-D 75/2)

[Photos: P.Dutoit/ICRC]

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HOME | WHAT'S NEW | SEARCH | SITE TREE

1 January 1996

Cambodia : Photo gallery on mines

Some 25 kilometres west of Battambang, one of an all-female mine-clearance team, trained by western experts, unearths this deadly device. It is painstaking, delicate and repetitive work. None of the women has been injured so far. (Ref.KH-D 75/5)

[Photos: P.Dutoit/ICRC]

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Tipica scala temporale nelle operazioni di Sminamento Umanitario

TIPICAL TIMESCALE OF ACTUAL DEMINING

1) METAL DETECTOR LOCATES THE POSITION OF THE BURIED TARGET WITHIN 5 cm.

1 minute / m^2

2) DEMINING PERSONEL PROBES THE SPOT WITH A ROD (20-25 cm LONG) TO DETERMINE SIZE AND SHAPE OF THE BURIED TARGET.

2 - 20 minutes (depending of the soil)

SUSPECT MINE CONFIRMED ⇒

3) TO DIG IT OUT : 10 minutes

4) TO CLEAR IT : 20 minutes

TOTAL TIME : 33 - 51 minutes / mine

MOREOVER: 1) SOME MINE HAVE NO METAL PARTS

2) METAL DETECTORS FALSE ALARM RATE F 1000 : 1

3) 1 DEMINER INJURIED OR DEAD PER 1000 MINES DETECTED

→ THE CURRENT METHOD IS UNACCETTABLY SLOW, EXPENSIVE, DANGEROUS AND HAS ONLY INSUFFICIENT IMPACT ON THE GLOBAL PROBLEM.

Humanitarian De-mining in Balkans. I

As a consequence of the recent conflicts in the Balkan Area, the Republic of Croatia , the Republic of Bosnia-Herzegovina and the Kosovo region are seriously affected by the problem of landmines (LM) and abandoned unexploded ammunitions (UXO). Data reported at the recent 5th EOD Conference in Liubljana (Sept. 1999) show that suspect areas are very large (6000 km^2 in Croatia and 2300 km^2 in BiH).

In BiH 18330 minefields, for a total of 300 km^2 , are documented, with 250000 anti-personnel mines (APM) and 50000 anti-tank mines (ATM). This accounts for roughly 1/3 of the estimated mines in BiH.

In Croatia, 9000 minefields have been already documented, containing 30-40 % of the total 1 million mines estimated for that country. In this case, also the UXO problem is quite important, due to the 3000 tons of unexploded ammunitions scattered in that country.

The problem of the landmines in Kosovo is not completely ascertained. Only the mine fields deployed by the Federal Yugoslav Army are 616 (containing 30000 mines). No documentation is available about mines deployed by UCK. In addition, more than 1000 cluster bombs have been used in the NATO attacks in Kosovo, leading to a sizeable UXO problem.

Humanitarian Demining in Balkans . II

- Furthermore, a large number of mines are laid in areas difficult to be approached like forest, buildings, etc. The clearing capacity of the Croatian humanitarian demining in 1999 has been approximately 26 km^2 and approximately 9.3 km^2 were reduced by means of the existing conventional technology. For the year 2000 Croatia plans to clean about 35 km^2 and to reduce suspected area for about 15 km^2. In BiH, the reported figure is of 15 km^2 cleared since 1994, which means 3-4 km^2 per year.
- It is clear that the dimensions of the problem implies a very long time to clear completely the Balkan area by using the actual technologies. As already pointed out in several documents, the goal is the increase in the productivity of the single Humanitarian Demining team (6 deminers and 2 dogs), which is actually limited to 300-400 m^2/day for commercial organizations. The safety issue of actual demining technologies is also an important point, since the actual rate of landmine victims in the population (about 200 per year) and in the demining teams (6/km^2).

Croatia

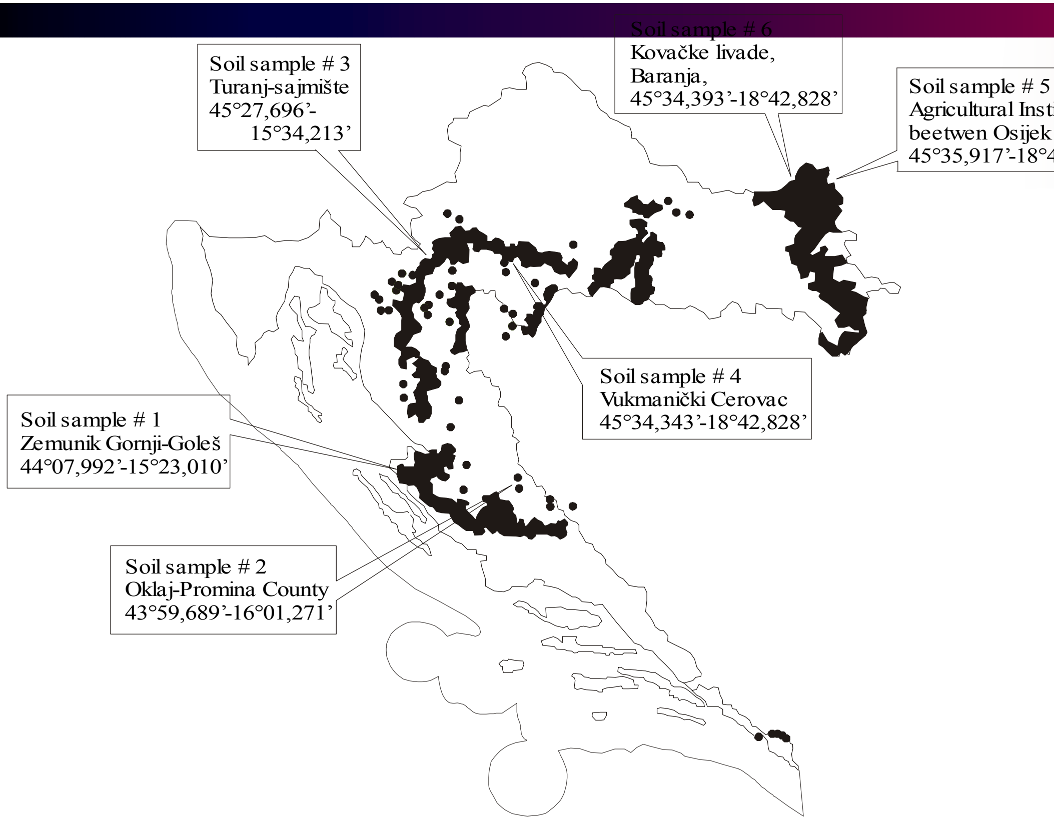


Fig 1. Mane affected area of the Republic of Croatia and location of soil sampling points.

Bosnia-Erzegovina

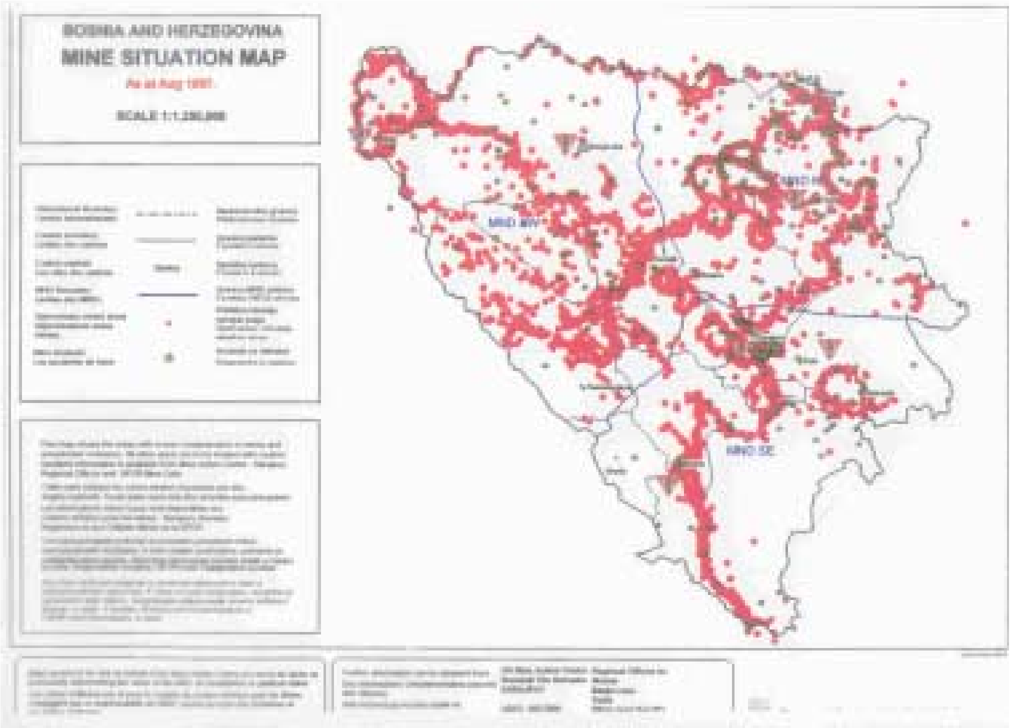


Table 1: Characteristics of the landmines found in Croatia (adapted from V. Valkovic et al). The metal content is used to classified metal mines (m) from plastic mines (n).

Mine name	Type	Buried (B) Surface (S)	Metal content	Dimension (mm)	Total weight (kg)	Weight Explosive (kg)	Kill/casualty Radius (m)	Landmine Statistics in permill
PMR 2A	AP	S	M	Φ66x122	1.70	0.10	1/25	344
TMA 3	AT	B	N	Φ260x80	6.50	6.50		147
PMA 2	AP	B	N	Φ60x33	0.135	0.10	1/25	95
PMA 3	AP	B	N	Φ104x40	0.183	0.035	1/25	71
TMR P6	AT	B/S	M	Φ290x137	7.20	5.10		65
TMM 1	AT	B	M	Φ250x85	8.65	5.60		63
PROM 1	AP	B/S	M	Φ75x329	3.00	0.425	50/100	54
TMA 4	AT	B	N	Φ280x65	6.30	5.50		52
TMA 5	AT	B	N	300x275x113	6.60	5.50		51
PMA 1	AP	B	N	142x68x35	0.40	0.20	1/25	7
MRUD	AP	S	M	231x46x89	1.50	0.90	50^{++}/200	8
TMA 1	AT	B	N	Φ310x100	6.50	5.40		3
TMA 2	AT	B	N	330x260x100	6.50	5.40		3
PMR 3	AP	S	M	Φ80x150	1.70	0.41	20/100	1

The H. D. context

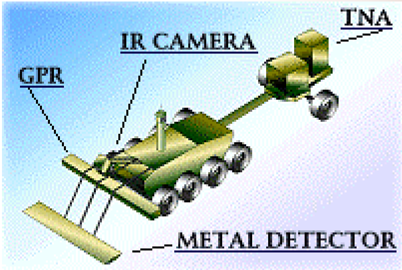
- **Humanitarian Demining (H.D.) is an intrinsically complex problem, even if only technical aspects are considered. Differences in the mine-field type, soil and vegetation are very large over the countries affected by the landmine problem.**
- **HD does not include only the clearance of minefields in open agricultural lands, but also the search of hidden or buried explosives in urban or industrial zones, the clearance of roads, railways and infrastructures.**
- **Actual operations in HD are generally considered to be slow, expensive and unsafe. The Ottawa treaty sets the goal of cleaning the minefields in the next 10 years. This can be achieved only if new tools for demining will became available in the next future.**

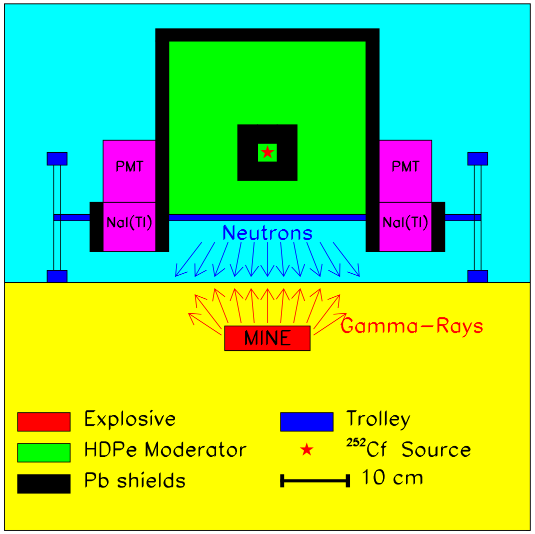
H. D. Requirements and Status

- **REQUIREMENTS : increase of the global efficiency in HD operations by developing new technologies capable of larger "net cleaning speed" (i.e. cleaned mm^2/h per deminer). Future sensors will have 99.5 % detection efficiency for A/P mines and will reduce the false alarm rate.**
- **NEW TECHNOLOGIES: GP RADAR, IR CAMERA, EMI DETECTORS, ARTIFICIAL NOSES, NEUTRONS, NQR, X-RAYS, MECHANICAL SYSTEMS**
- **STATUS : actually, each single considered technology does not fulfill the HD requirements. Only multisensor systems (or the sequential use of different sensors) are believed to fulfill the requirements. The choice of specific sensors depends strongly on the specific operation constrains.**

Nuclear sensors based on thermal neutron capture reactions

- **The capture reaction of thermal neutrons on nitrogen nuclei contained in common explosives is used to detect landmines through the emission of the characteristic 10.8 MeV photon.**
- **Thermal neutron sensors have been used in the ILDC (Can) and in the VMDT (USA) multisensor systems as <u>confirmation detectors</u>.**
- **Published results from in-field tests demonstrated that it is possible to detect A/T landmines in t<1 m.**





Thermal Neutron Sensor: EXPLODET GOALS

1) Optimise the moderator
2) Search for alternative low cost gamma-ray detectors
3) Minimise electronics and front-end cost and complexity
4) Automated gamma-ray spectrum analysis and evaluation to allow very simple MMI.

DESIGN GOALS (1997):

1) Size: 50 cm x 50 cm diameter
2) Weight 100 kg
3) Material cost below 50 kUSD

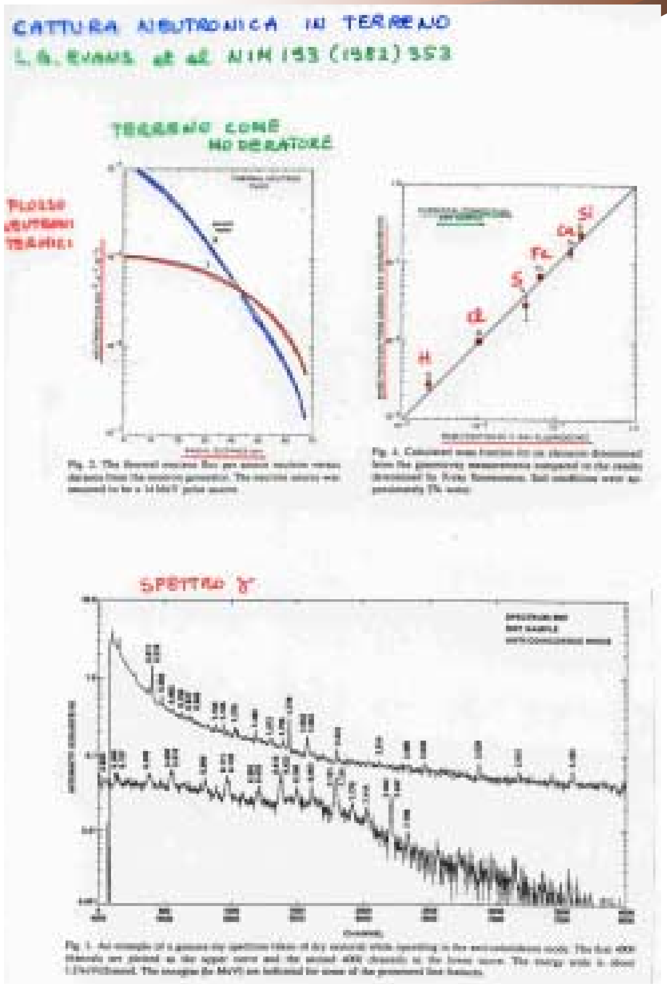
Proprieta’ dei moderatori

PROPRIETA' DEI DIVERSI MODERATORI

- NEUTRONI MONOENERGETICI
  $E_n = 14$ MeV
- SIMULAZIONI MONTECARLO
  SI VALUTA IL NUMERO DI NEUTRONI/$cm^2 \cdot s$ PER OGNI NEUTRONE EMESSO DALLA SORGENTE
- DISTANZA DALLA SORGENTE
  10 cm

TERRENO	2% ACQUA	10^{-5}
TERRENO	16% ACQUA	10^{-4}

POLIETILENE (HDP)	10^{-3}
Be	7×10^{-3}
2 cm U + HDP	4×10^{-3}
2 cm Pb + HDP	2×10^{-3}
6 cm Pb + HDP	$3\text{-}4 \times 10^{-3}$



Calcoli di Monte Carlo sulle proprietà dei moderatori

FLUSSO DI NEUTRONI TERMICI IN MODERATORE INFINITO

S. Cluzeau et al NIM B79 (1993) 851

$\frac{\text{neutroni}}{cm^2 \cdot s}$ per neutrone emesso dalla sorgente

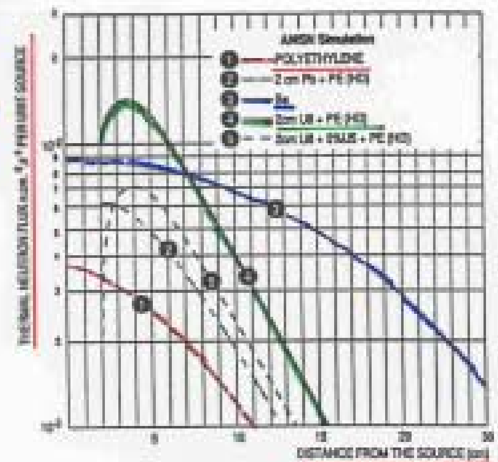


Fig. 2. Computed thermal neutron flux with various moderator materials.

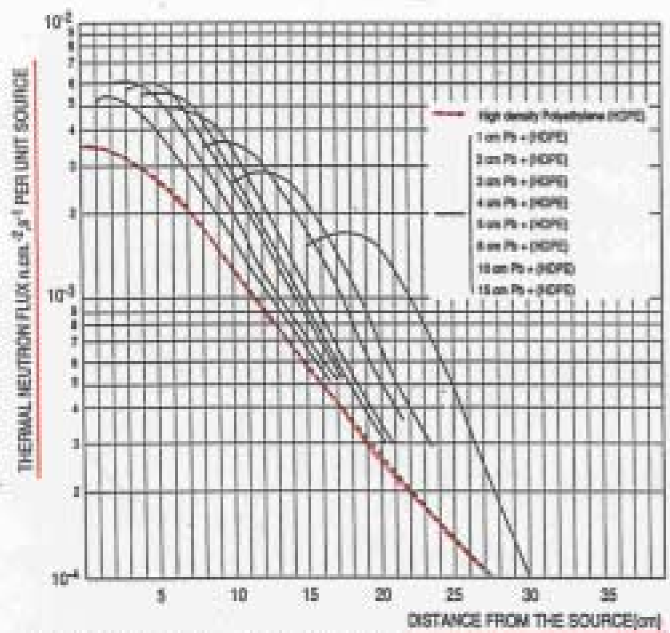
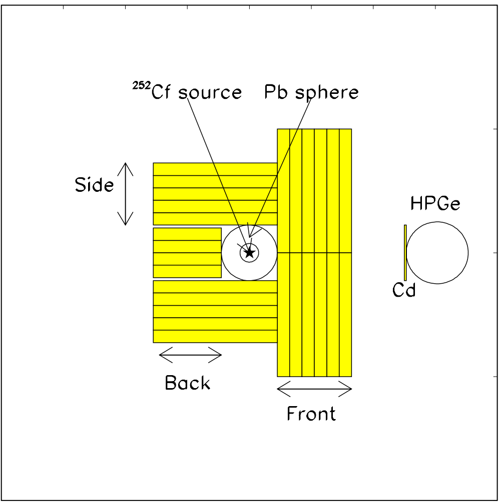
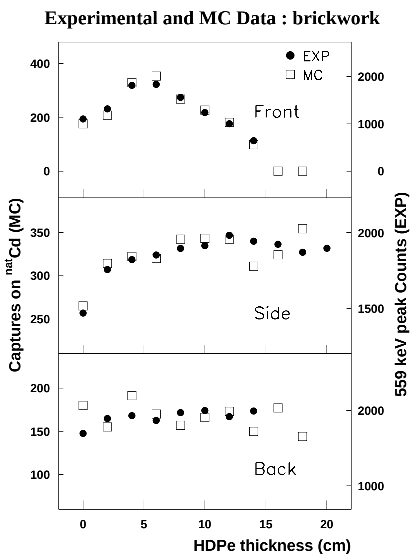
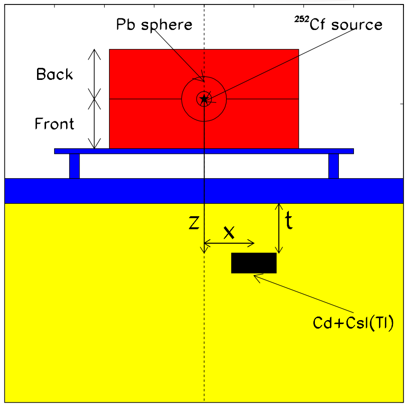


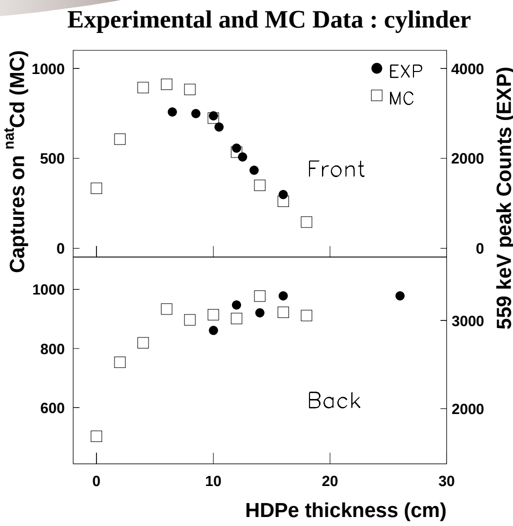
Fig. 3. Computed thermal neutron flux in a composite Pb + HDPE moderator.

Thermal Neutron Sensor: Optimization of the moderator I









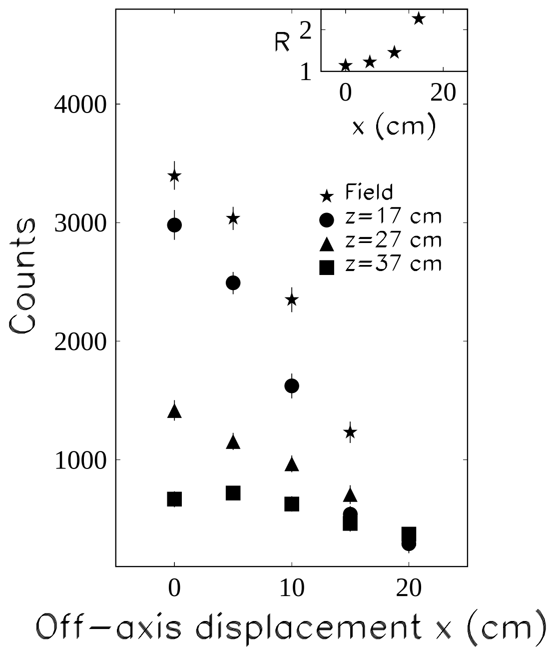
Final moderator dimensions:

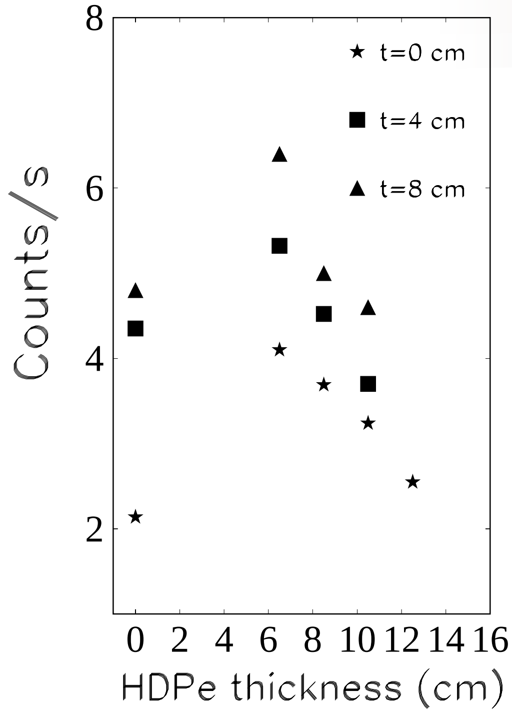
R=19 cm back thickness: 10 cm

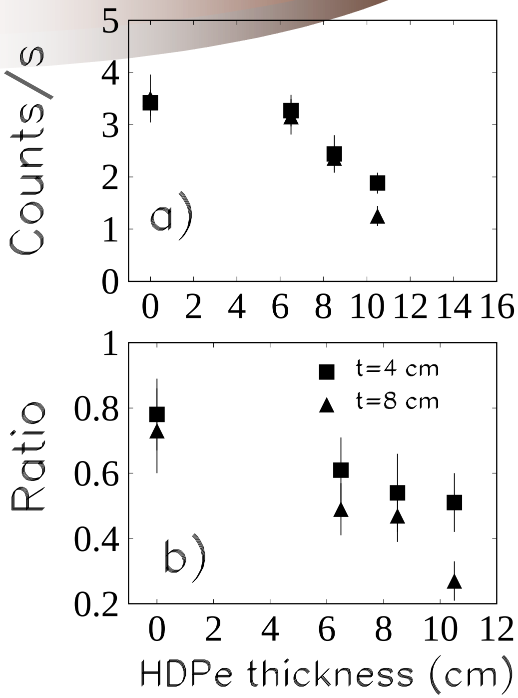
inner lead sphere r_1=1.5 cm r_2=4.5 cm

<u>L. Zuin et al. NIMA 449 (2000)416</u>

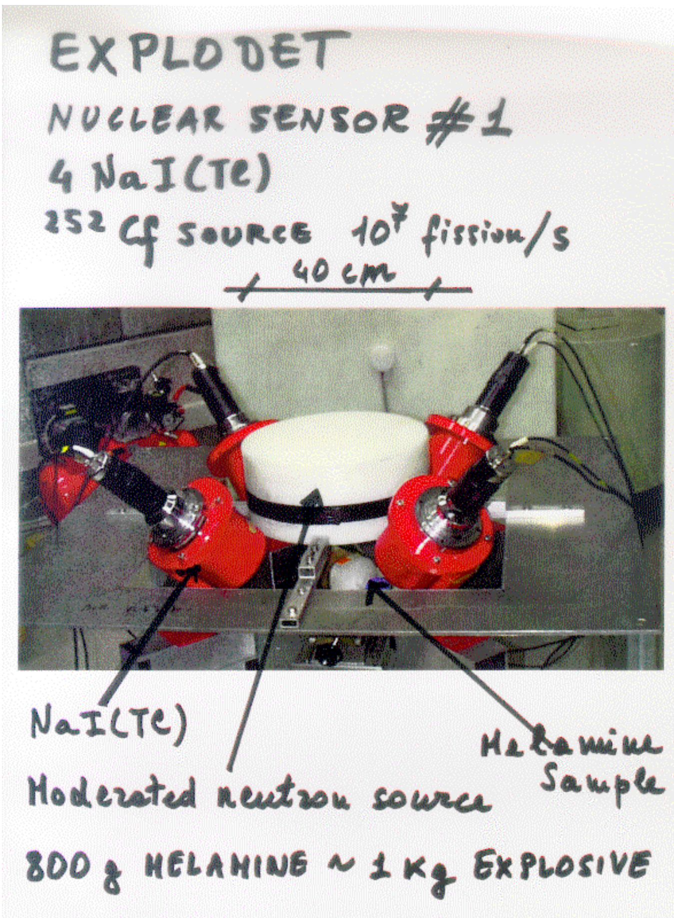
Thermal Neutron sensor: Optimization of the moderator II

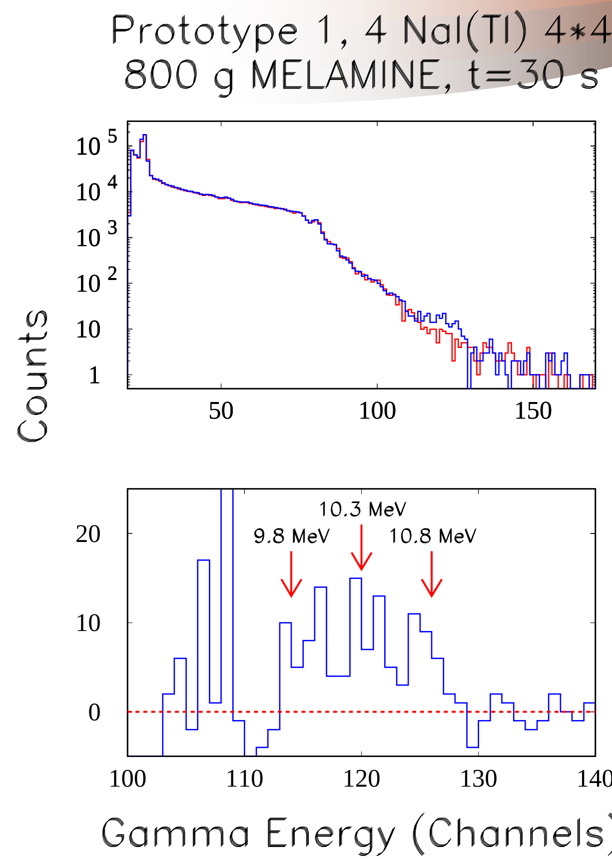






Thermal Neutron sensor: Explodet#1 prototype





G. Salvagna, Thesis, Univ. Padova 2000

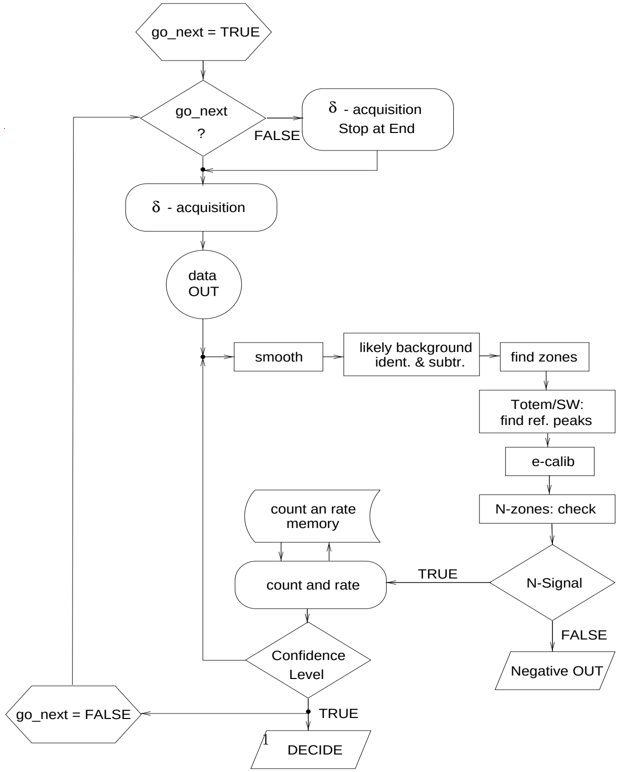
Thermal Neutron sensor: Development of low cost DAQ

- DAQ PCI card containing 4 Flash ADC channels with external trigger. Sampling rate is up to 20 MHz.
- Up to 4 cards can be used in a single PC.
- Differential linearity is within $1\text{-}2 \cdot 10^{-3}$.
- DIGITAL SIGNAL PROCESSING to obtain automatic pile-up rejection.

S. Moretto, Thesis Univ. Padova 1999

Thermal Neutron sensor: On-line data analysis

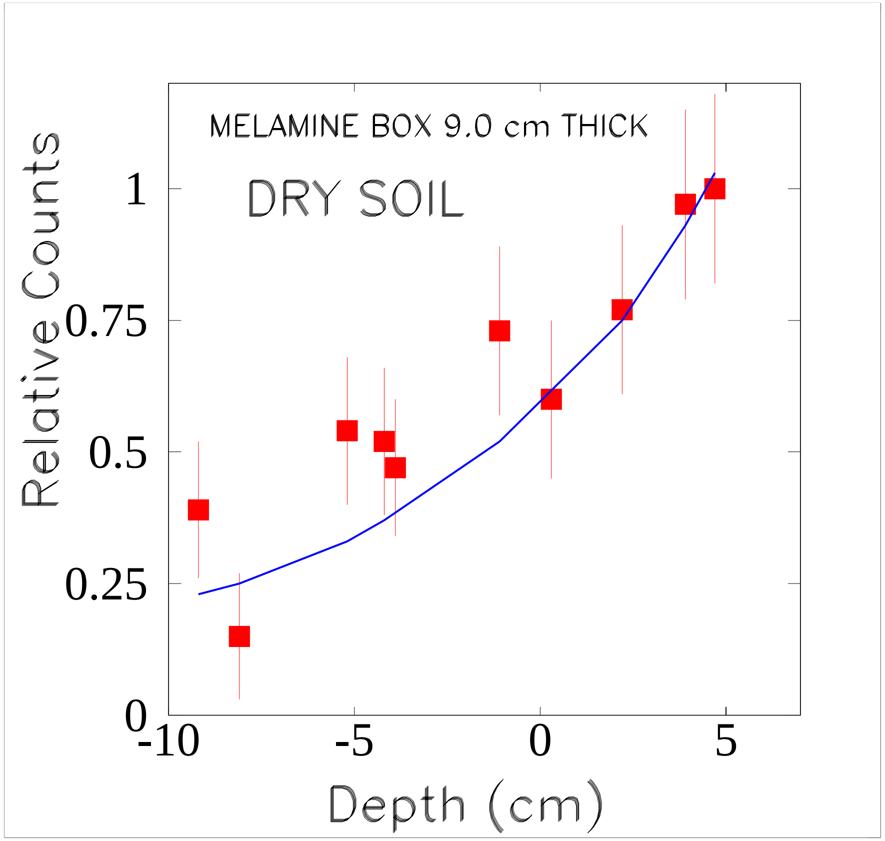
- The data acquisition is divided in short time intervals: at the end of each interval data are transferred to the on-line analisys system performing the following tasks:
  - 1) Likely background subtraction;
  - 2) Calibration of the energy scale using the relevant structure in the spectrum, NN are used;
  - 3) Identification of the region of interest and 3-gaussian fit of the ^{14}N structures.
  - 4) Check the presence of explosive
  - 5) Stop / Continue DAQ decision.

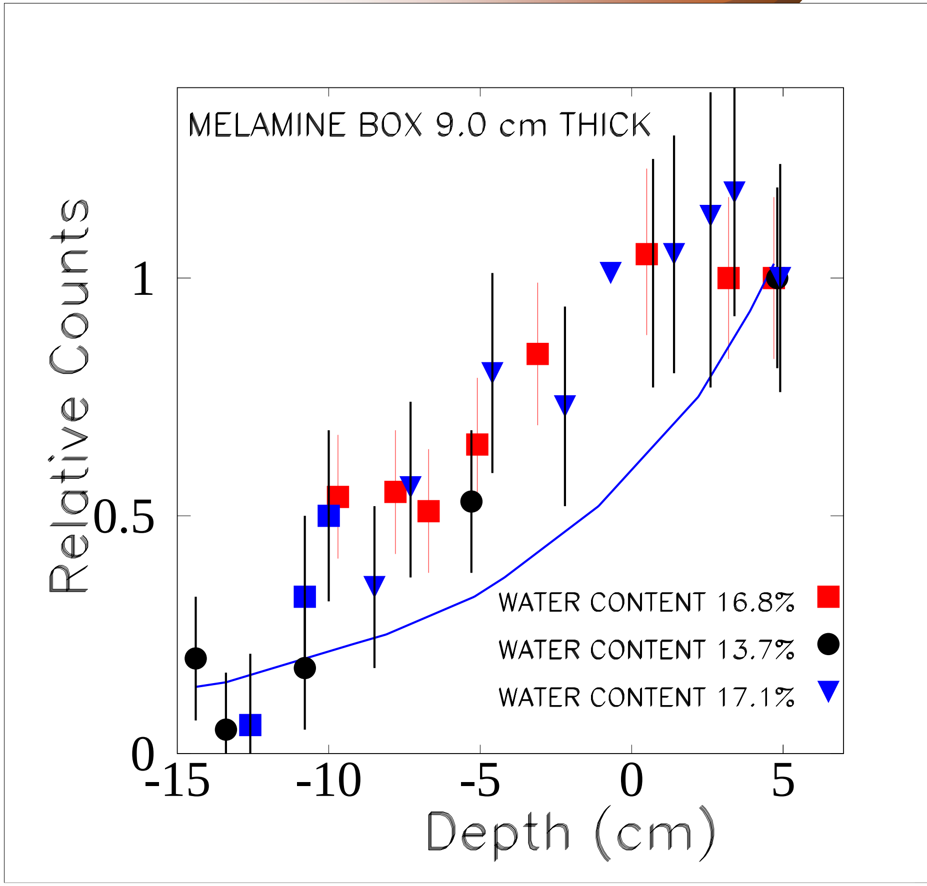


S. Pesente

NIM A to be published

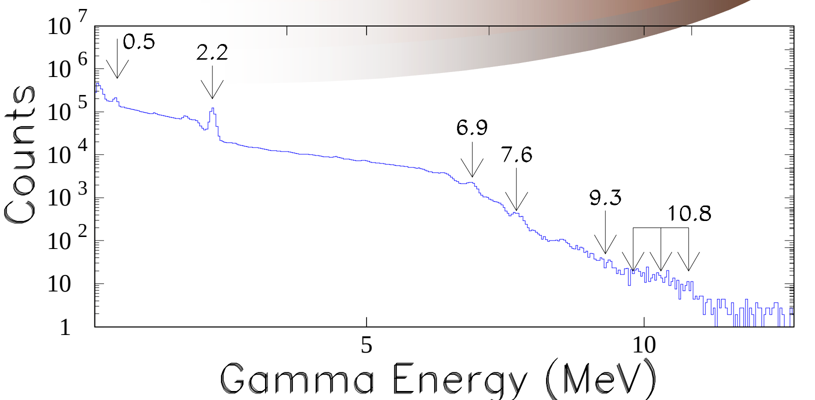
Thermal Neutron sensor: Sensitivity vs buried depth.

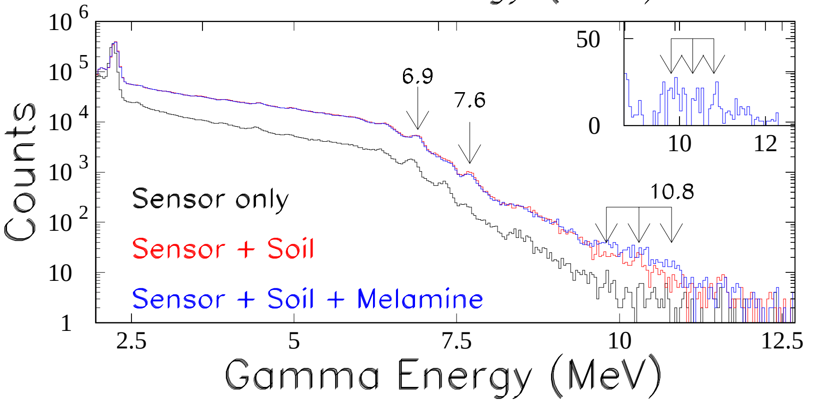




Thermal Neutron sensor: Actual limits

- **The intrinsic sensitivity of the method is determined by the signal-to-noise ratio (i.e. the background due to the interaction of neutrons with sensor materials and soil).**
- **The background is increased by a factor 2 due to the reactions on the soil nuclei.**
- **The intensity of the tagging radiation (10.8 MeV) depends on the depth of the buried landmine, the soil composition and water content.**





Thermal Neutron sensor: Radiation Hazard

- **A sealed 5 mCi ^{252}Cf source (1.3 x 10^7 n/s) enclosed in a 380 cm^3 lead shell and an additional 77 x 103cm^3 of HDPe will produces the following doses:**
- **AT CONTACT: 275 μSv/h (n+γ)**
- **AT 1 m DISTANCE: 28 μSv/h (n+γ)**
- **Italian Legislation: 1 mSv/year for non classified personnel (i.e. 36 hours at 1 meter, 140 hours at 2 meters)**

Thermal Neutron sensor: Future Developments

- Reduce costs and complexity of the thermal neutron sensors.
- Fully automated operation of the sensor.
- Reduce the ^{252}Cf activity and increase the efficiency of the gamma-ray detectors.
- Use as confirmation detectors in scanning systems capable to determine the depth of the hidden object.
- Use of active shielding for the gamma-ray detectors to lower the background level in the spectra and increase the sensitivity (from A/T to A/P landmines).
- Use pulsed electronic neutron source to lower the background in the spectra and to reduce the problem related to the handling of radioactive materials (from A/T to A/P landmines).

SCHEMA DI MISURA CON UNA SORGENTE PULSATA:

R.C. Hertzog et al IEEE TNS 26 (1979) 1558.

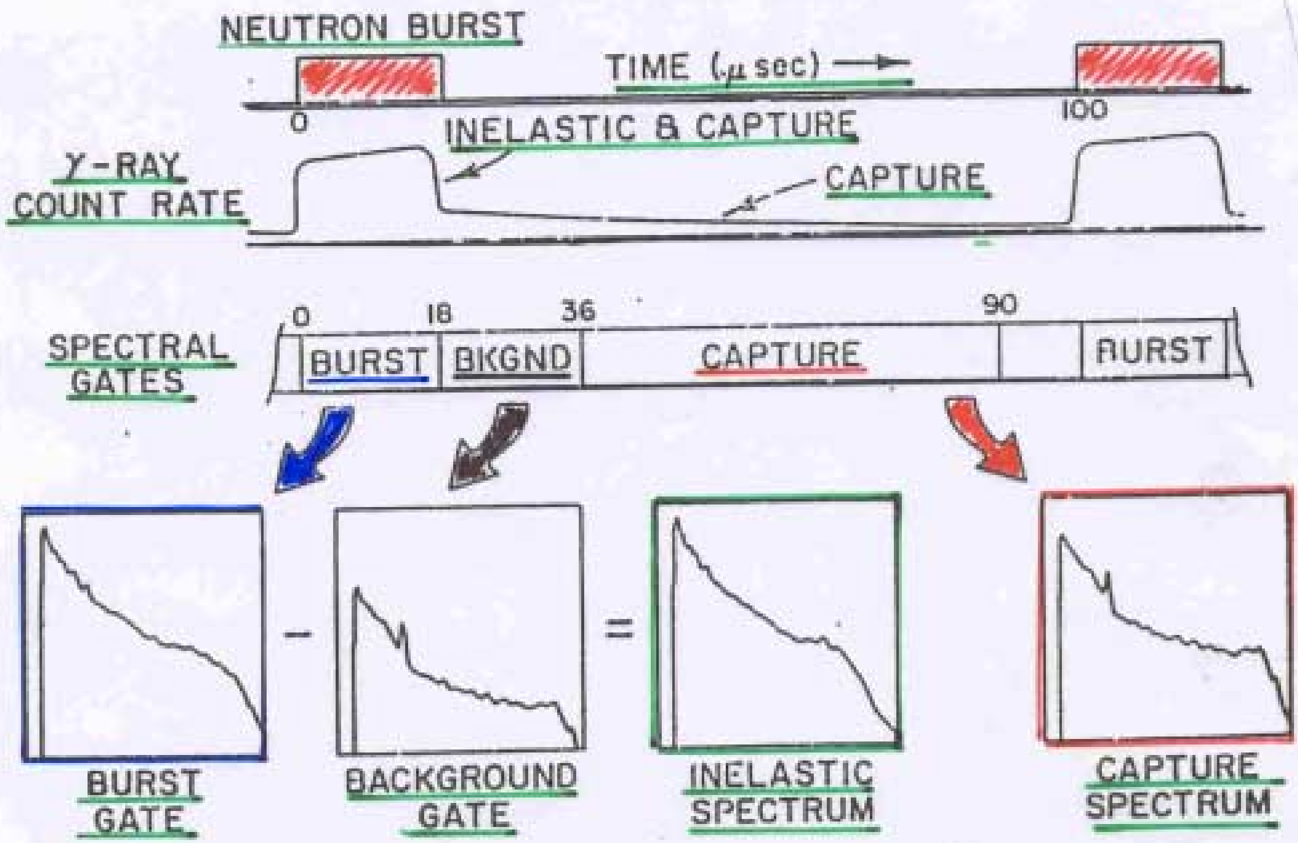
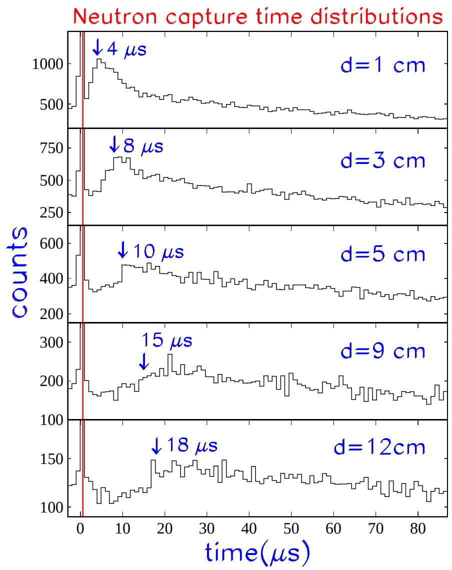
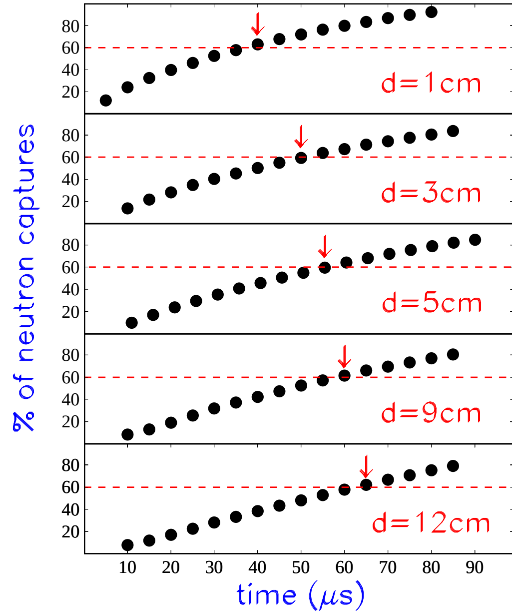


Fig. 4 - "Inelastic-Capture" mode timing diagram.

Thermal Neutron sensor using a pulsed neutron source.

- **The ^{252}Cf will be replaced by an electronic portable source using the D+T neutron producing reaction.**
- **Despite the increase in cost and complexity, electronic sources <u>lower the radiation hazard</u> connected with the radioactive sources and can also <u>reduce the background</u> when operated in pulsed mode, thanks to the time difference between prompt gamma rays and capture events.**
- **Preliminary measurements have been performed.**



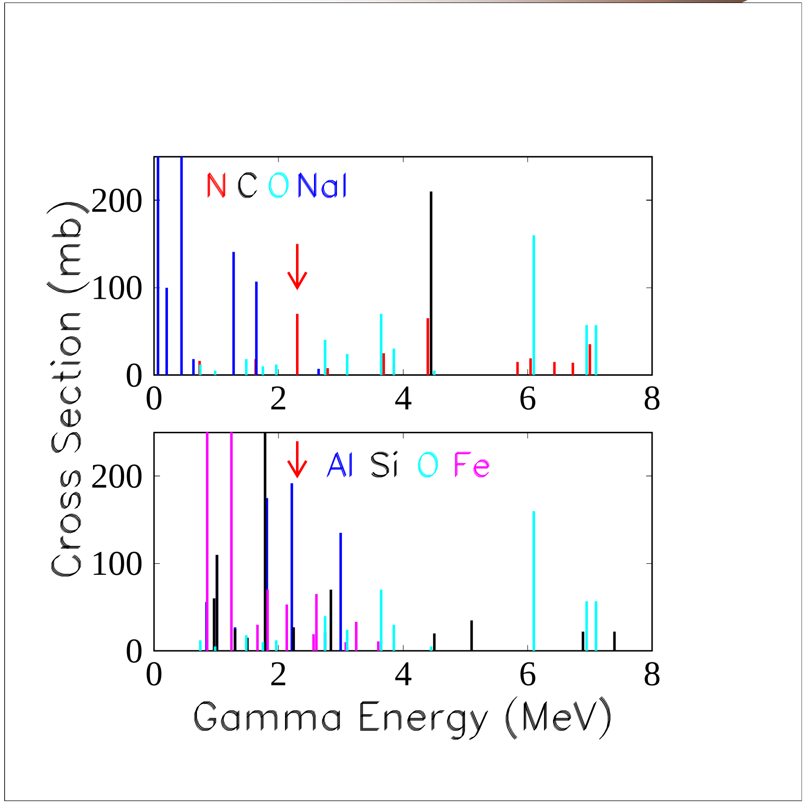


Nuclear sensors based on fast neutron induced reactions

- Inelastic scattering or, in general, fast neutron induced reactions have been used to detect hidden explosives through the emission of characteristic gamma-rays.
- Fast neutron analysis has several advantages respect to the use of thermal neutrons : 1) the production cross sections of the characteristic gamma-rays are larger and 2) the neutron flux from the source is not reduced by the moderator (factor 10^{-2}-10^{-3}).
- Fast neutron analysis allows, in principle, the determination of the ratio between Oxigen, Carbon and Nitrogen nuclei, to discriminate more effectively explosives from other materials.
- Using nanosecond pulsed neutron beams and large gamma-ray detector arrays it is possible to obtain 3-D scans of large volumes (as airport containers).

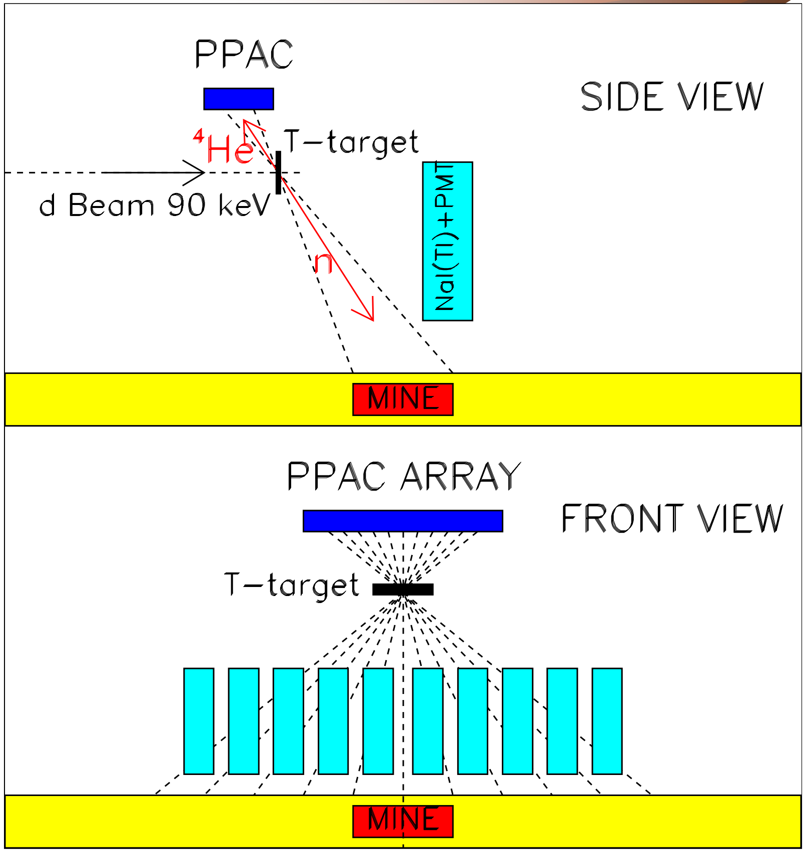
Fast neutron sensors for Humanitarian Demining I

- **Increase of cost and complexity going from ^{252}Cf to D+T electronic neutron sources.**
- **The expected γ-ray spectra are complicated because of the background lines from nuclei in the soil.**
- **The proposed use of high resolution detectors (as HPGe) seems to be unrealistic for the decrease in efficiency respect to scintillators and for the further increase in complexity.**



Fast neutron sensors for Humanitarian Demining II

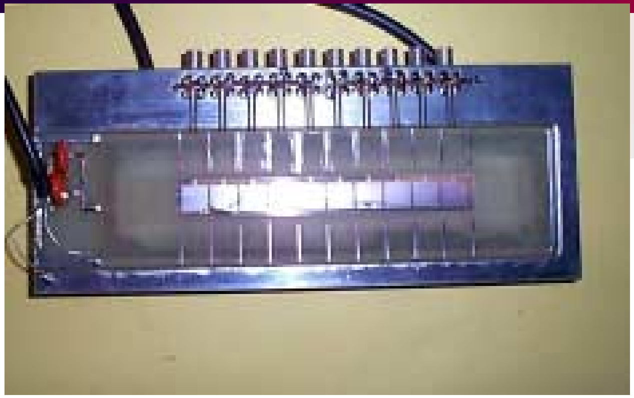
- **The background in the γ-ray spectra can be reduced by using <u>nanosecond pulsed neutron sources</u> or the associated particle technique (<u>APT</u>) to tag the neutron beam.**
- **Portable ns-pulsed electronic neutron sources are not available, whereas APT portable sources were developed in the past.**
- **Novel APT-based sensors for HD would allow to detect in short time A/T as well as A/P.**



Fast netron sensors for H. D.: EXPLODET plans .

- **Basic R&D work is in progress by using D^+ beams from the LNL VdG. The following sub-systems will be built and tested:**
  - **The vacuum chamber with a rotating TiT target.**
  - **The AP charged particle array using PPAC.**
  - **The gamma-ray array using BaF scintillators.**
  - **The DAQ and automated data analysis sistem using NN.**
- **The sub-systems will be than assembled on a portable 110 kV open-end D^+ accelerator to study a full scale prototype of mobile sensor.**
- **Evaluated performances for a future APT based sensor: possibility of 3D imaging; scan speed about 1 km/h for 1 m wide lane and 1 kg explosive (or 0.1 km/h for 0.1 kg).**

Associated Particle Detector (PPAC-PS)

Portable open-end Accelerator for the Production of Tagged Neutrons

JINR Dubna prototype:

Beam D^+ E=110 keV.

Target T-Ti 1.5 Curie.

Neutron Flux limited to 10^7 n/s in the EXPLODET version.

CF 100 flange for the mounting of the AP detector.

Vacuum 10^{-6} mb by an external pumping unit .

Control System: portable PC

Test of first prototype: November-December 2000.

Cost for the second unit to be delivered Aug. 2001: about 70 kUSD

The DIAMINE project: an innovative smart NBT sensor for Humanitarian Demining.

The DIAMINE project considers the problem of de-mining in the Balkan region. Here, about 54% of the mine are detected by MD. The low metal mine represent the 46% of the total and are difficult to detect with MD. 26 % of the total, are large plastic ATM (5-6 kg of TNT). The low metal AP mines (35-400 g of TNT) are about 20% of the total.

The DIAMINE goal is the increase in productivity of the single HD team (currently made of 6 de-miners and 2 dogs), which is presently limited to 300-400 m^2/day for commercial organisations. This increase is strictly related to the possibility of introducing new cost-effective tools useful for:

1) the reduction of the false alarm rate of Metal Detectors;
2) the possibility of detecting with good efficiency also fully plastic mine;
3) the availability of hand-held systems to be used in difficult access areas.

New tools have to be accepted by de-miners, not involving dramatic changes in their standard operating procedures.

The aim of DIAMINE is to develop a full scale prototype of a hand-held detector using the neutron back-scattering technique (NBT). Moreover, it was deemed interesting to integrate a MD, suitably modified for compatibility, with the NBT.

The neutron backscattering technique: state of the art I

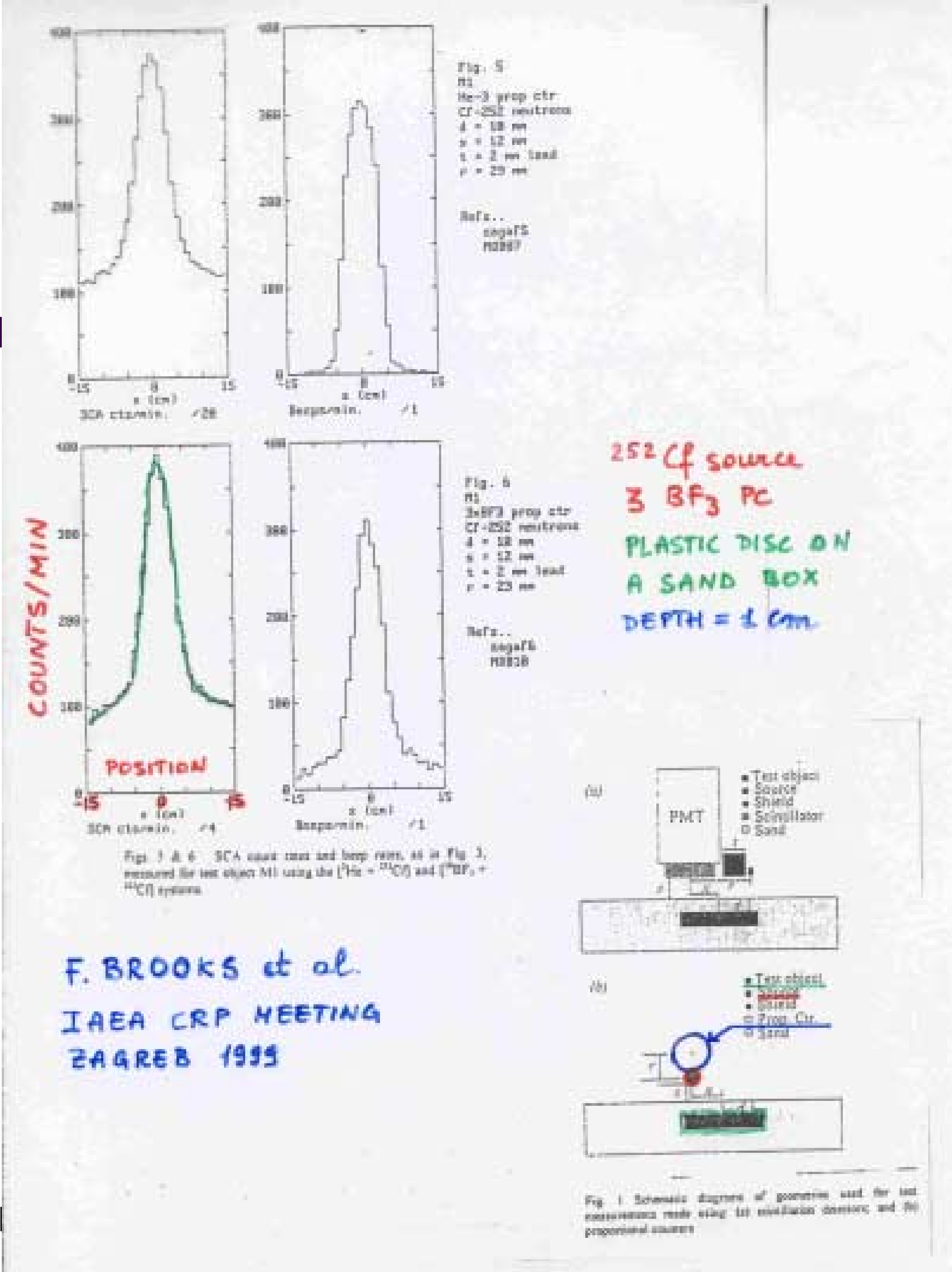
Neutron back-scattering technique (NBT) is sensitive to the hydrogen contained in the hidden material and can be used to detect minimum metal content or fully plastic land-mines, which are difficult to detect with conventional EM methods, as MD. These types of mines represents a large problem in the Balkan area.

NBT sensors have been developed and tested in the past using ^{252}Cf sources and point-like neutron detectors.

Reported results demonstrate that:

1) NBT sensors can be made light-mass so that hand-held systems are possible.
2) The counting rate of the NBT sensor is sufficiently high to scan the soil even if low activity sources are employed.

Test di laboratorio realizzati presso l’ Universita’ di CapeTown in Sud Africa.



NBS field tests

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Figure 1. Hand-Held Neutron Thermalization Detector

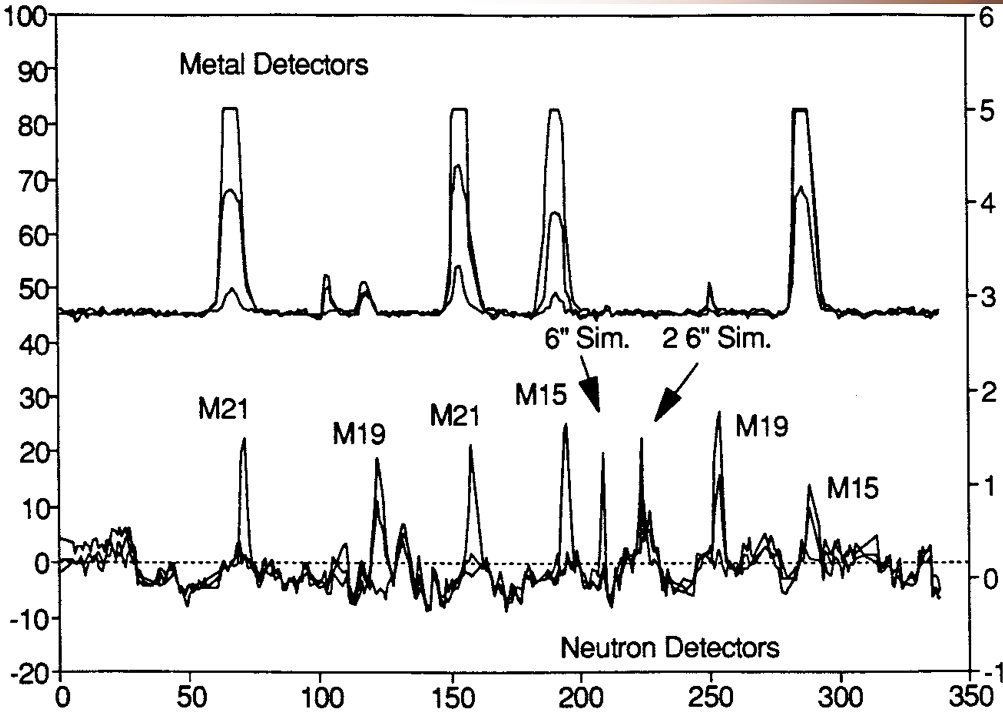


Figure 11. Metal and Neutron Detector Signals

The neutron backscattering technique: state of the art II

Field tests made by SAIC in US demonstrated the capability of the NBT to detect fully plastic landmines (as the M19). However, the reported detection efficiency was rather poor (36/46) and the false alarm rate unsatisfactory (14 per 700 m^2).

In our opinion, the poor performance of that generation of sensors is essentially caused by:

1) The dependence of the beep-rate (count rate) on the sensor-soil distance;
2) The background level due to the soil moisture;
3) The soil inhomogeneities.

However, experimental data from those NBT sensors demonstrated also that:

1) The NBT sensor is working also in case of wet soil if the background level is properly adjusted;
2) The experimental distribution of the neutrons thermalized by the explosive is correlated with the shape of the hidden object (possibility of imaging).

The DIAMINE project: an innovative smart NBT sensor for Humanitarian Demining.

DIAMINE proposes to develop a novel, smart NBT sensor to be used in a hand-held system. It will employ a large-area position-sensitive neutron detector and ancillary sensors for distance and speed.

The advantages of the proposed system are:

1) **Large neutron efficiency**, to reduce the source activity and the associated radiation hazard.

2) Possibility of imaging of the hidden object to get : **authomatic subtraction of the background and shape identification**.

3) On-board evaluation of the data from NBT and auxiliary sensors to provide **simple feedback to the operator** trough an user-friendly MMI.

4) Possibility of **coupling with Metal Detector**.

The DIAMINE proposal: PRELIMINARY MC CALCULATIONS. I

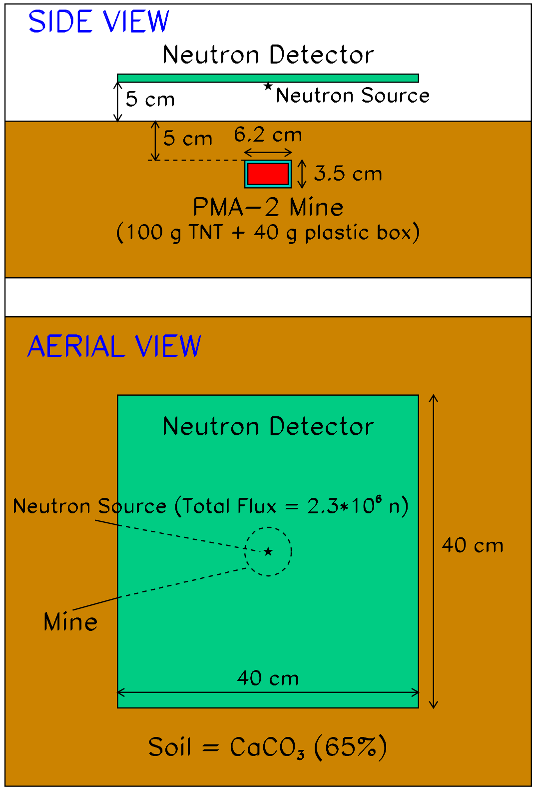
Monte Carlo calculations have been performed considering PMA2 or TMA3 mines buried at 5 cm depth in soil. The 40 x 40 cm^2 detector, is placed at 5 cm from the soil surface.

The signal to background ratio is maximized when scattered thermal neutrons are considered (energy filtering). This filtering will be operated by the neutron converter in the detector.

Interrogation Time (99.7%conf. lev.)

PMA-2 0.6 s (0%W) 1.7 s (5%W)

TMA-3 0.002 s (0%W) 0.13s (5%W)



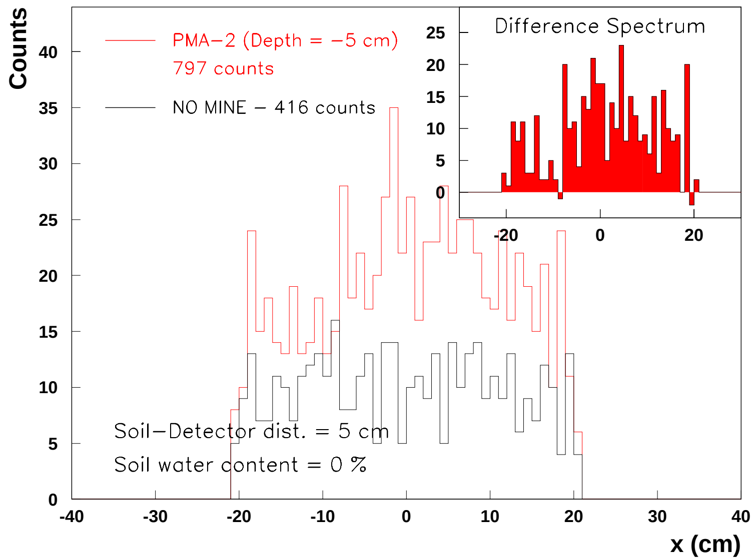
The DIAMINE proposal:
PRELIMINARY MC CALCULATIONS II

Imaging

Irradiation time: 23 s

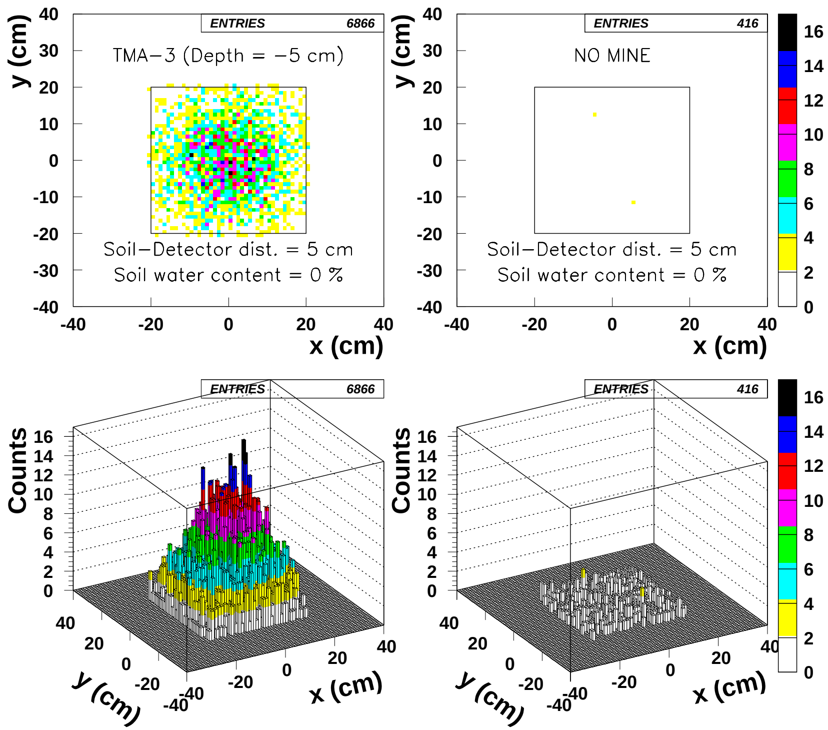
PMA-2

Neutrons hits on detector ($E_n \leq 50$ meV)



TMA-3

Neutrons imaging ($E_n \leq 50$ meV)



The DIAMINE proposal: an innovative smart NBT sensor for Humanitarian Demining.

THE THERMAL NEUTRON DETECTOR

General requirements:

1) High detection efficiency for thermal neutrons, 40 x 40 cm^2 area, 2 x 2 cm^2 read-out pixel size, radiation hardness.
2) Low efficiency for fast neutrons and gammas.
3) Light mass, mechanical robustness.
4) Low cost, possibility of production by external companies.
5) Possibility of coupling with Metal Detectors.

Possible candidates:

1) MultiWires Proportional Chambers (MWPC)
2) Resistive Plate Chambers (RPC)
3) $LiPO_3$-Glass

The DIAMINE proposal: an innovative smart NBT sensor for Humanitarian Demining.

THE RADIATION HAZARD IS NEGLIGIBLE!

A sealed ^{252}Cf source producing 1×10^5 n/s has been used to measure the dose for the operator of a hand-held system.

1) The measured dose is: 1.5 μSv/h (n+γ). The limit in EC countries is 1 mSv/year for non classified personnel. This means 660 h of operation (i.e. 26 working weeks of 5 days, 5 h per day). Recommended limits for exposure of radiation workers are 15 mSv/year in EC and 50 mSv/year in USA.
2) Activation of soil is completely negligible.
3) Sealed sources will not cause contamination of the soil even in case of mine explosion.

The DIAMINE proposal: an innovative smart NBT sensor for Humanitarian Demining.

COMPUTING AND MM INTERFACE

Input Data:

1) Total counts and neutron image from NBT detector;
2) NBT detector-soil distance;
3) Scanning speed;
4) Metal Detector output.

Computing:

1) Verify the correct use of the sensor (i.e. Scanning speed)
2) Correct the NBT input data for background and solid angle effects.
3) Filter and process the neutron image.
4) Perform data fusion with MD

MMI interface:

1) Make and comunicate decision to the operator with simple messages.

DIAMINE project: Partnership

Industry: LABEN (Italy) (Project Co-ordinator)
CAEN (Italy)
NEURICAM (Italy)
WIENER (Germany)
VALLON (Germany)

Research: INFN (Italy) (Technical Scientific Co-ordinator)
IOP-SAS (Slovak Republic)
JRC-IRMM (Belgium)
Trencin University (Slovak Republic) (Subcontractor)
Ruder Boscovic (Croatia) (Subcontractor,
Scientific De-miners Representative)