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CLASSIFICATION UNCLASSIFIED	**SYSTEM NUMBER** 514409

TITLE

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The Development of A Thermal Neutron Activation (TNA) System as a Confirmatory Non-metallic Land Mine Detector

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Introduction : The preponderance of buried land mines represents a threat to military forces worldwide. (Current estimates put the number of mines at 110 million covering 64 countries, with a growth of about 2 million per year.[1]) The Canadian Department of National Defence (DND) has a clear need to detect and locate these buried landmines when carrying out its peacekeeping activities. This problem has been addressed by the DND Improved Landmine Detection Project (ILDP) which has designed, constructed and is testing a multisensor system. The confirmatory element of the ILDP system involves positive detection of mines using Thermal Neutron Activation (TNA) and subsequent detection of nitrogen gamma rays. This work describes the design and development of the system (both from electronic and radiation shielding aspects) and the results of laboratory and field trials. The TNA system is shown capable of confirming the existence of the vast majority of anti-tank (AT) mines and many anti-personnel (AP) mines in time periods ranging from a few seconds to a few minutes.

The development of a thermal neutron activation(TNA) system as a confirmatory non-metallic land mine detector. DRES-SL-2000-0152.

Background :

1) ILDP System

A comprehensive report by Defence Research Establishment Suffield (DRES) [2] concluded that no one detector could satisfy the needs of land mine (especially non-metallic land mine) detection. Rather a suite of four detection systems mounted on a single vehicle - as shown in fig (1) was proposed.

The three detection systems on the front of the vehicle - Electromagnetic Induction Metal Detector (EMI), Ground Probing Radar (GPR) and Forward Looking Infrared Imager(IR) - work in concert as the primary system to detect a possible mine site. Each detector has advantages and drawbacks, but the combination of the three should serve to significantly reduce false alarms. Once a prospective mine site has been determined, it is physically marked and the confirmatory detector - TNA - is positioned above the mark. By examination of the activated gamma-ray spectrum, the TNA will either confirm or deny the existence of a mine at that particular location by counting for a preset amount of time.

The accuracy of the primary system in locating potential mine sites was estimated as ± 30 cm (1 foot). This served to determine source strength, detector type, shielding, mass and size for the TNA system.

2) TNA for Non-metallic Landmine Detection

All landmines contain explosives which in turn contain Nitrogen. Thus for the ILDP TNA system it was decided that, in the strictest sense, a nitrogen detector rather than an explosive (or landmine) detector would be built.

Upon thermal neutron capture Nitrogen emits a number of prompt gamma rays. For landmine detection, the most attractive of these is the highest energy transition at 10.835 MeV which occurs with 15.00 % probability [3]. The main reason for choosing this transition is that at this high energy there will be virtually no competing reactions - save the weak 10.611 MeV transition from neutron capture in ^{30}Si (Si is a common constituent in most soils). The judicious choice of this transition also allowed for the use of poor-resolution (NaI(Tl)) detectors as opposed to high-resolution cryogenically-cooled detectors (intrinsic Ge).

In order to clarify the above, fig (2) shows the results of early DREO experiments using a weak ^{252}Cf source (1 x 10^6 n/s) and a 2" x 2" NaI(Tl) detector. Here an explosive simulant, containing 1 kg of N, was used. Positive detection of Nitrogen reduces to the detection of a statistically significant number of counts above background in the energy region of interest - roughly 9 to 11 MeV. The excessive count time for this experiment (about 8 hours) clearly indicated the need for a stronger ^{252}Cf source and/or more efficient detectors in the final ILDP TNA system.

ILDP TNA System :

1) Basic System Parameters

Based upon the primary detection accuracy and a scoping study, it was decided that the ILDP system would consist of the components as listed in table 1.

Table 1
ILDP TNA System Components

Neutron Source Type	^{252}Cf
Neutron Source Intensity	1 x 10^8 n/s
Gamma-ray Detector Type	3" x 3" NaI(Tl)
Number of Detectors	4 @ every 90^0
Source-Detector Distance	30 cm

2) Shielding

Choice of shielding materials was based upon two considerations - shielding of the NaI(Tl) detectors from direct neutron and gamma-ray radiation from the ^{252}Cf source and biological shielding for personnel in the area. The computer code MCNP4A [4] was used to ascertain the effects of various combinations of materials. Fig (3) shows the final configuration.

This configuration lowered the count rate at the detectors to about 200,000 cps - which was a baseline for the electronics design described below.

The measured dose equivalent rates were 55 mRem/h neutron and 2.6 mRem/h gamma at the surface of the TNA head, and 1.8 mRem/h neutron and 0.8 mRem/h gamma at 1 m from the surface.

3) Detectors and Electronics

Fig (4) gives a block diagram of the detector and electronics system used for the ILDP TNA system. The sophisticated electronics were necessary since the observed count rates at the detector, even with the shielding described above, was roughly 200,000 cps. The main contributor to these counts are gamma-rays from the ^{252}Cf source, however neutron capture gamma rays from a variety of sources, including the NaI(Tl) crystal itself, contribute.

The NaI(Tl) crystal and photomultiplier tube are commercially-available models, but were pre-qualified based upon their abilities to handle both the rates and high energies expected. The base was built specifically for this project.

The first part of the electronics serves to lower the counting rate to 5,000 cps. This is accomplished by means of a fast linear gate controlled by a constant fraction discriminator (CFD) whose threshold was set to approximately 5 MeV. The linear gate is open for 160 ns for each accepted pulse. However it was observed that pileup was a problem when the gate was open, necessitating the use of pile-up rejection circuitry.

The pile-up rejector, specially constructed for this work, employed a gated-integrator technique [5] which rejected pulses based upon shape distortion compared to "normal". Both pre- and post-pile-up events could be detected. Using this technique, distortion in pulses as closely spaced as 15 ns could be detected, and the pile-up pulse would be rejected.

4) Data Acquisition and Analysis

a) Energy Calibration

As a prelude to data analysis accurate energy calibration was essential. This was accomplished by allowing the system to acquire a "background" spectrum - i.e. a spectrum with the TNA head sitting over an area known not to contain a mine. Three peaks generated by neutron activation in Aluminum within the head were prominent enough to be used for calibration - the full energy peak from the 6.103 MeV transition and the double and single escape peaks from the 7.726 MeV transition at 6.704 MeV and 7.215 MeV, respectively. A linear extrapolation of this fit into the energy region of interest was then performed. Fig (5) gives the result of experiments at DREO, showing both the effects of the pileup rejection circuitry and the energy calibration peaks.

b) Statistical Analysis of Data

Following acquisition of the background spectrum, the TNA head could then be moved to a marked location (suspected land mine site) and another spectrum acquired. Using the standard Gaussian detection limit approach [6] to low-level counting, the false alarm and mine detection probabilities were based upon the number of excess counts in the energy region of interest. Under certain circumstances of large background fluctuations or abnormal structure in the background spectrum (such as excessive silicon in the soil, for example) the detection limit statistical approach can generate false positive indications of a mine. To improve upon the detection probability, a combined Gauss-Bayes statistical approach was employed.[7] A comparison of the two techniques will appear in a future paper.

Field Trials

Field trials of the ILDP TNA system were held at specially prepared mine fields at Defence Research Establishment Suffield (DRES) in Jan 1997. Weather conditions during these trials were adverse, but realistic - temperatures between - 20^{0}C and - 30^{0}C, with winds up to 50 km/h and snow cover of over 30 cm. Fig (6) shows the system in the field.

During the trials, four mines (M15, TMA3, M21 and TMA5A) representing different masses of nitrogen, were buried at different depths and interrogated. Additionally, different masses of C4 plastic explosive (34 % N by mass) were surface-buried and interrogated. Figs (7) and (8) show spectral results for these while the table below summarizes the experimentally determined count time for 93% detection probability. This count time was arrived at by an iterative solution to the statistical analysis techniques described above, based upon the experimentally measured background and net counting rates.

Table 2
Results of DRES Mine Detection Trials

Mine	Nitrogen Mass	Burial Depth (to top of mine)	Count Time for Positive Detection(93%) (s)
M15	3.6 kg	surface	5
M15	3.6 kg	3 "	19
TMA3	1.2 kg	surface	6
TMA3	1.2 kg	3 "	11
TMA3	1.2 kg	6 "	37
M21	1 kg	3 "	31
TMA5A	870 g	4 "	48
C4	680 g	surface	8
C4	680 g	3 "	20
C4	340 g	surface	14
C4	170 g	surface	45
C4	85 g	surface	254
C4	40 g	surface	> 1000

Several features should be noted. Firstly, for the case of the largest AT mine (M15) there is considerable structure below 9 MeV. This is likely due to neutron capture in other elements in the M15 mine - and the large peak at about 7.1 MeV may be the first escape from the prominent iron capture transition. This is supported by the fact that the M15 is encased in steel, while C4 and the other non-metallic mines are not. Secondly there is an indication of structure in the background around 10.1 MeV, which could be the first escape from the Si-capture peak mentioned earlier (the soil at DRES is quite sandy, and thus high in Si-content). Silicon activation will eventually determine the final lower detection limit of the system. Thirdly, from the table and the figures, the lower detection limit of the system as it stands right now is slightly under 100 g of N (for reasonable count times of less than 5 minutes). This means that the system is capable of detecting almost all AT mines (at depths down to 6") and many larger AP mines - which would be surface buried. Finally one should note that there is virtually no difference in the positive detection counting times for some of the mines examined here, despite their large differences in mass of N (500 g to 3.6 kg). This is due to a convolution of the thermal neutron flux profile (which drops rapidly with depth) and the distribution of Nitrogen within the mines (for the physically larger M15, there is far more Nitrogen at greater depths than for C4, for example).

Experiments were also conducted to determine the radial field of view of the system. The results of these appear in table (3).

Table 3
Radial Variation in System Sensitivity (M15 Mine Surface Buried)

Radial Distance of Mine to Source (cm)	Count Time for Positive Detection (93 %) (s)
0	5
10 (between detectors)	4
20 (between detectors)	9
30 (under detector)	8

30 (between detectors)	80
40	> 1000

The field of view is quite constant out to about 25 cm, begins to drop rapidly thereafter, and at 40 cm detection is not possible (this is physically outside of the TNA head). The above serves to illustrate the importance of accurately locating the mine with the primary systems.

Discussion and Conclusions :

The ILDP TNA system has proven itself capable of confirmatory detection of land mines having N masses of greater than about 100 g in a few minutes, over a radial area of about 1200 cm^2. This will enable almost all AT and large AP mines to be positively detected. Smaller surface buried AP mines (containing less than 100 g N) will be eliminated by such techniques as flailing. The system has clearly shown the ability to perform in adverse weather conditions.

Current plans call for the ILDP system to be fielded in 1998. Prior to this, several changes / modifications to the system will be studied or made, including

i) Replacement of the current electronics modules (which are at NIM BIN level) with a miniaturized box. This is expected to be completed by fall 1997.

ii) Fully automate energy calibration, data acquisition and data analysis techniques as well as integrating TNA results into the full ILDP system. This is expected to be completed by fall 1997.

iii) Decide on whether or not to replace the current radioisotopic source with a more intense version (about 1×10^9 n/s) or a Cockroft-Walton neutron generator. Increasing the source strength would, of course, decrease count times - by roughly a factor of 5 for the mines measured here, but would put more strain on the electronics and require more biological shielding, and thus increased mass. A neutron generator has the advantage of only being radioactive when on -

possibly lowering shielding requirements, and (potentially) having a lower background in the region of interest. However, the accelerator would be more complex and costly than the radioisotopic source. This decision will also be made late this year.

References :

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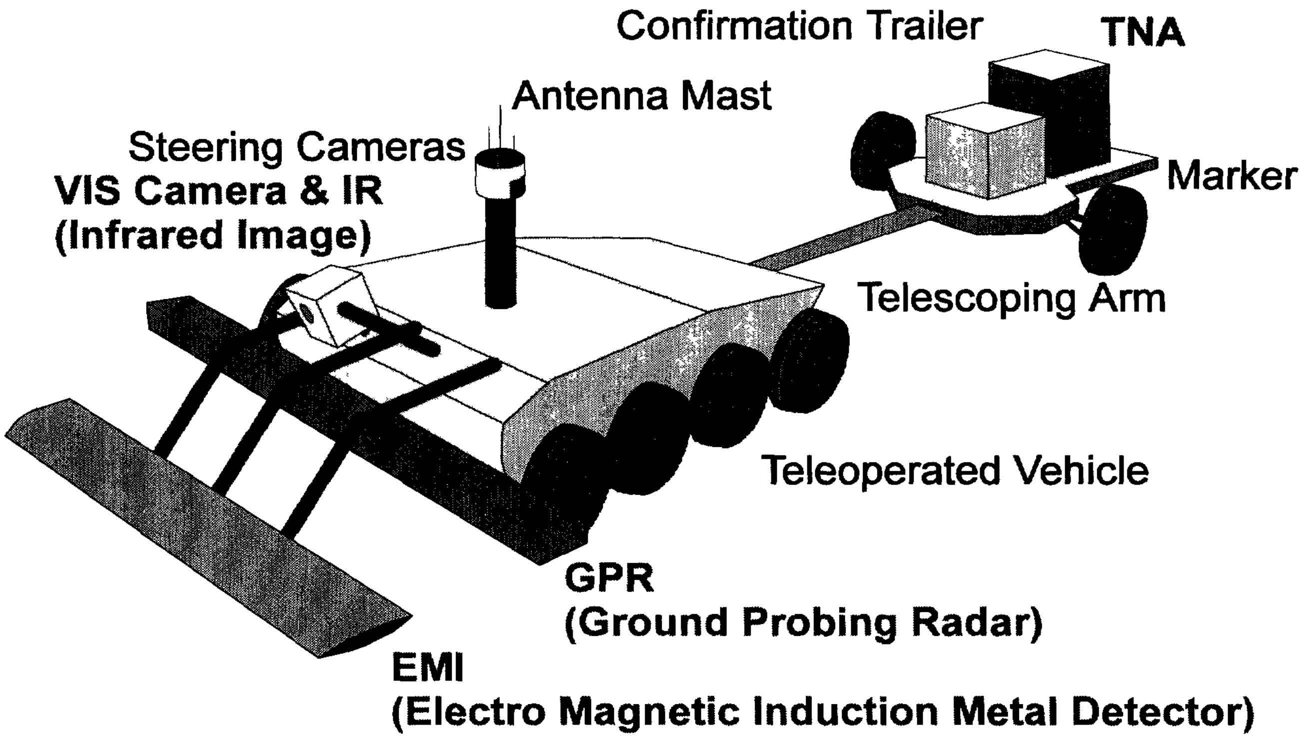

Fig 1) Conceptual drawing of DND ILDP system showing the three primary detection systems and the TNA confirmatory detection system

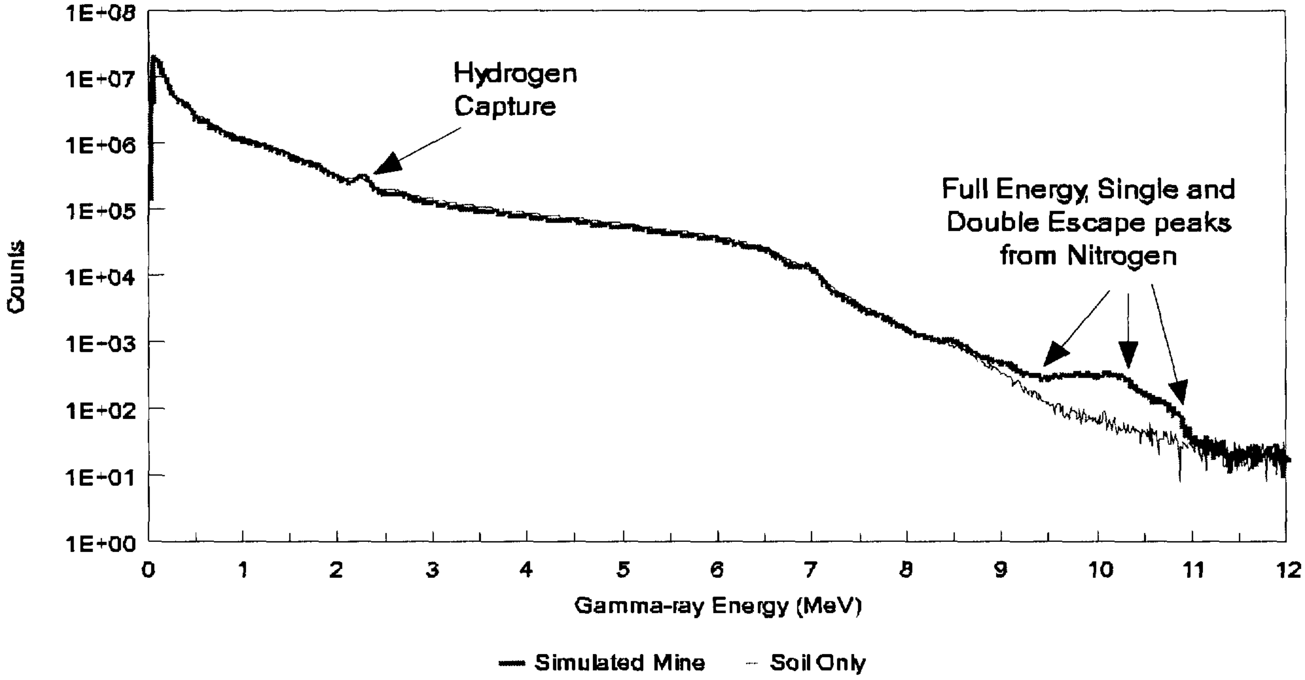

Fig 2) Simulation experiment at DREO using weak ^{252}Cf source and one 2" x 2" NaI(Cl) detector with a 1 kg N "mine", for an 8 hour run

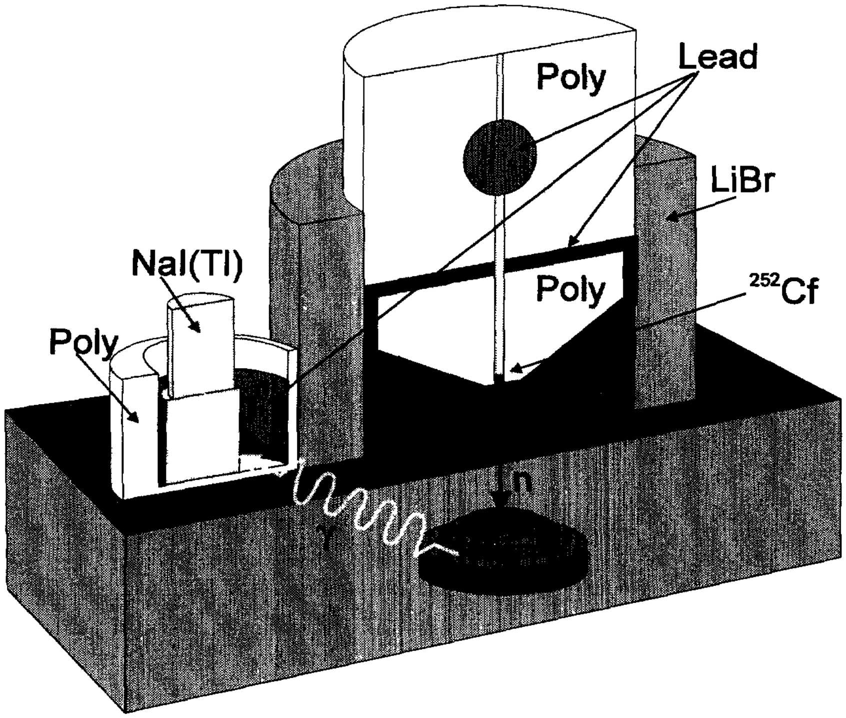

Fig 3) Cut-away diagram of ILDP TNA head showing shielding materials

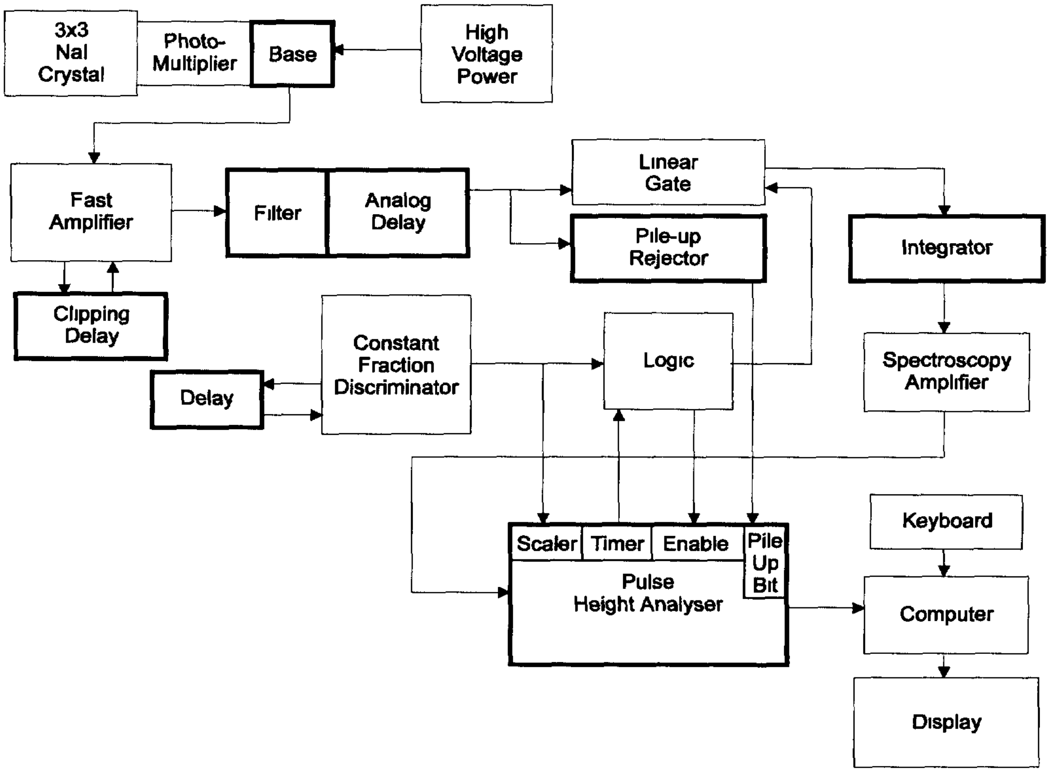

Fig 4) Block diagram of electronics for ILDP TNA system. The electronics were designed to handle the very high count rates encountered near the source.

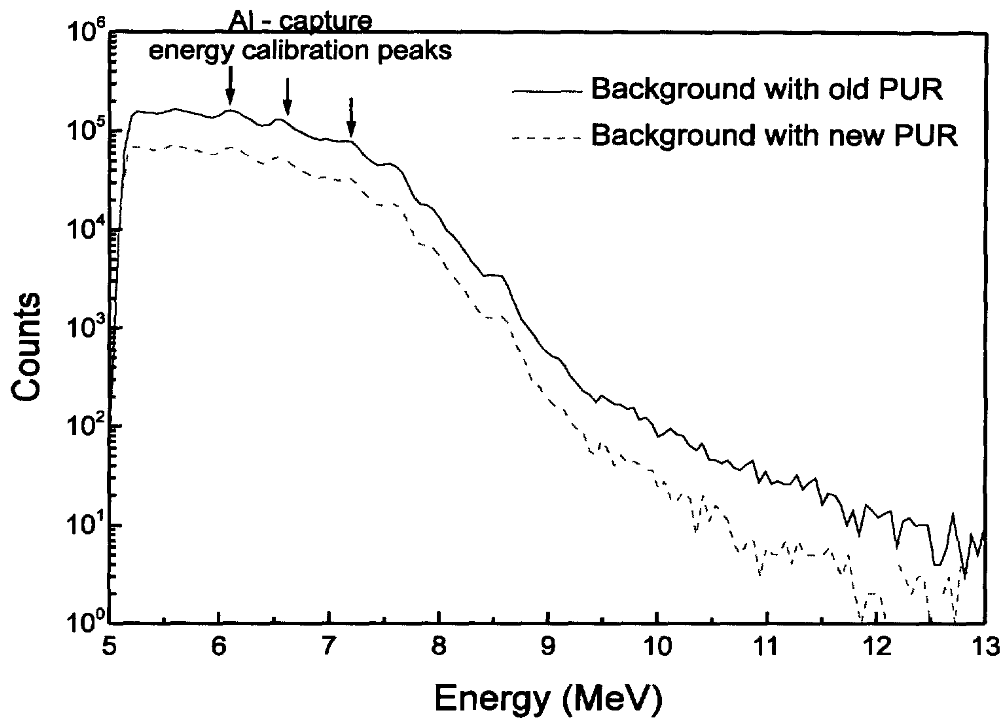

Fig 5) Effects of pileup rejectors on measured energy spectrum. Note the large effects in the energy region of interest, roughly 9 - 11 MeV.

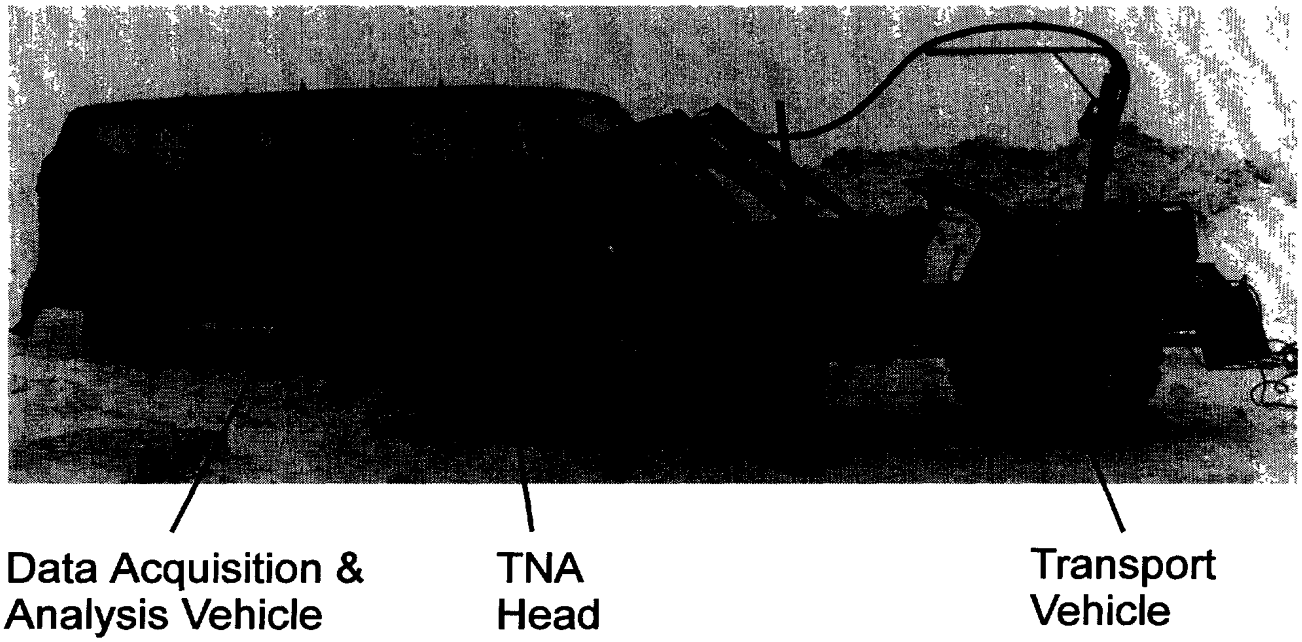

Fig 6) Field trials of ILDP TNA system at DRES.

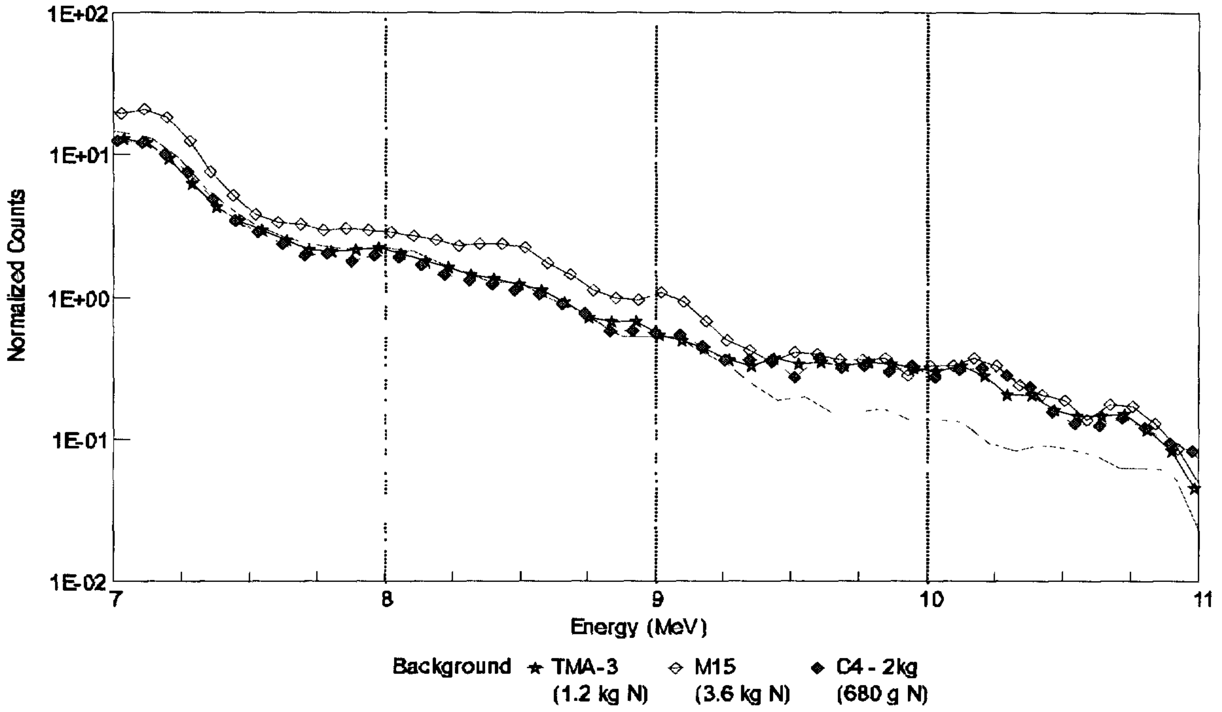

Fig 7) Acquired energy spectra at DRES for "large" mines. all runs are 10 minutes. Note the structure in the M15 spectrum, due to the metallic shell.

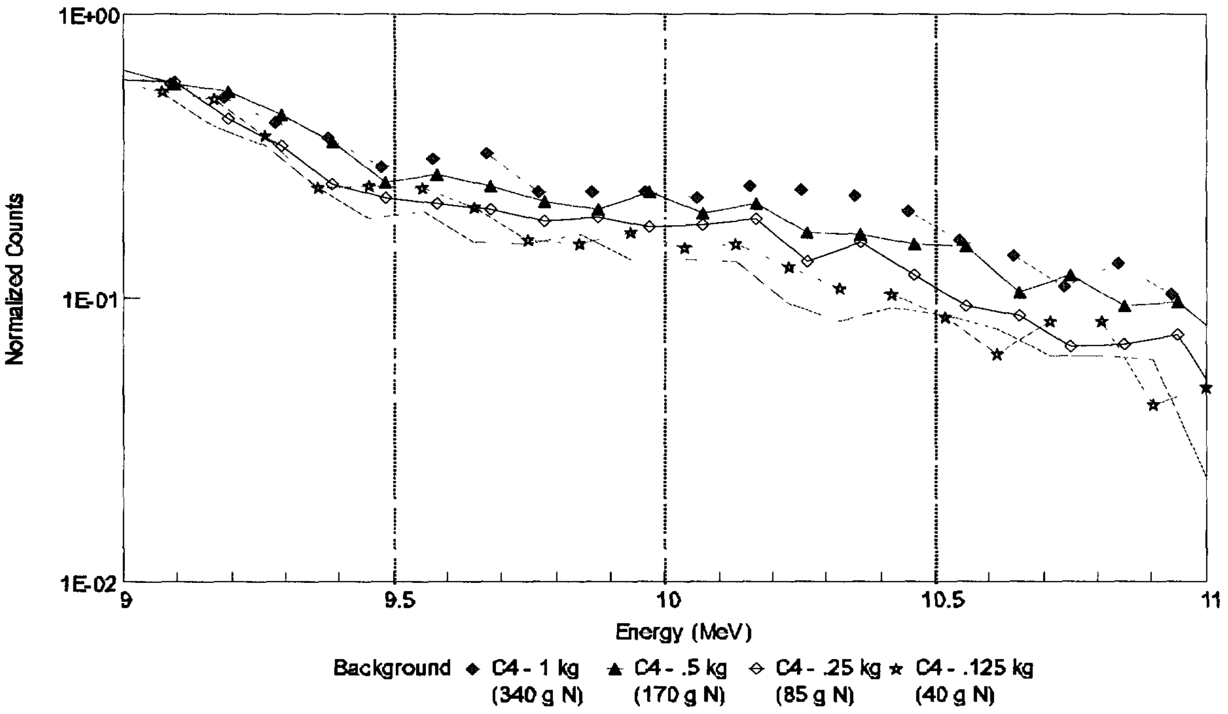

Fig 8) Acquired energy spectra at DRES for "small" mines. All runs are 10 minutes. All save the .125 kg (C4) (40 g N) could be positively detected in less than 5 minutes.

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