Research and Development of Landmine Detection System by a Compact Fusion Neutron Source

September 14, 2004
Monona Terrace Community and Convention Center
Madison, WI

IAE, Kyoto University
Kiyoshi Yoshikikawa
PROGRAMME COMPONENTS

Mine and UXO Clearance

Anti-Personnel = 258,735
Anti-Tank = 12,185
UXO = 2,172,037

Total devices destroyed = 2,442,957
Mined area cleared = 254 sq km
Battle Area cleared: 450 sqkm
MRE Trained : 9,700,000

10/12/2002
Impact - Current Victims

No National Survey

- 150 – 300 Victims/Month
- 50% UXO’s

10/12/2002
**HISTORY**

- Mechanical clearance began soon after WW1
- Flails and Rollers were soon tested

**EARLY FLAIL**

Early mine plow?

Early mine detection
### Characteristics of the landmines found in Croatia

<table>
<thead>
<tr>
<th>Mine</th>
<th>Type</th>
<th>Buried -B, Surface -S</th>
<th>Metal Content</th>
<th>Dimensions</th>
<th>Weight total</th>
<th>Weight explo.</th>
<th>Kill/Casualty radius</th>
</tr>
</thead>
<tbody>
<tr>
<td>PMR_2A</td>
<td>AP</td>
<td>S</td>
<td>m</td>
<td>φ66×122</td>
<td>1.70</td>
<td>0.10</td>
<td>1/25</td>
</tr>
<tr>
<td>TMA_3</td>
<td>AT</td>
<td>B</td>
<td>n</td>
<td>φ260×80</td>
<td>6.50</td>
<td>6.50</td>
<td></td>
</tr>
<tr>
<td>PMA_2</td>
<td>AP</td>
<td>B</td>
<td>n</td>
<td>φ60×33</td>
<td>0.135</td>
<td>0.10</td>
<td>1/25</td>
</tr>
<tr>
<td>PMA_3</td>
<td>AP</td>
<td>B</td>
<td>n</td>
<td>φ104×40</td>
<td>0.183</td>
<td>0.035</td>
<td>1/25</td>
</tr>
<tr>
<td>TMR_P6</td>
<td>AT</td>
<td>B, tilt rod on S</td>
<td>m</td>
<td>φ290×137</td>
<td>7.20</td>
<td>5.10</td>
<td></td>
</tr>
<tr>
<td>TMM_1</td>
<td>AT</td>
<td>B</td>
<td>m</td>
<td>φ250×85</td>
<td>8.65</td>
<td>5.60</td>
<td></td>
</tr>
<tr>
<td>PROM_1</td>
<td>AP</td>
<td>B, protruding assembly on S</td>
<td>m</td>
<td>φ75×329</td>
<td>3.00</td>
<td>0.425</td>
<td>50/100</td>
</tr>
<tr>
<td>TMA_4</td>
<td>AT</td>
<td>B</td>
<td>n</td>
<td>φ280×65</td>
<td>6.30</td>
<td>5.50</td>
<td></td>
</tr>
<tr>
<td>TMA_5</td>
<td>AT</td>
<td>B</td>
<td>n</td>
<td>300×275×113</td>
<td>6.60</td>
<td>5.50</td>
<td></td>
</tr>
<tr>
<td>PMA_1</td>
<td>AP</td>
<td>B</td>
<td>n</td>
<td>142×68×35</td>
<td>0.40</td>
<td>0.20</td>
<td>1/25</td>
</tr>
<tr>
<td>MRUD</td>
<td>AP</td>
<td>S</td>
<td>m</td>
<td>231×46×89</td>
<td>1.50</td>
<td>0.90</td>
<td>50/200</td>
</tr>
<tr>
<td>TMA_1</td>
<td>AT</td>
<td>B</td>
<td>n</td>
<td>φ310×100</td>
<td>6.50</td>
<td>5.40</td>
<td></td>
</tr>
<tr>
<td>TMA_2</td>
<td>AT</td>
<td>B</td>
<td>n</td>
<td>330×260×100</td>
<td>6.50</td>
<td>5.40</td>
<td></td>
</tr>
<tr>
<td>PMR_3</td>
<td>AP</td>
<td>S</td>
<td>m</td>
<td>φ80×150</td>
<td>1.70</td>
<td>0.41</td>
<td>20/100</td>
</tr>
</tbody>
</table>
Requirements for Landmine Detection

>30g in depth of 20cm, 100% detection


### Nuclear methods under development

#### Methods to find buried objects

<table>
<thead>
<tr>
<th>Name</th>
<th>Principle</th>
<th>Advantages</th>
<th>Issues</th>
<th>Status</th>
<th>CRP Groups</th>
</tr>
</thead>
<tbody>
<tr>
<td>X-ray Backscatter</td>
<td>X-rays backscattered form soil can be imaged using collimated detectors</td>
<td>Real time images sufficiently detailed to identify landmine size and type, independent of surface clutter.</td>
<td>Limited x-ray penetration depth into soil, speed of ground coverage, portability, cost (minimum $250K).</td>
<td>Tested with plastic and metal antitank mines as well as anti-personnel mines.</td>
<td>Shope (USA)</td>
</tr>
<tr>
<td>Neutron Backscatter</td>
<td>Quantity of neutrons backscattered from soil can indicate concentrations of hydrogen.</td>
<td>Focuses on plastic landmines, insensitive to metallic clutter, emulates a metal detector (simple to use), simple and low cost, portability (&lt;$10K)</td>
<td>Sensitivity to hydrogen clutter, possible depth limitation, dependence of soil moisture stand off distance dependence.</td>
<td>Successful in laboratory</td>
<td>Brooks (SAF) Bom (HOL)</td>
</tr>
<tr>
<td>Positron annihilation Compton scatter imaging (PACSI)</td>
<td>Gamma rays backscattered from soil can indicate density of buried objects.</td>
<td>Simple and low cost method for forming 3D images to a depth of 20-30 cm. Potentially low cost (about 10 k$)</td>
<td>Experimental test needed.</td>
<td>Demonstrated in computer simulation.</td>
<td>Tickner (AUL)</td>
</tr>
</tbody>
</table>

#### Methods to identify composition of buried objects

<table>
<thead>
<tr>
<th>Name</th>
<th>Principle</th>
<th>Advantages</th>
<th>Issues</th>
<th>Status</th>
<th>CRP Groups</th>
</tr>
</thead>
<tbody>
<tr>
<td>Neutron-induced gamma rays</td>
<td>Neutrons enter the soil and cause emission of gamma rays. Identify elemental compositions from the gamma ray energies.</td>
<td>Identify composition of buried objects to determine presence of explosives. Compact portable system. Easy operated training.</td>
<td>Speed limited by neutron source strength. Background gamma rays must be subtracted.</td>
<td>The PELAN method (Prof. Vourvopoulos) has been demonstrated successfully with unexploded ordnance and is ready for field testing in minefield.</td>
<td>Vourovoupolous (USA) Hussein (CAN) Valkovic (CRO) Viesti (ITA) Ringbom (SWE)</td>
</tr>
<tr>
<td>Backscattered neutrons</td>
<td>Measure the energies of backscattered neutrons.</td>
<td>Good penetration of neutrons into soil. High neutron cross sections.</td>
<td>Neutron energy measurement requires complex electronics &amp; analysis.</td>
<td>Tested in laboratory, and verified by simulations</td>
<td>Csikai (HUN) Hlavac (SLV) Kuznetsof (RUS) Hussein (CAN)</td>
</tr>
</tbody>
</table>
The battery-powered, hand-held HYDAD-H landmine detector. (Univ. of Cape Town).

$^3$He proportional N counter with $^{252}$Cf source.
Prototype of the mobile device with $2 \mu g^{252}\text{Cf}$ source with various investigated objects: TNT imitators, metallic cylinder, wet root etc.
R&D of Landmine Detection System by a Compact Fusion Neutron Source

K. Yoshikawa, Inst. of Advanced Energy, Kyoto Univ.

PELAN TRIALS, 8/99, OHIO, Battle

Pipe bomb
**Outline of Project**

**Sensing technique**

In 5 years, develop techniques to be able to identify

- Landmine exists?
- Plastic or LM? Then what kind?
- Then, where is it?

**Detection thru neutron-related reactions, able to identify**

- Constituents: \( (n, \gamma), (n,n'\gamma) \)
- Location: tomography, and by Innovative IEC neutron source;
  \( >10^8 n/s \), in Pulse, CW modes
R&D Organization & Budget

supported by JST

(Japan Science and Technology Corporation Agency)

1) R&D of compact IEC

CW/pulse IEC
Kyoto-U., Kansai-U.

CW/Pulse power supply
TIT

2) R&D of LM Detection

Diagnostics
Kyoto-U., TIT, Kyushuu-U.

Tomography
Kyoto-U., JAERI, Wakasa-bay

Energy Res. Center,
Total system
Kyoto-U., Nikki Co.

Budget (2002.9-2006.3); approx. US$2~2.5M
Detection Method of Landmine -1-

Atomic number ratio in the explosive has a unique value

<table>
<thead>
<tr>
<th>Kind of Explosives</th>
<th>Atomic Number Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>H</td>
</tr>
<tr>
<td>TNT</td>
<td>3</td>
</tr>
<tr>
<td>Pentrite</td>
<td>8</td>
</tr>
<tr>
<td>Hexogen</td>
<td>2</td>
</tr>
<tr>
<td>Ammonium Nitrite</td>
<td>4</td>
</tr>
</tbody>
</table>

• Measurement of Capture $\gamma$-rays
  
  $H(n, \gamma)$ reaction --- 2.22MeV $\gamma$-ray emission
  
  $N(n, \gamma)$ reaction --- 10.83MeV $\gamma$-ray emission

• Measurement of Back Scattering Neutrons
  
  $H(n, n)$ reaction --- Scattering cross section of $H$ is large
Detection Method of Landmine -2-

Neutron Detector

\(^3\)He Proportional Counter

Organic Scintillator

(\(\gamma\)-rays are detectable)

\(\gamma\)-ray Detector

NaI Scintillator

CsI Scintillator

BGO Scintillator

Landmine (Explosive)

2.45 MeV Neutrons

Capture \(\gamma\)-rays

Slowing Down (Thermal Neutrons)

Back Scattered Neutrons

D-D Neutron Source

Tomography technique is applicable by using plural detectors
If one could measure the time behavior of capture $\gamma$-rays, it would be possible to obtain information concerning buried depth of landmine, since thermal neutrons reach their peak at a certain time after the injection of neutron pulse depending on the depth from ground surface.

If one could measure the time behavior and time-dependent spectrum of back scattered neutrons, it would be possible to obtain information concerning buried depth of landmine.
R&D of Landmine Detection System by a Compact Fusion Neutron Source

K. Yoshikawa, Inst. of Advanced Energy, Kyoto Univ.

16th ANS TOFE, September 14-16, 2004, Madison, WI

$\gamma$-ray Detector or Neutron Detector

Neutron Shield

$\gamma$-ray Shield or Neutron Shield

D-D Neutron Source

Neutron Intensity $= a/4\pi r^2$

$\gamma$-ray Intensity $= a'\sigma \Omega /4\pi r'^2$

Neutron Capture Cross Section: $\sigma$
D-D Neutron Source

Neutron Detector

Neutron Shield

γ-ray Detector

γ-ray Shield

Example of array of neutron source and detectors
Compact Power Supply Mountable on Vehicle

Components and specifications: DC and Pulse operation

- **Compact Generator (16kW)**
- **Control (UPS: 2kW)**

- **HV DC** (CVCC 100kV, 120mA, 12kW)
- **Pulse** (100kV, 10A, 50µs, >200pps)
- **Measurement system (2kW)**

Present status

- Switch used in oil → Condenser → H.V. DC Power Supply ↓

Issues of development

- Compactness
- Robustness
- Modular type
- Molded
- Fail safe system
- High Voltage Connection
- Dry type connection
Circuit of Prototype Pulse Generator System

CW Discharge: –60 kV, 60 mA
Pulsed Discharge: –54 kV, 3 A, 40 µs, 100 Hz
Typical Waveforms (Long Pulse)

The delay will be reduced by assistance of magnetron discharge developed at Kyoto Univ.

Pressure: 14.0 mTorr/H₂
Charging Voltage: -20.0 kV
Storage Capacitor: 1.1 µF
Effect of SSW2

Pressure: 14.0 mTorr/H₂, Charging Voltage: -20.0 kV, Storage Capacitor: 1.1 µF

Suppression of the neutron generation caused by the afterglow of discharge pulse
Higher S/N ratio for landmine detection
Experimental Setup

Conventional IECF Device 
f450 x 310

DC Power Supply

50Ω Resistor Module

2kΩ Resistor Module

100Ω Resistor Module

SSW1

SSW2

Storage Capacitor

Coaxial Cable 
20D-2V, 30 m
The maximum neutron production rate $2.0 \times 10^8$ n/s for $-51$ kV, 7.3 A obtained in a pulsed discharge.
Magnetron-type Ion Source at Negative Potential

\[ \Delta r \]

\[
\begin{align*}
\text{Magnet1} & : L_i = 20 \\
\text{Magnet2} & : L_o = 6
\end{align*}
\]

\[
P(H_2) = 3.0\text{Pa}, \ V = 3.0\text{kV}, \ I = 40\text{mA}
\]
Controllability of Pulse Operation
Magnetron Discharge

IEC Pulse Operation

<table>
<thead>
<tr>
<th>Voltage</th>
<th>Current</th>
</tr>
</thead>
<tbody>
<tr>
<td>5 mTorr, 40 kV</td>
<td>5 mTorr, 60 kV</td>
</tr>
</tbody>
</table>

- Magnetron
- IEC

![Graphs showing pulse operation](image-url)
Design & Fabrication of an Ultra-small Neutron Source

- $1 \times 10^{-6}$ Pa achieved after baking
- a $65\phi$ O.D cathode supported by upper feedthrough
- $9\text{CF}34$ flanges for ion production by magnetron discharge

200$\phi$ vacuum chamber
Hollow cathode and its support
Ultra-compact & high-voltage standing capability

Preliminary testing
- CF70 flange feedthrough for 100kV
- 80kV applied for $10^{-5}$ Pa
- Neutron production for 30 ~ 40kV

100kV feedthrough

IECF discharge (30kV, 6mA, 2.25Pa)

Star mode
The ion source setting on the horizontal plane is very efficient.
Ion Bombardment

Numerical simulation

About 50% ions are lost by hitting the feed-through

In the IEC simulation, we cannot neglect the existence of the feed-through and the cathode structure.
Star Mode Discharge (1Pa, 10kV)

Photo of Star mode

Ionization by electron
Simulation

2.45 MeV Neutron source

20 cm

TNT Landmine

10 ~ 30 cm

(SiO$_2$+Al$_2$O$_3$+H$_2$O+etc)
Capture reaction rate of N and H

- Largely depend on depth of landmine and water content in the ground
  - In case of shallow position, high water contents causes high capture reaction rate
  - In case of deep position, optimum water contents causes high capture reaction rate
  - In case of water contents less than 5%, reaction rate does not depend on depth.
Experiment with 14MeV DT neutron source with melamine (C$_3$H$_6$N$_6$)

• NE213 scintillator was used for neutron spectrum measurement
• Low energy neutron was increased about 5 % with Melamine
• Same as calculated results
Experiment with \( ^{252}\text{Cf} \) neutron source (1)
Experiment with $^{252}$Cf neutron source (2)

- NE213 scintillator was used for neutron spectrum measurement
- Low energy neutron was increased about 4 % with Melamine
- Same as calculated results
Goal of Project

Detection thru neutron-related reactions, able to identify LM with an Innovative IEC neutron source

Constituents and Location

