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Trial of Ground-penetrating Radar, Neutron and Magnetometry Methods in Arid Soil in Egypt

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HYDAD-D (left) and PRIS (right) devices, with their operating crews. The string marking the test lane can be seen in both images. A minor problem was reading HYDAD-D's oscilloscope screen in strong sunlight.

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Metal detection and digging are somewhat unsatisfactory approaches to locating landmines. This report presents and examines alternative detection solutions, such as ground-penetrating radar as well as neutron and magnetometry methods. A case study of these techniques in a laboratory setting and in Egyptian soil reveals their effectiveness.

by John F. Crawford

The Problem

Current methods of finding landmines, based largely on metal detection and careful digging, are not completely satisfactory. Various other techniques are being used or under study—notably ground-penetrating-radar, neutron and magnetometry methods. As discussed below, soil moisture has an adverse effect on the first two techniques.

Ground-penetrating radar. Unlike pulsed radar, continuous-wave radars work by transmitting at a certain frequency (typically for a millisecond) and then stepping to the next frequency. The reflected signal is measured in amplitude and phase at each frequency and stored. After the specified frequencies (typically 256) have been scanned, a fast Fourier transform is carried out on a laptop. This converts from frequency information to time (i.e., space) information, which is displayed to the operator on a laptop screen. GPRs detect discontinuities in the soil's dielectric constant, such as a landmine. In nonmagnetic soil, radio frequency energy penetrates a distance set by the "skin depth" $\sqrt{\rho\lambda / Z\pi}$

	Type	Quantity	Charge weight	Total weight	Comments
APM	VS-50	2	43 g	185 g	w/o 18 g metal plate
	PMN	2	240 g	600 g	
	Box	2	ca 200 g	N/A	1 wood, 1 plastic
ATM	T-80	2	4.5 kg	N/A	plastic
	TM-46	1	5.7 kg	8.6 kg	steel
	Israel	1	10.5 kg	N/A	steel
	M-71	1	6.25 kg	9.8 kg	steel
	Mk-7	1	8.89 kg	13.6 kg	steel

Table 1: Available anti-personnel and anti-tank mines.
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No.	Object	Depth (cm)	HYDAD-D	PRIS GPR	Depth (cm)	Remarks
0	DLM-2	0				See note 0
1	Scrap	0	False Positive	False Positive	5-10	
2	PMN	20	True Positive	True Positive	15	
3	Empty		True Negative	True Negative		
4	PMN	10	True Positive	True Positive	20	
5	VS-50	20	True Positive	False Negative		See note 5
6	Scrap	20	True Negative	False Positive	5-10	
7	Empty		False Positive	True Negative		
8	Empty		True Negative	False Positive	15	See note 8
9	Empty		True Negative	True Negative		
10	Scrap	10	True Negative	False Positive	15	
11	Box	0	True Positive	True Positive	5-10	Wood
12	VS-50	10	True Negative	True Positive	15	See note 12

Notes:
0. DLM-2 was a small dummy landmine supplied by the IAEA; it was visible, and was used for calibration only

5. See second bullet under Comments and Conclusions.

8. Although this position was nominally empty, three soft-drink ring-pulls were buried here

12. HYDAD-D was misbehaving during this measurement, the last of the trial; on its return to Cape Town it turned out to have a fault that might have caused it to miss this mine.

Table 2: APM lane results. Column 3 shows the cover depth; Column 6 the depth estimated by PRIS.

where ρ is the soil resistivity, λ is the RF wavelength and Z is the impedance of free space (about 120π Ω). With increasing soil moisture, both ρ and δ diminish, and the RF does not penetrate the ground very well.

Neutron methods. Explosives contain significant amounts of hydrogen; for example, TNT contains 2.2% hydrogen by weight, or, more meaningfully, 24% by number. Therefore explosives moderate neutrons effectively. This effect can be exploited for explosive detection as follows: Fast neutrons from a suitable source, such as Californium or Americium-Beryllium, are moderated by the soil, and then detected by slow neutron counters (usually ^{3}He proportional counters). An excess of hydrogen, e.g., in a mine's explosive, will yield an enhanced count rate. However, this effect depends on the soil not containing too much hydrogen, the presence of which will prevent the neutrons from penetrating and will moderate them, weakening and obscuring the signal. Thus in soil containing the same amount of hydrogen as the explosive, e.g., as water, there will be no signal.

Magnetometry. Magnetometry is an established technique in archaeology. In addition to finding very small amounts of iron, a magnetometer is sensitive to rust. Thus even heavily corroded steel mines, such as those commonly found in North Africa, should be detectable.

No.	Object	Depth (cm)	PRIS GPR	Depth (cm)
1	M-71	21	True Positive	15
2	T-80	21	True Positive	20
3	Empty		True Negative	
4	Empty		True Negative	
5	TM-46	35	True Positive	30
6	Mk-7	27	True Positive	20-25
7	Empty		True Negative	
8	Empty		True Negative	
9	Empty		True Negative	
10	Israel	30	True Positive	25
11	Empty		True Negative	
12	Empty		True Negative	

Table 3: ATM lane results. Column 3 shows the cover depth; Column 5 the depth estimated by PRIS. Because of the size of these mines, there were no false results and PRIS was able to estimate their depths fairly well. Time did not permit HYDAD-D to be tested on this lane.

Egypt as a Test Area

Both GPR and neutron methods should perform better where the soil is dry, as is the case in North Africa for most of the year. Beyond that, magnetometry should be effective against the steel-cased mines that are common there. Given the successful tests of these techniques in the laboratory,[1] a natural next step appeared to be to organize a combined test in Egypt of as many devices as possible, especially GPR and neutron methods. The idea was first discussed at the International Atomic Energy Agency's Technical Meeting on Combined Devices for Humanitarian Demining and Explosives Detection in Padova, Italy, in November 2006, where many of the laboratory tests were reported.

Three stepped-frequency continuous-wave GHz GPRs were available. A team from *Raumfahrt Systemtechnik* in Salem, Germany, brought two such devices, both of which they had designed and built: the Handheld Operational Demining System (HOPE) and Potash Roof Inspection System.[2] HOPE works from 2 to 6 GHz and PRIS from 0.55 to 3.8 GHz. Beyond that, the Egyptian National Research Institute of Astronomy and Geophysics provided a Geophysical Survey Systems, Inc. MF20 GPR working at 0.1 to 0.8 GHz and 1 to 2 GHz, and a fluxgate magnetometer. Two neutron detectors were available: the Hydrogen Density Anomaly Detector-D[3] from the University of Cape Town, South Africa, and the Egyptian Scanning Landmine Detector (ESCALAD),[4] built by a collaboration of Dutch and Egyptian institutes.

Methodology

In a convenient part of the Inshas Centre of the Egyptian Atomic Energy Authority, two test lanes were marked out in flat, dry, sandy soil by means of strings stretched between pegs. Every 2 m, a position was marked with a knot. At each position an object could be buried (either a mine or scrap metal) or else nothing was buried there; selection among these three options was done at random. Objects were covered to depths of 0, 10 or 20 cm, again at random. Surface objects were covered by just enough soil to conceal them. The soil at empty positions was disturbed enough to avoid providing a visual clue. The trials were "single blind" in the sense that the testees were not told which objects were in which positions. Five anti-personnel mines and five anti-tank mines (see Table 1 on previous page) were buried in the test lanes; two additional mines were required for simultaneous tests with other equipment. The two photos on the previous page show HYDAD-D and PRIS with their operators.

Test Lane Results

Table 2 (previous page), and 3 (above) show the results of the above tests. Neither HYDAD-D nor PRIS detects landmines as such; rather they detect proxies in the form of hydrogen anomalies and radar reflections, respectively. Accordingly, the statements "Positive" and "Negative" in the Tables refer to the apparent presence or absence of these proxies. "True" and "False," on the other hand, refer to the presence or absence of a mine.

The following are remarks on the APM test lane results:

- The Dimension Laser Metrology-2 calibrator was 4 m away from Position 1; the other positions were 2 m apart.
- HYDAD-D took about 30 minutes to measure each position on the APM lane; this can be improved to only a few minutes.[5]
- PRIS took less than 60 minutes to measure all 12 positions in a lane; these results are more fully described elsewhere.[6]
- The MF20 GPR made a scan of the whole lane in only a few minutes.

The following are remarks on the ATM test lane results:

- In a separate test, HYDAD-D saw such a strong signal from some of these mines that the signal confused part of the software.
- In a separate test in a different area of the test field, PRIS missed one of the T-80 mines, apparently because a cover plate was missing.

Extra Results

Although the trial concentrated on the test lanes, some further useful results were obtained:

- As an exercise, a PMN was buried 15 cm deep. The PRIS GPR was used to scan the area in the manner of a metal detector. The PMN was found with no difficulty.
- A fluxgate magnetometer belonging to the National Research Institute of Astronomy and Geophysics could detect steel ATMs at several meters. A caesium magnetometer—some orders of magnitude more sensitive—is on order.

Comments and Conclusions

A number of conclusions came out of this testing, including the following:

- As expected, the dry Egyptian soil made it easier to detect the mines.
- A VS-50, well-known as a difficult mine for conventional metal detectors, was seen at a depth of at least 20 cm by HYDAD-D. Those involved in this work believe this to be a record. Given that the VS-50s provided were not fitted with optional metal plates,[7] this result may be competitive with what conventional metal detectors would have been able to do.
- Because Egyptian soil is dryer than even a comparable sandy European soil, PRIS was able to see about 0.7 m into the ground—about twice as deep as in Europe.
- The University of Cape Town's HYDAD-D device and the RST GPRs were transported as normal airline luggage—not even as excess baggage in the HYDAD-D case, because some standard electronic units that the device needed were available in Cairo. However, a few small obstacles were encountered. The equipment brought in from Europe and South Africa was held up overnight by customs at Cairo Airport, because the official on duty lacked the authority to clear the equipment. On release the next morning, the RST radars—HOPE and PRIS—had to be unpacked, reassembled and switched on. HYDAD-D had to be unpacked, reassembled, connected to equipment supplied in Cairo, and switched on. After minor problems were overcome, the equipment was assembled and worked more or less nominally. This indicates the equipment's state of development. HOPE and PRIS worked as expected; their antennas have since been redesigned, partly as a result of this test.
- The weather during our test (4–8 November 2007) was excellent for our purposes: sunny, not hot by local standards, with light winds.
- ESCALAD gave a great deal of trouble, apparently due to interference from a nearby radio transmitter, to dust in electrical connectors, and to a mismatch between the strength of its neutron source and its minimum practicable speed. ESCALAD is the first device of its kind, and this was its first field trial after satisfactory laboratory tests.[8]
- In part because of this work, improvements have been made to the equipment. A further test, also involving γ backscattering and Superconducting Quantum Interference Device magnetometry is planned for November 2010.

See Endnotes, Page 82

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- Dr. Victor Bom, Delft University of Technology, Netherlands, in collaboration with the Egyptian Atomic Energy Authority's ESCALAD neutron detector

Local participants:

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Originally from the United Kingdom, **John Crawford** is a retired Swiss scientific civil servant who started out as a particle physicist in the 1960s, went on to work in cancer therapy and accelerator physics, and then on landmine problems. These problems are important and interesting enough to keep him involved during his retirement.

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