Field Tests of the HYDAD-D Landmine Detector

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The HYDAD–D landmine detector [1] has been field tested in South Africa and in Egypt, using both a dummy landmine and real (disabled) anti-personnel landmines. A hand-held version of the detector and a version that incorporates a motor-driven scanner were tested. The test results demonstrate that HYDAD–D can detect the VS 50 anti-personnel landmine (mass 185 g) when buried at a cover depth of 20 cm in dry sand.

I. INTRODUCTION

The HYdrogen Density Anomaly Detector (HYDAD) [1] is a device that detects hydrogen-rich objects by observing the energy-moderation of fast neutrons by hydrogen. In landmines, for example, the explosive content, together with any plastic material that may be present, constitute a detectable hydrogen target. The HYDAD–D landmine detector [1, 2] basically consists of an isotopic source of fast neutrons, two identical slow neutron detectors and appropriate signal processing equipment. Laboratory tests have demonstrated [1, 2] that HYDAD–D can detect antipersonnel landmines equivalent to the IAEA dummy landmine DLM2 [3] when buried at depths up to 15 cm in dry sand. In this paper we present results from two further series of tests of HYDAD–D: firstly, outdoor tests that were carried out, using DLM2, in the grounds of iThemba LABS, South Africa; and secondly, "blind" tests carried out in the grounds of the Inshas Centre of the Egyptian Atomic Energy Authority, near Cairo, using real (but disabled) landmines [4].

II. THE HYDAD–D LANDMINE DETECTOR

The upper panel of Fig. 1 shows a schematic diagram of the geometry of HYDAD–D. The centre and lower panels illustrate how hydrogen is detected. The fast neutron source S and the slow neutron detectors A and B form a unit in which the centres of A and B are 14 cm apart and S is midway between. This unit is held about 1 cm above the sand surface and scanned back and forth in the x-direction, repeatedly crossing the site under examination, at position $x = x_0$. Suppose, for example, that a landmine or other object is buried in homogeneous dry sand under a cover depth c at this site. A and B are identical ^{3}He-proportional counters of diameter 5 cm and active length 10 cm, filled to a pressure of 5 bar. These counters are quite insensitive to fast neutrons and γ-rays but highly sensitive to neutrons that have been moder-

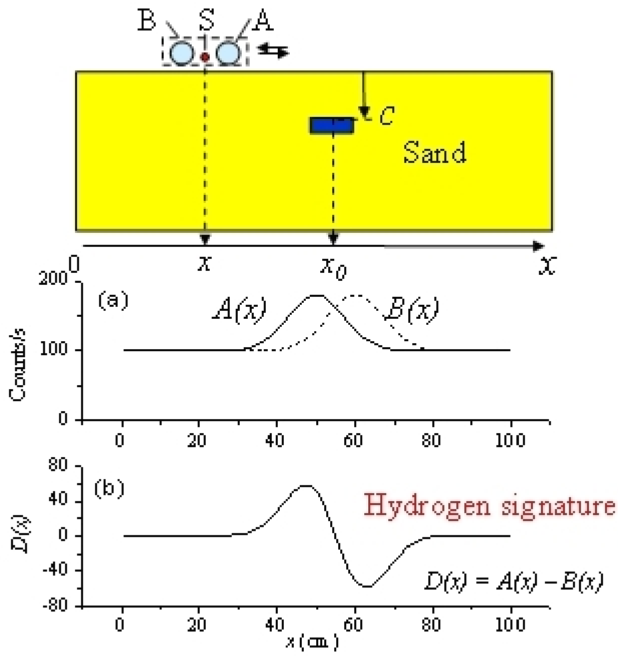

FIG. 1: Schematic diagrams showing the HYDAD–D geometry (top panel) and the formation of the hydrogen signature (centre and lower panels).

ated to eV or thermal energy. Hydrogen (^{1}H) is an efficient neutron moderator. Thus, if the object is rich in hydrogen then the detector count rates $A(x)$ and $B(x)$ vary as shown in panel (a) and the difference $D(x)$ between them therefore has the form shown in panel (b). On the other hand, if the object is not hydrogen-rich, or if there is no object present, then $D(x)$ will remain close to zero over the full range of the scan. A $D(x)$-function of the form shown in Fig. 1 panel (b) is thus the "signature" of a landmine or other hydrogen-rich object.

In this paper we report tests of two versions of the HYDAD–D system: firstly, a version that incorporates a motor-driven scanner; and secondly, a hand-held version. Figure 2 shows the components of the hand-held system laid out as they would be prior to assembly for operation. Figure 3 shows the hand-held system in use during tests carried out at iThemba LABS (top) and at the Inshas

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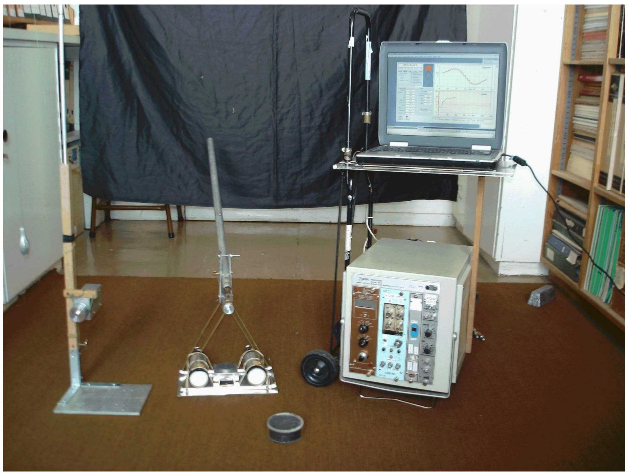

FIG. 2: Components of the hand-held version of HYDAD–D, showing: the detectors and neutron source (centre); the position tracker unit (left); and the electronics and laptop computer (right). The dummy landmine DLM2 is in the centre foreground. The laptop display is the same as that shown in Fig. 4.

Centre (bottom).

The count rate information from the slow neutron detectors is processed on-line in the laptop computer (Fig. 2) to obtain a signature function $S(x)$ and an indicator parameter function $P(N)$ [1]. The signature function is given by

$$S(x) = < D(x) > /\sigma_D \tag{1}$$

where σ_D is the standard deviation of $< D(x) >$, the brackets $<>$ indicate that a rolling average is taken (see Ref. [1]) and N is the total number of counts recorded by the detectors since the start of the scan. A least-squares fit is made of the hydrogen signature (Fig. 1 pannel (b)) to the experimentally measured signature $S(x)$. $P(N)$ is then determined from the chi-square obtained from this fit and the amplitude and symmetry of the signature, as described in Ref. [1]. The calculations of $S(x)$ and $P(N)$ are updated at regular intervals during the scan and presented on the computer display. The calculation time required for each update is much less than one second.

Figure 4 shows an example of the final laptop display obtained from a calibration run made using 200 ml of carbonated water in a light metal container (an unopened can of soda water) as the test object. The black histogram and the red curve in the plot of $S(x)$ show the measured and fitted signatures respectively. The "traffic light" on the left indicates the current "state" of the scan. It changes colour according to the value of $P(N)$ as the scan proceeds. The state is either "negative" (green), corresponding to $P < 3$; or "positive" (red), corresponding to $P > 6$; or "uncertain" (yellow), corresponding to P in the range $3 - 6$ [2]. The numerical information presented in the rest of the display is not relevant for our present purpose. In addition to being analysed on-line, the counts data from the detectors are also recorded during the scan, so that the analysis can be repeated off-line and with different analysing parameters, if desired.

The value of x at which the fitted signature (red curve $S(x)$ in Fig. 4) changes from positive to negative provides an estimate of the location x_0 (see Fig. 1) of a detected object. The data acquisition software actuates an audio output when the detector position x is close to x_0, and $P(N)$ is also > 6. The frequency of the audio output changes from high to low as $S(x)$ changes sign, to alert the operator to the presence and position of the detected object. A movie clip showing this feature in operation is available in these proceedings [5].

The value of $P(N)$ shown in the display (Fig. 4) is arbitrarily set at a an initial "seed" value of $P(N) = 4$ at the start of each scan. After the scan has progressed through ten or more updates the average of the previous ten updated values of $P(N)$ is taken, in other words a rolling average. The value shown prior to the completion of ten updates is an average of the values measured so far and the seed value.

The operator checks the display plots of $P(N)$ and

FIG. 3: The hand-held HYDAD–D detector in operation out-of-doors at iThemba LABS, South Africa (top) and at the Inshas Centre, Egypt (bottom).

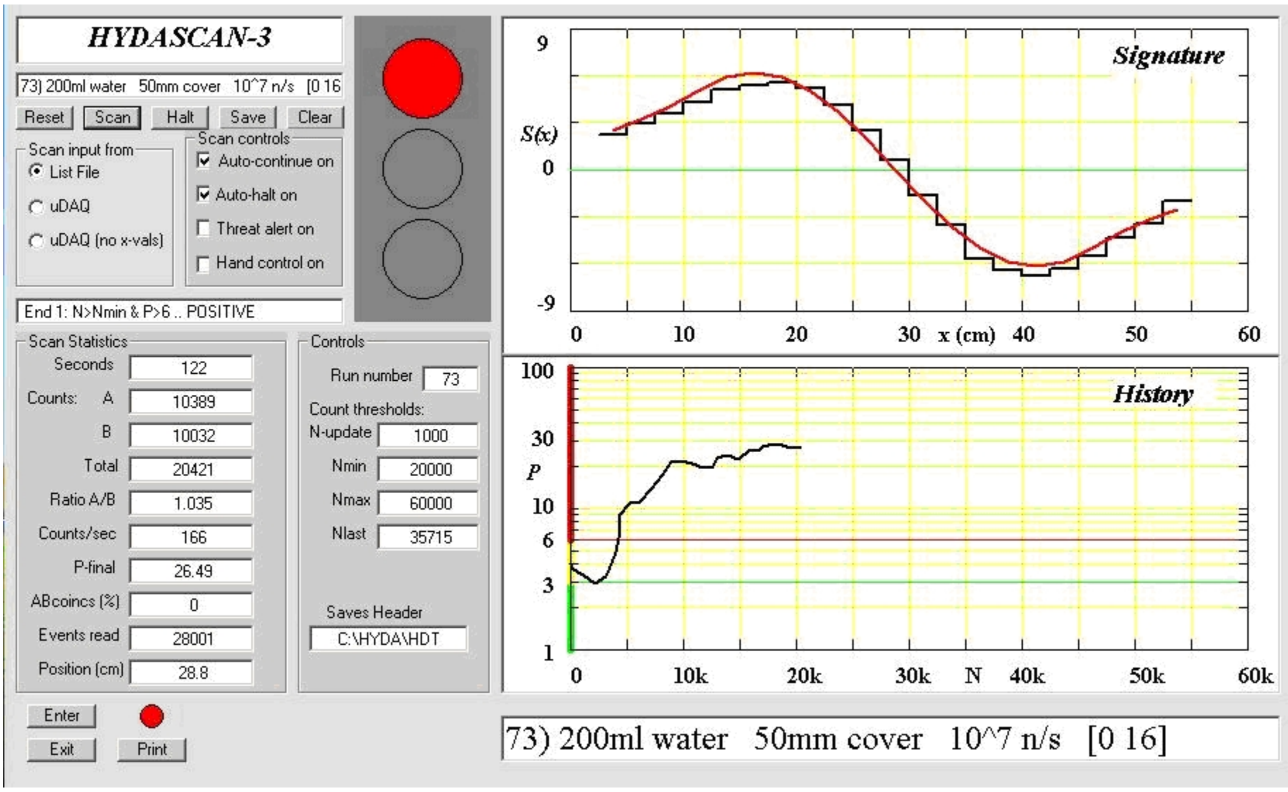

FIG. 4: Final display obtained from a calibration run. The test object was a 200 ml water sample contained in a light metal canister, at a cover depth of 5 cm.

$S(x)$ as the scan proceeds, to monitor the operation of the instrument. The criteria used to decide how long a scan should continue are arbitrary and based on the operating experience gained using HYDAD–D. They are reviewed regularly and are presently as follows. The scan is terminated after the number of counts N exceeds a selected minimum value, typically 20000, and either: (i) $P(N) > 6$; or (ii) $P(N) < 3$ and has been so for at least 5 successive updates of the display. In case (i) the result of the scan is positive. In case (ii) it is negative. If neither of these conditions is satisfied at $N = 20000$ then the scan continues until either a result (positive or negative) is obtained, as described above, or N reaches a preset maximum value, typically 60000. If the latter, then the result of the scan is taken as uncertain (yellow) and a new scan is started. If the second scan also gives an uncertain result then the combination of two successive yellows is conservatively regarded as a positive (red) result. The final result is thus always either positive or negative.

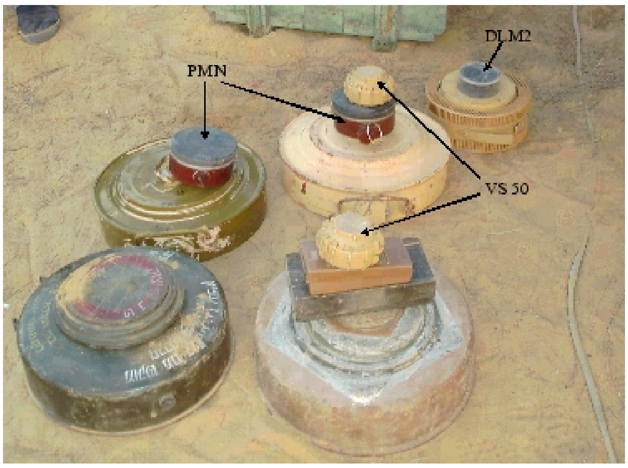

FIG. 5: Landmines (ATM and APM) and the dummy landmine DLM2 that were used in the tests. The labels indicate the three types of test object for which results are presented in this paper.

III. FIELD TEST MEASUREMENTS

Figure 5 shows a photograph of some of the test objects used in the field tests. They include anti-tank mines (ATM), anti-personnel mines (APM) and the dummy landmine DLM2. The ATM and APM were previously rendered safe by disabling their detonator mechanisms. The labels in Fig. 5 indicate the test objects that were used in the work discussed in this paper, namely DLM2 and two types of APM, the PMN and the VS 50. DLM2 [3] consists of 100 g of TNT-simulant (a compressed mixture of inert chemicals) sealed in an acrylic container of mass 100 g. The PMN was manufactured in

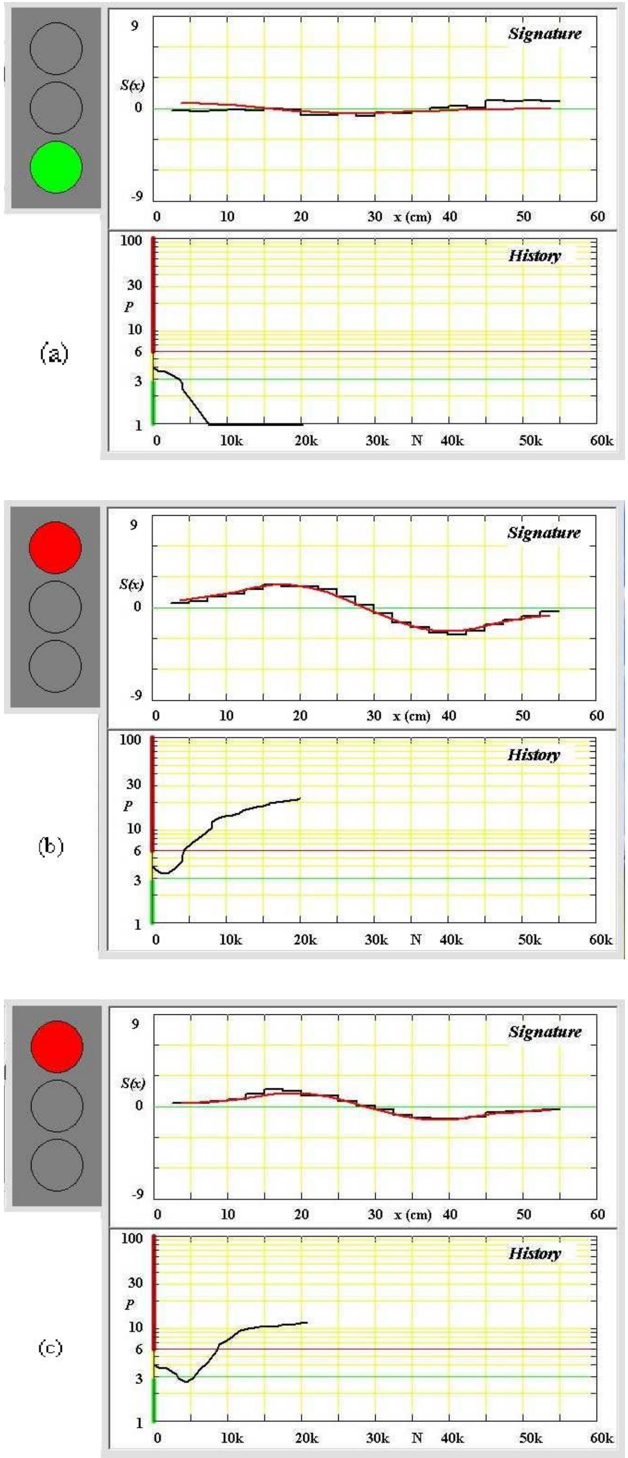

FIG. 6: Final displays obtained from scans made at iThemba LABS using: (a) no test object, (b) DLM2 at cover depth 3 cm, and (c) DLM2 at cover depth 12 cm.

the former USSR and contains 200 g of TNT in a plastic, rubber and metal container of mass 350 g. The VS 50 originates from Italy, contains 43 g of RDX explosive sealed in a plastic container of mass 140 g, and typically incorporates only a very small quantity (< 5 g) of metal.

In each test measurement the landmine or other test object, if any, was located below a clearly indicated point, the "test site", on the ground surface ($x = x_0$ in Fig. 1). The detector was scanned along a straight line that crossed over this point, as described in Sec. II. This procedure is similar to that which would be followed if HYDAD–D were to be used as a so-called "confirmation sensor", in other words a sensor that is used to investigate a site that has previously and independently been flagged as suspect by another landmine detector.

Circumstances necessitated that there had to be some differences between the equipment used in the field tests carried out in South Africa and in Egypt respectively. For example, a different neutron source, provided by the Egyptian Atomic Energy Authority, was used for the measurements made in Egypt, in order to avoid having to transport radioactive materials across national boundaries.

A. Field tests at iThemba LABS, South Africa

The iThemba LABS tests were made using an AmBe source that emitted 10^7 neutrons per second. A motor-driven scanning system was used and the outdoor terrain in which the tests were carried out was similar to that illustrated in the top panel of Figure 3. The only landmine-like object available for these tests was DLM2.

Figure 6 shows final displays obtained from three different HYDAD–D scans. The duration of each scan was about two minutes. Only the graphical areas of the displays (the plots of $S(x)$ and $P(N)$ and the traffic light) are shown. Panel (a) shows results obtained with no test object present in the soil. The function $S(x)$ in this case shows no resemblance to a hydrogen signature and $P(N)$ decreases steadily from the "seeded" initial value of 4 to a value of less than 1. The result is therefore negative, as expected. Panels (b) and (c) show the results of scans in which DLM2 was buried at cover depths $c = 3$ and 12 cm respectively. Hydrogen signatures that indicate positive results are clearly evident in both of these displays. In addition, the positions x_0 of the detected object estimated from the signature $S(x)$, as described above, are within 1 cm of the known positions of DLM2 in the two measurements.

B. Field tests at the Inshas Centre, Egypt

The Inshas test measurements were made using a ^{252}Cf source that emitted 5×10^6 neutrons per second. The hand-held version of HYDAD–D was used, as shown in the bottom panel of Fig. 3. These tests were single blind tests. The locations of the test sites were indicated to the detector operators prior to the commencement of the measurements. No other information was provided until all tests were completed and the results submitted.

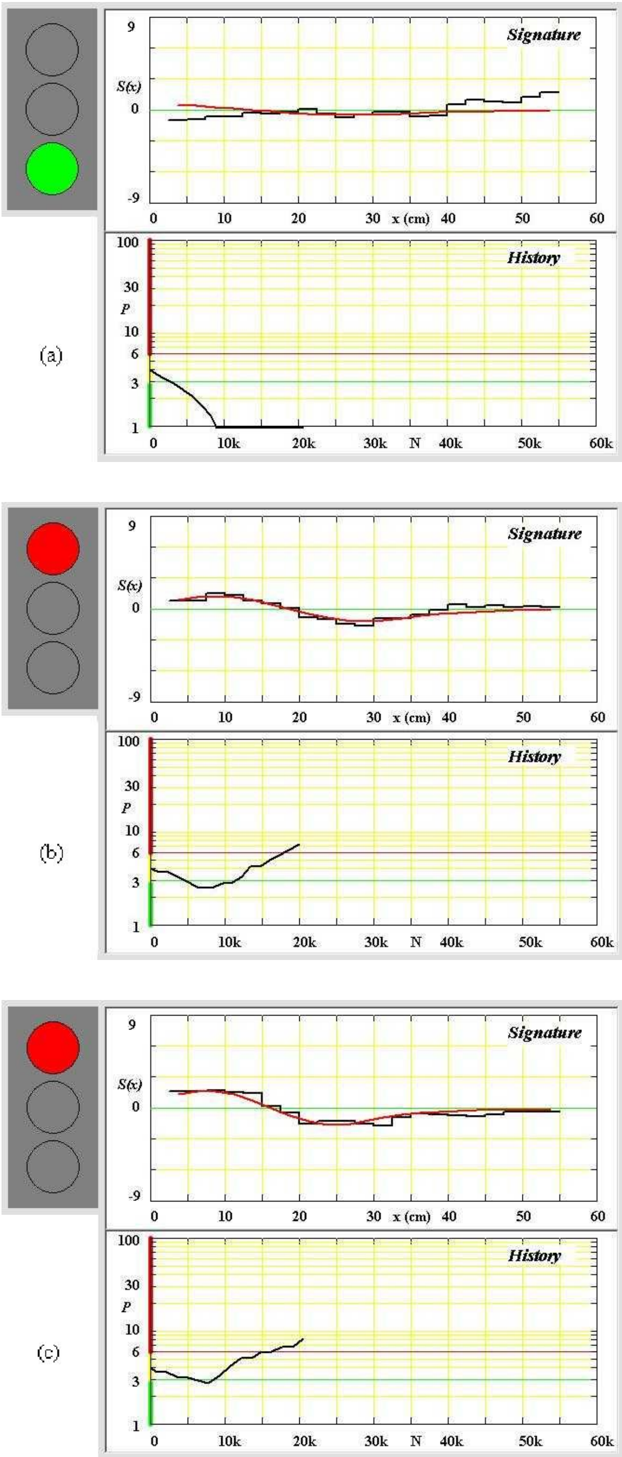

FIG. 7: Final displays obtained from blind tests scans made at the Inshas center: (a) no test object, (b) PMN APM at cover depth of 10 cm, and (c) VS 50 APM at a cover depth of 20 cm.

Figure 7 shows results obtained from three of the blind scans made at Inshas Centre. The duration of each of these scans was also about two minutes. Panel (a) shows the final display obtained from a scan made over a site containing no test object. The result is negative. Panels (b) and (c) show displays obtained from measurements made with the PMN APM at a cover depth of 10 cm and the VS 50 APM at a cover depth of 20 cm respectively. Hydrogen signatures are clearly recognisable, indicating clear positive results for both measurements. The positive-to-negative cross-over positions of the fitted signatures $S(x)$ also provide good estimates (within about 2 cm) of the positions x_0 of the landmines.

IV. DISCUSSION AND CONCLUSIONS

The results presented in Figs. 6 and 7 mark some significant advances in the development of HYDAD–D. Firstly, they mark the transition from the laboratory phase [1, 2] to field tests, that is measurements under conditions in which it cannot be assumed that the soil is uniform, dry and free from vegetation, as is usually the case in the laboratory. Secondly and thirdly, the results shown in Fig. 7 are the first HYDAD–D results obtained using real landmines and the first obtained under single blind test conditions. And fourthly, results obtained using both a motor-driven scanner and a hand-held system are presented.

Figures 6 and 7 provide a limited basis for comparing results obtained using the motor-driven and hand-held versions of HYDAD–D. They do not permit an accurate comparison of the two modes, however, because the two sets of measurements were made under different conditions. They nevertheless suggest that the motor-driven scanner will perform better (Fig. 6) than the hand-held scanner (Fig. 7), probably because the motor-driven scanning action is smoother and better controlled. Other points that favour the motor-driven version are that the operator is: (a) free to stand further away from the neutron source, and thus be less exposed to radiation; and (b) able to devote his or her full attention to the results appearing on the computer screen, without having to hold and move the detector. On the other hand, the hand-held system may perhaps prove more acceptable to experienced mine-detector operators because it is similar in appearance and method of operation to the hand-held metal detectors that they are already familiar with.

Several conditions have to be satisfied in order for HYDAD–D to perform well. Firstly, the soil must be as dry as possible. HYDAD–D is useful only for soil of water content $< 10\%$ by weight. Secondly, it is essential that the electrical power supplied to the equipment be free from any kind of interference. Thirdly, the equipment must be rugged and well-adapted (mechanically and electrically) to the operational conditions. The test areas at the Inshas Centre met the first requirement very well. In the tests carried out at iThemba LABS, on the other hand, the "background" count rates ($A(x)$ and $B(x)$ at $x \ll x_0$ or $x \gg x_0$) varied over a range of $4 : 1$ between sets of measurements made at different times. This appeared to be due to changes in the soil moisture content, arising from different weather conditions in the periods preceding each test series. The dependence of the sensitivity of HYDAD–D on both the amount and the depth-distribution of soil moisture still needs to be investigated carefully.

The second and third requirements were under good control during the measurements made at iThemba LABS. However, this was not so for the measurements made at Inshas Centre, mainly because the preparations made in Cape Town, prior to transporting the equipment to Cairo, failed to take proper account of differences between the operating conditions at iThemba LABS and Inshas. The HYDAD–D measurements made at Inshas were consequently hampered by problems and delays. The average time spent at each test site was about 30 minutes. It should not have been more than about 5 minutes; 3 minutes to move equipment over from the previous site studied and 2 minutes for the measurement. The additional time was spent on identifying and dealing with electrical and mechanical problems. These problems could probably have been avoided if more careful preparations had been made beforehand.

In spite of these difficulties the performance of HYDAD–D in the single blind tests carried out at the Inshas Centre was encouraging [4]. A comprehensive review of the Inshas tests, including results obtained from all of the detectors that participated, is presented in the contribution of John Crawford to these proceedings [4]. It is hoped that there may soon be further tests of this type in Egypt and that HYDAD–D will again participate in the tests.

Acknowledgements

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[3] F.D. Brooks, M. Drosg, A. Buffler and M.S. Allie, "Detection of anti-personnel landmines by neutron scattering and attenuation", Appl. Rad. Isot., 61 (2004) 27.

[4] J. Crawford, "Trial of Various Methods in Arid Soil at the Inshas Centre near Cairo", contribution to these proceedings.

[5] see the movie clip "Brooks.mpg" in these proceedings.