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Development and Testing of HYDAD-D Landmine Detectors

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Abstract: The HYDAD-D landmine detector [1] has been field-tested in South Africa, using a dummy landmine, and in Egypt, using real antitank and antipersonnel landmines. Results from these tests are presented and the information they provide about the strengths and limitations of the HYDAD-D sensor is discussed.

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1. Introduction

The HYDAD-D landmine detector [1] is a hydrogen sensor that consists of an isotopic source of fast neutrons and a pair of slow neutron detectors. When used to detect a landmine it responds to hydrogen contained in the explosive material and in any plastic components that may also be present, for example in the mine casing. HYDAD-D has been field-tested in South Africa and in Egypt [2]. We present some results obtained in these field tests and describe some modifications and improvements to HYDAD-D that have followed from the experiences and lessons learned during the transition from a laboratory environment into the real world.

2. The HYDAD-D detector

Figure 1 shows schematic diagrams of the geometry and the "hydrogen signature" of HYDAD-D. The slow neutron detectors, A and B, are two identical ^{3}He proportional counters that are quite insensitive to fast neutrons and gamma rays but very sensitive to thermal and epi-thermal neutrons. Fast neutrons emitted from the Am-Be neutron source S are not efficiently moderated to thermal energy by the sand, as long as the sand is dry. However a landmine or any other hydrogen-rich object becomes a source of thermal neutrons when irradiated by fast neutrons. Suppose that such an object is present in the sand at position $x = x_0$ and cover depth c. If the source-detector system BSA scans in the x-direction, just above the surface, along a path that passes directly over the object, then detector A will respond more strongly than detector B as S approaches $x = x_0$ from the side $x < x_0$, and vice-versa as S moves on to $x > x_0$ (Figure 1a). The difference between the detector count rates $D(x) = A(x) - B(x)$ therefore describes an excursion of the form shown in Figure 1b. If no hydrogen-rich object were present then $D(x)$ would remain close to zero over the full length of the scan. Figure 1b is thus the HYDAD-D signature of a hydrogen-rich object, possibly a landmine.

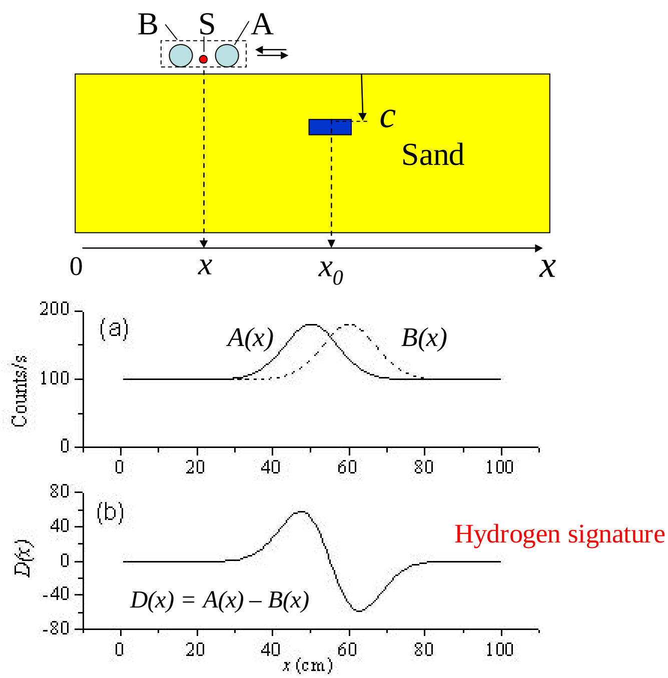

Fig. 1: Schematic diagrams of the HYDAD-D geometry (top panel) and the formation of the hydrogen signature (middle and lower panels).

The HYDAD-D detector can be operated either as a hand-held detector or by means of a motor-driven scanner. Figure 2 shows a photograph of the hand-held instrument in operation during field tests held at the Inshas Centre of the Egyptian Atomic Energy Authority in November 2007. Apart from the method used to scan, the operation of the hand-held and motor-driven instruments is identical. The detector scans back and forth over the site under investigation, while a laptop computer gathers data from the detectors. The laptop computes and displays a signature function $S(x)$ and an indicator parameter $P(N)$ [1], where N is the total number of events accumulated. The computer display is updated each time that N has been incremented by a preset amount. The scan may be terminated either when the operator decides to do so, or automatically, after certain criteria are satisfied. The result of the scan is determined by the value of P at termination: positive (red) if $P > 6$; negative (green) if $P < 3$; and uncertain (yellow) if P lies in the range 3-6. In the event of an uncertain result the scan may be repeated until a definite yes-or-no result is obtained, as described in ref. [2].

3. Field tests

The hand-held version of HYDAD-D (Figure 2) and the version which incorporates a motor-driven scanner were field-tested in the grounds of the iThemba LABS in South

Fig. 2: The hand-held HYDAD-D sensor in action at the Inshas Centre, Egypt.

Africa. Only the hand-held instrument was transported to Cairo, for testing at the Inshas Centre of the Egyptian Atomic Energy Authority. In both sets of tests the landmine, or other test object (or no object at all) was buried below a clearly indicated “site” (point on the sand surface such as $x = x_0$ in Figure 1) and the sensor was scanned along a straight line that passed over this point as described in section 2. This procedure is similar to that which might be followed if HYDAD-D were to be used as a “confirmation sensor”, in other words as a sensor that is used to investigate a site that has previously and independently been flagged as suspect by another landmine detector.

3.1 Field tests at iThemba LABS, South Africa

The only landmine-like test object available to us in South Africa was the dummy landmine, DLM2 [1]. In this section we present results from some of the test measurements made at iThemba LABS (iTL) using the motor-driven scanner. The neutron source S (Figure 1) was an AmBe source that emitted 10^7 neutrons per second. The results that we present here were obtained in two different sets of measurements made under similar conditions, but separated by an interval of 10 days. The moisture content of the soil at the time of the measurements, estimated from the background count rates of the detectors, was less than 5 % by weight.

Figure 3 shows a final computer display from a scan in which DLM2 was buried at a cover depth (see Figure 1) of c = 5 cm. The black histogram in the upper right panel shows the experimentally measured signature, *S(x)*. The red curve is the fit of the signature function (Figure 1b) to the experimental data. The scan was terminated after about 2 minutes, at N = 13200, when it became clear from both *S(x)* and the large value of P = 18 that the result was positive. The red “traffic light” in the display is to draw the operator’s attention to the positive result.

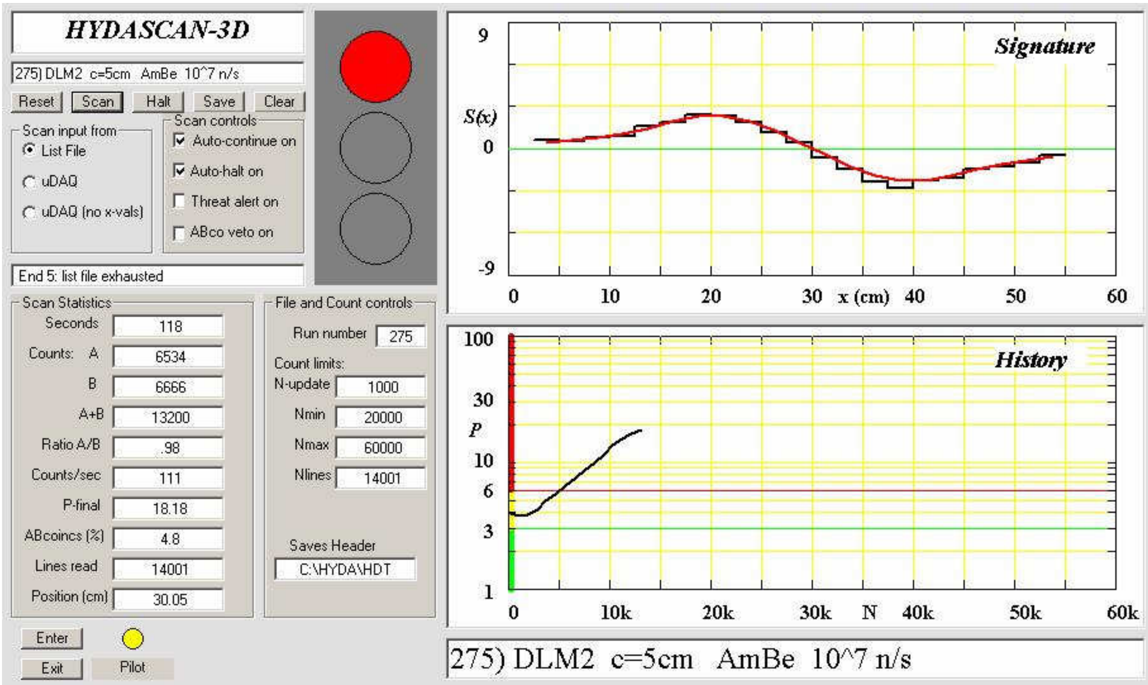

Fig. 3: Final laptop display obtained from a motor-driven scan made at iThemba LABS, using the AmBe source (10^7 n/s), with DLM2 at a cover depth of 5 cm.

The HYDAD-D software includes an audio alarm [2] to alert the operator to the presence and position of a landmine, or other hydrogen-rich object, while data acquisition is in progress. The alarm is activated when the sensor is close to the object, if $P > 6$. The position of the object is indicated by the positive-to-negative cross-over point x_0 in the fitted signature. The alarm sounds when the sensor position x is close to x_0. The frequency of the alarm changes from high to low as $S(x)$ changes from positive to negative, and vice-versa.

Figure 4a shows the final display from a scan made shortly before that shown in Figure 3, with the scanner at the same position as for Figure 3, but prior to burying DLM2 in the ground. This scan was carried on for 165 seconds (N = 17870) and produced a signature $S(x)$ which clearly does not resemble that shown in Figure 1b, hence the negative, or green result, as expected.

Figure 4b shows the final display from a scan made prior to that shown in Figure 4a, under the same conditions as Figure 4a (without DLM2 present), but at a another position closer to the buildings in the iTL grounds. Whereas the signature presented in Figure 4a shows relatively small excursions from zero over the full measured range of x, as would be expected if the ground composition was more or less uniform, that in Figure 4b shows clear positive and negative excursions. However, the result is classified negative (green) because the excursions are not consistent with the signature shown in Figure 1b. After repeating this scan and obtaining the same result the ground beneath the scanned region was investigated by digging. The inspection revealed several fragments of plastic material at depths of about 8 cm and larger, suggesting that the observed signature could be interpreted as a superposition of multiple HYDAD signatures from several hydrogen-rich objects, perhaps including some beyond the range of *x* covered in the scan.

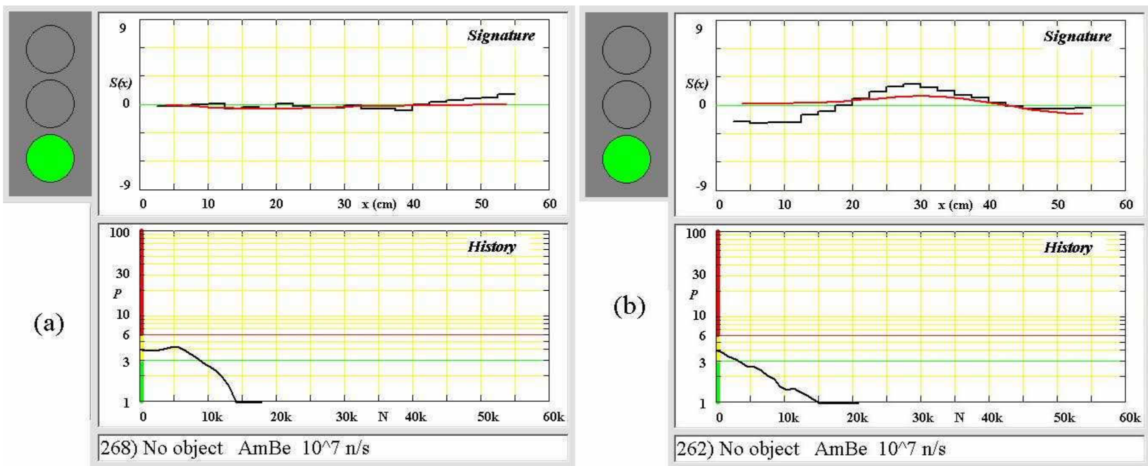

Fig. 4: Final laptop displays (plots and "traffic light" only) obtained from motor-driven scans, using the AmBe source, with no test object present, at two different positions, (a) and (b), about 10 m apart, in the iTL grounds.

At least three valuable lessons were learned from this experience. Firstly, development and testing should preferably be conducted at positions far away from buildings, in order to avoid debris that may have been buried (dumped and covered with soil) at the time of construction. Secondly, a reminder that, in the real world, as distinct from the laboratory, "hydrogen-rich litter" can occur anywhere and will cause difficulties for HYDAD-D. And thirdly, it became clear that the conditions for classifying a result as negative should be tightened, for example by requiring that the signature $S(x)$ should be consistent (within some specified limit) with zero over the full range of x. Thus any result that failed to classify as either red or green according to these terms should be classified as uncertain (yellow). This modification is now being implemented in the HYDAD-D software.

Figure 5a shows the final display from a scan made under conditions like those applying to Figure 3, except that the cover depth of DLM2 was 19 cm instead of 5 cm and the measuring time was 3.5 min instead of 2 min. A signature is detected, giving a positive result, but the amplitude of the signature is reduced compared with that observed in Figure 3. Figure 5b shows the display obtained from a scan in which the cover depth was increased to 23 cm. This increase weakens the signature just enough to reduce the indicator parameter P to the red-yellow boundary (P = 6). These results show that HYDAD-D is capable of detecting DLM2 at cover depths up to about 20 cm under the conditions that applied for the measurements shown in Figure 5. However, if the "background signature", that is the signature observed without DLM2 present, had been like that shown in Figure 4b rather than like Figure 4a, then the HYDAD-D signature would probably have been obscured in both of these measurements!

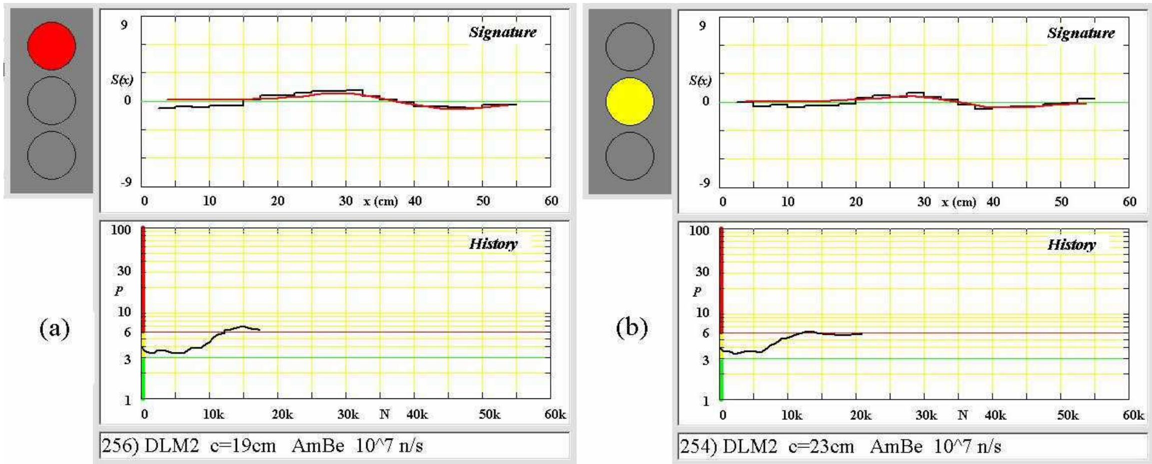

Fig. 5: Final displays obtained from motor-driven scans, using the AmBe source, at position A in the iTL grounds, with DLM2 buried at cover depths of: (a) 19 cm; and (b) 23 cm.

3.2 Field tests at the Inshas Centre, Egypt

The hand-held HYDAD-D detector (Figure 2) was one of several types of landmine detector that were field-tested at the Inshas Centre of the Egyptian Atomic Energy Authority in November 2007. A ^{252}Cf source which provided 5 x 10^6 neutrons per second was provided by the Inshas Centre and the test objects were real landmines which had previously been rendered safe to handle by disabling their detonator mechanisms. A summary and overview of the Inshas tests together with results obtained by all participants has been published [3]. We present and discuss some of the results obtained in the tests of HYDAD-D.

The programme at the Inshas Centre included a set of 12 so-called “single blind” tests. Independent supervisors marked out 12 positions (test sites), spaced 2 metres apart, in a line along the sand surface, and buried a single object, or no object at all, at each site. The test objects included real anti-personnel mines (APM) and some metal items. They were buried at cover depths between 2 and 20 cm. No information other than the positions of the test sites was provided to the detector operators until all test measurements had been completed and the results submitted to the supervisors.

Figure 6 shows final computer displays obtained from two scans that were included among the blind tests. Both scans gave negative results, and were confirmed to be correct after the tests were completed.

Figure 7 shows the final display obtained from a scan in which the test object was a T-80 anti-tank mine (ATM) containing a charge of 4.5 kg TNT in a plastic container of

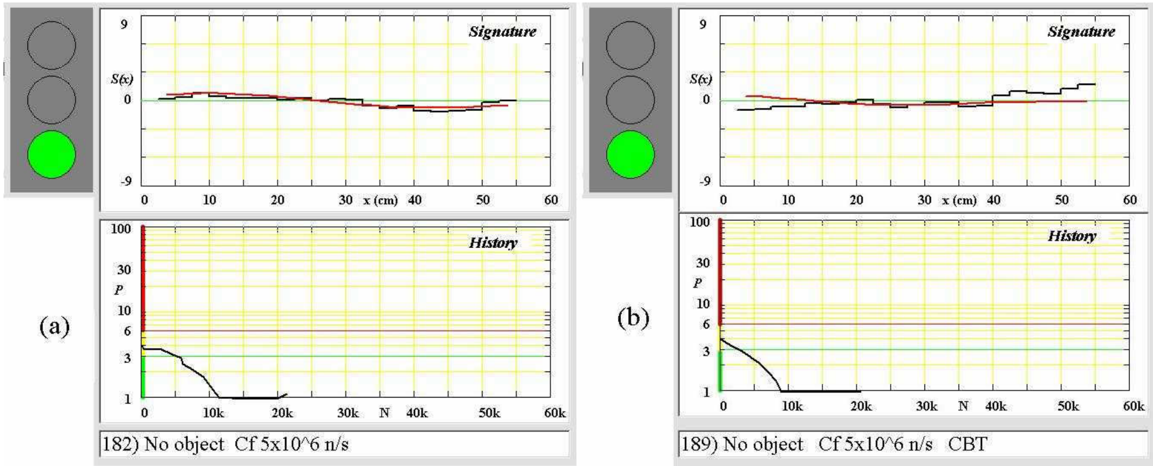

Fig. 6: Final displays from two different "single blind" scans made at the Inshas Centre, Egypt, using the hand-held HYDAD-D sensor, incorporating the Inshas ^{252}Cf source (5 x 10^6 n/s). Both sites were afterwards confirmed to have been "no-object" sites.

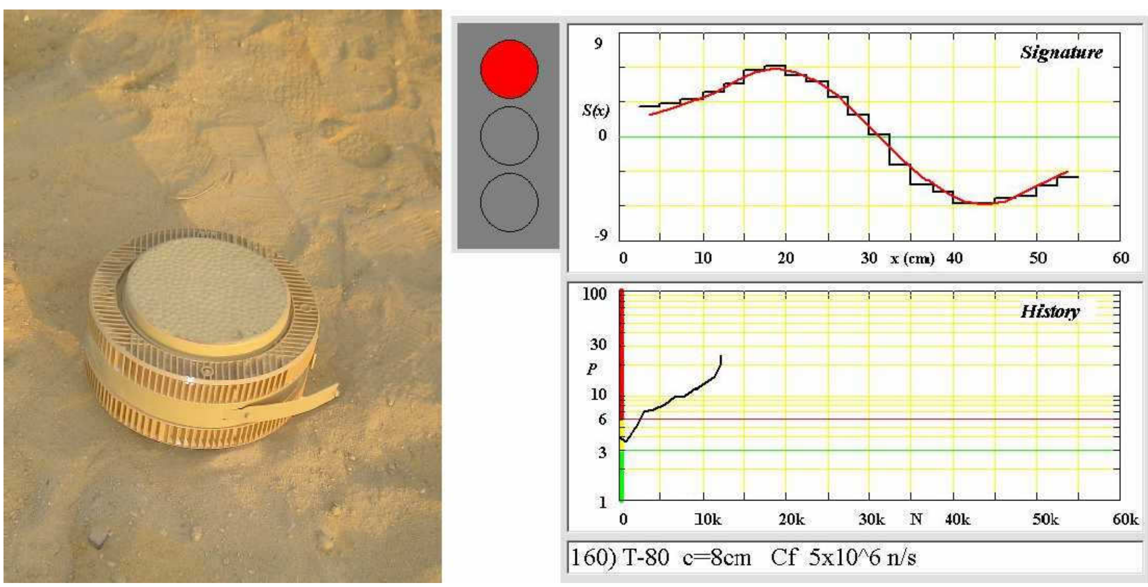

Fig. 7: Photograph (left) of a T-80 antitank landmine and the final display (right) obtained from a scan made using the hand-held HYDAD-D sensor, incorporating a ^{252}Cf neutron source (5 x 10^6 n/s). The landmine was buried at a cover depth of 10 cm and the scan time was 30 s. The T-80 contains 4.5 kg of TNT in a plastic casing of diameter 20 cm.

unknown mass, estimated to be approximately 0.5 kg. The cover depth was 10 cm. A strong, clear signature was observed, as shown in the figure, giving a clear positive result from a scan of duration about 30 seconds.

Figures 8 and 9 show final displays from HYDAD-D scans in which the test objects were the following types of APM: a PMN buried at a cover depth of 10 cm (Figure 8); and a

VS50 buried at a cover depth of 20 cm (Figure 9). Clear positive signatures were obtained in both measurements.

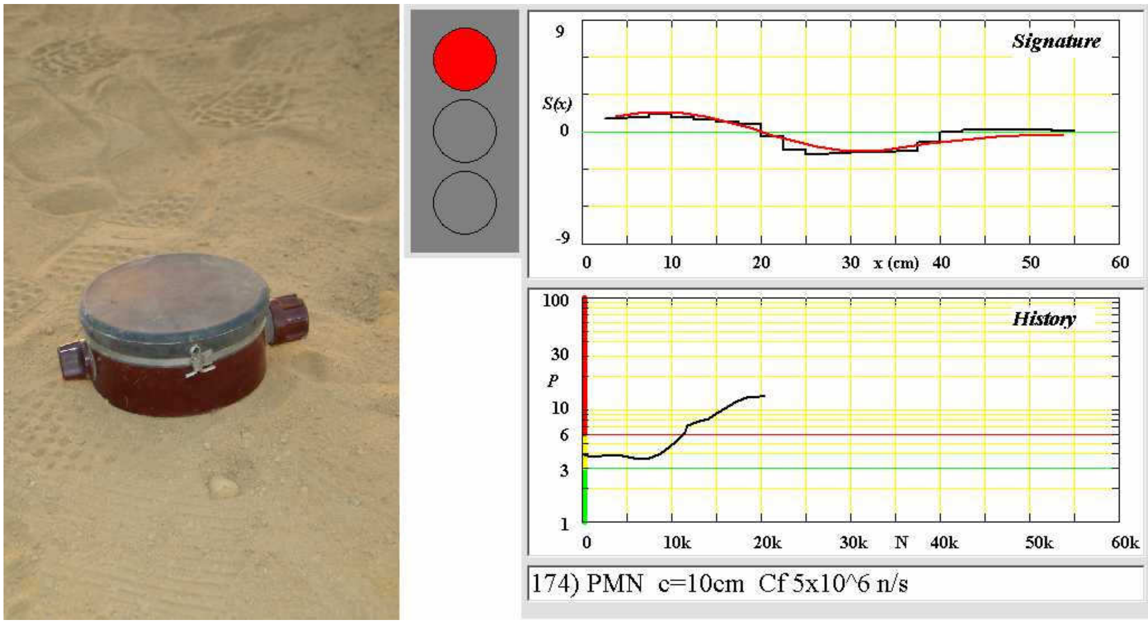

Fig 8: As for Fig. 7, but for a PMN antipersonnel landmine, diameter 11 cm, total mass 550 g, containing 200 g TNT in a rubber, metal and plastic casing. The scan was a single blind scan of duration 2 min.

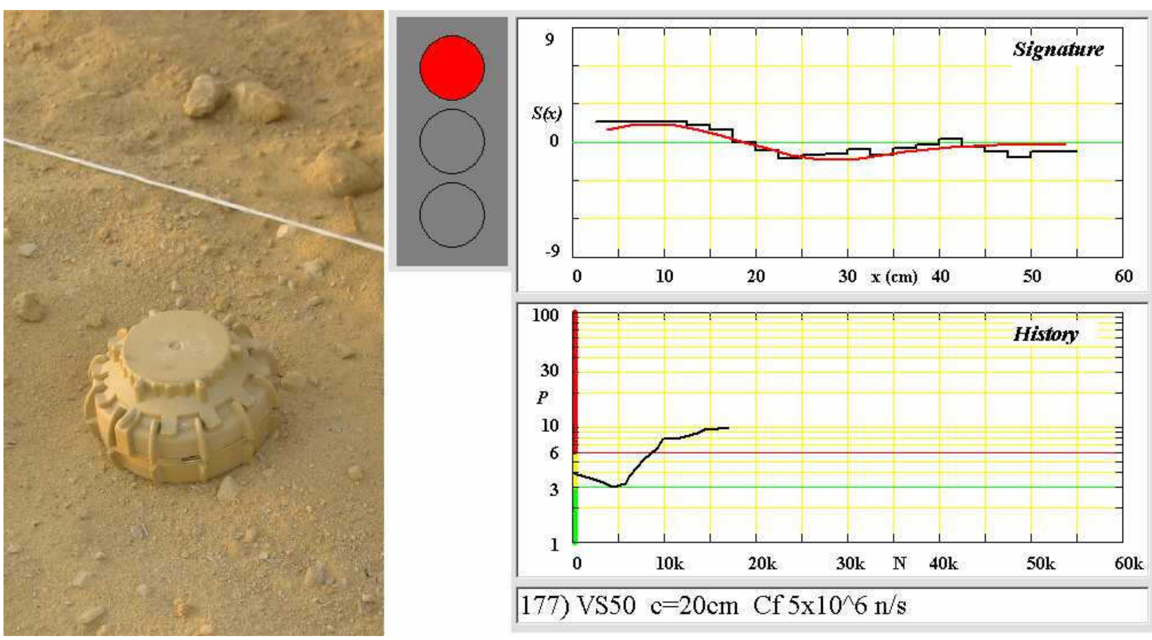

Fig. 9: As for Fig. 8, but for a VS50 antipersonnel landmine, diameter 9 cm, total mass 185 g, containing 43 g RDX and < 5 g metal, in a plastic casing. The scan was a single blind scan of duration 2.5 min.

4. Discussion and conclusions

The results presented in Figures 3-9 demonstrate the potential of HYDAD-D for field operation and illustrate some of the limitations of this sensor that appeared in the transition from laboratory testing to field testing. Methods for overcoming or containing these limitations are now being investigated.

The results of the tests carried out at the Inshas Centre, as shown in Figures 6-9 and in ref. [3], are especially interesting and important because these tests were: (a) made using real landmines; (b) made in conditions ideal for HYDAD-D (dry and apparently uniform sand); and (c) tests in which several different types of sensor were investigated under the same conditions [3]. Efforts are now being made to organize another series of tests in Egypt, in collaboration with the Dr Riad Megahid's research group at the Inshas Centre and with the Egyptian demining authorities.

The results obtained from the tests carried out at iTL, using the dummy landmine DLM2, and from the tests carried out at the Inshas Centre, using real APM, have indicated that limiting cover depth attained by HYDAD-D under close to ideal conditions is about 20 cm for these types of landmine. Previous laboratory investigations [1] have shown that this limit can be extended if the neutron source is located below the sand surface at depths of 10-20 cm. Methods for achieving this in a practicable way, under field conditions, are now being investigated.

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