Experimental Cairo Testing and Evaluation

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I- INTRODUCTION

The North Western Coast Region of Egypt was the theatre of many decisive battles during WWII. For more than sixty years the left over mines and explosive remnants of war (ERW) have caused thousands of human casualties and blocked the development potential of this important part of the country. It is believed that millions of mines and unexploded ordnance (UXO) such as aircraft bombs, artillery projectiles and other ERW have been hidden over the years by sand at different depths. Meanwhile it is encouraging to notice the growing international concern over the damaging socio economical effects of landmines and ERW to Egypt. The world has over the last two decades seen a growth of humanitarian demining activities in many of the mine affected countries around the world.

The UNDP Mine Action Program in Egypt, was launched in January 2007 as a result of the agreement signed on 9 November 2006 with the UNDP. With the objective of deciding on which metal detectors to use in the demining activities it was decided to organize in Egypt test trials for metal detectors manufactured by the World's five leading manufacturers. The test trials, to which I was appointed technical advisor and rapporteur of the jury, were conducted between 12- 18 May 2007 at a specially designed and prepared test field in the vicinity of the 6^{th} of October City, close to Cairo. The Egyptian Armed forces built all test lanes, supplied them with the required target mines and provided all services. The lane officers were staff members from Cairo University.

II-TEST LANES

The following tests were performed:

1. Maximum detection depth in air (two special jigs were used).
2. Detector footprint (spatial sensitivity profile) in air (tool added to jig)**.**
3. Resolution of two nearby targets (two lanes with different types of clean soil).
4. Maximum detection depth in soil (four 6 m x 1 m lanes with different types of clean soil : pure sand , sand with added hematite and black earth).
5. Reliability test by regular metal detectors for two types of rendered-safe mines in eight lanes with soil similar to 4. above. In every lane, 24 mines were located within an active area of 24 m x 1 m. An area of 1 m x 1 m in each lane was dedicated to ground compensation and left free of targets.
6. Reliability test for detectors which are able to discriminate between different metallic objects. Two lanes similar to 5. above with the two targets in addition to artificial metallic clutter .
7. Maximum detection depth of metal cased mines and UXO located below a specially prepared ramp with a maximum height of two meters.

For the purpose of training local detectors and detector preparation , each company was offered four 4 m x 1 m lanes containing different soil types for training local deminers . A private tent for storage was also provided for each cimpany.

III-COMPANIES AND DETECTOR MODELS :

CEIA :

a-MIL-D1 Mine Detector (MD)

b-MIL-D1/DS (UXO) :

EBINGER :

a-EBEX 422 GC (MD)

b-TREX 204 (MD)…..(For evaluation)

c-SC 728 (SC 20 type) (MD)…(For evaluation)

d-UPEX 740M (UXO)

FOERSTER :

a-MINEX 2FD 4.530 (MD)

b-FEREX 4.032 DLG (UXO)

MINELAB :

a- F3 (MD)

b- F4 (UXO) Discriminating detector.

VALLON :

a- VMH3CS (MD)

b- VMR2 (Dual Sensor)

c- VMH3CS with large search head (UXO)

d-VMXC1 (UXO)

It should be mentioned that the EBEX 422 GC MD had some technical difficulties and could not be repaired locally. Thus this detector was not tested. The search head of the F4 detector was damaged during transport and required some repair . Thus it could not join the group of detectors early enough to be tested in the blind lanes and a full set of data could not be obtained. Nevertheless , using a small search coil , we were able to subject it to a reduced number of tests as a mine detector in all blind lanes and also to the regular UXO detector test. This detector was operated only by the manufacturer representatives.

IV- TARGETS

In each blind lane 24 targets were placed at different depths. Both TS-50 and PMN rendered-safe AP mines were used. While a rendered-safe TS-50 mine (T*) is more difficult to detect (contains less metal) than a live one , our rendered-safe PMN mine (P*) contained the safety pin and is easier to detect than a live one. The T* targets were placed at depths of 5,10,15 and 20 cm while the P* targets, which contain more metal, were placed at depths of 35, 40, 45 and 50 cm in eight lanes with different types of soil. Each detector was tested by four dedicated operators, one provided by the company and three by the Egyptian army.

For the UXO test the following deactivated targets were used:

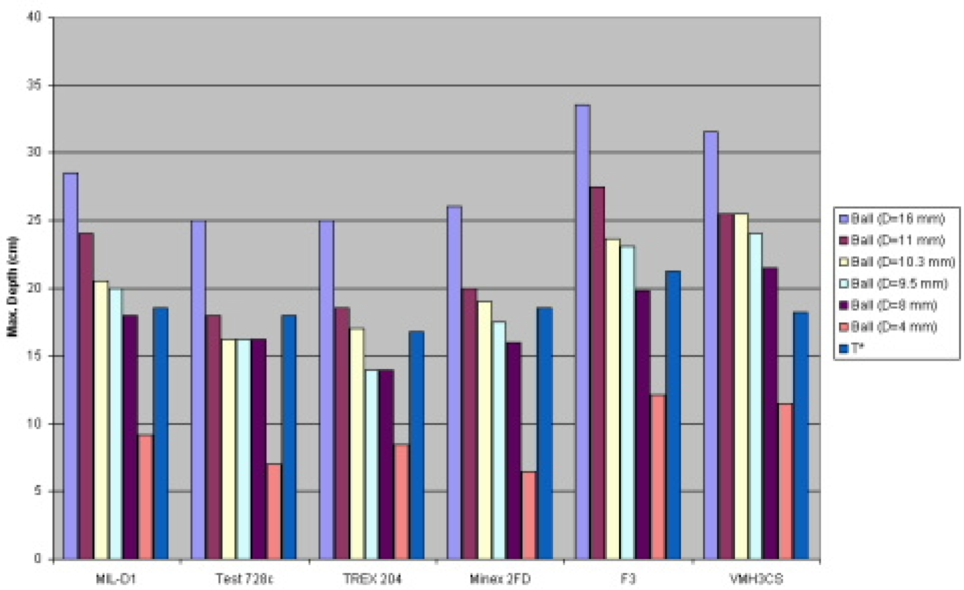
1. MK7 AT mine , G. Britain (25cm diameter).
2. M71, AT mine , Egypt (25 cm diameter)
3. T80 , AT mine , Egypt (15 cm diameter)
4. Projectile, solid metal, 10 kg.
5. Projectile, solid metal, 1 kg.
6. Projectile , solid metal, 0.9 kg.
7. Projectile , solid metal, 0.160 kg.

Again every UXO detector was tested by the four dedicated company deminers along the ramp.

V-RESULTS :

1-Results of the test of maximum detection depth in air are presented in Fig. 1. For spherical metallic targets, F3 leads, followed by VMH3CS and then MIL-D1. For T*

Fig. 1 : Maximum Detection Depth in Air



Targets F3 leads again. It is followed by MIL-D1 ,MINEX-2FD, VMH3CS and SC 728 with the four detectors having very close scores,

It should be mentioned that the two discriminating detectors were not submitted to this test by the producing companies during the regular trial time. Later on, we ran this test on both the F4 and the magnetic detector of the VMR2 using the T* target achieved greater detection depth than other regular metal detectors listed above. These results can be seen in Fig.2F and 2G which also shows that the GPR sensor of the VMR2 has a more limited detection depth than the MD part..

The sensitivity profiles in air are shown in fig.2. A-G . Considering the T* most detectors tested have a rather constant sensitivity within a radius of 10 cm , except for the MIL-D1 and F3 whose sensitivity drops by nearly 40% at a radius of 10 cm.

The proximity test results are shown in Fig.3 A-B for two different types of soil . F3 and SC 728 showed the best target resolution for two targets whose top is flush with the ground surface.

Results of the test of the detection depth in the soil are shown in Fig. 4, where we show the number of deminers who succeeded in detecting a target at each depth. This graph could be correlated in that way with the probability of detection in blind tests. Thus deminer quality and the limited statistics affect the results. We still believe that this is a better way to judge the sensitivity of detectors in soil than presenting the average maximum detection depth and to our knowledge this method has not been used before. From the figure we can deduce that MINEX-2FD, F3 and VMH3S detectors lead for the T* targets while MIL-D1 and MINEX-2FD lead for the deeper-buried and larger P* target.

Fig.2A :Sensitivity Profile in Air for Ceia (MIL-D1)

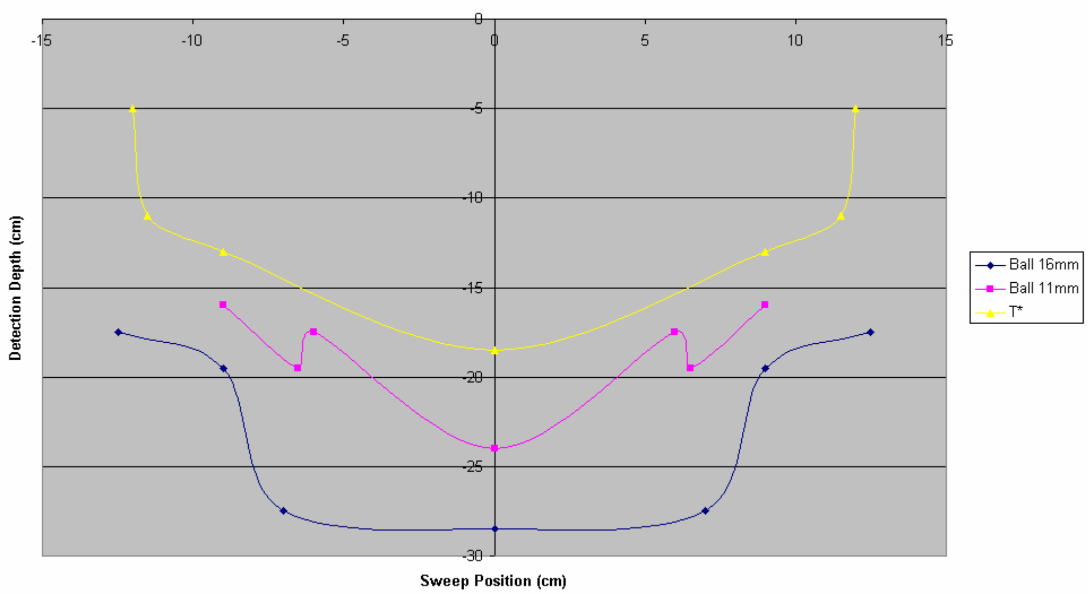


Fig.2.B. **Sensitivity Profile in Air for Ebinger (Test 728c)**

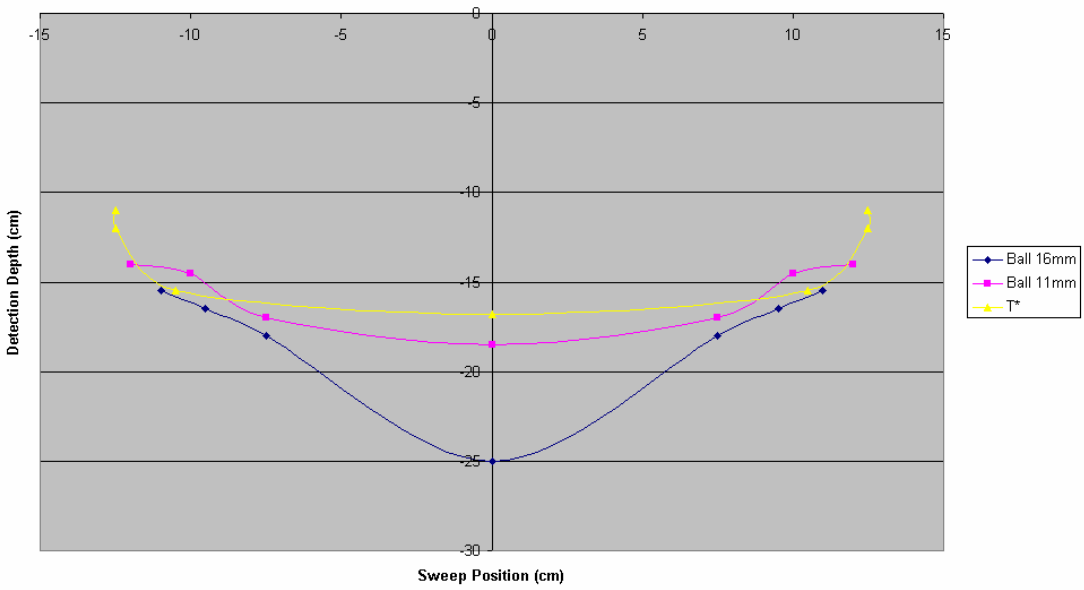


Fig.2.C **:Sensitivity Profile in Air for Foerster (Minex 2FD)**

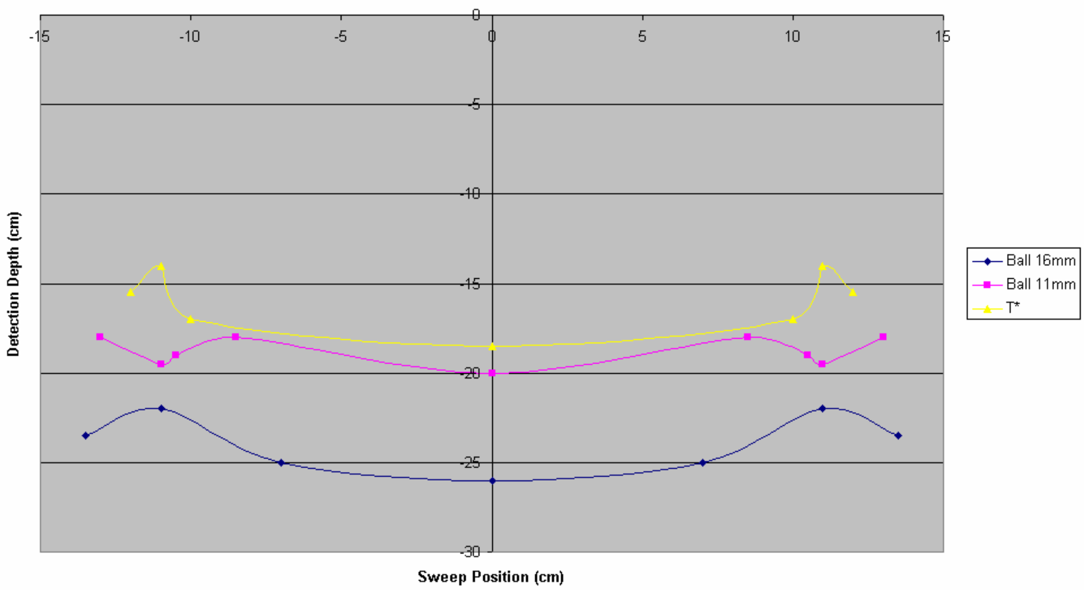


Fig.2.D :Sensitivity Progfile in Air for Minelab (F3)

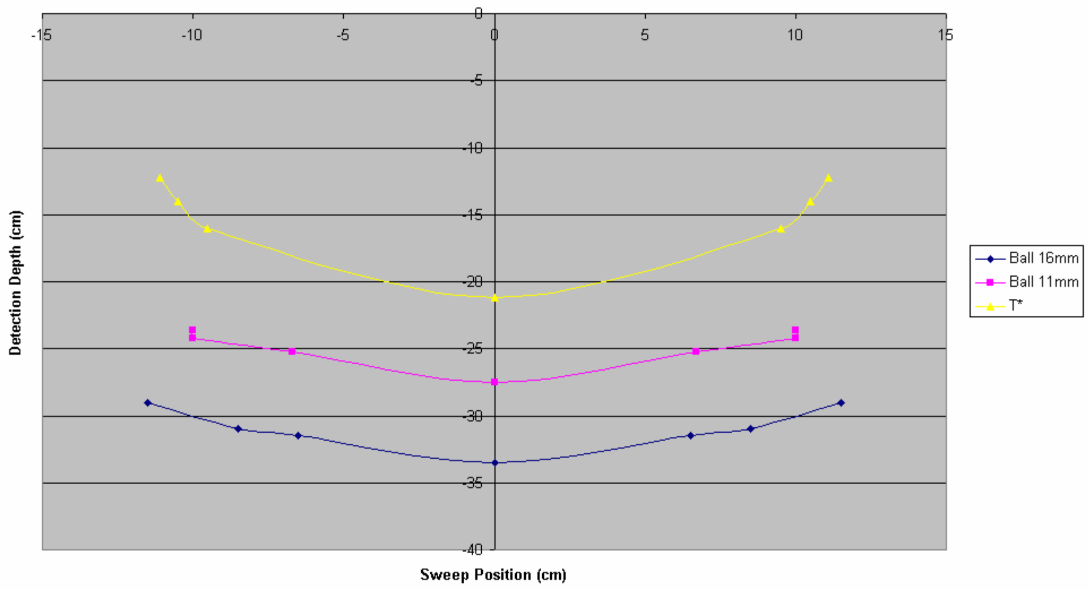


Fig.2.E : Sensitivity Profile in Air for Vallon (VMH3CS)

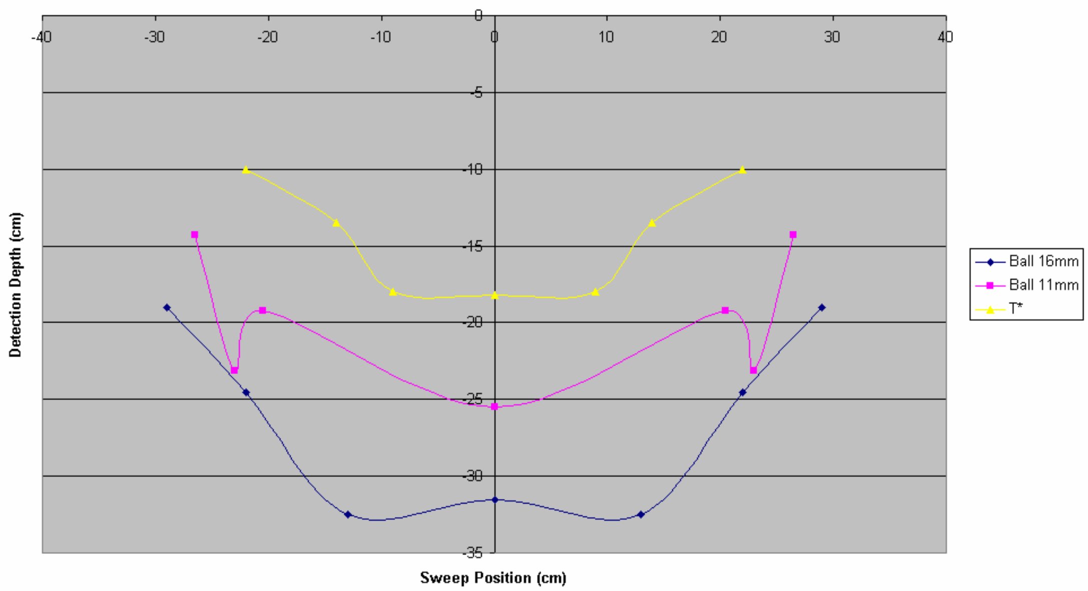


Fig.2F:Sensitivity Profile in Air for Minelab (F4)

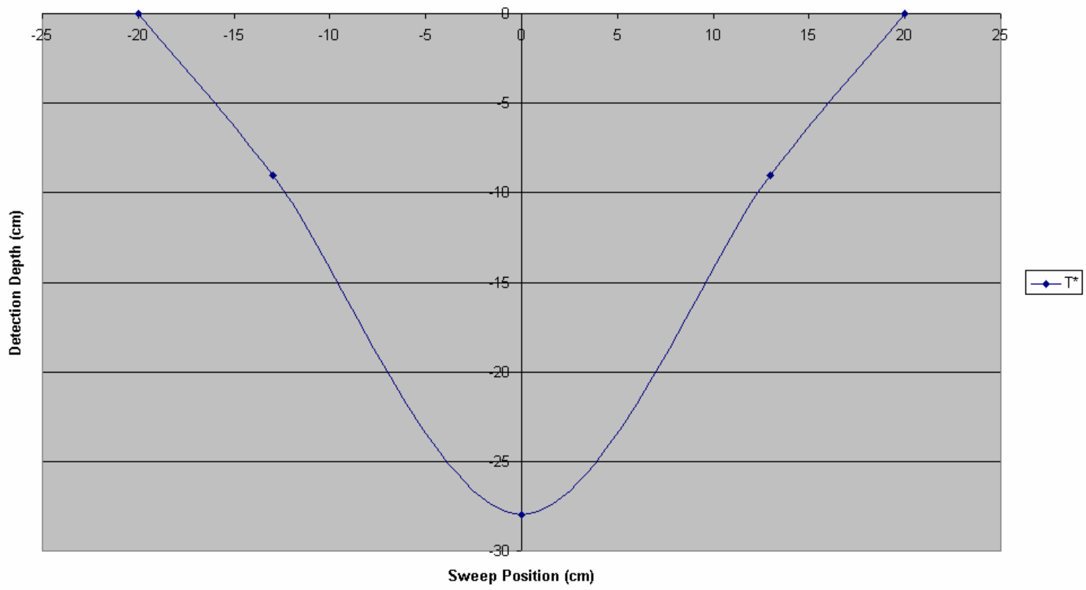
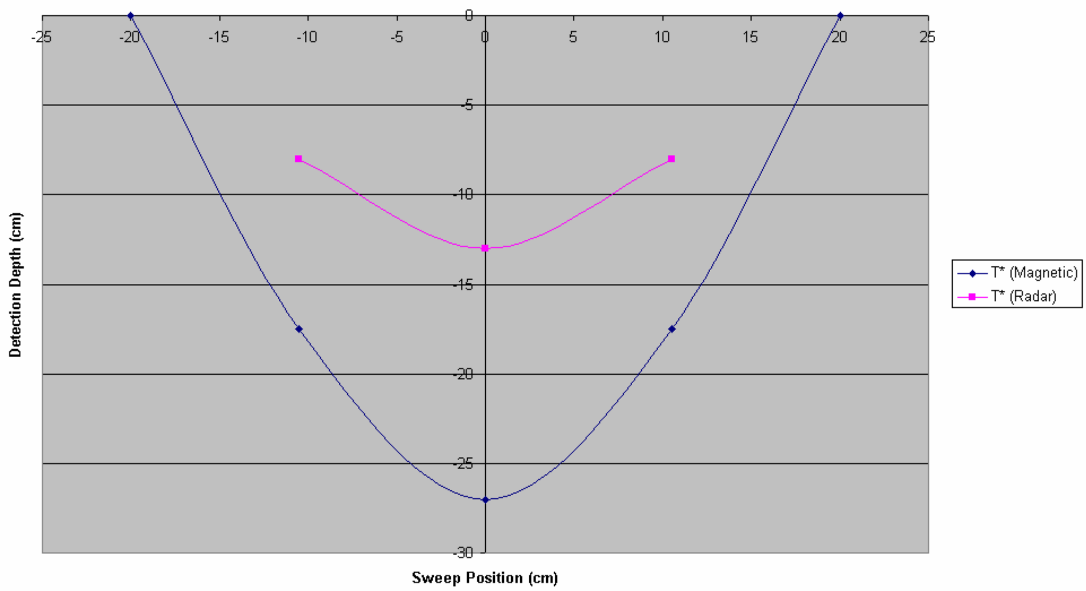
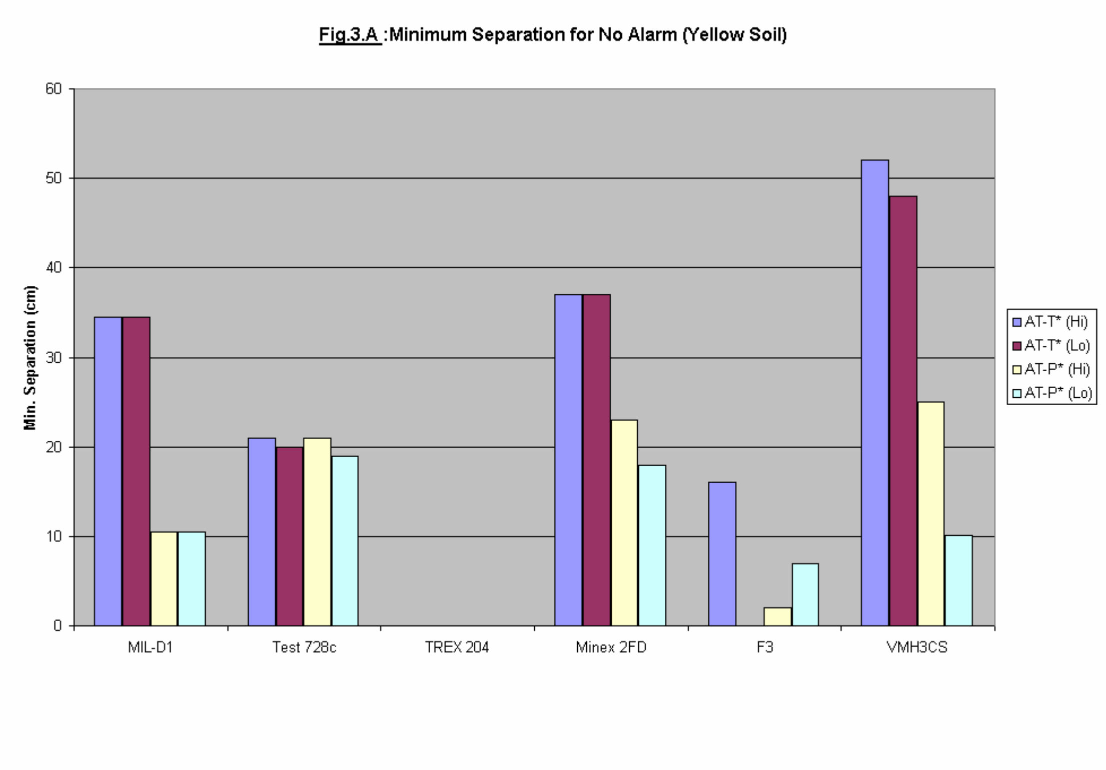
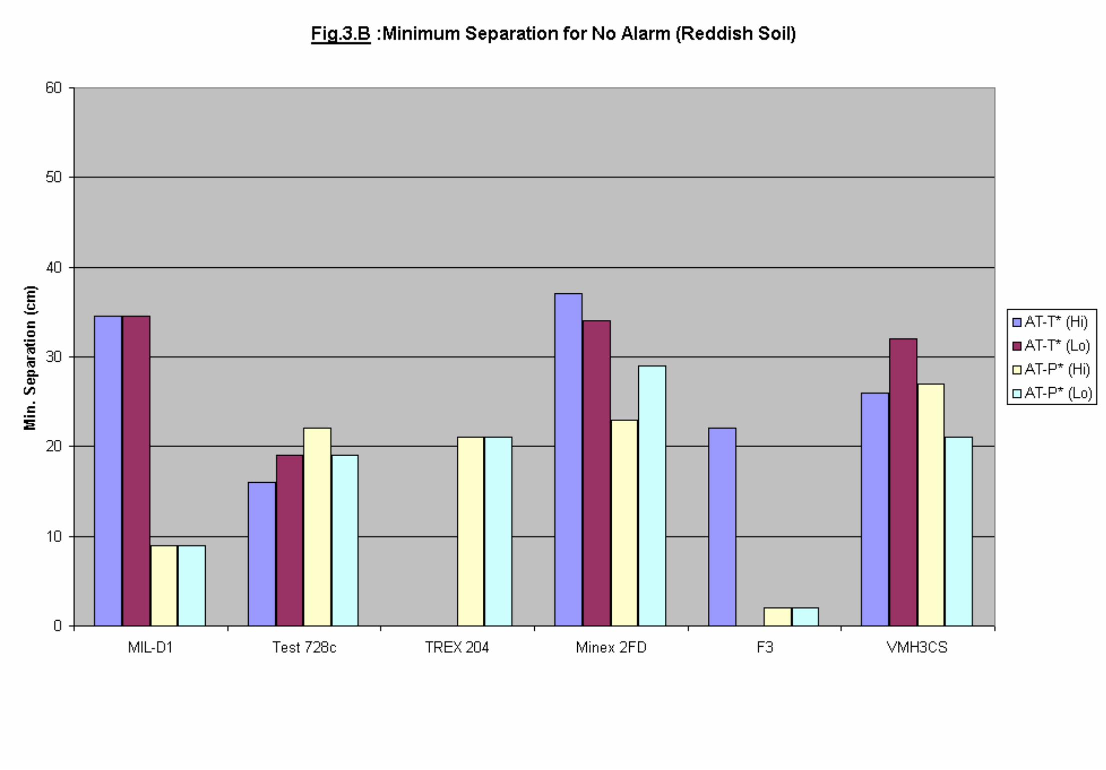


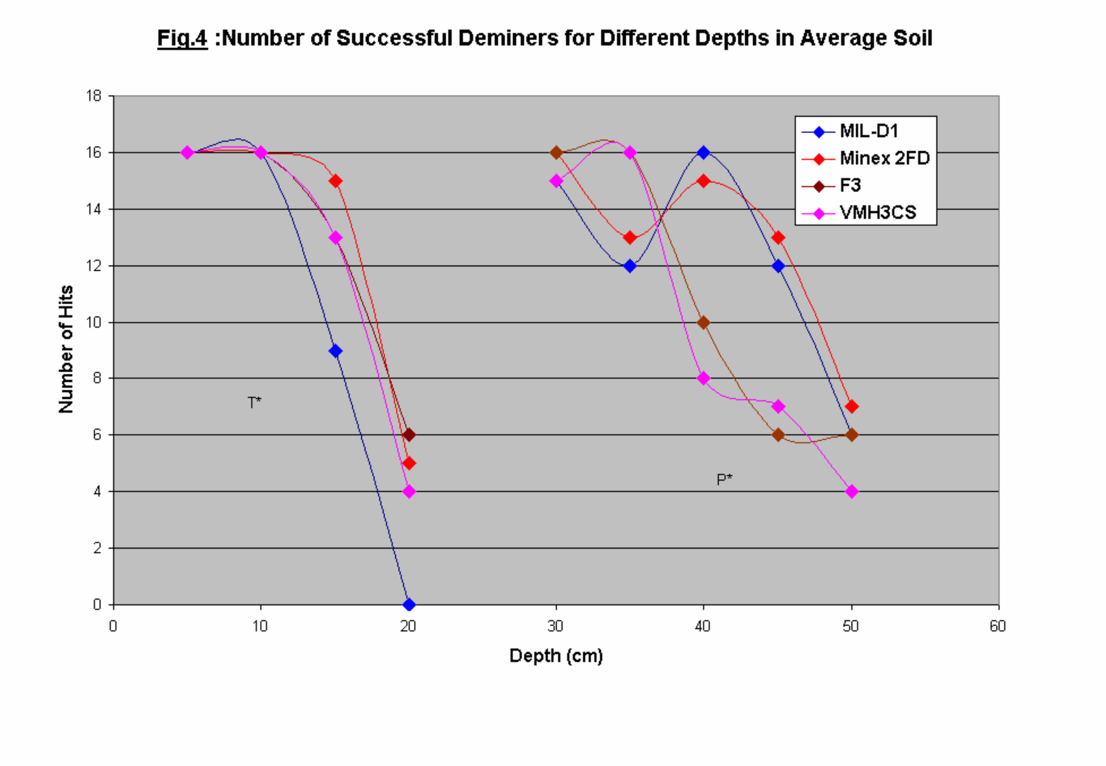
Fig.2G :Sensitivity Profile in Air for Vallon (VMR2)

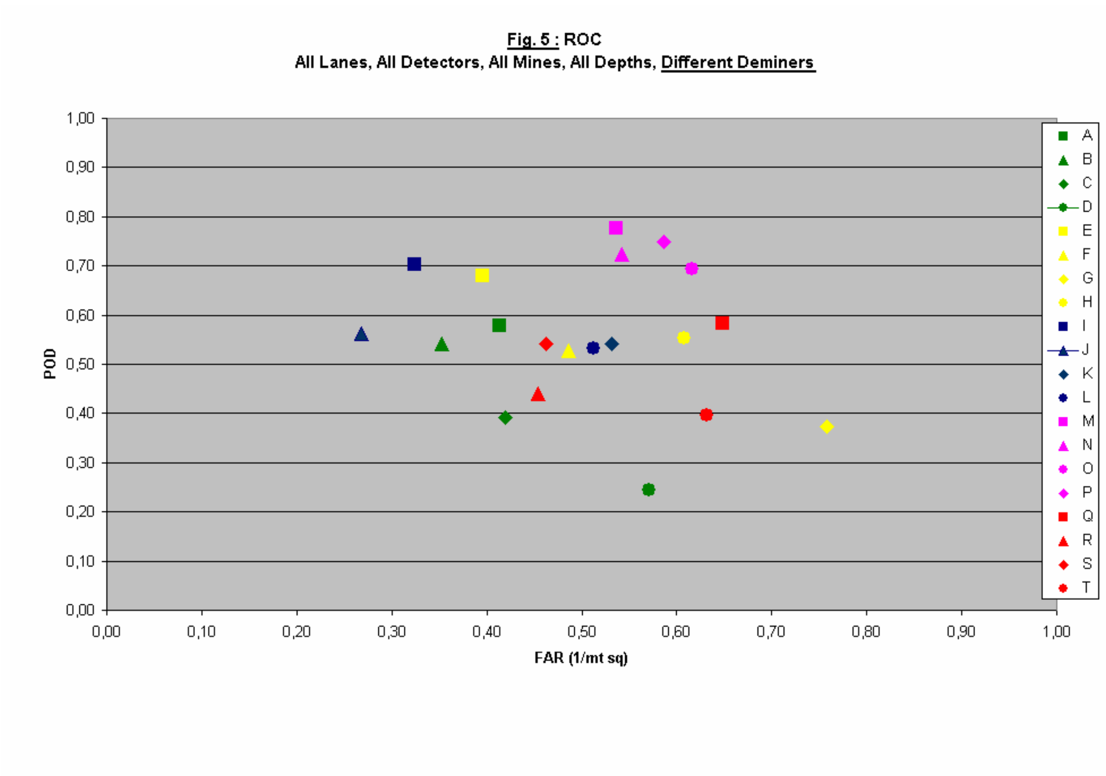






2- The PoD and ROC plots for the results of the blind tests of the regular mine detectors are shown in Figs. 5-12 . The ROC chart of all deminers is shown in Fig.5. Deminers A-D used the MIL-D1, E-H both the SC 728 and the TREX 204, I-L the MINEX 2FD 4.530, M-P the F3 and Q-T the VMH3CS. Company representatives were denoted by A,E,I,M and Q respectively. The figure shows the wide spread of the probabilities of detection and the false alarm rates of various deminers.

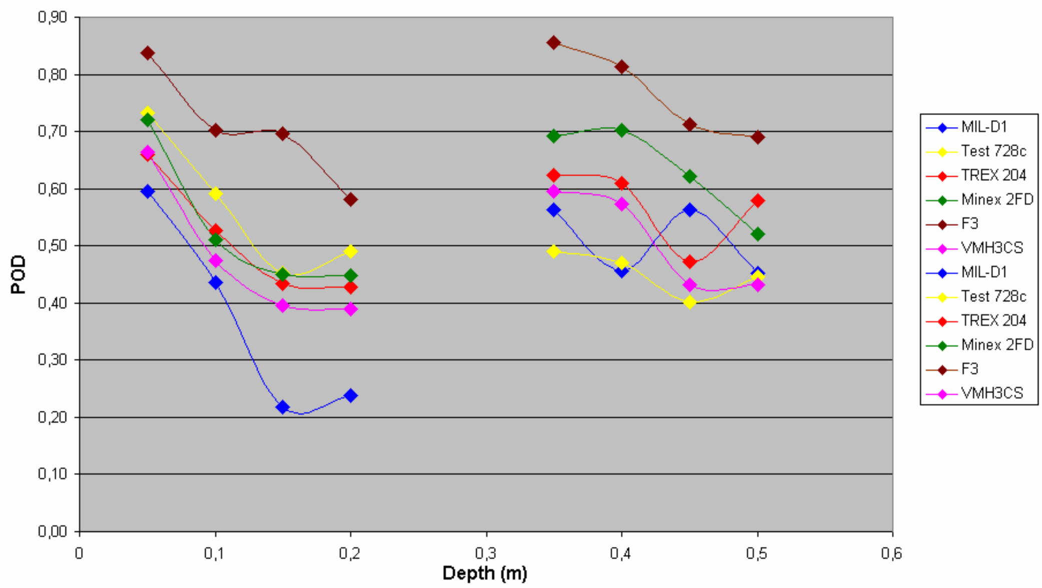




Figs. 6 and 7 show the PoD and ROC results for each detector in all lanes where we notice that F3 leads by having the highest probability of detection and is followed by the MINEX-2FD. We consider the detection probability to be an important measure of detector quality as it is related directly to deminer safety. The effect of a higher false alarm rate is a slowdown of the search, which is preferable to accidents.

For some unexplained reason the scores of lane 8 were abnormally low for all detectors with some targets remaining undetected by all detectors. When the scores of lane 8 are ignored, we obtain the results shown in Figs. 8 and 9, where the scores of all companies uniformly improve. The F3 leads again , followed by MINEX-2FD.

<u>Fig. 6</u>: Probability of Detection
All Lanes, All Deminers.



<u>Fig. 7</u>:ROC
All Lanes, Both Mines, All Deminers, All Depths

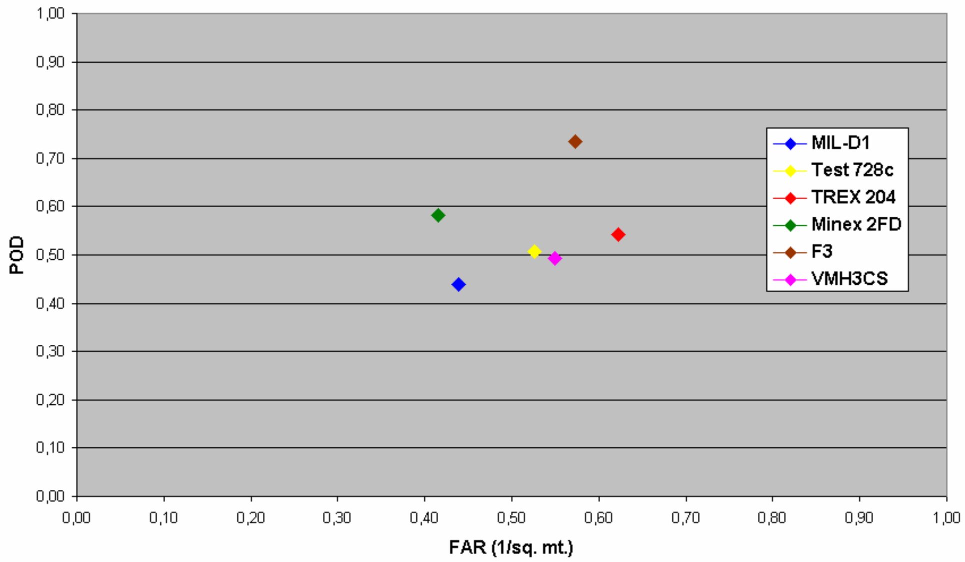


Fig. 8 : Probability of Detection
All Lanes, All Deminers (Without Lane 8)

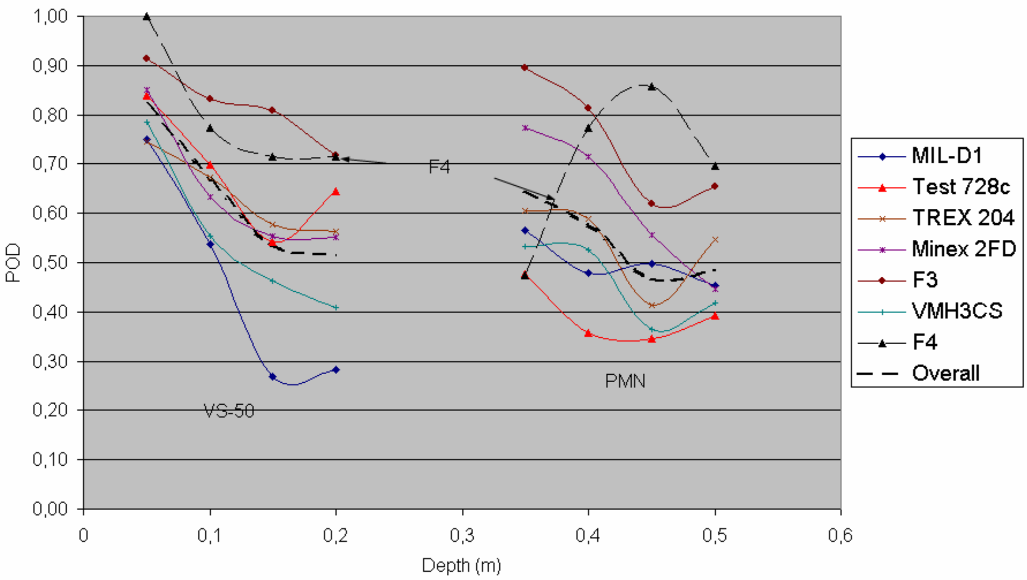
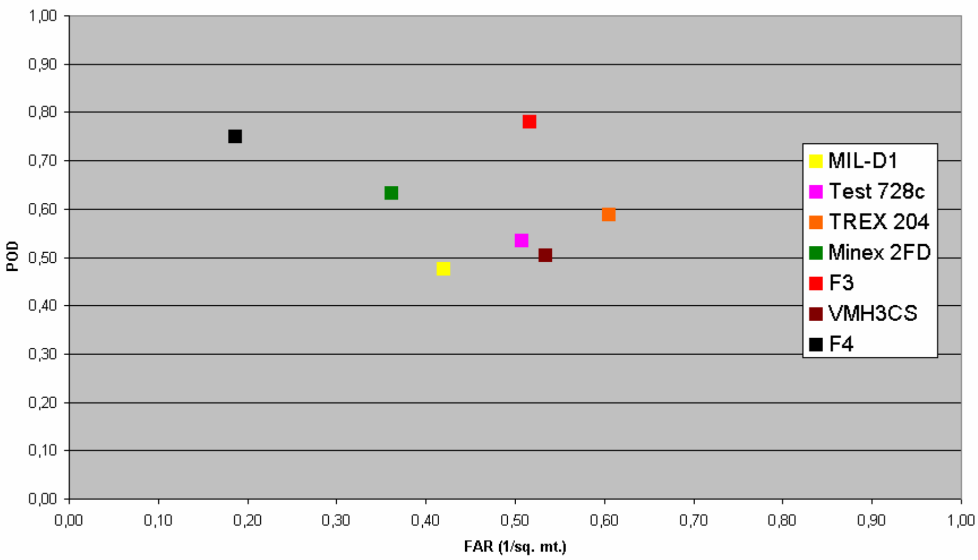
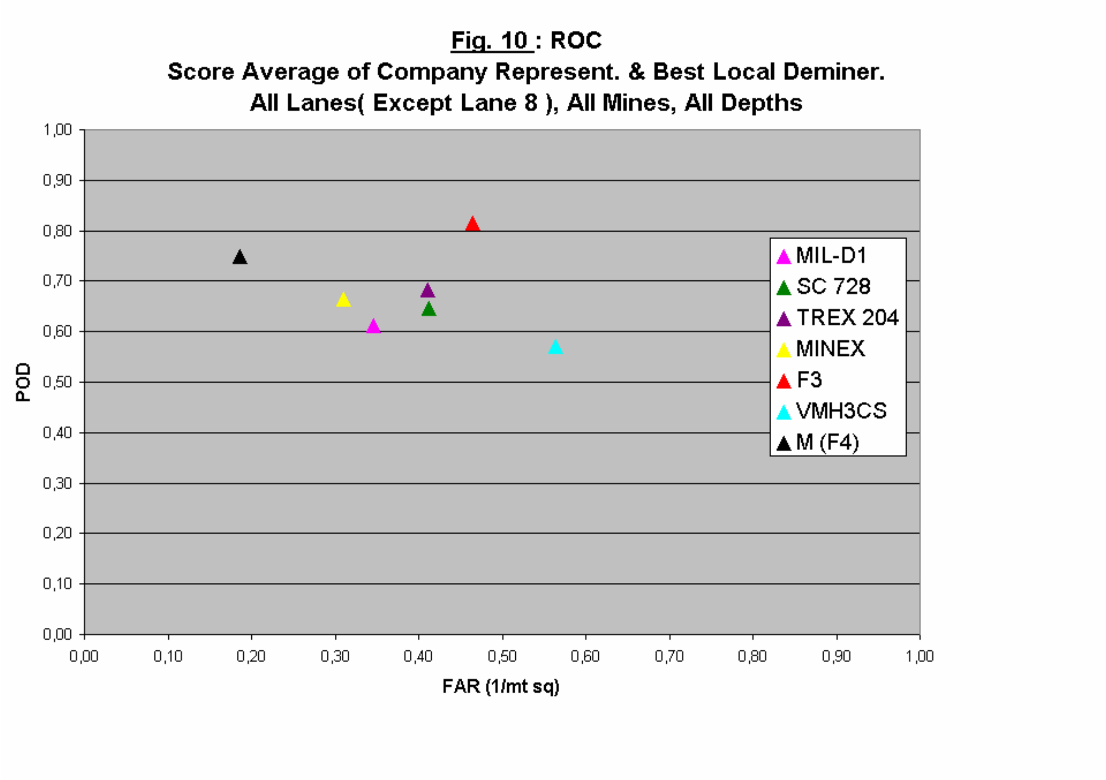


Fig. 9 : ROC
All Lanes, All Mines, All Deminers, All Depths (Without Lane 8)



Having noticed the wide and nonuniform spread of the scores of the four deminers testing each detectors , we prepared another ROC plot in Fig. 10, where we average the ROC scores of the company deminer and the best local deminer of his group. This may have some value if we notice the short time allowed for training the deminers on the respective detectors, that we are testing the detector and not the operator and that deminers with low scores must either improve or leave. For comparison, we also show the score of the F4 detector which went only through a reduced number of tests.



In Fig.10 the F3 detector has the highest PoD and is followed by the group of TREX 204, MINEX-2FD, SC 728 and MIL-D1. The lowest FAR is still obtained by the MINEX. It should be noted again that the detector F4 did not undergo a full reliability trial and was operated only by the manufacturer representatives.

We may finally note that deminers using the MIL-D1, MINEX 2FD ,TREX 204, Test 728C , F3 and VHM3CS needed an average of 28.5, 38.4, 27.5, 26.2, 40.9 and 31.3 minutes respectively to cover the 24 square meters of each test lane . Deminers comments were mainly concerned with language problems during training, ground compensation, detector weight and the convenience of using the headphones. Actually the trials resulted in a wealth of information which should be evaluated carefully and are expected to be very helpful for the demining activities, both locally and abroad.

The unfiltered overall PoD and ROC charts for all detectors, all lanes, all targets and all deminers are shown in Figs. 11 and 12.

3- As mentioned above, two lanes were prepared to test the two detectors with discrimination capability ,who, in principle can distinguish between real targets and metallic clutter. Each of the two lanes included a total of 24 T* and P* targets together with a large number 7.62 mm, 1 inch and 1.5 inch projectiles. The scores showed a promising step forward in target detection and could have been better had we trained the detectors to recognize the introduced clutter. The receiver operating characteristics are shown in Fig.13 for both the F4 and the VMR2 detectors. While both detectors have nearly similar probabilities of detection , F3 has a much lower false alarm rate. We admit here that adequate testing would have required more preparations and detector training for target and clutter recognition.

MINELAB asked to try the repaired F4 on the regular blind test lanes with the company deminer alone performing the test. The Probability of Detection (PoD) and the Receiver Operating Characteristics (ROC) plots are shown in Figs. 14 and 15 respectively.

Fig. 11 :Probability of Detection
All Lanes, All Deminers, All Detectors

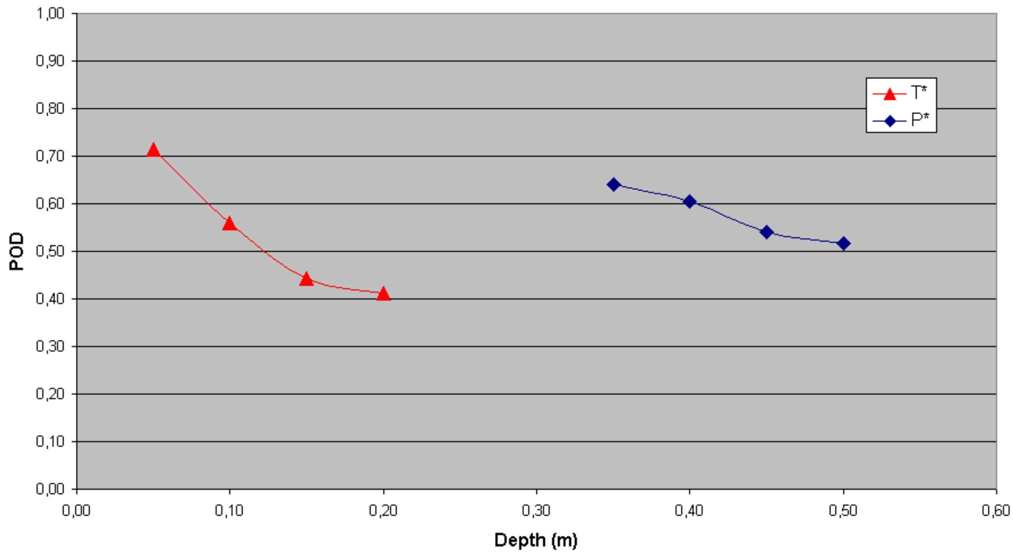


Fig.12 :Receiver Operating Characteristics
All Lanes, All Deminers, All Detectors, All Mines, All Depths

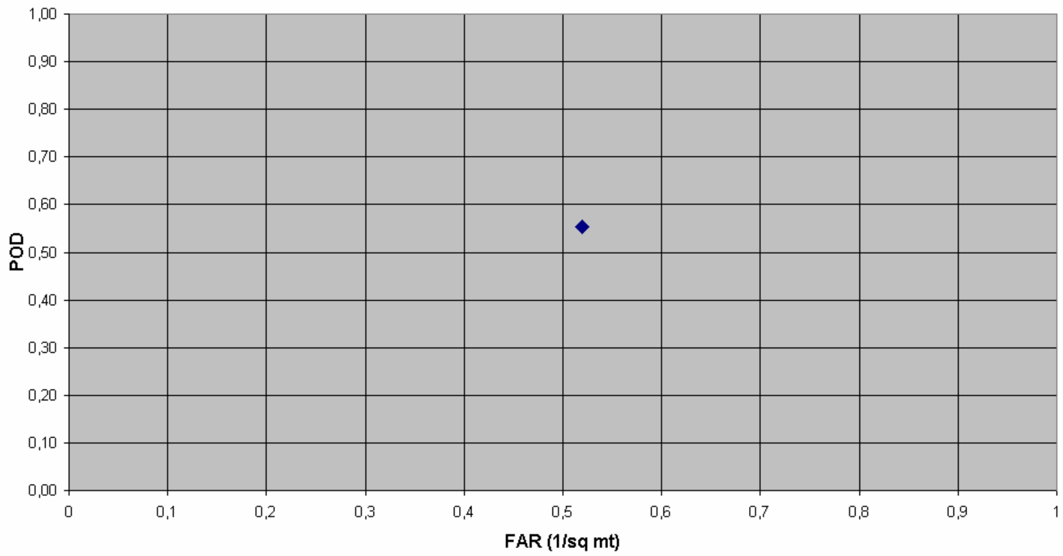


Fig. 13 : **Soil Intelligent Test**
Receiver Operating Characteristics

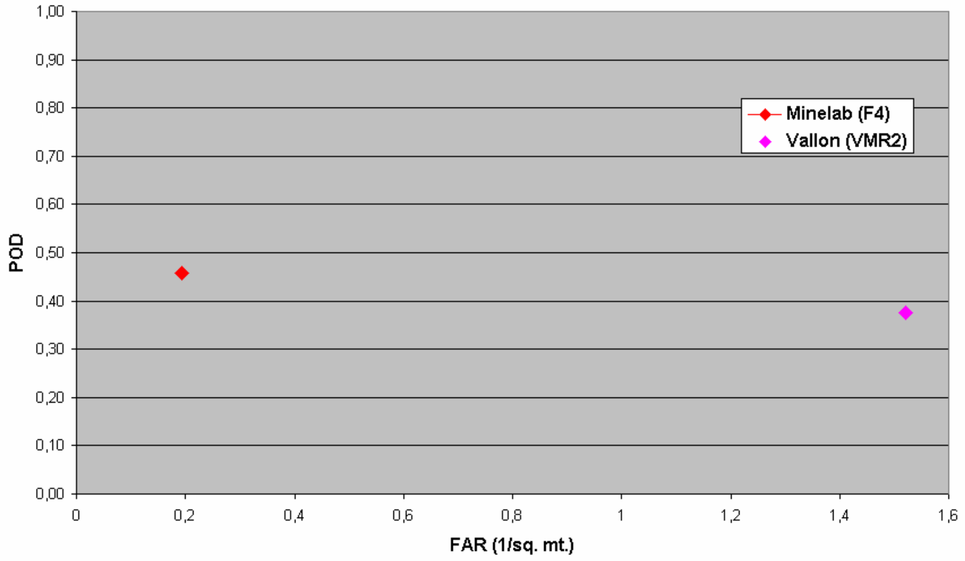
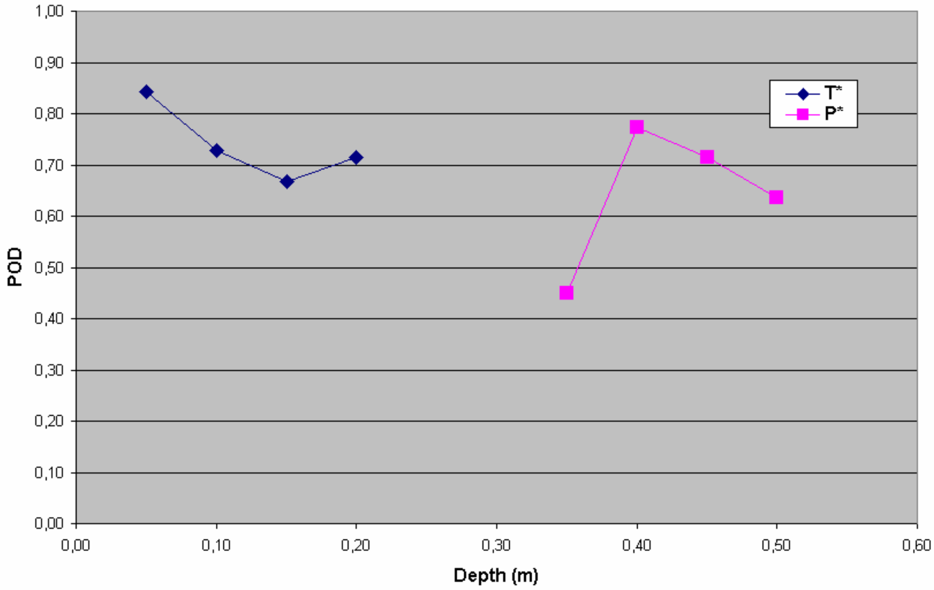
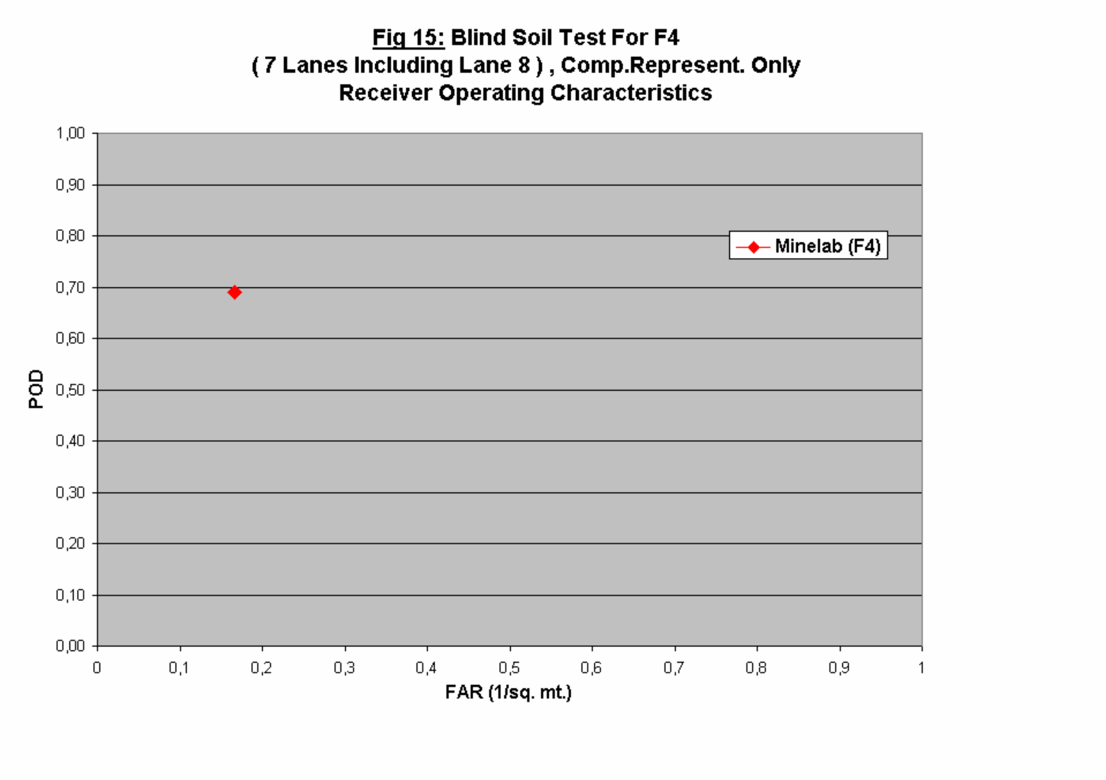


Fig.14: **Blind Soil Test For F4**
(7 Lanes including Lane 8),Comp.Represent. Only,
Probability of Detection vs. Depth for Minelab F4



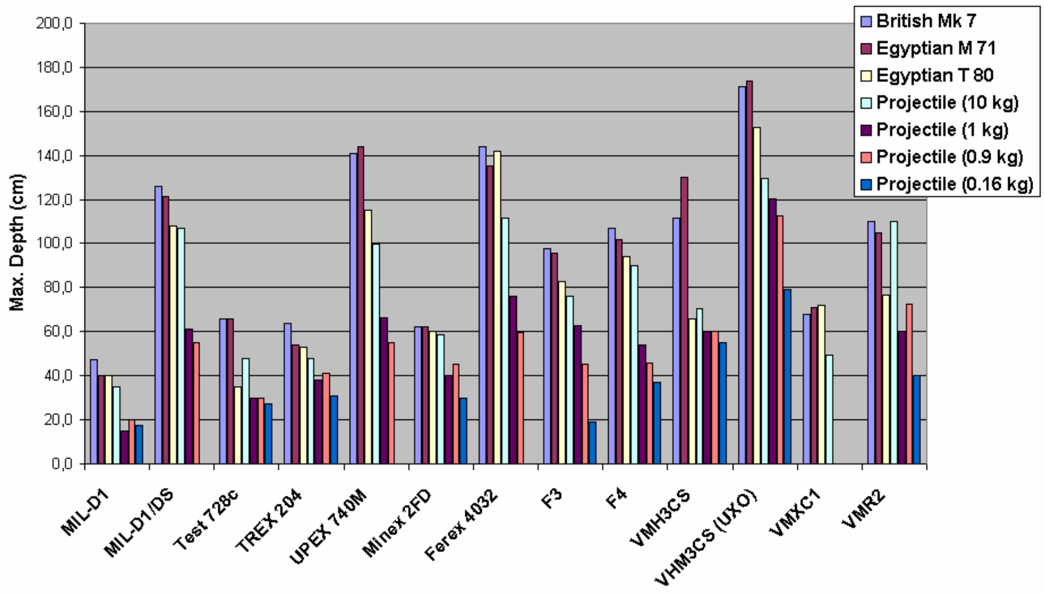


4- The maximum detection depth of UXO by different detectors in soil is shown in Fig 16 .The chart shows that the VHM3CS with the large search head gets the first position, followed by both the FEREX4032 and the UPEX740M. The FEREX was used only in the manual mode. Use of the data logger mode, which requires a later computer analysis, was not accommodated for. Also the large search coil of the F4 detector broke during transportation and could not be employed. Thus the F4 could only use the regular mine detection head .

It was also decided to test the capability of regular mine detectors in searching for UXO. Fig.16 shows a wide distribution in their maximum detection depth. The VHM3CS with the regular head was the leader, followed by VMR2, F4 and F3 respectively.

There were some comments from the deminers related to the detector weight , needed sweep speed and error signals resulting from the sensitivity to detector leveling and ground compensation.

Fig. 16 :Unexploded Ordnance (UXO) Maximum Detection Depth



VI- CONCLUSIONS and RECOMMENDATIONS:

It should be mentioned that we were proud to have this great selection of companies producing the best metal detectors . In a car race both car and driver are blended together to produce the final result and this is also true in the field of demining . An inexperienced deminer or one that was not trained well enough can lower the score significantly , similar to the effect of an insensitive detector or one with poor ground compensation. We admit that we did not allow companies a large enough selection of deminers and also some faced a few unexpected difficulties such as the electronic failure of the well known EBEX 422GC and the unfortunate breakage during transport of the large search head of the F4 detector (for UXO detection). The time allowed for training and acquainting the local deminers with the detectors they were to operate was only half a day and more time would definitely have helped . Normally two days are necessary for adequate training for one detector. Unfortunately we did not have time to do so. The language barriers between deminers and company representatives should be dealt with more professionally in the future. As in all multifaceted, challenging and realistic endeavors many sources of error are always present and must be dealt with to reach a higher level of perfection. Such trials depend strongly on the human element and this needs time to be influenced. Obviously time means money for all parties involved and there is a strong need for optimization of the trial process.

We are certain that the Cairo demining trials were successful in many ways. Our local deminers now have excellent training grounds. They were introduced to the most advanced metal detector technologies and they were trained by professionals representing the manufacturers. The experience of evaluating detector and deminer performance is very useful and should be developed to help in procuring the best detectors and offering the best training. The detectors with discrimination capability (which can distinguish targets from clutter) made their appearance during the Cairo trials and did very well in spite of the limited time and the presence of some unforeseen technical problems.

So it should be mentioned that errors are always present in the results of all scientific experiments, specially due to human factors. To decide on an optimum mine detector is not an easy task. The following issues are some important factors that must be considered when deciding on what detector to procure :

1. Is the detector needed as a mine detector, a UXO detector or both ?
2. Is the detector sensitivity adequate to reach the required depths ?
3. Does the detector posses adequate ground compensation to cancel effects of ground conductivity and magnetic susceptibility for different types of soils , thus resulting in better detection and a reduced false alarm rate ?
4. Is the footprint wide enough to allow for better detection at a given rate of advance along the path ?
5. Does the detector have extra features that allow for distinguishing targets from metallic clutter with enough reliability ? (Signature detectors - Dual detectors -…) .
6. Are detector controls easy and safe to handle (not allowing faulty setups) and is the detector comfortable and light enough)
7. Are the warning signals and signals of proper functionality easy to distinguish?
8. Is the detector robust enough and comfortable to adjust and use and is the battery lifetime adequate ?

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In this report, we have tried to present the concrete and objective results obtained in different manners and referred to the comments of the monitors. To proceed, the present results should be considered as important guidelines which hopefully should help in making a better judgment on the needed detectors . More local deminers are now familiar with different models and specific features can be rechecked before a final choice is made. Detector robustness could also be tested in a real mine field before the final decision is made

As mentioned above, deminer complaints were mostly related to the influence of ground effects on target detection and false alarm. Some complained from headphones or from the weight of a large search coil that must be moved swiftly (for UXO detection) . Having more time would have been helpful and decisions could have been made at ease. But this does not mean that an adequate amount of information has not been collected. We know that when searching for mines, F3 has the highest probability of detection while MINEX-2FD has the least false alarm probability. As mentioned above , we consider the probability of detection to be much more important than the false alarm rate because to miss a mine (lower PoD) can injure or kill a person while a false alarm just “costs time” for investigation. We also know that the VHM3CS achieved the largest detection depth when searching for UXO, followed by the FEREX 4.032 and the UPEX 740M. There was no time to prepare adequate tests to study how those UXO detectors will function in the presence of other close targets and clutter, but this should be done in the future. Besides, the success of detectors with discrimination capability was established. Unfortunately the

F4 detector UXO search head was damaged during transport which limited its testing as a UXO detector.

Finally a word of thanks should go to all those who worked hard to prepare the trials and to prepare the fields. Securing the necessary funds, establishing the international contacts with different groups, sending the invitations, local security arrangements, lodging and accommodation, airport arrivals and departures, designing the test lanes and the random target locations and hosting our visitors are some but not all the tasks that had to be done in a limited time. We should also think of the hundreds of mines that had to be transported and then buried under tons of sand of different properties at exact depths and all the sandbags that had to be moved to create the lanes.

Our hope is to make our land safer for every one and to make the demining task much safer to those silent workers !

VII : List of Abbreviations :

AP Mine : Antipersonnel Mine.

AT Mine : Antitank Mine.

Clutter : Unwanted objects resulting in a receiver signal.

ERW: Explosive Remnants of War.

GICHD: Geneva International Centre for Humanitarian Demining

GPR : Ground penetrating radar.

MD : Metal Detector

PoD: Probability of Detection.

ROC: Receiver Operating Characteristics .

UNDP : United Nations Development Programme.

UXO: Unexploded Ordnance

WWII: Second World War.

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