ACHIEVING 100% QUALITY ASSURANCE IN FERROUS EXPLOSIVE ORDNANCE DISPOSAL

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ABSTRACT

The development of digital explosive ordnance detection technologies has for the first time made it possible to quantify and verify the performance of unexploded ordnance (UXO) detection. Explosive ordnance disposal (EOD) has been transformed from a skilled an to a science.

The factors affecting ferrous UXO detection are complex and involve sixteen major variables. Some of these arc associated with the magnetic properties of the ordnance and the environment where it is located. Other variables arc assigned to the data acquisition specifications.

In-house research over the last ten years has produced purpose designed detection instrumentation which when used according to specified procedures permits 100% quality assurance limits to be defined. The survey specification and 100% assurance depth are unique to each search locality.

The TM-4 magnetometer system is a computerised instrument which interfaces multiple optically pumped type magnetic field sensors to geodetic DGPS positioning technology. Real-time interpretation of target position, depth and mass is available to the field operator. The TM-4 is a hand-portable instrument suitable for use on land or under water. The TM-4 may be operated from an all-terrain vehicle or remotely operated platform. Survey coverage rates vary from 2 Ha (5 acres) to 15 Ha (35 acres) per day.

Survey specifications are first computed from reconnaissance measurements collected at each clearance site. Computer-aided interpretation identifies ferrous targets to be disposed of. It quantifies the detection depth for a representative range of UXO items and documents the whole operation in a GIS type data-base.

No longer is it appropriate to generalise the performance of a detection system. We can now quantify the depth at each specific locality to which a particular type of ordnance can be detected with 100% confidence. When it comes to UXO detection, the continued use of technologies that do not comply with this quality assurance may be deemed negligent. The ramifications of this technical development include lower insurance risk exposure, increased land value after rehabilitation and a cleaner, safer environment for our children.

Magnetic Properties

The detectibility of UXO primarily depends upon the mass of the ordnance and its depth of burial with large items close to the surface being most readily detected. However, each type of ordnance will exhibit a distribution of magnetic properties due to variables in manufacture, the time that the abject has been buried and its orientation in the ground. The magnetic properties of the local geology, interference from temporal magnetic sources and the magnetic latitude of the site, each influence the search effectiveness.

Search Parameters

The effectiveness of a search is also dependent on the type and sensitivity of the magnetometer used. The optically pumped type magnetic sensor is more sensitive than the fluxgate type. Total field measurement is inherently more effective in locating deep objects than is magnetic gradient measurement because the gradient signal is always less than the total field signal. Other vital parameters controlling the search effectiveness are the sensor elevation above ground, the measurement sample interval and line spacing, and the tolerances permitted in each of these.

SPECIFYING THE SEARCH DATA ACQUISITION PARAMETERS

At each search site, the magnetic noise from geological and electromagnetic sources must first be measured at some known elevation above ground. The optimum sensor elevation may then be computed for a magnetometer of given sensitivity and type. At this elevation, the signal-to-noise ratio is a maximum. Figure 2 shows the optimum magnetic sensor elevation for detecting ferrous ordnance in a locality where the geological magnetic noise measured 0.5 m above ground was 0.75 nT. In this example the "signal" source was an 81mm mortar buried I m below ground. In the case of the total field, TM-4 magnetometer, the optimum sensor elevation is 1 m at which height the signal-to-noise ratio is 175. In the case of the vertical difference, fluxgate type magnetometer, the optimum sensor elevation is 0.35 m at which height the signal-to-noise ratio is only 11.

There are well established theorems relating to the sampling of continuously varying functions such as the spatially varying magnetic field of the Earth. It has been determined that the sampling requirements both along survey transects and between transects, must not exceed the elevation of the sensor above ground level. At the location associated with Figure 2, the optimum TM-4 sensor elevation is 1 m and the required maximum sample interval is therefore also Im. However, after giving due consideration to acceptable operator tolerances, (20% in sensor elevation and transmit separation) the measurement density required at this site is five measurements per square metre consisting of 0.2 m sample intervals along transects separated by one m. Fewer measurements could result in magnetic disturbances due to small, near surface objects being missed. Only when the magnetic field has been fully defined by the appropriate measurement density, can the performance of the survey be quantified. If a vertical gradiometer were used instead of a total field magnetic sensor, the magnetic field would only be fully defined if the line spacing were reduced to 0.35 m (+ - 35 mm!) and the sample interval reduced to 0.1 in. Thus three times the survey effort is required to collect data and 6 times the data volume must be processed

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QUANTIFYING 100% SEARCH EFFECTIVENESS

100% search effectiveness is described in terms of depth and UXO type. The depth to which 100% search effectiveness is achieved, is defined as the depth to which the risk of missing a specified object is insurable - nominally less than one part per hundred thousand.

At each locality to be searched, the geological magnetic noise amplitude is measured at a particular elevation above ground The optimum sensor elevation is then computed. The optimum sensor elevation in turn determines the minimum survey data acquisition specification necessary to achieve 100% search effectiveness. Collecting more data than necessary may result in higher data acquisition cost and therefore lower cost-efficiency.

The area to be searched must be systematically mapped through the measurement of data at the defined sample specifications. With knowledge of the geological noise level, the instrument sensitivity and the data acquisition parameters (Including tolerances), the measurement detection limits can be computed. The statistical distribution of the magnetic properties of a range of ordnance types has been determined and with this information it is possible define the depth to which 100% detection of those items can be guaranteed. The 100% detection assurance depth may be most conveniently represented by the detection limit line drawn on a graph that plots the magnetic anomaly due to a range of ordnance items as a function of their depth.

Figure 3 provides a typical example of such an assurance graph from a site where the geological magnetic noise was a moderate 2.5 nT measured 1 m above ground. At this location the sensor elevation was 1 m, the line spacing was 1 m and the sample interval along lines was 0.2 m.

CASE STUDIES

UNEXPLODED ORDNANCE

Figure 4 shows the magnetic disturbance due to numerous items of ordnance contaminating a disused artillery proofing range in Australia. Figure 5 shows the unperturbed magnetic field after all items of ordnance from this site had been recovered. The only remaining magnetic disturbance was confirmed to be resulting from flakes of rust shed from a dumped motor vehicle that had been previously located on the site. The search assurance graph in Figure 3 refers to this site.

BURIED INDUSTRIAL WASTE

Industrial, military, medical and domestic waste usually contain ferrous components. Where not properly constrained, chemical materials may leach from such sites contaminating soil and ground-water. At a site in eastern Germany this situation was identified and the source of contamination had to be located. Figure 6 shows an isometric image of the magnetic field mapped with a dual sensor TM-4 magnetometer. The zones containing magnetic interference define two adjacent pit sites where industrial waste was buried.

FACTORS AFFECTING UXO DETECTION

MAGNETIC PROPERTIES

- UXO type and mass
- Orientation of UXO in the ground
- Depth of UXO below ground surface
- Time UXO has been in the ground
- Composition and manufacture of individual items
- Magnetic properties of the soil where UXO is buried
- Magnetic interference from temporal sources
- Magnetic latitude of the search site

SEARCH PARAMETERS

- Magnetometer type - total intensity, or gradiometer
- Magnetometer sensitivity
- Elevation of sensor above ground
- Sample interval along search line
- Search line spacing
- Tolerance allowed in sensor elevation
- Tolerance allowed in search line spacing
- Whether a base-station magnetometer has been used

THE SEARCH ASSURANCE DEPTH IS A FUNCTION OF 16 VARIABLES!

FIGURE 1 The sixteen major variables affecting the detection of ferrous ordnance.

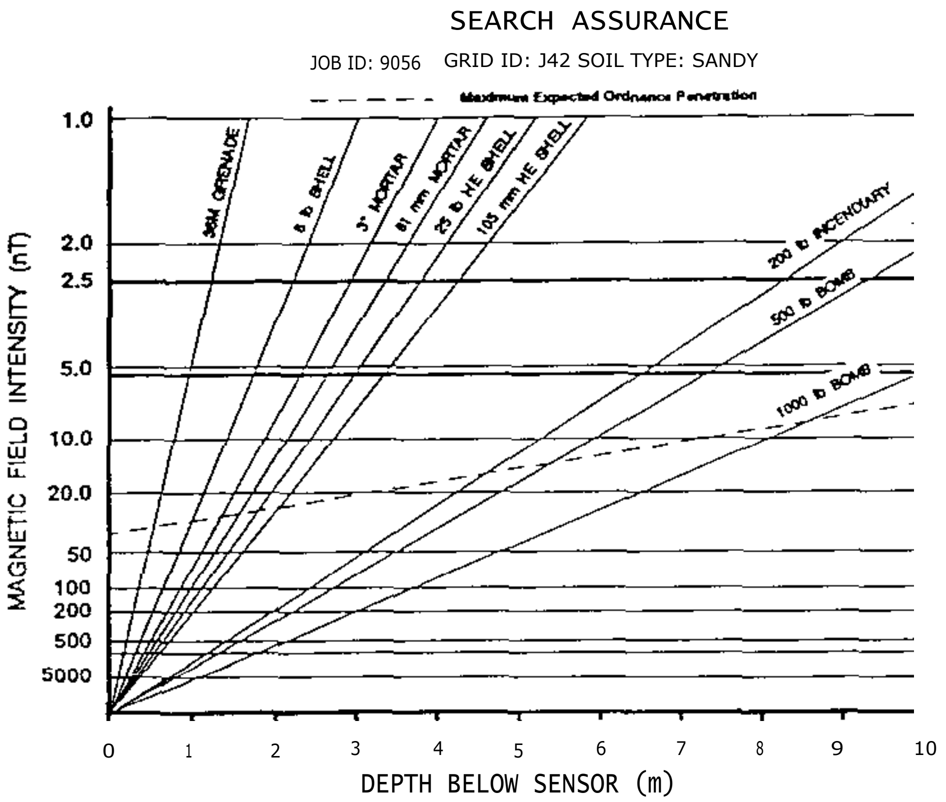


FIGURE 3 An example of a TM-4 assurance graph for a particular search area where the soil type was "sandy" and where the magnetic noise threshold was determined to be 2.5 nT.

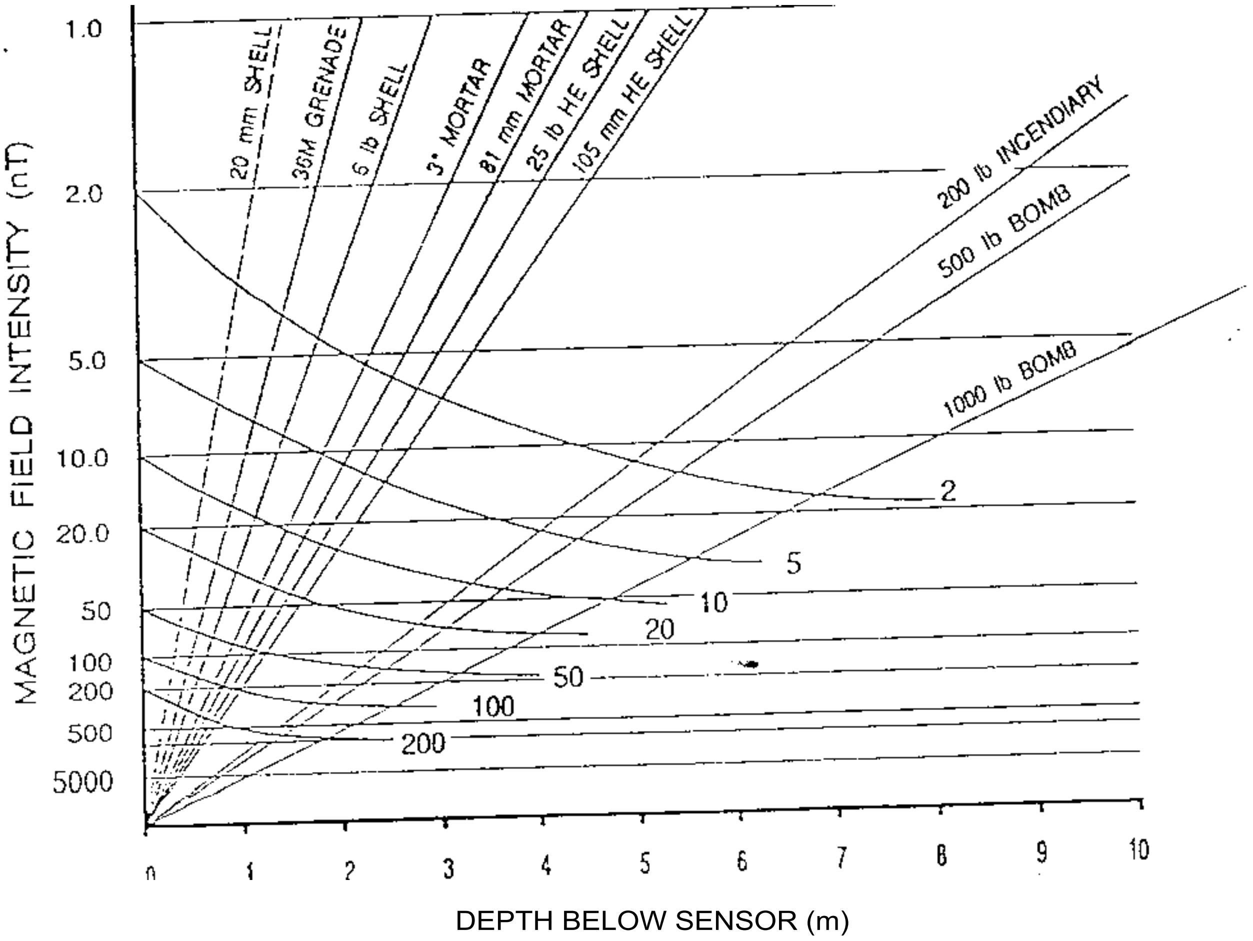
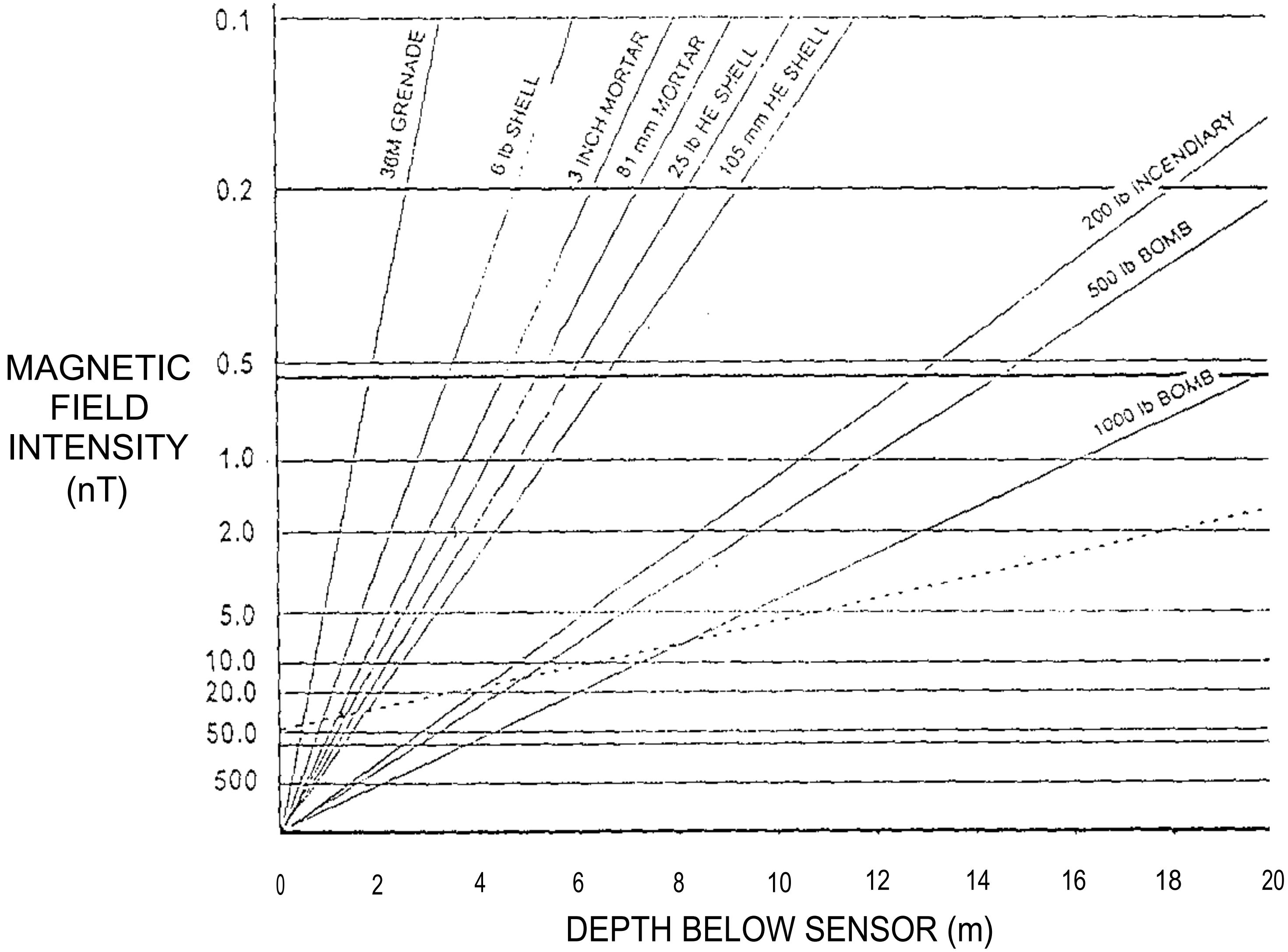


Figure 3. Total magnetic intensity and gradient anomaly amplitudes plotted as a function of depth below the sensor for a selection of ordnance devices. The normal, horizontal grid lines refer to total field amplitudes as measured by the TM-4 and M k22 magnetometers. The curved lines refer to the gradient anomaly amplitudes as measured by the Forster 4.021 and CAST gridiometers.

-----Maximum Expected Ordnance Penetration—



APPENDIX C

UNEXPLODED ORDNANCE PENETRATION

Ordnance Type	Estimated Maximum Unexploded-Ordnance Penetration (in feet)	
	Sandy Soil	Clayey Soil
20 mm		3.0
60mm	1.0	3.0
81 mm	3.0	6.5
2.75 inch	3.5	7.5
4.2 inch	4.0	8.5
105 mm	5.5	11.5
106 mm	5.5	10.5
76 mm	6.0	12.0
90 mm	7.0	13
155 mm	8.5	16.5
152 mm	7.5	15.0
[illegible]	12.0	24.0
8 inch	12.0	24.0
500 lb		35.0
1,000 lb	33.0	43.0
2,000 lb	40.0	52.0

(Naval Explosive Ordnance Technology Center 1990)

During Period III, from 1961 to the present, test items consisted of the following: flat- and high angle trajectory gun projectiles ranging in size from 20 mm to 8 inches; cluster bombs; general purpose bombs (aircraft delivered); aircraft-fired 20-mm and 30-mm gun projectiles; and 2.75-inch line-of sight rocket systems (Mason and Hanger 1992).

1.2.3.2.2 Target Depth and Orientation

Based on information from interviews with the EOD experts and from available research, the following general assumptions were made regarding the depth and orientation of the items expected to be found in UXO-contaminated sites at JPG:

All 20-mm and 30-mm aircraft- and ground- delivered flat trajectory gunfire will typically result in the projectile penetrating the ground no more than 12 inches in a terminal position horizontal to the plane of the surface; ground launched 40-mm projectiles will typically be found within 36 inches of the surface, and, due to the very short, bluntly rounded feature of the ogive, could be found at virtually any orientation; mortar rounds are generally found not more than 48 inches from the surface and are oriented between 45 and 90 degrees from the plane of the surface due to their high angle trajectory; 240-nun to 8-inch Howitzer projectiles will typically be found horizontal to, or at a slight angle from, the surface plane, at depths up to 12 feet; general purpose bombs (from 100 to 2,000 lb) were found at depths exceeding 20 feet deep and at no predictable orientation to the surface plane (most are assumed to be horizontal to the surface or at a 5 to 45 degree angle to the surface plane).

In its study (Department of the Army 1975), the Engineer Studies Group, Office of the Chief Engineer, Department of the Army, developed a generalized solution to produce the estimates for maximum UXO penetration shown in Appendix C. Bomb penetration data is available (Naval Explosive Ordnance Technology Center 1990).

13 CONCLUSIONS

The conclusions on target types, orientation, and false positives and false negatives are presented in the following sections.

13.1 Target Types

Based on available research, PRC assumes that approximately 10 percent of all items test fired at JPG were 20-mm rounds. The remaining 90 percent of the items are assumed to be other types of gun projectiles, land mines, hand grenades, and general purpose bombs.

1.3.2 Target Depth and Orientation

Based upon expert opinion, experience, and available research, PRC concludes that the small caliber (20-mm to 2.75-inch) test items should be implanted randomly between 6 and 24 inches beneath the surface, generally oriented parallel to the plane of the surface, with 10 to 15 percent of each category implanted up to 36 inches and/or at oblique, difficult to detect orientations with respect to the surface to challenge the effectiveness of the demonstrator's technology. Targets larger than 8 inches in diameter will be implanted at up to 10 feet deep and at a variety of randomly chosen orientations to the surface plane. At least 10 percent of the larger targets will be intentionally oriented in oblique, difficult to detect positions in order to challenge the capabilities of the demonstrator.

13.3 False Positive and False Negative Targets

Because no practical way exists to determine the type and extent of subsurface anomalies (for example, metal scrap, glass containers, trash cans, and so forth) other than UXO present on contaminated JPG sites, PRC relied on the advice of the EOD experts cited in Appendix B, and on the U.S. Army Corps of Engineers, Huntsville Division. These experts have designed "false positive" and "false negative" information targets which typify anomalies likely to be mistaken for ordnance items during survey operations. This information will enable evaluators to determine the demonstrator's ability to detect subsurface anomalies, as well as the ability to accurately classify anomalies during the survey phase. The quantity of these targets in each,quadrant increases from 0 in Area Alpha to 29 in Area Delta in order to determine the demonstrator's ability to characterize the targets effectively on an increasing basis (that is, as density increases).