The Second Interim Evaluative Report on the Program on Electromagnetic Sensing of Buried Objects: Electromagnetic Fields Division, National Bureau of Standards, Fiscal Year 1987 (1988)

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Electromagnetic Fields Division

National Bureau of Standards Fiscal Year 1987

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This report, submitted for the Panel by the Acting Chairman, Leon Peters, Jr., covers the activities on the program on Electromagnetic Sensing of Buried Objects of the Electromagnetic Fields Division of the Center for Electronics and Electrical Engineering of the National Bureau of Standards for fiscal year 1987. The Panel meeting was on May 6, 1987, in Boulder, Colorado.

Introduction and Purpose

At the request of the Director of the National Bureau of Standards (NBS), the National Research Council has established a special ad hoc panel of the Board on Assessment of NBS programs for fiscal years 1986, 1987, and 1988--the Panel for Electromagnetic Sensing of Buried Objects--within the Electromagnetic Fields Division of the NBS. The purpose of this Panel is to provide a critical review of the NBS program for developing measurement standards for evaluating electromagnetic methods of detecting subterranean objects. Specifically, the Panel has been requested to:

1. Provide a technical review of the work of NBS in the area.
2. Provide technical guidance to NBS on the program.
3. Suggest avenues that warrant investigation in the course of the program.

4. Provide a critical review of the scope of the activities of NBS in the program area.

5. Provide a critical technical review of the final report (draft) prepared by NBS in fiscal year 1988 on the program.

The National Bureau of Standards is receiving other-agency support from the U.S. Army to develop standards and test procedures to enable the sponsor to evaluate the performance of electromagnetic mine detectors. Out of this work, it is hoped that test methods and procedures are prescribed that will provide a basis for evaluating and comparing the performance of mine detectors.

The initial meeting of the Panel was held on May 13, 1986, and the second meeting was held on May 8, 1987, in Boulder, Colorado. This interim report is a report of that second meeting, and it includes highlights of the background information presented and the comments and recommendations by the Panel. The subsequent Panel meeting and report of fiscal year 1988 will respond to the remainder of the Panel's charge.

Background

It should be emphasized that NBS has taken on a task of great magnitude. The general problem of detecting mines with a satisfactory false-alarm rate has been pursued by many competent people over many years. To expect a complete set of satisfactory standards and tests to categorize not yet existing systems represents an immense task. This report will review this effort with complete candor with the belief that only by commenting openly can this panel be of any real value. These comments are not intended to fault the excellent staff and their achievements with regard to this problem.

The first report, An Interim Evaluative Report on the Program on Electromagnetic Sensing of Buried Objects, Electromagnetic Fields Division, Fiscal Year 1986, provides the reader with the background for the current report. NBS also provided their interim technical reports to the Panel. Before the May 8, 1987, meeting, NBS provided an overall discussion document of their progress to the Panel members. At the meeting on May 8, 1987, NBS presented an update on their complete program and have since supplied the Panel with copies of their viewgraphs.

Review of Progress Since the First Report

As may be observed from reading the first report, the first meeting of the Panel was to review past and present mine-detector technologies, to suggest standard targets and soils, to provide preliminary definitions as necessary for investigating suitable performance measures, and a resulting progress report.

The review of past and present mine-detector technologies was extremely limited in scope. It was a general conclusion that detectors for metal mines are straightforward, as is stated

in the NBS discussion document, and the Panel is in agreement with this conclusion. However, the only plastic mine detector considered was the AN/PRS-7, and this was done only briefly. No pulsed or wideband systems were considered. It is important to note at this time that it is as important to identify the mine as it is to detect it because of the abundance of false targets in the real world. This is also true for the metal mine.

The standard targets under consideration, as observed in the NBS discussion document, included metallic cylinders and Teflon and nylon spheres. Spheres with a maximum diameter of 98.5 mm were used. This was detectable by the AN/PR-7 mine detector and discussion centered on the use of smaller spheres. Fort Belvoir personnel observed that larger test objects of more realistic shape should be considered.

Standard soils were also considered, and no completely satisfactory soil was introduced. The difficulty is in the need for moisture in the "soil" and it then became difficult to maintain the desired properties. Tertiary mixtures were recommended. For very lossy soils, test tanks with liquid media were recommended. It might be observed that mines are usually buried close to the surface, the detection wavelengths are usually large compared with the burial depth and thus the soil is not an extremely sensitive parameter. This is particularly true for dielectric mines that are dominated by internal reflections.

NBS did consider measurements of both permittivity and permeability. They are now in the process of considering time-domain techniques. However, measurement of electrical properties should be done in situ but most discussion focuses on the use of sample holders.

A major part of the NBS effort is focused on some very competent theoretical analyses using the Born approximation. This effort is of substantial scientific merit but contains limitations that may make it impractical for the study of mines. In particular, the identification features essential to mine detection would require the analysis to include several resonances or frequencies higher than would be valid using the Born approximation.

Recommendations

The Panel made the following suggestions at the May 8, 1987, meeting:

1. The metal-detector evaluation appears to be coming to a satisfactory conclusion; it remains to evaluate the influence of magnetic soils on the system.
2. The theoretical analysis should continue and should include higher frequencies.
3. General Dynamics Corporation should send the Mobile Variable Parameter Test Set to NBS for additional measurements.
4. Soil and soil standards need to be generated. This should include an in situ monitor.

5. Test shapes should be more mine-like including air gaps, firing pins, etc.

6. There should be a requirement for stability, particularly for bridge-type instruments.

7. The performance of broadband systems should be assessed.

8. Clutter represents a very significant parameter even though it is beyond the scope of the present project.

9. The U.S. Army should list and distribute important parameters and generate quantitative definitions for mine detectors.

10. A performance matrix should be generated by NBS.

11. The U.S. Army needs to be involved more deeply.

The following sections are intended to elaborate on the above recommendations.

1. The metal mine-detection component of the NBS project appears to be in good shape. Electromagnetic characterization of the magnetic soil lane at Fort Belvoir requires an in situ measurement of the effective soil magnetic permeability μ_r. There is a complication in this measurement because electromagnetic induction sensors (loops) respond to the product of the magnetic permeability μ_r and the earth conductivity σ. For this reason, environmental characterization of the magnetic test lane requires a noninductive method to establish the effective μ_r. One such method would be a magnetostatic measurement as described by Richard Geyer at the May 8, 1987, meeting in Boulder.

2. The current NBS analysis is generally concerned with the first resonance of the mines. This is not adequate for target identification purposes. Nearly every small scatterer--stones, buried debris, etc.--will have the same resonance behavior as these targets. Sufficient data need to be generated, both theoretical and experimental, to provide the target identification specialists the tools needed to separate the mine from such debris. Since the actual system must have this ability, so should the test requirements to be provided by NBS.

3. The Electronics Division of General Dynamics Corporation is updating a mobile measurement system known as the Mobile Variable Parameter Test Set, which was originally designed and assembled by NBS. This work is sponsored by the U.S. Army Belvoir Research and Development Center (BRDC). One objective is to refurbish the measurement system, which will include a computerized network analyzer, data acquisition equipment, and a carriage to support an antenna or detecting system. Another objective is to perform field tests of mine detectors and subsystems. The project is scheduled to be completed in March 1988. The test set will be completed in approximately 5 months, and then field tests will be started.

The test set's capabilities include measuring phase and intensity of monochromatic fields with frequencies between 100 MHz and 3.0 GHz; these fields will be radiated and received by antennas of diverse types. Time-domain measurements also will

be possible by frequency synthesis. The test set will also be capable of measuring, digitizing, and recording audio outputs of detector systems.

Discussions with Panel members and U.S. Army personnel have suggested that the test set and its operation may be of interest to NBS personnel in their current project, which is developing standards for systems that may be recommended but may not be possible to execute in Boulder.

4. In the reported tests all models are simple geometrical shapes. These models are acceptable for metal detectors but are less than adequate for plastic land mines. Details such as air gaps and metal fuse assemblies may have an impact on detectability. The Panel recommends that more realistic models of targets be used in the evaluation of detectors of nonmetallic mines.

5. Stability in instrumentation is an important feature not to be overlooked. This is particularly true for bridge-type instruments, which under normal conditions are well balanced. But drift often occurs as the instruments are warmed up or subject to ambient temperature changes. An instrument that may operate perfectly but only for a short duration is definitely unacceptable as a piece of military hardware. The Panel recommends that a stability criteria be included in the evaluation.

6. Broadband systems need to be evaluated. In fact, they are the major hope for detecting dielectric mines. The simple fact is that direct coupling from transmitter to receiver and direct scattering from the ground interface will always be several orders of magnitude (an understatement) above the desired scattering from the mines so that no processing will separate it from these unwanted signals. Broadband systems used to create high-resolution radars are essential if successful dielectric mine detection is to be achieved.

7. The Panel recognizes the importance of clutter (anomalous objects) in the ground. Such clutter will undoubtedly limit the performance of any realizable mine-detection system, and some attention eventually must be given to define suitable standards that deal with this problem. However, this is beyond the scope of the present effort, and the focus should continue to be on the definition of standard targets in standard environments, and on the detection of such targets in those environments. This should not, however, preclude the detection of two or more such standard targets in close proximity to each other.

8. A mine-detection performance matrix should be generated by NBS to be used as a guide for testing mine detectors. Such a matrix should be presented to the Panel for evaluation at the 1988 Panel meeting.

At the May 13, 1986, Panel meeting, comments and questions were made concerning the goals of this effort. These comments still appear to be valid and hence are repeated here.

Comments

1. More detail is desirable in the NBS short- and long-range plan for developing measurement standards for evaluating electromagnetic methods for detecting buried objects.
2. More specific statements are desirable concerning the final utilization of the resulting projects of the NBS project. During the May 13, 1986, meeting, the Panel questioned the efficiency of developing alternative new theoretical formulations to the problems of high- and low-frequency modeling. Even with the adoption of existing codes, such as the unimoment, the Panel commented that the time allocated in Phase I appeared to be inadequate. NBS responded that the plane-wave scattering-matrix formulation provides a framework for combining all available information involving the antenna, interface, and buried target in a self-consistent manner. It is not intended to provide alternative new formulations to scattering problems. Also, it was stated that some theoretical work will be conducted throughout all of the phases of the project.

Questions

The Panel that met May 13, 1986, raised the following more general and specific questions:

1. Is NBS responsible for prescribing the procedures for the experimental and theoretical acceptance tests?
2. What is the role of "numerical modeling" in the development of test procedures and standards? Are existing codes to be used or are new codes to be developed? What will be the use of such data?
3. How realistic is the present time allocation of the modeling effort?
4. Are test procedures and test systems to include "standard" air-earth interface conditions, surface roughness, undulations and/or sensor tilt?
5. If mine-detector developers propose detection schemes involving short pulse, will the anticipated test standards be sufficient?
6. Is there any hardware to be delivered to the U.S. Army?
7. Is the standard test procedure expected to incorporate considerations of clutter, e.g., due to the metal fragments that are often present in a battlefield?
8. Are test procedures to be developed for separate subsystems as well as for final detection systems?
9. Are imaging, signal processing and target identification signature methods to be developed?
10. Is there to be a performance index to indicate the ability to determine size, shape, and material composition of a target?
11. The U.S. Army should further clarify their specific needs for test methods and procedures and the manner in which these tests will be applied.