SECTION 1. EXECUTIVE DIGEST

1.1 INTRODUCTION

The U.S. Army Corps of Engineers, Engineering and Support Center, Huntsville (USAESCH) was established as the Mandatory Center of Excellence (CX) for the Ordnance and Explosive program within the U.S. Army Corps of Engineers. The mission is to safely eliminate or reduce risks from ordnance, explosives, a recovered chemical warfare materiel at current or formerly used defense sites. The Center of Expertise is responsible for Ordnance and Explosive (OE) activities in support of Defense Environmental Restoration Program for Formerly Used Defense Sites (DERP - FUDS), Installation Restoration (IR), Base Realignment and Closure (BRAC), and Services for Others (SFO) programs. These programs currently have over 2000 projects in inventory with normally 60-80 active projects at any given time.[1]

1.2 BACKGROUND AND HISTORY

The U.S. Army Corps of Engineers is responsible for removing Ordnance and Explosives from approximately 14,000,000 acres at more than two thousand different DERP - FUDS and BRAC sites. Most of these sites were part of the military downsizing after World War II and the Korean War and are already turned over to the civilian population. Also, some of the more recent sites to be closed have not been involved in any ordnance firing activities since about 1960[2]. The earlier sites, especially those near population centers, need to be restored (to an ordnance-free condition) as soon as feasible. This places particular emphasis on the ordnance and the vacuum tube fuzes used prior to about 1960 and their sensitivity to electromagnetic (EM) radiation from instruments used to detect or evaluate the unexploded ordnance (UXO).

By the end of World War II ordnance with vacuum tube fuzes had reached such a level of sophistication that, between the end of World War II (1945) and the end of the Korean War (1954), there was limited research and development in new conventional ordnance. This resulted in very little development of new types of electrical fuzes for the ordnance used during this time period.

The discovery of the transistor, by Walter H. Brattain and John Bardeen of Bell Laboratories, occurred on December 23, 1947[4]. In 1951 semiconductor materials were commercially available. In 1954 the first fully transistorized radio and computer were built. In 1955 transistors were available for the first time in production quantities. In 1956 investigations began into the use of transistors in fuze circuits. In 1959 the first integrated circuit microchip was made. The development of solid state transistors and microchip technology started new work to reduce the weight of mechanical fuzes and to replace the sometime unreliability vacuum tube proximity fuzes. Early vacuum tube fuzes would only withstand about a 4-ft drop due to the fragile capacitor and ampoule. The first electronic hybrid (transistors and vacuum tubes) fuze, the M532, was made in the early 1960s for a mortar round. The first fully transistorized fuze, the M429, was made in the

1965-1970 time period for a 2.75" rocket to use in the Vietnam War. The M514A1E1 (later named M728) was the first fully transistorized artillery fuze and was made in the late 1960s to early 1970s[29].

With development efforts, production, testing for safe fuze operation, and approval for military use, it was not until about 1968 that transistors were made in production quantities for Army fuzes and the mid-1970s for Navy units[28]. There were some statistical field tests of pre-production items prior to production approval. Thus, before about 1960, electronic fuzes were all vacuum tube units. Indeed these miniature vacuum tube fuze units have such a long shelf life that some units are still in inventory. Since the initial fuze research and development activities were classified at the secret level and very closely guarded, all early dud items over land test sites were promptly recovered and evaluated. During statistical field firing testing of large numbers of fuzed ordnance, some with high explosives, some of the resulting duds may have been left on the test range(s). This effort addresses only ordnance fielded up to about 1960, and thus does not include the transistorized fuzes introduced in the 1960s, or more modern electronics containing integrated circuits.

1.3 TASK OBJECTIVES

The primary objective of this task is to catalog the commonly used U.S. fuzes up to about 1960, the type of EM energy to which these ordnance are most sensitive, and the amount of EM energy required to cause the fuze to function (a highly undesired effect during restoration). The second objective is to quantify and footprint the output energy of the primary geophysical instruments for the U.S. Army Corps of Engineers' restoration program. This Electronic Fuze Evaluation effort is to provide a comparison of the EM signatures of the geophysical instruments with the sensitivity of the electronic fuze systems and identify circumstances most likely to cause problems. This report documents the first part of this effort by cataloging vacuum tube fuzes commonly used by the U.S. up to 1960, the type of EM energy to which these ordnance are most sensitive, and the amount of EM energy required to cause the fuze to function.

1.4 STUDY RESTRICTIONS

This study was restricted to assessing the potential hazard of buried ordnance to EM energy from geophysical instruments. Since the Corps of Engineers' procedure of first doing a thorough visual walk-through examination and removal of any questionable items for a UXO site, prior to any site examination with instruments, only buried ordnance was addressed in this study.

Prior to 1942 fuze systems were entirely mechanical systems which are regarded as being inherently safe to low-level EM radiation. An example of a mechanical time fuze is shown in Figure 1-1. Early electrical fuze units, and even modern units, have continued to use clockwork mechanical subsystems. Figure 1-2 shows a Mark 45 fuze that used miniature vacuum tubes (nosetip), a short-term, wet-cell electrolytic battery (center), and a mechanical safety and arming mechanism. (Initial research in thermal batteries[25] was conducted in the late 1950s and early 1960s.) The Mark 45 fuze and similar units were used extensively during World War II and the Korean War. Figure 1-3 shows a modern fuze system with a mechanical Safety and Arming Mechanism. This study was restricted to only the electrical/electronic fuzes, since these units may have a different sensitivity to the low-level EM energy of common geophysical instruments. This study task was further restricted to cataloging the electro-magnetically sensitive vacuum tube fuzes that were commonly used by the U. S. up to 1960 for US munitions only (no landmine, submarine, submunition, air-to-air, or seamine/torpedo fuzes). These generally include electronic fuzing systems developed and used between 1942 and 1960 for; US artillery and mortar rounds, US aerial bombs, US air-to-ground rockets and missiles, US ground-to-air missiles, and US ground-to-ground rockets and missiles. No laboratory or field testing of any fuze, ordnance, or geophysical instrument was conducted during this study. This report focuses on the vacuum tube electronic fuzes fielded prior to 1960.

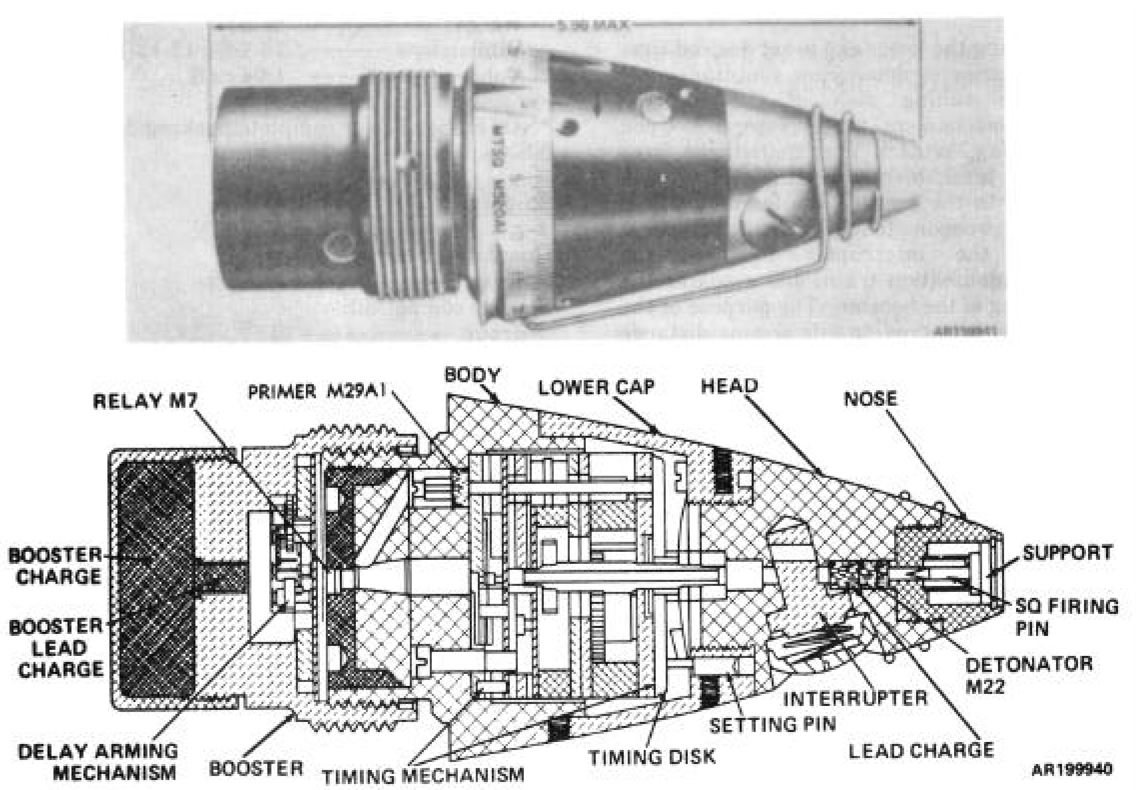

Figure 1-1. Mechanical-Time Fuze for Impact Detonation or Airburst.

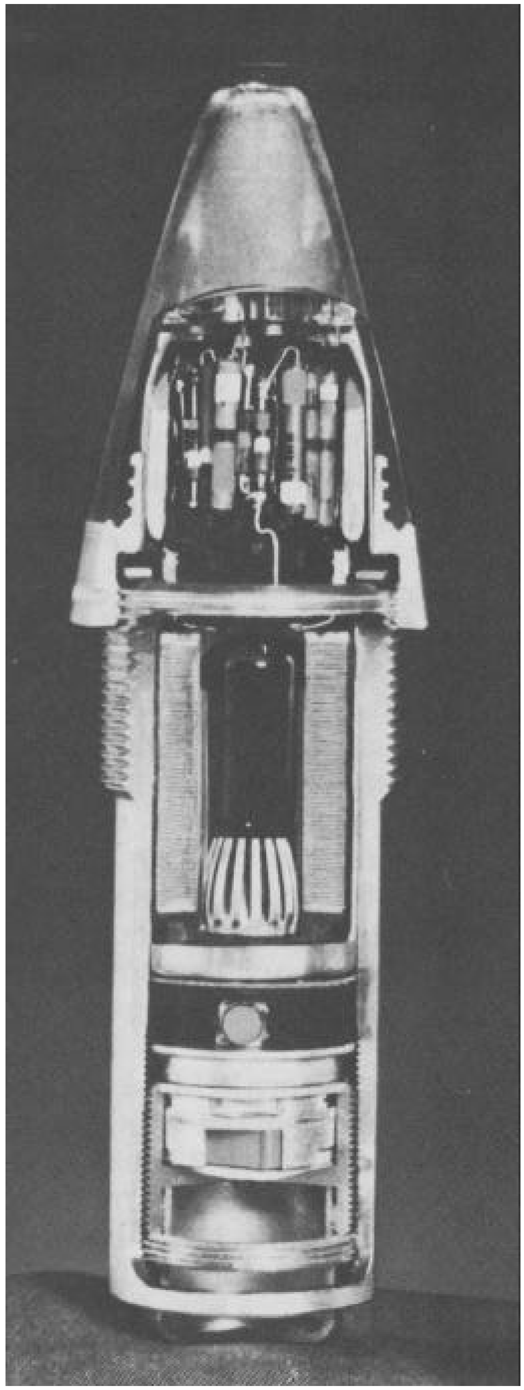

Figure 1-2. A Mark 45 Fuze made by Eastman Kodak Company.

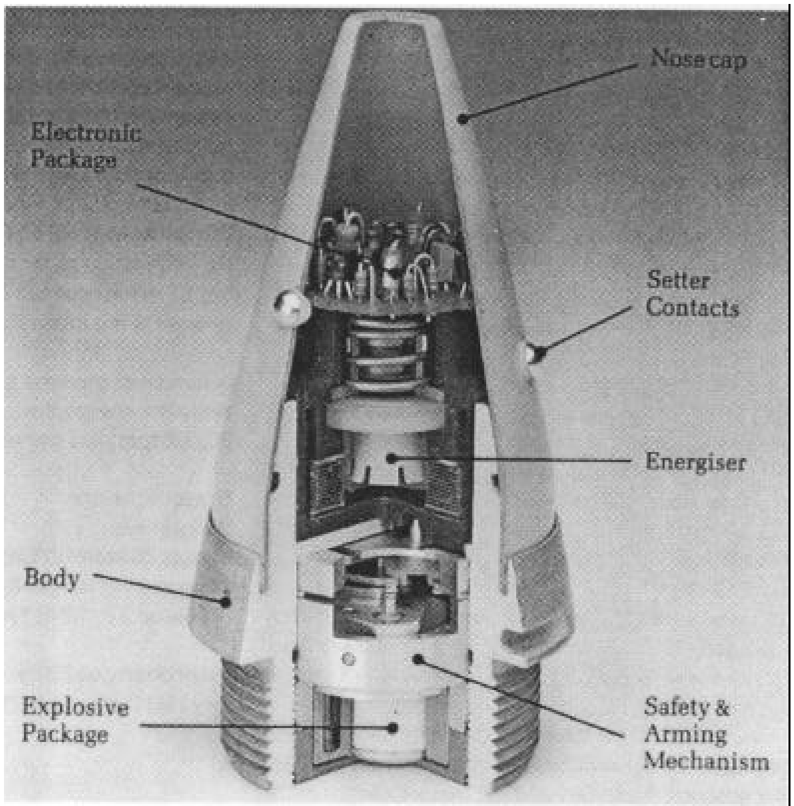

Figure 1-3. Example of a Modern Fuze with Electronic Initiator Package.

1.5 EXPLOSIVE TRAIN

The fuze part of the explosive train ignites or initiates the high explosives in the weapon. Fuzes are generally made separately and stored separately, due to their greater sensitivity to external stimuli, until the ordnance is to be readied for field use. The fuze unit has machined threads near its base for mounting in the ordnance shell containing the high explosive. From the standpoint of the explosive train, it is convenient to divide the explosives into three classes; primary explosives, priming mixtures, and high explosives[23]. The electrical fuzes, called variable time (VT) fuzes during WWI and Korean War because of security reasons are commonly called proximity fuzes today, combined mechanical and electrical (vacuum tube) circuits for anti-aircraft and anti-personnel ammunition. These proximity fuzes were used extensively during WWII and the Korean War.

The distinguishing characteristic of primary explosives is their extreme sensitivity to heat and shock. They are the most sensitive of the explosives and occupy the "starting" position in the explosive train and are frequently called initiators. The more common primary explosives of this time period were; mercury fulminate, lead azide, lead styphnate, diazodinitrophenol, tetracene, and nitromannite. These materials can be easily and reliably ignited with minimal energy from a hot filament or exploding bridgewire (100 - 4,500 ergs), provided the energy is input in a relatively short period of time or the material is heated to its explosive temperature. The fundamental circuit for the electronic bridgewire fuze is shown in Figure 1-4. The electronic bridgewire element is often referred to as an electronic blasting cap, as shown in Figure 1-5. For proximity fuzes the bridge element consisted of small metal wire or a thin strip of carbon film in parallel with a total resistance value of about 700 to 15,000 ohms.

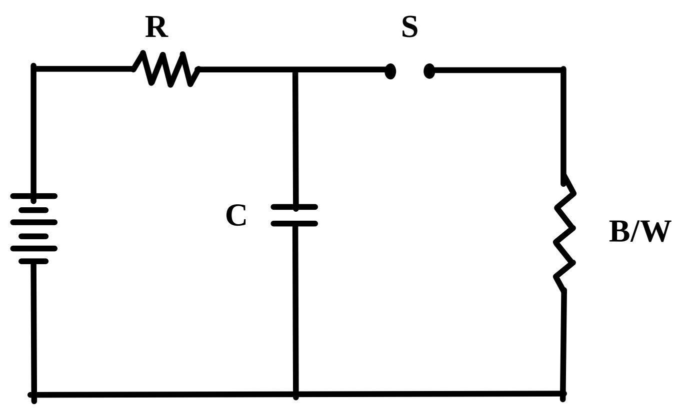

Figure 1-4. Fundamental Circuit of EBW Fuze.

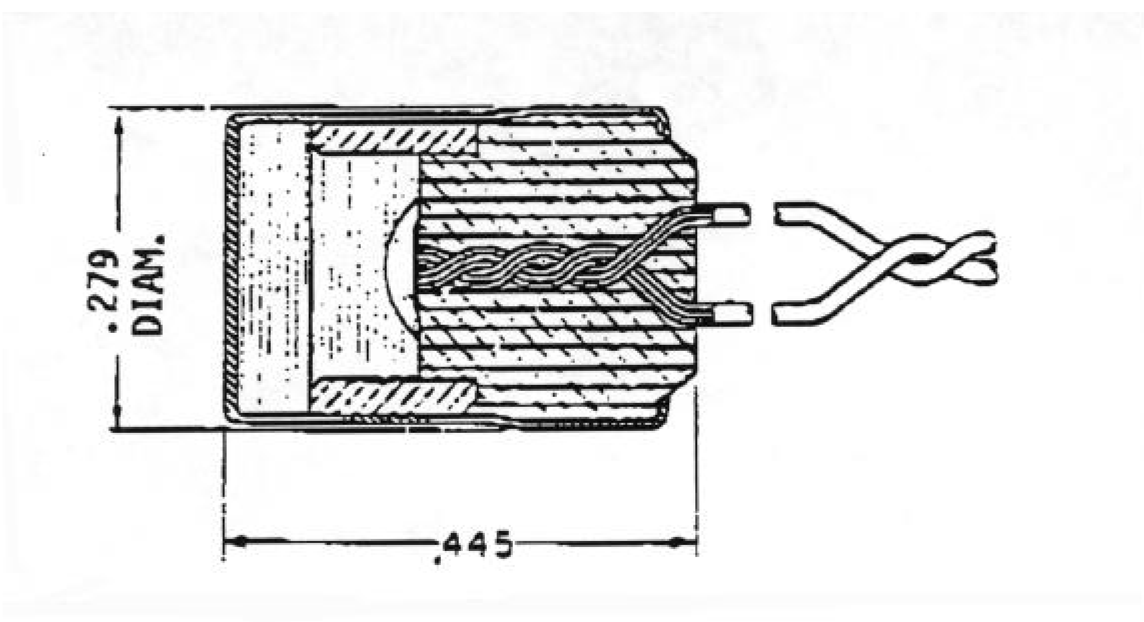

Figure 1-5. Electronic Blasting Cap.

Fuzes requiring as little as 10 ergs to initiate can be made, but this extremely high sensitivity creates a pronounced safety problem even for the designer! For safety reasons, fuze systems were generally designed for higher than minimal energy for initiation by proper selection of the primary explosive mixture and bridge circuit electrical properties. Early experimental fuzes were made and tested that required little more than 100 ergs to initiate the primary explosive, but these units were susceptible to initiation by static electricity. Later fuzes fielded during WWII required a minimum about 200 - 500 ergs for sure fire conditions. After WWII, high voltage circuits were used in some ordnance items to directly ignite the less sensitive priming mixtures and gave greater fuze safety.

Priming mixtures frequently contain mixtures of a primary explosive material, an oxidizing agent, fuels, and a binder material. Priming mixtures, sometimes called boosters, are ignited by the primary explosive and they in turn ignite the high explosives. Priming mixtures are generally less sensitive than the primary explosive, but more sensitive than the high explosives. Priming mixtures sometimes have additives to make them conductive, either for the purposes of electrical initiation by currents passed through the mixture or to decrease the sensitivity to static electric discharges. (After about 1980 when high voltage circuits were used to directly ignite the priming mixtures, reliable fuze systems requiring as much as 1.69 joules {= 1.69×10^7 ergs} were commonly produced.)

High explosives have the characteristic of low sensitivity to heat or shock and function under the influence of the shock of the primary explosive or of another high explosive. Most high explosive, unlike primary explosives, when in an unconfined state will burn without exploding when ignited with a flame.

1.6 FUZE TYPES

Prior to the early 1960s, the types of fuzes fielded included; all mechanical systems and hybrid systems containing electrical timing systems (vacuum tube units and other electrical components). Fuzes are also categorized according to application and function. The hybrid systems were generally referred to as electrical fuzes and were used in artillery, bombs, mortars, and rockets. All fuze units have, as a result of government design requirements, multiple safety features to prevent accidental arming and firing. Although the primary explosive of the fuze is the most sensitive component in the explosive train, it sensitivity varies depending on the type of fuze system. Mechanical fuzes were commonly used for point detonation and detonation at a fixed mechanical time. (Mechanical fuzes are of a clockwork design and generally have many components as a result of extensive safety requirements.) From the beginning, all electronic fuzes were required to have multiple safety features and a self-destruct feature. Electrical circuits are generally required for the fuze to function as a precise proximity device.

During WWII slightly over 22,000,000 proximity fuzes were produced. Of these, about 1,500,000 were fired at the enemy, about 330,000 were used in testing and R&D. The large balance of fuzes and the general scale-back after WWII were the primary reasons why there was little fuze development between WWII and the Korean War. The

Radio Frequency (RF) proximity fuzes, commonly called variable time or VT fuze, developed during WWII commonly had 4 or 5 miniature vacuum tubes in the transmitter and receiver circuits, plus other electrical components for electrical signal conditioning. These units formed the basic designs for all vacuum tube units produced between WWII and their gradual replacement by transistorized units in the 1960s and 1970s. Appendix A lists the VT fuzes produced as of 15 August 1945 and some of those produced between 1945 and 1960. (Detailed production information for 1945 - 1960 has been hard to find.)

The all-mechanical fuze systems are of a clockwork design and generally require the high G's of launch to start the arming sequence and to activate a spring-loading device (to build up potential energy) which rotates and moves multiple mechanical components to align the firing train. It is then referred to as "an in-line explosive train" that is fully armed and ready to fire. Then the spring-loaded unit drives a firing pin into a small charge (the primary explosive) to start the detonation process (similar to conventional firearms). Fortunately, these all-mechanical fuze systems have no way to collect and store the EM energy from geophysical instruments to initiate any of the firing steps. The EM instruments can only couple energy to the mechanical fuze system by negligible heating and magnetization effects. Neither heating nor magnetization is used to move any of the components of an all-mechanical fuze design. The shock pulse from ground impact (or from thunder and lightning) would far exceed the forces on the firing pin of a buried and armed fuze than would be generated by heating or magnetization from geophysical instruments alone. For these reasons, an all-mechanical fuze is regarded as being inherently safe to the weak EM fields of geophysical instruments used to detect unexploded ordnance.

Electrical fuzes were designed to operate in the proximity of its intended target (aircraft, ground, water, or structures) and were called proximity fuzes, or variable time (VT) fuzes. Two types of proximity fuzes were developed during WWII, the radio and the photoelectric proximity fuzes. About 400,000 of each type were manufactured by 1943. The photoelectric fuze required light for operation and would sometimes function early when the sun moved into and out the field of view of the photoelectric lens. For these reasons, manufacture of photoelectric fuzes was cancelled in 1943 and the term proximity or VT fuze generally referred to the radio proximity fuze. The radio proximity fuze consisted of a diode detector arrangement that utilized the Doppler effect (frequency shift) between its transmitted waves and the reflected waves. The Doppler frequency was amplified and used to close the switch, discharging the capacitor and into the bridgewire.

Pre-1960 proximity fuzes, with their miniature vacuum tubes require high voltages for stable operation. Standard vacuum-tubes for commercial applications generally utilized 5 to 10 volts a-c for the tube filaments and d-c bias voltages over one hundred volts[5]. The miniature vacuum tubes used in early electronic fuzes operated with several d-c voltages[28]: heater element at 1.5 - 3 V, bias at negative 5 – 10 V, screen at near 100 V, and the plate at about 170 V. The EM fields from geophysical instruments would not be sufficient for anything close to normal vacuum tube electrical operations, and especially so if the electrical circuit is enclosed inside the metal shell (Faraday cage) of a buried ordnance. If the shell is ruptured, the EM fields could strike the electrical circuit and its components directly (after some attenuation by the soil). Depending on circuit design, at lower voltages there may be little or no current in the circuit. For ruptured and damaged ordnance, it may be feasible to couple energy into the electric detonator from one or more circuit loops.

1.7 GEOPHYSICAL INSTRUMENTS

The geophysical instruments evaluated during this study included: 1) the EM61 and EM31 made by Geonics, 2) total field magnetometers [or flux gate radiometers], 3) ground penetrating radars [GPR], 4) the GEM3 FDEM sensor made by Geophex, and 5) the AN/PSS-12 mine detector made by Schiebel Instruments. These are the primary instruments of interest with regards to a potential hazard from their EM fields initiating a fuze. These instruments are discussed in more detail in Section 2 and Appendix A.

Fluxgate gradiometers, such as the Schonstedts, Magna-Trak, and Foerster Mark 26 instruments were not considered in this study. Due to their design they produce EM emissions lower than, or at most comparable to, cesium vapor magnetometers.

1.8 CONCLUSIONS

The results of this study indicate that electronically initiated fuzes and fuzes with some electrical components are more sensitive to electromagnetic energy from geophysical instruments than the all-mechanical fuzes. The all-mechanical fuzes are regarded as being safe to the low-level electromagnetic fields produced by geophysical instruments. The hazard associated with electrical fuzes depends strongly on the condition of the explosive train and state of the fuze. If the ordnance did not fire because the fuze did not arm and the buried ordnance was not damaged on impact, then it should be insensitive to the fields produced by geophysical instruments. If the ordnance was properly armed but did not fire due to a malfunction or if it received significant damage on impact, then a detailed analysis of the possible configurations and operational states must be made to properly assess the hazards associated with the ordnance. If the ordnance shell was not ruptured on impact the sensitivity to EM fields will be much less than if the shell is ruptured. The likelihood of a detonation is a strong function of the strength of the EM field and thus the distance between the instrument and the ordnance. Our analysis indicates that if the instruments are carried at one meter above the ground, the risk of UXO detonation is low. However, instruments at ground level can pose a serious detonation risk for an armed fuze immediately below the surface.

1.9 RECOMMENDATIONS

It is recommended that additional study of the sensitivity of electrical proximity fuzes made before 1960 be conducted. Specifically, it is recommended that all geophysical instruments used for detection and evaluation of pre-1960 UXO be tested prior to field use to determine whether they will activate unshielded primary explosives. The testing should be performed for any fielded instrument configuration at close distances (~1 cm) most likely to start the detonation process. In addition to the instrument manufacturer's analysis to support a claim for safe operation, laboratory and field tests of the instruments should be conducted with unshielded primary explosives of representative highly sensitive fuzes in various "damaged states" to verify safety.

Specific recommendations for pre-1960 UXO detection include:

a) Never place any operating geophysical instrument, its electronics, data processor, or battery pack on the ground in an area of UXO. (The dependence of the energy coupled to the initiator with the instrument magnetic field and its height above ground are addressed in subsection 2.4.3, equations 7 and 8, and in Tables 2-3 and 2-4.)
b) Current data indicates that Ground Penetrating Radar (GPR) units pulled across the ground should not be used for UXO activities until further notice.
c) Do not use the EM61, EM31, or the GEM-3 units around trash piles.
d) The GEM-3, EM31, and the EM61 are to be used at heights above ground of 1 meter. Do not allow these instruments, or their accessories, to come within 0.5 meters of the ground when they are turned on.
e) For pre-1960 UXO work, use only geophysical instruments indicated in Table 1-1 to be safe for this activity. (A conservative criterion of no more than 1 erg per second of energy coupled to a fuze circuit of 50-cm^2 area was used as a safety cut-off limit.)
f) Follow all safety regulations and operating procedures during UXO activities.
g) CAUTION: In trash piles containing <u>large</u> quantities of wire, the magnetic coupling between any evaluated geophysical instrument and a damaged UXO may be sufficient to cause detonation. THEREFORE, AVOID USE OF THE EVALUATED GEOPHYSICAL INSTRUMENTS WHEN A LARGE TRASH PILE CONDITION IS SUSPECTED.

Table 1-1. Safety Summary for Geophysical Instruments

Type	**Vendor/System**	**Safety Comments and Recommendations**
TDEM	Geonics EM61	Safe when carted at 0.42 meter height (or carried at 1 meter height), <u>except at trash piles</u>. DO NOT OPERATE AT HEIGHTS LESS THAN 0.4 METERS!
FDEM (conductivity)	Geonics EM31	Safe when operated at 1 meter height, <u>except at trash piles</u>. DO NOT OPERATE AT HEIGHTS LESS THAN 0.3 METER!
Cesium Vapor Magnetometer	Geometrics G-858	Safe when operated at 1 meter height. DO NOT LET OPERATING INSTRUMENT CONTACT GROUND.
Cesium Vapor Magnetometer	Scintrex/ V-920	Safe when operated at 1 meter height. DO NOT LET OPERATING INSTRUMENT CONTACT GROUND.
Total Field Magnetometer	ADI/TM-4	Safe when operated at 1 meter height. DO NOT LET OPERATING INSTRUMENT CONTACT GROUND.
Flux Gate Gradiometer	Foerster/ Ferex 4.021	Safe when operated at 1 meter height. DO NOT LET OPERATING INSTRUMENT CONTACT GROUND.
GPR (Pulse, TD)	SSI/ Pulse EKKO IV/100	DO NOT USE FOR UXO ACTIVITIES! This is a ground contact instrument that might set off a low activation energy fuze.

GPR (Pulse, TD)	SSI/ Pulse EKKO 1000	DO NOT USE FOR UXO ACTIVITIES! This is a ground contact instrument that might set off a low activation energy fuze.
FDEM	Geophex Ltd./GEM-3	Safe when operated at 1 meter height, except at trash piles. DO NOT OPERATE AT HEIGHTS LESS THAN 0.5 meter!
Mine Detector	Schiebel/ AN/PSS-12	

NOTES: TDEM – time domain electromagnetic; FDEM – frequency domain electromagnetic; ADI – Australian Defense Industries; GPR – ground penetrating radar; SSI – Systems and Software, Inc.