An Active Electromagnetic Safety Proving System for UXO Clearance

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Abstract

The use of active electromagnetic (EM) instruments to detect UXO that contain piezoelectric or electronic fuses is hazardous. These instruments operate by inducing electrical currents in metal objects in close proximity. This induced current generates a magnetic field, which is sensed by the instrument. If UXO containing piezoelectric fusing or other electrically sensitive fuses are exposed to active EM instruments the induced current may function the high explosive components of the UXO. Since the majority of active EM instruments are hand operated or towed by light unarmoured vehicles this is a serious concern.

This paper proposes the use of an Active EM Safety Proving System to mitigate this hazard. By towing an array of active EM emitters that produce the exact waveform generated by the EM instrument to be used in the proposed clearance area a safety factor is generated. The magnitude of the safety factor can be adjusted by varying the power output by the proving emitters.

The Safety Proving Emitters can be towed behind a suitably armoured vehicle. In this mode a considerable clearance area can be made safe rapidly and economically. An

additional benefit of this process is that one sweep by the EM Safety Proving System mitigates the hazard for all subsequent usage of the active EM instrument.

Background

The author was acting as a technical consultant to XTech Explosive Decontamination Inc. on the Canadian Forces Base Calgary Sarcee Range Clearance Project in 1997. Some of the ordnance used on this range were composed largely of non-ferrous materials and utilized a piezoelectric fuse. The two UXO detection instruments available were the Vallon fluxgate magnetometer and the Geonics EM61. Operation of the fluxgate magnetometer posed no safety hazard as it does not actively emit EM energy, however, the ordnance being searched for were composed primarily of non-ferrous materials which were not detectable by this instrument. The EM61 was very effective at locating non-ferrous ordnance, however, the emission of EM energy posed a safety risk for the operator as discussed above.

In order to carry on with UXO clearance operations the hazard associated with the operation of the EM61 had to be mitigated. A number of options were considered with the following key factors used to evaluate the alternatives:

Key Factors

- **Cost:** As this work would be carried out by a civilian clearance company the successful alternative would have to be cost effective. Both in terms of capital and operating costs.

- **Effectiveness:** The chosen alternative had to provide an acceptable safety factor for the personnel conducting the active EM surveys.

- **Robustness:** The chosen alternative would be required to withstand operations in hostile environments and difficult terrain.

- **Productivity:** The chosen option would have to mitigate the hazard of using active EM instruments at a production rate sufficient to not hamper a large scale clearance operation.

- **Adaptability:** The best alternative would be able to mitigate the hazard from a variety of UXO allowing this alternative to be applied at other clearance areas. It would also be valuable if the chosen alternative could be utilized to mitigate the hazard of other active EM instruments, particularly units with higher power emission than the EM61.

Review of Alternatives

Four alternatives were reviewed and evaluated based on the Key Factors noted above. A brief description of each option is provided with comments regarding the Key Factors.

Remote Vehicle

By towing the active EM instrument with a remotely operated vehicle the hazard to the operator is effectively mitigated. A number of tele-operation packages are available for use with most vehicles. The operator will need to be approximately 250m from the instrument or protected in some manner if he is closer.

- **Cost:** The cost of a tele-operation kit makes this an expensive option on the order of $400,000 - $600,000 CDN of capital cost to implement. This cost would include the tele-operation kit, vehicle and GPS system for navigation.

- **Effectiveness:** This alternative is very effective at mitigating the hazard to the operator. Note that once an area has been surveyed with a remote EM instrument it cannot be considered safe for subsequent EM surveys. If any hazardous UXO remain in the survey area it may only require a slightly different ground track for the EM instrument to function the item on the second survey.

- **Robustness:** The ruggedness of this option is dependent on the quality of the components selected. The more durable the components the higher the cost.

- **Productivity:** The productivity of this option will be lower than a man operated instrument. This is a result of the inability of a remotely operated vehicle to follow the precise ground track required to conduct an EM UXO survey. A significant overlap of survey ground tracks will be required to ensure full coverage of the survey area, which will reduce productivity. Typically two EM surveys are utilized in clearance procedures. The first to identify targets for investigation and the second as a quality control measure to ensure no UXO remain in the cleared area. As the EM instrument will require remote operation for both surveys the degradation in productivity is compounded. Productivity will also be compromised in difficult terrain where the operator will have difficulty piloting the vehicle do to vegetation or soil conditions.

- **Adaptability:** This option offers excellent adaptability as the towed instrument can be changed with little difficulty and no reduction in hazard mitigation.

Towed by Armoured Vehicle

By towing the active EM instrument with a suitably armoured vehicle the hazard to the operator is effectively mitigated. A number of military armoured vehicles would be suitable and civilian pattern vehicles can be fitted with armour packages.

- **Cost:** The cost of this option will largely depend on the vehicle and armour selected. A nominal capital cost of $200,000 CDN was used for comparison purposes. This assumes a hazard equivalent to a 155mm high explosive shell detonating in close proximity to the towed EM instrument.

- **Effectiveness:** This alternative is very effective at mitigating the hazard to the operator. Note that once an area has been surveyed with a towed EM instrument it cannot be considered safe for subsequent EM surveys. If any hazardous UXO remain in the survey area it may only require a slightly different ground track for the EM instrument to function the item on the second survey.

- **Robustness:** The ruggedness of this option is dependent on the quality of the components selected. The more durable the components the higher the cost.

- **Productivity:** The productivity of this option will be lower than a man operated instrument. This is a result of the inability of an EM instrument towed by a large armoured vehicle to follow the precise ground track required to conduct an EM UXO survey. A significant overlap of survey ground tracks will be required to ensure full coverage of the survey area, which will reduce productivity. Typically two EM surveys are utilized in clearance procedures. The first to identify targets for investigation and the second as a quality control measure to ensure no UXO remain in the cleared area. As the EM instrument will need to be towed for both surveys the degradation in productivity is compounded.

- **Adaptability:** This option offers excellent adaptability as the towed instrument can be changed with little difficulty and no reduction in hazard mitigation.

Laboratory Testing and Certification

We can attempt to assess the potential EM hazard of an instrument by testing it with fuses that are currently available. The EM characteristics of an instrument can also be modeled and studied with theoretical fuse models to determine threat levels.

- **Cost:** The cost of this option will depend on the extensiveness of the testing protocols. During this review it was determined that the cost to conduct a useful testing program would not be commercially viable. However, public organizations may have the resources to conduct this work.

- **Effectiveness:** The effectiveness of this option is questionable. There are four main problems with this option:

    1. A number of fuses that pose a threat are not available for testing due to age or other factors.
    2. It is impossible to simulate/model the mechanical damage and weathering that takes place when ordnance impacts the ground without functioning and remains undisturbed for decades.
    3. In order to overcome the limitations of testing/modeling noted above an excessively high safety factor must be built into to the testing procedures. This will disqualify certain EM instruments for use that would in fact be considered safe at a more reasonable safety factor.
    4. If a type of fuse is encountered that has not been tested the time required to initiate and complete testing could be extensive. In the same way if circumstances require an untested EM instrument to be used a significant delay may ensue. This is of course a serious problem for a commercial UXO clearance project.

- **Robustness:** This factor is not applicable to this option.

- **Productivity:** This factor is not applicable to this option.

- **Adaptability:** This option offers poor adaptability in that each EM instrument and fuse combination must be tested/modeled. New EM instrument, significant variations on existing EM instruments or untested fuses will all render this mitigation option useless until testing can be conducted.

EM Safety Proving Emitter (Selected Option)

By towing an active EM emitter with the exact signal characteristics (with the exception of a variable power output) of the instrument to be used a safety factor for the operator can be generated. The towed EM emitter would emit a duplicate signal to the EM instrument, but at higher power levels. The towing vehicle would require sufficient armour to protect the operator. Once this towed emitter has proved the ground it is safe for man operated EM instruments to survey the clearance area.

- **Cost:** The cost of this option will largely depend on the vehicle and armour selected. A nominal capital cost of $200,000 CDN was used for comparison purposes. This assumes a hazard equivalent to a 155mm high explosive shell detonating in close proximity to the towed EM instrument.

- **Effectiveness:** This alternative is very effective at mitigating the hazard to the operator. By varying the output signal's power the magnitude of the safety factor achieved can be varied. Because a safety factor has been achieved once an area has been covered by the Safety Proving Emitter it is safe for all subsequent EM surveys by that type of EM instrument. This method will successfully mitigate the threat of any EM sensitive fuses that may be in the clearance area.

- **Robustness:** The ruggedness of this option is dependent on the quality of the components selected. The more durable the components the higher the cost. It should be noted that all delicate electronic components can be protected inside the towing vehicle.

- **Productivity:** Overall productivity of this option will be lower than a man operated EM instrument. However, this method has several productivity advantages over the other reviewed alternatives:

  1. The rate of coverage of the Safety Proving Emitter is greater than a man operated EM survey allowing survey areas to be quickly made safe and become available for EM survey teams.
  2. Once an area is made safe several EM survey teams can be deployed simultaneously.
  3. Once an area is made safe there is no requirement to conduct subsequent Safely Proving Emitter operations if the same type of EM instrument is used for any follow on surveys.

- **Adaptability:** This option offers excellent adaptability to different fuse threats, as it is not dependent on any a priori knowledge of the fuses that may be in the area. Although the Safety Proving Emitter only mitigates the threat for a specific EM instrument the emitter can be easily modified to mitigate the threat for a different EM instrument. If desired one pass of the Safety Proving Emitter can mitigate for multiple types of EM instruments.

EM Safety Proving Emitter System (EM61 Application)

General

As discussed in the background section of this paper the catalyst for the development of an Active EM Safety Proving System was the need to utilize the Geonics EM61 for the detection of non-ferrous ordnance as part of the Canadian Forces Base Calgary Sarcee Range Clearance Project. The Canadian Department of National Defence reviewed the EM Safety Proving Emitter System concept and approved its use on this project. A prototype was constructed with the help of Geonics Ltd. The technical and operation details regarding the system that was constructed are provided below.

Technical Description

The EM61 Safety Proving Emitter System consist of 5 main components:

High Powered EM61 Emitter

This sub-system consists of a custom made variable powered EM61 emitter coil constructed by Geonics Ltd. The power output by this emitter can be varied from 1 to 25 times that of a standard EM61. The components of this sub-system include:

- Emitter coils
- DC power supply (variable power supply)
- Signal generation electronics
- 5 kW gasoline generator
- custom trailer

Differential GPS

This sub-system consists of a Trimble Pro XR receiver with a vehicle mounted antenna and base station. A data file is collected while the Proving Emitter is in operation as a record and quality control tool. The GPS system is not used for navigation purposes.

Foam Marking System

An agricultural temporary foam marking system is used during EM Safety Proving Emitter operations to clearly indicate the vehicle's actual ground track.

Towing Vehicle

The vehicle that tows the EM Safety Proving Emitter must be able to traverse the terrain that requires EM surveying and provide sufficient protection for the operator. Two vehicles have been used to accomplish this task. The first was an M113 armoured personnel carrier and the second a six wheel-drive 5-ton military dump truck. While both vehicles meet the necessary requirements the 5-ton dump truck was a more versatile vehicle that could be drive long distances on road and has become the vehicle of choice.

Armour Protection

As noted above the vehicle towing the EM61 Safety Proving Emitter must be armoured sufficiently to protect the operator from the highest UXO threat present in the survey area. Both the M113 and the 5-ton dump have been armoured using a combination of sandbags and explosive blast blankets. A lightweight ceramic armour package is being designed for the 5-ton dump that will provide the necessary protection with less weight and bulk than sandbags.

Operation of EM61 Safety Proving Emitter

Site Preparation

The survey site must have vegetation removed to allow the prime mover and towed EM61 Safety Proving Emitter to easily traverse the area. Effort spent preparing the site well will pay dividends in higher productivity for the EM61 Safety Proving Emitter and subsequent EM61 manual surveys.

A Differential GPS receiver is used to mark the proposed survey area. Temporary stakes are used to identify the survey area boundaries for the EM61 Safety Proving System operator.

Weather Conditions

As all electronics are housed inside the cab of the 5-ton dump the EM61 Safety Proving System can operate under adverse weather conditions if necessary. The foam marking system will not function well in temperatures below freezing or in rain, but alternative marking systems can be utilized.

High-Powered EM61 Emitter Power Levels

The output power level of the high-powered EM61 emitter can be varied from 1 to 25 times the power output by a standard EM61. The choice of power level used by the EM61 Safety Proving Emitter is critical as too low a power level will not achieve a satisfactory safety factor, while too high a power level will likely function sensitive UXO damaging the equipment. The ideal power level will provide a sufficient safety factor for follow on EM61 surveys, while minimizing the risk to the Safety Proving Emitter equipment. For the Sarcee Range Clearance the power output has been set at 3 times the power output of a standard EM61. This value was determined empirically and may change as circumstances dictate.

Proving Ground Track

A number of different ground track patterns were attempted. Depending on the terrain and survey area layout a different pattern was adopted. By using the foam marking system the actual track followed by the vehicle could be identified and the next ground track could follow the actual path of the previous pass. This ensures proper overlap of ground tracks avoiding the possibility of missing any areas.

Differential GPS

A vehicle mounted differential GPS receiver is used to log the actual ground track followed by the vehicle. This provides a confirmatory record of the EM61 Safety Proving Emitter's operation.

Equipment Damage

All delicate electronics are stored in the 5-ton dump truck's cab to protect them from damage. The 5 kW generator and foam marking tanks are stored in the rear of the dump. The only components actually towed behind the vehicle are the EM61 high-powered emitter coils, the foam marking solenoids and associated cables/hoses. This provides the maximum protection for the various components. Exposing only those components on the trailer to the direct effects of any functioning UXO.

Personnel Safety

During the operation of the EM61 Safety Proving Emitter all personnel that are not protected should be kept a minimum of 250 metres from the work site.

Proving Rates

The prototype EM61 Safety Proving System used on the Sarcee Range Clearance Project has an actual coverage rate of 5800 square metres per hour. This is a conservative rate based on difficult terrain and vegetation conditions. Under ideal conditions or with a larger emitting array this productivity figure can be dramatically improved.

Further Work

The EM61 Safety Proving Emitter has worked successfully in mitigating the hazards associated with use of the EM61 on the Sarcee Clearance Project. The following is a list of modifications and applications of this concept to improve the usefulness of the EM Safety Proving Emitter System:

- Add more high-power EM61 coils to towed array for wider coverage area on each ground track. Due to the difficult terrain encountered in most military ranges a practical limit of approximately 4 metres in anticipated.

- Develop EM Safety Proving Systems for other active EM instruments.

- Install lightweight ceramic armour package on EM61 Safety Proving Emitter prime mover.