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TEM CELL SAFETY REPORT

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DEFENCE RESEARCH ESTABLISHMENT OTTAWA
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Radiation Effects Section
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ABSTRACT

Although the design of the Defence Research Establishment (DREO) Electromagnetic Pulse (EMP) Transverse Electromagnetic (TEM) cell includes devices for the protection of both operator and machine, safe use of the system depends upon the operator. This document describes the potential hazards of the system and recommends appropriate precautions to be followed during operation and maintenance. Safe and reliable operation can be expected if the machine is operated by personnel acquainted with its function and who follow the procedures outlined in this manual.

RÉSUMÉ

Le centre de recherche pour la défense Ottawa (CRDO) a conçu et construit une cellule de champ électromagnétique transversal pour générer des impulsions électromagnétique (IEM) de plus de 50 kV/m. Malgré que des dispositifs pour protéger l'équipement et l'opérateur aient été inclus, la sécurité demeure principalement la responsabilité de l'opérateur. Ce document décrit les dangers potentiels du système et énumère les précautions à suivre durant son opération et son entretient. Ce système ne doit être utilisé que par le personnel autorisé et ayant pris connaissance de ce document.

EXECUTIVE SUMMARY

In order to test the susceptibility of a piece of equipment to an Electromagnetic Pulse (EMP), an accurate electric and magnetic field is required. One means of generating such fields is with a Transverse Electromagnetic (TEM) cell. This device is essentially a square co-axial line with known field properties.

Although the design of the DREO EMP TEM cell includes devices for the protection of both operator and machine, safe use of the system depends upon the operator. This document describes the potential hazards of the system and recommends appropriate precautions to be followed during operation and maintenance.

Safe and reliable operation can be expected if the machine is operated by personnel acquainted with its function and who follow the procedures outlined in this manual. Anyone not familiar with this system should study this entire manual thoroughly before attempting to operate or service the system or components. Only qualified personnel should attempt to operate the system.

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INTRODUCTION

In order to test the radiated susceptibility of a piece of equipment an accurate electromagnetic field is required. One means of generating such a field is with a Transverse Electromagnetic (TEM) cell. This device is essentially a square co-axial line with known field properties, see Fig. 1.

The TEM cell is located in Building 39 of the DREO complex. It is 6 meters in length and has a cross-section of 2 meters square. These dimensions allow testing of objects up to approximately ½-m height and width. The tapers at each end of the cell are 2-m long with one apex housing the 50-kV pulse generator and the other a high voltage termination. Access to the test volume is through the 1-m hatch at the side of the 2-m long central portion of the cell.

WARNING

Read and understand this document in its entirety before operating or servicing the DREO EMP TEM cell. As with all industrial equipment, this system contains inherent hazards requiring strict safety precautions in its operation and maintenance.

Although the design of the DREO EMP TEM cell includes devices for the protection of both operator and machine, safe use of the system depends upon the operator. This document describes the potential hazards of the system and recommends appropriate precautions.

Safe and reliable operation can be expected if the machine is operated by personnel acquainted with its function and who follow the procedures outlined in this manual. Anyone not familiar with this system should study this entire manual thoroughly before attempting to operate or service the system or components. Only qualified personnel should attempt to operate this system.

1.0 GENERAL SAFETY HAZARDS

As with all high voltage equipment, the TEM cell contains inherent hazards. Operators must follow strict safety precautions in its operation and maintenance.

Some of the hazards inherent to this system are:

a. Electric shock
b. Pneumatic energy
c. Electromagnetic radiation
d. Ionizing radiation
e. Capacitor Rupture

A discussion of each of these hazards follows.

WARNING

High voltage is used in the operation of this equipment. Death on contact may result if you fail to observe safety precautions. Learn where the high voltage areas are in each piece of equipment and do not touch high voltage connections when installing, operating, or maintaining this equipment. Lethal voltages may be present in the system even after firing. Before working on the equipment, remove line power and ground points of high voltage points with a shorting bar.

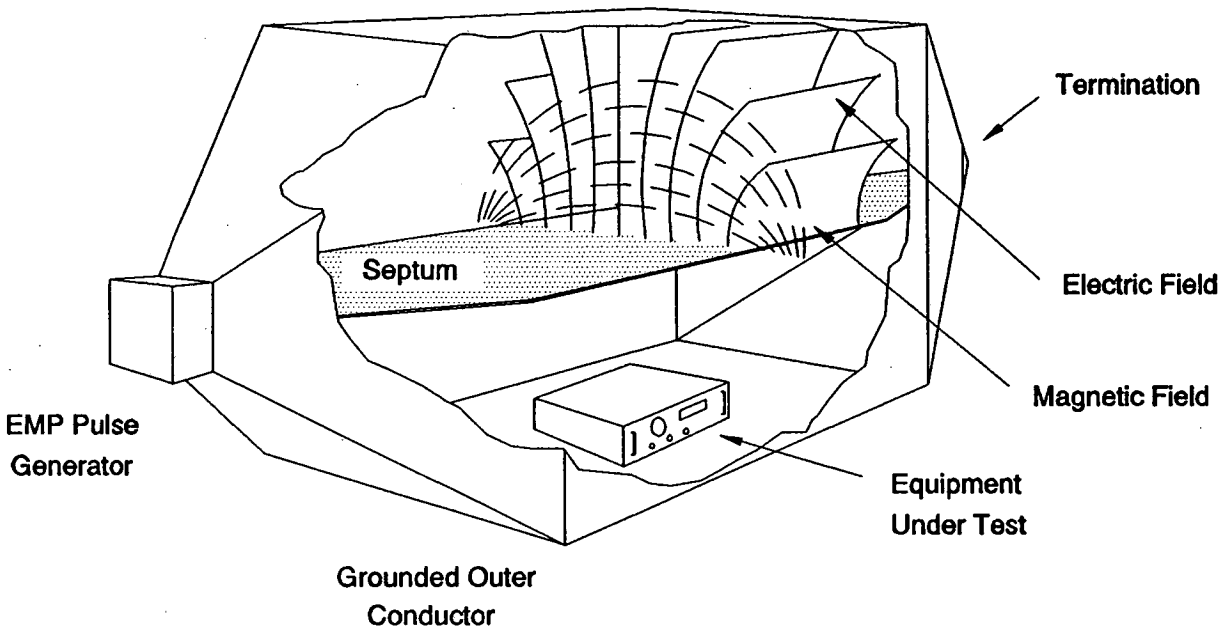

Figure 1: Schematic representation of the DREO EMP TEM cell. The unit is a square co-axial line with the septum acting as the inner conductor. A representation of the Electric and Magnetic field is shown in the upper portion of the cell.

1.1 Electric Shock Hazard

The following safety precautions are recommended:

a. Keep away from live circuits. Remember that in a high voltage circuit an arc can "jump" across several centimeters and, therefore, it is not necessary to establish physically contact to receive an electrical shock;

b. Use an insulated, hand-held shorting bar to discharge and ground all capacitors before touching high voltage circuits. High voltage may be present in capacitors even after firing;

c. Never operate, service, or adjust the equipment except in the presence of someone who can render aid in case of electrical shock;

d. Instruct all users and those involved with maintenance in methods of cardiopulmonary resuscitation (CPR) and;

e. Advise users of the fastest access to medical help in case of electrical shock. Post signs with this information.

1.2 Pneumatic Energy Hazard

Although this equipment and its components are designed with adequate safety factors, the operator should be aware that a pneumatic energy (high pressure gas) hazard exists. The following safety precautions should be followed to minimise this hazard.

a. Always tie or chain a gas cylinder to a substantial structure to avoid the injuries and equipment damage that could result from its falling. A gas cylinder weighs 130 lb when empty. Its shape makes it unstable when set on its end unless properly secured;

b. Pneumatic energy of about 0.6 MJ is stored in a standard gas cylinder of 220 ft^3 at 2000 psig. Ensure that the heavy steel screw-on-nozzle cover is fitted to the gas cylinder before releasing the cylinder from its restraint;

c. Do not work on the equipment while the gas pressurized spark-gap switch is under pressure; and

d. Do not allow the gas pressure in the spark gap to exceed 80 psig

1.3 Fire Hazard

Potential for an electrical fire exists. It is therefore recommended that bay area of Building 39 be equipped with Class BC fire extinguishers.

1.4 EMP Hazard

The DREO EMP TEM cell produces intense electromagnetic fields within its working volume. Under normal operating conditions these fields are contained by the outer walls of the cell. To avoid unnecessary exposure the access hatches should be closed when the pulse generator is operating. No attempt should be made to defeat any installed interlocks.

1.5 Radiation Hazard

The spark gap located in the EMP generator may produce soft X-rays. The X-rays are shielded in normal operation by the metal cover. Use caution when operating the TEM cell with the generator access hatch open.

1.6 Capacitor Rupture

There is a remote possibility that a capacitor will violently rupture during charging or discharging. The metal housing will contain all debris but caution is advised when operating the unit with the generator access hatch open.

2.0 SPECIFIC PRECAUTIONS

A high voltage pulse generator presents a number of hazards that are potentially lethal. These range all the way from the obvious danger of direct personnel contact with the high voltage electrical connections of the pulse generator system to other more subtle hazards. For example, the failure of an insulator can, without warning, present high voltage where it is not expected. Such hazards are not always obvious. A lethal electric shock can be received from a capacitive high voltage system, even after the power supply has been turned off and disconnected, even after it has been shorted to ground, and even after many days has elapsed since it was last used.

This section specifies precautions to be taken when dealing with each of the hazards listed above including special safety equipment required. Only trained operators will be allowed to operate the pulse generator.

2.1 Electrical

The primary danger in the TEM cell is from the high voltage on the High Voltage Power Supply (HVPS). The areas to avoid are the pulse generator, the HVPS, and the cell septum during pulsing.

The pulse generator can store lethal voltages. Should the pulse generator fail to trigger during normal operation:

a. Manually bleed the pressure from the spark gap and let the pulse generator self-fire into the load.

b. If the voltage is too low to cause self-firing, turn off the power supply and allow the energy to drain through the charge resistors and power supply, monitoring the voltage on the HVPS until the meter reads zero. Discharge the capacitors manually using a shorting bar.

2.2 Capacitors

Check that the capacitors are discharged, shorted and grounded before you work on the pulse generator or the HVPS. If the charge lead is removed from an ungrounded capacitor, relaxation may occur and the capacitor may recharge to a dangerous level after several hours (even if it was previously grounded!!). Store a capacitor with a shorting wire connected to its terminals.

It is not sufficient to ground each side of a capacitor independently. BOTH sides of the capacitor must be SIMULTANEOUSLY shorted to ground.

When discharging a capacitor it is preferred that a resistive lead be used to limit the initial current flow and prolong the capacitor life. Once the charge has been dissipated, a short circuit lead should be connected to the circuit in order to maintain a zero potential level.

2.3 Compressed Gasses

These potential energy hazards are unleashed only when the compressed gas is not contained. Safety precautions are therefore directed towards ensuring the mechanical integrity of the cylinders and regulating the gasses to lower working pressures at the cylinder outlets. The gasses will be regulated at the cylinder to no more than 80 psig. Gas cylinders will be transported and handled so as to avoid severe mechanical shock. Gas cylinders will be properly secured to a gas bottle rack when brought to the site. Steel nozzle covers will be attached over the necks of the cylinders whenever the cylinders are moved.

The polytubing and spark gap in the pulse generator are the portions of the TEM cell subject to any gas pressure. The pressure in the spark gap is the limiting value and should not exceed 80 psig.

2.4 Gas Toxicity

In general, only non-toxic gasses such as synthetic air and nitrogen are used as an insulating medium in the spark gap of the pulse generator. However, since any gas other than air is a potential asphyxiant and since there may by small quantities of toxic byproducts generated by the electrical discharge, it is recommended that the spark gap be vented outside of the building. The operating area should be well ventilated in order to provide the operators with a sufficient supply of fresh air.

2.5 Fire

Appropriate fire extinguishers shall be used on pulse generator fires to minimize equipment damage. The phone number of the fire department is posted near the telephone.

2.6 Good Operating Environment

One of the safety hazards that can exist is confusion among operating personnel due to coiled cables and other miscellaneous equipment lying about. Good housekeeping and procedures cut down confusion, improve efficiency and reduce the possibility of accidents.

2.7 Unsuspected Damage

Prior to firing the pulse generator, a standard inspection procedure should be carried out for the entire system. This includes inspection of the umbilical cord and the grounds to the pulse generator and the control console. The pulse generator should have a mechanically strong, low-inductance ground return which connects to the building safety ground.

2.8 Induced Potentials

Fields close to the antenna or pulse generator can, under some conditions, present a shock hazard as a result of the induced electric field in an individual even though no direct connection has been made. Individuals wearing medical electronic devices, such as heart pacemakers should never be in the vicinity of any EMP generator. Again the severity of this problem is significantly reduced by the enclosed nature of the TEM cell.

2.9 Using a Shorting Bar

The shorting bar is not a guarantee that all charge has been bled off the pulse generator system. The shorting bar should be well made and capable of discharging the entire pulse generator energy without injury to the person using it. Redundant ground connection are strongly advised when in contact with the pulse generator.

2.10 Grounding During Maintenance or Repairs

WARNING

Always be particularly cautious if the system is acting in an unusual fashion.

WARNING

High voltage is used in the operation of this equipment. Death on contact may result if safety precautions are not observed. Check that the capacitors are discharged, shorted and grounded before working on the pulse generator or the HVPS. Redundant ground connections are strongly advised during pulse generator maintenance or adjustment.

WARNING

If the charge lead is removed from an ungrounded capacitor, relaxation may occur and the capacitor may eventually recharge to a dangerous level.

During maintenance, charging leads should either be grounded with sturdy clip leads at the pulse generator or completely removed. Grounding straps should be used to ground the high voltage points of the pulse generator that are being worked on. It is often helpful to tag these with large colored flags to make sure they are removed before the pulse generator is operated. Firing the pulse generator with grounding shorts in place can cause serious damage. Even if the pulse generator is deliberately fired with grounding leads in place, they do not protect personnel since the leads are inductive and do not act as a short for the high frequency pulse generator output.

2.11 Low Voltage Hazards

It must not be forgotten that power line mains and the voltages they carry, 115 Vac and 230 Vac, are a hazard that cause many deaths each year. Low voltage hazards must not be overlooked.

2.12 Adequate Personnel

Any time equipment is being operated there should be at least two people present and in sight of each other. These people are responsible for each other's safety, and should be instructed how to act in any type of accident. This rule is especially important during maintenance operations, when fewer than the normal crew is on hand.

3.0 GENERAL RULES

A system such as the EMP TEM cell is hazardous if improperly used. The pulse generator system can be used safely and effectively however, provided close attention is paid to the principles of safety, good operating procedures and proper maintenance. It is essential that all personnel associated with the pulse generator be competent in working with pulsed high voltage equipment. Safe and formal operating procedures must be established. In addition, procedures must be established for dealing with emergencies which might arise.

In an effort to simplify the implementation of this manual, an effort has been made to condense the information about the hazards discussed in this manual into a series of general rules to be followed when using the TEM cell. The list is not a substitute for reading the manual thoroughly, nor is it intended to take precedent over common sense. It is intended as a quick reminder of some of the difficulties that may be encountered when operating the system.

- From the moment the crew enters the building, one crew member, the safety officer, assumes responsibility for the safety of personnel and equipment.

- The firing button is connected to an interlock circuit. This circuit opens when the access door to the TEM cell is opened.

- During maintenance on the generator, grounding straps are to be connected to the charging leads and also to the high voltage parts that are being worked on. It is often helpful to flag these with large coloured flags to make sure they are removed before the pulse generator is operated. Firing the pulse with grounding straps in place can cause serious damage to the pulse generator.

- Any time equipment is being operated there should be at least two people present. These people are responsible for each other's safety, and have been instructed how to act during any type of accident. This is especially important during maintenance, when less than the normal crew is on hand. At any time, there must be at least one person not at risk.

- All people must be properly trained for their jobs and responsibilities including familiarity with the safety procedures.

- All equipment in the EMP facility (except equipment in the test volume) must be connected to safety ground. This is particularly important for the HVPS.

- Maintenance and construction personnel are to be accompanied by a member of the EMP group.

- The site is to be kept tidy at all times - there must be no unnecessary equipment lying about. All unused equipment, cables, tools must be in their assigned storage areas.

- The above list is not (and can never be) totally complete. When working with the TEM cell, or in any other industrial environment, it is important that you use common sense and good judgment. Keep your eyes and ears open at all times, lethargy is the most dangerous aspect of testing. Be extremely cautious when a problem occurs in the system, unknown situations may present unknown dangers. Above all else, if you don't understand or feel comfortable with some aspect of the system - **ask about it**. A high voltage circuit is not sympathetic towards ignorance.

4.0 SYSTEM OPERATION

4.1 Daily System Start-up

The best means of preventing problems is to eliminate them before they arise. The most reasonable way to implement this philosophy is to establish a routine whereby the most likely problem areas are checked on an ongoing basis. The following is a suggested routine, however, it may not always be sufficient since variations resulting from the object being tested etc. cannot always be anticipated.

a. Begin system start-up with an inspection walk around the TEM cell;

b. Check air cylinders; they should be on line and the gasses regulated to <80 psi;

c. Check that pulse generator control and gas lines are properly connected;

d. Check that the safety ground is intact at all contact points;

e. Check that the charge line from the HVPS to the pulse generator is properly installed;

f. Check any other relevant equipment or situation;

g. Apply 110 V ac power to the HVPS and auxiliary systems.

4.2 Normal Shot Cycle

The following instructions outline the procedure for a normal shot cycle.

a. Pulse generator operator (hereafter referred to as "the operator") sets the desired charge voltage on the HVPS.

b. The operator sets the appropriate spark gap spacing and gas pressure.

WARNING

Ensure the HVPS has been shut off and the capacitors have been discharged before adjusting the spark gap in the pulse generator.

WARNING

The delivery pressure on many regulators will slowly creep upwards with time. It is recommended that this pressure be checked periodically and shut off when not in use.

c. Verify diagnostics are ready.

d. Prior to firing, the operator must ensure that all of the site crew is not in any danger.

e. The operator turns on high voltage and begins experimentation.

4.3 Emergency Procedure

If an emergency arises, quickly shut off the HVPS and the main valve on the gas cylinder. This is probably the safest way to diffuse a dangerous situation. Should any high voltage remain on the HVPS after shut-down, as indicated on the charge meter, discharge the capacitors following the procedure described in Section 2.1.

4.4 End of Working Day Check List

a. Turn off the high voltage and allow voltage to drop to zero, then shut off the main power on the HVPS;

b. Turn off all gasses at the bottles.

WARNING

It is important that the main cylinder valve, not secondary valve on the regulator, be shut off. If only the latter is closed and there is a small leak in this valve the spark gap may re-pressurize. Since the delivery pressure on many regulators will slowly creep upwards with time, it is possible that the critical pressure of the spark gap will be exceeded and violent rupture will result.

c. Turn off power to all auxiliary systems.

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Transverse Electromagnetic (TEM) Cell

Safety