NAVSWC TR 91-328

RISK ASSESSMENT FOR NOTES

BY PAUL M. PRICE

PROTECTION SYSTEMS DEPARTMENT

SEPTEMBER 1991

NAVAL SURFACE WARFARE CENTER

Dahlgren, Virginia 22448-5000 • Silver Spring, Maryland 20903-5000

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FOREWORD

This report assesses the safety risks concerning the placement of the Naval Ordnance Transient Electromagnetic Simulator (NOTES) at the Pumpkin Neck site near Dahlgren, Virginia. NOTES uses high voltage capacitors and an electrical transmission line, to simulate an electromagnetic pulse (EMP). EMP is an electrical disturbance produced by high-altitude nuclear weapons explosions. NOTES will provide a simple and inexpensive way to test Navy systems including ordnance in the EMP environment. For a system definition of NOTES see Appendix A.

NOTES produces an extremely short duration electromagnetic pulse that propagates down a transmission line in which the device to be tested is placed. At the far end of this transmission line an array of resistors dissipates most of the energy in the pulse. The remaining energy continues to propagate outside the transmission line, but the intensity of the pulse decreases rapidly the further it travels. NOTES can generate one of these electromagnetic pulses every 5 minutes.

In non-technical terms, an EMP is a radio wave of very short duration, similar to the electrical disturbance produced near lightning in a thunderstorm. In more technical terms, EMP is the field of force associated with an electric charge in motion, having both electric and magnetic components, and containing electromagnetic energy.

NOTES is not yet in operation; however, NAVSWC has extensive experience with operation of EMP generators. From this experience, we can predict typical NOTES operations (Appendix B).

Appendix C contains detailed information about the EM fields for NOTES.

Contributions to this document came from many sources including the EMPRESS I RISK ASSESSMENT by Events Analysis, Mr. Felipe Sanchez, and Mr. Eugene Carroll; the NOTES E.A. by Mr. Michael Ryder; Typical NOTES test from Mr. George Brackett. Thanks also to Mr. Van Kenyon, Mr. Fred Warnock, Mr. Thomas Peacock, Mr. Dennis Vaught and Dr. Robert Amadori.

Approved by:

M. J. TINO, Head
Protection Systems Department

ABSTRACT

The purpose of this study is to systematically identify and analyze the safety risks associated with the operation of the Naval Ordnance Transient Electromagnetic Simulator (NOTES) in Pumpkin Neck, Virginia. NOTES initiates an extremely short duration electromagnetic pulse (EMP) that propagates down a parallel plate transmission line.

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SECTION I

PURPOSE OF THE STUDY

The purpose of this study is to identify and analyze the safety risks associated with the operation of NOTES at Pumpkin Neck, Virginia.

Study objectives are to:

A. Perform a safety risk evaluation of the NOTES operation.

B. Analyze other operations and activities that can interfere with the operation of NOTES.

C. Evaluate other operations that can be affected by NOTES.

Specific sub-objectives are to identify the potential for electromagnetic pulse-induced harm to:

A. Personnel and facilities.

B. Ordnance operations.

C. Electrical and electronic component systems.

SECTION II

BRIEF DESCRIPTION OF STUDY EVENTS

This study is based on the existing Risk Assessment of an EMP simulator very similar to NOTES called EMPRESS I. The main difference is that EMPRESS I is designed to launch a propagating electromagnetic wave, while NOTES is designed to guide an electromagnetic wave inside a transmission line.

This study included the following:

- Review of potential impact areas using projected field strengths.
- Identification of potential safety concerns.
- Adoption of risk assessment criteria.
- Assignment of a relative risk level to each concern.
- Determination of means to mitigate or control these risks.
- Preparation of Suggested Disclosure Statement.

REVIEW OF POTENTIAL IMPACT AREAS USING PROJECTED FIELD STRENGTHS

Areas within range of NOTES were reviewed to define what persons or objects might be at risk from the effects of NOTES pulsing. This search included both induced electrical charges on "receivers" and induced voltages on conductors.

IDENTIFICATION OF POTENTIAL SAFETY CONCERNS

The next step was to link those potential EMP-induced charges and voltages to postulated or observed harm that might be done to "non-test" objects. Any indications or logical reasons suggesting harmful outcomes might occur were considered.

ADOPTION OF RISK ASSESSMENT CRITERIA AND ASSIGNMENT OF RELATIVE RISK

After the EMP effects were traced and defined, the relative risks associated with each effect were estimated. This risk assessment is primarily based on the hazard severity, but has also taken into account the hazard probability.

DETERMINATION OF MEANS TO MITIGATE OR CONTROL THESE RISKS

Having defined the safety concerns and each concerns relative risk, means of mitigating each risk to an acceptable level were defined and evaluated.

PREPARATION OF SUGGESTED DISCLOSURE STATEMENT

Controls in the Standard Operating Procedures (SOP) will reflect actions designed to achieve a level of risk to NOTES employees, neighbors, the public, and NOTES equipment, which is low enough to be considered acceptable. Some residual low-level safety risks have been accepted (involving - at worst - a minor injury or equipment failure sometime during the life of the facility), and will continue to exist during NOTES pulsing and operations. A recommended Disclosure Statement (Appendix D) describing NOTES risks is available for distribution to parties working or living near the NOTES facility.

SECTION III

RISK ASSESSMENT AND ABATEMENT ACTIONS

This section describes and discusses the results of the NOTES risk assessment. Included in this section are the list of safety risks, the estimated risk levels, the related uncertainties, and the means planned to mitigate each risk.

SAFETY CONCERNS REGARDING NOTES

Nine categories potentially vulnerable to the electromagnetic effects associated with NOTES were found:

1. Ordnance operations
2. NOTES operations
3. Overflying aircraft
4. Personal medical devices
5. Fuel transfer
6. EMP-induced voltage in cars and ungrounded buildings
7. Automobile electronics
8. Building TV and radio antennas
9. Electrical power lines

A tenth safety concern not related to electromagnetic effects is:

10. Industrial type operations

Four principal energy pathways by which EMP could do harm were identified, and checked with various experts and operational personnel. The combined list of energy sources, persons and objects at risk and energy pathways formed the basis of the rest of this study.

As each postulated electromagnetic risk was identified, it was added to an Energy Tracking Flow Chart (see Figure 1). This chart shows the paths that energy could travel after leaving NOTES and the potential harmful outcome of each. Each possible outcome was then assigned a risk level as indicated by the shading in Figure 1.

ASSESSMENT OF RISKS ASSOCIATED WITH SAFETY CONCERNS

Estimated risk levels for possible harmful interactions

Risks are assessed based on the criteria specified in MIL-STD-882B "System Safety Program Requirements." Figure 2 summarizes this risk assessment code criteria.

In assigning Risk Assessment Codes (RACs) for possible harmful interactions, the EMP field strength and the effects caused by this EMP field were assumed to fall off smoothly and rapidly with distance. Thus, the effects of EMP on an object, such as digital computer, would vary from severe to slight based on whether the object were placed under NOTES or 100 meters from NOTES.

An exception to this risk estimating procedure was made for ordnance operations and pacemaker wearers (with heart block afflictions). For these special cases, an assumption was made that at some threshold level of exposure, EMP could produce consequences of a fail or no fail kind, without the usual range of small to grave consequences. Thus these exposures were arbitrarily assigned a RAC 1 value within a specified field strength contour where such effects were hypothesized. This field strength is 200 V/m for ordnance and 5,000 V/m for pacemakers. The basis for these levels is given later in this document.

Four risks, if uncontrolled, were assigned RAC 1 values (high risk) during the Study. RACs with values 1 & 2 must be controlled. These risks included:

- Risk of unplanned ordnance detonation inside the NOTES 200 V/m field strength contour.
- Postulated risk to employees of contact with high-voltage energy sources at NOTES.
- Postulated risk to low-flying aircraft by EMP, upsetting computer-assisted flight controls.
- Postulated risk to users with pacemakers inside the NOTES 5 kV/m field strength contour.

Two risks, if uncontrolled, were assigned RAC 2 values during the study:

- Risk of potentially disabling injury to NOTES operating employees from linear kinetic or mass and gravity energy sources in industrial-type operations.
- Postulated risk of vapor explosions from fuel transfers

All other risks were assigned a RAC 3 or 4 value (moderate to minor).

Risks to Ordnance operations (1)

Explosives and explosives handling regularly occur at the Pumpkin Neck site. These operations include:

- Transportation of undamaged ordnance,
- Stress testing and ignition of ordnance,
- Transfer of damaged ordnance,
- Storage of both damaged and undamaged ordnance.

If not coordinated with the NOTES facility, any of the above operations could lead to the unplanned detonation of the Electronic Explosive Devices (EEDs), which in turn could lead to the detonation of a much larger explosive. This risk of unplanned detonation if uncontrolled is set to an RAC of 1.

Ignition of Ordnance & Transfer of Good Ordnance. References 1 & 2 provide the basis for the maximum allowable EMP fields to which ordnance may be subjected. From these references, it was determined that HERO UNSAFE ORDNANCE (ordnance in the maximum electromagnetic coupling configuration) should not be exposed to EMP fields that exceed 200 V/m. For compatible ordnance and EMP pulser operations, the following restrictions apply:

HERO UNSAFE ORDNANCE	200 V/m
HERO SUSCEPTIBLE ORDNANCE	2,000 V/m
HERO SAFE ORDNANCE	10,000 V/m

Reference 3 provides definitions for these classifications and the HERO status of ordnance at Pumpkin Neck.

Therefore, ordnance and NOTES operations are compatible (RAC of 3) as long as the ordnance operations are outside the 200-V/m field strength. On the Pumpkin Neck site all ordnance operations but transportation and storage are outside 200 V/m. Because of the severity of the hazard, NAVSWC management has decided not to do NOTES EMP testing when ordnance is in any unsafe condition at Pumkin Neck. This non-concurrent approach will be monitored by the range control officer at Dahlgren who controls all ordnance operations on the Pumpkin Neck site. This requirement of non-concurrent operations reduces the estimated risk of ordnance operation from NOTES to a RAC of 3.

Transfer and Storage of Damaged Ordnance. The explosive ordnance demolition team at the Naval Surface Warfare Center stores, transports and demolishes ordnance at Pumpkin Neck. The ordnance generally consists of bulk explosives and failed test rounds of various sizes. In this condition, much of the ordnance is classified as HERO UNSAFE ORDNANCE. Magazines 9433 and 9434 are used to store this ordnance for future destruction. In preparation for destruction this ordnance is removed and transported to the demolition area, requiring transit through the active NOTES pulser EMP fields. Transportation of ordnance

to the magazines, whether by land through the main gate or by water across Machodoc Creek, also requires transiting the NOTES pulser field.

The RF shielding properties of magazines 9433 and 9434 were determined by means of a controlled field test. A radio transmitter was placed at each of four points around the magazine and the EM environment both inside and outside the magazine was then measured. While measuring inside, the magazine doors were first opened, then closed. The difference, or attenuation factor, of the outside to the inside measured field intensity data was then calculated.

Magazines 9433 and 9434 are located approximately 720 feet and 780 feet from NOTES. Based on the estimated NOTES field strength contours items stored in magazine 9433 will receive 400 V/m; while those in magazine 9434 will receive 417 V/m.

Results from the magazine RF isolation tests produce the following minimum attenuation values:

Magazine	Status	Attenuation Factor (dB)
9433	Door opened	8
	Door closed	14.5
9434	Door opened	32
	Door closed	40

By adjusting the aforementioned predicted NOTES pulser field strength directly outside the magazines, by the attenuation factor of the magazines, the following fields will be produced inside the magazines:

Magazine	Status	RF Field (V/m)
9433	Door opened	66
	Door closed	15
9434	Door opened	0.25
	Door closed	0.04

These values are well below the 200-V/m HERO criterion established for RF pulser operation. Therefore the RAC for storage can be lowered to an RAC of 3. These predicted internal fields will be confirmed by actual meaasurement before NOTES is cleared for operation.

Risks to NOTES Operations (2)

Because of the high voltages on the transmission line, and the proximity of operating personnel to these high voltages, this was estimated to be a RAC 1 risk if uncontrolled. The risk will be controlled by physical barriers and interlock devices, also a CPR training requirement and "buddy" procedures are required for NOTES operators, resulting with an RAC of 3.

Risks to Overflying Aircraft (3)

Aircraft flying over the NOTES site might be equipped with computer-assisted or "fly-by-wire" flight controls which have unknown sensitivity to EMP, so this postulated risk was assigned a RAC of 1 if uncontrolled. The area around the NOTES site is restricted for aircraft, and NOTES will not be pulsed while low-flying aircraft are overhead (as is the policy at EMPRESS I); therefore, aircraft exposure is unlikely to occur, resulting in a RAC of 4.

Risks to Persons with Electronic Medical Devices (Pacemakers) (4)

Pacemakers are electronic medical devices that regulate or stimulate the heartbeat of persons with heart problems by sending specially timed electrical pulses affecting heart muscles. It has been recognized for many years that radio frequency energy may affect the functioning of pacemakers. These effects have been investigated, and pacemaker failure could result in serious personal injury. Therefore a RAC of 1 is assigned for the uncontrolled case. People with pacemakers should not go in EMP fields of over 5 kV/m. For NOTES, 5 kV/m lies entirely within government property and within sight of the pulser operators; therefore, pulser operations will not commence until the operator has determined that no one in the 5-kV/m range is wearing a pacemaker. This mitigates the RAC to 4.

Other types of devices such as timed-release medication devices, motion control systems in prostheses, and defibrillator implants may be affected by EMP, and thus require future monitoring for EMP effects. It has not been established whether the failure mode of these devices is to fail "safe" or otherwise. These devices typify the kinds of developments that will require continuing future surveillance. No RAC can be assigned to these possibilities without further research, but their survival in other exposures to radio frequency energy environments, both natural and manmade, suggest this is probably a low risk.

Risks with Fuel Transfer (5)

If a pulse occurs as fuel is being dispensed, say into a lawn mower, and the fueling nozzle is not grounded then EMP might induce enough current flow through volatile vapors to start a fire. Such a fire has a low probability, and would likely result in a limited fire with injurious but sublethal effects, and is estimated to be a RAC of 2. The risk is controlled by the monitoring of operations within the 5-kV/m hazard area, and by suspending pulsing until positive confirmation can be obtained that refueling will not be done within those hazardous areas, which will reduce the risk to an estimated RAC of 4.

Risks on Cars and Ungrounded Buildings (6)

EMP can induce a significant voltage on a vehicle, which is a large ungrounded conductor acting as a capacitor. Should a person provide a pathway from the "charged" car to ground during a pulse, electrical shock can occur. Reports from individuals who discovered this phenomenon firsthand indicate that it does not pose a threat of severe injury. Therefore, it should be assigned a RAC of 4.

Ungrounded metal buildings pose a greater risk from lightning strikes than NOTES pulsing, because of the larger energies available from lightning. However, because of the potential for shock from induced voltages in ungrounded buildings, and because grounding and bonding systems can degrade with time, this was assigned a RAC of 4.

Risks to Automobile electronics (7)

The location in which vehicles will be parked for NOTES will be subjected to fields of thousands of volts per meter. Vehicles have been parked at EMPRESS I in 10-kV/m fields without mishaps; however, mechanisms to produce harm exist. Such a loss should be confined to property damage, because such damage would be noticed before the vehicle could be moved in an unsafe condition. This risk was assigned an estimated RAC of 4.

Risks to Building TV and Radio Antennas (8)

Much as with automobile electronics, consumer electronics are susceptible to the effects of EMP. The levels needed to do damage (several thousand V/m) are contained on government property, and then only in the area immediately around the NOTES facility. Commercial electronics in the building near the main gate will not be harmed by EMP from NOTES. Such losses in the immediate area around NOTES will be confined to property damage, and was assigned an estimated RAC of 4. Electronic surge suppressers would reduce this risk to a RAC of 5.

Risks to Electrical Power Lines (9)

EMP from NOTES will couple to conductors inducing voltages and currents that will propagate on the conductors. The electrical power system is made up of conductors susceptible to this phenomenon. Fortunately the power lines at the Pumpkin Neck site are buried underground and thus are shielded from the effects of the EMP. For that reason this was assigned a RAC 5.

Industrial Type Operations (10)

Risks to employees arise during industrial type operations. Linear energy and mass and gravity energy exchanges are possible during the movement of the pulser antenna. The weight of the antenna is

sufficient to produce serious injury to operators and serious damage to the antenna in an accidental fall. Also, test stands constructed to hold test objects during the pulse tests can be operated in a way that heavy objects could fall and injure employees or the test object. Pressurized gas cylinders also have the potential for producing serious injury to employees if they fall or get damaged, and are propelled by the contents. Because of the potential consequences and frequency, these potential risks were assigned a RAC 2 value. The risks are controlled primarily by assignment of trained, certified operators and clear operator responsibilities for tasks, which should reduce the estimated risks to a RAC 3.

OTHER RISKS

Risks to Boats

No significant risk to persons or equipment in boats is expected from NOTES, due to the remote location and the limited propagation of NOTES (no significant fields lie over navigable waterways).

Health

No evidence of long-term health effects of EMP exposure to operating employees has been found, even with repeated exposures to 100 kV/m. Originally, an annual physical examination program for EMPRESS I workers was mandatory. It operated for several years, but disclosed no observable effect and was discontinued. Until a risk is either hypothesized or observed, no RAC value can be assigned.

The above risks were considered the main risks of interest found during this study.

ABATEMENT OF RISKS

Options were developed so abatement of the risks could be accomplished by the most desirable course of action.

Control principles

Different views of control approaches surfaced during the study:

- If it can happen, fix something. This zero-risk approach lacks a sense of priorities and does not provide a basis for prudent expenditure of public funds.
- Keep the risks "as low as reasonably achievable" (ALARA). Controversy often arises when implementation requires interpretation of "reasonably achievable."

- Identify the risks and controls that would achieve the lowest reasonably achievable risk (consider safety, health, performance, costs, mission and other risks). Disclose residual (accepted) risks to the those who bear them, so the effected person can decide what other action they might want to take. Finally, monitor risks to ensure they remain as predicted. This approach was deemed most appropriate for a Research, Test, Development and Engineering activity exploring the frontiers of knowledge.

Suspension of pulsing (nonconcurrent operations) is the principle control for the most serious risks. NOTES operations will be suspended during ordnance operations, and when autos, aircraft or people are in restricted areas. Three things make NOTES an excellent system for nonconcurrent operations:

- No chance of NOTES self firing. (NOTES is stable)
- Positive operator control of NOTES. At any time during the charging cycle, the operator can dump the accumulated charge in such a way that EMP is not produced.
- No lingering energy. The energy associated with the EMP dissipates in less than 1μs.

RAC 1 Controls

RAC 1 risks are not permitted to exist at the NOTES facility. Controls implemented for RAC 1 risks shall reduce those risks to RAC 3 levels.

Ordnance Operations. Because of the severity of the hazard, management has made the decision not to do concurrent ordnance and EMP testing when ordnance is in an unsafe condition at Pumpkin Neck. This non-concurrent approach will be monitored by the range control officer at Dahlgren who controls all ordnance operations on the Pumpkin Neck site. Non-concurrent operations reduces the risk of EMP induced ordnance explosions to a RAC of 3.

In addition to this nonconcurrent operation approach, NOTES will have safety and warning devices. NOTES will be designed with a key lock control system. Without the master key, the system can not charge the capacitor bank, and NOTES cannot pulse. Procedures will be developed, so that before charging the capacitor bank the operator must:

- Have permission for firing from range control,
- Ensure that the hazardous area around NOTES is secure, and
- Activate warning devices.

Potential Injury to Employees by Contact with High Voltage Lines. This risk occurs within the NOTES site and is under the direct control of the NOTES staff. The primary action is to prohibit pulsing when anyone is within the high-voltage hazard area, which is clearly visible

from the control room. Clearly visible high-voltage warning signs will be posted in high-voltage hazard areas. High-voltage equipment is to be operated and maintained only by trained personnel.

Potential Upset of Computer-Assisted Flight Controls over NOTES During Pulsing. The RAC 1 value was assigned for computer-controlled (fly-by-wire) aircraft that might operate near the facility, and in part to accommodate the uncertainty about the effects of EMP on aircraft at this time. Both considerations support the option to suspend NOTES operations during aircraft overflights. While all indicators suggest that no problem exists, and control is not required, a policy decision has been made not to pulse during low aircraft overflights. Therefore procedures will be developed requiring the operator to ensure that the hazardous area for aircraft is secure before charging the capacitor bank, and remains secure until after NOTES is pulsed.

Potential Injury to Certain Heart Pacemaker Users. This risk occurs within the NOTES site and is under the direct control of the NOTES staff. The primary action is to prohibit pulsing until all personnel within the 5,000-V/m field strength area have been determined not to be wearing pacemakers. This 5,000-V/m area is expected to be visible from the control room. Clearly visible warning signs will be posted on the approaches to all areas where pacemaker hazards may exist.

RAC 2 Controls

RAC 2 risks should be reduced to RAC 3. The principles discussed in the preceding section are applicable to these risks to define the control options that could be employed.

Industrial Type Operations. Operation of material handling equipment will be accomplished only by a fully trained and currently certified operators. Gas cylinder stowage and handling will be done according to required procedures, only by personnel who have been specifically trained in that task. Test stands are designed to permit loading in the "down" position, and will be so loaded. Persons handling test devices or equipment will not position themselves underneath such equipment at any time.

Quarterly and annual inspections will be conducted and reported to ensure that the procedural and other requirements are functioning as planned.

Control of Potential Fueling Fires. This risk occurs within the NOTES site and is under the direct control of the NOTES staff. The primary action is to prohibit pulsing while fueling within the 5,000-V/m field strength area. This 5,000-V/m area is expected to be visible from the control room.

SECTION IV

SUMMARY OF SAFETY RISK ASSESSMENT

This risk assessment identified and defined, within the limits of present knowledge, the risks resulting from NOTES operations. Each of these risks was categorized using standard risk assessment codes, and for each major risk means were defined to mitigate the risk to an acceptable level.

Given that this report's recommendations are implemented, the risk associated with the operations of NOTES at Pumpkin Neck will be reduced to levels acceptable under Navy System Safety regulations, NAVOSH regulations (Navy Ocupational, Safety and Health), and the Environmental Safety regulations.

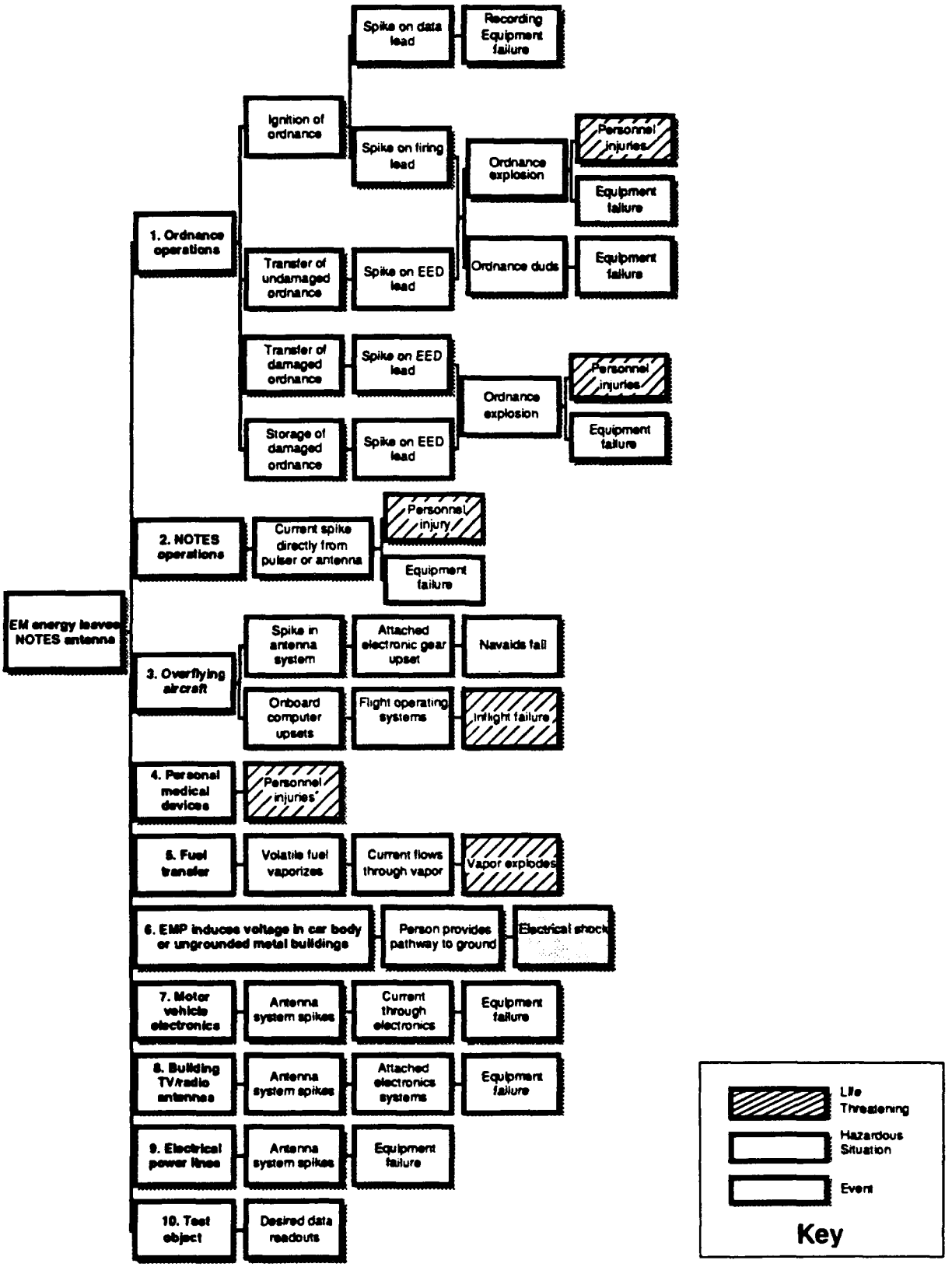

FIGURE 1. NOTES ENERGY TRACKING FLOW CHART

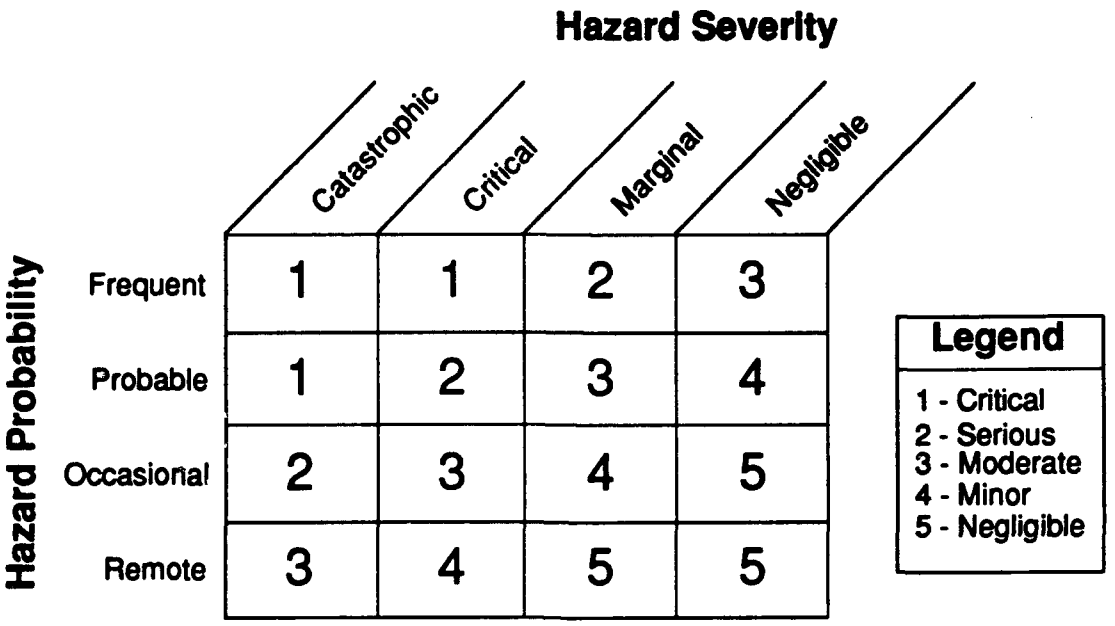

FIGURE 2. RISK ASSESSMENT CODES

NOTES Risk Chart

	Risk Uncontrolled	Primary Control	Risk with Control
1. Ordnance operations	1 - Critical	Nonconcurrent operation	3 - Moderate
2. NOTES operations (High voltage)	1 - Critical	Interlocks & Procedures	3 - Moderate
3. Overflying aircraft	1 - Critical	Nonconcurrent operation	4 - Minor
4. Personal medical devices	1 - Critical	Nonconcurrent operation	4 - Minor
5. Fuel transfer	2 - Serious	Nonconcurrent operation	4 - Minor
6. EMP induced voltages	4 - Minor	N/A	4 - Minor
7. Automobile electronics	4 - Minor	N/A	4 - Minor
8. Building TV/Radio antennas	4 - Minor	Surge Suppressors	5 - Negligible
9. Electrical Power lines	5 - Negligible	N/A	5 - Negligible
10. Industrial type operations	2 - Serious	Training & Procedures	3 - Moderate

FIGURE 3. NOTES RISK CHART

REFERENCES

1. NSWC ltr 8020 F52:WSR:hah of 28 Sep 83.

2. SY82A Presentation: "Naval Aircraft Vertical Electromagnetic Pulse Simulator Reactivation at Naval Air Test Center of 12 Feb 88" (presented at EMP Simulator Impact on Ordnance Mtg. by SY82A, 16 Feb 88).

3. Electromagnetic Radiation Hazards (Hazards to Ordnance), NAVSEA OP 3565/NAVAIR 16-1-529/NAVELEX 0967-LP-624-6010, Volume II, Change 7 of 15 Aug 1988.

APPENDIX A

NOTES SYSTEM DEFINITION

An artist's conception of the proposed NOTES Facility is shown in Figure A-1. A pulse generator, consisting of a charging circuit and a large bank of capacitors, will be housed in the Pulser Building. A number of wires will radiate out from this building on an upward angle of 15° from the ground. This set of wires is referred to as the Top Plate. This Top Plate, along with the grid of wires referred to as a Ground Plane, form the two plates of an electrical circuit known as a transmission line.

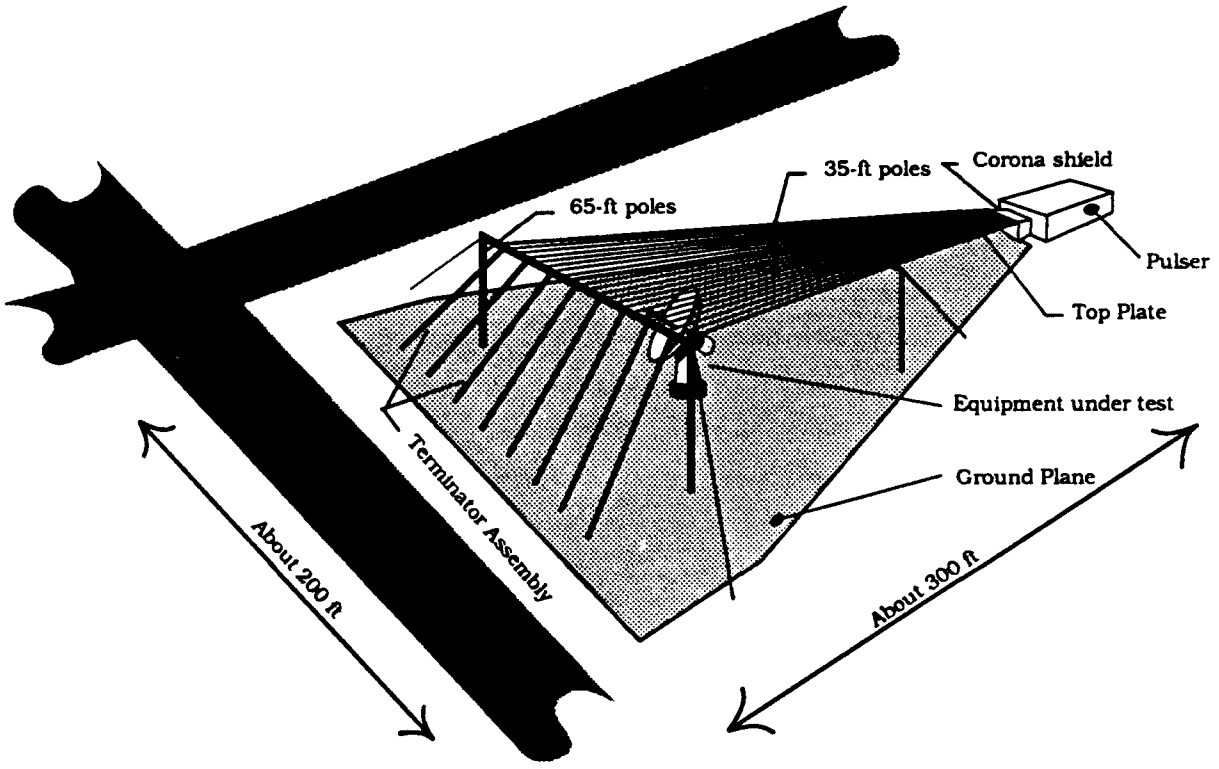

FIGURE A-1. NOTES FACILITY

Two familiar examples of commonly used transmission lines are a twin-lead television antenna wire, and a coaxial cable used to connect a

television set to a video cassette recorder (VCR). They are used to carry an electromagnetic signal from an antenna to a television set, and from a VCR to a television set, respectively.

The transmission line of the NOTES Facility is essentially the same as these other two transmission lines, only much larger in size. Like the other two, it is used to carry an electromagnetic signal, this time from the Pulser Building to another set of wires referred to as the Terminator Assembly. The electromagnetic signal carried by this transmission line is an EMP pulse.

Although the electrical signals carried by the two television transmission lines mentioned above are used at the termination of those lines (the television set), the EMP signal carried by the NOTES transmission line is used within the transmission line itself (see the equipment under test in Figure A-1). This item of electronic equipment, or piece of Naval ordnance, is attached to other equipment that record the effects as the EMP passes through the Working Volume and interacts with the test item. As the EMP passes by the item under test, electrical currents and voltages are induced into it. These currents may upset the operation of the test item, or may damage it by burning out specific components, such as a transistor or circuit board.

The ultimate goal of the testing is to determine the vulnerability of the test item, and the steps needed to be taken to protect this type of equipment from the upsetting or damaging effects of EMP.

CONSTRUCTION

During the construction phase of NOTES, the area to contain the Ground Plane, the parking lot, the Pulser Building, several pads (not shown in Figure A-1) for test vans, and the access road will be cleared of all vegetation. This clearing would extend out 30 feet from the ground plane in all directions.

The access road, parking lot, and part or all of the Ground Plane, will be covered with gravel.

The Pulser Building will then be constructed. It will be a minimum of 24 feet long, 24 feet wide, and 12 feet high, but might be as large as 30 feet wide, 40 feet long, and 12 feet high. It will be provided with interior lighting and heating, and with air conditioning for at least the control area of the building.

Electrical power will be provided to the Pulser Building through a primary power 125-kVA electrical service.

Four test vans will be placed near the Pulser Building, and if funds permit, concrete pads will be provided for their support. These vans will be powered by a separate 50-kVA electrical service.

Two 50-ft-high wooden poles and two 35-ft-high wooden poles will be erected, as shown in Figure A-1. These will support the Top Plate of

the transmission line, which will be installed in the installation phase of NOTES. Provisions will be made so that the Top Plate could be raised and lowered as needed.

The following items might be included in the construction phase of NOTES: a local well for water; a holding tank with no drain field, for the temporary storage of sewage; a toilet, sink, and shower; a working deep sink; a hose bib on the inside of the Pulser Building; and exterior lighting, including flood lamps on the Pulser Building to illuminate the Working Volume, test vans, the building entrance, and the roll up door area.

It is anticipated that many of the items mentioned in the previous paragraph may be later added to NOTES. However, it should be noted that the minor construction money used to build NOTES comes with the requirement that improvements to the physical plant cannot be initiated within 2 years of the date of beneficial occupancy of the facility.

If the decision is made to include the local water well, State Water Control Board Standards for Water Wells and the State Department of Health Water Works Regulations will be adhered to. Before construction all proper permits will be requested from the Commonwealth of Virginia.

INSTALLATION

During the installation phase of NOTES, the pulser will be installed in the Pulser Building, the Top Plate and the Terminator Assembly of the transmission line will be put into place, and the associated electrical and computerized equipment for the remainder of the facility operations will be installed.

Included in the installation will be the transfer of less than 1,000 gallons of Gulf Transcrest HI oil into the Pulser Building. This lubricant mixture will be used as a dielectric medium in the pulser to prevent arcking within the pulse generator.

APPENDIX B

TYPICAL NOTES TEST

OFF-SITE PREPARATION

A typical test would be an assessment test of an engineering prototype of a new system to be installed topside on Navy ships. Analysis and detailed test planning would precede the test by several months. Special instrumentation would be installed in the system to be tested prior to shipment to NOTES.

PULSER PREPARATION

Run a preventive maintenance check

- Check all safety systems
- Fire a number of test shots (with the same checks used in the actual test)
- Record the Pulser operational characteristics

Calibrate the on-site instrumentation

Map the fields in the working volume

ON-SITE PREPARATION

Upon arrival at NOTES, the prototype would be set up and final instrumentation installation would be made. If active system tests were part of the plan, the system would be powered up and baseline tests run.

ACTUAL TEST

A typical test might run for one or two weeks.

Each day would begin with the Pulser operators (two) making the appropriate contacts (by checklist) to obtain clearance to pulse.

Establish and check communications links

Post warning signs, barricades, etc.

Post site monitors to ensure that personnel remain clear of hazardous areas

Check the instrumentation system

Check the test object

Established communications between Pulser operators and all on-site test personnel

If appropriate, test-fire the Pulser

Once all pretest preparations had been made, and clearances received, the daily test program would commence. Overall conduct of the test would be under the designated Test Director (TD), who might be assisted by several other engineers or technicians (depending on the test object). The TD would monitor the status of the test object, and call for a pulse from the Pulser operator when ready. The Pulser Operator (PO), who has overriding responsibility for facility safety, would first ensure that all safety requirements were satisfied, and then commence the Pulser charging sequence. This would be accompanied by safety procedures such as a flashing red light, warning Klaxon, and announcement of Pulser charging status over communications links (PA system, radio links). Instrumentation would be armed by the Data System Operators (DSOs) (one or two for most tests). After a successful firing, the PO would announce "all clear." DSOs would perform quality checks on acquired data, and inform the TD of the results. When satisfactory data had been acquired, the TD would inform the PO to stand down while test engineers performed re-instrumentation of the test object. After changing test points, the test would continue as before. An active systems test might also be accompanied by System Operators at a console to operate the system and monitor performance in various system configurations.

If at any time during the test day a hazardous condition occurred, the TD or PO would immediately suspend operation until the condition is corrected. A request by another activity for the facility to cease operations would also result in immediate suspension of pulsing until clearances were again received. At the end of the test day, the facility, instrumentation system, and test object would be secured.

After completion of the test program, the DSOs would transfer the data to White Oak for processing. POs would perform maintenance as required and prepare for the next test.

APPENDIX C

NOTES TECHNICAL EVALUATION

The Naval Surface Warfare Center is planning to construct a bounded wave simulator on the Pumpkin Neck portion of NAVSWC at Dahlgren Virginia. This facility named the Naval Ordnance Transient Electromagnetic Simulator or NOTES. NOTES simulates the effects of the Electromagnetic Pulse (EMP), which is a short-duration pulse of radio-frequency energy, and is similar to the radio-frequency pulse generated by natural lightning. Figures C-1 & C-2 show the time domain plot of the Electric fields (E fields) expected from NOTES, figure C-3 shows the frequency domain plot of the E fields expected from NOTES, and Figure C-4 shows the site for NOTES and the E field contours at that site. The E field contours in Figure C-4 are our best estimate based on bounded wave simulators similar to NOTES.

The following is a list of the major characteristics of the NOTES facility:

- Bounded Wave (not designed as a propagating antenna)
- Stationary pulser and antenna
- Pulse generated by discharging a ~7 nF capacitor through a 100Ω antenna

  (The 7 nF capacitor is initially charged to 1.1 million volts)
- Working volume 10 meters high by 4 meters by 8 meters Vertically polarized E field E/H ≈ 377Ω Maximum E field in the working volume of 100 kV/m
- Single pulse (at least five minutes between pulses)

  No continuous wave output

  Output waveform approximately a double exponential.

  Rise time of between 3 and 10 ns {10% to 90%}

  Fall time of about 1.5 μs {90% to 10%}

The following equations are for a double exponential electromagnetic pulse propagating through free space. This double exponential waveform approximates the output of NOTES.

The E field of this double exponential pulse is given by the equation:

$$V(t) = E_{max}(e^{-\alpha t} - e^{-\beta t}) \text{ in Volts/meter.}$$

Where $\alpha \approx 1.43\ 10^6$ for a fall time of 1.5μs (90% to 10%), $\beta \approx 3.14\ 10^8$ for a rise time of 7 ns (10% to 90%), and E_{max} is the peak E field.

The power contained in this pulse at any given time is shown next.

$$P(t) = \frac{V(t)^2}{R} = \frac{|E_{max}(e^{-\alpha t} - e^{-\beta t})|^2}{120\,\pi} \quad \text{in watts/meter}^2$$

Note, R is the impedance of free space.

$$\text{Peak Power}(t) \cong \frac{E_{max}^2}{120\,\pi} \quad \text{in watts/meter}^2$$

The equation for the total energy in this pulse passing through an area of one square meter perpendicular to the direction of the wave is shown next.

$$\frac{\text{Energy}}{m^2} = \int_0^{\infty} P(t)\,dt = \int_0^{\infty} \frac{\left[E_{max}(e^{-\alpha t} - e^{-\beta t})\right]^2 dt}{120\,\pi} = \frac{E_{max}^2}{120\,\pi}\left(\frac{1}{2\alpha} + \frac{1}{2\beta} - \frac{2}{\alpha+\beta}\right)$$

Using the values previously given for α and β:

$$\text{Total Energy} = 9.2X10^{-10}\,(E_{max})^2 \quad \text{in joules/meter}^2$$

Table C-1 shows for several peak E fields, the total energy and the maximum power passing through a square meter. The average energy passing through a square meter for multiple pulses would be the total energy per pulse passing through that area divided by the time between pulses or 5 minutes. For example the average energy passing through a square meter from a 200-V/m double exponential pulse is 3.7×10^{-5} /300 seconds or 1.2×10^{-7} j/m^2/s.

TABLE C-1. TOTAL ENERGY AND PEAK POWER FOR SELECTED E FIELDS

Emax (V/m)	Total Energy (J/m^2)	Peak Power (W/m^2)	Location
200	3.7×10^{-5}	1.1×10^{2}	See Contours
500	2.3×10^{-4}	6.6×10^{2}	See Contours
1,000	9.2×10^{-4}	2.7×10^{3}	See Contours
10,000	9.2×10^{-2}	2.7×10^{5}	Near field
50,000	2.3	6.6×10^{6}	Near field
100,000	9.2	2.7×10^{7}	Under Antenna

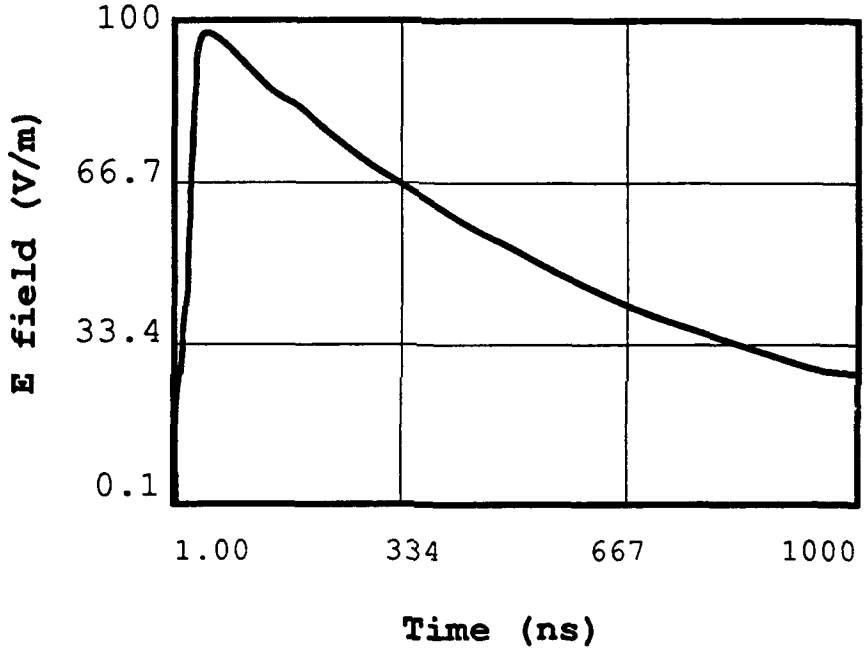

FIGURE C-1. NOTES OUTPUT PULSE (TIME DOMAIN)

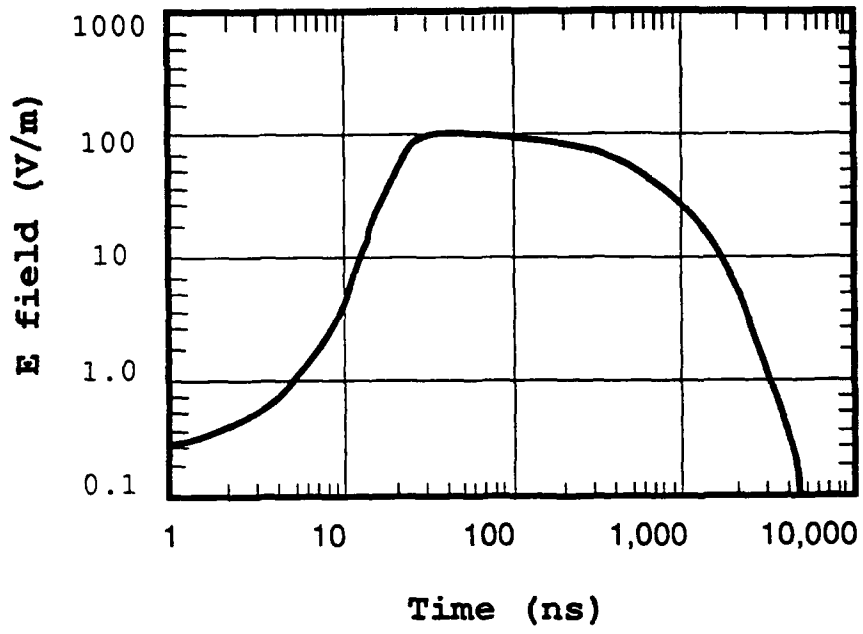

FIGURE C-2. NOTES OUTPUT PULSE (TIME DOMAIN & LOG LOG)

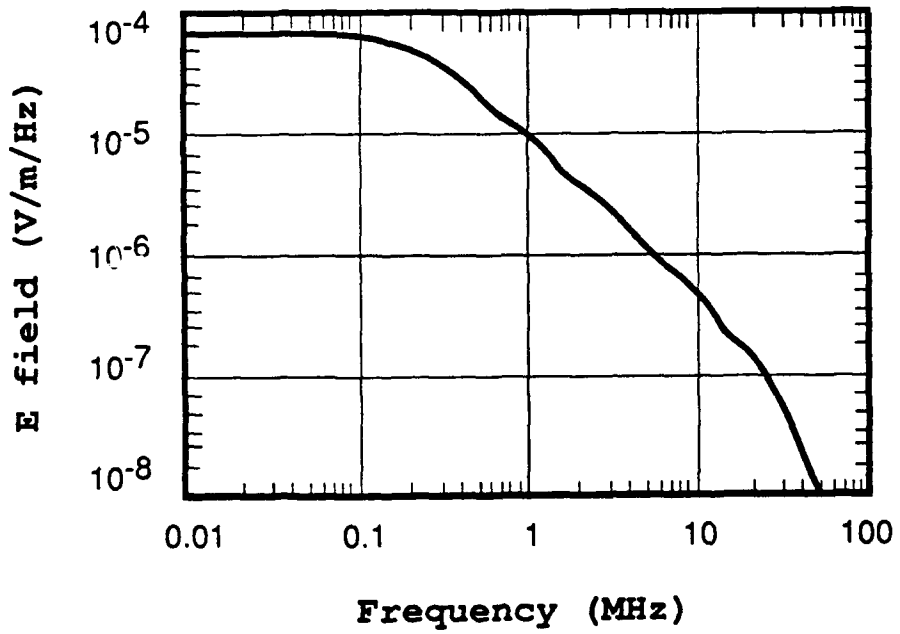

FIGURE C-3. NOTES OUTPUT PULSE (FREQUENCY DOMAIN)

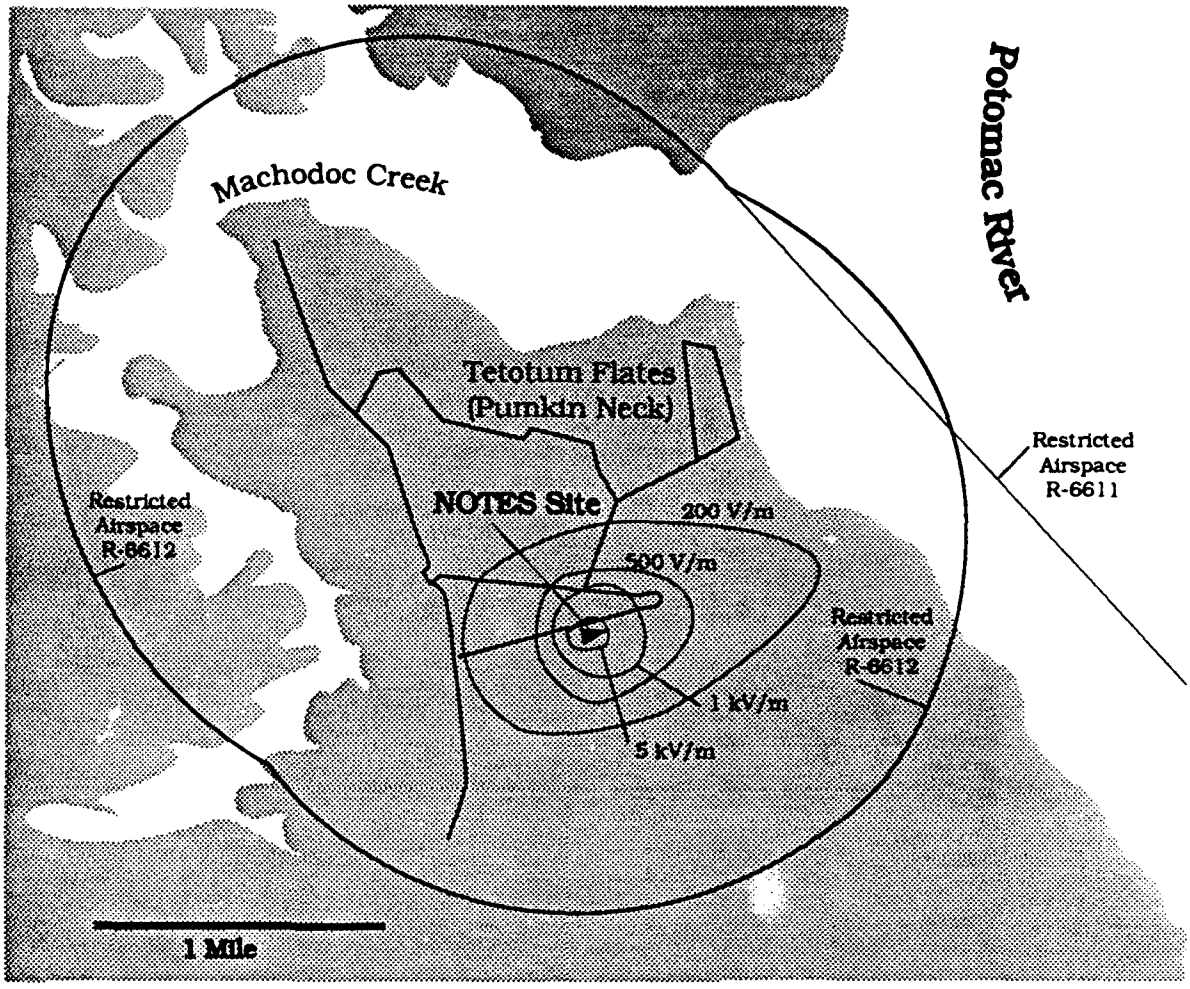

FIGURE C-4. NOTES SITE AND E FIELD CONTOURS

APPENDIX D

DISCLOSURE STATEMENT

The electromagnetic signals generated by NOTES may present a problem to certain types of equipment and operations close to the facility. The EM pulse diminishes in strength as it travels away from the antenna, and the concern about effects of the pulse decreases as distance as the distance increases.

When electromagnetic signals (radio, TV, radar, EMP, etc.) contact a conductor such as an antenna, power cable or even a metal fence, it will cause current to flow in the conductor and voltage to be generated at the ends of the conductor. A problem arises when these currents and voltages are large enough to affect the operation of the electronic equipment or produce sparks. Closer to NOTES, the pulses are larger and the associated currents and voltages are higher. Also the amount of current and voltage generated is greater for long conductors than short ones, and greater for ungrounded conductors than grounded ones.

At what distance do I need to consider the EMP from NOTES?

Only if you are on government property at the Pumpkin Neck site. (Fields external to Government property are below known damage thresholds. Any equipment that sensitive would be disturbed by distant lightning.)

What types of electrical equipment are sensitive to EMP signals?

Sensitive: Computers

Digital controls

Sensitive FM, Radio, TV receivers

Inexpensive FM, Radio, TV receivers

Least Sensitive: Old-style vacuum tube equipment

Motors:

electric razors, hair blowers, fans, dishwashers,

refrigerators, air conditioners

Heaters:

space, baseboard, toasters, ovens, irons

NOTE: Although an item like an oven or a refrigerator may not be sensitive, any digital controls on it may be sensitive.

How do EMP-generated currents and voltages get into the systems?

The conductors inside the equipment itself are normally too short to have large currents or voltages generated in them; however, all or most of them are connected to long conductors, such as:

The power cord to the house wiring and then to the power lines outside.

The antenna cable to the antenna.

The cables that connect a computer to a printer, FM receiver to a power amplifier, or thermostat to a furnace.

How can sensitive equipment be protected from currents and voltages generated in these long(er) conductors?

If the equipment does not have to be operated at the same time as NOTES is operating:

Turn off the equipment.

Better yet -- disconnect the power cord from the outlet.

Disconnect any antenna cables.

Disconnect cables between units (least important).

If the equipment must be operated at the same time as NOTES is operating:

Install a plug-in power line surge suppresser between the power outlet and the equipment.

Install shielded antenna cables between the antenna and the receiver, with the receiver connected to a good ground.

If the antenna is rotatable, aim it away from the NOTES antenna.

Install shielded cables between units of computer, hi-fi or other interconnected systems, with appropriate grounding.

NOTE: All these protective measures are equally important for protecting equipment from currents and voltages generated in conductors by nearby lightning strikes during storms, or power line surges.

What other hazards may exist?

Most of the other hazards are related to high voltages producing sparks or shocks.

Sparks might be a problem if they occur near combustible materials or vapors, such as gasoline fumes.

WARNING: As a safety precaution, the refueling of lawn mowers or other power equipment from metal gasoline cans should not be attempted when NOTES is operating in areas where the field strength exceeds 5,000 volts/meter. This area lies entirely within government property in sight of NOTES.

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13. ABSTRACT *(Maximum 200 words)*

The purpose of this study is to systematically identify and analyze the safety risks associated with the operation of the Naval Ordnance Transient Electromagnetic Simulator (NOTES) in Pumpkin Neck, Virginia. NOTES initiates an extremely short duration electromagnetic pulse (EMP) that propagates down a parallel plate transmission line.

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