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TEST OPERATIONS PROCEDURE

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NUCLEAR ENVIRONMENT SURVIVABILITY

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1. SCOPE.

This Test Operations Procedure (TOP) is a general outline on test and analysis procedures required to determine the effects of a specified nuclear environment on Army materiel. The purpose of these test and analysis procedures is to ascertain the degree to which the Operational Requirements Document (ORD), Capabilities Development Document (CDD), Army Regulation (AR) 70-75[1**], Independent Evaluation Plan (IEP)/Independent Assessment Plan (IAP) criteria, and Army Nuclear Hardening Criteria (NHC) are met. Army materiel can consist of complete end items, subsystems, Line Replaceable Units (LRUs), components or piece-parts of major systems. All materiel must be tested and analyzed to its NHC with respect to the performance of all its mission essential functions. Realistic hardware, and practical test configurations and scenarios must be tested and analyzed in order to achieve an accurate and complete Nuclear Survivability Test and Assessment (NTSA). All NTSAs must include a three phase approach in order to meet the requirements of Department of Defense Instruction (DODI) 5000.1[2], AR 70-75 and its NHC[3].

This TOP adheres to an integrated set of test principles and procedures that will result in timely, reliable, and consistent data for nuclear survivability analysis. This document is encouraged for use by all nuclear survivability testers (government and contractor) for test planning, for test conduct, and for acquiring and analyzing data in technical and customer tests.

2. FACILITIES AND INSTRUMENTATION.

2.1 Nuclear Airblast Facilities and Instrumentation.

2.1.1 Nuclear Airblast Criteria Parameters.

These criteria parameters must be thoroughly analyzed to ensure that acceptable facilities and appropriate instrumentation are utilized.

Airblast Parameter	Unit
Peak Overpressure (P)	[kPa]
Overpressure Duration (t_p)	[sec]
Overpressure Impulse (I_p)	[kPa-sec]
Peak Dynamic Pressure (q)	[kPa]
Positive Duration (t_q)	[sec]
Dynamic Pressure Impulse (I_q)	[kPa-sec]
Peak Underpressure (P_{neg})	[kPa]
Arrival Time (t_a)	[sec]

Performance criteria requirements of the test system include allowable downtime and recovery procedures, operate through, acceptable damage and degradation, and the availability of and time required to implement repair and replacement parts.

** Superscript numbers correspond to those in Appendix J, References

2.1.2 Nuclear Airblast Facilities.

Acceptable test facilities can be categorized as either large-scale High-Explosive (HE) field tests, or threat relatable shock tubes. Major military systems should utilize a large-scale HE field test because of the system's size, mass, and response; while existing shock tubes should be utilized for small systems or subsystems that are attached to a rigid structure. In general, items that can translate or be damaged by ground shock should be tested at an HE event. Examples of acceptable facilities are:

Facility	Type	Location	Comments
Large Blast / Thermal Simulator (LB/TS)	Shock Tube/ Thermo-chemical Reaction	White Sands Missile Range, NM	Tube Width - 20.0 meters (m) Max Overpressure - 241 kPa Max Duration - 3300 milliseconds (ms) 0.1 kiloton (kT) - 3 megaton (MT) System Level

Other Nuclear Airblast facilities are listed in "A Complete Guide to Nuclear Weapons Effects (NWE) Simulator Facilities and Applications", (2001 Edition)[4]. It must be noted that this edition was the last published NWE Simulator Facilities and many of these facilities are not currently operational. The Test Officer (TO) must ensure that the airblast test facility utilized is the foremost facility available for the desired criteria, test system configuration, and the anticipated responses.

It is important that a pretest analysis be performed so that the best test facility will be selected to provide the best available stimulus for producing the primary responses in the test system. It is emphasized that available facilities will provide only a simulated nuclear blast environment. Therefore, in addition to test data adequate analysis must be performed to account for the facility deficiencies which must be known, quantified, and documented.

2.1.3 Nuclear Airblast Instrumentation.

Measurement Parameter	Preferred Device	Measurement Accuracy
Pressure	Pressure Transducers	±10%
Strain	Strain Gages	±10%
Acceleration	Accelerometers	±10%
Translation	High Speed Camera	250 - 400 frames per second (fps)
Damage	Digital Camera	> 2 Mega-pixels

These measuring devices should be positioned at locations on the test item based upon the pretest response analysis. Data transmissions are normally through twisted pair cable. Transmitted data are normally input to adjustable gain instrumentation amplifiers and transient data recorders with an operating bandwidth of 200 kilohertz (kHz).

2.2 Nuclear Thermal Radiation Facilities and Instrumentation.

2.2.1 Nuclear Thermal Radiation Criteria Parameters.

These criteria parameters must be thoroughly analyzed to ensure that acceptable facilities and appropriate instrumentation are utilized.

Thermal Radiation Parameter	Unit
Pulse Width	[sec]
Thermal Flux (Q_{dot})	[kJ/m²-sec]
Thermal Fluence (Q)	[kJ/m²]
Time to Maximum Irradiance (t_{max})	[sec]

Performance criteria requirements of the test system include allowable downtime and recovery procedures, operate through, acceptable damage and degradation, and the availability of and time required to implement repair and replacement parts.

2.2.2 Nuclear Thermal Radiation Facilities.

Acceptable test facilities can be categorized as solar collectors, electrical resistance heaters, or thermo-chemical reactions. For system level response, usually thermo-chemical reactions are used because they are the only facilities that can irradiate these large systems, while solar collectors and electrical resistance heaters are preferred and should be utilized on small systems, material samples, and when spectrum fidelity is a concern. Examples of acceptable facilities are:

Facility	Type	Location	Comments
1. White Sands Solar Furnace	Solar Collector	WSMR, NM	Excellent Spectrum / Subsonic Wind Tunnel / Shaped Nuclear Thermal Pulse / No limit on Fluence Peak flux - 100 cal/cm^2-sec Area - 15 cm diameter
2. DNA Xenon Lamps	Electrical Resistance Heater	Wright Patterson Air Force Base, OH	Wind and Load Peak Flux - 1748 cal/cm^2-sec Max Fluence - 474 cal/cm^2 Area - 10 x 11 cm Component and LRU level

Other Nuclear Thermal facilities are listed in "A Complete Guide to Nuclear Weapons Effects (NWE) Simulator Facilities and Applications", (2001 Edition). It must be noted that this edition was the last published NWE Simulator Facilities guide and many of these facilities are not currently operational. The TO must ensure that the thermal radiation test facility utilized is the best one to accurately simulate desired test environment criteria and test item response in order to adequately test the system configuration. It is emphasized that available facilities will provide only a simulated nuclear thermal radiation environment. Therefore, in addition to good test data, adequate analysis must be performed to account for the facility deficiencies which must be known, quantified, and documented.

2.2.3 Nuclear Thermal Radiation Instrumentation.

Measurement Parameter	Preferred Device	Measurement Accuracy
1. Temperature	Calorimeters	±5 °C
	Thermocouples	±5 °C
2. Damage	Digital Camera	> 2 Mega-pixals

The nuclear thermal radiation pulse will be monitored and recorded generally through the use of a calorimeter. The waveform generated by the calorimeter will be utilized to determine the simulated thermal radiation environment against the thermal NHC specified for the system. Thermocouples should be attached to the test item to monitor thermal response and recorded utilizing analog and digital recording instruments.

2.3 High Altitude Electromagnetic Pulse (HEMP) / Source Region Electromagnetic Pulse (SREMP) Facilities and Instrumentation.

2.3.1 HEMP / SREMP Criteria Parameters.

These criteria parameters must be thoroughly analyzed to ensure that acceptable facilities and appropriate instrumentation are utilized.

HEMP Parameter	SREMP Parameter	Unit
Electric Field – E-field	E-field	[volts/meter]
Magnetic Field – H-field	H-field	[amp-turns/meter]
Risetime	Risetime	[nanoseconds]
	Gamma Dose Rate	[cGy(Si)/sec]
Pulse Width	Pulse Width	[nanoseconds]

Performance criteria requirements of the test system include allowable downtime and recovery procedures, operate through, acceptable damage and degradation, re-boot, and the availability of and time required to implement repair and replacement parts.

2.3.2 HEMP / SREMP Facilities.

Acceptable HEMP test facilities can be categorized as radiating HEMP, hybrid HEMP, or bounded wave HEMP. Simulators in these categories can be vertically or horizontally polarized. Vertically polarized simulators should be utilized on systems who respond vertically such as missiles or those possessing large vertical antennas. Horizontally polarized simulators should be utilized on all military land systems, distributed systems, and aircraft. No facility as of this date has been defined as a SREMP facility. However, a gamma dose rate (GDR) facility, the HERMES III facility located at Sandia National Laboratories (SNL), Albuquerque, NM, is currently being utilized for this type of testing. Examples of acceptable facilities are the following:

Facility	Type	Location	Comments
1. DNA ARES	Bounded Wave/Vertical	Kirtland Air Force Base (KAFB), NM	Max E-Field -97 kV/m Area -40 x 33 x 40h m QSTAG 244, Ed. 4 or MIL-STD 2169B (Approx.) System level
2. USA Horizontal Polarized Dipole (HPD)-II	Radiating/Horizontal	WSMR, NM	Max E-Field - 65 kV/m Area - 76 m Diameter QSTAG 244, Ed. 4 MIL-STD-2169B System level
3. HERMES-III	SREMP	Sandia National Laboratories (SNL), NM	System level

Other HEMP / SREMP facilities are listed in "A Complete Guide to Nuclear Weapons Effects (NWE) Simulator Facilities and Applications", (2001 Edition). It must be noted that this edition was the last published NWE Simulator Facilities guide and many of these facilities are not currently operational. The TO must ensure that the HEMP test facility utilized is the foremost facility to accurately simulate desired criteria and test system response in order to adequately test the system configuration. More than one facility may be required to adequately test a system to account for horizontal and vertical responses as well as SREMP effects. It is emphasized that available facilities will provide only a simulated HEMP /SREMP environment. Therefore, in addition to good test data, adequate analysis must be performed to account for the facility deficiencies which must be known, quantified, and documented.

2.3.3 HEMP / SREMP Instrumentation / Dosimetry.

Measurement Parameter	Preferred Device	Measurement Accuracy
Current	Current Probes	±5%
E-Field	D-Dot Probe	±5%
H-field	B-Dot Probe	±5%
Gamma Dose	CaF_2 (Mn)	±10%
Gamma Dose Rate	Compton Diode	±10%
Test Setup	Digital Camera	> 2 Mega-pixals

The data acquisition system for the free-field tests should consist of transient digitizers with an operating bandwidth of 250 Megahertz (MHz) and 500 MHz (small test items), with a 1 Giga-sample per second sampling rate. Fiber optic data transmission system must be equal to the operating bandwidth. All utilized probes must be responsive to at least 1 Gigahertz (GHz).

Measurements of each illumination must be monitored by a B-dot probe (measures the time rate of change in the H-Field) or D-dot probe (measures the time rate of change in the E-Field) so that the magnitude of the E-field and pulse shape information is obtained. This information should be digitized, analyzed, and stored for a later detailed analysis.

In the case of SREMP testing, the gamma dose and dose rate at selected locations on the test system will be measured using Calcium Fluoride Manganese CaF_2 (Mn) Thermoluminescent Dosimeter (TLDs) and Compton diodes, respectively. The measured gamma dose values will be expressed in cGy(Si) and cGy(tissue) by these general ratios, however the "Annual Book of American Society for Testing and Materials (ASTM) Standards[5]", E666 and E668 must be referenced for each test:

$$cGy(Si)/cGy(CaF_2) = 1.02 \text{ and } cGy(tissue)/cGy(CaF_2) = 1.13, \text{ respectively.}$$

2.4 Gamma Dose Rate Facilities and Instrumentation.

2.4.1 Gamma Dose Rate Criteria Parameters.

These criteria parameters must be thoroughly analyzed to ensure that acceptable facilities and appropriate instrumentation are utilized.

Prompt gamma radiation pulses generate the production of charge carriers and subsequent photocurrents. These damaging photocurrents which flow across device junctions induce transient upset, latch-up and/or burnout in the semiconductor devices.

Gamma Dose Rate Parameter	Units
Peak GDR	[cGy(Si)/sec]
Pulse Width	[nanoseconds]
Energy	[Mev]

Performance criteria requirements of the test system include allowable downtime and recovery procedures, operate through, acceptable damage and degradation, and the availability of and time required to implement repair and replacement parts.

2.4.2 Gamma Dose Rate Facilities.

Acceptable test facilities can be categorized as electron Linear Accelerators (LINAC), or Flash X-Ray simulators. Major military systems and subsystems should utilize flash X-ray simulators because they can irradiate large test systems; while LINACs should be utilized on electronic piece-parts, components, and circuit card assemblies because of cost effectiveness, pulse-width variability, and quick turn-around times. Examples of acceptable facilities are:

Facility	Type	Location	Comments
1. USA WSMR LINAC	LINAC	WSMR, NM	Max Dose Rate - 2E11 cGy(Si)/sec Pulse Width - 10 ns to 10 s Piece part and component level
2. USA WSMR REBA	Flash X-ray	WSMR, NM	Max Dose Rate - 2.6E11 cGy(Si)/sec Pulse Width - 50 to 85 ns Up to system level
3. DOE SNL HERMES III	Flash X-ray	KAFB, NM	Max Dose Rate - > 5E12 cGy(Si)/sec Pulse Width - 20 ns Large system level

Other GDR facilities are listed in "A Complete Guide to Nuclear Weapons Effects (NWE) Simulator Facilities and Applications", (2001 Edition). It must be noted that this edition was the last published NWE Simulator Facilities guide and many of these facilities are not currently operational. The TO must ensure that the GDR test facility utilized is the foremost facility to accurately simulate desired criteria over an adequate exposure area and test item responses in order to adequately test the system configuration. It is emphasized that available facilities will provide only a simulated GDR environment. Therefore, in addition to good test data, adequate analysis must be performed to account for the facility deficiencies which must be known, quantified, and documented.

2.4.3 Gamma Dose Rate Instrumentation / Dosimetry.

Measurement Parameter	Preferred Device	Measurement Accuracy
Photocurrent	Photocurrent Probes	±5%
Gamma Dose	**CaF_2 (Mn) TLD	±10%
Gamma Radiation Pulse	PIN Diode Compton Diode	±10% ±10%
Current	Multimeter/Digitizer Oscilloscope	±10%
Voltage	Multimeter/Digitizer Oscilloscope	±5%

** Other materials may be utilized instead of CaF_2 (Mn) to determine gamma dose. However, the material's calibration and detection must conform to the procedures outlined in "Annual Book of ASTM Standards, Section 12".

The gamma dose is generally measured using CaF_2 (Mn) TLDs. The measured gamma dose values will be expressed in cGy(Si) and cGy(tissue) by these general ratios, but the "Annual Book of ASTM Standards", E666 and E668 must be referenced for each test:

$$cGy(Si)/cGy(CaF_2) = 1.02 \text{ and } cGy(tissue)/cGy(CaF_2) = 1.13, \text{ respectively.}$$

Each radiation pulse will be measured using a PIN or Compton diode and digitized on a transient digitizing system. The pulse-width (FWHM) of each radiation pulse will be obtained from this digitized signal. The GDR for each pulse will then be determined from the dose recorded on the TLDs and divided by the pulse-width obtained from the digitizers.

2.5 Neutron Fluence Facilities and Instrumentation.

2.5.1 Neutron Fluence Criteria Parameter.

This criteria parameter must be thoroughly analyzed to ensure that acceptable facilities and appropriate instrumentation are utilized.

Fast neutrons interact with semiconductor material in electronic piece-parts by elastic collisions with lattice atoms which decrease minority carrier lifetimes and increase device resistivity. This resulting damage alters electrical parameters of the device which can cause failure in the semiconductor devices or circuit applications.

Neutron Fluence Parameter	Units
Neutron Fluence	[1 Mev(Si) n/cm^2]

Performance criteria requirements of the test system include allowable downtime and recovery procedures, operate through, acceptable damage and degradation, and the availability of and time required to implement repair and replacement parts.

2.5.2 Neutron Fluence Facilities.

Acceptable test facilities can be categorized as a Fast Burst Reactor (FBR) or a Training, Research, Isotopes, General Atomics (TRIGA) reactor. (Sometimes, Californium-252 is utilized for piece-part testing.) These reactors generally can be utilized in the pulse or steady-state mode of operation. In the pulse mode of operation, the FBR can generate neutron fluence up to 5E14 n/cm^2 with energies > 10 keV and GDR up to 1E9 cGy(Si)/sec with a pulse-width of approximately 50 µsec. However, when total neutron fluence is the primary concern, the steady-state mode of operation is typically used. Examples of acceptable facilities are:

Facility	Type	Location	Comments
1. USA WSMR Fast Burst Reactor	FBR	WSMR, NM	Peak Pulse Power - 6.5E4 MW Neutron Fluence - 7E13 n/cm^2 FWHM Pulse Width - 40 to 3000 s Up to system level

Other neutron fluence facilities are listed in "A Complete Guide to Nuclear Weapons Effects Simulator Facilities and Applications", (2001 Edition). It must be noted that this edition was the last published NWE Simulator Facilities guide and essentially all of these facilities are not currently operational. The TO must ensure that the neutron fluence test facility utilized is the foremost facility to accurately simulate desired criteria and test item responses in order to adequately test the system configuration. It is emphasized that available facilities will provide only a simulated neutron fluence environment. Therefore, in addition to good test data, adequate analysis must be performed to account for the facility deficiencies which must be known, quantified, and documented.

2.5.3 Neutron Fluence Instrumentation / Dosimetry.

Measurement Parameter	Preferred Device	Measurement Accuracy
Neutron Fluence	** Sulfur Activation Foil	±10%
Gamma Dose	**CaF_2 (Mn) TLD	±10%
Current	Multimeter/Digitizer Oscilloscope	±5%
Voltage	Multimeter/Digitizer Oscilloscope	±5%

** Other materials or techniques may be utilized instead of sulfur and CaF_2 (Mn) to determine neutron fluence and gamma dose, respectively. However, the material's calibration and detection must conform to the procedures outlined in "Annual Book of ASTM Standards, Section 12".

The neutron fluence at each test location will be measured using sulfur activation foils which measure neutrons with energies greater that 3 MeV; but, the "Annual Book of ASTM Standards", E720, E721, and E722 (specifically E722-93) must be referenced. The measured fluence will be converted to 1 MeV(Si) equivalent damage fluence by the following relationship:

1 MeV(Si) eq. neutron fluence = K * (3 MeV neutron fluence)

where K is experimentally determined with respect to many factors, such as energy, spectrum, and source-to-target distance.

The gamma dose will be measured using CaF_2 (Mn) TLDs. The measured gamma dose values will be expressed in cGy(Si) and cGy(tissue) by these typical ratios, but the "Annual Book of ASTM Standards", E666 and E668 must be referenced for each test:

cGy(Si)/cGy(CaF_2) = 1.02 and cGy(tissue)/cGy(CaF_2) = 1.13, respectively.

2.6 Gamma Total Dose Facilities and Instrumentation.

2.6.1 Gamma Total Dose Criteria Parameter.

This criteria parameter must be thoroughly analyzed to ensure that acceptable facilities and appropriate instrumentation are utilized.

Gamma Total Dose (GTD) generates hole-electron pairs through the process of ionization in the semiconductor material resulting in trapped charges. These total dose effects are exhibited either as a change in electrical parameters or as a catastrophic failure in semiconductor devices.

Gamma Total Dose Parameter	Units
GTD	[cGy(Si)]

Obtaining the proper total gamma dose test criterion can be difficult. The TO must first obtain NHC and identify the subheading: "Silicon Absorption / Displacement Damage". Under this subheading, is the title " Max Combined Neutron and Gamma Ionizing Dose, (cGy(Si))" referred to as D_i. In addition, the correct utilized value should have in quotes (single pulse duration of 60 seconds). This acquired value is the actual Vertical Plane Center (VPC) GTD to be received by the test item.

Performance criteria requirements of the test system include allowable downtime and recovery procedures, operate through, recovery time, degradation and/or acceptable damage, and the availability of and time required to implement repair and replacement parts.

2.6.2 Gamma Total Dose Facilities.

Acceptable test facilities typically utilize a Cobalt-60 source or multiple Cobalt-60 sources. Large systems are extremely difficult to test adequately because no large scale DOD /DOE gamma dose facility is available. Therefore, most testing should be accomplished at the piece-part, component, LRU, and subsystem level. Whole body irradiations are typically limited to surfaces < 1.5 m on a side for gradient and disposition rate reasons. Examples of acceptable facilities are:

Facility	Location	Comments
1. USA WSMR Gamma Radiation Facility (GRF)	WSMR, NM	Max Dose Rate - 1700 cGy(Si)/sec Exposure Area - 13 x 6 x 4 height m 8 sources Piece-part, Component, LRU, subsystem and system level
2. SNL Gamma Facility	KAFB, NM	Max Dose Rate - 600 cGy(Si)/sec Exposure Area - 15.2 cm dia. x 20.3 height cm Piece-part, Component, small LRU/subsystem level

Other GTD facilities are listed in "A Complete Guide to Nuclear Weapons Effects Simulator Facilities and Applications", (2001 Edition). It must be noted that this edition was the last published NWE Simulator Facilities guide and many of these facilities are not currently operational The TO must ensure that the GTD test facility utilized is the foremost facility to accurately simulate desired criteria over an adequate exposure area and test item responses in order to adequately test the system configuration. It is emphasized that available facilities will provide only a simulated GTD environment. Therefore, in addition to good test data, adequate analysis must be performed to account for the facility deficiencies which must be known, quantified, and documented.

2.6.3 Gamma Total Dose Instrumentation / Dosimetry.

Measurement Parameter	Preferred Device	Measurement Accuracy
Gamma Dose	**CaF_2 (Mn) TLDs	±10%
Current	Multimeter/Digitizer Oscilloscope	±5%
Voltage	Multimeter/Digitizer Oscilloscope	±5%

** Other materials may be utilized instead of CaF_2 (Mn) to determine gamma dose. However, the material's calibration and detection must conform to the procedures outlined in "Annual Book of ASTM Standards, Section 12".

The gamma dose will be measured using CaF_2 (Mn) TLDs. The measured gamma dose values will be expressed in cGy(Si) and cGy(tissue) by these typical ratios for Cobalt 60, but the "Annual Book of ASTM Standards", E666 and E668 must be referenced for each test:

$cGy(Si)/cGy(CaF_2) = 1.02$ and $cGy(tissue)/cGy(CaF_2) = 1.13$, respectively.

3. REQUIRED TEST CONDITIONS.

3.1 Test Preparation.

3.1.1 Scope of Testing.

Once a test program is initiated, the first concern of the TO is the establishment of the objectives and the scope of the program. In essence, these questions must be addressed: What equipment and support items are required, how must the equipment be tested in order to maximize determination of its performance, what test environments and at what assembly levels must testing occur, what data are required and how will it be collected, how must the information be processed and analyzed in order to obtain an accurate and complete survivability analysis of the test system and ultimately the system configuration to the criteria environment. The TO must thoroughly understand the operation of all mission essential functions, test criteria, test facility limitations, test objectives, operational and maintenance procedures, performance and operational checkouts, material composition, instrumentation, dosimetry, system integration, environmental considerations, NWE, Transient Radiation Effects on Electronics (TREE), statistical processes, and safety considerations to adequately devise a realistic test scenario, test schedule, and performance analysis program.

3.1.2 Cost Estimates.

Upon devising an appropriate test scenario, a DTC cost estimate must be prepared in accordance with (IAW) DTC Pamphlet 73-1[6], Developmental Test Guide. The TO must ensure that the cost estimate adequately accounts for all reasonable expenditures of the proposed nuclear test and analysis program. These direct expenditures are for man-hours, material and supplies, travel, contractual service, equipment, minor construction, facilities, repair and replacement of test related consumables. IAW the National Defense Authorization Act 2003, only direct expenditures can be charged to DoD or DoD sponsored customers. Additionally, these cost estimates must be posted in the U.S. Army Test and Evaluation Command (ATEC) Decision Support System (ADSS) and VISION Digital Library (VDL).

3.1.3 Test Coordination.

From the initiation to the completion of the test program, test coordination is a constant and essential task. The TO must coordinate effectively with a multitude of various personnel in order to properly plan, resource, execute, and determine the nuclear survivability of a test system. Without proper and effective test coordination, a NTSA program will experience cost overruns, unnecessary test delays, inadequate test data, improper determinations, and improper usage of manpower. In conclusion, test coordination is one of the most important aspects to a TO and is essential to the conduct of a successful NTSA program.

3.1.4 Environmental Impact.

An important pretest requirement IAW AR 200-1, Environmental Protection and Enhancement[7], and AR 200-2, Environmental Effects of Army Actions[8], is an environmental analysis. This analysis will help alleviate environmental problems that could interfere with the test schedule and completion of the NTSA program. The proper documents must be completed and submitted to the environmental office and/or personnel who regulate and control environmental practices at the test execution site prior to start-of-test. The actual time requirement for document submission before test execution, is dependent on the level of preparation required, type of system, and required documentation as well as the workload of the environmental office. Most of the required information can be obtained from the Project Manager’s (PM's) office.

3.1.5 Safety Analysis.

Another important pretest coordination task is the safety analysis which must be prepared IAW AMC-R 385-100, Safety Manual[9]. Like the environmental analysis, it should be prepared, submitted, and approved As Soon As Possible (ASAP) to alleviate safety problems which could affect the completion of the NSA program. The safety analysis can usually be obtained from the PM's office or system's contractor. If a complete initial safety analysis is needed, extra time and funds must be allotted to identify the necessary safety procedures and prepare the documentation.

3.1.6 Preferred Nuclear Environment Test Methodology.

The TO must ensure that sufficient analysis is performed to account for deficiencies in the simulated nuclear test environment versus the United States Army Nuclear and Combating Weapons of Mass Destruction Agency (USANCA) environments, variations between the test and production configuration, and the corresponding variations in hardware response. One must initially assume that neither the test environment nor hardware is accurate representations of the NHC and system configuration, respectively. There will be differences which must be identified and quantified in order that a survivability analysis can be successfully performed. To accurately achieve compliance with the test objective, one must accomplish the following:

First, perform the pretest analysis to identify:

a. Instrumentation and dosimetry for required response and environment data.

b. Test hardware for each environment.

c. Location of instrumentation and dosimetry.

d. Test facilities and limitations.

e. Test levels per environment.

f. Test system's performance and operational checkouts to adequately analyze all mission essential functions.

g. Required test data per environment.

h. Safety margins of Hardened Critical Items (HCIs)

i. Electromagnetic (EM) energy paths and port-of-entries.

j. Potential test system's responses.

k. Potential susceptibilities and hardness levels in all nuclear environments with respect to the USANCA criteria.

l. Test system's configuration with respect to each environment.

m. Test system's configuration baseline.

n. Differences between test and production configuration.

Second, the TO must thoroughly document and analyze the test hardware which is to be utilized during the NTSA. This documentation and determination includes the test system's material composition, shape, size, mass, fastening schemes, shielding and attenuation characteristics, nuclear hardening concepts and devices, mission essential functions, and HCIs and circuits. Then, the TO must analyze the test hardware relative to fielded or proposed fielded system hardware and identify all of the relevant differences. With all this information, the TO can identify and establish the test system and proposed system baseline configuration. This baseline will be utilized for the survivability analysis as well as a basis for analysis of all product improvements, Engineering Change Proposals (ECPs), and configuration changes to ensure that the test system remains nuclear survivable during production, maintenance, and deployment.

Third, the TO must identify the environmental tests that will best meet the requirements identified in the pretest analysis. The nuclear test environments are Nuclear Airblast, Nuclear Thermal Irradiation, Electromagnetic Pulse (EMP) (Endo-atmospheric (SREMP) and Exo-atmospheric (HEMP)) and Initial Nuclear Radiation (INR) (GDR, GTD, and neutron fluence). All INR testing should be conducted in the following sequence: GDR, neutron fluence, and GTD. This sequence is based on actual occurrence and the fact that some semiconductor devices may generate inaccurate failure thresholds if this acknowledged sequence is not preserved. If time constraints or test facility scheduling forces the PE to deviate from this INR test sequence, analysis must be performed to insure that any out-of-sequence related effects on the test system are identified and accounted for. Testing conducted in the EMP, nuclear airblast, and nuclear thermal radiation environments can usually be performed independently with disregard to the test sequence because of the nature of their effects. However, HEMP is preferred after airblast and thermal because: HEMP is produced by an exo-atmospheric detonation and can occur after a surface/near-surface event, and the response of the damaged test item is likely to be more adverse. Synergistic effects on the test system, particularly for thermal and airblast, must be determined because it is real and may significantly enhance damage.

Lastly, the TO must analyze and determine the test system's performance with a detailed post-test analysis. This post-test analysis includes test environments and results of the pretest analysis, documentation and detailed determination of the test system's performance, determination of all shortcomings and failures, and determination of obtained environmental data against the USANCA criteria. In order to effectively determine criteria compliance, the TO must thoroughly understand the simulation fidelity of each test facility. All test facilities have one or more parameter deficiencies; therefore, these deficiencies must be well understood and analysis performed to establish the effects of these parameter deficiencies on the results of the test. With this analysis, the TO can adequately determine the environmental test parameters against the desired USANCA criteria. In order to effectively analyze survivability of the system configuration, the TO must thoroughly understand the differences between the test system's and the system's configuration, and corresponding effects on the analyzed system.

Combined with the piece-part /circuit analysis, pretest analysis or other analytical data, the TO will then be able to analyze the survivability of the system's configuration to the USANCA requirements.

3.1.7 Test Plan.

The TO must incorporate all the factors and ideas presented in paragraphs 3.1.1 through 3.1.6 into a test plan that must be written IAW DTC Pamphlet (Pam) 73-1. It is critical that all required steps in DTC Pam 73-1 are followed. The test plan must be developed by the TO, submitted to DTC approximately sixty days prior to, and approved by DTC approximately thirty days prior to test execution. Test plans should contain the following information:

I. Section 1: Introduction.
   1.1 System Description.
   1.2 Summary.
   1.5 Unique Test Personnel Requirements.
II. Section 2: Subtests. (for each test environment).
   2.1 Name of Subtest.
   2.1.1 Objectives.
   2.1.2 Criteria and Data Analysis/Procedure
   2.1.3 Test Procedures and Data Required.
III. Section 3: Appendices.
   A. Test Criteria.
   B. Test Schedule.
   C. Informal Coordination.
   D. References.
   E. Abbreviations.
   F. Distribution List.

Events are likely to occur during the test execution that causes the TO to utilize sound engineering judgment to deviate from the original test plan. Major deviations must be approved by Headquarters (HQ) DTC before implemented. All deviations must be documented in the detailed test report.

3.2 Test Execution.

3.2.1 Pretest Analysis / Modeling.

Before the execution of any nuclear test program, a pretest analysis must be performed. During the pretest analysis, the TO must thoroughly examine the test system and manipulate engineering principals and nuclear effects responses to estimate where potential nuclear survivability problems exist. The TO must also determine test facilities to ensure that the best facility is scheduled, sufficient data acquisition is available and scheduled, and required test configurations/orientations can be tested. In order to perform an adequate pretest analysis, the TO must have accurate schematics, part lists, details of deliberate hardening methods/hardware, previous test and/or analytical data, material composition, wiring diagrams, cable shielding details, and piece-part specifications. Based on the pretest analysis, the TO can establish functional models where significant data can be obtained on the expected performance of the test system through all the different nuclear environments.

3.2.2 Piece-Part / Circuit Analysis Program.

One of the major limitations in NTSA programs is the difficulty of establishing survivability confidences on systems with extremely small sample sizes. To effectively establish confidence levels and the survivability of the baseline system, the TO is expected to implement an analysis program. For INR, this program will utilize piece-part test data, circuit analysis, modeling methods, and statistical procedures to determine design margins and confidence levels. The piece-part / circuit analysis program will identify all potential nuclear survivability deficiencies by accounting for response variances due to different manufacturing processes. For EMP, this program will identify and analyze grounding schemes, cabling, cable shielding, transient and terminal protection devices. For airblast and thermal analysis, the material composition, shape, size, mass, and fastening schemes are analyzed. Only by having adequate design margins in all nuclear survivability environments, can an acceptable airblast, thermal, HEMP, and/or INR survivability analysis is performed on the system's baseline configuration.

3.2.3 Test Organization and Documentation.

The formulation of a detailed test plan and effective test coordination prior to the test execution is critical to test organization and execution, and cost effectiveness. Test organization consists of a set of preset procedures for accomplishing specific test execution tasks. Proper test organization will result in superior test execution. The TO must assign and explain to each test support personnel their specific tasks and schedules. Examples include test system and dosimetry placement, probe placement, test documentation, data acquisition, performance checkouts, maintenance procedures, etc. The most important of these specific tasks is test documentation. The TO must ensure that all aspects of the nuclear test program are carefully, completely, and correctly documented. To achieve effective documentation, test specific control forms should be generated. Improper documentation can lead to an inaccurate and incomplete NTSA. In conclusion, careful organization and adequate documentation of the test is essential.

3.2.4 Sound Engineering Judgment.

During the entire execution of the test, the TO must utilize sound engineering judgment to effectively test and analyze the test item and maintain schedules and costs. Sound engineering judgment becomes extremely critical when schedule impacts occur such as facility downtime, inclement weather, failures and/or re-prioritization. Under such conditions, the TO must determine the problem, deviate from the original test plan, and devise an alternate plan or set of procedures. The TO must also devise work-arounds that maximize completion of testing and test objectives. Any deviations from the test plan shall be recorded and reported in the test report.

3.3 Test Reporting and Life-Cycle.

3.3.1 Data Reduction and Analysis.

After the completion of all survivability testing, the TO must conduct data reduction and analysis on the raw data. The raw test data are manipulated into an understandable format and documented in Appendix B and summarized in the Test Results section of the test report. The actual data reduction procedures selected is dependent upon the performance parameters, the test environment, and the criteria parameters. All data reduction procedures must be standardized for each individual test and documented. Clear and concise data reduction and analysis will enhance and enrich the final product, the survivability analysis.

3.3.2 Statistical and Error Analysis.

Other forms of analysis that should be performed on the test data are statistical and error analysis. The TO should use statistical analysis to obtain the nuclear survivability probability of electronic piece-parts based on test data, circuit analysis, and safety margins. The preferred probability with confidence is 99/90 tolerance level (0.99 probability of survivable with a 90 percent confidence). Also, statistical analysis should be utilized to obtain the criteria compliance between actual environment parameters and desired criteria. An error analysis should be performed to account for and eliminate sources of error present in the raw test data. Possible sources of error are: instrumentation and data acquisition, human, test setup, probe, dosimetry, and roundoff. The TO utilizes this error analysis to help predict how accurate the simulated test environment was to the specified USANCA environment and to ensure that test system received its nuclear survivability criteria taking the predicted error into account.

3.3.3 Survivability Analysis of the System Configuration versus USANCA Criteria.

Based on data processed (system and environmental), the TO analyzes nuclear survivability of the test system to each test environment. The TO then proceeds to analyze the nuclear survivability of the system's configuration to each of the USANCA environments. To accomplish this, the TO must first identify and define the test system's configuration, test environments, and safety margins. The TO then uses this information to establish nuclear survivability of the test system configuration to the test environments. The test results and environments are then corrected to represent the USANCA environments by accounting for differences and deficiencies. Finally, the TO analyzes the baseline system configuration performance against the corrected or USANCA environments. This is the NTSA of the baseline configuration and is the information for the Technical Analysis of the test report. Also, the system's baseline configuration and analysis is the basis for analyzing effects of product improvements or other system configuration changes or repairs on the hardness level and survivability of the system during its lifetime. These future analyses will involve additional piece-part / circuit analysis and piece-part testing where data are not available.

3.3.4 Test Record / Reports.

After the TO has completed all test execution, data analyses, and survivability analysis, a detailed test report or test record must be written IAW DTC Pam 73-1. It is critical that all required steps in DTC Pam 73-1 are followed. The test record / report must be completed and submitted to DTC no later than the time frames specified in Table 6.2 (DTC Pam 73-1) after test completion and approved by DTC. Test Record / Reports should contain the following information:

Foreword.
I. Section 1: Executive Digest.
1.1 System Description.
1.2 Summary.
1.3 Conclusions.
1.4 Recommendations.
II. Section 2: Subtests. (for each test environment).
2.1 Name of Subtest.
2.1.1 Objectives.
2.1.2 Criteria and Analysis.
2.1.3 Test Procedure and Findings.
III. Section 3: Appendixes.
A. Test Criteria.
B. Test Data.
C. Recommendation for Classification of Risk.

If no additional appendices are required to adequately quantify the test results and findings, the following appendixes are required to close the test report and will be lettered consecutively:

D. References.
E. Abbreviations.
F. Distribution List.

The highlighted portions of the previous list (Summary, Test Findings, & Technical Analysis) are the most significant sections of the test report. The PE must give special consideration to ensure these sections are concise, detailed, complete, accurate and comprehensible.

3.3.5 Life-Cycle Nuclear Survivability Program.

The production, operation, maturity, storage, maintenance, modification, and ambient environments must not introduce any form of susceptibilities or unacceptable levels of degradation into a nuclear survivable system. To ensure continued nuclear survivability, a Life-Cycle Nuclear Survivability (LCNS) program must be established IAW the NHC, AR 70-75, and the DODD 5000.1. The basic purpose of the LCNS program is to control all changes to the baseline configuration during production and product improvements, ensure that an acceptable hardness level is preserved during maintenance by using certified spare parts and procedures, and verifying that the hardness level is not degraded to an unacceptable level during fielding, storage, and operating in the ambient environments.

3.4 Nuclear Airblast Pretest Analysis.

During the pretest analysis, the TO must analyze and identify the high risk susceptibilities and test conditions of the test system to the airblast environment. To do this, the TO must effectively:

a. Identify potentially susceptible subsystems and/or system components based upon exposure conditions, materiel composition, shape, size, mass, and fastening schemes.

b. Identify test system's configuration.

c. Define data acquisition requirements

d. Analyze contractor's program documentation.

e. Analyze hardening and analysis performed by contractor.

f. Define baseline performance checks for test hardware.

g. Identify the most realistic and severe test configuration and orientation with respect to GZ or the source.

h. Identify the type, number, and location of gages to measure response of areas of concern.

i. Analyze potential test facilities to determine the one best for test system or test item(s).

j. Analyze selected test facility's response producing parameters and calculate the expected system response utilizing engineering principals.

k. Perform structural analysis of mechanical and structural response of the test system and of mission critical external fixtures/appendages to the transient loads induced by the blast wave utilizing finite element methods or similar analytical techniques.

l. If appropriate, perform analyses using a Verification, Validation and Accreditation (VV&A) approved code.

m. Identify detailed photography scheme.

3.5 Nuclear Thermal Radiation Pretest Analysis.

During the pretest analysis, the TO must analyze and identify the high risk susceptibilities and test conditions of the test system to the thermal radiation environment. To do this the TO must effectively:

a. Identify potentially susceptible subsystems and/or system components based upon exposure conditions, materiel composition, shape, size, and mass.

b. Identify test system's configuration.

c. Define data acquisition requirements

d. Analyze contractor's program documentation.

e. Analyze hardening and analysis performed by contractor.

f. Define baseline performance checks for test hardware.

g. Identify the most realistic and severe test configuration and orientation with respect to the thermal radiation source.

h. Identify the type, number, and location of gages to measure response of areas of concern.

i. Analyze potential test facilities to determine the one best for test system or test item(s). More than one may be required.

j. Analyze selected test facility's response producing parameters and calculate the expected system's thermal response utilizing engineering principals.

k. If appropriate, perform analyses using a Verification, Validation and Accreditation (VV&A) approved code.

l. Define and document all pretest visual inspections and quantified performance check baselines.

m. Identify detailed photography scheme on all exposure areas.

3.6 HEMP / SREMP Pretest Analysis.

During the pretest analysis, the TO must analyze and identify the high risk susceptibilities and test conditions of the test system to the HEMP / SREMP environments. To do this the TO must effectively:

a. Analyze drawings and circuits to determine potentially harmful energy paths. The analysis should be concentrated on external unshielded cables of significant length and interface of these cables into subsystems of the test system.

b. Identify test system's configuration.

c. Identify and determine all points-of-entries.

d. Analyze grounding scheme and shielded cables to include backshells and connectors for shielding effectiveness.

e. Determine inherent hardness afforded by the system to its mission critical electronics.

f. Define data acquisition requirements.

g. Analyze contractor's program documentation.

h. Analyze hardening and analysis performed by contractor.

i. Define baseline performance checks for test hardware.

j. Utilize peak pulse power data to analyze the piece-part and Terminal Protection Devices (TPDs) that are inputs to these large energy paths.

k. Fabricate Breakout Boxes (BOBs) for all cables of concern to enable actual pin measurements to be performed during testing and current injection.

l. Analyze potential test facilities to determine the one best for the test system or its test item(s).

m. Identify the type and location of current and differential voltage probes to be utilized to measure predicted cables and pins of concern.

n. Identify all test orientations.

o. Identify test levels based on results of hardening determination.

p. Identify all test configurations and operating modes.

q. Identify the location for all dosimetry (SREMP).

3.7 Gamma Dose Rate Pretest Analysis.

During the pretest analysis, the TO must analyze and identify high risk HCI's and test conditions of the test system to the GDR environment. To accomplish this, the TO must effectively:

a. Identify all HCIs based upon technology. Consider existing circuit hardening in this screening.

b. Identify test system's configuration.

c. Define data acquisition requirements.

d. Analyze contractor's program documentation.

e. Analyze hardening and analysis performed by contractor.

f. Define baseline performance checks for test hardware.

g. Analyze potential test facilities to determine the one best for the test system and/or its test item(s). At least two different facilities will likely be required - one for piece-parts/components and one for LRUs and/or systems.

h. Identify the most realistic and severe test setup/circuit with respect to the radiation exposure.

i. Identify all current limiting, power removal, and/or GDR hardening applications.

j. Identify the type, number, and location for all dosimetry and data acquisition required to collect real time response data.

k. Establish the baseline configuration of the test system.

l. Identify test orientations.

m. Identify test levels based on results of hardening determination.

n. Identify test configurations and operating modes.

o. Acquire test data for all high priority HCIs.

p. Analyze all HCI circuit performance characteristics.

q. Determine HCI safety margins based upon test data, circuit analysis, and statistical techniques.

r. Analyze potential for Dose Enhancement Effects.

3.8 Neutron Fluence Pretest Analysis.

During the pretest analysis, the TO must analyze and identify high risk HCIs and test conditions of the test system to the neutron fluence environment. To accomplish this, the TO must effectively:

a. Identify HCIs based upon technology.

b. Identify test system's configuration.

c. Define data acquisition requirements.

d. Analyze contractor's program documentation.

e. Analyze hardening and analysis performed by contractor.

f. Define baseline performance checks for test hardware.

g. Analyze potential test facilities to determine the one best for the test system and/or its test item(s).

h. Identify the most realistic and severe test setup with respect to the neutron source.

i. Identify the type, number, and location for all dosimetry and data acquisition required to collect real time response data.

j. Establish the baseline configuration of the test system.

k. Acquire test data for all high priority HCIs.

l. Analyze all HCI circuit performance characteristics.

m. Determine HCI safety margins based upon test data, circuit analysis and statistical techniques.

n. Identify test orientations with respect to the neutron source.

o. Identify test levels based on results of the hardening determination.

p. Identify test configurations and operating modes.

q. Assess potential for Dose Enhancement Effects.

3.9 Gamma Total Dose Pretest Analysis.

During the pretest analysis, the TO must analyze and identify high risk HCIs and test conditions of the test system to the GTD environment. To accomplish this, the TO must effectively:

a. Identify HCIs based upon technology.

b. Identify test system's configuration.

c. Define data acquisition requirements.

d. Analyze contractor's program documentation.

e. Analyze hardening and analysis performed by contractor.

f. Define baseline performance checks for test hardware.

g. Analyze potential test facilities to determine the one best for the test system and/or its test item(s).

h. Identify the most realistic and severe test setup with respect to the radiation source.

i. Identify circumvention and/or GTD hardening techniques.

j. Identify the type, number, and location for all dosimetry and data acquisition required to collect real time response data.

k. Establish the baseline configuration of the test system.

l. Identify test orientations for exposure.

m. Identify test configurations and operating modes.

n. Identify test levels based on results of hardening determination.

o. Acquire test data for all high priority HCIs.

p. Analyze all HCI circuit performance characteristics.

q. Determine HCI safety margins based upon test data, circuit analysis and statistical techniques.

r. Analyze potential for Dose Enhancement Effects.

4. TEST PROCEDURES.

4.1 Nuclear Airblast.

4.1.1 General.

4.1.1.1 Test System.

Survivability of the test hardware when exposed to the airblast test environment will be analyzed by:

a. Performing a detailed pretest analysis (this supplements planning and allows the TO to develop improved experimental designs and enhance successful testing).

b. Ensuring that the test hardware is properly deployed and in a realistic operational state and configuration as established by the pretest analysis.

c. Establishing the performance baseline of the test hardware prior to the event.

d. Determining effects by visual inspections, performance of the baseline checks, and detailed failure diagnosis.

e. Determining performance/operational data of the test hardware.

f. Analyzing both still and high speed motion photography of the test hardware taken before, during, and after the airblast event.

g. Analyzing response measurements from instruments such as acceleration, pressure, and strain gages.

h. Determining damage and/or degradation in regards to impacts on mission accomplishment.

i. Analyzing test environment data.

4.1.1.2 Baseline System.

The survivability of the baseline system configuration when exposed to the airblast USANCA environments will be analyzed by:

a. Analyzing the differences between the test and USANCA environments.

b. Analyzing the differences between the test and baseline configurations.

c. Determining the response of the baseline configuration to the USANCA environment.

4.1.2 Test Setup.

The test setup is based upon results obtained from the pretest analysis and should consist of:

a. Position the test hardware at the desired test location and in the correct test configuration.

b. Prior to the event, the complete test hardware must be examined to ensure proper operation and establish the performance baseline.

c. Instrument the test hardware IAW the pretest analysis to acquire critical response data of the test hardware. Instrumentation includes pressure transducers, accelerometers, and strain gages. Ensure instrumentation is calibrated.

d. Photograph the pretest setup to include instrumentation locations

e. Setup, check, and calibrate the complete data acquisition system. Check the cables to ensure adequate attachment to the transducers, data recorders, and amplifiers; and that they are sufficiently protected against the blast wave. Set-up amplifiers and transient digitizers IAW predictions of the pretest analysis. All data acquisition calibration should be accomplished at the test location to ensure accuracy.

f. Setup, checkout, and calibrate backup data channels for critical areas and responses.

g. Setup, checkout, and calibrate the pressure transducers to measure the principal free-field environmental parameters.

h. Setup the high speed motion cameras to record the response of the test hardware during the event. Typical speeds are 250 and 400 Frames Per Second (fps).

i. Ensure the test hardware is in the proper operational mode for the test.

4.1.3 Test.

After the airblast environment has been produced and the test area is considered safe, a comprehensive damage analysis must be performed on the test hardware. This damage analysis will consist of post-event photography, a detailed visual inspection, displacement measurements, and complete post-event performance/operational checks. Response data obtain from pressure transducers, accelerometers, and strain gages will be processed and thoroughly analyzed and determined. All pertinent pre-event and post-event information must be clearly and accurately documented and analyzed. Diagnostics of all failed and mission degraded areas must be performed and the results determined.

The test environment data will be processed, analyzed, and determined. The eight test environment parameters will be analyzed against the USANCA parameters to determine criteria compliance. These criteria compliances must be utilized in correcting induced and projected responses in the test system and baseline configuration, respectively.

4.2 Nuclear Thermal Radiation.

4.2.1 General.

4.2.1.1 Test System.

Survivability of the test hardware when exposed to the test thermal radiation environment will be analyzed by:

a. Performing a detailed pretest analysis.

b. Establishing the performance baseline of the test hardware prior to testing to include pretest photography, performance and operational checks, and visual inspections.

c. Determining effects by repeating all performance baseline procedures and visual checks on each test item after exposure to thermal radiation.

d. Exposing mission critical items to at least 1.3X with 1.5X desired to establish safety margins and confidence levels.

e. Analyzing photography of the test hardware.

f. Analyzing all instrumentation data (thermocouples & calorimeters).

g. Analyzing all environmental data.

h. Determining damage and/or degradation in regards to impacts on mission accomplishment.

4.2.1.2 Baseline System.

The survivability of the baseline system configuration when exposed to the thermal radiation USANCA environments will be analyzed by:

a. Analyzing the differences between the test and USANCA environments.

b. Analyzing the differences between the test and baseline configurations.

c. Determining the response of the baseline configuration to the USANCA environment.

4.2.2 Test Setup.

Before testing, the performance of each test item identified in the pretest analysis will be baselined and documented utilizing photographs, visual inspections, and, performance and operational checks. All problems identified will be documented and corrected if detrimental to the thermal radiation test program. The thermal radiation environment will then be monitored using calorimeters and adjusted until the specified thermal pulse is generated. Upon verifying the content of the generated pulse, the calorimeter will be removed and the instrumented test item will be properly positioned in the test chamber. Test setup photographs will be taken. Likewise, the above setup procedures will be repeated for each remaining set of criteria.

4.2.3 Test.

After the thermal exposure, the pretest baseline check procedures will be performed. The test item will be repositioned to expose another thermal sensitive area to 1.0X, if required. If the test item survives, a second test sample will be positioned for testing to 1.3X to confirm the previous results and to provide confidence. If this test item fails, a third sample will be exposed to 1.0X to confirm the result of the first test and to provide additional confidence. If the sample survives 1.3X, then, the third sample will also be exposed to 1.3X. This procedure will be repeated until all thermal sensitive areas and/or samples have been exposed and all sets of criteria have been addressed. It is essential that mission critical test items or test samples should be exposed to 1.3X to establish a safety margin to ensure nuclear thermal radiation survivability. All exposed areas will be photographed. Failures will be diagnosed and analyzed as to the cause and effects on mission performance. Response data will be processed, analyzed, and determined. All pertinent data will be documented and analyzed. Where necessary, diagnostics of all failed areas must be performed and the results determined.

The test environment data will be processed, analyzed, and determined. The four critical test environment parameters will be analyzed against the USANCA parameters to determine criteria compliance. These criteria compliances must be utilized in correcting induced and projected responses in the test system and baseline configuration, respectively.

4.3 HEMP / SREMP.

4.3.1 General.

4.3.1.1 Test System.

Survivability of the test system when exposed to the test HEMP and/or SREMP environment will be analyzed by:

a. Performing the detailed pretest analysis.

b. Calibrating required Data Acquisition Systems (DAS).

c. Establishing the performance and operational baseline for the test system prior to testing.

d. Determining effects by repeating the performance and operational baseline checks or abbreviated checks after each illumination.

e. Illuminating the test system in the pre-selected orientations, configurations, and modes at 0.5, 0.75, 1.0, and 1.5 times (if possible) its E-field criterion level as defined in the pretest analysis phase. Determining all upsets, failures, downtimes, mission performance impacts, and corrective actions.

f. Analyzing response and environmental data.

g. Current injecting at 1X, 3X, and 5X based upon simulator signals and/or damped sinusoidal waveforms obtained from CS115 and CS116 in Military Standard (MIL-STD) 461E[10] and 464A[11] references.

h. Acquiring Shield Cable Test (SCT) measurements for baselining the test system and for the LCNS database.

i. Analyzing system response in both the time and frequency domains.

The TO must ensure that accurate, consistent and documented operational checks are utilized. Many of the problems induced by the illumination will be transient upsets and will be correctable by recycling power.

4.3.1.2 Baseline System.

The survivability of the baseline system configuration when exposed to the HEMP/SREMP USANCA environments will be analyzed by:

a. Analyzing the differences between the test and USANCA environments.

b. Analyzing the differences between the test and baseline configurations.

c. Determining the response of the baseline configuration to the USANCA environment.

4.3.2 Test Setup.

Prior to testing, the complete test system will be analyzed to ensure proper operation and establish the performance baseline. All problems identified will be documented and corrected if detrimental to the HEMP and/or SREMP test program. The test facility will perform calibration and noise measurements on the DAS to ensure that accurate data acquisition will be achieved. The DAS utilized must account for all introduced error and be adequately protected against EM interference. The test system will be positioned in its first orientation in the facility's test volume based upon facility mapping data. Breakout boxes will be installed, dosimetry positioned (SREMP), and current and/or voltage probes will be positioned based on information obtained from the pretest analysis. The baseline or abbreviated baseline checks will be performed. Test setup photographs will be taken. These procedures will be repeated for each test orientation and configuration at each test level.

4.3.3.1 Test.

The test system will be illuminated by simulated HEMP and/or SREMP waveforms. After illumination, the test system will be analyzed to identify and quantify effects by using the pretest baseline checks and diagnostic checks, if necessary. Test probes and new dosimetry will be repositioned, if required, and the test system will be illuminated again. This procedure will be implemented until sufficient data are obtained for all functional modes and system configurations on all cables identified in the pretest analysis. At the completion of the first successful test system orientation, the system's orientation will be altered IAW the pretest analysis unless the test results dictates differently. Once adequate data are obtained for the initial test level, the test level will be incremented as specified in paragraph 4.3.1.e. The levels specified in paragraph 4.3.1 can be altered based on engineering judgments of the results/effects of the on-going test. Multiple illuminations or a substantial test sample size (seven test items is preferred) must be utilized to provide statistical confidence in the HEMP and/or SREMP survivability of the test system. Failures and significant upsets will be diagnosed as to cause and impacts on mission accomplishment. Response data will be processed, analyzed, and determined. All pertinent data will be analyzed.

The test environment data will be processed, analyzed, and determined. The four critical test environment parameters will be analyzed against the USANCA parameters to determine criteria compliance. These criteria compliances must be utilized in correcting induced and projected responses in the test system and baseline configuration, respectively.

4.3.3.2 Current Injection and SCT.

Current injection techniques are essential to distributed systems and should be utilized as an integral part of the EMP test. Current injection is greatly beneficial in the context of determining safety margins and, enhancing and verifying HEMP simulator results. But, current injection should not be the primary means of obtaining accurate HEMP data.

Based upon the actual response measurements and cable/pins identified in the pretest analysis, there will be current injected, direct or inductive, at the maximum measured current level up to a level recommended for the subassemblies by CS115 and CS116 of MIL-STD 461E or 464A references. Also, dominant coupling frequencies obtained from the simulator tests will be current injected. Current and/or voltage probes will be positioned on the injected cables and response measurements will be obtained. The baseline or abbreviated baseline checks will be performed.

Circuit response measurements will be made at each test level IAW CS115, CS116, and dominant coupling frequencies. These data will be digitized and stored so that a detailed analysis can be performed and, to update and compare against the LCNS database. Also, these data will be utilized to provide preferred safety margins such as 3X and 5X to account for variations in hardening features/devices and between systems, and input electronic piece-parts. A thorough baseline performance check will be performed at the completion of current injection testing.

The SCT should be performed on shielded cables of concern identified in the pretest analysis or during simulator testing. These data will be obtained from a spectrum analyzer and stored so that a detailed analysis can be performed. The SCT results will be utilized to baseline the performance of shielded cables for model verification and for comparison during future LCNS tests.

4.4 Gamma Dose Rate.

4.4.1 General.

4.4.1.1 Piece-Part.

Survivability of the test system's electronic piece-parts when exposed to the GDR test environment will be analyzed by:

a. Requiring testing of a minimum of 10 samples of high risk HCI vendor-parts that are identified in the pretest analysis and for which inadequate test data exists. One must adequately conduct the cost trade between part costs (i.e. parts < $50), to determine the best solution between 10 versus 30 samples.

b. Detailed characterization of all critical performance parameters of each high risk HCI requiring testing.

c. Calibrating the DAS.

d. Establishing HCI performance characteristics by monitoring transient response of the Device Under Test (DUT) and repeating the pretest performance baseline checks after each exposure.

e. Performing a detailed circuit analysis.

f. Irradiating the vendor-parts while energized.

g. Establishing Design Margins (DMs) (99/90) utilizing the results of the circuit analysis and the characterization/test program conducted at 1X, 2X, 3X and 5X, unless consistent piece-part failures dictates other reasonable DMs.

h. If the probability of a nuclear event occurring on a LRU while powered is small, then the LRU(s) can be eliminated from GDR testing,

i. Accepting/rejecting high risk HCIs based on DMs which are defined as:

$$DM = \frac{\text{Effects Threshold Level}}{\text{Criteria Dose Rate Level}}$$

4.4.1.2 Test System.

Survivability of the test system when exposed to the GDR test environment will be analyzed by:

a. Performing a detailed pretest analysis.

b. Analyzing deliberate hardening devices and/or techniques for adequacy.

c. Establishing performance and configuration baseline of the test system prior to testing.

d. Irradiating the system while energized and operating.

e. Establishing the system' operational status by identifying and quantifying effects on performance and performance differences after each GDR exposure by repeating the baseline and diagnostic checks as necessary.

f. Instrumenting the test system, installing Break-out Boxes (BOBs), and calibrating the DAS.

g. Irradiating the test system in different configurations, orientations, and modes.

h. Determining and documenting all upsets and/or damage, downtime, mission performance impacts, and necessary corrective action procedures.

i. Stressing the system by utilizing multiple exposures at the criterion level.

j. Exposing mission critical items to levels that can be utilized to verify a specified DM of at least 2X with 5X desired.

k. Determining survivability of the test item/system to the test environment.

Upsets and/or latch-ups are expected. The first corrective action attempt will be to recycle power.

4.4.1.3 Baseline System.

The survivability of the baseline system configuration when exposed to the GDR USANCA environment will be analyzed by:

a. Analyzing the differences between the test and USANCA environments.

b. Analyzing the differences between the test and baseline configurations.

c. Determining the response of the baseline configuration to the USANCA environment.

4.4.2 Test Setup.

4.4.2.1 Piece-Part.

Prior to testing, a detailed pretest performance characterization of each of the high risk HCIs in its specified test circuit must be performed. Characterization data will be collected on eleven samples of each vendor-part utilizing mainframe digital, analog, and/or mixed signal testers. The characterization program should include all major manufacturers' parameter specifications. Before testing, the desired Source-To-Target (STT) distances and pulse-widths required for each test level and configuration must be mapped and calibrated utilizing CaF_2 (Mn) TLDs and a PIN Diode. Each of the DUTs will then be positioned, in turn, centered upon the facility's beamwidth at the determined STT distance to receive the first required test level. A PIN diode will be positioned next to the DUT in the beam to measure each individual pulse-width. Calibrated probes to measure the response of the DUT are positioned on individual pins of the DUT to monitor currents, voltage, and induced photocurrents during irradiation. These probes are the input to a DAS. The DAS should utilize double shielded data cables or fiber optics to transmit signals to the transient digitizers and waveform processors. Protection of the DAS against Radio Frequency (RF) fields must be provided for, otherwise, instrumentation may be damaged or data corrupted by spurious signals. Finally, the DUT's test circuit is energized and its performance baseline is accurately established.

4.4.2.2 System.

Prior to testing, a performance baseline for the test system will be established. Problems identified will be documented and corrected if detrimental to the GDR analysis program. The various STT distances and exposure areas will be determined from previous test data, then

refined by measurements. An area equal to the area of active electronics will be mapped using CaF_2 (Mn) TLDs. The selection of each STT distance will also include the requirement that the GDR gradient across the target area is less than 10%. The test system will be powered during each irradiation. The system will be positioned at the first STT distance to receive a specified percent of the criterion GDR level based upon the pretest analysis. In place and prior to irradiation, the test system's baseline and operational status will be re-verified. The GDR level should be applied to the VPC of the test volume of the system. The TLDs and pulse shape measuring devices such as Compton

Diodes will be positioned at selected locations on the test system to measure the received gamma dose and pulse-width, respectively. The current, voltage, and/or transient photocurrent probes are positioned IAW the pretest analysis. The DAS should be setup using double shielded data cables or fiber optics, transient digitizers, and waveform processors. Protection of the DAS against RF fields must be provided for, otherwise, instrumentation may be damaged or data corrupted by spurious signals.

4.4.3 Test.

4.4.3.1 Piece-Part.

Ten samples of each vendor-part will be characterized, irradiated at 1X the criterion level while biased, and characterized again. This procedure will be repeated at 2X, 3X, and 5X the criterion level unless a valid failure occurs such as the vendor-part failing to meet manufacturer's specifications, upset, latch-up or burnout. An eleventh sample will be characterized and kept as a control device. If a valid failure occurs at or below the criterion level, the vendor-part fails qualification. If a valid failure occurs above the criterion level, then this information along with the circuit analysis will be utilized to establish the DM which, in turn, will be utilized to determine acceptance/rejection. After the DUTs have been irradiated by a GDR pulse, all circuit operational checks should be initiated within 3 minutes after the irradiation IAW MIL-STD-883[12], Methods 1020, 1021, and 1023. The facility's access time must be taken into consideration in order to provide an accurate analysis of determining whether special action should be initiated. The test environment will be analyzed against the USANCA environment and criteria compliance established. This criterion compliance will be utilized in determining the survivability analysis of the vendor-part against the USANCA criteria.

4.4.3.2 System Level.

After the energized system has been irradiated at 1X the criterion level by a pulse of bremsstrahlung photons, all operational checks should be initiated within 5 minutes or the allowable downtime of the test item after the irradiation. The time duration after irradiation to initiate the baseline checks is dependent on the safety procedures of the utilized test facility. This facility access time must be taken into consideration in order to provide an accurate analysis of determining whether special action should be initiated. If determined to be operational to an acceptable level, the test system's dosimetry will be replaced and the test system will be repositioned and irradiated again. All necessary operation checks between GDR pulses should be thorough, but as abbreviated as possible to achieve an efficient test program. This process will

be repeated until all configurations, modes, orientations and levels identified by the pretest analysis or on-going test results have been accurately tested, analyzed, and documented. The preferred test levels for system level testing are 1X, 1.5X, 2X, and 3X the criterion level with a preferred sample size of seven. If an upset or latch-up occurs, the problem will be documented and diagnosed. Testing will not be continued until the problem is completely understood and its effects on the system have been analyzed. If the problem is upset or latch-up, the affected subsystem(s) will be identified and testing will be repeated to ensure that the problem was environment induced. Test/diagnostic circuits will be employed to collect information required in determining the cause and impacts on missions. Usually, resolution can be made at the vendor-level employing the methods described in paragraph 4.4.3.1 above. Work arounds, as necessary, will be implemented to complete the testing. A follow-up investigation will be performed to identify the failure to the vendor-part level.

A final operational baseline check will be performed on the test system at the end of the test. If possible, sufficient number of test systems should be tested, analyzed, and documented as specified above to achieve extremely important statistical confidence in the GDR survivability of the test system.

The test environment data will be processed, analyzed, and determined. The critical test environment parameters will be analyzed against the USANCA parameters to determine criteria compliance. This criterion compliance must be utilized in correcting induced and projected responses in the test system and baseline configuration, respectively.

4.5 Neutron Fluence Test Procedures.

4.5.1 General.

4.5.1.1 Piece-Part.

Survivability of the test system's electronic piece-parts when exposed to the neutron fluence test environment will be analyzed by:

a. Requiring testing of 10 samples of high risk HCI vendor-parts that are identified in the pretest analysis and for which inadequate test data exists. One must adequately conduct the cost trade between part costs (i.e. parts < $50), to determine the best solution between 10 versus 30 samples.

b. Detailed characterization of all critical performance parameters of each high risk HCI requiring testing.

c. Establishing HCI performance characteristics by repeating the pretest performance baseline checks after each exposure.

d. Performing a detailed circuit analysis.

e. Irradiating the vendor-parts while not energized.

f. Establishing DMs (99/90) utilizing the results of the circuit analysis and the characterization/test program conducted at 1X, 2X, 3X, and 5X, unless consistent piece-part failures dictates other reasonable DMs.

g. Accepting/rejecting high risk HCIs based on DM which is defined as:

$$\text{DM (1 Mev Equivalent)} = \frac{\text{Fluence at Which Circuit / Device Fails}}{\text{Criteria Neutron Fluence Level}}$$

4.5.1.2 Test System.

Survivability of the test unit/system when exposed to the neutron fluence test environment will be analyzed by:

a. Performing a detailed pretest analysis.

b. Analyzing deliberate hardening devices and/or techniques for adequacy.

c. Establishing performance and configuration baseline of the test unit/system prior to testing.

d. Irradiating the unit/system while not energized.

e. Establishing the unit/system's operational status by identifying and quantifying effects on performance and performance differences after each neutron fluence exposure by repeating the baseline and diagnostic checks as necessary.

f. Irradiating the test system in different orientations.

g. Determining and documenting all damage, downtime, mission performance impacts, and necessary corrective action procedures.

h. Exposing mission critical items to levels that can be utilized to verify a specified DM of at least 2X with 3X highly desired.

i. Determining survivability of the test unit/system to the test environment.

4.5.1.3 Baseline System.

The survivability of the baseline system configuration when exposed to the neutron fluence USANCA environment will be analyzed by:

a. Analyzing the differences between the test and USANCA environments.

b. Analyzing the differences between the test and baseline configurations.

c. Determining the response of the baseline configuration to the USANCA environment.

4.5.2 Test Setup.

4.5.2.1 Piece-Part.

Prior to testing, a detailed pretest performance characterization of each of the high risk HCIs in its specified test circuit must be performed. Characterization data will be collected on eleven samples of each vendor-part using mainframe digital, analog, and/or mixed signal testers. The characterization program should consist of all major manufacturers' specifications. Before testing, the desired STT distances and reactor modes required for each test level must be obtained. The various STT distances will be determined from previous test data, and then refined by measurements, if necessary, utilizing sulfur fluence detectors. Each of the DUTs will then be positioned at the determined STT distance to receive the first required exposure level. Pairs of TLDs and sulfur detectors will be placed beside each of the vendor-parts to measure the received gamma dose and neutron fluence, respectively.

4.5.2.2 Test Unit/System.

Prior to testing, a performance baseline for the test unit/system will be established. Problems identified will be documented and corrected if detrimental to the neutron fluence analysis program. The various STT distances will be determined from previous test data and then refined by measurements. An area equal to the area of neutron sensitive piece-parts will be mapped using CaF_2 (Mn) TLDs and sulfur fluence detectors. The selection of each STT distance will also include the requirement that the neutron fluence gradient across the target area is less than 10%. The test unit/system will be deployed and tested in a realistic configuration at the first STT distance. The specified neutron fluence level should be applied to the VPC of the test unit/system's exposure volume of concern. The TLDs and sulfur detectors will be positioned at selected locations on the test unit/system. Sulfur detectors and TLDs should also be positioned at locations at each of these STT distances in a relatively free-field environment to measure the received gamma dose and neutron fluence, respectively. If required to adequately determine the neutron fluence response of an operate through system, the data acquisition should be accomplished utilizing photocurrent probes, double shielded data cables or fiber optics, transient digitizers, and waveform processors. If the gradient requirement of 10% cannot be met and the test item does not possess an operate through requirement, the test item can be disassembled, exposed in the neutron fluence environment, reassembled, and analyzed to determine the effects on the mission essential functions on the test item.

4.5.3 Test.

4.5.3.1 Piece-Part Level.

Ten samples of each vendor-part will be characterized, irradiated at 1X the criterion level, and characterized again. This procedure will be repeated at 2X, 5X, and 10X the criterion level unless a valid failure occurs such as the vendor-part failing to meet its circuit's specifications. An eleventh sample will be characterized and kept as a control device. If a failure occurs, at or

below the criterion level, the vendor-part fails qualification. If a failure occurs above the criterion level, then this information along with the circuit analysis will be utilized to establish the DM which, in turn, will be utilized to determine acceptance/rejection. After the DUTs have been irradiated by neutrons, all post characterization should be initiated within 24 hours after the irradiation IAW MIL-STD-883, Methods 1017. The test environment will be analyzed against the USANCA environment and criteria compliance obtained. This criterion compliance will be utilized in determining the survivability analysis of the vendor-part against the USANCA criteria.

4.5.3.2 Unit/System Level.

After the unit/system has been irradiated at 1X the criterion level, all operational checks should be initiated ASAP after the irradiation. For non-powered experiments, usually one hour is the typical time interval between exposure and checkout. The actual access time after irradiation to perform operational checks is dependent on the safety procedures of the utilized test facility. If determined to be operational to an acceptable level, the test unit's/system's dosimetry will be replaced and the test hardware will be repositioned and irradiated again. This process will be repeated until all test levels and conditions identified by the pretest analysis or on-going test results, have been accurately tested, analyzed, and documented. The preferred test levels for system level testing are 1X, 1.5X, 2X, and 3X the criterion level and the preferred sample size is seven. If a failure occurs, the problem will be documented and diagnosed. Testing will not be continued until the problem is completely understood and its effects on the system have been analyzed. The affected subsystem(s) will be identified and testing may be repeated on a second sample to determine whether the problem was environment induced. Test/diagnostic circuits may be employed to collect information required in determining the cause and impacts on missions. Usually, resolution can be made at the vendor-part level employing the methods described in paragraph 4.5.3.1 above. Work arounds, as necessary, will be implemented to complete the testing. A follow-up investigation will be performed to identify the failure to the vendor-part level. A final operational baseline check will be performed on the test system at the end of the test. If possible, sufficient number of test units/systems should be tested, analyzed, and documented as specified above to achieve extremely important statistical confidence in the neutron fluence survivability of the test unit/system.

The test environment data will be processed, analyzed, and determined. The critical test environment parameters will be analyzed against the USANCA parameters to determine criterion compliance. This criterion compliance must be utilized in correcting induced and projected responses in the test system and baseline configuration, respectively.

4.6 Gamma Total Dose Test Procedures.

4.6.1 General.

4.6.1.1 Piece-Part.

Survivability of the test system's electronic piece-parts when exposed to the GTD test environment will be analyzed by:

a. Requiring testing of 10 samples of high risk HCI vendor-parts that are identified in the pretest analysis and for which inadequate test data exists. One must adequately conduct the cost trade between part costs (i.e. parts < $50), to determine the best solution between 10 versus 30 samples.

b. Detailed characterization of all critical performance parameters of each high risk HCI requiring testing.

c. Establishing HCI performance characteristics by repeating the pretest performance baseline checks after each exposure.

e. Irradiating the vendor-parts in one continuous pulse of less than one minute duration while energized and operating.

f. Establishing DMs (99/90) utilizing the results of the circuit analysis and the characterization/test program conducted at 1X, 1.5X, 2X, and 3X, unless consistent piece-part failures dictates other reasonable DMs.

g. If the probability of an nuclear event occurring on a the LRU while powered is small, then the LRU(s) can possibly be eliminated from total gamma dose testing.

h. Accepting/rejecting high risk HCIs based on DM which is defined as:

$$DM = \frac{\text{Failure Absorbed Dose}}{\text{Criteria Total Dose Level}}$$

4.6.1.2 Test System.

Survivability of the test system to the GTD test environment will be analyzed by:

a. Performing a detailed pretest analysis.

b. Analyzing deliberate hardening devices and/or techniques for adequacy.

c. Establishing performance and configuration baseline of the test system prior to testing.

d. Irradiating the system while energized and operating.

e. Establishing the system's operational status by identifying and quantifying effects on performance and performance differences after each total gamma dose exposure by repeating the baseline and diagnostic checks as necessary.

f. Instrumenting the test system, installing Break-out Boxes (BOBs), and calibrating the DAS.

g. Irradiating the test system in different configurations, orientations, and modes, as required.

h. Determining and documenting all upsets and/or damage, downtime, mission performance impacts, and necessary corrective action procedures.

i. Exposing mission critical items to levels that can be utilized to verify a specified DM of at least 2X with 3X highly desired.

j. Determining survivability of the test system to the test environment.

4.6.1.3 Baseline System.

The survivability of the baseline system configuration when exposed to the GTD USANCA environment will be analyzed by:

a. Analyzing the differences between the test and USANCA environments.

b. Analyzing the differences between the test and baseline configurations.

c. Determining the response of the baseline configuration to the USANCA environment.

4.6.2 Test Setup.

4.6.2.1 Piece-Part.

Prior to testing, a detailed pretest performance characterization of each of the high risk HCIs in its specified test circuit must be performed. Characterization data will be collected on eleven samples of each vendor-part using mainframe digital, analog, and mixed signal testers. The characterization program should consist of all major manufacturer's specifications. Before testing, the desired STT distances and runtimes required for each test level and configuration must be mapped and calibrated utilizing CaF_2 (Mn) TLDs. TLDs will be placed next to each of the DUTs to measure the received gamma dose. Each of the DUTs or set of DUTs will then be positioned at the STT distance to receive the first required test level. Next, the DUT's test circuit will be energized and its baseline performance accurately established. Calibrated probes to measure the response of the DUT are positioned on individual pins of the DUT to monitor currents and voltages during irradiation. These probes are the input to a DAS. The DAS should utilize double shielded data cables to transmit signals to the transient digitizers and waveform processors.

4.6.2.2 System.

Prior to testing, a performance baseline for the test system will be established. Problems identified will be documented and corrected if detrimental to the total gamma dose analysis program. The various STT distances and exposure areas will be determined from previous test

data, then refined by measurements. The area equal to the area of gamma dose sensitive electronics will be mapped using CaF_2 (Mn) TLDs. The selection of each STT distance will also include the requirement that the total gamma dose gradient across the target area is less than 10%. The test system will be deployed at the first STT distance and tested in realistic configurations based on the pretest analysis. The test system will be powered during each irradiation. In place and prior to irradiation, the test system's baseline and operational status will be re-verified. The GTD level should be applied to the VPC of the test system exposure volume of concern. The TLDs will be positioned at selected locations on the test system to measure the received gamma dose. If required to adequately determine the total gamma dose response of the test system, a DAS will be setup and using voltage and/or current probes along with double shielded data cables, transient digitizers, and waveform processors. If at all possible, the total gamma dose exposure should be deposited on the test item within one minute.

4.6.3 Test.

4.6.3.1 Piece-Part Level.

Ten samples of each vendor-part will be characterized, irradiated at 1X the criterion level while biased and operating, and characterized again. The GTD must be delivered to the vendor-part in one continuous pulse within one minute. This procedure will be repeated at 1.5X, 2X, and 3X the criterion level unless a valid failure occurs such as the vendor-part failing to meet manufacturer's specifications or the circuit requirements. An eleventh sample will be characterized and kept as a control device. If a valid failure occurs, at or below the criterion level, the vendor-part fails qualification. If a failure occurs above the criterion level, then this information along with the circuit analysis will be utilized to establish the DM which, in turn, will be utilized to determine acceptance/rejection. After the DUT has been irradiated by gammas, all circuit operational checks should be initiated within 5 minutes after the irradiation IAW MIL-STD-883, Method 1019. The test environment will be analyzed against the USANCA environment and criteria compliance will be determined. This criterion compliance will be utilized in determining the survivability of the vendor-part against the USANCA criteria.

4.6.3.2 System Level.

After the energized and operating system has been irradiated at 1X the criterion level by gamma photons, all operational checks should be initiated within 5 minutes after the irradiation. The time duration after irradiation to initiate the baseline and operational checks is dependent on the safety procedures of the utilized test facility. If determined to be operational to an acceptable level, the test system's dosimetry will be replaced and the test system will be repositioned and irradiated again. All necessary operation checks between total gamma dose exposures should be thorough, but as abbreviated as possible to achieve an efficient test program. This process will be repeated until all configurations, modes, orientations and levels identified by the pretest analysis or on-going test results have been accurately tested, analyzed, and documented. The preferred test levels for system level testing are 1X, 1.5X, and 2X the criterion level and the preferred sample size is five. If a failure occurs, the problem will documented and diagnosed. Testing will not be continued until the problem is completely understood and their effect on the system has been analyzed. The affected subsystem(s) will be identified and testing may be

repeated on a replacement subsystem to ensure that the problem was environment induced. Test/diagnostic circuits will be employed to collect information required in determining the cause and impacts on missions. Usually, resolution can be made at the vendor-part level employing the methods described in paragraph 4.6.3.1 above. Work arounds, as necessary, will be implemented to complete the testing. A follow-up investigation will be performed to identify the failure to the vendor-part level. A final operational baseline check will be performed on the test system at the end of the test. If possible, sufficient number of test systems should be tested, analyzed, and documented as specified above to achieve extremely important statistical confidence in the total gamma dose survivability of the test system.

The test environment data will be processed, analyzed, and determined. The critical test environment parameters will be analyzed against the USANCA parameter to determine criterion compliance. This criterion compliance must be utilized in correcting induced and projected responses in the test system and baseline configuration, respectively.

5. DATA REQUIRED.

5.1 Nuclear Airblast.

a. Detailed description of the method of producing the airblast environment to include photographs displaying test system configuration with respect to the origin of the airblast environment.

b. Detailed description of all operational and performance baseline checks for all test items comprising the test system.

c. Results from the pretest analysis to include data from the contractor's test/analysis and other airblast test/analysis programs performed on similar military systems.

d. Detailed description (to include composition of the exposed material and hardening hardware) serial numbers, and dimensions of all test items in the test system.

e. Results of the airblast environment measurements with the peak static overpressure expressed in kilopascals(kPa)(±4%), the overpressure duration expressed in milliseconds (ms)(±4%), the overpressure impulse expressed in kPa-ms(±4%), the peak dynamic pressure expressed in kPa(±4%), the dynamic pressure positive duration expressed in ms(±4%), the dynamic pressure impulse expressed in kPa-ms(±4%), the peak static underpressure expressed in kPa(±4%), and the arrival time expressed in seconds (±4%).

f. Detailed description, serial numbers, and location to include photographs of placement of all response measuring gages such as pressure transducers, strain gages, load cells, and accelerometers.

g. Detailed description of the DAS hardware/software.

h. Calibration and percent error data for all data acquisition equipment.

i. Detailed photographs of the test system before and after exposure of airblast environment.

j. Results of pre- and post-exposure visual inspections and pre- and post-exposure performance/operational checks.

k. Results of all failure diagnostics.

l. Expected system acceleration, pressure, or strain responses for gage selection and setting up data recording equipment.

m. Baseline configuration of the test system and proposed production system.

n. List and description of all expected test system support equipment.

o. Detailed description of mission essential functions.

p. Manikins' response measurements, including acceleration (g ±4%), pressure (kPa ±4%), pressure duration (ms ±4%), and peak force (newtons ±4%).

q. Complete set of pretest calculated peak static overpressure levels versus radial distance of test system position from source.

r. High-speed (250 and/or 400 frames per second) motion-picture camera photographs of the test system during the event.

s. Test Incident Reports (TIRs).

5.2 Nuclear Thermal Radiation.

a. Detailed description of the test facility and method of producing the thermal radiation environment to include photographs displaying test item or system configuration with respect to the thermal radiation environment source.

b. Results of pretest thermal radiation analysis on the test item and/or system, identifying potentially high risk test items and/or areas.

c. Results from the pretest analysis to include data from the contractor's test/analysis and other thermal radiation test/analysis programs performed on similar military systems.

d. Detailed description of all performance and operational baseline checks for all items in the test system to be tested.

e. Detailed description (to include composition of the material), serial numbers, and dimensions of all test items in the test system.

f. Materiel Safety Data Sheets (MSDS) for all irradiated test items.

g. Results of the thermal radiation environment measurements with the total energy expressed in [cal/cm²] (±7%), maximum irradiance expressed in [cal/cm²-sec] (±7%), time to maximum irradiance expressed in seconds (±7%), and pulse-width (FWHM) (±7%) expressed in seconds.

h. Detailed description of the DAS hardware/software.

i. Calibration and percent error data for all data acquisition equipment.

j. Photographs of the test item, before and after exposure to the thermal radiation environment.

k. Results of pre- and post-exposure visual inspections and pre- and post-exposure performance and operational checks.

l. Results of failure diagnostics.

m. Detailed description of mission essential functions.

n. Detailed description of test item configurations.

o. Baseline configuration of the test system and proposed production system.

p. Detailed description of all expected test item support equipment.

q. TIRs.

5.3 HEMP / SREMP.

a. Detailed description of the method and facility of producing the HEMP and SREMP environment to include photographs of the test facility setup showing test system location relative to the HEMP and SREMP source.

b. Complete set of pretest mapping data of the facility with the E-field expressed in volts/meter (±5%), rise time and pulse-width expressed in nanoseconds (ns) (±5%), frequency expressed in Hertz (±5%), and H-field amplitude expressed in amp-turns/meter (±5%), GDR expressed in cGy(Si)/sec (±5%), duration of each gamma radiation pulse expressed in seconds (±5%).

c. Results from the pretest analysis to include data from the contractor's HEMP and SREMP test/analysis programs as well as other such programs performed on similar military systems.

d. Detailed description of system performance and operational checks utilized to baseline the system and determine its post-illumination operational status.

e. Complete list of all active electronic piece-parts utilized in the test system.

f. Complete set of electrical schematics and interconnect diagrams.

g. Detailed description, serial numbers, and dimensions of each subsystem of the test system.

h. Detailed description of all system cables to include type, composition, and dimensions.

i. Detailed description of all backshells and connectors to include attachment methodology, type, and composition.

j. Detailed description of the grounding scheme utilized on the test system.

k. Complete list of safety and environmental concerns.

l. Detailed description of all mission essential functions.

m. Detailed description of all deliberate EM hardening techniques/hardware to include manufacturer's specifications.

n. Detailed description of pretest selected system configurations, orientations, and modes utilized during the test.

o. Detailed description and documentation of all inspections, downtime (sec) (±10%), performance and operational checks, and maintenance procedures.

p. Detailed description of the facility's data acquisition system to include probe calibration data, noise measurements, hardware and software.

q. Detailed description of utilized current and voltage probes, BOBs and probe locations employed on the test system.

r. Results of all HEMP and SREMP environment and test points measurements to include real time response and Fast Fourier Transforms (FFTs).

s. Results obtained from the pretest analysis, Shielded Cable Tests (SCTs), and Current Injection tests (CI).

t. Detailed description of the method and facility producing the SCTs and CIs.

u. Detailed description of recovery procedures and time.

v. Detailed description of the method and facility of producing the GDR test environment including photographs of the test facility setup showing test system location relative to the gamma radiation source.

w. Results and locations of dosimetry utilized (SREMP).

x. Complete set of pretest mapping data in radiation absorbed dose (cGy) in silicon (cGy(Si))(±10%) and cGy(tissue) (±10%) for each expected test location.

y. Results of all energy coupling and protection hardware analysis to include DMs.

5.4 Gamma Dose Rate.

a. Detailed description of the method and facility of producing the GDR test environment including photographs of the test facility setup showing test system location relative to the gamma radiation source.

b. Complete set of pretest mapping data in radiation absorbed dose (cGy) in silicon (cGy(Si))(±10%) and cGy(tissue) (±10%) for each expected test location.

c. Rise time and pulse-width (FWHM) of each gamma pulse.

d. Results from the pretest analysis to include data from other GDR test/analysis programs performed on similar military systems.

e. Test data and/or analytical data and analysis on the HCIs and the test system from contractor such as Design Parameter Reports (DPRs).

f. List of all active electronic piece-parts utilized in the test system.

g. Piece-part characterization and test data on HCIs from available databases.

h. Detailed description, serial numbers, and dimensions of each subsystem of the test system.

i. Results of applicable piece-part tests and circuit analysis to include DMs.

j. Description of statistical method(s) used to determine DMs.

k. Detailed description and electrical schematics of test circuits utilized.

l. Detailed description of all mission essential functions.

m. Duration of each gamma radiation pulse (sec) (±10%).

n. Total gamma dose expressed in cGy(Si) and cGy(tissue) (±10%).

o. Detailed description of all utilized data acquisition procedures and hardware/software.

p. Detailed description of expected system configurations, orientations, and modes.

q. Detailed description and documentation of all inspections, downtime (sec) (±10%), operational checks, and maintenance procedures.

r. Type and location of dosimeters on the test system for each test exposure.

s. Conversion factors (±10%) used to convert cGy(CaF_2) to cGy(Si) and cGy(tissue).

t. Complete list of safety and environmental concerns.

u. TIRs.

v. Diagnostic data on all failure(s) or unacceptable degradation(s).

5.5 Neutron Fluence.

a. Detailed description of the method and facility of producing the neutron fluence test environment including photographs of the test facility setup showing test system location relative to the neutron fluence source.

b. Time duration (sec) (±1 sec.) and nominal power level (watts) (±5%) for each steady-state operation.

c. Documentation of each radiation pulse signature to include the shape, width at FWHM (sec) (±10), and burst size (Delta T °C) (±10%).

d. Results of the pretest analysis and data from other neutron fluence test/analysis programs performed on similar military systems.

e. Test data and/or analytical data and analysis on HCIs and the test system from contractor such as DPRs.

f. List of all active electronic piece-parts utilized in the test system.

g. Piece-part characterization and test data on HCIs from available databases.

h. Detailed description (to include material composition, serial numbers, and dimensions of each test item of the test system.

i. Complete set of electrical schematics.

j. Results of applicable piece-part test and circuit analysis to include DMs.

k. Description of statistical method(s) used to determine DMs.

l. Detailed description of all mission essential functions.

m. Detailed description of utilized data acquisition procedures, hardware/software.

n. Detailed description of test item or system configurations, orientations, and modes.

o. Detailed description and documentation of all inspections, downtime (sec) (±10%), operational checks, and maintenance procedures.

p. Type and location of dosimeters on the test system for each test exposure.

q. Conversion factors (±10%) used to convert cGy(CaF_2) to cGy(Si) and cGy(tissue).

r. Complete list of safety and environmental concerns.

s. TIRs.

t. Diagnostic data on all failure(s) or unacceptable degradation(s).

u. Results of all neutron environment measurements with neutron fluence expressed in terms of 1 Mev (Si) equivalent damage fluence (n/cm²), (±10%) neutron dose expressed in cGy(Si) (±10%), and gamma dose expressed cGy(Si) and cGy(tissue) (±10%).

v. Complete list of possible expected radioactive isotopes and corresponding half-lifes.

5.6 Gamma Total Dose.

a. Detailed description of the method and facility of producing the GTD test environment including photographs of the test facility setup showing test system location relative to the gamma radiation source.

b. Complete set of pretest mapping data in radiation absorbed dose (cGy) in silicon (cGy(Si))(±10%) and cGy(tissue) (±10%) for each expected test location.

c. Results of the pretest analysis and data from other total gamma dose test/analysis programs performed on similar military systems.

d. List of all active electronic piece-parts utilized in the test system.

e. Test data and/or analytical data and analysis on HCIs and the test system from contractor such as DPRs.

f. Piece-part characterization and test data on HCIs from available databases.

g. Detailed description, serial numbers, and dimensions of each subsystem of the test system.

h. Detailed description and electrical schematics of test circuits utilized.

j. Results of piece-part tests and circuit analysis to include DMs.

k. Description of statistical method(s) used to determine DMs.

l. Detailed description of all mission essential functions.

m. Duration of each gamma radiation pulse (sec) (±5%).

n. Total gamma dose expressed in cGy(Si) and cGy(tissue) (±10%).

o. Detailed description of all utilized data acquisition procedures.

p. Detailed description and documentation of all inspections, downtime (sec) (±10%), operational checks, and maintenance procedures.

q. Type and location of dosimeters on the test system for each test exposure.

r. Conversion factors (±10%) used to convert cGy(CaF_2) to cGy(Si) and cGy(tissue).

s. Complete list of safety and environmental concerns.

t. TIRs.

u. Diagnostic data on all failure(s) or unacceptable degradation(s).

See Appendix G, Page G-2 for an example of system test data documentation.

6. PRESENTATION OF DATA.

6.1 Data Appropriation and Compliance.

Results from the pretest analysis, and all other applicable nuclear survivability programs will be analyzed and, whenever possible, incorporated into all facets of the NTSA on the test system. The incorporation of all available analytical and test data will be used to enhance and reduce the overall scope of the test program.

Data from free-field environment measurements will be utilized to define the test environment and quantify the differences between the test and criterion environments. Differences greater than 15% between the primary parameter values will be analyzed to determine the effect on the test results. Procedures and analysis utilized will be clearly documented.

Results from the pretest analysis, system test and post-test determination/analysis, and environment compliance will be integrated into an analysis of the survivability of the test system's configuration to the test and then the USANCA environments. The final analysis of the test system may show different damage and mission impacts than the test system's results due to extrapolation and correction of environmental and test results to account for variances and differences.

The USANCA NTSA requirements are usually derived from the following documents:

a. QSTAG 244, Edition 4: Nuclear Survivability Criteria for Military Equipment[13].

b. QSTAG 620, Edition 2: Nuclear Survivability Criteria for Communications-Electronics Equipment[14].

c. MIL-STD-2169B: High Altitude Electromagnetic Pulse (HEMP) Environment[15].

The final survivability analysis of the baseline system configuration to the USANCA requirements will utilize, incorporate, and integrate data and results of the test system survivability determination and analysis of the configuration differences. This final survivability analysis of the baseline configuration may show results different than the test system analysis due to extrapolations and/or corrections for configuration differences.

6.2 Data Reduction.

All raw data collected during nuclear survivability testing must be processed to remove data acquisition and dosimetry error and to refine simulation deficiencies. All analytical procedures and methods utilized to process these raw data must be documented along with example calculations in " Appendix B: Test Data" of a detailed test report. The entire collection of raw data should not be presented in the test report because of its excessive bulk. Reduced data that are pertinent to the analysis and support the determinations should be included in tabular form in the main body.
Quantitative and analytical techniques along with adequate response measurements must be utilized during all nuclear survivability testing. A simple GO / NO-GO test is not acceptable and will not enable the survivability of the system to be determined.

The data must demonstrate that the test hardware was adequately tested to its specified criteria in each nuclear test environment. The test environments will then be processed and combined with the pretest results, along with the body of data analyzed, so that the survivability of the test configuration can be determined. Analytical techniques such as PSPICE, Messenger-Spratt and curve fitting must be discussed with constraints and inputs to enable the reader to determine adequacy. All analytical data reduction methods must be identified and presented in Appendix B of the test report.

Testing in the HEMP/SREMP and nuclear airblast environment must include data in both the frequency and time domains as well as pertinent processed data in Appendix B of the test report.

Statistical analysis such as computing the mean, standard deviation, 99/90 tolerance limit, minimum data, DMs, and criteria compliance percentages should be performed on all nuclear survivability system test data. Type and quality of data will determine the statistical methods to be employed.

Whenever an electronic piece-part possesses sample size of eleven or more and the data can be assumed to come from a normally distributed population, a 99/90 tolerance limit will be calculated. This statistical figure, calculated from the mean, standard deviation and sample size, is the limit below (or above, depending on the specific parameters of interest) which we expect (with 90% confidence) 99% of the population to survive. In cases where the underlying distribution of the data is not known and cannot be assumed to be normal, nonparametric statistics should be used. In these cases, larger sample sizes will be required to provide the same confidence of attaining the DM. It should be noted that some adjustment to the desired confidence level and/or population proportion may be necessary for nonparametric techniques (e.g., the 90/90 nonparametric tolerance limit requires a sample size of 22, the 95/90 nonparametric tolerance limit requires a sample size of 45, and the 99/90 nonparametric tolerance limit requires a sample size of 230). Any changes in population proportions or confidence levels should be coordinated with the AEC independent evaluator or DTC independent assessor.

In electronic piece-part testing, the minimum preferred sample size is eleven because one device is utilized as a control device; these devices are required for the GDR, GTD and NF phases. If possible, a minimum of four electronic devices should be tested to all required test environments.

In system level testing, the preferred sample size of seven is desired to provide an acceptable level of statistical confidence. However, this sample size is extremely difficult to obtain in system level testing. Therefore, stress testing is used to provide additional confidence in the results. Typical stress levels are 1X, 2X, and 4X for INR, 1.3X for airblast and thermal radiation, and 25 illuminations at HEMP/SREMP criteria or 10 illuminations at 1.5X HEMP/SREMP criteria.
Additional data reduction and analytical techniques can be found in the following documents:

a. TOP 1-2-618[16].

b. TOP 1-2-619[17].

c. TOP 1-2-620[18].

6.3 Data Presentation.

Data must be presented in a clear and concise manner, so they are easy to understand and support the conclusions regarding the nuclear survivability of test item/system hardware as depicted in Appendix G. To accomplish this, a combination of charts, graphs, drawings, tables, and photographs should be utilized.

a. Tables should be utilized to present the following data:

(1) Irradiation / Illumination Test Results Summary.

(2) Equipment Test Matrix.

(3) Criteria Compliance.

(4) Test Point Data.

(5) Statistical Analysis.

(6) Criteria and Test Standards.

(7) Test Comparisons.

b. Photographs should be utilized to present the following data:

(1) Dosimetry Locations.

(2) Test Configurations, Orientations, and Set-ups.

(3) Test Facility's Data Acquisition Set-up.

(4) Locations of Other Utilized Measuring Devices.

(5) Real Time Response (airblast).

(6) Test Facility Layout.

(7) Visible Damage.

c. Drawings should be utilized when photography is not available or inadequate to display critical data supporting the results and/or conclusions. Drawings may also be utilized to illustrate airblast and/or thermal damage and/or effects and test orientations / configurations.

d. Charts and Graphs should be utilized to present the following data:

(1) Test Schedules.

(2) Criteria Compliance.

(3) Previous Test Comparisons.

(4) Comparisons of Test Point Data with the Test Item in Different Configurations, Orientations, or Modes.

(5) Test Program Status.

e. Circuit analysis and DM determination for each high risk HCI must be provided in Appendix B. As a minimum, the data must include:

(1) Test Circuit Layout.

(2) Utilized Analytical Techniques.

(3) Application of Utilized Data.

(4) Design Margins.

APPENDIX A: GENERAL NUCLEAR WEAPON EFFECTS.

The detonation of a nuclear weapon generates the following four primary effects or energy distributions: blast, thermal radiation, Initial Nuclear Radiation (INR), and residual nuclear radiation. A fifth effect is generated by the interaction of the INR with the atmosphere and is designated electromagnetic effects. These distributions illustrated in Figure A-1 are for a generic tactical event at or near the surface. Height-Of-Burst (HOB), weapon type, and weapon configuration do have an affect on the shown energy distributions.

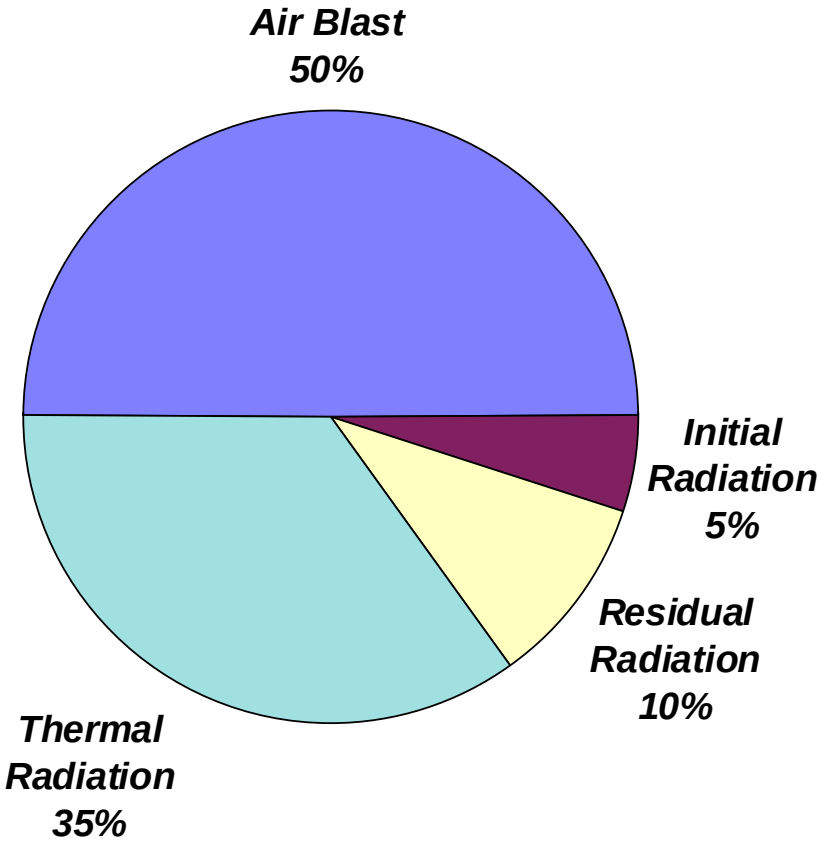


Figure A-1: Nuclear Weapon Energy Distribution.

A.1 Blast Effects.

The blast effects of a nuclear weapon is extremely similar to those caused by a conventional weapon explosion, but possessing a much larger magnitude and longer duration. The blast wave travels radially in all directions from Ground Zero (GZ), initially at a speed greater than sound, but decreases as a function of radial distance to subsonic and finally to zero. Blast effects are considered the most damaging to exposed military equipment except armor. Blast effects are typically the greatest cause of collateral damage, but is not typically the greatest personnel casualty producer.

A.2 Thermal Effects.

The thermal pulse of a nuclear weapon is characterized by an intense blinding flash and an immense thermal pulse. The great intensity of this flash can cause blindness to military personnel, either temporary or permanent. The thermal radiation is emitted in two distinct separate pulses. The first thermal pulse occurs as a result of X-ray interaction with weapon materials and is insignificant since it contains very little energy. The second pulse contains tremendous energy and is considered militarily significant and generally the largest casualty producer of exposed personnel. The thermal pulses have two damage producing mechanisms which are: direct damage produced by generated heat and, secondary damage caused by fires and explosions from the ignition of surrounding materials. The blast wave may suppress some fires caused by these thermal pulses. The blast wave combined with the thermal pulse may create synergistic effects.

A.3 Initial Nuclear Radiation Effects.

The INR pulse of a nuclear weapon consists of gamma photons and neutrons which are emitted within a few tens of nanoseconds after the event. These highly penetrative gamma photons and neutrons are extremely damaging to military personnel and electronics. The magnitude of this radiation at a given distance from GZ is dependent upon weapon yield, type and height of burst, terrain and atmospheric conditions. For middle to high yield weapons, the damaging effects generated by the blast wave and thermal radiation greatly surpasses INR effects for unprotected equipment and personnel.

A.4 Residual Radiation Effects.

The residual radiation effects of a nuclear weapon consists of radioactive weapon debris, radioactive fallout, rainout, and Neutron Induced Activity (NIA) which sustains for longer than one minute after weapon detonation. The two militarily significant radiations which compose residual radiation are beta particles and gamma photons. Residual radiation has essentially no damaging effects on military systems, but presents major difficulties on military personnel in the area surrounding GZ, downwind of GZ and troop movement through contaminated areas.

A.5 Electromagnetic Effects.

The electromagnetic environment of a nuclear weapon consists of the ionization of the surrounding atmosphere and Electromagnetic Pulse (EMP). The gamma photons, neutrons, beta particles, X-rays, and positive ions emitted from the nuclear detonation causes electrons to be ejected from their perspective atoms, thus ionizing the atmosphere in the burst vicinity. This increase in electron density attenuates or refracts all electromagnetic signals from a few seconds to several hours depending on weapon yield and HOB. A nuclear detonation distributes approximately one millionth of its energy in the form of an intense EMP with a frequency content of a few hertz (Hz) to several hundred MHz. The two EMP situations which are based upon weapon HOB are Endo-Atmospheric (SREMP) and Exo-Atmospheric (HEMP). SREMP occurs with an atmospheric event at an altitude of less than 40 km above sea level, possessing an extremely large electric and magnetic field over the burst vicinity. HEMP occurs from an event occurring at an altitude greater than 40 km above sea

level and possesses a large electric and magnetic field over a diverse area. Of the two EMP situations, HEMP is considered the most militarily significant. In fact, HEMP is a line-of-sight phenomenon and can cause damage over hundreds of thousands even millions of square miles. HEMP has the greatest range of damage of all nuclear effects.

A.6 Time History of Effects.

All effects produced by a nuclear weapon are dependent upon weapon yield, type of weapon, HOB, atmospheric conditions, and distance from GZ. See Figure A-2 on the following page for the sequence and time history of nuclear weapon effects from an example 27 kT weapon detonation at a HOB of 180 m at a distance of 1 km.

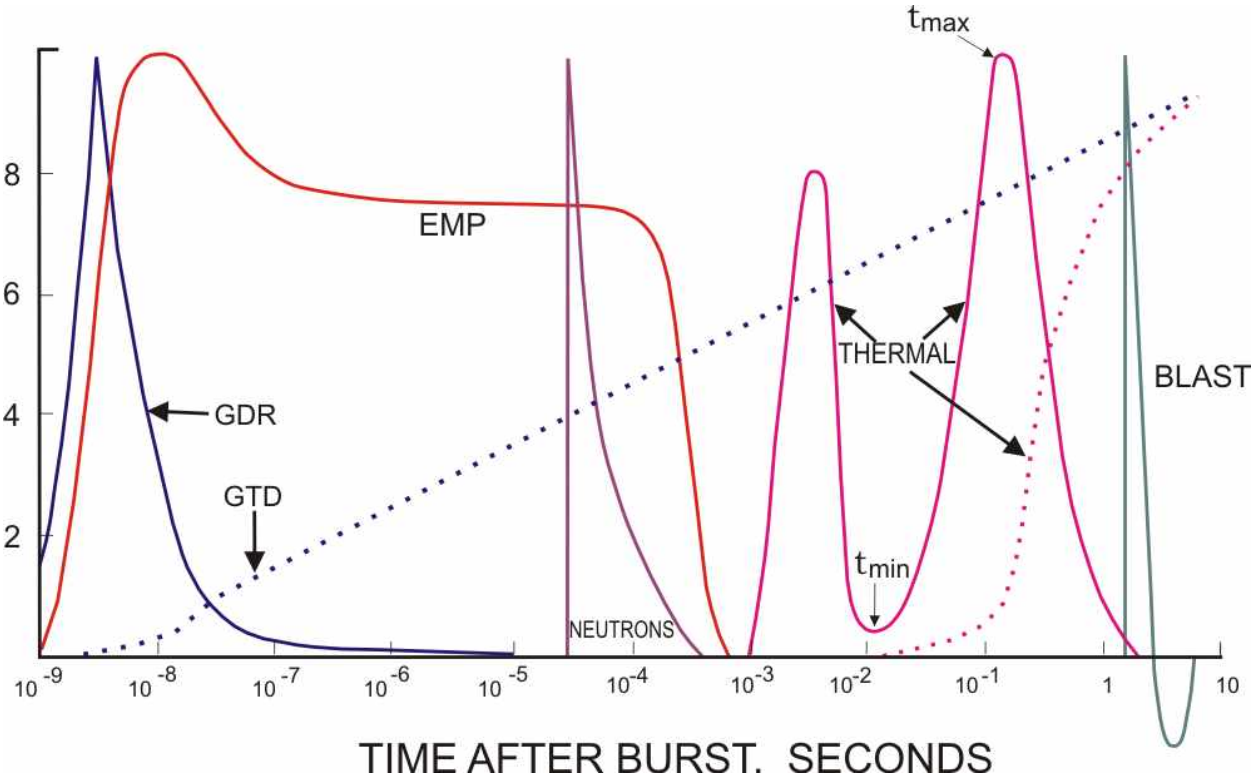


Figure A-2. Example Time History from 27 kT Nuclear Weapon.

The information provided in Appendices B through E where referenced from the following publications:

a. The Effects of Radiation on Electronic Systems[19].
b. The Effects of Nuclear Weapons[20].
c. Nuclear Weapons and Their Effects[21].

APPENDIX B: NUCLEAR AIRBLAST ENVIRONMENT AND EFFECTS.

Approximately fifty percent of the total energy generated by an Endo-Atmospheric detonation (HOB less than 40 km above sea level) of a normal type of nuclear weapon is in the formation of a tremendous blast or shock wave. Since the air density is relatively high up to 40 km above sea level, the nuclear weapon detonation generates extremely high velocity atoms which transfer tremendous energy to the closest layer of air, compresses a layer of surrounding air, and causes it to propagate outward from the center of the explosion. In the process of compressing a layer of air, a rarefaction occurs in the vacated space creating, in effect, a negative pulse, which propagates outward. Energy is then transferred to each successive air layer and upon emerging from the fireball, this energy release has assumed the characteristics of a blast or shock wave. Initially exceeding the speed of sound, this transfer of energy and momentum forces the air layers to form the shock front of the blast wave.

The blast wave generates five significant damage parameters: static overpressure, dynamic pressure, impulse, duration, and negative overpressure. The first damage parameter overpressure which is defined as the transient pressure above the ambient pressure that acts on objects from all sides and tends to crush inwardly due to pressure differences. The variation of the overpressure with time depends on the energy yield of the explosion, the distance from the point of burst, and the medium in which the weapon is detonated. The second damage parameter is dynamic pressure which is defined as the air pressure which results from the mass air flow or wind behind the shock front of the blast wave that tends to overturn, tumble, or tear apart materiel. It is equal to the product of one half of the air density through which the blast wave passes and the square of the wind velocity behind the shock front as it impinges on the object or structure. The third significant damage parameter is impulse which is defined as the product of the overpressure or dynamic pressure from the blast wave and the time during which it acts at a given point. More specifically, it is the integral, with respect to time of overpressure or dynamic pressure, between the times of arrival of the blast wave and where that parameter returns to zero at a given point. The fourth significant parameter is duration which is the time in which a phase of the overpressure or dynamic pressure acts upon an object. The final damage parameter is defined as the transient pressure below the ambient pressure that oftentimes enhances damage by pulling back on objects that may be unstable and experiencing forces in the opposite direction. Blast damage will increase with an increase in any of the above parameters. A typical blast wave is illustrated in Figure B-1.

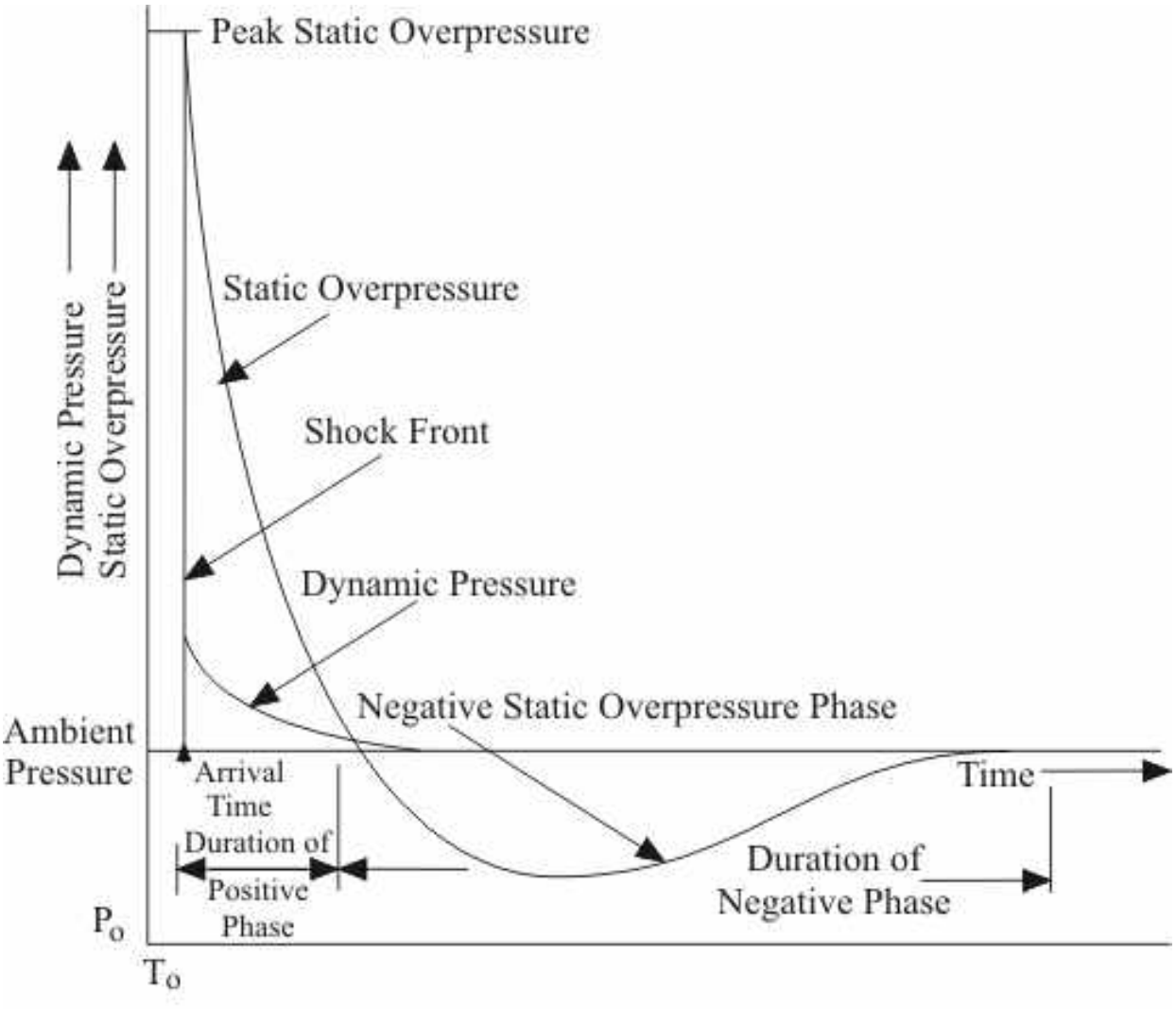


Figure B-1. Typical Blast Wave with Respect to Time at a Fixed Location.

Peak static overpressure decreases with increasing range from GZ, but the duration of the positive and negative phases of the overpressure increases with range. Since target damage caused by overpressure is a function of pressure multiplied by the duration, the magnitude of potential damage does not decrease at the same rate as overpressure attenuation. Many military materiels that have volume with thin walls are damaged by peak static overpressure and are referred to as "diffraction sensitive" targets.

The dynamic pressure is applied on a target for a longer duration than the overpressure because the moving air has mass and therefore momentum which causes it to take longer to come to rest. Most military materiel targets are damaged primarily by dynamic pressure and are referred to as "drag sensitive" targets. The relationship between the peak dynamic pressure and the peak static overpressure is expressed by the Rankine-Huguenot equation which reduces to the following equation, Equation B-1 on the following page:

$$q = \frac{5}{2} X \frac{P^2}{7Po + P}$$

Equation B-1: Rankine-Huguenot Equation.

q = dynamic pressure
P = overpressure
Po = ambient pressure

See Table B-1 for examples of the relationships between peak static overpressure, dynamic pressure, and wind velocity for an Ideal Shock Front.

Table B-1. Overpressure and Dynamic Pressure Relationships.

Peak Overpressure (PSI)	Peak Dynamic Pressure (PSI)	Maximum Wind Velocity (MPH)
100	**123**	**1,415**
72	**74**	**1,168**
50	**41**	**934**
30	**17**	**669**
20	**8.1**	**502**
10	**2.2**	**294**
5	**0.6**	**163**
2	**0.1**	**70**

The HOB of weapon detonation is highly significant in maximizing blast damage. In order to inflict the greatest blast damage on a specific target, the optimum HOB is calculated which will obtain the most effective Mach Stem. Near GZ, the incident and reflected ground shock fronts are separate. But, as the initial blast wave compresses and heats the surrounding air, it generates a swifter medium to which the reflected wave can propagate. Since the reflected wave travels faster because of this heated medium, it joins the initial blast wave and forms an almost vertical and reinforced shock front called the Mach Stem. The location where the incident and reflected waves converge is called the Triple Point. The formation of the Mach Stem produces an immediate and significant rise in exerted pressures which decreases with increasing range from GZ.

In addition, the shock front is also reflected by the face of the target. The pressure of this reflected target wave is added to the initial overpressure exerted on the target resulting in a greater overpressure than the original shock front. See Figure B-2 for Mach Stem formation and Figure B-3 for ground pressure against increasing range from GZ.

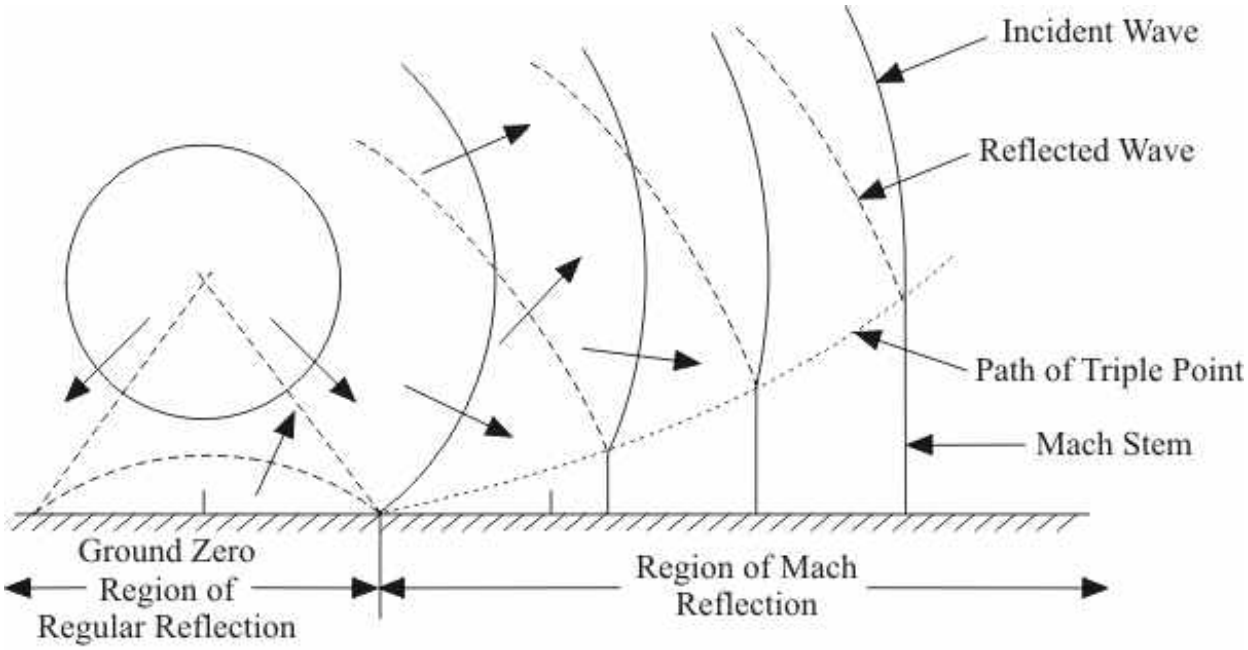


Figure B-2. Formation of the Mach Stem

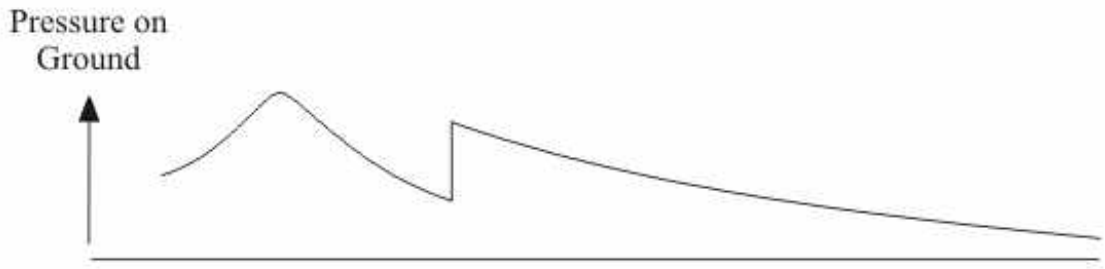


Figure B-3. Ground Pressure Versus Increasing Distance From GZ

A nuclear detonation, particularly a burst that occurs under or near the surface, will transmit a shock wave through the surrounding earth. Ground shock is important in damaging underground targets and shelters, but its effect on materiel targets located on the surface is insignificant in comparison to the effects caused by airblast. Thus, ground shock is not normally considered in the evaluation of survivability/ vulnerability of tactical military materiel.

In conclusion, military targets which are exposed to the effects of a nuclear airblast will have the following two distinct sequential effects. First, the overpressure will attempt to crush the target. If the target contains openings, this pressure difference will quickly diminish until equilibrium is established and the crushing effect will be minimized; if the target is closed, it will experience crushing forces for a short period of time. The combination of the blast wind and diffraction loading acting upon the object will exert a force on the object causing it to translate from GZ. Diffraction loading is the force of the static overpressure acting on the front face before the shock front envelops the target. Second, the dynamic pressure will apply drag loading on the

object. Drag loading is the force on an object due to the transient winds accompanying the passage of the blast wave. Damage caused by drag loading depends upon the duration and strength of the positive phase of the blast wave.

Nuclear airblast testing requires the use of both experimental and analytical techniques to determine the response of systems and components to the blast wave. Adequate testing of a system requires the accurate simulation and analysis of the nuclear airblast environment in terms of overpressure, dynamic pressure, impulse, duration, and negative overpressure of the entire system under study. Detonation altitude, weapon yield and type, and system configuration, deployment, and mission essential functions must be considered to adequately determine the damaging effects on military systems caused by the blast wave.

APPENDIX C: NUCLEAR THERMAL RADIATION ENVIRONMENT AND EFFECTS.

Approximately thirty-five percent of the total energy generated by an endo-atmospheric detonation of a generic nuclear weapon is in the form of thermal radiation. After the detonation of a thermonuclear weapon, the core of the explosion attains an exceedingly high temperature in the tens of million degrees. As a consequence of these exceedingly high temperatures, the core radiates electromagnetic energy which peaks to the soft X-ray spectrum. The absorption of these X-rays by the surrounding air produces tremendous heat which creates the fireball. This generated fireball radiates electromagnetic energy from 250 nanometers in the ultraviolet to 4000 nanometers in the infrared and produces the damaging thermal effects upon military targets. These damaging effects have two governing mechanisms, the total heat delivered and the rate of delivery. As weapon yield is increased, the larger the fireball becomes which significantly increases the total amount of energy that must be dissipated and the duration of energy dissipation. Since this duration is significantly greater for higher yields, the delivery rate of thermal radiation is greatly reduced; therefore, reducing the damaging effects to a military target receiving similar thermal doses from different weapon yields.

In other words, for a specific thermal dose (total energy), a smaller yield weapon can inflict greater damage upon a specified target than a higher yield weapon because the smaller yield delivers the thermal radiation quicker. The three distinct factors which affect the damaging effects of thermal radiation are blast wave screening, inverse square law, and, absorption and scattering due to the atmosphere.

The first factor is blast wave screening. As discussed earlier, the thermal radiation is emitted in two distinct separate pulses. The first pulse is generated by the interaction of the fireball radiating maximum energy and the departure of the shock front. As the fireball's radius increases, the shock front departs from the fireball heating the surrounding air to incandescence which absorbs the thermal radiation from the fireball. This incandescence screens the fireball and causes the shock front to emit thermal radiation instead of the fireball. This process is called blast wave screening. The result is a thermal pulse of little energy and significance in regards to damage effects. As the shock front expands, the cooling of the air allows the fireball to become visible and generates the second thermal pulse. Since this second pulse contains tremendous energy, it is militarily significant. See Figure C-1 for an example of the thermal radiation output of a nuclear weapon.

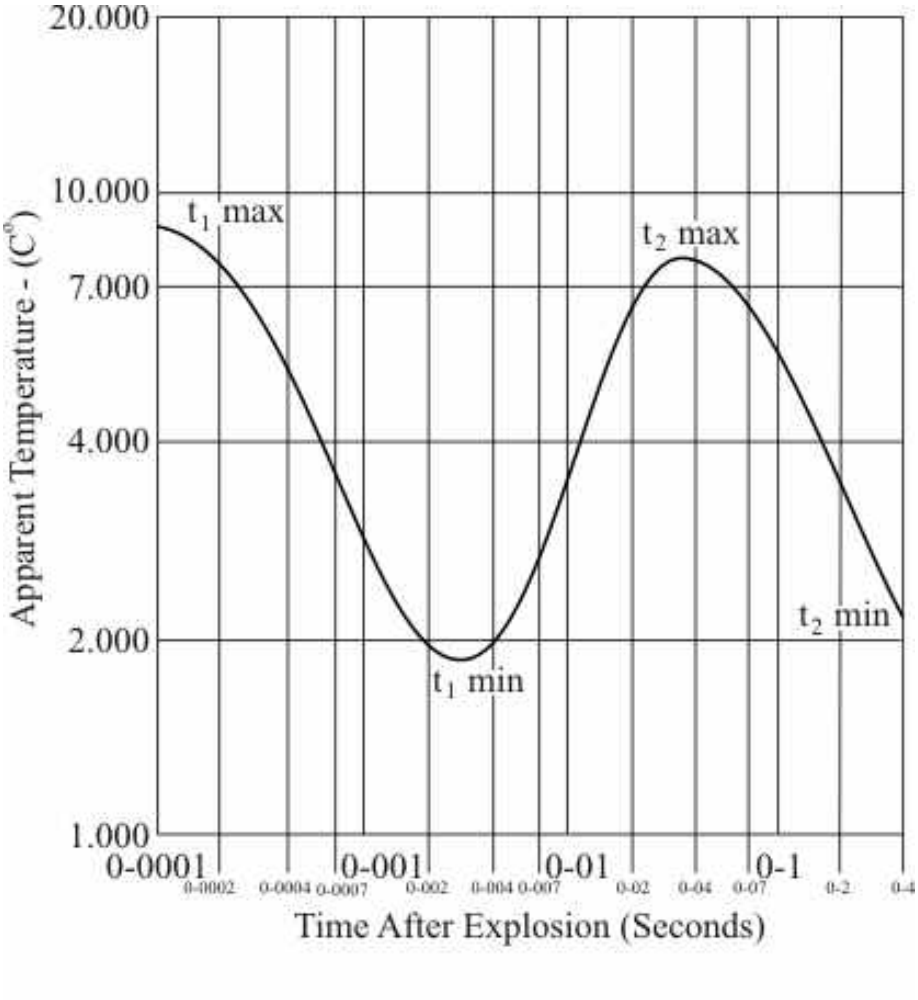


Figure C-1. Fireball Temperature Versus Time During 1 kT.

The second factor affecting thermal radiation is the inverse square law effect. The inverse square law pertains to all forms of electromagnetic radiation and states that the thermal dose varies as the total energy emitted and inversely as the square of the range from the point of burst. See Figure C-2 for inverse square law equation and Figure C-3 on the following page for slant ranges for specified thermal exposures.

$$Q\ (\text{cals/cm}^2) = \frac{E^{\tau}}{4\,\pi\,R^2}$$

Figure C-2. Inverse Square Law

E = Total Energy Emitted
R = Range in centimeters
τ = Transmissivity of the Surrounding Atmosphere from the Burst to the Target

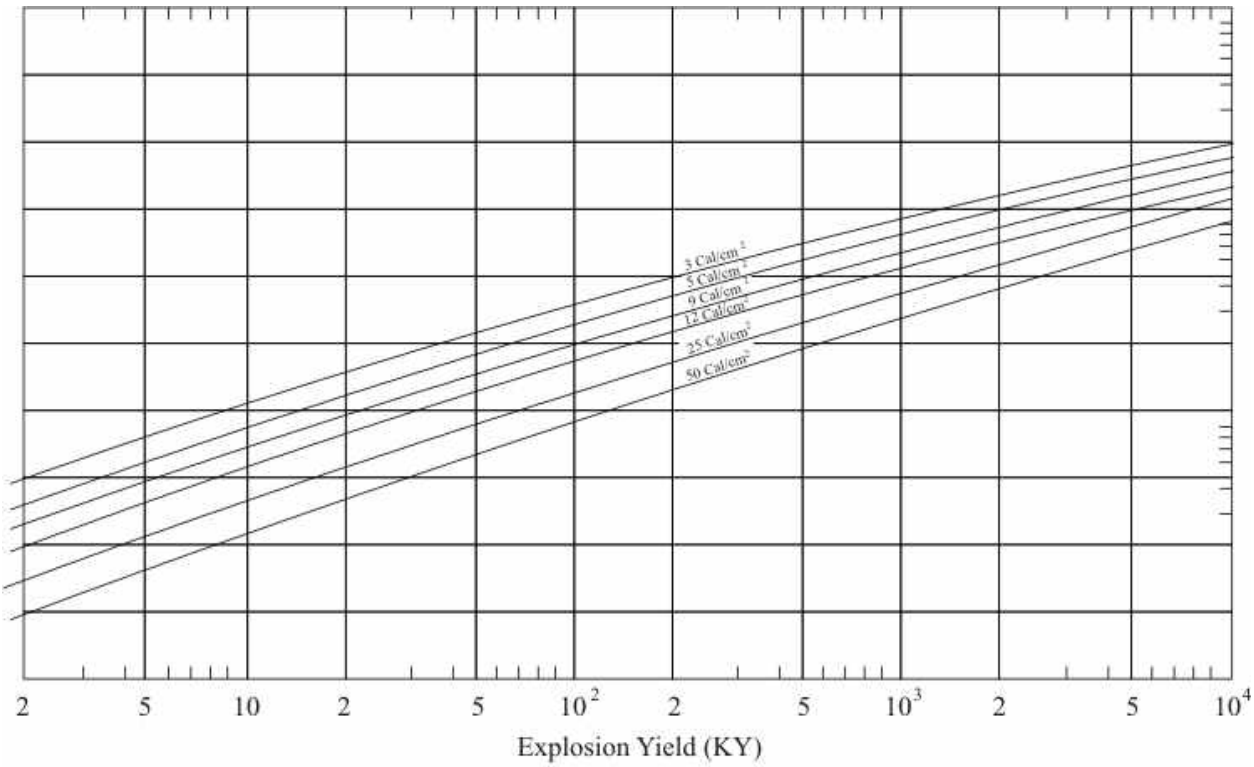


Figure C-3. Slant Ranges for Specified Thermal Doses.

The third factor affecting thermal radiation is absorption and scattering due to the atmosphere. As the thermal radiation passes through air, the air molecules absorb a portion of the energy in the X-ray and ultra-violet frequency spectrum. Scattering of the thermal radiation occurs when air contains water droplets and/or dust particles. These droplets and particles reflect the thermal radiation from a single line of sight direction to a multitude of directions. This scattering effect only reduces the thermal radiation applied upon a target slightly, because the scattered energy from other directions reinforces this line of sight radiation. Visibility is an extremely important parameter in determining the effectiveness of thermal radiation upon its target. In poor visibility conditions such as fog or smoke, the effects of thermal radiation are greatly reduced if the weapon HOB is above these conditions. In this circumstance, the thermal radiation is not only affected by absorption, but also by reflection. In the case of ground bursts, the thermal radiation effects are significantly diminished by the absorption and scattering caused by greater amount of generated debris and the shielding effects of terrain and surface irregularities.

The thermal effects of a nuclear weapon are an intense blinding flash and an immense thermal pulse. The great intensity of this flash can cause blindness to military personnel, either temporary or permanent. The severity of blindness is dependent on individual reflexes, flash intensity, pulse duration, and the protective posture of personnel. The thermal radiation is emitted in two distinct separate pulses. The first thermal pulse contains little energy, therefore it is insignificant. The second pulse contains tremendous energy, it is militarily significant and generally the largest casualty producer. The thermal pulse have two damage producing mechanisms which are direct damage produced by generated heat and, secondary damage produced by fires and explosions caused by ignition of surrounding materials. The blast wave may suppress some fires caused by the thermal pulses. Also, smoking of the exposed object will attenuate the undelivered energy of the thermal pulse. See Figure C-4 for fireball power and thermal energy emitted versus normalized time.

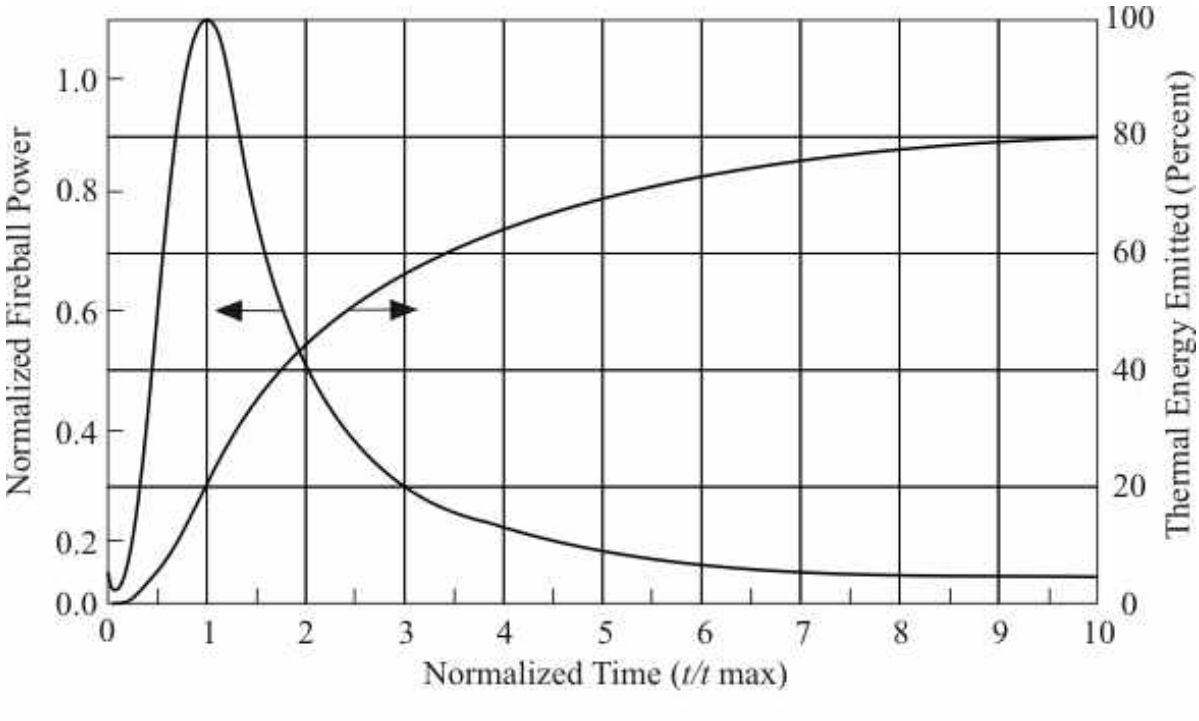


Figure C-4. Normalized Fireball Power and Thermal Energy Emitted Versus Normalized Time.

To determine the resistance of an item of materiel to thermal radiation, the test system must first be examined to determine potential problem areas. These are usually associated with combustible materials such as plastics, exposed ammunition, casing and containers, fabrics, rubber, and wood. Non-combustible materials include optics, sensors, and low melting point materials. Charring of paint is of no consequence, nor is the charring or discoloration of any material, provided that such damage does not interfere with the operation of the equipment. The fact that gasoline may spill out when motorized equipment is overturned should not be interpreted as suggesting that it will be ignited by thermal radiation, because the thermal pulse will have passed by the time the spilling occurs. Adequate resistance to thermal radiation can sometimes be confirmed by a visual examination that proves the item free of heat-sensitive areas.

At other times, it may be necessary to expose components of the item to facilities which simulate the thermal pulse. Typical problems that may be associated with thermal radiation are: destruction of insulation on wires, distortion of plastic moving parts, burning of rubber on tires and tracks, blackening and/or cracking of optical devices, weakening of materials, ignition of exposed propellants and ammunition, burning of tarpaulins and other fabrics, and ignition of combustibles which could lead to fire damage. Thermal damage is of little consequence when a system will suffer more severe damage from blast effects. See Table C-1 for examples of thermal radiation exposure required to ignite certain materials. Smaller yield weapons require less cal/cm^2 to ignite the same materials because of the faster rate or flux (cal/cm^2-sec) that the thermal energy is deposited on the material.

Table C-1. Approximate Thermal Radiation Exposure Required for Material Ignition.

Material	Radiant Exposure (Cal/cm^2) from 1kT Weapon	Radiant Exposure (Cal/cm^2) from 20 kT Weapon	Radiant Exposure (Cal/cm2) from 1MT Weapon
Tan Cotton Shirting	**5**	**7**	**11**
Newspaper	**2**	**3**	**6**
Battle Dress Uniform	**15**	**20**	**30**
NBC Suit	**15**	**20**	**30**
Truck Canvas Canopy	**15**	**20**	**30**
Dry Grass and Undergrowth	**2 - 3**	**3 - 4**	**5 - 7**
Cardboard	**6**	**8**	**13**
Plastics	**4 - 6**	**8 - 10**	**9 - 13**
Heavy Burlap	**6**	**8**	**12**

APPENDIX D. ELECTROMAGNETIC ENVIRONMENT AND EFFECTS.

The electromagnetic environment produced by a nuclear weapon consists of the ionization of the atmosphere and generation of an EMP. The gamma rays, neutrons, beta particles, X-rays, and positive ions emitted from the nuclear detonation causes electrons to be ejected from their perspective atoms, thus ionizing the atmosphere in the burst vicinity. This increase in electron density attenuates or refracts all electromagnetic signals from a few seconds to several hours depending on weapon yield and HOB. Radio communications depend on propagation of transmitted waves through the atmosphere. Depending on the specific frequency, this propagation occurs in one of two paths, ground or sky waves. Low frequencies utilize the ground wave path, while the high frequency band utilizes the sky wave path which is reflected back to earth by the ionosphere. Very High Frequency (VHF) and Ultra High Frequency (UHF) penetrate the ionosphere, therefore, any disturbance in the ionosphere does not affect communications in these frequency bands. See Table D-1 for frequency band effects caused by atmosphere ionization.

Table D-1. Frequency Band Effects Caused by Atmosphere Ionization.

BAND	FREQUENCY RANGE	EFFECTS ON COMMUNICATIONS
VLF	3 - 30 kHz	Limited Effects
LF*	30 - 300 kHz	Drastic Reduction of Sky Wave Path, but No Effects on Ground Wave Path
MF**	300 - 3000 kHz	Same as LF
HF***	3 - 30 MHz	Considerable Effects
VHF	30 - 300 MHz	Limited Effects, but Propagation Enhancement Possible
UHF	300 - 3000 MHz	Limited Effects
RADAR	3000 - 10000 MHz	Attenuated and Refracted

* Low Frequency
** Middle Frequency
***High Frequency (HF)

A nuclear detonation distributes approximately one millionth of its energy in the form of an intense EMP with a frequency content of a few Hz to several hundred MHz. The area affected by EMP and the characteristics of the pulse, is a function of burst altitude and weapon design and yield. Typical EMP intensity is in the order of tens of thousands of volts/meter. This compares with the order of 200 volts/meter for nearby radars, 10 volts/meter for communication equipment, and 0.01 volts/meter for typical metropolitan area ambient. Two characteristics of

EMP which result in a threat to electrical equipment are field amplitude and broad frequency spectrum. There are three basic mechanisms for EM coupling to a conducting structure: electrical induction, the basic mechanism for linear conductors; magnetic induction, the principal mechanism when the conducting structure forms a closed loop; and earth transfer impedance for buried conductors. Devices which may be susceptible to functional damage due to electrical transients include active electronic devices, passive electronic components, semiconductor devices, squibs and pyrotechnic devices, meters, and power cables. Operational upset can be expected in digital processing systems, memory units, guidance systems, and power distribution systems. Damage mechanisms include dielectric breakdown, thermal effects and interconnection failures. The two EMP situations which are based upon burst altitude are (Endo-Atmospheric) SREMP and (Exo-Atmospheric) HEMP.

The first EMP situation, SREMP, occurs within the atmosphere at an altitude of less than 40 km above sea level, and possesses an extremely large electric and magnetic field over the burst vicinity. Of particular concern are events at or within 1 km of the surface. Only within these limits are tactical surface systems close enough to the event to have the potential to be adversely affected by SREMP. SREMP is generated by collisions between photons from gamma radiation and molecules of the atmosphere. These highly energetic photons eject electrons from the surrounding air molecules, producing ionized air molecules . This immense separation of charge creates an intense E-Field of several 100,000 volts/meter and a large associated H-Field of 500 ampere-turns/meter. Ninety percent of its energy is contained in the 100 Hz to 10 kHz range. See Figure D-1 for an example of the SREMP waveform and Figure D-2 for relative energy versus frequency for an Endo-Atmospheric Burst on the following page.

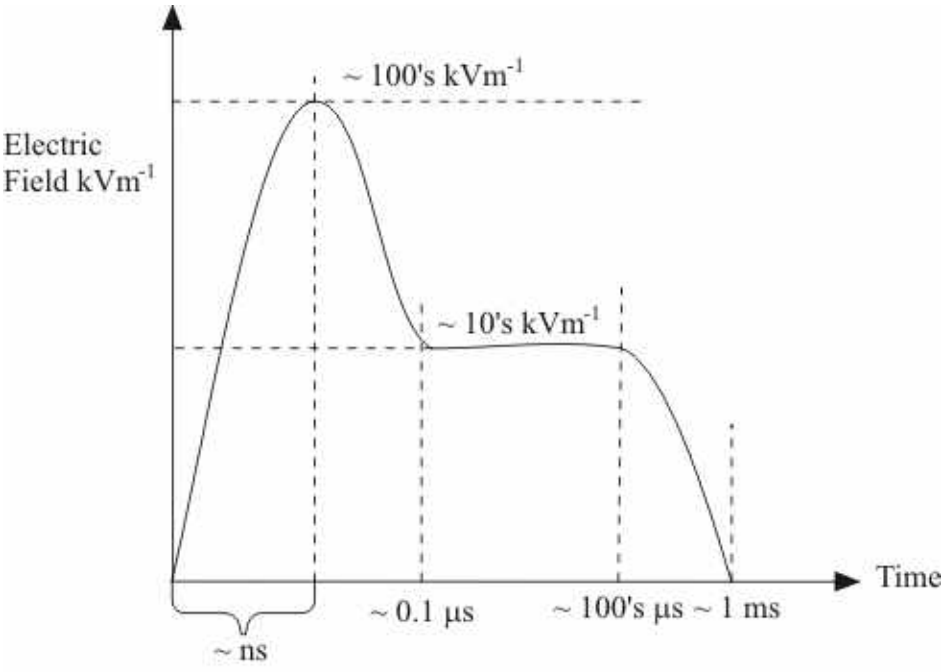


Figure D-1. Endo-Atmospheric EMP Waveform.

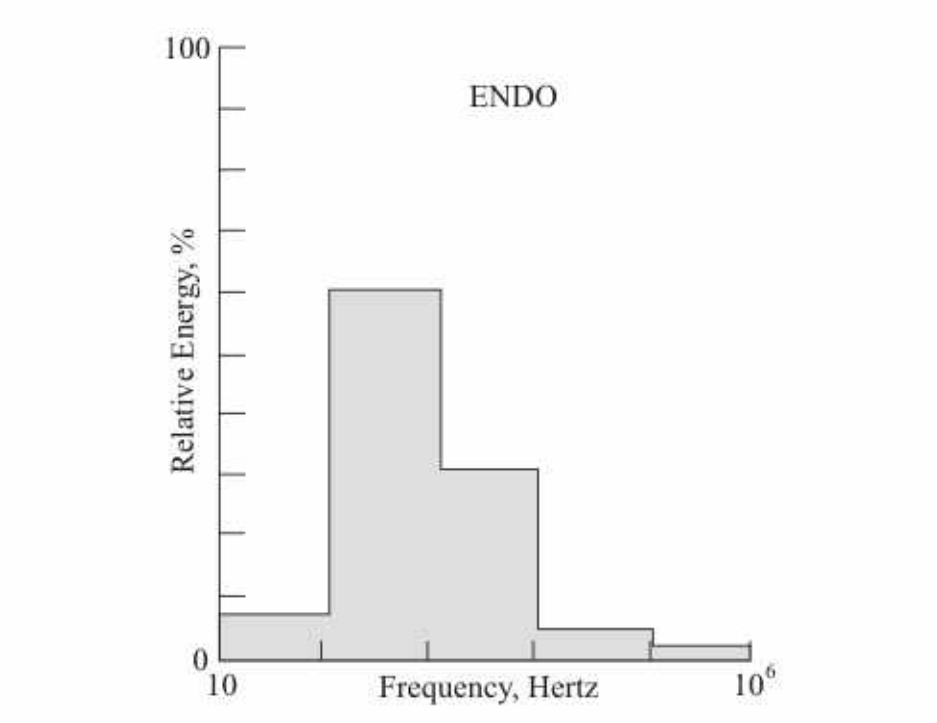


Figure D-2. Endo-Atmospheric Relative Energy Versus Frequency.

The second EMP situation, HEMP, occurs at an altitude greater than 40 km above sea level, and possesses a large electric and magnetic field over a diverse area. This tremendous area of effects is the reason HEMP is considered militarily significant and the most damaging of the two EMP situations. The HEMP is generated by gamma photons being absorbed by the atmospheric molecules at altitudes from 20 to 40 kilometers. This absorption causes electrons to be deflected by the earth's magnetic field into a spiral path about the field lines, causing them to radiate electromagnetic energy. See Figure D-3 for formation of HEMP and Figure D-4 on that next page for the detailed geometry of this phenomenon.

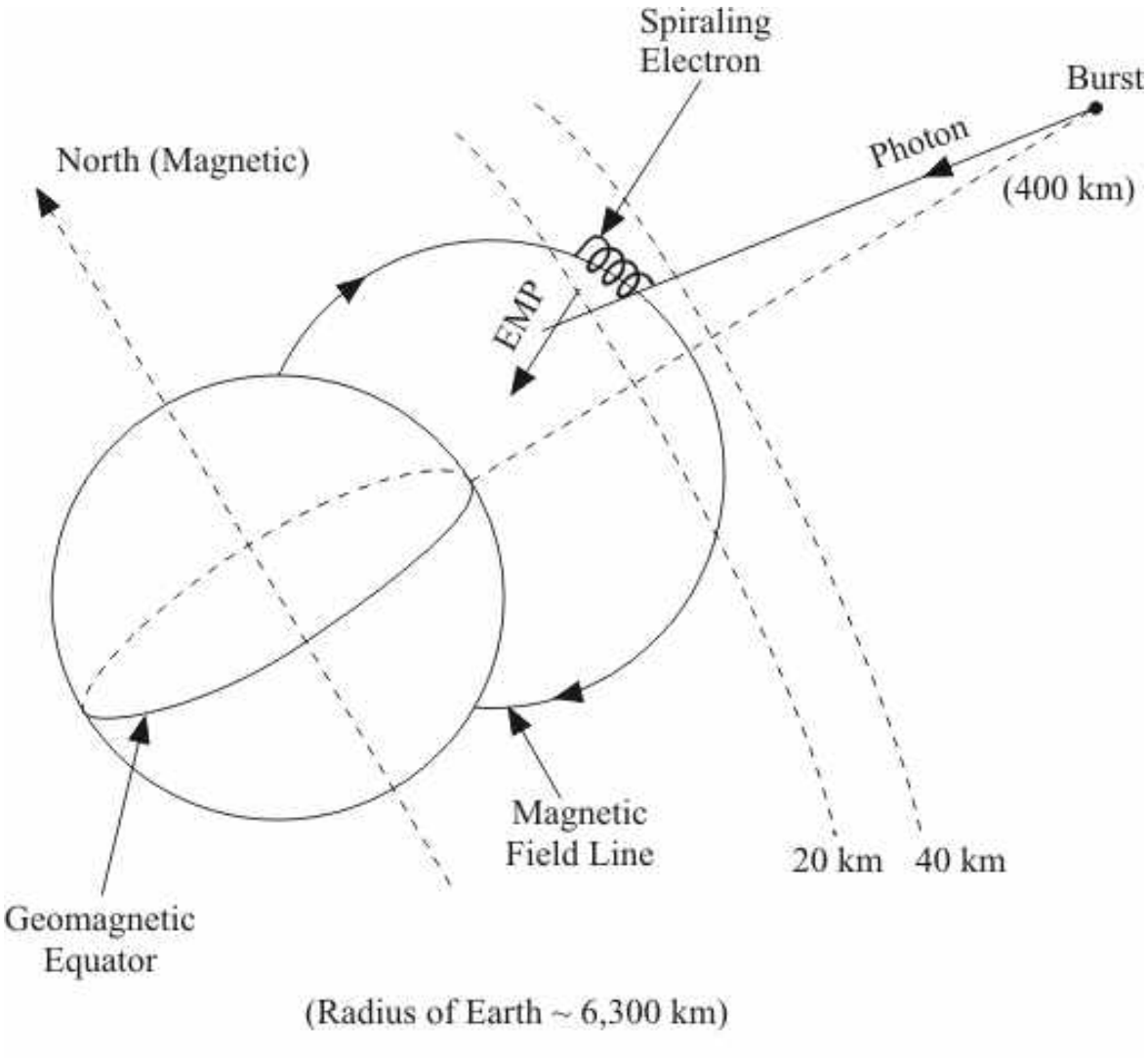


Figure D-3. Formation of Exo-Atmospheric EMP.

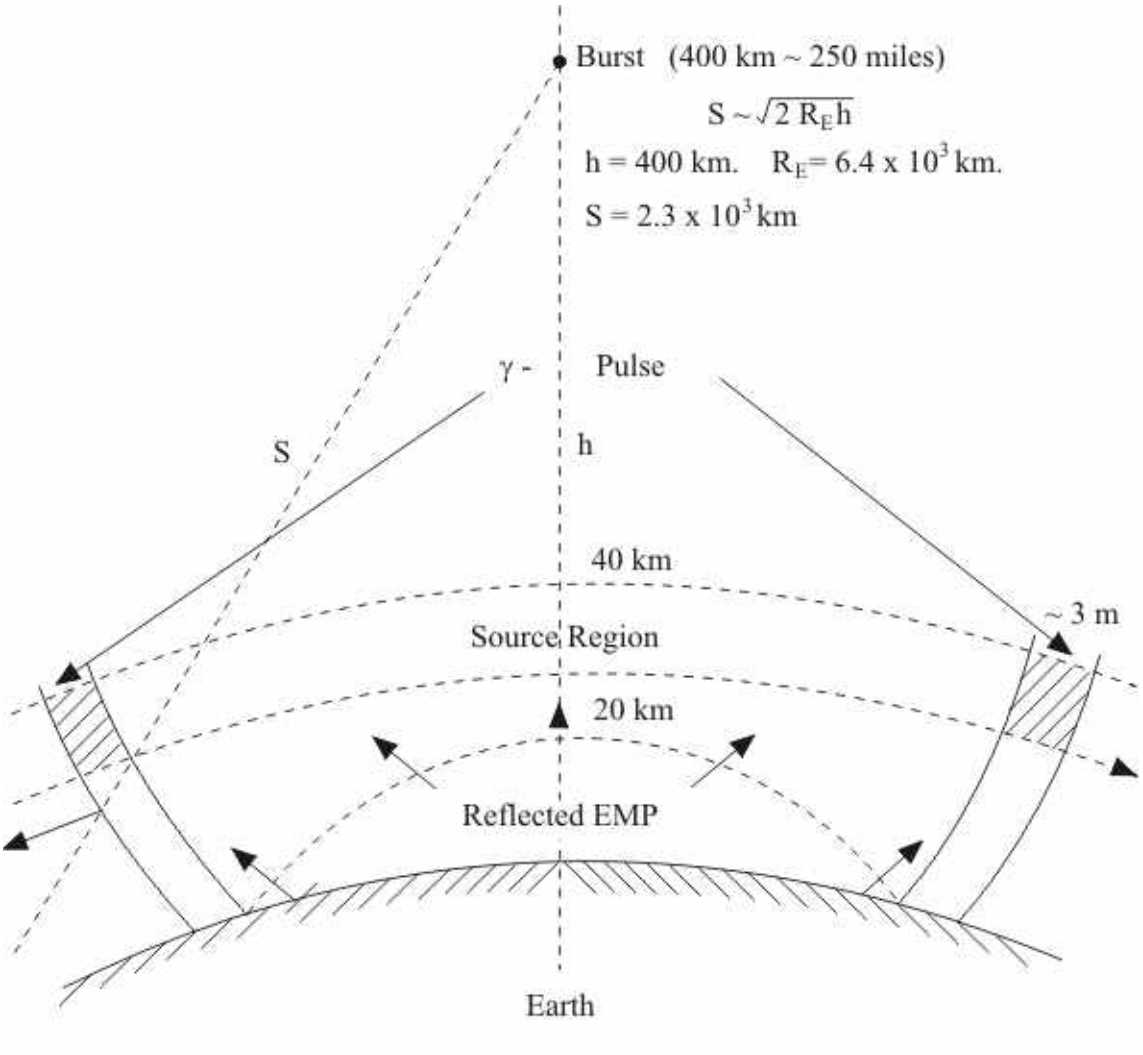


Figure D-4. Detailed Geometry for Exo-Atmospheric Burst.

The waveform and frequency content of HEMP is drastically different from its SREMP counterpart. This electron radiated energy creates a large, diverse E-Field in the range of tens of kilovolts/meter and an associated H-Field in the range of 10 to 100 ampere-turns/meter. Ninety percent of its energy is contained in the 100 kHz to 10 MHz range. See Figure D-5 for an example of the HEMP waveform and Figure D-6 for relative energy versus frequency for an Exo-Atmospheric Burst on the following page.

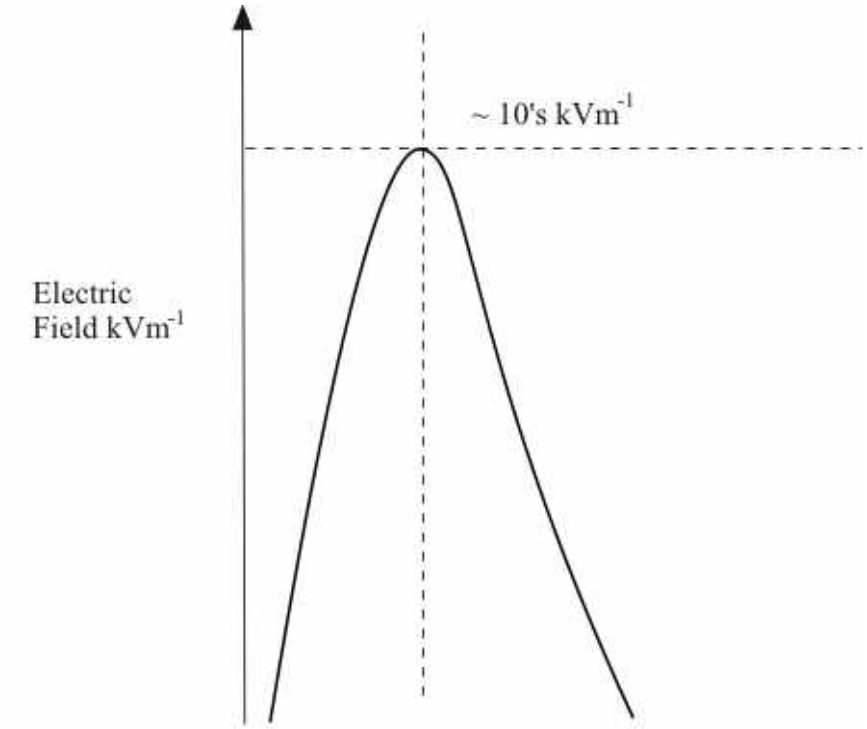


Figure D-5. Exo-Atmospheric EMP Waveform.

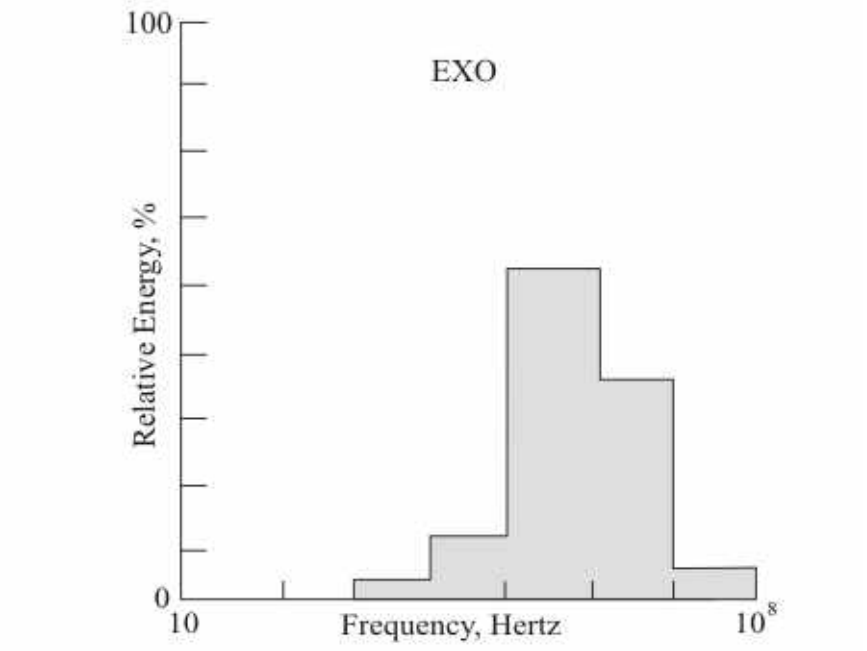


Figure D-6. Endo-Atmospheric Relative Energy Versus Frequency.

See Figure D-7 for an example of the diverse coverage in area and corresponding generate E-

Field contours by an Exo-Atmospheric burst.

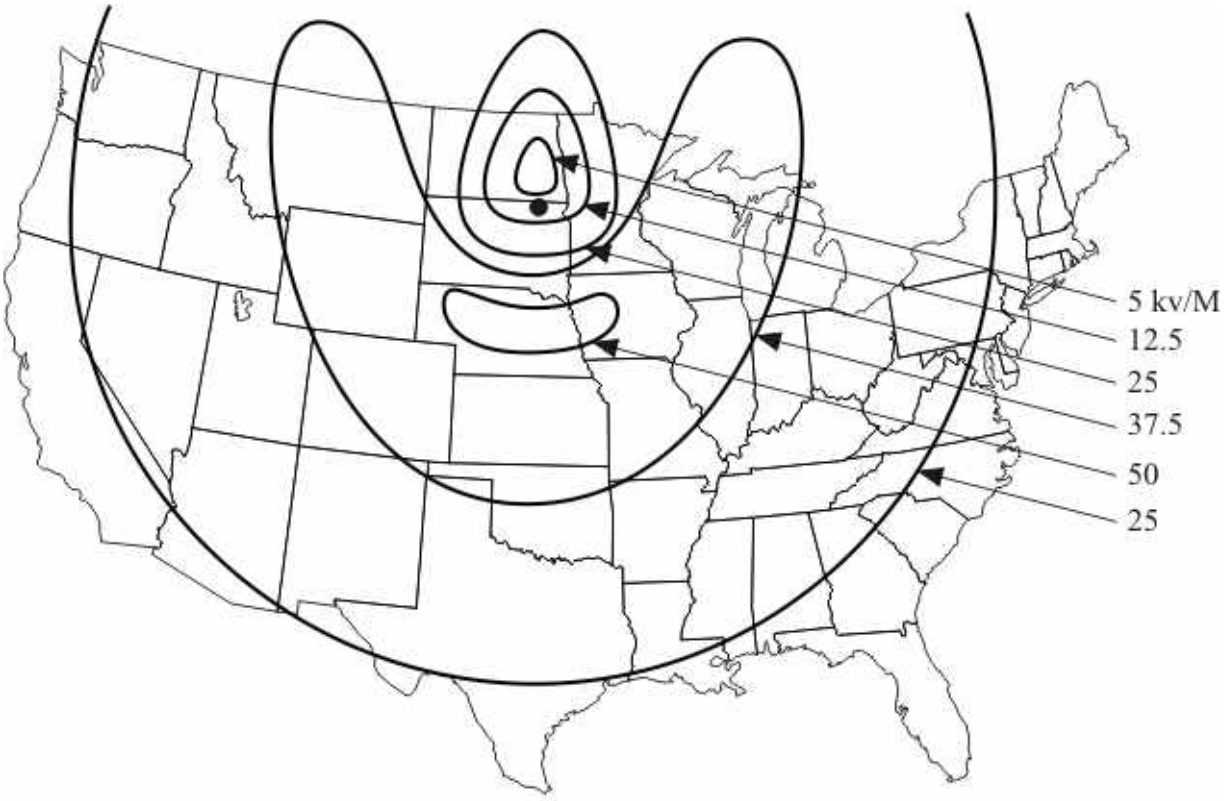


Figure D-7. Generated E-Field Contours at the Earth's Surface from a HEMP.

EMP testing requires the use of both experimental and analytical techniques to determine the response of systems and components to the EMP. Adequate testing of a system requires simulation of the EMP environment in terms of amplitude, time and geometrical effects of the entire system under study. Detonation altitude, angles of arrival and polarization of the field must be considered. Frequency domain calculations may be applied to determine critical resonant frequencies inherent to the test system. Current injection techniques must be utilized for distributed systems as an integral part of the EMP test. Current injection is greatly beneficial in the context of determining safety margins and, enhancing and verifying HEMP simulator results. But, current injection should not be the primary means of obtaining accurate HEMP data.

Also, deliberate hardening devices like terminal protection devices must be analyzed, tested if necessary, to determine safety margins. Likewise, the attenuation afforded by enclosures must be analyzed so that its effects on the survivability of the enclosed electronics can be quantified.

APPENDIX E. NUCLEAR RADIATION EFFECTS.

E.1 GENERAL RADIATION CHARACTERISTICS.

Approximately fifteen percent of the energy delivered by the detonation of a nuclear weapon is produced as (non-thermal) radiation. There are four types of radiation which are worthy of attention.

The first type of radiation is called alpha radiation and is comprised of a stream of alpha particles which are essentially the nuclei of helium atoms. This type of radiation has exceeding slight penetrating power causing essentially no effects on material or on military personnel because it can be stopped by a single sheet of paper. Military casualties are only produced by alpha radiation when it is internally introduced into the body. Therefore, alpha radiation is not considered militarily significant to equipment.

The second type of radiation is called beta radiation and is comprised of a stream of beta particles which are electrons. This type of radiation has slight penetrating power and can just barely penetrate the skin. The only effect caused by initial beta radiation on military personnel are skin burns called "Beta Burns." Since there are essentially no notable effects on material or on military personnel, initial beta radiation has little military significance.

The third type of radiation is called gamma radiation which is comprised of photons or electromagnetic waves very similar to X-rays, but have shorter wavelengths, usually more energetic and, therefore, has substantially greater penetrating power. Since gamma radiation can travel great distances through air and pass through extremely thick materials, gamma radiation is extremely significant to military systems containing electronics.

The last type of radiation is called neutron radiation and is comprised of a particle stream of neutrons. Neutrons are one of the elementary particles which comprise the nucleus of all atoms and possess no charge. Since neutrons usually have much greater penetrating power than gamma radiation, neutrons are extremely significant to military systems containing electronics.

E.2 RESIDUAL RADIATION ENVIRONMENT AND EFFECTS.

The residual radiation effects of a nuclear weapon consists of radioactive weapon debris and fallout, and NIA which sustains for longer than one minute after weapon detonation. The effects of residual activity can cover an extensive area and can persist for long durations which are dependent upon weapon yield and design, HOB, soil composition, and atmospheric conditions. The radiation composition of residual radiation consists of alpha particles , beta particles, and gamma radiation. A more detailed examination of the two primary residual radiation effects, NIA and fallout follow:

The first effect, NIA occurs in the vicinity of GZ and is caused by neutron capture in the system and various materials which exist on the earth's surface near GZ. This process of neutron capture produces radioactive isotopes that emit beta and/or gamma radiation. The duration of significant radiation emission is dependent upon the isotopes created.

The normally predominant effect, fallout, is highly dependent upon the type of weapon burst. In air bursts, the vaporized radioactive products condense into small particles in the range of 20 μm in diameter. These extremely small particles are conveyed high in the atmosphere and descend to earth over an exceedingly prolonged time. By this process, the fallout has significantly decayed and has been greatly dispersed by winds resulting in a very low radioactivity level which is militarily insignificant.

On the other hand, during ground or near ground bursts, vast quantities of soil and debris are drawn into the fireball forming condensation centers for vaporized radioactive products. This results in a massive cloud of radioactive particles with diameters up to 500 μm. The rate at which these particles descend to earth is based upon increasing mass and atmospheric conditions. In other words, the denser the particle, the quicker it will fall to earth unless adverse atmospheric conditions prevail. The outcome of this type of burst is steadily increasing radioactivity the closer to GZ the measurement point because of the decrease in decay time and the increase in radioactive particles.

Residual radiation has essentially no damaging effects on military systems, but presents major difficulties on military personnel in the area surrounding GZ and downwind of GZ. Gamma radiation is the primary concern when providing protection for military personnel against residual radiation. The effects of both alpha and beta radiations may be made insignificant for military concerns by thin layers of materials. Combat vehicles, particularly tanks and armored personnel carriers, because of their armor and massive metal construction, inherently provide a considerable amount of shielding against residual radiation.

The amount of shielding provided is almost a direct function of the mass of material between the individual and the radiation source. The effectiveness of material in attenuating radiation may be represented by its "half-value thickness", the thickness of the particular material which absorbs half of the gamma radiation incident upon it. The amount of shielding provided for each crew member is expressed in terms of "protection factor" defined as follows:

$$\text{Protection Factor} = \frac{\text{Free Field Radiation level at 3 feet above the ground}}{\text{Radiation level at personnel location}}$$

The protection factor is the ratio of the radiation dose a person would receive if he were standing in the open in a fallout field to the dose he would receive in the vehicle at the same location. Some tanks may provide protection factors against residual radiation as high as 20, whereas a 1/4-ton truck may provide a protection factor of 1.25. The term "transmission factor" is also used. It is essentially the inverse of the protection factor and is defined as:

$$\text{Transmission Factor} = \frac{\text{Dose inside Shield}}{\text{Dose outside Shield}}$$

Typical transmission factors for shelters and vehicles against initial and residual radiation are contained in Table E-1.

Table E-1. Typical Transmission Factors for Nuclear Radiation Effects.

Shielding Item	Residual Radiation Transmission Factor	Neutrons Initial Radiation Transmission Factor	Gamma Initial Radiation Transmission Factor
Armored Personnel Carrier	0.6	0.7	0.7
Light Tank	0.2	0.3	0.2
Medium Tank	0.1	0.3	0.1
¼-Ton Truck	0.8	1.0	1.0
¾-Ton Truck	0.7	1.0	1.0
2½-Ton Truck	0.6	1.0	1.0
4- To 7-Ton Truck	0.5	1.0	1.0
Foxhole	0.1	0.3	0.2
Open Trench	0.1	0.3	0.2
Shelter with 3ft of Earth Cover	0.005	0.05	0.02

E.3 INITIAL NUCLEAR RADIATION ENVIRONMENT AND EFFECTS.

Initial nuclear radiation is defined as that nuclear radiation which is emitted by a nuclear explosion within the first minute after the nuclear weapon burst. Initial nuclear radiation is composed of alpha particles, beta particles, gamma radiation and neutrons. Only, the highly penetrative gamma rays and neutrons are extremely damaging to military personnel and electronics in military systems. The magnitude of this radiation is dependent upon weapon yield, type and HOB, and distance from GZ. For middle to high yield weapons, the damaging effects on systems generated by the blast wave and thermal radiation surpasses INR effects. However, for tanks, APCs, and similar systems, and for small yield weapons, INR is the more dominant effect on electronics and personnel.

The gamma radiation that is produced by a nuclear detonation comes from various sources, such as the initial fission reaction, fission product decay and NIA in the warhead debris and in the surrounding air molecules. Prompt gamma photons are those produced during fission and as a result of neutron interactions with weapon materials in the first □sec. Capture gamma photons are those emitted as the result of the capture of a neutron by a nucleus. Other examples of gamma radiation sources are delayed and inelastic gamma photons.

The neutron radiation produced by a nuclear detonation comes from two main sources, prompt neutrons and delayed neutrons. Prompt neutrons constitute over 99 percent of the total neutron production and are released in the initial □sec during the warhead fission and/or fusion processes. Delayed neutrons are emitted within the first minute and are produced by the interaction of the prompt neutrons with atoms in their path. Neutrons are also produce by the action of high energy gamma photons on the weapon materials, but they are insignificant.

As the distance from GZ increases, the effects of INR are significantly reduced by two factors. These factors are that the intensity of INR decreases according to the inverse square law, and air scattering and absorption. The inverse square law is the principle factor for decreases in INR levels. The factor of air scattering and absorption has very little effect on neutron dose, but affects gamma radiation dose significantly. Figure E-1 is an example of initial radiation effects from a 1kT airburst and Figure E-2 provides INR scaling factors versus weapon yield.

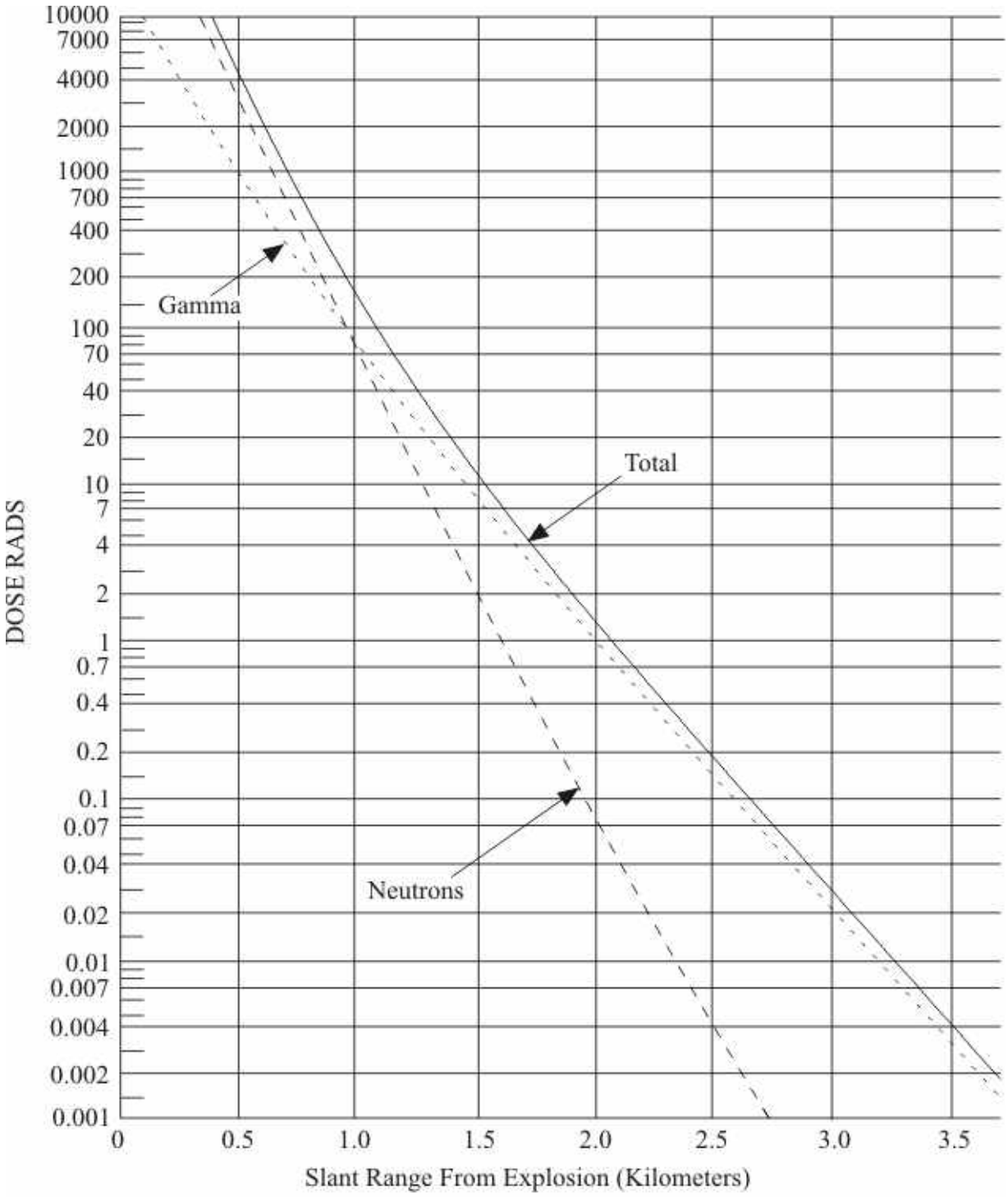


Figure E-1. Initial Radiation Effects from 1-kT Air Burst.

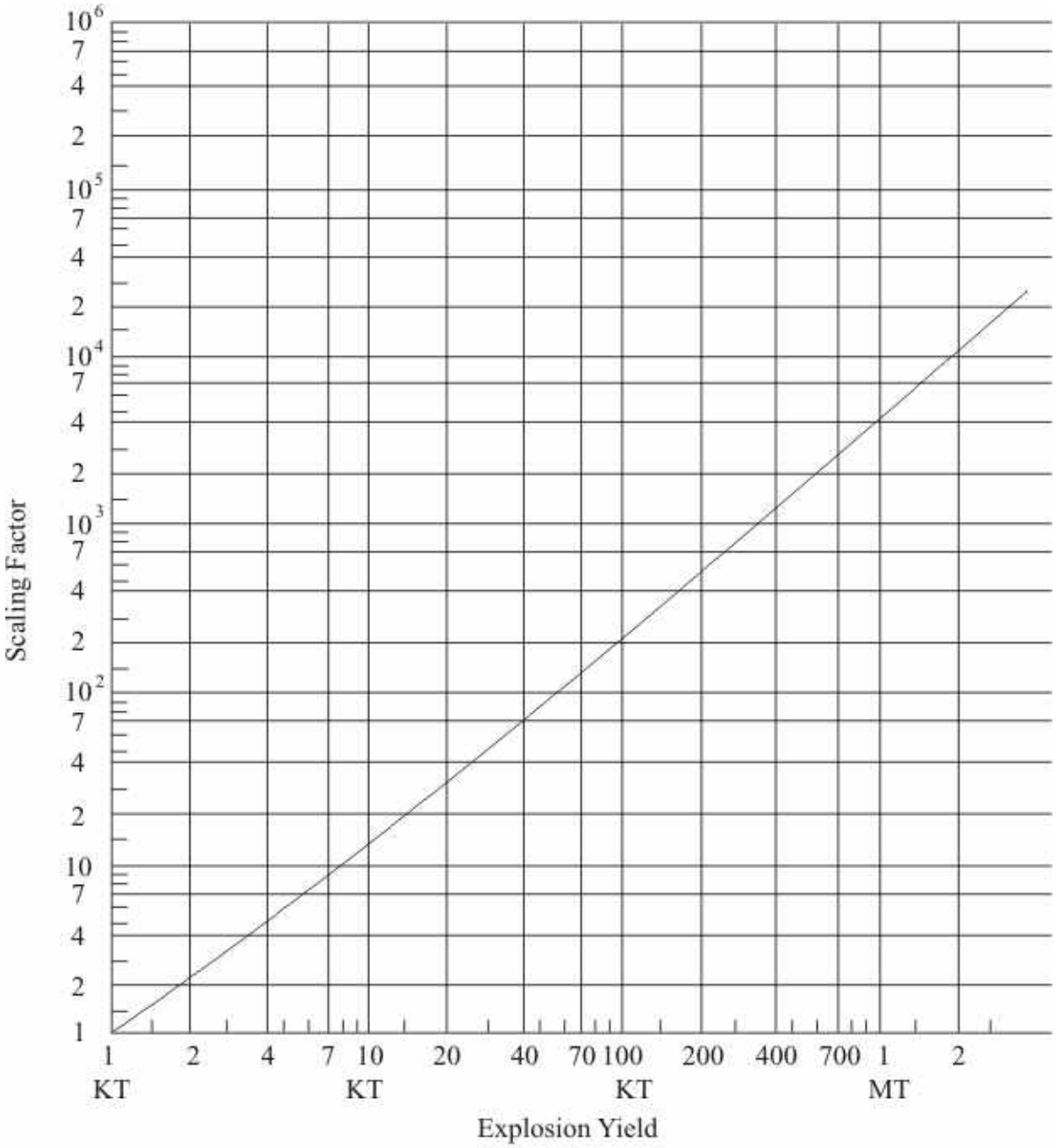


Figure E-2. INR Scaling Factors Versus Weapon Yield.

The INR shielding tests involve the exposure of materiel to neutron and gamma radiation sources to measure the protection afforded to the crew and the most vulnerable electronic components by the walls of the vehicle. These radiation sources must have spectra that collectively approximate the spectra from nuclear weapons. See Table E-1 for typical transmission factors of INR effects on military equipments and shelters.

The INR tests are only concerned with the effects on military personnel and equipment from gamma radiation and neutrons. The damaging effects produced by INR are only militarily significant in the consideration of the drastic effects it induces on electrical properties of semiconductor devices. To adequately test and analyze these drastic effects, three test environments based upon the time history of nuclear weapon radiation effects have been developed. These tests are: GDR, total gamma dose, and neutron fluence.

The GDR test determines the effects of the initial gamma pulse created by a nuclear detonation on powered semiconductor devices primarily of the Metal-Oxide-Semiconductor (MOS) technology. The GDR pulse generates damaging photocurrents which produces transient upsets, latch-up, and burnout in semiconductor devices.

The neutron fluence test determines the effects of lattice displacement damage generated by neutron fluence on semiconductor devices primarily of the bipolar technology. The semiconductor piece-parts of a test system generally receive the most damage by neutrons. Neutron damage results in a decrease of the minority carrier lifetime and an increase in bulk resistivity of the semiconductor material. These effects severely alters the electrical characteristics of the piece-parts, and, in some cases, the induced damage is severe enough to cause complete device failure or failure in its circuit application.

The total gamma dose test determines the effect of total ionizing dose deposited on semiconductor devices. The production of hole-electron pairs through ionization creates trapped charge in the semiconductor material. The total dose effects in semiconductors are exhibited either as a change in electrical parameters or as a catastrophic failure. Of particular concern is N-channel MOS technology which is the sensitive to gamma dose.

See Table E-2 for testing requirements on generic part families and Tables E-3 through E-5 for specific environmental concerns.

Table E-2. INR Testing Requirements for Generic Part Families.

Generic Damage Levels:

GDR: Upset < 1E9 cGy(Si)/sec
Damage < 1E9 cGy(Si)/sec
Based Upon 20 nsec Pulse-width

GTD: < 1600 cGy(Si)

Neutron Fluence : < 1E12 n/cm2

Generic Part Family	Gamma Dose Rate Testing	Gamma Total Dose Testing	Neutron Fluence Testing	Comments
1. Diodes	No	No	No	
2. PIN Diodes	Yes	No	No	
3. Temperature Compensated Diodes	No	No	Yes	
4. Zener Diodes	No	No	No	** Special Circuit Situations
5. High Fτ (> 50 MHz) Transistors	No	No	No	** Special Circuit Situations
6. Low Fτ (< 50 MHz) Transistors	No	No	Yes	
7. Power Transistors	No	No	Yes	
8. Crystals	No	Yes	Yes	
9. Crystals Oscillators	**Yes	Yes	Yes	**Technology Dependent
10. Operational Amplifiers	No	No	Yes	
11. Comparators	Yes	No	Yes	
12. CMOS* Analog Switches	Yes	**Yes	Yes	**Certain Manufacturers
13. Fixed Regulators	No	No	Yes	

* Complimentary Metal Oxide Semiconductor (CMOS)

Table E-2. INR Testing Requirements for Generic Part Families (Cont).

Generic Part Family	Gamma Dose Rate Testing	Gamma Total Dose Testing	Neutron Fluence Testing	Comments
14. DC to DC Converters	**Yes	**Yes	**Yes	**Technology Dependent
15. ADC	**Yes	**Yes	**Yes	**Technology Dependent
16. DAC	**Yes	**Yes	**Yes	**Technology Dependent
17. JFETs	Yes	No	Yes	
18. MOSFETs	Yes	Yes	Yes	
19. Discrete Timers	No	No	No	
20. Linear Timers	No	No	Yes	
21. SCRs	Yes	No	Yes	
22. Unijunction Transistors	No	No	Yes	
23. Discrete Opto-Electronics	No	No	Yes	
24. Opto-Couplers	No	No	Yes	
25. EE PAL	**Yes	**Yes	No	** Technology Dependent
26. TTL PAL	No	No	No	
27. UV PAL	No	Yes	No	
28. EE PROM	**Yes	**Yes	No	** Technology Dependent
29. UV PROM	**Yes	No	No	** Technology Dependent
30. TTL PROM	No	No	No	
31. NMOS* PROM	No	Yes	No	
32. Static RAMs	Yes	Yes	No	
33. IDT RAMs	Yes	Yes	No	

*NMOS – N-Channel Metal Oxide Semiconductor

Table E-3. Gamma Dose Rate (GDR) Concern Thresholds.

Piece-Part Type	Technology	GDR Upset Threshold (cGy(Si)/sec)	GDR Latch-up / Burnout Threshold (cGy(Si)/sec)	Comments
Analog Switches	CMOS	1E7 – 1E8	1E8 – Above	Extremely sensitive to latch-up and burnout / current limiting and power removal critical to survivability / circuit acceptability / Must limit power to device safe region
Analog Switches	MOS/JFET	1E7 – 5E8	5E8 – Above	Extremely sensitive to latch-up and burnout / current limiting and power removal critical to survivability / circuit acceptability
Charge Coupled Devices (CCDs)	CCD	5E6 – 5E8	5E8 – Above	Extremely sensitive to latch-up and burnout / current limiting and power removal critical to survivability / circuit acceptability
Comparators	Bipolar / Linear	1E7 – 5E8	5E8 – Above	Sensitive to latch-up and burnout / current limiting and power removal critical to survivability / circuit acceptability. Change of state
Comparators	CMOS	1E7 – 5E8	5E8 – Above	Extremely sensitive to latch-up and burnout / current limiting and power removal critical to survivability / circuit acceptability/ Change of state
Crystal Oscillators	Hybrid	1E7 – 1E9	1E9 – Above	Slight effects on frequency / Low Risk @ tactical GDR levels – Concern with control circuitry
Crystals	Linear	1E7 – 1E9	1E9 – Above	Slight effects on frequency / Low Risk @ tactical GDR levels
Darlingtons	Bipolar / Linear	1E7 – 1E9	1E9 – Above	Potential concern @ tactical GDR levels / photocurrent generation will occur. Configuration dependent / Must limit power to device safe region
DC/DC Converter with Magnetic Feedback	Hybrid	1E7 – 1E9	1E9 – Above	Sensitive to latch-up and burnout / current limiting and power removal critical to survivability / circuit acceptability
DC/DC Converters with Optical Feedback	Hybrid	5E6 – 1E9	1E9 – Above	Sensitive to latch-up and burnout / current limiting and power removal critical to survivability / circuit acceptability

Table E-3. Gamma Dose Rate (GDR) Concern Thresholds (Continued).

Piece-Part Type	Technology	GDR Upset Threshold (cGy(Si)/sec)	GDR Latch-up / Burnout Threshold (cGy(Si)/sec)	Comments
Digital Devices	CML* ()	1E8 – 1E10	> 1E10	Not concern @ tactical GDR levels / photocurrent generation will occur
Digital Devices	ECL**	5E8 – 1E10	> 1E10	Not concern @ tactical GDR levels / photocurrent generation will occur. Change of state
Digital Devices	Gallium Arsenide	1E8 – 1E10	> 1E10	Not concern @ tactical GDR levels / photocurrent generation will occur. Change of state
Digital Devices	I2L	1E8 – 5E9	5E9 – Above	Not concern @ tactical GDR levels / photocurrent generation will occur. Change of state
Digital Devices	TTL	1E7 – 1E9	1E9 – Above	Low Risk concern @ tactical GDR levels / photocurrent generation will occur / Change of state
Digital Potentiometers	CMOS	5E7 – 1E9	1E9 – Above	Sensitive to latch-up and burnout / current limiting and power removal critical to survivability / circuit acceptability / Data loss
Diodes – High Frequency	Bipolar / Linear	1E6 - Above	N/A	Not concern @ tactical GDR levels / photocurrent generation will occur
Diodes – Light Emitting (LEDs)	Bipolar / Linear	1E6 - Above	N/A	Not concern @ tactical GDR levels / photocurrent generation will occur
Diodes – Light Emitting (LEDs)	Gallium Arsenide Variants	1E6 - Above	N/A	Not concern @ tactical GDR levels / photocurrent generation will occur
Diodes – Photo	Bipolar / Linear	1E6 - Above	N/A	Not concern @ tactical GDR levels / photocurrent generation will occur
Diodes – Rectifier	Bipolar / Linear	1E6 - Above	N/A	Not concern @ tactical GDR levels / photocurrent generation will occur
Diodes – Reference / Zener / Suppression	Bipolar / Linear	1E6 - Above	N/A	Not concern @ tactical GDR levels / photocurrent generation will occur
Diodes – Signal	Bipolar / Linear	1E6 - Above	N/A	Not concern @ tactical GDR levels / photocurrent generation will occur

* Current Mode Logic (CML)
* Emitter Coupled Logic (ECL)

Table E-3. Gamma Dose Rate (GDR) Concern Thresholds (Continued).

Piece-Part Type	Technology	GDR Upset Threshold (cGy(Si)/sec)	GDR Latch-up / Burnout Threshold (cGy(Si)/sec)	Comments
Fully Programmable Gate Array (FPGA)	CMOS	1E7 – 5E8	1E8 – Above	Sensitive to latch-up and burnout / current limiting and power removal critical to survivability / circuit acceptability. Loss of data
Insulated Gate Bipolar Transistors (IGBTs)	IGBT	1E7 – 1E9	1E9 – Above	Significant photocurrent generation will occur / Circuit Application is critical to acceptability. Configuration dependent
Logic Devices	TTL	1E7 – 1E9	1E9 – Above	Low Risk concern @ tactical GDR levels / photocurrent generation will occur / Change of state
Memory - DRAM	CMOS	5E7 – 5E8	5E8 – Above	Sensitive to latch-up, memory corruption and burnout / current limiting and power removal critical to survivability / circuit acceptability Change of state
Memory – EEPROM & Flash	CMOS	5E7 – 5E8	5E8 – Above	Sensitive to latch-up, memory corruption and burnout / current limiting and power removal critical to survivability / circuit acceptability Change of state
Memory – EEPROM & Flash	CMOS	5E7 – 5E8	5E8 – Above	Sensitive to latch-up, memory corruption and burnout / current limiting and power removal critical to survivability / circuit acceptability Change of state
Memory - FIFO	CMOS	5E7 – 5E8	5E8 – Above	Sensitive to latch-up, memory corruption and burnout / current limiting and power removal critical to survivability / circuit acceptability / Change of state
Memory - PROM	TTL	1E7 – 1E9	1E9 – Above	Low Risk concern @ tactical GDR levels / photocurrent generation will occur / Change of state
Memory - ROM	TTL	1E7 – 1E9	1E9 – Above	Low Risk concern @ tactical GDR levels / photocurrent generation will occur / Change of state

Table E-3. Gamma Dose Rate (GDR) Concern Thresholds (Continued).

Piece-Part Type	Technology	GDR Upset Threshold (cGy(Si)/sec)	GDR Latch-up / Burnout Threshold (cGy(Si)/sec)	Comments
Memory – SDRAM	CMOS	5E7 – 5E8	5E8 – Above	Sensitive to latch-up, memory corruption and burnout / current limiting and power removal critical to survivability / circuit acceptability / Change of state
Memory – SRAM	CMOS	5E7 – 5E8	5E8 – Above	Sensitive to latch-up and burnout / current limiting and power removal critical to survivability / circuit acceptability / Data loss
Micro-Controllers	CMOS	5E7 – 5E8	5E8 – Above	Sensitive to latch-up, memory corruption and burnout / current limiting and power removal critical to survivability / circuit acceptability / Change of state
Micro-Processors	Bipolar	1E7 – 1E9	1E9 – Above	Sensitive to latch-up, memory corruption and burnout / current limiting and power removal critical to survivability / circuit acceptability / Change of state
Micro-Processors	CMOS	5E7 – 5E8	5E8 – Above	Sensitive to latch-up, memory corruption and burnout / current limiting and power removal critical to survivability / circuit acceptability / Change of state
MOSFETs – N-Channel	NMOS	1E7 – 1E9	1E9 – Above	Significant photocurrent generation will occur / Greatest concern – Push / Pull Configuration Burnout
MOSFETs – P-Channel	PMOS*	1E7 – 1E9	1E9 – Above	Significant photocurrent generation will occur / Greatest concern – Push / Pull Configuration Burnout
Multiplexers	CMOS	1E7 – 1E8	1E8 – Above	Extremely sensitive to latch-up and burnout / current limiting and power removal critical to survivability / circuit acceptability / Must limit power to device safe region
Multiplexers	MOS/JFET	1E7 – 5E8	5E8 – Above	Extremely sensitive to latch-up and burnout / current limiting and power removal critical to survivability / circuit acceptability

*PMOS – P-Channel Metal Oxide Semiconductor

Table E-3. Gamma Dose Rate (GDR) Concern Thresholds (Continued).

Piece-Part Type	Technology	GDR Upset Threshold (cGy(Si)/sec)	GDR Latch-up / Burnout Threshold (cGy(Si)/sec)	Comments
Operational Amplifiers	BICMOS	1E7 – 5E8	5E8 – Above	Extremely sensitive to latch-up and burnout / current limiting and power removal critical to survivability / circuit acceptability
Operational Amplifiers	BIMOS	1E8 – 1E9	1E9 – Above	Extremely sensitive to latch-up and burnout / current limiting and power removal critical to survivability / circuit acceptability
Operational Amplifiers	Bipolar / Linear	1E7 – 5E8	5E8 – Above	Sensitive to latch-up and burnout / current limiting and power removal critical to survivability / circuit acceptability
Operational Amplifiers	CMOS	1E7 – 5E8	5E8 – Above	Extremely sensitive to latch-up and burnout / current limiting and power removal critical to survivability / circuit acceptability
Opto-Couplers – Photo-Diodes	Bipolar / Linear	1E6 – 1E10	> 1E10	Not concern @ tactical GDR levels / photocurrent generation will occur
Opto-Couplers – Photo-Transistor / Diode	Bipolar / Linear	1E6 – 1E10	> 1E10	Not concern @ tactical GDR levels / photocurrent generation will occur
Opto-Electronics --Solid State Relays	Hybrid	1E6 – 1E9	1E9 – Above	Sensitive to latch-up and burnout / current limiting and power removal critical to survivability / circuit acceptability
Passive Devices	Many	N/A	> 1E13	Not concern @ tactical GDR levels / Applicable to secondary effects, corrective actions and circuit acceptability
Programmable Logic Device – EEPROM	CMOS	1E7 – 5E8	5E8 – Above	Sensitive to latch-up, memory corruption and burnout / current limiting and power removal critical to survivability / circuit acceptability / Change of state
Programmable Logic Device – SRAM	CMOS	1E7 – 5E8	5E8 – Above	Sensitive to latch-up, memory corruption and burnout / current limiting and power removal critical to survivability / circuit acceptability / Change of state

Table E-3. Gamma Dose Rate (GDR) Concern Thresholds (Continued).

Piece-Part Type	Technology	GDR Upset Threshold (cGy(Si)/sec)	GDR Latch-up / Burnout Threshold (cGy(Si)/sec)	Comments
Silicon Controlled Rectifiers SCRs/ Thyristor	Bipolar / Linear	N/A	1E6 – 1E9	Significant photocurrent generation will occur due to Four Layer Path / Will turn On due to photocurrent generation / primary Nuclear Event Detection Device
Timers	Bipolar / Linear	1E7 – 5E8	5E8 – Above	Sensitive to latch-up and burnout / current limiting and power removal critical to survivability / circuit acceptability
Timers	CMOS	1E7 – 5E8	5E8 – Above	Sensitive to latch-up and burnout / current limiting and power removal critical to survivability / circuit acceptability
Transistors GBWP < 50 MHz	Bipolar / Linear	1E7 – 1E9	1E9 – Above	Not concern @ tactical GDR levels / photocurrent generation will occur / Configuration dependent
Transistors GBWP > 50 MHz	Bipolar / Linear	1E7 – 1E9	1E9 – Above	Not concern @ tactical GDR levels / photocurrent generation will occur / Configuration dependent
Transistors - Junction Field Effect (JFET)	FET	1E7 – 1E9	1E9 – Above	Not concern @ tactical GDR levels / photocurrent generation will occur / Configuration dependent
Transistors – Photo	Bipolar / Linear	1E7 – 1E9	1E9 – Above	Not concern @ tactical GDR levels / photocurrent generation will occur / Configuration dependent
Uni-Junction Transistors (UJTs)	Bipolar / Linear	1E7 – 1E9	1E9 – Above	Not concern @ tactical GDR levels / photocurrent generation will occur / Configuration dependent
Voltage References	Bipolar / Linear	1E7 – 1E9	1E9 – Above	Sensitive to latch-up and burnout / current limiting and power removal critical to survivability / circuit acceptability
Voltage References	CMOS	1E7 – 5E8	5E8 – Above	Sensitive to latch-up and burnout / current limiting and power removal critical to survivability / circuit acceptability

Table E-3. Gamma Dose Rate (GDR) Concern Thresholds (Continued).

Piece-Part Type	Technology	GDR Upset Threshold (cGy(Si)/sec)	GDR Latch-up / Burnout Threshold (cGy(Si)/sec)	Comments
Voltage Regulators – Linear – Fixed and Adjustable	Bipolar / Linear	1E7 – 1E9	1E9 – Above	Sensitive to latch-up and burnout / current limiting and power removal critical to survivability / circuit acceptability
Voltage Regulators – Linear – Fixed and Adjustable	CMOS	1E7 – 5E8	5E8 – Above	Sensitive to latch-up and burnout / current limiting and power removal critical to survivability / circuit acceptability
Voltage Regulators – Switching	Bipolar / Linear	1E7 – 1E9	1E9 – Above	Sensitive to latch-up and burnout / current limiting and power removal critical to survivability / circuit acceptability
Voltage Regulators – Switching	CMOS	1E7 – 5E8	5E8 – Above	Sensitive to latch-up and burnout / current limiting and power removal critical to survivability / circuit acceptability

Table E-4. Gamma Total Dose (GTD) Concern Thresholds.

Piece-Part Type	Technology	GTD Threshold Range (cGy(Si)	Comments
Analog Switches	CMOS	1K – Above	Increased Rds(ON) and leakage currents
Analog Switches	MOS/JFET	2K – Above	Increased Rds(ON) and leakage currents
Charge Coupled Devices (CCDs)	CCD	10K - Above	Not concern @ tactical GTD levels
Comparators	Bipolar / Linear	10K - Above	Not concern @ tactical GTD levels
Comparators	CMOS	3K - Above	Increase in Vos
Crystal Oscillators	Hybrid	5K - Above	Slight effects on frequency / Low Risk @ tactical GTD levels – Concern with control circuitry
Crystals	Linear	10K - Above	Slight effects on frequency / Low Risk @ tactical GTD levels
Darlingtons	Bipolar / Linear	10K - Above	Not concern @ tactical GTD levels
DC/DC Converter with Magnetic Feedback	Hybrid	10K - Above	Not concern @ tactical GTD levels
DC/DC Converters with Optical Feedback	Hybrid	3K - Above	The optical feedback design is the most sensitive to the GTD
Digital Devices	CML	10K - Above	Not concern @ tactical GTD levels
Digital Devices	ECL	10K - Above	Not concern @ tactical GTD levels
Digital Devices	Gallium Arsenide	> 20K	Not concern @ tactical GTD levels
Digital Devices	I2L	10K - Above	Not concern @ tactical GTD levels
Digital Devices	TTL	10K - Above	Not concern @ tactical GTD levels
Digital Potentiometers	CMOS	1.5K - Above	The primary concern is the EEPROM input becoming all “1s” / Data corruption and shift in Logic Thresholds
Diodes – High Frequency	Bipolar / Linear	> 20K	Not concern @ tactical GTD levels
Diodes – Light Emitting (LEDs)	Bipolar / Linear	> 20K	Not concern @ tactical GTD levels
Diodes – Light Emitting (LEDs)	Gallium Arsenide Variants	> 20K	Not concern @ tactical GTD levels
Diodes – Photo	Bipolar / Linear	> 20K	Not concern @ tactical GTD levels
Diodes – Rectifier	Bipolar / Linear	> 20K	Not concern @ tactical GTD levels

Table E-4. Gamma Total Dose (GTD) Concern Thresholds (Continued).

Piece-Part Type	Technology	GTD Threshold Range (cGy(Si)	Comments
Diodes – Reference / Zener / Suppression	Bipolar / Linear	> 20K	Not concern @ tactical GTD levels
Diodes – Signal	Bipolar / Linear	> 20K	Not concern @ tactical GTD levels
Fully Programmable Gate Array (FPGA)	CMOS	3K – Above	Data corruption and shift in Logic Thresholds
Insulated Gate Bipolar Transistors (IGBTs)	IGBT	2K - Above	Increase in VCE(Sat)
Logic Devices	TTL	10K - Above	Not concern @ tactical GTD levels
Memory - DRAM	CMOS	3K – Above	Data corruption and shift in Logic Thresholds
Memory – EEPROM & Flash	CMOS	1.5K - Above	The primary concern is the EEPROM input becoming all "1s" / Data corruption and shift in Logic Thresholds / Data Loss can occur @ 8K Rads(Si)
Memory - EPROM	CMOS	1.5K - Above	The primary concern is the EEPROM input becoming all "1s" / Data corruption and shift in Logic Thresholds / Data Loss can occur @ 8K Rads(Si)
Memory - FIFO	CMOS	5K – Above	Data corruption and shift in Logic Thresholds
Memory - PROM	TTL	10K - Above	Not concern @ tactical GTD levels
Memory - ROM	TTL	10K - Above	Not concern @ tactical GTD levels
Memory – SDRAM	CMOS	3K – Above	Data corruption and shift in Logic Thresholds
Memory – SRAM	CMOS	2K – Above	Data corruption and shift in Logic Thresholds
Micro-Controllers	CMOS	3K – Above	Data corruption and shift in Logic Thresholds
Micro-Processors	Bipolar	10K - Above	Not concern @ tactical GTD levels
Micro-Processors	CMOS	3K – Above	Data corruption and shift in Logic Thresholds
MOSFETs – N-Channel	NMOS	1.5K - Above	Decrease in Vgs(th) and increase in Rds(ON)
MOSFETs – P-Channel	PMOS	1.5K - Above	Increase in Vgs(th) and increase in Rds(ON)
Multiplexers	CMOS	1K – Above	Increased Rds(ON) and leakage currents
Multiplexers	MOS/JFET	2K – Above	Increased Rds(ON) and leakage currents

Table E-4. Gamma Total Dose (GTD) Concern Thresholds (Continued).

Piece-Part Type	Technology	GTD Threshold Range (cGy(Si)	Comments
Operational Amplifiers	BICMOS	3K – Above	Increase in Vos and decrease in Large Signal Voltage Gain
Operational Amplifiers	BIMOS	3K – Above	Increase in Vos and decrease in Large Signal Voltage Gain
Operational Amplifiers	Bipolar / Linear	> 20K	Not concern @ tactical GTD levels
Operational Amplifiers	CMOS	3K – Above	Increase in Vos and decrease in Large Signal Voltage Gain
Opto-Couplers – Photo-Diodes	Bipolar / Linear	5K – Above	Decrease in transmissivity of material between diodes
Opto-Couplers – Photo-Transistor / Diode	Bipolar / Linear	5K – Above	Decrease in transmissivity of material between diodes / transistor pair
Opto-Electronics - -Solid State Relays	Hybrid	2K – Above	Device will not Turn ON, due to threshold shifts
Passive Devices	Many	> 20K	Not concern @ tactical GTD levels / Applicable to secondary effects, corrective actions and circuit acceptability
Programmable Logic Device – EEPROM	CMOS	1.5K - Above	The primary concern is the EEPROM input becoming all "1s" / Data corruption and shift in Logic Thresholds
Programmable Logic Device – SRAM	CMOS	2K – Above	Data corruption and shift in Logic Thresholds
Silicon Controlled Rectifiers (SCRs) / Thyristors	Bipolar / Linear	10K - Above	Not concern @ tactical GTD levels
Timers	Bipolar / Linear	10K - Above	Not concern @ tactical GTD levels
Timers	CMOS	2K – Above	Changes in Logic Thresholds

Table E-4. Gamma Total Dose (GTD) Concern Thresholds (Continued).

Piece-Part Type	Technology	GTD Threshold Range (cGy(Si)	Comments
Transistors GBWP < 50 MHz	Bipolar / Linear	10K - Above	Not concern @ tactical GTD levels
Transistors GBWP > 50 MHz	Bipolar / Linear	10K - Above	Not concern @ tactical GTD levels
Transistors - Junction Field Effect (JFET)	FET	> 20K	Not concern @ tactical GTD levels
Transistors – Photo	Bipolar / Linear	10K - Above	Not concern @ tactical GTD levels
Uni-Junction Transistors (UJTs)	Bipolar / Linear	10K - Above	Not concern @ tactical GTD levels
Voltage References	Bipolar / Linear	10K - Above	Not concern @ tactical GTD levels
Voltage References	CMOS	2K - Above	The primary concern is charge pumps internal to the reference
Voltage Regulators – Linear – Fixed and Adjustable	Bipolar / Linear	10K - Above	Not concern @ tactical GTD levels
Voltage Regulators – Linear – Fixed and Adjustable	CMOS	3K - Above	
Voltage Regulators – Switching	Bipolar / Linear	10K - Above	Not concern @ tactical GTD levels
Voltage Regulators – Switching	BiMOS / BiCMOS/ CMOS	2K - Above	

Table E-5. Neutron Fluence (NF) Concern Thresholds.

Piece-Part Type	Technology	NF Threshold Range (n/cm^2)	Comments
Analog Switches	CMOS	> 3E12	
Analog Switches	MOS/JFET	> 3E12	
Charge Coupled Devices (CCDs)	CCD	2E12 - Above	Increase in dark current and Decrease in Charge Transfer Efficiency (CTE)
Comparators	Bipolar / Linear	1E12 - Above	Increase in Bias Currents, Vos and Decrease in Open Loop Gain and Sink Current
Comparators	CMOS	> 5E12	
Crystal Oscillators	Hybrid	> 5E12	Slight effects on frequency / Low Risk @ tactical NF levels – Concern with control circuitry
Crystals	Linear	> 5E12	Slight effects on frequency / Low Risk @ tactical NF levels
Darlingtons	Bipolar / Linear	1E12 - Above	Messenger-Spratt cannot account for actual Darlington NF degradation
DC/DC Converter with Magnetic Feedback	Hybrid	2E12 - Above	Slight Increases / Decreases in Output Voltage
DC/DC Converters with Optical Feedback	Hybrid	5E11 - Above	The optical feedback design is the most sensitive to the NF / Output Voltage goes to Zero or Input Voltage
Digital Devices	CML	> 1E13	Not concern @ tactical NF levels
Digital Devices	ECL	> 1E13	Not concern @ tactical NF levels
Digital Devices	Gallium Arsenide	> 1E13	Not concern @ tactical NF levels
Digital Devices	I2L	> 1E13	Not concern @ tactical NF levels
Digital Devices	TTL	> 1E13	Not concern @ tactical NF levels
Digital Potentiometers	CMOS	1E12 - Above	Device will not re-program due to charge pump failure
Diodes – High Frequency	Bipolar / Linear	> 1E13	Not concern @ tactical NF levels
Diodes – Light Emitting (LEDs)	Bipolar / Linear	5E11 - Above	Substantial Decrease in Light Output / Generally not an issue due to diagnostic circuit application
Diodes – Light Emitting (LEDs)	Gallium Arsenide Variants	8E11 - Above	Substantial Decrease in Light Output
Diodes – Photo	Bipolar / Linear	3E11 - Above	Substantial Decrease in Light Detection/ Increases in Dark Current / Circuit application is critical

Table E-5. Neutron Fluence (NF) Concern Thresholds (Continued).

Piece-Part Type	Technology	NF Threshold Range (n/cm^2)	Comments
Diodes – Rectifier	Bipolar / Linear	> 1E13	Not concern @ tactical NF levels
Diodes – Reference / Zener / Suppression	Bipolar / Linear	1E12 - Above	Decrease in Output Voltage
Diodes – Signal	Bipolar / Linear	> 1E13	Not concern @ tactical NF levels
Fully Programmable Gate Array (FPGA)	CMOS	> 1E13	Not concern @ tactical NF levels
Insulated Gate Bipolar Transistors (IGBTs)	IGBT	8E11 - Above	Increase in VCE(Sat)
Logic Devices	TTL	> 1E13	Not concern @ tactical NF levels
Memory - DRAM	CMOS	> 1E13	Not concern @ tactical NF levels
Memory – EEPROM & Flash	CMOS	1E12 - Above	Device will not re-program due to charge pump failure
Memory – EPROM	CMOS	> 5E12	Not concern @ tactical NF levels
Memory - FIFO	CMOS	> 1E13	Not concern @ tactical NF levels
Memory - PROM	TTL	> 1E13	Not concern @ tactical NF levels
Memory - ROM	TTL	> 1E13	Not concern @ tactical NF levels
Memory – SDRAM	CMOS	2E11 – Above	Data Corruption through insufficient refresh rate / Missing Bits
Memory – SRAM	CMOS	> 1E13	Not concern @ tactical NF levels
Micro-Controllers	CMOS	> 1E13	Not concern @ tactical NF levels
Micro-Processors	Bipolar	> 1E13	Not concern @ tactical NF levels
Micro-Processors	CMOS	> 1E13	Not concern @ tactical NF levels
MOSFETs – N-Channel	NMOS	> 1E13	Not concern @ tactical NF levels
MOSFETs – P-Channel	PMOS	> 1E13	Not concern @ tactical NF levels
Multiplexers	CMOS	> 3E12	
Multiplexers	MOS/JFET	> 3E12	

Table E-5. Neutron Fluence (NF) Concern Thresholds (Continued).

Piece-Part Type	Technology	NF Threshold Range (n/cm^2)	Comments
Operational Amplifiers	BICMOS	1E12 - Above	Increase in Bias Currents, Vos and Decrease in Open Loop Gain
Operational Amplifiers	BIMOS	1E12 - Above	Increase in Bias Currents, Vos and Decrease in Open Loop Gain
Operational Amplifiers	Bipolar / Linear	1E12 - Above	Increase in Bias Currents, Vos and Decrease in Open Loop Gain
Operational Amplifiers	CMOS	> 5E12	
Opto-Couplers – Photo-Diodes	Bipolar / Linear	1E12 - Above	Substantial Decrease in Current Transfer Ratio
Opto-Couplers – Photo-Transistor / Diode	Bipolar / Linear	5E11 – Above	Substantial Decrease in Current Transfer Ratio
Opto-Electronics - -Solid State Relays	Hybrid	5E11 – Above	Device will not Turn ON, due to insufficient drive
Passive Devices	Many	> 1E14	Not concern @ tactical NF levels / Applicable to secondary effects, corrective actions and circuit acceptability
Programmable Logic Device – EEPROM	CMOS	1E12 – Above	Device will not re-program due to charge pump failure
Programmable Logic Device – SRAM	CMOS	> 1E13	Not concern @ tactical NF levels
Silicon Controlled Rectifiers (SCRs) / Thyristors	Bipolar / Linear	5E11 – Above	Substantial Increase in Holding Current requirement
Timers	Bipolar / Linear	1E12 – Above	Increase in Reset Time / Circuit application is critical
Timers	CMOS	> 1E13	Not concern @ tactical NF levels
Transistors GBWP < 50 MHz	Bipolar / Linear	5E11 - Above	Substantial Decrease in Gain
Transistors GBWP > 50 MHz	Bipolar / Linear	3E12 - Above	Substantial Decrease in Gain

Table E-5. Neutron Fluence (NF) Concern Thresholds (Continued).

Piece-Part Type	Technology	NF Threshold Range (n/cm^2)	Comments
Transistors - Junction Field Effect (JFET)	FET	> 1E13	Not concern @ tactical NF levels
Transistors – Photo	Bipolar / Linear	3E11 - Above	Extremely sensitive to NF degradation
Uni-Junction Transistors (UJTs)	Bipolar / Linear	5E11 - Above	Substantially Increases RB1 and RB2
Voltage References	Bipolar / Linear	7E11 - Above	Significant shift in Output Voltage (Increase or Decrease) / Substantial Increase in Line & Load Regulation
Voltage References	CMOS	> 5E12	
Voltage Regulators – Linear – Fixed and Adjustable	Bipolar / Linear	7E11 - Above	Significant shift in Output Voltage (Increase or Decrease) / Substantial Increase in Line & Load Regulation
Voltage Regulators – Linear – Fixed and Adjustable	CMOS	> 5E12	
Voltage Regulators – Switching	Bipolar / Linear	7E11 - Above	Significant shift in Output Voltage (Increase or Decrease) / Substantial Increase in Line & Load Regulation
Voltage Regulators – Switching	BiMOS / BiCMOS	7E11 - Above	Significant shift in Output Voltage (Increase or Decrease) / Substantial Increase in Line & Load Regulation
Voltage Regulators – Switching	CMOS	> 3E12	

APPENDIX F: DETAILED TEST PLAN SUBTEST EXAMPLE.

2.6 High-Altitude Electromagnetic Pulse (HEMP).

2.6.1 OBJECTIVES.

a. To assess the survivability of the M1A2 V2 when exposed to the HEMP environment specified in MIL-STD 2169B and using the MIL-STD 464A E-Field parameter.

b. To update the M1 Abrams LCN&ES database and identify the baseline configuration of the M1A2 V2 for the Life-Cycle management and control as specified in AR 70-75, and MIL-STDs 2169B and 464A. This will be accomplished by entering into the Life-Cycle database pertinent data, results and information from this HEMP test.

2.6.2 CRITERIA.

2.6.2.1 HEMP Levels. The M1A2 V2 shall perform all its mission essential operational performance functions following exposure to the HEMP environment specified in SA-SA00001D. The tank shall remain combat effective without component replacement. The tank will be subjected to Early-time (E1) peak electric field intensity from MIL-STD 464A using the two timing parameters of the E1 HEMP waveform defined in MIL-STD 2169B. The M1 Abrams does not have an operate-through requirement; instead, it is allowed to experience upsets that can be re-set by the crew to achieve full operational capability within the allowable downtime of seven minutes after the HEMP event. The HEMP criteria levels for the M1A2 V2 are:

E-field	**=**	**Omitted**	**[volts/meter]**
H-field	**=**	**Omitted**	**[amp-turns/meter]**
Rise Time	**=**	**Omitted**	**[seconds]**

2.6.2.2 Omission. The two E1 HEMP timing levels are extracted from the MIL-STD 2169B and SA-SA00001D, which are classified SECRET. The E1 HEMP timing criterion levels are, therefore, omitted from this document in order to maintain its UNCLASSIFIED status. The E1 HEMP peak E-Field of 50 kilovolts per meter (kV/m) is extracted from MIL-STD 464A. The E1 HEMP criteria of MIL-STD 2169B are available by contacting TEDT-WS-SV, WSMR, or by obtaining a copy from the U.S. Army Nuclear and Combating Weapons of Mass Destruction Agency (USANCA). The E1 HEMP criterion levels will be provided in the classified Detailed Test Report (DPT).

2.6.2.3 HEMP Description. The M1A2 V2 will only be subjected to the Early-Time Waveform of the HEMP environment produced by an exo-atmospheric nuclear detonation. The HEMP environment has two additional waveform components, E2 for Intermediate-Time and E3 for Late-Time. These two waveforms will not be considered for the M1A2 SEP V2 because they are applicable for systems connected by very long cables (E2) or to systems connected to the power grid or communications lines (E3).

The E2 and E3 HEMP waveforms will contribute some energy coupling to the M1A2 V2; but, the amount of energy coupled by these two waveforms to this discrete system will be insignificant relative to E1. Also, energy coupled by these two waveforms will not be additive since they will be out of time phase with each other as well as with E1.

2.6.2.4 LCN&ES. IAW AR 70-75, MIL-STDs 2169B and 464A, a life-cycle program shall be established and implemented for mission critical systems such as the M1A2 V2 Tank. In addition, the M1A2 V2 Tank's operational performance requirements shall be met throughout its rated life cycle. The production, operation, maturity, maintenance, storage, upgrades, enhancements, ambient environment, and DMS solutions and technology insertions, shall not introduce any HEMP susceptibilities or unacceptable levels of degradation into the M1A2 V2 Abrams tank.

2.6.3 TEST PROCEDURES.

2.6.3.1 General Procedures. The HEMP survivability program for the M1A2 V2 will include testing at SVAD HEMP simulator, the Horizontal Polarized Dipole–II (HPD-II). The survivability of the M1A2 V2 to its HEMP criteria level will be assessed by:

a. Performing a pre-test energy coupling analysis.

b. Establishing its complete performance baseline prior to HEMP testing, using baseline self test checks, Diagnostic tests.

c. Performing detailed bulk current measurements on cables identified in the pre-test analysis (external cables, POE and internal cables).

d. Testing the SUT in different configurations. The M1A2 V2 will be tested in two hull orientations with respect to the electric field vector, i.e., longitudinal axis parallel to electric field vector, and perpendicular to the electric field vector. For each hull orientation, the turret will be tested in two positions: 1) gun over the drivers hatch, and 2) gun over the curbside. In each of these four hull-turret orientation-positions (configurations), the SUT will be illuminated by a series of HEMP pulses. At each E-Field level for each test configurations, if no failures occur, the M1A2 V2 SUT will be illuminated, at a minimum, twice more or until all data acquisition has been completed.

e. Illuminating the M1A2 V2 SUT in four configurations to 75%, 100% and 120% of its E-Field criterion level.

f. Illuminating the M1A2 V2 SUT in a fully operational mode, i.e. the tank will be fully operational with engine in TAC idle , fire control in the NORMAL mode, and communications, etc., powered ON. The final drive will be disconnected as deemed necessary. All hatches except the drivers will be opened during exposures.

g. Repeating the necessary pre-test baseline checks on the M1A2 V2 SUT after each illumination.

h. Illuminating the SUT multiple times. The number of test pulses performed will depend on how many tank harness shields are monitored for HEMP induced currents. It is planned to measure all accessible cables; no physical changes will be made to access data points. Unacceptable effects will be investigated to quantify, determine the cause, and identify fixes.

i. Diagnosing all effects. Most HEMP responses are manifested as system upsets. In the event of an upset, the system power will be cycled to determine if normal operation can be restored. If normal operation is restored, the illumination will be repeated to verify the effect. If system operation is not restored, further investigation will be performed to determine the affected LRU.

j. Documenting upsets, failures, downtime, and corrective actions; most problems induced will be transient upsets and will be correctable by cycling power OFF/ON.

k. Identifying and classifying all failures to the electronic piece-parts/component level.

2.6.3.2 Test Equipment. The following test equipment is scheduled for this test.

a. Simulator: HPD-II Free field HEMP simulator and antenna.

b. Data transmitter Links: Nanofast® OP300 fiber-optic.

c. Inductive current probes: EATON® 91550-2.

d. Environment reference probe: MGL-2 D-dot free field probe.

e. Environment monitoring probe: EG&G ADC-4 Free-Field probe.

f. Environment data recording device: Tektronix® TDS 7154B Digital Phosphor Oscilloscopes.

2.6.3.3 Test Facility. The HEMP testing performed on the M1A2 V2 SUT will utilize the SVAD HPD-II facility, which generates the E1-type HEMP waveform defined in MIL-STD 2169B. The HPD-II provides a horizontally polarized EM Environment (EME), which is ideal for a horizontally coupling system like the M1A2 V2 Tank.

2.6.3.4 Pre-test Analysis. A pre-test analysis will be conducted to:

a. Evaluate and incorporate pertinent test data and results from previous tests.

b. Analyze drawings and circuits to identify potentially harmful energy paths.

c. Identify test system's internal configuration.

d. Identify and determine all energy coupling POEs.

e. Analyze grounding schemes and identify EM barrier features such as shielded cables to include connectors / backshells.

f. Evaluate deliberate hardening devices and techniques.

g. Define DAS requirements.

h. Identify cables for measurements.

i. Identify test levels, orientations, configurations, and operational modes based on the results of the hardening determination.

2.6.3.5 System Setup.

a. Prior to testing, the M1A2 V2 SUT will be functionally checked to ensure proper operation. Problems will be documented, reported, and corrected if detrimental to the HEMP survivability assessment program on the M1A2 V2.

b. The M1A2 V2 SUT in a pre-test analysis selected configuration will be positioned in the HEMP facility near the center of the test volume for the desired test level (defined by the peak E-Field). The M1A2 V2 SUT will then be powered and a functional check performed.

c. A bulk current probe will be placed near (but not attached to) the longest cable length in the SUT and an EM noise measurement taken to establish the data collection base. This type of base-line measurement will be made for all of the current probes.

d. Bulk current measurements will be obtained on cables identified in the pre-test analysis as being potential paths for harmful levels of HEMP induced energy. Pin current measurements will only be collected if a failure is identified. The pin current data will be utilized in a failure analysis and/or to perform corrective actions.

2.6.3.6 System Test. The M1A2 V2 SUT will be illuminated by a transverse electromagnetic wave whose E-Field magnitude is approximately 75% of the E1 HEMP criterion value. After illumination, the M1A2 V2 will again be checked to establish the functional status of the system. At the completion of each successful test series (all cables measured), the M1A2 V2 SUT will be changed to account for energy coupling into different cable layouts and functions in the system. Once the series of four hull-turret orientation-positions and modes described in Para 2.6.3.1.d have been completed, then the E-Field magnitude will be increased to the next E-Field level and the test procedures repeated. These procedures will be repeated for the third E-Field test level.

2.6.3.7 Effects Procedure. If an effect / anomaly occur, it will be documented and diagnosed. Testing will not be continued until the problem is understood, and its effect on the M1A2 V2 SUT has been assessed as well as potential impacts on the M1A2 V2 SUT results if testing is continued. If an upset occurs, the M1A2 V2 power will be cycled OFF/ON. If the SUT fully recovers, testing will be repeated at the same level and test orientation to determine whether the problem was EME induced or an anomaly. Borderline cases may require an additional test exposure or Current Injection (CI) testing to explicitly establish whether the effect was environmentally induced. If the SUT does not recover, then follow-up checks, measurement review, and review of the pre-test analysis will be used to identify the energy path and the affected electronic piece-part/component. If the effect is a failure, diagnostic checks will be performed to determine energy path and victim(s). If the operational status of the SUT can be restored, an engineering judgment will be made of potential risk to the SUT if testing is continued. Every effort will be made to complete testing.

2.6.3.8 Environment Measurements. Measurements of each illumination will be made using an Electric Flux Density per unit time (D-dot) probes, so that the magnitude of the E-Field and pulse shape can be determined. This information will be digitized, reviewed, and stored for later environment compliance analysis. Injected current signals will be measured using a calibrated bulk current probe, reviewed and then stored for later stress level compliance analysis and upset / problem evaluations.

2.6.4 DATA REQUIRED.

a. Detailed description of each HEMP environment to include photographs of the test facility setup showing test system position relative to the HEMP antenna array.

b. Complete set of pre-test mapping data of each HEMP illumination level with the Electric Field expressed in Volts/meter (V/m) (±5%), rise time and pulse width expressed in nanoseconds (ns) (±5%), frequency expressed in Hertz (Hz)(±5%), and Magnetic Field (H-Field) amplitude expressed in Amp-turns/meter (±5%).

c. Detailed description of the M1A2 V2 functional checks used to baseline the M1A2 V2 SUT to determine its post-illumination capabilities.

d. Visual inspection, logs, test conductor notes, and photographs.

e. Detailed description, serial numbers, and the M1A2 V2 subsystems.

f. Detailed description and recording of all inspections, downtime and recovery time (sec) (±10%), and checkout data.

g. Log of Tank baseline checks from the Operator manuals, i.e., self-test, and as needed diagnostic tests with descriptions of discrepancies.

h. Tank physical and operating configuration during each subtest illumination.

i. Log sheets of test illumination to include induced upsets or failures.

j. Description and calibration of current / voltage measuring probes and the DAS. In addition, description of all probe locations is required.

k. Results of all facility environment measurements expressed in the same units as listed in Para 2.6.4.b above.

l. Results of all current and voltage measurements, and Fast Fourier Transforms data obtained from the DAS.

m. Results of previous HEMP and CI tests performed by the contractor or another government agency on the M1A2 V2 or Abrams series tank.

n. Detailed description of all deliberate HEMP hardening devices and/or techniques employed on the M1A2 V2.

o. Percent error incorporated into the DAS.

p. Calibration dates for all test equipments.

q. TIRs, if applicable.

2.6.5 DATA ANALYSIS / PROCEDURE.

2.6.5.1 Data. The pre-test analysis will consist of evaluating results from the previous M1A2 V2 HEMP program and reviewing the test system's configuration. Pertinent data, results and information will be incorporated into the test planning of the SVAD HEMP program for the M1A2 V2. The incorporation of all test data will be used to enhance and reduce the scope of testing. Pertinent data will be included in the SVAD failure diagnostics, post-test analysis / assessment, and documented in the detailed test report to support the test results.

2.6.5.2 Criteria Compliance. The HEMP environmental data from the HPD-II facility will be corrected to account for the percent error associated with the DAS:

a. A mean and standard deviation will be established from the error corrected HPD-II E-Field parameters.

b. The H-Field parameter will be derived by dividing this mean error corrected HPD-II E-Field parameter by 377 ohms.

c. A mean and standard deviation rise time will be established from the HPD-II E-Field data.

d. The HPD-II E-Field data, test point current data and test point FFTs will be examined using MATLAB to determine the primary coupling frequency or coupling frequency range, critical damping factor, and energy content.

e. The data in Paragraphs 2.6.5.2a through 2.6.5.2d will be compared and evaluated against the MIL-STD 2169B E1 HEMP criteria to determine criteria compliance.

2.6.5.3 System Configuration Compliance. The test system configuration will be evaluated against the expected production configuration and all differences will be identified and documented. Differences that could impact the results will be discussed in the final report. The existing baseline configuration will be updated and documented.

2.6.5.4 Effects Analysis. Effects will be scored at the test level of occurrence. Cause(s) and victim(s) will be identified, and impact(s) on the M1A2 V2 mission will be discussed. Failures or operational performance degradation occurring at levels above criteria will be classified as system shortcomings, unless verified by additional data and/or energy coupling analysis to be valid as a result of manufacturing variations or assembly. This information will be used primarily to provide the needed level of confidence in the survivability assessment of the M1A2 V2 to meet its defined HEMP criteria.

2.6.5.5 System Performance. Comparison of pre- and post-illumination functional checkout data for the M1A2 V2 test system will be used to determine the effects of the HEMP test environment on the M1A2 V2. Degradation resulting in system performance outside specifications, or total failure(s), will be addressed with regards to cause(s), victim(s), test level at which they occurred, allowable downtime, and mission impact.

2.6.5.6 Survivability Assessment. A HEMP survivability assessment will be performed on the production or baseline configuration against the HEMP criteria using the results of Paragraphs 2.6.5.2 through 2.6.5.5. This assessment may produce results different than obtained during the testing due to corrections for manufacturing variations and/or test environment deficiencies.

2.6.5.7 LCN&ES. Both, the configuration for the test system and proposed baseline production system will be archived into the M1A2 V2 Life-Cycle program database along with pertinent test data and results, extrapolated results, and information from this HEMP subtest. This database will enable implementation of the Life-Cycle program of Hardness and Sustainment Assurance, and Surveillance tests.

2.8 Gamma Dose Rate (GDR).

2.8.1 OBJECTIVES.

a. To assess the survivability of the M1A2 V2 to the effects of the GDR environment as specified in SA-SA00001D and USANCA documents.

b. To assess the survivability utilizing the procedures in TOPs 1-2-612 and 1-2-618.

c. To update the M1A2 V2 LCN&ES program GDR database by inputting pertinent data, results and information resulting from this subtest.

2.8.2 CRITERIA.

2.8.2.1 GDR Test Levels. The M1A2 V2 shall perform all its mission essential operational performance functions following exposure to the GDR environment specified in SA-SA00001D and the USANCA criteria (same level). The M1A2 V2 shall remain combat effective without component replacement. The M1A2 V2 does not have an "operate through" requirement (DECU must circumvent and regain control of engine) and recovery of mission essential functions by crew within seven minutes is permissible. The M1A2 V2 will be exposed to 100% and 150% of the M1A2 GDR criterion levels. The GDR criterion levels for the M1A2 V2 are:

Peak GDR = Omitted [cGy(Si)/sec] (SA-SA0001D and USANCA)

2.8.2.2 Omission. The GDR test levels are extracted from the SA-SA00001D document and USANCA documents. The GDR survivability levels are classified CONFIDENTIAL and the GDR criterion level is, therefore, omitted from this document in order to maintain its **UNCLASSIFIED** status. The criterion is available by contacting TEDT-WS-SV, WSMR. The GDR criterion level will be stated in the classified Detailed Test Report (DTR).

2.8.2.3 Lifecycle. IAW AR 70-75 and the DCSOPS NWE Memorandum, a life-cycle program shall be established and implemented for mission critical systems such as the M1A2 V2 Abrams Tank. The production, operation, maturity, maintenance, sustainment, upgrades, DMS solutions and technology insertions, storage and ambient environment shall not introduce GDR susceptibilities or unacceptable levels of GDR hardness degradation into the M1A2 V2. In addition, the M1A2 V2 Tank's operational performance requirements shall be met throughout its rated life cycle.

2.8.3 TEST PROCEDURES.

2.8.3.1 General. The survivability of the M1A2 V2 to its GDR criterion level will be assessed by:

a. Establishing the M1A2 V2 SUT performance baseline before exposure using the system diagnostics tests.

b. Exposing the M1A2 V2 SUT and all equipments to 100% and then 150% of its GDR criterion levels.

c. Repeating the pre-test baseline checks after each GDR irradiation to establish a functional status.

d. Illuminating the M1A2 V2 SUT in different test positions and hull-turret orientations, in order to insure that all GDR sensitive areas are adequately exposed and to validate the adequacy of intentional GDR hardening.

e. Documenting upsets, failures, downtime, and corrective actions.

2.8.3.2 Test Facility. The GDR environment for the M1A2 V2 will be provided at the HERMES-III, the largest flash X-ray in the world. This flash X-ray facility produces Bremsstrahlung photons, which simulates the GDR environment resulting from the detonation of a nuclear weapon. The average end-point photon energy will be approximately 19 MeV with a Full Width Half Maximum (FWHM) pulse-width of approximately 28 nsec.

2.8.3.3 Pre-test Analysis. A pre-test analysis will be conducted to:

a. Incorporate pertinent test data and results from previous programs.

b. Identify all GDR Hardness Critical Items (HCIs) based upon technology.

c. Identify test system's internal configuration.

d. Define DAS and dosimetry requirements.

e. Analyze hardening and analysis performed by contractor.

f. Identify the most realistic and severe test setup with respect to the HERMES-III anode.

g. Identify all current limiting, power removal, and/or GDR hardening applications.

h. Identify test levels, orientations, configurations, and operational modes.

2.8.3.4 System Test Setup.

a. A calibrated Compton Diode probe will be utilized to monitor the output of the HERMES-III. This probe will be located at a constant position relative to the exit anode to provide consistent pulse-width measurements of the GDR test environment.

b. Before testing begins, a calibration GDR irradiation will be performed to map the simulator's output. These values will be used for determining the initial Source-To-Target (STT) distance to achieve 100% and 150% of the GDR criterion. As testing proceeds, the STT distance will be refined using the environmental data acquired from the previous irradiation.

c. The M1A2 V2 and electronics in the incident beam of the HERMES-III output will be monitored with Calcium-Fluoride-Manganese doped (CaF_2(Mn)) Thermoluminescent Dosimeters (TLDs), which provide the GTD received by the monitored location.

d. The SUT will be positioned at the first STT distance and a pre-test baseline checkout performed utilizing engine power. Any abnormalities will be documented / corrected prior to start of test if judged detrimental to the GDR test.

2.8.3.5 System Test.

a. After a pulse of photons has irradiated the powered M1A2 V2 SUT, all operational checks will be initiated within five minutes, unless delayed by test facility constraints. If the SUT is determined to be operational to an acceptable level, the TLDs will be replaced and the M1A2 V2 will be re-positioned and/or re-oriented for the next GDR environment.

b. These procedures will be repeated for each combination of position and hull-turret orientation until all equipments have been exposed to 100% or as close to this value as can be obtained.

c. The SUT will be positioned at the STT distance to achieve 150% of the GDR criterion level. The procedures described for the 100% test will be repeated for the 150% test.

d. Since the GTD that is received by the M1A2 V2 SUT during each GDR exposure is small (2 to 150 Rads(Si)), delivered in a very short pulse duration (~28 nsec) and the annealing time between irradiations lengthy (30 - 60 minutes during the test day and 14 hours between test days), the M1A2 V2 SUT can be utilized in subsequent configurations. Essentially, no permanent GTD effects are introduced by these test procedures.

2.8.3.6 Response Procedure. If a response occurs, it will be documented and diagnosed. First attempt to recover operational functionality is to cycle power OFF / ON. If operational capability is restored, testing will be repeated at the same combination of position, hull-turret orientation and GDR level in an attempt to reproduce the same response (GDR induced effect) or to show an anomaly. Following a successful re-test, testing IAW approved procedures will continue. If operational capability is not restored after two OFF/ON cycles, then diagnostic procedures will be implemented to quantify the response and identify the victim. Testing will not be continued until the response is understood and its effect on the SUT has been assessed. If permanent damage occurs, the affected unit will be identified then diagnosed to the lowest assembly level achievable on-site. After completion of testing, the failed unit will be returned to GDLS for complete failure analysis. On site, the failed unit will be replaced or repaired (replacement of a CCA), and the SUT exposed again at the same level unless it has been determined that the failure was GDR induced. In that case, the replaced unit/item will be sufficiently shielded to prevent repeat of damage and testing will be continued. Every effort will be made to complete the GDR assessment of the M1A2 V2.

2.8.3.7 Dosimetry. The gamma dose at selected locations on the M1A2 V2 SUT will be measured using CaF_2(Mn) TLDs. The measured gamma dose values in cGy (CaF_2(Mn)) will be expressed in cGy(Si) and cGy(tissue) by the ratios:

$$\mathbf{cGy(Si)/cGy(CaF_2(Mn)) = 1.02 \text{ and } cGy(tissue)/cGy(CaF_2(Mn)) = 1.108}$$

Each radiation pulse will be measured using a Compton Diode and digitized on a transient digitizing oscilloscope. The FWHM pulse-width of each radiation pulse will be obtained from this digitized signal. The GDR for each pulse will then be determined from the converted dose recorded on the TLDs divided by the pulse-width obtained from the oscilloscope.

2.8.4 DATA REQUIRED.

a. Visual inspections, logs, test conductor notes, and photographs of any damage.

b. Baseline data from M1A2 V2 SUT checks.

c. Detailed description and photographs of the method of producing the GDR test environment showing M1A2 V2 SUT position relative to the gamma radiation source.

d. Complete set of pre-test mapping data in radiation absorbed dose in centi-Grays (cGy), in silicon (cGy(Si))(±7%) and tissue (cGy(tissue)) (±7%) for each test location.

e. Pulse-width duration of each gamma radiation pulse (nsec) (±5%).

f. Gamma dose expressed in cGy(Si) and cGy(tissue) (±7%).

g. Location of TLDs on the M1A2 V2 SUT for each test orientation and test exposure.

h. List of all HCIs used in the M1A2 V2 Abrams Tank.

i. Detailed description and recording of all inspections, downtime (sec) (±10%), checkout data, and pre- and post-test results.

j. Go/no-go log of tank performance checks from self-tests and diagnostic tests with descriptions of discrepancies.

k. Tank physical and operating configuration during each subtest irradiation.

l. Detailed description of any deliberate hardening devices and/or techniques.

m. Conversion factors (±3%) used to convert cGy(CaF_2(Mn)) and Roentgens to cGy(Si) and cGy(tissue). (you did not mention instrument that measures in R)

n. Results from previous GDR tests performed at SVAD on the M1A2 production tank.

o. TIRs, if applicable.

2.8.5 DATA ANALYSIS / PROCEDURE.

2.8.5.1 <u>Data</u>. Results from other Abrams GDR tests and analysis performed by SVAD, GDLS and subcontractors will be evaluated as part of the pre-test evaluation and incorporated into the test planning on the GDRSA for the M1A2 V2. The incorporation of all test data especially the test performed by SVAD will be used to enhance and reduce the scope of the M1A2 V2 GDRSA program. Pertinent data will be included in the SVAD post-test analysis, survivability assessment, and the detailed test report. Differences greater than 20% will be analyzed particularly in terms of the effect on the test results.

2.8.5.2 Criteria Compliance. The GDR criterion as expressed in Para 2.8.2 will be compared to the test levels that will be determined in the following manner.

a. A mean incident surface gamma dose for each target area will be established from the TLDs.

b. A mean non-incident surface gamma dose for each target area will be established from the TLDs.

c. A mean Geometric Center–Vertical Plane (GCVP) gamma dose for each target area will be established by adding the incident and non-incident gamma dose values and dividing by 2.

d. The GDR value will be established by taking the GCVP gamma dose value in cGy(Si) for each target area and dividing by the FWHM pulse-width value (nsec) for each GDR irradiation.

e. If adequate dosimetry placement as specified in Paragraphs 2.8.5.2a and 2.8.5.2b cannot be conducted for a target area because of space or access restrictions, then the LRU's GCVP will be approximated using available TLD dose values and dividing by the GDR FWHM pulse-width.

f. The data in Para 2.8.5.2.d will be compared and evaluated against the M1A2 V2 criterion and criterion compliance determined.

g. Total dose readings at each location will be compared to the sum of the individual readings to check accuracy.

2.8.5.3 System Configuration Compliance. The M1A2 V2 test configuration will be evaluated against the proposed production configuration. All differences will be identified, discussed and documented. Differences that could impact the results will be discussed in the final report. The existing M1A2 V2 baseline configuration will be updated.

2.8.5.4 Response Analysis. Environment induced response(s) will be scored at the test level of occurrence, cause(s) and victim(s) will be identified, and impact on the M1A2 V2 mission critical performance parameters will be discussed. As necessary, data and analysis will be included from the extensive SVAD HCI INR database, especially, in support of diagnostics. Failures or degradation occurring at levels above criterion will be classified as system shortcomings, unless shown to be valid based on the data and/or data from HCI tests plus circuit analysis. This information will be used primarily to provide additional confidence in the response of a sample size of one for a very large and complex electronic integrated system.

2.8.5.5 System Performance. Comparison of pre- and post-irradiation functional checkout data for the M1A2 V2 will be the primary metric used to determine the effects of the test environment on the M1A2 V2 SUT. Observations and engineering judgment will also be used. Degradation resulting in M1A2 V2 performance outside specifications, or total failure(s), will be addressed with regards to cause(s), test level at which they occurred, allowable downtime, and mission impact.

2.8.5.6 Survivability Assessment. A GDR survivability assessment will be performed on the production or baseline configuration against the M1A2 V2 GDR criterion level using the results of Paragraphs 2.8.5.2 through 2.8.5.5. This assessment may produce results different than those obtained directly during the testing phase due to compliance corrections.

2.8.5.7 LCN&ES. Both, the configuration for the test system and proposed baseline production system will be archived into the M1A2 V2 program Life-Cycle database along with pertinent test data and results, extrapolated results, and information from this GDR subtest. This database will enable implementation of the Life-Cycle program of Hardness and Sustainment Assurance, and Surveillance tests.

APPENDIX G: DATA DOCUMENTATION.

TESTING DOCUMENTATION EXAMPLE.

TEST CONDUCTOR: John Anderson DATE: 20 March 07

FACILITY: HPD-II Facility PAGE_1__ OF _10_

Shot # and Item #	Utilized Equipment Serial #s	Test Level kV/m	Test Orientation	Test Mode	Pretest and Post-test Results	Test Points and Comments
1 # 5723	M1A2 V2 S/N# 26264 *Test Setup #1*	1st	Tank Parallel to E-Field Distance = 15 Meters GCVP of Tank	Powered and Operational Hull = Turret - 0°	pre - OK post – OK	11 8-Input Multiple Links. – See Test Point Information
2 #5724	Same as 1 Above	1st	Same as 1 Above	Same as 1 Above	pre - OK post – OK	Same as 1 Above
3 # 5725	Same as 1 Above	1st	Same as 1 Above	Same as 1 Above	pre - OK post – OK	Same as 1 Above
4 # 5726	Same as 1 Above	1st	Same as 1 Above	Same as 1 Above	pre - OK post – OK	Same as 1 Above
5 # 5727	Same as 1 Above	1st	Same as 1 Above	Same as 1 Above	pre - OK post – OK	Same as 1 Above
6 # 5728	Same as 1 Above	1st	Same as 1 Above	Same as 1 Above	pre - OK post – OK	Same as 1 Above
7 # 5729	Same as 1 Above	1st	Same as 1 Above	Same as 1 Above	pre - OK post – OK	Same as 1 Above

General Comments: E-Field = Electric Field

Table G-1. (U) HEMP Test Point – Current Probe Information Example.

Link Name	Input #	Test Point ID	Test Point Description
Alpha	0	DID1	DID J1
Alpha	1	DID2	DID J2
Alpha	2	DID3	DID J3
Alpha	3	HMP1	HMPU J1
Alpha	4	HMP7	HMPU J7
Alpha	5	HMP8	HMPU J8
Alpha	6	HMP9	HMPU J9
Alpha	7	HMPX	HMPU J10
Bravo	0	HPDE	HPDU J14
Bravo	1	HPDB	HPDU J11
Bravo	2	HPD1	HPDU J1
Bravo	3	HPD8	HPDU J8
Bravo	4	HPD7	HPDU J7
Bravo	5	HPDD	HPDU J13
Bravo	6	HPDC	HPDU J12
Bravo	7	HPDA	HPDU J10
Charlie	0	HPD9	HPDU J9
Charlie	1	HPD6	HPDU J6
Charlie	2	HPD5	HPDU J5
Charlie	3	HPD4	HPDU J4
Charlie	4	FEA2	FEA J2
Charlie	5	TCU1	TCU J1
Charlie	6	DEC3	DECU J3
Charlie	7	DEC5	DECU J5
Delta	0	AIM6	AIM J6
Delta	1	AIM7	AIM J7
Delta	2	AIM1	AIM J1
Delta	3	AIM2	AIM J2
Delta	4	AIM3	AIM J3
Delta	5	AIM5	AIM J5
Delta	6	RS21	RSM2 J1
Delta	7	RS22	RSM2 J2



Figure G-1. (U) M1A2 V2 HEMP Test Setup – Hull ⎪⎪ and Turret 0° Example.

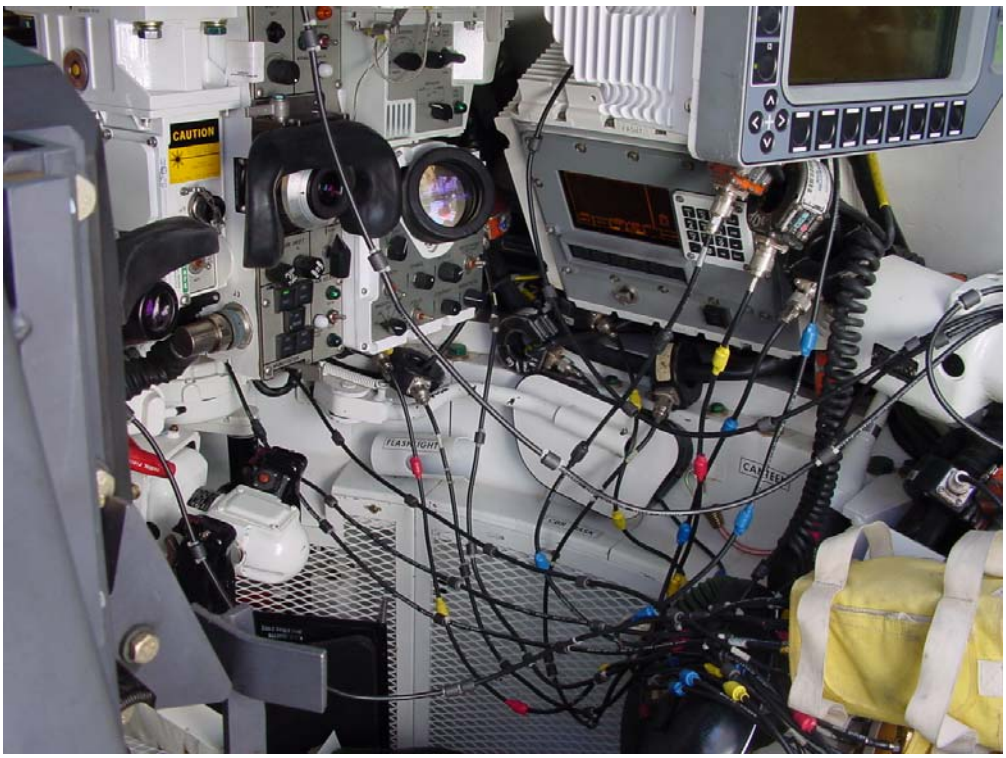


Figure G-2. (U) M1A2 V2 HEMP Test Setup – Instrumentation Example.

Table G-2. (U) HEMP Current Test Point Example.

TestID	Orien	Shot#	Peak I	ResFreq	LowFreq	HighFreq	Bandwidth	Q
CEU1	parallel-1-turret-front	5723	-0.72343	2.37E+07	2.33E+07	2.59E+07	2.54E+06	9.3128
RSC1	parallel-1-turret-front	5723	-0.78004	2.37E+07	2.34E+07	2.58E+07	2.40E+06	9.86972
AIM6	parallel-1-turret-front	5724	0.254524	1.52E+07	1.40E+07	1.62E+07	2.20E+06	6.90684
CDU1	parallel-1-turret-front	5724	0.854443	2.54E+07	2.17E+07	2.60E+07	4.36E+06	5.84013
CIT1	parallel-1-turret-front	5724	-0.87288	2.32E+07	2.25E+07	2.38E+07	1.29E+06	17.9898
DID1	parallel-1-turret-front	5724	-0.21612	3.15E+07	3.02E+07	3.21E+07	1.93E+06	16.3001
GCD4	parallel-1-turret-front	5724	0.879601	2.30E+07	2.18E+07	2.34E+07	1.58E+06	14.5688
HPD9	parallel-1-turret-front	5724	-0.26658	4.33E+07	4.26E+07	4.51E+07	2.51E+06	17.2656
HPDE	parallel-1-turret-front	5724	0.221622	3.17E+07	3.06E+07	3.22E+07	1.58E+06	20.1163
AIM7	parallel-1-turret-front	5725	-0.22246	1.19E+07	1.14E+07	1.22E+07	863666	13.7974
DID2	parallel-1-turret-front	5725	-0.15849	4.51E+07	4.43E+07	4.62E+07	1.93E+06	23.4194
HPD6	parallel-1-turret-front	5725	-0.43752	5.16E+07	5.02E+07	5.23E+07	2.12E+06	24.2788
HPDB	parallel-1-turret-front	5725	-0.18246	2.27E+07	2.19E+07	2.37E+07	1.84E+06	12.3403
MMU1	parallel-1-turret-front	5725	0.046358	2.37E+07	2.28E+07	2.59E+07	3.11E+06	7.63901
RSC4	parallel-1-turret-front	5725	0.72278	3.38E+07	3.29E+07	3.43E+07	1.42E+06	23.7429
AIM1	parallel-1-turret-front	5726	0.216101	4.89E+07	4.76E+07	4.97E+07	2.10E+06	23.3346
CDU2	parallel-1-turret-front	5726	1.65474	2.38E+07	2.29E+07	2.48E+07	1.96E+06	12.1048
CEU3	parallel-1-turret-front	5726	-7.05391	2.59E+07	2.53E+07	2.69E+07	1.68E+06	15.3943
DID3	parallel-1-turret-front	5726	0.235663	4.56E+07	4.44E+07	4.66E+07	2.25E+06	20.2586
FCE4	parallel-1-turret-front	5726	2.53957	2.39E+07	2.27E+07	2.48E+07	2.15E+06	11.1238

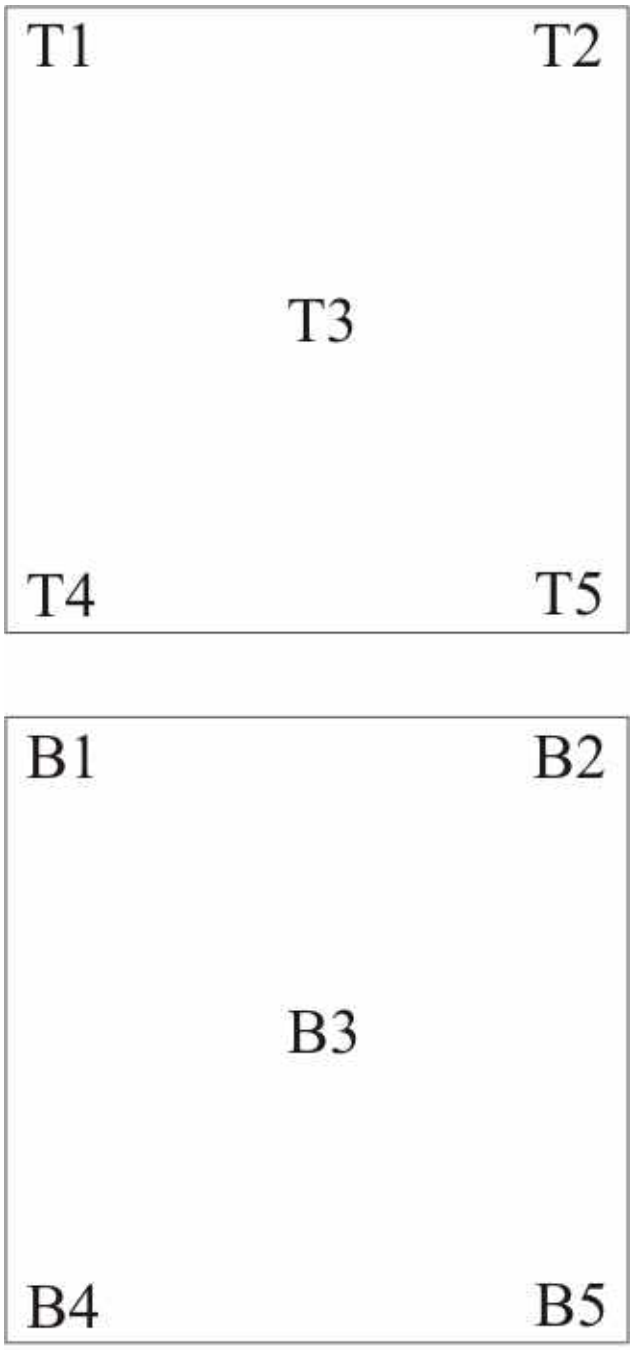


Figure G-3. Example Dosimetry Locations.

Where: T – Top or the Incident Side of Test Item WRT the Radiation Source.
B – Bottom or the Non-Incident Side of Test Item WRT the Radiation Source.



Figure G-4. (U) Gamma Total Dose Test Setup Example.

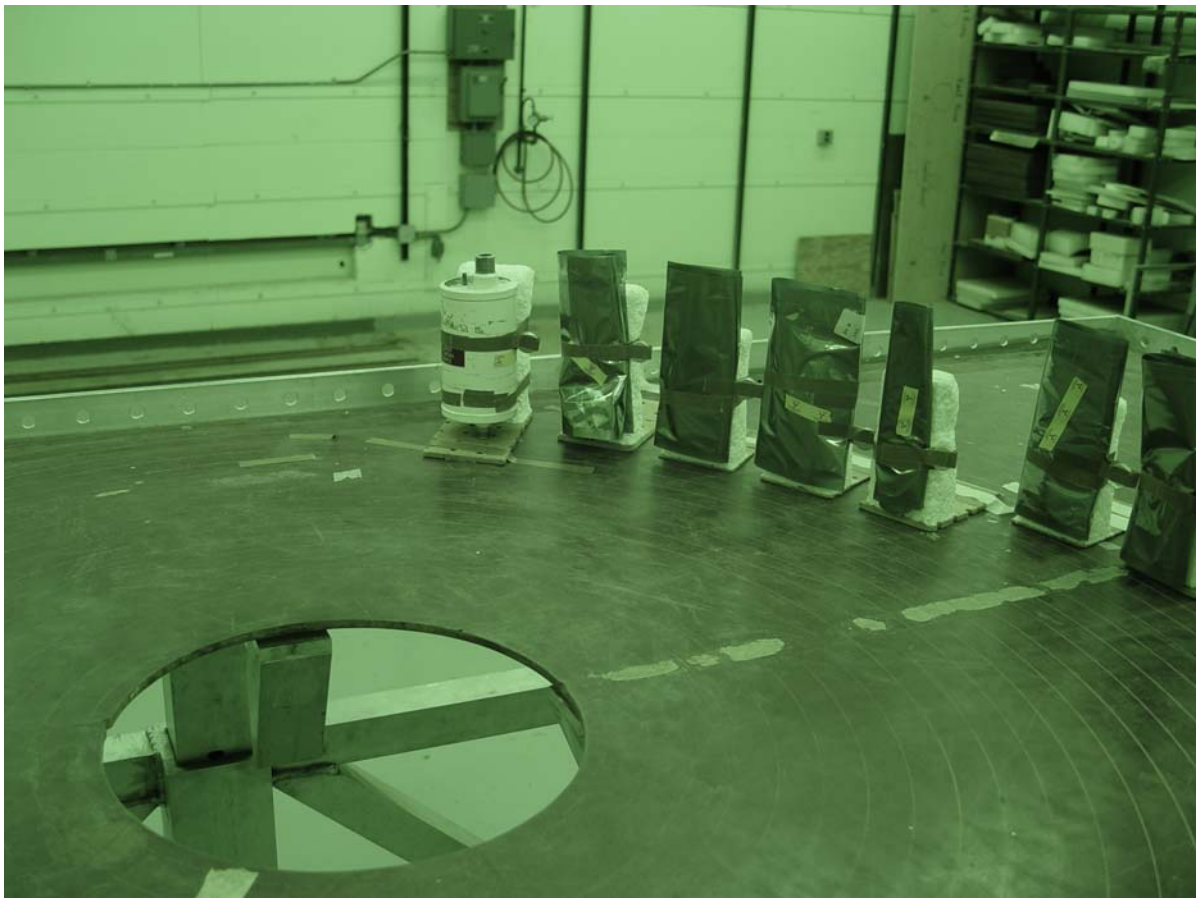


Figure G-5. (U) Neutron Fluence Test Setup Example.

APPENDIX H. ABBREVIATIONS.

ADSS - Army Decision Support System

amp - Ampere

AR - Army Regulation

ARES - Advanced Research Electromagnetic Simulator

ASAP - As Soon As Possible

ASTM - American Society for Testing and Materials

ATEC - Army Test and Evaluation Command

BOBs - Breakout Boxes

CaF_2(Mn) - Calcium Fluoride (Manganese)

Cal - Calorie

CCD - Charge Coupled Device

CDD - Capabilities Development Document

cGy - centiGray

CI - Current Injection tests

cm - centimeter

CML - Current Mode Logic

CMOS - Complimentary Metal Oxide Semiconductor

DAS - Data Acquisition System

DM - Design Margin

DOD - Department of Defense

DODD - Department of Defense Directive

DOE - Department of Energy

DTC - Developmental Test Command

DUT - Device Under Test

E - Total Energy Emitted

ECL - Emitter Coupled Logic

ECP - Engineering Change Proposal

E-Field - Electric Field

EM - Electromagnetic

EMP - Electromagnetic Pulse

FBR - Fast Burst Reactor

FFT - Fast Fourier Transform

fps - Frames Per Second

$F\tau$ - Gain Bandwidth Product

FWHM - Full Width Half Maximum

GDR - Gamma Dose Rate

GHz - Gigahertz

GRF - Gamma Radiation Facility

GTD - Gamma Total Dose

Gy - Gray (100 RADs)

GZ - Ground Zero

HCI - Hardened Critical Item

HE - High Explosive

HEMP - High Altitude Electromagnetic Pulse

HERMES - High Energy Radiation Megavolt Electron Source

HF - High Frequency

H-Field - Magnetic Field

HOB - Height of Burst

HPD - Horizontal Polarized Dipole

HQ - Headquarters

Hz - Hertz

IAP - Independent Assessment Plan

IAW - In Accordance With

IEP - Independent Evaluation Plan

INR - Initial Nuclear Radiation

I^2L - Current Injection Logic

KAFB - Kirtland Air Force Base

kHz - Kilohertz

kJ - Kilo-Joules

kPa - Kilo Pascals

kT - Kiloton

kV/m - Kilovolts Per Meter

LB/TS - Large Blast / Thermal Simulator

LCNS - Life Cycle Nuclear Survivability Program

LF - Low Frequency

LINAC - Linear Accelerator

LRU - Line Replaceable Unit

LST^2L - Low Power Schottky TTL

m - Meter

m^2 - Square Meter

mA - Milliampere

MeV - Mega-electron Volt

MF - Middle Frequency

MHz - Megahertz

MIL-STD - Military Standard

MOS - Metal Oxide Semiconductor

ms - millisecond

MSDS - Materiel Safety Data Sheets

MT - Megaton

NHC - Nuclear Hardening Criteria

NIA - Neutron Induced Activity

NMOS - N-Channel Metal Oxide Semiconductor

ns - Nanosecond

NTSA - Nuclear Test and Survivability Analysis

ORD - Operational Requirements Document

P - Overpressure

PAM - Pamphlet

PE - Project Engineer

PM - Project Manager

PMOS - P-Channel Metal Oxide Semiconductor

PMOS/SOS - P-Channel Metal Oxide Semiconductor/ Silicon on Sapphire

Po - Ambient Pressure

Psi - Pounds per square inch

Psi-sec - Pounds per square inch-second

q - Dynamic Pressure

Q - Thermal Fluence

Q_{dot} - Thermal Flux

QMR - Qualitative Materiel Requirement

QSTAG - Quadripartite Standardization Agreement

R - Range in centimeters

REBA - Relativistic Electron Beam Accelerator

RF - Radio Frequency

RAD - Radiation Absorbed Dose

Ref - Reference

s, sec - second

SCT - Shielded Cable Test

Si - Silicon

SN - Serial Number

SNL - Sandia National Laboratories

SREMP - Source Region Electromagnetic Pulse

STT - Source-to-target

Subj - Subject

τ - Transmissivity

TEM - Transverse Electromagnetic wave

TEMP - Test and Evaluation Master Plan

TIR - Test Incident Report

TLD - Thermoluminescent Dosimeter

TO - Test Officer

TOP - Test Operations Procedure

TPD - Terminal Protection Device

TREE - Transient Radiation Effects on Electronics

TRIGA - Training, Research, Isotopes, General Atomics

TTL - Transistor - Transistor Logic

UHF - Ultra High Frequency

USA - United States Army

USANCA - United States Army Nuclear and Combating Weapons of Mass Destruction

μsec - microsecond

UV - Ultraviolet

VDL - Vision Digital Library

VHF - Very High Frequency

VLF - Very Low Frequency

V/m - Volts per Minute

VPC - Vertical Plane Center

VV&A - Validation, Verification and Accreditation

WSMR - White Sands Missile Range

APPENDIX I. GLOSSARY.

Absorption	The process by which radiation imparts some or all of its energy to any material through which it passes.
Attenuation	The process by which a beam of radiation is reduced in intensity when passing through some material. It is the combination of absorption and scattering processes and leads to a decrease in flux density of the beam when projected through matter.
Blast Wave	A pulse of air in which the pressure increases sharply at the front, accompanied by winds, propagated continuously from an explosion.
Beta Particle	Charged particle emitted from the nucleus of an atom, with a mass and charge equal in magnitude to that of the electron.
Calorie (gram-calorie)	Amount of heat necessary to raise the temperature of one gram of water l deg C (from 14.5 deg C) (abbreviation: cal)
Curie	The unit quantity of any radioactive nuclide in which 3.7 x 10E10 disintegrations occur per second.
Decay, Radioactive	Disintegration of the nucleus of an unstable nuclide by spontaneous emission of charged particles and/or photons.
Dose	A general term denoting the quantity of radiation or energy absorbed. For special purposes, it must be appropriately qualified. If unqualified, it refers to absorbed dose.
Dosimeter	Instrument to detect and measure accumulated radiation exposure. A common dosimeter is a pencil-size ionization chamber with a self reading electrometer, used for personnel monitoring.
Dynamic Pressure	The air pressure which results from the mass air flow (or wind) behind the shock front of a blast wave. It is equal to the product of half the density of the air through which the blast wave passes and the square of the particle (or wind) velocity behind the shock front as it impinges on an object, or structure.
Fission, Nuclear	A nuclear transformation characterized by the splitting of a nucleus into at least two other nuclei and the release of a relatively large amount of energy.
Fusion, Nuclear	Act of combining two or more atomic nuclei into a heavier element, releasing substantial amounts of energy.

Gamma, Prompt	Gamma radiation emitted at the time of fission of a nucleus.
Gamma Ray	Short-wavelength electromagnetic radiation of nuclear origin (range of energy from 10 Kev to 9 Mev) emitted from the nucleus.
Impulse (per unit area)	The integral, with respect to time, of the overpressure (or dynamic pressure), the integration being between the time of arrival of the blast wave and that at which the overpressure (or dynamic pressure) returns to zero at the given point.
Ionization	The process by which a neutral atom or molecule acquires a positive or negative charge.
Isotopes	Nuclides having the same number of protons in their nuclei, and hence the same atomic number, but differing in the number of neutrons, and therefore in the mass number. Isotopes of the same element have almost identical chemical properties.
Mev	One million electron volts (10E6 ev). An electron volt is the amount of energy acquired by an electron when it falls through a potential of 1 volt.
Neutron	A neutral particle of approximately one atomic mass unit, present in all atomic nuclei except those of ordinary hydrogen.
Neutron Flux	The product of the neutron density and the neutron velocity, expressed as neutrons per unit area per unit time.
Nuclear Radiation	Particulate and electromagnetic radiation emitted from atomic nuclei in various nuclear processes. The important nuclear radiations from the weapon detonations are gamma, alpha and beta particles, and neutrons.
Overpressure	The transient pressure that exceeds ambient conditions. It is manifested in the shock or blast wave from an explosion. Usually expressed in pounds per square inch (psi).
Thermal Radiation	Electromagnetic radiation emitted (in two pulses from an air burst) from the fireball as a consequence of its high temperature; it consists essentially of ultraviolet, visible, and infrared radiations. In the early stages(first pulse of an air burst), when the temperature of the fireball is extremely high, the ultraviolet radiation predominates; in the second pulse, the temperatures are lower and most of the thermal radiation lies in the visible and infrared regions of the spectrum. From a high-altitude burst, the thermal radiation is emitted in a single short pulse.

X-rays	Penetrating electromagnetic radiations whose wavelengths are shorter than those of visible light. They are usually produced by bombarding a metallic target with fast electrons in high vacuum. In nuclear reactions, it is customary to refer to photons originating in the nucleus as gamma rays and those originating in the extra-nuclear part of the atom as x-rays. These rays are sometimes called roentgen rays after their discoverer, W. C. Roentgen.

APPENDIX J. REFERENCES.

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