



Appendix **E** Nuclear Survivability

E.1 Overview

It is common to confuse *nuclear weapon effects survivability* with *nuclear weapon system survivability*.

Nuclear weapon effects survivability applies to the ability of any and all personnel and equipment to withstand the blast, thermal radiation, nuclear radiation, and electromagnetic pulse (EMP) effects of a nuclear detonation and thus includes, but is not limited to, the survivability of nuclear weapon systems.

Nuclear weapon system survivability is concerned with the ability of U.S. nuclear deterrent forces to survive against the entire threat spectrum that includes, but is not limited to, nuclear weapon effects. The vast range of potential threats include:

- conventional and electronic weaponry;
- nuclear, biological, and chemical weapons;

- advanced technology weapons such as high-power microwaves and radio frequency weapons;
- terrorism or sabotage; and
- the initial effects of a nuclear detonation.

See **Figure E.1** for a summary of the differences between nuclear weapon effects and nuclear weapon system survivability. An overlap occurs when the threat to the survivability of a nuclear weapon system is a nuclear detonation and its effects. **Figure E.2** illustrates the intersection between nuclear effects survivability and system survivability.

Put simply, nuclear weapon effects survivability refers to the ability of any and all personnel, equipment, and systems, including, but not limited to, nuclear systems, to survive nuclear weapon effects. Nuclear weapon system survivability refers to nuclear weapon systems being survivable against any threat, including, but not limited to, the nuclear threat.

Nuclear hardness describes the ability of a system to withstand the effects of a nuclear detonation and to avoid internal malfunction or performance degradation. Hardness measures the ability of a system's hardware to withstand physical effects, such as overpressure, peak velocities, energy absorbed, and electrical stress. This reduction in hardware vulnerability can be achieved through a variety of well-established design specifications or through the selection of well-built and well-engineered components. This appendix does not address residual nuclear weapon effects such as fallout nor does it

Figure E.1 Nuclear Weapon Effects versus System Survivability



discuss nuclear contamination survivability.¹

E.2 Governance

Department of Defense Instruction (DoDI) 3150.09, *The Chemical, Biological, Radiological, and Nuclear (CBRN) Survivability Policy*² establishes the CBRN Survivability Oversight Group

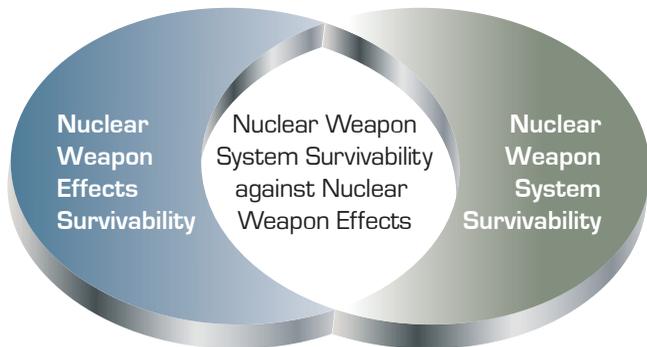
(CSOG) to oversee implementation of DoD-CBRN survivability policy; ensure CBRN survivability receives proper emphasis during the development of the defense planning guidance and in the acquisition process during a system's requirements definition phase consistent with the CBRN threat; refer recommendations for action by the Under Secretary of Defense for Acquisition, Technology and Logistics (USD(AT&L)) or others; and conduct other responsibilities as outlined in the instruction. The CSOG is chaired by the Assistant Secretary of Defense for Nuclear, Chemical, and Biological Defense Programs (ASD(NCB)), but the day-to-day implementation activities are overseen by two principal-level working groups. The CSOG-CBRN on contamination survivability is chaired by the Deputy Assistant Secretary of Defense for Chemical and Biological Defense; the CSOG-N on nuclear survivability is chaired by the Deputy Assistant Secretary of Defense for Nuclear Matters.

DoDI 3150.09 also establishes the mission-critical system (MCS) designation and reporting process for DoD systems. It is DoD policy that the MCS components of the force are equipped to survive and operate in chemical, biological, and radiological (CBR) or nuclear environments as a deterrent to adversary use of weapons of mass destruction against the United States, its allies, and interests. The ability of the force to operate in these environments must be known and assessed on a regular basis and MCS must survive and operate in CBR, nuclear, or combined CBRN environments specified.

¹ For information on fallout and nuclear contamination, see Samuel Glasstone and Philip Dolan, *The Effects of Nuclear Weapons*, 3rd Edition, United States Department of Defense and the Energy Research and Development Administration, 1977.

² DoDI 3150.09 was first issued in September 2008 and subsequently updated in 2015.

Figure E.2 Intersection of Nuclear Weapon Effects Survivability and System Survivability



The process for reporting those systems is conducted annually and run by the Office of the ASD(NCB). The mission-critical reports (MCRs) identify the Military Departments' and Missile Defense Agency (MDA) MCS and CBRN MCS, and assess the current survivability status of their CBRN MCS. Once all the reports are complete, the Military Departments and the MDA review all CBRN MCRs for gaps and limitations in the CBRN survivability of the systems and infrastructure upon which the Military Departments and the MDA rely and provide a summary of the review to the ASD(NCB). After the MCRs and summary reviews are complete, the Combatant Commanders (CCDRs) review for adequacy in supporting the Combatant Command's (CCMD) operational, contingency, and other plans, which may require operations in CBR-contaminated environments, nuclear environments, or combined CBRN environments. The Joint Staff reviews the CCDRs' assessments and provides (1) an assessment to the ASD(NCB) on the posture of the DoD to operate successfully in CBR environments and nuclear environments, and (2) if necessary, written guidance to the Military Departments and the MDA on which systems should be added to the MCRs.

E.3 Nuclear Weapon Effects Survivability

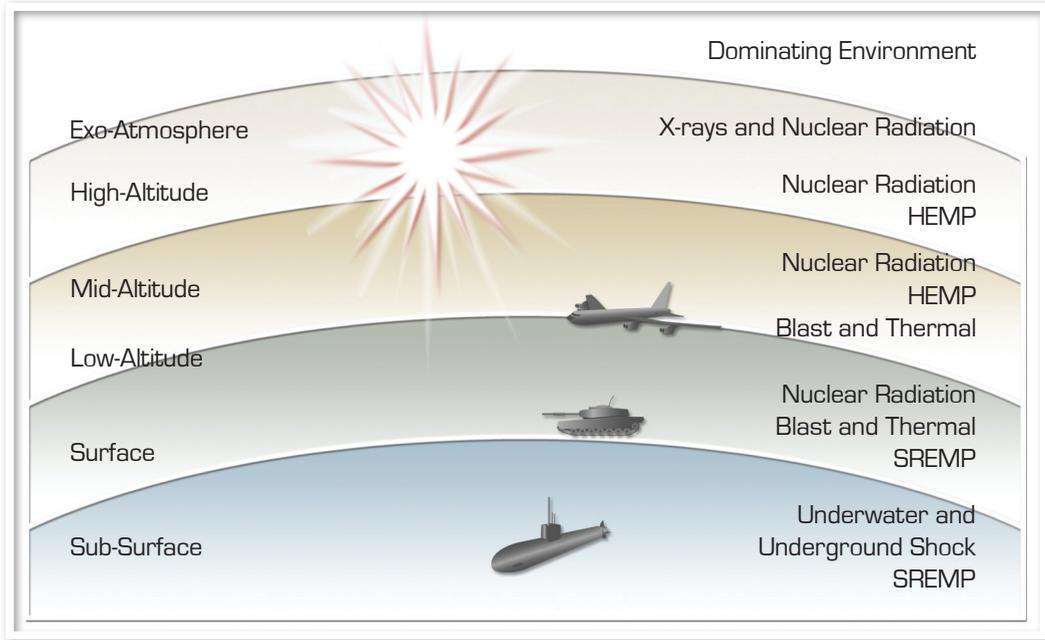
Each of the primary (e.g., blast, thermal, and prompt radiation) and secondary (e.g., delayed radiation) environments produced by a nuclear detonation cause a unique set of mechanical and electrical effects. Some effects are permanent while others are transient; however, both can cause system malfunction, system failure, or loss of combat capability.

E.3.1 Nuclear Weapon Effects on Military Systems

The nuclear environments and effects that may threaten the survivability of a military system vary with the altitude of the explosion. The dominant nuclear environment refers to the effects that set the survival range between the target and the explosion.³ Low-altitude, near-surface, and surface bursts damage most ground targets within the damage radii, which is principally a function of the yield of the weapon. Also, high-altitude bursts produce high-altitude electromagnetic pulse (HEMP) effects over a very large area that may damage equipment containing vulnerable electronics on the ground and in the air. **Figure E.3** shows the nuclear environments that dominate the survival for typical systems based on various heights of burst from space to below the Earth's surface.

³ The survival range measures the distance from the detonation necessary to survive nuclear weapon effects.

Figure E.3 Dominant Nuclear Environments as a Function of Altitude



Nuclear weapon-generated X-rays are the chief threat to the survival of strategic missiles in flight above the atmosphere and to satellites. Neutron and gamma ray effects also create serious problems for these systems but do not normally set the survivability range requirements. Neutron and gamma ray effects dominate at lower altitudes where the air absorbs most of the X-rays. Air-blast and thermal radiation effects usually dominate the survival of systems at or near the surface; however, neutrons, gamma rays, and source-region EMP (SREMP) may also create problems for structurally hard systems that are near the detonation. SREMP is produced by a nuclear burst within several hundred meters of the Earth's surface and is localized out to a distance of three to five kilometers from the burst. SREMP can couple into electrical power lines and other long conductors leading to the potential for damage beyond the localized SREMP field. The final result of the detonation-generated EMP is a tremendous surge of low-frequency electric fields that can couple into a system through designed and unintended antennas, generating a flow of electrical current that overloads and destroys electrical components and renders the equipment nonoperational.

Underwater shock and ground shock are usually the dominant nuclear weapon effects for submerged submarines and buried facilities, respectively. HEMP is the dominant threat

for surface-based systems located outside the target zone such as command, control, communications, computers, and intelligence (C4I) facilities or sophisticated electronics associated with ground-based defense systems and equipment.

Nuclear weapon effects survivability requirements vary with the type of system, its mission, operating environment, and the threat. For example, the X-ray, gamma ray, and neutron survivability levels used for satellites are very low (i.e., more susceptible to these radiation sources) compared with the survivability levels used for missiles and reentry vehicles (RVs) or reentry bodies (RBs). Satellite levels are usually set so that a single nuclear weapon, detonated in the region containing several satellites, does not damage or destroy more than one satellite. The levels used for RVs, however, are very high because the RV or RB is the most likely component of an intercontinental ballistic missile (ICBM) or a submarine-launched ballistic missile (SLBM) to be attacked by a nuclear weapon at close range. The ICBM or SLBM bus and booster have a correspondingly lower requirement in consideration of its range from the target and the time available to target them.

When a system is deployed within the Earth's atmosphere, the survivability criteria are different. Systems operating at lower altitudes do not have to consider X-ray effects because the range of damaging X-ray effects is typically contained inside the range for the more dominant thermal blast effects. Outside the range for damaging blast effects, gamma rays and neutrons generally set the survival range for most systems operating at lower altitudes. The survival ranges associated with gamma rays and neutrons are generally so great that these ranges overcome problems from air blast and thermal radiation. Two of the most challenging problems in this region are the prompt gamma ray effects in electronics, which can disrupt or damage sensitive electronics components, and the total radiation dose delivered to personnel and electronics.

Between an altitude of 10 kilometers and the Earth's surface, there is a transition region in which the denser air begins to absorb more of the ionizing radiation and the air-blast environment becomes more dominant. Aircraft in this region have to survive combined air-blast, thermal radiation, and nuclear radiation effects.

On the Earth's surface, air blast and thermal radiation are the dominant nuclear weapon effects for personnel who must be at a safe distance from the range of these two effects in order to survive. Because of this, air blast and thermal radiation typically set the safe

distance, or survival range requirements, at the surface for most systems and particularly for nuclear weapons with yields exceeding 10 kilotons (kt).

This is not necessarily true for blast-hardened systems such as battle tanks or hardened facilities designed to survive closer to a nuclear detonation. The very high levels of ionizing radiation associated with a nuclear detonation usually require systems to be at greater distances from the detonation to avoid personnel casualties and damage to electronic equipment. This is especially true for lower yield weapons, where the effects of radiation can be dominant compared to the air blast. For example, a battle tank survives at a distance of less than half of a kilometer from a 10-kt explosion if the only consideration is structural damage to the tank. However, at the same distance ionizing radiation from the detonation significantly affects the crew and the tank's electronics.

Because line-of-sight thermal effects are easily attenuated by intervening material (e.g., buildings or trees) and have a large variation of effect on the target, they are harder to predict. Traditionally, thermal effects are not taken into consideration when targeting. Advanced computer modeling and simulation of thermal effects are now at a state of maturity that they can be used to assess effects on buildings, personnel, and equipment. Estimates of ignition probability for buildings in urban environments can be used to provide higher-fidelity estimates of damage and casualties. Surface-launched missiles and associated buses and payloads are the most challenging systems to design for survivability. They typically are designed to survive the effects of air blast, thermal radiation, HEMP, ionizing radiation, SREMP, and even X-rays in the course of their payload delivery.

E.3.2 Nuclear Weapon Effects on Personnel

Several of the effects of nuclear weapons are a threat to personnel. The flash from a nuclear weapon can cause temporary blindness to unprotected eyes, even when not looking directly at the detonation. Thermal radiation can cause burns directly to the skin or can ignite clothing, but only via direct line-of-sight exposure. Initial nuclear radiation (gamma rays and neutrons) can cause an acute dose of ionizing radiation leading to degraded performance, radiation sickness, and death. Residual radiation can cause significant exposure for days to weeks after the detonation. The blast wave can cause immediate casualties to exposed personnel or impact and roll a vehicle causing personnel injuries. EMP does not cause injuries directly but can cause casualties indirectly (e.g., instantaneous destruction of electronics in an aircraft in flight).

Effects survivability concepts for manned systems must consider the effect of a temporary loss of the “man-in-the-loop” and, therefore, devise ways of overcoming the problem. Hardened structures provide increased personnel protection against all nuclear weapon effects. As a rule of thumb, survivability criteria for manned systems are based on the ability of 50 percent of the crew to survive the nuclear event and complete the mission.

Systems with operators outside in the open air have a less stringent nuclear survivability requirement than do systems such as armored vehicles or tanks where the operators are in a hardened shelter. At distances from the detonation where a piece of equipment might survive, an individual outside and unprotected might become a casualty. Therefore, the equipment would not be required to survive either. Conversely, because an individual in a tank could survive at a relatively close distance to the detonation, the tank would be required to survive. The equipment need not be any more survivable than the crew.

E.3.3 Nuclear Weapon Effects Survivability Measures

Nuclear weapon effects survivability may be accomplished by timely resupply, redundancy, mitigation techniques (to include operational techniques), or a combination thereof, and hardening.

Timely resupply is the fielding and positioning of extra systems or spares in the theater of operation that can be used for timely replacement of equipment lost to nuclear weapon effects. The decision to rely on reserve assets can significantly affect production because using and replacing them would result in increased production quantities and costs.

Redundancy is the incorporation of extra components into a system or piece of equipment, or the provision of alternate methods to accomplish a function so if one fails, another is available. The requirement for redundancy increases production quantities for the redundant components and may increase the cost and complexity of a system.

Mitigation techniques are methods used to reduce the vulnerability of military systems to nuclear weapon effects. These may include but are not limited to:

- *Avoidance*, such as the incorporation of measures to eliminate detection and attack. Avoidance techniques are very diverse. For example, avoidance may include stealth tactics that use signal reduction or camouflage. This approach may or may not affect production and can be costly.

- *Active defense*, such as radar-jamming or missile defense systems. Active defense can be used to enhance a system's nuclear weapon effects survivability by destroying incoming nuclear weapons or causing them to detonate outside the susceptible area of the protected system.
- *Deception*, such as the employment of measures to mislead the enemy regarding the actual system location. These measures include decoys, chaff, aerosols, and other ways to draw fire away from the target. The effect of deception on production depends on the approach. Some deception measures can be quite complex and costly, such as the decoys for an ICBM system while others can be relatively simple and inexpensive.

Hardening is the employment of any design or manufacturing technique that increases the ability of an item to survive the effects of a nuclear environment. Systems can be nuclear hardened to survive prompt nuclear weapon effects, including blast, thermal radiation, nuclear radiation, EMP, and in some cases, transient radiation effects on electronics (TREE). For a description of these effects, see *Appendix C: Basic Nuclear Physics and Weapons Effects*. Hardening mechanisms include shielding, robust structural designs, electronic circumvention, electrical filtering, and vertical shock mounting.

Hardening impacts production by increasing the complexity of the product. Therefore, hardening measures are less costly if designed and produced as a part of the original system rather than as a retrofit design and modification. Production controls to support hardness assurance, especially in strategic systems, may also be required.

Mechanical and structural hardening consists of using robust designs, protective enclosures, protective coatings, and the proper selection of materials. Electronics and electrical effects hardening involve using the proper components, special protection devices, circumvention circuits, and selective shielding. Nuclear weapon effects on personnel are minimized by avoidance, radiation shielding protection, and automatic recovery measures. The automatic recovery measures compensate for the temporary loss of the "man-in-the-loop" and mitigate the loss of military function and the degradation of mission accomplishment.

Trade-off analyses are conducted during the acquisition process of a system to determine the method or combination of methods that provide the most cost-effective approach to nuclear weapon effects survivability. The impact of the approach on system cost, performance, reliability, maintainability, productivity, logistics support, and other

requirements is examined to ensure maximum operational effectiveness consistent with program constraints. However, the different approaches to hardening are not equally effective against all initial nuclear weapon effects.

Threat effect tolerance is the intrinsic ability of a component or piece of equipment to survive some level of exposure to nuclear weapon effects. The exposure level equipment tolerates depends primarily on the technologies it employs and how it is designed. The nuclear weapon effects survivability of a system can be enhanced when critical elements of the system are reinforced by selecting and integrating technologies that are inherently harder. This approach may affect production costs because harder components may be more expensive.

E.4 Nuclear Weapon System Survivability

Nuclear weapon system survivability refers to the capability of a nuclear weapon system to withstand exposure to a full spectrum of threats without suffering a loss of ability to accomplish its designated mission. Nuclear weapon system survivability applies to a nuclear weapon system in its entirety including, but not limited to, the nuclear warhead. The entire nuclear weapon system includes all mission-essential assets, the nuclear weapon and delivery system or platform, as well as associated support systems, equipment, facilities, and personnel. Included in a system survivability approach is the survivability of the delivery vehicle (RB, RV, missile, submarine, or aircraft), personnel operating the nuclear weapon system, supporting command and control links, and supporting logistical elements.

System survivability is a critical concern whether nuclear weapons and forces are non-dispersed, dispersing, or already dispersed. The capability to survive in all states of dispersal enhances both the deterrent value and the potential military utility of U.S. nuclear forces.

E.4.1 Nuclear Force Survivability

DoDI 3150.09 establishes policy and procedures for ensuring the survivability of CBRN MCS, which includes all U.S. strategic and tactical nuclear forces, and many U.S. general purpose forces, in CBR, nuclear, or combined CBRN environments. Nuclear survivability is defined in DoDI 3150.09 as “the capability of a system or infrastructure to withstand exposure to nuclear environments without suffering loss of ability to accomplish its designated mission through its life-cycle. Nuclear survivability may be accomplished by

hardening, timely resupply, redundancy, mitigation techniques (including operational techniques), or a combination. Includes EMP survivability.”

In addition to DoDI 3150.09, DoD Directive (DoDD) 5210.41, *Security Policy for Protecting Nuclear Weapons* and its corresponding manual, DoD S-5210.41-M, govern nuclear force security.

It is often difficult to separate measures to enhance survivability from those that provide security. For instance, in hostile environments, hardened nuclear weapon containers as well as hardened weapon transport vehicles provide security and enhance survivability during transit. Many of the measures to enhance nuclear weapon system survivability and protect against the effects of nuclear weapons can be the same. Hardening and redundancy, for example, as well as threat tolerant designs, resupply, and mitigation techniques apply to both.

E.4.2 Nuclear Command and Control Survivability

Nuclear weapon systems include the nuclear weapons and the associated Nuclear Command and Control System (NCCS). The security and survivability of weapons systems command and control is addressed in DoDI 3150.09, DoDD 5210.41, DoD 5210.41-M, and DoDD S-5210.81, *United States Nuclear Weapons Command and Control*, which establishes policy and assigns responsibilities related to the U.S. NCCS. The policy states that the command and control of nuclear weapons shall be ensured through a fully survivable and enduring NCCS. The DoD supports and maintains survivable and enduring facilities for the President and other officials to perform essential nuclear command and control (NC2) functions. The USD(AT&L), in conjunction with the Military Departments, establishes survivability criteria for related nuclear weapon equipment.

E.4.3 Missile Silos

The survivability of ICBM silos is achieved through the physical hardening of the silos and through its underground location, which protects against air-blast effects. The geographical dispersal of the missile fields also adds to system survivability by exacerbating any targeting resolution.

E.4.4 Containers

Nuclear weapon containers can provide ballistic protection as well as protection from nuclear and chemical contamination. Containers can also provide safety, security, and

survivability protection. In the past, considerable research and development was devoted to enhancing the efficacy of containers for use with nuclear weapons for artillery systems.

E.4.5 Weapon Storage Vault

A weapon storage vault (WSV) is an underground vault located in the floor of a hardened aircraft shelter. A WSV holds up to four nuclear weapons and provides ballistic protection in the lowered position through its hardened lid and reinforced sidewalls. The United States calls the entire system the *weapon storage and security system* whereas the North Atlantic Treaty Organization (NATO) refers to it as the *weapon security and survivability system*. However, both the United States and NATO denote the entire system by the same acronym, WS3. The WS3 is currently in use in Europe.

E.5 Nuclear Effects Testing and Evaluation

Nuclear weapon effects testing refers to tests conducted to measure the response of objects to the energy output of a nuclear weapon. Testing, which since 1992 has been conducted through the use of simulators and not actual nuclear detonations, remains essential to the development of nuclear-survivable systems while test and evaluation of nuclear hardness is considered throughout the development and acquisition process. These testing and analysis methods are well-established and readily available, although there is continued need to ensure simulator capabilities are maintained for both DoD and DOE/NNSA needs. Modeling and simulation plays an important role in nuclear weapon effects survivability design and development. Computer-aided modeling, simulation, and analysis complements testing by helping engineers and scientists to estimate the effects of the various nuclear environments, design more accurate tests, predict experimental responses, select the appropriate test facility, scale testing to the proper level and size, and evaluate test results. Analysis also helps to predict the response of systems that are too costly or difficult to test. Analysis is limited, however, due to inherently numerous, non-linear responses often encountered in both nuclear weapon effects and digital electronics.

Simulators used to test nuclear weapons effects are usually limited to a relatively small exposure volume and generally used for single nuclear environment tests, such as X-ray, neutron, prompt gamma ray, or EMP effects. Free-field EMP, high explosive (HE), and shock tube tests are notable exceptions because these can be tested, in many cases, at the system level. Additionally, in certain situations, at its fast burst reactor (FBR) the Army can test full systems.

Figure E.4 lists the types of simulators commonly used for nuclear weapon effects testing. The Defense Threat Reduction Agency (DTRA) maintains a *Guide to Nuclear Weapon Effects Simulation Facilities and Applications – Support for the Warfighter*, currently the 2014 Edition, which includes comprehensive descriptions of all available facilities in the United States for nuclear survivability testing.

Test	Type of Simulator	Size of Test
X-rays Effects (Hot)	<ul style="list-style-type: none"> ■ Low-Voltage Flash X-ray Machines 	<ul style="list-style-type: none"> ■ Components and small assemblies
X-rays Effects (Cold)	<ul style="list-style-type: none"> ■ Plasma Radiators 	<ul style="list-style-type: none"> ■ Components
Gamma Ray Effects	<ul style="list-style-type: none"> ■ Flash X-ray Machines ■ Linear Accelerator ■ Fast Burst Reactor (FBR) 	<ul style="list-style-type: none"> ■ Components, circuits, and equipment
Total Dose Gamma Effects	<ul style="list-style-type: none"> ■ Cobalt 60 ■ FBR 	<ul style="list-style-type: none"> ■ Components, circuits, and equipment
Neutron Effects	<ul style="list-style-type: none"> ■ Pulsed Reactors ■ Neutron Surrogates (i.e. Ions) ■ Neutron Spallation Sources 	<ul style="list-style-type: none"> ■ Components, circuits, and equipment
Blast Effects (Overpressure)	<ul style="list-style-type: none"> ■ Small Shock Tubes ■ Large Shock Tubes ■ HE Tests 	<ul style="list-style-type: none"> ■ Components, parts, and equipment ■ Small systems and large equipment ■ Vehicles, radars, shelters, etc.
EMP	<ul style="list-style-type: none"> ■ Pulsed Current Injection (PCI) ■ Free Field 	<ul style="list-style-type: none"> ■ Point of Entry (POE) Systems
Thermal Effects	<ul style="list-style-type: none"> ■ Thermal Radiation Source (TRS) ■ Flash Lamps and Solar Furnace 	<ul style="list-style-type: none"> ■ Equipment, large components ■ Components and materials
Shock Effects (Dynamic pressure)	<ul style="list-style-type: none"> ■ Large Blast Thermal Simulator (LBTS) ■ Explosives 	<ul style="list-style-type: none"> ■ Equipment, large components ■ Systems

Figure E.4 Simulators Commonly Used for Effects Testing

E.5.1 X-ray Effects Testing

X-ray environments are the most challenging to simulate in a laboratory. Historically, underground nuclear effects tests were done principally to study X-ray effects. Existing X-ray facilities only partially compensate for the loss of underground testing, and opportunities for improving the capabilities of X-ray facilities are both limited and costly.

Because X-rays are rapidly absorbed in the atmosphere, they are only of concern for systems that operate in space or high-altitude. Additionally, the X-ray environment within

a system is a strong function of the distance and orientation of the system with respect to the nuclear burst.

X-ray effects tests are usually conducted using flash X-ray machines (FXRs) and plasma radiation sources. FXRs are used to simulate the effects from higher-energy hard (hot) X-rays whereas plasma radiation sources are used to simulate the effects from lower-energy soft (cold) X-rays.

FXRs consume large amounts of electric power, which is converted into intense, short pulses of energetic electrons. The electrons are normally accelerated into a metal target that converts a small portion of its energies into a pulse of X-rays. The resulting photons irradiate the test specimen. The output characteristics of FXRs depend on the design of the machine and vary considerably from one design to the next. Radiation pulse duration ranges from 10 to 100 nanoseconds and output energies range from a few joules for the smallest machines to several hundred kilojoules for the largest. The rapid discharge of this much energy in a short time period results in power levels ranging from billions to trillions of watts.

X-ray effects testing usually requires a machine capable of producing high power with an output voltage of around one million volts. The resulting radiation tends to resemble the hard X-rays that reach components inside enclosures. The machine's output energy and power usually determines the exposure level and test area and volume. Most X-ray tests in FXRs are limited to components and small assemblies.

Soft X-ray effects testing is designed to replicate surface damage to exposed components in space applications and is normally performed with a plasma radiation source (PRS). The PRS machine generates cold X-rays by driving an intense pulse of electric energy into a bundle of fine wires or gas puff to create irradiating plasma. The energy of the photons produced by the PRS is a function of the wire material or gas and tends to be in the one to three kiloelectron-Volt (keV) range. These X-rays have very little penetrating power and deposit most of their energy on the surface of the exposed objects. The exposure level and test volume depends on the size of the machine. Test objects are normally limited to small material samples and components.

Larger test objects can be subjected to blow-off impulse testing using light-initiated high explosives (LIHE) or magnetically driven flyer plates. The National Ignition Facility (NIF) located at the Lawrence Livermore National Laboratory (LLNL) in California uses

high-energy laser beams to create plasma radiating sources generating cold-warm X-rays for component-level testing.

Currently, there are a number of pulsed-power facilities used to generate X-ray environments. The DOE/NNSA operates the LIHE, Saturn, and Z facilities at Sandia National Laboratories (SNL) and the NIF at LLNL. The DoD operates the Modular Bremsstrahlung Source (MBS), Pithon, and Double Eagle at the DTRA West Coast Facility in California. These facilities are currently in various states of readiness based on predicted future use.

E.5.2 Gamma Dose-Rate Effects Testing

All solid-state components are affected by the rapid ionization produced by prompt gamma rays. Gamma dose-rate effects dominate TREE in non-space-based electronics and the effects do not lend themselves to strict analyses since these are usually nonlinear and are very difficult to model. Circuit analysis is often helpful in bounding the problem, but only active tests have proven to be of any real value in replicating the ionizing effects on components, circuits, and systems.

Two machines used for gamma dose-rate testing are FXRs and linear accelerators (LINACs). The FXRs used for dose-rate effects tests operate at significantly higher voltages than FXRs used for X-ray effects tests and produce gamma radiation that is equivalent, in most respects, to the prompt gamma rays produced by an actual nuclear explosion.

LINACs are primarily used for component-level tests because the beam produced by most LINACs is fairly small in size and of relatively low intensity. LINACs produce a pulse or a series of pulses of very energetic electrons. The electron pulses may be used to irradiate test objects or to generate bremsstrahlung radiation.⁴

LINACs are restricted to piece-part size tests and are typically operated in the electron beam mode when high-radiation rates are required. The two biggest drawbacks to the use of the LINAC are its small exposure volume and relatively low-output intensity.

Most dose-rate tests are active, that is, it requires the test object to be powered up and operating for testing. Effects, such as component latch-up, logic upset, and burnout, can

⁴ Bremsstrahlung is literally “braking radiation.” It is caused by the rapid deceleration of charged particles interacting with atomic nuclei and produces electromagnetic radiation covering a range of wavelengths and energies in the X-ray regions.



E-4 airborne command post on the EMP simulator for testing

only occur using active testing. Tests must be conducted in a realistic operating condition and the test object must be continuously monitored before, during, and after exposure.

SNL operates the High-Energy Radiation Megavolt Electron Source (HERMES) pulsed-power facility to simulate prompt gamma environments at extreme dose rates for the DOE/NNSA. The DoD currently operates smaller gamma ray facilities used to test systems at lower levels, including the PulseRad 1150 at L3 Communications Titan Corporation in California and the LINAC Facility at White Sands Missile Range in New Mexico.

E.5.3 Total Dose Effects Testing

The objective of total dose effects testing is to determine the amount of performance degradation suffered by components and circuits exposed to specified levels of gamma radiation. A widely used simulator for total dose effects testing is the cobalt-60 (Co60) radioactive isotope source. Other sources of radiation, such as high-energy commercial X-ray machines, LINACs, and the gamma rays from nuclear reactors, are also used for testing.

E.5.4 Neutron Effects Testing

The objective of most neutron effects testing is to determine the amount of performance degradation in susceptible parts and circuits caused by exposure to a specified neutron fluence at a specified pulse width. Neutron effects on electronics can be simulated using a number of platforms including the FBR at White Sands Missile Range, the pulsed Annular Core Research Reactor (ACRR) located at SNL, the Ion Beam Laboratory surrogate source located at SNL, or the Los Alamos Neutron Science Center (LANSCE) neutron spallation source located at Los Alamos National Laboratory (LANL). Other platforms exploiting nuclear fusion reactions such as the NIF at LLNL and the Z Facility at SNL are currently being investigated as neutron sources and techniques using Dense Plasma Focus (DPF); these could potentially provide pulsed neutron capability for future effects testing.

E.5.5 Electromagnetic Pulse Effects Testing

There are two general classes of EMP effects tests, injection tests and free-field tests. An injection test simulates the effects of the currents and voltages induced by HEMP on cables by artificially injecting current pulses onto equipment cables and wires. Injection tests are particularly well-suited to the evaluation of interior equipment that is not directly exposed to HEMP.

A free-field test is used to expose equipment, such as missiles, aircraft, vehicles, and radar antenna, to HEMP. Most free-field HEMP testing is performed with either a broadcast

simulator or a bounded wave EMP simulator. Both types of simulators use a high-power electrical pulse generator to drive the radiating elements. In the broadcast simulator, the pulse generator drives an antenna that broadcasts simulated EMP to the surrounding area. Objects are positioned around the antenna at a range corresponding to the desired electrical field strength. The operation of the equipment is closely monitored for upset and damage. Current and voltage measurements are made on equipment cables and wires to determine the electrical characteristics of the EMP energy coupled into the system.

In the bounded wave simulator, the pulse generator drives a parallel plate transmission line consisting of a horizontal or vertical curtain of wires and a ground plane. The test object is placed between the wires and the ground plane. The energy travels down the line, passes the test object, and terminates in a resistive load. As the pulse passes the test object, it is subjected to the electric field between the lines. Some simulators locate test instrumentation in a shielded chamber below the ground plane.

Free-field EMP simulators are available at the Patuxent River Naval Air Station in Maryland and at White Sands Missile Range.

E.5.6 Air-Blast Effects Testing

The military relies more on structural analyses for determining air-blast effects than on testing. This is because of the confidence engineers have in computer-aided structural analyses and the difficulty and costs associated with air-blast testing. Exposed structures and equipment like antennas, radars, radomes, vehicles, shelters, and missiles that have to be evaluated for shock and blast effects are usually subjected to an evaluation consisting of a mix of structural analyses, component testing, or scale-model testing. The evaluation may also include full-scale testing of major assemblies in a HE test or in a large shock tube.

Shock tubes vary in size from small laboratory facilities to large, full-scale devices. The DTRA Large Blast Thermal Simulator (LBTS), currently in caretaker status, can accommodate test objects as large as a helicopter. The LBTS replicates ideal and non-ideal air-blast environments. Shock tubes have the advantage of being able to generate shock waves with the same positive phase-time duration as the actual blast environment.

HE tests were conducted by the Defense Nuclear Agency, the DTRA predecessor, at Stallion Range located at White Sands Missile Range. These tests were used to validate

the survivability and vulnerability of many systems before the LBTS became operational. The explosive source was normally several thousand tons of ammonium nitrate and fuel oil (ANFO) housed in a hemispherical dome. The test objects were placed around the dome at distances corresponding to the desired peak overpressure, or dynamic pressure of an ideal blast wave. HE tests produced shock waves with fairly short positive duration corresponding to low-yield nuclear explosions. HE test results needed to be extrapolated for survivability against higher yield weapons and for non-ideal air-blast effects. Structures composed of heat sensitive materials, such as fiberglass and aluminum which lose strength at elevated temperatures, are normally exposed to a thermal radiation source before the arrival of the shock wave.

E.5.7 Thermal Radiation Effects Testing

The majority of thermal radiation effects testing is performed with high intensity flash lamps, solar furnaces, liquid oxygen, or powdered aluminum flares, called a thermal radiation source (TRS). Flash lamps and solar furnaces are normally used on small material samples and components. A TRS is used for larger test objects and frequently used in conjunction with the large HE tests. The DTRA LBTS features a thermal source that allows test engineers to examine the combined effects of thermal radiation and air blast.

E.5.8 Shock Testing

High-fidelity tests exist to evaluate systems for survivability to nuclear underwater and ground shock effects because, for these factors, conventional explosive effects are very similar to those from nuclear weapons. Machines such as hammers, drop towers, and slapper plates, are used for simulating shock effects on equipment. Explosives are also used for shock testing. The Navy uses explosives with floating shock platforms (barges) to simulate underwater shock and subjects one ship of each class to an explosive test at sea. The Army and the Air Force employ similar methods.

E.6 Military Standards

DTRA and its predecessor agencies have developed, and regularly update, military standards (MIL-STDs) designed to aid in the design, development, test, and evaluation of DoD systems subjected to nuclear and EMP environments. These MIL-STDs cover nuclear-generated EMP survivability of aircraft, maritime, and other systems in coordination with the Air Force and the Navy, as well as the broader community of stakeholders. The following are some of the relevant MIL-STDs:

MIL-STD-1766, Nuclear Hardness and Survivability Program Requirements for ICBM Weapon Systems defines nuclear hardness and survivability requirements and practices for use during the concept exploration, demonstration and validation, full-scale development, production, and deployment phases of the acquisition life-cycle of ICBM weapon systems.

MIL-STD-2169C, HEMP Environment Standard (Classified) defines high-altitude EMP environments for system hardness design and testing.

MIL-STD-3023, HEMP Protection for Military Aircraft establishes design margin, performance metrics, and test protocols for HEMP protection of military aircraft with nuclear EMP survivability at three hardness levels. This MIL-STD may also be used for aircraft that support multiple missions. Subsystems of the aircraft required to fully comply with the provisions of the standard are designated as Mission-Critical Subsystems having a HEMP survivability requirement. This approach also allows for consideration of platforms not yet addressed in this standard, such as Unmanned Aerial Vehicles.

MIL-STD-188-125, HEMP Protection for Ground-Based C4I Facilities Performing Critical, Time Urgent Missions is in the process of being updated. DTRA is investigating present capabilities and shortfalls of power filters as well as utilizing test results from EMP simulators.

MIL-STD-4023, Maritime EMP Standard establishes performance metrics, test protocols, and hardness margin levels for HEMP protection of military surface ships that must function when subjected to a HEMP environment.

Satellite System Nuclear Survivability (SSNS) Environment Standard defines nuclear weapon environment levels for evaluating satellite system performance in nuclear scenarios.

Comprehensive Atmospheric Nuclear Environments Standard (CANES) provides detailed nuclear environments and effects for a number of different nuclear weapon-types as a function of height of burst. A supplement to this MIL-STD covers nuclear-disturbed communication environments and nuclear ground burst environments.