Appendix C

Nuclear Weapons Effects Survivability and Testing

C.1 *Overview*

It is common to confuse nuclear weapons effects survivability with nuclear weapons 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. Thus, nuclear weapons effects survivability includes, but is not limited to, nuclear weapons systems.

Nuclear weapons system survivability is concerned with the ability of our nuclear deterrent forces to survive against the entire threat spectrum that includes, but is not limited to, nuclear weapons effects. The vast range of potential threats include: conventional and electronic weaponry; nuclear, biological, and chemical contamination; advanced technology weapons such as high-power microwaves and radio frequency weapons; terrorism or sabotage; and the initial effects of a nuclear detonation.

In simple terms, nuclear weapons effects survivability refers to any and all personnel, equipment, and systems (including, but not limited to, nuclear systems) being able to survive nuclear weapons effects. Nuclear weapons system survivability refers to nuclear weapons systems being survivable against any threat (including, but not limited to, the nuclear threat). See Figure C.1 for a summary of the differences between nuclear weapons effects and nuclear weapons system survivability. An overlap occurs when the threat to the survivability of a nuclear weapons system is a nuclear detonation and its effects. Figure C.2 illustrates the intersection between nuclear effects survivability and systems survivability.

Nuclear weapons effects survivability refers to the capability of a system to withstand exposure to a nuclear weapons effects environment without suffering the loss of its ability to accomplish its designated mission. Nuclear weapons effects survivability may be accomplished by hardening, timely re-supply, redundancy, mitigation techniques (to include operational techniques), or a combination thereof. Systems can be nuclear hardened to survive prompt nuclear weapons 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 B, *The Effects of Nuclear Weapons*.

Nuclear Weapons **Effects** Survivabilty	Nuclear Weapons **System** Survivabilty
Survivability of **Everything** - Nuclear Weapons - Nuclear Force Personnel - Nuclear Force Equipment - Conventional Weapons - Conventional Force Personnel - Conventional Equipment Against the Effects of **Nuclear Weapons**	Survivability of **Nuclear Forces** - Nuclear Weapons - Nuclear Force Personnel - Nuclear Force Equipment Against the Effects of **Any Threat** - Nuclear Weapons - Chemical, Biological Weapons - Conventional Weapons - Advanced Technology Weapons - Special Ops Attack - Terrorist Attack

Figure C.1 Nuclear Weapons Effects vs System Survivability

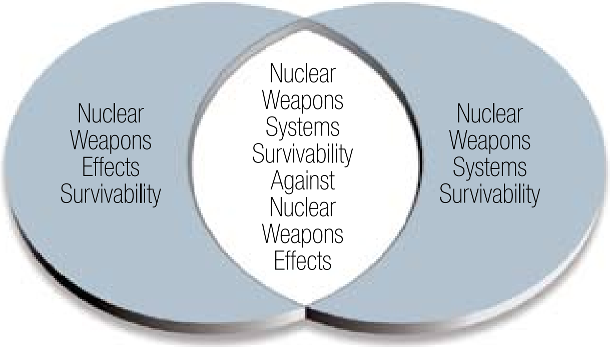

Figure C.2 Intersection of Nuclear Effects Survivability and Systems Survivability

Nuclear hardness describes the ability of a system to withstand the effects of a nuclear detonation and 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 weapons effects such as fallout, nor does it discuss nuclear contamination survivability.[1]

Mechanical and structural effects hardening consists of using robust designs, protective enclosures, protective coatings, and the proper selection of materials.

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[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.

Electronics and electrical effects hardening involves using the proper components, special protection devices, circumvention circuits, and selective shielding. Nuclear weapons 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 weapons effects survivability. The impact of the nuclear weapons effects survivability approach on system cost, performance, reliability, maintainability, productivity, logistics support, and other requirements are examined to ensure maximum operational effectiveness consistent with program constraints. The different approaches to hardening are not equally effective against all initial nuclear weapons effects.

C.2 Nuclear Weapons Effects Survivability

Each of the primary and secondary environments produced by a nuclear detonation causes a unique set of mechanical and electrical effects. Some effects are permanent and others are transient. Both types can cause system malfunction, system failure, or loss of combat capability.

C.2.1 Nuclear Weapons 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.[2] Low-air, near-surface, and surface bursts will damage most ground targets within the damage radii. Also, high-altitude bursts produce high-altitude electromagnetic pulse (HEMP) effects over a very large area that may damage equipment with vulnerable electronics on the ground. Figure C.3 highlights the nuclear environments that dominate the survival for typical systems based on various heights of burst from space to below the Earth's surface.

Nuclear weapons-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

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[2] The *survival range* measures the distance from Ground Zero (GZ) necessary to survive nuclear weapons effects.

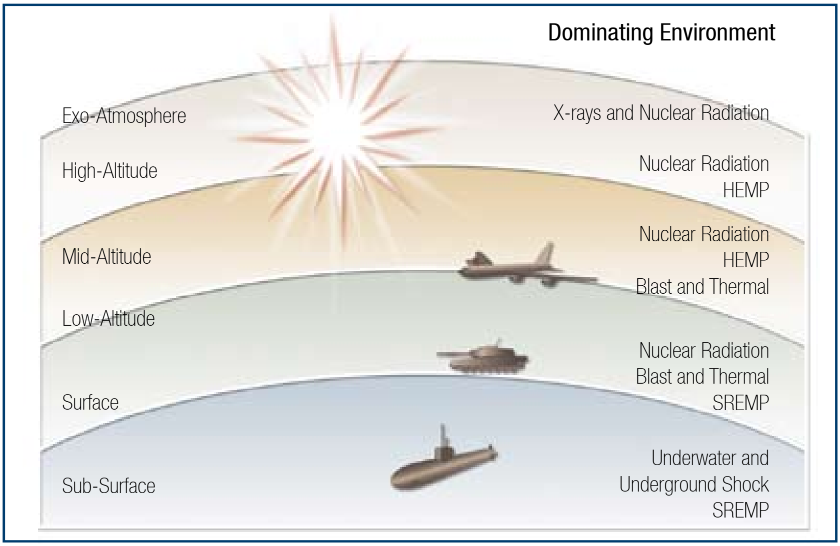

Figure C.3 Dominant Nuclear Environments as a Function of Altitude

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 explosion. 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. The final result of the EMP generated by the detonation is a tremendous surge of low frequency photons that can enter a system through designed and unintended antennas, generating a flow of electrical current that overloads and destroys electrical components, and renders the equipment non-operational.

Underwater shock and ground shock are usually the dominant nuclear weapons effects for submerged submarines and buried shelters, respectively. HEMP is the dominant threat for surface-based systems located outside the target zone such as Command, Control, Communications, and Intelligence (C^3I) facilities or sophisticated electronics.

Nuclear weapons effects survivability requirements vary with the type of system, its mission, its operating environment, and the threat. For example, the X-ray, gamma ray, and neutron survivability levels used for satellites are very low compared with the survivability levels used for missiles and Re-entry Vehicles (RVs), or Re-entry Bodies (RBs). Satellite levels are usually set so that a single nuclear weapon, detonated in the region containing several satellites, will not damage or destroy more than one satellite. The levels used for RVs, on the other hand, are very high because the RV/RB is the most likely component of an ICBM/SLBM to be attacked by a nuclear weapon at close range. The ICBM/SLBM bus and booster have a correspondingly lower requirement in consideration of their range from the target and the time available to target them.

When a system is deployed within the Earth's atmosphere the criteria are different. Systems operating at lower altitudes do not have to consider X-ray effects. The 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 the air blast and thermal radiation. Two of the most challenging problems in this region are the prompt gamma ray effects in electronics and the total radiation dose delivered to personnel and electronics.

The area between ten km down to the surface is somewhat of 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 air-blast, thermal radiation, and nuclear radiation effects.

On the ground, air blast and thermal radiation are the dominant nuclear weapons 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 threats with yields exceeding ten kilotons (kt).

This is not necessarily true for blast-hard systems that can survive closer to a nuclear explosion such as a battle tank or hardened shelter. Very high levels of ionizing radiation usually require systems to be at greater distances from ground zero (GZ) to avoid personnel casualties and damage to electronic equipment. This is especially true for smaller yield weapons. For example, a battle tank will probably survive at a distance of less than one-half km from a ten kt explosion if the only consideration is structural damage. However, ionizing radiation from the detonation affects the crew and the tank's electronics. Because thermal effects are easily attenuated and have a large variation of effect on the target, they are hard to predict. Consequently, thermal effects are not normally taken into consideration when targeting. Although they are a large part of a nuclear weapon's output, thermal effects do not govern survivability considerations for materiel objects, but they are always considered for exposed personnel.

Surface-launched missiles are in a category by themselves because they operate in so many different environmental regions. Missiles have to survive the effects of air blast, thermal radiation, HEMP, ionizing radiation, SREMP, and even X-rays.

C.2.2 Nuclear Weapons Effects on Personnel

Several of the effects of nuclear weapons are a threat to personnel. Thermal radiation can cause burns directly to the skin or can ignite clothing. Fires can spread to other locations, causing people to be burned due to an indirect effect of thermal radiation. Initial nuclear radiation (gamma rays and neutrons) can cause a significant acute dose of ionizing radiation. Residual radiation can cause significant exposure for days to weeks after the detonation. The blast wave can cause immediate casualties to exposed personnel, or could impact and roll a vehicle causing personnel injuries inside the vehicle. EMP will not cause injuries directly, but it can cause casualties indirectly, e.g., instantaneous destruction of electronics in an aircraft in flight could cause persons in the aircraft to be killed or injured.

Effects survivability concepts for manned systems must consider the impact 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 weapons 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 GZ where a piece of equipment might survive, an individual outside and unprotected might become a casualty. Therefore, his 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. Because EMP has no effects on personnel, all systems should, in theory, have an equal requirement for EMP survivability.

C.2.3 Nuclear Weapons Effects Survivability Measures

There are a number of measures that enhance nuclear weapons effects survivability of equipment. Some of these measures can be achieved after production and fielding, but most measures require hardening features that are most effective if they are a part of the design development from the beginning. These measures are also much cheaper if they are designed and produced as a part of the original system rather than as a retrofit design and modification.

Timely Re-supply 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 weapons effects. The decision to rely on reserve assets can have a significant impact on 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 that 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 techniques that can be utilized to reduce the vulnerability of military systems to nuclear weapons effects. These may include but are not limited to:

- *Avoidance,* or the incorporation of measures to eliminate detection and attack. Avoidance techniques are very diverse. For example, avoidance may include stealth tactics that utilize 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 weapons effects survivability by destroying incoming nuclear weapons or causing them to detonate outside of the susceptible area of the protected system; and
- *Deception,* or 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 impact of deception on production depends on the approach. Some deception measures can be quite complex and costly, such as the decoys for an Intercontinental Ballistic Missile (ICBM) system; 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. 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. It may also introduce a requirement for production controls to support hardness assurance, especially in strategic systems.

Threat Effect Tolerance is the intrinsic ability of every component and piece of equipment to tolerate/survive some level of exposure to nuclear weapons effects. The exposure level that a piece of equipment will tolerate depends primarily on the technologies it employs and how it is designed. The nuclear weapons 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 the harder components may be more expensive.

C.3 Nuclear Weapons System Survivability

Nuclear weapons system survivability refers to the capability of a nuclear weapon system to withstand exposure to a full spectrum of threats without suffering loss of its ability to accomplish its designated mission. Nuclear weapons 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 the delivery system or platform; and 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); the forces operating the nuclear weapon system; the supporting command and control links; and the supporting logistical elements.

Nuclear weapons system survivability is concerned with the entire threat spectrum that includes, but is not limited to, nuclear weapons effects. The vast range of potential threats include: conventional and electronic weaponry; nuclear, biological, and chemical contamination; advanced technology weapons such as high-power microwaves and radio frequency weapons; terrorism or sabotage; and the effects of a nuclear detonation.

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.

Survivability of nuclear forces is defined in DoD Directive 3150.3, *Nuclear Force Security and Survivability*, as, "the capability of nuclear forces and their nuclear control and support systems and facilities in wartime to avoid, repel, or withstand attack or other hostile action, to the extent that essential functions (ability to perform assigned nuclear mission) can continue or be resumed after onset of hostile action."

It is often difficult to separate measures to enhance survivability from those that provide security to the force or its components. In a potential wartime environment, for example, hardened nuclear weapons containers as well as hardened weapons transport vehicles provide security and enhance survivability during transit. Many of the measures to enhance nuclear weapons system survivability and to protect against the effects of nuclear weapons can be the same. Hardening and redundancy, for example, as well as threat tolerant designs, re-supply, and mitigation techniques apply to both.

C.3.1 Nuclear Force Survivability

Until recently, DoD Directive 3150.3 governed nuclear force security and survivability program requirements. The Directive is outdated and is expected to be cancelled. The scope and requirements outlined in DoD Directive 3150.3 will be broadened and covered by two documents: one current DoD Directive and its corresponding manual (DoDD 5210.41 and DoD S-5210.41-M) pertaining to nuclear force security; and one future DoD Instruction entitled *Chemical, Biological, Radiological, and Nuclear (CBRN) Survivability Program*.

C.3.2 Nuclear Command and Control Survivability

Nuclear weapons systems include not only the nuclear weapons but also the associated command and control (C^2) support. The security and survivability of weapons systems C^2 is addressed in DoD Directive 3150.3, *Nuclear Force Security and Survivability*, DoD Directive 5210.41, *Security Policy for Protecting Nuclear Weapons*, and DoD Manual 5210.41-M, *Nuclear Weapons Security Manual*.

DoD Directive S-5210.81, *United States Nuclear Weapons Command and Control*, establishes policy and assigns responsibilities related to the U.S. Nuclear Command and Control System (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 C^2 functions. The Under Secretary of Defense for Acquisition, Technology, and Logistics (USD(AT&L)), in conjunction with the Services, establishes survivability criteria for related nuclear weapons equipment.

C.3.3 Missile Silos

Air Force Intercontinental Ballistic Missile (ICBM) systems are deployed in missile silos. The survivability of these silos is achieved through the physical hardening of the silos and through their underground location, which protects against air blast effects. The dispersal of the multiple missile fields also adds to system survivability by complicating any targeting resolution.

C.3.4 Containers

Nuclear weapons 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.

C.3.5 Weapons Storage Vault

The Weapons Storage Vault (WSV) is an underground vault located in the floor of a hardened aircraft shelter. A WSV can hold up to four nuclear weapons and provide ballistic protection in the lowered position through its hardened lid and reinforced sidewalls. The U.S. calls the entire system (including the electronics), the *Weapon Storage and Security System*. NATO calls it the *Weapon Security and Survivability System*. Both the U.S. and NATO refer to the entire system by the same acronym, WS3. The WS3 is currently in use in Europe.

C.4 *Tests and Evaluation*

Nuclear weapons effects testing refers to tests conducted to measure the response of objects to the energy output of a nuclear weapon. Testing (using simulators and not actual detonations) is essential to the development of nuclear survivable systems and is a consideration throughout the development and acquisition process. These testing and analysis methods are well-established and readily available. Analysis plays an important role in nuclear weapons effects survivability design and development. Computer-aided 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, by the inability to model complex items or to handle the large, non-linear responses often encountered in both nuclear weapons effects and digital electronics.

C.4.1 Testing

Because the U.S. is no longer conducting underground nuclear tests, all nuclear weapon effects testing is done by simulators. These simulators are usually limited to a relatively small exposure volume and generally used for single environment tests, such as X-ray effects tests, neutron effects tests, prompt gamma ray effects tests, and EMP effects tests. Free-field EMP, high explosive (HE), and shock tube tests are notable exceptions since they can be tested at the system level. Additionally, in certain situations, the Army can test full systems for neutron and gamma fluence, and total dose at its Fast Burst Reactors (FBR). Figure C.4 lists the types of simulators commonly used for nuclear weapons effects testing.

Test	Type of Simulator	Size of Test
X-rays Effects (Hot)	▪ Low-Voltage Flash X-ray Machines	▪ Components and small assemblies
X-rays Effects (Cold)	▪ Plasma Radiators	▪ Components
Gamma Ray Effects	▪ Flash X-ray Machines ▪ Linear Accelerator ▪ FBR	▪ Components, circuits, and equipment
Total Dose Gamma Effects	▪ Cobalt 60 ▪ FBR	▪ Components, circuits, and equipment
Neutron Effects	▪ FBR	▪ Components, circuits, and equipment
Blast Effects (Overpressure)	▪ Small Shock Tubes ▪ Large Shock Tubes ▪ HE Tests	▪ Components, parts, and equipment ▪ Small systems and large equipment ▪ Vehicles, radars, shelters, etc.
EMP	▪ Pulsed Current Injection (PCI) ▪ Free Field	▪ Point of Entry (POE) Systems
Thermal Effects	▪ Thermal Radiation Source (TRS) ▪ Flash Lamps and Solar Furnace	▪ Equipment, large components ▪ Components and materials
Shock Effects (Dynamic pressure)	▪ Large Blast Thermal Simulator (LBTS) ▪ Explosives	▪ Equipment, large components ▪ Systems

Figure C.4 Simulators Commonly Used for Effects Testing

C.4.2 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 they are rapidly absorbed in the atmosphere, X-rays 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 distance and orientation of the system with respect to the nuclear burst.

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

Flash X-ray machines, commonly referred to as FXRs, generate large amounts of electric power, which is converted into intense, short pulses of energetic electrons. The electrons are normally stopped in a metal target that converts a small portion of their energy into a pulse of X-rays. The resulting photons irradiate the test specimen. The electron pulse may also be used to simulate some X-ray effects. The output characteristics of FXRs depend on the design of the machine and vary considerably from one design to the next. Radiation pulse widths range from ten 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 matter of nanoseconds results in power levels ranging from billions to trillions of watts.

X-ray effects testing usually requires a machine capable of producing a trillion watts or more in power with an output voltage of around one million volts. The X-rays produced by a machine of this type tend 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/volume. Most X-ray tests in FXRs are limited to components and small assemblies.

Cold X-ray effects testing is designed to replicate surface damage to exposed components in space applications, and it 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 a 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.

Currently, there are a number of pulsed power facilities used to generate X-ray environments. The DOE operates both the Saturn and Z facilities. The DoD operates the Decade, Pithon, and Double Eagle facilities. These facilities are currently in various states of readiness based on predicted future use.

C.4.3 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; the effects do not lend themselves to strict analyses because they 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.

The two most popular machines used for gamma dose-rate testing are the FXRs and the linear accelerator, or LINAC. The FXRs used for dose-rate effects tests operate at significantly higher voltages than the 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 and is 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.[3]

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

Most dose-rate tests are active; that is, they require the test object to be powered up and operating for testing. Effects like component latch-up, logic upset, and burnout will not occur in the absence of power. Tests must be conducted in a realistic operating condition and the test object must be continuously monitored before, during, and after exposure.

Sandia National Laboratories operates the High-Energy Radiation Megavolt Electron Source (HERMES) pulsed—power facility to simulate prompt gamma environments at extreme dose rates for the DOE. The DoD currently operates smaller gamma-ray facilities used to test systems at lower levels. These include the PulseRad 1150 at Titan International and the Relativistic Electron Beam Accelerator (REBA) at White Sands Missile Range.

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[3] *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.

C.4.4 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. The most popular and widely used simulator for total-dose effects testing is the Cobalt-60 (Co60) 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 but not with the frequency or the confidence of the Co60 source.

C.4.5 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. The most popular device for simulating the effects of neutrons on electronics is a bare, all metal, unmoderated fast-burst reactor (FBR). A FBR produces a slightly moderated fission spectrum, which it can deliver in either a pulsed or steady-state mode. Both the Army and Sandia National Laboratories currently have a fast-burst reactor.

C.4.6 EMP 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/or 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-powered electrical pulse generator to drive the radiating elements. In the broadcast type 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-type 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 Patuxent River Naval Air Station in Maryland and at White Sands Test Range in New Mexico. These facilities can test most systems.

C.4.7 Air-Blast Effects Testing

The military relies more on structural analyses for determining air-blast effects than on testing. This is due to the confidence engineers have in computer-aided structural analysis and to 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 that consists 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 high explosive (HE) test or in a large shock tube.

Shock tubes vary in size from small laboratory facilities to very large, full-scale devices. The Defense Threat Reduction Agency (DTRA) Large Blast/Thermal Simulator (LBTS) can accommodate test objects as large as a helicopter. It can simulate 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 former Defense Nuclear Agency at the "Stallion Range," in White Sands, New Mexico. These tests were used to validate the survivability/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 produce shock waves with fairly short positive duration corresponding to low-yield nuclear explosions. HE test results have to be extrapolated for survivability against higher yield weapons and for non-ideal air-blast effects. Structures constructed of heat sensitive materials, like fiberglass and aluminum (which lose strength at elevated temperatures), are normally exposed to a thermal radiation source before the arrival of the shock wave.

C.4.8 Thermal Radiation Effects Testing

The majority of thermal radiation effects testing is performed with high intensity flash lamps, solar furnaces, liquid oxygen, and powered aluminum flares, called thermal radiation sources (TRS). Flash lamps and solar radiators are normally used on small material samples and components. TRS is used for larger test objects and was 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.

C.4.9 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. There is a family of machines, such as hammers, drop towers, and slapper plates, for simulating shock effects on various weights and sizes of 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.