**Statement of**

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**INTRODUCTION**

Mr. Chairman, I am Dr. George Ullrich, the Deputy Director at the Defense Special Weapons Agency in the Department of Defense. I appreciate the opportunity to appear before you today to discuss this important issue.

It is interesting to note that exactly 52 years ago to the day, the world's first nuclear device was exploded at Trinity site, located on an isolated stretch of New Mexico desert in what is now the White Sands Missile Range. Among the team who witnessed that momentous event was Enrico Fermi, Nobel laureate and perhaps the most brilliant of the Manhattan Project physicists. It was said that he was probably the last man of the twentieth century who actually knew all of the physics of his day. I mention it because it was Enrico Fermi who, prior to the Trinity Event, first predicted that nuclear explosions were capable of generating strong electromagnetic fields. Since then we have learned a great deal more about nuclear-induced electromagnetic phenomena and, in particular, about the phenomenon of high altitude Electro-Magnetic Pulse, commonly called "EMP."

The most common perception of a nuclear detonation is that represented by a mushroom cloud -- a burst at or near the surface of the earth. Such a burst results in a variety of weapons effects, most prominently blast and thermal, whose extent can reach up to several miles from ground zero, depending on yield. The only exception is radioactive fallout from a surface burst, which at low levels can traverse the entire globe. A high altitude burst, detonated at heights ranging from 50 to several hundreds of kilometers above the earth's surface, is also capable of generating a wide variety of effects and disturbed environments, the most far-reaching being EMP. Depending primarily on the burst height and to a lesser extent on yield, a high altitude burst can bathe a continental size region in EMP. Such a detonation causes particular concern because of the sensitivity of modern electronics to strong electromagnetic fields. A knowledgeable adversary could attempt to exploit such a perceived weakness, thereby severely degrading the U.S. technological advantage, and he could do so in a way that would not likely provoke an immediate nuclear retaliation

A less well known effect of high altitude bursts, but also one with potentially devastating consequences, is the artificial "pumping" of the Van Allen belt with large numbers of electrons. The bomb-induced electrons will remain trapped in these belts for periods exceeding one year. All unhardened satellites traversing these belts in low earth orbit could demise in a matter of days to weeks following even one high altitude burst.

The United States' national military strategy is based, in significant part, on our technological advantages in such fields as electronics and computers. These are the enabling technologies for achieving Information Dominance, which contributed to our success in the Gulf War and will be vital on future battlefields. As outlined in A National Security Strategy for a New Century, The White House, May 1997, our national military strategy also emphasizes the importance of responding to asymmetries -- that is, unconventional approaches that avoid or undermine our strengths while exploiting our vulnerabilities. To quote from the report, "Because of our dominance in the conventional military arena, adversaries who challenge the United States are likely to do so using asymmetric means...such as WMD..." To preserve our technological advantage, DoD develops radiation hardened systems and tests them to assure survivability.

However, due to size and power reductions, modern electronics are inherently more vulnerable to some of the effects produced by a nuclear detonation. And each new generation, smaller and needing less power, exacerbates these vulnerabilities. Furthermore, as we make greater use of more affordable commercial parts and components, we potentially introduce new vulnerabilities into our military systems. Additionally, the military's increasing reliance on commercial space-based systems makes it more vulnerable to the nuclear weapon effects being discussed.

In my presentation today, I will provide a brief overview of the effects produced by nuclear weapons, to include lessons learned during both the United States' and Soviet Union's atmospheric nuclear test programs. Particular emphasis will be given to the most significant effects in a scenario in which an adversary uses one or a few nuclear weapons detonated at a high altitude. I will discuss what we have learned about providing affordable protection. Finally, I will mention what we do to simulate these threat level environments and how we perform testing to validate EMP hardness.

I should also note that the programs I will discuss are components within a broader set of Defense Department activities directed at sustainment of critical DoD nuclear mission competencies. These activities are described in detail in -- the May 1997 report by the Secretary of Defense on Nuclear Weapon Systems Sustainment Programs previously delivered to the Committee.

**HIGH ALTITUDE NUCLEAR DETONATION EFFECTS**

Based on over a half-century of research, we have developed an understanding of the effects produced by nuclear weapons. Since the end of the Cold War, we have added to our knowledge based on an analysis of information made available from the Soviet Union’s nuclear test programs.

To understand the military consequences that can result from the high altitude detonation of even a single nuclear weapon, I will address:

* High Altitude EMP (or HEMP)
* System Generated EMP (SGEMP) and
* other Radiation Effects.

In keeping with your request, Mr. Chairman, I will direct most of my remarks to the topic of high altitude EMP.

**High Altitude EMP**

A nuclear weapon detonated at high altitude releases some of its energy in the form of gamma rays. These gamma rays collide with air molecules and produce what are called Compton electrons. The Compton electrons, in turn, interact with the earth's magnetic field, producing an intense electromagnetic pulse that propagates downward to the earth's surface. The initial gamma rays and resultant EMP move with the speed of light. The effects encompass an area along the line of sight from the detonation to the earth's horizon. Any system within view of the detonation will experience some level of EMP. For example, if a high-yield weapon were to be detonated 400 kilometers (250 miles) above the United States, nearly the entire contiguous 48 states would be within the line-of-sight. The frequency range of the pulse is enormously wide -- from below one hertz to one gigahertz. Peak electric fields can reach tens of thousands of volts per meter. All types of modern electronics are potentially at risk, from Boston to Los Angeles; from Chicago to New Orleans.

One of our earliest experiences with HEMP dates back to the resumption of atmospheric nuclear testing in 1962 following a three year testing moratorium. Starfish Prime, a 1.4 megaton device, was detonated at an altitude of 400 kilometers over Johnston Island. Failures of electronic systems resulted in Hawaii, 1,300 kilometers away from the detonation. Street lights and fuses failed on Oahu and telephone service was disrupted on the island of Kauai. Subsequent tests with lower yield devices produced electronic upsets on an instrumentation aircraft that was approximately 300 kilometers away from the detonations.

Soviet scientists had similar experiences during their atmospheric test program. In one test, all protective devices in overhead communications lines were damaged at distances out to 500 kilometers; the same event saw a 1,000 kilometer segment of power line shut down by these effects. Failures in transmission lines, breakdowns of power supplies, and communications outages were wide-spread.

**System Generated EMP**

When gamma and x-rays from a high altitude detonation encounter a satellite in space they excite and release electrons as they penetrate the interior of the system. This phenomena is referred to as system generated electromagnetic pulse (SGEMP) because the accelerated electrons create electromagnetic transients. Systems must be configured with special cables, aperture protection, grounding, and insulating materials in order to survive these transients.

SGEMP impacts space system electronics in three ways. First, x-rays arriving at the spacecraft skin cause an accumulation of electrons there. The electron charge, which is not uniformly distributed on the skin, causes current to flow on the outside of the system. These currents can penetrate into the interior through various apertures, as well as into and through the solar cell power transmission system. Secondly, x-rays can also penetrate the skin to produce electrons on the interior walls of the various compartments. The resulting interior electron currents generate cavity electromagnetic fields that induce voltages on the associated electronics which produce spurious currents that can cause upset or burnout of these systems. Finally, x-rays can produce electrons that find their way directly into signal and power cables to cause extraneous cable currents. These currents are also propagated through the satellite wiring harness.

**Other Radiation Effects**

A high-altitude detonation presents a double radiation threat to space based assets. Systems not protected by the Earth's shadow are exposed to the direct weapon outputs (gamma rays, x-rays, neutrons) and can be upset or damaged immediately if their range from the weapon is such that the radiation environments exceed electronic device tolerance levels. The second threat comes from the weapon-produced electrons that enhance the earth's natural Van Allen radiation belts. Satellites that repeatedly transit these enhanced radiation belts in their orbits will eventually exceed their total radiation dose tolerance and will degrade, then fail.

Weapon debris carries a significant percentage of the energy of the detonation and this radioactive material releases enormous numbers of high energy electrons through beta decay. This phenomena creates an artificial "trapped electron" radiation belt. The size and intensity of the belt is highly dependent on the yield, altitude, and latitude of the detonation. The energies of the weapon-induced trapped electrons are significantly higher than those of the natural environment. For example, a 50 kiloton (KT) weapon detonated at a 120 km altitude (75 miles) can produce electron densities several orders of magnitude higher than the natural electron environment in low earth orbit. These elevated electron densities can last for months to years and significantly increase the total ionizing dose accumulated by space assets that transit these belts. This increase in total dose accumulation can dramatically shorten the lifetime of satellite systems. Projected lifetimes of up to ten years can be reduced to a mere two months after such an event.

**AFFORDABLE HEMP PROTECTION**

We understand how to provide effective protection against EMP effects. The basic approach is to provide a shield that prevents damaging electrical pulses from entering a system. This requires protection at all electrical and mechanical penetrations. EMP hardening protocols have been published in standard handbooks and computer programs have been developed to facilitate system hardness designs.

EMP protection is also affordable. If accomplished during the design phase, the cost of EMP protection is a small fraction, one-to-five-percent, of overall system development costs. Done after the fact, when the unprotected system has already been fielded, it can be significantly more expensive.

To contribute to cost savings, we have an effort underway to develop integrated hardening methodologies that provide protection against multiple hazards. Our initial work focuses on integrated protection against the effects of both high altitude EMP and high powered microwaves produced with non-nuclear sources.

**SIMULATION TO VALIDATE HEMP PROTECTION**

We acquired much of our understanding of high altitude EMP effects and the protection needed from the development and effective use of nuclear weapon effects simulators. DoD currently operates a suite of simulators that provides the needed capabilities for large area, threat-level field illumination, direct current injection techniques, and low-level, continuous wave (CW) illumination to evaluate shield integrity and energy coupling efficiencies. These simulators are used in combination to validate a system's overall EMP protection.

**STATE OF UNDERSTANDING**

High Altitude EMP, System Generated EMP, and Radiation Effects are genuine, widespread hazards produced by even one nuclear weapon. We know how to protect against these EMP and radiation threats. Such protection is affordable, if provided for at an early stage in system design and development. For a tactical system, the cost can be as little as 1% of the total development investment; for strategic systems, a target of 5% is reasonable. Retrofitting protection after a system has been deployed can be considerably more expensive.

The pace of new developments in the fields of electronics and computers can be daunting. There is a new generation of microelectronics technology every eighteen months. Some of these new technologies are inherently more susceptible to nuclear threats. DoD has recognized and responded to these and other challenges. As outlined in the Secretary’s May 1997 report on Nuclear Weapon Systems Sustainment Programs, additional funds have been programmed to ensure that core DoD requirements for advanced radiation hardened microelectronics technology are met. More recently, a Radiation Hard Oversight Council was established to ensure these efforts have appropriate visibility and oversight.

EMP does not distinguish between military and civilian systems. Unhardened systems, such as commercial power grids, telecommunications networks, and computing systems, remain vulnerable to widespread outages and upsets due to HEMP. While DoD hardens assets it deems vital, no comparable civil program exists. Thus, the detonation of one or a few high-altitude nuclear weapons could result in devastating problems for the entire U.S. commercial infrastructure. Some detailed network analyses of critical civil systems would be useful to better understand the magnitude of the problem and define possible solution paths.