# Electromagnetic Pulse

An Online Continuing Education Course for Engineers

**Course Number: E-4027**

**Credit: 4 Hours / 4 PDH / 4 CPD**

# Electromagnetic Pulse

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# Introduction

An electromagnetic pulse (EMP) is a burst of electromagnetic radiation that results from the detonation of a nuclear weapon and/or a suddenly fluctuating magnetic field. The resulting rapidly changing electric fields and magnetic fields may couple with electric systems to produce damaging current and voltage surges.

In military terminology, a nuclear bomb detonated hundreds of kilometers above the Earth's surface is known as a high-altitude electromagnetic pulse (HEMP) device. Nuclear electromagnetic pulse has three distinct time components that result from different physical phenomena. Effects of a HEMP device depend on a very large number of factors, including the altitude of the detonation, energy yield, gamma ray output, interactions with the Earth's magnetic field, and electromagnetic shielding of targets. The high-altitude nuclear weapon-generated electromagnetic pulse (EMP) is one of a small number of threats that has the potential to hold society seriously at risk.

Briefly, a single nuclear weapon exploded at high altitude above the United States will interact with the Earth's atmosphere, ionosphere, and magnetic field to produce an electromagnetic pulse (EMP) radiating down to the Earth and additionally create electrical currents in the Earth. EMP effects are both direct and indirect. The former are due to electromagnetic "shocking" of electronics and stressing of electrical systems, and the latter arise from the damage that - upset, damaged, and destroyed - electronics controls then inflict on the systems in which they are embedded. The indirect effects can be even more severe than the direct effects.

The electromagnetic fields produced by weapons designed and deployed with the intent to produce EMP have a high likelihood of damaging electrical power systems, electronics, and information systems. Their effects on dependent systems and infrastructures could be sufficient to qualify as catastrophic to the U.S.

Depending on the specific characteristics of the attacks, unprecedented cascading failures of major infrastructures could result. The primary avenues for catastrophic damage are through the electric power infrastructure and thence into telecommunications, energy, and other infrastructures. These, in turn, can seriously impact other important aspects of life, including the financial system; means of getting food, water, and medical care to the citizenry; trade; and production of goods and services. The recovery of any one of the key national infrastructures is dependent on the recovery of others. The longer the outage, the more problematic and uncertain the recovery will be.

Because of the ubiquitous dependence on the electrical power system, its vulnerability to an EMP attack, coupled with the EMP's particular damage mechanisms, creates the possibility of long-term, catastrophic consequences. The implicit invitation to take advantage of this vulnerability, when coupled with increasing proliferation of nuclear weapons and their delivery systems, is a serious concern. A single EMP attack may seriously degrade or shut down a large part of the electric power grid in the geographic area of EMP exposure effectively instantaneously. There is also a possibility of functional collapse of grids beyond the exposed area, as electrical effects propagate from one region to another.

The time required for full recovery of service would depend on both the disruption and damage to the electrical power infrastructure and to other national infrastructures. Larger affected areas and stronger EMP field strengths will prolong the time to recover.

***Widespread functional collapse of the electric power system in the area affected by EMP is likely.***

There is a point in time at which the shortage or exhaustion of sustaining backup systems, including emergency power supplies, batteries, standby fuel supplies, communications, and manpower resources that can be mobilized, coordinated, and dispatched, together lead to a continuing degradation of critical infrastructures for a prolonged period of time.

Electrical power is necessary to support other critical infrastructures, including supply and distribution of water, food, fuel, communications, transport, financial transactions, emergency services, government services, and all other infrastructures supporting the national economy and welfare. Should significant parts of the electrical power infrastructure be lost for any substantial period of time, and the consequences are likely to be catastrophic, and many people may ultimately die for lack of the basic elements necessary to sustain life in dense urban and suburban communities. Such impacts are likely in the event of an EMP attack unless practical steps are taken to provide protection for critical elements of the electric system and for rapid restoration of electric power, particularly to essential services. The recovery plans for the individual infrastructures currently in place essentially assume, at worst, limited upsets to the other infrastructures that are important to their operation. Such plans may be of little or no value in the wake of an EMP attack because of its long-duration effects on all infrastructures that rely on electricity or electronics.

This course looks at the history of EMP effects as well as other catastrophic events to the electric power grid. The course explains the technical aspects of EMP, described the electric power system structure, and provides an overview of the vulnerabilities and mitigation options that electric utilities may employ to protect their systems from the effects of EMP.

# Chapter 1
# History of Electromagnetic Pulse

To understand how an electromagnetic pulse may impact and disrupt the electric grid we can look at history to see the inadvertent impact of above ground nuclear tests during the last century and we can look at how other major electrical grid disruptions have affected the electric system. We will first look at nuclear tests from the 1940's through the 1960's.

**EMP Results from Nuclear Tests**

The fact that an electromagnetic pulse is produced by a nuclear explosion was known since the earliest days of nuclear weapons testing, but the magnitude of the EMP and the significance of its effects were not realized for some time.

During the first United States nuclear test in July 1945, electronic equipment was shielded due to Enrico Fermi's expectation of an electromagnetic pulse from the detonation. The official technical history for that first nuclear test states, "All signal lines were completely shielded, in many cases doubly shielded. In spite of this many records were lost because of spurious pickup at the time of the explosion that paralyzed the recording equipment." During British nuclear testing in 1952–1953 there were instrumentation failures that were attributed to "radio flash," which was then the British term for EMP.

The high altitude nuclear tests of 1962, as described below, increased awareness of EMP beyond the original small population of nuclear weapons scientists and engineers. The larger scientific community became aware of the significance of the EMP problem after a series of three articles were published about nuclear electromagnetic pulse in 1981 by William J. Broad in the weekly publication Science.

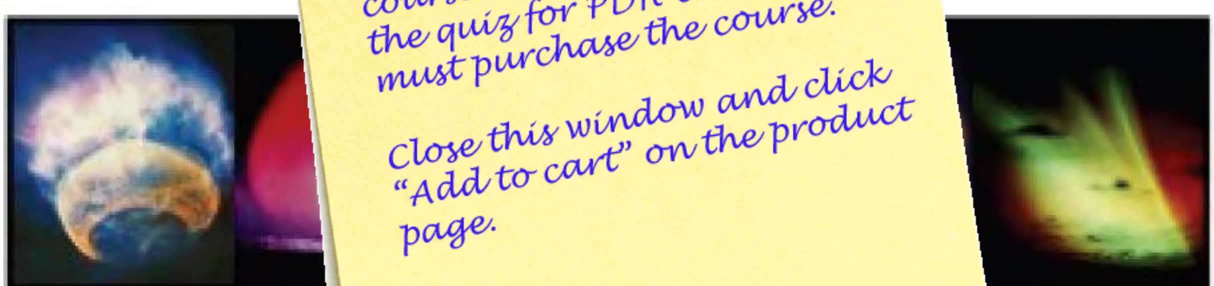
In July 1962, a 1.44 megaton United States nuclear test in space, 400 kilometers above the mid-Pacific Ocean, called the *Starfish Prime test*, demonstrated to nuclear scientists that the magnitude and effects of a high altitude nuclear explosion were much larger than had been previously calculated. Starfish Prime also made those effects known to the public by causing electrical damage in Hawaii, about 900 miles away from the detonation point, knocking out about 300 streetlights, setting off numerous burglar alarms and damaging a telephone company microwave link.

The EMP damage of the Starfish Prime test was quickly repaired because of the ruggedness of the electrical and electronic infrastructure of Hawaii in 1962. Realization of the potential impacts of EMP became more apparent to some scientists and engineers during the 1970s as more sensitive solid-state electronics began to come into widespread use.

Starfish Prime was the first successful test in the series of United States high-altitude nuclear tests in 1962 known as *Operation Fishbowl*. The subsequent Operation Fishbowl tests gathered more data on the high-altitude EMP phenomenon.

The *Bluegill Triple Prime* and *Kingfish* high-altitude nuclear tests of October and November 1962 in Operation Fishbowl finally provided electromagnetic pulse data that was clear enough to enable physicists to accurately identify the physical mechanisms that were producing the electromagnetic pulses.

The images in Figure 1 below were tak... ...en 1958 and 1962. The images, from left to ri... ...d Starfish high altitude tests, which were cond... ...s you can see in the images, burst condition... ...gly different phenomena and differe...





The relatively small magnit... ...out 5.6 kV/meter) and the relatively small amount ... ...mple, only 3 percent of streetlights extinguished) led some scienti... ...believe, in the early days of EMP research, that the problem might not be as significant as was later realized. Newer calculations showed that if the Starfish Prime warhead had been detonated over the northern continental United States, the magnitude of the EMP would have been much larger (22 to 30 kV/meter) because of the greater strength of the Earth's magnetic field over the United States, as well as the different orientation of the Earth's magnetic field at high latitudes. These new calculations, combined with the accelerating reliance on EMP-sensitive microelectronics, heightened awareness that the EMP threat could be a very significant problem.

In 1962, the Soviet Union also performed a series of three EMP-producing nuclear tests in space over Kazakhstan, which were the last in the series called *The K Project*. Although these