II. Science

An EMP Attack on the U.S. Power Grids and Critical National Infrastructure

There are 12,000 nuclear weapons in the world. Three of them can destroy the U.S.

by Steven Starr

March 22—*Steven Starr, one of the nation's foremost nuclear weapons experts, is the former Clinical Laboratory Science Program Director at the University of Missouri.*

Late one cold winter night, during a massive winter storm that covers most of the Central and Eastern United States, a 100-kiloton nuclear warhead suddenly explodes 100 miles above Dallas, Texas. Two minutes later, identical nuclear warheads explode over Las Vegas, Nevada, and Columbus, Ohio. Each nuclear high-altitude detonation produces an enormous electromagnetic pulse (EMP); the three EMPs together blanket most of the continental United States.

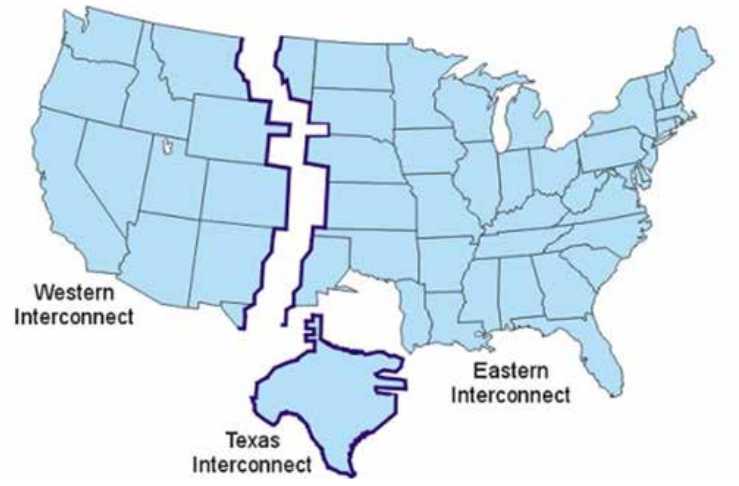
In a few billionths of a second, the initial EMP E1 waves induce massive voltages and currents into powerlines throughout the three U.S. power grids (**Figure 1**). Any unshielded modern electronic device plugged into the grid instantly has its circuits fried; this includes all the computers and devices that control the operation of most U.S. critical national infrastructure—including the Emergency Power Systems and active Emergency Core Cooling Systems of at least 26 commercial nuclear reactors. Huge surges of electricity created by the E1 waves wreck the control panels of High-Voltage Substations and destroy the computers at power plants and power distribution centers. The combined effects of this catastrophic damage cause all three U.S. power grids to suddenly collapse.

Federal government of the United States

The detonation of a 1.44-megaton W49 nuclear warhead 250 miles above Johnston Island in 1958 produced the first recorded high-altitude electromagnetic pulse effects. The photo was taken 860 miles away in Hawaii, far enough away to prevent severe retinal burns in the eyes of observers in Honolulu (military officials had moved the site of the test from Bikini Atoll because the nuclear fireball could blind people up to 400 miles away).

A few seconds later, the following EMP E3B Heave Waves destroy most of the Extra High Voltage (EHV) Circuit Breakers and at least 1/3 of the Large Power Transformers (LPTs) that are required for the long-distance transmission of 90% of the electricity in the U.S. The damage and destruction of the EHV Circuit Breakers and LPTs will leave entire regions of the U.S. without electric power for a year or longer.

FIGURE 1



United States EPA

The Three U.S. Electric Power Grids.

treme weather conditions were chosen to maximize the destructive effects of the EMP.

The detonations suddenly light up the skies above the U.S. They are soundless because the atmosphere at such high altitudes is too thin to transmit sound waves. No blast effects or fires are created on Earth, but massive bursts of powerful gamma rays released by the detonations travel downward at 186,000 miles per second. As the gamma rays enter the atmosphere, they rip the electrons from air molecules and send them spinning toward Earth at almost the speed of light. The Earth's magnetic field interacts with these massive clouds of spinning electrons, creating gigantic EMP E1 waves that sweep downwards faster than lightning.

The Nuclear Strike

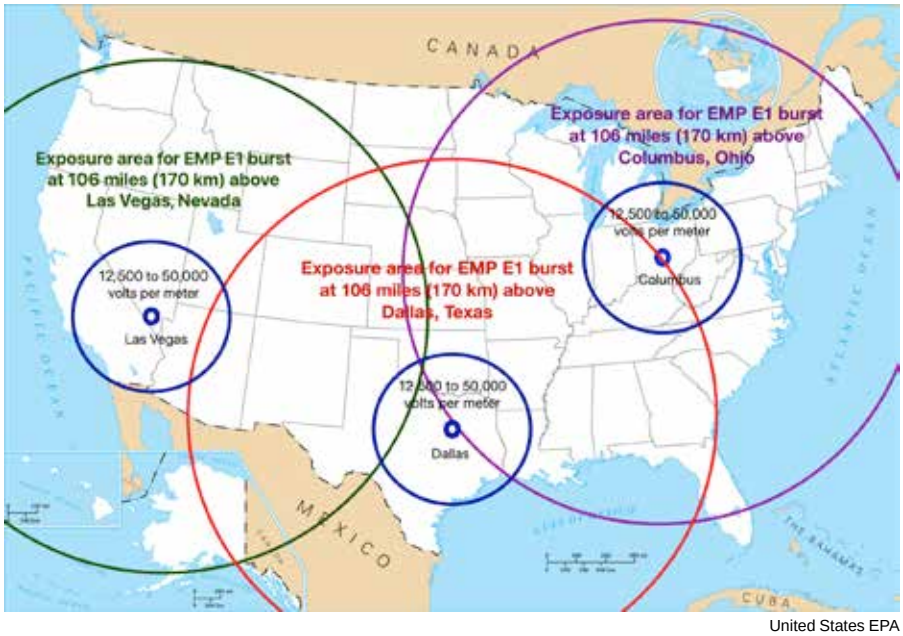
The nuclear warheads are "delivered" to their target areas by ballistic missiles launched from a submarine located 200 miles south of Pensacola in the Gulf of Mexico. The submarine requires less than one minute to fire the three missiles from a depth of 150 feet. The missiles are fired on depressed trajectories to reduce the time required for their warheads to reach their designated targets; their flight times last 5 to 7 minutes from launch to detonation. U.S. Early Warning systems spot the launches, but U.S. missile defense systems don't have enough time to intercept the missiles or their nuclear warheads before they explode high over the U.S.

The location of these three high-altitude nuclear detonations did not have to be precise—detonations over other eastern and western locations (over Indiana, Ohio, Kentucky, Alabama, or Seattle and Los Angeles) would produce very similar results. However, the detonations had to occur above the Earth's atmosphere and during the darkest hours of the night; the time, the altitude of 106 miles, and the ex-

EMP E1 Destroys the Solid-State Electronics Required to Operate Critical National Infrastructure

EMP does not harm people, animals, or plants, nor will it cause structural damage to buildings. However, an EMP E1 wave will instantly induce highly destruc-

FIGURE 2



United States EPA

Exposure areas for EMP E1 waves from nuclear detonations 106 miles above Columbus, Ohio; Dallas, Texas; and Las Vegas, Nevada. The large circles depict the ranges of EMP E1 exposure, and the inner blue circles illustrate the areas where power surges created by EMP E1 incident waves can damage solid-state electronic devices that are not plugged into the grid.

tive electric voltages and currents into any electrically conductive material located in the huge circular areas beneath the nuclear detonations. Each nuclear detonation creates a large circular area of EMP E1 exposure covering more than 100 thousand square miles (**Figure 2**).

The EMP E1 waves induce 2 million volts and currents of 5,000 to 10,000 amps within medium distribution power lines. Overvoltages of 200,000 to 400,000 volts (beyond design capacity) occur in the 15 kilovolt-class (kV) power distribution lines that connect to most homes, farms, and businesses. In less than one-millionth of a second, these damaging voltages and currents surge through the U.S. power grids**.** Unless specifically protected from EMP E1, *any modern electronic device that contains solid-state circuitry (microchips, transistors, and integrated circuits) that is plugged into the grid will be disabled, damaged, or destroyed by this huge blast of electricity. This includes the electronic devices required to operate most U.S. critical national infrastructure*.

The regions located beneath the points of detonation (depicted as dark blue circles in **Figure 2**) suddenly experience EMP E1 waves powerful enough to induce damaging voltages and currents into electronic devices that are *not* plugged into the grid. 50,000 volts and 100 amps of current surge into unshielded AC power cords. Cell phones are disabled along with cell towers; almost all forms of telecommunication cease. Virtually everything powered by electricity suddenly stops working.

Ground, air, and sea transportation systems, water and sanitation systems, telecommunication systems, and banking systems are all knocked out of service. Food and fuel distribution cease. Emergency medical services become unavailable. The electronic devices that society depends on have suddenly stopped working.

EMP E1 Knocks Out Power Through the Destruction of Glass Insulators on 15 kV Power Lines

The massive voltages and currents induced in power transmission lines, combined with extreme weather conditions, act to short-circuit and destroy millions of glass insulators that are commonly used on 15-kilovolt (kV) electric power distribution lines throughout the United States (**Figure 3**). 78% of all electricity in the U.S. is delivered to end users (residential, agricultural, commercial) through these 15 kV lines. *The loss of a single glass insulator on a line can knock out power distribution on the entire line.*

FIGURE 3

Flashover destroys glass insulators on a power distribution line.

As subzero weather conditions prevail across much of the U.S., the lights and power suddenly go out in American homes.

Chaos

In an instant, almost every electronic device required for modern living stops working. The computers, modems, routers, programmable logic controllers, and Supervisory Control and Data Acquisition (SCADA) systems used to monitor, control, and automate complex industrial processes all go dead. All Hell breaks loose.

Cars won't run. Planes fall from the sky. All rail, port, and air traffic control ceases to function. GPS and fiber optic systems fail. Water delivery systems fail. Motorized valves that control the flow of gas and oil in millions of miles of pipelines suddenly freeze, causing ruptures and explosions. Control is lost at refineries and offshore platforms. Major furnace and boiler explosions take place at coal-fired power plants. Control over all industrial processes and assembly lines is lost. Remote-control systems in every industry suddenly cease operations.

Annie Jacobsen, in her remarkable book, *Nuclear War: A Scenario* (pp. 264-267), vividly describes

what happens after a Super-EMP weapon is detonated over the central U.S. Russian and Chinese open-source military texts describe Super-EMP weapons that create EMP E1 waves two to four times more powerful than those described in this article:

> Of America's 280 million registered vehicles, 10 percent of the vehicles on the road [are] suddenly not running anymore…. Without power steering or electric brakes, vehicles coast to a stop or crash into other vehicles, into buildings, into walls. Stalled and crashed vehicles block lanes of traffic on roads and bridges everywhere, no longer just in places where people have been fleeing nuclear bombs but in tunnels and on overpasses, on big and small roads, in driveways and in parking lots across the nation…. Electric pumping of fuel has just come to a permanent and fatal end….
>
> There will be no more fresh water. No more toilets to flush. No sanitation. No streetlights, no tunnel lights, no lights at all, only candles, until there are none left to burn. No gas pumps, no fuel. No ATMs. No cash withdrawals. No access to money. No cell phones. No landlines. No calling 911. No calls at all. No emergency communication systems except some high-frequency (HF) radios. No ambulance services. No hospital equipment that works. Sewage spills out everywhere. It takes less than fifteen minutes for disease-carrying insects to swarm. To feed on piles of human waste, on garbage, on the dead….
>
> Billions of gallons of water passing through America's aqueducts surge uncontrollably. Dams burst. Mass flooding begins sweeping infrastructure and people away … thousands of subway trains, passenger trains, and freight trains traveling in every direction, many on the same tracks, collide with one another, crash into walls and barriers, or derail. Elevators stop between floors, or speed to the ground and crash. Satellites (including the international space station) shift out of position and begin falling to Earth. America's fifty-three remaining nuclear power plants, are now operating on backup systems, have just begun to collectively run out of time.

FIGURE 4

Nuclear Regulatory Commission

Commercial nuclear reactors are located in areas circled in red that experience peak EMP E1 incident fields equal to 12,500 volts per meter to 50,000 volts per meter.

However, not all nuclear plants will be running on emergency backup systems.

Reactor Meltdowns at Nuclear Power Plants

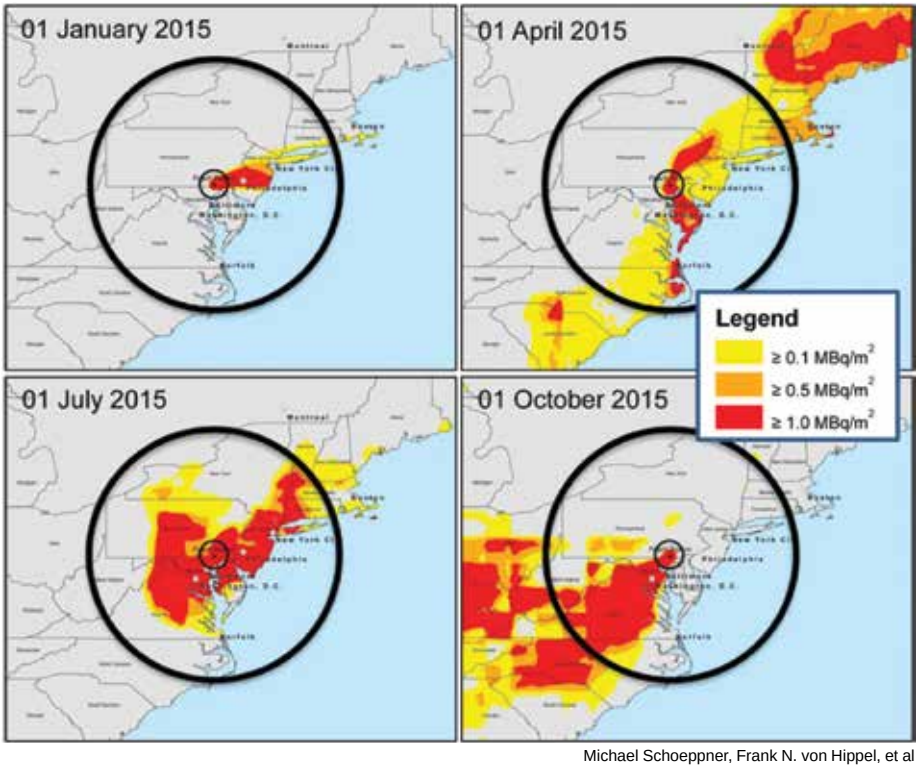
Thousands of solid-state electronic components (control units, motor-driven pumps, motor-operated valves, temperature and pressure sensors, rectifiers, inverters, switches, etc.) are required to monitor, control, and safely operate nuclear reactors. These components are found throughout the various parts of the active Emergency Core Cooling Systems at each nuclear reactor; many are also found within the Emergency Diesel Generators and Battery Banks that make up the Emergency Power Systems at each nuclear power plant (which are required to safely shut down and cool the nuclear reactors when offsite electrical power is lost at the plant). *All of these solid-state components lack specialized shielding to protect them from the high voltages and currents created by EMP E1.*

26 nuclear power plants are located in EMP E1-

saturated areas (**Figure 4**) where damaging electric voltages and currents are induced within the unshielded cables, lines, and solid-state electronic equipment located *inside* buildings and structures. E1 also strikes the many above-ground power lines, phone lines, cables, etc. that enter and exit these plants.

The moment the E1 waves knocked out the grids, the loss of off-site electric power triggered an emergency shutdown of every nuclear reactor operating in the U.S. No electricity is required for an emergency shutdown. However, emergency cooling systems *must* begin cooling the nuclear reactor core within seconds following an emergency shutdown. A failure to remove the hundreds of millions of watts of heat that remain in the reactor core (the heat is produced by the highly radioactive fuel rods) will cause the reactor core to overheat to the point of self-destruction in a matter of several hours or less.

FIGURE 5



Michael Schoeppner, Frank N. von Hippel, et al

Contamination areas from a hypothetical fire in a single high-density spent fuel pool at the Peach Bottom Nuclear Power Plant in Pennsylvania releasing 1600 PBq of Cesium-137 on four dates in 2015.

In a millionth of a second, the damaging voltages and currents created by the EMP E1 wave disables the emergency power systems within the nuclear power plants where the reactors are located. The solid-state controls in the gigantic Emergency Diesel Generators no longer work; the AC/DC interfaces located between the Battery Banks and plant electric systems have failed. *There is no longer any off-site or on-site electric power available to run the active Emergency Core Cooling Systems,* which would not work anyway because the solid-state electronics found in the motor-operated pumps and valves are damaged and disabled.

The loss of the active Emergency Core Cooling Systems and Emergency Power Systems has suddenly made it impossible for these 26 nuclear reactors to remove the massive heat remaining within their reactor cores following their emergency shutdowns. A forced flow of water cannot be resumed through the reactor core. (Hundreds of thousands of gallons of water are pumped through the core each minute during normal operation.)

The failure of these emergency systems will rapidly lead to reactor core meltdowns at each of these nuclear power plants—as it did in 2011 at Fukushima when three reactors melted down following the loss of all offsite and onsite electric power. Because U.S. nuclear power plants (and those of many other nations) are not designed or retrofitted to withstand the effects of EMP, they became radiological targets of opportunity for an EMP attack.

The U.S. Nuclear Regulatory Commission (NRC) maintains that EMP poses no danger to the nuclear power plants that it regulates—although it has never conducted the comprehensive testing necessary to validate its theories. (In 2019, the Electromagnetic Defense Task Force of the U.S. Air Force forced the NRC to respond to their concerns about the lack of EMP protection at U.S. nuclear power plants, but the NRC continued to maintain that U.S. nuclear power plants

are in no danger from EMP.)

Spent Fuel Pool Fires at Nuclear Power Plants

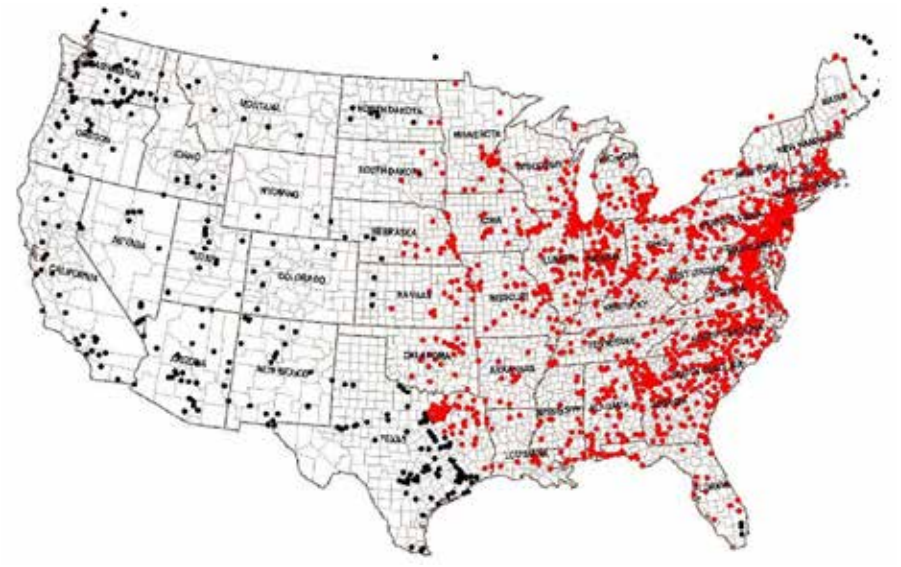
A complete loss of off-site and on-site electrical power at a nuclear power plant also makes it impossible to operate the large cooling systems required to remove heat from the spent fuel pools, where highly radioactive used or "spent" uranium fuel rods are stored. These pools are located next to U.S. commercial nuclear reactors—outside the primary containment structures—and they contain some of the largest concentrations of radioactivity on the planet. Intensely radioactive spent fuel generates a huge amount of heat that must continuously be removed from the pool, or else the water in the pool will heat to the point of boiling.

Without a working cooling system, diesel pumps must be used to put cool water into the spent fuel pools. Even if working pumps can be found, nuclear power plants are only required to have a 7-day supply of diesel fuel on hand. (If the diesel fuel is stored underground, it is unlikely there will be working pumps to move the fuel to the generators following the EMP attack.) The meltdown of the reactor and the corresponding release of radiation, combined with a limited supply of diesel fuel, will make it impossible to prevent the water in these pools from boiling off in a matter of days.

When falling water levels in the pools eventually expose the spent fuel to steam and air, this causes the rods to heat to the point of rupture or ignition and release enormous amounts of radioactivity. Fuel rods recently removed from the reactor core begin burning at temperatures exceeding 1,800 degrees Fahrenheit, and the fire spreads to older rods in the pool. The radioactivity released from one spent fuel pool fire can release dozens of times more radiation than was released by the meltdown of the Chernobyl nuclear power plant.

The enormous amounts of radiation (**Figure 5**) *released by the destroyed reactors and their 26 burning spent fuel pools will turn large areas of the continental U.S. into uninhabitable radioactive exclusion zones.*

FIGURE 6



Prepared for Oak Ridge National Laboratory

1765 Extra High Voltage Substations Exposed to E1 from the nuclear detonation over Columbus, Ohio, which are 83% of such substations in the U.S.

When the 7-day supplies of diesel fuel run out for the generators still operating at the remaining 68 U.S. commercial nuclear reactors, their spent fuel pools will also boil off, causing the spent fuel rods to self-destruct and spread even more radioactive fallout across the U.S.

EMP E1 Wave Begins Destruction of U.S. Power Grids

When the huge EMP E1-induced power surge struck the Extra High Voltage substations across the U.S. (**Figure 6**), it destroyed most of the protective solid-state relays that shield electrical systems within the grid from damage. This included the relays that activated the approximately 5,000 Extra High Voltage (EHV) Circuit Breakers (345 kV and larger), which provided the primary protection to the Large Power Transformers (LPTs) from transient damaging currents.

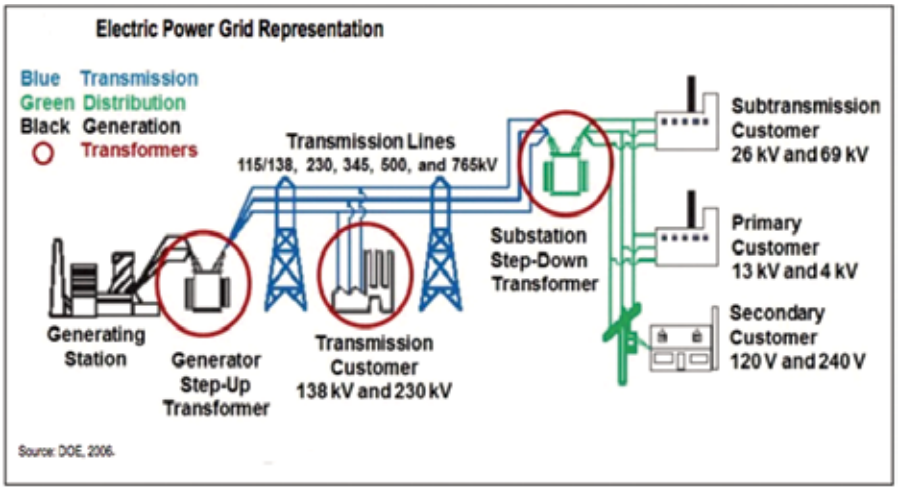
LPTs are used at power generation facilities to increase the voltage before long-distance transmission (this reduces power loss) and then at the end of transmission lines to reduce (step down) the voltage when power is distributed to American households, agriculture, and industry. LPTs are *required* for the long-distance transmission of electric power in the U.S. (**Figure 7**). *90% of the electricity in U.S. power grids passes through aging 345 kV (345,000 volts),*

500 kV, and 765 kV LPTs; there are only several thousand of these LPTs within the three U.S. national power grids (**Figure 8**).

The E1-induced power surge destroyed the series capacitors on power transmission lines that protected LPTs from dangerous power surges. The electronics within the LPT cooling systems were also damaged, and tiny holes were burned in the insulation of the windings within the LPTs. This left the LPTs susceptible to internal short circuits and overheating.

In other words, the EMP E1 waves disabled the safety systems required to protect LPTs, as well as damaging some LPTs. This left the LPTs vulnerable to the effects of the following EMP E3B waves.

FIGURE 7



Federal Energy Regulatory Commission

The role of Large Power Transformers (LPTs) in the power grid. LPTs are circled in red. The E1-induced power surge destroyed the series capacitors on power transmission lines that protected LPTs from dangerous power surges.

EMP E3B Waves Wreck the EHV Circuit Breakers and LPTs—U.S. Grids Go Down for a Year or Longer

Scientists have confirmed, by "all means of measurement", that the threat potential posed by EMP E3 exceeds the intended stress limit the aging U.S. power network is designed and tested to withstand. (There are two forms of E3: the E3A Blast Wave and the E3B Heave Wave. Both forms are quite damaging, but the effects of E3A are felt more than 1,000 miles north of the point of detonation. For detonations over the continental U.S., E3B plays the important destructive role.)

Because the U.S. has failed to shield its electric power grids from EMP, all the 765 kV LPTs, two-thirds of the 500 kV LPTs, and at least 20% of the 345 kV LPTs are quite vulnerable to the effects of EMP E3. *Both the LPTs and the EHV Circuit Breakers that protect them are damaged, disabled, and destroyed by the combined effects of the E1 and E3B waves.*

The EMP E3B waves induce Direct Current (DC) within long power transmission lines as well as in the Earth itself. The loss of the protective relays (following the E1 waves) allows direct currents of hundreds to thousands of amps to flow into EHV Circuit Breakers

FIGURE 8

CC/Terna S.p.A.

Moving a 460,000-pound Large Power Transformer (LPT) is hard. LPTs, like the one shown, cannot be quickly installed even after their replacements are manufactured and delivered to the U.S.

and LPTs. The EHV Circuit Breakers explode and LPTs overheat and self-destruct. LPTs often contain many thousands of gallons of oil for cooling and high-voltage insulation purposes; this oil becomes fuel for generating large fires that rapidly engulf major portions of the substation and/or power plant facility where the LPTs are located.

The loss of LPTs and EHV Circuit Breakers in the power grids leaves most of the United States without electric power for a year or likely longer. This is because EHV Circuit Breakers and LPTs are not stockpiled. It currently takes 40 to 60 weeks to replace EHV Circuit Breakers. LPTs must be custom-designed and manufactured and about 80% of LPTs are made overseas. The current wait time for LPT manufacture is 80 to 210 weeks.

Societal Collapse

It is the dead of Winter, in the middle of a major winter storm, and electricity is no longer available for most Americans, who now find themselves in dark, freezing cold homes where nothing works anymore. No lights, heat, running water, phone, internet, TV, and soon, no food. If their cars can still start, they will find the highways blocked with vehicles disabled by the EMP E1 wave. Gasoline can no longer be pumped out of underground tanks. Food deliveries to the cities stop. People attempt to flee from regions that are downwind from destroyed nuclear reactors and spent fuel pools and are receiving massive radioactive fallout. Society collapses as millions of starving and freezing people do anything to try to survive.

The Chairman of a Congressional Committee that investigated the effects of a nuclear EMP attack on the United States has estimated that most Americans would not survive an EMP attack that knocked out U.S. power grids and disabled critical national infrastructure. Despite such warnings, the United States has not acted to shield its power grids and critical national infrastructure—including its nuclear power plants—from the effects of EMP.

The U.S. Can Protect Its Power Grids and Critical National Infrastructure

Technology exists that could effectively protect the U.S. power grid from destruction. Likewise, the vulnerable electronic components of U.S. critical national infrastructure and nuclear power plants can also be shielded to a large degree from the effects of EMP. Detailed technical papers explain how this can be accomplished. Cost estimates to add this protection are in the tens of billions of dollars—a small fraction of what the U.S. spends each year on its defense budget.

The U.S. military long ago acted to shield its weapons and communication systems from EMP. However, all attempts to mandate that U.S. critical national infrastructure be shielded from EMP have been defeated. Twice—in 2013 and 2015—bills mandating EMP protection failed to come to a final vote in Congress because the nuclear and electrical utilities lobbied against them. Their opposition arose from the wording in the bills requiring the utilities to pay for EMP shielding.

Consequently, no significant steps have yet been taken to install equipment and modifications that would protect the U.S. national electric grid and U.S. critical national infrastructure from EMP.

Author's note: If one or more Super-EMP weapons were used in an attack against the United States, the effects of the attack could be significantly more severe than those described in this paper.

For a more detailed explanation, see *Nuclear High-Altitude Electromagnetic Pulse: A Mortal Threat to the U.S. Power Grid and U.S. Nuclear Power Plants*.