Before the
UNITED STATES NUCLEAR REGULATORY COMMISSION
Rockville, Maryland

In the Matter of a Proposed Rulemaking
Regarding Amendment of 10 CFR Part 50,
"DOMESTIC LICENSING OF PRODUCTION
AND UTILIZATION FACILITIES"

Docket No.______________________

PETITION FOR RULEMAKING

This Petition for Rulemaking is submitted pursuant to 10 CFR 2.802, "Petition for Rulemaking," by the Foundation for Resilient Societies. The Petitioner requests that the U.S. Nuclear Regulatory Commission (NRC), following public notice and opportunity for comment, adopt regulations that would require facilities licensed by the NRC under 10 CFR Part 50 to assure long-term cooling and automated water makeup of spent fuel pools.

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STATEMENT OF PETITIONER'S INTEREST

Petitioner is an association within the United States, has an interest in the health and safety of its citizens, and has a further interest in large land areas of the United States not becoming contaminated with nuclear radiation and therefore being uninhabitable for hundreds of years.

SUMMARY OF CURRENT SITUATION

Spent fuel pools are currently used at all operating nuclear power plants. Fuel rods continue to generate substantial heat after removal from the reactor core, necessitating active cooling in water pools. There are 104 nuclear power reactors operating in the United States at 65 sites in 31 states. Each site has one or more spent fuel pools. Spent fuel contains a number of radioactive elements resulting from fission within the reactor core, the most significant being Ruthenium-106 with a half-life of one year and Cesium-137 with a half-life of 30 years. Should spent fuel rods become uncovered by water, the zirconium cladding of the rods would likely catch fire.

While there are multiple scenarios that could cause uncovering of spent fuel rods and result in zirconium fire, for the purposes of this Petition, the most significant scenario is long-term loss of outside power supplied by the commercial electric grid. Current design criteria for nuclear power plants and associated spent fuel pools assume reliable and quickly restored commercial grid power. In the event of a long-term loss of commercial grid power, extending beyond a month, it is likely that water in spent fuel pools would heat up and boil-off, fuel rods would become uncovered by water, zirconium cladding would catch fire, and large amounts of fatal radiation would be released into the atmosphere.

In October 2010, Oak Ridge National Laboratory released "Electromagnetic Pulse: Effects on the U.S. Power Grid," a series of comprehensive technical reports for the Federal Energy Regulatory Commission (FERC) in joint sponsorship with the Department of Energy and the Department of Homeland Security. These reports disclose that the commercial power grids in two large areas of the continental United States are vulnerable to severe space weather. The reports conclude that solar activity and resulting large earthbound Coronal Mass Ejection (CME), occurring on average once every one hundred years, would induce a geomagnetic disturbance and cause probable collapse of the commercial grid in these vulnerable areas. Excess heat from induced currents in transmission lines would permanently damage approximately 350 extra high voltage transformers. The replacement lead time for extra high voltage transformers is approximately 1-2 years. As a result, about two-thirds of nuclear power plants and their associated spent fuel pools would likely be without commercial grid power for a period of 1-2 years.

Commercial grid outage of 1-2 years far exceeds the current design criteria for nuclear power plants and associated spent fuel pools. Accordingly, the NRC should adjust design criteria for nuclear power plants and associated spent fuel pools to minimize risk and avoid radiation fatalities. This Petition proposes requirements for unattended spent fuel pool cooling at nuclear power plants.

SPECIFIC ISSUES FOR SPENT FUEL POOLS

Risk of Spent Fuel Pools

Spent fuel pools have long been recognized by the NRC as a risk. In order to prevent overheating and boil-off of water in spent fuel pools, active cooling and/or continual replenishment of water is required. Nuclear power plants have been operated for many years without off-site repositories for spent fuel. With each reactor refueling, spent fuel has been added to water pools with limited capacity. Originally, these pools were designed for temporary storage until spent fuel had cooled sufficiently for transport off-site. The typical spent fuel pool now contains 10-30 years of fuel stored in high density racks that were not part of the original pool design. Spent fuel pools are in industrial-design buildings that vent to the atmosphere and do not provide radiation containment.

NUREG-0933, "Resolution of Generic Safety Issues: Issue 82: Beyond Design Basis Accidents in Spent Fuel Pools (Rev. 3) (NUREG-0933, Main Report with Supplements 1–33)" summarizes current spent fuel storage practices and the risk of radiation release to the atmosphere:

> A typical spent fuel storage pool with high density storage racks can hold roughly five times the fuel in the core. However, since reloads typically discharge one third of a core, much of the spent fuel stored in the pool will have had considerable decay time. This reduces the radioactive inventory somewhat. More importantly, after roughly three years of storage, spent fuel can be air-cooled, i.e., such fuel need not be submerged to prevent melting. (Submersion is still desirable for shielding and to reduce airborne activity, however.)
>
> If the pool were to be drained of water, the discharged fuel from the previous two refuelings would still be "fresh" enough to melt under decay heat. However, the zircaloy cladding of this fuel could be ignited during the heatup.[543] The resulting fire, in a pool equipped with high density storage racks, would probably spread to most or all of the fuel in the pool. The heat of combustion, in combination with decay heat, would certainly release considerable gap activity from the fuel and would probably drive "borderline aged" fuel into a molten condition. Moreover, if the fire becomes oxygen-starved (quite probable for a fire located in the bottom of a pit such as this), the hot zirconium would rob oxygen from the uranium dioxide fuel, forming a liquid mixture of metallic uranium, zirconium, oxidized zirconium, and dissolved uranium dioxide. This would cause a release of fission products from the fuel matrix quite comparable to that of molten fuel.[545] In addition, although confined, spent fuel pools are almost always located outside of the primary containment. Thus, release to the atmosphere is more likely than for comparable accidents involving the reactor core.

NRC also examined the risk of spent fuel pools in NUREG-1738, "Technical Study of Spent Fuel Pool Accident Risk at Decommissioning Nuclear Power Plants," February 2001. This study calculated the length of time between cessation of active cooling and water uncovering of spent fuel rods. This time varies from 4 to 22 days, depending on reactor design and age of fuel.

> Analyses were performed to evaluate the thermal-hydraulic characteristics of spent fuel stored in the spent fuel pools (SFPs) of decommissioning plants and determine the time available for plant operators to take actions to prevent a zirconium fire. These are discussed in Appendix 1A. The focus was the time available before fuel uncovery and the time available before the zirconium ignites after fuel uncovery. These times were utilized in performing the risk assessment discussed in Section 3.
>
> To establish the times available before fuel uncovery, calculations were performed to determine the time to heat the SFP coolant to a point of boiling and then boil the coolant down to 3 feet above the top of the fuel. As can be seen in Table 2.1 below, the time available to take actions

> before any fuel uncovery is 100 hours or more for an SFP in which pressurized-water reactor (PWR) fuel has decayed at least 60 days.

Table 2.1 Time to Heatup and Boiloff SFP Inventory Down to 3 Feet Above Top of Fuel (60 GWD/MTU)

DECAY TIME	PWR	BWR
60 days	100 hours (>4 days)	145 hours (>6 days)
1 year	195 hours (>8 days)	253 hours (>10 days)
2 years	272 hours (>11 days)	337 hours (>14 days)
5 years	400 hours (>16 days)	459 hours (>19 days)
10 years	476 hours (>19 days)	532 hours (>22 days)

NUREG-1738 identified nine events that could cause uncovering of spent fuel and resulting zirconium cladding fires:

> The staff identified nine initiating event categories to investigate as part of the quantitative assessment on SFP risk:
>
> 1. Loss of offsite power from plant centered and grid-related events
> ***2. Loss of offsite power from events initiated by severe*** **weather**
> 3. Internal fire
> 4. Loss of pool cooling
> 5. Loss of coolant inventory
> 6. Seismic event
> 7. Cask drop
> 8. Aircraft impact
> 9. Tornado missile
>
> (Emphasis added.)

The National Research Council of the National Academies of Science also authored a report on spent fuel pools. "Safety and Security of Commercial Spent Nuclear Fuel Storage" was developed at the request of the U.S. Congress with sponsorship from the NRC and Department of Homeland Security and released in 2005. While the National Research Council report focused on the risk of uncovered spent fuel due to terrorist attack, many of its findings are also applicable to other events that would result in a “loss-of-pool-coolant” scenario. The National Research Council report confirmed the loss-of-pool-coolant scenario as described in the Nuclear Regulatory Commission report, "Technical Study of Spent Fuel Pool Accident Risk at Decommissioning Nuclear Power Plants."

> A terrorist attack that either disrupted the cooling system for the spent fuel pool or damaged or collapsed the pool itself could potentially lead to a loss-of-pool-coolant event. The cooling system could be disrupted by disabling or damaging the system that circulates water from the pool to heat exchangers to remove decay heat. This system would not likely be a primary target of a terrorist attack, but it could be damaged as the result of an attack on the spent fuel pool or other targets at the plant (e.g., the power for the pumps could be interrupted). The loss of cooling

capacity would be of much greater concern were it to occur during or shortly after a reactor offloading operation, because the pool would contain a large amount of high decay-heat fuel.

The consequences of a damaged cooling system would be quite predictable: The temperature of the pool water would rise until the pool began to boil. Steam produced by boiling would carry away heat, and the steam would cool as it expanded into the open space above the pool.[13] Boiling would slowly consume the water in the pool, and if no additional water were added the pool level would drop. It would likely take several days of continuous boiling to uncover the fuel. Unless physical access to the pool were completely restricted (e.g., by high radiation fields or debris), there would likely be sufficient time to bring in auxiliary water supplies to keep the water level in the pool at safe levels until the cooling system could be repaired. This conclusion presumes, of course, that technical means, trained workers, and a sufficient water supply were available to implement such measures. The Nuclear Regulatory Commission requires that alternative sources of water be identified and available as an element of each plant's operating license.

Cooling Systems for Spent Fuel Pools

NUREG-1738, "Technical Study of Spent Fuel Pool Accident Risk at Decommissioning Nuclear Power Plants," contains a diagram and description of a typical spent fuel cooling system.

Figure 2.1 Simplified Diagram of Spent Fuel Pool Cooling and Inventory Makeup Systems

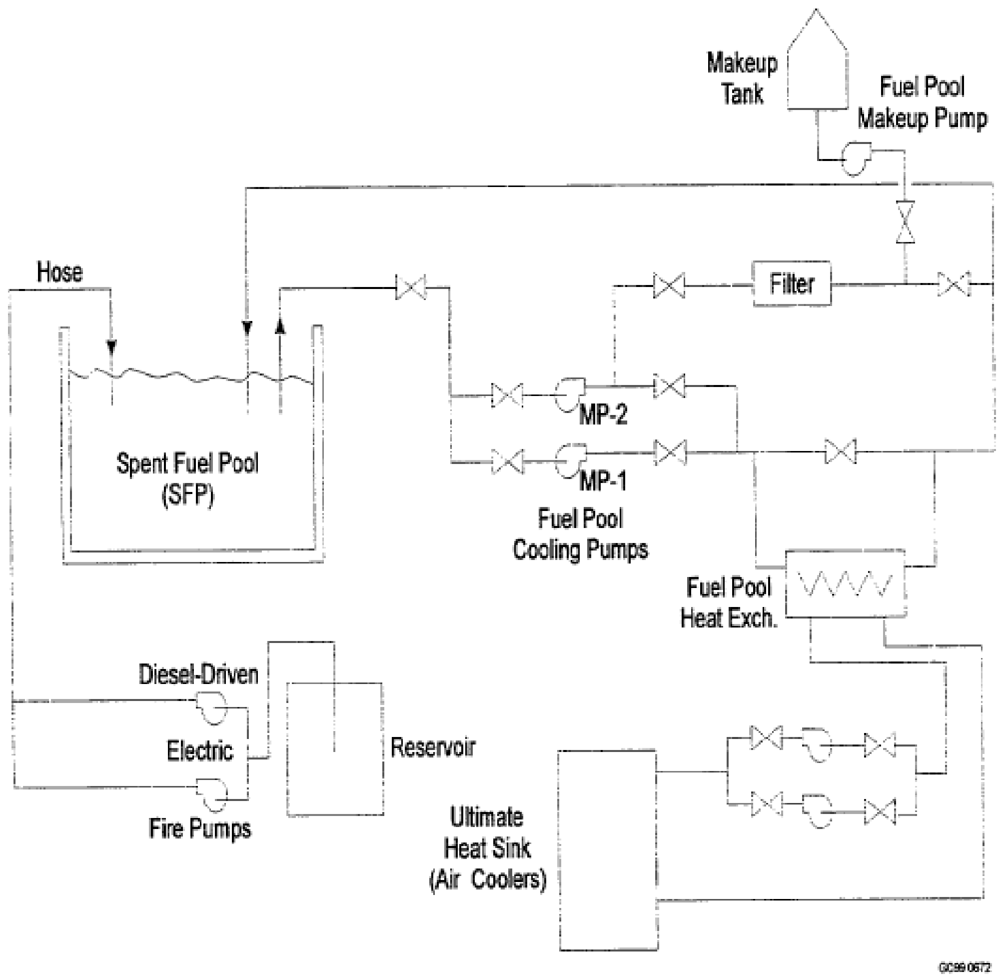

Figure 2.1 is a simplified drawing of the system assumed for the development of the model. The spent fuel pool cooling (SFPC) system is located in the SFP area and consists of motor-driven pumps, a heat exchanger, an ultimate heat sink, a makeup tank, filtration system and isolation valves. Suction is taken via one of the two pumps on the primary side from the SFP and is passed through the heat exchanger and returned back to the pool. One of the two pumps on the secondary side rejects the heat to the ultimate heat sink. A small amount of water is diverted to the filtration process and is returned to the discharge line. A regular makeup system supplements the small losses because of evaporation. In the case of prolonged loss of SFPC system or loss of inventory events, the inventory in the pool can be made up using the firewater system. There are two firewater pumps, one motor-driven (electric) and the other diesel-driven, which provide firewater throughout the plant. A firewater hose station is provided in the SFP area. The firewater pumps are assumed to be located in a separate structure.

As described in the NUREG-1738, pumps to provide active cooling of the spent fuel pool are powered by electric motors. Without a continual source of alternating electric current, the motors would stop powering the circulation pumps and active cooling would cease.

As shown in Figure 2.1 of NUREG-1738, alternate systems exist to provide makeup water should active cooling by water circulation cease—specifically, electrically-driven and diesel-driven pumps. In theory, as long as electricity or diesel fuel is available, and makeup water pumps do not mechanically break down, and operators are on-site to monitor the water level and start up the pumps, and the makeup water reservoir contains water, water could be added to the spent fuel pools. Adding makeup water would keep the temperature of the spent fuel rods at or below the boiling point of water (100 degrees Celsius), which is substantially below the ignition point for zirconium (900 degrees Celsius).

To summarize, active cooling systems for spent fuel pools are primarily dependent on a continual supply of electric power. While diesel-driven pumps for makeup water can be used as a stopgap measure when electric power is not available, their continuing use would require diesel fuel and human operator attention.

Alternating Current Power Sources for Nuclear Power Plants and Spent Fuel Pools

Design criteria for nuclear power plants and associated spent fuel pools specify three levels of alternating current power sources:

1. Offsite power, also known as the "commercial grid"
2. Onsite power, also known as emergency backup generation
3. Alternate ac sources

10 CFR Part 50.63, "Loss of all alternating current power," specifies the critical role of reliable and quickly restored offsite power, also commonly referred to as "commercial grid," in nuclear power plant design criteria:

> **§ 50.63 Loss of all alternating current power.**
>
> (a) *Requirements*. (1) Each light-water-cooled nuclear power plant licensed to operate under this part, each light-water-cooled nuclear power plant licensed under subpart C of 10 CFR part 52 after the Commission makes the finding under § 52.103(g) of this chapter, and each design for a light-water-cooled nuclear power plant approved under a standard design approval, standard design certification, and manufacturing license under part 52 of this chapter must be able to withstand for a specified duration and recover from a station blackout as defined in § 50.2. The specified station blackout duration shall be based on the following factors:
>
> (i) The redundancy of the onsite emergency ac power sources;
>
> (ii) The reliability of the onsite emergency ac power sources;
>
> ***(iii) The expected frequency of loss of offsite power; and***
>
> ***(iv) The probable time needed to restore offsite power.***

Because offsite electric power is the default design criteria power source for nuclear power plants, it is required to be supplied in a high-reliability, dual-circuit configuration. Appendix A to Part 50--General Design Criteria for Nuclear Power Plants, describes the importance of reliable offsite power for the maintenance of vital safety functions:

> Electric power from the transmission network to the onsite electric distribution system shall be supplied by two physically independent circuits (not necessarily on separate rights of way) designed and located so as to minimize to the extent practical the likelihood of their simultaneous failure under operating and postulated accident and environmental conditions. A switchyard common to both circuits is acceptable. Each of these circuits shall be designed to be available in sufficient time following a loss of all onsite alternating current power supplies and the other offsite electric power circuit, to assure that specified acceptable fuel design limits and design conditions of the reactor coolant pressure boundary are not exceeded. One of these circuits shall be designed to be available within a few seconds following a loss-of-coolant accident to assure that core cooling, containment integrity, and other vital safety functions are maintained.

In the event of failure of electric power from the redundant transmission network circuits, also commonly referred to as "grid power," the first level of backup is onsite alternating current power. Onsite alternating current power is commonly supplied by emergency diesel generators as described in Regulatory Guide 1.9, "Application and Testing of Safety-Related Diesel Generators in Nuclear Power Plants”:

> 10 CFR 50.63, “Loss of All Alternating Current Power,” requires that each light-water-cooled nuclear power plant must be able to withstand and recover from a station blackout [i.e., loss of offsite and onsite emergency alternating current (ac) power systems] for a specified duration. The reliability of onsite ac power sources is one of the main factors contributing to the risk of core melt as a result of a station blackout…Most onsite electric power systems use diesel generators as the chosen onsite emergency power source.
>
> (Ellipses not in original document.)

The typical onsite storage of diesel fuel for emergency generators is sufficient for only seven days of continuous operation as described in NRC Regulatory Guide 1.137, "Fuel-Oil Systems for Standby Diesel Generators":

> c. Section 5.4, "Calculation of Fuel Oil Storage Requirements," of the standard sets forth two methods for the calculation of fuel-oil storage requirements. These two methods are (1) calculations based on the ***assumption that the diesel generator operates continuously for 7 days at its rated capacity***, and (2) calculations based on the time-dependent loads of the diesel generator. For the time-dependent load method, the minimum required capacity should include the capacity to power the engineered safety features.
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> (Emphasis added.)

Should both offsite grid power and onsite emergency power from diesel generators be lost, the nuclear power plant would enter a station blackout condition. NRC Regulatory Guide 1.155, “Station Blackout” describes the expected duration of station blackouts in current design criteria. Required capability to withstand station blackouts is limited to only 16 hours:

> The term "station blackout" refers to the complete loss of alternating current electric power to the essential and nonessential switchgear buses in a nuclear power plant. Station blackout therefore involves the loss of offsite power concurrent with turbine trip and failure of the onsite emergency ac power system, but not the loss of available ac power to buses fed by station batteries through inverters or the loss of power from "alternate ac sources." Station blackout and alternate ac source are defined in § 50.2. Because many safety systems required for reactor core decay heat removal and containment heat removal are dependent on ac power, the consequences of a station blackout could be severe. In the event of a station blackout, the capability to cool the reactor core would be dependent on the availability of systems that do not require ac power from

the essential and nonessential switchgear buses and on the ability to restore ac power in a timely manner.

The concern about station blackout arose because of the accumulated experience regarding the reliability of ac power supplies. Many operating plants have experienced a total loss of offsite electric power, and more occurrences are expected in the future. In almost every one of these loss-of-offsite-power events, the onsite emergency ac power supplies have been available immediately to supply the power needed by vital safety equipment. However, in some instances, one of the redundant emergency ac power supplies has been unavailable. In a few cases there has been a complete loss of ac power, but during these events ac power was restored in a short time without any serious consequences. In addition, there have been numerous instances when emergency diesel generators have failed to start and run in response to tests conducted at operating plants.

Based on § 50.63, all licensees and applicants are required to assess the capability of their plants to maintain adequate core cooling and appropriate containment integrity during a station blackout and to have procedures to cope with such an event. This guide presents a method acceptable to the NRC staff for determining the specified duration for which a plant should be able to withstand a station blackout in accordance with these requirements. ***The application of this method results in selecting a minimum acceptable station blackout duration capability from 2 to 16 hours***, depending on a comparison of the plant's characteristics with those factors that have been identified as significantly affecting the risk from station blackout. These factors include redundancy of the onsite emergency ac power system (ie., the number of diesel generators available for decay heat removal minus the number needed for decay heat removal), the reliability of onsite emergency ac power sources (e.g., diesel generators), the frequency of loss of offsite power, and the probable time to restore offsite power.

(Emphasis added.)

Time between Commercial Grid Outage and Zirconium Ignition

Should commercial grid power fail, backup diesel generators can provide power for 7 days without resupply of diesel fuel under typical emergency plans. Should emergency diesel generators cease functioning, current design criteria specify "alternate ac sources" to be available for a period of only 2 to 16 hours. Once electric power is no longer supplied to circulation pumps, the spent fuel pool would begin to heat up and boil; total time from cessation of active cooling to water uncovering of zirconium cladding would be 4 to 22 days, depending on reactor design and average decay years of spent fuel. Again depending on fuel decay years, from water uncovering to ignition of the zirconium cladding could be an additional 2 to 24 hours. Absent any addition of makeup water to the spent fuel pool, the total time from commercial grid outage to spontaneous zirconium ignition would likely be 12-31 days.

PROPOSED AMENDMENT TO 10 CFR PART 50

Petitioner requests that 10 CFR Part 50 be amended because the North American commercial grids are vulnerable to outage caused by severe space weather such as Coronal Mass Ejection and resulting geomagnetic disturbance and therefore cannot be relied on to provide continual power for active cooling and/or water makeup of spent fuel pools. Moreover, existing means of onsite backup power are designed to operate for only a few days, while spent fuel requires active cooling for several years after removal from the reactor core.

NRC should require all Part 50 licensees as of January 1, 2013 to meet these new requirements:

> Emergency systems to provide long-term cooling and water makeup for spent fuel pools shall be able to rely exclusively on on-site resources for a period of two years without human operator intervention and fuel resupply. Automated means of power sufficient to assure safety may include, but are not limited to: solar power, wind turbine, hydroelectric power, and other on-site means of generating electricity. This additional backup power must be dedicated to cooling and water makeup of spent fuel pools. If weather-dependent power sources such as solar or wind turbine are to be used, sufficient battery storage must be provided to maintain continual power during weather conditions which may temporarily constrict generation. Two independent cooling and water makeup systems shall be provided with a combined Mean Time Between Failure (MTBF) of 100,000 hours and an availability of 99% during normal operations (before loss of outside power).

RATIONALE FOR PROPOSED AMENDMENT

At the time of drafting of the current text of 10 CFR 50, vulnerability of the North American commercial grids to severe space weather had not been comprehensively studied, nor had probabilities and consequences for widespread and long-term power grid outage been determined. A primary rationale for this proposed amendment is a recently documented vulnerability of the North American power grids to severe space weather which could cause multiple-year power outages. In addition, a government-sponsored study of second-order effects of commercial grid failure on petrochemical fuel and food supplies shows that any assumption of outside assistance to nuclear power plants, including resupply of diesel fuel and food, may not be valid.

Risks from Severe Space Weather

In a previous Denial of Petition for Rulemaking (PRM-50-67), NRC recognized North American Electric Reliability Corporation (NERC) as the nation's authority on reliability of the electric power grid. At the time of the denial, NRC referenced data from NERC to argue that long-term onsite backup power for nuclear power plants was not necessary. In recent years, the authority of NERC on electric reliability has been further codified in law. The Federal Energy Regulatory Commission (FERC), pursuant to the Energy Policy Act of 2005, has certified NERC as the nation's Electric Reliability Organization and charged it with developing procedures for the establishment, approval and enforcement of mandatory electric reliability standards.

In a June 2010 report titled, "High-Impact, Low-Frequency Event Risk to the North American Bulk Power System," jointly sponsored by NERC and the Department of Energy, NERC now concedes that the North American power grids have significant reliability issues in regard to High-Impact, Low-Frequency (HILF) events such as severe space weather. The NERC HILF report explains commercial grid vulnerability to space weather:

> Intense solar activity, particularly large solar flares and associated coronal mass ejections can create disturbances in the near-Earth space environment when this activity is directed towards the Earth. The coronal mass ejection's solar wind plasma can then connect with the magnetosphere causing rapid changes in the configuration of Earth's magnetic field, a form of space weather called a geomagnetic storm. Geomagnetic storms produce impulsive disturbance of the geomagnetic field over wide geographic regions which, in turn, induce currents (called geomagnetically-induced currents or GIC) in the complex topology of the North American bulk power system and other high-voltage power systems across the globe. For many years it has been known that these storms have the potential to pose operational threats to bulk power systems; both contemporary experience and analytical work support these general conclusions. The electric sector has taken some meaningful steps to mitigate this risk as outlined in the January 2009 Report by National Academy of Sciences "Severe Space Weather Events—Understanding Societal and Economic Impacts Workshop Report," but more work is needed.
>
> More recently, a number of investigations have been carried out under the auspices of the EMP Commission and also for FEMA under Executive Order 13407 and FERC in partnership with the Departments of Energy, Homeland Security, and Defense. These investigations have been undertaken to examine the potential impacts on the U.S. electric power grid for severe geomagnetic storm events and EMP threats. In addition, this analysis was formative in the National Academy of Sciences "Severe Space Weather Events—Understanding Societal and

> Economic Impacts Workshop Report." ***These assessments indicate that severe geomagnetic storms have the potential to cause long-duration outages to widespread areas of the North American grid.***
>
> (Emphasis added.)

The HILF report further concludes that damage from space weather could not be quickly repaired:

> The design of transformers also acts to further compound the impacts of GIC flows in the high voltage portion of the power grid...***These transformers generally cannot be repaired in the field, and if damaged in this manner, need to be replaced with new units, which have manufacture lead times of 12–24 months or more in the world market.***
>
> (Emphasis added.)

NERC and technical consultants conducted detailed analysis in preparation of the HILF report:

> Metatech conducted a simulation based on a 4800 nT/min disturbance, shown in Figure 11 which calculated the pattern of GIC flows in the U.S. power grid and the boundaries of regions of power grid that could be subject to progressive collapse, such as what occurred to the Québec Interconnection in March 1989. The simulation results indicate that more than a thousand EHV transformers will have sufficient GIC levels to simultaneously be driven into saturation. Further, this would suddenly impose an increase of over 100,000 MVARs of reactive demand on the system, a scenario that could trigger a widespread voltage collapse, resulting in system instability and, likely, a short-duration blackout. The analysis also indicates that the GIC in over 350 transformers will exceed levels where the transformer is at risk of irreparable damage. Figure 12 provides an estimate of "Percent Loss" of EHV transformation capacity by state for the same 4800 nT/min threat environment. ***Such large-scale damage could lead to prolonged restoration and long-term chronic shortages of electricity supply capability to the impacted regions, arguably for multiple years.***
>
> (Emphasis added.)

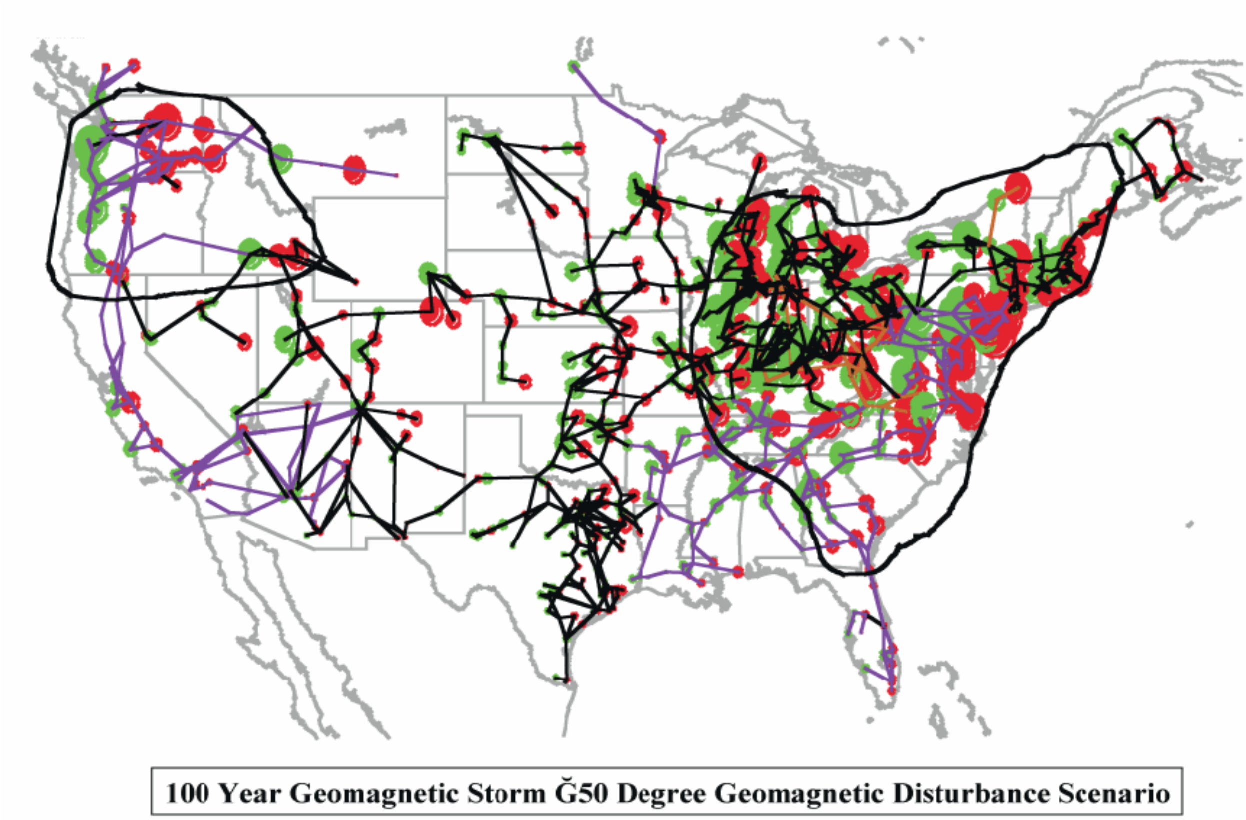


Figure 11: The simulation results showing the pattern of GIC flows in the U.S, grid for a 4800 nT/min geomagnetic field disturbance at 50 degrees geomagnetic latitude. The above regions outlined are susceptible to system collapse due to the effects of the GIC.

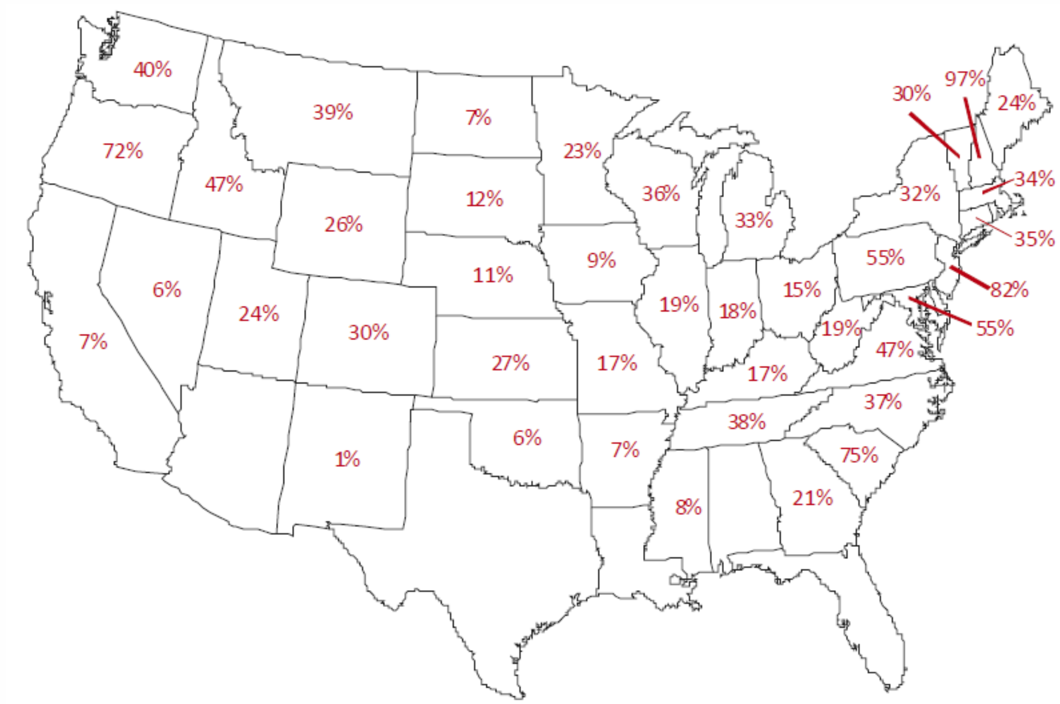


Figure 12: A map showing the At-Risk EHV Transformer Capacity by State for this disturbance scenario, regions with high percentages could experience long duration outages that could extend multiple years.[63]

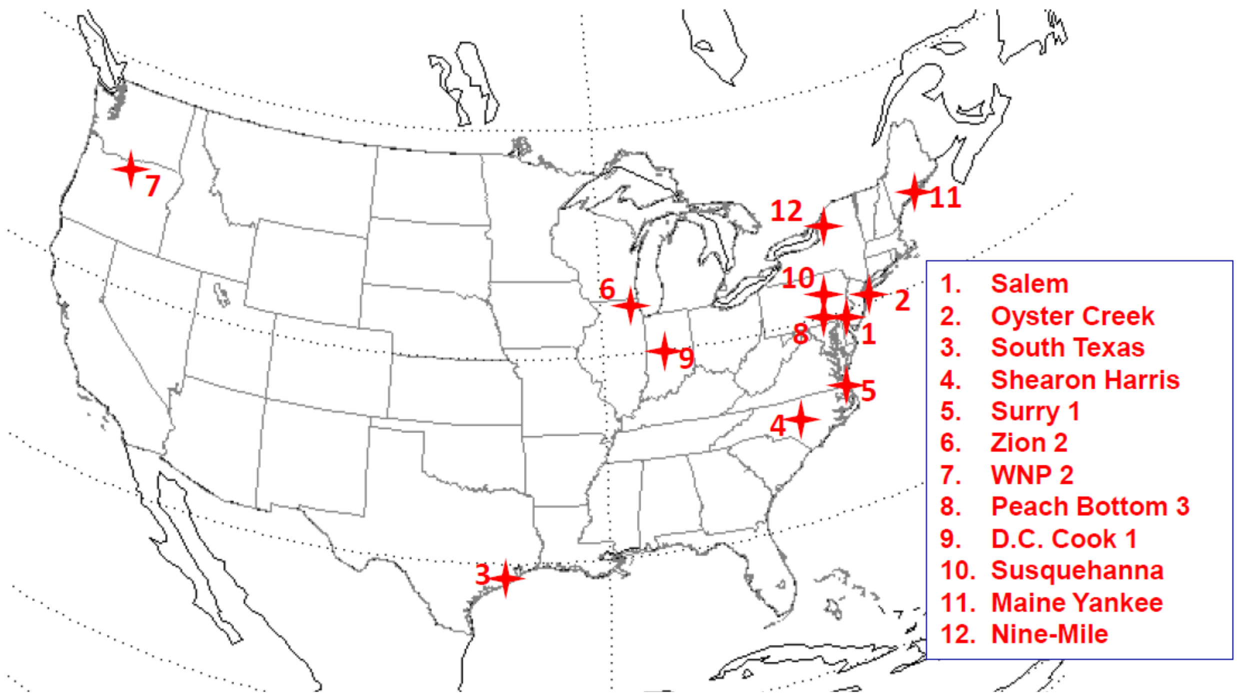
Extra High Voltage (EHV) transformer damage would not be evenly distributed. For example, in New Hampshire, location of the Seabrook nuclear power plant, 97% of transformer capacity is at-risk to severe space weather.

In 2008, a National Research Council formed a Committee on the Societal and Economic Impacts of Severe Space Weather Events and published a report, "Severe Space Weather Events—Understanding Societal and Economic Impacts." The report described several severe space weather events over the past one-hundred and fifty years. The report reads in part:

> Our knowledge and understanding of the vulnerabilities of modern technological infrastructure to severe space weather and the measures developed to mitigate those vulnerabilities are based largely on experience and knowledge gained during the past 20 or 30 years, during such episodes of severe space weather as the geomagnetic superstorms of March 1989 and October-November 2003. As severe as some of these recent events have been, the historical record reveals that space weather of even greater severity has occurred in the past—e.g., the Carrington event of 1859 and the great geomagnetic storm of May 1921—and suggests that such extreme events, though rare, are likely to occur again some time (sic) in the future. While the socioeconomic impacts of a future Carrington event are difficult to predict, it is not unreasonable to assume that an event of such magnitude would lead to much deeper and more widespread socioeconomic disruptions than occurred in 1859, when modern electricity-based technology was still in its infancy.

> The Executive Director of Systems Operations at PJM Interconnection provided a specific example of space weather impact on power grid operations as part of the above referenced National Research Council report. (PJM is a regional transmission organization with 164,905 MW of generating capacity that coordinates the movement of wholesale electricity over 56,250 miles of transmission lines in all or parts of Delaware, Illinois, Indiana, Kentucky, Maryland, Michigan, New Jersey, North Carolina, Ohio, Pennsylvania, Tennessee, Virginia, West Virginia, and the District of Columbia.)
>
> One example of a space weather event that had a major impact was the March 1989 superstorm. During this storm, a large solar magnetic impulse caused a voltage depression on the Hydro-Quebec power system in Canada that could not be mitigated by automatic voltage compensation equipment. The failure of the equipment resulted in a voltage collapse. Specifically, five transmission lines from James Bay were tripped, which caused a generation loss of 9,450 MW. With a load of about 21,350 MW, the system was unable to withstand the generation loss and collapsed within seconds. The province of Quebec was blacked out for approximately 9 hours.
>
> Also during this storm, a large step-up transformer failed at the Salem Nuclear Power Plant in New Jersey. That failure was the most severe of approximately 200 separate events that were reported during the storm on the North American power system. Other events ranged from generators tripping out of service, to voltage swings at major substations, to other lesser equipment failures.

A presentation by John Kappenman titled "Impact of Severe Solar Flares, Nuclear EMP and Intentional EMI on Electric Grids," at the Electric Infrastructure Security (EIS) Summit in London, England on September 20, 2010, described the effects of solar storms on high voltage transformers. A long duration solar storm in October 2003 damaged 15 high voltage transformers in South Africa. After the March 1989 storm, 12 large Generator Step Up (GSU) transformers at United States nuclear power plants failed within 25 months; geomagnetically-induced current is the suspected cause of these failures:

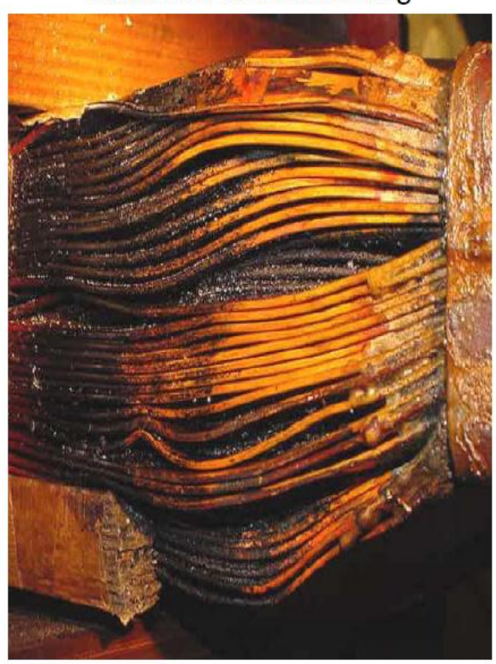


GSU Transformer Failures at Nuclear Power Plants within 25 Months of 1989 Solar Storm
Source: Impact of Severe Solar Flares, Nuclear EMP and Intentional EMI on Electric Grids

Damaged Core on Salem Nuclear Power Plant Transformer

Station 3 Gen Transformer 4
HV winding failure

Station 3 Gen. Transformer 5
evidence of overheating



Courtesy Eskom, Makhosi, T., G. Coetzee

Damaged Winding and Core on Eskom Transformers in South Africa

Source: Impact of Severe Solar Flares, Nuclear EMP and Intentional EMI on Electric Grids

In October 2010, Oak Ridge National Laboratory released "Electromagnetic Pulse: Effects on the U.S. Power Grid," a series of comprehensive technical reports for the Federal Energy Regulatory Commission (FERC) in joint sponsorship with the Department of Energy and the Department of Homeland Security. The executive summary of this report series reads in part:

> In 1989, an unexpected geomagnetic storm triggered an event on the Hydro-Québec power system that resulted in its complete collapse within 92 seconds, leaving six million customers without power. This same storm triggered hundreds of incidents across the United States including destroying a major transformer at an east coast nuclear generating station. ***Major geomagnetic storms, such as those that occurred in 1859 and 1921, are rare and occur approximately once every one hundred years.*** Storms of this type are global events that can last for days and will likely have an effect on electrical networks world wide. Should a storm of this magnitude strike today, it could interrupt power to as many as 130 million people in the United States alone, requiring several years to recover.

The Oak Ridge National Laboratory report further describes the effects of a geomagnetic storm expected to occur, on average, every 100 years:

> By simulating the effects of a 1 in 100 year geomagnetic storm centered over southern Canada, the computer models estimated the sections of the power grid expected to collapse during a major EMP event. This simulation predicts that over 300 EHV transformers would be at-risk for failure or permanent damage from the event. With a loss of this many transformers, the power system would not remain intact, leading to probable power system collapse in the Northeast, Mid-Atlantic and Pacific Northwest, affecting a population in excess of 130 million (Figure 1). Further simulation demonstrates that a storm centered over the northern region of the United States could result in extending the blackout through Southern California, Florida and parts of Texas.
>
> In addition to causing the immediate damage and failure of transformers, there is also evidence that GIC may be responsible for the onset of long-term damage to transformers and other key power grid assets. Damaged transformers require repair or replacement with new units. ***Currently most large transformers are manufactured in foreign countries and replacements would likely involve long production lead times in excess of a year.***
>
> (Emphasis added.)

Notably, the "Areas of Probable Power System Collapse" as illustrated in Figure 1 of the Oak Ridge National Laboratory report largely coincide with many locations of United States nuclear power plants and associated spent fuel pools. Seventy-one out of 104 spent fuel pools are within areas of probable power system collapse that would result from a severe geomagnetic storm expected to occur, on average, every 100 years.

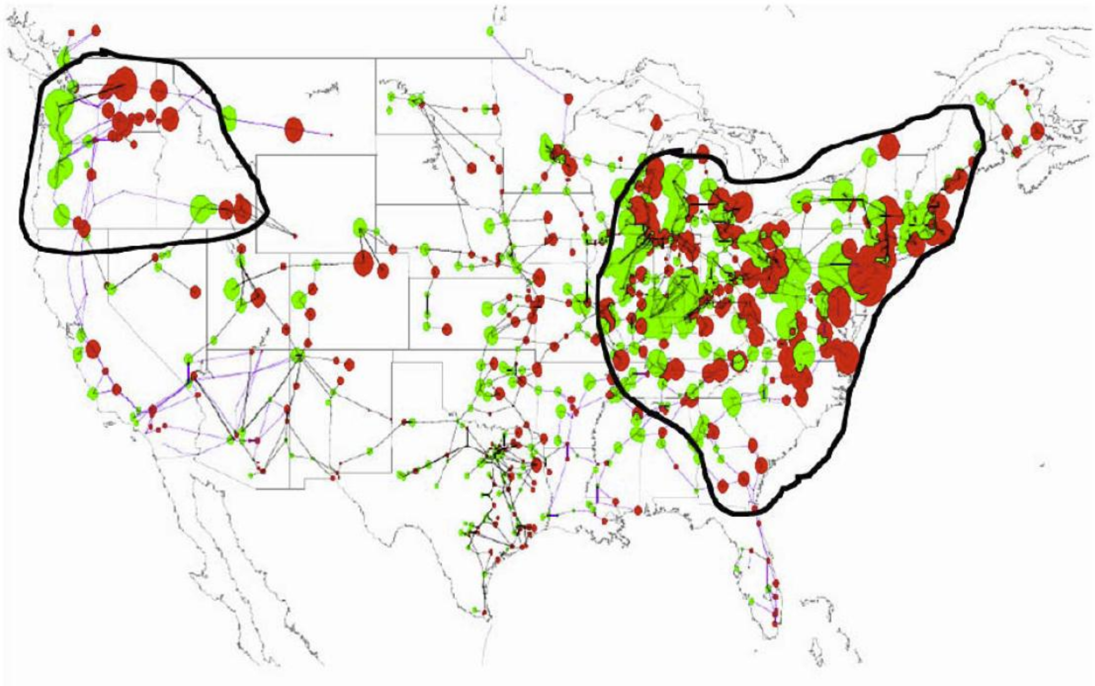
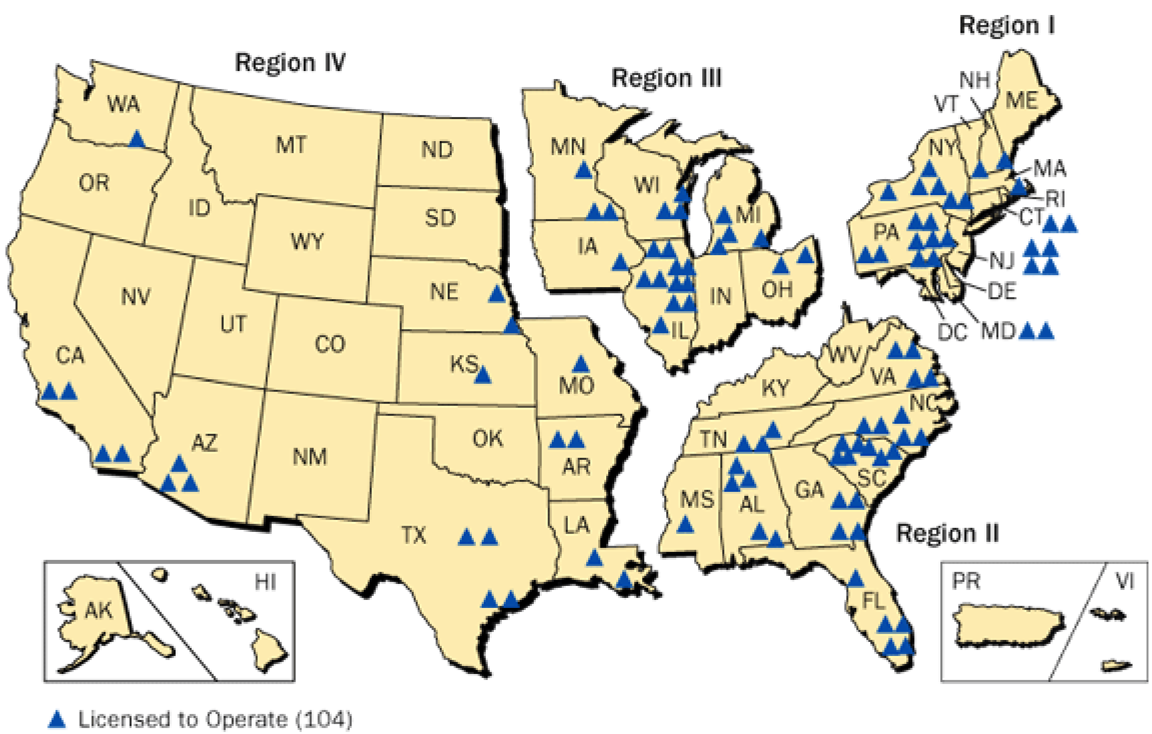


Figure 1. **Areas of Probable Power System Collapse**



Locations of United States Nuclear Power Plants

Source: Nuclear Regulatory Commission, as of October 20, 2010

Disruption of Petrochemical Fuel Resupply

In 2008, the Commission to Assess the Threat to the United States from Electromagnetic Pulse (EMP) Attack published a report on Critical National Infrastructures. An EMP can be caused by detonation of a nuclear weapon at high altitude. Significantly, the so-called "E3" pulse resulting from a nuclear detonation would cause an effect in long-haul power transmission lines nearly identical to the geomagnetically-induced current (GIC) of severe space weather. The Commission's report reads in part:

> There are a wide variety of potential threats besides EMP that must be addressed, which can have serious to potentially catastrophic impacts on the electrical system. Common solutions must be found that resolve these multiple vulnerabilities as much as possible. For example, in the course of its work, the Commission analyzed the impact of a 100-year solar storm (similar to E3 from EMP) and discovered a very high consequence vulnerability of the power grid. Steps taken to mitigate the E3 threat also would simultaneously mitigate this threat from the natural environment.

The study of the EMP Commission is illustrative of second-order effects of commercial grid outage on petrochemical infrastructure. The EMP Commission concluded:

> The petroleum and natural gas infrastructures are critically dependent on the availability of assured electric power from the national grid, as well as all the other critical national infrastructures, including food and emergency services that sustain the personnel manning these infrastructures. In turn, all these infrastructures rely on the availability of fuels provided by the petroleum and natural gas sector. Petroleum and natural gas systems are heavily dependent on commercial electricity during the entire cycle of production, refining, processing, transport, and delivery to the ultimate consumer. ***The availability of commercial power is the most important dependency for the domestic oil sector.***
>
> (Emphasis added.)

According to the work of the EMP commission, in the aftermath of a large induced current in the bulk power transmission system—whether this current is induced by a nuclear EMP or severe space weather—continued regular delivery of petrochemical fuels would be in doubt. In the event of widespread commercial grid power outage, nuclear plant operators cannot depend on resupply of diesel fuel for emergency backup generators once initial fuel stored on-site is exhausted.

Disruption of Food and Water Supply

The above-referenced Critical National Infrastructures report authored by the EMP commission also examined the potential effect of long-term power failure on food and water supplies. The report reads in part:

> Should the electrical power system be lost for any substantial period of time, the Commission believes that the consequences are likely to be catastrophic to civilian society. Machines will stop; transportation and communication will be severely restricted; heating, cooling, and lighting will cease; ***food and water supplies will be interrupted***; and many people may die. "Substantial period" is not quantifiable but generally outages that last for a week or more and affect a very large geographic region without sufficient support from outside the outage area would qualify. (Emphasis added.)

Under current emergency plans, on-site nuclear power plant personnel would be required to maintain systems for active cooling and/or water makeup of spent fuel pools. It is probable that these personnel might go an extended period of time without resupply of food and potable water. In addition, any stored supplies of food and potable water for critical personnel would be subject to theft and pilferage during an extended commercial grid outage. As a result, active cooling, water makeup systems should be able to operate in unattended mode for a period of at least two years.

Lack of DHS Plan for a Scenario of North American Power Grid Collapse

The Department of Homeland Security does not currently have a plan to prevent or recover from a regional or national scenario of North American power grid collapse. The Department of Homeland Security publishes an extensive document disclosing disaster planning, the National Preparedness Guidelines. These Guidelines can be accessed at:

> http://www.dhs.gov/xlibrary/assets/National_Preparedness_Guidelines.pdf

The Guidelines read in part:

> Homeland Security Presidential Directive-8 (HSPD-8) of December 17, 2003 (*"National Preparedness"*) directed the Secretary of Homeland Security to develop a national domestic ***all-hazards*** preparedness goal. As part of that effort, in March 2005 the Department of Homeland Security (DHS) released the Interim National Preparedness Goal. Publication of the *National Preparedness Guidelines* (*Guidelines*) finalizes development of the national goal and its related preparedness tools.
>
> The *Guidelines*, including the supporting *Target Capabilities List*, simultaneously published online*,* supersedes the Interim National Preparedness Goal and defines what it means for the Nation ***to be prepared for all hazards***. There are four critical elements of the *Guidelines*:
>
>> (1) The ***National Preparedness Vision,*** which provides a concise statement of the core preparedness goal for the Nation.
>>
>> (2) The ***National Planning Scenarios,*** which depict a diverse set of high-consequence threat scenarios of ***both potential terrorist attacks and natural disasters****.* Collectively, the 15 scenarios are designed to focus contingency planning for homeland security preparedness work at all levels of government and with the private sector. The scenarios form the basis for coordinated Federal planning, training, exercises, and grant investments needed to prepare for ***emergencies of all types***.
>
> (Emphasis added.)

The Guidelines purport to include all consequential hazards, both from both potential terrorist attacks and natural disasters. The Guidelines continue:

> While preparedness applies across the all-hazards spectrum, the 2002 National Strategy for Homeland Security attaches special emphasis to preparing for catastrophic threats with "the greatest risk of mass casualties, massive property loss, and immense social disruption." To illustrate the potential scope, magnitude, and complexity of a range of major events, the Homeland Security Council—in partnership with the Department of Homeland Security (DHS), other Federal departments and agencies, and State, local, tribal, and territorial governments—developed the National Planning Scenarios. The 15 Scenarios include terrorist attacks, major disasters, and other emergencies. They are listed in Figure B-1.

Figure B-1: National Planning Scenarios	
Improvised Nuclear Device	Major Earthquake
Aerosol Anthrax	Major Hurricane
Pandemic Influenza	Radiological Dispersal Device
Plague	Improvised Explosive Device
Blister Agent	Food Contamination
Toxic Industrial Chemicals	Foreign Animal Disease
Nerve Agent	Cyber Attack
Chlorine Tank Explosion	

Notably, none of the fifteen purportedly all-inclusive National Planning Scenarios include a scenario for severe space weather/geomagnetic disturbance and associated long-term and widespread commercial grid outage. Lack of DHS inclusion of a geomagnetic disturbance scenario is not inadvertent. Metatech, a firm consulting to the Commission to Assess the Threat to the United States from Electromagnetic Pulse (EMP) Attack, suggested inclusion of a such a scenario and DHS staff declined to do so. Because current DHS scenarios do not include geomagnetic disturbance and resulting commercial grid outage, replacement of high-voltage transformers and resupply of diesel fuel, food, and potable water to nuclear power plants could be substantially delayed or never occur.

Persistent NRC Concerns Regarding Reliability of Commercial Grid Power

For over thirty years, the NRC has had persistent concerns about the reliability of commercial grid power and its effect on nuclear power plant risk. In August 1988, Oak Ridge National Laboratory and the NRC published ORNL/NRC/LTR-98/12, "Evaluation of the Reliability for the Offsite Power Supply as a Contributor to the Risk of Nuclear Plants." The abstract for ORNL/NRC/LTR-98/12 reads in full:

> The objective of this project (job code number J2528) is to provide technical expertise from the Oak Ridge National Laboratory (ORNL) to assist the Nuclear Regulatory Commission (NRC) staff assessing the nature of any changes in the reliability of the national electric power grid to supply offsite power to nuclear power plants due to electric industry restructuring. Specifically, the task is to determine the potential for increases in the frequency of loss-of-offsite power (LOOP) events associated with grid related offsite power events.
>
> NRC is responsible for the evaluation of issues related to the design and operation of offsite power grid systems with regard to interrelationships between the nuclear unit, the utility grid and interconnecting grids, the functional performance, design and operation of on-site power systems, and the interface between the offsite and on-site power systems to include performance related issues for electrical components.
>
> Safe nuclear plant operation requires a source of power capable of maintaining acceptable static and dynamic voltage and frequency limits while supplying minimum amounts of auxiliary power. The preferred power source for safe plant operation is the offsite electric power system or power grid.
>
> Accident sequences initiated by LOOP are important contributors to risk for most nuclear plants. In 1979, the NRC identified the loss of all alternating current (AC) electrical power to the nuclear plant, called station blackout (SBO), as an unresolved safety issue. SBO was shown to be an important contributor to the total risk from nuclear power plant accidents. A task action plan A-44 was issued in July 1980 to address this issue and the results were published in a final report

issued in June 1988 as NUREG-1032, *Evaluation Station Blackout Accidents at Nuclear Power Plants*. In essence, the findings were that the grid was assumed to be stable and reliable.

At this time, the electric power industry in the United States is dominated by vertically integrated utilities. These were interconnected initially to primarily increase reliability, but now utilities use the interconnections for commercial transactions as well. Each utility or a small group of utilities form a control area containing customers for which they are jurisdictionally responsible. The control areas are divided into reliability councils. In addition, there are power pools which are associations of utilities that have joined for the purpose of reducing the cost of producing and delivering power through coordinated operation. However, there are reliability constraints on the individual systems as indicated in North American Electric Reliability Council (NERC) reports submitted to the U.S. Department of Energy (DOE). These constraints include, but are not limited to, low reserve margins, a shortage of transmission facilities, and technical problems in transmitting power over long distance lines.

Two relatively new factors are emerging: nonutility generation and industry restructuring. It is anticipated that, in the not too distant future, power suppliers, whether utilities, independent power producers (IPPs), or power marketers will actively compete for sales to customers who may be located anywhere on the power grid. Regional grid control will be the responsibility of centralized Independent System Operators (ISOs) in many regions. The locations, membership, responsibilities, and authority of all ISOs have yet to be defined. It is expected that these ISOs will be charged with maintaining grid reliability to facilitate the marketing of power. It is also uncertain how the current method of reliability standard maintenance through voluntary compliance with guidelines established by consensus associations will transition to the new utility structure. These uncertainties raise questions with respect to the continued supply of reliable offsite power to nuclear power plants.

Any reliability study of offsite power sources needs to consider both the quality of the voltage and frequency as needed by the nuclear generating station, the probability of the frequency and duration of a LOOP event to the subject station, and potential impacts which can occur during events (i.e., transients, low voltage, and frequency degradation). The industry structure is shifting from one with vertically integrated control by corporate entities that both own nuclear plants and have essentially autonomous authority over reliability rules and procedures. The new structure may have many commercially independent entities. There will be an as-yet undefined standards setting and enforcement process responding to commercial pressure as well as a desire to maintain reliability. These factors raise the concern, will nuclear plant offsite power requirements always be fulfilled? Also, what guarantees by the transmission provider interconnected with the nuclear plant need to be in place so that reliable power in accordance with voltage and frequency requirements can be assured for safe operation?

The answers to these and other potentially complicated questions as tasked to the NRC staff by the Commission can be provided through the performance of engineering studies, such as this by ORNL, to assess potential changes in the reliability of the grid to supply offsite power. The results of this project show that some nuclear plants are more vulnerable to grid-centered loss-of offsite power than others. Vulnerability from the grid is discussed in detail in this report.

The Oak Ridge National Laboratory/NRC study was prescient in its list of concerns resulting from electric industry deregulation:

1.2 Overview of Concerns

Restructuring of the electric power industry is resulting in the increasing number of financially independent entities whose operations can influence a nuclear plant's offsite power supply. Historically, the nuclear plant owner also owned and operated the transmission system, the control area, and the other generators in the immediate area and was fully responsible for the reliability of the power system. Now, each of these can be owned and operated by separate commercial entities, and there is also a NERC regional security coordinator with authority to coordinate system operator actions when reliability is threatened. This arrangement presents the following concerns:

- A key factor in providing the required offsite power quality is a determination of the offsite power design basis.
- Requirements for the nuclear plant. Some of the utilities which were visited do not appear to be addressing this important analysis in a thorough manner.
- Each entity must be aware of the nuclear plant's power requirements and must have procedures to provide that the correct action is taken under varying conditions.
- There must be contractual arrangements between these entities that assure the nuclear plant owners/operators and the NRC that required actions will be taken.
- National standards do not exist yet to guide these entities in structuring their reliability activities. Regional and local standards often lack the rigor required to function in a commercially contentious environment.
- There may be significant costs associated with both the analysis and the system operation constraints required to provide the adequacy and reliability of the offsite power supply.
- In the event of a regional or control area grid blackout, there is concern that key black start units (see Appendix D for definitions) may be under the control of a new, independent financial entity. The reliability of these units is unknown unless blackout simulation testing is also covered under contract and regularly performed.

In December 2005, Idaho National Laboratory and NRC published NUREG/CR-6890, Vol. 2, "Reevaluation of Station Blackout Risk at Nuclear Power Plants--Analysis of Station Blackout Risk." The executive summary from this report reads in part:

> The availability of alternating current (ac) power is essential for safe operations and accident recovery at commercial nuclear power plants. This ac power is normally supplied by offsite power sources via the electrical grid but can be supplied by onsite sources such as emergency diesel generators (EDGs). A subset of LOOP scenarios involves the total loss of ac power as a result of complete failure of both offsite and onsite ac power sources. This is termed station blackout (SBO). In SBO scenarios, safe shutdown relies on components that do not require ac power, such as turbine-driven pumps or diesel driven pumps. The reliability of such components, along with direct current battery depletion times and the characteristics of offsite power restoration, are important contributors to SBO risk. Historically, risk models have indicated that SBO is an important contributor to overall plant risk, contributing as much as 70 percent or more. Therefore, LOOP, restoration of offsite power, and reliability of onsite power sources are important inputs to plant probabilistic risk assessments (PRAs).
>
> Based on concerns about SBO risk and associated emergency diesel generator reliability, the U.S. Nuclear Regulatory Commission (NRC) established Task Action Plan (TAP) A-44 in 1980. The NRC report NUREG-1032, *Evaluation of Station Blackout Accidents at Nuclear Power Plants*, issued in 1988, integrated many of the efforts performed as part of TAP A-44. In 1988 NRC also issued the SBO rule, 10 CFR 50.63, and the accompanying regulatory guide, RG 1.155. That rule required plants to be able to withstand an SBO for a specified duration and maintain core cooling during that duration. As a result of the SBO rule, plants were required to enhance procedures and training for restoring offsite and onsite ac power sources. In addition, to meet the rule's requirements, some plants chose to make modifications such as adding additional emergency ac power sources. Emphasis was also placed on establishing and maintaining high reliability of the emergency power sources.
>
> Finally, a widespread grid-related LOOP occurred on August 14, 2003. That event resulted in LOOPs at nine U.S. commercial nuclear power plants. As a result of that event, the NRC initiated a comprehensive program that included updating and reevaluating LOOP frequencies and durations as well as SBO risk.

Regulatory Actions after the 2003 Northeast Blackout

On August 14, 2003, a grid blackout spread over the northeastern United States and parts of Canada. An article published in Scientific American, "The 2003 Northeast Blackout--Five Years Later," (August 13, 2008) described the event:

> On August 14, 2003, shortly after 2 P.M. Eastern Daylight Time, a high-voltage power line in northern Ohio brushed against some overgrown trees and shut down—a fault, as it's known in the power industry. The line had softened under the heat of the high current coursing through it. Normally, the problem would have tripped an alarm in the control room of FirstEnergy Corporation, an Ohio-based utility company, but the alarm system failed.
>
> Over the next hour and a half, as system operators tried to understand what was happening, three other lines sagged into trees and switched off, forcing other power lines to shoulder an extra burden. Overtaxed, they cut out by 4:05 P.M., tripping a cascade of failures throughout southeastern Canada and eight northeastern states.
>
> All told, 50 million people lost power for up to two days in the biggest blackout in North American history. The event contributed to at least 11 deaths and cost an estimated $6 billion.

The Scientific American article describes new regulatory standards after the 2003 Northeast Blackout:

> In February 2004, after a three-month investigation, the U.S.–Canada Power System Outage Task Force concluded that a combination of human error and equipment failures had caused the blackout. The group's final report made a sweeping set of 46 recommendations to reduce the risk of future widespread blackouts. First on the list was making industry reliability standards mandatory and legally enforceable.
>
> Prior to the blackout, the North American Electricity Reliability Council (NERC) set voluntary standards. In the wake of the blackout report, Congress passed the Energy Policy Act of 2005, which expanded the role of the Federal Energy Regulatory Commission (FERC) by requiring it to solicit, approve and enforce new reliability standards from NERC, now the North American Electricity Reliability Corporation.
>
> FERC has so far approved 96 new reliability standards…Standard PER-003, for example, requires that operating personnel have at least the minimum training needed to recognize and deal with critical events in the grid; standard FAC-003 makes it mandatory to keep trees clear of transmission lines; standard TOP-002-1 requires that that grid operating systems be able to survive a power line fault or any other single failure, no matter how severe. FERC can impose fines of up to a million dollars a day for an infraction, depending on its flagrancy and the risk incurred.
>
> If the standards have reduced the number of blackouts, the evidence has yet to bear it out. A study of NERC blackout data by researchers at Carnegie Mellon University in Pittsburgh found that the frequency of blackouts affecting more than 50,000 people has held fairly constant at about 12 per year from 1984 to 2006. Co-author Paul Hines, now assistant professor of engineering at the University of Vermont in Burlington, says current statistics indicate that a 2003-level blackout will occur every 25 years.
>
> (Ellipsis not in original.)

A speech by Jeffery Merrifield, Commissioner of the NRC, at the American Nuclear Society Executive Conference on Grid Reliability, Stability and Off-Site Power (July 24, 2006) describes the effect of the 2003 Northeast Blackout on nuclear power plants:

> **(Slide 2)** On August 14, 2003, I was the Acting Chairman on what I thought was going to be just another routine day at the NRC. I had a series of scheduled meetings that day, including a briefing on grid reliability, where the staff discussed the trends in loss of offsite power events at nuclear power plants. The staff informed me that the number of these events was decreasing, which was encouraging. They also mentioned, however, that the duration of individual events was tending to be longer.
>
> Around 4:00 p.m. that afternoon, Bill Travers, the EDO at that time, came into my office and informed me that the staff was assembling in our Operations Center in response to the automatic shutdown of several nuclear plants in the Northeast and Midwest. At that time, we did not know whether it was caused by multiple operational events or, perhaps by a coordinated act of terrorism.
>
> **(Slide 3)** As information continued to pour in the rest of the afternoon and into the evening hours, we came to learn that nine nuclear power plants in the U.S., as well as 11 in Canada, and a host of coal-fired power plants had been disconnected from the grid because of electrical instabilities, resulting in the blackout of major portions of the Northeast and Midwest in the U.S. and parts of Canada.
>
> **(Slide 4)** In fact, virtually every power plant east of the Mississippi experienced voltage swings of variable amplitude, though plants further from the Northeast corridor saw only minor voltage perturbations.
>
> **(Slide 5)** By the next morning, after a long night at the Ops Center, we were only beginning to understand the magnitude of the blackout. ***I participated in several conference calls, including calls with the White House Situation Room, to discuss the causes of the event with the staff of the National Security Council as well as various Cabinet members.***
>
> (Emphasis not in original.)

Notably, the gravity of the 2003 situation for nuclear power plants necessitated coordination with the National Security Council, a high-level group that includes the President, Vice President, Secretary of State, Secretary of the Treasury, Secretary of Defense, and Assistant to the President for National Security Affairs and which is advised by the Chairman of the Joint Chiefs of Staff and the Director of National Intelligence.

In his speech, Commissioner Merrifield described current design philosophy for nuclear power plants regarding commercial grid power:

> **(Slide 6) WHY DOES NRC CARE ABOUT GRID STABILITY?**
>
> Nuclear power reactors must be cooled continuously, even when shut down. The numerous pumps and valves in the reactor cooling systems therefore must have access to electrical power at all times, even if the normal power supply from the grid is degraded or completely lost.
> As a regulator, we want to minimize the time a nuclear power plant is subjected to a complete loss of offsite power, otherwise known as Station Blackout. Even though plants are designed with emergency diesel generators to supply power to pumps and valves that keep the reactor cool when normal power is lost, we do not like to challenge those diesel generators any more than is absolutely necessary.

The NRC was concerned about grid reliability long before the 2003 blackout event. On August 12, 1999, while the Callaway plant (in Missouri) was offline in a maintenance outage, the plant saw the offsite power supply voltage fall below minimum requirements for a 12-hour period. The voltage drop they observed was caused by peak levels of electrical loading and the transport of large amounts of power on the grid adjacent to Callaway. The licensee noted that the deregulated wholesale power market contributed to conditions where higher grid power flows were likely to occur in the area near Callaway. Alliant Energy had to spend ten's of millions of dollars to install new transformers with automatic tap changers to keep voltage above minimum requirements, and capacitor banks to improve the reactive power (volt-amps reactive, or VARs) factor in the Callaway switchyard.

As a result of deregulation, many electric utilities were split into electric generating companies and transmission and distribution companies. Thus, nuclear power plants now must rely on outside entities to maintain the switchyard voltage within acceptable limits. Over time, some transmission companies have become less sensitive to the potential impacts that grid voltage can have on nuclear plant operations.

A big part of our risk-informed regulatory strategy depends on plants having access to reliable offsite power. We assume that there will be very few times when a plant will be subjected to a total loss of offsite power, and when such condition exists it will be for a relatively short period of time (hours or days rather than weeks). Our strategy of allowing more on-line maintenance to be performed on certain important safety equipment such as the emergency diesel generators makes sense as long as the risk of a plant trip remains very low during the period of time that equipment is out of service. This philosophy relies on the fact that a total loss of offsite power is a rare occurrence that will be corrected in a short period of time.

(Emphasis not in original.)

After the 2003 Northeast Blackout, an extensive series of meetings between NRC, NERC, FERC, and the electric power and nuclear generation industries ensued. These meetings resulted in an NRC Generic Letter and new NERC reliability standard for nuclear power plants and their commercial grid suppliers.

The background section of NRC Generic Letter 2006-2, “Grid Reliability and the Impact on Plant Risk and the Operability of Offsite Power” (February 2006), reads in full:

BACKGROUND

Based on information obtained from inspections and risk insights developed by an internal NRC expert panel (further described below), the staff is concerned that several conditions associated with assurance of grid reliability may impact public health and safety and/or compliance with applicable regulations. These conditions include use of long-term periodic grid studies and informal communication arrangements to monitor real-time grid operability, potential shortcomings in grid reliability evaluations performed as part of maintenance risk assessments, lack of preestablished arrangements identifying local grid power sources and transmission paths, and potential elimination of grid events from operating experience and training. The staff identified these issues as a result of considering the August 14, 2003, blackout event.

On August 14, 2003, the largest power outage in U.S. history occurred in the Northeastern United States and parts of Canada. Nine U.S. NPPs tripped. Eight of these lost offsite power, along with one NPP that was already shut down. The length of time until power was available to the switchyard ranged from approximately one hour to six and one half hours. Although the onsite emergency diesel generators (EDGs) functioned to maintain safe shutdown conditions, this event was significant in terms of the number of plants affected and the duration of the power outage.

The loss of all alternating current (AC) power to the essential and nonessential switchgear buses at a NPP involves the simultaneous loss of offsite power (LOOP), turbine trip, and the loss of the onsite emergency power supplies (typically EDGs). Such an event is referred to as a station blackout (SBO). Risk analyses performed for NPPs indicate that the SBO can be a significant contributor to the core damage frequency. Although NPPs are designed to cope with a LOOP event through the use of onsite power supplies, LOOP events are considered precursors to SBO. An increase in the frequency or duration of LOOP events increases the probability of core damage.

The NRC issued a regulatory issue summary ((RIS) 2004-5, “Grid Operability and the Impact on Plant Risk and the Operability of Offsite Power,” dated April 15, 2004) to advise NPP addressees of the requirements in Title 10 of the *Code of Federal Regulations* (10 CFR) Section 50.65, “Requirements for monitoring the effectiveness of maintenance at nuclear power plants;” 10 CFR 50.63, “Loss of all alternating current power;” 10 CFR Part 50, Appendix A, General Design Criterion (GDC) 17,[1] “Electric power systems;” and plant technical specifications on operability of offsite power. In addition, the NRC issued Temporary Instruction (TI) 2515/156, “Offsite Power System Operational Readiness,” dated April 29, 2004, and TI 2515/163, “Operational Readiness of Offsite Power,” dated May 05, 2005, which instructed the regional offices to perform followup inspections at plant sites on the issues identified in the RIS.

The NRC needs additional information from its licensees in the four areas identified above in order to determine if regulatory compliance is being maintained.

On April 26, 2005, the Commission was briefed on grid stability and offsite power issues by a stakeholder panel that included representatives of the Federal Energy Regulatory Commission, the North American Electric Reliability Council (NERC), the National Association of Regulatory Utilities Commissioners, PJM Interconnection (one of the country’s largest transmission system operators), a FirstEnergy Corporation executive representing the Nuclear Energy Institute (NEI), and the NRC staff. In light of this briefing, the Commission issued a staff requirements memorandum (SRM) dated May 19, 2005, in which the Commission directed the staff to review NRC programs related to operator examination and training and ensure that these programs adequately capture the importance of grid conditions and offsite power issues to the design, assessment, and safe operation of the plant, including appropriate interactions with grid operators. The SRM further directed the staff to determine whether the operator licensing program needs to be revised to incorporate additional guidance on grid reliability.

(Emphasis added.)

In January 2010, FERC and NERC established a reliability standard for coordination between commercial grid suppliers and nuclear power plant operators. This standard recognizes the urgency for restoration of commercial grid power for safety considerations. The standard reads in part:

Standard NUC-001-2 — Nuclear Plant Interface Coordination

3. Purpose: This standard requires coordination between Nuclear Plant Generator Operators and Transmission Entities for the purpose of ensuring nuclear plant safe operation and shutdown.

R9. The Nuclear Plant Generator Operator and the applicable Transmission Entities shall include, as a minimum, the following elements within the agreement(s) identified in R2: [Risk Factor: Medium]

> R9.3.5. Provision for considering, within the restoration process, the requirements and urgency of a nuclear plant that has lost all off-site and on-site AC power.

NERC Standard NUC-001-2 requires urgent restoration of commercial grid power for nuclear power plants. However, without actual planning and financial investment for a condition of geomagnetic disturbance, this paper standard provides ineffectual protection.

Lack of NERC Reliability Standard for Geomagnetic Disturbance

While NUC-001-02 recognizes the urgency of providing reliable off-site power to nuclear power plants, NUC-001-02 does not specifically require electric utilities to protect against severe space weather. In particular, NERC has not published a reliability standard for protection against geomagnetic disturbance. Were such a standard to exist, it could specify a system for forecasting geomagnetic disturbance and require operational plans to shut down high voltage transmission equipment when such this condition is predicted. Moreover, standards for protective devices, such as blocking devices for high voltage transformers, could be specified.

The NERC Board of Trustees recognized the need for action on geomagnetic disturbance twenty years ago, in the aftermath of the 1989 Quebec blackout caused by space weather. A NERC report, "March 13, 1989 Geomagnetic Disturbance," recommends the use of blocking devices to protect high voltage transformers:

> **Neutral-Blocking Capacitor**
>
> Capacitors installed between transformer neutrals and grounds can be very effective in blocking ground-induced currents. Ideally, the capacitor should be very simple, should not increase voltage stress on transformer insulation, should not have to be bypassed during faults (eliminating the necessity for a complex bypass device) and should have a low 60 Hz impedance (to avoid any impact on the system grounding coefficient). The cost of such a device, will of course, have to be weighed against its simplicity, robustness, and reliability. Hydro-Québec is currently studying a capacitor of this sort and if findings are promising, a prototype will be installed for field testing and evaluation of long-term reliability and performance.

Below is the full text of the 1990 Board of Trustees position statement on solar magnetic (geomagnetic) disturbance forecasting and the need for protective measures:

NERC Position Statement on
Solar Magnetic Disturbance Forecasting
Approved by the Board of Trustees
July 9, 1990

The North American Electric Reliability Council (NERC) strongly urges that improvements be made to the SMD forecasting accuracy of the National Oceanic & Atmospheric Administration. With the current activity on the sun projected to continue well into the 1990s, NERC believes that a forecasting procedure to provide at least one hour notice and an accuracy of at least 90% is required. This security margin will allow sufficient time to implement special operating procedures.

The geomagnetic induced currents (GIC) that are imposed on electric systems as a result of severe solar magnetic disturbances (SMD) pose a threat to the reliability of the interconnected electric networks in the U.S. and Canada. The GICs cause transformers to saturate and overheat. This results in depressed system voltages, failure or misoperation of critical system voltage control devices, and damage to the transformers themselves. On March 13, 1989, a severe SMD caused the total shutdown of the Hydro-Québec system in Canada. Electric utilities across the northern latitudes of the U.S also experienced transformer damage, depressed voltages, and the forced tripping of several voltage control devices. While no widespread blackouts have yet occurred, the incident demonstrated the potential damage to equipment and risk to system reliability. As a result, several control areas have established SMD operating guidelines and study groups.

The nature of the sudden onset of SMD requires that an effective SMD forecasting mechanism be in place to provide system operators with sufficient time to take preventive measures to protect the reliability of the network. Current forecasting technology has not proved to be sufficiently accurate or timely.

In 2005, NERC prepared a draft reliability guideline for geomagnetic disturbances. This draft can be found at:

> http://www.nerc.com/files/GMD_Guideline_v2_clean.pdf)

Since 2005 there have been numerous meetings and updates on the subject of geomagnetic disturbance but no reliability guideline or standard has been published.

Due to the complexity of protecting the commercial grid, it is exceedingly unlikely that grid reliability will be improved in the near future. The HILF report explains the magnitude of effort required:

> The interconnected and interdependent nature of the bulk power system requires that risk management actions be consistently and systematically applied across the entire system to be effective. The magnitude of such an effort should not be underestimated. The North American bulk power system is comprised of more than 200,000 miles of high-voltage transmission lines, thousands of generation plants, and millions of digital controls. More than 1,800 entities own and operate portions of the system, with thousands more involved in the operation of distribution networks across North America. These entities range in size from large investor-owned utilities with over 20,000 employees to small cooperatives with only ten. The systems and facilities

> comprising the larger system have differing configurations, design schemes, and operational concerns. Referring to any mitigation on such a system as “easily-deployed,” “inexpensive,” or “simple” is an inaccurate characterization of the work required to implement these changes.

The HILF report also describes the likely timeframe of any protective measures:

> The Proposals for Action outlined in this report are intended to provide input into a formal action plan to address these issues. They do not, in and of themselves, constitute this plan. The effort needed to address these risks will require intense coordination and a significant resource commitment from all entities involved. ***The time needed to address these issues and complete the work contemplated herein will be measured in years.*** NERC and the U.S. DOE will work together with the electric sector, manufacturers, and other government authorities to support the development and execution of a clear and concise action plan to ensure accountability and coordinated action on these issues going forward.
>
> (Emphasis added.)

In summary, after many years of consideration, no regulatory standards or laws require electric utilities to protect against severe space weather and resulting geomagnetic disturbance. Any eventual measures to improve commercial grid reliability will extend far into the operational life of nuclear power plants and associated spent fuel pools. In the absence of such legal standards, and actual measures taken to implement standards, the NRC has an immediate regulatory obligation to act independently to protect spent fuel pools from the effect of long-term commercial grid outage.

Previous NRC Analysis of Probability of Zirconium Cladding Fires

The NRC staff calculated the probability of an accident resulting in a zirconium cladding fire and associated radiation release in NUREG-1738, "Technical Study of Spent Fuel Pool Accident Risk at Decommissioning Nuclear Power Plants," February 2001. On the basis of probabilistic risk assessment, NUREG-1738 concluded that the risk of a zirconium cladding fire is low, principally because human operators would have several days to react to a loss of active cooling and because offsite assistance would be available. The study summarized the risk from zirconium fires:

> This study documents an evaluation of spent fuel pool (SFP) accident risk at decommissioning plants. The study was undertaken to develop a risk-informed technical basis for reviewing exemption requests and a regulatory framework for integrated rulemaking...The staff based its sensitivity assessment on the guidance in Regulatory Guide (RG) 1.174, An Approach for Using Probabilistic Risk Assessment In Risk-Informed Decisions On Plant-Specific Changes to the Licensing Basis."...The results of the study indicate that the risk at SFPs is low and well within the Commission's Quantitative Health Objectives (QHOs). The risk is low because of the very low likelihood of a zirconium fire even though the consequences from a zirconium fire could be serious.
>
> (Ellipses not in original document.)

NUREG-1738 examined a number of accident scenarios, including one that involved loss of offsite power in the aftermath of severe weather:

Table 3.1 Spent Fuel Pool Cooling Risk Analysis — Frequency of Fuel Uncovery (per year)

INITIATING EVENT	Frequency of Fuel Uncovery (EPRI hazard)	Frequency of Fuel Uncovery (LLNL hazard)
Seismic event [5]	$2x10^{-07}$	$2x10^{-06}$
Cask drop [6]	$2.0x10^{-07}$	same
Loss of offsite power[7] initiated by severe weather	$1.1x10^{-07}$	same
Loss of offsite power from plant centered and grid-related events	$2.9x10^{-08}$	same
Internal fire	$2.3x10^{-08}$	same
Loss of pool cooling	$1.4x10^{-08}$	same
Loss of coolant inventory	$3.0x10^{-09}$	same
Aircraft impact	$2.9x10^{-09}$	same
Tornado Missile	$<1.0x10^{-09}$	same
Total[8]	$5.8x10^{-07}$	$2.4x10^{-06}$

For the purposes of a departure point for the analysis of this Petition, "Loss of offsite power initiated by severe weather" is the scenario closest to a severe space weather scenario. This scenario assumes that it might be difficult for offsite help to reach the spent fuel pool site. When all factors are considered, NRC probabilistic risk assessment shows a chance of zirconium fire of 1.1 in 10 million per year. This extremely low probability relies heavily on the assumed intervention of human operators at the spent fuel pool site, as described in Industry Decommissioning Commitments (IDC). (While these commitments are for decommissioned plants, similar licensure obligations exist at operating nuclear power plants with spent fuel pools.)

NUREG-1738 explains the conditions of loss of offsite power from severe weather events:

> **3.4.4 Loss of Offsite Power from Severe Weather Events**
>
> This event represents the loss of SFP cooling because of a loss of offsite power from severe weather-related events (hurricanes, snow and wind, ice, wind and salt, wind, and one tornado event). Because of the potential for severe localized damage, tornadoes are analyzed separately in Appendix 2E. The analysis is summarized in Section 3.5.3 of this study.
>
> Until offsite power is recovered, the electrical pumps are unavailable and the diesel-driven fire pump is available only for makeup. Recovery of offsite power after severe weather events is assumed to be less probable than after grid-related and plant-centered events. In addition, it is more difficult for offsite help to reach the site.
>
> The calculated fuel uncovery frequency for this event is 1.1×10^{-7} per year. As in the previous cases, this estimate was based on IDCs #2, #5, #8, #10 and on assumptions documented in SDA #2 and SDA #3. In addition, IDC #3, the commitment to have procedures in place for communications between onsite and offsite organizations during severe weather, is also important in the analysis for increasing the likelihood that offsite organization can respond effectively.

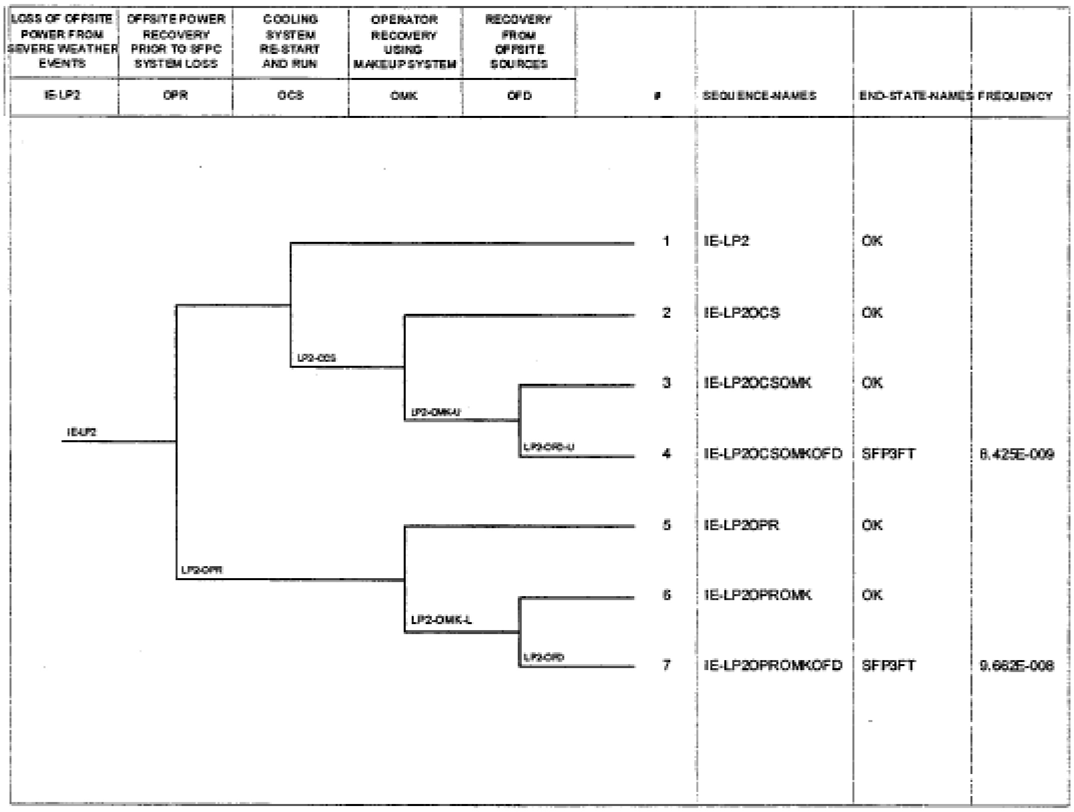
Table 4.1-1 delineates commitments which assume that both onsite and offsite personnel will be available in the aftermath of a severe weather event and associated widespread commercial grid outage.

Table 4.1-1 Industry Decommissioning Commitments (IDCs)

IDC No.	Industry commitments
1	Cask drop analyses will be performed or single failure-proof cranes will be in use for handling of heavy loads (i.e., phase II of NUREG-0612 will be implemented).
2	Procedures and training of personnel will be in place to ensure that onsite and offsite resources can be brought to bear during an event.
3	Procedures will be in place to establish communication between onsite and offsite organizations during severe weather and seismic events.
4	An offsite resource plan will be developed which will include access to portable pumps and emergency power to supplement onsite resources. The plan would principally identify organizations or suppliers where offsite resources could be obtained in a timely manner.
5	SFP instrumentation will include readouts and alarms in the control room (or where personnel are stationed) for SFP temperature, water level, and area radiation levels.
6	SFP seals that could cause leakage leading to fuel uncovery in the event of seal failure shall be self limiting to leakage or otherwise engineered so that drainage cannot occur.
7	Procedures or administrative controls to reduce the likelihood of rapid draindown events will include (1) prohibitions on the use of pumps that lack adequate siphon protection or (2) controls for pump suction and discharge points. The functionality of anti-siphon devices will be periodically verified.
8	An onsite restoration plan will be in place to provide repair of the SFP cooling systems or to provide access for makeup water to the SFP. The plan will provide for remote alignment of the makeup source to the SFP without requiring entry to the refuel floor.
9	Procedures will be in place to control SFP operations that have the potential to rapidly decrease SFP inventory. These administrative controls may require additional operations or management review, management physical presence for designated operations or administrative limitations such as restrictions on heavy load movements
10	Routine testing of the alternative fuel pool makeup system components will be performed and administrative controls for equipment out of service will be implemented to provide added assurance that the components would be available, if needed.

The analysis in NUREG-1738 uses a probabilistic risk assessment that assumes both onsite and offsite resources:

Figure 4.4 Severe weather related loss of offsite power event tree



4.4.6 Summary

Table 4.4 presents a summary of basic events used in the event tree for Loss of Offsite Power from severe weather events.

As in the case of the loss of offsite power from plant centered and grid related events, based on the assumptions made, the frequency of fuel uncovery can be seen to be very low. Again, a careful and thorough adherence to NEI commitments 2, 5, 8 and 10, the assumption that walkdowns are performed on a regular, (once per shift) basis is important to compensate for potential failures to the instrumentation monitoring the status of the pool, the assumption that the procedures and/or training are explicit in giving guidance on the capability of the fuel pool makeup system, and when it becomes essential to supplement with alternate higher volume sources, the assumption that the procedures and training are sufficiently clear in giving guidance on early preparation for using the alternate makeup sources, are crucial to establishing the low frequency. NEI commitment 3, related to establishing communication between onsite and offsite organizations during severe weather, is also important, though its importance is somewhat obscured by the assumption of dependence between the events OMK and OFD. However, if no such provision were made, the availability of offsite resources could become more limiting.

Table 4.4 Basic Event Summary for Severe Weather Loss of Offsite Power Event Tree

Basic Event Name	Description	Basic Event Probability
IE-LP2	LOSP event because of severe-weather-related causes	1.1E-02
HEP-DIAG-SFPLP2	Operators fail to diagnose loss of SFP cooling because of loss of offsite power	1.0E-5
HEP-RECG-DEPEN	Failure to recognize need to cool pool given prior failure	5.0E-2
HEP-SFP-STR-LP2	Operators fail to restart and align the SFP cooling system once power is recovered	5.0E-4
HEP-RECG-FWST-SW	Operators fail to diagnose need to start the firewater system	1.0E-4
HEP-FW-START-SW	Operators fail to start firewater pump and provide alignment	1.0E-3
HEP-FW-REP-DEPSW	Repair crew fails to repair firewater system	7.0E-2
HEP-FW-REP-NODSW	Repair crew fails to repair firewater system	1.8E-2
HEP-INV-OFFST-SW	Operators fail to provide alternate sources of cooling from offsite	8.0E-2
REC-OSP-SW	Recovery of offsite power within 24 hours	2.0E-2
SPC-CKV-CCF-H	Heat exchanger discharge check valves – CCF	1.9E-5
SPC-CKV-CCF-M	SFP cooling pump discharge check valves - CCF	3.2E-5
SPC-HTX-CCF	SFP heat exchangers – CCF	1.9E-5
SPC-HTX-FTR	SFP heat exchanger cooling system fails	2.4E-4
SPC-HTX-PLG	Heat exchanger plugs	2.2E-5
SPC-PMP-CCF	SFP cooling pumps – common cause failure	5.9E-4
SPC-PMP-FTF-1	SFP cooling pump 1 fails to start and run	3.9E-3

Table 4.4 Continued. Basic Event Summary for Severe Weather Loss of Outside Power Event Tree

Basic Event Name	Description	Basic Event Probability
SPC-PMP-FTF-2	SFP cooling pump 2 fails to start and run	3.9E-3
FP-2PUMPS-FTF	Failure of firewater pump system	6.7E-4
FP-DGPUMP-FTF	Failure of the diesel-driven firewater pump	1.8E-1

Close examination of the "Loss of offsite power initiated by severe weather" scenario shows that the NRC's calculated low probability of a zirconium fire is heavily dependent on a number of assumptions: quick restoration of offsite power, availability of diesel fuel, intervention of onsite human operators, and availability of offsite assistance. But as previously outlined in this Petition, these assumptions are in doubt in a scenario of long-term and widespread commercial grid outage. Most significantly, the NRC probability calculation assumes a 98% chance of offsite power recovery within 24 hours; however, as previously discussed, it is likely to take 1-2 years to replace transformers damaged by severe space weather. As a result, previous NRC analysis of the probability of zirconium fires in spent fuel pools is not applicable to a scenario of long-term and widespread commercial grid outage caused by severe space weather.

Probability of Zirconium Fires Due to Severe Space Weather

Under current design criteria and licensure requirements, and assuming no long-term human operator intervention, and also assuming that zirconium-cladded fuel rods uncovered by water would spontaneously ignite, the probability of a zirconium fire in a spent fuel pool could be roughly approximated by the probability of a long-duration commercial grid outage to the associated nuclear power plant. As previously described in this Petition, for the 71 nuclear power reactors and associated spent fuel pools in an "Area of Probable Power System Collapse," the chance of a long-term commercial grid outage in any given year is 1.0E-2, or one in one hundred. If one were to assume no outside assistance for any nuclear power plant and spontaneous ignition of zirconium cladding regardless of time elapsed since removal of fuel rods from the reactor core, the probability of zirconium fire would be the same as the probability of long-term commercial grid outage.

While many might consider the above assumptions to be reasonable and realistic, for the purposes of this Petition, we propose that the probability of zirconium fires at spent fuel pools due to severe space weather and resulting long-term commercial grid outage would be more precisely determined by the individual probabilities of three events:

1. Severe space weather of sufficient intensity to cause long-term and widespread commercial grid outage.
2. Outside assistance becoming unavailable to nuclear power plants and associated spent fuel pools.
3. Spontaneous ignition of zirconium fire should fuel rods become uncovered by water.

We examine the probability of each of these events below and then calculate estimates for the overall probability of zirconium fires at multiple nuclear power plants and associated spent fuel pools.

Probability of Severe Space Weather and Resulting Commercial Grid Outage

Severe space weather caused by solar activity is a rare event that occurs much less frequently than other natural phenomena such as earthquakes, hurricanes, volcanic eruptions, wildfires, etc. Unlike other natural phenomena which are localized in their effects, severe space weather has the potential to affect large areas of the planet nearly simultaneously. The sun has a regular 11-year cycle of sunspot activity and throughout each cycle significant flares and Coronal Mass Ejections (CMEs) occur. Fortunately, the resulting Coronal Mass Ejections (CME) are not always pointed at earth, but those relatively small CMEs that do arrive at earth allow astronomers to observe and judge their statistical frequency while most activity on earth goes on unaffected.

A significant body of knowledge indicates large CMEs caused by solar activity hit the earth roughly every 100 years on average, implying a 1E-2 (1%) yearly probability. Two incidences of severe space weather have occurred in recently recorded history—the 1859 Carrington Event and an event of comparable magnitude in 1921**.** However, it should be noted that only these two storms have received recent scientific forensic analysis; there are a number of other significant storms that may be similarly large but have not as of yet received any detailed analysis in a modern forensic basis. Smaller CMEs hit the earth on a more regular basis, allowing researchers to imply the frequency and magnitude of more severe CMEs.

The effect of space weather on power grids is not theoretical or speculative—space weather has already caused widespread blackouts such as the 1989 Quebec blackout. Because nuclear power plants typically have large high voltage transformers under high base load, these plants and surrounding grid infrastructure are most likely to experience long-term commercial grid outage. For example, the same CME that caused the 1989 Quebec blackout permanently damaged a transformer at the Salem nuclear power plant in New Jersey.

Research on the effect of CMEs and resulting geomagnetic disturbance on power grids has been conducted for many years by multiple researchers. Below is the list of citations from the NERC and Department of Energy-sponsored report on High Impact Low Frequency events:

Additional References on Geomagnetic Disturbance Events:

1. P. R. Barnes and J. W. Van Dyke, “Potential Economic Costs From Geomagnetic Storms,” Geomagnetic Storm Cycle 22: Power System Problems on the Horizon, Special Panel Session Report, IEEE PES Summer Meeting, IEEE Publication 90TH0357-4-PWR,1990.
2. V. D. Albertson, “Geomagnetic Disturbance Causes and Power System Effects,” Effects of Solar-Geomagnetic Disturbances on Power Systems, Special Panel Session Report, IEEE PES Meeting, 90TH0291-5 PWR, , July 12, 1989.
3. Dan Nordell et al., “Solar Effects on Communications,” Geomagnetic Storm Cycle 22:Power System Problems on the Horizon, Special Panel Session Report, IEEE PES Summer Meeting, IEEE Publication 90TH0357-4-PWR,1990.
4. Robert J. Ringlee and James R. Stewart, “Geomagnetic Effects on Power Systems,” IEEE . Power Eng. Rev. 9(7), (July 1989).
5. P. R. Gattens et al., “Investigation of Transformer Overheating Due to Solar Magnetic Disturbances,” Effects of Solar-Geomagnetic Disturbances on Power Systems, Special

Panel Session Report, IEEE PES Summer Meeting, IEEE Publication 90TH0291-5 PWR,1989.

6. J. D. Aspnes and R. P. Merritt, “Effect of DC Excitation on Instrument Transformers, Geomagnetically Induced Currents,” IEEE Trans. Power Apparatus and Syst. PAS-102 (1 l), 3706-3712 (November 1983).
7. D. H. Boteler et al., “Effects of Geomagnetically Induced Currents in the B. C. Hydro 500 kV System,” IEEE Trans. Power Delivery 4(l), (January 1989).
8. IEEE Power System Relaying Committee, Working Group Kl 1, “The Effects of Solar Magnetic Disturbances on Protective Relaying, ” Geomagnetic Storm Cycle 22: Power System Problems on the Horizon, Special Panel Session Report, IEEE PES Summer Meeting, IEEE Publication 90TH0357-4-PWR, 1990.
9. D. Larose, “The Hydro-Québec System Blackout of March 13, 1989,” Effects of Solar Geomagnetic Disturbances on Power Systems, Special Panel Session Report, IEEE PES Summer Meeting, IEEE Publication 90TH0291-5 PWR, 1989.
10. D. A. Fagnan, P. R. Gattens, and R. D. Johnson, “Measuring GIC in Power Systems,” Geomagnetic Storm Cycle 22: Power System Problems on the Horizon, Special Panel Session Report, IEEE PES Summer Meeting, IEEE Publication 90TH0357-4-PWR,1990.
11. V. D. Albertson, “Measurements and Instrumentation for Disturbance Monitoring of Geomagnetic Storm Effects,” Eflects of Solar-Geomagnetic Disturbances on Power Systems, Special Panel Session Report, IEEE PES Summer Meeting, IEEE Publication 9OTHO291-5 PWR, 1989.
12. L. Bolduc et al., “Currents and Harmonics Generated in Power Transformers By DC Polarization,” presented at the meeting of the IEEE T&D Working Group on Geomagnetic Disturbances and Power System Effects, IEEE PES Summer Meeting, Minneapolis, Minn., July 18, 1990.

Other published research on the effect of space weather on electric grids includes:

1. J.G. Kappenman, L.J. Zanetti, W.A. Radasky, “Space Weather From a User’s Perspective: Geomagnetic Storm Forecasts and the Power Industry”, EOS Transactions of the American Geophysics Union, Vol 78, No. 4, January 28, 1997, pg 37-45.
2. J.G. Kappenman, W.A. Radasky, J.L. Gilbert, I.A. Erinmez, “Advanced Geomagnetic Storm Forecasting: A Risk Management Tool for Electric Power Operations”, IEEE Plasma Society Special Issue on Space Plasmas, December 2000, Vol 28, No. 6, pages 2114-2121.
3. I.A. Erinmez, J.G. Kappenman, W.A. Radasky, “Management of the Geomagnetically Induced Current Risks on the National Grid Company’s Electric Power Transmission System,” Journal of Atmospheric and Solar Terrestrial Physics (JASTP) Special Edition for NATO Space Weather Hazards Conference, June 2000, Vol 64, (2002) pp. 743-756.
4. W.A. Radasky, J.G. Kappenman, R. Pfeffer, “Nuclear and Space Weather Effects on the Electric Power Infrastructure,” NBC Report, Fall/Winter 2001, pages 37-42.
5. Kappenman, J. G., “Storm sudden commencement events and the associated geomagnetically induced current risks to ground-based systems at low-latitude and midlatitude locations,” Space Weather, 1(3), 1016, doi:10.1029/2003SW000009, 2003.
6. Kappenman, J., “The Evolving Vulnerability of Electric Power Grids,” Space Weather, 2, S01004, doi:10.1029/2003SW000028, 2004.
7. John G Kappenman, William A. Radasky, James L. Gilbert, “Electric Power Grid Vulnerability to Natural and Intentional Geomagnetic Disturbances,” 2005 Zurich EMC Conference Paper, February 2005.
8. Kappenman, J. and W. Radasky, “Too Important to Fail, Space Weather,” Space Weather, 3, S05001, doi:10.1029/2005SW000152, 2005.
9. John G. Kappenman, “Great Geomagnetic Storms and Extreme Impulsive Geomagnetic Field Disturbance Events – An Analysis of Observational Evidence including the Great Storm of May 1921,” 35th COSPAR Assembly publication in Advances in Space Research, August 2005.
10. Kappenman, J. G., “An overview of the impulsive geomagnetic field disturbances and power grid impacts associated with the violent Sun-Earth connection events of 29–31

> October 2003 and a comparative evaluation with other contemporary storms," Space Weather, 3, S08C01, doi:10.1029/2004SW000128, 2005.

Direct observations and extensive research clearly shows that the probability of long-term commercial grid outage caused by space weather falls well within the range that NRC considers reasonably foreseeable. Moreover, unless and until a better estimate is developed, the Oak Ridge National Laboratory probability estimate of 1E-2 (one in one hundred) per year for severe space weather sufficient to collapse two large portions of the North American power grid should be accepted.

Probability of Outside Assistance

Should electric power for active cooling of spent fuel pools cease, the probability preventing of a zirconium fire then becomes is largely dependent on the willingness and ability of human operators to remain onsite to operate and maintain the pump and firewater system. The use of ad-hoc systems to provide makeup water could be operationally challenging and risky to workers. NUREG-0933, "Resolution of Generic Safety Issues: Issue 82: Beyond Design Basis Accidents in Spent Fuel Pools," makes this clear:

> Ultimately, makeup to the pool could be supplied by bringing in a fire hose (60 gpm would suffice). Although one would expect that the failure probability associated with bringing in a hose (over a period of four or more days) would be very low, it must also be remembered that working next to 385,000 gallons of potentially contaminated boiling water on top of a 10-story building is not a trivial problem.

"Safety and Security of Commercial Spent Nuclear Fuel Storage" also examined the difficulty of supplying makeup water once active cooling has ceased and water has boiled off:

> Most immediately, ionizing radiation levels in the spent fuel building rise as the water level in the pool falls. Once the water level drops to within a few feet (a meter or so) of the tops of the fuel racks, elevated radiation fields could prevent direct access to the immediate areas around the lip of the spent fuel pool building by workers. This might hamper but would not necessarily prevent the application of mitigative measures, such as deployment of fire hoses to replenish the water in the pool.

Despite the human dangers of maintaining spent fuel pools under a condition of long-term loss of outside power, we assume for the purposes of this Petition that all necessary personnel are willing to remain on-site. Continued maintenance of spent fuel pools then is conditional on explicit and implicit provision of outside assistance. Explicit outside assistance could include fire trucks to pump makeup water and resupply of diesel fuel for backup generators. Implicit outside assistance would include supply of food and water for site personnel. Other implicit outside assistance would include ongoing security assistance by local authorities and provision of spare parts for cooling and makeup water systems.

In the event of long-term power loss affecting approximately one-third of the US population, including major east coast metropolitan areas, any long-term provision of outside assistance would be in doubt. In particular, when the power grid is down, it is dubious that one could call up the local fire department, order up a fire truck, have the fire truck and firefighter operators stay at the spent fuel site for a period of months or years, and obtain resupply of diesel fuel for the fire truck all the while.

The most pessimistic probability assumption would be for no long-term outside assistance. The lack of any Department of Homeland Security plan for long-term and widespread commercial grid outage buttresses this pessimistic assumption. Classified plans may exist for military assistance for nuclear power plants; however, even these plans would fall apart if military personnel have no long-term supplies of food and water. And if several dozen nuclear power plants were to be without outside power for an extended period, any available government resources would be stretched thin. Nonetheless, for the purposes of this Petition, we assume a 5E-1 (50%) chance of continuing outside assistance to nuclear power plants over a two year period, an assumption that many would find optimistic.

Probability of Zirconium Ignition after Becoming Uncovered by Water

As a bounding assumption, NUREG-1738 assumed that zirconium fire would occur if the tops of fuel rods became uncovered by water, regardless of complicating factors such as the length of time since the most recent refueling, density of fuel rods in the pool, and circulation of air within the spent fuel pool. Subsequent classified analysis of the probability of zirconium fires was performed by Sandia National Laboratories. "Mitigation of Spent Fuel Pool Loss-of-Coolant Inventory Accidents and Extension of Reference Plant Analyses to Other Spent Fuel Pools," Sandia Letter Report, Revision 2 (November 2006), incorporates and summarizes the Sandia Studies. This document is designated "Official Use Only—Security Related Information."

In response to a Freedom of Information Act request, a redacted version of a Sandia report, "MELCOR 1.8.5 Separate Effect Analyses of Spent Fuel Pool Assembly Accident Response," June 2003, was released. The original report consisted of 95 pages, but the redacted version consists of little more than a portion of the executive summary, principal headings in the table of contents, and a partial list of tables and figures. In total, the redacted version runs 12 pages, with nearly 5 pages of white space redactions. The report covered two scenarios: "Complete Loss-of-Coolant Inventory Accident" and "Partial Loss-of-Coolant Accident." The executive summary of this report reads in part:

> In 2001, United State Nuclear Regulatory Commission (NRC) staff performed an evaluation of the potential accident risk in a spent fuel pool (SFP) at decommissioning plants in the United States [NUREG-173 8]. The study was prepared to provide a technical basis for decommissioning rulemaking for permanently shutdown nuclear power plants. The study described a modeling approach of a typical decommissioning plant with design assumptions and industry commitments; the thermal-hydraulic analyses performed to evaluate spent fuel stored in the spent fuel pool at decommissioning plants; the risk assessment of spent fuel pool accidents; the consequence calculations; and the implications for decommissioning regulatory requirements. It was known that some of the assumptions in the accident progression in NUREG-1738 were necessarily conservative, especially the estimation of the fuel damage. Furthermore, the NRC desired to expand the study to include accidents in the spent fuel pools of operating power plants. Consequently, the NRC has continued spent fuel pool accident research by applying best-estimate computer codes to predict the severe accident progression following various postulated accident initiators. This report presents the results of separate effect calculations used to better understand the postulated accident behavior in SFPs.
>
> The MELCOR 1.8.5 severe accident computer code [Gauntt] was used to simulate the SFP accident response. MELCOR includes fuel degradation models for BWR and PWR fuel, radiation, convection, and conduction heat transfer models, air and steam oxidation models, hydrogen burn models, two-phase thermal-hydraulic models, and fission product release and transport models. Hence, it contains the basic models to address questions and phenomena expected during a spent fuel pool accident.

> Table E-1 summarizes the types of calculations that were performed. The types of calculations are divided into four parts; Part I - Decay heat evaluations, Part 2 - Separate Effect Air Cases, Part 3 - Separate Effect Water Cases, and Part 4 - Separate Effect Propagation Cases.

The body of the Sandia report reads in part:

> **Background**
>
> In 2001, the NRC staff performed an evaluation of the potential accident risk in a SFP at decommissioning plants in the United States [NUREG-1738]. The study was prepared to provide a technical basis for decommissioning rulemaking for permanently shutdown nuclear power plants. The study described a modeling approach of a typical decommissioning plant with design assumptions and industry commitments; the thermal-hydraulic analyses performed to evaluate spent fuel stored in the spent fuel pool at decommissioning plants; the risk assessment of spent fuel pool accidents; the consequence calculations; and the implications for decommissioning regulatory requirements. It was known that some of the assumptions in the accident progression in NUREG-1738 were necessarily conservative, especially the estimation of the fuel damage. Furthermore, the NRC desired to expand the study to include accidents in the spent fuel pools of operating power plants. Consequently, the NRC has continued spent fuel pool accident research by applying best-estimate computer codes to predict the severe accident progression following various postulated accident initiators. The present report documents the use of separate effect models to develop a methodology to perform SFP accident analyses as well as to assess the importance of uncertain and variable parameters. In Section 1.1, a description of the key phenomena expected in a SFP accident is presented. Two types of SFP accidents will be described, air cases and partial water cases. The present report examines the coolability of various assembly configurations to both complete and partial loss-of-coolant inventory accident (i.e., air and water cases, respectively). Next, Section 2 discusses the SFP geometry, the analysis methodology, and the MELCOR separate effects input model. Section 3 gives the results from the simulations. Finally, Section 4 gives the conclusions and Section 5 gives the references.

Petitioner does not know the complete contents of the classified Sandia studies. However, any reasonable person would conclude that there are certainly some circumstances under which zirconium cladding will spontaneously heat up and catch fire. If this was not true, the reports would not be classified.

Nearly all spent fuel pools store fuel rods in high density racks surrounded by boron partitions to prevent criticality. Under a gradual boil-off scenario, the water at the bottom of the partitions would prevent natural air convection cooling from occurring. Gradual boil-off would be the least favorable convection cooling case and as a result, the chance of spontaneous zirconium ignition is greatly increased. The National Academies of Science report, "Safety and Security of Commercial Spent Nuclear Fuel Storage," describes the risk of spontaneous zirconium ignition in the case of gradual boil-off, here referred to as a “partial-loss-of-pool-coolant” scenario:

> The global analysis modeled the actual design and fuel loading pattern of the reference BWR spent fuel pool. The pool was divided into seven regions based on fuel age. Within each of those seven regions, the model for the fuel racks was subdivided into 16 zones. The grouping of assemblies into zones reduced the computational requirements compared to modeling every assembly.[18] Two scenarios were examined: (1) a complete loss-of-pool-coolant scenario in which the pool is drained to a level below the bottom of spent fuel assemblies; and (2) a partial-loss-of-pool-coolant scenario in which water levels in the pool drain to a level somewhere between the top and bottom of the fuel assemblies. In the former case, a convective air circulation path can be established along the entire length of the fuel assemblies, which promotes convective air cooling of the fuel, in the latter case, an effective air circulation path cannot form because the bottom of

> the assembly is blocked by water. Steam is generated by boiling of the pool water, and the zirconium cladding oxidation reaction produces hydrogen gas. This analysis suggests that circulation blockage has a significant impact on thermal behavior of the fuel assemblies. The specific impact depends on the depth to which the pool is drained.
>
> The global analysis examined the thermal behavior of fuel assemblies in the pool at 1, 3, and 12 months after the offloading of one-third of a core of spent fuel from the reactor. Sensitivity studies were carried out to assess the importance of radiation heat transfer between different regions of the pool, the effects of building damage on releases of radioactive material to the environment, and the effects of varying the assumed location and size of the hole in the pool wall.
>
> The results of these analyses are provided in the committee’s classified report. For some scenarios, the fuel could be air cooled within a relatively short time after its removal from the reactor. If a loss-of-coolant event took place before the fuel could be air cooled, however, a zirconium cladding fire could be initiated if no mitigative actions were taken. Such fires could release some of the fuel’s radioactive material inventory to the environment in the form of aerosols.
>
> ***For a partial-loss-of-pool-coolant event, the analysis indicates that the potential for zirconium cladding fires would exist for an even greater time (compared to the complete-loss-of-pool-coolant event) after the spent fuel was discharged from the reactor because air circulation can be blocked by water at the bottom of the pool.*** Thermal coupling between adjacent assemblies will be due primarily to radiative rather than convective heat transfer. However, this heat transfer mode has been modeled simplistically in the MELCOR runs performed by Sandia.
>
> (Emphasis not in original.)

A key finding of the National Academy of Sciences "Safety and Security of Commercial Spent Nuclear Fuel Storage" report confirms that spent fuel stored in water pools needs an active heat removal system for at least one year after removal from the reactor core:

> **FINDING 3A**: Pool storage is required at all operating commercial nuclear power plants to cool newly discharged spent fuel. Freshly discharged spent fuel generates too much decay heat to be passively air cooled. This fuel must be stored in a pool that has an active heat removal system (i.e., water pumps and heat exchangers) for at least one year before being moved to dry storage. Most dry storage systems are licensed to store fuel that has been out of the reactor for at least five years. Although spent fuel younger than five years could be stored in dry casks, the changes required for shielding and heat-removal could be substantial, especially for fuel that has been discharged for less than about three years.

For the purposes of this Petition, we assume that if spent fuel rods that have been outside the reactor core for one year or less, they will spontaneously ignite if gradual water boil-off and uncovering of fuel rods occurs. Nuclear power plants have a typical refueling cycle of 18-24 months. Here we make the optimistic assumption that refueling takes place every 24 months. As a result, at any random point in time, there would be 50% chance of spontaneous zirconium cladding ignition, because half of the time between refueling the rods would have been out of the core one year or less (12 months/24 months = 50%).

Plant-Specific Probability of Zirconium Cladding Fires

To calculate the plant-specific probability of zirconium cladding fires at spent fuel pools, one must multiply the individual probabilities of three factors:

- Probability of long-term Loss of Outside Power (LOOP)
- Probability of outside aassistance
- Probability of spontaneous zirconium ignition

The probability of long-term LOOP at a specific nuclear power plant is dependent on the probability of severe space weather and resulting power system collapse in any given year and also dependent on the number of years remaining in reactor licensure period. The probability of LOOP can be calculated using the probability formula:

$$Pt = 1 – (1\text{-}Py)^{Yt}$$

Where:

Pt = Total Probability
Py = Individual Year Probability
Yt = Number of Years

Notably, under this formula, there is never a 100% probability of an event occurring, even over a specific period of 100 years if the yearly probability is one-in-one-hundred, or 1%. In fact, the probability for a specific one-hundred year period is 63%. For a specific 150 year period the probability is 78%. (Although over a long period, events would occur every one hundred years, *on average*.) With understanding of this formula, one can see why although 150 years has passed since the 1859 Carrington Event, the passage of time without another space weather event of comparable magnitude is not proof that another event will not likely occur. (It does show, however, that the United States has been extraordinarily lucky that a severe space weather event has not occurred since the post-World War II build-out of the modern high voltage electric grid.)

As previously described in this Petition, we assume the probability of no outside assistance to be 50% and the probability of spontaneous ignition of zirconium cladding to be 50%. When calculations are done on a plant-specific basis, zirconium fire probabilities range from 0.3% at Vermont Yankee to 7.9% at Vogtle 2 in Georgia.

Probability of Zirconium Fire at Spent Fuel Pools

Preliminary Estimates Over Remaining Reactor Operation

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Probability of No Outside Assistance	**50%**
Probability of Spontaneous Zirconium Ignition	**50%**

Within Area of Probable Power System Collapse	State	Plant	Years Remaining in Reactor Operation	Long-Term LOOP Probability	Probability of Water Boil-Off	Zirconium Fire Probability
yes	Alabama	Browns Ferry 1	22	19.8%	9.9%	5.0%
yes	Alabama	Browns Ferry 2	23	20.6%	10.3%	5.2%
yes	Alabama	Browns Ferry 3	25	22.2%	11.1%	5.6%
no	Alabama	Farley 1	26	0.0%	0.0%	0.0%
no	Alabama	Farley 2	30	0.0%	0.0%	0.0%
no	Arizona	Palo Verde 1	14	0.0%	0.0%	0.0%
no	Arizona	Palo Verde 2	15	0.0%	0.0%	0.0%
no	Arizona	Palo Verde 3	16	0.0%	0.0%	0.0%
no	Arkansas	Arkansas Nuclear 1	23	0.0%	0.0%	0.0%
no	Arkansas	Arkansas Nuclear 2	27	0.0%	0.0%	0.0%
no	California	Diablo Canyon 1	13	0.0%	0.0%	0.0%
no	California	Diablo Canyon 2	14	0.0%	0.0%	0.0%
no	California	San Onofre 2	11	0.0%	0.0%	0.0%
no	California	San Onofre 3	11	0.0%	0.0%	0.0%
yes	Connecticut	Millstone 2	24	21.4%	10.7%	5.4%
yes	Connecticut	Millstone 3	34	28.9%	14.5%	7.2%
no	Florida	Crystal River 3	5	0.0%	0.0%	0.0%
no	Florida	St Lucie 1	25	0.0%	0.0%	0.0%
no	Florida	St Lucie 2	32	0.0%	0.0%	0.0%
no	Florida	Turkey Point 3	21	0.0%	0.0%	0.0%
no	Florida	Turkey Point 4	22	0.0%	0.0%	0.0%
yes	Georgia	Hatch 1	23	20.6%	10.3%	5.2%
yes	Georgia	Hatch 2	27	23.8%	11.9%	5.9%
yes	Georgia	Vogtle 1	36	30.4%	15.2%	7.6%
yes	Georgia	Vogtle 2	38	31.7%	15.9%	7.9%
yes	Illinois	Braidwood 1	15	14.0%	7.0%	3.5%
yes	Illinois	Braidwood 2	16	14.9%	7.4%	3.7%
yes	Illinois	Byron 1	13	12.2%	6.1%	3.1%
yes	Illinois	Byron 2	15	14.0%	7.0%	3.5%

Probability of Zirconium Fire at Spent Fuel Pools

Preliminary Estimates Over Remaining Reactor Operation

Probability of No Outside Assistance	**50%**
Probability of Spontaneous Zirconium Ignition	**50%**

Within Area of Probable Power System Collapse	State	Plant	Years Remaining in Reactor Operation	Long-Term LOOP Probability	Probability of Water Boil-Off	Zirconium Fire Probability
yes	Illinois	Clinton	15	14.0%	7.0%	3.5%
yes	Illinois	Dresden 2	18	16.5%	8.3%	4.1%
yes	Illinois	Dresden 3	20	18.2%	9.1%	4.6%
yes	Illinois	La Salle 1	11	10.5%	5.2%	2.6%
yes	Illinois	La Salle 2	12	11.4%	5.7%	2.8%
no	Illinois	Quad Cities 1	21	0.0%	0.0%	0.0%
no	Illinois	Quad Cities 2	21	0.0%	0.0%	0.0%
no	Iowa	Duane Arnold	3	0.0%	0.0%	0.0%
no	Kansas	Wolf Creek	34	0.0%	0.0%	0.0%
no	Louisiana	River Bend	14	0.0%	0.0%	0.0%
no	Louisiana	Waterford	13	0.0%	0.0%	0.0%
yes	Maryland	Calvert Cliffs 1	23	20.6%	10.3%	5.2%
yes	Maryland	Calvert Cliffs 2	25	22.2%	11.1%	5.6%
yes	Massachusetts	Pilgrim	1	1.0%	0.5%	0.3%
yes	Michigan	Cook 1	23	20.6%	10.3%	5.2%
yes	Michigan	Cook 2	26	23.0%	11.5%	5.7%
yes	Michigan	Enrico Fermi 2	14	13.1%	6.6%	3.3%
yes	Michigan	Palisades	20	18.2%	9.1%	4.6%
no	Minnesota	Monticello	19	0.0%	0.0%	0.0%
no	Minnesota	Prairie Island 1	2	0.0%	0.0%	0.0%
no	Minnesota	Prairie Island 2	3	0.0%	0.0%	0.0%
no	Mississippi	Grand Gulf	13	0.0%	0.0%	0.0%
no	Missouri	Callaway	13	0.0%	0.0%	0.0%
no	Nebraska	Cooper	3	0.0%	0.0%	0.0%
no	Nebraska	Fort Calhoun	22	0.0%	0.0%	0.0%
yes	New Hampshire	Seabrook	19	17.4%	8.7%	4.3%
yes	New Jersey	Hope Creek	15	14.0%	7.0%	3.5%
yes	New Jersey	Oyster Creek	18	16.5%	8.3%	4.1%
yes	New Jersey	Salem 1	5	4.9%	2.5%	1.2%
yes	New Jersey	Salem 2	9	8.6%	4.3%	2.2%

Probability of Zirconium Fire at Spent Fuel Pools

Preliminary Estimates Over Remaining Reactor Operation

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Probability of No Outside Assistance	**50%**
Probability of Spontaneous Zirconium Ignition	**50%**

Within Area of Probable Power System Collapse	State	Plant	Years Remaining in Reactor Operation	Long-Term LOOP Probability	Probability of Water Boil-Off	Zirconium Fire Probability
yes	New York	FitzPatrick	23	20.6%	10.3%	5.2%
yes	New York	Ginna	18	16.5%	8.3%	4.1%
yes	New York	Indian Point 2	2	2.0%	1.0%	0.5%
yes	New York	Indian Point 3	4	3.9%	2.0%	1.0%
yes	New York	Nine Mile Point 1	18	16.5%	8.3%	4.1%
yes	New York	Nine Mile Point 2	35	29.7%	14.8%	7.4%
yes	North Carolina	Brunswick 1	25	22.2%	11.1%	5.6%
yes	North Carolina	Brunswick 2	23	20.6%	10.3%	5.2%
yes	North Carolina	Harris	35	29.7%	14.8%	7.4%
yes	North Carolina	McGuire 1	30	26.0%	13.0%	6.5%
yes	North Carolina	McGuire 2	32	27.5%	13.8%	6.9%
yes	Ohio	Davis-Bessie	6	5.9%	2.9%	1.5%
yes	Ohio	Perry	15	14.0%	7.0%	3.5%
yes	Pennsylvania	Beaver Valley 1	5	4.9%	2.5%	1.2%
yes	Pennsylvania	Beaver Valley 2	16	14.9%	7.4%	3.7%
yes	Pennsylvania	Limerick 1	13	12.2%	6.1%	3.1%
yes	Pennsylvania	Limerick 2	18	16.5%	8.3%	4.1%
yes	Pennsylvania	Peach Bottom 2	22	19.8%	9.9%	5.0%
yes	Pennsylvania	Peach Bottom 3	23	20.6%	10.3%	5.2%
yes	Pennsylvania	Susquehanna 1	11	10.5%	5.2%	2.6%
yes	Pennsylvania	Susquehanna 2	13	12.2%	6.1%	3.1%
yes	Pennsylvania	Three Mile Island	23	20.6%	10.3%	5.2%
yes	South Carolina	Catawba 1	32	27.5%	13.8%	6.9%
yes	South Carolina	Catawba 2	32	27.5%	13.8%	6.9%
yes	South Carolina	Oconee 1	22	19.8%	9.9%	5.0%
yes	South Carolina	Oconee 2	22	19.8%	9.9%	5.0%
yes	South Carolina	Oconee 3	23	20.6%	10.3%	5.2%
yes	South Carolina	Robinson	19	17.4%	8.7%	4.3%
yes	South Carolina	Summer	31	26.8%	13.4%	6.7%

Probability of Zirconium Fire at Spent Fuel Pools

Preliminary Estimates Over Remaining Reactor Operation

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Probability of No Outside Assistance	**50%**
Probability of Spontaneous Zirconium Ignition	**50%**

Within Area of Probable Power System Collapse	State	Plant	Years Remaining in Reactor Operation	Long-Term LOOP Probability	Probability of Water Boil-Off	Zirconium Fire Probability
yes	Tennessee	Sequoyah 1	9	8.6%	4.3%	2.2%
yes	Tennessee	Sequoyah 2	10	9.6%	4.8%	2.4%
yes	Tennessee	Watts Bar	24	21.4%	10.7%	5.4%
no	Texas	Comanche Peak 1	19	0.0%	0.0%	0.0%
no	Texas	Comanche Peak 2	22	0.0%	0.0%	0.0%
no	Texas	South Texas 1	16	0.0%	0.0%	0.0%
no	Texas	South Texas 2	17	0.0%	0.0%	0.0%
yes	Vermont	Vermont Yankee	1	1.0%	0.5%	0.3%
yes	Virginia	North Anna 1	27	23.8%	11.9%	5.9%
yes	Virginia	North Anna 2	29	25.3%	12.6%	6.3%
yes	Virginia	Surry 1	21	19.0%	9.5%	4.8%
yes	Virginia	Surry 2	22	19.8%	9.9%	5.0%
yes	Washington	Columbia	12	11.4%	5.7%	2.8%
yes	Wisconsin	Kewaunee	2	2.0%	1.0%	0.5%
yes	Wisconsin	Point Beach 1	19	17.4%	8.7%	4.3%
yes	Wisconsin	Point Beach 2	22	19.8%	9.9%	5.0%

Probable Fatalities Due to Zirconium Cladding Fires

NUREG-1738 predicted early fatalities and long-term consequences should zirconium cladding fires occur. A summary of tabular information in NUREG-1738 concludes:

> An examination of Figure 3.7-1 indicates the following:
>
> - ***Early fatality consequences for spent fuel pool accidents can be as large as for a severe reactor accident even if the fuel has decayed several years.*** This is attributable to the significant health effect of ruthenium, and the ruthenium-106 half-life of about 1 year. There is also an important but lesser contribution from cesium.
> - A large ruthenium release fraction is important to consequences, but not more important than the consequences of a reactor accident large early release.
> - The effect of early evacuation (if possible) is to offset the effect of a large ruthenium release fraction. This effect is comparable to that for reactor accidents.
> - For the low ruthenium source term, no early fatality is expected after 1 year decay even with late evacuation.
>
> For the longer term consequences Figure 3.7-2 indicates:
>
> - ***Long-term consequences remain significant as long as a fire is possible. These consequences are due primarily to the effect of cesium-137, which remains abundant even in significantly older fuel because of its long (30-year) half-life.*** Ruthenium and evacuation have notable long-term consequences but do not change the conclusion.
>
> (Emphasis added.)

NUREG-1738 contains the following estimates of individual fatality risk:

Table 3.7-2 Consequences of an SFP Accident With a Low Ruthenium Source Term (per event)

Time After Shutdown	Mean Consequences for Low Ruthenium Source Term (Surry population, 95% evacuation)			
	Early Fatalities	Societal Dose (p-rem within 50 miles)	Individual Risk* of Early Fatality (within 1mile)	Individual Risk* of Latent Cancer Fatality (within 10 miles)
Late Evacuation				
30 days	2	5.58×10^{6}	1.27×10^{-2}	1.88×10^{-2}
90 days	1	5.43×10^{6}	9.86×10^{-3}	1.82×10^{-2}
1 year	1	5.28×10^{6}	7.13×10^{-3}	1.68×10^{-2}
2 years	-	5.12×10^{6}	5.64×10^{-3}	1.58×10^{-2}
5 years	-	4.90×10^{6}	3.18×10^{-3}	1.43×10^{-2}
10 years	-	4.72×10^{6}	1.63×10^{-3}	1.29×10^{-2}
Early Evacuation				
30 days	-	4.12×10^{6}	8.36×10^{-4}	9.92×10^{-4}
90 days	-	4.02×10^{6}	6.83×10^{-4}	9.62×10^{-4}
1 year	-	3.95×10^{6}	5.44×10^{-4}	9.09×10^{-4}
2 years	-	3.87×10^{6}	4.41×10^{-4}	8.71×10^{-4}
5 years	-	3.77×10^{6}	2.54×10^{-4}	8.14×10^{-4}
10 years	-	3.69×10^{6}	1.47×10^{-4}	7.70×10^{-4}

* Conditional on event - Total frequency for all events is shown in Table 3.1 as less than 3×10^{-6} per year.

The consequences in Table 3.7-1 are based on the upper bound source term described in Appendix 4B. With the exception of ruthenium and fuel fines, the release fractions are from NUREG-1465, "Accident Source Terms for Light-Water Nuclear Power Plants" (Ref. 1), and include the ex-vessel and late in-vessel phase releases. The ruthenium release fraction is for a volatile fission product in an oxidic (rather than metallic) form. This is consistent with the experimental data reported in Reference 8. The source term is considered to be bounding for several reasons. First, rubbling of the spent fuel after heatup to about 2500 OK is expected to limit the potential for ruthenium release to a value less than that for volatile fission products. Second, following the Chernobyl accident, ruthenium in the environment was found to be in the metallic form (Ref. 2). Metallic ruthenium (Ru-106) has about a factor of 50 lower dose conversion factor (rem per Curie inhaled) than the oxidic ruthenium assumed in the Melcor Accident Consequence Code System (MACCS) calculations. Finally, the fuel fines release fraction is that from the Chernobyl accident (Ref. 3). This is considered to be bounding because the Chernobyl accident involved more extreme conditions (i.e., two explosions followed by a prolonged graphite fire) than an SFP accident. In subsequent discussions, this source term is referred to as the high ruthenium source term.

The consequences obtained using the source term in NUREG-1465 (which treats ruthenium as a less volatile fission product) in conjunction with SFP fission product inventories are provided in Table 3.7-2 for comparison. In subsequent discussions, this source term is referred to as the low ruthenium source term.

> The consequence calculations for both the high and low ruthenium source terms assume that all of the fuel assemblies discharged in the final core off-load and the previous 10 refueling outages participate in the SFP fire. These assemblies are equivalent to about 3.5 reactor cores. Approximately 85 percent of all the ruthenium in the pool is in the last core off-loaded since the ruthenium-1 06 half-life is about 1 year. For cesium-1 37, with a 30-year half-life, the inventory decays very slowly and is abundant in all of the batches considered. The staff assumed that the number of fuel assemblies participating in the SFP fire remains constant and did not consider the possibility that fewer assemblies might be involved in an SFP fire in later years because of substantially lower decay heat in the older assemblies. Based on the limited analyses performed to date, fire propagation is expected to be limited to less than two full cores 1 year after shutdown (see Appendix 1A). Thus, the assumption that 3.5 cores participate adds some conservatism to the calculation of long-terms effects associated with cesium, but is not important with regard to the effects of ruthenium.

The above fatality estimates were originally developed for the population surrounding the Surry site in Virginia but as NUREG-1738 describes, the estimates can be applied to other populations because they are for individual risk rather than population risk. For the purposes of analysis in this petition, we selected the individual risks for one year after shutdown, the equivalent of one year after removal of fuel rods from the reactor core. For optimism, we used individual risk estimates for "Consequences of an SPF Accident With a Low Ruthenium Source Term (per event)," as specified in Table 3.7-2 in NUREG-1738, instead of the high ruthenium source term estimates. We also selected the "95% Late Evacuation" scenario; while the actual evacuation percentage might be substantially lower in the case of grid outage and attendant communication system failures, we confine ourselves to the NUREG-1738 fatality estimates for the sake of optimism.

Population within a radius of plant sites can be estimated using block data from the 2000 US Census (the most recent data currently available). For each plant we obtained the population within 1 mile and 10 mile radiuses using the LandView6 computer program from the US Census Bureau. Zirconium fire probabilities for each plant can be multiplied by population and individual risk factors to obtain probable early fatalities and cancer deaths.

Because most nuclear power plants are located in unpopulated areas, the number of residents within 1 mile of plants is low in most cases. In fact, 37 out of 104 plant sites have no residents within 1 mile. Accordingly, the estimates for early fatalities are low.

However, the number of people living within 10 miles of nuclear power plant sites is more significant, ranging from 2,851 for the Columbia site in Washington State to 257,474 at the Indian Point site north of New York City.

For some plants, probable deaths are zero because they are sited outside of the Area of Probable Power System Collapse. Over the United States as a whole, including areas outside of the Area of Probable Power System Collapse, we estimate 3.92 probable early fatalities and 3,170 probable cancer deaths for the period over which the reactors continue operating.

Probable Fatalities Due to Loss of Power for Spent Fuel Pools

Preliminary Estimates Over Remaining Reactor Operation

Page 1 of 4

Probability of No Outside Assistance **50%**
Probability of Spontaneous Zirconium Ignition **50%**

Within Area of Probable Power System Collapse	State	Plant	Zirconium Fire Probability	Pop. within 1 Mile	Pop. within 10 Miles	Probable Early Fatalities	Probable Cancer Fatalities
yes	Alabama	Browns Ferry 1	5.0%	0	32,751	0.00	27
yes	Alabama	Browns Ferry 2	5.2%	0	32,751	0.00	28
yes	Alabama	Browns Ferry 3	5.6%	0	32,751	0.00	31
no	Alabama	Farley 1	0.0%	0	9,795	0.00	0
no	Alabama	Farley 2	0.0%	0	9,795	0.00	0
no	Arizona	Palo Verde 1	0.0%	0	3,302	0.00	0
no	Arizona	Palo Verde 2	0.0%	0	3,302	0.00	0
no	Arizona	Palo Verde 3	0.0%	0	3,302	0.00	0
no	Arkansas	Arkansas Nuclear 1	0.0%	231	45,451	0.00	0
no	Arkansas	Arkansas Nuclear 2	0.0%	231	45,451	0.00	0
no	California	Diablo Canyon 1	0.0%	0	24,084	0.00	0
no	California	Diablo Canyon 2	0.0%	0	24,084	0.00	0
no	California	San Onofre 2	0.0%	0	74,169	0.00	0
no	California	San Onofre 3	0.0%	0	74,169	0.00	0
yes	Connecticut	Millstone 2	5.4%	517	117,615	0.20	106
yes	Connecticut	Millstone 3	7.2%	517	117,615	0.27	143
no	Florida	Crystal River 3	0.0%	0	18,663	0.00	0
no	Florida	St Lucie 1	0.0%	0	160,073	0.00	0
no	Florida	St Lucie 2	0.0%	0	160,073	0.00	0
no	Florida	Turkey Point 3	0.0%	0	104,389	0.00	0
no	Florida	Turkey Point 4	0.0%	0	104,389	0.00	0
yes	Georgia	Hatch 1	5.2%	0	8,339	0.00	7
yes	Georgia	Hatch 2	5.9%	0	8,339	0.00	8
yes	Georgia	Vogtle 1	7.6%	0	2,990	0.00	4
yes	Georgia	Vogtle 2	7.9%	0	2,990	0.00	4
yes	Illinois	Braidwood 1	3.5%	884	32,361	0.22	19
yes	Illinois	Braidwood 2	3.7%	884	32,361	0.23	20
yes	Illinois	Byron 1	3.1%	21	24,887	0.00	13
yes	Illinois	Byron 2	3.5%	21	24,887	0.01	15

Probable Fatalities Due to Loss of Power for Spent Fuel Pools

Preliminary Estimates Over Remaining Reactor Operation

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Probability of No Outside Assistance	**50%**
Probability of Spontaneous Zirconium Ignition	**50%**

Within Area of Probable Power System Collapse	State	Plant	Zirconium Fire Probability	Pop. within 1 Mile	Pop. within 10 Miles	Probable Early Fatalities	Probable Cancer Fatalities
yes	Illinois	Clinton	3.5%	0	12,326	0.00	7
yes	Illinois	Dresden 2	4.1%	134	64,843	0.04	45
yes	Illinois	Dresden 3	4.6%	134	64,843	0.04	50
yes	Illinois	La Salle 1	2.6%	5	13,923	0.00	6
yes	Illinois	La Salle 2	2.8%	5	13,923	0.00	7
no	Illinois	Quad Cities 1	0.0%	0	30,985	0.00	0
no	Illinois	Quad Cities 2	0.0%	0	30,985	0.00	0
no	Iowa	Duane Arnold	0.0%	7	101,695	0.00	0
no	Kansas	Wolf Creek	0.0%	0	4,846	0.00	0
no	Louisiana	River Bend	0.0%	53	24,633	0.00	0
no	Louisiana	Waterford	0.0%	256	80,758	0.00	0
yes	Maryland	Calvert Cliffs 1	5.2%	30	40,524	0.01	35
yes	Maryland	Calvert Cliffs 2	5.6%	30	40,524	0.01	38
yes	Massachusetts	Pilgrim	0.3%	613	69,854	0.01	3
yes	Michigan	Cook 1	5.2%	114	53,351	0.04	46
yes	Michigan	Cook 2	5.7%	114	53,351	0.05	52
yes	Michigan	Enrico Fermi 2	3.3%	21	87,086	0.00	48
yes	Michigan	Palisades	4.6%	29	31,619	0.01	24
no	Minnesota	Monticello	0.0%	94	43,181	0.00	0
no	Minnesota	Prairie Island 1	0.0%	219	26,923	0.00	0
no	Minnesota	Prairie Island 2	0.0%	219	26,923	0.00	0
no	Mississippi	Grand Gulf	0.0%	0	7,628	0.00	0
no	Missouri	Callaway	0.0%	11	6,238	0.00	0
no	Nebraska	Cooper	0.0%	0	4,665	0.00	0
no	Nebraska	Fort Calhoun	0.0%	17	17,244	0.00	0
yes	New Hampshire	Seabrook	4.3%	852	117,769	0.26	86
yes	New Jersey	Hope Creek	3.5%	0	32,622	0.00	19
yes	New Jersey	Oyster Creek	4.1%	1,275	120,110	0.38	83
yes	New Jersey	Salem 1	1.2%	0	32,622	0.00	7
yes	New Jersey	Salem 2	2.2%	0	32,622	0.00	12

Probable Fatalities Due to Loss of Power for Spent Fuel Pools

Preliminary Estimates Over Remaining Reactor Operation

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Probability of No Outside Assistance	**50%**
Probability of Spontaneous Zirconium Ignition	**50%**

Within Area of Probable Power System Collapse	State	Plant	Zirconium Fire Probability	Pop. within 1 Mile	Pop. within 10 Miles	Probable Early Fatalities	Probable Cancer Fatalities
yes	New York	FitzPatrick	5.2%	10	38,737	0.00	34
yes	New York	Ginna	4.1%	177	53,810	0.05	37
yes	New York	Indian Point 2	0.5%	1,510	257,474	0.05	22
yes	New York	Indian Point 3	1.0%	1,510	257,474	0.11	43
yes	New York	Nine Mile Point 1	4.1%	10	38,571	0.00	27
yes	New York	Nine Mile Point 2	7.4%	10	38,571	0.01	48
yes	North Carolina	Brunswick 1	5.6%	314	24,186	0.12	23
yes	North Carolina	Brunswick 2	5.2%	314	24,186	0.12	21
yes	North Carolina	Harris	7.4%	0	53,629	0.00	67
yes	North Carolina	McGuire 1	6.5%	120	118,694	0.06	130
yes	North Carolina	McGuire 2	6.9%	120	118,694	0.06	137
yes	Ohio	Davis-Bessie	1.5%	90	17,061	0.01	4
yes	Ohio	Perry	3.5%	189	76,201	0.05	45
yes	Pennsylvania	Beaver Valley 1	1.2%	470	145,409	0.04	30
yes	Pennsylvania	Beaver Valley 2	3.7%	470	145,409	0.12	91
yes	Pennsylvania	Limerick 1	3.1%	661	213,586	0.14	110
yes	Pennsylvania	Limerick 2	4.1%	661	213,586	0.19	148
yes	Pennsylvania	Peach Bottom 2	5.0%	127	41,081	0.04	34
yes	Pennsylvania	Peach Bottom 3	5.2%	127	41,081	0.05	36
yes	Pennsylvania	Susquehanna 1	2.6%	163	53,058	0.03	23
yes	Pennsylvania	Susquehanna 2	3.1%	163	53,058	0.04	27
yes	Pennsylvania	Three Mile Island	5.2%	358	185,780	0.13	161
yes	South Carolina	Catawba 1	6.9%	191	140,492	0.09	162
yes	South Carolina	Catawba 2	6.9%	191	140,492	0.09	162
yes	South Carolina	Oconee 1	5.0%	18	71,183	0.01	59
yes	South Carolina	Oconee 2	5.0%	18	71,183	0.01	59
yes	South Carolina	Oconee 3	5.2%	18	71,183	0.01	62
yes	South Carolina	Robinson	4.3%	600	33,649	0.19	25
yes	South Carolina	Summer	6.7%	24	10,567	0.01	12

Probable Fatalities Due to Loss of Power for Spent Fuel Pools

Preliminary Estimates Over Remaining Reactor Operation

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Probability of No Outside Assistance **50%**

Probability of Spontaneous Zirconium Ignition **50%**

Within Area of Probable Power System Collapse	State	Plant	Zirconium Fire Probability	Pop. within 1 Mile	Pop. within 10 Miles	Probable Early Fatalities	Probable Cancer Fatalities
yes	Tennessee	Sequoyah 1	2.2%	637	83,152	0.10	30
yes	Tennessee	Sequoyah 2	2.4%	637	83,152	0.11	33
yes	Tennessee	Watts Bar	5.4%	0	19,322	0.00	17
no	Texas	Comanche Peak 1	0.0%	0	28,126	0.00	0
no	Texas	Comanche Peak 2	0.0%	0	28,126	0.00	0
no	Texas	South Texas 1	0.0%	0	2,779	0.00	0
no	Texas	South Texas 2	0.0%	0	2,779	0.00	0
yes	Vermont	Vermont Yankee	0.3%	412	33,943	0.01	1
yes	Virginia	North Anna 1	5.9%	93	15,516	0.04	15
yes	Virginia	North Anna 2	6.3%	93	15,516	0.04	16
yes	Virginia	Surry 1	4.8%	0	117,247	0.00	94
yes	Virginia	Surry 2	5.0%	0	117,247	0.00	98
yes	Washington	Columbia	2.8%	4	2,851	0.00	1
yes	Wisconsin	Kewaunee	0.5%	35	9,911	0.00	1
yes	Wisconsin	Point Beach 1	4.3%	2	20,361	0.00	15
yes	Wisconsin	Point Beach 2	5.0%	2	20,361	0.00	17
Totals						**3.92**	**3,170**

Event Fatalities Due to Power System Collapse

While the preceding analysis examined probable fatalities due to power system collapse, actual fatalities would not be piecemeal—either radiation release would occur and result in fatalities, or not. In the present section, we show a projection of total fatalities from zirconium fires and radiation release. To avoid double-counting of population surrounding nuclear power plants and spent fuel pools, the analysis is done on a per-site basis rather than a per-pool basis.

The MELCOR severe accident computer code used by the NRC estimates fatalities based on societal dose of radiation, using a linear relationship between dose and fatalities. If two spent fuel pools ignite rather than one, the projected fatalities would be twice as large. Accordingly the below analysis multiplies the individual risk of fatalities from NUREG-1738 by the number of reactors (and associated spent fuel pools) at a site.

Our analysis shows that 11,598 individuals live within 1 mile of nuclear power plant sites and 3.6 million live within 10 miles of sites. In the event of a long-term commercial power grid collapse, 119 early fatalities and 77,705 cancer deaths are projected, assuming that outside assistance cannot be provided to nuclear power plants and that all spent fuel pools experience spontaneous zirconium ignition. This projection would represent an upper probabilistic bound for radiation fatalities, within the individual risk methodology of NUREG-1738.

Reasonable people might assert that the individual risk methodology of NUREG-1738 is unduly optimistic. NUREG-1738 assumes no early fatalities for individuals living more than one mile away from nuclear power plant sites and assumes no cancer deaths for individuals living more than 10 miles away. Nonetheless, for the sake of optimism, we use the NUREG-1738 methodology.

Spent Fuel Pool Fatalities in Event of Power System Collapse

Preliminary Estimates

Risks from NUREG-1738:

Individual Risk of Early Fatality (Within 1 Mile), Late Evacuation	0.71%
Individual Risk of Latent Cancer Fatality (Within 10 Miles), Late Evacuation	1.68%

Within Area of Probable Power System Collapse	State	Nuclear Power Plant Site	Number of Reactors	Population within 1 Mile	Population within 10 Miles	Early Fatalities	Latent Cancer Fatalities
yes	Alabama	Browns Ferry 1/2/3	3	0	32,751	0	1,651
no	Alabama	Farley 1 & 2	2	0	9,795	0	0
no	Arizona	Palo Verde 1/2/3	3	0	3,302	0	0
no	Arkansas	Arkansas Nuclear 1 & 2	2	231	45,451	0	0
no	California	Diablo Canyon 1 & 2	2	0	24,084	0	0
no	California	San Onofre 2 & 3	2	0	74,169	0	0
yes	Connecticut	Millstone 2 & 3	2	517	117,615	7	3,952
no	Florida	Crystal River 3	1	0	18,663	0	0
no	Florida	St Lucie 1 & 2	2	0	160,073	0	0
no	Florida	Turkey Point 3 & 4	2	0	104,389	0	0
yes	Georgia	Hatch 1 & 2	2	0	8,339	0	280
yes	Georgia	Vogtle 1 & 2	2	0	2,990	0	100
yes	Illinois	Braidwood 1 & 2	2	884	32,361	13	1,087
yes	Illinois	Byron 1 & 2	2	21	24,887	0	836
yes	Illinois	Clinton	1	0	12,326	0	207
yes	Illinois	Dresden 2 & 3	2	134	64,843	2	2,179
yes	Illinois	La Salle 1 & 2	1	5	13,923	0	234
no	Illinois	Quad Cities 1 & 2	2	0	30,985	0	0
no	Iowa	Duane Arnold	1	7	101,695	0	0
no	Kansas	Wolf Creek	1	0	4,846	0	0
no	Louisiana	River Bend	1	53	24,633	0	0
no	Louisiana	Waterford	1	256	80,758	0	0
yes	Maryland	Calvert Cliffs 1 & 2	2	30	40,524	0	1,362
yes	Massachusetts	Pilgrim	1	613	69,854	4	1,174
yes	Michigan	Cook 1 & 2	2	114	53,351	2	1,793
yes	Michigan	Enrico Fermi 2	1	21	87,086	0	1,463
yes	Michigan	Palisades	1	29	31,619	0	531
no	Minnesota	Monticello	1	94	43,181	0	0
no	Minnesota	Prairie Island 1 & 2	2	219	26,923	0	0
no	Mississippi	Grand Gulf	1	0	7,628	0	0
no	Missouri	Callaway	1	11	6,238	0	0
no	Nebraska	Cooper	1	0	4,665	0	0
no	Nebraska	Fort Calhoun	1	17	17,244	0	0

Spent Fuel Pool Fatalities in Event of Power System Collapse (continued)

Preliminary Estimates

Risks from NUREG-1738:

Individual Risk of Early Fatality (Within 1 Mile), Late Evacuation	**0.71%**
Individual Risk of Latent Cancer Fatality (Within 10 Miles), Late Evacuation	**1.68%**

Within Area of Probable Power System Collapse	State	Nuclear Power Plant Site	Number of Reactors	Population within 1 Mile	Population within 10 Miles	Early Fatalities	Latent Cancer Fatalities
yes	New Hampshire	Seabrook	1	852	117,769	6	1,979
yes	New Jersey	Hope Creek/Salem 1 & 2	3	0	32,622	0	1,644
yes	New Jersey	Oyster Creek	1	1,275	120,110	9	2,018
yes	New York	FitzPatrick	1	10	38,737	0	651
yes	New York	Ginna	1	177	53,810	1	904
yes	New York	Indian Point 2 & 3	2	1,510	257,474	22	8,651
yes	New York	Nine Mile Point 1 & 2	2	10	38,571	0	1,296
yes	North Carolina	Brunswick 1 & 2	2	314	24,186	4	813
yes	North Carolina	Harris	1	0	53,629	0	901
yes	North Carolina	McGuire 1 & 2	2	120	118,694	2	3,988
yes	Ohio	Davis-Bessie	1	90	17,061	1	287
yes	Ohio	Perry	1	189	76,201	1	1,280
yes	Pennsylvania	Beaver Valley 1 & 2	2	470	145,409	7	4,886
yes	Pennsylvania	Limerick 1 & 2	2	661	213,586	9	7,176
yes	Pennsylvania	Peach Bottom 2 & 3	2	127	41,081	2	1,380
yes	Pennsylvania	Susquehanna 1 & 2	2	163	53,058	2	1,783
yes	Pennsylvania	Three Mile Island	1	358	185,780	3	3,121
yes	South Carolina	Catawba 1 & 2	2	191	140,492	3	4,721
yes	South Carolina	Oconee 1/2/3	3	18	71,183	0	3,588
yes	South Carolina	Robinson	1	600	33,649	4	565
yes	South Carolina	Summer	1	24	10,567	0	178
yes	Tennessee	Sequoyah 1 & 2	2	637	83,152	9	2,794
yes	Tennessee	Watts Bar	1	0	19,322	0	325
no	Texas	Comanche Peak 1 & 2	2	0	28,126	0	0
no	Texas	South Texas 1 & 2	2	0	2,779	0	0
yes	Vermont	Vermont Yankee	1	412	33,943	3	570
yes	Virginia	North Anna 1 & 2	2	93	15,516	1	521
yes	Virginia	Surry 1 & 2	2	0	117,247	0	3,939
yes	Washington	Columbia	1	4	2,851	0	48
yes	Wisconsin	Kewaunee	1	35	9,911	0	167
yes	Wisconsin	Point Beach 1 & 2	2	2	20,361	0	684
Totals				**11,598**	**3,558,068**	**119**	**77,705**

Comparison of Spent Fuel Pool Risk to NRC Safety Goals

NUREG-1738 contains a summary of NRC safety goals as they pertain to spent fuel pools:

> **SFP Risk Relative to the Safety Goal Policy Statement**
>
> The "Policy Statement on Safety Goals for the Operation of Nuclear Power Plants," issued in 1986, establishes goals that broadly define an acceptable level of radiological risk to the public as a result of nuclear power plant operation. These goals are used generically to assess the adequacy of current requirements and potential changes to the requirements. The Commission established two qualitative safety goals that are supported by two quantitative objectives for use in the regulatory decision-making process. The qualitative safety goals stipulate the following:
>
> - Individual members of the public should be provided a level of protection from the consequences of nuclear power plant operation such that individuals bear no significant additional risk to life and health.
> - Societal risks to life and health from nuclear power plant operation should be comparable to or less than the risks of generating electricity by viable competing technologies and should not be a significant addition to other societal risks.
>
> The following quantitative health objectives (QHOs) are used in determining achievement of the safety goals:
>
> - The risk to an average individual in the vicinity of a nuclear power plant of prompt fatalities that might result from reactor accidents should not exceed one-tenth of 1 percent (0.1 percent) of the sum of prompt fatality risks resulting from other accidents to which members of the U.S. population are generally exposed.
>
> The risk to the population in the area near a nuclear power plant of cancer fatalities that might result from nuclear power plant operation should not exceed one-tenth of 1 percent (0.1 percent) of the sum of cancer fatality risks resulting from all other causes.
>
> These QHOs have been translated into two numerical objectives as follows:
>
> - The individual risk of a prompt fatality from all "other accidents to which members of the U.S. population are generally exposed," such as fatal automobile accidents, is about $5x10^{-4}$ per year. One-tenth of 1 percent of this figure implies that the individual risk of prompt fatality from a reactor accident should be less than $5x10^{-7}$ per reactor year.
> - "The sum of cancer fatality risks resulting from all other causes" for an individual is taken to be the cancer fatality rate in the U.S. which is about 1 in 500 or $2x10^{-3}$ per year. One-tenth of 1 percent of this risk means that the risk of cancer to the population in the area near a nuclear power plant due to its operation should be limited to $2x10^{-6}$ per reactor year.

We calculated probable individual risks by determining the yearly probability of a spent fuel pool event and then multiplying by individual risks for "Consequences of an SPF Accident With a Low Ruthenium Source Term (per event)" as specified in Table 3.7-2 in NUREG-1738. We then compared probable individual risks to the NRC Safety Goals for Operation of Nuclear Power Plants.

As the below analysis shows, the probable individual risk of early fatalities at spent fuel pools exceeds the NRC safety goal by a factor of 35.7. The probable individual risk of cancer deaths exceeds the NRC safety goal by a factor of 21.0.

Spent Fuel Pool Risks for Individuals per Reactor Year

	Early Fatality	Cancer Death
Probability of Long-Term Loss of Outside Power	1.0E-02	1.0E-02
Probability of No Outside Assistance	5.0E-01	5.0E-01
Probability of Spontaneous Zirconium Ignition	5.0E-01	5.0E-01
Overall Probability of SFP Radiation Release	2.5E-03	2.5E-03
Individual Risk from SFP Event	7.13E-03	1.68E-02
Probable Individual Risk	1.78E-05	4.20E-05
NRC Safety Goal	5.00E-07	2.00E-06
Ratio of Probable Individual Risk to NRC Goal	35.7	21.0

NUREG-1738 also states the appropriate standard to be used in evaluating Large Early Release Frequency (LERF) for spent fuel pools:

> In the study, the staff stated that consequences of an SFP fire are sufficiently severe that the RG 1.174 large early release frequency baseline of $1x10^{-5}$ per reactor year is an appropriate frequency guideline for a decommissioning plant SFP risk and a useful measure in combination with other factors such as accident progression timing, for assessing features, systems, and operator performance for a spent fuel pool in a decommissioning plant.

We calculated the probability of LERF by multiplying the yearly probability of a long-term LOOP event, the probability of outside assistance being unavailable, and the probability of spontaneous zirconium ignition. As the below analysis shows, the risk of LERF from spent fuel pools exceeds the NRC staff guideline by over 2 orders of magnitude.

LERF Spent Fuel Pool Risk per Reactor Year

	Frequency per Reactor Year
Probability of Long-Term Loss of Outside Power	1.0E-02
Probability of No Outside Assistance	5.0E-01
Probability of Spontaneous Zirconium Ignition	5.0E-01
Overall Probability of SFP LERF	2.5E-03
NRC LERF Guideline	1.0E-05
Ratio of Probable SPF LERF to NRC Guideline	2.5E+02

For the purposes of this Petition we assume that the estimates for probability of long-term loss of outside power, probability of outside assistance, and probability of spontaneous zirconium ignition are midpoint estimates. Still, because the resulting risk assessments for spent fuel pools exceed the NRC goals for individual risk and the LERF guideline by 1-2 orders of magnitude, any of these individual probabilities could be more optimistic by an order of magnitude and the NRC safety goals would still not be met. For example, severe space weather could occur only once in one thousand years, on average, and the safety goals for individual risk would not be met. For the LERF guideline, two of three probabilities could be more optimistic by an order of magnitude and the guideline would still not be met; for example, severe space weather once in one thousand years, 95% chance of outside assistance, and/or zirconium fire only if the fuel rods have been out of the reactor core 2 months or less.

Hypothetical Design for Emergency Makeup Water System

A low-cost solution to provide emergency makeup water to spent fuel pools on an unattended basis could consist of a renewable electric power source, electrically-powered water pumps, float switches to detect water level in the spent fuel pool, and piping from a nearby water source such as a river or lake. (Nearly all nuclear power plants are adjacent to bodies of water.)

Spent Fuel Pool Water Boil-Off Rates

Time After Discharge (days)	Decay Power from Last Core (Megawatts)	Total Heat Load (Megawatts)	Boil-off Rate (Gallons per Minute)	Water Level Decrease (ft/hour)
2	16.4	18.4	130	1.00
10	8.6	10.6	74	0.60
30	5.5	7.5	52	0.42
60	3.8	5.8	41	0.33
90	3.0	5.0	35	0.28
180	1.9	3.9	27	0.22
365	1.1	3.1	22	0.18

Notes: Using typical pool sizes, it is estimated that for BWRs, we have 1040 ft3/ft depth, and for PWRs, we have 957 ft3/ft depth. Assume = 1000 ft3/ft depth for level decreases resulting from boil-off.

The sizing and cost of such a system would largely depend on the boil-off rates from the spent fuel pool. As data in above figure show (taken from NUREG-1738 Table 3.1, "Time to Bulk Boiling, and Boil-off Rates") boil-off rates depend on the time after discharge of fuel rods from the reactor core.

Example components, sources, and costs are presented below. While an appropriately designed and tested system would no doubt cost more than this estimate, we seek to show that the costs of such a system would be moderate. In any case, a simple emergency makeup water system that could operate unattended would be more reliable than the current sole dependence on human operators.

Components and Costs for Emergency Makeup Water System

	Quantity	Cost per Unit	Total Cost
5HP Electric Water Pump, 180 GPM	2	$1,300	$2,600
Solar/Wind Power System	4	$20,000	$80,000
Float Switch Control System	2	$100	$200
2 Inch Plastic Piping to Water Source	2	$10,000	$20,000
Miscellaneous Components	2	$25,000	$50,000
			$152,800

CONCLUSION

Ample evidence now exists, both analytical and experiential, that severe space weather has significant probability of causing widespread and persistent commercial grid outages. Nuclear plant licensees would have extreme difficulty cooling and protecting spent fuel pools under conditions of long-term commercial grid outage. Resupply of diesel fuel for backup generators and pumps would be improbable. Resupply of food and potable water for human operators and security personnel is in doubt. Commercial grid outage in excess of 30 days would likely cause water uncovering of spent fuel rods and result in zirconium cladding fires. Zirconium fires would result in substantial and fatal radiation release to the atmosphere. The data for these conclusions come not from the work of advocacy groups or private citizens, but from the work of government-sponsored commissions and regulatory bodies. Petitioner takes the reasonable position that nuclear power plant licensees should be required to implement design changes of moderate cost that would prevent fatalities and extensive radiation contamination of United States territory.