PRM-50-96

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, opportunity for comment, and public hearing, adopt regulations that would require facilities licensed by the NRC under 10 CFR Part 50 to assure long-term cooling and unattended water makeup of spent fuel pools.

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1 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. Petitioner has no financial interest in any companies providing backup power systems.

2 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 catch fire under some circumstances.

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 basis 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 dangerous radionuclides 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. The information in the Oak Ridge reports is new and significant information. 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 collapse of the commercial grids 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.

Extreme value theory is commonly used to gauge the probability of 100-year floods and other natural disasters that occur infrequently but whose probability can be estimated by the occurrence of smaller and more common events. When extreme value theory is applied to the one-in-one-hundred-year frequency supplied by the Oak Ridge National Laboratory, the resulting probability of long-term loss of outside power is 33% over the standard 40-year licensure term for nuclear power plants and associated spent fuel pools.

Loss of outside power with probability of 1% per year and duration of 1-2 years far exceeds the current design basis for nuclear power plants and associated spent fuel pools. Accordingly, the NRC should adjust the design basis for nuclear power plants and associated spent fuel pools to minimize risk and avoid potential radiation fatalities. This Petition proposes requirements for unattended spent fuel pool cooling at nuclear power plants in light of this new and significant information provided by Oak Ridge National Laboratory.

3 PREVIOUS RELATED PETITIONS FOR RULEMAKING

Three previous petitions for rulemaking have been submitted on the subjects of spent fuel pools, electromagnetic pulse, and long-term commercial power grid outage. All of these petitions were denied. None of these petitions addressed the fundamental issue raised in the current Petition—the issue of long-term commercial grid outage caused by severe space weather and resulting geomagnetic disturbance.

In 1982, Petitions for Rulemaking PRM-50-32, 32A, and 32B were filed by Ohio Citizens for Responsible Energy, et. al. These petitions concerned a high-altitude nuclear weapon detonation causing a large electromagnetic pulse (EMP). This pulse could induce large currents and voltages in electrical systems at nuclear power plants and might cause equipment failures. Like the issues raised in the current Petition, the issues of petitions PRM-50-32, 32A, and 32B could affect many plants simultaneously. In response to the petitions, Sandia National Laboratories conducted a study, "Interaction of Electromagnetic Pulse with Commercial Nuclear Power Plant Systems," NUREG/CR-3069 (February 1983). The analysis in the study was "limited to those systems required for safe shutdown of the nuclear power plant" and concluded that shielding provided by reactor buildings, as well as the inherent resiliency of equipment, would prevent damage.

The safe shutdown analysis for PRM-50-32/32A/32B covered only the so-called "early time" (E1) pulse from EMP and did not address the so-called "magnetohydrodynamic pulse" (also commonly referred to as the "E3" or long pulse). The magnetohydrodynamic pulse is functionally equivalent to the pulse that would be caused by severe space weather and resulting geomagnetic disturbance. It is notable that the authors of the Sandia report were aware of the potential for magnetohydrodynamic pulse to induce currents in electrical transmission lines, although in 1983 it was not well understood that the induced currents could also permanently damage high voltage transformers:

> It is known that the magnetohyrodynamic (MHD) EMPO which follows the early time HEMP can persist for tens to hundreds of seconds with peak electric field intensities of 10 to 100 V/km over large areas. It was concluded that the low-frequency currents induced by an MHD-EMP on the transmission line would be conducted to ground via the wye-connected secondary of the main transformer. Also, because of the inherent dc isolation of the delta connected primary of this transformer, the dc components would be blocked and not coupled into the plant. The response would most likely be disconnection of the transformer from the grid. This would not affect the safe shutdown capability so the MHD-EMP was not considered further in this study.

Significantly, the Sandia study did not address the issue of magnetohydrodynamic pulse causing long-term commercial grid outage.

In 1998, Nuclear Information and Resource Service (NIRS) filed a petition for rulemaking (PRM-50-66) requesting that the NRC amend its regulations to require licensees of operating nuclear power plant facilities to make emergency plans to cope with computer-related failures resulting from the Year 2000 (Y2K) issue, including long-term failure of commercial power grids. The petition requested that the NRC require long-term backup sources of electric power at nuclear power plants, including wind, solar, or hydroelectric. A principal reason for the denial of the petition was a determination by the North American Electric Reliability Corporation (NERC) that the North American power grids were unlikely to fail because of the Y2K issue. Notably, NERC has never made a determination that severe space weather and resulting geomagnetic disturbance are unlikely to cause grid failures—in fact, NERC has specifically identified geomagnetic disturbance as a potential high-impact event for the North American power grids.

In November 2006, the Massachusetts Attorney General filed a Petition for Rulemaking regarding the safety of spent fuel pools under conditions of high-density storage, docketed as PRM-51-10. The California Attorney General filed a similar Petition for Rulemaking, docketed as PRM-51-12. Because of the similarities in PRM-51-10 and PRM-51-12, the NRC evaluated the two petitions together. These petitions requested that the NRC consider the environmental impacts of zirconium fires in spent fuel pools resulting from accidents or malicious acts, such as terrorist attacks. Notably, the issue of long-term loss of commercial grid power was not addressed in either of these petitions. The denial of the petitions by the NRC asserted that the risk of spent fuel pool fires is low, principally because of redundant safety systems that are dependent on commercial grid power and/or outside assistance to the nuclear power plant.

4 SPECIFIC ISSUES FOR SPENT FUEL POOLS

4.1 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-1353, "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 not in original.)

A National Research Council of the National Academies of Sciences 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.

4.2 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

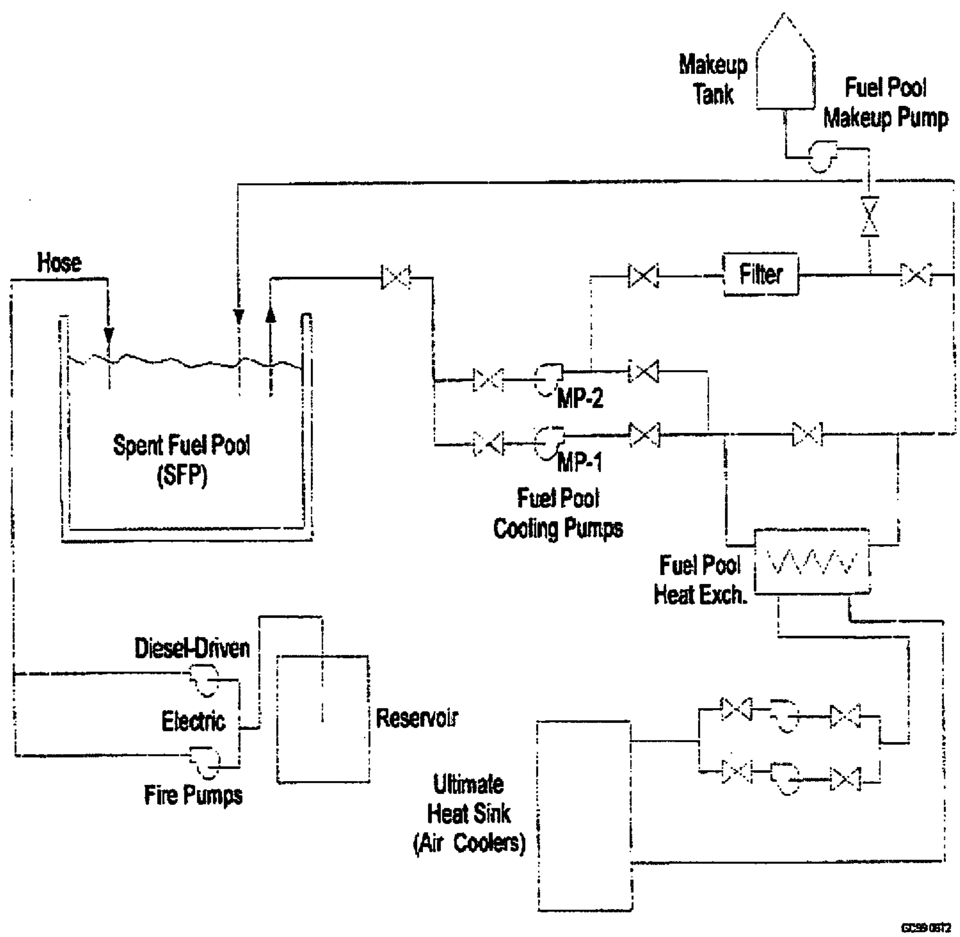

Figure 2.1 is a simplified drawing of the system assumed for the development of the model. The spent fuel pool cooling (SFPC) system is located in the SFP area and consists of motor-driven pumps, a heat exchanger, an ultimate heat sink, a makeup tank, filtration system and isolation valves. Suction is 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.

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

Design basis 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," (commonly referred to as the Station Blackout rule) specifies the critical role of reliable and quickly restored offsite power, also commonly referred to as "commercial grid," in nuclear power plant design basis:

§ 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 designed default 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.
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> (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 not in original.)

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.
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> (Emphasis not in original.)

5 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 suggested requirements:

> Licensees shall provide reliable emergency systems to provide long-term cooling and water makeup for spent fuel pools using only on-site power sources. These emergency systems shall be able to operate for a period of two years without human operator intervention and without off-site fuel resupply. Backup power systems for spent fuel pools shall be electrically isolated from other plant electrical systems during normal and emergency operation. If weather-dependent power sources are to be used, sufficient water or power storage must be provided to maintain continual cooling during weather conditions which may temporarily constrict power generation.

Petition specifically requests a rulemaking via amendment to the CFR. The issues raised by the current Petition affect the design basis for nuclear power plants and associated spent fuel pools. In the past when a fundamental issue with grid reliability was raised, it was addressed with 10 CFR Part 50.63, "Loss of all alternating current power." The issues raised by the instant Petition are of similar import and should also require amendment to the CFR. Other regulatory actions such License Amendment, Regulatory Guidance, and Generic Letter are focused on interpretation of, or compliance with, existing regulation rather than establishing new regulation.

Mitigative action outside of a CFR amendment would not provide sufficient regulatory guidance nor assure the public that safety has been protected.

The petitioner is only *suggesting* CFR wording to address the issues raised by the current Petition. NRC should have the regulatory flexibility to consider both staff input and stakeholder comments and then modify the suggested CFR wording to reflect staff input and comments, while still conforming to the overall intent of the petition. The implementation deadline of January 1, 2013 is a *suggested* date, based on the availability of commercial off-the-shelf equipment and the impending 2012/2013 solar maximum.

6 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.

6.1 Risks from Severe Space Weather and Geomagnetic Disturbance

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 not in original.)

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 not in original.)

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.***
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> (Emphasis not in original.)

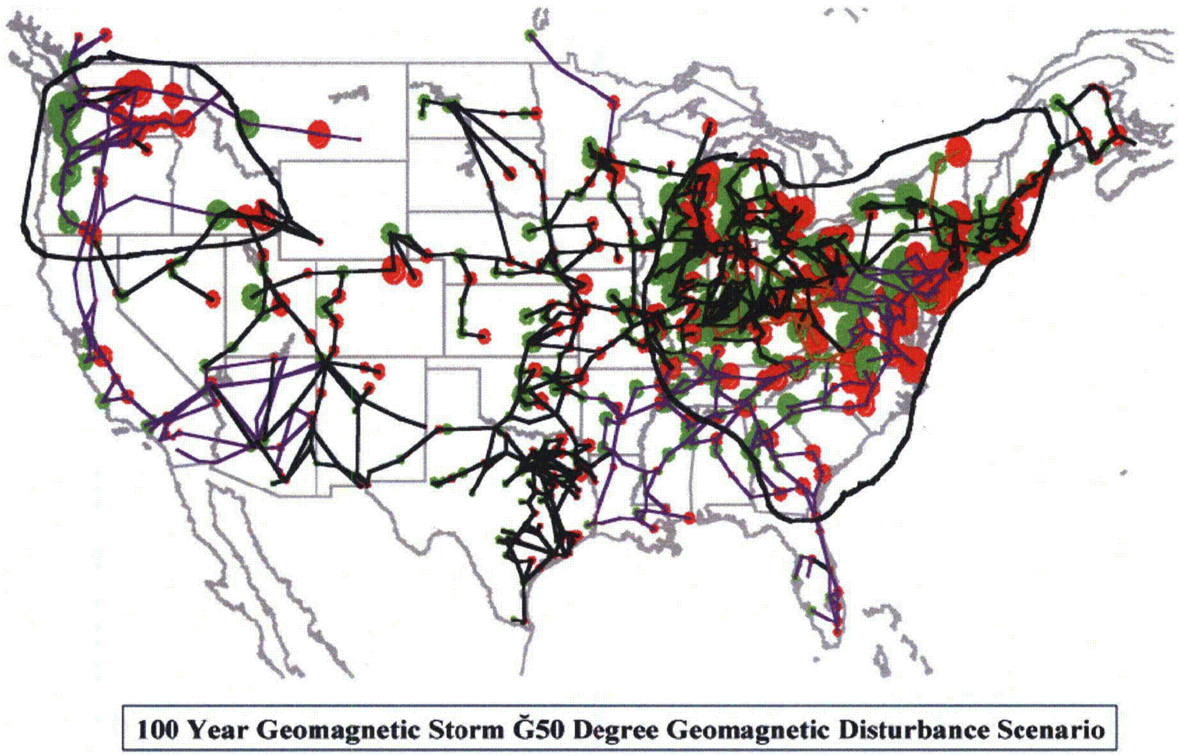


Figure 11: The simulation results showing the pattern of GIC flows in the U.S, grid for a 4800 nT/min geomagnetic field disturbance at 50 degrees geomagnetic latitude. The above regions outlined are susceptible to system collapse due to the effects of the GIC.

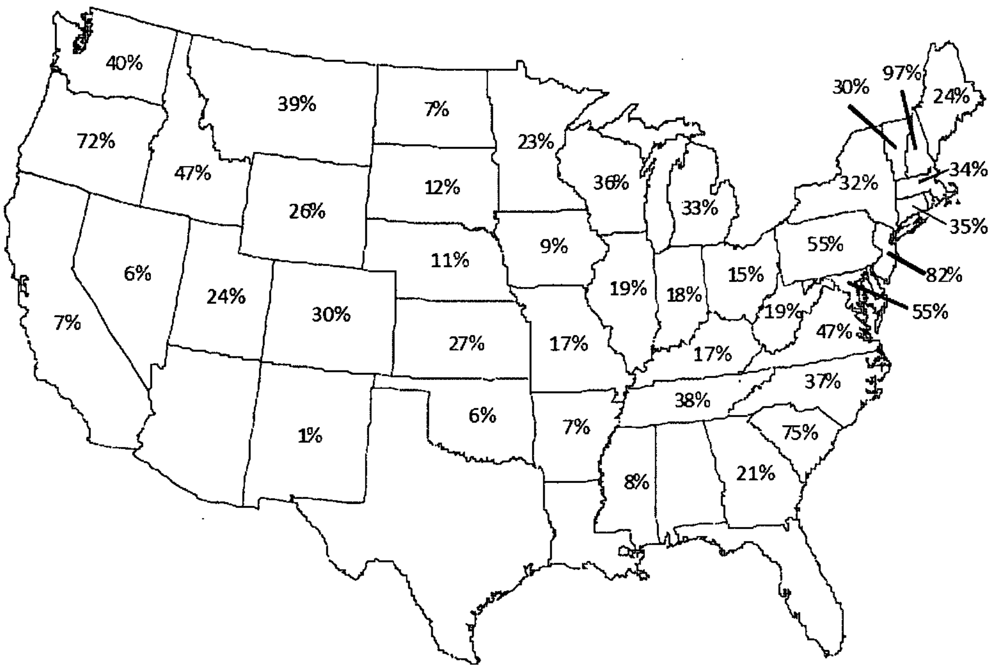


Figure 12: A map showing the At-Risk EHV Transformer Capacity by State for this disturbance scenario. regions with high percentages could experience long duration outages that could extend multiple years.[63]

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 of the National Academies of Sciences 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:

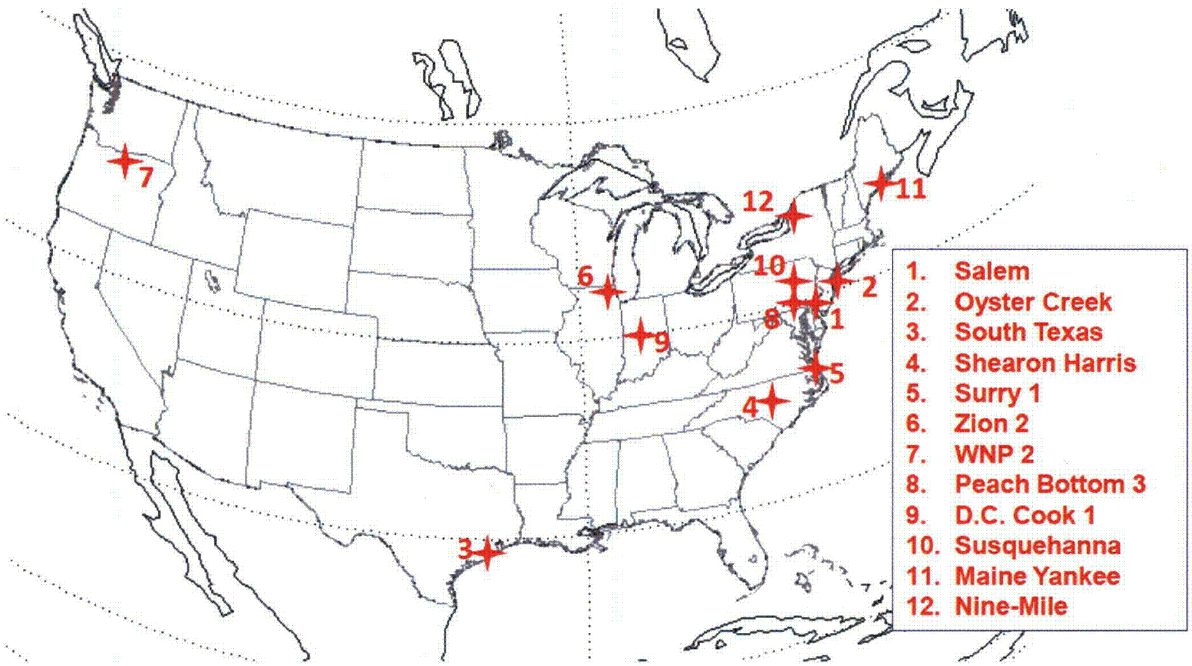
> Our knowledge and understanding of the vulnerabilities of modern technological infrastructure to severe space weather and the measures developed to mitigate those vulnerabilities are based largely on experience and knowledge gained during the past 20 or 30 years, during such episodes of severe space 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:

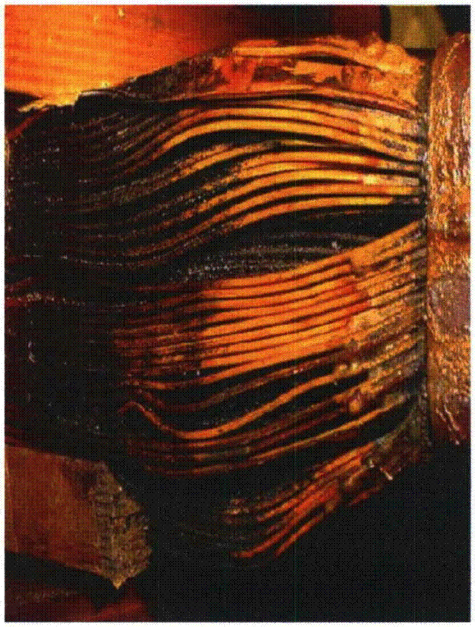


GSU Transformer Failures at Nuclear Power Plants within 25 Months of 1989 Solar Storm
Source: Impact of Severe Solar Flares, Nuclear EMP and Intentional EMI on Electric Grids

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. Oak Ridge should be given deference over non-governmental entities in determinations of commercial grid reliability. NRC has previously relied on Oak Ridge to study grid reliability as it relates to nuclear power plants.

The executive summary of the Oak Ridge 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 not in original.)

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.

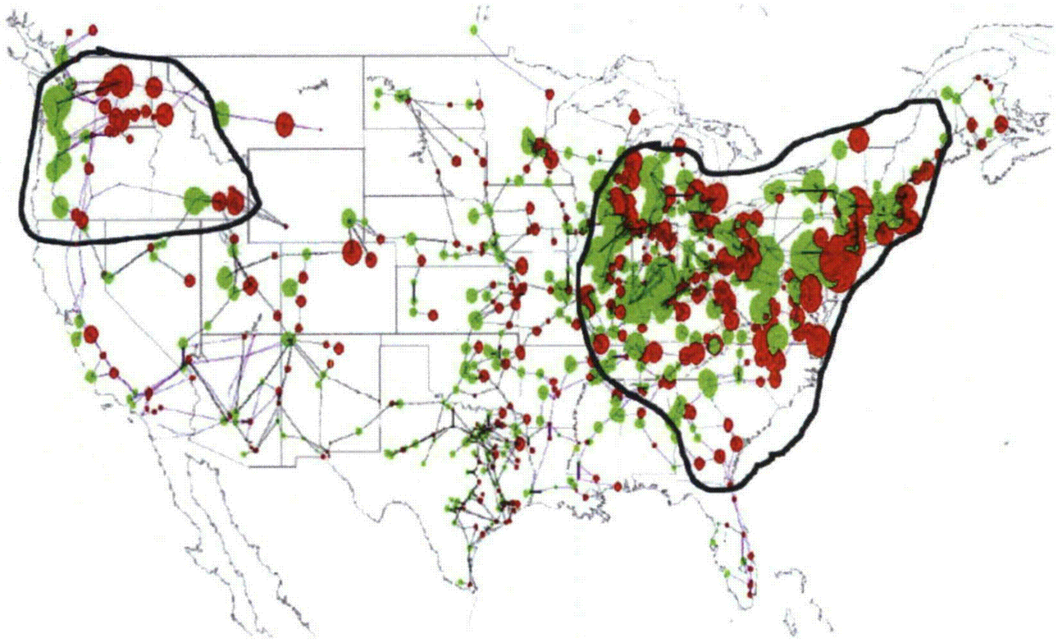
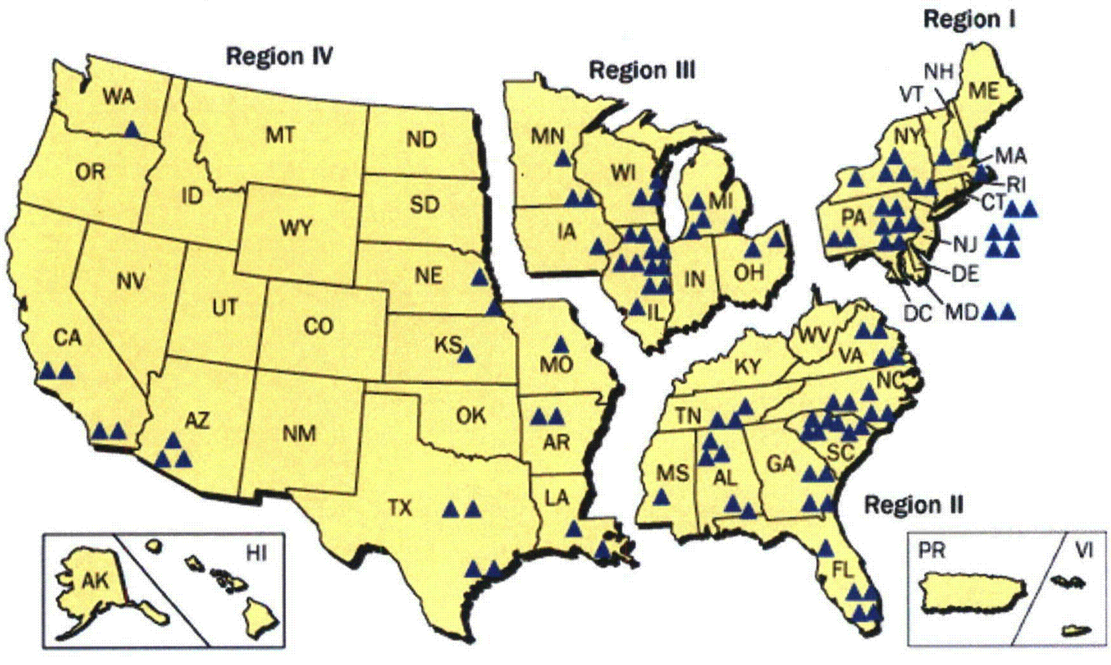


Figure 1. **Areas of Probable Power System Collapse**



Locations of United States Nuclear Power Plants

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

6.2 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 not in original.)

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, a reasonable person would conclude that nuclear plant operators cannot depend on resupply of diesel fuel for emergency backup generators once initial fuel stored on-site is exhausted.

6.3 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 not in original.)

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 can be reasonably implied that these personnel might go an extended period of time without resupply of food and potable water.

6.4 Lack of DHS Preparation for a Scenario of Long-Term Power Grid Collapse

The Department of Homeland Security does not have sufficient planning and physical preparation to ensure recovery from a regional or national scenario of long-term 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 not in original.)

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.

The Federal Emergency Management Agency (FEMA), a component of DHS, has published a plan to coordinate response to disasters, the "National Response Framework." According to the FEMA website, "The National Response Framework presents the guiding principles that enable all response partners to prepare for and provide a unified national response to disasters and emergencies—from the smallest incident to the largest catastrophe. The Framework establishes a comprehensive, national, all-hazards approach to domestic incident response." This document, also available on the FEMA website, "Overview: ESF and Support Annexes Coordinating Federal Assistance In Support of the National Response Framework" describes the role of emergency support annexes:

> The National Response Framework (NRF) presents the guiding principles that enable all response partners to prepare for and provide a unified national response to disasters and emergencies – from the smallest incident to the largest catastrophe. The Framework defines the key principles, roles, and structures that organize the way we respond as a Nation. It describes how communities, tribes, States, the Federal Government, and private-sector and nongovernmental partners apply these principles for a coordinated, effective national response. The National Response Framework is always in effect, and elements can be implemented at any level at any time. This Overview supports and provides additional guidance concerning the Framework. In particular, this document focuses on the essential processes for requesting and receiving Federal assistance and summarizes the key response capabilities and essential support elements provided through the Emergency Support Function (ESF) Annexes and Support Annexes.
>
> The Overview includes the following topics:
>
> 1. Key Players: Organizations and entities that may either need assistance or provide assistance
> 2. Federal Assistance: Descriptions of the processes for requesting and obtaining Federal assistance in support of States, tribes, local jurisdictions, and other Federal partners
> 3. Emergency Support Function Annexes: Summaries of the 15 ESF Annexes, which group Federal resources and capabilities into functional areas to serve as the primary mechanisms for providing assistance at the operational level

4. Support Annexes: Summaries of the 8 Support Annexes, which describe essential supporting aspects that are common to all incidents

The Framework also includes Incident Annexes that address specific categories of contingencies or hazard situations requiring specialized application of Framework mechanisms. The Incident Annexes are not directly addressed or summarized in this support document. Readers should review the Incident Annexes on the NRF Resource Center, http://www.fema.gov/NRF.

Incident Annexes include a specific annex for the energy sector. This Energy Annex can be found at:

http://www.fema.gov/pdf/emergency/nrf/nrf-esf-12.pdf

Notably, the Energy Annex and all other supporting documents implicitly assume that federal, state, and local governmental functions would continue more-or-less uninterrupted during a condition of long-term commercial grid collapse where 130 million people would be without electricity, including the population in the Washington DC area.

A notable aspect of DHS/FEMA planning is not clearly described in documents available on government websites, but can be learned at briefings by government officials: physical preparation by FEMA, including acquisition and storage of food, water, fuel, and replacement parts is *de minimis*. Instead, FEMA plans assume that goods can be purchased from commercial vendors, e.g., Walmart. There are no current domestic manufacturers of extra high voltage transformers and physical inventory of these transformers is negligible.

Because current DHS/FEMA planning and physical preparation does not address a specific scenario of geomagnetic disturbance and resulting long-term 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. Any statements that paper planning would ensure long-term outside assistance to nuclear power plants with 100% certainty are speculative and unsupported by the actual level of planning and physical preparation at FEMA and other government agencies.

6.5 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.

(Emphasis not in original.)

Notably, the comprehensive NRC program to update and reevaluate LOOP frequencies and durations did not include estimates of frequencies and durations for LOOPs caused by geomagnetic disturbance. This is despite definitive geomagnetically-induced damage to the GSU transformer at the Salem nuclear power plant during the March 1989 geomagnetic storm and suspected damage to eleven other GSU transformers at United States nuclear power plants during the same storm.

6.6 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 not in original.)

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 installation of equipment to protect against geomagnetic disturbance, this paper standard provides ineffectual protection.

6.7 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 require operational plans to disconnect high voltage transmission equipment when geomagnetic disturbance is predicted. Moreover, standards for protective devices, such as blocking devices for high voltage transformers, could be specified and enforced.

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 protection against geomagnetic disturbance will be achieved 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 not in original.)

Some regional electric reliability organizations (so-called "regional entities") and Independent System Operators (ISO) have operational plans whereby commercial power grids might be managed to avoid damage from geomagnetic disturbance. An example is "Procedures for Solar Magnetic Disturbances Which Affect Electric Power Systems," by Northeast Power Coordinating Council (NPCC) (January 2007), which describes protection of the power grid covering New York State, the six New England States, and parts of Canada. Because the area covered by the NPCC has not yet experienced a large geomagnetic disturbance, there is no certainty that their operational plan would work. Moreover, ISO and regional entity plans, to the extent that plans exist at all, typically instruct that human operators "reduce the loading" rather than disconnect vulnerable transformers entirely. For example, "Procedures for Solar Magnetic Disturbances Which Affect Electric Power Systems," specifies these operator actions:

> 4.2 Operator Action With the Onset of an SMD
>
> On receiving from the Solar Terrestrial Dispatch a geomagnetic storm alert predicting at least a 40% probability of activity at levels of Kp 7, Kp 8 or Kp 9, or notification of significant GIC activity, **system operators** may evaluate the situation and consider the following actions where appropriate:
>
> 4.2.1 Discontinue maintenance work and restore out of service high voltage transmission lines to service. Avoid taking long lines out of service.
>
> 4.2.2 Maintain the system voltage within an acceptable operating range to protect against voltage swings.
>
> 4.2.3 Reduce the loading on interconnections, critical transmission facilities, and critical transmission interfaces to 90%, or less, of their agreed limits.
>
> 4.2.4 Reduce the loading on generators operating at full load to provide reserve power and reactive capacity.
>
> 4.2.5 Consider the impact of tripping large shunt capacitor banks and static VAR compensators.
>
> 4.2.6 Dispatch generation to manage system voltage, tie line loading and to distribute operating reserve.

4.2.7 Bring equipment capable of synchronous condenser operation on line to provide reactive power reserve.

(Emphasis in original.)

Any operational plan would rely on uncertain forecasts from the National Oceanic and Atmospheric Administration (NOAA). NOAA, in turn, relies on data from satellite assets that may not work perfectly and also have operational lifespans that are a fraction of the 40-year standard licensure period for nuclear power plants.

An article published by NASA, "Solar Shield—Protecting the North American Power Grid" (October 2010) describes the necessity of disconnecting transformers during geomagnetic disturbances and also describes the space weather forecasting process:

...***During extreme storms, engineers could safeguard the most endangered transformers by disconnecting them from the grid.*** That itself could cause a blackout, but only temporarily. Transformers protected in this way would be available again for normal operations when the storm is over.

The innovation of Solar Shield is its ability to deliver transformer-level predictions. Pulkkinen explains how it works: "Solar Shield springs into action when we see a coronal mass ejection (CME) billowing away from the sun. Images from SOHO and NASA's twin STEREO spacecraft show us the cloud from as many as three points of view, allowing us to make a 3D model of the CME, and predict when it will arrive."

While the CME is crossing the sun-Earth divide, a trip that typically takes 24 to 48 hours, the Solar Shield team prepares to calculate ground currents. "We work at Goddard's Community Coordinated Modeling Center (CCMC)," says Pulkkinen. The CCMC is a place where leading researchers from around the world have gathered their best physics-based computer programs for modeling space weather events. ***The crucial moment comes about 30 minutes before impact when the cloud sweeps past ACE, a spacecraft stationed 1.5 million km upstream from Earth.*** Sensors onboard ACE make *in situ* measurements of the CME's speed, density, and magnetic field. These data are transmitted to Earth and the waiting Solar Shield team.

"We quickly feed the data into CCMC computers," says Pulkkinen. "Our models predict fields and currents in Earth's upper atmosphere and propagate these currents down to the ground." With less than 30 minutes to go, Solar Shield can issue an alert to utilities with detailed information about GICs.

Pulkkinen stresses that Solar Shield is experimental and has never been field-tested during a severe geomagnetic storm. A small number of utility companies have installed current monitors at key locations in the power grid to help the team check their predictions. So far, though, the sun has been mostly quiet with only a few relatively mild storms during the past year. The team needs more data.

(Emphasis not in original.)

As the NASA article describes, for effective protection of extra high voltage transformers, the transformers must be disconnected from the grid; mere reduction of loading may not be sufficient. Because of the social and political consequences of grid blackouts due to "false alarms," human operators may be reluctant to reduce load enough to prevent damage from geomagnetically-induced currents.

The article also describes the necessary role of the ACE spacecraft in the L1 orbital position. Notably, the ACE spacecraft gives approximately 30 minutes warning while NERC Board of Trustees had asked for one hour notice for "sufficient time to implement special operating procedures." Regardless of NERC requests for sufficient time to allow human intervention, the laws of physics cannot be altered to place the L1 orbital position farther from the earth.

The ACE spacecraft is past its designed operational lifetime and no replacement is planned. The January 2009 report by National Academy of Sciences "Severe Space Weather Events— Understanding Societal and Economic Impacts Workshop Report," explains the status of the space weather instrumentation and monitoring:

> INSTRUMENTATION AND MONITORING:
> THE SPACE WEATHER OBSERVATION SYSTEM
>
> A number of participants offered comments on the current status and future prospects of the nation's system for monitoring space weather. One of these comments was the observation that there in fact *is no* system specifically dedicated to monitoring space weather. As noted by Daniel Baker (University of Colorado at Boulder), many of the measurements used by the Space Weather Prediction Center (SWPC) for operations are actually taken from instruments designed and tasked for scientific missions. Baker raised the question: Should our operational capacity for space weather monitoring be dependent on scientific instruments and satellites? Is it prudent to rely in this way on "the kindness of strangers"?
>
> Pursuing this theme, several participants commented on a perceived fragility, or lack of robustness, in the nation's capacity for space weather monitoring. John Kappenman (Metatech Corporation) observed that ***many key parts of the system have no backups: single points of failure, he argued, could substantially degrade or even halt operations. A critical weakness in the present system, noted by a number of participants, is the reliance on the aging Advanced Composition Explorer (ACE) spacecraft as virtually the nation's sole upstream solar wind monitor. ACE, positioned at L1,[1] is now 11 years old, well beyond its planned operational life, and the detector heads are losing gain. "There could be an electronic failure," Charles Holmes (NASA Headquarters) pointed out. "So it is a vulnerable system."***
>
> As Baker noted, the loss of L1 solar wind measurements such as are provided by ACE "would be a devastating loss to the national space weather capability." In a presentation given the previous day, Thomas Bodgan of NOAA's Space Weather Prediction Center listed as one of NOAA's "critical new directions" to "secure [an] operational L1 monitor." It was clear from the comments of the participants, however, that no clear replacement for ACE is coming on line soon. Devrie Intriligator (Carmel Research Center, Inc.) noted that the possibility of an L1 monitor supplied by private industry had been discussed at other workshops. Although the Chinese are planning an L1 monitor as part of the KuaFu space weather project, it will not be launched for several years. Moreover, as William Murtagh (NOAA) cautioned, national security concerns must be taken into account when decisions about the follow-on to ACE are being made. On an encouraging note, Murtagh reported that the NASA Authorization Act (House Rule 6063, Section 1101) charges the Office of Science and Technology Policy to work with NOAA, NASA, other federal agencies, and industry to develop a plan for sustaining solar wind measurements from an L1-based spacecraft.
>
> (Emphasis not in original.)

"Severe Space Weather Events— Understanding Societal and Economic Impacts Workshop Report" explains why current power grid operational procedures may not be adequate:

> Operational procedures used now by U.S. power grid operators have been developed largely from experiences with recent storms, including the March 1989 event. These procedures are generally designed to boost operational reserves and do not prevent or reduce GIC flows in the

> network. For large storms (or increasing dB/dt levels) both observations and simulations indicate that as the intensity of the disturbance increases, the relative levels of GICs and related power system impacts will also increase proportionately. Under these scenarios, the scale and speed of problems that could occur on exposed power grids have the potential to impact power system operators in ways they have not previously experienced. Therefore, as storm environments reach higher intensity levels, it becomes more likely that these events will precipitate widespread blackouts in exposed power grid infrastructures. The possible extent of a power system collapse from a 4800 nT/min geomagnetic storm (centered at 50° geomagnetic latitude) is shown in Figure 7.1. Such dB/dt levels—10 times those experienced during the March 1989 storm—were reached during the great magnetic storm of May 14-15, 1921.

"Severe Space Weather Events— Understanding Societal and Economic Impacts Workshop Report" concludes with a discussion of why space weather forecasts may not be the most effective method of protecting against geomagnetic disturbance:

> Much of the discussion appeared to support, explicitly or implicitly, the proposition that the nation does in fact need a strong capacity for producing predictions and warnings about space weather events. One participant, though, offered a contrarian view. Thomas Stansell (Stansell Consulting) argued that attention should focus first not on prediction, but on mitigation—on construction of hardened infrastructure able to continue operations without interruptions straight through severe space weather events. For electric power delivery, satellite operations, and other core systems, he claimed, extended service interruptions are unacceptable: hardened systems are essential. Better mitigation would in turn make prediction less valuable. Advances in mitigation, Stansell argued, would undermine the rationale for allocating resources toward monitoring space weather conditions, or predicting severe space weather events. A strategy based on mitigation would also imply different priorities for research.

By conducting a simple and very optimistic probability calculation, one can easily see the fallacy of primary reliance on space weather forecasts and operational plans such as "Procedures for Solar Magnetic Disturbances Which Affect Electric Power Systems." As explained before, this plan does not require shutting down the commercial grid to protect against geomagnetic disturbance; instead the plan recommends to "Reduce the loading on interconnections, critical transmission facilities, and critical transmission interfaces to 90%, or less, of their agreed limits." As a result, there is no 100% assurance that the extra high voltage transformers will be protected. Let us optimistically assume a 90% chance that the operational plan would protect extra high voltage transformers. Let us optimistically assume that any space weather forecast would be correct 90% of the time, which was the goal set by the NERC Board of Trustees in 1990. Finally, let us optimistically assume a 90% chance that the necessary satellite assets would be on station and operating through the life of nuclear power plants. By multiplying these three extremely optimistic probabilities, we find only a 73% chance that space weather forecasts and operational plans would protect against long-term loss of commercial grid power.

Gerry Cauley, President and CEO of NERC, testified at a February 8, 2011 technical conference held at FERC that a meeting to discuss mitigation plans for geomagnetic disturbance will not be held until April 2011:

> Let me turn now to a second category of emerging risk that I consider urgent because of the potential consequences of physically damaging bulk power equipment and controls, that of geomagnetic disturbances caused by solar flares. We will be convening industry experts at a conference in April this year to validate near-term, cost-effective actions that can be taken to better prepare the North American grid for large scale interference with the Earth's magnetic field. We will be leveraging the mitigation strategies completed in Canada and the Northeast to mitigate these risks after the 1989 Quebec disturbance. NERC will issue an alert with a set of specific near-term actions and a timetable for responses.

Intentions for the North American power grids to be protected against damage from geomagnetic disturbance, based on meetings that have not yet happened and operational plans that may not work, are speculative and should not be the basis for nuclear safety.

After diligent search, Petitioner was unable to find any studies or plans, government-sponsored or otherwise, that describe how the North American power grids could be reconfigured after loss of 300 extra high voltage transformers (representing approximately one-third of power transmission capacity) into localized "islands of power" that would reliably provide commercial grid power to nuclear power plants and associated spent fuel pools. Therefore, any hopes that the North American power grids could somehow be quickly reconfigured after damage from geomagnetic disturbance must be considered speculative—and such speculations should not be the basis for nuclear safety.

6.8 Role of Other Government Agencies

Legislation and appellate court decisions have suggested that NRC may leave certain matters to other agencies of the US Government, if these agencies adequately address concerns of public health and safety. In the instant case of protection of nuclear power plants against commercial grid failure caused by geomagnetic disturbance, this legal theory cannot apply, for three reasons. First, there is no federal agency with the clear legal authority to set and enforce a reliability standard on geomagnetic disturbance. Second, experience within the existing legal structure has demonstrated that no federal agency can indirectly establish a reliability standard on geomagnetic disturbance within a reasonable timeframe. Third, other government agencies do not currently have the appropriations and physical assets to protect public health and safety in regard to geomagnetic disturbance.

FERC was granted limited legal authority over electric grid reliability by the Electricity Modernization Act of 2005. The Act required that an Electric Reliability Organization (ERO) be certified by FERC. NERC has been certified as the ERO by FERC. NERC is thus charged with setting electric reliability standards which then must be approved by FERC:

> **Subtitle A—Reliability Standards**
> Electricity Modernization Act of 2005
>
> SEC. 1211. ELECTRIC RELIABILITY STANDARDS.
> (a) IN GENERAL.—Part II of the Federal Power Act (16 U.S.C. 824 et seq.) is amended by adding at the end the following:
> "SEC. 215. ELECTRIC RELIABILITY...
>
> "(b) JURISDICTION AND APPLICABILITY.—(1) The Commission shall have jurisdiction, within the United States, over the ERO certified by the Commission under subsection (c), any regional entities, and all users, owners and operators of the bulk-power system, including but not limited to the entities described in section 201(f), for purposes of approving reliability standards established under this section and enforcing compliance with this section. All users, owners and operators of the bulk-power system shall comply with reliability standards that take effect under this section.
> "(2) The Commission shall issue a final rule to implement the requirements of this section not later than 180 days after the date of enactment of this section.
> "(c) CERTIFICATION.—Following the issuance of a Commission rule under subsection (b)(2), any person may submit an application to the Commission for certification as the Electric Reliability Organization. The Commission may certify one such ERO if the Commission determines that such ERO—

"(1) has the ability to develop and enforce, subject to subsection (e)(2), reliability standards that provide for an adequate level of reliability of the bulk-power system; and
"(2) has established rules that—
"(A) assure its independence of the users and owners and operators of the bulk-power system, while assuring fair stakeholder representation in the selection of its directors and balanced decisionmaking in any ERO committee or subordinate organizational structure;
"(B) allocate equitably reasonable dues, fees, and other charges among end users for all activities under this section;
"(C) provide fair and impartial procedures for enforcement of reliability standards through the imposition of penalties in accordance with subsection (e) (including limitations on activities, functions, or operations, or other appropriate sanctions);
"(D) provide for reasonable notice and opportunity for public comment, due process, openness, and balance of interests in developing reliability standards and otherwise exercising its duties; and
"(E) provide for taking, after certification, appropriate steps to gain recognition in Canada and Mexico.
"(d) RELIABILITY STANDARDS.—(1) The Electric Reliability Organization shall file each reliability standard or modification to a reliability standard that it proposes to be made effective under this section with the Commission.
"(2) The Commission may approve, by rule or order, a proposed reliability standard or modification to a reliability standard if it determines that the standard is just, reasonable, not unduly discriminatory or preferential, and in the public interest. The Commission shall give due weight to the technical expertise of the Electric Reliability Organization with respect to the content of a proposed standard or modification to a reliability standard and to the technical expertise of a regional entity organized on an Interconnection-wide basis with respect to a reliability standard to be applicable within that Interconnection, but shall not defer with respect to the effect of a standard on competition. A proposed standard or modification shall take effect upon approval by the Commission.
"(3) The Electric Reliability Organization shall rebuttably presume that a proposal from a regional entity organized on an Interconnection-wide basis for a reliability standard or modification to a reliability standard to be applicable on an Interconnection-wide basis is just, reasonable, and not unduly discriminatory or preferential, and in the public interest.
"(4) The Commission shall remand to the Electric Reliability Organization for further consideration a proposed reliability standard or a modification to a reliability standard that the Commission disapproves in whole or in part.
"(5) The Commission, upon its own motion or upon complaint, may order the Electric Reliability Organization to submit to the Commission a proposed reliability standard or a modification to a reliability standard that addresses a specific matter if the Commission considers such a new or modified reliability standard appropriate to carry out this section.

(Ellipsis not in original)

Under this legislative structure, the ERO (NERC) "has the ability to develop and enforce, subject to subsection (e)(2), reliability standards that provide for an adequate level of reliability of the bulk-power system." In the drafting of standards, the FERC role is limited to approval of standards developed by the ERO: "The commission may approve, by rule or order, a proposed reliability standard or modification to a reliability standard if it determines that the standard is just, reasonable, not unduly discriminatory or preferential, and in the public interest." If FERC determines that a necessary standard is missing or inadequate, its actions are limited to ordering that the ERO develop a standard: "The Commission, upon its own motion or upon complaint, may order the Electric Reliability Organization to submit to the Commission a proposed reliability standard or a modification to a reliability standard that addresses a specific matter if the Commission considers such a new or modified reliability standard appropriate to carry out this section." Notably, FERC cannot dictate the wording of a standard and therefore cannot unilaterally set or enforce a standard on geomagnetic disturbance.

Five years after passage of the Electricity Modernization Act of 2005, the designated ERO (NERC) has not proposed a standard on protection geomagnetic disturbance and FERC has not ordered a standard on geomagnetic disturbance. In the past when FERC has encouraged development of a standard to provide reliable power to nuclear power plants, interested parties have mounted legal and regulatory challenges, an example being the development of the NERC Standard NUC-001-1, which was modified to Standard NUC-001-2 after industry complaints. In light of existing regulatory and legal structure, and demonstrated experience within this structure, it is speculative to suggest that NERC/FERC will develop, approve, implement, and enforce a regulatory standard on geomagnetic disturbance anytime soon. Such speculations should not be the basis for nuclear safety.

There are no current appropriations for a replacement to the ACE space weather monitoring satellite. Future space weather forecasting capability may rely not on the assets of a US Government agency, but on a satellite controlled by the People's Republic of China.

In summary, after over 20 years of evident need, there is no regulatory standard or law requiring electric utilities to protect against severe space weather and resulting geomagnetic disturbance. There is no federal agency that has the clear legal authority to set reliability standards on geomagnetic disturbance. The non-governmental entity responsible for electric reliability, NERC, has delayed 20 years in setting a reliability standard for geomagnetic disturbance. By written account of responsible parties, any eventual measures to protect the commercial grid against geomagnetic disturbance will become effective far into the operational life of nuclear power plants and associated spent fuel pools. In the absence of future appropriations for government-controlled space weather forecasting resources, clear regulatory and legal authority of other government agencies, and actual measures taken to implement electric reliability standards for geomagnetic disturbance, the NRC has an regulatory obligation to act on its own to protect spent fuel pools.

6.9 NRC Probabilistic Risk Assessment

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 this Probabilistic Risk Assessment (PRA), 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 comparison to the PRA analysis of this Petition, "Loss of offsite power initiated by severe weather" is the scenario closest to a severe space weather/geomagnetic disturbance scenario. This scenario assumes that it might be difficult for offsite help to reach the spent fuel pool site. When all factors are considered, the NRC PRA shows a chance of zirconium fire of 1.1 in 10 million per year. (The report assumed fire would occur if the fuel was uncovered by water.) 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.

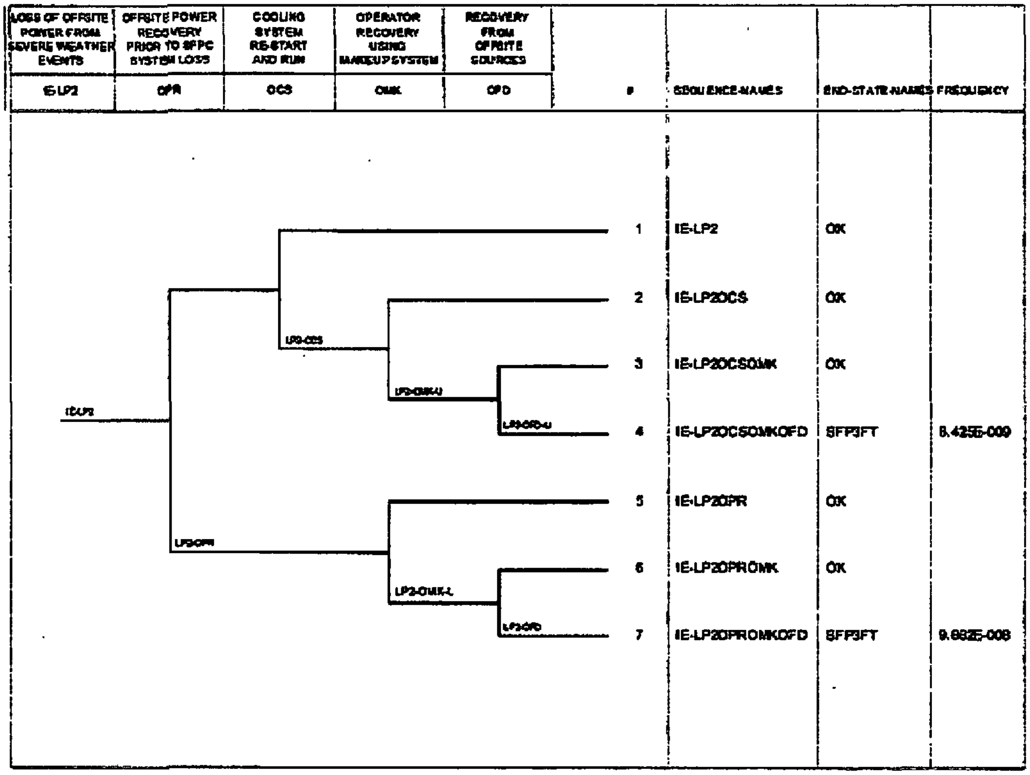
Table 4.1-1 delineates commitments which assume that both onsite and offsite personnel will be available in the aftermath of a severe weather event and associated widespread commercial grid outage.

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 PRA 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 at least 1-2 years to replace extra high voltage transformers damaged by geomagnetic disturbance. 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 geomagnetic disturbance.

6.10 Petitioner's Probabilistic Risk Assessment

The use of Probabilistic Risk Assessment has been well established in NRC regulatory procedure, including the rulemaking process. The NRC published "Policy Statement on the Use of Probabilistic Risk Assessment (PRA)" on August 16, 1995 (60 FR 42622). This statement reads in part:

> **IV. The Commission Policy**
>
> Although PRA methods and information have thus far been used successfully in nuclear regulatory activities, there have been concerns that PRA methods are not consistently applied throughout the agency, that sufficient agency PRA/statistics expertise is not available and that the commission is not deriving full benefit from the large agency and industry investment in the developed risk assessment methods. Therefore the Commission believes that overall policy on the use of PRA nuclear regulatory policy should be established so that the many potential applications of PRA can be implemented in a consistent and predictable manner that promotes regulatory stability and efficiency. This policy statement sets forth the Commission's intention to encourage the use of PRA and to expand the scope of PRA applications in all nuclear regulatory matters to the extent supported by the state of the art in terms of methods and data. Implementation of the policy statement will improve the regulatory process in three areas: Foremost through safety decision-making enhanced by the use of PRA insights; through more efficient use of agency resources; and through a reduction in unnecessary burdens on licensees.
>
> Therefore, the Commission adopts the following policy statement regarding the expanded NRC use of PRA:
>
> (1) The use of PRA technology should be increased in all regulatory matters to the extent supported by the state of the art in PRA methods and data in a manner that complements the NRC deterministic approach and supports the NRC's traditional defense in depth philosophy

(2) PRA and associated analyses (e.g., sensitivity studies, uncertainty analyses, and importance measures) should be used in regulatory matters, where practical within the bounds of the state-of-the-art, to reduce unnecessary conservatism associated with regulatory requirements, regulatory guides, license commitments, and staff practices. Where appropriate, PRA should be used to support the proposal for additional regulatory requirements in accordance with 10 CFR 50.109 (Backfit Rule). Appropriate procedures for including PRA in the process for changing regulatory requirements should be developed and followed. It is, of course, understood that the intent of this policy is that existing rules and regulations shall be complied with unless these rules and regulations are revised.

(3) PRA evaluations in support of regulatory decisions should be as realistic as practicable and appropriate supporting data should be publicly available for review.

(4) The Commission's safety goals for nuclear power plants and subsidiary numerical objectives are to be used with appropriate consideration of uncertainties in making regulatory judgments on the need for proposing and backfitting new generic requirements on nuclear power plant licensees.

Under current design basis 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 the current 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, according to the best scientific evidence now available. 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 conduct a simple PRA to more precisely gauge the probability of zirconium fires at spent fuel pools due to geomagnetic disturbance and resulting long-term Loss of Outside Power (LOOP). The purpose of this PRA is to show that an amendment to the CFR is required. We do not attempt to conduct a PRA for any proposed solution, because we do not know the specific implementations that may selected by licensees should the current Petition be approved.

The chance of zirconium fires would be more precisely determined by the individual probabilities of three events:

1. Severe space weather of sufficient intensity to cause geomagnetic disturbance and 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 use the estimates in a PRA for spent fuel pools under the scenario of long-term LOOP.

6.10.1 Probability of Long-Term LOOP

Severe space weather and resulting geomagnetic disturbance 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 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 extreme 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 and geomagnetic disturbance 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

11. Session Report, IEEE PES Summer Meeting, IEEE Publication 90TH0357-4-PWR,1990.V. D. Albertson, "Measurements and Instrumentation for Disturbance Monitoring of Geomagnetic Storm Effects," Effects of Solar-Geomagnetic Disturbances on Power Systems, Special Panel Session Report, IEEE PES Summer Meeting, IEEE Publication9OTHO291-5 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 should consider reasonably foreseeable. The October 2010 Oak Ridge National Laboratory report, "Electromagnetic Pulse: Effects on the U.S. Power Grid," was produced for the Federal Energy Regulatory Commission (FERC) in joint sponsorship with the Department of Energy and the Department of Homeland Security. This report determined a specific frequency and a specific outcome: "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."

The Oak Ridge National Laboratory has staff devoted to the study of the electric grid at its Power and Energy Systems Group. Moreover, the Oak Ridge National Laboratory has an extensive history of publishing work on the effects of electromagnetic pulse on the electric grid. Examples of previous published work are "Electric Utility Experience Industry with Geomagnetic Disturbances" (November 1991) and "HEMP Emergency Planning and Operating Procedures for Electric Power Systems" (July 1993).

For the purposes of this Petition, we use the Oak Ridge National Laboratory probability estimate of 1E-2 (one-in-one-hundred) per year for severe space weather and geomagnetic disturbance sufficient to collapse two large portions of the North American power grid. Outright rejection of the Oak Ridge estimate, or wholesale substitution of the Oak Ridge work with the work of a less qualified body, could be arbitrary, without substantial evidence, and in direct conflict with the demonstrated fact of previous damage of extra high voltage transformers due to geomagnetic disturbance. To the extent that there might be uncertainty in the Oak Ridge estimate, a reasonable person would use sensitivity analysis to determine if any conclusions would be affected by the degree of uncertainty.

6.10.2 Probability of No Outside Assistance

Should electric power for active cooling of spent fuel pools cease, the probability preventing of a zirconium fire then becomes partly 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 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 not 100% certain 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.

Petitioner does not assert, based on personal conjecture, that absolutely no outside assistance would be available to nuclear power plants under a condition of 1-2 years commercial grid outage. Neither does Petitioner assert, based on personal conjecture, a 100% probability that nuclear power plants experiencing long-term commercial grid outage will continue to receive outside assistance, including supplies of fuel, simply because a government plan promises such support. Petitioner does rely on the findings of the congressionally-chartered EMP Commission that supplies for food, fuel, and potable water will be restricted during long-term grid outage. Petitioner then reasonably implies that outside assistance to nuclear power plants will be similarly restricted for 1-2 years. Use of personal conjecture to assert that supplies of food, water, and fuel will continue to be freely available, or wholesale substitution of the work of the EMP Commission for the work of a less-qualified body, could result in an arbitrary conclusion without substantial evidence.

Classified plans may exist for military assistance to nuclear power plants; however, just because a plan is classified does not mean it will be 100% effective. Even military plans would be reduced in effectiveness if personnel are restricted in access to supplies of food, water, and fuel. 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. While we may wish that the military or other federal agency would ride to the rescue in the event of widespread grid outage, Petitioner is reminded of the old proverb, "If wishes were horses, then beggars would ride." Wishes for certainty of a favorable outcome have no place in probabilistic risk assessment.

For the purposes of this Petition, Petitioner assumes a 5E-1 (50%) chance of continuing outside assistance to nuclear power plants over a 1-2 year period of commercial grid outage. This represents a reasonable midpoint estimate.

6.10.3 Probability of Spontaneous Zirconium Ignition

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.

(Emphasis not in original.)

Other public evidence suggests that zirconium cladding may spontaneously ignite with a much longer decay time than one year; for example, 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)" reads "...after roughly three years of storage, spent fuel can be air-cooled, i.e., such fuel need not be submerged to prevent melting."

In summary, there is substantial evidence in the public record, including evidence from the classified Sandia report, that zirconium-cladded fuel rods in a dense configuration and under a partial loss of coolant scenario would spontaneously ignite for a substantial period of time after removal from the reactor core, perhaps as long as three years. There is minimal evidence in the public record that zirconium-cladded fuel rods in a dense configuration and under a partial loss of coolant scenario would be safe less than one year after removal from the reactor core.

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 (partial loss of coolant) occurs. Nuclear power plants have a typical refueling cycle of 18-24 months. Here we make the bounding 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%).

While there may be some uncertainty in the assumption of 50% chance of spontaneous zirconium ignition, any reasonable person would not reject the assumption outright but would instead use sensitivity analysis before coming to any conclusions about the safety of spent fuel pools. To reject this quantified assumption outright with a qualitative statement such as "this assumption is overly conservative" could be arbitrary and without substantial evidence.

Petitioner recognizes that the period since removal from the reactor core that would result in spontaneous zirconium ignition, as determined by experimentation or modeling, may constitute classified information. But the mere fact that this information might be classified should not be grounds for denial of the Petition; such a decision could be arbitrary and without substantial evidence in the public record. In any case, the classification of information regarding the safety of various decay periods would have absolutely no effect on the probability of spontaneous zirconium ignition; paper documents do not change the laws of physics.

6.10.4 PRA Event Tree for Long-Term LOOP Scenario

To determine the probability of zirconium cladding fires at spent fuel pools after the initiating event of long-term loss of outside power, one must take into account the individual probabilities of three events:

- Long-term LOOP
- No outside aassistance
- Spontaneous zirconium ignition

Below is presented a simple Probabilistic Risk Assessment (PRA) event tree to estimate a frequency for spontaneous zirconium ignition.

Basic Event Summary for Long-Term Loss of Outside Power

Basic Event Name	Description	Basic Event Probability
LTLOOP	Loss of Outside Power for 2 Years	1.00E-02
NOA	No Outside Assistance/No Long-Term Presence of Human Operators Onsite	5.00E-01
SZI	Spontaneous Zirconium Ignition	5.00E-01

Long-Term Loss of Outside Power Event Tree

Long-Term LOOP	No Outside Assistance	Spontaneous Zirconium Ignition	#	Sequence Name	End State Name	Frequency
		LTLLOOP-NOA-SZI	1	LTLLOOP-NOA-SZI	Zirconium Ignition	2.50E-03
	LTLLOOP-NOA					
LTLOOP			2	LTLLOOP-NOA	OK	5.00E-03
			3	LTLOOP	OK	1.00E-02

As the above assessment shows, the frequency for zirconium cladding fires is estimated at 2.5E-3 or 0.25% per reactor year.

6.10.5 Individual Risk Estimates

NUREG-1738 predicts early fatalities and long-term consequences should zirconium cladding fires occur. A textual summary of graphical 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 not in original.)

NUREG-1738 uses two scenarios to determine estimates of individual risk. Table 3.7-1 below displays results from the High Ruthenium Source Term scenario and Table 3.7-2 displays results from the Low Ruthenium Source Term scenario.

Table 3.7-1 . Consequences of an SFP Accident With a High Ruthenium Source Term (per event)

Time After Shutdown	Mean Consequences for High 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	192	2.37×10^{7}	4.43×10^{-2}	8.24×10^{-2}
90 days	162	2.25×10^{7}	4.19×10^{-2}	8.20×10^{-2}
1 year	77	1.93×10^{7}	3.46×10^{-2}	8.49×10^{-2}
2 years	19	1.69×10^{7}	2.57×10^{-2}	8.42×10^{-2}
5 years	1	1.45×10^{7}	8.96×10^{-3}	7.08×10^{-2}
10 years	-	1.34×10^{7}	4.68×10^{-3}	6.39×10^{-2}
Early Evacuation				
30 days	7	1.35×10^{7}	2.01×10^{-3}	4.79×10^{-3}
90 days	4	1.29×10^{7}	1.87×10^{-3}	4.77×10^{-3}
1 year	1	1.12×10^{7}	1.50×10^{-3}	4.33×10^{-3}
2 years	-	9.93×10^{6}	1.12×10^{-3}	3.70×10^{-3}
5 years	-	8.69×10^{6}	3.99×10^{-4}	2.93×10^{-3}
10 years	-	8.13×10^{6}	2.05×10^{-4}	2.64×10^{-3}

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

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	$5.58x10^{6}$	$1.27x10^{-2}$	$1.88x10^{-2}$
90 days	1	$5.43x10^{6}$	$9.86x10^{-3}$	$1.82x10^{-2}$
1 year	1	$5.28x10^{6}$	$7.13x10^{-3}$	$1.68x10^{-2}$
2 years	-	$5.12x10^{6}$	$5.64x10^{-3}$	$1.58x10^{-2}$
5 years	-	$4.90x10^{6}$	$3.18x10^{-3}$	$1.43x10^{-2}$
10 years	-	$4.72x10^{6}$	$1.63x10^{-3}$	$1.29x10^{-2}$
Early Evacuation				
30 days	-	$4.12x10^{6}$	$8.36x10^{-4}$	$9.92x10^{-4}$
90 days	-	$4.02x10^{6}$	$6.83x10^{-4}$	$9.62x10^{-4}$
1 year	-	$3.95x10^{6}$	$5.44x10^{-4}$	$9.09x10^{-4}$
2 years	-	$3.87x10^{6}$	$4.41x10^{-4}$	$8.71x10^{-4}$
5 years	-	$3.77x10^{6}$	$2.54x10^{-4}$	$8.14x10^{-4}$
10 years	-	$3.69x10^{6}$	$1.47x10^{-4}$	$7.70x10^{-4}$

* Conditional on event - Total frequency for all events is shown in Table 3.1 as less than $3x10^{-6}$ per year.

NUREG-1738 explains the differences between the High Ruthenium Source Term and Low Ruthenium Source Term scenarios:

> 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-106 half-life is about 1 year. For cesium-137, 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 journal article"Reducing the Hazards from Stored Spent Power-Reactor Fuel in the United States," April 21, 2003, Robert Alvarez, et al., (published in Science and Global Security, spring 2003) analyzed the risk from zirconium cladding fires at spent fuel pools. The NRC published a subsequent rebuttal to the article on its website, "Fact Sheet on NRC Review of Paper on Reducing Hazards from Stored Spent Nuclear Fuel." This rebuttal reads in part:

Overestimation of Radiation Release

In estimating fuel damage, the paper again makes reference to past NRC studies which conservatively assumed bounding pool configurations for cooling analysis and conservatively assumed the extent of radiation release. In the 1997 Brookhaven National Laboratory (BNL) study, "Severe Accidents in Spent Fuel Pools in Support of Generic Safety Issue 82," (NUREG/CR-4982), it was assumed that 10-100% of the cesium-137 was released to the atmosphere. Similarly in NUREG-1738 the base case assumed the release of 75% of the total cesium-137 inventory. The assumption of such a large release in NUREG-1738 was a large conservatism which was tolerable for the purposes of that study. However, it is neither a realistic estimate nor an appropriate assumption for a risk assessment of security issues where realism is needed. Ongoing research to address these issues includes more detailed realistic analyses of the thermal response of fuel to loss of water scenarios and more detailed, realistic analyses of the radionuclide releases for those scenarios where adequate cooling is not maintained. Based on preliminary analyses, we conclude that spent fuel in pools is more easily cooled even in the event of a complete loss of water. Further, preliminary analysis indicates that previous NRC estimates of the quantities of fission products released were high by likely an order of magnitude. Earlier NRC studies used large conservatisms, in generic calculations, with simplified modeling.

The NRC rebuttal reads, "Further, preliminary analysis indicates that previous NRC estimates of the quantities of fission products released were high by likely an order of magnitude." As the rebuttal states, NRC analysis divergent with NUREG-1738 was preliminary and, significantly, not published for peer review.

The PRA of this Petition does not use the assumptions of "Reducing the Hazards from Stored Spent Power-Reactor Fuel in the United States," but does use individual risk estimates from NUREG-1738. 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. We also selected the "95% Late Evacuation" scenario; while the actual evacuation percentage might be substantially lower in the case of commercial grid outage, we confine ourselves to the estimates published in NUREG-1738.

We took care to not use the estimates derived from bounding assumptions (the High Ruthenium Source Term) in our PRA, but instead rely on the more optimistic estimates of individual risk from the Low Ruthenium Source Term scenario.[1] The difference between the individual risks of latent cancer fatalities for the high and low ruthenium source term scenarios is a factor of 5.05. Although the individual risk estimates were originally developed for the population surrounding the Surry site in Virginia, the estimates can be applied to other populations because they are for individual risk rather than population risk.[2]

There is uncertainty in the assumptions used in the NUREG-1738 regarding the fraction of Cesium-137 released, as there is uncertainty in any set of assumptions. However, any reasonable person would not reject the individual risk estimates from NUREG-1738 outright but would instead use sensitivity analysis. To reject published estimates with a statement such as "these assumptions might be overly conservative by an order of magnitude" could be arbitrary and without substantial evidence, especially if any work divergent from NUREG-1738 is unpublished.

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[1] Individual risk estimates in NUREG-1738 assume 3.5 reactor cores in the spent fuel pool, equivalent to the last 10 refuelings. Information provided at http://www.nrc.gov/waste/spent-fuel-storage/nuc-fuel-pool.html shows that nearly all spent fuel pools are at full capacity in 2011 (approximately 8 reactor cores per pool). While Ruthenium decays quickly, the majority of Cesium-137 with a half-life of 30 years would remain in older reactor cores. Individual risk estimates for latent cancer fatalities in NUREG-1738 may be optimistic if zirconium fire propagates to all cores in the spent fuel pool, resulting in more Cesium-137 releases than assumed in the NUREG-1738 estimates.

[2] NUREG-1738 states: "Although the above comparisons focus on the Surry site, the results are expected to be generally applicable to other sites as well. The QHOs represent risk to the average individual within 1 mile and 10 miles of the plant, and should be relatively insensitive to the site-specific population."

6.10.6 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 5×10^{-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 5×10^{-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 2×10^{-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 2×10^{-6} per reactor year.

We calculated probable individual risks by determining the yearly probability of a spent fuel pool zirconium fire 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 for a "One Year After Shutdown, Late Evacuation" scenario. 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 a factor of 250.

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

6.10.7 Sensitivity Analysis

For the purposes of this Petition we take the probability for long-term loss of outside power as presented by Oak Ridge National Laboratory. The probability of outside assistance is a midpoint estimate of the Petitioner using the EMP Commission reports and scenarios from the Department of Homeland Security. The probability of spontaneous zirconium ignition is a midpoint estimate of the Petitioner using data from NUREG-1738 and studies by the National Academy of Sciences and Sandia National Laboratories. While the Petitioner believes its assumptions to be optimistic, a rigorous PRA requires sensitivity analysis. The below sensitivity analysis presents more even optimistic single-variable assumptions and then compares risk results to the NRC safety goals and LERF guideline.

Sensitivity Analysis for Single-Variable Assumptions

	Ratio of Risk Result to NRC Goal/Guideline		
Assumption	**Early Fatalities**	**Cancer Deaths**	**LERF**
Severe Space Weather Once Every 1000 Years	3:6	2.1	25.0
Space Weather Forecasting System, 95% Forecast Accuracy, 100% Operational Plan Effectiveness	1.8	1.1	12.5
Probability of Outside Assistance at 95%	3.6	2.1	25.0
No Spontaneous Zirconium Ignition with Decay Time of 1 Month or More	3.0	1.8	20.8
Order of Magnitude Downward Adjustment to Early Fatality and Latent Cancer Death Individual Risks	3.6	2.1	250.0

The above analysis shows that individual assumptions could be more significantly more optimistic and the NRC safety goals and LERF guideline would still not be met. For example, severe space weather and resulting geomagnetic disturbance could occur only once in one thousand years, on average, and the NRC safety goals and LERF guideline would still not be met. Alternatively, 95% of nuclear power plants could receive outside assistance and the NRC safety goals and LERF guideline would still not be met. Spontaneous zirconium ignition could be assumed to occur only within a decay time of one month and the NRC safety goals and LERF guideline would still not be met. A space weather forecasting system with 95% accuracy could be provided to power grid operators, also assuming that commercial grid operational plans are 100% effective, and the NRC safety goals and LERF guideline would still not be met.

Even if one were to make two or more assumptions significantly more optimistic, the LERF guideline would still not be met in most circumstances. The below table shows more optimistic multiple-variable assumptions and then compares results to the NRC safety goals and LERF guideline.

Sensitivity Analysis for Multiple-Variable Assumptions

	Ratio of Risk Result to NRC Goal/Guideline		
Assumptions	**Early Fatalities**	**Cancer Deaths**	**LERF**
Severe Space Weather Once Every 200 Years, 95% Forecast Accuracy, 100% Operational Plan Effectiveness	0.9	0.5	6.3
Probability of Outside Assistance at 95%, No Spontaneous Zirconium Ignition with Decay Time of 1 Month or More	0.3	0.2	2.1
Severe Space Weather Once Every 200 Years, 95% Forecast Accuracy, 100% Operational Plan Effectiveness, Probability of Outside Assistance of 95%	0.1	0.1	0.6

As the above table shows, it is possible to construct rosy scenarios where the NRC safety goals would be met. It is much harder to construct a realistic scenario where the LERF guideline would be met. The LERF guideline remains unmet in most circumstances because the fundamental risk with spent fuel pools is the large and probable release of radioactive material, as the unabbreviated name of the LERF guideline suggests: *Large Early Release Frequency*. The NRC safety goals are easier to meet because the individual risk estimates from NUREG-1738 assume 95% evacuation. There is, of course, an exceedingly good reason why the most tortured and unrealistic assumptions are necessary to construct a scenario where both the NRC safety goals and LERF guideline are met: Petitioner has identified a real problem that needs a real solution, not just administrative action.

6.10.8 Site-Specific Consequence Estimates

In order to estimate probabilistic benefits from bringing spent fuel pools within NRC safety goals, site-specific analysis is required. Each spent fuel pool is surrounded by a unique configuration of human population. Moreover, spent fuel pools vary in the number of years remaining in reactor licensure period.

6.10.8.1 Site-Specific Probability of Zirconium Cladding Fires

To calculate the site-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 no outside assistance
- Probability of spontaneous zirconium ignition

The probability of long-term LOOP at a specific site is dependent on the probability of severe space weather/geomagnetic disturbance 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 formula from extreme value theory:

$$Pe = 1 - [1-(1/T)]^n$$

Where:

P_e = Event Probability
T = Return Period (Years between Extreme Events)
n = Number of Years

Notably, under extreme value theory, there is never a 100% probability of an event occurring, even over a specific period of 100 years if the annual probability is one-in-one-hundred, or 1%. In fact, the probability for a specific one-hundred year period is 63%. (Although over a long time, events would occur every one hundred years, *on average*.) For the period 1921-2010 since the last severe space weather event, the probability of a severe space weather event was 60%.

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, resulting zirconium fire probabilities range from 0% for plants outside the Area of Probable Power System Collapse to 7.9% for the Vogtle 2 plant in Georgia.

These probability calculations assume that in the event of a widespread and long-term commercial grid collapse affecting most of the eastern United States population centers, grid power will continue uninterrupted to the rest of the country. However, the Area of Probable Power System Collapse—and by implication, plant specific risk—was determined assuming no cascading failures and no secondary economic effects. Because of the real possibility of a more severe geomagnetic disturbance than projected in the Oak Ridge report, and of long-term grid outages extending beyond the Area of Probable Power System Collapse, the proposed rule in the current Petition should not be site-specific, but should apply to all nuclear power plants and associated spent fuel pools.

Probability of Zirconium Fire at Spent Fuel Pools

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	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

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

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

Estimates Over Remaining Reactor Operation

Page 4 of 4

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%

6.10.8.2 Probable Fatalities Due to Zirconium Cladding Fires

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 latent 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.

Reasonable people might assert that the individual risk methodology of NUREG-1738 used to calculate probable fatalities 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 latent cancer deaths for individuals living more than 10 miles away. Nonetheless, for the sake of optimism, we use the NUREG-1738 methodology.

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

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	3,203	0.00	0
no	Arizona	Palo Verde 2	0.0%	0	3,203	0.00	0
no	Arizona	Palo Verde 3	0.0%	0	3,203	0.00	0
no	Arkansas	Arkansas Nuclear 1	0.0%	231	46,451	0.00	0
no	Arkansas	Arkansas Nuclear 2	0.0%	231	46,451	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

Estimates Over Remaining Reactor Operation

Page 2 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	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

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	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

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	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**

6.10.8.3 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. 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 MACCS2 consequence code severe accident computer code used by the NRC estimates fatalities based on societal dose of radiation, using a directly proportional relationship between dose and fatalities.[3] 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.

[3] NUREG-1738, page 3-13, "Because latent cancer fatalities are directly proportional to societal dose through a dose-to-cancer-risk conversion factor within the MACCS2 consequence code (Ref. 9), results for latent cancer fatalities are not displayed separately."

Spent Fuel Pool Fatalities in Event of Power System Collapse

Event 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)

Event 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**

7 DEFENSE-IN-DEPTH

The NRC "Policy Statement on the Use of Probabilistic Risk Assessment (PRA)" reads in part:

> **(C) Defense-In-Depth Philosophy**
>
> In the defense-in-depth philosophy, the Commission recognizes that complete reliance or safety cannot be placed on any single element of the design, maintenance, or operation of a nuclear power plant. Thus, the expanded use of PRA technology will continue to support the NRC's defense in depth philosophy by allowing quantification of the levels of protection and by helping to identify and address weaknesses or overly conservative regulatory requirements applicable to the nuclear industry. Defense-in-depth is a philosophy used by the NRC to provide redundancy for facilities with "active" safety systems, e.g., commercial nuclear power, as well as the philosophy of a multiple barrier approach against fission product releases. Such barrier principles are mandated by the Nuclear Waste Policy Act of 1982, which provides redundancy for a geologic repository to contain and isolate nuclear waste from the human environment.

Spent fuel pools are not within physical containment but are instead located in industrial-style metal buildings with numerous openings and gaps to the outside atmosphere. As currently designed and licensed, the first level of defense-in-depth for spent fuel pools is the active cooling system dependent on offsite power. The second level of defense in depth is the large volume of water in the pool. The third level of defense-in-depth are human operators that can establish supplementary makeup water and cooling systems.

"Regulatory Guide 1.174 - An Approach for Using Probabilistic Risk Assessment in Risk-Informed Decisions on Plant-Specific Changes to the Licensing Basis" (Revision 1, November 2002) explains how the defense-in-depth philosophy should be maintained:

> Consistency with the defense-in-depth philosophy is maintained if:
>
> - A reasonable balance is preserved among prevention of core damage, prevention of containment failure, and consequence mitigation.
> - Over-reliance on programmatic activities to compensate for weaknesses in plant design is avoided.
> - System redundancy, independence, and diversity are preserved commensurate with the expected frequency, consequences of challenges to the system, and uncertainties (e.g., no risk outliers).
> - Defenses against potential common cause failures are preserved, and the potential for the introduction of new common cause failure mechanisms is assessed.
> - Independence of barriers is not degraded.
> - Defenses against human errors are preserved.
> - The intent of the General Design Criteria in Appendix A to 10 CFR Part 50 is maintained.

As currently designed and licensed, defense-in-depth for spent fuel pools suffers from a number of flaws under a scenario of long-term LOOP. First, there is no physical containment. Second, there is overreliance on human operators to make up for a weakness in design. Third, there is no effective redundancy for a risk event—geomagnetic disturbance and long-term LOOP—that has an expected frequency that is reasonably foreseeable and not remote or speculative. Fourth, the active cooling system, any portable makeup water systems, and long-term presence of human operators onsite are subject to a common mode failure—failure of the commercial power grid. Because of these factors, there is no effective defense-in-depth for spent fuel pools under the current design basis.

8 PREVIOUS MITIGATIVE ACTIONS

The terrorist attacks of September 11, 2001 focused attention on the risk of spent fuel pools. Mitigation strategies were developed for spent fuel pools, some of which may be classified and therefore unavailable for full public examination. The NRC denial of Petitions for Rulemaking PRM-51-10 and PRM-51-12 describe the existence of these mitigation strategies:

> Additional mitigation strategies implemented subsequent to September 11, 2001, enhance spent fuel coolability and the potential to recover SFP water level and cooling prior to a potential SFP zirconium fire. The Sandia studies also confirmed the effectiveness of additional mitigation strategies to maintain spent fuel cooling in the event the pool is drained and its initial water inventory is reduced or lost entirely. Based on this more recent information, and the implementation of additional strategies following September 11, 2001, the probability, and accordingly, the risk, of a SFP zirconium fire initiation is expected to be less than reported in NUREG-1738 and previous studies.

The NRC denial of Petitions for Rulemaking PRM-51-10 and PRM-51-12 describes additional study and strategies for the "Partial Drain-Down" scenario, a scenario which is essentially equivalent to the gradual boil-off scenario that is of concern to the current Petition:

> 2. Partial Drain-Down.
>
> Air cooling is less effective under the special, limited condition where the water level in the SFP drops to a point where water and steam cooling is not sufficient to prevent the fuel from overheating and initiating a zirconium fire, but the water level is high enough to block the full natural circulation of air flow through the assemblies. This condition has been commonly referred to as a partial draindown, and is cited in the Thompson Report. Under those conditions, however, it is important to realistically model the heat transfer between high- and low-powered fuel assemblies. ***The heat transfer from hot fuel assemblies to cooler assemblies will delay the heat-up of assemblies, and allow plant operators time to take additional measures to restore effective cooling to the assemblies.*** Further, for very low-powered assemblies, the downward flow of air into the assemblies can also serve to cool the assembly even though the full circulation flow path is blocked. Also, as discussed further in this document, all nuclear plant SFPs have been assessed to identify additional, existing cooling capability and to provide new supplemental cooling capability which could be used during such rare events. This supplemental cooling capability specifically addresses the cooling needs during partial draindown events, and would reduce the probability of a zirconium fire even during those extreme events.
>
> (Emphasis not in original.)

As indicated in the bolded text above, additional study after NUREG-1738 indicates that heat transfer from hot fuel assemblies to cooler assemblies will ***delay the heat-up of assemblies***. Additional study does not indicate that enhanced heat transfer will prevent zirconium cladding from eventually heating up and catching fire under some circumstances. The benefit of a delay would be additional time to "allow plant operators time to take additional measures to restore effective cooling to the assemblies." But in a case where plant operators were no longer on-site, or where outside assistance is no longer available, the delay would not necessarily result in a prevention of zirconium fire, except in the rare case where a delay of a few extra hours or days would increase fuel decay time until zirconium fire would not occur. (This borderline condition would be statistically rare and would not substantially affect the probability of zirconium fire. For example, if delayed heat-up provided an extra five days of time and the borderline condition were at one year of fuel decay, the probability would be affected by 5 days/365 days = 1.4%.)

The NRC denial of Petitions for Rulemaking PRM-51-10 and PRM-51-12 also describes license amendments to enhance spent fuel pool safety:

> 3. License Amendments.
>
> In January 2006, the nuclear industry proposed a combination of internal and external strategies to enhance the spent fuel heat removal capability systems at every operating nuclear power plant. The internal strategy implements a diverse SFP makeup system that can supply the required amount of makeup water and SFP spray to remove decay heat. The external strategy involves using an independently-powered, portable, SFP coolant makeup and spray capability system that enhances spray and rapid coolant makeup to mitigate a wide range of possible scenarios that could reduce SFP water levels. In addition, in cases where SFP water levels cannot be maintained, leakage control strategies would be considered along with guidance to maximize spray flows to the SFP. Time lines have been developed that include both dispersed and non-dispersed spent fuel storage. The NRC has approved license amendments and issued safety evaluations to incorporate these strategies into the plant licensing bases of all operating nuclear power plants in the United States.

As described above, there are two safety enhancements in the license amendments—an "internal strategy" and an "external strategy." The internal strategy consists of a "diverse SFP makeup system that can supply the required amount of makeup water and SFP spray to remove decay heat." But any internal strategy that relies on electric power would suffer from the same long-term loss of outside power vulnerability as the motor-driven circulation pumps normally used for spent fuel pool cooling. Any internal strategy relying on petrochemical-fueled pumps would not be assured resupply of fuel. And finally, any internal strategy relying on human operators would not work if the operators were no longer on site.

While the "external strategy" is not described in detail, one might imagine a portable spray system or a hose from a firetruck. But as outlined elsewhere in the current Petition, under conditions of long-term and widespread commercial grid failure, there is no assurance that portable cooling systems can be airlifted or trucked in, nor any assurance that firetrucks will promptly arrive and permanently stay on site.

In addition to mitigative strategies for spent fuel pools, in recent years the NRC, FERC, and NERC have taken steps to improve commercial grid reliability for nuclear power plants. The required participation of nuclear power plant licensees is spelled out in "NRC Generic Letter 2006-02: Grid Reliability and the Impact on Plant Risk and the Operability of Offsite Power" (February 1, 2006). All addressees were required to submit written responses to the Generic Letter regarding their compliance with regulatory requirements for electric power sources and associated training. While Generic Letter (GL) 2006-2 may have produced greater coordination between nuclear power plants and electric transmission system operators, GL 2006-2 did not require protection of the electric transmission system from severe space weather and resulting geomagnetic disturbance. As a result, any mitigative actions flowing from GL 2006-2 are not applicable to the current Petition.

9 PREVIOUS NRC RESPONSE TO RELICENSING COMMENTS ON GEOMAGNETIC DISTURBANCE

Petitioner searched the NRC ADAMS online information system and found that at least one other party has concerns regarding geomagnetic disturbance that are similar to the concerns of the Petitioner. "Generic Environmental Impact Statement for License Renewal of Nuclear Plants, Supplement 45, Regarding Hope Creek Generating Station and Salem Nuclear Generating Station, Units 1 and 2, Draft Report for Comment Appendices" available under the NRC ADAMS system contains the comments of Mr. John Greenhill. The commenter observes that a one-in-one hundred year solar storm could produce a continent-wide, long-term outage of the power grid due to damage to damage to step-up transformers. Mr. Greenhill also expresses concerns about fuel running out for emergency diesel generators and commercial vendors being unable to resupply fuel:

Reproduction of Email From John Greenhill to NRC

Eccleston, Charles

From:	Greenhill, John [John.Greenhill@dhs.gov]
Sent:	Saturday, November 21, 2009 9:24 PM
To:	SalemEIS; HopeCreek@nrc.gov
Cc:	Eccleston, Charles; Warren Udy
Subject:	Salem and Hope Creek Nuclear Plants 20 year license extensions

Dears Sirs

There were incidents on 3/13/1989 and 9/19/1989 at the Salem 1,2and Hope Creek nuclear plants sites when geomagnetic storms caused damage to the single phase, generator step-up transformers which caused them to be taken out of service.

The damage was due to geomagnetically induced currents (GIC) caused by the geomagnetic storms.

Questions:

1. Is there a publically available report that describes these incidents?
2. What was the magnitude of the currents that caused the damage?
3. How long did the damaging currents persist?
4. What was the protective relay system in place at that time such as the IEEE Std C37.91-1985?
5. Where there any modifications to the transformer protective system put into effect?
6. How will the step-up transformers at Salem and Hope Creek sites be protected if a super geomagnetic storm (10 times the size of the 1989 storms) occurs during the 20 year extension? The next solar maximum is expected 2013-2014.
7. Do the sites have spare step-up transformers?

The TMI Generic Environmental Impact Statement for License (NUREG-1437 Supplement 37) table 5-2 shows the following

Table 5-2. TMI-1 Internal Events Core Damage Frequency

Initiating Event	CDF (Per Year)	% Contribution to CDF
Loss of Offsite Power	7.73×10^{-6}	32.6
Transients	5.80×10^{-6}	24.5
Small and Very Small LOCA	4.66×10^{-6}	19.7
Loss of Nuclear Service River Water	3.67×10^{-6}	15.5
Steam Generator Tube Rupture	9.93×10^{-7}	4.2
Internal Floods	4.50×10^{-7}	1.9
Large and Medium LOCA	2.06×10^{-7}	< 1
ISLOCA	1.80×10^{-7}	<1
Total CDF (internal events)	$\mathbf{2.37 \times 10^{-5}}$	**100**

The probability of a super solar storm of the 1859 or 1921 size is about 1/100 years or 1 %/year. This size storm could lead to a continental wide, long term (many months) outage of the bulk power grid because of damage to all the U.S. step-up transformers. This damaged would be similar to the damage that occurred at Salem New Jersey in 1989 during a fairly mild solar storm. With such an outage, the emergency generators (that drive the cooling pumps) fuel supply could run out and may not be replaced because all the commercial fuel suppliers would be out of fuel as well due to the failure of the electrical pumps. Without fuel for the cooling pumps, the core damage frequency (CDF) appears to be several orders larger that the CDF given in the table 5-2. Perhaps s solar storm initiating event should be included in all the final EIS documents including the Salem and Hope Creek..

John D. Greenhill, P.E.
Department of Energy
National Communications System
Department of Homeland Security
Email: john.greenhill@dhs.gov
Phone: 703-235-5538

Official comments from Mr. Greenhill and the NRC response follow:

Comment: I am unable to attend the hearings on 11/15/09 but would like to submit the following questions. There were incidents on 03/13/1989 and 9/19/1989 at the Salem 1 and 2 Nuclear Plants sites when geomagnetic storms caused damage to the single phase, generator step-up transformers which caused them to be taken out of service. The damages were due to geomagnetically induced currents caused by the geomagnetic storms.

Questions:

Is there a publically available report that describes these incidents?
What was the magnitude of the currents that caused the damage?
How long did the damaging currents persist?
What was the protective relay system in place at that time such as the IEEE Std C37.91 1985?
Where there any modifications to the transformer protective system put into effect?
How will the step-up transformers at Salem and hope Creek sites be protected if a super geomagnetic storm (10 times the size of the 1989 storms) occurs during the 20 year extension?
Do the sites have spare step-up transformers?

An initial cursory look shows a possible problem with the draft EIS when one examines table 5-2. The probability of a super solar storm of the 1859 or 1921 size is about 1/100 years or 1 % year. This size storm leads to a continental long term (many months) grid outage because of damage to all the U.S. step-up transformers similar to the damage that occurred at Salem New Jersey in 1989 during a fairly mild solar storm. With such an outage the emergency generators (that drive the cooling pumps) fuel supply would run out and could not be replaced because the commercial fuel suppliers would be out of fuel as well. Without fuel for the cooling pumps, the core damage frequency (CDF) appears to be several orders larger that the CDF given in the table 5-2. Perhaps a solar storm initiating event should be included in all the final EIS documents including the Salem and Hope Creek. SHC-18-1; SHC-18-2; SHC-18-3

Response: *The seven questions listed in the comment above have been provided to the appropriate NRC Region I staff and a separate response was provided to the commenter. These questions raise concerns that are related to current operational issues at the plant but do not fall within the scope of the license renewal environmental review and, therefore, will not be evaluated in development of the SEIS.*

With respect to the comment's suggestion that solar storms should be included as an initiating event for severe accident mitigation alternatives (SAMA), the staff considers the issue as follows: The SAMA analysis considers potential ways to further reduce the risk from severe reactor accidents in a cost-beneficial manner. The process for identifying and evaluating potential plant enhancements involves use of the latest plant-specific, peer-reviewed probabilistic risk assessment (PRA) study. These risk assessment studies typically show that loss of offsite power (LOSP) and station blackout (SBO) sequences are among the dominant contributors to core damage frequency (CDF) for nuclear power plants and account for about 20 to 50 percent of the CDF. As a result, enhancements to mitigate SBO events initiated by a LOSP are routinely identified and evaluated in the SAMA analysis. Consideration of SBO events initiated by a solar storm would not be expected to result in identification of additional SAMAs to mitigate LOSP and SBO events since license renewal applicants already perform a search for potential means to mitigate these risk contributors.

Consideration of solar storms would not be expected to substantially impact the CDF for LOSP/SBO events because postulated damage to generator step-up transformers would not affect the operation of the emergency diesel generators (EDGs). The EDGs would function to cool the reactor core until connections to the electrical grid are reestablished or alternative means of core cooling are established. Onsite fuel storage is typically sufficient to provide for at least 7 days of EDG operation and would be replenished during this period, as demonstrated at the Turkey Point plant following Hurricane Andrew in 1992 (NRC, 1992). Even with a major disruption in the supply chain, the 7-day period is sufficient for alternative arrangements to be made to *resupply fuel for nuclear power plant EDGs in accordance with the National Response Framework (see National Response Framework, Emergency Support Function #12 – Energy Annex, www.fema.gov/pdf/emergency/nrf/nrf-esf-12.pdf). Alternative means of core cooling would be viable in the longer term, given that core cooling requirements (e.g., required pumped flow rates) would be substantially reduced days and weeks after reactor shutdown, and given the substantial industry and Federal resources that would be available to facilitate these measures.*

If there is incompleteness in current PRAs with respect to an underestimate of the frequency or consequence of solar storm-initiated LOSP/SBO events, the sensitivity analysis performed on the SAMA benefit calculation would capture the increased benefit that might result from a more explicit consideration of solar storm-induced events. This analysis typically involves increasing the estimated benefits for all SAMAs by an uncertainty multiplier of approximately 2 to determine whether any additional SAMA(s) would become cost-beneficial and retaining any such SAMA(s) for possible implementation. In summary, the consideration of solar storm initiated events would not be expected to alter the results of the SAMA analysis since enhancements that address these types of events are already considered in the applicants' search for SAMAs to mitigate SBO/LOSP events, and any potential underestimate of the benefit of these SAMAs would be captured in existing applications by the use of the uncertainty multiplier on the SAMA benefits.

Petitioner disagrees with the contentions of NRC staff in regard to Mr. Greenhill's comments and would also disagree if the same contentions were made in regard to the current Petition. The reasons for specific disagreements follow:

1. NRC staff states, "Consideration of SBO events initiated by a solar storm would not be expected to result in identification of additional SAMAs to mitigate LOSP and SBO events since license renewal applicants already perform a search for potential means to mitigate these risk contributors." After a thorough search of the NRC ADAMS database, Petitioner was unable to find any evidence that licensees already perform searches in the SAMA process for potential means to mitigate the risk of solar storms or geomagnetic disturbance.

2. NRC staff states, "Onsite fuel storage is typically sufficient to provide for at least 7 days of EDG operation and would be replenished during this period, as demonstrated at the Turkey Point plant following Hurricane Andrew in 1992 (NRC, 1992)." Petitioner is concerned that multiple nuclear power plants would be affected simultaneously by long-term LOOP, while the Hurricane Andrew event at Turkey Point was an isolated incident. Moreover, the vast majority of national infrastructure was not affected by Hurricane Andrew. Therefore replenishment of fuel at Turkey Point is not predictive of replenishment of fuel during a long-term and widespread commercial grid outage.

3. NRC staff states, "Even with a major disruption in the supply chain, the 7-day period is sufficient for alternative arrangements to be made to resupply fuel for nuclear power plant EDGs in accordance with the National Response Framework (see National Response Framework, Emergency Support Function #12 – Energy Annex, www.fema.gov/pdf/emergency/nrf/nrf-esf-12.pdf)." The NRC response about the adequacy of government planning is an assertion, unsupported by quantification. As explained in Section 6.4 of this Petition, "Lack of DHS Preparation for Scenario of Long-Term Power Grid Collapse," there is no 100% assurance that this paper plan would provide outside assistance to dozens of nuclear power plants in the event of power grid collapse. There is no experience with use of the National Response Framework under a condition of widespread power outage, although the experience with Hurricane Katrina

would indicate that government emergency planning is not a sure solution. Use of any assumption regarding outside assistance, including resupply of diesel fuel, needs a quantitative value to be used in a PRA.

4. NRC staff states, "Alternative means of core cooling would be viable in the longer term, given that core cooling requirements (e.g., required pumped flow rates) would be substantially reduced days and weeks after reactor shutdown, and given the substantial industry and Federal resources that would be available to facilitate these measures." It is by no means 100% certain that "substantial industry and Federal resources that would be available" during a condition of long-term and widespread commercial grid collapse. Any assumption regarding availability of industry and Federal resources must meet the burden of substantial evidence and also needs a quantitative value to be used in a PRA.

5. NRC staff states, "If there is incompleteness in current PRAs with respect to an underestimate of the frequency or consequence of solar storm-initiated LOSP/SBO events, the sensitivity analysis performed on the SAMA benefit calculation would capture the increased benefit that might result from a more explicit consideration of solar storm-induced events. This analysis typically involves increasing the estimated benefits for all SAMAs by an uncertainty multiplier of approximately 2 to determine whether any additional SAMA(s) would become cost-beneficial and retaining any such SAMA(s) for possible implementation." Again, Petitioner could find no evidence that licensees include any estimates in current PRAs for the frequency or consequence of ***solar storm-initiated*** LOSP/SBO events. To the extent that current PRAs contains risk estimates for other weather-related LOSP/SBO events, these estimates are inapplicable because LOSP/SBO events in current PRAs are assumed to have duration of days, while a solar storm-initiated LOSP/SBO event would have a duration of months or years.

10 TECHNICAL FEASIBILITY ASSESSMENT

The requirements of the current Petition are well within the capabilities of existing commercial off-the-shelf technology. Numerous industries require highly reliable unattended power generation, including oil, gas, and telecommunications. As a result, a well-developed supplier base exists with multiple technology options. The below table shows options for highly reliable unattended power generation.

High Reliability Unattended Power Production

Technology	Example Vendor	Typical Unit Capacity	Cost/KW
Organic Rankine Cycle	Ormat Technologies	4 KW	$20,000
Solar Photovoltaic	Solar Electric Supply	5 KW	$60,000
Thermoelectric Generator	Global Thermoelectric	0.5 KW	$40,000

Generated power could be used to run electric pumps to provide makeup water. Makeup water by itself could provide sufficient cooling for spent fuel pools since the high latent heat of vaporization provides substantial cooling capacity. Required pump capacity would depend on the time since discharge of fuel from the reactor core. Below is a table derived from NUREG-1738 which shows the required pumping capacity in gallons per minute as a function of time after fuel discharge. Because diesel generators could supply power for spent fuel circulation pumps for up to 7 days after fuel discharge (in the event of loss of outside power immediately after refueling), a pumping capacity of 130 gallons per minute would provide substantial safety margin.

Spent Fuel Pool 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 ft^3/ft depth, and for PWRs, we have 957 ft^3/ft depth. Assume = 1000 ft^3/ft depth for level decreases resulting from boil-off.

A 5 HP electric motor running at 80% typical efficiency would consume approximately 5 kilowatts of power. Multiple units of any of the above high reliability power production technologies could supply this amount of power. A pump attached to a 5 HP motor would typically generate approximately 100 feet of head through a 2 inch pipe at 160 gallons per minute. As the boil-off rate charge shows, after only a few months the duty cycle for any power generation solution would dramatically decline.

The Organic Rankine Cycle technology for power production is particularly intriguing because this technology can use waste heat below the boiling temperature of water as an energy source. An obvious source of waste heat would be the water contained in the spent fuel pool. The typical spent fuel pool generates 3 megawatts of heat one year after fuel discharge from the reactor. Another source of heat for Organic Rankine Cycle is propane.

An additional advantage of Organic Rankine Cycle turbines are their high reliability, with a demonstrated Mean Time Between Critical Failure of 200,000 hours and an operational lifetime in excess of twenty years. A makeup water system based on Organic Rankine Cycle turbines powered by waste heat could run not only for two years, but until the waste heat produced by the spent fuel is insufficient to bring the pool water to high temperature.

Solar power systems are designed to run unattended for long periods and consist of only three basic components: photovoltaic panels, charge controllers, and batteries. The normal unattended lifetime of these components are in excess of ten years if telecommunications-grade batteries are used. If a solar power system were to be used for spent fuel cooling, it should be recognized that a reservoir of makeup water—either internal or external to the spent fuel pool—could be a source of stored cooling during inclement weather.

Thermoelectric generators were originally designed to provide power on Apollo moon missions and are highly reliable with minimal maintenance requirements. The life expectancy of a thermoelectric generator is 15-20 years. Thermoelectric generators have no moving parts. The most appropriate fuel source would be propane. Annual maintenance consists of checking (but not replacing) the fuel filter, pressure regulator, and burner orifice.

Because of the distinctive power requirements for spent fuel pool cooling—initial high power at the time of fuel discharge followed by much lower power requirement—a hybrid system could provide both cost efficiency and high reliability. For example, a propane-powered Organic Rankine Cycle turbine could be used to provide high power initially, with a lower kilowatt solar system used after several months of fuel decay. In the later stages of fuel decay, weather interruption of solar power might be acceptable if the spent fuel pool and/or associated reservoirs stored sufficient water to allow non-continuous makeup water supply. Multiple redundant units could be employed to provide sufficient power in the early stages of fuel decay and greater reliability in the later stages of fuel decay.

The control system used to meter makeup water into the spent fuel pool could be extremely simple, consisting of little more than float switches and/or float values. An intermediate water reservoir could be used to reduce on/off cycling of the electrically-operated pump(s) and power generation system(s).

Highly reliable electrically-driven pumps and control mechanisms are available in the off-the-shelf commercial market. Municipal water systems and sewage treatment facilities use such equipment. Likewise, reliable propane storage is available and commonly used for distribution facilities.

Petitioner does not present a PRA for spent fuel pools that includes a specific backup power and makeup water solution, because Petitioner does not know the precise requirements of CFR amendment that might be approved or how licensees may choose to implement a change to the CFR. Petitioner has shown that multiple technology options exist that could be combined into a feasible and highly reliable solution. For the purposes of advocating Petition approval, Petitioner should not have to design an optimal solution; Petitioner should only have to show that a practical and cost-effective solution could exist.

No doubt the reliability of any specific solution would not be 100%. In fact, because of the wide divergence between the current risk of spent fuel pools and the NRC safety goals/LERF guideline, it would be challenging to design a specific solution that would completely close this safety gap. But a partially-effective solution would reduce risk far more than no solution at all; the lack of a perfect solution should not be grounds for denial of this Petition nor should it be a reason to not attempt any solution at all.

Some early readers of this Petition have speculated as to whether backup power solutions and associated fuel would be susceptible to theft. Nowhere in this Petition has Petitioner used speculation about human behavior in a PRA. Instead, the PRA is confined to the probability of physical events and direct physical consequences, e.g., without electricity for refineries, fuel resupply might be interrupted. Prediction of second-order effects of human behavior, including theft, social dissolution, widespread scavenging, etc., could be without sufficient evidence. In any case, such speculations should not be the basis to not attempt any solution at all.

11 COST-BENEFIT COMPARISION

As the previous technical feasibility assessment shows, the cost per kilowatt of reliable backup power is moderate and as little as 5 kilowatts of backup power might suffice. We expect the other costs of an emergency makeup water system, including fuel storage, pumps, piping, and control systems to be moderate as well. Electrically-operated pumps cost only a few thousand dollars and float values/float switches cost even less. Based on a backup power system with peak capacity of 5-10 kilowatts, we estimate that a complete unattended makeup water system could cost as little as $1 million per spent fuel pool. Early readers of this Petition have indicated that nuclear industry requirements could raise the cost to $10 million, but we use $1 million as a first-order estimate.

The probabilistic benefit of providing emergency makeup water systems for spent fuel can be computed by multiplying avoided fatalities by a standard figure per fatality of $4 million. We estimate the per-pool benefit to be $110 million.[4] This cost-benefit calculation does not assume that the any solution would be 100% effective; for the sake of example we assume only 90% effectiveness of a solution.

Cost-Benefit Calculations

Probable Fatalities	3,174
Benefit per Avoided Fatality	$4M
Total Benefits	$12,696M
Number of Spent Fuel Pools	104
Estimate of Solution Effectiveness	90%
Estimate of Solution Benefit per Pool	$110M
Estimate of Solution Cost per Pool	$1M
Ratio of Benefits to Costs	110

Thus, the per-pool benefit would be 110 times our estimated solution costs. Or put another way, up to $110 million could be spent to protect each spent fuel pool and the estimated benefits would still exceed the estimated costs.

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[4] This cost-benefit calculation does not include avoidance of radioactive contamination on land surrounding nuclear power plants and is therefore conservative.

12 CONCLUSION

Potential interruption of active cooling for spent fuel pools due to geomagnetic disturbance and resulting long-term loss of outside power presents an unacceptable risk to public health and safety. Using the NRC-approved method of Probabilistic Risk Assessment (PRA), Petitioner has shown that spent fuel pools as currently designed and licensed do not meet NRC standards for safety. Amendment to the Code of Federal Regulations is required to rectify this situation.

The probability, duration, and geographic scope of initiating events for Petitioner's PRA—severe space weather, geomagnetic disturbance, and resulting long-term loss of outside power—have been well-documented by Oak Ridge National Laboratory, the government agency best suited to make such a determination. Moreover, the probability of such events is not remote or speculative; similar but smaller events have occurred in the past and have resulted in equipment damage and commercial grid outage. These smaller but similar events allow the probability of a more extreme event to be established.

Other assumptions used in the Petitioner's PRA include the probability of outside assistance, the probability of spontaneous zirconium ignition, and individual risk estimates of early fatalities and latent cancer deaths. The probability of outside assistance is an optimistic midpoint assumption buttressed by the work of the congressionally-chartered EMP Commission and public documents available from the Department of Homeland Security. The probability of spontaneous zirconium ignition is an optimistic midpoint assumption based on the work of Sandia National Laboratories, NRC, and the National Academy of Sciences. Individual risk estimates of early fatalities and latent cancer deaths come directly from NRC staff work.

Other pessimistic but highly probable events were excluded from the Petitioner's PRA. These events include the possibility of cascading power grid outages beyond the geographic scope determined by Oak Ridge National Laboratory, grid outages caused by other secondary effects, emergency evacuation below the 95% level, and early fatalities and latent cancer deaths outside a 10 mile radius from nuclear power plants.

Results of the Petitioner's PRA for spent fuel pools show that NRC safety goals, as determined by quantitative health objectives (QHOs), are violated by a factor of 35.7 for early fatalities and a factor of 21.0 for latent cancer deaths. NRC guidelines for LERF are violated by a factor of 250. Because of the large differences between NRC safety goals/guidelines and PRA results, sensitivity analysis shows that assumptions could be significantly more optimistic and the safety goals/guides would still not be met. For example, the frequency of the initiating event—long term loss of outside power—could be one-in-one-thousand-years rather than one-in-one-hundred-years and the NRC safety goals/guidelines would still be violated. A simple probability analysis shows that a well-developed system of space weather forecasting, combined with operational procedures to manage commercial power grids under conditions of geomagnetic disturbance, would still not reduce risk sufficiently to meet NRC safety goals/guidelines.

Site-specific population data from the US Census Bureau can be used to estimate probabilistic deaths. Probabilistic deaths are 4 for early fatalities and 3,170 for latent cancer deaths. Should the initiating event of long-term LOOP actually occur, Petitioner estimates radiation-induced deaths of over 77,000.

When an alternative safety assessment based on the defense-in-depth philosophy is performed, spent fuel pools exhibit the following issues under a scenario of long-term loss of outside power:

- Lack of physical containment
- Potential common mode failures in the case of long-term LOOP
- Overreliance on human operators to make up for weaknesses in design
- Lack of system redundancy when presented with an event of expected frequency

Petitioner has proposed multiple technical solutions that are practical, commercially-available, and of moderate cost. When a cost-benefit analysis is performed, the benefits of the proposed solutions exceed estimated costs by a factor of 110. Because of the large difference between costs and benefits, actual costs of a solution could be much higher and still be justified.

The data used to support the Petitioner's PRA assumptions 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.

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Rulemaking Comments

From: Thomas Popik [thomasp@resilientsocieties.org]
Sent: Monday, March 14, 2011 2:57 PM
To: Bladey, Cindy; Rulemaking Comments
Subject: Formal Submission of Petition for Rulemaking
Attachments: Petition_For_Rulemaking_Resilient_Societies_Final.pdf

Ms. Bladey:

Attached please find the formal submission of our Petition for Rulemaking. This version has been extensively modified from the draft submission previously provided to your agency.

We will be providing a copy to the House Energy and Commerce Committee in anticipation of their March 16 hearing with Commissioner Jaczko and Secretary Chu as witnesses.

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