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Enhancement of NRC Station Blackout Requirements for Nuclear Power Plants

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Abstract – ***The U.S. Nuclear Regulatory Commission (NRC) established a Near-Term Task Force (NTTF) in response to Commission direction to conduct a systematic and methodical review of NRC processes and regulations to determine whether the agency should make additional improvements to its regulatory system and to make recommendations to the Commission for its policy direction, in light of the accident at the Fukushima Dai-ichi Nuclear Power Plant.***

The NTTF's review resulted in a set of recommendations that took a balanced approach to defense-in-depth as applied to low-likelihood, high-consequence events such as prolonged station blackout (SBO) resulting from severe natural phenomena.

Part 50, Section 63, of Title 10 of the Code of Federal Regulations (CFR), "Loss of All Alternating Current Power," currently requires that each nuclear power plant must be able to cool the reactor core and maintain containment integrity for a specified duration of an SBO. The SBO duration and mitigation strategy for each nuclear power plant is site specific and is based on the robustness of the local transmission system and the transmission system operator's capability to restore offsite power to the nuclear power plant.

With regard to SBO, the NTTF recommended that the NRC strengthen SBO mitigation capability at all operating and new reactors for design-basis and beyond-design-basis external events. The NTTF also recommended strengthening emergency preparedness for prolonged SBO and multiunit events.

These recommendations, taken together, are intended to clarify and strengthen US nuclear reactor safety regarding protection against and mitigation of the consequences of natural disasters and emergency preparedness during SBO.

The focus of this paper is on the existing SBO requirements and NRC initiatives to strengthen SBO capability at all operating and new reactors to address prolonged SBO stemming from design-basis and beyond-design-basis external events. The NRC initiatives are intended to enhance core and spent fuel pool cooling, reactor coolant system integrity, and containment integrity.

I. INTRODUCTION

At 14:46 Japan standard time on March 11, 2011, the Great East Japan Earthquake—rated a magnitude 9.0—occurred at a depth of approximately 25 kilometers (15 miles), 130 kilometers (81 miles) east of Sendai and 372 kilometers (231 miles) northeast of Tokyo off the coast of Honshu Island. This earthquake resulted in the automatic shutdown of 11 nuclear power plants at four sites along the northeast coast of Japan (Onagawa 1, 2, and 3; Fukushima

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Dai-ichi 1, 2, and 3; Fukushima Dai-ni 1, 2, 3, and 4; and Tokai 2). The earthquake precipitated a large tsunami that is estimated to have exceeded 14 meters (45 feet) in height at the Fukushima Dai-ichi Nuclear Power Plant site. The earthquake and tsunami produced widespread devastation across northeastern Japan, resulting in approximately 25,000 people dead or missing, displacing many tens of thousands of people, and significantly impacting the infrastructure and industry in the northeastern coastal areas of Japan.

On March 11, 2011, Units 1, 2, and 3 were in operation, and Units 4, 5, and 6, were shut down for routine refueling and maintenance activities; the Unit 4 reactor fuel was offloaded to the Unit 4 spent fuel pool.

As a result of the earthquake, all of the operating units appeared to experience a normal reactor trip within the capability of the safety design of the plants. The three operating units at Fukushima Dai-ichi automatically shut down, apparently inserting all control rods into the reactor. As a result of the earthquake, offsite power was lost to the entire facility. The emergency diesel generators started at all six units providing alternating current (ac) electrical power to critical systems at each unit, and the facility response to the seismic event appears to have been normal.

Approximately 40 minutes following the earthquake and shutdown of the operating units, the first large tsunami wave inundated the site followed by multiple additional waves. The estimated height of the tsunami exceeded the site design protection from tsunamis by approximately 8 meters (27 feet). The tsunami resulted in extensive damage to site facilities and a complete loss of ac electrical power at Units 1 through 5, a condition known as station blackout (SBO). Unit 6 retained the function of one of the diesel generators.

The operators were faced with a catastrophic, unprecedented emergency situation. They had to work in nearly total darkness with very limited instrumentation and control systems. The operators were able to successfully cross-tie the single operating Unit 6 air-cooled diesel generator to provide sufficient ac electrical power for Units 5 and 6 to place and maintain those units in a safe shutdown condition, eventually achieving and maintaining cold shutdown.

Despite the actions of the operators following the earthquake and tsunami, cooling was lost to the fuel in the Unit 1 reactor after several hours, the Unit 2 reactor after about 71 hours, and the Unit 3 reactor after about 36 hours, resulting in damage to the nuclear fuel shortly after the loss of cooling. Without ac power, the plants were likely relying on batteries and turbine-driven and diesel-driven pumps. The operators were likely implementing their severe accident management program to maintain core cooling functions well beyond the normal capacity of the station batteries. Without the response of offsite assistance, which appears to have been hampered by the devastation in the area, among other factors, each unit eventually lost the capability to further extend cooling of the reactor cores.

In the days following the Fukushima Dai-ichi nuclear accident in Japan, the U.S. Nuclear Regulatory Commission (NRC) directed the staff to establish a senior-level agency task force to conduct a methodical and systematic review of the NRC's processes and regulations to determine whether the agency should make additional improvements to its regulatory system and to make recommendations to the Commission for its policy direction.

The Commission direction was provided in a tasking memorandum dated March 23, 2011 (COMGBJ-11-0002), from Chairman Gregory B. Jaczko to the Executive Director for Operations. The tasking included objectives for a near-term and a longer term review.

In SECY-11-0093, "Near-Term Report and Recommendations for Agency Actions Following the Events in Japan," dated July 12, 2011, the NTTF provided its recommendations to the Commission, including the need for revising the U.S. SBO rule 10 CFR 50.63. The staff requirements memorandum (SRM) for SECY-11-0093, dated August 19, 2011, directed the staff to "identify and make recommendations regarding any NTTF recommendations that can, and in the staff's judgment, should be implemented, in part or in whole, without unnecessary delay." In SECY-11-0124 and SECY-11-0137 the staff provided, for Commission consideration, its recommendations on those NTTF action items that should be initiated, in part or in whole, without delay, and the associated prioritization for each. In SRM dated October 18, 2011 (SRM-SECY-11-0124), the Commission directed the staff to initiate a rulemaking on Recommendation 4.1 -- "Station blackout regulatory actions," in the form of an advance notice of proposed rulemaking (ANPR).

II. STATION BLACKOUT RULE

The availability of ac electrical power is essential for the safe operation and accident recovery of commercial nuclear power plants. Offsite power sources normally supply this power from the electrical grid to which the plant is connected. As defined in 10 CFR 50.2, the term:

Station blackout (SBO) means the complete loss of alternating current (ac) electric power to the essential and nonessential switchgear buses in a nuclear power plant (i.e., loss of offsite electric power system concurrent with

turbine trip and unavailability of the onsite emergency ac power system). Station blackout does not include the loss of available ac power to buses fed by station batteries through inverters or by alternate ac sources as defined in 10 CFR 50.2, nor does it assume a concurrent single failure or design basis accident (DBA). At single unit sites, any emergency ac power source(s) in excess of the number required to meet minimum redundancy requirements (i.e., single failure) for safe shutdown (non-DBA) is assumed to be available and may be designated as an alternate power source(s) provided the applicable requirements are met. At multi-unit sites, where the combination of emergency ac power sources exceeds the minimum redundancy requirements for safe shutdown (non-DBA) of all units, the remaining emergency ac power sources may be used as alternate ac power sources provided they meet the applicable requirements. If these criteria are not met, station blackout must be assumed on all the units.

Because many safety systems required for reactor core decay heat removal and containment heat removal are dependent on ac power, the consequences of an SBO event could be severe. In the event of an SBO, the capability to cool the reactor core would be dependent on the availability of systems that do not require ac power from the essential or nonessential switchgear buses and on the ability to restore ac power in a timely manner. Unavailability of power can have a significant adverse impact on a plant's ability to achieve and maintain safe-shutdown conditions. In fact, risk analyses performed for nuclear power plants indicate that the loss of all ac power can be a significant contributor to the risk associated with plant operation, contributing more than 70 percent of the overall risk at some plants. Therefore, a LOOP and its subsequent restoration are important inputs to plant risk models. These inputs must reflect current industry performance to ensure appropriate safety enhancements are implemented and to provide plant operators with the most accurate information and equipment are available to address LOOP-initiated scenarios.

One important subset of LOOP-initiated scenarios involves SBO situations in which the affected plant must achieve safe shutdown by relying on components that do not require ac power, such as turbine- or diesel-driven pumps. Thus, the reliability of such components, direct current (dc) battery depletion times, and characteristics of offsite power restoration are important contributors to SBO risk.

The concern about SBO arose because of the accumulated experience regarding the reliability of ac power supplies. Many operating plants have experienced a total LOOP, and more occurrences are expected in the future. In almost every one of these LOOP 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 a number of instances when emergency diesel generators have failed to start and run in response to tests conducted at operating plants.

The SBO rule was developed based on insights gained from several plant-specific probabilistic safety studies, operating experience and reliability, accident sequence, and consequence analyses completed between 1975 and 1988. WASH-1400, "Reactor Safety Study," issued in 1975, indicated that SBO could be an important contributor to the total risk from nuclear power plant accidents. In 1980, the Commission designated the issue of SBO as Unresolved Safety Issue (USI) A-44, "Station Blackout." The technical findings of the staff's studies of the SBO issue are presented in NUREG-1032, "Evaluation of Station Blackout Accidents at Nuclear Power Plants, Technical Findings Related to Unresolved Safety Issue A 44."

The final rule containing SBO requirements was published on July 21, 1988, in the Federal Register (53 FR 23203). The Commission issued the SBO Rule due to operating experience suggesting that both onsite and offsite emergency ac power systems might be less reliable than originally anticipated, even for plants designed to meet GDC 17 (Electric power systems) of Appendix A to 10 CFR Part 50. The objective of the rule is to reduce the risk of severe accidents resulting from SBO by maintaining highly reliable ac electric power systems and, as additional defense-in-depth, assuring that plants can cope with an SBO for a specified duration.

The SBO rule requires that nuclear power plants have the capability to withstand an SBO and maintain core cooling and containment integrity for a specified duration. The specified SBO duration is determined based on (1) the redundancy of the onsite emergency ac power sources, (2) the reliability of the onsite emergency ac power sources, (3) the expected frequency of LOOP, and (4) the probable time needed to restore offsite power. The assumption used for a LOOP at a plant site was an initiating event resulting from a switchyard-related event due to random faults, or an external event, such as a grid disturbance, or weather events such as high winds and snow and ice loading that affects the offsite power system either throughout the grid or at the plant. LOOP events caused by fire, flood, or seismic activity were not explicitly addressed in the SBO rule.

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III. SBO RULEMAKING

In SECY-11-0124 and SECY-11-0137 the staff provided, for Commission consideration, its recommendations on those NTTF action items that should be initiated, in part or in whole, without delay, and the associated prioritization for each item.

The Commission approved the staff's proposed actions to implement without unnecessary delay the NTTF recommendations as described in SECY-11-0124. Specifically, in SRM dated October 18, 2011 (SRM-SECY-11-0124), the Commission directed the staff to initiate a rulemaking on Recommendation 4.1 - - "Station blackout regulatory actions," in the form of an ANPR. Subsequently, in SRM-SECY-11-0137 dated December 15, 2011, the Commission approved the staff's proposed prioritization of the NTTF recommendations and supported action on the Tier 1 and Tiers 2 & 3 recommendations subject to the direction in the SRM.

In SRM-SECY-11-0124, the Commission encouraged the staff to craft recommendations that continue to realize the strengths of a performance-based system as a guiding principle. The Commission indicated that, to be effective, approaches should be flexible and able to accommodate a diverse range of circumstances and conditions. The Commission stated that for consideration of events beyond the design basis, a regulatory approach founded on performance-based requirements will foster development of the most effective and efficient, site-specific mitigation strategies, similar to how the agency approached the approval of licensee response strategies for the "loss of large area" event addressed in 10 CFR 50.54(hh)(2).

Following the terrorist events of September 11, 2001, the NRC ordered licensees to develop and implement specific guidance and strategies to maintain or restore core cooling, containment, and spent fuel pool cooling capabilities using existing or readily available resources that can be effectively implemented under the circumstances associated with loss of large areas of the plant due to explosions or fire. After further development, these requirements were imposed as license conditions for individual licensees and formalized in the rulemaking of March 27, 2009, in 10 CFR 50.54(hh)(2) (74 FR 13969). Events at the Fukushima Dai-ichi Nuclear Power Station following the March 11, 2011, earthquake and tsunami highlighted the further potential benefits of these strategies in mitigating the effects of prolonged station blackouts or other events that challenge key safety functions.

The new SBO requirements would be intended to improve safety by providing greater assurance that SBO conditions can be mitigated.

Potential revisions to the SBO rule include addressing additional natural phenomena events (e.g., flooding and earthquakes), clarifying testing requirements for equipment used to mitigate consequences of an SBO event, requiring licensees to routinely update SBO analyses to reflect changing operational environments, and requiring licensees to address long-term cooling and water makeup of spent fuel pools.

LOOP events caused by natural phenomena such as the Fukushima event were not considered to occur with sufficient frequency to require explicit criteria and were not considered in the current SBO rule. However, nuclear power plants were required to enhance procedures and training for restoring both offsite and onsite ac power sources. Also, in order to meet the requirements of the current SBO rule, some licensees chose to make nuclear power plant modifications, such as adding additional ac power sources. The NRC and its licensees also increased their emphasis on establishing and maintaining high reliability of onsite emergency power sources.

The existing testing recommendations for equipment required to mitigate an SBO event are described in NRC Regulatory Guide 1.155, "Station Blackout." The NRC is reviewing these testing recommendations and considering whether it needs to clarify or expand the existing testing recommendations and/or potentially include testing of SBO related equipment as technical specification requirements.

The NRC also notes that licensees are currently not required to and have not been updating their coping analysis or SBO duration evaluations to address the current operational environment. The SBO rule parameters that are subject to change over time are: number of LOOP events at a particular site, duration of LOOP events, recovery time for offsite power, frequency of grid blackout events, and diesel generator reliability. Changes to these parameters have a significant effect on the SBO duration and coping analyses originally performed by the licensees of nuclear power plants. Based on the number of LOOP events and grid blackout events that have occurred in the last 20 years, SBO duration times for some of the nuclear power plants would potentially change.

A lesson-learned from the Fukushima event is that SBO conditions stemming from beyond design basis external hazards can occur without the capability of recovery offsite ac power. The existing SBO rule does not require long-term cooling and water makeup of spent fuel pools during an SBO event, and instead assumes recovery of ac power following the coping period.

The ANPR, which was published in the Federal Register on March 20, 2012 (77 FR 16175), was structured around questions, including questions on the items

discussed above, intended to solicit information that supports development of an enhanced SBO rule and that supports assembling a complete and adequate regulatory basis that enables rulemaking to be successful.

If the NRC develops a sufficient regulatory basis that supports issuance of a proposed rule and the NRC Commission approves moving forward, then there will be an opportunity for additional public comment in connection with the publishing of the proposed rule. If supporting guidance is developed for the proposed rule, stakeholders will have opportunities to provide feedback on the guidance as well.

IV. CONCLUSION

In light of the unfortunate events that transpired in Japan in March of 2011, the NRC is rigorously evaluating its current regulations to determine whether any changes are necessary to address potential vulnerabilities for the existing and future fleet of nuclear reactors in the United States. The possible revision to the SBO rule is just one of a number of changes that can be directly tied to the events that occurred in Japan. The NRC recognizes that changes to the requirements and subsequent implementation could be a challenge for licensees. Given this, the NRC requests that stakeholders get involved early and often in the rulemaking process to provide comments.

REFERENCES

1. SECY-11-0093, "The Near-Term Report and Recommendations for Agency Actions following the Events in Japan," Agencywide Documents Access and Management System (ADAMS) Accession No. ML111861807, July 12, 2011.

2. 10 CFR 50.63, "Station Blackout," 53 FR 23215 and 63 FR 50480, June 21, 1988 and September 22, 1988.

3. Staff Requirements, SECY-11-0093, "The Near-Term Report and Recommendations for Agency Actions following the Events in Japan," ADAMS Accession No. ML112310021, August 19, 2011.

4. SECY-11-0124, "Recommended Actions to be Taken Without Delay from the Near-Term Task Force Report," ADAMS Accession Nos. ML11245A127 and ML11245A144, September 9, 2011.

5. SECY-11-0137, "Prioritization of Recommended Actions to be Taken in Response to Fukushima Lessons Learned," ADAMS Accession Nos. ML11272A203 and ML11272A204, October 3, 2011.

6. Staff Requirements, SECY-11-0124, "Recommended Actions to be Taken Without Delay from the Near-Term Task Force Report," ADAMS Accession No. ML112911571, October 18, 2011.

7. WASH-1400, "Reactor Safety Study," ADAMS Accession No. ML072350618 issued 1975.

8. NUREG-1032, "Evaluation of Station Blackout Accidents at Nuclear Power Plants, Technical Findings Related to Unresolved Safety Issue A 44," June 1988. Accessible from U. S. Department of Energy's Information Bridge http://www.osti.gov/bridge/purl.cover.jsp?purl=/5122568-gvK0cy/5122568.pdf.

9. Staff Requirements, SECY-11-0137, "Prioritization of Recommended Actions to be Taken in Response to the Fukushima Lessons-Learned," ADAMS Accession No. ML113490055, December 15, 2011.

10. 10 CFR 50.54(hh)(2), 74 FR 13969, March 27, 2009.

11. Regulatory Guide 1.155, "Station Blackout," August 1988.