NRC STAFF ASSESSMENT AND PLANNED ACTIONS RELATED TO NATIONAL ACADEMY OF SCIENCES STUDY OF THE LESSONS LEARNED FROM THE FUKUSHIMA NUCLEAR ACCIDENT FOR IMPROVING SAFETY AND SECURITY OF U.S. NUCLEAR POWER PLANTS

Summary

The National Academy of Sciences (NAS) report entitled "Study of the Lessons Learned from the Fukushima Nuclear Accident for Improving Safety and Security of U.S. Nuclear Power Plants—Phase 2," included several findings and recommendations related to the safety and security of nuclear power plants. The study paid particular attention to the safety and security of spent fuel storage, including reevaluating findings and recommendations from previous NAS reports.[1] The U.S. Nuclear Regulatory Commission (NRC) staff has assessed the NAS findings and recommendations to determine whether additional actions or studies are warranted. Several of the NAS recommendations are addressed by recent reviews and assessments performed by the staff and by recent Commission decisions. The staff did not identify a need to initiate new activities or otherwise redirect resources to address recommendations in the Phase 2 study. As the NRC pursues its ongoing regulatory activities, the staff will consider if and how insights from the NAS study should be incorporated into associated studies, analyses, and decisionmaking.

The staff concludes that spent fuel continues to be stored safely and securely at nuclear power plants in both spent fuel pools (SFPs) and dry casks. The security of U.S. nuclear power plants remains extremely robust. The NRC assessment of the current NAS study reflects an extensive history of how spent fuel safety and security have been assessed and improved in the United States. Significant enhancements to the safety and security of nuclear power plants, including SFPs, were made following the terrorist events of September 11, 2001, and the Fukushima accident in 2011. SFP safety was enhanced at U.S. reactors when licensees implemented new NRC requirements to develop strategies for SFP cooling following losses of large areas of the plant due to fires, explosions, or extreme natural events. The NRC will continue to cooperate with other Federal agencies and international organizations to assess threats to nuclear power plants and to improve risk assessment techniques. The staff will continue to bring policy matters to the Commission for consideration and action as appropriate.

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[1] Previous NAS reports refer to a study carried out in 2003-2004. That study focused on the safety and security of commercial spent fuel storage and resulted in two reports: a report containing classified and other security-sensitive information issued in 2004 (referred to as NAS 2004) and an abbreviated version suitable for unrestricted public release, issued in 2006 (referred to as NAS 2006). A description of the NRC's assessment and actions related to that study are provided in a report to Congress issued in March 2005 (Agencywide Documents Access and Management System (ADAMS) Accession No. ML050280428).

Background

The conference report associated with the Consolidated Appropriations Act, 2012, directed the NRC to fund an NAS study of the lessons learned from the events at the Fukushima nuclear plant. The National Research Council (an operating agency of NAS) subsequently undertook an assessment for improving the safety and security of nuclear plants in the United States.[2] The study was organized to address the following issues:

1) causes of the Fukushima nuclear accident, particularly with respect to the performance of safety systems and operator response following the earthquake and tsunami;

2) reevaluation of the conclusions from previous NAS studies on safety and security of spent nuclear fuel and high-level radioactive waste storage, particularly with respect to the safety and security of current storage arrangements and alternative arrangements in which the amount of commercial spent fuel stored in pools is reduced;

3) lessons that can be learned from the accident to improve commercial nuclear plant safety and security systems and operations; and

4) lessons that can be learned from the accident to improve commercial nuclear plant safety and security regulations, including processes for identifying and applying design-basis events for accidents and terrorist attacks to existing nuclear plants.

The NAS study was carried out in two phases. Phase 1 focused on the causes of the Fukushima Dai-ichi accident and safety-related lessons learned for improving nuclear plant systems, operations, and regulations, exclusive of spent fuel storage. The Phase 1 report, "Lessons Learned from the Fukushima Dai-ichi Nuclear Accident for Improving Safety of U.S. Nuclear Plants," was issued in July 2014. The report documented various findings and recommendations. The staff review of and responses to the Phase 1 recommendations are described in Enclosure 6 of SECY-15-0059, "Seventh 6-Month Status Update on Response to Lessons Learned from Japan's March 11, 2011, Great Tohoku Earthquake and Subsequent Tsunami," dated April 9, 2015. The staff's review of the Phase 1 report found that the NAS recommendations were being adequately addressed by activities undertaken by the NRC and nuclear industry following the Fukushima accident. The report associated with Phase 2 of the NAS study was issued in May 2016 and focused on three issues:

1) security-related lessons learned from the Fukushima Dai-ichi accident for improving nuclear plant systems, operations, and regulations;

2) lessons learned from the accident for improving safety of spent fuel storage; and

3) reevaluation of the findings and recommendations from previous NAS reports on spent fuel storage safety and security.

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2 The previous NAS studies were prepared by the National Resource Council and are referred to within the NAS Phase 2 report using the abbreviation NRC (e.g., NRC (2006) for the NAS report issued in 2006). The NAS report also refers to the U.S. Nuclear Regulatory Commission by its full name or by the abbreviation USNRC. Within this document, abbreviations in quoted findings and recommendations are updated in brackets to match the reminder of the enclosure.

In conjunction with the evaluation documented in SECY-15-0059, this paper responds to Commission direction in the staff requirements memorandum (SRM) dated May 23, 2014, on COMSECY-13-0030, "Staff Evaluation and Recommendation for Japan Lessons-Learned Tier 3 Issue on Expedited Transfer of Spent Fuel," dated November 12, 2013. The staff was asked to consider the NAS study and report to the Commission the NAS findings and how they comport with further work on spent fuel management.

Assessments and Planned Actions for NAS Recommendations

The major findings and related recommendations from the Phase 2 report are provided in the following sections, along with the staff's assessment and planned actions related to each recommendation.

Recommendation 2.1: Spent Fuel Pool Monitoring and Remote Cooling Capabilities

Finding 2.1: The spent fuel storage facilities (pools and dry casks) at the Fukushima Dai-ichi plant maintained their containment functions during and after the March 11, 2011, earthquake and tsunami. However, explosions in the Unit 1, 3, and 4 reactor buildings damaged spent fuel handling facilities and equipment, introduced heavy debris into the pools, and provided enhanced pathways for releases of radioactive materials from the damaged reactors into the environment. These events hindered efforts by plant operators to monitor conditions in the pools and restore critical pool-cooling functions. The lack of reliable real-time information about the pools created substantial difficulties in responding to the accident and led to increased public anxiety. Nevertheless, plant personnel were able to improvise and provide needed cooling to avoid pool uncovery and potential radiological consequences. The leakage of water into the Unit 4 pool from the reactor well/dryer-separator pit was a key factor for determining its water level and may have prevented fuel uncovery before plant personnel were able to add water.

Recommendation 2.1: The U.S. nuclear industry and its regulator should give additional attention to improving the ability of plant operators to measure real-time conditions in [SFPs] and maintain adequate cooling of stored spent fuel during severe accidents and terrorist attacks. These improvements should go beyond the current post-Fukushima response to include hardened and redundant (1) physical surveillance systems (e.g., cameras), (2) radiation monitors, (3) pool temperature monitors, (4) pool water-level monitors, and (5) means to deliver pool makeup water or sprays even when physical access to the pools is limited by facility damage or high radiation levels.

NRC Staff Assessment and Planned Actions:

After the Fukushima accident, the NRC identified possible improvements to the monitoring and cooling of SFPs, performed assessments, and issued orders to require additional instrumentation and capabilities to supply water to SFPs. The additional SFP level indications required by the NRC enable operators to maintain an awareness of SFP conditions during beyond-design-basis events and security events that might disable other installed equipment and instrumentation. This awareness of the conditions within the SFP supports the operators' need to prioritize response actions to maintain or restore cooling to the reactor core and SFP.

The added capabilities for SFP cooling built upon the enhancements made following the terrorist events of September 11, 2001, and include a means to supply makeup water to the pool without accessing the refueling floor. The Fukushima Near-Term Task Force (NTTF) recommended and the NRC considered requiring additional instruments for SFP water temperature and other means of monitoring conditions within the SFP, but concluded that the actions taken adequately addressed the lessons learned from the Fukushima accident and requiring additional enhancements was not warranted. Additional details on the NRC's assessments and actions taken are provided below.

In SRM-SECY-12-0025, dated March 9, 2012, the Commission approved the issuance of Order EA-12-049, "Mitigation Strategies for Beyond-Design-Basis External Events," and Order EA-12-051, "Reliable Spent Fuel Pool Instrumentation." These orders were two of the highest priority actions taken by the NRC to enhance safety because of the Fukushima accident.

Order EA-12-049 requires all nuclear power plant licensees to develop, implement, and maintain guidance and strategies to maintain or restore core cooling, containment, and SFP cooling capabilities following a beyond-design-basis external event.

Order EA-12-051 requires all nuclear power plant licensees to have a reliable indication of the water level in [SFPs] capable of supporting identification of the following pool water level conditions by trained personnel: (1) level that is adequate to support operation of the normal fuel pool cooling system, (2) level that is adequate to provide substantial radiation shielding for a person standing on the SFP operating deck, and (3) level where fuel remains covered and actions to implement make-up water addition should no longer be deferred.

In SECY-15-0059, "Seventh 6-Month Status Update on Response to Lessons Learned from Japan's March 11, 2011, Great Tohoku Earthquake and Subsequent Tsunami," dated April 9, 2015, the NRC responded to a similar recommendation in the NAS Phase 1 report related to requiring instrumentation for monitoring critical thermodynamic parameters in SFPs.

The NRC's assessment of the NAS recommendation in that report was as follows:

> In the course of developing Order EA-12-051, the NRC considered requiring instruments for SFP water temperature and area radiation levels, as the NTTF had recommended. In light of the underlying technical justification for requiring the reliable level instrumentation, avoiding distracting resources from addressing problems with the reactor plant itself, which can progress more rapidly, the NRC concluded that these extra sensors would not be necessary. SFPs at reactor facilities in the U.S. are licensed to rely on heat removal through boiling water within the SFP. The loss of water within the SFP occurs through boil-off at a slow rate such that the level instrumentation alone can supply sufficient information for the operators to prioritize resources to mitigate events.

As a part of the additional requirements developed after the terrorist events of September 11, 2001, the NRC required licensees to have capabilities and strategies to provide SFP cooling following the loss of large areas due to fires or explosions. This requirement was incorporated into Section 50.54(hh)(2) of Title 10 of the *Code of Federal Regulations* (10 CFR). The NRC has endorsed guidance provided in Nuclear Energy Institute (NEI) 06-12, "B.5.b Phase 2 & 3 Submittal Guideline," for licensees complying with the requirements of

10 CFR 50.54(hh) in areas of firefighting, mitigating fuel damage, and minimizing radiological releases. The guidance specifies that portable, power-independent pumping capabilities must be able to provide at least 500 gallons per minute (gpm) of bulk water makeup to the SFP, and at least 200 gpm of water spray to the SFP. Recognizing that the SFP is more susceptible to a release when in a nondispersed configuration, the guidance also specifies that the portable equipment is to be capable of being deployed within 2 hours for a nondispersed configuration, from the time plant personnel diagnose that external SFP makeup is required, and within 5 hours when the SFP is in a dispersed (e.g., 1 × 4 pattern) configuration.

After the Fukushima Dai-ichi accident, the NRC took extensive actions to ensure that portable equipment is available to mitigate a loss of cooling water in the SFP. To meet the requirements of Order EA-12-049, the NRC endorsed NEI document NEI 12-06, "Diverse and Flexible Coping Strategies (FLEX) Implementation Guide." Section 3.2.2, "Minimum Baseline Capabilities," of NEI 12-06 provides guidance for supplying makeup water to the SFP. This guidance document states: "The FLEX fluid connections for core and SFP cooling functions are expected to have a primary and an alternate connection or delivery point (e.g., the primary means to put water into the SFP may be to run a hose over the edge of the pool)."

The NRC finds that this guidance will provide additional mechanisms for mitigating a loss of SFP cooling water beyond that required by 10 CFR 50.54(hh)(2). An example of such an upgrade is the installation of a remote connection for SFP make-up water that can be accessed away from the SFP refueling floor. These requirements will ensure additional mitigation capability is in place in the unlikely event in which degrading conditions occur in the SFPs because of beyond-design-basis external events. The additional capabilities could also be useful during security events when either parameter indications or communications related to an attack reveal that the cooling of the spent fuel might be compromised.

In conclusion, the staff has evaluated NAS Recommendation 2.1 and concludes that the additional requirements for spent fuel pool monitoring and cooling capabilities imposed on U.S. nuclear power plants following the Fukushima accident adequately address the lessons learned from that accident. The NAS report does not provide new information that would change the staff's previous findings that SFP instrumentation and pool makeup capabilities beyond those imposed by NRC orders would not provide a substantial increase in the overall protection of the public health and safety or the common defense and security. Therefore, the staff does not plan to perform additional analyses or pursue imposing additional regulatory requirements as described in NAS Recommendation 2.1. Many licensees are already in compliance with the orders issued by the NRC related to mitigating strategies and SFP level instrumentation. The staff is in the process of documenting the acceptability of licensees' plans for mitigating strategies and inspecting each licensee's implementation of the orders related to mitigating strategies and SFP level instrumentation. Additionally, the NRC is preparing a final rule on mitigation of beyond-design-basis events. This rule, if approved by the Commission, will incorporate the requirements of Orders EA-12-049 and EA-12-051 into the CFR, taking into account lessons learned in their implementation and feedback from stakeholders received during the rulemaking process.

Recommendation 3.1: Beyond-Design-Basis External Event Security Requirements

Finding 3.1: Extreme external events and severe accidents such as occurred at the Fukushima [Dai-ichi] plant can cause widespread and long-lasting disruptions to security infrastructure, systems, and staffing at nuclear plants. Such disruptions can create opportunities for malevolent acts and increase the susceptibility of critical plant systems to such acts.

Recommendation 3.1: Nuclear plant operators and their regulators should upgrade and/or protect nuclear plant security infrastructure and systems and train security personnel to cope with extreme external events and severe accidents. Such upgrades should include:

- Independent, redundant, and protected power sources dedicated to plant security systems that will continue to function independently if safety systems are damaged;

- Diverse and flexible approaches for coping with and reconstituting plant security infrastructure, systems, and staffing during and following extreme external events and severe accidents; and

- Training of security personnel on the use of these approaches.

The U.S. nuclear industry should consider expanding its [FLEX] capability to address this recommendation. The [NRC] should support industry's efforts by providing guidance on approaches and by overseeing independent review by technical peers (i.e., peer review).

NRC Staff Assessment and Planned Actions:

The NRC has numerous requirements for security system redundancies and backup power supplies, and preplanned compensatory measures are required to be implemented in the event that normal security systems are degraded. The NRC performed various assessments and took regulatory actions after the terrorist events of September 11, 2001, and the Fukushima accident on March 11, 2011. The requirements imposed on licensees improved the integration of safety and security activities at nuclear power plants and added capabilities to support responding to a variety of external threats and hazards. For example, licensees are required to maintain the capability to detect and assess unauthorized persons at all times. The NRC also requires in 10 CFR 73.55 that licensees have a tested uninterruptible power supply for these systems, secondary power supplies within vital areas to support alarms and certain communications equipment, and continuous communication with onsite and offsite resources for command and control.

Additionally, the NRC is preparing a final rule on mitigation of beyond-design-basis events. This rule, if approved by the Commission, will result in a more integrated accident response capability, including an enhanced emergency preparedness capability for beyond-design-basis threat and/or accident events. The proposed changes will affect many aspects of the facility, including requirements associated with emergency preparedness, off-site coordination, and safety/security interface. As currently drafted, the proposed rule would require licensees to be capable of mitigating an extended loss of alternating current power resulting from beyond-design basis threat and/or accident events through a variety of response guidelines (FLEX support guidelines, emergency operating procedures, etc.), as well as the training and qualification of personnel that are designated to perform duties and responsibilities in accordance with those guidelines. Although not specifically designed to mitigate security threats concurrent with a natural disaster, the actions being implemented under Order EA-12-049 and this rule provide additional response capabilities that could be used during such an event.

The actions taken have also improved coordination within the nuclear industry and with local and Federal agencies that might be called upon to respond to security events or natural disasters affecting a nuclear power plant. The NRC considered additional measures to enhance security at nuclear power plants but concluded that the actions taken adequately addressed the lessons learned from the terrorist events of September 11, 2001, and the Fukushima accident. A key consideration in this evaluation was the unlikely nature of a security event such as the design-basis threat occurring coincident with a natural disaster large enough to significantly affect a site's security posture. This initiating event, while theoretically possible, is not a vulnerability that can be easily exploited given the enhanced measures taken at nuclear power plants.

In conclusion, the staff has evaluated NAS Recommendation 3.1 and finds that existing security requirements for U.S. nuclear power plants and additional capabilities implemented following the Fukushima accident provide adequate protection against possible disruptions to security infrastructure following a natural disaster. The additional requirements proposed by NAS to address concurrent natural disasters and security events would not provide the substantial increase in the overall protection of the public health and safety or the common defense and security required for the NRC to impose additional regulatory requirements. The staff is in the process of documenting the acceptability of licensees' plans for mitigating strategies and inspecting each licensee's implementation of the orders related to mitigating strategies and SFP level instrumentation. The staff will also continue with the mitigating strategies rulemaking activities. In addition, the NRC will continue to inspect and assess licensees' security programs, work with other Federal agencies to assess possible threats, and participate in interagency and international efforts to ensure an appropriate level of security is maintained for NRC-regulated facilities.

Recommendation 4.1A: Use of Risk in Security Activities

Finding 4.1: The understanding of security risks at nuclear power plants and spent fuel storage facilities can be improved through risk assessment. Event trees and other representational formalisms can be used to systematically explore terrorist attack scenarios, responses, and potential consequences. Expert elicitation can be used to rank scenarios; develop likelihood estimates; and characterize adaptive adversary responses to various preventive, protective, or deterrence actions. The identification of scenarios may be incomplete, and the estimates developed through expert elicitation are subjective and can have large uncertainties. Nevertheless, risk assessment methods that focus on the risk triplet—scenarios, likelihoods, and consequences—can contribute useful security insights.

Recommendation 4.1A: The U.S. nuclear industry and the [NRC] should strengthen their capabilities for identifying, evaluating, and managing the risks from terrorist attacks. Particular attention is needed to broaden scenario identification, including asymmetric attacks; account for the adaptive nature of adversaries; account for the performance of plant security personnel in responding to the identified scenarios; estimate the potential onsite and offsite consequences of attack scenarios, including radioactive releases and psychological impacts; and develop strategies for countering the identified threats.

NRC Staff Assessment and Planned Actions:

The NRC has used and will continue to use risk insights in the security area to ensure an appropriate level of security is maintained at NRC-regulated facilities. Some aspects of the risk-informed approach described in the NAS report are included in existing security programs, including developing security plans and testing those plans in exercises. As opportunities arise, the NRC will cooperate with other Federal agencies to develop or use risk management approaches to improve the protection of critical infrastructure and key assets. Consistent with the NRC's probabilistic risk assessment (PRA) policy statement, the staff considers risk insights, as appropriate, in processing security-related licensing actions and supports further use of risk assessment techniques in security applications. Additional details on the NRC's assessments and actions taken are provided below.

The traditional approach to plant security evolved to include designing and putting in place systems, barriers, and personnel to detect, delay, and respond to possible attempts by adversaries to sabotage a nuclear power plant. Security programs were enhanced based on lessons learned from studies, drills, and operating events. Physical protection requirements for power reactors (see 10 CFR 73.55, "Requirements for Physical Protection of Licensed Activities in Nuclear Power Reactors against Radiological Sabotage") mandate the need for two onsite alarm stations to ensure that a single act cannot disable the ability to detect and assess alarms, initiate and coordinate a response, summon offsite assistance, and provide command and control. Although security programs incorporated some plant structures and features (e.g., walls, access points), plant designs, and the arrangement of key safety systems were primarily defined by other design objectives (e.g., design-basis events involving equipment failures or natural events). Lessons learned from some events included the need to better coordinate systems and procedures related to plant security and the operation of key safety systems. The need to coordinate the activities related to plant safety and security were incorporated into NRC regulations (see 10 CFR 73.58, "Safety/Security Interface Requirements for Nuclear Power Reactors," and Regulatory Guide 5.74, "Managing the Safety/Security Interface"). The relationships between safety and security features also supported further study of using risk assessment techniques to evaluate both security and non-security related events. The NRC and industry response to the terrorist events of September 11, 2001, included plant changes as part of mitigating strategies to maintain or restore core cooling, containment, and spent fuel pool cooling capabilities under the circumstances associated with loss of large areas of the plant due to explosions or fire. The NRC works continually with other Federal agencies to assess the possible nature and likelihood of security threats, and determine if changes to plant security programs are needed.

The staff is working with licensees and organizations to enhance the use of risk management and risk assessment techniques in the security arena. Examples of ongoing work include engagement with industry on methods involving consequence based approaches, the use of PRA, and the use of computer modeling tools to inform site-specific protective strategies. Licensees are required by 10 CFR 73.55(b)(4) to identify site-specific conditions, including target sets, that should be considered in the implementation of their physical protection programs. Licensees use PRAs among several assessment/analytic tools in determining potential target sets within the nuclear power plant. Risk insights are also used in other aspects of developing security programs and testing those programs in various drills and exercises, including the NRC's force-on-force security inspections. Another example of work in this area relates to the NRC's review of Revision 16 to the Monticello Protective Security Plan (ADAMS

Accession No. ML15286A032), submitted in October 2015, which uses computer modeling and other analytic techniques to inform the licensee's security plan, including the appropriate number of armed responders and armed security officers at the plant. These activities include broadening scenario identification, including asymmetric attacks and accounting for the adaptive nature of adversaries, as well as the licensees' ability to detect, delay, and respond to various security events.

Staff have also participated in meetings with subject matter experts and stakeholders to provide additional insights in the areas of security that might benefit from developing and implementing improved risk-informed approaches.

Additional examples of ongoing work in the security area that are using risk insights include:

- Staff is developing an approach to grade special nuclear material security requirements based on the attractiveness of the nuclear material to the adversary. This will allow licensees (fuel cycle facilities and research and test reactors) to use alternative measures for varying levels of radiological hazard.

- Regarding cyber security (see 10 CFR 73.54), reactor cyber security implementation is under way. As part of this effort, the highest-consequence critical digital assets (CDAs) are being addressed using a consequence-based approach, which will allow for the consideration of lesser requirements for CDAs with lower consequences.

- Staff is working with the International Atomic Energy Agency (IAEA) on a coordinated research project to develop nuclear security assessment methodologies. This project will allow for member countries to have equivalent standards on the conduct of security assessments. Case studies are underway (or have been completed) for a nuclear power plant, an irradiator facility, transport of radioactive materials, low enriched uranium fuel fabrication facility, and a spent fuel storage facility. These assessments are conducted with the use of risk insights.

The NRC's Policy Statement on the Regulation of Advanced Reactors was revised in 2008 to provide expectations and guidance on security matters to prospective applicants so that they can use this information early in the design stage of new reactors to identify potential mitigative measures and design features that provide a more robust and effective security posture. Designers of small modular reactors and non-light-water reactors are integrating plant safety features and security measures and using PRAs in the design of both plant safety and physical protection systems. The staff are working with potential applicants and other stakeholders to improve the security framework and manage the risks from terrorist attacks for future nuclear power plants.

The NAS report describes possible asymmetric threats where an adversary might choose to attack a plant's support infrastructure (e.g., offsite power and water supplies, key personnel) rather than mounting a direct assault on the plant. Attacks on offsite targets would have effects similar to events addressed by requirements for the design and operation of nuclear power plants (e.g., loss of offsite power). Such actions could cause plant transients and economic losses, but they are unlikely to lead to more severe reactor accidents or the release of radioactive material. Other Federal, State, and local agencies have robust programs for assessing threats and developing plans to protect critical infrastructure and key assets. Unlike the series of events that occurred at Fukushima, which included the loss of plant safety systems because of the tsunami, it is unlikely that adversaries could initiate cascading failures leading to a radiological release without mounting an assault against a facility and its associated security systems and personnel.

In conclusion, the staff has evaluated NAS Recommendation 4.1A and finds that existing security requirements and the NRC's continuous interactions with other Federal agencies to assess possible threats sufficiently address the security-related risks to nuclear power plants. The staff did not identify a need to initiate new activities or otherwise redirect resources to revise existing programs or accelerate initiatives to enhance the use of risk assessment techniques in the security area. The NRC will continue to work with other Federal agencies, licensees, and other stakeholders, as described above, to improve the use of risk assessment techniques and risk management in maintaining security at nuclear power plants.

Recommendation 4.1B: Security Risk Assessment of Spent Fuel Storage

Recommendation 4.1B: The [NRC] should sponsor a spent fuel storage (wet and dry storage) security risk assessment for U.S. nuclear plants. The primary objectives of this assessment should be to (1) develop and exercise the appropriate methodologies for characterizing risk and estimating uncertainties, and (2) explore the benefits of risk assessment for enhancing security at U.S. nuclear plants. This assessment should be subjected to independent review by technical peers (i.e., peer review) as part of the development process.

***NRC Staff Assessment and Planned Actions*:**

The NRC is participating in activities evaluating how risk assessment techniques might improve defining and implementing an appropriate level of security at NRC-licensed facilities. Currently, the staff is working with the IAEA to develop nuclear security assessment methods for nuclear facilities, including spent fuel storage facilities. The NRC also works in coordination with other Federal agencies in assessing possible threats and establishing requirements to address security-related risks. Additional details on the NRC's assessments and actions taken are provided below.

After the terrorist events of September 11, 2001, the NRC conducted security assessments at nuclear facilities. These assessments evaluated attacks with large aircraft and ground assaults using a variety of methods as well as expected response to these assaults by both on-site (licensee) and off-site (Federal, State, and local) resources/agencies. These assessments considered PRA-like insights in terms of event sequences and consequences. The assessments did not specifically attempt to estimate frequencies or probabilities associated with the threats and defensive measures. Additionally, the NRC analyzed several different dry cask storage designs, which were viewed as representative of the entire population of dry cask storage systems. The results of these assessments indicated that no immediate changes in the security requirements for independent spent fuel storage installations (ISFSIs) were necessary. The NRC's assessment of the findings and recommendations in the 2006 report issued by NAS similarly concluded that activities to improve risk analysis techniques for spent fuel storage would continue but that spent fuel continues to be stored safely and securely at nuclear power plants in both SFPs and dry casks.

The staff is working with the IAEA on a coordinated research project to develop nuclear security assessment methodologies. One aspect of this project is to develop a standardized methodology on the conduct of security assessments for a spent fuel storage facility. This assessment would be conducted with the use of risk insights.

In conclusion, the staff has evaluated NAS Recommendation 4.1B and did not identify new information or security concerns that would warrant regulatory actions. Insights and suggestions from the NAS report are consistent with other observations from within and outside the NRC on the current and potential uses of risk assessment techniques for evaluating plant security. As a result, the staff does not see a need to initiate new activities or otherwise redirect resources to revise existing programs or accelerate initiatives to enhance the use of risk assessment techniques associated with the security risk assessment of fuel storage.

Recommendation 4.3: Independent Assessment of NRC Security Programs

Finding 4.3: The [NRC] has not carried out an independent examination of surveillance and security measures for protecting stored spent fuel that was recommended by [NAS 2006].[3]

Recommendation 4.3: The independent examination of surveillance and security measures for protecting stored spent fuel recommended by [NAS 2006] should include an examination of the effectiveness of the [NRC's] programs for mitigating insider threats.

NRC Staff Assessment and Planned Actions:

The NRC establishes strategic goals and measures and provides routine reports regarding its performance. Because the nature of the agency's safety and security strategic objectives is to prevent or minimize undesirable outcomes, the desired trends for all of its performance indicators are to maintain these outcomes at either zero or at very low levels. As an independent agency created by Congress in 1974, the NRC issues annual reports of its performance in maintaining the safety and security of commercial nuclear power plants. The agency is subject to the oversight of applicable congressional committees. In the security arena, the NRC works closely with other Federal agencies to identify and address possible threats. In addition to the NAS studies, the NRC has obtained independent assessments in the security area from the NRC's Office of the Inspector General (OIG), U.S. Government Accountability Office (GAO), and other oversight bodies. Regarding the specific mention of insider threats in the NAS report, the NRC has established requirements and oversees licensees' programs to protect against such threats. Additional details on the NRC's assessments and actions taken are provided below.

Independent assessments of the effectiveness, adequacy, and efficiency of programs, including security program requirements for protecting spent nuclear fuel and insider threat mitigation, can be beneficial. The NRC performs such independent assessments of licensees' programs. Various organizations independent from the NRC routinely assesses the NRC's regulation and

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3 The 2006 NAS report Recommendation 2C stated: Although the committee did not specifically investigate the effectiveness and adequacy of improved surveillance and security measures for protecting stored spent fuel, an assessment of current measures should be performed by an [organization independent of the NRC and the nuclear industry]."

oversight of licensees. The NRC's OIG has full operational independence to select, plan, and conduct its work. Additionally, the GAO is required to maintain a high degree of integrity, objectivity, and independence for audits of government entities, such as the NRC.

There have been numerous assessments of the NRC's spent fuel safety and security regulatory programs by both the OIG and GAO since 2001.

Examples of OIG audits pertaining to security issues include:

- Audit OIG-12-A-10, "Audit of NRC's Management of the Baseline Security Inspection Program," dated March 8, 2012. This audit identified a recommendation for a more systematic approach to analyzing security findings data across the board that can help staff better identify licensee performance trends. The staff is currently developing a new computer program that will respond to the OIG recommendation.

- Audit OIG-11-A-10, "Audit of NRC's Oversight of ISFSI Security," dated May 3, 2011. This report provided a number of recommendations to improve the agency's ISFSI security program. The staff accepted and implemented the OIG recommendations.

- Audit OIG-10-A-21, "Audit of NRC's Oversight of the Access Authorization Program for Nuclear Power Plants," dated September 30, 2010. This report touched on the insider threat mitigation program by making a number of recommendations to the NRC's access authorization program. The staff agreed with and implemented all of the OIG recommendations.

Examples of GAO audits pertaining to security issues include:

- Report GAO-12-797, "Spent Nuclear Fuel: Accumulating Quantities at Commercial Reactors Present Storage and Other Challenges," dated August 2012. One of the objectives of this report was to examine the key safety and security risks posed by spent fuel stored at reactor sites and actions to help mitigate these risks. GAO recommended that the NRC develop a mechanism for locating all classified studies. The NRC generally agreed with the findings and the recommendation in the report.

- Report GAO-07-1197R, "Nuclear Security: DOE [Department of Energy] and NRC Have Different Security Requirements for Protecting Weapons-Grade Material from Terrorist Attacks," dated September 2007. This report examined DOE's and the NRC's requirements for protecting Category I special nuclear material from terrorist threats. The NRC agreed with several of the recommendations; however, the NRC disagreed with a recommendation to develop a common design basis threat for facilities that store and process Category I special nuclear material.

- Report GAO-03-426, "Spent Nuclear Fuel: Options Exist to Further Enhance Security," dated July 2003. Considering that this report was issued shortly after the terrorist events of September 11, 2001, the NRC was still in the midst of developing and implementing new safety and security requirements. Safety and security measures have been greatly enhanced since that time.

Additionally, the NRC hosts peer-review missions, including the IAEA's Integrated Regulatory Review Service (IRRS) and International Physical Protection Advisory Service (IPPAS). The NRC's first IRRS mission was held in October 2010 and focused on the operating power reactor program. A follow-up mission occurred in February 2014 and reviewed the NRC's response to the 2010 mission's findings and the NRC's response to the Fukushima accident. An IPPAS mission was hosted by the United States in October 2013 and reviewed nuclear security-related legislative and regulatory framework.

In addition to its self-assessments and independent assessments from outside organizations, the NRC gains insights into security and safety programs from many other sources. The staff routinely assesses information gained from operating experience reported to the agency or gathered as part of the inspection program. The staff also gains insights from drills and exercises, including the force-on-force security inspections. Additional insights and related assessments result from petitions, correspondence, and other public interactions. The NRC is also able to compare its security programs with those of other countries though its participation in various international organizations. Close cooperation with other Federal agencies includes the opportunity for security specialists outside of the NRC to assess and provide suggestions on the protection of commercial nuclear facilities.

The Phase 2 NAS study made specific mention of including potential issues with insider threats within the recommended independent assessment. All commercial nuclear power plants employ an insider threat mitigation program, which is a defense-in-depth approach that is based on requirements codified 10 CFR Part 73, "Physical Protection of Plants and Materials." The approach for complying with these requirements is incorporated into the security plans for each nuclear plant and these plans are a condition of the plant's license to operate. The overall objective of the NRC's insider threat mitigation program is to provide for licensee oversight and monitoring of the initial and continuing trustworthiness and reliability of individuals having unescorted access and unescorted access authorization at nuclear plants. To accomplish this objective, the insider threat mitigation program includes overlaying components that use initial screening for trustworthiness and reliability, behavior observation once access has been granted, self-reporting, physical security such as limitations on access to vital areas and detection of contraband, cyber security, and fitness-for-duty. The initial and continuing monitoring of individuals includes a criminal history check with the Federal Bureau of Investigation, pre-access alcohol and drug testing, random and for-cause drug and alcohol testing, psychological testing and evaluation, documented annual reviews by immediate supervisors, and reinvestigation of individuals in selected positions. The security requirements are complemented by instrumentation, inspections, and other aspects of plant operation that provide confidence in the readiness of plant equipment to maintain or restore safety functions.

In summary, the staff has evaluated NAS Recommendation 4.3 and concludes that it is not necessary to redirect resources to another independent assessment given that the NRC's requirements and related programs to ensure security of nuclear power plants and spent fuel storage will continue to be subject to independent reviews by the OIG, GAO, and other organizations. The staff will continue to benefit from independent insights gained from interactions with other Federal agencies, international bodies, licensees, and other stakeholders.

<u>Recommendation 4.6: End-to-End Validation of MELCOR</u>

Finding 4.6: Additional analyses and physical experiments carried out by the [NRC] and Sandia National Laboratories since [NAS 2006] was completed have substantially improved the state of knowledge of boiling water reactor (BWR) and pressurized water reactor (PWR) spent fuel behavior following partial or complete loss of pool water. These studies and experiments have addressed the following important issues:

- Fuel damage state and timing as a function of fuel age and pool water loss;
- Propagation of zirconium cladding fires to other assemblies in the pool; and
- Potential mitigation strategies (dispersion of hot fuel assemblies in the pool, water sprays, water replacement) for delaying or preventing fuel damage following pool water loss.

These experiments have resulted in significant validation of MELCOR that is used to model coolant loss in SFPs. However, the code is unable to adequately model flows when stratification occurs and plumes form in the pool or above-pool environment. Moreover, key portions of code lack validation, and there has been no end-to-end validation of the code for modeling coolant loss in SFPs.

Recommendation 4.6: The U.S. Nuclear Regulatory Commission should (1) sponsor an end-to-end validation of the MELCOR code for use in modeling coolant loss in SFPs, and (2) validate key submodels in the code with particular attention paid to:

- Modeling the thermal and chemical behavior of spent fuel assemblies in partially drained pools.
- Modeling the thermal and chemical response of spent fuel assemblies to the application of water sprays.
- Modeling and validating for stratified flows in fully and partially drained pools.

NRC Staff Assessment and Planned Actions:

The staff has assessed NAS Recommendation 4.6 and has determined that the most important phenomena relevant to severe accident progression (e.g., fuel heatup and radioactive release) are modeled in MELCOR, supported by experimental validation, and are sufficient for current regulatory applications. The staff considers the code to be a state-of-the-art tool for severe accident and source term analysis, which can be used to inform regulatory decisions, where uncertainties are appropriately considered in the analyses results. Improvements, including those specifically mentioned in the NAS report, are continuously evaluated and are being implemented as appropriate to further reduce uncertainties. Additional details on the NRC's assessments and actions taken are provided below.

With respect to the capabilities of the code and its validation, the staff believes that MELCOR can mechanistically model the important physical phenomena given inherent uncertainties in accident progression phenomenology and is suitable for the current regulatory applications.

The code models have been developed over the past few decades, and the code has been benchmarked against many experiments including separate and integral effects tests for a wide range of phenomena (including situations where the nuclear fuel is partially covered by water) as documented in Volume 3 of the computer program manuals (ADAMS Accession No. ML15300A476). As noted in the NAS report, code assessments include a series of experiments conducted between 2004 and 2012 that specifically investigated fuel heatup and ignition during SFP accidents. The findings from the experimental programs and the MELCOR assessments have been documented in NUREG/CR-7143 for BWR assemblies and NUREG/CR-7215/16 for PWR assemblies. Since any new regulatory application of MELCOR requires a targeted assessment of the code, the staff believes that an "end-to-end" validation effort is not cost effective or necessary.

When being used to inform regulatory decisions, MELCOR is used to perform best estimate analysis, and uncertainty analysis is used to better understand and bound phenomenological uncertainties. The uncertainties need to be appropriately considered in the analysis results to take into account issues such as those raised in the NAS study. For example, Section 9 of the SFP study (NUREG-2161, "Consequence Study of a Beyond-Design-Basis Earthquake Affecting the Spent Fuel Pool for a U.S. Mark I Boiling Water Reactor," dated September 2014) is devoted to discussion of the major uncertainties that can affect the radiological releases (e.g., hydrogen combustion, core concrete interaction, multiunit or concurrent accident, fuel loading). In addition, the regulatory analysis in COMSECY-13-0030, "Staff Evaluation and Recommendation for Japan Lessons-Learned Tier 3 Issue on Expedited Transfer of Spent Fuel," dated November 12, 2013, relied on SFP study insights for the BWRs with Mark I and II containments, and even then, the results were conservatively biased toward higher radiological releases. For other designs, the release fractions were based on previous studies (e.g., NUREG-1738, "Technical Study of Spent Fuel Pool Accident Risk at Decommissioning Nuclear Power Plants," dated February 2001) that used simplifying assumptions biasing the results towards higher radiological releases.

In addition, the staff has recently completed an overall assessment of its approach to SFP severe accident evaluations. In SECY-15-0146, "Denial of Petition for Rulemaking Requesting Amendments Regarding Spent Fuel Pool Severe Accident Evaluations (PRM-50-108; NRC-2014-0171)," dated November 19, 2015, the staff evaluated a petition for rulemaking that raises a similar issue as what NAS recommends. One particular issue that the staff evaluated in this paper, among others, was an assertion that MELCOR is not currently sufficient to provide a conservative evaluation of postulated SFP accident/fire scenarios. The staff provided a similar rationale as discussed above and recommended the Commission deny the petition. The Commission decision approving the denial of this petition is documented in SRM-SECY-15-0146, dated April 4, 2016.

Nevertheless, additional assessment of MELCOR for certain aspects of partial draindown, fluid flow stratification, and spray flow modeling suggested in the NAS report can enhance the code capabilities and the user's confidence in the results. The DENOPI (SFP loss-of-cooling and loss-of-coolant accident) project that is coordinated by the French research organization Institut de Radioprotection et de Sûreté Nucléaire is aimed at producing additional quantitative information about SFP accidents, especially under partial draindown conditions. The NRC is cognizant of these efforts through its bilateral Cooperative Severe Accident Research Program agreements with France and other countries involved in MELCOR applications. The staff supports these activities and will use the results of this effort to enhance MELCOR capabilities.

In addition, the staff continues to be involved in various activities coordinated by the Nuclear Energy Agency including research projects dealing with SFP accident phenomenology. The staff participated recently in a project focused on the development of phenomena identification and ranking table for spent fuel pool accidents. Although the staff's evaluation is that the use of MELCOR in its present state where uncertainties are appropriately considered is sufficient for current regulatory applications, it believes that improvements in MELCOR capabilities are important and will be pursued in a cost effective manner.

In conclusion, the staff has evaluated NAS Recommendation 4.6 and concludes that MELCOR models the most important severe accident phenomena, is sufficiently supported by appropriate experimental validation, and is sufficient for current regulatory applications. The NRC will continue to evaluate available information from testing programs, international activities, and other sources to validate and improve analysis tools such as MELCOR. Uncertainties in the analysis tools will continue to be addressed when they are used to support regulatory decisions.

Recommendation 4.8: Spent Fuel Dispersal and Remote Cooling Capabilities

Finding 4.7: The [NRC] has not analyzed the vulnerabilities of spent fuel pools to the specific terrorist attack scenarios identified in Recommendation 3E-1 in [NAS 2004].[4]

Finding 4.8: The [NRC] and the U.S. nuclear industry have made good progress in implementing actions to address Recommendation 3E-2 in [NAS 2006]. The [NRC] has directed plant licensees to:

- Reconfigure their spent fuel in pools to achieve at least a 1 × 4 dispersion of high- and low-decay-heat assemblies, unless such configuration can be shown to be inapplicable or unachievable. This configuration must be achieved following each fuel offload from the reactor not later than 60 days after reactor shutdown.

- Develop guidance and implement strategies to maintain and restore spent fuel pool cooling following explosions and fires. To address this requirement, the U.S. nuclear industry has developed and adopted guidance and strategies for spent fuel pool water makeup and water sprays.

However, additional work is needed to more fully implement Recommendation 3E-2 in [NAS 2006].

Recommendation 4.8: The NRC should take the following actions to more fully implement Recommendation 3E-2 in [NAS 2006]:

- Reexamine the need for the 60-day limit for fuel dispersion and reduce the allowable time if feasible.

- Reexamine and, if needed, redesign the water makeup and spray systems and strategies to ensure that they can be implemented when physical access to pools is hindered or the site becomes inaccessible.

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4 A description of the NRC's assessment and actions related to the previous NAS study are provided in a report to Congress issued in March 2005 (ADAMS Accession No. ML050280428).

***NRC Staff Assessment and Planned Actions*:**

The staff revisited the issue of spent fuel dispersal and provided its results to the Commission in SECY-14-0136, "Response to Commission Direction on Spent Fuel Pool Limited Term Operational Vulnerabilities," dated November 26, 2014. The Commission was informed of the staff's conclusion that SFPs are safe and secure and no additional regulatory action is necessary in this area. In addition, the NRC issued orders after the Fukushima accident requiring equipment to maintain SFP cooling following a beyond-design-basis event, which includes the capability to connect cooling water without accessing the refueling floor. The staff is currently conducting inspections at all sites to validate that this capability has been established. Additional details on the NRC's assessments and actions taken are provided below.

In SRM-COMSECY-13-0030, dated May 23, 2014, the Commission directed the staff to:

> …provide an information paper (classified if necessary) to the Commission, detailing staff's views and considerations regarding the treatment of limited term operational vulnerabilities associated with the discharge of spent fuel from cores into pools and explaining how agency requirements and guidance assure the protection of public health, safety and security; if new vulnerabilities or issues are identified the staff should promptly inform the Commission…

The phrase "limited term operational vulnerabilities" refers to the allowable period of time for licensees to achieve a dispersed (e.g., a 1 × 4) spent fuel configuration in the SFP following discharge from the reactor core, which is stipulated in guidance documents to be 60 days.

The staff's assessment of SFP limited term operational vulnerabilities, as described in SECY-14-0136, is that current requirements for SFP mitigation measures are sufficient to ensure adequate protection of public health and safety, as well as common defense and security. In the expedited transfer analysis (COMSECY-13-0030), the staff concluded that the risks from potential SFP accidents are a small contributor to the overall risks for public health and safety (less than one percent of the Commission's quantitative health objectives). As discussed in that paper, the additional risk associated with the storage of spent fuel assemblies in a nondispersed configuration for a limited period of time does not provide a sufficient safety benefit to justify proceeding with regulatory action. Additionally, the staff noted that based on an assessment of licensee SFP operational practices, licensees generally place spent fuel in a final dispersed (e.g., 1 × 4 pattern) configuration before the 60-day limit.

During the development of COMSECY-13-0030, the staff did not prepare or provide to the Commission a cost/benefit assessment of other possible regulatory actions, such as requiring alternate loading patterns within a high density pool or requiring enhancements to accident mitigation capabilities. For these cases, the staff found that if the major action (expedited transfer of spent fuel to dry cask storage) is a marginal safety improvement, similar or lesser actions would likewise not provide a substantial safety improvement.

In addition to preexisting requirements, the NRC required numerous safety improvements after the terrorist events of September 11, 2001, and the Fukushima Dai-ichi accident, including the additional SFP capabilities required by Order EA-12-049 and Order EA-12-051 (e.g., diverse SFP makeup connections and SFP level instrumentation), as discussed previously. These initiatives have enhanced the safety of SFPs. Additionally, after the terrorist events of September 11, 2001, the NRC required licensees to put in place supplemental security measures. These enhancements help provide a high level of assurance that a terrorist attack cannot affect the SFP safety systems. In conclusion, the staff determined that SFPs are safe and secure and that no additional regulatory action is necessary at this time.

As a follow up item to COMSECY-13-0030, the Commission directed the staff to issue an information notice (IN) to inform licensees of the potential added safety benefit of adopting a 1 × 8 configuration. In response to this direction, the NRC issued IN 2014-14, "Potential Safety Enhancements to Spent Fuel Pool Storage," dated November 14, 2014. This IN discussed insights from the SFP study (NUREG-2161) regarding an unlikely, beyond-design-basis seismic event. The IN emphasized that storing spent fuel in more favorable loading patterns, placing fuel in dispersed patterns immediately after core offload, and taking action to improve mitigation strategies when the SFP heat load is high may help licensees further reduce the risk associated with the SFP.

In conclusion, the staff has evaluated NAS Recommendation 4.8 and concludes that the requirements for cooling capabilities for and dispersion of spent fuel within SFPs adequately address the lessons learned from the Fukushima accident. As described in COMSECY-13-0030, the staff considered analysis results, operating history, and limited safety benefits of possible plant changes and found that further studies as recommended by NAS would be unlikely to support additional regulatory requirements related to the storage of spent fuel. NAS did not identify any new information that would cause the staff to reconsider the conclusions reached in COMSECY-13-0030. The staff is in the process of documenting the acceptability of licensees' plans for mitigating strategies and inspecting each licensee's implementation of the orders related to mitigating strategies and SFP level instrumentation. The staff will also continue with the mitigating strategies rulemaking activities. In addition, the NRC will continue to inspect and assess licensees' security programs, work with other Federal agencies to assess possible threats, and participate in interagency and international efforts to ensure an appropriate level of security is maintained for NRC regulated facilities.

Recommendation 4.10: ISFSI Security Rulemaking

Finding 4.10: The [NRC] is incorporating the results of its dry cask vulnerability analyses into its regulations through rulemaking. The rulemaking was still in progress when the present study was being completed; consequently, the committee was unable to evaluate its technical soundness and completeness.

Recommendation 4.10: The [NRC] should give high priority to completing its analyses on dry cask storage vulnerabilities and rulemaking.

NRC Staff Assessment and Planned Actions:

The Commission recently decided to extend the schedule to complete a dry cask storage security rulemaking. The purpose of the delay is to allow for regulatory and research programs to evolve in this area. As discussed in its justification for requesting delay of the rulemaking, the staff indicated that existing security regulations, additional requirements provided in security orders, and regular security inspections continue to provide high assurance of adequate protection of public health and safety. The rulemaking was therefore viewed as a lower priority activity that could be delayed in light of higher priority rulemakings and the agency's declining budget environment. Additional details on the NRC's assessments and actions taken are provided below.

COMSECY-15-0024, "Proposed Rulemaking on Security Requirement for Facilities Storing Spent Nuclear Fuel and High-Level Radioactive Waste," dated September 11, 2015, provides the staff's technical approach, and updated recommendation on the timeline for a proposed rule to develop security requirements for facilities providing interim storage of spent nuclear fuel and high-level radioactive waste. This was in response to previous Commission direction to pursue rulemaking in this area. Because of developments in the nuclear industry since the issuance of SRM-SECY-10-0114 and the SRM to an earlier paper, SECY-07-0148, "Independent Spent Fuel Storage Installation Security Requirements for Radiological Sabotage," the staff recommended delaying this security rulemaking for up to 5 years.

The recent number of power reactors permanently ceasing operations, in part, has prompted the Commission to direct the staff to conduct rulemaking to govern the transition of power reactors to decommissioning. The staff's evaluation of resources and expertise necessary to support both the decommissioning and ISFSI security rulemakings revealed additional interface issues warranting further consideration, including when a dose-based regulatory approach for ISFSIs should be implemented during the facility's life cycle.

Concurrently, the environment for spent fuel storage and disposal continues to evolve. Aside from ISFSIs, the staff has received one application (Waste Control Specialists) to construct an interim consolidated spent fuel storage facility and expects to receive another in 2017. Although the staff remains confident that existing requirements ensure adequate protection, construction and operation of these facilities, if licensed, will require the staff to reexamine potential security scenarios to support the technical basis for the subject rulemaking.

Although the agency continues to evaluate the appropriate approach for this rulemaking, the existing security regulations for ISFSIs, together with the additional requirements in the security orders issued after September 11, 2001, provide continued high assurance of adequate protection of public health and safety regardless of the license type or location. Additionally, triennial security inspections for ISFSIs ensure industry compliance with all current requirements. Not pursuing the subject rulemaking would leave in place two different but acceptable licensing approaches for security of ISFSIs, general and specific. The staff does not currently plan to accelerate the timeline to initiate the rulemaking within 5 years. However, the staff may conduct a technical review sooner, if necessitated by external factors.

In conclusion, the staff has evaluated NAS Recommendation 4.10 and concludes that it is not necessary to reprioritize or reschedule activities related to the ISFSI security rulemaking. The staff will continue to pursue improvements in the regulatory and research programs related to the security of dry cask storage facilities. The rulemaking activity will benefit from these insights and will be completed in accordance with the priorities and schedules established by the Commission.

Recommendation 4.11: Spent Fuel Storage Risk Assessment

Finding 4.11: The [NRC] has completed a technical analysis of [SFP] accident consequences to inform a regulatory decision on expedited transfer of spent fuel from pool to dry cask storage. The analysis was carried out in accordance with prescribed [NRC] regulatory guidance and provides valuable technical information about the effects of various accident scenarios on spent fuel storage in pools. However, the analysis did not consider spent fuel storage sabotage risks, dry cask storage risks, or certain health consequences that would likely result from a severe nuclear accident. The analysis also used simplifying bounding assumptions that make it technically difficult to assign confidence intervals to the consequence estimates or make valid risk comparisons. A risk assessment that evaluates the three questions of the risk triplet and that accounts for uncertainties in both probability and consequence estimates is needed to address Finding 4E in [NAS 2006] to determine whether "earlier movements of spent fuel from pools into dry cask storage would be prudent to reduce the potential consequences of terrorist attacks on pools at some commercial nuclear plants."

Recommendation 4.11: The [NRC] should perform a spent fuel storage risk assessment to elucidate the risks and potential benefits of expedited transfer of spent fuel from pools to dry casks. This risk assessment should address accident and sabotage risks for both pool and dry storage. The sabotage risks should be assessed using the methodology developed in response to the present committee's Recommendation 4.1B.

NRC Staff Assessment and Planned Actions:

As previously discussed, the NRC has performed or sponsored a number of studies of spent fuel storage, for both SFPs and dry cask storage. Relatively recent studies have included an evaluation of BWR SFPs in NUREG-2161 and dry cask storage in NUREG-1864, "A Pilot Probabilistic Risk Assessment of a Dry Cask Storage System at a Nuclear Power Plant." The staff is continuing to gather regulatory and technical insights on the security of dry cask storage for use in a planned rulemaking related to that topic. As noted earlier, the Commission has dispositioned the issue of expedited transfer of spent fuel from SFPs to dry casks and decided that the agency should not pursue this matter given the thorough analyses that have been done. The staff will also continue to cooperate with other Federal agencies and international bodies to assess security threats and take action if appropriate. Additional details on the NRC's assessments and actions taken are provided below.

The accident at the Fukushima Dai-ichi nuclear facility in Japan led to additional questions about the safe storage of spent fuel and whether the NRC should require the expedited transfer of spent fuel from SFPs to dry cask storage at nuclear power plants in the United States. This issue was identified by staff as needing further study to determine if regulatory action was warranted. On October 9, 2013, the NRC released the study later published as NUREG-2161 and on November 12, 2013, the NRC delivered a regulatory analysis to the Commission in COMSECY-13-0030. These documents concluded that SFPs are very robust structures with large safety margins, and that proposed regulatory actions for SFP safety improvements were not warranted. Citing the low risk to public health and safety from SFP storage, the Commission subsequently concluded that regulatory action need not be pursued in SRM-COMSECY-13-0030.

The main issue that NAS raises is whether the staff appropriately considered all of the factors that should be evaluated in a thorough analysis of a proposed regulatory action. The analysis methods are specified by various guidance documents. The two documents that govern the NRC's regulatory analysis process are NUREG/BR-0058, Revision 4, "Regulatory Analysis (RA) Guidelines of the NRC," dated September 2004 (RA Guidelines), and NUREG/BR-0184, "Regulatory Analysis Technical Evaluation Handbook," dated January 1997 (RA Handbook). These documents are the well-established, Commission-approved directives for identifying all attributes affected by the proposed alternative and analyzing them either quantitatively or qualitatively. The staff followed this guidance when conducting the regulatory analysis contained in COMSECY-13-0030.

In COMSECY-13-0030, the staff used bounding or conservative values in the analysis for several parameters, particularly in the high estimate cases, to ensure that design, operational, and other site variations among the new and operating reactor fleet were addressed and to generally increase the calculated benefits from the proposed action. This approach does differ from analyses undertaken to provide best estimate characterizations of risks but proved sufficient for the regulatory decisions needing to be made by the NRC. The staff does not agree that further analysis of the factors recommended by NAS would have resulted in a different conclusion or is needed to provide further support of the decisions made.

The staff's analysis in COMSECY-13-0030 and the supporting references did not include events caused by sabotage. Security issues were extensively assessed in various studies and regulatory analyses following the terrorist attacks of September 11, 2001, and enhanced security requirements were imposed to provide high assurance of adequate protection from radiological sabotage of the nuclear power plant reactor and SFP. The NRC did not include sabotage in the COMSECY-13-0030 analysis as it was determined that these types of security issues were previously addressed and resolved. Plant security is one of many topics within the NRC's risk-informed, performance-based framework that are assessed in combination with but not fully integrated into PRA models. The NRC continually monitors threat conditions and should any new or significant security concerns arise that may require regulatory action, the NRC will make adjustments, as appropriate, in the governing security requirements to ensure their effective implementation.

In performing economic analyses, such as that contained in COMSECY-13-0030, the NRC considers public health, occupational health, environmental considerations, and two categories of property—onsite and offsite. Generally, onsite property is owned or controlled by the license- or certificate-holder and located within the boundaries of the licensed facility, whereas offsite property is located outside of the site boundaries, and is not owned or controlled by the license- or certificate-holder. However, in these economic analyses, the distinction between offsite and onsite property goes beyond the location or ownership of the property. Onsite property costs include replacement power, decontamination costs, and costs associated with refurbishment or decommissioning. Offsite property costs include both the direct costs associated with property damage (e.g., diminution of property values) and indirect costs (e.g., tourism, manufacturing, and agriculture disruption).

However, there are limits based on considerations of health, safety, or property damage that is too far attenuated from NRC authority under the Atomic Energy Act (AEA). For example, in *Metropolitan Edison Co. v. People against Nuclear Energy*, 678 F.2d 222 (D.C. Cir. 1982), the U.S. Court of Appeals for the D.C. Circuit evaluated the reach of the AEA in providing protection against radiological harm. Specifically, the D.C. Circuit ordered the Commission to study the "alleged psychological health impacts arising from the proposed restart" under the National Environmental Policy Act and, with respect to the AEA, "to submit to the court a statement of [the Commission's] reasons for concluding that the [AEA] did not require consideration of psychological health in the restart proceeding." On March 30, 1982, the Commission complied with the court's order by filing a Memorandum and Order, in which the Commission determined that consideration of psychological effects was not intended under the AEA, as there was no precedent in establishing a requirement that "health and safety" in Sections 2 and 103 of the AEA be interpreted to include psychological health.[5] The D.C. Circuit upheld the Commission's Memorandum and Order regarding the AEA, stating that it agreed with the Commission's decision "not to consider psychological stress issues under the AEA," 678 F.2d at 250. See SECY-12-0110, "Consideration of Economic Consequences within the U.S. Nuclear Regulatory Commission's Regulatory Framework," dated August 14, 2012, for further discussion of AEA case law suggesting limits to the Commission's discretion.

In terms of more fully accounting for uncertainties in scenario probabilities and consequences, the staff agrees that quantifying uncertainty is a best practice, which is addressed in many guides and references. The explicit identification and quantification of sources of uncertainty in regulatory analyses leads to better decisionmaking by providing a means to understand this uncertainty (e.g., the effect of data, assumptions, accident frequency, and consequence), effect of variations within different regulatory analysis groupings (e.g., categories of licensees), and the potential range of incremental costs and benefits that result. However, resource and scheduling limitations may necessitate using limited scope or historical PRA studies as bases for evaluating the effect of regulatory alternatives.

Furthermore, the Commission has directed that the staff improve its methods of quantitative analysis, including the treatment of uncertainty to support the development of realistic estimates of the costs of implementing proposed requirements (SRM-SECY-14-0087, "Staff Requirements – SECY-14-0087 – Qualitative Considerations of Factors in the Development of Regulatory Analysis and Backfit Analysis," dated March 4, 2015). The staff is developing guidance for implementing the Commission's direction. This guidance will address qualitative factors assessment methodology, cost estimating best practices, and the treatment of uncertainty in regulatory and backfit analyses.

In conclusion, the staff has evaluated NAS Recommendation 4.11 and concludes that the various analyses performed or sponsored by the NRC have been sufficient to support regulatory decisions on the safety and security of spent fuel pools. The staff is continuing to gather regulatory and technical insights on the security of dry cask storage for use in a planned rulemaking related to that topic. The staff will also continue to cooperate with other Federal agencies and international bodies to assess security threats and take action if appropriate.

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[5] *Metropolitan Edison Co.*, CLI-82-6, 15 NRC 407 (1982).