Fukushima, 5 Years Fast Forward

Background

March 11, 2016, marks the 5th anniversary of the devastating accident at Japan's Fukushima Dai-ichi nuclear power station. The earthquake that occurred off Japan's east coast that day damaged, among other things, the electrical breakers and distribution towers that supplied power to the Fukushima Dai-ichi site, resulting in what is known as a "loss of all offsite power" event. Although onsite emergency diesel generators properly started and provided power to the station's emergency systems, a tsunami soon overwhelmed the site, flooding emergency diesel generator and switchgear rooms, rendering the emergency systems inoperable. With no cooling to remove reactor decay heat, core damage occurred on the three reactors that had been operating. The other three reactors had been previously shut down for routine maintenance and did not experience core damage.

As the accident progressed, the lack of emergency cooling caused the temperatures and pressures to increase in the primary containment structures of Units 1, 2, and 3, which contributed to containment leakage, inhibited the ability to inject water into the reactors using low-pressure sources and resulted in the release of a large amount of contaminated material to the environment. Hydrogen generated from the damaged reactor fuel leaked from the containment structures, accumulated in the reactor buildings of Units 1, 3 and 4, and exploded, destroying the upper levels of the buildings resulting in additional releases of contaminated material to the environment. A comprehensive description of the accident is available in the International Atomic Energy Agency (IAEA) report, "The Fukushima Daiichi Accident," which can be found at http://www-pub.iaea.org/books/IAEABooks/10962/The-Fukushima-Daiichi-Accident.

The Fukushima Dai-ichi accident had an immediate, profound impact on the nuclear power industry worldwide. As such, evaluating the accident and identifying possible safety enhancements became an urgent priority for regulators and the nuclear industry in all countries with nuclear power plants.

Overview of U.S. Response to the Fukushima Accident

The U.S. Nuclear Regulatory Commission's (NRC's) 24-hour Operations Center in Rockville, Maryland, began monitoring the accident shortly after the earthquake and tsunami occurred. The NRC's initial focus was on potential tsunami effects on California's nuclear power plants, as well as other nuclear materials users on the west coast, in Hawaii, Alaska, and U.S. pacific territories. By the afternoon of March 11, the agency had fully staffed the Operations Center and had begun interactions with Japanese regulators. The NRC sent two experts that weekend to assist the U.S. Embassy in Tokyo and by March 14, had sent several additional staff to provide technical support to the U.S. Embassy and the Japanese Government.

The NRC and U.S. nuclear industry quickly moved to reassess the safety of domestic nuclear power plants in light of the accident. The NRC issued an information notice, a bulletin, and initiated two near-term NRC inspection procedures that directed power plant operators and NRC inspectors to:

(1) Confirm the reliability of licensees' strategies intended to maintain or restore core cooling, containment, and spent fuel pool (SFP) cooling capabilities under the circumstances associated with loss of large areas of the plant due to explosions or fire.

(2) Inspect the readiness of nuclear power plant operators to implement severe accident management guidelines.

In addition to and in parallel with NRC actions, the Institute of Nuclear Power Operations asked nuclear power plant licensees to:

- Verify the capability to mitigate internal and external flooding events required by station design.

- Perform walkdowns and inspections of important equipment needed to mitigate fire and flood events to identify the potential that the equipment's function could be lost during seismic events and develop mitigating strategies for identified vulnerabilities.

- Increase sensitivity to spent fuel storage event response and ensure that a high state of readiness is maintained to respond to events that challenge spent fuel storage integrity.

- Develop plant-specific information concerning coping times and design limitations for extended loss of power events.

On March 23, 2011, the NRC established the "Near-Term Task Force" (NTTF), comprised of senior NRC managers and staff, to conduct a review of the information available from the events at Fukushima Dai-ichi and make recommendations for potential improvements to the safety of U.S. nuclear power plants. On July 12, 2011, the NTTF issued its report, titled, "Near-Term Report and Recommendations for Agency Actions Following the Events in Japan." The NTTF concluded that although U.S. reactors were safe, enhancements to existing safety and emergency preparedness requirements were recommended.

NRC staff prioritized the NTTF recommendations using a three-tiered approach. The Tier 1 recommendations were those actions that should be put into place without unnecessary delay. The Tier 2 recommendations were those actions that needed further technical assessment or required personnel with critical skill sets who were engaged in working on the higher priority Tier 1 recommendations. The Tier 3 recommendations were longer-term actions that were dependent on the completion of a shorter-term activity or needed greater study to support a regulatory action.

As part of the implementation of the Tier 1 actions, the NRC issued three orders on March 12, 2012, to U.S. nuclear power plants with the following requirements for operators:

(1) The mitigating strategies order requires licensees to develop strategies to maintain key safety functions for an indefinite period of time following a beyond-design-basis natural event.

(2) The spent fuel pool instrumentation order requires licensees to install reliable level instrumentation in their SFPs.

(3) The hardened containment vent order requires licensees of certain types of reactors to have reliable hardened vents for their containments. The ability to vent these containments is needed to control temperature and pressure inside the containments and is important in preventing fuel damage, particularly during a long-term station blackout events.

In response to the mitigating strategies order, the nuclear industry developed a strategy called "FLEX," which is the foundation of its overall response. The FLEX approach adds equipment—such as pumps, generators, and battery chargers—in diverse locations throughout the plant site.

The equipment will be commercial-grade with engineered specifications, with requirements for equipment testing and maintenance subject to NRC oversight. The strategy is flexible in that it does not mandate installation of permanent equipment. Instead, it requires that the plant sites obtain, prepare, and maintain portable equipment that could be used to mitigate virtually any event. The equipment will be able to connect to a variety of locations for injecting coolant and providing a continuous supply of electricity. The objective of FLEX is to ensure plant-specific capability to cope for an indefinite period through a combination of installed plant capacity, portable onsite equipment, and offsite resources.

The FLEX strategy was informed by the industry's response to the September 11, 2001, terrorist attacks, in which additional equipment—such as portable generators, water pumps, hoses, and batteries—were put in place to mitigate the effects of possible large fires and explosions. The FLEX approach offers an additional layer of mitigation for events that are beyond what a plant was originally designed to withstand. Multiple means of obtaining power and water fulfill the key safety functions of reactor cooling, containment integrity, and SFP cooling that would prevent damage to nuclear fuel and protect the public and the environment.

FLEX equipment ranges from diesel-driven pumps and electric generators to ventilation fans, hoses, fittings, cables, and communications gear. The new equipment will be stored at diverse locations at the sites and protected to ensure that it can be used if other systems in a facility's multilayered safety strategy are compromised.

The U.S. nuclear power industry has also established two national response centers (one in Memphis, Tennessee, and another in Phoenix, Arizona) for the purposes of extra equipment storage and rapid deployment.

In response to the spent fuel pool instrumentation order, all operating reactors are installing reliable level instrumentation in their SFPs. During the accident at Fukushima, the plants lost the ability to cool the SFPs and plant operators could not determine how much water was in the pools. This caused concern that if enough water boiled away or was otherwise lost, the spent fuel rods could become uncovered as the water receded and potentially release significant amounts of radiation. It was later learned that the spent fuel was always covered, but the information gap diverted significant attention and extremely limited resources from more important tasks during the accident. The SFP level instrumentation order would preclude that from happening.

Licensees were required to promptly start implementation of the first two orders and complete full implementation no later than two refueling outages after issuance of the orders or by December 31, 2016, whichever came first.

The Fukushima accident disabled the plants' ability to cool their reactor cores, causing heat and pressure to build within the containment buildings that surround the reactors. This buildup eventually damaged the containment buildings releasing radioactive materials and combustible gases. The NRC issued an order on March 12, 2012, requiring all U.S. nuclear power plants with the Fukushima-style containment design to install a reliable, hardened vent that can remove heat and pressure before potential damage to a reactor core occurs. This not only helps preserve the integrity of the containment building, but can also help delay reactor core damage or melting. After issuing the order, other NRC evaluations examined the benefits of venting *after* reactor core damage occurs. In June 2013, the NRC modified the order to ensure those vents will remain functional in the conditions following reactor core damage. This order is to be implemented no later than startup from the second refueling outage that begins after June 30, 2014, or June 30, 2018, whichever comes first.

In addition to the three Orders, the NRC required licensees to respond to an information request. Unlike an order, a request for information does not impose a new requirement on a licensee, but requires them to submit information to be used by the NRC to determine if additional regulatory action is necessary to ensure safety. The request for information directed licensees to take the following actions:

(1) Conduct examinations of existing seismic and flood protection measures and report the results to the NRC.

(2) Reevaluate seismic and flooding hazards at each site using present day methods and inform the NRC of the results of those assessments.

(3) Complete an assessment of capabilities associated with emergency preparedness communication and staffing for multiunit and large scale events and report the results to the NRC.

As an element of the information request, NRC asked licensees of U.S. nuclear power plants to perform a detailed inspection, or "walkdown," of their seismic and flooding protection features. The plants had to ensure the features met current requirements, and also identify, correct, and report any degraded conditions. Additionally, operating reactor sites are using present-day information to reevaluate the earthquake and flooding effects—or hazards—that could affect their sites. These newly reevaluated hazards, if worse than what the plant was originally designed for, will be analyzed to determine if plant structures, systems, or components need to be updated to protect against the new hazard. The NRC will review each step in the analysis process and take action to require plant changes as necessary.

The accident at Fukushima highlighted how complicated emergency response can be if multiple reactors on the same site are affected at the same time and electrical power is unavailable. In response, the NRC asked in the information request that U.S. nuclear power plant management assess how many emergency staff members are needed to respond to a large accident that could affect multiple reactors at their site, and make changes to emergency plans as necessary. The NRC also asked the plants to assess and ensure that they can power the communications equipment these staff will need to respond to such an accident effectively. This includes power for radios for response teams, cellular telephones, and satellite telephones.

The implementation of the Tier 1 actions has and will continue to enhance the already robust protection of U.S. nuclear power plants by adding additional independent and redundant layers of defense to compensate for potential failures and external hazards that may exceed the design basis of a facility.

A number of the NRC's Tier 2 and 3 recommendations are being addressed by ongoing Tier 1 activities. The NRC staff has developed plans for resolving the remaining Tier 2 and 3 recommendations. Those plans were provided to the NRC Commission in a November 2015 paper.

The NRC's most recent status update on the agency's activities related to lessons learned from the accident was documented in an October 2015 report to the Commission.

Conclusion

The Fukushima Dai-ichi accident prompted all countries with nuclear power plants to evaluate the accident to identify possible safety enhancements as a high priority. While country-specific differences exist in the response to the accident, common focus areas—protection from external hazards, mitigation of beyond-design-basis events, and strengthening of emergency preparedness—were broadly adopted.

A number of initiatives were undertaken in the U.S. to enhance nuclear power plant safety in light of lessons learned from the accident. These initiatives include a reexamination of the response of their nuclear power plants to external events of higher magnitude than previously considered, using the latest data technology; upgrading the capability of the existing power sources and are installing new sources of electrical power; enhancing the ability to vent containments and mitigate hydrogen production; installing SFP level indications; strategically placing portable equipment on site that can be installed quickly to provide emergency cooling; and establishing remote response centers for the purposes of additional equipment storage and rapid deployment.

Finally, the Fukushima Dai-ichi accident has demonstrated that if adversity strikes, the global nuclear community will unite to identify common, well-informed approaches to improve nuclear safety.