

U.S. Nuclear Power Safety One Year After Fukushima

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Contents

<i>Tables</i>	<i>iv</i>
<i>Executive Summary</i>	<i>v</i>
1. Introduction	1
2. The Accident at Fukushima Dai-ichi	5
3. The NRC's Response	9
NRC Near Term Task Force	11
4. UCS Perspectives on the Task Force and Its Recommendations	17
NTTF Recommendation 1	18
NTTF Recommendations 4.1 and 4.2 and the Nuclear Industry's "Diverse and Flexible Coping Capability" (FLEX) Approach	21
NTTF Recommendation 7.4	23
5. Conclusions	25

Tables

1. Recommendations of the Near Term Task Force	27
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Executive Summary

The March 11, 2011, disaster at Japan's Fukushima Dai-ichi nuclear plant was triggered by a massive earthquake and tsunami far more destructive than those it was designed to withstand. The earthquake seriously damaged the electrical grid around the plant, thereby cutting off its normal source of AC power and disabling the equipment needed to keep the plant's radioactive reactor cores from overheating. And the tsunami overwhelmed a nominally protective sea wall, flooded the site, and disabled the backup AC power source as well as other critical electrical equipment. This one-two punch plunged the plant into a "station blackout"—with the only remaining electrical source being DC power supplied by banks of batteries, which could only last several hours at best and in actuality did not perform consistently.

The plant's workers valiantly tried to rise to the challenge. They pulled batteries from vehicles in the parking lot and carried them into areas of the reactor buildings that were dark, hot and increasingly radioactive. They searched for electrical panels that were still functional. And in an attempt to inject water into the overheating cores, they manually operated valves and jury-rigged alternate cooling systems using hoses and diesel-powered fire pumps.

But these heroic efforts ultimately proved futile in the face of such extreme conditions. Like nuclear dominoes, the cores of Units 1, 3, and then 2 overheated and melted, producing large quantities of radioactive steam and hydrogen gas, some of which leaked into the buildings surrounding the reactor containment structures. When the hydrogen detonated, the roofs and upper walls of the Unit 1, 3, and 4 reactor buildings were blown apart, and there is evidence that the Unit 2 containment structure was breached as well. As a result, large amounts of radiation were released into the atmosphere, countryside, and ocean. The area within 12 miles of the Fukushima site remains so contaminated that the approximately 80,000 people who lived there have been unable to return to their homes, and hot spots as far as 25 miles away from the plant site have also been evacuated.

A year later, what are the implications for U.S. nuclear power safety? To its credit, the Nuclear Regulatory Commission (NRC) swung into action immediately after the accident and has been engaged ever since. Many of its proposals to safeguard against such a calamity here are good in principle, but their effectiveness will depend on how well they are implemented, and how quickly. It took 10 years for the agency to fully implement safeguards prompted by the 9/11 terrorist attack, and it will take at least five years to institute changes in response to Fukushima. However, speed is not always a virtue. The nuclear industry is acting too hastily by

launching a voluntary program before the NRC has had the opportunity to specify what measures are needed to adequately protect the public

Fukushima Reactors Similar to Ours. The designs of the Fukushima reactors closely resemble those of many U.S. reactors, and the respective emergency response procedures are comparable as well. But while most U.S. reactors may not be vulnerable to that site's specific earthquake/ tsunami sequence, they are vulnerable to other severe natural disasters. Moreover, similarly serious conditions could be created by a terrorist attack.

While Fukushima had a hardened vent system, as do 23 similarly designed U.S. reactors, to reduce heat and pressure within the containment during an accident, this system did not work effectively because it required electrical power to operate. As at Fukushima, most U.S. reactors also lack instrumentation that would allow operators in the control room to monitor key parameters, such as the level and temperature of the water in the spent fuel pools. In Japan and the United States alike, the possibility of an accident affecting more than one reactor at a multiunit site has simply been ignored in present accident mitigation and emergency response strategies. And while U.S. reactors, like Japanese reactors, are required to have plans to cope with a station blackout, these plans would have been useless under the conditions experienced at Fukushima.

NRC Swings into Action. The initial response of the U.S. Nuclear Regulatory Commission (NRC) to the Fukushima tragedy was commendable. As the disaster evolved, the agency fielded a large number of inquiries—such as from the media, the American public, and Capitol Hill—in a timely and responsive manner. Based on the very limited information available at the time, the NRC recommended that the federal government advise U.S. citizens located within 50 miles of Fukushima to evacuate. While the radiological release is now believed to have been smaller than what the NRC assumed in developing this advisory, it was the proper call based on the scant information available at the time.

Just a few weeks later, the NRC announced the formation of a task force to review the accident and identify measures to reduce vulnerabilities at U.S. reactors. In its report released July 12, 2011, that task force made 12 recommendations, some with multiple parts. The NRC later placed all but one of these recommendations into three categories of priority: Tier 1 items, which are expected to be handled largely by means of orders issued to plant owners before the first anniversary of the accident; Tier 2 items, to be addressed through rulemaking within five years of the accident; and Tier 3 items, to be dealt with through means and a schedule to be outlined by September 2012. Thus the NRC settled on a subset of recommendations for near-term implementation, and it put the remaining ones on the back burner. Even for the Tier 1 recommendations, however, the Commission would not require licensees to fully implement changes for nearly five years from now.

Leaving the Most Important Recommendation for Last. A major flaw in the NRC’s approach is that it has relegated the task force’s first and primary recommendation to last in line (beyond even the Tiers 1, 2, and 3 in which the other 11 recommendations were placed). In Recommendation 1 the task force proposed that the Commission clarify its “patchwork” regulatory framework for severe (“beyond-design-basis”) accidents such as the one at Fukushima; because many of the other 11 recommendations involve measures to address such severe accidents, Recommendation 1 would be basic to their implementation.

At present it is only required that reactors be designed to handle some types of accidents—so-called “design-basis” accidents—but not most “beyond-design-basis” accidents such as the one at Fukushima. Thus the NRC regulations governing such severe accidents are fragmented and uneven—there are some NRC requirements that apply to some types of beyond-design-basis events, but not others. The task force aimed, through Recommendation 1, to fundamentally address this inconsistency, but the NRC has significantly impaired the reform process by moving the task force’s key recommendation out of sequence, thus introducing major uncertainties about the other 11 recommendations’ implementation.

For example, one of those recommendations is that plant owners be required to implement measures that allow plant workers to better cope with a station blackout. The precedent is that after 9/11, the NRC required plant owners to install equipment, such as portable diesel-fueled pumps and generators, to protect their facilities from events such as prolonged station blackouts caused by aircraft attacks. However, because aircraft attacks are defined as beyond-design-basis events, the NRC consequently did not require that this equipment meet high standards of quality or reliability or be protected from earthquakes, flooding, or other natural disasters. Indeed, this equipment was never intended for use after natural disasters, and inspections post-Fukushima have confirmed that at many sites some of the equipment would not survive earthquakes or floods.

Nuclear Industry Jumping the Gun. As the NRC systematically develops its preferred course of action, the nuclear industry has jumped into the breach by proposing a program called “Diverse and Flexible Coping Capability,” or FLEX, as the foundation of its Fukushima response. Under the FLEX approach, the 9/11-inspired equipment would be supplemented and relocated so that it might also help in the event of a severe natural disaster. This equipment would not be hardened, which is costly to achieve, but instead would be dispersed to numerous locations, both on and away from reactor sites. The industry’s hope is that enough equipment would be scattered around so that at least some of it would be available after catastrophic events.

But without clearly defined ground rules for these efforts, it is hard to gauge how much additional protection they would actually provide. For instance, the NRC is proposing that licensees provide “reasonable protection” for emergency equipment,

but has not yet defined how such a requirement could be met. Further, a major procedural problem is that the industry has already started purchasing FLEX equipment before the NRC has had the opportunity to develop such guidelines—these purchases would make it politically difficult for the NRC to later institute requirements on industry to replace equipment already procured. By failing to first address the fundamental requirements for such equipment in a consistent manner, the NRC has created a policy vacuum. Meanwhile, and in contrast, regulators in France are moving to require that French reactor operators develop a so-called “hard core” of safety equipment designed to survive beyond-design-basis events.

NRC Deferring Action on Key Issues. The Union of Concerned Scientists (UCS) released its own recommendations for improving reactor safety and protection of public health in July 2011. Three of them—enlargement of emergency evacuation zones, expansion of potassium iodide distribution, and accelerated transfer of spent fuel from pools to dry casks—were later chosen by the NRC staff for further evaluation. However, the NRC placed these recommendations into the Tier 3 category, thereby deferring action for an as-yet-unspecified period of time. Moreover, the staff has “determined that the current regulatory approaches to these issues are acceptable” and will “review new information that becomes available as a result of specific ongoing activities to confirm this conclusion and gain additional insights.”

Meanwhile, U.S. reactors remain vulnerable to Fukushima-like severe disasters. The NRC does have a plan to reduce these vulnerabilities, but it must proceed more expeditiously to fully implement the lessons learned from Fukushima. Unless the NRC strengthens measures to prevent and mitigate such “beyond-design-basis” accidents, it may be only a matter of time before a similar disaster happens here.

CHAPTER 1

INTRODUCTION

It was thought that the six reactors at Japan's Fukushima Dai-ichi nuclear plant were prepared for an earthquake, a tsunami, a loss of onsite alternating-current power, and an unexpected challenge to reactor core cooling. Because the plant was located in an area of known seismic activity, its buildings and safety systems were designed to handle the forces imposed by an earthquake's ground motion. Likewise, an 18-foot sea wall was in place to protect the plant against tsunamis. Banks of batteries could power essential emergency equipment for up to eight hours if both the normal power source and its backup diesel generators were unavailable. The plant had hardened containment vents to allow reactor core cooling, even in the unlikely case that all other emergency cooling systems failed. And the plant's workers had been trained in procedures for responding to such contingencies.

But March 11, 2011, demonstrated the inadequacy of these measures, as events that began unfolding that day were far more extreme than those the plant was designed to withstand. An earthquake and the tsunami it created seriously harmed the electrical grid and the onsite emergency diesel generators. The batteries and the backup systems they powered, which together delayed significant damage to two of the three reactor cores of the units operating at the time, did not prevent such damage. Despite the hardened vents, there was no timely containment venting, resulting in reactor core overheating and melting, followed by hydrogen explosions that caused not only extensive damage to three of the reactor buildings but also the dispersal of radioactive materials. And while workers followed their rehearsed scripts, the accident did not.

The reactor designs at Fukushima Dai-ichi closely resemble those of many U.S. reactors, and Japanese and U.S. reactors have comparable emergency-response procedures as well. But while most U.S. reactors may not be subject to the one-two punch of an earthquake and tsunami, they are vulnerable to other disasters, including dam failures. Since Fukushima, four U.S. nuclear plants have been challenged by tornadoes, flooding, and an earthquake (see box, "A Sampling of Weather-Related Risks"). Moreover, similarly serious conditions could be created by a terrorist attack.

What has changed in the past year to ensure that a disaster like the one at Fukushima does not happen in the United States? As we discuss in some detail below, the U.S. Nuclear Regulatory Commission (NRC), which is responsible for ensuring nuclear power safety in this country, has identified steps to reduce the vulnerabilities of U.S. reactors. However, even the steps that are nominally fast-track will not be implemented for at least several years; the remaining steps will

take more than five years to carry out. And it is not yet clear how effective these measures will be. Effectiveness critically depends on the ground rules that govern the measures' implementation—and the NRC and the nuclear industry have yet to work these rules out in depth.

One especially large cloud hanging over the NRC's head is the Commission's failure to address the primary recommendation of its own task force, which was formed in the wake of Fukushima. This recommendation is that the agency clarify the regulatory framework for handling "beyond-design-basis" events—such as the extended loss of power that caused the widespread damage at Fukushima—which are more severe than those a reactor is traditionally designed to withstand. Currently, there are some NRC requirements that apply to some types of beyond-design-basis events, but not others. Because the majority of the other recommendations deal with beyond-design-basis threats, the regulatory framework first needs to be clarified to provide the proper foundation. But the NRC instead relegated that task to the end of the line.

A Sampling of Weather-Related Risks

Nature dealt a crippling blow to Fukushima Dai-ichi, but with local variation of specifics it could have been any reactor on Earth. In the past year and in the United States alone, reactors faced weather-related emergency conditions four times. While none of these events caused a disaster like that experienced at Fukushima, they all involved steps down the same path. In all cases, natural hazards either disabled or challenged the normal source of power. In many cases, the backup source of power was also impaired. These events exposed the very vulnerabilities that the task force recommendations seek to reduce:

- On April 16, 2011, a tornado damaged the electrical switchyard at the Surry nuclear plant in Virginia and caused the automatic shutdown of both reactors from near full power. The emergency diesel generators automatically started in response to the loss of power from the electrical grid, and they drove emergency equipment until the electrical grid was restored about 24 hours later.
- On April 27, 2011, a tornado damaged the electrical grid near the Browns Ferry nuclear plant in Alabama and caused the automatic shutdown of all three reactors from near full power. One of the emergency diesel generators for Unit 3 was out of service at the time for scheduled maintenance, but the remaining generators automatically started in response to failure of the electrical grid. However, the emergency diesel generator for the security system failed and the diesel-powered fire pump failed as well during the event. Also, the operators of Unit 1 did not notice that water in the reactor core was decreasing until it dropped low enough to automatically start a makeup system. Despite those complications, the overall system successfully cooled the reactor cores and spent fuel pools until normal power from the electrical grid was recovered five days later.
- On June 6, 2011, operators at the Fort Calhoun nuclear plant in Nebraska declared an “unusual event”—the least serious of the U.S. Nuclear Regulatory Commission’s four emergency classifications—as floodwaters rose around the site’s one reactor, which had been shut down for refueling since April. The operators upgraded the emergency classification to an “alert”—the second-least serious category—on June 7 because of a fire in a room filled with electrical power panels. The emergency condition was downgraded back to unusual event later that day after workers extinguished the fire and ascertained that its damage posed no safety threat. The flooding persisted for weeks, however. On June 26, workers accidentally damaged a temporary berm that had been erected around the plant’s main power transformers. As a precautionary measure, the operators switched to using the emergency diesel generators until July 11, when workers finished repairing the temporary berm and removing the water that had leaked through the damaged one. The plant’s operators returned it to normal status on August 29, 84 days after the unusual event had been declared, as flood waters dropped back below the hazard level. Fort Calhoun remained shut down through the end of 2011 to correct other safety problems unrelated to the flood.
- On August 23, 2011, an earthquake whose epicenter was about 11 miles from the North Anna nuclear plant in Virginia caused the automatic shutdown of both reactors from full power when the plant’s connection to the electrical grid was broken. In response, the emergency diesel generators automatically started. Workers manually shut down one of these generators 49 minutes later, because of an engine coolant leak, and they started an alternate emergency diesel generator to replace it. The connection to the electrical grid was reestablished about nine hours later. The magnitude of the earthquake exceeded the design-basis earthquake level and necessitated extensive inspections and testing to verify that the ground motion had not damaged safety equipment. The reactors restarted nearly three months after the event.

CHAPTER 2

THE ACCIDENT AT FUKUSHIMA DAI-ICHI

On March 11, 2011, only the Unit 1, 2, and 3 reactors at the Fukushima Dai-ichi nuclear plant were operating and the Unit 4, 5, and 6 reactors were shut down for refueling and maintenance. Once the earthquake hit, all three operating reactors automatically shut down within seconds. The earthquake caused the failure of the electrical grid, which normally provides power to the equipment used to cool the irradiated fuel in reactors and spent fuel pools. But onsite emergency diesel generators automatically started within seconds to supply electricity to safety equipment that cooled the reactor cores in the three operating reactors.

About 46 minutes after the earthquake, several tsunami waves, including one now estimated to have been at least 50 feet high, overwhelmed the site's protective sea wall. Seawater flooded the site, thereby disabling the emergency diesel generators, leaving the plant without its normal and backup sources of electrical power, and plunging it into a station blackout. The extensive damage to the electrical grid and emergency diesel generators meant that neither source would be restored within a short time.

The plant had banks of batteries to provide a backup to the diesel generators. (Although the direct-current [DC] power provided by batteries cannot fully replace the alternating current [AC] power provided by the generators, batteries can power a subset of emergency equipment capable of cooling the reactor cores.) These battery banks were designed with an eight-hour capacity on the assumption that either the electrical grid or the emergency diesel generators would be restored to service within that period. However, the flooding caused by the tsunami also caused damage to many electrical distribution panels, which meant that even DC battery power could not be delivered to certain critical systems for a period of time after the tsunami.

On Units 2 and 3, the batteries enabled operation of steam-driven pumps that provided makeup water to the reactor vessel housing the reactor core, which delayed the onset of core damage for nearly two days at Unit 3 and nearly three days at Unit 2.¹ However, no such system was available for Unit 1, and core damage began within a few hours after the tsunami.

¹ One unusual aspect of the accident is that the steam-driven pumps at Units 2 and 3, continued operating after the station batteries were exhausted and in fact “appear to have run for many hours under conditions that exceed established operating limits for the turbine-driven pumps.” (U.S. NRC, “State-of-the-Art Reactor Consequence Analyses Report, Draft Report for Comment,” NUREG-1935, January 2012, p. 95. Available at <http://www.nrc.gov/reading-rm/doc-collections/nuregs/staff/sr1935/>) The reason for this is not understood, which underscores how much is still unknown about the progression of the Fukushima accident.

Portable diesel-powered pumps and fire trucks were the sole remaining means of providing makeup cooling water to the reactor cores, but these small pumps could only inject water into the reactor vessel if the pressure inside the vessel were low enough. To lower that pressure required releasing some of the reactor vessel's water into the containment structure. However, the associated valves required electric power to open, and attempts to do so manually, using car batteries, were not always successful. In addition, steam within the containment had to be intentionally vented to make room for the steam and water discharged into it from the reactor vessel. But operators in the control room could not open the valves to the containment vents, owing to the station blackout, the loss of DC power, and other technical problems. Instead, workers had to enter hot and dark reactor buildings carrying batteries and air cylinders to manually open those valves. These conditions prevented timely successful venting.

Over the next few hours following the station blackout, the water level inside the Unit 1 reactor vessel slowly dropped as decay heat from the reactor fuel boiled the water away. Eventually, the water level dropped below the top of the reactor core. As the exposed metal surfaces of the fuel rods heated up, a chemical reaction produced large amounts of hydrogen gas. This hydrogen was released from the reactor vessel through valves to the containment, leaked out of the containment, and collected inside the Unit 1 reactor building; on March 12, the hydrogen ignited. The resulting explosion ruptured the reactor building, facilitating the release of contaminated steam and dispersal of radioactive debris.

Units 2 and 3 followed Unit 1's path when their batteries were depleted and their makeup pumps eventually stopped. Nearly two days after the Unit 1 explosion, Unit 3 followed suit. Unit 2 was the last one of the three to undergo a core melt. Although the reactor building was not destroyed, Unit 2 may have experienced a hydrogen explosion and, on March 14 its containment may have ruptured. The reactor building on Unit 4 also was destroyed by an explosion. At the time, it was believed that water in the spent fuel pool had dropped below the fuel and that the damaged fuel produced the hydrogen. However, it now appears the water level remained adequate for cooling and that some or all of the hydrogen entered the Unit 4 reactor building via a ventilation exhaust duct shared with Unit 3.

The loss of electrical power did disrupt the cooling of the spent fuel in the spent fuel pools. However, the destruction of the roofs and upper walls of the Unit 1, 3, and 4 reactor buildings created large openings that allowed helicopters, truck-mounted water cannons, and trucks ordinarily used to spray concrete to get water into these buildings' spent fuel pools. As water boiled away from the uncooled spent fuel pools, this crude method kept the fuel in the bottom of the pools covered to prevent further fuel damage. Because water was not recirculated to the pools but instead evaporated or drained away, the method has been referred to as "feed-and-bleed" cooling.

Although the reactor operators had emergency procedures to follow and indeed tried to implement them, these procedures simply were not thorough enough to enable plant personnel to take the actions necessary to prevent core damage under the site's extremely harsh circumstances, which included earthquake debris and numerous aftershocks. The interactions between multiple units also created conditions that operators had not anticipated; for instance, the explosion at Unit 1 disrupted Unit 2's emergency water injection and containment venting efforts.

A few days after the accident began, the U.S. NRC became concerned that the irradiated fuel in the Unit 4 spent fuel pool was no longer covered with water and would be damaged by overheating; the NRC's fear was based on photographs appearing to indicate that steam was no longer being released from the pool. By that time, the Unit 4 reactor building had been compromised by a hydrogen explosion, leaving no barrier against the release of radioactivity from damaged fuel in the spent fuel pool. Weeks later, however, reliable data strongly suggested that fuel in the Unit 4 spent fuel pool had not overheated to the point of burning and had not released large amounts of radioactivity.

Efforts also were underway to provide feed-and-bleed cooling of the damaged reactor cores. When venting finally permitted it, workers injected seawater into the reactor vessels using fire engines. The seawater absorbed the thermal energy emitted by the reactor core and boiled away through relief valves into the containment structure. Thus seawater cooled the reactor cores en route to slowly flooding the containments. A large fraction of this contaminated water flowed into the basements of the reactor turbine buildings, and some of it escaped into the sea before workers were able to plug the leaks.

Units 1 to 4 remained in a station blackout condition for about nine days before workers were able to restore AC power. In the ensuing weeks and months, workers also installed closed-loop cooling systems for the Unit 1, 2, and 3 reactor cores and all the spent fuel pools; injected nitrogen into the Unit 1, 2, and 3 containments for protection against further hydrogen explosions; built systems to treat the large amounts of radioactive water created during the accident; installed barriers to reduce leakage of radioactive water from the site; and installed a polyester cover around the damaged Unit 1 reactor building.

The core damage, containment leakage, and hydrogen explosions caused the release of a substantial amount of radioactive material into the environment, much of it to the atmosphere. While winds blew a large fraction of the material over the ocean, wind shifts and precipitation resulted in the contamination of a large region around the facility. In particular, a plume extending to the northwest of the site deposited significant amounts of iodine-131, cesium-134, and cesium-137 up to nearly 30 miles away. (The iodine-131, with an eight-day half-life, has now decayed away; but the cesium-137, with a half-life of 30 years, will persist for hundreds of years if not cleaned up.)

Japan established a mandatory evacuation region of about 400 square miles, including a “restricted area” within 12 miles (20 km) of the site and an additional region where potential radiation doses for residents were projected to exceed 20 millisieverts (2 rem) in the first year after the accident.² In addition, hundreds of square miles were contaminated to levels that would result in doses between 5 and 20 millisieverts in the first year. Although Japan has not yet finalized a plan for addressing this contamination, it is clear that many years of costly recovery and cleanup lay ahead.

² An annual dose of 20 millisieverts is the lowest threshold recommended by the International Commission on Radiological Protection (ICRP) for evacuation of the public following a radiological accident. The U.S. Environmental Protection Agency also uses this threshold for establishing an evacuation area in the first year after an accident, but the Agency reduces the threshold to 5 millisieverts per year thereafter. The use of a 20-millisievert threshold was controversial in Japan because it is as high as the ICRP’s annual recommended dose limit for occupational radiation exposure, and it is far higher than the 1-millisievert-per-year recommended dose limit for members of the public as a result of routine exposure to artificial radiation sources.

CHAPTER 3

THE NRC'S RESPONSE

The Fukushima Dai-ichi accident compelled the NRC to mount a significant response, which, at least initially, was commendable. The NRC expanded staffing levels for several weeks at its 24/7 Incident Response Center (IRC), which monitored conditions in Japan and issued status reports several times daily. The NRC's Public Affairs and Congressional Affairs staff answered a large number of inquiries from federal and state government officials, media representatives, and citizens. From our review of numerous emails between NRC staff (made available in response to FOIA requests), the staff responded to most inquiries in a timely manner—and with as much candid and complete information as was possible. However, until March 14, when Japan formally requested help from the U.S. government, the NRC itself was hampered by a lack of first-hand information about the accident.

Several years before the accident (in September 2006), the NRC permitted the Union of Concerned Scientists (UCS) inside its IRC to observe an emergency exercise, which included simulation of a handful of inquiries from elected officials and the media, conducted for the Farley nuclear plant. We came away concerned that this exercise did not adequately test whether the NRC's infrastructure could handle the volume of inquiries likely to be received during an actual emergency. But the NRC's response performance during the Fukushima crisis resolved our concern. From our review, it appears that the NRC staff handled a large influx of inquiries without compromising the timeliness or quality of the responses.

Based on the limited information available, on March 16 the NRC advised the U.S. government to recommend that American citizens in Japan evacuate out to 50 miles from the stricken plant. The NRC used a computer code called RASCAL to model the potential radiation exposures from the accident under two different scenarios. The first assumed that only Unit 2 melted down and had a total containment failure, resulting in an unfiltered release. The second scenario assumed that Units 2 and 3 experienced 33-percent core melts and that 100 percent of the spent fuel in the Unit 4 pool melted down. In both cases, the NRC found that the U.S. Environmental Protection Agency dose threshold for immediate evacuation—1 rem over four days—would be exceeded at 50 miles from the release site. (The threshold would likely have been exceeded even farther away, but the RASCAL code can only calculate out to 50 miles.)

While hindsight revealed that the actual atmospheric releases were far smaller than what the NRC assumed, it made the right call at the time. The Japanese government ultimately implemented protective actions in some areas as far as 25 miles from Fukushima—far beyond its 12-mile evacuation order. Given the limited

and uncertain information available as the accident was unfolding, the U.S. government's recommendation was reasonable and prudent.

Back home, however, many observers, including the UCS, noted that the NRC's 50-mile evacuation recommendation in Japan did not appear to be consistent with its domestic requirements for 10-mile evacuation zones; the recommendation in fact revealed that the NRC understood that severe accidents at nuclear plants could pose serious public health risks well beyond 10 miles. The NRC disputed that there was an inconsistency, responding that "these [emergency planning] zones are not limits but rather provide for a comprehensive emergency planning framework that would allow expansion of the response efforts beyond the zones should radiological conditions warrant such expansion."³

The NRC has not adequately explained, however, why it is confident that large numbers of people could be rapidly evacuated after a major accident at any U.S. nuclear plant—especially from regions beyond the 10-mile zone, where there is currently no evacuation planning. This situation is of particular concern for reactors in densely populated areas, such as the Indian Point plant about 25 miles from New York City.

In the wake of Fukushima, the NRC did not require any immediate changes to its domestic safety policies, whether on emergency planning or in any other respect. In fact, for weeks after the accident the NRC defended the safety of U.S. nuclear plants by arguing that in contrast to Japanese plants, U.S. plants had measures in place that would have enabled them to withstand a Fukushima-scale accident. These measures included (1) procedures to "cope" with a station blackout for a certain time period, (2) equipment known as "B.5.b." that was required by NRC after the 9/11 attacks to provide the capability to mitigate damage due to fires and explosions caused by a deliberate aircraft impact, and (3) plans that were voluntarily developed by utilities known as "severe-accident management guidelines" (SAMGs).

The adequacy of the station blackout mitigation procedures, B.5.b equipment, and SAMGs in the face of a Fukushima-like accident was called into question after the NRC conducted two series of inspections at every nuclear power plant in the United States.

The first series examined each plant's readiness and capability to cope with station blackouts and severe natural disasters (e.g., a tsunami, flood, tornado, or hurricane) and still assure cooling of the reactor cores and spent fuel pools. These inspections determined that existing capabilities might be insufficient. For example, some of the B.5.b equipment, such as portable diesel-driven pumps and generators, was

³ Nuclear Regulatory Commission (NRC). 2012. *Expanded NRC questions and answers related to the March 11, 2011, Japanese earthquake and tsunami (February 15, 2012)*. ML120040283. Washington, DC. Online at <http://pbadupws.nrc.gov/docs/ML1200/ML120040283.pdf>.

housed within buildings vulnerable to tornadoes and earthquakes and thus might not be available in the event of an accident caused by severe acts of nature. In addition, the inventory of portable pumps and generators was in many cases insufficient to handle the needs of multiple reactors at a given site. In fact, this discovery shouldn't have been a surprise: the B.5.b. equipment was not intended for use after natural disasters such as earthquakes and floods, and hence the NRC did not require the equipment to be protected against such events. Similarly, the NRC's station blackout regulations did not require that plant owners assume multiple reactors would be affected or that the blackout would occur concurrently with another event, such as an earthquake.

The second series of inspections investigated the SAMGs—emergency procedures and associated operator training that would guide the response to a severe accident, such as the one at Fukushima, after core damage began. These inspections revealed that the emergency response procedures to be used by operators at U.S. reactors are often out of date⁴ and that the operators are seldom, if ever, trained on them. At some sites, these procedures were not even readily available to the operators in the control room. Again, this shouldn't have been a surprise. SAMGs are voluntary initiatives and as such do not have to meet any regulatory standards.

NRC Near Term Task Force

On April 1, 2011, the NRC announced the formation of a six-member Near Term Task Force (NTTF), which was given 90 days to examine the Fukushima Dai-ichi accident and recommend measures to reduce vulnerabilities at U.S. reactors. The task force's report, released on July 12,⁵ contained 12 overarching recommendations, most of which included several sub-recommendations. (See Table 1.)

The task force outlined an implementation strategy patterned after the one employed by the NRC after 9/11 regarding security upgrades. The NRC would issue orders to plant owners for safety upgrades in the short term, and this would be followed by rulemaking both to codify the ordered upgrades as well as to implement longer-term upgrades.⁶

⁴ For example, the NRC found that the emergency procedures for controlling hydrogen generated during an accident at the Watts Bar nuclear plant in Tennessee directed operators to use equipment that had been physically removed years earlier.

⁵ Nuclear Regulatory Commission (NRC). 2011. *Recommendations for enhancing reactor safety in the 21st century: The Near-Term Task Force Review of insights from the Fukushima Dai-ichi accident*. Washington, DC: NRC. Online at <http://pbadupws.nrc.gov/docs/ML1118/ML111861807.pdf>.

⁶ The NRC can impose safety requirements through rulemaking or orders. Rulemaking requires the NRC to solicit and review comments from the public as well as from other stakeholders, such as the industry. Orders provide the faster method because the time required to solicit and review public comments on proposed rules is not required. However, for regulatory changes that affect all nuclear plants, the NRC cannot simply issue orders as a substitute for rulemaking procedures that are required by law.

The 12 recommendations are:

1. The NRC should clarify regulatory requirements governing “beyond-design-basis” or severe accidents such as the one that occurred at Fukushima.
2. The NRC should require plant owners to periodically reevaluate the seismic and flooding risks to reactors and upgrade protection as necessary.
3. The NRC should assess ways to prevent, and improve protection against, seismically induced fires and floods, and it should require that plant owners implement such steps.
4. The NRC should require plant owners to better cope with a sustained loss of normal and backup (e.g., emergency diesel generator) power supplies.
5. The NRC should require plant owners to install reliable hardened containment vents at boiling water reactor facilities with Mark I and Mark II containments.
6. The NRC should identify ways to prevent hydrogen explosions in the containment or other buildings during an accident.
7. The NRC should require plant owners to upgrade methods for adding water to a spent fuel pool during an accident and to install instruments to monitor the temperature and level of the water in the spent fuel pool.
8. The NRC should require reactor owners to integrate the procedures used in the event of “beyond-design-basis” accidents and terrorist aircraft attacks with those used during design-basis accidents and transients, and to include all such plans in its regulatory framework.
9. The NRC should require reactor owners to modify emergency plans, including methods for radiation dose assessment and onsite and offsite communications, to cope with the sustained loss of normal and backup (e.g., emergency diesel generator) power supplies and accidents involving multiple reactors at the same nuclear plant.
10. The NRC should pursue additional topics related to events involving sustained loss of normal and backup (e.g., emergency diesel generator) power supplies and accidents involving multiple reactors at the same nuclear plant. These topics include, for example, protective gear for response workers, further improvements to communication and notification systems, and cyberlinks.
11. The NRC should pursue additional emergency response issues such as (a) delivering equipment to a nuclear plant site following severe acts of nature

involving offsite infrastructure impediments (e.g., failed bridges, blocked roadways) or (b) competing priorities for emergency response resources.

12. To complement Recommendation No. 1, the NRC should integrate oversight of “beyond-design-basis” requirements into its routine reactor oversight processes.

Of these recommendations, the task force considered its first one to be the most important one because it provided the necessary foundation for the 11 others.

On August 19, 2011, the Commission directed its staff to review the task force report, and to provide it with three papers that would form the basis of Commission decisions.⁷ The first paper, due within 21 days and delivered on September 9, identified those recommendations that could be implemented in whole or in part in the short term. The second paper, due within 45 days and delivered on October 3, prioritized the recommendations and identified all the required regulatory actions along with their associated challenges. The third, due within 18 months, is supposed to outline how to move forward on the task force’s first recommendation. Thus the Commission relegated the task force’s prime recommendation to the end of the line.

The NRC staff formed a steering committee to direct the agency’s longer-term review and its application of lessons learned from Fukushima.⁸ Also created was a Japan Lessons Learned Project Directorate within the NRC’s Office of Nuclear Reactor Regulation to manage the implementation of safety upgrades linked to Fukushima. The steering committee functions at a strategic level while this project directorate operates on a tactical level.

In the paper submitted to the Commission on October 3 (frequently termed the “45-day paper”), the NRC staff also informed the Commission about six potential recommendations arising from its meetings with external stakeholders that warranted consideration. These recommendations were:

1. *Filtration of containment vents.* The task force had recommended providing reliable hardened vents for boiling water reactors with Mark I and Mark II containments. Based on existing measures at foreign reactors, stakeholders recommended that the containment vents also be equipped with filters that

⁷ Commission papers are used by the NRC to establish policies and allocate resources. The NRC staff submits a paper that frames an issue and frequently describes several options for addressing it. The Commission votes on the issue, with a simple majority determining the direction to be subsequently provided to the staff.

⁸ The NRC-staffed steering committee, chaired by the Deputy Executive Director for Reactor and Preparedness Programs, includes the directors of the Offices of Nuclear Reactor Regulation, Nuclear Security and Incident Response, New Reactors, Research, and Nuclear Material Safety and Safeguards; the Regional Administrators for Regions II and IV; and the Deputy Director of the Office of Federal and State Materials and Environmental Management Programs. The steering committee is supported by an advisory committee of representatives from the Offices of General Counsel, Public Affairs, Congressional Affairs, and International Programs.

would reduce the amount of radioactivity released to the atmosphere during a reactor accident.

2. *Instrumentation for seismic monitoring.* Because the August 2011 earthquake at the North Anna nuclear plant in Virginia revealed insufficient seismic information collection at U.S. nuclear plants, the NRC staff recommended that seismic monitoring instrumentation be upgraded.
3. *Basis of emergency planning zone size.* The current “inhalation” emergency planning zone, which is the area where planning for evacuation of residents and distribution of potassium iodide (KI) is required, is a roughly circular region with a 10-mile radius around each nuclear power plant. But based on projected radiation dose estimates at Fukushima, the U.S. government recommended as a safety precaution that residents within 50 miles of an American plant evacuate the region for several months after the accident. Stakeholders noted the apparent inconsistency and recommended that the emergency planning zone around reactors be expanded in accordance with site-specific parameters.
4. *Pre-staging of potassium iodide beyond 10 miles.* To complement item 3 above, stakeholders recommended that KI be available for persons living beyond 10 miles from nuclear plants.
5. *Transfer of spent fuel to dry storage.* Although the spent fuel in the pools at Fukushima Dai-ichi apparently survived the accident without damage, U.S. nuclear plants might not have been as fortunate. U.S. plants typically contain several times as much spent fuel as the one at Fukushima Dai-ichi Unit 4, and stored in a densely packed configuration that would be harder to cool in the event of a rapid loss of pool water. Stakeholders recommended that the spent fuel pool hazard be decreased by accelerating the transfer of irradiated fuel to dry storage, thereby reducing the density of the fuel remaining in the pools.
6. *Loss of ultimate heat sink.* In addition to disabling the emergency diesel generators, the tsunami disabled Fukushima’s “ultimate heat sink”—the systems, such as seawater pumps and motors, used to remove heat from the reactor coolant system and to cool emergency systems throughout the plant following an accident. As a result, the only means of removing heat was through the venting of steam from the containments. In addition, other equipment needed to be kept cool in order to function. For example, the emergency diesel generators, had they survived the tsunami, would have needed cooling water from the ultimate heat sink to avoid being disabled by overheating.

The Commission approved the staff’s recommendations for the prioritization and implementation of the last 11 Task Force recommendations on December 15, with minor adjustments. (See Table 1 for the prioritization of all the recommendations and sub-recommendations.) It placed all but the first recommendation into three

categories: Tier 1 recommendations, whose implementation will be initiated by orders to plant owners in March 2012 and completed roughly five years later; Tier 2 recommendations, whose implementation will be initiated by final rules issued in March 2016 and completed several years later; and Tier 3 recommendations, whose implementation has not yet been scheduled (but will likely occur after the Tier 2 completion target).⁹ The Commission directed the staff to provide a paper within nine months (by September 2012) for the schedule and plan for addressing the Tier 3 recommendations.

The NRC staff has made further suggestions regarding the above six issues. In particular it now proposes that only items 1, 2, and 6 be addressed in the near-term and that items 3, 4, and 5—emergency planning zone size, expansion of KI distribution, and accelerated transfer of spent fuel to dry casks—be relegated to Tier 3. Moreover, the staff has “determined that the current regulatory approaches to these issues are acceptable” and will “review new information that becomes available as a result of specific ongoing activities to confirm this conclusion and gain additional insights.”

⁹ The NRC staff expects it will take at least two years from March 11, 2012, for the implementation of the Tier 1 upgrades and has not even defined the timelines for the Tier 2 upgrades.

CHAPTER 4

UCS PERSPECTIVES ON THE TASK FORCE AND ITS RECOMMENDATIONS

The task force conducted an in-house evaluation. It held no public meetings and provided no opportunities for external stakeholders to share their insights regarding the problems revealed by the Fukushima accident and possible solutions. While UCS would have preferred to exchange information and perspectives with the task force before its report was finalized, we accept that expediency necessitated this atypical NRC process.

After the report was released, the NRC Commission and its staff conducted many public meetings regarding the Fukushima lessons learned. While Commission meetings are typically webcast and transcribed, NRC staff meetings are not. But several of the NRC staff meetings on this subject were webcast and transcribed, broadening the audience who could participate. UCS appreciates these arrangements. UCS was also invited to participate in two Commission briefings to provide our views on the task force recommendations.

These public meetings provided opportunities for input rather than merely being window dressing. This was evidenced by the fact that the NRC staff's 45-day paper identified six additional potential recommendations put forth by external stakeholders, including UCS, during these meetings. Even though the task force report has now been issued, the door remains open for additional insights.

We believe that the NRC decision to form a Fukushima steering committee and project directorate was a sound one; it should allow the NRC to efficiently and effectively pursue implementation of the Fukushima-inspired safety upgrades without having these efforts interfere with other agency tasks. The NRC successfully applied this approach with the formation of the Office of Nuclear Security and Incident Response after 9/11 and with the formation of the Office of New Reactors to handle requests for new reactor licenses. Applying dedicated resources to the oversight and implementation of Fukushima safety upgrades should facilitate them without detracting from other ongoing work.

Nevertheless, in the three subsections below, the UCS offers its perspectives on one recommendation and three sub-recommendations in particular. Our hope is that this analysis will be seriously considered by the NRC and used to enlighten the Commission's decision making on the rest of the task force's 12 recommendations and numerous sub-recommendations.

NTTF Recommendation 1

Unfortunately, the Commission put a major obstacle in the path to successful implementation of the Near Term Task Force (NTTF) recommendations when it relocated Recommendation 1 to the end of the process.

The NTTF report provided ample background and justification for Recommendation 1, including:

The Commission has come to rely on design-basis requirements and a patchwork of beyond-design-basis requirements and voluntary initiatives for maintaining safety. Design-basis requirements include consideration of anticipated operational occurrences and postulated accidents such as loss-of-coolant accidents. Beyond-design-basis considerations such as ATWS [anticipated transients without scram]¹⁰ and SBO [station blackout] are discussed below. Voluntary initiatives have addressed some severe accident considerations (through the IPE [individual plant examination] and IPEEE [individual plant examination of external events] programs), shutdown risk issues, containment vents for BWR Mark I designs, and SAMGs [severe accident management guidelines].

During a public meeting on July 28, 2011, Gary Holahan, one of the six task force members, explained how this recommendation moved to the top spot:

Might be worth mentioning that originally, this recommendation ... was in the section of the report on NRC programs, so in fact it ... was near the back of the report. I think, throughout our deliberations, it became more and more clear that the framework issue was influencing how we were thinking about the other issues. And it presented the others in a more coherent light and a more consistent manner. [So it made sense] to bring that recommendation up front, to lay it out, because it not only constitutes a recommendation for how the agency could go forward and deal with severe accidents and beyond-design-basis events but it also helps clarify the other issues— prevention, mitigation, and the emergency preparedness—[and] how they follow on in the report.

However, the NTTF may have doomed Recommendation 1 by its very wording: *The Task Force recommends establishing a logical, systematic, and coherent regulatory framework for adequate protection that appropriately balances defense-in-depth and risk considerations.*¹¹ This wording could be construed to mean that the existing framework is illogical, unsystematic, incoherent, and does not provide

¹⁰ATWS refers to deteriorating conditions in the plant that should trigger the automatic shut down (scram) of the reactor but fail to do so.

¹¹ The NRC's regulations employ a defense-in-depth approach to nuclear safety, embodied in measures such as fully redundant emergency systems for reactor core cooling, containment systems that limit the amount of radioactivity released to the environment, and emergency planning to protect the public in event of an accident. Risk is taken into account in the robustness and reliability of defense-in-depth barriers—but not all barriers are equal. Risk factors seek to allocate resources commensurate with the importance of the individual barriers.

adequate protection of public safety. The language in the full report put this recommendation in proper context and refuted the notion that NRC's efforts to date have been illogical and incoherent. But the implications of this wording produced a negative reaction by NRC's senior managers—it appeared to suggest that they had made poor decisions in the past. Had the task force worded the recommendation differently, it would likely have been better accepted. For example, it could have been written along the lines of “The Task Force recommends incorporating beyond-design-basis requirements more clearly into the existing regulatory framework to appropriately broaden a defense-in-depth philosophy.”

A more fundamental problem with Recommendation 1 stems from differences in the NRC's traditional handling of design-basis events and beyond-design-basis events—differences that the recommendation aims to address.

The NRC requires that nuclear plants be capable of experiencing design-basis events without extensive damage to irradiated fuel and without large radiological releases. Such events include the postulated rupture of the largest-diameter pipe connected to the reactor vessel, coincident with the worst single failure. Often, the single failure assumes that one of the emergency diesel generators—and all of the safety equipment it powers—are unavailable. This scenario results in the fastest loss of cooling water inventory from the reactor vessel, coupled with the slowest makeup capability. If safety studies indicate that the reactor core can be successfully cooled in this situation, the NRC assumes that lesser challenges can also be handled successfully.

The NRC imposes strict requirements on the so-called “safety-related” structures, systems, components, controls, and procedures that must remain functional during and after design-basis accidents. Safety-related equipment must meet the regulatory quality assurance standards specified in 10 CFR Part 50 Appendix B with regard to design, fabrication, construction and, testing, and it must be qualified to function after design-basis earthquakes and other natural events. Such equipment can only be purchased by specialized vendors and is generally far more expensive than commercial-grade off-the-shelf equipment. Safety-related procedures must be approved by the NRC, and if violations are found the procedures are subject to later inspection and enforcement.

The NRC also limits how long nuclear plants can operate outside the bounds of its safety studies. For example, if one of the emergency diesel generators were taken out of service for repairs, the problem would have to be fixed within a short time; otherwise, shutdown of the reactor would be required. The out-of-service emergency diesel generator decreases the likelihood that the plant's response to a ruptured pipe would be successful, as one of the in-service emergency diesel generators could also fail during such an event.

Beyond-design-basis events feature greater challenges, such as multiple unrelated failures of emergency systems. The NRC desires, rather than requires, that nuclear

plants be able to experience beyond-design-basis events successfully. For example, in 1988 the NRC required that plant owners evaluate their facilities for vulnerabilities to beyond-design-basis events, but it did not require upgrades to address any of the vulnerabilities they found. Some plant owners implemented measures to upgrade protection against some of the identified vulnerabilities, whereas other plant owners implemented no upgrades at all. To this day, NRC inspectors cannot cite an owner for a violation if they find that a voluntary safety upgrade is ineffective or has been removed.

Over time, the NRC has imposed requirements to address certain beyond-design-basis accident issues. For instance, station blackout events are considered beyond-design-basis accidents under the regulations, but the NRC came to realize that SBOs were a significant threat that could not be controlled through voluntary measures alone. As a result, the NRC required that licensees develop measures to “cope” with SBOs for a limited period of time. However, because SBOs are still considered beyond-design-basis, the equipment installed to cope with them is not considered “safety-related” and does not have to meet Appendix B quality assurance standards. Similarly, the NRC required owners of boiling water reactors to provide the means for venting the containment during a severe accident. But whereas the containment venting system for design-basis accidents has to provide this function even when impaired by the worst-case single failure, the containment venting system for beyond-design-basis accidents need not have such redundancy and reliability.

NNTF Recommendation 1 sought to better define the NRC’s expectations regarding beyond-design-basis events. The recommendation did not go so far as to suggest that all events be treated as design-basis events, and therefore subject to comparably stringent regulation. Instead, the recommendation sought to clarify the NRC’s expectations and requirements regarding beyond-design-basis events so as to promote consistency of protection across the fleet of U.S. reactors.

Whatever its motivation, the Commission directed its staff to relegate Recommendation 1 to the end of the line and proceed first with the remaining 11 recommendations, most of which address measures for better protection during beyond-design-basis events. As the task force chronicled at some length in its report, past efforts on beyond-design-basis issues have resulted in inconsistent implementation across the reactor fleet. To help remedy that situation, Recommendation 1 sought to establish a cleaner linkage between design-basis events and beyond-design-basis events in the NRC’s regulatory programs so as to provide the proper foundation for implementing the other recommendations. But absent that foundation, the implementation of the 11 task force recommendations will likely only add more patches to the existing patchwork and widen the safety-level gap between the reactors.

NTTF Recommendations 4.1 and 4.2 and the Nuclear Industry’s “Diverse and Flexible Coping Capability” (FLEX) Approach

In December 2011, the Nuclear Energy Institute (NEI), on behalf of the U.S. nuclear industry, proposed to the NRC its framework for implementing the Fukushima lessons learned, which it called the “Diverse and Flexible Coping Capability,” or “FLEX,” approach. FLEX is rooted in the observation that the fundamental cause of Fukushima was an extended station blackout (SBO) and loss of ultimate heat sink, and that expanding prevention of core and spent fuel damage and assuring containment function during a prolonged station blackout, regardless of the cause, should be the focus of post-Fukushima reforms.

Toward that end, the NEI has proposed that plant owners purchase additional portable equipment, such as diesel-driven pumps and portable generators, to provide diverse and flexible means of providing water and backup power for all reactors at a site. This equipment would be “reasonably” protected against natural phenomena. FLEX would also include the creation of off-site response centers that house additional emergency equipment and supplies. The idea is that if there is enough equipment stored in enough places, both onsite and offsite, there is a good chance that at least some of the equipment would survive most potential beyond-design-basis scenarios and be available for use. For example, equipment would be stored both underground (to protect it from seismic damage) and at high elevations (to protect it from flooding). Some have referred to this approach as “B.5.b. on steroids.” The NEI argues, in fact, that if FLEX were implemented it would automatically reduce the need for most of the other NTTF recommendations.

At first glance this sounds like a reasonable approach, but its effectiveness would crucially depend on the implementing details. The NEI’s operating assumption behind FLEX is that the current “design basis” is the right one—that is, there is no need to expand the design basis to encompass more severe events such as larger earthquakes or higher flood levels. This means that the events FLEX would be designed to address—namely, extended SBOs and loss of ultimate heat sink—would remain in the beyond-design-basis category. As a result, FLEX equipment would not have to be “safety-related” and thus would not need to meet nuclear-grade quality assurance standards. Similarly, the procedures and training associated with the equipment would not have to meet the highest standards for NRC approval and oversight.

In the absence of a clear regulatory basis for FLEX, the notion of “reasonable protection” of equipment is undefined. But the industry has expressed its view that it would prefer to have lots of commercial-grade equipment scattered about rather than have fewer pieces of equipment that meet nuclear-grade standards, and that this approach obviates the need for hardening of equipment against natural disasters. As Chip Pardee of Exelon Nuclear put it in a December 2011 public

meeting,” It’s cheaper to buy three [pumps] than one and a heckuva big building [to put it in].”

However, the NRC has not yet decided whether the design basis should be expanded—this is what Recommendation 1 is designed to address—so the FLEX approach currently consists of the industry trying to “wag the dog” by moving forward before the NRC has taken the time to develop its own approach. The NEI has said that many licensees are already buying FLEX equipment; such “facts on the ground” could make it politically difficult for the NRC to impose higher standards, which this equipment might fail to meet. An NRC official explained to UCS that the FLEX equipment need not be safety-related at this point, but if the Commission decides to later expand the design basis, the equipment would have to be upgraded. This is a problematic strategy, as the industry could run to Congress and complain that the NRC was imposing standards that would render useless all the equipment it had just bought. The NRC needs to tell the industry in no uncertain terms that it is purchasing FLEX equipment at its own risk.

France is going in a different direction in developing its own post-Fukushima safety upgrades. In December 2011, the French Nuclear Safety Authority (ASN) released its review of the “stress tests” conducted on French nuclear plants and its approach for upgrading safety. The ASN is requiring French plants to implement a so-called “hard core” consisting of a diesel generator and backup water supply “capable of withstanding large-scale onsite and external hazards exceeding the baseline safety requirements, and of coping with total loss of electrical power supplies or cooling means, in order to prevent core meltdown in these situations.”¹² In other words, the “hard core” safety equipment would be hardened to be able to withstand events beyond the plant’s design basis. This might make more sense than the current FLEX approach, which would involve multiple pieces of equipment not intended to individually survive even design-basis events, much less beyond-design-basis events.

The FLEX approach, which is focused on the *prevention* of core or spent fuel damage, also fails to anticipate the possible need for additional measures to be used following a loss-of-coolant event. In discussions with the NRC staff about this framework, industry representatives described plans to install multiple connection points for backup water makeup and power sources. Those connection points could be within containment buildings in areas that quickly become off-limits, as a result of lethal radiation levels, should fuel damage occur. FLEX should be designed to be able to cope with situations both before and after core damage occurs.

Again, the French approach appears to be superior, in that intrinsic to the “hard core” are the objectives both of preventing severe accidents and of limiting their progression should they occur.

¹² Autorité de Sûreté Nucléaire (ASN). 2011. *Complementary safety assessments of the French nuclear power plants*. Online at en.calameo.com/read/000219164dcf195ce2633.

The UCS twice advised the Commission during briefings that the development of NRC’s post-9/11 B.5.b requirements did not set a good example for the development of post-Fukushima requirements. As revealed by an NRC report and documented in a post on the UCS’s *allthingsnuclear* blog,¹³ in developing the B.5.b measures the industry repeatedly emphasized that the spectrum of potential “damage states” occurring after an aircraft attack was so broad that there was no point in trying to be too specific about how any one scenario could be mitigated. As a result, the measures developed by the industry, and eventually approved by the NRC, were too general and did not address important issues such as whether they could be realistically implemented in high-radiation environments. Part of the problem was that the NRC decreed that aircraft attacks were beyond-design-basis events, and therefore that B.5.b. measures did not have to meet safety-related criteria. The UCS argued that post-Fukushima mitigation measures should be developed by defining a range of specific and realistic accident scenarios and by ensuring that there was a credible success path for each one. Licensees cannot protect against every possible event, but they should at least be able to show they can effectively protect against a range of different events.

Unfortunately, the Commission did not accept the UCS recommendation, and it specifically endorsed the B.5.b approach as a model for post-Fukushima modifications.¹⁴ Subsequently, the NEI’s Tony Pietrangelo said that the Commission’s statement amounted to a codification of the FLEX approach. As a result, the industry is continuing to advise against assessing the performance of FLEX against specific hazards. Thus it remains unclear whether FLEX as currently conceived will be any more effective in protecting against Fukushima-scale accidents than is B.5.b in protecting against aircraft attacks. It is encouraging, however, that the staff has recommended to the Commission that full compliance with the 4.2 order should include the development of detailed procedures, which the B.5.b order did not require.

The NRC should consider an approach that combines the virtues both of FLEX and the French “hard core.”

NTTF Recommendation 7.4

In this recommendation, the task force advises that particular B.5.b measures—those required by the NRC as emergency means to spray makeup water into spent fuel pools—be upgraded so that they could survive seismic events. If spent fuel pool cooling were lost for extended periods, or something caused water to suddenly drain from a spent fuel pool, water sprayed into the pool could protect its irradiated fuel from overheating and thus from incurring damage.

¹³ Union of Concerned Scientists (UCS). 2011. *NRC document details the secret history of nuclear industry stonewalling after 9/11*. September 9. Cambridge, MA. Online at allthingsnuclear.org/post/10004506819/nrc-document-details-the-secret-history-of-nuclear.

¹⁴ Nuclear Regulatory Commission (NRC). 2011. *Recommended actions to be taken without delay from the Near-Term Task Force report*, SRM-SECY-11-0124. Washington, DC: NRC. October 18.

The measures were specifically intended to address the situation following an aircraft attack—they were not designed for the aftermath of other types of events, such as earthquakes—and for security reasons they were developed in secret without public input. Nevertheless, the renewed (post-Fukushima) attention to the issue of spent fuel pool makeup provides a good opportunity for reviewing the B.5.b strategy, whether in response to aircraft attacks or to any other event.

In boiling water reactors with Mark I and Mark II containment designs, such protection could come at an excessively high price. At these facilities, the spent fuel pool is located within the reactor building, and all the emergency pumps that protect the reactor core from overheating are located in this building's basement. Water evaporating from a boiling spent fuel pool would, after condensing, drain to that basement. In addition, if the rate at which water was sprayed into a spent fuel pool exceeded the rate at which water was draining from it, the pool would overflow and drain to the basement as well. Such an artificial tsunami could wreak as much havoc as did the natural tsunami at Fukushima by submerging and thus disabling vital emergency equipment. In other words, the operators could be forced to choose between two evils: (1) turn on the water sprays to save the spent fuel, but risk losing the reactor core; or (2) save the reactor core by not turning on the water sprays, but risk losing the spent fuel. The operators have to be provided with better options than picking which irradiated fuel to sacrifice.

CHAPTER 5

CONCLUSIONS

As we observe the first anniversary of Fukushima, UCS notes that none of the lessons that the NRC extracted from the tragedy have been implemented at U.S. reactors. To date, the NRC has only outlined three pathways for getting to the necessary safety upgrades, and it has actually added bumps to those pathways by failing to heed its own task force's prime recommendation.

Failing to integrate regulatory processes for design-basis events with those for beyond-design-basis events will likely result in new safety measures being inconsistently applied across the fleet of U.S. reactors—the very situation that the task force sought to avoid. Thus while at some point down this bumpy road Americans living near certain plants might become better protected, people living near other plants might be less well protected or, possibly, not protected at all.

Because the NRC's job is to ensure the safety of *all* Americans, such discrepancies point to a major lapse of duty. They also expose a great many people to a great deal of unnecessary risk.

Table 1. Recommendations of the Near Term Task Force (NTTF)¹⁵

Source	Recommendation
	<i>NRC Tier 1 issues:</i> Orders expected to be issued in March 2012; implementation expected to take at least two years.
NTTF 2.1	Order licensees to reevaluate the seismic and flooding hazards at their sites against current NRC requirements and guidance, and, if necessary, update the design-basis and SSCs [structures, systems, and components] important to safety to protect against the updated hazards.
NTTF 2.3	Order licensees to perform seismic and flood protection walk-downs to identify and address plant-specific vulnerabilities and to verify the adequacy of monitoring and maintenance for protection features, such as watertight barriers and seals, in the interim period until longer term actions are completed to update the design basis for external events.
NTTF 4.1	Initiate rulemaking to revise 10 CFR 50.63 to require each operating and new reactor licensee to (1) establish a minimum coping time of eight hours for a loss of all AC [alternating current] power, (2) establish the equipment, procedures, and training necessary to implement an “extended loss of all AC” coping time of 72 hours for core and spent fuel pool cooling and for reactor coolant system and primary containment integrity as needed, and (3) preplan and pre-stage offsite resources to support uninterrupted core and spent fuel pool cooling, and reactor coolant system and containment integrity as needed, including the ability to deliver the equipment to the site in the time period allowed for extended coping, under conditions involving significant degradation of offsite transportation infrastructure associated with significant natural disasters.
NTTF 4.2	Order licensees to provide reasonable protection for equipment currently provided pursuant to 10 CFR 50.54(hh)(2) from the effects of design-basis external events and to add equipment as needed to address multiunit events while other requirements are being revised and implemented.
NTTF 5.1	Order licensees to include a reliable hardened vent in BWR Mark I and Mark II containments.
NTTF 7.1	Order licensees to provide sufficient safety-related instrumentation, able to withstand design-basis natural phenomena, to monitor key spent fuel pool parameters (e.g., water level, temperature, and area radiation levels) from the control room.
NTTF 8.1	Order licensees to modify the EOP [emergency operating procedure] technical guidelines—required by Supplement 1, “Requirements for Emergency Response Capability,” to NUREG-0737, issued January 1983 (GL 82-33)—in order to (1) include EOPs, SAMGs [severe accident management guidelines], and EDMGs [extreme damage mitigation guidelines] in an integrated manner, (2) specify clear command and control strategies for their implementation, and (3) stipulate appropriate qualification and training for those who make decisions during emergencies.
NTTF 8.2	Modify Section 5.0, “Administrative Controls,” of the Standard Technical

¹⁵ Source: Nuclear Regulatory Commission (NRC). 2011. *Recommendations for enhancing reactor safety in the 21st century: The Near-Term Task Force Review of insights from the Fukushima Dai-ichi accident*. Washington, DC: NRC. Online at <http://pbadupws.nrc.gov/docs/ML1118/ML111861807.pdf>.

	Specifications for each operating reactor design to reference the approved EOP technical guidelines for that plant design.
NTTF 8.3	Order licensees to modify each plant's technical specifications to conform to the above changes.
NTTF 8.4	Initiate rulemaking to require more realistic, hands-on training and exercises on SAMGs and EDMGs for all staff expected to implement the strategies and those licensee staff expected to make decisions during emergencies, including emergency coordinators and emergency directors.
NTTF 9.3	Order licensees to do the following until rulemaking is complete: Determine and implement the required staff to fill all necessary positions for responding to a multiunit event.
NTTF 9.4	Order licensees to complete the ERDS [emergency response data system] modernization initiative by June 2012 to ensure multiunit site monitoring capability.
<i>NRC Tier 2 issues:</i> The NRC staff will develop and issue a final rule addressing these recommendations by mid-March 2016—five years after Fukushima. Implementation is expected to take several years more.	
NTTF 7.2	Order licensees to provide safety-related AC electrical power for the spent fuel pool makeup system.
NTTF 7.3	Order licensees to revise their technical specifications to address requirements to have one train of onsite emergency electrical power operable for spent fuel pool makeup and spent fuel pool instrumentation when there is irradiated fuel in the spent fuel pool, regardless of the operational mode of the reactor.
NTTF 7.4	Order licensees to have an installed seismically qualified means to spray water into the spent fuel pools, including an easily accessible connection to supply the water (e.g., using a portable pump or pumper truck) at grade outside the building.
NTTF 7.5	Initiate rulemaking, licensing activities, or both to require the actions related to the spent fuel pools described in detailed recommendations 7.1 to 7.4.
<i>NRC Tier 3 Issues:</i> The NRC staff will provide the Commission with a paper by September 2012 that makes recommendations about how to proceed with the following issues:	
NTTF 2.2	Initiate rulemaking to require licensees to confirm seismic hazards and flooding hazards every 10 years and address any new and significant information. If necessary, update the design basis for SSCs important to safety in order to protect against the updated hazards.
NTTF 3	Evaluate potential enhancements to the capability to prevent or mitigate seismically induced fires and floods.
NTTF 5.2	Reevaluate the need for hardened vents for other containment designs [besides Mark I and Mark II], considering the insights from the Fukushima accident. Depending on the outcome of the reevaluation, appropriate regulatory action should be taken for any containment designs requiring hardened vents.
NTTF 6	Identify insights about hydrogen control and mitigation inside containments, or in other buildings, as additional information is revealed through further study of the Fukushima Dai-ichi accident.
NTTF 9.1	Initiate rulemaking to require EP [emergency preparedness] enhancements for multiunit events in the following areas: <ul style="list-style-type: none"> • Personnel and staffing • Dose-assessment capability • Training and exercises • Equipment and facilities
NTTF 9.2	Initiate rulemaking to require EP enhancements for prolonged SBO [station

	<p>blackout] in the following areas:</p> <ul style="list-style-type: none"> • Communications capability • ERDS capability • Training and exercises • Equipment and facilities
NTTF 9.3	<p>er licensees to do the following until rulemaking is complete:</p> <p>Determine and implement the required staff to fill all necessary positions for responding to a multiunit event.</p> <p>Add guidance to the emergency plan that documents how to perform a multiunit dose assessment (including releases from spent-fuel pools) using the licensee's site-specific dose-assessment software and approach.</p> <p>Conduct periodic training and exercises for multiunit and prolonged SBO scenarios. Practice (simulate) the identification and acquisition of offsite resources, to the extent possible.</p> <p>Ensure that EP equipment and facilities are sufficient for dealing with multiunit and prolonged SBO scenarios.</p> <p>Provide a means to power communications equipment needed to communicate onsite (e.g., radios for response teams and between facilities) and offsite (e.g., cellular telephones, satellite telephones) during a prolonged SBO.</p> <p>Provide a means to maintain ERDS capability throughout an accident.</p>
NTTF 10.1	Analyze current protective equipment requirements for emergency responders and guidance based on insights from the accident at Fukushima.
NTTF 10.2	Evaluate the command and control structure and the qualifications of decision makers to ensure that the proper levels of authority and oversight exist in the correct facility for a long-term SBO, multiunit accident, or both.
NTTF 10.3	<p>uate ERDS to do the following:</p> <p>Determine an alternate method (e.g., via satellite) to transmit ERDS data that does not rely on hardwired infrastructure, which could be unavailable during a severe natural disaster.</p> <p>Determine whether the data set currently being received from each site is sufficient for modern assessment needs.</p> <p>Determine whether ERDS should be required to transmit continuously so that no operator action is needed during an emergency.</p>
NTTF 11.1	Study whether enhanced onsite emergency response resources are necessary to support the effective implementation of the licensees' emergency plans— including the ability to deliver the equipment to the site under conditions involving significant natural events whereby degradation of offsite infrastructure or competing priorities for response resources could delay or prevent the arrival of offsite aid.
NTTF 11.2	Work with FEMA [the Federal Emergency Management Agency], the states, and other external stakeholders to evaluate insights from the implementation of EP at Fukushima in order to identify potential enhancements to the U.S. decision-making framework, including the concepts of recovery and reentry.
NTTF 11.3	Study the efficacy of real-time radiation monitoring onsite and within the EPZs [emergency planning zones], including consideration of AC independence and real-time availability on the Internet.
NTTF 11.4	Conduct training, in coordination with the appropriate federal partners, on radiation, radiation safety, and the appropriate use of potassium iodide in the local community around each nuclear power plant.
NTTF 12.1	Expand the scope of the annual ROP [reactor oversight process] self-assessment and biennial ROP realignment to more fully include defense-in-depth considerations.

NTTF 12.2	Enhance NRC staff training on severe accidents, including the training of resident inspectors on SAMGs.
<i>In parallel with Tier 1, 2, and 3 issues:</i> The NRC staff will provide the Commission with a paper by mid-February 2013 that outlines their recommended approach for addressing these recommendations.	
NTTF 1.1	Draft a Commission policy statement that articulates a risk-informed defense-in-depth framework, including extended design-basis requirements in the NRC's regulations as essential elements for ensuring adequate protection.
NTTF 1.2	Initiate rulemaking to implement a risk-informed defense-in-depth framework consistent with the above-recommended Commission policy statement.
NTTF 1.3	Modify the Regulatory Analysis Guidelines to more effectively balance the defense-in-depth philosophy with the current emphasis on risk-based guidelines.
NTTF 1.4	Evaluate the insights from the IPE and IPEEE efforts—as summarized in NUREG-1560, <i>Individual plant examination program: Perspectives on reactor safety and plant performance</i> , issued December 1997; and in NUREG-1742, <i>Perspectives gained from the Individual Plant Examination of External Events (IPEEE) program</i> , issued April 2002—to identify potential generic regulations or plant-specific regulatory requirements.
<i>Potential future recommendations:</i>	
SECY-11-0137 ¹⁶ Item 1	The reliable hardened containment vents provided for boiling water reactor Mark I and II containments should be equipped with filters.
SECY-11-0137 Item 2	Seismic monitoring instrumentation should be made more useful.
SECY-11-0137 Item 3	The basis of the emergency planning zone size should be reviewed and adjusted as necessary.
SECY-11-0137 Item 4	The basis for pre-staging potassium iodide beyond 10 miles should be reviewed and adjusted as necessary.
SECY-11-0137 Item 5	The transfer of irradiated fuel from spent fuel pools to dry storage should be accelerated.
SECY-11-0137 Item 6	The ultimate heat sink should be made to be reliable during beyond-design-basis events.

¹⁶ Borchardt, R.W. 2011. *Prioritization of recommended actions to be taken in response to Fukushima lessons learned*, SECY-11-0137. Memo from the Nuclear Regulatory Commission's executive director for operations to the NRC commissioners. Washington, DC: NRC. October 3. Available at <http://pbadupws.nrc.gov/docs/ML1126/ML11269A204.pdf>