After Fukushima Daiichi: Developments on several fronts

By Dick Kovan, E. Michael Blake, and Tim Gregoire

With a reactor producing electricity for the first time under Japan's new regulatory system, recovery work at Fukushima Daiichi has met some milestones, and regulatory response in the U.S. is gaining some clarity.

As was the case in the first few years after the accidents at Three Mile Island and Chernobyl, the aftermath of the March 2011 accident at the Fukushima Daiichi plant in Japan remains an aspect of a great many tasks, decisions, and outlooks related to nuclear power worldwide. The degree of significance varies, depending on the locale; obviously, Fukushima Daiichi matters more in Japan than anywhere else, which is why the restart of Kyushu Electric Power Company's Sendai -1 power reactor in early August was a pivotal moment in the process of eventual emergence from the accident's aftermath.

Despite there being essentially no connection between the resumption of nuclear power in Japan and the 70th anniversary of the bombing of Hiroshima and Nagasaki by the United States, the events were nonetheless conflated in some media coverage. Public protests of the Sendai-1 restart were covered as indicating dissatisfaction with Japanese Prime Minister Shinzo Abe, although the old top-down system of reactor siting, construction, and operation, headed by the Ministry of International Trade and Industry and its successor agencies, has been supplanted by a more rigorous (if still not completely transparent) process, in which both a national regulatory agency and local authorities must be satisfied before nuclear electricity can be produced.

While the Sendai-1 restart indicates that the new process, which is much closer to the kind of independent regulation that exists in the United States than to the old promotional system, can lead to the resumption of nuclear electricity production, this particular restart does relatively little to change the conditions that have existed in Japan since March 2011. Kyushu is Japan's third-largest island, so the main island of Honshu will not derive economic recovery, reduced oil imports, cleaner air, or more abundant air-conditioning just because Sendai-1 is in service. As the table on page 35 shows, however, there are more reactors in the approval pipeline, and barring local opposition, nuclear power should be producing a significant percentage of Japan's electricity next year, just not as large a percentage as before Fukushima Daiichi.

Photo: Tepco

In very foggy conditions on August 2, a crane lifts the severely damaged fuel handling machine (FHM) from the Fukushima Daiichi-3 spent fuel pool.

It should also be remembered—and it often isn't, outside of Japan—that the earthquake and tsunami killed more than 15,000 people, with about 2,500 others still missing, mainly to the north of Fukushima Prefecture, along the east coast of Honshu. The main aftereffects of the tsunami-induced accident at Fukushima Daiichi were land contamination, dispersal of radioactive material to ocean water, property damage, and long-term regional evacuation. There may be long-term health effects to plant workers, but no human lives were lost.

At the plant

Tokyo Electric Power Company (Tepco) personnel successfully removed the severely damaged fuel handling machine (FHM) from the Fukushima Daiichi-3 spent fuel pool on August 2. The extraction from the pool of the 20-metric-ton FHM, which Tepco said was the largest and most complex piece of rubble in the unit's heavily damaged

Reactor restart applications

This table lists (in chronological order by date of submission) the power reactors for which restart applications have been submitted to Japan's Nuclear Regulation Authority (NRA). In addition to Sendai-1 and -2, a few other reactors have passed some of the milestones set by the NRA to qualify for restart. As with 10 CFR Part 52 licensing of new reactors in the United States, this is a new process for the applicants, and reactor owner-operators are still working out their relationship with the NRA, which holds much more authority than the pre-Fukushima regulator.

With one exception—J-Power's Ohma, which is under construction—the reactors listed in the table were in operation prior to the accident. If approved by the NRA, Ohma will be the first new reactor to begin operation under the new system.

Nineteen operable reactors and two that are not yet operable are not included in the table. Some of them are older, smaller units for which the owners may not see the restart process as cost-beneficial. For all of the reactors that are not included in the table, regardless of age or size, the lack of application submittals may have arisen from consideration of the work that must be done—and the data that must be gathered—to produce an acceptable application. The only owner that has not submitted at least one application is the government-owned Japan Atomic Energy Agency, whose Monju liquid-metal fast-breeder reactor had startup issues long before the Fukushima accident occurred (Monju first went critical in 1994 but has never been declared commercial). The other reactors that have not been closed but for which restart has not yet been sought are Chubu's Hamaoka-5, Chugoku's Shimane-3 (under construction), Hokuriku's Shika-1, Japan Atomic Power's Tsuruga-2, Kansai's Ohi-1 and -2, Kyushu's Genkai-2, Shikoku's Ikata-1 and -2, Tohoku's Onagawa-1 and -3, and Tokyo Electric Power's Fukushima Daini-1 through -4 and Kashiwazaki Kariwa-1 through -5.—*E.M.B. and D.K.*

Reactors with Restart Applications

Applicant	Facilities	Receipt Date	Basic Design Approval	Detailed Design Approval	Safety Program Approval
Hokkaido Electric Power Company	Tomari-1 & -2	7/8/13			
Hokkaido Electric Power Company	Tomari-3	7/8/13			
Kansai Electric Power Company	Ohi-3 and -4	7/8/13			
Kansai Electric Power Company	Takahama-3	7/8/13	2/12/15	4/8/15	
Kansai Electric Power Company	Takahama-4	7/8/13	2/12/15		
Shikoku Electric Power Company	Ikata-3	7/8/13	7/15/15		
Kyushu Electric Power Company	Sendai-1	7/8/13	9/10/14	3/18/15	5/27/15
Kyushu Electric Power Company	Sendai-2	7/8/13	9/10/14	5/22/15	5/27/15
Kyushu Electric Power Company	Genkai-3 & -4	7/12/13			
Tokyo Electric Power Company	Kashiwazaki Kariwa-6 & -7	9/27/13			
Chugoku Electric Power Company	Shimane-2	12/25/13			
Tohoku Electric Power Company	Onagawa-2	12/27/13			
Chubu Electric Power Company	Hamaoka-4	2/14/14			
Japan Atomic Power Company	Tokai-2	6/20/14			
Hokuriku Electric Power Company	Shika-2	8/12/14			
J-Power	Ohma	12/16/14			
Kansai Electric Power Company	Mihama-3	3/17/15			
Kansai Electric Power Company	Takahama-1 & -2	3/17/15			
Chubu Electric Power Company	Hamaoka-3	6/16/15			

reactor building, clears the way for the company to remove the remaining rubble and the 514 spent fuel assemblies that remain in the pool.

The FHM was used to move fuel assemblies in the reactor building, placing them into the reactor core and transferring used fuel to the spent fuel pool located at the top of the reactor building. Given the condition of both the FHM and the reactor building, the FHM had to be carefully removed without causing any further damage to the spent fuel pool or to the fuel assemblies. This was achieved using two 600-ton cranes that lowered the machine to the ground.

Although the operation took less than two hours, preparations for it were carried out over several months. After investigating the conditions inside the pool, Tepco prepared operational procedures for lifting the FHM and took various precautionary steps to protect against any risks associated with such an operation. According to the Japan Atomic Industrial Forum, Tepco designed a special device for lifting the FHM, testing it on a mock-up of the debris in the pool. The hooks and clamps needed to lift the FHM were adapted with fail-proof mechanisms, and additional protective boards were installed in the pool.

Meetings were held with local residents to explain what actions would be taken. On the day of the operation, all other work in the area was suspended to ensure that staff and equipment were available for any possible eventuality. The main body of the FHM will be cut into pieces for transfer to appropriate storage areas according to the level of activity.

Praising the workers who carried out this operation, chief decommissioning officer Naohiro Masuda said, "It paves the way for continued progress and is a milestone in reducing the risk of removing spent fuel assemblies." According to the government's latest mid- to long-term decommissioning road map, as revised in June, Tepco expects to begin removing spent fuel at Unit 3 in 2017.

One of Tepco's greatest challenges in the cleanup is the management of the large vol-

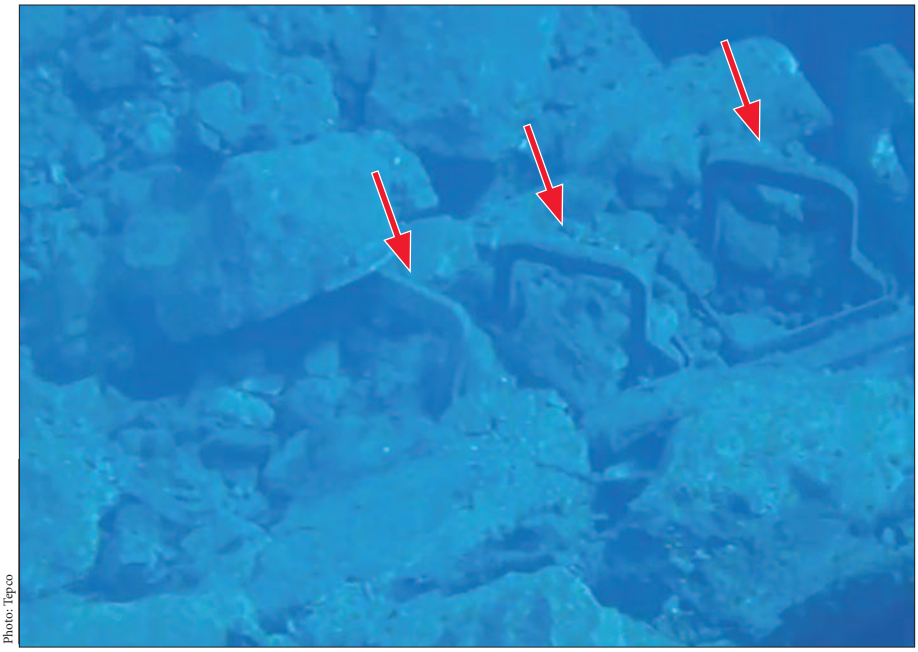

Photo: Tepco

On August 4, using an underwater camera to investigate the rubble inside the Unit 3 spent fuel pool, workers observed bent handles on the tops of nuclear fuel assemblies (indicated by arrows) that were damaged by the FHM.

umes of water contaminated by radioactive materials. On July 30, Tepco announced that after overcoming numerous technical challenges, it has removed the last of the retained water from the trenches (underground tunnels housing pipes and cables) on the seaside of Units 2 and 3. Removal of the highly contaminated water is expected to reduce the potential risk of water leaking out and contaminating the environment, the company said.

After the accident, according to Tepco, approximately 400 cubic meters of groundwater flowed into Fukushima's buildings every day. To block the water flow between the trenches and the turbine buildings, Tepco initially tried a method whereby it would freeze some of the accumulated water. Through trial and error, however, the company adopted a strategy of filling the inside of the trenches directly with special liquid cement while removing the retained water.

Tepco said that it completed the removal of the water from Unit 2 on June 30, and from Unit 3 on July 30. The entire project has been essentially completed, the company said, and all that remains is to fill the vertical shafts up to where the turbine buildings meet. This is intended to prevent any further inflow of water from the turbine buildings.

"One of our most important goals this year is to reduce any risk of water leakage and to prevent the possibility of environment or ocean contamination," Masuda said. "Completion of the water removal from the trenches is an important milestone toward achieving that goal."

The removed water, which has a slightly higher saline concentration than other water managed at the site, will be stored onsite and eventually treated by the treatment systems in place at Fukushima to remove cesium, strontium, and other radionuclides.

Elsewhere in Japan

Control rods were lifted at Sendai-1 at 10:30 a.m. on August 11, and criticality was reached at around 11 p.m. Grid connection took place on August 14. These events marked the first time (with one exception, as noted later) that a Japanese power reactor was restarted following the progressive shutdown of all of the country's power reactors in the wake of the Fukushima Daiichi accident. The industry and the government are now hopeful that this will launch the restart of most of the 43 operable reactors over the next few years.

Sendai-1 is an 846-MWe pressurized water reactor located in Kagoshima Prefecture and owned and operated by Kyushu Electric Power Company. The next significant milestone in the restart process, which should take place in September, is an integrated load performance test to verify that plant systems are operating normally and that the facility is ready to commence regular commercial service.

The startup also marks the end of a period of one year and 11 months when not a single nuclear plant was in operation in Japan following the shutdown of Kansai Electric Power Company's Ohi-3 and -4 in September 2013 for a required periodic inspection. The period without any nuclear-powered generation would have been much longer had the government not made special provisions for the two Ohi units to restart in July 2012, at which time all other operable nuclear plants remained shut down without the possibility of restarting. Once they were off-line, for their annual regulatory inspections or for any other reason, no plants were able to gain authorization to restart under the old regulatory process.

To move forward with nuclear power, a new regime was put in place in which a new regulatory body, since named the Nuclear Regulation Authority (NRA), was created to develop a new set of standards and regulations for licensing reactor operation. The new regulations, which reflect the lessons learned from the accident, were brought into effect on July 8, 2013, nearly two and a half years after the accident.

Photo: Tepco

Fukushima Daiichi workers on July 10 fill Shaft D of the Unit 2 seawater trench with a special liquid cement.

Kyushu Electric began the licensing process to restart Sendai-1 and -2 on the day the new regulatory standards went into effect. Applications were also filed that day for Tomari-1, -2, and -3, owned and operated by Hokkaido Electric Power Company; Ohi-3 and -4 and Takahama-3 and -4, owned and operated by Kansai Electric; and Ikata-3, owned and operated by Shikoku Electric Power Company.

The NRA introduced a three-step licensing process, the first of which involves the NRA's examining a plant's basic design to determine whether it is compatible with the new regulations. Under this process, the submission of the application kicks off a lengthy period of assessment in which issues identified by the NRA have to be resolved with the license applicant, leading to changes and improvements in the basic design.

A safety issue of particular concern to the NRA for the Sendai site was the existence of many active volcanoes within a 160-km radius. Nevertheless, the process for resolving questions moved forward, with the NRA soon bestowing priority status on the Sendai units and intensifying its assessment activity in March 2014. On July 16, 2014, the NRA issued draft safety assessments for the two units, the first ones to be completed, which were made available for public comment. Following a review of the results of the consultation, as well as of comments provided by the Japan Atomic Energy Commission and the Ministry of Economy, Trade and Industry, on September 10, 2014, the NRA cleared the basic design and granted permission to implement approved changes in the design.

Steps two and three of the licensing process involved the NRA's reviewing Kyushu Electric's "detailed design and construction" plan for the units, as well as the "operational safety programs" put in place by the operator, which include procedures for responding to accidents. The NRA approved the construction plan on March 18, and on March 30, it launched pre-startup inspections of the plant, aimed at ensuring that the actual systems and components were as specified in the basic design.

On May 27, the NRA approved Kyushu Electric's operational safety programs, which provide rules for the operation and management of the plants and include emergency response plans in case of external events such as fire, floods, or other natural disasters, or a serious accident.

In the meantime, Kyushu Electric had obtained approval from the Kagoshima Prefecture assembly and governor and the Satsumasendai city council and mayor to restart the two units. Therefore, as soon as the required pre-startup inspections were completed, the operator was able to begin the restart process, beginning with the loading of fuel, which took place between July 7 and July 10. Finally, on the morning of August 11, Kyushu Electric started up Sendai -1. The utility will now be able to focus more on the startup of Sendai-2, which could take place in a few months.

In the United States

On July 28, the Nuclear Regulatory Commission issued a staff requirements memorandum on the agency staff's closure plan for flooding hazard reevaluation. The staff's initial proposal, submitted to the commissioners last November, had proposed the integration of flooding hazard work with the development of mitigating strategies for beyond-design-basis events, but the commissioners did not agree on this point (*NN*, May 2015, p. 15). The plan that has been approved carries through the other points of the original proposal: to hasten improvements at the plants where they are found to be most needed, rather than wait for the completion of the flooding hazard assessment process, which has taken longer than originally anticipated, and the development of clear guidance for the second phase of the assessment process.

The intent is for each plant to deploy (as needed) mitigating strategies for reevaluated flooding hazards, and for the flooding portion of the March 2012 NRC letter to licensees (technically referred to as a "request for information," but with actions to be carried out based on the information) to be closed, with a graded approach to determine each plant's need for an integrated assessment, and the development of criteria and guidance to support regulatory actions (as needed). The term "integrated assessment" may not seem very formidable, but it would entail the most strenuous and exhaustive effort envisioned by the NRC. In the interest of finding and fixing the most significant hazards, the agency has stated that sites with local intense precipitation that exceeds their current design bases need to assess and remedy only that hazard; for sites with beyond-design-basis flood hazards other than local intense precipitation, existing flood protection can be evaluated for its sufficiency.

This was the NRC's latest action in connection with one of the most influential documents ever developed by the agency, formally titled *Recommendations for Enhancing Reactor Safety in the 21st Century: The Near-Term Task Force Review of Insights from the Fukushima Dai-ichi Accident,* known more familiarly as the NTTF report. Issued in July 2011, it set down the 12 recommendations that have directed the NRC's work in this area ever since, and while some of the recommendations have been altered, partially combined, and shifted in priority, the NTTF report remains the organizing principle in how the NRC and reactor licensees (and, more recently, fuel cycle facility licensees) address the concerns that arose from the Fukushima Daiichi accident. The report had no regulatory force of its own, but the recommendations and many of the actions proposed to fulfill them have been the basis of NRC orders, information requests, and rulemakings that provide such force.

At no time has the NRC declared any licensed power reactor in the United States to be unsafe, based on concerns arising from Fukushima Daiichi. That said, there was one instance in which a plant—Omaha Public Power District's Fort Calhoun—was taken out of the Reactor Oversight Process (without being given the "unacceptable performance" designation) because of flooding that exceeded the site's coping mechanisms and other shortcomings found later. Fort Calhoun, however, would probably have received such treatment after the Missouri River flooding in 2011 (and to a lesser extent in 2010) even if there had not been a tsunami in Japan in March 2011.

An August 2011 earthquake in the vicinity of the North Anna plant in Virginia briefly exceeded the plant's design basis, and some minor damage to non-safety-related structures was found. After Fukushima Daiichi, NRC officials did some soul-searching over the concept of "adequate protection," and it was affirmed that existing safety practices and regulations for normal operation and safe-shutdown capability are sufficient, and Fukushima-related modifications have to some extent raised the profile of issues that were already under consideration (such as the coping time for a reactor in an off-normal condition with no operator action).

Much of the post-Fukushima activity in the United States will be ongoing for several years into the future, especially in areas that involve rulemaking. It is possible to say, however, that some actions have been completed, and that the state of knowledge about potential hazards and vulnerabilities has been improved. The Nuclear Energy Institute's Diverse and Flexible Coping Strategies (FLEX) effort has established centers in Memphis and Phoenix, where backup emergency equipment and supplies are stored and can be deployed to a plant anywhere in the country if the plant's existing emergency equipment is disabled by an event that also threatens the plant.

FLEX also includes guidance, endorsed by the NRC, for each plant's own response. TVA Nuclear stated in June that its two-unit Watts Bar plant in Tennessee is the first plant in the country to be in full compliance with NRC requirements for coping with beyond-design-basis external events. TVA has stated that the site's FLEX-guided gear is sufficient to ensure cooling of the reactors, their containments, and spent fuel pool storage through the extended loss of AC power and access to the ultimate heat sink. NN