Mitigating the Risks of Spent Nuclear Fuel in Japan

March 30, 2017

By Yukari Sekiguchi,
Program Coordinator and Research Associate

On November 21, 2016 at 5:59 a.m., a 6.9-magnitude earthquake triggered a one-meter (39 inches) tsunami that hit the Fukushima Daiichi Nuclear Power Plant—the same nuclear power plant struck six years ago by a record-breaking earthquake and tsunami, which resulted in a meltdown of the cores of three reactors. The accident six years ago prompted renewed international focus on safety measures at nuclear facilities and led to some significant policy changes, but the most recent earthquake demonstrated that, even in the area most affected by the March 11, 2011 accident, vulnerabilities remain.

In 2011, most of the damage at the Fukushima Daiichi Nuclear Power Plant resulted from a failure of the cooling systems of reactors No. 1, 2, and 3. The cooling system for more than 1,000 spent fuel rods in the pool in the No. 4 reactor (which was not operating on March 11) shut down, but the dry storage facilities at Fukushima were just fine. After the 2016 earthquake, the cooling systems of the spent nuclear fuel pool at the Fukushima Daini Nuclear Power Plant shut down for 90 minutes. The earthquake shook the water cooling tank and its sensor detected abnormally low water levels, leading to the shutdown. Luckily, none of the reactors at the Daini sites had been operational for some time, but the earthquake itself was not an unusual event. Significant earthquakes of 6.0-6.9 magnitude occur on average 17 times per year in and around Japan – 1/10 the total number of earthquakes in the world.[1] The 2016 demonstrates that the cooling systems for spent nuclear fuel pools remain vulnerable, particularly given the high level of seismic activity. So why are there still only two dry-cask storage facilities total in Japan?

Spent fuel storage is an urgent issue in Japan for many reasons, including safety. Even before the Fukushima accident in 2011, spent fuel with pools in Japan were rapidly filling up, creating pressure to increase storage capacity. In 2016, Japanese government revised the grants paid to municipalities to encourage them to accept the installation of dry-cask storage and the

[1] Japan Meteorological Agency. http://www.jma.go.jp/jma/kishou/know/faq/faq7.html

Nuclear Regulation Authority (NRA) eased earthquake-related and other regulations on storing spent fuel to provide incentives to increase the use of dry-cask facilities, but the public seems to oppose all things nuclear. A March 2017 poll conducted by the Mainichi Shimbun newspaper showed 55% of people opposed to restarting nuclear power.[2]

Figure 1: Location of Fukushima Daiichi and Daini Nuclear Power Plants

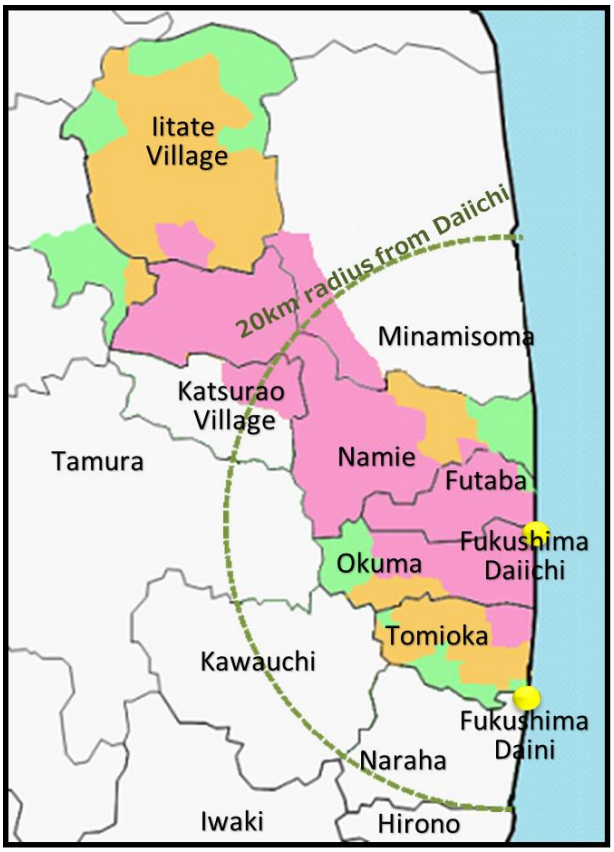

Figure 1 Source: Japanese government.

EARTHQUAKE ON NOVEMBER 21, 2016- THE STATUS OF FUKUSHIMA DAIICHI AND DAINI NUCLEAR POWER PLANTS

There are two nuclear power facilities in Fukushima- Fukushima Daiichi and Daini. Fukushima Daiichi, which received the most damage as a result of the 2011 earthquake, is undergoing decommissioning. At the time of the 2011 accident, three reactors were operating (No. 1, 2, 3), and three were not (No. 4, 5, 6). The fuel in the operating reactors melted as a result of the accident, and that clean-up is just beginning because radiation levels have made it difficult for robots to assess exactly where the fuel is. Spent fuel that had been stored at all the reactors is gradually being shifted away from the reactor pools to common storage pools. This activity will not be completed for a few years.

The Daini Plant has 4 reactors, all of which shut down safely after the 2011 earthquake, but which have not yet reopened. All of the fuel at those reactors was extracted and placed in wet storage pools at the reactors following the 2011 earthquake.

At 5:59 a.m. on November 21, 2016, a strong earthquake occurred off the shore of northeast Japan. After that earthquake, TEPCO initially said that there were no irregularities at the Fukushima Daiichi Nuclear Power Plant. According to the NRA, however, around 6:10 a.m., the cooling

[2] "原発再稼働、反対５５％　賛成２６％、差拡大," *Mainichi*, March 13, 2017. http://mainichi.jp/articles/20170313/k00/00m/010/101000c

systems for the spent nuclear fuel pool at the No. 3 reactor of the Fukushima Daini Nuclear Power Plant, where 2,544 nuclear fuel rods are stored, shut down. TEPCO later said the earthquake "shook" water in the cooling tanks temporarily, leading to a decline in levels and an automatic shutdown of the cooling systems. The system returned to normal operation after 90 minutes.

There were problems with the cooling systems in both 2011 and 2016. In 2011, emergency power was overwhelmed by the tsunami; emergency cooling for the common storage and No. 6 reactor pools was restored only because the emergency diesel generator at No. 6 (on higher ground) survived. When cooling systems are lost, the increased heat and/or exposure to air can damage fuel and release radioactivity, or can cause a criticality accident because the geometry of the fuel or the balance of neutron absorption can shift. According to a 2015 OECD report,[3] the degradation and release of radioactivity phenomena are fundamentally the same for "loss-of-cooling-accidents" involving spent nuclear fuel in pools as for those involving fuel in reactors. Although incidents in pools tend to happen more slowly because the fuel is not as "hot" as fuel in a reactor, the fuel cladding is the only barrier to the environment once the coolant is lost. This means, potentially, faster degradation.

Though the consequences of the 2016 earthquake were far less severe than in 2011, they once again highlight the continued vulnerability of spent nuclear fuel pools.

WET VERSUS DRY SPENT FUEL STORAGE

After irradiation in a reactor, spent nuclear fuel must spend several years cooling down before it can be handled safely. Typically, such fuel is stored and monitored in pools of water (known as spent fuel pools) at the reactor for about five years until the fuel has cooled sufficiently. After that, it can be transferred to other storage sites, whether wet or dry. Dry storage generally entails steel and concrete casks on concrete pads that provide radiation shielding but also natural air circulation to dissipate heat. This passive approach to cooling requires no electricity and is fairly robust. It is an additional expense, however. Absent incentives to move the fuel (e.g., lack of storage space) from reactor pools, therefore, spent nuclear fuel can sometimes can spend much longer than 5 years at reactors.

The United States and Europe are installing dry-cask storage facilities. The market for dry storage in the Americas, where there is the highest demand, was more than 600 million dollars in 2015 and is expected to over 1 billion dollars by 2020.[4]

[3] "Status Report on Spent Fuel Pools under Loss-of-Cooling and Loss-of-Coolant Accident Conditions". oecdncea.org. Nuclear Energy Agency. 4 May 2015. (website), p.11. https://www.oecdnea.org/nsd/docs/2015/csni-r2015-2.pdf

[4] World Nuclear Association. http://www.world-nuclear.org/information-library/nuclear-fuel-cycle/nuclear-wastes/storage-and-disposal-of-radioactive-wastes.aspx

WHY DOES JAPAN NEED DRY-CASK STORAGE FACILITIES?

It took three years for TEPCO to transfer all of the spent fuel rods from the pool of No. 4 reactor of Fukushima Daiichi to a common pool. At the Fukushima Daiichi Nuclear Power Plant, there are now 6,726 fuel rods in the common pool including the transferred fuels from No.4 reactor, as well as 1,412 rods in dry-cask storage, 392 in the pool of No.1 reactor, 615 in the pool of No.2 reactor, and 566 in the pool of No.3 reactor.[5] All fuel rods at the Fukushima Daini Nuclear Power Plant are stored in the reactor pools.

Many other countries have managed a shortage of storage space by removing spent fuel from pools after around five years and then placing it in air-cooled dry casks. In the early 1980s, just as in Japan, the United States had to seek alternative options, including dry-cask storage, to increasing fuel storage capacity. The first dry storage was installed in 1986 at the Surry Nuclear Power Plant in Virginia. Since then, the installation of dry-cask storage has grown in the United States. As of October 2016, more than 60 nuclear power plants have installed dry-cask storage.[6]

In Japan, only two nuclear power plants (Fukushima Daiichi and Tokai 2) have moved to dry-cask storage facilities in the years since the nuclear accident. Instead, many operators have opted to use more compact racks to increase fuel storage capacity and allow utilities to extend use of the existing spent fuel pools. Kyushu-EPCO, owner of Genkai Nuclear Power Plant, has decided to re-rack its spent fuel pool of No. 3 reactor, decreasing the distance between assemblies from 36.5 cm to 28.2 cm in order to increase its capacity by 1,034 nuclear fuel rods.[7] According to documents of Federation of Electric Power Companies, as of October 20, 2016, Mihama and Genkai nuclear power plants are also planning to re-rack their fuel.[8]

The issue of spent fuel storage in Japan is complicated by the country's controversial reprocessing policies. Reprocessing spent fuel involves taking it apart and separating the highly radioactive fission products from the unused uranium and the resultant plutonium. Both can be recycled into new fuel. Japan has about 17,000 tU (metric tons of uranium) of nuclear spent fuel and no permanent disposal site. Under Japan's current nuclear fuel cycle policy, utilities store their spent fuel at reactors until it can be transported to the Rokkasho

[5] Naraha Town. News release, February 3, 2016. 福島第一原子力発電所の 廃止措置等に向けた現状の取組み. http://www.town.naraha.lg.jp/information/files/28.2.26%E5%8E%9F%E7%99%BA%E2%91%A4.pdf.

[6] NRC. Backgrounder on Dry Cask Storage of Spent Nuclear Fuel. https://www.nrc.gov/reading-rm/doc-collections/fact-sheets/dry-cask-storage.html

[7] "規制委の田中俊一委員長も「苦し紛れの方策」と酷評…それでもやるのか、玄海原発のリラッキング," *Sankei*, January 31, 2017. http://www.sankei.com/life/news/170131/lif1701310001-n1.html

[8] The Federation of Electric Power Companies of Japan. News release, October 20, 2016. 使用済燃料貯蔵対策への対応状況について. https://www.fepc.or.jp/about_us/pr/oshirase/__icsFiles/afieldfile/2016/10/20/press_20161020_1.pdf.

Reprocessing Plant (RRP) for recycling. Eventually, the separated plutonium would be used in fast breeder reactors, although it can also be combined with uranium to create mixed oxide fuel for existing fleet of thermal reactors. A further wrinkle in Japan's plans has been the decision last year to decommission the pilot Monju fast breeder reactor. Meanwhile, the Rokkasho reprocessing plant is not yet ready to begin reprocessing operations, and the disconnect between plutonium stockpiles and usage policy has raised significant security and nonproliferation concerns.

Until the Rokkasho plant is ready to operate, existing spent fuel storage is approaching its maximum capacity. Once plants run out of storage space, whether dry or wet, the utilities cannot continue to operate the plant. As of the end of September 2016, Kashiwazaki-Kariwa, Hamaoka, Takahama, Ohi, and Tokai Daini are already in excess of 90% of their spent fuel storage capacity.[9] Kashiwazaki-Kariwa Nuclear Power Plant, currently shutdown, will reach full capacity within three years after the plant restarts.

Japan is not the only nuclear power state facing this challenge. In Asia, Taiwan and South Korea have similar problems. In the case of Taiwan, the public opposes dry-cask storage, leaving Taiwan with few options. [10] South Korean officials also cite public opposition to dry-cask storage as a significant barrier.

For its part, Japan planned to begin operations in 2012 at Japan's first off-site interim storage facility for 5,000 tU of spent fuel in Mutsu city in the Aomori prefecture. However, the Mutsu interim storage facility is still delayed as a result of the Nuclear Regulation Authority (NRA)'s safety review after the Fukushima nuclear accident.[11] In addition to the Mutsu interim storage facility, the NRA is also currently assessing the safety of a dry-cask storage facility at Hamaoka Nuclear Power Plant in the Shizuoka Prefecture.

[9] The Federation of Electric Power Companies of Japan. News release, October 20, 2016. 使用済燃料貯蔵対策への対応状況について. https://www.fepc.or.jp/about_us/pr/oshirase/__icsFiles/afieldfile/2016/10/20/press_20161020_1.pdf.

[10] Sharon Squassoni, "Workshop Report Nuclear Security And regional Fuel Cycle Decisions: Northeast Asia," January 26, 2016. https://csis-prod.s3.amazonaws.com/s3fs-public/legacy_files/files/publication/20160126_Sharon_Squassoni_Workshop_Report_Nuclear_Security_And_Regional_Fuel_Cycle_Decisions_Northeast_Asia%20.pdf

[11] "中間貯蔵施設、稼働２年延期＝使用済み核燃料－青森県むつ市."*Jiji*, September 13, 2016. http://www.jiji.com/jc/article?k=2016091300927&g=eco

Table 1: Stockpile of Spent Nuclear Fuel as of September 30, 2016 and Estimates

Stockpile of Spent Nuclear Fuel as of September 30, 2016						Estimates[12]		
Utility	Plant	1 core (tU)	1 refueling's worth (tU)	Control capacity (tU)[13]	Spent fuel stock (tU)	Control capacity (tU)	Spent fuel stock (tU)	Percentage of Storage Utilization (%)
Hokkaido	Tomari	170	50	1020	400	1020	600	59
Tohoku	Onagawa	260	60	790	420	790	660	84
	Higashidori	130	30	440	100	440	220	50
TEPCO	Fukushima-1	580	140	2,260	2,130	2,260	2,130	94
	Fukushima-2	520	120	1,360	1,120	1,360	1,120	82
	Kashiwazaki-Kariwa	960	230	2,910	2,370	2,920[14]	2,920	100
Chubu	Hamaoka	410	100	1,300	1,130	1,700[15]	1,530	90
Hokuriku	Shika	210	50	690	150	690	350	51
Kansai	Mihama	70	20	760	470	620[16]	550	89
	Takahama	290	100	1,730	1,220	1,730	1,620	94
	Ohi	360	110	2,020	1,420	2,020	1,860	92
Chugoku	Shimane	100	20	680	460	680	540	79
Shikoku	Ikata	120	40	1,020	640	1,020	800	78
Kyushu	Genkai	230	80	1,130	900	1,600[17]	1220	76
	Sendai	140	50	1,290	890	1,290	1090	84
JAPC	Tsuruga	90	30	920	630	920	750	82
	Tokai-2	130	30	440	370	510	490	96
Total		4,770	1,260	20,730	14,830	21,570	18,450	

Table 1 Source: FEPCO. https://www.fepc.or.jp/about_us/pr/oshirase/__icsFiles/afieldfile/2016/10/20/press_20161020_1.pdf

[12] These estimates of spent fuel stock are calculated under the following conditions and do not assume any specific plant restart schedules: For a given NPP, all reactors are taken into consideration except for Fukushima-Daiichi, Hamaoka No. 1 & 2, Mihama No. 1 & 2, Ikata No.1, Shimane No. 1, Genkai No. 1, and Tsuruga No. 1; Estimated stocks are obtained as the sum of the stock as of the end of September 2016 and four-cycles' worth (four refuelings' worth) of spent fuels; and it is assumed that one cycle consists of 13 months of operation and three months of periodic inspection. (Accordingly, four cycles are equivalent to about five years.)

[13] Basically, the control capacity is the storage capacity minus [1 core + 1 refueling's worth]. As for NPPs which have ceased operation, the control capacity is taken to be equal to the storage capacity.

[14] For Kashiwazaki-Kariwa No. 5 reactor, although work to reinforce the storage capacity (by re-racking) of the spent fuel storage facilities has not been conducted yet, an estimated control capacity following the completion of the work is listed.

[15] For Hamaoka No. 4 reactor, an application for permission to construct dry storage facilities is being filed, and the estimated control capacity following the completion of such facilities is listed.

[16] For Mihama Unit 3, an application for permission to augment (by re-racking) the storage capacity of the spent fuel storage facilities is being filed, and the estimated control capacity following the completion of such facilities is listed.

[17] For Genkai No.3 reactor, an application for permission to augment (by re-racking) the storage capacity of the spent fuel storage facilities is being filed, and the estimated control capacity following the completion of such facilities is listed.

CHALLENGE OF PUBLIC CONCERNS

In 2015, Japanese government declared its intention to increase on-site storage capacity through re-racking, the installation of dry-cask storage facilities, and the construction of interim storage facilities. In order to provide incentives for the installation of dry-cask storage facilities, widely viewed as the safest storage strategy in earthquake-prone Japan, the government decided to raise subsidies granted for municipalities hosting nuclear power plants if they allow the adoption of a dry cask system. At the time, the government paid municipalities about 3,550 dollars for one ton of spent nuclear fuel kept at its nuclear plants, regardless of how it is stored. Since April 2016, it raised the amount to around 5,330 dollars for fuel kept in dry casks, while lowering it to about 2,670 dollars for those in water storage pools.[18] On October 17, 2016, the NRA also decided to ease rules on the dry-cask storage facilities, including easing regulations on earthquake resistance and allowing outdoor storage of casks to promote dry-cask storage facilities as the best way to reduce risks.[19]

After those efforts of the government and the NRA, as of October 20, 2016, all utilities declared their willingness to explore dry-cask storage as a future option.[20] However, utilities must first conclude a Nuclear Safety Agreement with local governments and municipalities in order to build dry-cask storage, an agreement required for full-scale operation of a nuclear power plant that covers the monitoring of radiation, emergency procedures, the right to make on-site inspections, and notification of new construction or expansion (including of dry-cask storage facilities). [21] This is the primary reason why there is no progress despite operators' willingness and clear practical and safety incentives. Securing consent for dry-cask storage from local communities tends to be difficult, and with continued delays in completing RRP, many local communities believe they may be forced to store spent fuel in its dry-casks for longer than promised.

Fukui Prefecture, for example, with 15 nuclear reactors, including the Monju fast breeder reactor, encourages nuclear plant operators to transfer spent fuel outside the prefecture by imposing a tax of $10 per kilogram that remains in the prefecture in pools for more than five years, a measured adopted on June 24, 2016. This spent nuclear fuel tax is estimated raise about 30 million dollars annually.[22] Elsewhere,

[18] METI.使用済燃料対策の強化へ向けた政府の取組について. http://www.meti.go.jp/committee/kenkyukai/energy_environment/shiyouzumi_nenryou/pdf/002_04_00.pdf.

[19] "乾式貯蔵、審査を緩和　規制委."*Mainichi Shimbun*, October 17, 2016. http://mainichi.jp/articles/20161017/k00/00m/040/108000c.

[20] The Federation of Electric Power Companies of Japan. News release, October 20, 2016. 使用済燃料貯蔵対策への対応状況について. https://www.fepc.or.jp/about_us/pr/oshirase/__icsFiles/afieldfile/2016/10/20/press_20161020_1.pdf.

[21] The Federation of Electric Power Companies of Japan. "Nuclear safety Agreement." http://www.fepc.or.jp/nuclear/chiiki/nuclear/kakunenryouzei/

[22] "「搬出促進割」で県外貯蔵促進へ　福井県会、核燃料税で見直し条例案," *Fukui Shimbun*, June 4, 2016. http://fukunawa.com/fukui/14385.html

however, there are some promising signs for a shift to dry-cask storage: Kansai EPCO, operator of Takahama, Ohi, and Mihama nuclear power plants, is planning to build dry-cask storage facilities in an interim storage center outside Fukui Prefecture as the prefectural government has requested.[23]

HOW TO MOVE FORWARD

The 2016 earthquake again awakened the public to the problem of the accumulation of radioactive spent fuel in cooling pools at reactor sites, but there are several factors still complicating improvements in spent fuel storage in Japan.

In order to promote dry-cask storage, it will be critical that operators secure consent from local communities. Of course, Japan is different from the United States because of its requirement for agreements with local governments, but the installation of dry-cask storage in the U.S. nonetheless grew without any major opposition because it had a clear advantage of avoiding transportation of nuclear waste.[24] It also has a demonstrated safety record: the United States Nuclear Regulatory Commission asserts that dry-cask storage has released no radiation that affected the public or contaminated the environment since the first installation.[25] In Japan, the NRA Chairman Shunichi Tanaka has also stressed that dry-cask storage is much safer than the pools, but the public remains concerned that dry-cask storage on site could become *de facto* permanent storage as a result of continued delays at RRP[26]

According to the METI, in the case of Tokai 2, it took more than five years to build dry-cask storage facilities on site.[27] It is necessary to hold early negotiations with local community, otherwise some of the capacity of spent nuclear fuel pools will reach their maximum in a few years once nuclear power plants restart. At the same time, central government must find a final disposal site for storing nuclear waste in the long run. In this context, utilities should explain to local communities that dry-cask storage is only a temporary solution until decisions about final disposal site is made by utilities and the central governments, so that the local community can understand that spent fuel has a place to go. Whether on- or off-site, spent fuel should be stored in a safe way.

Since the accident, much of the Japanese public does not have trust and confidence

[23] リサイクル燃料貯蔵センター. KEPCO, 2016 http://www.kepco.co.jp/energy_supply/energy/nuclear_power/shikumi/pdf/cycle_pamphlet.pdf

[24] Bodansky, David. 1996. Nuclear energy: principles, practices, and prospects. Woodbury, N.Y.: American Institute of Physics.

[25] "Backgrounder on Dry Cask Storage of Spent Nuclear Fuel." United States Nuclear Regulatory Commission - Protecting People and the Environment. https://www.nrc.gov/reading-rm/doc-collections/fact-sheets/dry-cask-storage.html.

[26] "NRA pushing dry cask storage, not pools, for spent nuclear fuel," *The Asahi Shimbun*, February 14, 2017. http://www.asahi.com/ajw/articles/AJ201702140004.html

[27] METI. News release, November 2012. 原子力政策の課題. http://www.enecho.meti.go.jp/committee/council/basic_problem_committee/033/pdf/33-4.pdf.

in the government, nuclear utilities, or the NRA. The recent reaction to the high radiation levels found during the research of the No.2 reactor of the Fukushima Daiichi revealed that there is still fear and suspicion of nuclear power. Therefore, a consensus-based approach is essential to restore public confidence and trust.