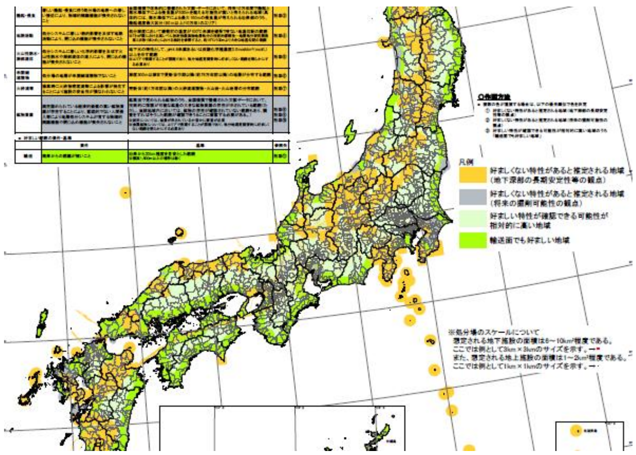
NAPSNET SPECIAL REPORT

OPTIONS FOR REMOTE INTERIM STORAGE OF NUCLEAR SPENT FUELS IN JAPAN



Banner image: Color-coded map identifies potential nuclear waste sites in Japan, from here

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SUMMARY

Japanese nuclear utilities are currently holding approximately 15,000 tonnes of spent fuel in spent fuel pools at reactor sites and in the spent fuel pool at the Rokkasho reprocessing facility. Much of the spent fuel in storage in spent fuel pools in Japan is in “dense packed” pools, which are significantly more vulnerable to fire and subsequent radiation release in the event of coolant loss due to accident or attack than are pools using non-dense-packed arrays. Moving cooled spent fuel out of spent fuel pools and into dry cask storage—in which dry spent fuel is stored in an inert atmosphere in massive steel and concrete casks—would reduce the vulnerability of the spent fuel in storage to terrorist attack or accidents. Moving Japan’s cooled spent fuel to one or more remote interim dry storage facilities would provide this type of vulnerability reduction, but faces numerous challenges. Some of these challenges are technical—largely identifying suitable sites and developing or adapting transport infrastructure—but most of the obstacles to interim spent fuel storage in Japan are political, social, and institutional.

Interim spent fuel facilities, both at-reactor and away-from reactor, are in used in and or proposed for use in a number of countries. Elements of such facilities typically include dry casks, the structures in or on which casks are placed, transportation and handling systems, and security and monitoring systems. For Japan, three options for siting of interim spent fuel facilities include coastal, and island locations, both of which benefit from easy transportation of spent fuel by sea to the facilities, and barge-mounted spent fuel storage, with one or a set of barges anchored at sea in protected locations such as inland waters off Japan.

For most of its history with nuclear power, Japanese official policy has been to recycle the plutonium in spent light-water reactor fuel to mixed oxide (MOx) fuel, with the use of MOx in either light water reactors (the “pluthermal” approach) or, eventually, in Fast Breeder Reactors (FBRs). The operation of Rokkasho has been delayed many times, and pool storage facilities at existing nuclear power plants are expected to be filled up shortly as reactors are restarted following extensive post-Fukushima safety review. Moving spent fuel from full spent fuel pools to pools at other reactors with available space is prohibited under the agreements between reactor operators and local municipalities. Although the continuing emphasis on plutonium recycle has been an impediment to development of interim spent fuel storage, a dry-cask-based facility has been built at Mutsu, near Rokkasho, and is scheduled to being operations in 2018. Dry cask storage is also used at the Fukushima site, and is planned for at least one other reactor site.

The required attributes of an interim spent fuel storage site, whether coastal, island-based, or barge-mounted, include:

- A location that is relatively remote from significant populations, and is protected as much as possible from seismic and tsunami hazards, as well as being relatively easy to secure and defend in the case of an attack scenario;
- A location that is accessible to berthing facilities so that spent fuel can be brought in from Japanese coastal reactors by ship, and can easily be transported from docks to the facility, preferably without transiting high-traffic areas. The facility itself would need to include equipment and processes for accepting and moving dry casks, and storing the casks, as well as monitoring and other security equipment and processes;

- And perhaps most importantly, a location where local residents, and local and regional government agencies, are accepting of the facility, or can be convinced to accept the facility through a process of consultation and offers of compensation.

Barge-mounted spent fuel storage would be new to Japan, and as a consequence faces a barrier of precedence—facilities not already demonstrated in similar countries are less likely to be adopted in Japan—but also pose a regulatory puzzle, as the safety criteria now applied to spent fuel storage in Japan are entirely land-based. That said, the presence of barge-based offshore petroleum stockpiles in Japan serves as an interesting precedent for barge-based spent fuel storage, and barge-based systems may provide ways around some siting issues.

The lack of public acceptance is a major challenge for siting new interim spent fuel facilities in Japan. Regulation of nuclear facilities has become stricter in the aftermath of the Fukushima accident, and it requires considerable effort and time for a new facility, or even an updated existing facility, to obtain approval by the Nuclear Regulation Authority. That said, a compensation scheme for the hosts of nuclear facilities, including spent fuel storage facilities, is well established in Japan, so that less-populated and depopulated municipalities in particular (where payments are spread over a smaller population, and where the towns lack industries or other economic activities) should have significant motivation to host interim storage facilities. Siting facilities on uninhabited islands, leaving (presumably) more compensation to be retained at the prefecture level and for communities not immediately adjacent to the facility, may be attractive.

Given the difficulties of siting spent fuel storage in Japan, it is likely that Japan would be receptive to discussing potential regional collaborations on spent fuel storage facilities.

Japanese electric companies and the agencies of the Japanese government involved with the nuclear sector are now aware of the importance of dry cask storage, and dry cask storage is now preferred to spent fuel pools, at least officially, since it offers advantages in costs and safety. What Japan lacks is public acceptance of spent fuel facilities, as well as open, transparent, and inclusive processes for public disclosure and discussion on nuclear sector matters. It is very important to have all processes in which Japan’s nuclear future are discussed be open, and to prepare good discussion platforms in order to foster public acceptance.

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1 Introduction

As a part of Nautilus Institute's MacArthur Foundation-funded "Reducing Risk of Nuclear Terrorism and Spent Fuel Vulnerability in East Asia" Project, a group of researchers are collaborating to explore ways of making the storage of spent fuel from nuclear energy facilities safer. Japanese nuclear utilities are currently holding approximately 15,000 tonnes of spent fuel in spent fuel pools at reactor sites and in the spent fuel pool at the Rokkasho reprocessing facility.[1] Much of the spent fuel in storage in spent fuel pools in Japan is in "dense packed" pools, which are significantly more vulnerable to fire and subsequent radiation release in the event of coolant loss due to accident or attack than are pools using non-dense-packed arrays. Moving cooled spent fuel out of spent fuel pools and into dry cask storage—in which dry spent fuel is stored in an inert atmosphere in massive steel and concrete casks—would reduce the vulnerability of the spent fuel in storage to terrorist attack or accidents. Moving Japan's cooled spent fuel to one or more remote interim dry storage facilities would provide this type of vulnerability reduction, but faces numerous challenges. Some of these challenges are technical—largely identifying suitable sites and developing or adapting transport infrastructure—but most of the obstacles to interim spent fuel storage in Japan are political, social, and institutional. Japan is not alone among nations in facing these non-technical obstacles. The Republic of Korea (ROK) and Chinese Taipei (Taiwan) face some of the same issues, and spent fuel storage decisions in the United States have been far from simple, though at-reactor dry cask storage has become common. Japan's situation is unique, however, in the combination of political and institutional constraints acting against interim spent fuel storage, and the post-Fukushima context of the decisions as to whether or not to restart Japan's nuclear reactors.

In the remainder of this introduction, we briefly review the background of this assessment of options for remote storage of spent nuclear reactor fuel in Japan, provide an overview of the dry cask storage situation in Japan and internationally, and describe the contents of the remaining sections of this Report.

1.1 Background

In the tragic aftermath of the March 2011 Sendai earthquake and tsunami and the resulting Fukushima nuclear plant disaster, all of Japan's fleet of nuclear reactors were shut down for safety checks for a period that, at the time, appeared indefinite. The period of reactor shut-down, in addition to the impacts on electricity supplies alluded to above, has included a period of national (and, for that matter, international) reflection and debate on the safety of nuclear reactors, and of Japan's future plans for nuclear power. A committee was convened in Japan to

[1] Nautilus Institute estimate for 2015, net of Japanese spent fuel reprocessed abroad and at Rokkasho. This value is somewhat lower than the over 13,000 tonnes reported in World Nuclear Organization (2016), "Japan's Nuclear Fuel Cycle", updated September 2016, and available as http://www.world-nuclear.org/information-library/country-profiles/countries-g-n/japan-nuclear-fuel-cycle.aspx.

explore different futures for the electricity and nuclear power sectors, and to recommend a course of action to the government. The committee explored options ranging from nearly full restart of Japan's reactor fleet, with a renewed commitment to recycling of nuclear spent fuel and, ultimately, use of recycled plutonium in fast reactors, to essentially no further use of nuclear power. Although a limited restart scenario was discussed and seemed to be favored, at the time, by the Noda administration, the incoming administration of Japanese President Shinzo Abe, in 2012, focused to some extent on a return to Japan's previous nuclear energy policy, but with less reliance on nuclear power, and with a partial restart of reactors on at least an interim basis.

A part of the ongoing anxiety and opposition toward nuclear power on the part of many citizens and groups in Japan is related to the management of spent nuclear fuel. Anxiety about spent fuel management is a symptom of a more unfocused pattern of a lack of confidence by many in Japan in nuclear technologies, and in the management of the nuclear sector. This lack of confidence was exacerbated by the events surrounding the Fukushima accident and its aftermath. Japan's policy has historically been to work toward reprocessing of spent fuel to separate fissile plutonium (Pu) for formulation into mixed oxide (MOx) fuel for use in the existing fleet of Japan's light water reactors (LWRs), along with fuel made using enriched uranium (UOx fuel). Ultimately, the goal of Japan's nuclear sector has been to develop a "closed" nuclear fuel cycle in fast neutron reactors that are designed to "breed" as much plutonium as they use. Fast reactors have been tested in Japan and a number of other countries, most notably France, with results that have thus far been considered less than satisfactory, with a number of incidents and accidents marking fast reactor deployment.[2] Widespread commercial deployment of fast reactor technology, if it occurs, is thus likely decades away.[3] Reprocessing of spent fuel, however, maintains the option for fast reactor deployment. Japan's reprocessing program has focused on bringing the reprocessing plant at Rokkasho into commercial operation. Rokkasho's operation has been delayed by a series of technical and other issues, although it did undergo testing with spent nuclear fuel in 2008. In part due to plans to reprocess fuel at Rokkasho, and in part (and relatedly) due to agreements with communities that host nuclear power plants to remove nuclear spent fuel that had been cooled in onsite spent fuel pools for reprocessing, most nuclear spent fuel in Japan continues to be stored mostly in at-reactor spent fuel pools. Although some spent fuel has been removed and placed in the spent fuel pool at Rokkasho, and prior to 2000, considerable spent fuel was sent to Europe (France and the United Kingdom) for reprocessing, Japan has to date made relatively little use of dry cask storage. Dry cask storage is a technique in which spent reactor fuel that has been cooled for five or more years in spent fuel pools is transferred to massive steel and (often) concrete casks designed for 50 to 100 years of service. Dry cask storage, though used extensively in the United States and other nations, has been employed to a limited extent and mostly only recently in Japan—for example, for fuel from the

[2] See, for example, Mycle Schneider (2009), "Fast Breeder Reactors in France", *Science and Global Security*, 17:36–53, 2009, available as https://www.princeton.edu/sgs/publications/sgs/archive/17-1-Schneider-FBR-France.pdf.

[3] In November 2015, the Nuclear Regulatory Agency in Japan rules that a new entity is required to operate the Monju breeder reactor safely. "Fast breeder reactor brings Japan's policy to crossroads," November 5, 2015, at: http://asia.nikkei.com/Politics-Economy/Policy-Politics/Fast-breeder-reactor-brings-Japan-s-policy-to-crossroads?page=1.

damaged Fukushima reactors and at the to-be-commissioned Mutsu Intermediate Storage Facility.[4]

Spent fuel pools in Japan, as in many other nations, are largely configured as "dense racked" or "dense-packed". This means that the racking system used to support the fuel assemblies placed in the pools maintain the assemblies close to each other—nearly as close as in a reactor core. To prevent neutrons released by cooling fuel assemblies from starting a nuclear chain reaction, as would occur in a reactor core, dense-packed spent fuel pools are fitted with neutron-absorbing dividers. These dividers, in addition to absorbing neutrons to prevent criticality in the stored spent fuel, impede the flow of heat away from fuel assemblies, heat that would be lost more easily through conduction and convection is an open racking system, in which assemblies are placed much further apart, is used. A serious concern regarding dense-racked spent fuel pools is that in the event of an accident, such as that at Fukushima, or a targeted terrorist attack, the loss of cooling water, either through the interruption of water pumped through the pool or from a rupture in the pool itself (or both) could ultimately, following a loss of pool water, lead to a rise in temperature sufficient to cause the zircaloy cladding of the fuel elements (which make up fuel assemblies) to ignite.[5] The resulting "pool fire" has the potential to spread a vast amount of radioactive material—much more than would result from a breach in the core of a reactor, because the inventory of radioactivity in a spent fuel pool is much higher than in a reactor core—over a wide area. In the Fukushima accident, the possibility of a spent fuel pool fire in the pool for reactor number 4 was of serious concern, as active cooling was interrupted for many weeks, and emergency cooling (for example, spraying water into the spent fuel pool with concrete pumping trucks) was required.[6]

Japan finds itself at a juncture where Japanese policymakers, with input from the nuclear technical community, academics, non-governmental groups, and many others, are working to decide the future of the Japanese nuclear power industry, and more broadly, the Japanese power sector in general. In the nuclear power industry, decisions facing Japan include not only whether (or how many) existing reactors to restart, and on what timeframe, but also whether to continue to use dense-packed spent fuel pools or shift to another storage method for cooled spent fuel, whether to restart its spent fuel reprocessing program, and, relatedly, whether to continue to aim toward an electricity sector future in which fast reactors play a key role.

This report focuses on the spent fuel management issue in Japan, and in particular, on the prospects and challenges for the implementation of one or more interim dry cask storage facilities in Japan, specifically in coastal, island, or barge-mounted configurations.

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[4] The first phase of the Mutsu facility, accommodating 3000 tonnes of spent fuel, was due to be commissioned in 2016, with the second phase (2000 tonnes) schedule for 2028 (World Nuclear Organization (2015), "Japan—Nuclear Fuel Cycle", available as http://www.world-nuclear.org/info/Country-Profiles/Countries-G-N/Japan--Nuclear-Fuel-Cycle/. See also Tatsuya Ishikawa (2013), "Current Status of Japan's Storage facility for Spent fuels", prepared for a conference held 2-4 July 2013, and available as https://www.iaea.org/OurWork/ST/NE/NEFW/Technical-Areas/NFC/documents/spent-fuel/TM-45455/Agenda-22-JAPAN-Current_status_of_Japans_ISFS.pdf.

[5] For a discussion of this issue see, for example, Gordon Thompson (2013), *Handbook to Support Assessment of Radiological Risk Arising From Management of Spent Nuclear Fuel*, Nautilus Institute Special Report dated May 14, 2013, available as http://nautilus.org/napsnet/napsnet-special-reports/handbook-to-support-assessment-of-radiological-risk-arising-from-management-of-spent-nuclear-fuel/.

[6] See, for example, OECD Nuclear Energy Agency, "Timeline for the Fukushima Daiichi nuclear power plant accident", available as https://www.oecd-nea.org/news/2011/NEWS-04.html.

1.2 Dry Cask Storage Internationally and in Japan

When the boiling water reactors (BWRs) and pressurized water reactors (PWRs) in widespread use today were first designed, their designers expected spent fuel to be cooled for a few years in spent fuel pools on reactor sites, then to be removed for reprocessing. In the United States, however, commercial reprocessing was unsuccessful, and as spent fuel began to accumulate in reactor spent fuel pools, other modes of spent fuel storage were sought. Dry cask storage was first implemented in the United States 30 years ago, and the US Nuclear Regulatory Commission (US NRC) summarizes the U.S. experience with dry cask storage as follows:

"Since the first casks were loaded in 1986, dry storage has released no radiation that affected the public or contaminated the environment. There have been no known or suspected attempts to sabotage cask storage facilities. Tests on spent fuel and cask components after years in dry storage confirm that the systems are providing safe and secure storage. The NRC also analyzed the risks from loading and storing spent fuel in dry casks. That study found the potential health risks are very small."[7]

U.S. reactor owners now operate dry cask storage at on the order of 75 sites around the country. Other nations, including Germany, the United Kingdom (UK), Sweden, China, and the ROK, also use dry cask storage, with some programs well established, and some (including China's) fairly new.

Japan has a great deal of experience with using transport casks, which are similar to dry casks in design. Transport casks were used to transport over 7000 tonnes of spent fuel by ship to reprocessing facilities in the UK and France between 1969 and the 1990s.[8] The use of dry cask storage in Japan, however, has been very limited until recent years, in part due to the historical emphasis on reprocessing and a closed fuel cycle in Japan, and in part due to the nature of the agreements between Japanese nuclear utilities and localities that host nuclear facilities (though these two factors are historically related). Dry cask storage is currently in use in Japan in several installations, though spent fuel pools remain the dominant storage mode. Dry casks were used at the Fukushima Daiichi plant prior to the March 2011 earthquake, tsunami, and subsequent nuclear accident at the plant, and have been and are being used to off-load the fuel from the crippled reactors, as those reactors (and their spent fuel pools) are decommissioned. As of March 2010, 408 tonnes of spent fuel were stored in dry casks at the Fukushima Daiichi site, constituting about 4 percent of stored spent fuel at the site at the time.[9] The dry casks at the Fukushima site were not damaged when the reactors were hit by the tsunami following the March 11 Great East Japan Earthquake. Dry casks are also being used in the Mutsu interim spent fuel storage facility on which construction started in 2010, and was reportedly completed in 2013, though initial operations have apparently been delayed until 2018 pending Nuclear Regulatory Agency (NRA) review.[10] The Mutsu facility is located in Aomori prefecture, near the Rokkasho reprocessing plant. The first stage of the Mutsu plant is designed to hold 3000

[7] US NRC (2015), "Backgrounder on Dry Cask Storage of Spent Nuclear Fuel", dated September, 2015, and available as http://www.nrc.gov/reading-rm/doc-collections/fact-sheets/dry-cask-storage.html.
[8] See World Nuclear Organization (2016), "Transport of Radioactive Materials", updated July, 2016, and
[9] Yumiko Kumano (2010), "Integrity Inspection of Dry Storage Casks and Spent Fuels at Fukushima Daiichi Nuclear Power Station", dated 16 November 2010, and available as http://www.nirs.org/reactorwatch/accidents/6-1_powerpoint.pdf.
[10] World Nuclear Organization (2016), "Japan's Nuclear Fuel Cycle", updated September 2016, and available as http://www.world-nuclear.org/information-library/country-profiles/countries-g-n/japan-nuclear-fuel-cycle.aspx.

tonnes of spent fuel in dry casks. A subsequent stage is planned to add 2000 tonnes of storage capacity.

1.3 Contents of this Report

The remaining sections of this report are organized as follows:

- **Section 2** summarizes international experience with and proposals for interim spent fuel storage facilities located remote from reactors, including facilities proposed for coastal, island, and barge-based locations. Section 2 also summarizes the key generic elements of interim spent fuel storage facilities.
- **Section 3** describes Japanese proposals developed to date for remote interim spent fuel storage facilities, including a description of the existing, but not yet operating, facility at Mutsu.
- **Section 4** reviews the key elements of a generic spent fuel storage facility for Japan, including both technical/environmental attributes and political/social/organizational attributes.
- **Section 5** briefly compares the relative attributes of a coastal, island, or barge-based dry cask spent fuel storage facility relative to existing spent fuel management systems now used in Japan.
- **Section 6** describes some of the key social and political barriers and challenges to developing additional remote interim spent nuclear fuel storage facilities in Japan.
- **Section 7** provides key conclusions from the analysis presented, and identifies potential next steps in research and discussions between stakeholders that might be needed in the further consideration of alternatives for nuclear spent fuel management in Japan.

2 International Experience with and Proposals for Remote Interim Spent Fuel Storage

The key goals of remote interim storage of spent fuel from nuclear reactors, whether civilian or military (for example, fuel from nuclear submarines, ice breakers, or other naval vessels) are typically to provide a site and facility for the storage of spent nuclear fuel that minimizes the danger of nuclear releases to the environment, including exposure to human populations, for at least many decades, and is easily securable from accident or attack. An additional goal is to move cooled spent fuel out of wet storage, typically in spent fuel pools at nuclear power plants (though sometimes at other facilities, such as reprocessing facilities) to relieve storage constraints in spent fuel pools. Interim spent fuel storage can be done using spent fuel pools, but if the goal is to store fuel for at least several decades, dry cask storage is more typically used. In the remainder of this section we provide a brief review of the typical technical elements of interim spent fuel storage facilities, then summarize international experience with and proposals for interim spent fuel storage facilities at coastal, island, and barge-based locations.

2.1 Typical Components of Interim Spent Fuel Storage Facilities

The typical components of interim storage facilities for spent nuclear fuel will usually include dry casks of one or more types, platforms, cavities, and/or buildings to accommodate the dry casks, transportation and cask handling systems, and site security and monitoring systems.

2.1.1 Dry Cask Storage

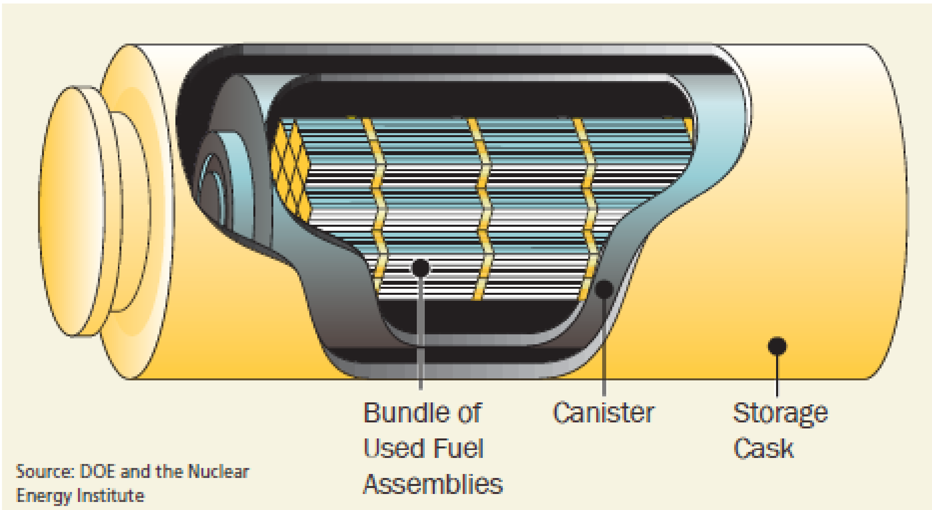
Dry cask storage has a number of technological variants, but typically involves placing a number of spent fuel assemblies that have been cooled in spent fuel pools for a number of years—usually at least five years—into a thick stainless steel cylinder from which air and water have been removed, and an inert gas such as argon is added. The spent fuel assemblies are then sealed into the cylinder by welding the cylinder shut or bolting on an air-tight lid. Stainless steel cylinders holding the fuel assemblies are then place in massive concrete vaults or "overpacks". Overpacks are cylinders of concrete or a combination of steel and concrete, usually with channels for air circulation, which surround the stainless steel cylinders and provide protection for workers and the environment from radiation coming from the spent fuel. Dry cask storage systems are designed to provide the required cooling for the spent fuel without the use of pumps or fans. A summary description of dry cask storage by the Nuclear Regulatory Commission (NRC) of the United States includes the following:[11]

"Cask systems are designed to contain radiation, manage heat and prevent nuclear fission. They must resist earthquakes, projectiles, tornadoes, floods, temperature extremes and other scenarios. The heat generated by a loaded spent fuel cask is typically less than is given off by a home-heating system. The heat and radioactivity decrease over time without the need for fans or pumps. The casks are under constant monitoring and surveillance."

[11] U.S. Nuclear Regulatory Commission (2015), "Backgrounder on Dry Cask Storage of Spent Nuclear Fuel". Dated September 2015, and available as http://www.nrc.gov/reading-rm/doc-collections/fact-sheets/dry-cask-storage.html.

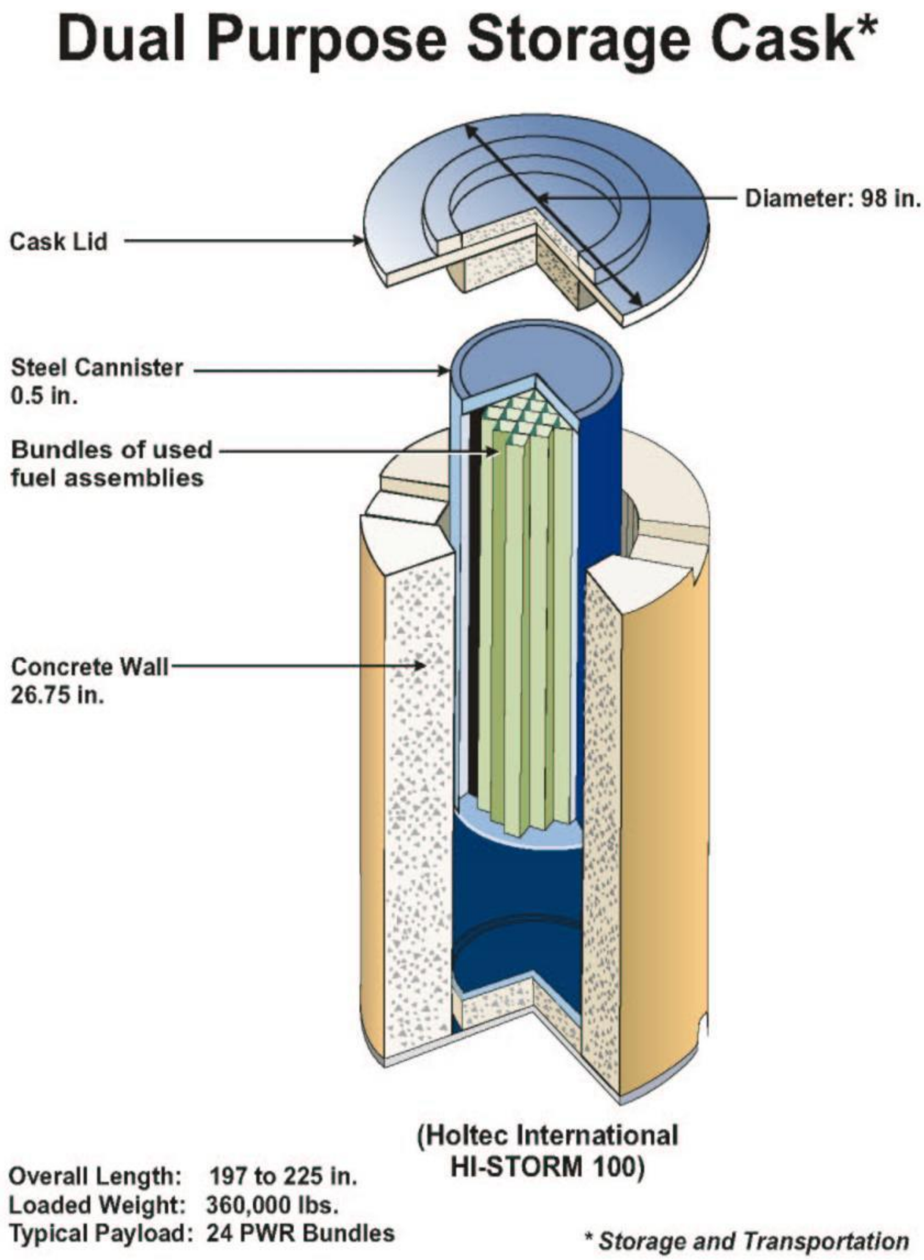
There are more than a dozen commercial suppliers of spent fuel casks and cask systems, and dozens of different cask models available.[12] Figure 2-1 shows a schematic of dry storage of bundles of spent fuel within a metal canister and a storage cask. Figure 2-2 shows an example of a multi-purpose cask used for storage and transportation of spent fuel.[13]

Figure 2-1: Schematic of Dry Cask Storage Containers



[12] See, for example, Appendix I and Appendix II of International Atomic Energy Agency (IAEA, 2007), *Operation and Maintenance of Spent Fuel Storage and Transportation Casks/Containers*, IAEA-TECDOC-1532, dated January 2007, and available as http://www-pub.iaea.org/MTCD/publications/PDF/te_1532_web.pdf.
[13] Figure 2-1 and Figure 2-2 from Earl Easton, Division of Spent Fuel Storage and Transportation, U.S. Nuclear Regulatory Commission, "Dry Cask Storage of Nuclear Spent Fuel", (undated, probably 2013), available as http://www.ncsl.org/documents/environ/Easton.pdf.

Figure 2-2: Example of Multi-purpose (Storage and Transport) Cask



Dry cask storage has been used for many years around the world, typically (though not exclusively) at nuclear reactor sites, to provide a secure means of storing spent fuel. Although dry cask storage is not intended to be a permanent storage solution for nuclear fuel, the expected service lifetimes of dry casks in nuclear spent fuel storage has been estimated at 50 to 100 years or more, making dry casks an attractive "bridge" technology until permanent storage/disposal technologies and locations can be developed and agreed upon, either by individual nations, or for regional international use.

2.1.2 Dry Cask Emplacements

Interim spent fuel storage facilities using dry casks employ a variety of different emplacement configurations. The simplest type of emplacement stores dry casks, either with or without a cylindrical concrete overpack (depending on the cask design) in a vertical configuration on a thick (for example, 60 cm) concrete pad. Figure 2-3 shows a dry cask installation on a concrete pad at a US reactor site.

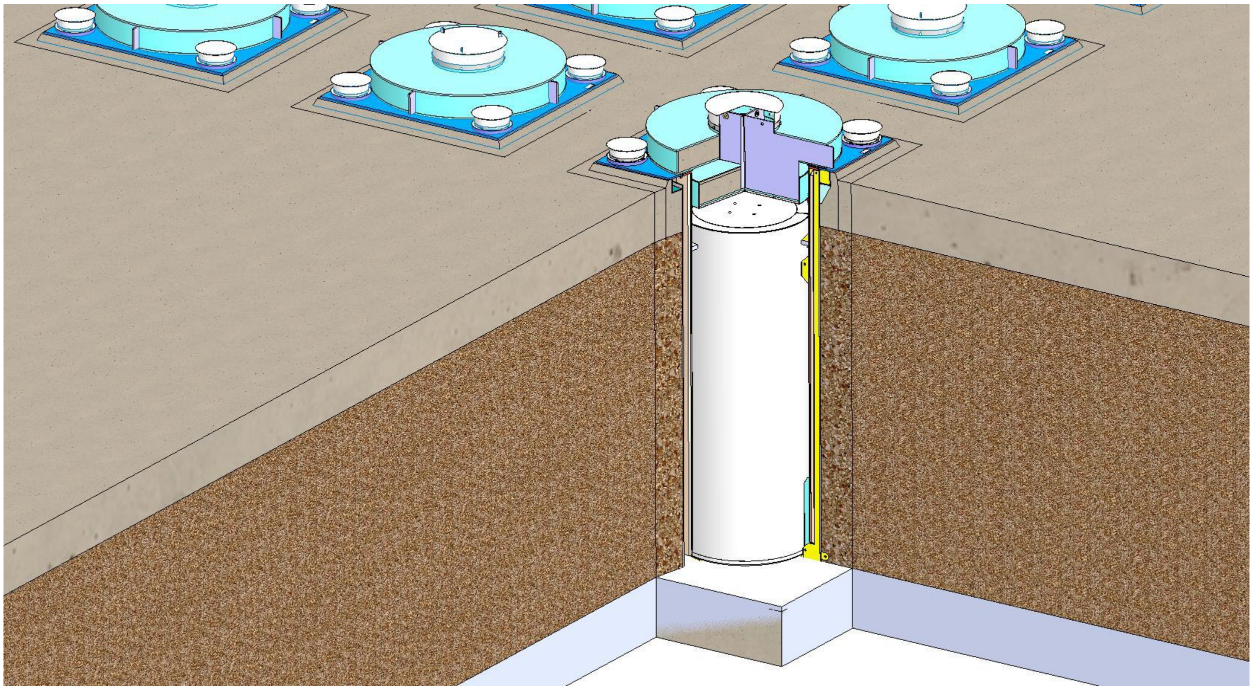
Figure 2-3: Dry Casks on a Concrete Pad at a US Reactor (Connecticut Yankee)[14]

Dry casks can also be recessed in holes in concrete pad, such as in the example shown in Figure 2-4. This configuration provides additional protection for the casks, for example, from seismic

[14] Connecticut Yankee (2016), "Fuel Storage & Removal", available as http://www.connyankee.com/html/fuel_storage.html. The site shown is on property owned by the reactor operator, but is over a kilometer from the reactor site itself.

events, extreme weather, tsunamis, or airplane/missile attacks, while retaining the ability to be monitored from the outside (such as by satellite).

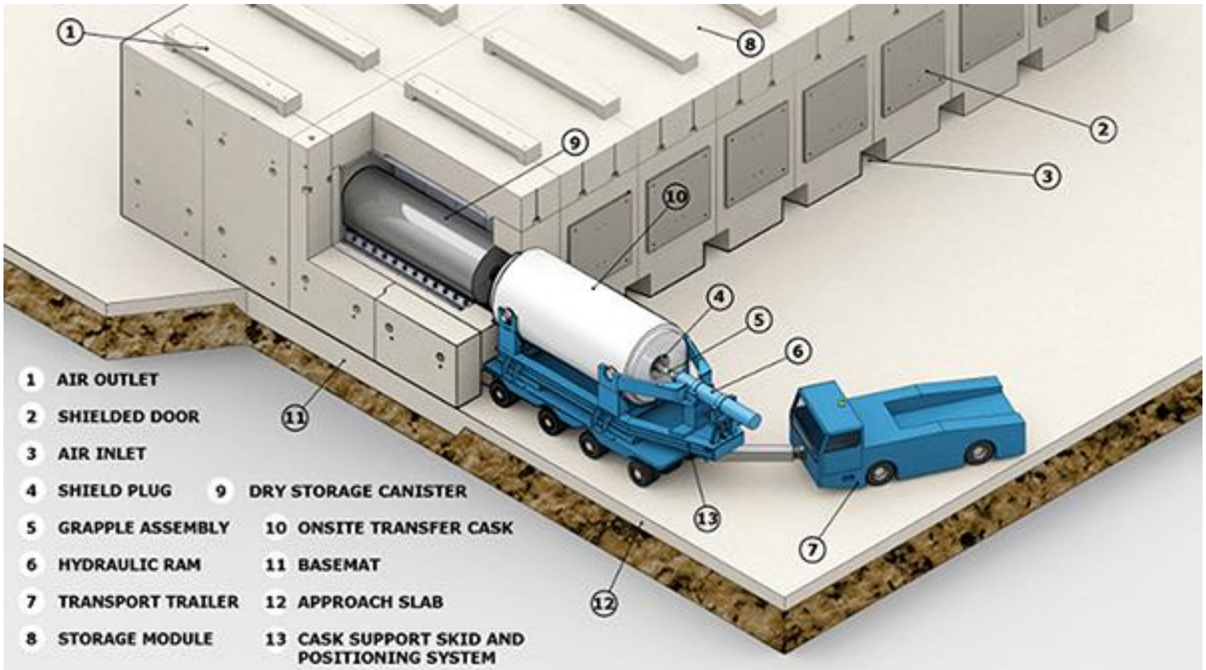
Figure 2-4: Example of Vertically Buried Dry Cask Storage with Recessed Casks [15]



A second alternative is to store dry cask horizontally in concrete vaults that provide protection from the elements (and attack) while including passive cooling channels, as shown in Figure 2-5.

[15] Image from William S. Woodward (2015), "Underground Interim Storage of Spent Nuclear Fuel–HI-STORM UMAX", presentation to the IAEA Conference on Management of Spent Fuel from Nuclear Power Reactors, Vienna, Austria: June 15-19, 2015. Available as http://www-pub.iaea.org/iaeameetings/cn226p/Session5/ID148Woodward.pdf. In this example, the HI-STORM UMAX system (Holtec International), the steel and concrete lid provides air inlets for passive cooling within the steel liner that surrounds the cask, and the cask sits on a concrete pad within a fill of concrete or another engineered material.

Figure 2-5: Example of a Horizontal Dry Cask Storage Installation with Cask Handling Equipment[16]



Dry casks can also be stored vertically or horizontally within a building constructed for the purpose. Such buildings typically have cranes or other equipment to move spent fuel casks from delivery bays to storage locations. Examples include Spain's planned "ATC" (Almacén Temporal Centralizado, or Centralized Interim Storage Facility),[17] and Japan's Mutsu interim spent fuel storage facility (see section 3, below).

2.1.3 Transportation and Handling Systems

Interim spent fuel storage installations include equipment for transportation and handling of dry casks. Some installations include equipment for moving spent fuel assemblies in and out of dry casks, including for evacuating, charging with inert gas, and sealing the metal canisters in which spent fuel is placed (the inner part of the cask), but in many instances those tasks will be performed prior to transportation at the nuclear power plant site from which the spent fuel originated. Depending on the expected life of the interim storage facility, equipment for moving spent fuel from old casks into new casks, perhaps after 100 or so years of storage, will eventually need to be a part of the facilities, along with equipment for opening and sealing spent fuel canisters. The full complement of equipment needed to handle the repackaging of spent fuel 100

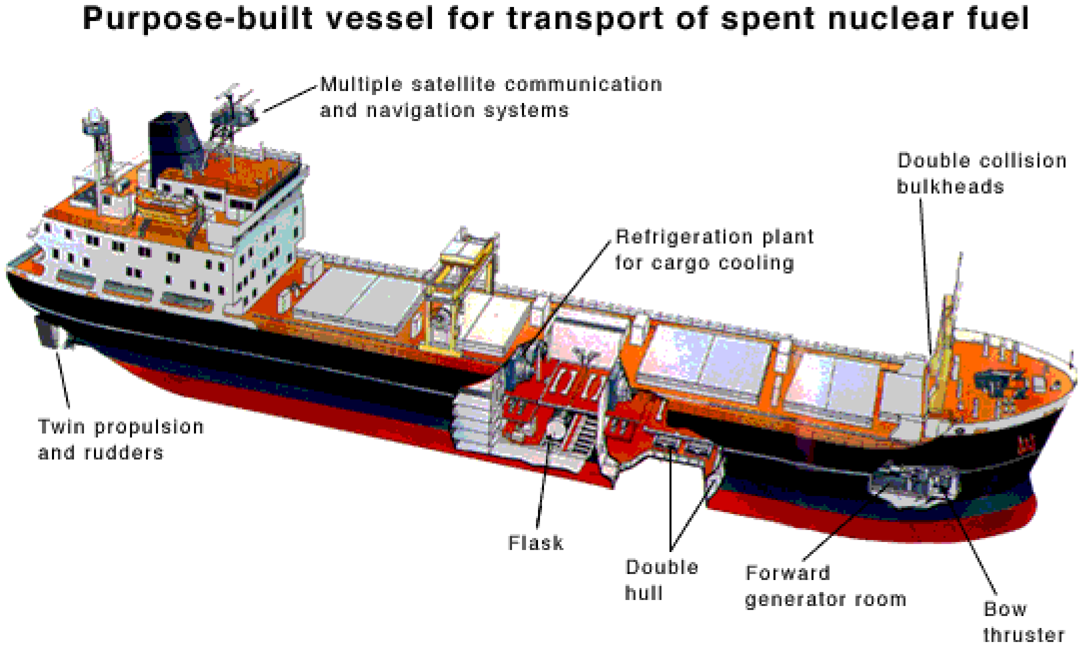
[16] Image from Gail Reitenbach (2015), "Dry Cask Storage Booming for Spent Nuclear Fuel", *Power Magazine*, dated 02/01/2015, and available as http://www.powermag.com/dry-cask-storage-booming-for-spent-nuclear-fuel/.
[17] See Equipos Nucleares, S.A. (2014), "Spanish Scenario for Spent Fuel Management", dated January 14, 2014, and available as https://www.inmm.org/AM/Template.cfm?Section=29th_Spent_Fuel_Seminar&Template=/CM/ContentDisplay.cfm&ContentID=4367.

years from now is not necessarily well-understood at present, as fuel may have degraded during storage (this is thought to be a potential problem for high-burnup fuel in particular[18]) and may thus require special handling in order to be safely repackaged. As advances continue in the field of remotely-operated (and, indeed, autonomous) robotics, one could expect that machines to safely handle and repackage degraded spent fuel will become more capable and available in the decades to come, but ongoing research and development (and financial support for same) will be needed to assure that this is the case.

Depending on the location of the interim spent fuel storage facility, spent fuel can arrive in dry casks, transport casks, or “dual purpose” (transport and storage) casks by specially designed ship, by road on specially-designed trailers, or by rail on specially designed rail cars. If spent fuel arrives by ship (see example in Figure 2-6), a crane/gantry system if typically used to move casks to a truck/trailer system that is used to move the casks the remaining distance to the storage facility. For dry casks arriving by rail, rail cars (see example in Figure 2-7) may arrive adjacent to the facility, with casks off-loaded by cranes or gantries to an on-site trailer or cask other cask handling system, or directly to the facility’s receiving bay. Dry casks arriving by truck are unloaded by to an on-site handling system (see example in Figure 2-9), which may resemble a large forklift or, for a facility in a building, may include a crane mounted on a beam that is integral to the building.

[18] "High burn-up” fuel has spent more time in an operating reactor core, in order to maximize use of the fissile material in the fuel (and improve fuel economics), and is thus significantly more radioactive and thermally hot than typical spent fuel, changing its storage characteristics, and possibly affecting the integrity of its cladding. See for example, Peter Rudling, Ron Adamson, Brian Cox, Friedrich Garzarolli and Alfred Strasser (2008), “High Burnup Fuel Issues”, *Nuclear Engineering And Technology*, Vol.40 No.1, February 2008, and available as https://www.kns.org/jknsfile/v40/JK0400001.pdf. Note that this reference does not specifically address the stability of high burn-up fuel under long-term storage, but describes some of the potential changes in nuclear fuels subjected to high burn-up. See also William Boyle (2014), “FY14 DOE R&D in Support of the High Burnup Dry Storage Cask R&D Project”, Nuclear Waste Technical Review Board Meeting, August 6, 2014, Idaho Falls, Idaho, available as http://www.nwtrb.gov/meetings/2014/aug/boyle.pdf.

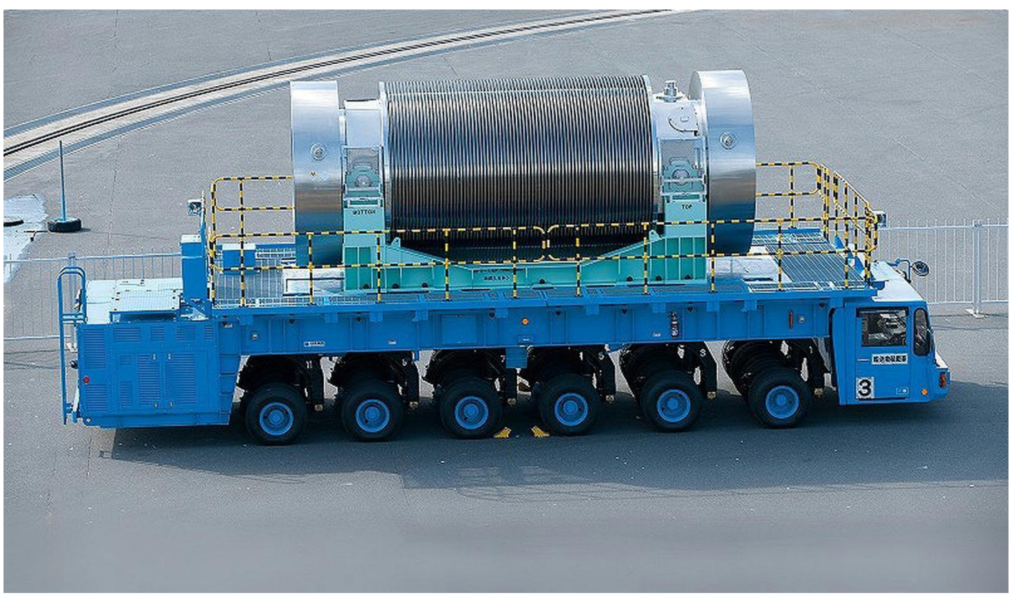
Figure 2-6: Example of Spent Nuclear Fuel Transport Vessel[19]



[19] Image from World Nuclear Organization (2016), "Transport of Radioactive Materials", last updated July, 2016, and available as http://www.world-nuclear.org/information-library/nuclear-fuel-cycle/transport-of-nuclear-materials/transport-of-radioactive-materials.aspx.

Figure 2-7: Example of Rail Car Carrying Spent Fuel Cask[20]

Figure 2-8: Example of Truck Used to Move Spent Nuclear Fuel Transport Casks in Japan[21]



[20] Associated Press (2014), "Feds want nuclear waste train, but nowhere to go", dated August 31, 2014, and available as http://www.dailymail.co.uk/wires/ap/article-2739081/Feds-want-nuclear-waste-train-go.html.
[21] Image from Cryptome (2011), "Fukushima Daiichi Nuclear Power Plant Photos 7", available as https://cryptome.org/eyeball/daiichi-npp7/daiichi-photos7.htm. Original image apparently from Tokyo Electric Power Company.

Figure 2-9: Vertical Cask Transporter in Use at Humboldt Bay (California, USA) Interim Storage Site[22]

[22] Tawni Hardwick, Lawrence Pulley, E. Don Strassman (2010), "Dry Cask Storage Pacific Gas & Electric – Humboldt Bay Power Plant", WM2010 Conference, March 7-11, 2010, Phoenix, AZ, available as http://www.wmsym.org/archives/2010/pdfs/10217.pdf.

Figure 2-10: Cask Handling Crane[23]

2.1.4 Site Security and Monitoring Systems

Security arrangements at remote interim spent fuel storage facilities typically consist of a combination of physical barriers, an on-site monitoring staff, on-site monitoring equipment, and remote monitoring equipment.

Physical barriers at an interim spent fuel storage site will include a surrounding fence to prevent unauthorized entry and deter intrusion, but may also include, for example, earthen berms and/or concrete walls to deter, deflect, or blunt attacks that might seek to penetrate the spent fuel casks. Examples of such attacks could include targeting casks with aircraft or with missiles. For dry casks stored on pads outdoors, spacing casks to reduce the probability that more than one cask will be significantly damaged in an aircraft or missile attack is also a possible security strategy.

Interim spent fuel storage facilities typically have around-the-clock onsite security personnel. These personnel are typically augmented by monitoring arrangements that allow off-site personnel to detect any intrusion or other emergency at the site remotely, and to respond to an intrusion or emergency.

Monitoring equipment for interim spent fuel storage facilities include cameras located in and around the facility to provide visual monitoring for on-site and off-site personnel, augmented by satellite monitoring. In addition, sensors are deployed, and networks set up, to monitor a number of parameters. Sensors can be set up both outside between casks and, in some cases, inside the air circulation areas inside individual casks to monitor parameters such as temperature, moisture, hydrogen, oxygen, fission gases, radiation, and pressure. Some sensors can detect fuel cladding temperatures. A number of organizations are pursuing research into improving monitoring facilities for interim spent fuel storage facilities using dry casks, including using cellular and satellite technology to avoid dependence on land-line based data systems.[24]

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[23] Image from “Cask Handling Cranes“, website of commercial vendor of cask handling equipment Konecranes, http://www.konecranesusa.com/industries/nuclear/nuclear-equipment/cask-handling-cranes.

[24] See, for example, William Boyle (2014), ibid, and H. Tsai, B. Craig, H. Lee, K. Mittal, Y. Liu, and J. Shuler (2014), “ARG-US Remote Area Modular Monitoring for Dry Casks and Critical Facilities”, INMM 55th Annual Meeting, July 20–24, 2014, Georgia USA, available as https://rampac.energy.gov/docs/default-source/tracking/inmm55_tsai_ramm.pdf.

2.2 Spent Fuel Storage in Coastal Locations

Coastal locations are common for existing and proposed interim storage facilities for nuclear spent fuel. A first major reason for this is that a large fraction of the nuclear reactors worldwide are located on coasts, primarily to ensure access to adequate supplies of cooling water for applications. Over 20 interim storage facilities in the United States are located, or are proposed to be located, at coastal locations, all at or near sites that host (or, in the case of decommissioned reactors, hosted) nuclear reactors.[25] A second major reason for hosting interim storage facilities at or near coasts is the proximity to maritime transport facilities that can be used to bring in and ship out dry casks. Coastal interim spent fuel storage facilities are also more easily secured from land attack than inland facilities, as the number of directions such an attack can come from are limited, and access to the site in one or more directions is cut off by the sea, but sea-borne attacks become possible and must be guarded against. Conversely, coastal locations may be more difficult for land-based security personnel to reach in the event of an emergency, though the coastal location opens up avenues for response by naval or coast guard vessels and personnel.

A number of coastal locations are being used or are being considered for interim spent fuel facilities:

- In Sweden, spent nuclear fuel from the nation's 12 reactors (two of which have been closed) has been transported since 1985 to a centralized interim storage facility ("CLAB") located at the Oskarshamn nuclear power plant, on the Baltic seacoast about 200 km South of Stockholm. The CLAB facility stores spent fuel, in the canisters in which it is shipped, in large water-filled pools, 30 m underground, but one report on the facility suggests "[i]f a centralized interim storage were to be built today it would likely be a dry storage facility, also likely underground for better physical protection".[26] The facility will be full well before the end of the operating life of Sweden's remaining reactors, so a dry storage facility may be added to CLAB, particularly if the development of Sweden's planned permanent underground (500 m) mined spent fuel repository does not proceed as rapidly as expected.

- In the United States, discussions have thus far failed to converge on sites for centralized spent fuel storage, and as a result interim spent fuel storage facilities are located throughout the country near existing or decommission reactors. The Maine Yankee interim storage facility, on the Atlantic Coast near Wiscasset, Maine, is an example of one of the many coastal spent fuel facilities, in this case, at a decommissioned nuclear power plant. That the U.S. Government (specifically, the Department of Energy) has long been the subject of litigation by the Maine Yankee Atomic Power Company and its sister companies over the Department of Energy's failure to meet its obligations to remove fuel from the reactor site underscores the political difficulty of maintaining distributed interim fuel storage sites and reaching agreement on centralized sites,

[25] See US NRC (2016), [Map of] U.S. Independent Spent Fuel Storage Installations (ISFSI)", labeled as "Current as of October 6, 2016), and available as http://www.nrc.gov/docs/ML1628/ML16286A019.pdf.

[26] Johan Swahn (2014), "Storage of spent nuclear fuel in Sweden: The role in management of nuclear waste and the ongoing license application for a spent fuel repository", undated, but probably 2014. Available as http://www.polsoz.fu-berlin.de/polwiss/forschung/systeme/ffu/veranstaltungen/termine/downloads/14_salzburg/Swahn-2014.pdf.

although efforts to find centralized sites continue.[27] The litigation has resulted in hundreds of millions dollars in damages awarded the Yankee companies and their ratepayers.[28]

- In the Republic of Korea, a limited amount of dry-cask storage is used at the Wolsong reactor site for CANDU (Canadian deuterium reactor) fuel, and dry storage has been recommended as a way to relieve spent fuel pool congestion at other reactor sites (all coastal). Centralized interim spent fuel storage facilities are under consideration in the ROK, but no specific sites have been identified to date.[29]
- In the Netherlands, the COVRA facility is located on an inlet to the North Sea near Vlissingen, near the existing Borssele reactor, and handles spent fuel (including highly-enriched uranium fuel) from research reactors and high level waste returned from reprocessing of spent fuel from commercial power reactors in the Netherlands carried out in France and the UK, as well as low- and intermediate-level radioactive wastes. COVRA was designed to hold wastes for 100 years. The facility stores highly radioactive wastes in massive concrete vaults, but the Netherlands apparently does not plan to use dry cask storage for spent fuel from commercial reactors at the COVRA facility (or elsewhere).[30]
- The most successful siting of a spent fuel storage facility—in this case, a spent fuel disposal facility—in the world is arguably that of Olkiluoto, a peninsula on Finland's west (Gulf of Bothnia) coast that already hosts a nuclear power plant, and will be host to a mined (400 m deep) repository for spent fuel placed in sealed copper canisters. The facility is set to open in 2020.[31]

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[27] Jeff Tollefson (2015), US government seeks sites for nuclear-waste storage", *Nature*, 24 March 2015, available as http://www.nature.com/news/us-government-seeks-sites-for-nuclear-waste-storage-1.17183.

[28] See, for example, "Maine Yankee: An Interim Storage Facility for Spent Nuclear Fuel" (undated, but probably 2014), available as http://www.maineyankee.com/public/MaineYankee.pdf; and "Maine Yankee: Spent Fuel Storage / Removal", 2016, available as http://www.maineyankee.com/.

[29] See, for example, World Nuclear Organization (2016), "Nuclear Power in South Korea, updated 20 September 2016, and available as http://www.world-nuclear.org/information-library/country-profiles/countries-o-s/south-korea.aspx; and Ferenc Dalnoki-Veress, Miles Pomper, Stephanie Lieggi, Charles McCombie, and Neil Chapman (2013), *The Bigger Picture: Rethinking Spent Fuel Management in South Korea*, James Martin Center For Nonproliferation Studies, Middlebury College, March, 2013, available as https://www.files.ethz.ch/isn/161248/130301_korean_alternatives_report1.pdf.

[30] See Netherlands Ministry of Economic Affairs (2015), Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management, National Report of the Kingdom of the Netherlands for the Fifth Review Conference=, dated (May 2015)

[31] Elizabeth Gibney (2015), "Why Finland now leads the world in nuclear waste storage", *Nature*, 2 December 2015, available as http://www.nature.com/news/why-finland-now-leads-the-world-in-nuclear-waste-storage-1.18903. See also Veijo Ryhänen (2011), "Management of Spent Fuel and Other Nuclear Waste in Finland -Progress of the Programme since the 1970s", IAEA Workshop on Building Partnership In Waste Disposal Programme Kuala Lumpur, 31 October–2 November, 2011, available as https://www.iaea.org/OurWork/ST/NE/NEFW/WTS-Networks/DISPONET/disponetfiles/MalaysiaTC2011/TCMalaysia2012-MngtSpentFuel_Ryhanen.pdf.

2.3 Spent Fuel Storage on Islands

Placing a spent fuel storage facility on an island is similar in concept to using a coastal location, except that transportation of spent fuel by ship becomes essentially obligatory, and security of the site must focus on threats from the sea, as well as from the air (the latter applies to all sites, except those relatively deep underground). In addition, island sites must be chosen to avoid excessive risk of damage by storms, as well as to tsunamis.

Starting in the late 1970s, and recurring again in the late 1980s and 1990s, the United States and other national partners, including (in some cases) Japan, considered building interim spent fuel storage facilities on islands in the North and Equatorial Pacific, first in the Marshall Islands, and then at Wake and Palmyra Islands. Potential sites on Midway Island and other locations in the Pacific were also discussed. An IAEA document describes the more recent Pacific Island proposals as follows:[32]

"..Marshall Islands (1995–97)…The President of the Marshall Islands proposed hosting a storage and disposal facility, with the revenues being used in part to clean up contamination from earlier bomb testing... The Government amended the law in 1995 to allow import of wastes. However there was strong opposition from Pacific states and from the US Government. As a result the project was 'frozen' and a subsequent change of Government led to its being dropped."

"…Wake Island/Palmyra Island (mid 1990s)…A USA based group, US Fuel and Security, initiated a scheme with the support of Minatom of the Russian Federation, involving storage and fuel leasing based on a Pacific island. The initial proposal was for Wake Island; later the target was Palmyra Island which was US privately owned at the time. In 1996 there was an attempt to purchase Palmyra Island from its private owner; this failed and in 2000 Palmyra Island was bought by US Nature Conservancy. In 1997, a request for using Wake Island was filed by US Fuel and Security with the US Government… There was strong opposition from the US Administration, however, and the proponents turned their attention to the Russian Federation …"

A 1982 document describing potential sites for spent nuclear fuel storage in the Pacific does include a rough schematic of how storage on an island might be designed, including what appears to be dry casks (as they existed at the time) sitting on a concrete pad over built-up coral fill.[33] No enclosure or other protection is included in the schematic, which probably was not intended to be comprehensive in its detail. A 1984 document, quoting U.S. Senate records from 1979, includes a map of Palmyra Island indicating the potential location of a spent fuel storage site along the lagoon on what was to have been an infilled area of coral reef.[34] We have so far been unable to located additional design details for any of the Pacific island-based proposals for multinational interim spent fuel storage, but such designs may exist. An entry in the US Congressional record from 1996 indicates that a regional interim spent fuel facility planned by a

[32] International Atomic Energy Agency (IAEA, 2004), *Developing multinational radioactive waste repositories: Infrastructural framework and scenarios of cooperation,* IAEA-TECDOC-1413, dated October, 2004, and available as http://www.arius-world.org/pdfs_pub/IAEA-TECDOC-1413.pdf.

[33] William Lawrence Spicuzza (1982), National Policy Implications of Storing Nuclear Waste in the Pacific Region, National Defense University National Security Affairs Issue Paper 82-1, available as www.dtic.mil/cgi-bin/GetTRDoc?AD=ADA111928.

[34] "Map 11" in Iraphne R.W. Childs, *Nuclear Wastes in the Pacific: Perceptions of the Risk,* Ph.D. Thesis, University of Hawaii, dated May, 1984, available from http://hdl.handle.net/10125/9793.

for-profit business for installation on Palmyra island was to have accommodated 200,000 tonnes of spent fuel (as well as excess plutonium and other nuclear materials), while providing up to $250 million per year to a trust fund for the Pacific Island Nations of the region.[35]

2.4 Spent Fuel Storage on Barges and Other Vessels

In addition to coastal locations and islands, spent nuclear fuel could also (or alternatively) be stored on barges or other vessels, presumably, for the most part, at anchor in sheltered waters. Nuclear power has provided motive power for naval vessels, including aircraft carriers, submarines, and other vessels, as well as for icebreakers operating in the Russian (and formerly Soviet) Arctic. In addition to the icebreakers, a small number of civilian vessels were built with nuclear propulsion, including the Japanese *Mutsu*, but civilian nuclear ships were not successful. Nuclear "barges" have also been used to provide power at coastal locations. The United States ship *Sturgis*, built from the bow and stern sections of a World War II Liberty ship into which a middle section containing a 10 MW-electric reactor was grafted, served to provide power at the Panama Canal during the 1960s and 1970s. After many years in storage on the US East Coast, the Sturgis was recently towed to Texas to be dismantled. Other examples of power barges are a pair of units being built in Russia for use in the Russian Arctic and Far East. China has announced plans to build as many as 20 nuclear power barges, for deployment at offshore oil and gas rigs and for other remote maritime projects.[36] Research on nuclear power barges also has a long history of research in several nations, including the ROK and Japan.[37]

[35] U.S. Congress (1996), *CONGRESSIONAL RECORD — HOUSE*, pages H6275-H6278, dated June 12, 1996, and available as https://www.congress.gov/crec/1996/06/12/CREC-1996-06-12-pt1-PgH6275-6.pdf.
[36] Dawn Stover (2016), "Floating nuclear power plants: China is far from first", *Bulletin of the Atomic Scientists*, dated June 2016, and available as http://thebulletin.org/floating-nuclear-power-plants-china-far-first9522.
[37] See, for example, IAEA (1998), Small power and heat generation systems on the basis of propulsion and innovative reactor technologies, Proceedings of an Advisory Group meeting held in Obninsk, Russian Federation, 20-24 July 1998, Report # IAEA-TECDOC-1172, available as http://www-pub.iaea.org/MTCD/publications/PDF/te_1172_prn.pdf.

Figure 2-11: The Nuclear Barge USS STURGIS Being Towed to Galveston, Texas to be Dismantled[38]

The nation with the most experience in storing spent fuel on floating vessels is Russia. Russia has used barges and other vessels to store spent nuclear fuel—mostly from naval reactors—and other nuclear wastes for many decades, with mixed results.

The nuclear service ship *Lepse*, originally designed a dry-goods ship before World War II but not completed, was refitted in the early 1960s to be used as a ship to refuel at sea nuclear submarines, icebreakers, and other ships powered by nuclear reactors. It was refitted again in 1981 to store nuclear spent fuel and wastes material, including for more than two decades at a dock a few kilometers from the Northwestern Russian city of Murmansk, on an inlet to the Barents Sea. After a long campaign to have the ship removed from the Murmansk area, the *Lepse* in 2012 was towed to the Nerpa shipyard, about 40 km by river/sea from Murmansk, where it was to be dismantled, and the nuclear materials isolated, in part using procedures that would need to be invented on-site.[39] Figure 2-12 and Figure 2-13 show the Lepse at dock in Murmansk and at sea, respectively.[40]

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[38] Image from American Nuclear Society (ANS, 2015), "Nuclear Power Barge Sturgis Begins Last Voyage*", ANS Nuclear Café*, posted on April 16, 2015, available as http://ansnuclearcafe.org/2015/04/16/nuclear-power-barge-sturgis-begins-last-voyage/.

[39] See, for example, Charles Digges (2012), "Lepse nuclear waste storage ship endangering Murmansk for decades finally headed for dismantlement", Bellona, September 12, 2012, available as http://bellona.org/news/nuclear-issues/radioactive-waste-and-spent-nuclear-fuel/2012-09-lepse-nuclear-waste-storage-ship-endangering-murmansk-for-decades-finally-headed-for-dismantlement.

[40] From Charles Digges (2012), "Lepse nuclear waste storage ship endangering Murmansk for decades finally headed for dismantlement", Bellona, September 12, 2012, available as http://bellona.org/news/nuclear-issues/radioactive-waste-and-spent-nuclear-fuel/2012-09-lepse-nuclear-waste-storage-ship-endangering-murmansk-for-decades-finally-headed-for-dismantlement.

Figure 2-12: Photo of the Russian Nuclear Materials Storage Ship Lepse at Dock in Murmansk

Figure 2-13: Older Photo of the Russian Nuclear Materials Storage Ship Lepse at Sea

The use of barges or other vessels for the storage of nuclear spent fuel would allow the construction of the vessels in multiple copies (and thus at lower cost) at a shipyard, but deployment of the vessels at any location offering desirable characteristics. Characteristics of suitable locations for barge-mounted spent fuel storage would presumably include locations that offer shelter from potential damage by storms and tsunamis, that can be adequately secured against terrorist attack, that are sufficiently remote from populations as to pose limited radiological risk, and that are (or can be made to be through compensation) acceptable to local authorities. Barge-mounted spent fuel storage is theoretically scalable, with additional barges added as more spent fuel is placed in storage. Storage barges would include facilities for lifting and moving spent fuel casks, facilities for holding and securing casks (presumably below decks, as is the case with many spent fuel transport ships), and, as with coastal and island-based (and indeed, any) interim spent fuel storage facilities, facilities to allow continuous monitoring of spent fuel casks and of the facility itself, and for guarding and securing the facility.

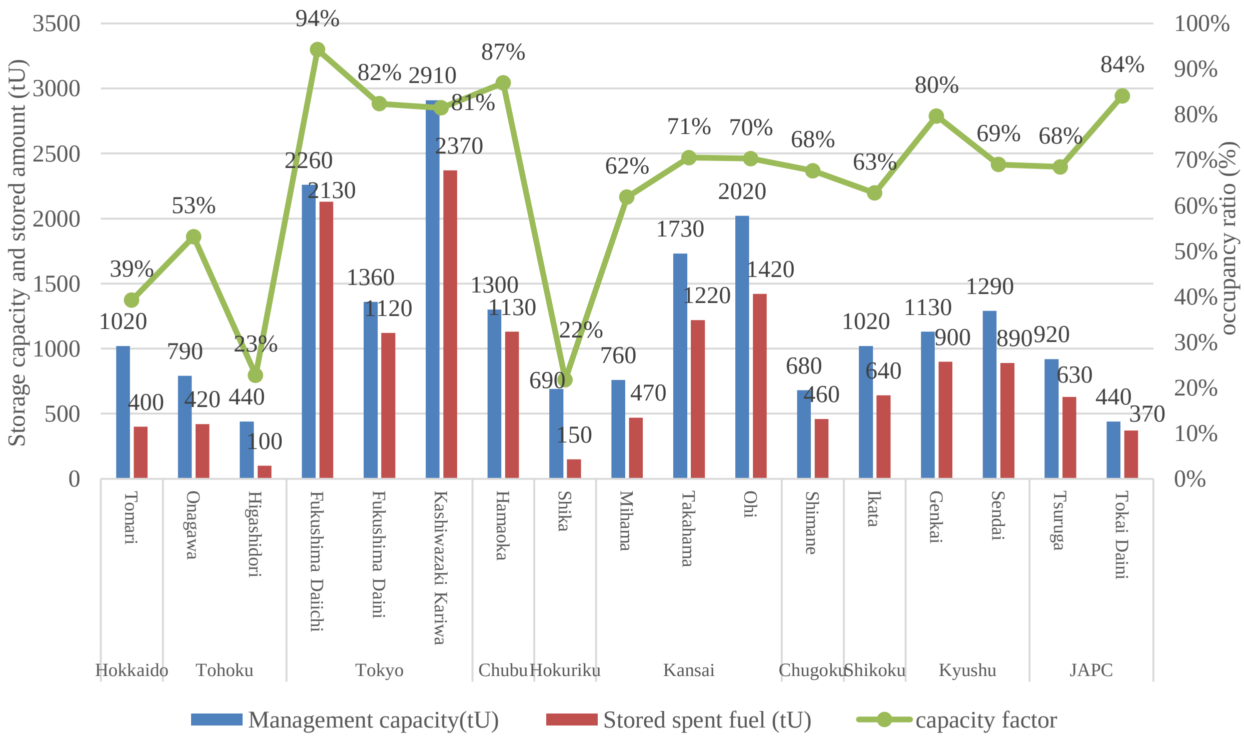
Presumably, a significant different between land-based interim spent fuel storage facilities and barge-based facilities would be that the barges themselves would need to be replaced or extensively refurbished periodically, perhaps more frequently than the fuel they store would need to be transferred between old and new dry casks. In addition, the barges themselves might be vulnerable to terrorist attack. Although the dry casks they store might well not be breached during such an attack, if the barges were sunk, retrieving the heavy casks from the wreck of the barge on the seabed would require a significant effort, and would probably be a cause for significant civil concern.

3 Japanese Proposals for Remote Interim Spent Fuel Storage Facilities

3.1 Introduction

In Japan, there is a growing demand for dry cask storage, since pool storage facilities at reactor sites currently about 70 percent full on average, and several plants have spent fuel pools that are over 80% percent occupied, as shown in Figure 3-1.

Figure 3-1: Occupied Ratio of Spent Fuel Pools at Reactor Site for Each Site (October, 2016)[41]



It has traditionally been Japanese national policy to reprocess all spent fuels in order to better utilize uranium resources, and to work toward a “closed” nuclear fuel cycle utilizing Fast Breeder Reactors (FBRs) in the “near” future. As a result, the government had not recognized the needs for spent fuel storage until the 1990s, when spent fuel pools at reactor sites were found

[41] Current agreements between reactor operators and local municipalities do not allow the movement of spent fuel from full spent fuel pools to pools at other reactor sites with available space. As a result, the high occupancy ratios for Tokyo Electric Company (TEPCO) and Kansai Electric Company (KEPCO) spent fuel pools has increased the pressure for construction of an additional interim storage facility, or, alternatively, to start full operation of the Rokkasho reprocessing plants, in order to have a places to put spent fuel once reactors restart.

to be filling up rapidly. A that point, a plan to develop an interim storage facility was prepared, and the Recyclable-Fuel Storage Company (RFS) was established by Tokyo Electric Company (TEPCO) and Japan Atomic Power Company (JAPC) in Mutsu City.

The RFS is a dry cask interim storage facility, which will, when opened, have a spent fuel capacity of 3000 tU for the first building, with another 2000 tU capacity in a planned second building. As of this writing (early 2017) the construction of the RFS facility is complete, and the facility is under review for its compliance with the new regulation criteria for all nuclear related facilities that were fully revised after the Fukushima disaster. Officially, the RFS is expected to start operations in late 2018.

A discussion is underway about the potential construction of another interim dry cask storage facility in Japan, but it has not been easy to find locations where new storage facilities can be sited. This difficulty has mostly been the result of lack of public acceptance toward the siting of any nuclear facility close to an existing population.

Since the period when no nuclear power plants were operating in Japan while their safety status was under review, post-Fukushima, five plants have been restarted, of which three are currently in operation, and five more plants have passed the process of review for compliance with the new regulatory criteria. In addition to these 10 plants that have already passed review, another 16 plants are under review by the Nuclear Regulatory Committee as is summarized in Figure 3-2. Ikata #3, which has already been restarted, can use MOx fuel, and the Rokkasho reprocessing plant and associated MOx fuel fabrication plant are expected to start in 2018 and 2019 respectively. As a result, assuming these facilities open as currently scheduled, elements of the closed nuclear fuel cycle as shown in Figure 3-3 (with the exception of the FBR) will be put into operation soon, although it will take almost 20 years to reprocess all of the spent fuel stored in Japan based on the current capacity of Rokkasho. **Error! Reference source not found.** shows he status of Japan's 50 nuclear reactors as of March, 2017.

Figure 3-2: Nuclear Fuel Cycle in Japan (as of March 2017)

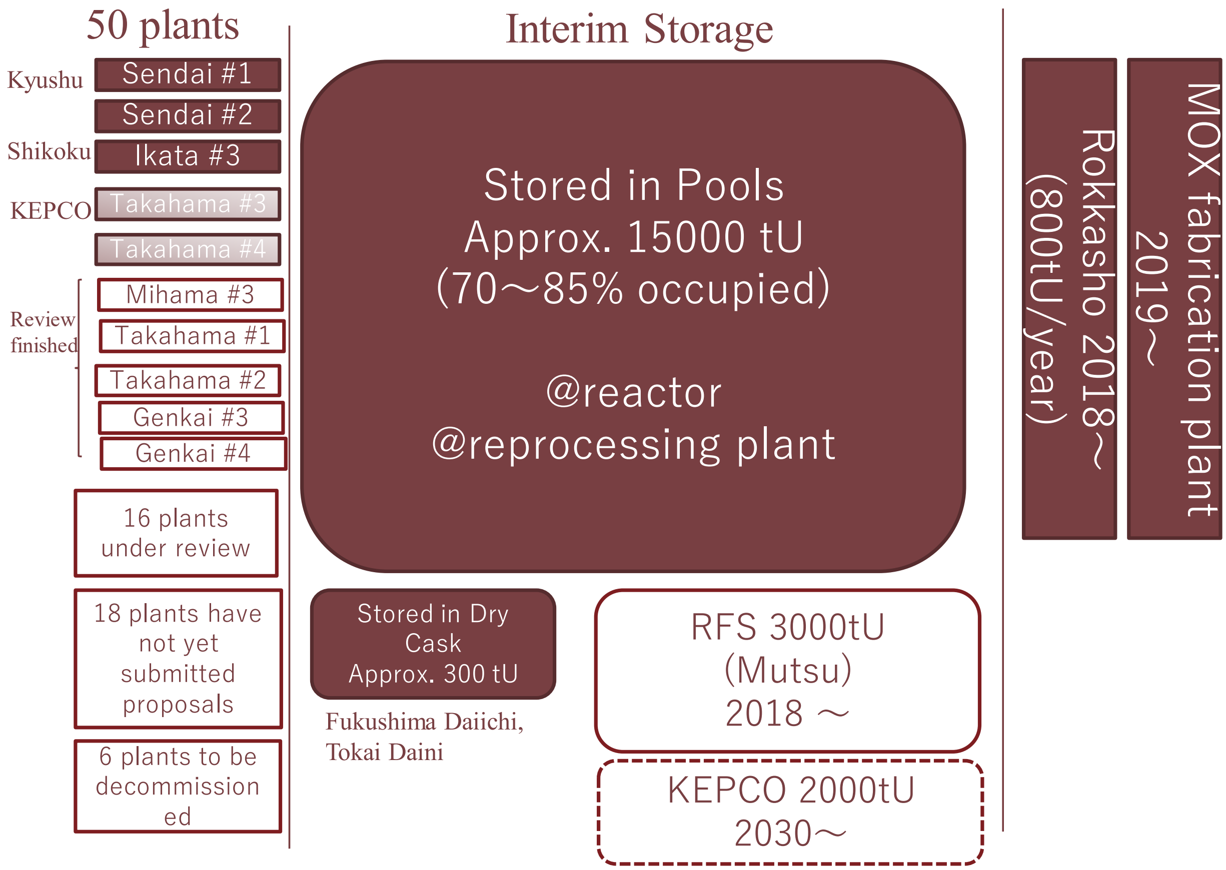


Figure 3-3: Possible Nuclear Fuel Cycle in Japan

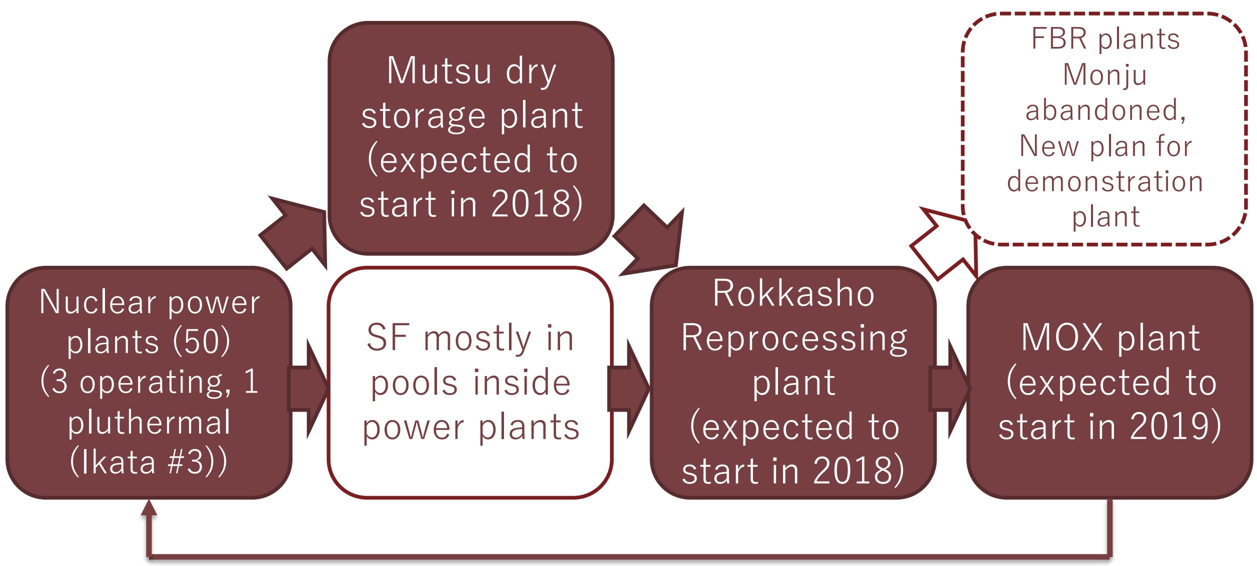
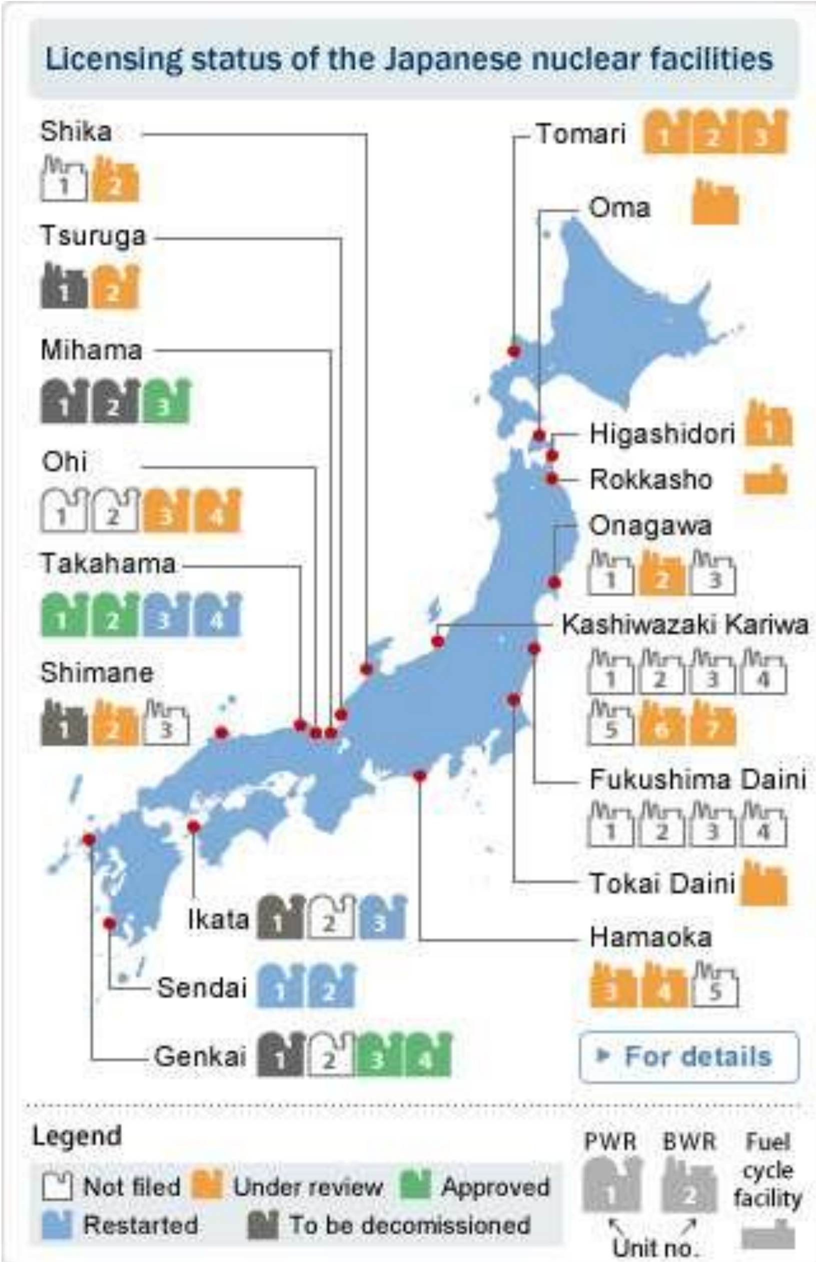


Figure 3-4: Current Status of Nuclear facilities in Japan



3.2 History of Spent Fuel Storage in Japan

For most of its history with nuclear power, Japanese official policy has been to recycle spent light-water reactor fuel to MOx fuel, with the use of MOx in either light water reactors (the "pluthermal" approach) or, eventually, in FBRs. The operation of the Rokkasho reprocessing plant has been delayed many times, and pool storage facilities at existing nuclear power plants are expected to be filled up shortly. There was no plan to move spent fuel from full spent fuel pools to the pools at other reactors with available space, and indeed doing so was prohibited under the agreements between reactor operators and local communities. The constraint of spent fuel pool capacity was a major concern that led the Japanese nuclear industry and regulators to forward with the operation of the Rokkasho reprocessing plant even though FBR capacity were not yet operating (and, indeed, FBR technology was not yet mature).

After the Fukushima accident, all nuclear plans went back to the drawing board, and whether to reprocess spent fuel was discussed at meetings of the Nuclear Commission. It was finally decided that Japan would maintain its plan to move ahead with a pluthermal and, ultimately, FBR nuclear fuel cycle, but the existence of problem with spent fuel stockpiles, and the dangers of possessing plutonium were recognized during the planning process, probably more clearly than in the past. In the Energy Basic Plan approved by the Cabinet in April 2014,[42] it is stated that, "it is important to take measures for final disposal of high level radioactive waste, however it will take a long period of time to find the way for it, so storage capacity needs to be increased until final disposal become possible, and options in technologies to store should be widened," and "new sites for storage should be widely considered whether they are inside or outside the power plants, and construction of the interim storage and dry storage facilities should be accelerated, and the government of Japan should enhance the measures to support these activities."

A ministerial meeting was convened from December 2013 until December 2015, and proposed the "Action Plan for the Management of Spent Fuel" in October, 2015.[43] In the Action Plan, the government's role is to support each utility, and the joint actions by utilities are with regard to management of spent fuel were to be increased. A joint council involving representatives of both government agencies (Ministry of Industry, Trade and Economy, METI) and utilities was established under the Action Plan to discuss future spent fuel management, as well as the public relationship between utilities, government, and the citizens of the nation and of the local areas hosting nuclear facilities. The council's role also includes consideration of mid- and long-term planning topics related to nuclear spent fuel production and management, such as estimating the amount of spent fuel to be produced by Japan's reactor fleet, the situation with pluthermal activities,[44] the spent fuel management considering outlook for operating the Rokkasho reprocessing plant, the alignment of nuclear facilities operations with national nuclear fuel cycle policy, and other topics. Also, the joint council requested that the utilities assemble plans for spent fuel management, and proposed enhancement of a fund to subsidize fuel cycle management, especially for the construction and operation of dry cask storage facilities for spent fuel.

Acting on a request included in the "Action Plan for the Management of Spent Fuel" proposed by the ministerial committee in October 2015, the Federation of Electric Power Companies of Japan compiled and published the summary of the plan submitted by each utility in November, 2015.[45] In the plan, in addition to the efforts to start commercial operation of the Rokkasho

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[42] Ministry of Industry, Trade and Economy. (METI, 2014, 日付不明). *Energy Policy in Japan. 参照先*, Agency for Natural Resources and Energy. Available in Japanese as http://www.enecho.meti.go.jp/category/others/basic_plan/.

[43] Ministerial Committee on Final Disposal of Nuclear Waste. (2015 年 10 月 6 日), *Action Plan for the Management of Spent Fuel. 参照先*. Cabinet Secretariat of Japan, available as http://www.cas.go.jp/jp/seisaku/saisyu_syobun_kaigi/pdf/1006siryou1.pdf.

[44] That is, the expected use of mixed-oxide (UOx and PuOx, or MOx) fuel in light-water reactors.

[45] Federation of Electric Power Companies of Japan. (2015 年 11 月 20 日), *Enhancement of Spent Fuel Management. 参照先*. Federation of Electric Power Companies of Japan, available as http://www.fepc.or.jp/about_us/pr/oshirase/__icsFiles/afieldfile/2015/11/20/press_20151120.pdf.

reprocessing plant, and the current efforts by utilities at reactor and non-reactor sites as summarized in Table 3-1. Additional plans described in the plan included re-racking of spent fuel storage facilities (spent fuel pools) to maximize their capacity, as well as proposals for the development of dry storage facilities inside and outside power plants sites, are described in Table 3-2. Figure 3-5, Figure 3-6, and Figure 3-7, respectively, show examples of re-racking to increase the capacity of spent fuel pools, and of at- and away-from reactor dry cask storage facilities.

Table 3-1: Nuclear Spent Fuel Management Measures Undertaken by Utilities in Japan as Described in Action Plan

Utilities	**Sites**	**Past Measures Taken**
Facilities at Power Plant Sites		
Hokkaido	Tomari	Commoditization[46] (#1 & 2 and #3)
Tohoku	Onagawa	Commoditization (#1 and #2 & 3)
	Higashidori	-
Tokyo	Fukushima Daiichi	Re-Racking (#1, 2, 3, 4, 5, 6) Shared pool Dry storage facility (#4, 5, 6)
	Fukushima Daini	Re-racking (#1, 2, 3, 4) Commoditization (#1, 2 ,3 ,4)
	Kashiwazaki-Kariwa	Extra rack (#1,3,4,6,7) Re-racking (#2,5) Commoditization (#1 & 2 & 5 and #3 & 4 & 6 & 7)
Chubu	Hamaoka	Re-racking (#1, 2, 3) Extra rack (#4) Dry storage facility*
Hokuriku	Shika	Re-racking (#1)
Kansai	Mihama	Commoditization (#1 and 3, #2 and 3) Re-racking (#2, 3)

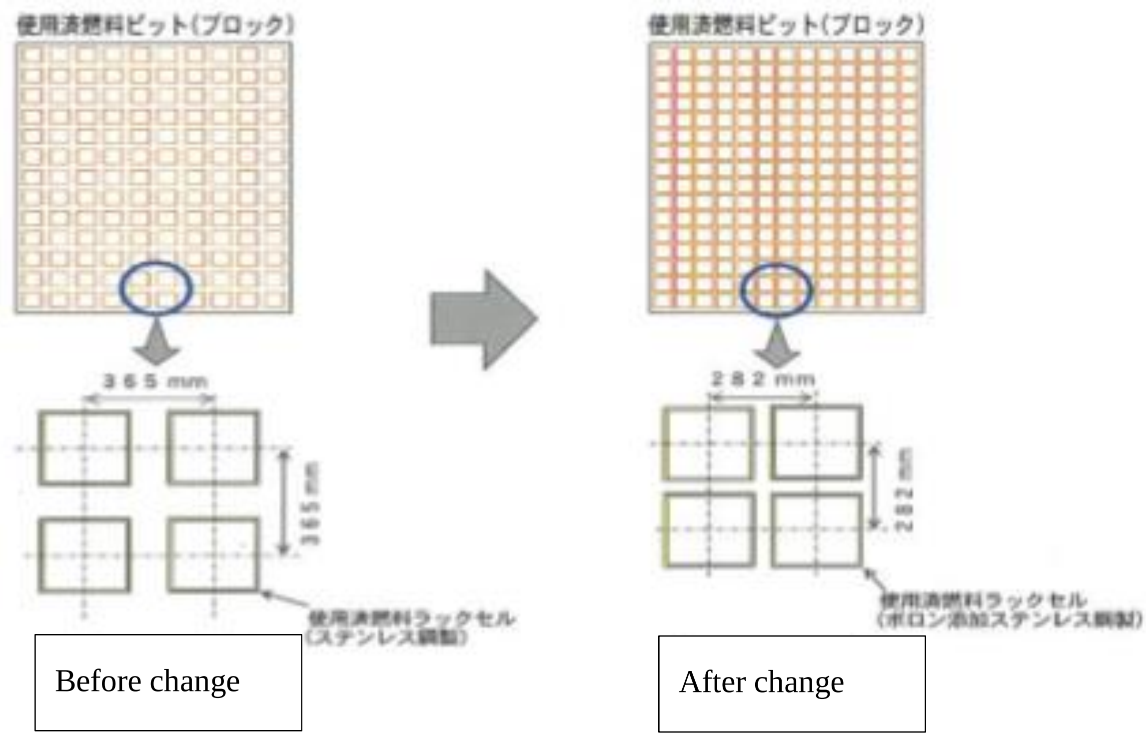
[46] "Commoditization" in this context means that plant operators are authorized to place spent fuel discharged from a specific unit of a nuclear plant in the spent fuel pool of another unit at the same plant where there is available capacity.

Utilities	**Sites**	**Past Measures Taken**
	Takahama	Commoditization (#1 and 3 &4, #2 and & #4, #3 and #4) Extra pool (#3, 4, area B) Re-racking (#3, 4, area A)
	Ohi	Commoditization (#1 & 2 and #3, #1 & 2 and #4) Extra pool (#3, 4, area B)
Chugoku	Shimane	Commoditization (#1 and #2) Extra rack, and re-racking (#1) Re-racking (#2)
Shikoku	Ikata	Commoditization (#1 & 2 and #3) Re-racking (#3)
Kyushu	Genkai	Commoditization (#1 & 2 and #4, #1 & 2 & 4 and #3*) Re-racking (#3)*
	Sendai	Re-racking (#1, 2)
The Japan Atomic Power Company	Tsuruga	Extra rack (#1) Commoditization (putting a rack on #2 for the spent fuel from #1) Re-racking (#1, 2)
	Tokai Daini	Re-racking Dry storage facility

Facilities Outside Power Plant Sites		
Utilities	**Area**	**Past Measures taken**
Tokyo Electric	Mutsu City	Dry storage facility* (Recyclable Fuel Storage Center)
The Japan Atomic Power Company		

*Review of request for permission to modify facility/operation in process.

Figure 3-5: Image of "Re-racking" in the Spent Fuel Storage Pools to Increase Storage Density[47]



[47] Figure 3-5 through Figure 3-7 are adapted from Federation of Electric Power Companies of Japan. (2015 年 11 月 20 日), *Enhancement of Spent Fuel Management. 参照先.* Federation of Electric Power Companies of Japan, available as http://www.fepc.or.jp/about_us/pr/oshirase/__icsFiles/afieldfile/2015/11/20/press_20151120.pdf.

Figure 3-6: Example of Onsite Dry Storage Facility (Tokai Daini)

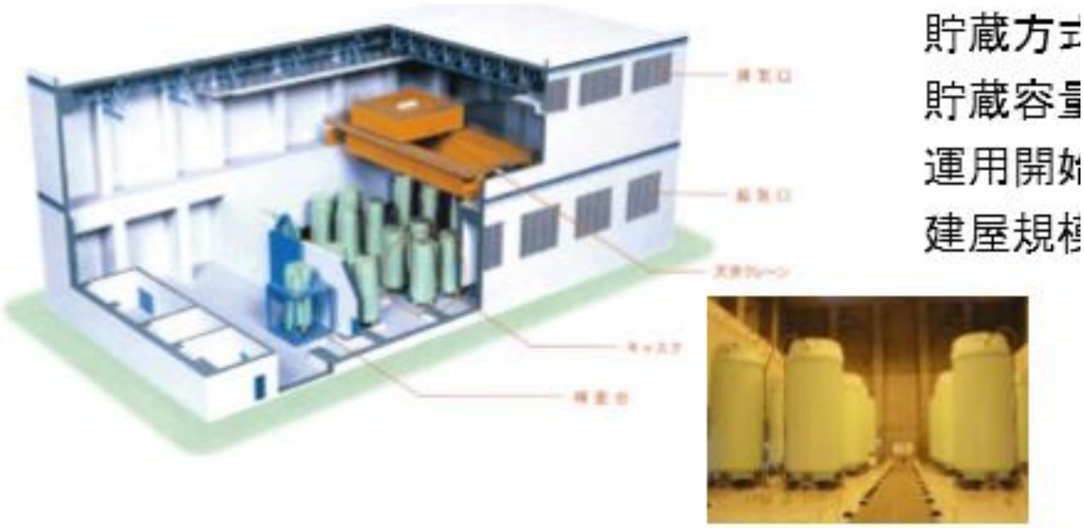
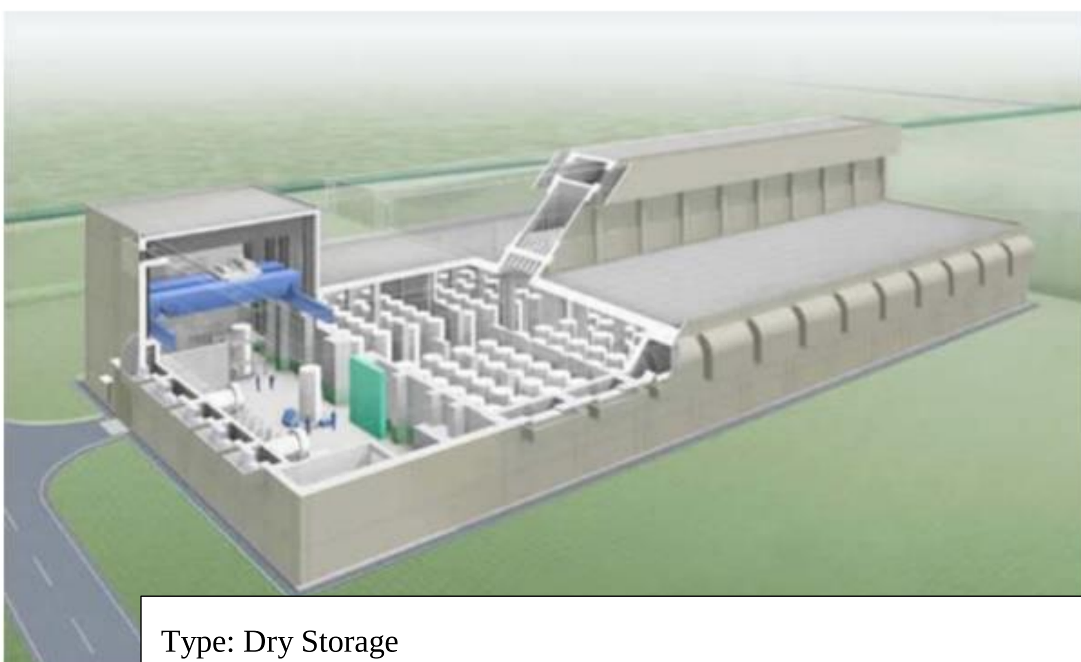


Figure 3-7: Example of Offsite Dry Storage Facility (Recyclable Fuel Storage Center)



Type: Dry Storage

Capacity: Final capacity 5000tU (3000tU for the first facility)

Period of storage: 50 years per facility

Size of the building: 130m×60m×30m (height)

Table 3-2: Current and Future Measures and Policies for Spent Fuel Management at Japanese Nuclear Plants

Utilities	**Plants**	**Current Policy**	**Future Policy**
Hokkaido	Tomari	Utilize current storage facilities.	Depending on the future occupancy of the current facility, consider several types of storage facilities including dry storage.
Tohoku	Onagawa	Utilize current storage facilities.	Consider onsite or offsite storage facilities including dry storage.
	Higashidori		
Tokyo	Fukushima Daiichi	Plan to discharge to a dry cask temporary storage facility.	Plan to discharge to a dry cask temporary storage facility.
	Fukushima Daini	Store in the current storage facilities.	Store in the current storage facilities. (Future storage plan is under consideration.)
	Kashiwazaki Kariwa	Plan to discharge to Recyclable Storage Center (which is under construction, plans to start operation in 2016 at a capacity of 3000 tU).	Plan to discharge to Recyclable Storage Center.
Chubu	Hamaoka	Plan to discharge to dry storage facility. (Permission requested, targeting starting operation in 2018, capacity of 400 tU.)	Continue with current policy, but consider building another dry storage facility inside or outside the power plant site.
Hokuriku	Shika	Utilize current storage facilities.	Consider onsite or offsite storage facilities including dry storage.
Kansai	Mihama	Proceed with the plan to build interim storage facilities outside the Fukui prefecture, with efforts to increase public and local understanding of the facilities and to explore additional possible siting alternatives. The plan is to finalize facility siting around 2020, and to start operation with capacity around 2000 tU around 2030.	In addition to current measures and policies, considering other possible measures aligned with national energy basic plan and action plans.
	Takahama		
	Ohi		

Utilities	**Plants**	**Current Policy**	**Future Policy**
Chugoku	Shimane	Utilize current storage facilities.	Depending on the future occupancy of the current facility, consider several types of storage facilities including dry storage.
Shikoku	Ikata	Utilize current storage facilities.	Considering discharging spent fuel to the onsite or offsite storage facilities. Currently considering dry cask storage, and investigating various technologies.
Kyushu	Genkai	Plan to increase the capacity of spent fuel storage by re-racking. (Re-racking is under review for the #3 unit, with projected capacity increase of 480 tU.)	Considering discharging spent fuel to onsite or offsite storage facilities. A dry storage facility inside the power plant site is under consideration for safety reasons.
	Sendai	Utilize current storage facilities.	
The Japan Atomic Power Company	Tsuruga	Plan to discharge to Recyclable Storage Center (now under construction, planned operation starting in 2016, capacity of 3000 tU).	Plan to discharge to Recyclable Storage Center
	Tokai Daini	Utilize dry storage facility onsite (70 tU capacity), and plan to discharge to Recyclable Storage Center described above.	plan to discharge to Recyclable Storage Center

In the *Action Plan for the Management of Spent Fuel*, as referenced above, it is stated that, the targeted capacity of spent fuel storage by 2020 is to be 4000 tU, with the addition of 2000 tU by 2030 (for a total of 6000 tU). Any plan for additional storage should be considered when proposals are raised. Table 3-3 summarizes the spent fuel inventories, spent fuel storage space, and estimates of the ratio of available storage space occupied at each power plant in Japan as of September 2016.

Table 3-3: Spent Fuel Inventories, Storage Space, and Other Parameters at Japanese Nuclear Plants[48]

Utilities	**Plants**	**As of September, 2016**				**Estimated Amount*1**		
		Per reactor core (tU)	**Per replace-ment (tU)**	**Manage-ment capacity*2 (tU)**	**Stored spent fuel (tU)**	**Manage-ment capacity*2 (tU) (A)**	**Stored spent fuel (tU) (B)**	**Occupied ratio (B)/(A) x100 (%)**
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
Tokyo	Fukushima Daiichi	580	140	2260	2130	2260	2130	94
	Fukushima Daini	520	120	1360	1120	1360	*3 1120	82
	Kashiwazaki Kariwa	960	230	2910	2370	2920	2920	100
Chubu	Hamaoka	410	100	1300	1130	1700	1530	90
Hokuriku	Shika	210	50	690	150	690	350	51
Kansai	Mihama	70	20	760	470	620	550	72
	Takahama	290	100	1730	1220	1730	1560	90
	Ohi	360	110	2020	1420	2020	1860	92
Chugoku	Shimane	100	20	680	460	680	540	79
Shikoku	Ikata	120	40	1020	640	1020	810	85
Kyushu	Genkai	230	80	1130	900	1600	1220	76
	Sendai	140	50	1290	890	1290	1090	84
The Japan Atomic Power Company	Tsuruga	90	30	920	630	920	750	82
	Tokai Daini	130	30	440	370	510	490	96
Total		4770	1260	20730	14830	21570	18400	

[48] Table 3-3 adapted from Federation of Electric Power Companies of Japan. (2016 年 10 月 20 日), *Enhancement of Spent Fuel Management. 参照先.* Federation of Electric Power Companies of Japan, available as http://www.fepc.or.jp/about_us/pr/oshirase/__icsFiles/afieldfile/2016/10/20/press_20161020_1.pdf

Notes for Table 3-3

*1: Estimates of stored spent fuel amounts assume the following condition, and are not necessarily the same as that produced by the actual restarts of nuclear plants. A. All units are assumed to be restarted excluding Fukushima Daiichi, Hamaoka #1, #2, Mihama "1, #2, Shimane #1, Genkai #1, and Tsuruga #1, which are slated to be decommissioned. B. Estimates of stored spent fuel are calculated by summing current stored amounts and adding spent fuel produced by 4 cycles (replacements). C. One cycle is assumed to be an operation period of 13 months plus a periodic inspection period of 3 months.

*2: Management capacity is basically storage capacity minus the amount of fuel in 1 reactor core and one refueling, but for the plants that have been shut down it is assumed to be same as storage capacity.

*3: For Fukushima Daini, no new spent fuel is assumed to be produced.

*4: For the Kashiwazaki Kariwa #5 plant, re-racking construction is not complete as yet, but the capacity listed is that expected after construction.

*5: For Kashiwazaki Kariwa, it is assumed that after 2.5 cycles (about 3 years), the site will reach its spent fuel management capacity.

*6: Hamaoka #1, 2 are in the process of being decommissioned, so their spent fuel capacity is excluded from the overall fuel pool management capacity for the site.

*7: For Hamaoka #4, a request for permission to build dry storage facility is under review; the spent fuel management capacity shown assumes that the dry storage facility is built and operated as planned.

*8: For Genkai #3, a petition for permission for re-racking is under review; the spent fuel capacity shown assumes that re-racking is completed.

*9: For Tokai Daini, 24 units (an addition of 7 units to the current capacity) of dry casks are assumed.

Note) Totals may not be equal to the sum of figures for individual plants.

3.3 Description of Existing Remote Interim Spent Fuel Storage Facilities

There are two existing interim spent fuel storage facilities in Japan utilizing dry cask storage that are located at reactor sites—one at the Fukushima Daiichi plant, and one at the Tokai 2 nuclear power plants. A third dry cask storage facility planned for the Hamaoka nuclear power plant is under construction.[49] The following tables (Table 3-4, Table 3-5, and Table 3-7) summarize the current, under-construction, and future planned dry cask interim spent fuel storage facilities located either on or off reactor sites.

[49] See, for example, Masafumi Takubo and Frank von Hippel (2013), *Ending plutonium separation: An alternative approach to managing Japan's spent nuclear fuel*. International Panel on Fissile Materials Report, dated November, 2013, and available as http://fissilematerials.org/library/rr12.pdf.

Table 3-4: List of Currently Existing Dry Storage Facilities

Site/company name	On/off site	Capacity	Start year	Notes
Fukushima Daiichi	On site	Approx. 100tU	1995	Moved to temporary dry storage facility inside Fukushima Daiichi site
Tokai Daini	On site	200tU	2001	Plan to add 70tU of capacity is ongoing

Table 3-5: List of Facilities Currently Under Construction

Site/company name	On/off site	Capacity	Start year	Notes
RFS (Mutsu, Aomori)	Off site	3000tU	Expected to start in 2018	Finished construction in 2013. Under review for new regulatory criteria.
Hamaoka	On site	400tU	-	Under review for new regulatory criteria.
Tokai Daini	On site	+70tU	-	

Table 3-6: List of Future Planned Facilities

Site/company name	On/off site	Capacity	Start year	Notes
RFS (Mutsu, Aomori)	Off site	+2000tU	-	
Ikata #1	On site	-	-	On-site facility at a nuclear power plant that is slated to be decommissioned.
By KEPCO	Off site	2000tU	2030	Governor of Fukui prefecture is against siting storage facilities inside Fukui.

The only dry cask interim spent fuel storage facility located away from reactors that has been developed to date in Japan is located at Mutsu city, in Aomori prefecture on the north end of the island of Honshu. Figure 3-8 shows an exterior view of the main storage building at the Mutsu facility as of August 2013, when the building was newly completed, and Figure 3-9 shows an interior view of a portion of the facility, including equipment to handle incoming casks.[50].

Figure 3-8: Exterior Photo of Mutsu Interim Spent Fuel Storage Facility as of August, 2013

[50] Images from Masumi Wataru (2013), "Spent Fuel Management in Japan and Key Issues On R&D Activities", INMM Spent Fuel Management Seminar, 14-16 Jan.2013,USA, available as https://rampac.energy.gov/docs/default-source/education/q26.pdf.

Figure 3-9: Interior Photo of Mutsu Interim Spent Fuel Storage Facility as of August, 2013

The history of the development of the Mutsu interim storage facility is as follows, and is summarized in Table 3-7. The Mutsu interim storage facility is run by the Recyclable-Fuel Storage Company. Tokyo Electric Company (TEPCO) started a feasibility study for the facility in April, 2001, and TEPCO made a request for cooperation to the Aomori Prefecture and the city of Mutsu in February, 2004. In January, 2005, a safety check and review of plans for the facility by experts was done, and the results of the review were reported to the Governor of the Prefecture, describing the planned safety policy for the facility as adequate.

Aomori Prefecture then conducted consultations with the prefectural assembly, the mayors of local municipalities, and the Prefectural Atomic Policy Forum of Aomori, provided explanatory meetings to the citizens of Aomori Prefecture, and a "Meeting to listen to the opinions about Interim Storage Facility of Nuclear Spent Fuel". Subsequently the "Agreement about Interim Storage Facility of Nuclear Spent Fuel" was signed in October, 2005 between the Aomori Prefecture, Mutsu City, TEPCO, and the Japan Atomic Power Co. (JAPCO).

In November, 2005, Recyclable-Fuel Storage Company was established by TEPCO and JAPCO in Mutsu City. In March, 2007, Recyclable-Fuel Storage Company submitted an application for a business license to the national government, which was approved in May, 2010 by the Minister of METI (Ministry of Economy, Trade and Industry). Construction on the Mutsu storage facility started in August, 2010.

After the Tohoku Earthquake on the Pacific coast of Japan, in March, 2011, construction on the Mutsu spent fuel facility was temporarily halted, but was restarted in March, 2012. The main storage building for the facility was completed in August, 2013.

In January, 2014, in order to initiate the process of reviewing the facility under the new regulatory criteria, the Recyclable-Fuel Storage Company submitted an application for review of the changes made to the facility related to compliance with the new rules to the Nuclear Regulation Authority (NRA).

***Table 3-7: History of Mutsu Interim Storage Facility*[51]**

June, 2000	Partial revision of the "Act on the Regulation of Nuclear Source Material, Nuclear Fuel Material and Reactors" enforced (enabling the storage of spent fuel outside nuclear power station sites)
November 2000	Technical survey concerning the siting of "Recyclable Fuel Storage Center" requested by Mutsu municipal government
April 2003	Report on feasibility study of siting submitted to Mutsu municipal government
July 2003	Siting request by the mayor of Mutsu-shi accepted by Tokyo Electric Power Company
October 19, 2005	Siting of "Recyclable Fuel Storage Center" approved by Aomori Prefectural government and Mutsu municipal government
	"Memorandum of Agreement on Intermediate Storage of Spent Fuel" signed by Aomori Prefectural government, Mutsu municipal government, Tokyo Electric Power Company and the Japan Atomic Power Company
November 21, 2005	Recyclable-Fuel Storage Company established in Mutsu-shi with the joint capital investment of Tokyo Electric Power Company and the Japan Atomic Power Company
March 22, 2007	Application for permission of spent fuel storage operation for the "Recyclable Fuel Storage Center" submitted to Minister of Economy, Trade and Industry
May 13, 2010	Granting of permission for spent fuel storage operation for the "Recyclable Fuel Storage Center"
August 27, 2010	Approval of design and construction method
August 31, 2010	Commencement of construction work for spent fuel storage facility

Table 3-8 presents an overview of the cost and other parameters of the Mutsu spent fuel storage facility, and Figure 3-10 presents a satellite view of the facility as of 2016.

[51] Table from Takamatsu, Tatsuki (2010, Recyclable-Fuel Storage Company, RFS), "Metal Casks Storage Schedule of Recyclable Fuel Storage Center in Mutsu", Presentation for ISSF2010 (International Seminar on Interim Storage of Spent Fuel), available as. http://criepi.denken.or.jp/result/event/seminar/2010/issf/pdf/2-1_powerpoint.pdf.

Table 3-8: Overview of Mutsu Storage Facility

Location	Mizukawame Sekine, Mutsu-shi, Aomori-ken 035-0022, Japan
Site area	26 ha (for the purpose of this facility)
Company	Recyclable-Fuel Storage Company (Capital: 3 billion yen, 80% by TEPCO, 20% by JAPC, established on Nov. 21st 2005)
Storage capacity	5000 ton (3000 ton for the 1st facility) Current facility's capacity: 3000t (weight of pre-irradiation metallic uranium) BWR spent fuel: 2600t (8X8 fuel, high combustion 8X8 fuel, New type 8X8 zirconium liner fuel) PWR: 400t (17X17 fuel) 288 metal casks
Storage type	Metallic Dry Cask Storage (both for transfer and storage)

Figure 3-10: Satellite View of Mutsu Spent Fuel Storage Facility as of 2016[52]

[52] Source: Google Maps.

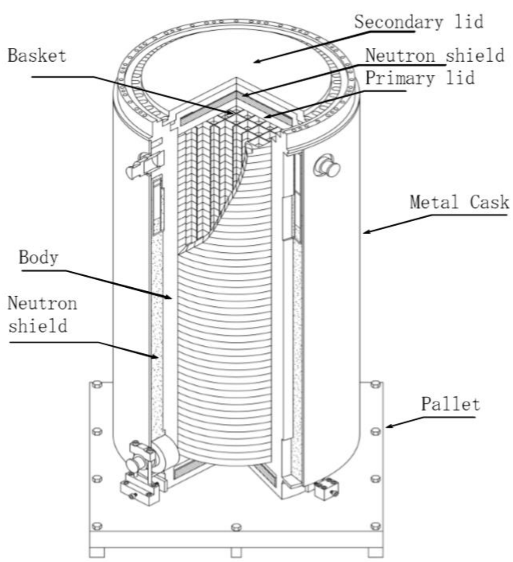
The Mutsu Interim Storage Facility is designed to accept spent fuel from the following nuclear plants: Kashiwazaki-kariwa #1-7 (BWR, TEPCO), Fukushima Daiichi #1-6 (BWR, TEPCO), Fukushima Daini #1-4 (BWR, TEPCO), Tokai 2 (BWR, JAPC), and Tsuruga #2 (PWR, JAPC). It is expected to store 4000 tU from TEPCO owned power plants, 1000 tU from JAPC owned power plants. The service period is expected to be 50 years for the facility as a whole and for each cask.

There is a plan to build second building at Mutsu, with the capacity to store and 2000 tU of spent fuel. If it is assumed that the second facility starts its service 10 to 15 years after the first facility is placed in service, the Mutsu facility was a whole will have 60 to 65 years to store spent fuel casks at the site. Takamatsu (2010) suggests that Mutsu’s operators expect approximately 200-300 tons of spent fuel to be brought into the facility each year, in about four individual shipments. Each shipment can carry 8 casks.

Transportation to the facility will be accomplished by ship, and the casks will be moved from the transport ship to specially designed trucks using cranes. Inspections will be done before the trucks carry the casks to the storage facility, but there will be no need to open the casks during the process until the casks are removed from the facility after the storage period.

Figure 3-11 shows the structure of the metal casks to be used in the Mutsu facility.

Figure 3-11: Structure of Metal Casks to be used in Mutsu Interim Storage Facility[53]



The metal casks have first and second covers, and the space between the two covers is under positive pressure, so that the space containing the spent fuel is shielded from the outside air. The metal cask is designed to block radiation from the spent fuel in storage through the use of gamma ray shield and neutron shield materials contained in the walls around the cask. The metal casks will prevent self-sustaining nuclear chain reaction from occurring by the array designs used to

[53] Source: http://criepi.denken.or.jp/result/event/seminar/2010/issf/pdf/2-2_powerpoint.pdf.

store the spent fuel position, as well as through the use of material that absorb neutrons. The metal casks to be used at Mutsu do not need dynamic (active) cooling facilities, as fuels in the casks are cooled by natural air circulation. Table 3-9 provides an overview of the sizes of the casks to be used at the Mutsu facility.

Table 3-9: Size and Weight of Casks to be Stored in Mutsu[54]

		BWR Large scale casks		BWR Medium scale casks	PWR casks
		Type1	Type2		
Scale	Length	5.4 m	5.4 m	5.5 m	5.1 m
	Diameter	2.5 m	2.5 m	2.4 m	2.6 m
Weight (fuels included)		118 t	119 t	116 t	117 t
No. of fuels stored in each cask		69	69	52	26

Regulation Scheme for Spent Fuel Storage

Before 1993, regulations in Japan specified that spent fuel should be stored inside nuclear power plant sites, but regulations changed to enable spent fuel storage outside the power plant site in 1993. There are two guidelines for spent fuel storage currently in force. The first is for spent fuel storage on-site approved by Nuclear Safety Commission in 1992, and the second covers facilities outside power plant sites. The latter is named “Storage Guidelines” and was established in 2002. As a result of the overall change in nuclear safety regulatory criteria after the Fukushima accidents, regulatory criteria also changed for pent fuel storage facilities in 2013. In the guidelines,

Table 3-10shows the seismic severity classification that RFS applies to their facilities, as well as requirements as described in the storage guideline published in 2002 for the facilities outside power plant sites, and requirement under the 1992 guidelines for facilities inside the power plant sites. “S” indicates the highest classification, followed by “A” and “B”. In order to pass the review under the new criteria established in 2013, facilities are directed to assume the type and severity of the a potential disaster, and are obliged to design the facility according to their assumption about the disaster. That is, the guidelines established in 2002 cannot simply be applied to the new evaluation required under the 2013 regulations. Historically, however, cask supporting structures have been built with very strong features that would allow them to withstand any earthquake, while a barge-based storage facility would face difficulties in the assessment of the sufficiency of its safety features simply because it is not connected to the ground. As such, new safety criteria specifically for barge-based storage systems would be required before such systems could be commissioned—which is a likely administrative impediment to barge-based spent fuel storage.

[54] Source: Nuclear Regulation Authority (2013), “Regulatory Criteria for Storage Facility of Nuclear Spent Fuel” (2013.4.16), available as https://www.nsr.go.jp/data/000048899.pdf.

Table 3-10: Seismic Severity Classification of RFS and Requirement in 2002 and 1992 Guidelines[55]

	RFS	Storage Guidelines 2002	1992 Guidelines (inside power plants)
Metallic Casks	S	-	S (for metallic storage casks)
Cask supporting structures	S	Basic safety functions of the casks should not be compromised by earthquake ground motion Ss	S
Buildings	B (RFS expects shielding function for building)	Same as above. B: When expecting shielding function.	C, but should check for earthquake ground motion Ss.

Safety Evaluation of RFS Facility under Storage Guideline of 2002

According to Kojima (2010), the safety evaluation of interim storage facilities by NISA (the Nuclear and Industrial Safety Agency) had 4 steps; 1) siting conditions, 2) safety designs of the facility, 3) Radiation dose evaluation under normal operating conditions, and 4) Overall safety evaluation.

The siting conditions for the Mutsu facility were summarized by Kojima (2010) as listed in Table 3-11: .[56] Many of these criteria are general, and would apply to other spent fuel storage facilities as well.

[55] https://www.nsr.go.jp/data/000048930.pdf

[56] Reference: Kojima, Shuhei (2010; Nuclear and Industrial Safety Agency, NISA) "The First Interim Storage Program & Safety Review – Points and Evaluations of Safety Review in Japan-, Presentation for ISSF2010 (International Seminar on Interim Storage of Spent Fuel). Available as http://criepi.denken.or.jp/result/event/seminar/2010/issf/pdf/2-2_powerpoint.pdf.

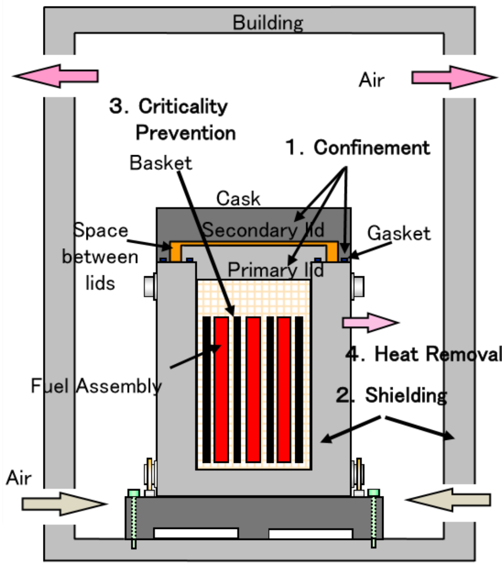
Table 3-11: Siting Criteria for the Mutsu Facility

1. Site	Located in the central part of the Shimokita Peninsula along the Tsugaru Straits, north of Mutsu City. Smooth tableland at 20-30m above sea level. The height of site renovation is 16m above sea level.
2. Earthquake	In the area within a 30 km radius from the site there are two active faults (Yokohama Fault and Shiriyazaki Southeast Offshore Fault) and these faults have an impact on the expected maximum values of the basic earthquake ground motion parameter Ss on the seismic design of the facility.
3. Volcano	The active volcano Osorezan, and the inactive Mutsu Hiuchidake Volcano are nearby, but studies confirmed the validity of an evaluation that the possibility that a volcanic disaster will affect the interim storage site and interfere with fundamental safety functions is extremely low during the service period of the facility.
4.1 Metrological Phenomena	Reflected in the design of spent fuel storage buildings and metal casks.
4.2 Hydraulic Phenomena	(floods, extra high tides and tsunamis) No probability of serious effects on safety functions of the facility.
4.3 Earthquake accompanying phenomena	(tsunamis caused by collapse of seabed slopes, etc.) No probability of serious effects on safety functions of the facility.
4.4 Social Environment	(Population distribution, settlements, industrial activities, and transportation infrastructure around the site) No interference with security

The design of safety systems for the spent fuel storage facility in Mutsu includes 1) Basic safety functions, 2) Radiation control and environmental safety, and 3) seismic designs, as described by Kojima (2010).

The basic safety functions include 1.1) Confinement (confining spent fuel assemblies safely), 1.2) Shielding (providing protection from radiation emitted by from spent fuel safely), 1.3) Criticality Prevention, and 1.4) Heat removal. These functions are reviewed for the operational period of 50 years. Figure 3-12 shows how each function is considered in the design of the facility and casks.

Figure 3-12: Safety Functions Reviewed for the Mutsu Interim Storage Facility

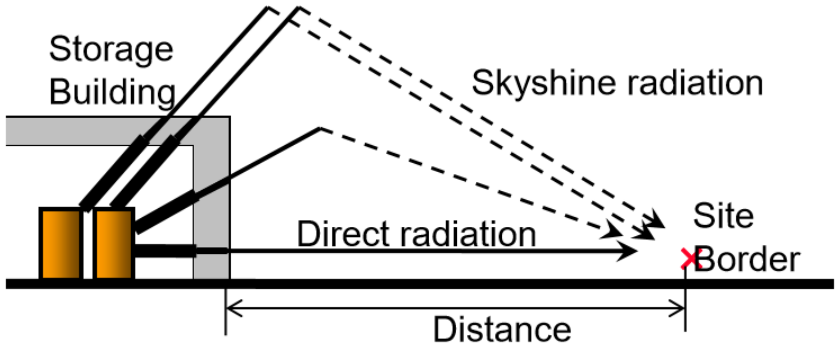


For radiation control and environmental safety, to ensure there are no emissions of radioactive materials during the confinement functions of the metal casks, and no radioactive wastes are emitted under normal conditions, requirements include a. an area monitoring system (γ-rays, neutrons), and b. environmental monitoring systems (monitoring post, Fluoroglass Dosimeter). Readouts from these devices are shown in a monitoring room at the facility to confirm and validate the safe operations of the casks and facility.

For seismic design, a value is assumed for the maximum basic earthquake ground motion parameter Ss likely to be experienced at the site, and designs for the buildings, metal casks, overhead cranes, and carrier wagons are confirmed to be valid for the magnitude of earthquake assumed for the site (as implied in the maximum Ss value).

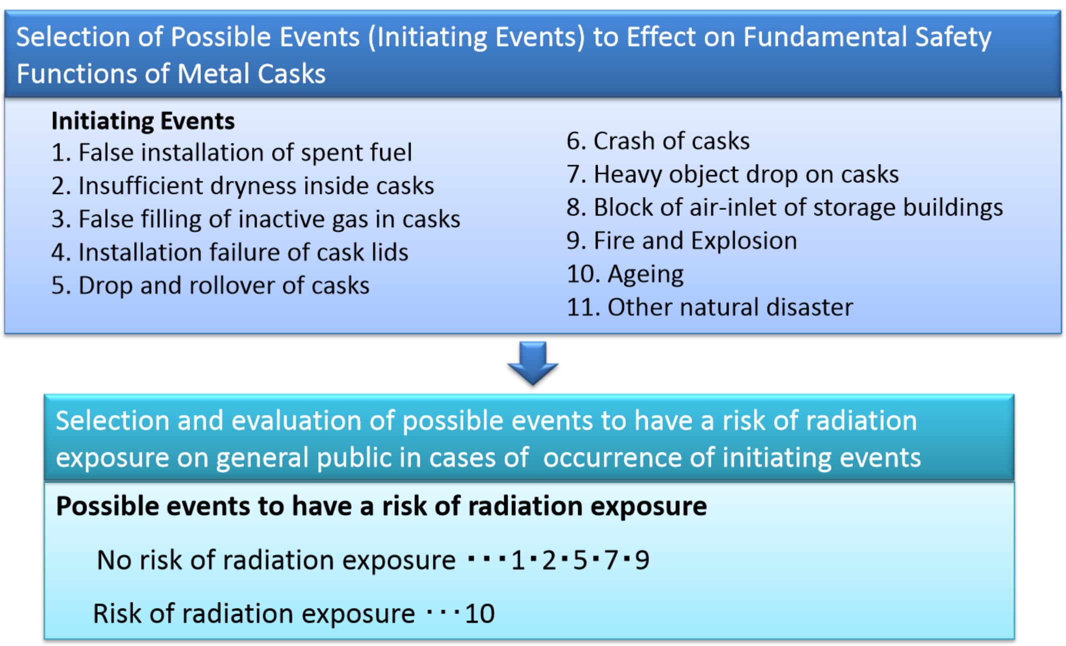
The final set of reviews are for "dose evaluation under normal conditions". These reviews are designed to confirm that the public dose under normal conditions is under 2.8 $X10^2$ mSv per year, which is well below the dose limit (1mSv/y). Figure 3-13 provides a diagram of the radiation monitoring dose evaluation scheme for Mutsu.

Figure 3-13: Image of Dose Evaluation under Normal Conditions[57]



For the overall safety evaluation, 11 possible events are evaluated for their risk of radiation exposure. For the Mutsu facility, the "10. aging" event was selected to have the greatest risk of radiation exposure, and was examined in detail (see Figure 3-14). The result of this evaluation confirmed that no excessive radiation exposure to the general public would occur even in the event of a maximum credible accident (Figure 3-15).

Figure 3-14: Events Reviewed for Possibility of Radiation Release



[57] Source: Kojima (2010), ibid.

Figure 3-15: Estimated Impact of a "10" Event on the Fundamental Safety Functions of Metal Casks

Selection of Significant Accidents from the Viewpoint of Radiation Exposure on General Public

Selected accident events

10. Aged deterioration: Shielding functions of metal casks are decreased when neutron shielding materials flow out from cracks caused by some reason during storage period

Confirmation of no risk of excessive radiation exposure on general public on the assumption of occurrences of maximum credible accident (effective dose for general public: 5.6×10^{-2}mSv)

In the review of the license for a facility regarding design and construction methods, the 15 items shown in Figure 3-16 are reviewed.

Figure 3-16: Items for the Review of a License Related to Design and Construction Methods[58]

In the review on a license for designs and construction methods, the evaluation criteria have 15 items as follows:

1. **Criticality prevention of spent fuel**
2. Damage prevention from fire
3. Seismic resistant
4. Material and structure
5. **Heat removal**
6. **Confinement function**
7. **Shielding**
8. Ventilation
9. Pollution prevention from contaminated materials by spent fuel
10. Significant facility for safety
11. Transfer and acceptance system
12. Measurement control facility
13. Waste facility
14. Radiation control facility
15. Emergency power system

[58] Reference: Nuclear Regulation Authority, "Regulatory Criteria for Storage Facility of Nuclear Spent Fuel" (2013.4.16) , available as https://www.nsr.go.jp/data/000048899.pdf.

3.4 Discussions of Other Interim Spent Fuel Storage Facilities in Japan

There have been no official discussions of major away-from-reactor interim spent fuel storage facilities in Japan other than Mutsu. According to newspaper reports, there have been, however, several requests for consideration of new interim spent fuel facilities coming either from local residents, who seek the economic rewards that come from a community hosting a facility—especially residents in areas where nuclear power plants are already sited—and from power companies such as KEPCO that are seeking sites to store their spent fuel.

The requests to invite proposals for dry cask storage facilities mainly have come from the residents of municipalities where nuclear power plants already exists, or of neighboring municipalities to existing nuclear power plants. Genkai City of Kyushu island, or Mihama city in Fukui prefecture have reported to have groups of residents who welcome storage facilities. The Governor of Fukui prefecture, however, is against siting additional storage facilities inside Fukui because Fukui prefecture has many nuclear power plants designed to generate electricity for the Tokyo and Kansai area. Karatsu City, which located next to Genkai City, and Obama City, which is located next to the Ohi nuclear power plant and very close to the Takahama plants as well as the Mihama plants, already bear most of the risks associated with hosting a nuclear facilty, but receive less subsidies since they are outside of the boundary of the nuclear plants, have reported to be a candidates for storage facilities.

Areas preserved for fossil power plant development but not yet used have also been reported to be considered to be candidates for hosting spent fuel storage facilities. One example is Gobo city in Wakayama prefecture, mentioned as a possible host for an interim storage facility for KEPCO.

There have also been discussions about shifting the purpose of the Rokkasho reprocessing plant for use as an interim storage facility, as has been reported in the *Asahi* newspaper in December 1st, 2016, based on a suggestion from Taro Kono, M.P.

Below we describe some of the recent newspaper reports of requests from communities to invite proposals for establishment of interim storage facilities.

According to the *Nishinihon Shinbun* (Western Japan Newspaper) (http://qbiz.jp/article/95850/1/) on October 13th, 2016, 34 residents in Karatsu-city, which is located next to the Genkai nuclear power plants in Saga Prefecture, requested to have an interim storage facility in the area near where they live. The area is sited within 6 km of the Genkai power plants, and suffers from depopulation as many of the younger generation have moved elsewhere. The residents have seen the Genkai town receive a better subsidy, than Karatsu-city, as a result of Genkai hosting the nuclear plant, and as the Karatsu-city residents judge that their risks would be the same whether or not a spent fuel storage facility is built, they requested to have an interim storage facility to be built in their area.

According to the *Nikkei* newspaper on November 29th, 2015 (http://www.nikkei.com/article/DGXLASDF20H0F_Q5A121C1EE8000/) the president of Kansai Electric Company (KEPCO), Mr. Yagi has announced a plan to construct a 2000 tU capacity interim storage facility by 2030, and a plan to finalize location by 2020. Mr. Yagi stated that Fukui prefecture would be excluded as a potential location for the interim storage facility since Fukui prefecture already hosts many nuclear power plants.

In December, 2012, Mayor Yamaguchi of Mihama town, where the Mihama nuclear power plants are sited, declared that the town meeting's decision in 2004 to request that an interim storage facility to be built in Mihama town is still effective, and hat the resident of the town is are willing to have the facility in Mihama. However, the Governor of Fukui prefecture, to which Mihama town belongs, has requested that KEPCO site any interim storage facility outside Fukui Prefecture.

Obama City in Fukui prefecture also decided to request, in March, 2004, that an interim storage facility be sited in their city,.

Gobo city in Wakayama prefecture has been reported to have been the lead candidate for KEPCO's interim storage facility site as of 2003. Gobo city has already hosts several fossil-fueled power plants owned by KEPCO, and there is space for another fossil fuel power plant, but KEPCO decided against building the plant. The City Council of Gobo City once considered a proposal to host an interim storage facility, but after the earthquake and nuclear accident in 2011, opinion against siting the facility become dominant. In a newspaper article in *Chunichi* Newspaper on January 28th, 2016 (http://www.chunichi.co.jp/article/feature/restart_enq/list/CK2016012802000041.html), it was noted that there still exist residents of Gobo city who are positively disposed to the idea of attracting an interim storage facility to their town, and KEPCO has planned a tour for residents to see an experimental interim storage facility.

3.5 Lessons from Previous Discussions of Interim Spent Fuel Storage Options in Japan

Although an interim storage facility has already built in Aomori prefecture in Japan, namely the Mutsu Interim Storage facility described above, the Mutsu facility is designed to accept spent fuel only from TEPCO and JAPC. In addition, if many of Japan's reactors are restarted and/or, for example, that reducing the density of spent fuel storage in existing at-reactor spent fuel pools (and the Rokkasho spent fuel pool) becomes a priority, considerable additional dry cask storage will be required. KEPCO, for example, has been seeking a place to site their interim storage facility, but has been having difficulty in identifying a site.

Any nuclear related facilities will have opposition from some groups of local residents, even though other groups might welcome the facility due to the large subsidy that communities can enjoy if they accept a facility.

Although there are huge amount of grants that local municipalities can obtain from accepting the siting of a facility in their territory, there is always a problem of public acceptance for local people. Locals fear that they could end up hosting the spent fuel housed in nominally "interim" storage effectively forever. Another bottleneck to developing new spent fuel facilities would be the stricter regulatory criteria adopted in 2013.

Also, there are feelings among residents of regions where nuclear facilities are sited that they are taking on "unfair" risks, that is, that they will be in danger if accidents occur, but the residents of electricity consuming regions, namely the Tokyo area and Osaka area, will not. The Governor of Fukui prefecture, Mr. Nishikawa, has expressed a strong opinion against siting an interim storage facility inside Fukui prefecture, since Fukui already hosts many facilities. Mr. Nishikawa is not against the nuclear power, since he has agreed to restart Takahama units #3 and 4.

4 Elements of a Generic Interim Spent Fuel Storage Facility for Japan

Although it is not possible, in a paper such as this, to identify specific sites in Japan where additional interim spent fuel storage facilities might be developed, it is possible to identify the attributes that a generic interim spent fuel facility would need to have, and thereby to consider the types of locations and sites in Japan where such a facility might be located. Below we first review the general attributes of a remote interim spent fuel facility, then examine more specifically the siting requirements, spent fuel transport and handling infrastructure, and what political/social/community attributes make a host location favorable for a facility. We follow these subsections with a description of the relative advantages and disadvantages of coastal, island, and barge-mounted facilities, and a brief evaluation of which generic types of areas in Japan might be best suited—or unsuited—for such a facility.

4.1 Review of Key Attributes Based on Existing Literature

The key attributes of additional Japanese facilities for storing spent nuclear reactor fuel on an interim basis, similar to the attributes of the Mutsu facility, would include the following:

- A location that is relatively remote from significant populations, and is protected as much as possible from seismic and tsunami hazards, as well as being relatively easy to secure and defend in the case of an attack scenario.
- A location that is accessible to berthing facilities so that spent fuel can be brought in from Japanese coastal reactors by ship, and can easily be transported from docks to the facility, preferably without transiting high-traffic areas. The facility itself would need to include equipment and processes for accepting and moving dry casks, and storing the casks, as well as monitoring and other security equipment and processes.
- A location where local residents, and local and regional government agencies, are accepting of the facility, or can be convinced to accept the facility through a process of consultation and offers of compensation.

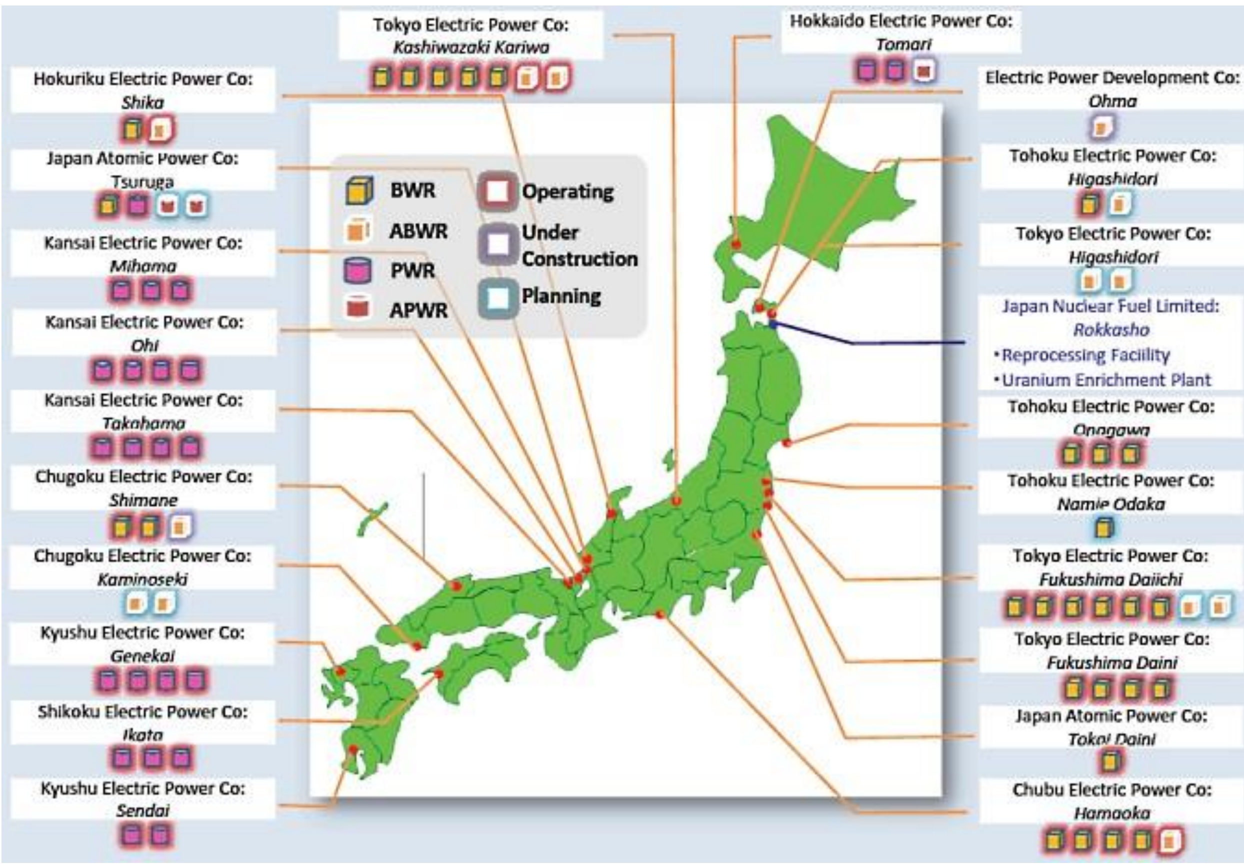
According to the Federation of Electric Power Companies of Japan (FEPC), spent fuel is shipped using a vessel specially designed for transportation. Spent fuel is shipped following a period of cooling at spent fuel pools at reactor sites. The ships used for spent fuel transportation have a double shell construction designed to minimize the possibility that the vessels will sink, even in the event of collisions or stranding.

4.2 Siting Requirements

As shown in Figure 4-1, all of Japan's major nuclear reactors and other nuclear facilities are located at or near the seacoast. Coastal locations are needed to provide adequate cooling water for reactors. Given the coastal location of reactors, the most convenient means of transporting heavy casks of spent fuel is by sea, and thus it makes sense that additional interim spent fuel storage facilities for Japan would be near or on the seacoast, or at sea.

As such, sites for additional spent fuel storage facilities in Japan would need access to berthing facilities large enough to accommodate the ships that are used to move spent fuel casks, or such facilities would need to be built near a new facility. In either case, a relatively sheltered harbor area with sufficient depth of water to accommodate the movement of the transport ships would be needed. The exception to this would be for barge- or vessel-mounted storage, which could presumably either be brought to the source of the spent fuel (to nuclear plants) and be loaded with casks directly, or would be anchored in a location where a spent fuel transport ship could come alongside and use cranes mounted on one or both vessels to accomplish cask transfer and storage.

Figure 4-1: Locations of Existing and Planned Nuclear Reactors in Japan[59]



Candidate sites for such facilities would include the three categories identified in section 2 of this paper—coastal sites, island sites, and barge- or vessel-mounted facilities, Vessels or barges could be anchored in sheltered locations either adjacent to land or at sea.

[59] Figure from World Nuclear Organization (2016), "Nuclear Power in Japan", updated 28 December 2016, and available as http://www.world-nuclear.org/information-library/country-profiles/countries-g-n/japan-nuclear-power.aspx.

Other attributes of good sites for spent fuel facilities include being far enough away from populations so that the activities of the site do not disrupt the daily life of nearby residents (for example, by blocking roads as casks are moved), but near enough (and with access to transportation infrastructure) such that a response to an emergency at the site can be mounted quickly. It would also be desirable that the facilities be near enough to the nuclear power plants that they serve that the sea voyage required to move casks to the facility is not that long—thus limiting the exposure of cask transport ships to accidents or attack while in service. The availability of existing infrastructure at the site—berths for ships, roads, and/or security systems, for example, would also be a plus, and would help to keep down the cost of new facilities.

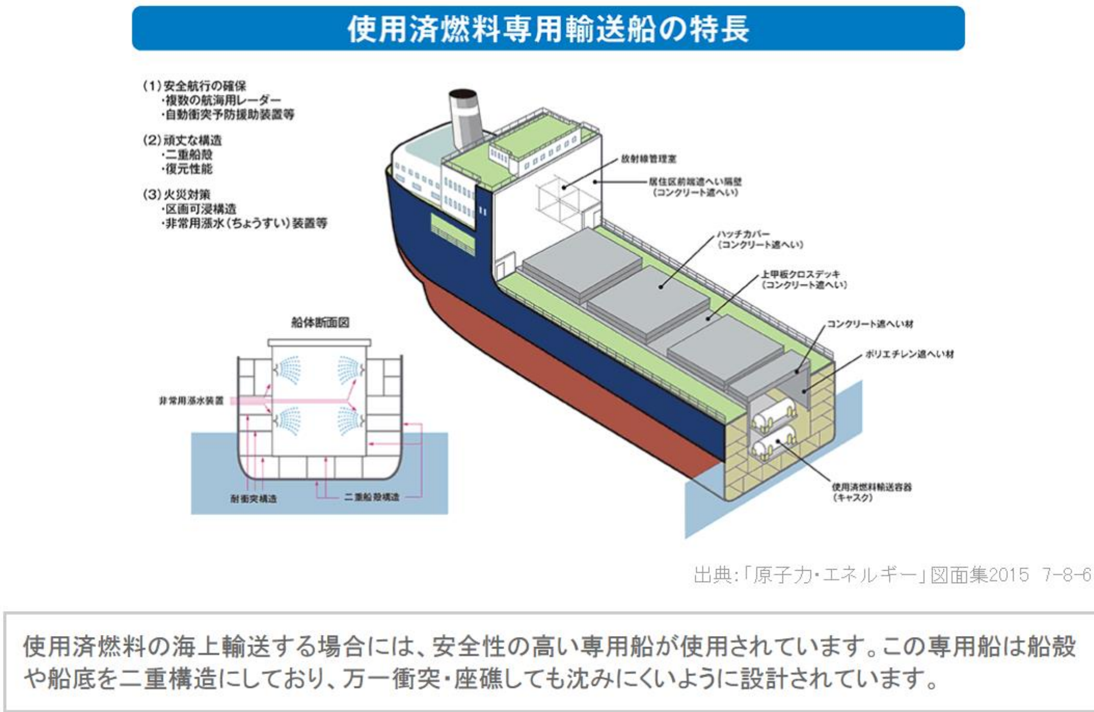
The facility itself should be large enough to accommodate thousands of metric tonnes of spent fuel. Since the transport-related infrastructure needed to move spent fuel casks is essentially the same for a facility accommodating, say, 1000 tonnes or 5000 tonnes, there are economies of scale for building larger facilities. The size of the storage facility itself is not large—for example, the footprint of the Mutsu facility is about 62 x 131 meters—but it is likely that the overall facility will need an area of tens of hectares to accommodate the required transport and security infrastructure, to provide space to separate the facility from any nearby unrelated activities, and for buildings and other infrastructure providing space for administration and other ancillary services.

4.3 Spent Fuel Transport and Handling Infrastructure

The required infrastructure for spent fuel transport to, and handling of casks around and within an interim spent fuel storage facility would include the following:

- Transport ships. Unless the facility is immediately adjacent to the nuclear power plant from which the spent fuel is coming, or close enough that road transport is practical, cask transport ships will be required. Several specially-designed transport spent fuel (and MOx fuel) transport ships have seen service in Japan for decades, including to move spent fuel to Europe for reprocessing, as well as to the Rokkasho reprocessing plant. For the Mutsu facility, and likely for additional facilities, the specially designed ships that will carry cooled spent fuel will have double-hulled construction to minimize the possibility that the vessel will sink even in the event of a collision or stranding at sea, as shown in Figure 4-2.

Figure 4-2: Schematic of Cask Transfer Ship[60]



- Cranes to move casks from transport ships onto trucks or transport trailers.
- Trucks and/or trailers to move casks between ship berths and the storage facility.
- Cask handling equipment, including overhead cranes, to move casks from trucks/trailers into the interior of the storage facility (for example, as shown in Figure 2-10).
- The storage building itself, which would be built to withstand severe earthquakes, and might store casks vertically, horizontally in cradles or in a vault arrangement, or vertically in holes in the floor of the facility. It is possible that an interim storage facility would simply store casks in an outdoor array, as is done at many nuclear plants in the US and elsewhere around the world, but using a building, though significantly more expensive, would likely provide better security, at least in some ways.[61]
- Optionally, the facility may include equipment for opening and removing fuel from casks, and for handling individual fuel assemblies and placing fuel into new casks. Such equipment would allow the facility to perform repairs in the unlikely event that a cask

[60] Source, Federation of Electric Power Companies (2016), "Characteristics of transport vessel specialized for spent fuel" (in Japanese), available as https://www.fepc.or.jp/nuclear/cycle/safety/sw_index_04/index.html.
[61] The use of a storage building, as opposed to an open array of casks, would help to protect casks from the elements and natural disasters, as well as from attacks launched from outside the building. On the other hand, in an attack scenario where a determined group of terrorists (for example) takes over a facility and cuts off communications with the outside world, a building would serve to shield what is happening inside the facility from monitoring via satellite.

failed before its operating lifetime had elapsed, and/or to transfer spent fuel to new casks to extend the effective operating life of the storage facility.

- Safety and radiation monitoring equipment, such as the arrangements and infrastructure in use at Mutsu and discussed in section 3, above.
- Site security, including human guards and onsite/offsite remote monitoring centers, as well as on-call security personnel who can provide back-up to on-site staff in the event of an emergency at the facility.

4.4 Political/Social/Community Attributes of Interim Spent Fuel Storage Site

Although, as noted above and below, an optimal site for a spent fuel storage facility will be physically separated from nearby communities, and especially larger communities, it is inevitable that the approval, or at least acquiescence, of local residents and provincial authorities will need to be obtained in order for construction of a facility to go forward. As storage facilities will be located on or near (for island and barge-mounted facilities) a coast, and will require ship berthing facilities and other infrastructure, it is unlikely that a site for a storage facility will be in an area where there are not at least some populations nearby.[62] Given that it will be necessary to negotiate with local residents and authorities, some of the attributes of attractive community hosts for a spent fuel facility might include:

- Experience of the community with hosting similar facilities in the past. For example, communities that are already host to a nuclear power plant (or a decommissioned plant) have experience with working with companies and agencies with regard to the plant, and know what they can expect in the way of compensation. Communities that host other facilities that serve an area broader than their own—large conventional power plants, national laboratories, or solid or toxic waste dumps, for example—might also be candidates. Moreover, the existence of such facilities typically implies the existence of infrastructure (port facilities and roads) that a spent fuel facility would need.
- Communities with municipal, prefectural, and provincial leadership that supports participation in a spent fuel facility. Communities suffering from the loss of population and/or economic opportunities, such as some of those described in section 3.3, above, may be more receptive to a package of compensation that can help the community and the broader area to provide needed social services, and, optimally, to generate some additional economic development.
- Communities that do not have a strong history of anti-nuclear activism. Although spent fuel facilities, especially those where dry casks are simply received and stored, and thus spent fuel is never removed from casks, have historically been quite safe, a community where anti-nuclear activism has historically been important may be one that is more difficult than most to convince to host a spent fuel facility.

[62] For example, it seems likely that any natural harbor that meets the requirements of cask transfer ships would have already been developed, over Japan's history, for fishing and/or other shipping activities.

Overall, a key element of convincing any community to host a spent fuel facility will be the approach taken to convince local residents, local, prefectural, and provincial leaders, and key thought leaders in the community of the benefits of the facility, and to incorporate the input of local residents to design a facility whose operation intrudes as little as possible on normal community life. Such an approach would require transparency and consistency in describing both the benefits and costs/risks (to the local community as well as to Japanese society) of the facility (as well as the risks to Japan if such facilities are NOT built), preparing compensation packages that are attractive and demonstrably dependable and long-term, being patient with local residents and authorities, and developing forums for communications between the community and the various actors (the site developer, construction companies, site operators, and cask transportation companies, for example) involved in the project.

It is assumed here that the participation of the community and local government in the project would be ultimately voluntary (if induced by persuasion of various types), but it is also possible (and is the case, at least, with final disposal sites for nuclear wastes) that the national government could designate a site and move forward with a facility (though still providing a fair compensation package) based on arguments of national security. There is some historical precedent for this approach in Japan, although it is not preferred.

4.5 Relative Advantages and Disadvantages of Coastal, Island, and Barge-mounted Interim Spent Facilities

The three types of interim spend fuel storage facilities considered here—coastal, island, and barge/vessel-based, may offer advantages and disadvantages relative to each other. These three general types of facility locations offer different levels of, for example ability to provide security from attack, security from accidents, security from the impacts of global warming, accessibility, potential frequency of required repairs/replacement, siting, and, of course, costs. The relative advantages and disadvantages of the three types of facilities relative to each of these criteria is discussed briefly below. These discussions should not, however, be considered comprehensive or definitive comparisons of the options, in part because particular facility designs and locations may have a significant influence how a facility performs with regards to any given criterion.

- **Security from attack.** Each of the three options—coastal, island, and barge/vessel-mounted, requires different consideration with regard to security from attack. All three are equally vulnerable to being hit by an attack launched from the air—such as a terrorist crashing a plane to the facility, although the damage caused by such an attack on a barge or vessel would likely be more severe than an attack on a coastal or island facility, which can be more heavily reinforced. Defending an island-based facility may be somewhat easier than for a coastal location, in that attacks can only come from the water, not the land (assuming that the island is not publically accessible). On the other hand, getting reinforcements to the site of an attack on an island-based (or barge/vessel-based) facility may be more difficult, as reinforcements would have to come from the air or sea. A barge/vessel-based facility is somewhat by definition more vulnerable to attack in that it can be sunk, including via submarine attack, although the more compact nature of the facility may make it harder for an attacker to infiltrate. A barge/vessel-based facility would presumably be accompanied by a force of security ships that would maintain a watch over incoming air, sea surface, and submarine traffic, and would respond accordingly.

- **Security from accidents**. To the extent that each of the three options provides the same services—for example, transfer and storage of casks with or without opening casks to "re-can" spent fuel—the security of the three types of storage from accidents related to cask/spent fuel handling should be similar. Coastal and island-based systems, with larger footprints than vessel- or barge-mounted systems, would arguably provide more space to use in recovering from such an accident, but on the other hand, due to their greater capacity, more space would be contaminated in the (however unlikely) event that a cask handling accident resulted in a radiation release. For accidents related to natural disasters, the relative performance of the three systems really would depend substantially on the design and location of the facility. It might be easier, for example, for a barge or vessel to ride out an earthquake without damage than a land-based facility (assuming that the barge or vessel was not damaged by tsunami). But a barge/vessel-based facility might be more susceptible to storm events, although it would presumably be anchored in sheltered waters. Spent fuel barges/vessels suffer from the additional accident mode of collisions with other vessels, or with land or other obstacles when they are moved. And of course a barge/vessel can be sunk, though design measures can reduce that possibility, and retrieving casks from a sunken vessel would not be easy.
- **Security from the impacts of global warming**. Global warming could affect a spent fuel facility largely through the impacts of sea level rise and increased severity of storms. Coastal or island-based facilities could presumably, in most locations, be built high enough above the waterline that sea level rise would not be an issue, with the possible exception of shipping infrastructure facilities, which could be affected by rising seas, especially if existing infrastructure is used. Floating spent fuel barges would presumably be immune to sea level rise considerations, but could be affected by more severe weather, probably more than a coastal or island-based facility would be.
- **Accessibility**. Accessibility of a spent fuel facility can be considered in two different respects—physical accessibility by the public, and thus to potential malevolent actors, which is a negative, and accessibility for the purpose of transferring spent fuel from nuclear power plants and other storage facilities, which is a positive. Barge/vessel and island-based facilities arguable offer reduced accessibility by potential malevolent actors, due to the need to cross a body of water to get to the facility. The accessibility of a facility to transfers of spent fuel is presumably more a question of the location and design of an individual facility, but the barge/vessel option does offer the possibility of bringing to facility to the origin of the spent fuel, which the other options do not.
- **Potential frequency of required repairs/replacement**. For coastal or island-based facilities, it seems likely that the lifetime of the facilities could be extended by replacing casks when they reach the end of their listed lives (or when needed as determined by monitoring results), and by replacing/updating other key pieces of equipment (controls and moving parts of cranes, for example) when needed. Barge/vessel facilities may require wholesale replacement of the vessels, as well as cask replacement, at the end of the operating life of the vessel, which seems unlikely to exceed 50 years (though some vessels of other types have certainly been in operation that long and longer).

- **Siting**. Presumably, the number of areas of sheltered ocean where a barge/vessel might be anchored is greater than the number of practical sites where coastal or island-based facilities might be built, once considerations such as seismicity, proximity to populations, and local acceptance are factored in. Any advantage that barge/vessel-mounted storage facilities might have in that regard, however, would depend in part on whether local communities have (or claim) jurisdiction over the offshore areas where spent fuel barges/vessels might be anchored, or at least the right to influence the siting of such facilities..
- **Costs**. It is difficult to accurately compare the potential costs of coastal- versus island- versus barge/vessel-based spent fuel storage facilities, since those costs will depend significantly on the particular design used and the particular location chosen, as well as the existing infrastructure available at a particular location that can be adapted for use by the facility. That said, it seems likely that for a facility of a given size and design, an island-based facility would most likely be more expensive than a coastal facility to build and operate, given the need to move people, materials, and equipment from one of the main islands of Japan to the island hosting the facility exclusively by sea (or possibly air). Economies of scale, on the other hand, may favor these land-based facilities over barge/vessel facilities, depending on the size of the facility required. Land-based facilities can accommodate thousands of casks, and can be expanded by buying more casks and building a larger building, or by expanding into more space in an existing building. Once the storage capacity of an existing barge or vessel has been reached, however, the only way to expand it is to add another vessel. It is unclear exactly how much spent fuel a purpose-built spent fuel storage barge would accommodate, but based on the capacity of ships in the various cask transport fleets—ships of about 100 meters long and 20 meters wide, designed to carry on the order of 10 to 20 casks[63]—it seems likely that an individual barge/vessel spent fuel facility, even if it were as large as some of the largest container ships currently in use would hold no more than 1000 tonnes of spent fuel, and probably more likely hundreds of tonnes (but this is just a guess on our part).

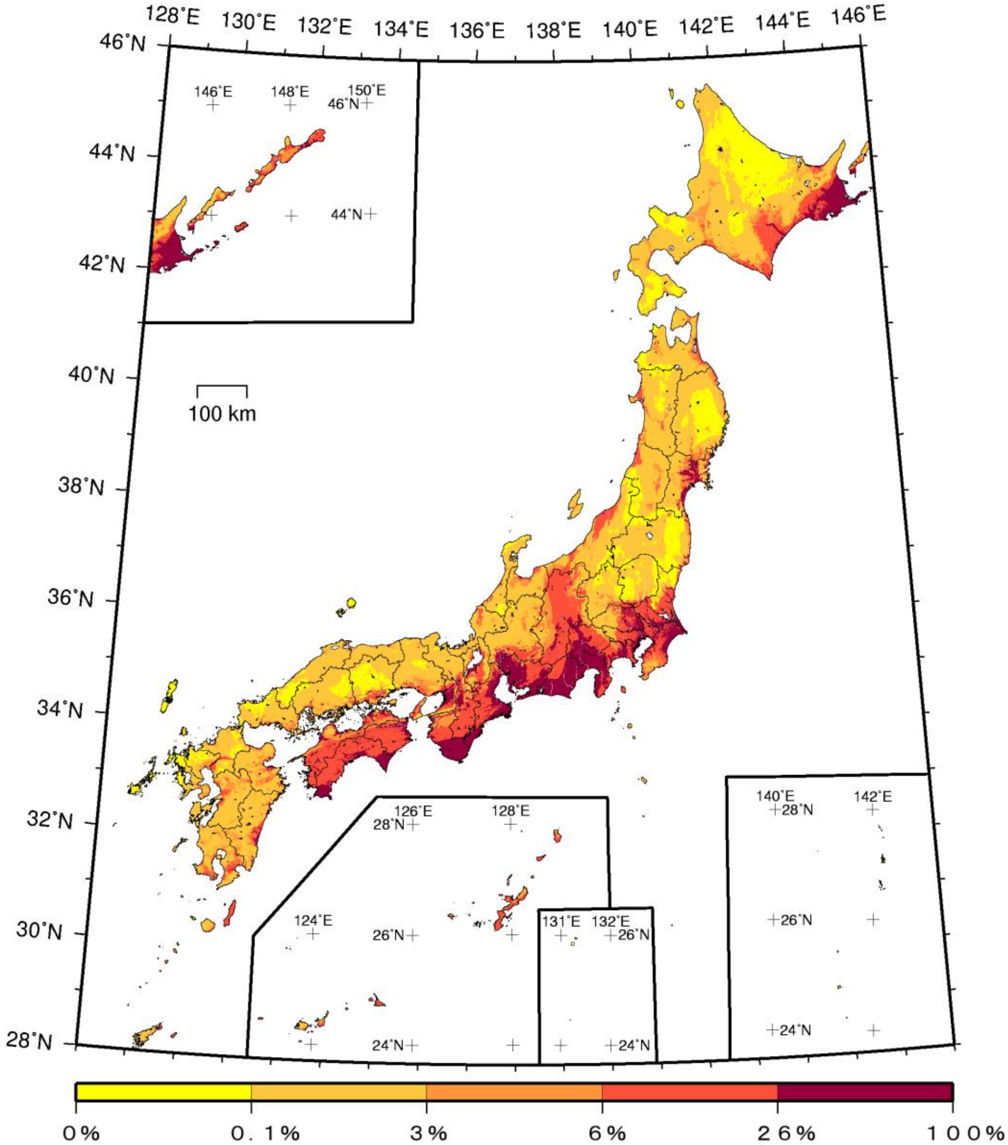
4.6 Areas of Japan Where Interim Spent Fuel Storage Might be Located

Two of the key attributes of an interim storage facility are that they be located in an area that is not (or is relatively less) prone to earthquakes and resulting tsunamis, and are located in areas that are not densely populated, though in both cases structural or other modifications to enhance the safety of the facility. Figure 4-3 shows the areas of Japan that are more and less prone to seismic activity, and Figure 4-4 provides a map of population density in Japan (as of 2005). Taken together, and factoring in the location of nuclear power plants, better candidate areas for interim spent fuel would appear to be in the southern areas of Hokkaido/northern areas of Honshu that face each other, which is the same general region where the Mutsu facility is

[63] See, for example, World Nuclear Organization (2016), "Transport of Radioactive Materials", updated October 2016, and available as http://www.world-nuclear.org/information-library/nuclear-fuel-cycle/transport-of-nuclear-materials/transport-of-radioactive-materials.aspx.

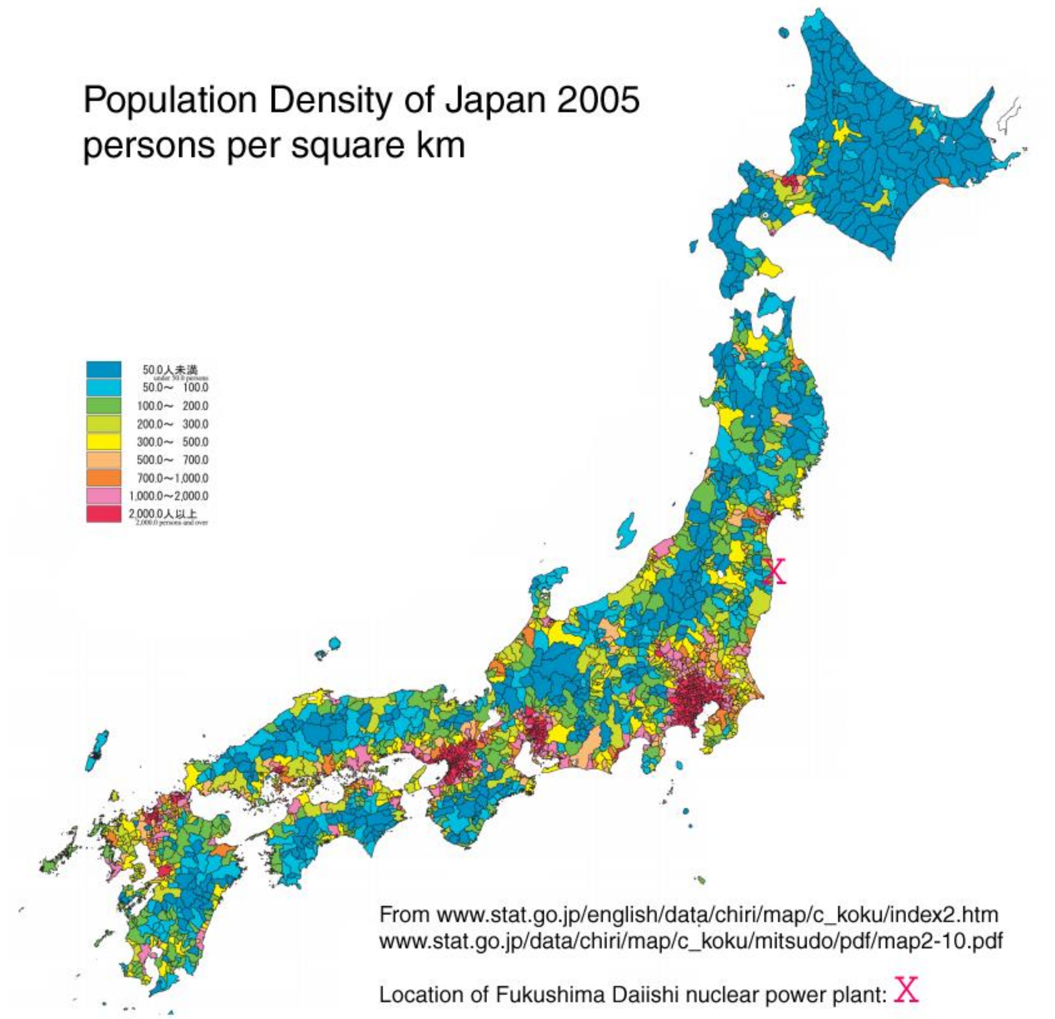
located, but not the Pacific coastal areas, parts of the west coast of Honshu facing the Sea of Japan, and islands in the sea of Japan near Honshu, as well as some of the less-inhabited inland sea areas on the West side of Kyushu. Although fairly distant from most of the nuclear power stations in Japan, the northern and western coast of Hokkaido also offer low population densities and low seismicity. It should be emphasized that none of the discussion above should be taken as an endorsement by the authors of siting interim spent fuel storage facilities in these areas, as detailed technical and economic feasibility studies, environmental assessments, and other evaluations would need to be done to identify candidate sites, as well as detailed consultations with regional authorities and local residents.

Figure 4-3: National Seismic Hazard Map for Japan[64]



[64] From Japan Seismic Hazard Information Station, National Research Institute for Earth Science and Disaster Resilience (2012), "What are the National Seismic Hazard Maps for Japan?", available as http://www.j-shis.bosai.go.jp/en/shm.

Figure 4-4: Japan’s Population Density by Area as of 2005



5 Remote Interim Spent Fuel Storage in Japan versus Existing Storage Systems

Remote interim spent fuel storage facilities of the types discussed above offer a number of advantages over the other technologies now in use for spent fuel management in Japan, including at-reactor spent fuel pools, and reprocessing facilities, but do have some disadvantages as well. Table 5-1 provides a brief comparison of the relative security, environmental, economic, political, and social/institutional attributes of a generic island/coastal/barge-mounted interim spent nuclear fuel storage facility for use in Japan, relative to a combination of (mostly) spent fuel pools and reprocessing that is the current practice, pending further government decisions on spent fuel management. The comparisons provided below are necessarily general and subjective in nature, given the generic interim spent fuel facility types considered in this paper.

5.1 Relative Political/social/institutional Attributes of Remote versus Existing Systems

In Table 5-1 we summarize the performance of Japan's current spent fuel management system relative to coastal/island or barge-mounted spent fuel storage facilities with respect to the following key attributes: 1) security from accident or attack, 2) potential radiological impacts of a major incident, 3) other environmental impacts, 4) economics, and 5) political, social and institutional considerations.

It is well known that dry cask storage is less expensive than the combination of pool storage and reprocessing, and is much less vulnerable to attacks or natural disasters. There has been no serious discussion regarding the potential construction of interim storage facilities in Japan in sufficient number or capacity to handle most of Japan's spent fuel, largely because Japan's overall national nuclear plan remains the pursuit of a closed nuclear fuel cycle. , The Fukushima disaster showed vulnerability of pool storage of spent fuel, however, and created an atmosphere in which those involved in nuclear sector planning were forced to take what might be described as a more realistic and transparent approach to discussions of spent fuel management options. Once all of the nuclear power plants that can potentially be restarted have been restarted, the problem of full and rapidly filling spent fuel pools will become a reality in the near future. Recent newspaper articles report that KEPCO is seriously seeking a location or locations for new interim dry spent fuel storage facility/facilities. The chairman of the Nuclear Safety Committee, Mr. Tanaka, has shown a strong preference to shift dense-packed pool storage into dry cask storage. It seems that the Japanese regulatory society is now swinging toward a preference for identifying and developing dry cask storage sites.

Table 5-1: Comparison of Existing Spent Fuel Management in Japan with Coastal, Island, or Barge-based Interim Spent Fuel Storage Options

Attribute of Spent Fuel Storage Option	Existing Spent Fuel Management in Japan	Coastal or Island-based Central Spent Fuel Storage	Barge-based Central Spent Fuel Storage
Security from Accident or Attack	Spent fuel pools must be guarded against accident (through a combination of utility services and safety upgrades, many of which are underway or completed in Japan) and on-site security, though many spent fuel pools, particularly dense-packed fuels, remain significantly more physically vulnerable than fuel in dry cask storage. Plutonium separated during reprocessing must be safeguarded carefully to guard against proliferation.	Spent fuel stored in casks is less vulnerable to an accident or attack that would cause a major radioactivity release, and thus arguably more easily secured, though the form of security services would vary by type of site. Proliferation vulnerability much lower than with reprocessing, so requirements for securing Pu would decrease.	Similar to coastal or island-based, but may be more different sites to secure (and, from the perspective of malevolent actors, to attack) than for larger coastal or island-based facilities. Additional security required to guard against attack from surface ships or submarines (or divers) relative to land-based facilities.
Potential Radiological Impacts of Major Incident	Loss of coolant without make-up in dense-packed spent fuel pools could lead to fire, broad atmospheric distribution of large amounts of radioactivity	Dry casks difficult to penetrate sufficient to cause broad exposure, fire, and quantity of radioactivity contained in a single cask is much less than in spent fuel pool.	Dry casks difficult to penetrate sufficient to cause broad exposure. If casks penetrated AND vessel sunk, could result in release of radioactive elements to ocean
Other Environmental Impacts	Under routine operation, production of high, intermediate and low-level wastes	and land use impacts related to land-based construction of additional facilities	Potential air/water pollution impacts related to construction of new vessels.

Attribute of Spent Fuel Storage Option	Existing Spent Fuel Management in Japan	Coastal or Island-based Central Spent Fuel Storage	Barge-based Central Spent Fuel Storage
	from reprocessing that require safe disposal, as well as impacts of energy use at Rokkasho.	(similar to those for large non-nuclear infrastructure projects)	
Economics	Most facilities already constructed, but operating costs of reprocessing may be significant.	New facilities would need to be constructed and operated, and land for the facilities acquired, but dry cask storage is much less expensive than the overall costs of reprocessing.	Barge-based systems possibly lower in cost than land-based systems, but economies of scale are not as strong.
Political, Social, and Institutional	Mostly existing facilities already sited, with local communities dependent on compensation payments, but local and national discussions ongoing about the safety of power plants, spent fuel storage in pools, MOx use, and reprocessing. Existing systems have support of nuclear vendors and operators, and of most of nuclear regulator community.	Potential hosts and local, prefecture, and provincial level may have objections to facilities, but may not be as aware of the relative radiological and other risks, and benefits, of interim spent fuel storage as of other nuclear facilities. Interim fuel storage not supported by nuclear vendor/operator regulator community to the same extent as existing systems. Governance of interim storage facility might be different than for existing systems.[65]	Because they are located offshore, jurisdiction over these facilities, and thus potential opposition, may be different than for land-based facilities.

[65] See, for example, M. Takubo and F. von Hippel (2013), Ending reprocessing in Japan: An alternative approach to managing Japan's spent nuclear fuel and separated plutonium, International Panel on Fissile Materials, November 2013, available as http://fissilematerials.org/library/rr12.pdf. Also note that

6 Social and Political Barriers and Challenges to Developing an Remote Interim Spent Nuclear Fuel Storage Facility

6.1 Opposition to Interim Spent Fuel Storage by the Nuclear Industry in Japan

Japan's nuclear sector has for the most part been pursuing a closed nuclear fuel cycle since the inception of the use of nuclear energy in Japan. In theory, under a closed nuclear fuel cycle, there should be no need for interim spent fuel storage other than in spent fuel pools and at reprocessing facilities. As a result, interim spent fuel storage facilities have not been a significant part of the national nuclear plan. Since the construction and operation of reprocessing plants, and also the FBR plants has not proceed as planned, however, spent fuel stored on site at the nuclear power stations has started filling existing pool capacity, and remote storage was allowed starting in 1993. RFS in Mutsu city has been built to accept spent fuel until Rokkasho starts operating at full capacity. Since the Fukushima accident, all the plans for the nuclear-related facilities have been under review, and also the operation of all nuclear power plants have been stopped for inspection under new safety regulations. At present, there have been 10 nuclear plants that have passed inspection the new regulations, and the Japanese nuclear industry is trying to return to pursuit of a closed nuclear fuel cycle. Mr. Tanaka, the current chairman of Nuclear Regulatory Commission, has a strong preference for dry cask storage as opposed to long-term storage of spent fuel in pools, and as larger numbers of the nuclear power plants slated for restart come on line, , the problem of safely storing the spent fuel will once again become critical.

6.2 Opposition to Interim Spent Fuel Storage by Residents of Host Regions

Due to the magnitude of the grants that host municipalities can receive, there are always groups of people in a community that are likely to welcome the idea of hosting an interim spent fuel storage facility. These groups typically make the argument that since dry cask storage technology has less risks than the nuclear power plants themselves, but the amounts of the grants available to the host community are comparable, it is rational to be willing host dry cask storage facilities. Opposition groups also typically always exist in any candidate host community, and their principal argument in opposition to hosting an interim storage facility is that in fact the facility will not ultimately be "interim", but rather that the community will serve as a host indefinitely, perhaps forever, once the community accepts the facility.

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the potential merger of spent fuel businesses of Hitachi, Toshiba, Mitsubishi announced in September of 2016 (Reuters, "Hitachi, Toshiba, Mitsubishi aim to merge nuclear fuel units – source", dated Sep 28, 2016, and available as http://www.reuters.com/article/japan-nuclear-fuel-idUSL3N1C44ZP) may arguably be the start of a shift in the structure and perhaps governance of the nuclear industry.

6.3 Attitudes toward Interim Spent Fuel Storage by Civil Society Organizations in Japan

A strong preference for dry cask storage rather than wet pool storage has developed in Japan since the danger of losing spent fuel pool coolant was seared into the public consciousness by news coverage of at the several-month aftermath of the disaster at the Fukushima power plants in 2011. Meanwhile, the dry casks that were in use at Fukushima at the time of the accident survived the earthquake and tsunami with no damage. At the same time, there have historically been objections toward any type of nuclear facilities among some groups of people, and the voices of these groups have, if anything, increased in volume since Fukushima. The balance between the need for additional spent fuel storage and a general aversion to siting any new nuclear facilities has yet to be set in Japan.

6.4 Existing Laws and Arrangements with Current Nuclear Facility Host Communities

There is a system of providing monetary grants to communities that host power supply facilities, and this system also applies to the siting of interim spent fuel storage facilities. Grants are paid to the prefecture in which the facility is based, to the municipality in which the facility is sited, and to municipalities adjacent to the municipality hosting the facility.

The scheduling of payments to the host community of a facility is typically as follows. There will first be a series of "Initial Payments", which begin once the community accepts the implementation of a feasibility study. If the parties decide to move forward with the construction of the facility, a "Midterm Payment" is provided annually to the host community starting when construction begins, and continuing until five years after the start of operations. After the start of operations, a set of ongoing grants, called "Grants for nuclear fuel cycle facilities", will come into effect. These grants are phased in over the first five years of operation, then continue until the spent fuel storage period ends. In 2015 a program of grants for communities that host nuclear power plants undergoing decommissioning was launched, and a similar program is expected to be applicable to interim storage facilities.

We have made a rough estimate of the subsidies that local government can receive if they agree to host an interim storage facility (see Figure 6-1). Initial grants, as indicated above, will be provided before construction starts, but the annual amount of these initial grants will grow significantly once the prefectural Governor approves of the project signaling that construction planning can begin in earnest. Grants to the community will be around 1.4 million USD annually during the first part of the feasibility study period, rising to a total of about 30 million USD annually during the construction period. This particular estimate assumes a total capacity for the facility similar to that of Mutsu, or about 3000 tU.

Figure 6-1: Estimated Grants to Local Government that Agree to Host Interim Spent Fuel Storage Facilities

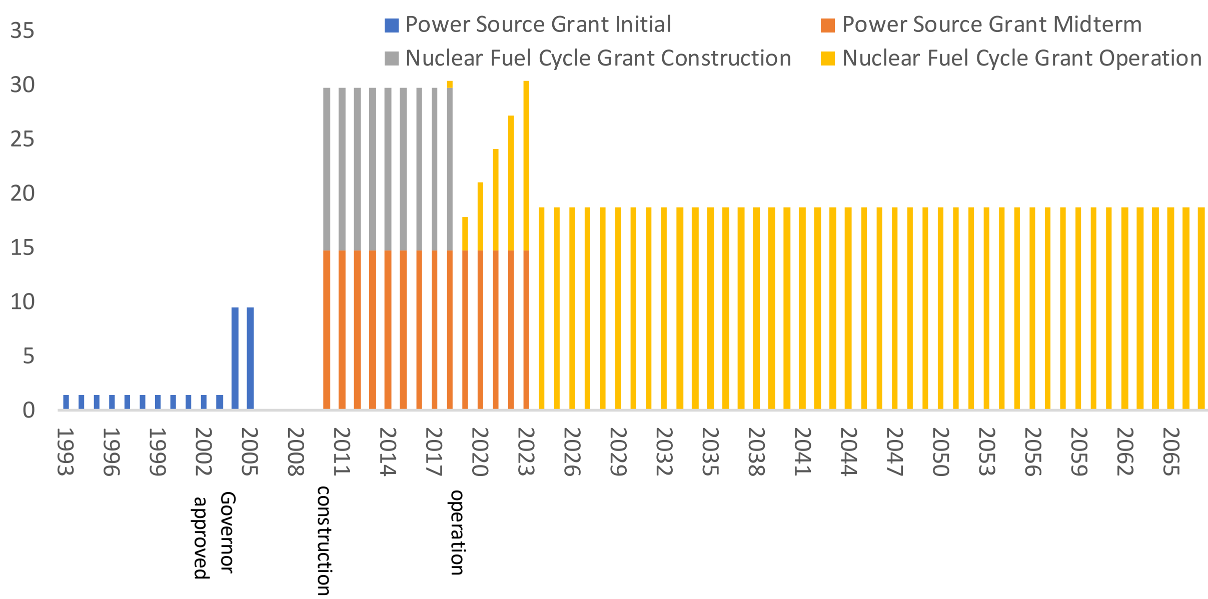
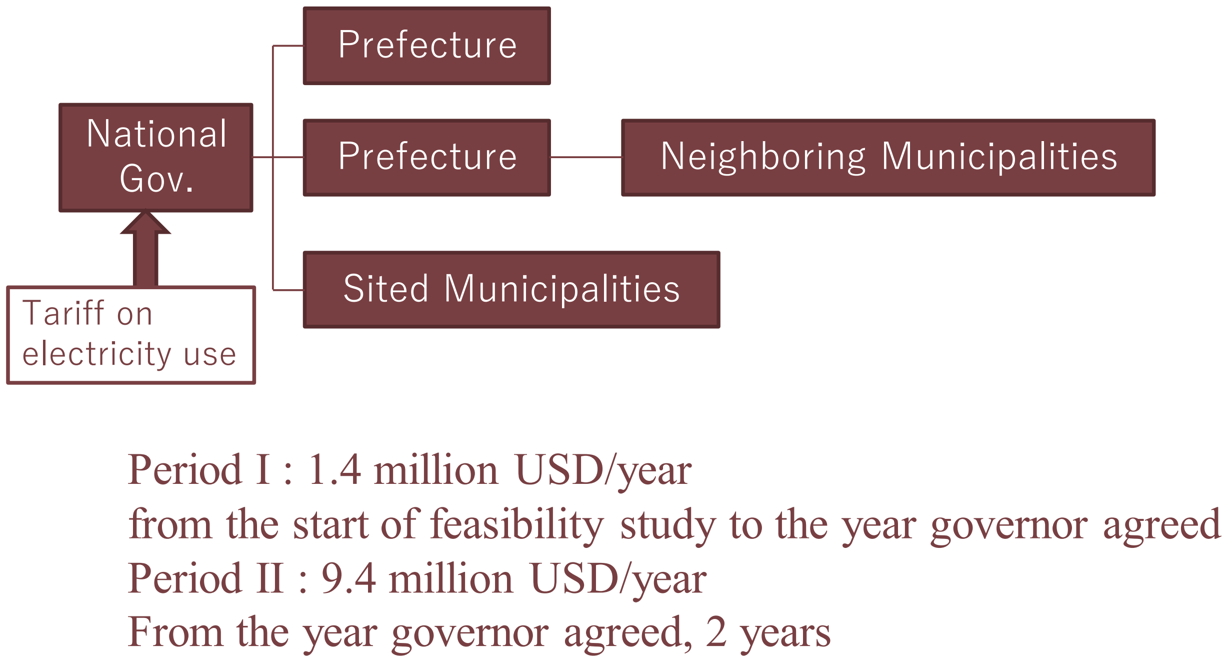


Figure 6-2, Figure 6-3, and Figure 6-4 show the details of each of the three types of grants.

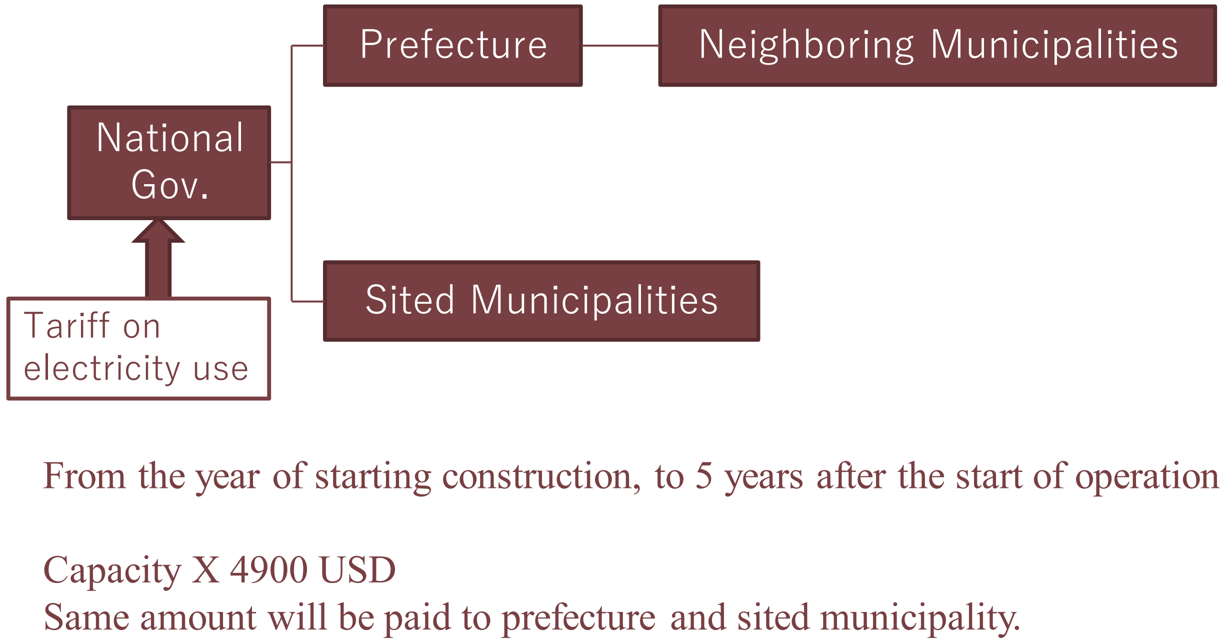
Initial grant payments will be paid to the prefecture, to neighboring municipalities through the prefecture, and directly to municipalities in which facilities are to be sited ("Sited Municipalities" in the figures below). Once the feasibility study starts, the grants will be 1.4 million USD per year (total, for all municipalities and the prefectural government), rising to 9.4 million USD per year once the Governor approves, but only for the final two years of the feasibility study.

Figure 6-2: Initial Payments for Interim Storage Facilities



Midterm payment will be paid from the year of the start of construction of the facility, through a date five years after the start of operations, with the amount of the payment determined by the capacity of the facility to store spent fuel.

Figure 6-3: Midterm Payments for Interim Storage Facilities



The final main grants consist of grants for construction and grants for operation. The amount of the grants depends on the facility capacity for the construction grants, and the amount of spent fuel in storage for the operation grants. The operation grants are to be paid annually until the storage period ends.

According to the *Daily Tohoku* newspaper, on June 25th 2016 (http://www.daily-tohoku.co.jp/tokusyu/kakunen/news/201606250P144283.html), grants delivered to municipalities in Aomori Prefecture, in which the Rokkasho reprocessing facility is located, totaled 15.4 billion yen in fiscal year 2015. For the five years since fiscal year (FY) 2011, annual grants have totaled more than 15 billion yen, and total grants since FY 1981 sum to more than 300 billion yen.

These grants, which are derived from fees paid by electricity consumers as a part of electricity tariffs, were also paid to communities hosting fossil fuel power and hydro power plants, but 99% of the grants made to community hosts are to those hosting nuclear related facilities. In the case of the Aomori area, grants are provide to the prefecture, to the four municipalities in which facilities are sited, and to the neighboring 11 municipalities.

In fiscal year 2015, Rokkasho village received grants totaling 2.8 billion yen, Mutsu City received 2.5 billion yen, and Aomori prefecture received 3.7 billion yen. Mutsu City's annual budget in 2008 was about 32 billion yen, so the annual grants provided represent somewhat less than 10 percent of the municipality's annual budget.[66] Figure 6-5 shows the annual grants to municipalities in Aomori Prefecture from 1988 through 2015.

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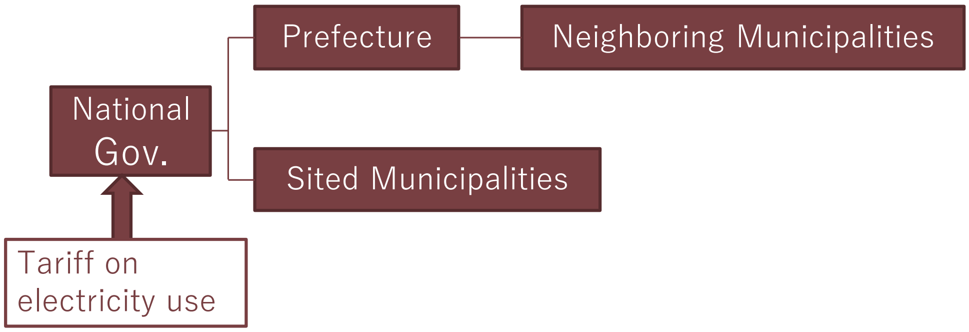
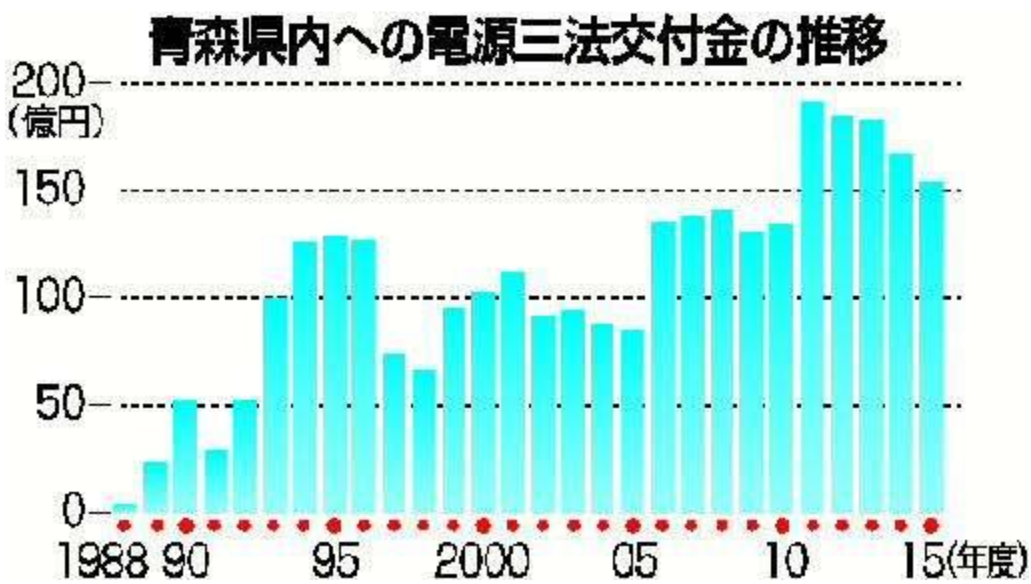
[66] See, for example, Sawai Masako (2005),," Mutsu City accepting intermediate storage facilities", Citizen's Nuclear Information Center (in Japanese), available as http://www.cnic.jp/modules/smartsection/item.php?itemid=22.

Figure 6-4: Grants for Construction and Operation of Nuclear Fuel Cycle Facilities



Grants for Construction:
from start of construction to the start of operation
Capacity(tU) x 5000 USD
Grants for Operation:
from next year of staring operation, to the end of operation
Stored amount (tU) x 6250 USD
Same amount will be paid to prefecture and sited municipality.

Figure 6-5: Total Grants from Electricity Tax to Municipalities in Aomori Prefecture (units, 100 million JPY)



As noted above, residents of host communities always are concerned that spent fuel, once placed in the facility, will be stored there forever. To ameliorate this concern, in the case of the Mutsu facility, RFS, the facility's operator, has a contract to remove the spent fuel starting on the date 50 years after the first dry cask was placed in the facility.

There have to date been no discussions in Japan, at least in the public literature or in conversations of which the nuclear sector experts interviewed by one of the authors (Takase) were aware, of siting dry cask storage facilities generically at coastal or island locations, nor of siting spent fuel facilities on barges in near-shore Japanese waters. In Japan, it is generally more difficult to start doing something with which other nations have limited or no experience, and thus a proposal to develop national remote coastal/island-based or barge-based central spent fuel storage facilities would as a consequence engender lengthy discussions and significant criticism. If, however, a plan for a regional Asian and/or Pacific collaborative spent fuel storage facility were to be developed, Japan might consider join such a regional collaborative, since Japan has many difficulties finding spent fuel storage locations that are acceptable to all stakeholders in its very limited land area.

7 Conclusions

7.1 Attributes of Sites for Remote Interim Spent Fuel Storage Facilities

The largest problem for siting interim spent fuel storage facilities is public acceptance. Even though dry cask technology has a relatively low risk of radiological release as a result of accident or attack, the public's general reluctance to accept any type of nuclear- related facilities near their own communities still exists. Japan already has a scheme to provide a large amount of compensation to the prefectural and local governments hosting interim spent fuel storage facilities, with the compensation continuing for long periods of time, and the offer of these grants can attract prefectural governments to consider hosting interim storage facilities on, for example, islands within the prefectural territory. Islands offering a solid geological setting may be possible host locations. The Japan Agency for Marine-Earth Science and Technology (JAMSTEC) has started to consider doing research for final deep borehole disposal in Minamitori Island, which is a part of the Tokyo prefecture, but has no residents. Minamitori Island has a stable geology, and can be a candidate not only for the deep borehole final disposal experiment, but also for the interim spent fuel storage.

Japan has a history of siting nuclear-related facilities in coastal areas, typically areas with low population densities. Coastal locations make it easy to get cooling water for the reactors. Coastal area also offer advantages in transporting nuclear fuel, both fresh fuel and spent fuel, by ship, which is the only transport mode that Japan has used to date for commercial reactor spent fuel (with the exception of short distances from nuclear facilities to ship berths, which are handled by truck).

With respect to potential barge-mounted interim storage facilities, Japan has potentially relevant experience related to operating two oil stockpiling facilities on barges/vessels (see Figure 7-1. Since all the safety criteria related to the storage of nuclear spent fuel have been developed assuming the storage structure sits on the ground, it would likely require a large effort to develop new safety criteria for the spent fuel facilities located on barges/vessels.

Figure 7-1: Oil Stockpiling Facilities in Japan (Shirashima and Kamigotou are on barges/vessels)

Stockpiling capacity by base

Petroleum		
1	640	Tomakomai
2	570	Mutsuogawara
3	450	Akita
4	175	Kuji
5	340	Fukui
6	150	Kikuma
7	560	Shirashima
8	440	Kamigotou
9	500	Shibushi
10	175	Kushikino

(Unit: ten thousand KL)

LP gas		
1	200	Kamisu
2	250	Nanao
3	400	Kurashiki
4	450	Namikata
5	200	Fukushima

(Unit: thousand tons)

7.2 Key Barriers and Challenges to Implementation of Remote Interim Spent Fuel Storage Facilities in Japan

As discussed in the previous section, the lack of public acceptance is a major challenge for siting new interim spent fuel facilities in Japan. Also, the regulation of nuclear facilities has become more strict in the aftermath of the Fukushima accident, and it is very hard to for a new facility, or even an updated existing facility, to obtain approval by the Nuclear Regulation Authority.

A compensation scheme for the hosts of nuclear facilities, including spent fuel storage facilities, is well established, so that less-populated municipalities in particular (where payments are spread over a smaller population) should have significant motivation to host interim storage facilities.

Earthquake are very frequent in Japan, and as was observed following the Great East Japan Earthquake, there is the possibility for large tsunamis following earthquakes. This is of particular concern for siting spent fuel storage in coastal areas, on islands, and on barges or vessels. Still, an important empirical example, is that spent fuel in dry casks already stored at Fukushima Daiichi power plant at the time of Great East Japan Earthquake safely survived the tsunami that severely damaged many other systems at the Fukushima plant.

Based on risks related to earthquakes and tsunamis, coastal or island-based spent fuel storage would likely be safer than barge-mounted or ship-based storage, since dry casks are very heavy, and would not be affected by a tsunami if land-based, but would create a significant problem associated with cask recovery if a barge or vessel holding spent fuel was wrecked, and the casks sank into the ocean.

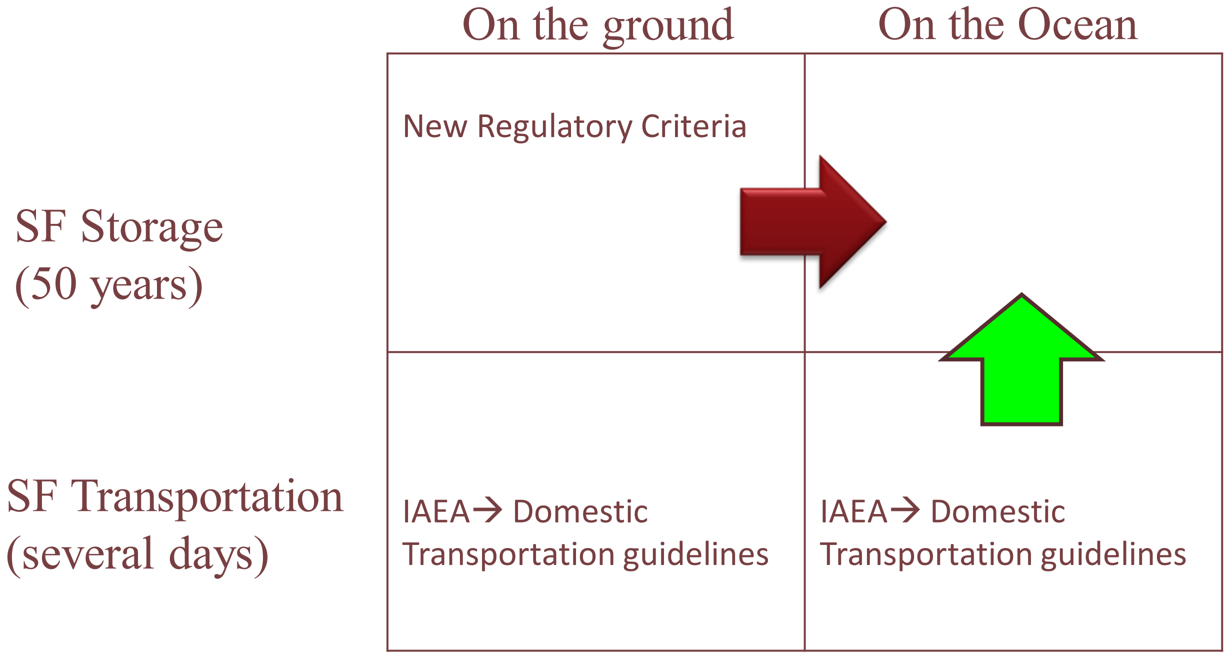
A practical advantage of island-based storage related to compensation grants and winning approval for siting at the prefectural level is that, especially on islands without residents, the prefectural government could receive compensation for hosting the facility, even though there are no people living on the island and thus no municipality directly hosting the facility.

7.3 Next Steps

It is very important for potential developers of spent fuel storage facilities to clearly disclose both the risks and merits of hosting such facilities. The transparency of the process of siting nuclear facilities in Japan has been improving, but additional effort to inform the public about risks, benefits, options, and the current spent fuel management situation will be required.

For potential barge/vessel-based spent fuel storage facilities, since Japan already transports spent fuel by ship, and operates oil stockpile facilities on barges/vessels, it may be possible to develop regulations/guidelines for barge/vessel-based storage from the starting point of the safety criteria already used for spent fuel transportation by ship, rather than from the existing land-based spent fuel storage criteria, which are a poor match to the situation of storage of spent fuel at sea and would take considerable time and effort to adapt to barge/vessel-based storage. The difference between spent fuel transportation and spent fuel storage on barge/vessels is only the duration of storage, suggesting that a more streamlined approach to developing safety standards for spent fuel storage at sea could be possible (see Figure 7-2).

Figure 7-2: Possible Approaches to Developing Guidelines/and Criteria for Barge/vessel Spent Fuel Storage in Japan



Japanese electric companies and the agencies of the Japanese government involved with the nuclear sector are now aware of the importance of dry cask storage, and dry cask storage is now preferred to spent fuel pools and reprocessing, at least officially, since it offers advantages in costs and safety. What Japan lacks is public acceptance of spent fuel facilities, as well as open, transparent, and inclusive processes for public disclosure and discussion on nuclear sector matters. It is very important to have all processes in which Japan's nuclear future are discussed be open, and to prepare good discussion platforms in order to foster public acceptance.