An Alternative to the Continued Accumulation of Separated Plutonium in Japan: Dry Cask Storage of Spent Fuel

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ABSTRACT
As of the end of 2017, Japan had a stockpile of 48 tons of separated plutonium. It will take more than a decade for Japan to convert most of that plutonium into “mixed-oxide” (MOX) fuel and load it into power reactors licensed to use such fuel. This is a very costly program. Including the cost of reprocessing, MOX fuel costs about ten times more than the low-enriched-uranium fuel that otherwise would be used by these reactors. Yet Japan has a policy to start separating more plutonium from spent reactor fuel as soon as the Rokkasho Reprocessing Plant can be put into operation – currently projected for 2021 after 24 years of delay due to a variety of technical problems and upgrades in safety requirements. Japan's government remains committed to this costly and troubled program primarily because, pending the availability of additional spent-fuel storage space on or off site, reprocessing is seen as the only way to get spent fuel out of reactor pools that are getting full. Because of concerns about the safety of dense-packed spent-fuel pools, however, the prefectures and towns hosting Japan's power reactors are beginning to accept on-site storage of spent fuel in dry casks. This is the option the United States and many other countries chose after they cancelled their reprocessing programs and their powerplant pools filled up. Its increasing availability in Japan, if backed by a determined policy to accelerate its introduction, should make it possible to cancel reprocessing in Japan as well.

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Introduction
Japan had accumulated 48 tons of separated plutonium as of the end of 2017 (including 0.6 tons to be allocated to Japan “around 2019”), 1 enough for about 6000 Nagasaki-type bombs. 2 This plutonium has been separated by chemically “reprocessing” Japan’s spent

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1 Japan’s Atomic Energy Commission states 47.3 tons as of the end of 2017 (10.5 tons in Japan, 21.2 tons in the UK, and 15.5 tons in France) (JAEC 2018) but then adds that “Approximately, 0.6 ton of plutonium from the remaining spent fuel contracted out to the UK is expected to be added to the stockpile around by 2019, when the reprocessing facility in the UK is scheduled to be closed.” Reprocessing of Japan’s LWR fuel was completed by March 2005 and Tokai magnox fuel by January 2006. What is left is a final allocation by UK’s Nuclear Decommissioning Authority. See the September 29 response from UK Nuclear Decommissioning Authority to Martin Forwood, campaign coordinator of CORE, a local group, reproduced in a slide, with Japanese translation inserted, at http://kakujoho.net/npp/pu_nda.html#d3.

2 The International Atomic Energy Agency assumes that 8 kg of plutonium is sufficient, including fabrication losses, to make a first-generation (i.e. Nagasaki-type) nuclear explosive (IAEA 2001, 23). Based on the ratio of US Cold War stocks of weapons plutonium to the number of US nuclear weapons, advanced designs used an average of about 3 kg of plutonium (USDOE 1996; USDOD 2017).
nuclear-power-reactor fuel in Europe and in Japan to recover the approximately 1% plutonium it contains.\(^3\)

The original purpose of this plutonium separation was to provide startup fuel for plutonium breeder reactors. During the 1960s and 1970s, all the major industrialized countries, including Japan, had programs to develop breeder-reactors because they expected that high-grade uranium ores would soon be depleted. In theory, liquid-sodium-cooled breeder reactors could eventually extract about 100 times as much fission energy from a kilogram of natural uranium as water-cooled reactors do today by converting the non-chain-reacting uranium-238, which comprises 99.3% of natural uranium, into chain-reacting plutonium. Water-cooled reactors efficiently exploit only the fission energy in chain-reacting U-235, which constitutes 0.7% of natural uranium.

The anticipated uranium shortage did not develop, however. Today, the cost of natural uranium accounts for only 2 to 6% of the cost of nuclear power generation.\(^4\) Most of the cost of nuclear power is due to the capital invested in the reactors and breeder prototype and “demonstration” reactors have turned out to be more costly and mostly far less reliable than light water reactors.\(^5\) In December 2016, after struggling for two decades to operate its own prototype, Monju, Japan decided to decommission it (Takubo 2017; Cochran et al. 2010).

Despite the shutdown of their breeder prototype and demonstration reactors, however, France has continued to separate plutonium from its spent low-enriched spent fuel and Japan still plans to start operations of its large reprocessing plant at Rokkashomura, Aomori Prefecture. Operations there, originally scheduled to begin in 1997 when the construction started in 1993, have been repeatedly delayed by technical problems and failures to satisfy post-Fukushima safety upgrade requirements. As of the end of 2017, 32 years since the local authorities accepted the request for cooperation to build the plant in 1985, it was not operational and projected to begin to operate in 2021.\(^6\) In the meantime, the construction cost estimate soared from 760 billion yen in 1993 to 2.85 trillion yen including 0.7 trillion yen for post-Fukushima required upgrades with another item called “other capital investment” amounting to 1.58 trillion yen to be spent for voluntary additional safety measures and equipment replacement (NuRO 2018). In the absence of breeder reactors, the plan is to mix the plutonium with uranium into “mixed-oxide” (MOX) fuel that will be used in conventional light-water reactors. Because of the high cost of reprocessing, the MOX fuel will cost roughly ten times as much as the low-enriched uranium fuel that otherwise would have been used (JAEC 2011, slide 28).\(^7\)

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\(^3\)Spent light water reactor fuel contains about 1 percent plutonium (Nuclear Energy Agency 1989). The Magnox fuel from Tokai I contained about 0.22 percent (NAC International 1995).

\(^4\)About one megawatt-day of thermal energy is released per gram of U-235 in light-water reactor fuel. This produces about one third of a megawatt-day or 8,000 kWh of electrical energy. About 75% of the 7.2 g of U-235 in one kilogram of natural uranium ends up in the enriched product. Therefore, about 43,000 kWh of electrical power are generated from a kilogram of natural uranium in a light-water reactor. For a natural uranium price of about $100/kg, see USEIA (2017, Table 5). This corresponds to about 0.00823/kWh. The levelized cost of nuclear power from a new nuclear power plant ranges from $0.04 to $0.10 /kWh (WNA 2018a).

\(^5\)Russia’s BN-600 has been the exception despite fourteen sodium fires early on in its operational lifetime, which started in 1980 (Saraev 1998). As of the end of 2017, it had realized a lifetime capacity factor (fraction of electric energy it would have produced had it operated at 100% capacity continually through its lifetime) of about 76 percent (IAEA PRIS 2018).

\(^6\)“Japanese Nuclear Fuel Reprocessing Plant Delayed Yet Again,” Nikkei Asian Review, 23 December 2017. https://asia.nikkei.com/Politics-Economy/Policy-Politics/Japanese-nuclear-fuel-reprocessing-plant-delayed-yet-again.

\(^7\)Assuming a zero percent discount rate and 7.5 kg of LEU spent fuel reprocessed per kg of MOX fuel produced.
Since 2005, the most-often-cited reason for continuing Japan’s commitment to reprocessing, despite the huge cost, has been the need to have an off-site destination for the spent fuel accumulating in the storage pools of Japan’s nuclear power plants. The concern has been that, in the absence of such a destination, the reactor pools would fill up and the reactors would have to be shut down. Thus, Japan’s Atomic Energy Commission argued (JAEC 2005, 33):

If we make a policy change from reprocessing to direct disposal [since it takes time for communities hosting nuclear power plants to] understand the new policy of direct disposal and accept the interim storage of spent fuel...it is likely that the nuclear power plants that are currently in operation will be forced to suspend operations, one after another, during this period due to the delay of the removal of spent fuel.

The intake pools at the Rokkasho Reprocessing Plant are virtually full. Therefore, little more spent fuel can be shipped to them until reprocessing operations begin.8

During the 2011 accident at the Fukushima Daiichi nuclear power plant, spent fuel in reactor pool 4 was in danger of being uncovered. If it had been uncovered, the temperature of the recently discharged fuel in the pool would have been raised by radioactive heat until its zirconium cladding caught fire. That would have spread to the other fuel in the pool releasing to the atmosphere 100 times more long-lived radioactivity than was released by the core meltdowns in units 1, 2 and 3 (von Hippel and Schoeppner 2016).

Commissioners of Japan’s post-Fukushima Nuclear Regulation Authority (NRA) therefore have been urging nuclear utilities to move their spent fuel to safer, air-cooled dry casks after it has cooled in their pools for several years. For example, on 19 September 2012, at his first press conference, NRA’s first chairman, Shunichi Tanaka urged that:9

Spent fuel not requiring active cooling should be put into dry casks...for five years or so cooling by water is necessary...I would like to ask utilities to go along those lines as soon as possible.

Although this was framed as a request and not an order, some host communities and prefectures are beginning to consider construction of on-site dry-cask storage acceptable. An alternative to shipping spent fuel to Rokkasho therefore has begun to appear.

Not operating the Rokkasho Reprocessing Plant would result in a net savings of about ¥10 trillion ($90 billion) over 40 years for Japan’s electricity ratepayers and would allow Japan to begin to work down its stockpile of nuclear-weapon-useable plutonium.

In this article, we describe:

1. The origins of spent fuel reprocessing as part of a global program to prepare for a shift from water-cooled to liquid-sodium-cooled plutonium breeder reactors;
2. The continuation of the reprocessing program in Japan as the only way to prevent spent fuel from accumulating at the nuclear powerplant sites;

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8The last shipment in October 2016 increased the amount of spent fuel in the 3000-ton-capacity pool to 2968 tons (about 99% full). JNFL proposed zero acceptance for Fiscal Years 2018 to 2020 (“Reprocessing Plant – Receiving No Nuclear Fuel till FY2020, JNFL Plan Submitted,” Kahoku Shimpo, 3 February 2018 (in Japanese)). http://www.kahoku.co.jp/tohokunews/201802/20180203_23024.html.

9Record of press conference of Japan's Nuclear Regulation Authority, 19 September 2012 (in Japanese). http://warp.ndl.go.jp/info:ndljp/pid/11036037/www.nsr.go.jp/data/000068514.pdf.
(3) Japan’s inability to balance its plutonium separation with plutonium use in reactor fuel, exacerbating international concerns about its growing stocks of separated weapon-useable plutonium; and
(4) The developing alternative to reprocessing – on-site dry-cask spent-fuel storage.

From the Dream of Breeding Plutonium to the Challenge of Plutonium Disposal

In the 1960s and 1970s, anticipating very high rates of growth of global nuclear capacity and worried that uranium prices would skyrocket as a result, the global nuclear-energy community decided to develop much more uranium-efficient liquid-sodium-cooled fast-neutron plutonium-breeder reactors. The leading industrialized countries of the time, including Japan, started reprocessing programs to recover the plutonium in light-water-reactor spent fuel to fabricate startup fuel for the breeders.

No shortage of uranium developed, however, and the real price of natural uranium in 2016 was about the same as in 1975 (US DOC 1991, Table 981; US EIA 2017, Table 5).10 Also, in most countries, liquid sodium-cooled breeder reactors proved to be more costly and much less reliable than water-cooled reactors. As a result, worldwide, only a few experimental, prototype, and “demonstration” breeder reactors were built. One by one, most of the advanced industrialized countries abandoned their development (Cochran et al. 2010).

France and Japan, which had built their spent-fuel management strategies around reprocessing, decided, however, to continue their reprocessing programs and use their accumulating separated plutonium to make fuel for their conventional reactors from whose spent fuel the plutonium had been recovered. Plutonium oxide powder is diluted with uranium oxide – usually depleted uranium from which most of the U-235 has been extracted for the production of low-enriched uranium – down to a concentration of several percent and then fabricated into “MOX” fuel. In France, that fuel reduces the need for low-enriched uranium fuel by about 15% (IPFM 2015, Table 3.1).

The economics are terrible, however. A 2011 analysis by Japan’s Atomic Energy Commission projected that the cost of reprocessing and MOX fuel fabrication at the Rokkasho site, including the cost of disposal of the radioactive waste from reprocessing, but excluding the cost of disposal of spent MOX fuel, would be about nine times higher than the cost of the LEU fuel, including the estimated cost of its storage and direct disposal (JAEC 2011).

Given the cost of reprocessing, virtually all of the foreign utilities that had been sending their spent fuel to France and the UK did not renew their reprocessing contracts. In 2012, the UK, which, unlike France and Japan, has not required its domestic utilities to reprocess, therefore decided that it would shut down in 2018 the reprocessing plant that it used to reprocess foreign LWR fuel.11

Japan had decided in the 1970s to build a commercial-scale reprocessing plant in Japan. This led to the construction by Japan Nuclear Fuel Limited (JNFL), of a reprocessing plant in Rokkasho, Aomori Prefecture owned mostly by Japan’s utilities. As nationally regulated regional monopolies, the utilities were allowed to pass the extra

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10 Using the US GDP deflator to compare prices (US Bureau of Economic Analysis 2018).
11 Reprocessing of the remaining metal spent fuel from the UK’s shutdown first-generation Magnox reactors is expected to continue till 2020 (UKNDA 2017, 12).
cost of reprocessing at the Rokkasho Reprocessing Plant (RRP) on to consumers in a cost-plus fee arrangement (Takubo 2008). In 2016, the government enacted a law to assure that reprocessing in this plant will be funded even if Japan’s nuclear utilities go bankrupt. Japan’s nuclear utilities are now required to pay the new government-established Nuclear Reprocessing Organization of Japan (NuRO) at the time of irradiation for the estimated future cost of fuel reprocessing and fabrication of the recovered plutonium into MOX fuel. NuRO has assigned its reprocessing responsibilities to JNFL (Suzuki and Takubo 2016).

There is no Japanese law explicitly requiring reprocessing. However, the law with regard to the licensing of construction of nuclear reactors required submission of an application containing information on “the method of spent fuel disposal,” which should not lead to “hindrance of the execution of the planned development and use of nuclear power.” In 2004, the JAEC stated that, because of government policy to proceed with reprocessing, it was reasonable that the government confirm reprocessing plans of would-be operators of nuclear power reactors before permission was given for construction (JAEC 2004). When the Nuclear Regulation Authority was established after the Fukushima Daiichi accident, the explicit requirement was dropped. But the requirement remains implicit in Japan’s law on the final disposal of radioactive waste, because that law does not include spent fuel as a waste form that can be placed in a deep geological repository.

New Reprocessing Rationale: Lack of Space for Spent Fuel at Reactor Sites

For more than a decade, Japan’s government has justified the continuation of its reprocessing program based on the concern that otherwise power-reactor spent fuel pools will become full, forcing the shutdown of the nuclear power plants. In order to make space for future spent fuel to be discharged into these cooling pools, older spent fuel would be sent to the Rokkasho Reprocessing Plant (RRP). Because of continuing delays in reprocessing, however, the intake pools at RRP are virtually full with nearly 3,000 tons of spent fuel. Therefore (the argument goes), the spent fuel in the RRP pools must be reprocessed as soon as possible in order to assure that storage space will be available for shipping more spent fuel from the reactor pools (JAEC 2005).

Paradoxically, in Mutsu, Aomori Prefecture, about 40 km away from RRP there is a spent-fuel storage building designed to store 3,000 tons of spent fuel in dry casks – about 150 reactor-years of discharges at an average of 20 tons per year.12 This storage facility has been built by the Recyclable Fuel Storage Facility Company (RFSC), set up by the Tokyo Electric Power Company (TEPCO) and Japan Atomic Power Company (JAPC), with plans to add another building with a 2,000-ton capacity. The position of Aomori Prefecture’s government, however, has been that its agreement for the operation of the Mutsu storage facility is premised on a clear prospect of operation of the reprocessing plant.13 It is therefore feared that, until reprocessing begins, Aomori

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12The 42 reactors in Japan, including Ohi 1&2 whose decommissioning was decided on 22 December 2017, that have not been permanently shut down have an average generating capacity of 950 Megawatts (electric) (IAEA PRIS 2018). For an average heat-to-electricity conversion of one third, an average capacity factor of 70 percent and an annual discharge of 20 tons, the average amount of fission energy released per kilogram of fuel would be about 36 thermal megawatt-days, a fairly typical “burnup” for Japan.

13“Interim Storage Facility Operation Premised on the Reprocessing Startup,” The Daily Tohoku, 16 January 2014 (in Japanese). http://www.daily-tohoku.co.jp/tokusyu/kakunen/news/201401160P000833.html.
prefecture may not even allow a proposed test shipment of a single cask of spent fuel to the Mutsu storage facility. The plan had been to complete post-Fukushima safety upgrades and begin to receive spent fuel at the facility in the latter half of 2018 but, on 28 June 2018, RFSC told the city and prefecture authorities that it was considering postponing opening due to the NRA’s prolonged safety examination.14

A July 1998 memorandum signed by the governments of Aomori Prefecture, Rokkasho Village and JNFL, with the Federation of Electric Companies of Japan (FEPC) acting as witness, stated (Nuke Info 1998; Aomori Prefecture 2012),

In case a certain execution of the reprocessing operation becomes extremely difficult, upon consultation among Aomori prefecture, Rokkasho village, and JNFL, JNFL shall promptly take appropriate and necessary measures, such as shipment of the spent fuel out of the facility.

A written statement issued by the Rokkasho Village assembly in September 2012 reasserted this position (Sekiguchi 2014, 5). The shipments could be carried out, however, only after agreement with the governors of the prefectures hosting the nuclear power plants.

The same September 2012 statement declared in addition that, if the reprocessing policy were abandoned, the village would no longer accept the radioactive wastes coming back from the past reprocessing of Japan’s spent fuel in France and the UK. The shipments of 1310 canisters of vitrified (glassified) high-level reprocessing waste from France were completed in 2007, however, and completion of shipments of an estimated 900 canisters from the UK is projected for 2020.15 As of the end of 2016, 520 canisters had been delivered (WNA 2017) with no shipment in 2017 and none planed for Fiscal Year 2018 (ending March 2019) (JNFL. n.d.).

France also plans to ship intermediate-level waste to Rokkasho – mostly chopped-up spent fuel cladding “hulls” from which the irradiated uranium oxide has been dissolved (Orano 2017, 35–36). There will be no such shipments from the UK because it decided instead to ship the radioactive equivalent amount of extra vitrified high-level waste.

Defenders of reprocessing inside and outside of Japan’s central government cite Aomori’s threats as a reason for not changing Japan’s reprocessing policy (Acton 2015). Might it be possible to negotiate an alternative package of economic development and employment plans for the village and prefecture? Based on the annual subsidies received by the village and the prefecture, it would appear possible. Since 1985, when Rokkasho Village agreed with JNFL’s predecessor organizations to host its reprocessing plant, enrichment plant, and low level waste, the village has received an annual subsidy, JNFL property tax, and industry contributions that amounted to about ¥7 billion in Fiscal Year (FY) 2011 while the prefecture received about ¥16 billion in FY2012 through “nuclear fuel taxes”, mostly on spent fuel stored at Rokkasho (Rokkasho Village 2016; Takubo and von Hippel 2013, 29). These total about ten percent of the estimated annual charges to the ratepayers for operating the reprocessing plant during the 2020s (JAEC 2011, slide 30).

14“Interim Storage Facility, Operations Delay Considered—Operating Company Conveyed to Aomori Prefecture,” Nikkei Shimbun, 28 June 2018 (in Japanese). https://www.nikkei.com/article/DGXMOZ32339550Y8A620C1EAF000/.
15“High Level Waste from UK to Rokkasho,” Nittere News 24, 27 February 2013 (in Japanese). http://www.news24.jp/articles/2013/02/27/07223902.html.
Japan’s Limited Ability to Use MOX Fuel

In 1997, Japan declared that its policy on plutonium stocks was that

The nuclear fuel cycle is promoted based on the principle that plutonium beyond the amount required to implement the program is not to be held, i.e. the principle of no surplus plutonium. (JAEC 1997)

In 2014, in a joint statement at the third Nuclear Security Summit held in Hague in the Netherlands, Prime Minister Shinzo Abe joined President Barak Obama to renew this commitment. They declared their “mutual goal of minimizing stocks of HEU and separated plutonium” and went on to “encourage others to consider what they can do to further HEU and plutonium minimization” (White House 2014).

Since 1996, however, because of the reprocessing of Japan’s spent fuel in Europe and the failure of its plutonium-fuel-use program, Japan has more than doubled its stockpile of separated plutonium to about 48 tons (Figure 1).

Despite its failure in plutonium management, Japan’s current plan is to operate the Rokkasho Reprocessing Plant as soon as its post-Fukushima safety upgrades have been completed, currently projected for 2021. RRP is designed to reprocess up to 800 tons of

Figure 1. Growth of Japan’s stock of plutonium over a quarter of a century. Most of the stock was separated from Japanese spent fuel shipped to France and the UK for reprocessing during the 1990s. If Japan’s domestic Rokkasho Reprocessing Plant operates at its design capacity, as currently planned after a startup period of a few years, the stock will increase again (Japan Atomic Energy Commission (JAEC) 1994–96; JAEC 1997–2017).

16Starting in the 1960s, Japan contracted with the UK to reprocess 1510 tons of fuel from its gas-cooled reactor, Tokai I. Japanese utilities contracted during 1971–78 with the UK to reprocess 2683 tons of light-water reactor (LWR) fuel and with France during 1975–77 to reprocess 2945 tons of LWR fuel. In total, about 7100 tons of spent fuel was sent to Europe between 1969 and 2001. On this, see documents prepared by Japan’s Ministry of Economy and Industry (METI) at the request of House of Representatives members Seiichi Kaneda, 21 February 2005 (in Japanese), http://www.cn_cip/files/repro_contract.pdf and Mizuho Fukushima, 16 January 2013 (in Japanese), http://kakujoho.net/ndata/pu_jp.html.

17“Further Delay to Completion of Rokkasho Facilities,” World Nuclear News, 28 December 2017. http://www.world-nuclear-news.org/WR-Further-delay-to-completion-of-Rokkasho-facilities-2812174.html; and “Reprocessing Plant–JNFL Delays the Completion Date by Three Years, 24th Delay, Citing Safety Improvement as the Reason,” Kahoku Shimpo, 23 December 2017 (in Japanese). http://www.kahoku.co.jp/tohokunews/201712/20171223_23020.html.
spent fuel per year. Given that a ton of spent fuel contains about 10 kg of plutonium (Nuclear Energy Agency 1989, Table 9) about 8,000 kg (8 tons) of plutonium could be separated annually, enough for about 1,000 Nagasaki-type bombs. In a 2011 Japan Atomic Energy Commission report, the startup plan would have the plant reprocess 80 tons in the first year, 320 in the second, 480 in the third, 640 in the fourth and 800 tons per year thereafter (JAEC 2011, slide 31). As will be shown below, reprocessing more than 400 tons of spent fuel per year would produce separated plutonium greatly in excess of Japan’s foreseeable ability to use it. In any case, before it can justify separating additional plutonium, Japan should deal with the 48 tons it already has.

In 1997, Japan’s Federation of Electric Power Companies (FEPC) projected that, by 2010, 16 to 18 of Japan’s light water reactors would have partial cores of MOX fuel and that annually thereafter about 8 to 10 tons of plutonium would be loaded into the reactors (FEPC 1999). In 2010, the time frame was shifted to “after FY 2015,” (FEPC 2010). The quantity of plutonium that would be used is given there as 5.5 to 6.5 tons per year of contained “fissile” plutonium, i.e. the isotopes Pu-239 and Pu-241, which are fissioned by the slow neutrons that sustain the chain reactions in light-water reactors. The fissile isotopes account for about two thirds of the mass of power-reactor plutonium.

Because of the concerns of host communities and prefectures about the safety of using MOX fuel, however, as of the end of 2010, cumulatively, only 1.9 tons of plutonium in MOX fuel had been loaded into four light-water power reactors and irradiated. After the Fukushima accident, restarts of reactors began in 2015. In 2016, irradiation of MOX fuel containing a total of 0.9 tons of plutonium began in two reactors (JAEC 2017a, 6). As of the end of 2017, therefore, Japan had loaded cumulatively since the first MOX fuel was delivered by France to Japan in 1999, a total of less than three tons of plutonium into its light water power reactors. The next step is to determine the future of MOX fuel use. As of the end of 2010, ten power reactors had been given government and prefectural approval to use MOX fuel (with prefectural approvals for two subsequently withdrawn). They are still the primary candidates to use MOX fuel (see Table 1). If they all operated, they would load about 4 tons of plutonium annually. However, seven years after the Fukushima Daiichi accident, only four reactors capable of loading a total of 2 metric tons of plutonium per year had restarted. An additional two of the MOX-licensed reactors might restart, which would increase the total potential plutonium loading to 2.6 tons per year. A seventh, Fukushima Daiichi-3, one of the reactors that suffered a core meltdown, is being decommissioned. No restart application has been submitted for an eighth, Onagawa-3, and the governors of the host prefectures have opposed restart of the final two, Hamaoka-4 and Kashiwazaki-Kariwa-3 (Table 1). The other reactors included in the 1997 FEPC plan but not licensed by 2011 (Tokai-2, Tsuruga-2, Shika-1, Oh-i-3 and/or 4, and Ohma) are unlikely to operate with MOX fuel for the foreseeable future, except for Ohma (see below). There has been no discussion among utilities of using MOX fuel in other reactors and thus that possibility is not considered here.

The great hope with regard to MOX fuel consumption is the Ohma reactor in Aomori Prefecture, which was under construction in 2011 and is designed to be fueled...
Table 1. The 10 reactors licensed to use MOX fuel before the Fukushima Daiichi accident (Nuclear and Industrial Safety Agency 2010; FEPC 2016).

| Reactor assumed to use MOX | Maximum plutonium use$^{21}$ (metric tons/yr) | Status as of 1 July 2018$^{22}$ |
|---------------------------|-----------------------------------------------|--------------------------------|
| Takahama-3 and 4          | 1$^{23}$                                      | Operating                      |
| Genkai-3                  | 0.4                                          | Operating                      |
| Ikata-3                   | 0.6                                          | Operations suspended by court$^{24}$ |
| Shimane-2                 | 0.3                                          | Restart applied for            |
| Tomari-3                  | 0.3                                          | Restart applied for, seismic issues$^{25}$ |
| **Subtotal**              | **2.6**                                      |                                |
| MOX use not expected in near term |                                |                                |
| Hamaoka-4                 | 0.6                                          | Restart applied for but prior consent for MOX use withdrawn and restart opposed by governor$^{26}$ |
| Onagawa-3                 | 0.3                                          | No restart application, safety issues$^{27}$ |
| Fukushima Daiichi-3       | 0.3                                          | In decommissioning             |
| Kashiwazaki-Kariwa-3      | 0.3                                          | No restart application, MOX use prior consent withdrawn$^{28}$ |
| **Total**                 | **4.1**                                      |                                |

20Six of them are either operating or it is assumed that they will soon operate again with MOX fuel in our scenarios.
21Annual maximum plutonium use estimate is based on FEPC (2010). The numbers in the FEPC table are given in quantities of “fissile” plutonium, i.e. the contained Pu-239 and Pu-241, which are fissioned by the slow neutrons in light water reactors. To get estimates for total plutonium use, we have multiplied by 1.51, the ratio of total to fissile plutonium in Japan’s stocks of separated plutonium as of the end of 2016 (JAEC 2017a).
22Restart information and plans regularly updated by the Federation of Electric Power Companies (Federation of Electric Power Companies n.d.) and Japan Nuclear Safety Institute (JNSI. n.d.).
23The FEPC table gives the following rates of use of fissile plutonium (in metric tons per year): Takahama-3 and Takahama-4 plus one or two units of the Ohi nuclear power plant, 1.1–1.4, which we scale by the reactor powers to 0.594–0.655 for Takahama-3 and 4 alone (FEPC 2010).
24In December 2017, the Hiroshima High Court ordered operations of Ikata-3 suspended until September 2018 because of an unresolved issue regarding the potential effects on it of possible eruptions of a nearby volcano (“Hiroshima High Court Orders Suspension of Ikata Nuclear Reactor in Ehime Prefecture, Revoking District Court Ruling,” Japan Times, 13 December 2017. https://www.japantimes.co.jp/news/2017/12/13/national/crime-legal/hiroshima-high-court-orders-suspension-ikata-nuclear-reactor-ehime-prefecture-revoking-district-court-ruling/#.Wj3ORd9l82w). The suspension was lifted 25 September 2018, “Injunction Lifted on Operation of Japanese Reactor,” World Nuclear News, 26 September 2018. http://www.world-nuclear-news.org/Articles/Injunction-lifted-on-operation-of-Japanese-reactor.
25An editorial in a local paper suggested that the utility has given up. “Tomari Stopped Six Years – We Should Take This Opportunity to Break Away From ‘Nuclear Power Dependence’,” Hokkaido Shimbun, 5 May 2018 (in Japanese). https://www.hokkaido-np.co.jp/article/186638/.
26After being reelected for his third term in 2017, the governor of Shizuoka Prefecture, Heita Kawakatsu said that he would not agree to a restart for Hamaoka-4 (“Governor States Firm Opposition to Hamaoka Plant Restart,” Asahi Shimbun, 29 June 2017. http://www.asahi.com/ajw/articles/AJ2017062900045.html).
27There was a great deal of seismic damage to Onagawa-2 as a result of the Fukushima earthquake (“1,130 Cracks, 70% Rigidity Lost at Onagawa Reactor Building,” Asahi Shimbun, 18 January 2017. http://www.asahi.com/ajw/articles/AJ201701180054.html). The fact that no application for restarting Onagawa-3 has been put forward suggests that the damage there may be even greater.
28The local and prefectural governments officially withdrew their prior consent for MOX use at Kashiwazaki-Kariwa-3 in 2001. “Niigata Village Says no to MOX Fuel Use at Nuke Plant,” Japan Times, 28 May 2001. https://www.japantimes.co.jp/news/2001/05/28/national/niigata-village-says-no-to-mox-fuel-use-at-nuke-plant/#.WeYj1EzWzYI. It has had 0.2 tons of plutonium in unused MOX fuel in its pool ever since (International Panel on Fissile Materials (IPFM) 2015, Table 6.1). Kashiwazaki-Kariwa-2, –3 and –4 have been shut down since an earthquake damaged the plant in 2007 (IAEA PRIS 2018). The mayor of Kashiwazaki insists that a plan to decommission the oldest five units of Kashiwazaki-Kariwa must be submitted as a condition for the restart of units 6 and 7. “Mayor: TEPCO’s Niigata Plant Must Close 5 Reactors,” Asahi Shimbun, 26 July 2017. www.asahi.com/ajw/articles/AJ201707260037.html; Burnie (2017). The new governor of Niigata Prefecture, elected in June 2018, also insists that there will be no restart till the ongoing process of examining the causes of the Fukushima accident is completed, “Kashiwazaki Kariwa Nuclear Power Plant Restart: ‘Feelings of the People of the Prefecture is Grave’, Says the Governor,” Asahi Shimbun, 6 August 2018 (in Japanese). https://digital.asahi.com/articles/ASL864K44L86ULFA00T.html.
be the first country to license a light-water reactor to operate with a full core of MOX fuel. Our analysis is based on the information that even without further delays, the Ohma reactor would not start until at least 2024 (Boyd 2017). J-Power announced on 4 September 2018 that the completion of post-Fukushima upgrade construction work would be delayed to the latter half of 2025 without giving an estimated startup date (J-Power 2018). If and when it does go into operation, if it were allowed to gradually increase its loading of MOX fuel to a full core, it could ultimately load MOX fuel containing about 1.66 tons of plutonium annually. As a result, with the first six reactors on Table 1 plus Ohma, Japan’s capacity to irradiate plutonium in light water reactors would increase to about 4.3 tons per year. This is still far less than the approximately eight tons per year that the RRP could separate operating at full capacity – or the 8 to 10 tons that FEPC originally projected would be loaded annually by 2010. Even if RRP did not operate, it would take more than a decade to load into reactors the separated plutonium that Japan has already accumulated. As of the end of 2017, there were only about 2 tons of plutonium in fabricated MOX fuel available in Japan for the reactors that might be in operation in 2018 and 2019. In July 2017, Kansai Electric Power Company (KEPCO) signed a contract for 32 MOX fuel assemblies, 16 each for Takahama-3&4, containing a total of about 1.45 tons of plutonium with the French nuclear-services company Areva (renamed “Orano” following its bankruptcy in 2016). From order to fuel delivery will be 2 to 3 years. During the next few years, therefore, the rate of loading of plutonium in MOX fuel into Japan’s power reactors will average about one ton per year.

Below, we consider two scenarios:

(1) The Ohma reactor is not completed but the first six reactors listed in Table 1 are all licensed to use MOX and, starting in 2020, load their maximum licensed quantity of a total of 2.6 tons of plutonium per year.

(2) In addition to the above six reactors, the Ohma reactor is completed and begins to operate in 2025 with one third of a core of MOX containing 0.55 tons of plutonium and thereafter increases its annual loading by increments of 0.22 tons per year to 1.66 tons of plutonium per year in 2030 as planned by the company. This would bring the total plutonium use by all of Japan’s reactors to 4.3 tons per year in 2030.

29Record of press conference of the Japan’s Nuclear Regulation Authority, 26 June 2013 (in Japanese). http://www.nsr.go.jp/data/000068639.pdf.
30The FEPC table shows the Ohma reactor using annually 1.1 tons of fissile plutonium. Multiplying by 1.51 gives 1.66 tons of total plutonium per year (FEPC 2010).
31As of the end of 2017, Genkai-3 had 0.801 tons of plutonium in MOX fuel in its pool waiting to be loaded. Ikata-3 had 0.198 tons, and Takahama-3 and –4 had 0.181 tons and 0.703 respectively. Genkai-3 began irradiating 0.640 tons in March 2018 (Japan Nuclear Safety Institute n.d.; World Nuclear Industry Report 2018b). Genkai-3 irradiated 0.677 tons of plutonium in 2009 and loaded but did not irradiate 0.640 tons in 2011, Takahama-3 irradiated 0.368 tons in 2010 and loaded 0.721 tons in 2015 (irradiated in 2016), and Takahama-4 irradiated 0.184 tons in 2016 (IPFM 2014; JAEC 2017a; 7 and, JAEC 2018; 6).
32“First MOX Fuel Contract in the Country Since the Fukushima Accident, KEPCO to Continue MOX Use at the Takahama Nuclear Power Plant,” Fukui Shim bun, 1 August 2017 (in Japanese). http://www.fukushimbun.co.jp/articles/-/222328. Based on past experience, the 2–3 years will include at least 10 months after signing of the contract for KEPCO to submit an application for production of the fuel to the NRA and one month from the application to the start of MOX fabrication.
33The plan is to start the Ohma reactor with 1/3 core of MOX and then gradually to increase to a full core after five to ten years, “Gradual Increase of the Ratio of MOX Fuel Loading,” J-Power (n.d.) (in Japanese). http://www.jp power.co.jp/ba/field/gensiryoku/project/aspect/mox/ratio/index.html.
Japan’s plutonium in France as of the end of 2017 amounted to 15.5 tons. In addition, there were about 2 tons of plutonium in French-made MOX already in the reactor pools of nuclear power plants in Japan awaiting loading. In the above scenarios, all this plutonium could be loaded into Japan’s reactors by the end of 2025.

With regard to Japan’s 22 tons of plutonium in the United Kingdom, the easiest strategy for Japan would be to accept the UK’s 2011 offer to dispose of foreign, mostly Japanese, plutonium together with more than 100 tons of its own in exchange for a disposal fee (UKDECC 2011, para 1.8). Japan’s government has not officially responded to that offer, however, although the UK had taken title to 8.5 tons of other countries’ plutonium as of January 2017. Japan’s reluctance is understandable since, if it asks the UK to dispose its plutonium as waste for a fee, it will be challenged by critics to reconcile this action with Japan’s official position that plutonium is a valuable energy resource worth separating from spent fuel at great cost. In its 2018 Status Report on Plutonium Management in Japan, Japan’s Atomic Energy Commission simply stated flatly, with regard to all of Japan’s plutonium in Europe, that

such plutonium is to be fabricated into mixed oxide fuels overseas and be utilized at light water reactors (LWRs) in Japan. (JAEC 2018)

Since the UK does not have a MOX plant, for the foreseeable future, the only feasible scenario for making MOX out of Japan’s plutonium in the UK would be to transfer it by ship to France for fabrication. If that could be done with appropriate international security and commercial arrangements, for the two scenarios above, Japan could load into its MOX-fueled reactors all of its separated plutonium currently in Europe by 2031 or 2033.

Assuming that the Rokkasho MOX plant was operable by then and able to process the 6.3 tons of plutonium in Japan that are in nitrate and oxide forms (JAEC 2017a) into MOX, that plutonium could be dealt with by 2032 or 2036. Figure 2 shows the scenarios for plutonium use.

![Figure 2. Scenarios for the use of Japan’s separated plutonium.](image-url)

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34See note 31. Not including the 0.4 tons of plutonium in MOX stored in the pools of Kashiwazaki-Karaiwa-3 and Hamaoka-4, which we do not expect to operate again.

35M. Forwood, Personal communication, 28 July 2018, based on UK government announcements reproduced at http://kakujoho.net/npt/cap_pujp.html#puswap.

36The base case assumes that six existing LWRs (Genkai-3, Ikata-3, Takahama-3&4, Shimane-2 and Tomari-3) use plutonium in MOX at the rate projected by Japan’s Federation of Electric Power Companies in 1997. The higher case assumes that the Ohma reactor is completed in 2025 and builds up its MOX use to a full core by 2030 as currently planned.
Thus, it would not be until the early to mid-2030s that capacity would become available to use MOX containing plutonium separated by the Rokkasho Reprocessing Plant operating at partial capacity. If reactor licenses are not extended in Japan beyond 40 years of operation, however, there will be few reactors left to load MOX fuel. In May 2018, the Abe Administration released a draft energy plan that proposed that the lifetimes of licensed reactors in Japan be extended to 60 years, which was adopted by the cabinet without much change two months later.

**Will Japan’s MOX Plant Function?**

Even if there were good economic and environmental reasons for Japan to reprocess, it would not make sense to separate more plutonium before JNFL has demonstrated the ability of the facility it has been building since October 2010 to use the plutonium to fabricate MOX fuel for Japan’s reactors. JNFL, however, plans to complete construction of its MOX fuel fabrication plant (J-MOX) a year after reprocessing begins.

The argument made by Japan’s Atomic Energy Commission for starting the reprocessing plant before the MOX plant is that a working stock of separated plutonium is needed to operate the MOX plant. As noted above, however, Japan already has 6.3 tons of separated plutonium in country in the form of plutonium oxide and plutonium nitrate solution. That would be more than enough for startup testing.

This is important because it is possible that J-MOX might never operate. The UK’s Sellafield MOX Plant provides a precedent for such a complete failure. MOX production began there in 2001 but, due to design defects, during the following nine years, the plant operated on average at 1% of its nominal throughput. In 2011, after the accident at Fukushima, the UK finally abandoned the effort to make the plant operable, leaving 22 tons of separated plutonium owned by Japan stranded in the UK with no firm plan for its disposal.

Starting plutonium separation at the RRP would similarly exacerbate Japan’s plutonium-disposal problem if J-MOX failed to operate. Given JNFL’s demonstrated failure for 24 years to operate RRP, why should it be assumed that it will be successful with J-MOX, if and when it is completed?

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37."[If the licenses are not extended beyond 40 years, Japan’s nuclear capacity will decrease to half of the present level in 2031, to less than 20% in 2038, and to zero in 2064 (assuming the three additional reactors: Ohma, Shimane 3 and TEPCO’s Higashidori) or to zero in 2049 without those...]” (METI 2015, 4).

38."20–22% Share of Nuclear Power at Core of Updated Energy Policy,” Asahi Shimbun, 14 May 2018. http://www.asahi.com/ajw/articles/AJ201805140045.html. See also the commentary in Kawahara (2018).

39."When the MOX fuel Plant starts operation, a certain amount of mixed powder will need to be stocked as its feedstock. In case the completion and operation of the RRP goes ahead of the MOX Fuel Fabrication Plant, the amount of mixed oxide powder stock will temporarily increase. Yet it should be done that way because a certain amount of mixed oxide powder will need to be stocked for the fabrication of MOX fuel" (JAEC 2017b, 7).

40.We have been told by a US Government official that the usability of this plutonium in the J-MOX plant is in question since much of the Pu-241 in the plutonium has decayed into americium-241. The americium could be removed, however, by running the plutonium through the RRP.

41."The design production capacity of the Sellafield MOX plant was 120 tons of MOX fuel per year. The plant produced 14 tons in ten years (Brady 2013) containing about one ton of plutonium.

42.The operator of the Sellafield MOX Plant had signed its only contract, with the Japanese utility, Chubu Electric, in 2010 to supply MOX fuel for the Hamaoka reactors. In August 2011, the UK Nuclear Decommissioning Authority announced its decision to abandon the plant in light of “the changed commercial risk profile for SMP arising from potential delays following the earthquake in Japan and subsequent events” (UKNDA 2011).

43."The latest Google Earth image available (15 October 2016) of the J-MOX construction site (40°57’28” N, 141°19’38” E) as of the time of this writing showed J-MOX construction still at the stage of construction of foundation walls, waiting for NRA’s approval to proceed to full-scale construction. The progress achieved as of the end of January 2018 was about 11.8% according to JNFL (JNFL 2018).
The Developing Alternative to Reprocessing: On-Site Dry-Cask Spent-Fuel Storage

In the United States, spent fuel pools are full to the point of being completely dense packed at virtually all US nuclear power plants. Therefore, before additional spent fuel can be discharged, the fuel that has cooled in the pools longest – typically 20 to 30 years – is removed and placed into passively air-cooled dry casks at each site (Figure 3).

In Japan, a law to allow construction of off-site interim storage facilities was passed in 1999 and the term “interim storage” has been often equated with off-site storage. The purpose at the time was to store excess spent fuel that would not be reprocessed at the Rokkasho reprocessing plant until a second reprocessing plant could be built. Given the reduced expectations for the future of nuclear power in Japan, however, it is exceedingly unlikely that Japan will ever build a second reprocessing plant.

In any case, despite the government’s encouragement to build off-site storage capacity, the Mutsu facility mentioned above is the only off-site spent fuel storage facility that has been built. That facility was named the Recyclable Fuel Storage Facility to make clear that it is a part of Japan’s spent fuel reprocessing strategy and not part of an alternative to reprocessing. The fact that it happens to be located in Amori Prefecture also gives the governor of that prefecture the leverage to block its use if reprocessing does not go forward.

Japan’s government would appear to face a dilemma in encouraging the construction of additional spent-fuel storage capacity. On the one hand, solution to the storage problem would mean losing an important rationale for reprocessing, which the government wants to avoid. On the other hand, due to the delayed startup of the RRP, the lack of solution to the storage problem could really lead to shutdown of reactors, which the government also wants to avoid.

Even in the absence of removal of older spent fuel from the reactor sites, however, it will be at least a decade before the on-site storage capacity at all but two of Japan’s nuclear power plants will be full. The reason is that fewer than half of the 54 reactors with operating licenses at the time of the Fukushima accident have applied for restart. As of the end of August 2018, only nine reactors had been put into operation after post-Fukushima safety upgrades. An additional five had been licensed to go back into operation when their safety upgrades have been completed. Eleven additional reactors had applied for licenses to restart, for a total of 25 (excluding Ohma, which is under construction, and Shimane-3, which is also under construction but almost complete).

According to our calculation using a Federation of Electric Power Companies of Japan document dated 24 October 2017, which includes planned capacity expansions (re-racking at Genkai-3, Mihama-3 and Kashiwazaki-Kariwa, and dry cask storage at Hamaoka-4 and Tokai-2), even if all the remaining license applications were approved in 2018, only 2 of Japan’s 15 nuclear power plants (excluding Fukushima Daiichi and...
Daini) would have almost 10 years of on-site storage remaining: Takahama (7 years) and Tokai-2 (6 years).

Although their restart has been applied for, the future of the oldest reactors at the Takahama plant, Takahama-1&2, is in question due to concerns about their safety. If they do not operate, the storage capacity of the plant’s pools will be sufficient for 13 years. Tokai-2, operated by JAPC, is one of the two nuclear power plants in Japan that obtained permission for on-site dry cask storage before the Fukushima accident (the other was Fukushima Daiichi). The local and prefectural governments have been pressing the plant to shift more spent fuel out of its pool to dry casks, because they consider casks a safer form of storage (IPFM 2015, 70). Therefore, if it does restart, Tokai-2 has support from its local and prefectural governments to expand its on-site dry cask storage capacity. JAPC is also planning to use the Mutsu facility for Tokai 2 spent fuel when it becomes available.

Dry cask storage is, indeed, safer than pool storage because it is passively air cooled (National Research Council 2006). For about a week after the 2011 Tōhoku earthquake and tsunami, a catastrophic fire was feared to be ongoing in the spent fuel pool of Unit 4 of the Fukushima Daiichi Nuclear Power Plant. As a result of the fortuitous leakage of water into the pool from the reactor “well,” which is not ordinarily filled with water, however, the pool’s water did not boil down to the level at which the fuel would have been uncovered and caught fire (National Research Council 2016, chap. 2).

Figure 3. Storage in the open of the lifetime spent fuel discharges of the decommissioned U.S. 175-MWe Connecticut Yankee Nuclear Power Plant (1961–91). Forty casks contain 93% of the lifetime output of the reactor. The three casks at the right contain radioactive components from the decommissioned plant, which was completely razed to make the site available for other purposes (Connecticut Yankee 2005). 47

47Connecticut Yankee image with permission obtained on 3 October 2018.
48Calculated from FEPC (2017). The years till full for Kashiwazaki Kariwa and Sendai are calculated as 9.7 years and 9.6 years respectively.
49“Takahama Units 1&2 Given Permission to Operate Over the 40-year Limit by Nuclear Regulation Authority – the First Among Aged Reactors,” Fukui Shimbun, 20 June 2016 (in Japanese). http://www.fukuishimbun.co.jp/articles/-/60350. A July 2016 article in the local paper reported that more than 50% of the prefecture population was opposed to operating license extensions for Takahama-1&2, “More Than 50% Opposed to Operation of Nuclear Power Plants Over the 40-Year Limit – Public Opinion Survey by Fukui Shimbun Concerning Takahama Units 1&2,” Fukui Shimbun, 13 July 2016 (in Japanese), http://www.fukuishimbun.co.jp/articles/-/60632.
50If the local population prefers rapid decommissioning of Takahama-1&2, including their pools, however, that would provide an additional incentive for early on-site dry-cask storage.
A loss of water from a dense-packed spent fuel pool leading to a fire could release to the atmosphere roughly 100 times more cesium-137 than was released by the Fukushima accident. Cesium-137 is the 30-year-half-life fission product that has made uninhabitable large areas downwind from the Chernobyl and Fukushima Daiichi nuclear accidents. The US Nuclear Regulatory Commission (NRC) estimated in 2013 that the cesium-137 release from a spent-fuel-pool fire could be reduced approximately 100-fold, i.e. to levels comparable to the actual Fukushima release, if nuclear utilities reduced the amount of spent fuel in their cooling pools to the most recent 5 years of discharges by transferring the rest to dry cask storage (USNRC 2013, Tables 35 and 52).

As a result of political pressure from the nuclear utilities through Congress, however, the NRC did not require US nuclear utilities to do so (US Nuclear Regulatory Commission (NRC) 2013; Lyman, Schoeppner, and von Hippel 2017; von Hippel and Schoeppner 2017).

In Japan, although the Nuclear Regulation Authority (NRA) has not required nuclear utilities to move away from dense-packed pools, its commissioners have encouraged the utilities to do so, pointing to the fact that the nine dry casks at Fukushima Daiichi survived with their spent fuel undamaged, even though the tsunami flooded and damaged their storage building. The decommissioning operation at the Fukushima Daiichi has shown that a temporary dry cask storage facility can be built relatively quickly. In order to make space in the central pool for spent fuel from the pools of the damaged reactors, about half of the older spent fuel in the central storage pool is being loaded into dry casks. As of September 2017, 30 of 65 planned casks were in place on a hill on the site (TEPCO 2017).

In June 2017, the NRA announced a simplified licensing approach for on-site dry cask storage (NRA 2017). It will no longer require a site-specific seismic safety analysis and will allow storage of dry casks outside buildings. Outdoor storage is standard practice in the United States (Figure 3) but a departure from previous practice in Japan and Western Europe. Such an arrangement would be even simpler than the makeshift one at Fukushima Daiichi where the casks are being placed horizontally in individual prefabricated concrete sheds (Ihara 2015). Depending on the final rules yet to be drafted as of August 2018, however, some additional radiation shielding might be required at Japan’s smaller reactor sites to reduce the radiation level from the casks to below regulatory limits at the site boundaries. Such shielding also would provide additional protection against projectiles.

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51 The release of Cs-137 into the atmosphere from the actual Fukushima accident has been estimated as in the range of 6–20 PBq, (UNSCEAR 2013, para. 25). The inventory in spent fuel pool #4 was about 900 PBq (Nishihara et al. 2012, 114). An analysis by Sandia National Laboratories concluded that, had there been a spent fuel pool fire, more than 80% of the cesium would have been released (Gauntt et al. 2012, Table 25).

52 Some of the reduction – a factor of 2 to 3 – is due to the lower inventory of Cs-137 in the spent fuel pools after the older fuel is transferred to dry-cask storage. A larger reduction factor is due to the NRC staff’s conclusion that, if water were lost from a low-density pool, not enough hydrogen would be generated by steam-zircalloy reactions to reach explosive levels and that, with the roof and walls surrounding the spent fuel pool intact, the fractional release into the atmosphere of the Cs-137 in the fuel would be reduced by more than an order of magnitude.

53 The casks shown in Figure 3 are thin metal canisters inside reinforced-concrete radiation shields. The only casks that have been licensed in Japan are thick steel casks, originally developed for transportation, either as dual-purpose transport and storage casks or as storage-only casks. The closest to this type of cask used in the United States are the Castor cast-iron casks, manufactured in Germany, at the Surry Nuclear Power Plant in Virginia, which also are stored outside, unlike in Germany.
In response to the NRA’s encouragement and to that of the national government, the movement toward on-site dry-cask storage has been accelerating in Japan:

- In October 2017, following the NRA’s policy changes to simplify the regulation of on-site dry cask storage, a spokesman for Chubu Electric Power Company, which operates Hamaoka nuclear power plant, announced its plan to file an application to change its January 2015 application for on-site dry-cask storage to casks placed outdoors (Ushio 2017). The local and prefectural governments and NGOs had been calling for speedy transfer of spent fuel to dry-cask storage for safety reasons (IPFM 2015, 71).
- Also, in October 2017, a spokesman for Tohoku Electric Power Company announced that it “will study the option of dry storage” at its Onagawa nuclear power plant (Ushio 2017).
- On 1 January 2018, it was reported that Kyushu Electric had decided to introduce on-site dry cask storage at its Genkai nuclear power plant. The former mayor of Genkai, in office for 12 years, had been supportive of the idea. The new mayor, who was elected in the July 2018 election, also supports on-site dry cask storage.
- On 25 May 2018, the Shikoku Electric Power Company filed for NRA permission to build dry cask storage at its Ikata nuclear power plant.

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54 On 6 October 2015, the Cabinet Council for Final Disposal of Nuclear Waste issued an “Action Plan Regarding Measures to Deal with Spent Nuclear Fuel” requesting utilities to come up with specific plans to deal with spent fuel (Cabinet Council for Final Disposal of Nuclear Waste 2017). In response, the Federation of Electric Power Companies issued a new plan including dry cask storage on 24 October 2017 (FEPC 2017), which we used in our calculations of years till full for Japan’s spent fuel pools.

55 “Without a Building, if Decided, the First in the Country – Dry Cask Storage at Hamaoka Nuclear Power Plant,” Shizuoka Shim bun, 17 August 2017 (in Japanese), http://www.at-s.com/news/article/social/shizuoka/hamaoka/392093.html.

56 “Cooling of Nuclear Fuel by Air, Toward Introduction of Dry Cask Storage at Genkai Nuclear Power Plant,” Yomiuri Shim bun, 1 January 2018 (in Japanese); “Kyushu Electric Company Considering On-Site Dry Cask Storage Facility – Storage of Spent Nuclear Fuel at Genkai and Sendai,” Saga Shim bun, 22 November 2015 (in Japanese), http://www.saga-s.co.jp/column/genkai_pluthermal/20201/252387. In a press conference on 30 August 2018, the company’s president confirmed that the company was preparing an application to NRA, “Kyusu Electric Power Company: Dry Cask Storage at Genkai Nuclear Power Plant – Application to NRA Being Prepared,” Mainichi Shim bun, 31 August 2018 (in Japanese), https://mainichi.jp/articles/20180831/ddp/008/020/020000c.

57 “Spent Nuclear Fuel – Mayor Kishimoto of Genkai Town, Saga Prefecture, Shows Understanding Over Dry Cask Storage,” Sankei Shim bun, 9 March 2017 (in Japanese), http://www.sankei.com/region/news/170309/rgn1703090007-n1.html.

58 “Genkai Mayor Election: Mr. Wakiyama, First Time Candidate, Elected – ‘Town Development With Revenues from Nuclear Power’,,” Saga Shim bun, 30 July 2018 (in Japanese), https://mainichi.jp/senkyo/articles/20180730/k00/00m/010/110000c. When the company president confirmed the plan to install dry cask storage at Genkai on 30 August 2018, the new mayor expressed support for the plan, “To On-Site Storage, the Mayor ‘unavoidable’,” Saga TV, 31 August 2018 (in Japanese), http://www.sagatv.co.jp/nx/news/detail.php?id=3513.

59 “Dry Cask Storage Facility at Ikata Nuclear Power Plant for Spent Fuel With Capacity to 1.5 Times–Shikoku Electric Power Company Plans to Operate it from FY2023,” Nikkei Shium bun, 26 May 2018 (in Japanese), https://www.nikkei.com/article/OGKZ030993440V20C18A5LA0000/?n_cid=SPTMG002. See also Yamada (2018).
In the meantime, in Fukui Prefecture, there has been an impasse between host communities and the governor of the prefecture on the issue of on-site storage. Despite the interest in on-site storage expressed by the leaders of the host towns of Mihama and Takahama,60 the governor of Fukui Prefecture, Issei Nishikawa has insisted that the spent fuel be transferred to storage outside the prefecture. On 7 January 2018, it was reported that Kansai Electric Power Company (KEPCO), which has all its reactors in Fukui Prefecture, was considering the Mutsu storage facility as an interim storage site for its spent fuel.61 The central government also is reported to be contemplating the idea of using the Mutsu facility, which is owned by TEPCO and JAPC, as a central storage site for other utilities.62 The mayor of Mutsu and the company set up to operate the facility for TEPCO and JAPC said, however, that they would not agree to such an idea.63

Combining the above information with the information released by Federeation of Electric Power Companies on 24 October 2017 (FEPC 2017), the following picture emerges: On-site dry-cask storage is in place in one nuclear power plant, has been applied for at a second and third, is to be proposed at a fourth and is being actively examined at a fifth and sixth, and will be examined in accordance with the storage situation at four others where the utilities seem to feel comfortable with the present pool capacity, for a total of two thirds of Japan’s 15 plants. Two utilities (with three sites not counting Fukushima Daini) co-own the offsite facility in Aomori Prefecture that is scheduled to become operable soon, but may not be allowed to ship spent fuel there if the future of the Rokkasho Reprocessing Plant is considered uncertain by the prefectural government. Table 2 summarizes this situation.

Thus, to the extent it ever existed, the danger that Japan’s nuclear power plants will be shut down when their spent fuel pools are full is fading. Although it has often been argued by reprocessing advocates that host communities will oppose on-site dry cask storage since it could become permanent storage, the examples cited above suggest otherwise. Dry-cask storage is increasingly seen as a necessary safety measure.

It also must be pointed out that spent MOX fuel cannot be processed by the Rokkasho Reprocessing Plant. In a 19 November 2014 press conference, then chair of NRA, Shunichi Tanaka, stated that, “in order to reprocess spent MOX fuel you have to build a new reprocessing plant” and “unless you operate a fast[-neutron] reactor, you

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60 In Fukui Prefecture, the communities Mihama and Takahama, which host KEPCO’s reactors, have shown interest in on-site dry cask storage, “Spent Fuel – ‘Dry Cask Storage Not Under Consideration’ – Stressing Transportation Out of the Prefecture, Governor in Press Conference,” Fukunawa, 27 May 2017 (in Japanese), http://fukunawa.com/fukui/26368.html. In November 2017, the neighborhood association of the district of Otomi in the town of Takahama next to the Takahama nuclear power plant, issued a statement calling for a swift shift to in-town dry cask storage, pointing to the dangers of pool storage revealed during the Fukushima accident. The committee is opposed to restarting the oldest two reactors at the plant. A committee member told a local paper that he considered safe storage a responsibility of the host community, “In-Town Storage of Spent Fuel in Dry Casks! – Policy Statement by a Neighborhood Association of a District Next to the Takahama Nuclear Power Plant,” Fukui Shimbun, 24 November 2017 (in Japanese), http://www.fukuishimbun.co.jp/articles/263950.

61 “KEPCO’s Spent Fuel Considered to Be Placed in the Interim Storage Facility at Mutsu City, Aomori Prefecture,” Asahi Shimbun, 7 January 2018 (in Japanese), https://digital.asahi.com/articles/ASL1674X116PLFA002.html; “Spent Nuclear Fuel – KEPCO Considering Storage in Aomori, Aiming at a Long-Period Operation of Nuclear Power Plants,” Nikkei Shimbun, 7 January 2018 (in Japanese), https://www.nikkei.com/article/DGXZ2ZQ542114000712018EA1000/.

62 “KEPCO: Spent Nuclear Fuel in Aomori – Plan to Request Approval for Interim Storage,” Mainichi Shimbun, 7 January 2018 (in Japanese), https://mainichi.jp/articles/20180107/k00/00m/040/107000c.

63 “Mutsu Mayor says ‘Unacceptable’,” Mainichi Shimbun, 7 January 2018 (in Japanese), https://mainichi.jp/articles/20180108/k00/00m/040/069000c.
cannot use the product of reprocessed MOX fuel.” 64 Even if the RPP is operated, in the case of the Ohma plant, which is to use a 100% MOX core after a phase-in period, the spent MOX fuel will most probably stay on site. If central interim storage is not available, spent MOX fuel will probably remain on site at other nuclear power plants as well until a geological repository is available.

Final Thoughts

The NRA’s secretariat considers the current goal of completion of the Rokkasho reprocessing plant in 2021 to be too optimistic. 65 The Mayor of Mutsu city appears to agree, saying: “Who would believe that the plant will really be completed three years later?” 66 His concern is that, due to the Aomori Prefecture’s desire to maintain maximum pressure to start operations at the Rokkasho Reprocessing Plant, the Mutsu storage facility cannot begin operations before the reprocessing plant. A delay in the operation of the reprocessing plant could mean a delay of tax and subsidy income for Mutsu.

The increasing willingness of host communities to consider on-site dry-cask storage for safety reasons suggests that Japan could cancel the operation of the Rokkasho Reprocessing Plant without worrying that the decision would cause shutdowns of nuclear power plants as long as its people choose to rely on nuclear power. The government should focus instead on accelerating the introduction of dry-cask storage. If it did so, it could save its electricity rate payers about a net ¥ 10 trillion ($90 billion). This is the difference between the costs of policy-continuation and policy-change: the estimated ¥ 12 trillion cost for additional construction and operation costs of the Rokkasho reprocessing and MOX plants for 40 years (Nuclear Reprocessing

64 Record of press conference of the Japan’s Nuclear Regulation Authority, 19 November 2014 (in Japanese) https://www.nsr.go.jp/data/000068848.pdf.
65 “The Reprocessing Plant Completion Target Date’s Delay by Three Years ‘Optimistic’ – NRA, Skeptical About JNFL Plan,” To-o Nippo, 26 December 2017 (in Japanese), http://www.toonippo.co.jp/news_too/nto2017/20171226031838.asp.
66 “Interim Storage Startup Time – ‘No Change’ Says RFS,” To-o Nippo, 23 December 2017 (in Japanese), http://www.toonippo.co.jp/news_too/nto2017/20171223031754.asp.
Organization of Japan (2018) vs. about ¥1 trillion for additional low-enriched uranium fuel to replace the MOX fuel that is currently planned to be made by the J-MOX plant (JAEC 2011, slides 30–34) plus about ¥1 trillion for building additional dry-cask storage for the fuel that otherwise would have been reprocessed. Ultimately, the availability of dry-cask storage will also facilitate reactor decommissioning, which requires removal of spent fuel from reactor pools.

The initial period of the 1988 US-Japan Nuclear Cooperation Agreement, in which the United States gave advance programmatic consent to Japan’s reprocessing for 30 years, expired in July 2018. Thereafter, either party may terminate the agreement after giving six months written notice. This situation provides an opportunity for a serious discussion of Japan’s reprocessing program. As Robert Gallucci, the chief US negotiator during the North Korean nuclear crisis of 1994, pointed out at an April 2016 discussion of reprocessing policy in Washington, DC, “this is an energy decision” for Japan to make but it “affects the national security of the United States and [Japan’s] neighbors in Northeast Asia. It is a matter of international security” (Gallucci 2016).

To increase its options with regard to the 8.2 tons of plutonium in Japan that are not in the form of MOX fuel useable in its commercial reactors (JAEC 2018, 4), Japan should conduct joint research and development work with the UK and US on plutonium disposal methods other than MOX. The UK faces the challenge of disposing of about 120 tons of civilian plutonium accumulated by the time reprocessing is ceased around 2020 (UK House of Parliament 2016). The US most dispose of about 50 tons of surplus weapons plutonium. The US is currently focusing on the option of diluting its plutonium with materials that would make its reextraction difficult and disposing of the mixture in a deep underground repository in a New Mexico salt bed (Sonne and Mufson 2018). The UK is developing a technique for immobilization and deep burial for at least a portion of its excess plutonium (CORE 2015). Cooperation of the three countries on plutonium disposal could further international security, non-proliferation and disarmament (von Hippel and Mackerron 2015).

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67 If the Rokkasho Reprocessing Plant operated at its full capacity for its design life of 40 years, it would reprocess 32,000 tons of spent fuel. The cost of Japan’s 3,000-ton-capacity dry-cask storage facility including casks, in Mutsu, whose construction was basically completed in 2013, was about ¥0.1 trillion (Recyclable-Fuel Storage Company n.d.). We have also assumed, following a 2006 analysis done for AREVA, that the extra costs of disposing of spent MOX fuel would obviate any savings in disposal costs from reprocessing (Boston Consulting Group 2006, 20).
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