Plutonium for Energy?

Explaining the Global Decline of MOX

[EXCERPT]

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MOX in Japan: Ambitious Plans Derailed

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This chapter assesses Japan's ambitious but so far largely derailed plans to use substantial amounts of mixed-oxide (MOX) fuel in light-water nuclear reactors (LWRs). Field interviews were conducted in Japan in 2018 with policymakers, power companies, scholars, and non-governmental organizations. The chapter explores the economics, security, safety, performance, and public acceptance of the MOX program. Japan had planned to commence commercial MOX use in 1997, but numerous scandals delayed the start by a dozen years until 2009. The program paused again in 2011 due to the Fukushima nuclear accident, and then restarted slowly in 2016. To date, only 3.4 tonnes of plutonium in MOX has been irradiated in LWRs, a tiny amount relative to Japan's remaining 47 tonnes of unirradiated, nuclear weapons-usable plutonium that is stockpiled in Europe and Japan, raising significant concerns for East Asian regional security. Japan's MOX fuel has also proved to be significantly more expensive than traditional low-enriched uranium (LEU) fuel. Despite such concerns, the Japanese government still envisions MOX as part of its long-term energy plan. This study recommends that Japan increase interim dry-cask storage of spent nuclear fuel and delay domestic reprocessing, at least until it proves that the MOX program can effectively consume the existing plutonium stockpile.

Japan is today the world's only country without nuclear weapons that nonetheless reprocesses its spent nuclear fuel to separate plutonium, which is a nuclear weapons-usable material. Through domestic and foreign reprocessing, Japan now owns 47 tonnes of unirradiated plutonium in various forms and locations. This large plutonium stockpile, enough to make thousands of nuclear weapons, has caused domestic and international concern and raised regional tension with historic enemies such as China, North Korea, and South Korea. Japan maintains a national policy to use this

stockpile in mixed oxide (MOX) plutonium-uranium fuel to generate energy in nuclear reactors, but current trends make it unlikely that the entire stockpile could be consumed in this way any time soon, if ever.

In 2012, Japan essentially finished construction (except for obtaining a final safety license) of a new domestic reprocessing facility, which could separate eight tonnes of plutonium annually once in operation, now slated for 2021 after many postponements. Japan declares that all plutonium separated in the future will also be used in the MOX program, but there are concerns that Japan's plutonium stockpile will continue to grow. Since reduction of Japan's plutonium stockpile and the rationale for domestic reprocessing both hinge on the success of its MOX program, Japan's past experience with such fuel merits close attention.

This study finds that Japan has continuously struggled with its MOX program, characterized by delays and public opposition. Japan had planned to commence commercial MOX use in 1997, but multiple scandals delayed the start by a dozen years until 2009. The program paused again in 2011, due to the Fukushima nuclear accident, and then restarted slowly in 2016. To date, only 3.4 tonnes of plutonium in MOX has been irradiated in light-water reactors (LWRs), a tiny amount relative to Japan's remaining 47 tonnes of unirradiated, nuclear weapons-usable plutonium that is stockpiled in Europe and Japan. Japan's MOX fuel has also proved to be significantly more expensive than traditional low-enriched uranium (LEU) fuel.

The rest of this chapter starts by reviewing the history of Japan's MOX program and its extensive delays. The following section discusses the utilization of MOX, including contracts, economics, security, safety, and performance. Attention then turns to Japanese public perceptions of MOX. The chapter concludes with policy recommendations for Japan and broader lessons for the world.

Japan's Nuclear Program

Japan's nuclear research program began in 1954, and in 1959 a small experimental boiling water reactor (BWR) began operation. In 1965, Japanese nuclear reactors began generating energy commercially. At the peak, Japan had nearly 60 operating commercial LWRs that supplied the country with 34 percent of its energy.[1]

In 1956, the Japanese Atomic Energy Commission (JAEC) released its first long-term plan for reprocessing spent nuclear fuel. The Japanese government stated the intention to separate plutonium for fast breeder reactors (FBRs), and it projected using FBRs for consumer energy by as early as 1985.[2] Japan started development of FBRs in the mid-1960s, and spent $17 billion from 1974 to 2011 on research and development of a commercially viable FBR,[3] but the efforts proved unsuccessful. In 2016, the government announced plans to decommission the prototype Monju FBR.[4] As the result of domestic and foreign reprocessing of Japan's spent fuel, more than 50 tonnes of plutonium have been separated, of which about 47 tonnes remains unirradiated: approximately 22 tonnes in the UK, 16 tonnes in France, and 10 tonnes in Japan.[5] (These figures are rounded and thus do not sum to the total.)

While breeder reactors were under development, MOX fuel use in LWRs was considered a helpful short-term mechanism to reduce Japan's plutonium stockpile.[6] Accordingly, in the 1960s, the Japanese Power Reactor and Nuclear Fuel Development Corporation (PNC) started research and development of MOX fuel for LWRs and advanced thermal reactors (ATRs). In December 1995, a sodium leak and fire at the Monju FBR caused it to go offline until 2010.[7] However, it was not until 2007 that the Japanese Cabinet confirmed an official policy shift, prioritizing use of MOX fuel in LWRs. Despite ending the FBR program, which was the original rationale for reprocessing, Japan plans to start commercial operation of its Rokkasho reprocessing plant in 2021, separating up to an additional eight tonnes of plutonium annually. All of Japan's separated plutonium is now planned to be used for MOX in LWRs.[8]

Japan's Basic Policy for Nuclear Energy states that, "in pursuing the effective use of plutonium, peaceful use is a major precondition. Japan, therefore, should continue to adhere strictly to the principle of not possessing plutonium without a specific purpose."[9] The policy states that the only current practical way of consuming plutonium is in the form of MOX fuel for LWRs. In July 2018, a new government energy plan pledged to "make efforts to cut the stockpile of plutonium."[10]

After the March 2011 Fukushima nuclear accident, all of Japan's nuclear power reactors shut down in an orderly manner during scheduled maintenance by May 2012. Restarting these reactors requires approval under the stricter regulations of a new Nuclear Regulation Authority (NRA), which is tantamount to relicensing and has been partial and gradual. As of July 2018, nine such reactors had restarted, although a court injunction suspended one in December 2017, leaving eight operating. Another five had been cleared for restart by the NRA, 12 were being reviewed by the NRA (including one under construction), 15 had not yet applied for restart (including one under construction), and 18 were being decommissioned (half of them based on decisions prior to the accident). Thus, out of Japan's historical total of 59 reactors (including two under construction), only eight were operating, of which three had some MOX fuel in their cores.[11]

Several government institutions share responsibility for Japan's nuclear power sector. The JAEC's original role was to promote nuclear power and establish basic policies for development and utilization of nuclear energy.[12] After Fukushima, the JAEC transitioned from promotion to management of the nuclear program. The Ministry of Economy, Trade, and Industry (METI) was formed in 2001 and has broad jurisdiction.[13] METI's electricity and gas industry department oversees nuclear energy policy, nuclear facilities development, and the nuclear fuel cycle.[14] The Nuclear Regulation Authority (NRA) was established in 2012, following the Fukushima accident, to rectify a perceived conflict of interest: the country's previous regulatory body was the Nuclear Industrial Safety Agency (NISA) within METI, which gave that ministry responsibility for both promoting and regulating the nuclear industry. NRA now operates under the Ministry of Environment, separating the nuclear regulation body from promotion of the nuclear industry. The Ministry of Education, Culture, Sports, Science, and Technology (MEXT) is responsible for research and development of the nuclear fuel cycle.

Power companies in practice must get approval from a prefecture's governor and the local mayor prior to starting, or restarting, a MOX program, although that is not technically required by law. In 2004, METI introduced a subsidy program to entice local governments to permit use or fabrication of MOX fuel.[15] In 2010, the government subsidy was ¥1 billion ($10 million) per year per facility for five years.[16]

Methods

During January 2018, interviews were conducted in Japan with current and former officials in government, utilities, industry, non-governmental organizations (NGOs), and academia. Utility reports in English were obtained from websites of major Japanese electric companies. The JAEC also has published translations of Japan's annual plutonium management reports. The University of Texas Briscoe Center holds archived publications of the Nuclear Control Institute (NCI), a defunct U.S.-based research center that had actively documented Japan's MOX plans. In addition, until 2014, the Citizen's Nuclear Information Center (CNIC), in Tokyo, published detailed timelines of each LWR using MOX fuel in Japan.

MOX Use in Thermal Reactors

In 1986, Japan first tested a small amount of MOX fuel in its Tsuruga-1 reactor, laying the groundwork for commercialization in LWRs.[17] In 1988 testimony submitted to the U.S. House Committee on Foreign Affairs, Dr. Milton Hoenig of NCI outlined Japan's plans to deploy MOX commercially in LWRs beginning in 1997. At the time, Japan planned to use 96 tonnes of plutonium in 12 LWRs from 1997 to 2017.[18] According to Matsukubo Hajime, a CNIC official who closely followed Japan's MOX program in the 1990s and early 2000s, the specifics of this plan were never made public by Japan's utilities or government. Japan did not meet the desired start date to deploy MOX by 1997. Nevertheless, on February 21, 1997, the Federation of Electric Companies issued a revised proposal including plans to use MOX fuel in 16 to 18 LWRs from 1999 to 2010.[19] In 2005, the deadline for expanding MOX to this many reactors was pushed back five years to 2015.

In the early 1990s, Japan signed contracts for MOX fuel supply from companies in the UK, France, and Belgium. Tokyo Electric Power Company (TEPCO) and Kansai Electric Power Company (KEPCO) were scheduled to be first to utilize MOX fuel.[20]

Due to technical and political issues, however, much of the MOX shipped to Japan has not been used.

Table 1
Initial MOX Contracts

Power Comp.	Supplier	Year of Con-tract	Assem-blies con-tracted	Reactors	Assem-blies received	Arrival	Pu (kg) in MOX received
KEPCO	BNFL	1995	16	Takahama -4	8 (returned in 2002)	1999	255 (returned in 2002)
				Takahama -3	0		
TEPCO	COMMOX (BN/ Cogema)	1995	60	Fukushima -3	32	1999	210
				Kashiwa-zaki-Kariwa-3	28	2001	205
TOTAL (net)			**76**		**60**		**415 kg**

Sources: Takagi, et al., *Comprehensive social impact assessment of MOX use in light water reactors*, 252. Masafumi Takubo, "Mixed Oxide (MOX) Fuel Imports/Use/Storage in Japan," April 2015, http://fissilematerials.org/blog/MOXtransportSummary10June2014.pdf.

In France, Cogema's La Hague facility reprocessed TEPCO's spent fuel, and the separated plutonium was used to fabricate MOX fuel in Belgium for TEPCO's Fukushima Daiichi-3 and Kashiwazaki-Kariwa-3 reactors. For the Fukushima reactor, Belgonucleaire's P0 plant in Dessel, Belgium, produced the fuel rods,[21] which were then combined into fuel assemblies by *Franco Belge de Fabrication de Combustible* (FBFC), also in Dessel. The contracted supplier was COMMOX, which was jointly owned by Belgonucleaire and Cogema, which co-owned FBFC. The 32 MOX fuel assemblies for TEPCO's Fukushima Daichii-3, containing 210 kg of plutonium, were trucked to France and then transported by sea to Japan in 1999.[22]

By contrast, KEPCO's spent fuel was reprocessed at the British Nuclear Fuel Ltd (BNFL) Sellafield reprocessing plant. BNFL also was contracted to fabricate the MOX fuel for KEPCO's Takahama-3 and -4 reactors.[23] In 1999, the first shipment for KEPCO from BNFL comprised eight MOX fuel assemblies containing 255 kg of plutonium.[24] The MOX fuel assemblies from BNFL and COMMOX were shipped together from Europe to Japan during July to September 1999.[25]

Delays

In October 1999, Dr. Edwin Lyman of NCI published a report stating that Japanese utilities were on the verge of loading MOX fuel into the Fukushima-3 and Takahama-4 reactors.[26] Soon after, however, reports emerged that BNFL had falsified quality-control data of the MOX fuel for the Takahama reactors. Takahama-4 was planned to be the first reactor to deploy MOX after receiving its shipment of eight assemblies in October 1999. Two months prior, however, BNFL discovered falsification of quality-control data for MOX fuel that it had produced for but not yet shipped to another KEPCO reactor, Takahama-3. BNFL reported this falsification to the UK's Nuclear Installations Inspectorate, to KEPCO, and to Mitsubishi Heavy Industries Ltd., in September 1999. This raised concerns that the data for the Takahama-4 fuel, just arriving in Japan, also had been falsified.

In September 1999, KEPCO, on the basis of its own analysis, reported that the Takahama-4 fuel was safe.[27] However, two anti-nuclear Japanese NGOs, Green Action and Mihama-no-Kai, had already sought to conduct independent analyses of the quality control for the Takahama-4 MOX fuel, asking Japanese officials to obtain the data from BNFL. According to Aileen Mioko Smith, director of Green Action, "the normally conservative Fukui legislature was convinced fairly easily and asked for all raw pellet data from Sellafield."[28] Rather than computer files that would have facilitated analysis, however, BNFL released paper books of the pellet size data. Undeterred, the two NGOs copied and distributed the paper data sets for local citizens to assist in reviewing. The NGOs submitted their analysis to KEPCO, the Fukui Prefectural Assembly, and the Ministry of International Trade and Industry (MITI, precursor to METI), providing evidence of various types of inspection-data falsification at Sellafield. In November, the UK regulatory authorities confirmed the falsification of Takahama-4 data.[29]

This falsification occurred at the MOX Demonstration Facility (MDF) at BNFL's Sellafield site. In the first step of the inspection process after production, each fuel pellet passed through an automated micrometer to measure pellet diameter. Pellets that failed to meet the predetermined acceptable threshold were automatically rejected. A sample of approximately five percent of the accepted pellets were supposed to undergo an additional check, in which a worker manually measured pellets with a micrometer and entered the data into a spreadsheet. In August 1999, however, a member of MDF's Quality Control Team noticed similarities in pellet diameter data in consecutive spreadsheets and disclosed this to BNFL. After further investigations, BNFL reported in September 1999 that the pellet diameter data had been falsified by workers who simply copied data between spreadsheets.[30] According to Smith, in addition to the copy and paste of Excel sheets, data figures were altered so that pellets of disqualifying size could be included as acceptable.[31]

Following these disclosures, the start dates for MOX in the Takahama-3 and -4 reactors were postponed. Unirradiated MOX assemblies containing 255 kg of plutonium were returned to the UK in 2002. BNFL paid ¥11.2 billion ($100 million) compensation to KEPCO.[32] In March 2004, the Takahama-3 and -4 reactors received renewed approval for MOX. However, due to an accident at the Mihama-3 reactor in August 2004, KEPCO further postponed plans to insert MOX at Takahama.

After the initial delay in MOX fuel at Takahama, Japanese citizens filed a lawsuit to stop the deployment of MOX also at Fukushima Daichii-3. Anti-nuclear activists suspected that the MOX fuel supplied by COMMOX also had poor quality control.[33] They presented evidence to the district court that production standards at Belgonucleaire and FBFC were even lower than those at BNFL, in support of their contention that COMMOX's pellet diameter data was likely also compromised.[34] The activists ultimately lost the case, but the court ruled that Belgonucleaire and FBFC should release their quality-control data.

In an unrelated incident, in 2001, reports surfaced that the Japanese power company TEPCO had falsified inspection data to hide the presence of cracks in certain reactors.[35] This domestic scandal, combined with the BNFL falsification, caused the governor of Fukushima to retract prior consent and refuse to deploy MOX at Fukushima. MOX assemblies that had been shipped to the Fukushima Daichii-3 reactor were not inserted but instead stored at a nuclear power plant.[36]

At Kashiwazaki-Kariwa, according to Smith, there had been years of popular resistance to even building the nuclear reactors, but the receipt of MOX assemblies from France in 2001 magnified public opposition. She recalls that in the small village of Kariwa, adjacent to Kashiwazaki city, "Several local legislators were concerned about general nuclear safety and, with the addition of MOX, could get enough legislators to approve a local referendum" on the introduction of MOX fuel. Anti-nuclear NGOs launched a comprehensive effort to educate the local populace, including by distributing informational leaflets. In the May 2001 referendum, 54 percent of Kariwa voters opposed the deployment of MOX, with a voter turnout of 88 percent.[37] There was some ambiguity, however, as to whether the referendum was legally binding, so in 2002 the mayor of Kariwa village was on the verge of approving MOX, but that year it was also revealed that TEPCO had concealed its periodic inspections data, so he demurred. In September 2002, the prefecture formally withdrew its approval for MOX. At the time of this writing, in July 2018, the fresh MOX assemblies still have not been inserted into the reactor, 17 years after they were delivered.[38] This poses a security risk because the unirradiated MOX contains over 200 kilograms of plutonium, sufficient for at least 20 nuclear weapons.

MOX Supply Contracts in the 2000s

According to a 2007 report by Areva (successor to Cogema), "an important milestone in restarting the Japanese MOX program was reached in 2006."[39] The French company indicated that three MOX fuel supply contracts had been signed for deliveries from 2007 to 2020, and production had started in 2007. Table 2 outlines the

contracts signed with Japanese utilities from 2006 to 2010. While 401 assemblies were contracted to be fabricated by Areva, only 133 had been received by Japanese utilities as of 2018.

Table 2
MOX Contracts in the 2000s with Areva

Contract Year	Power Company	Reactor	Assemblies contracted	Assemblies received by 2018	Arrival	Pu (kg) in MOX received
2006	Chubu	Hamaoka-4	108	28	2009	213
2006	Kyushu	Genkai-3	36	16 20	2009 2010	677 801
2006	Shikoku	Ikata-3	21	21	2009	831
2008	KEPCO	Takahama -3 & -4	48	12 20 16	2010 2013 2017	552 901 703
2009	Chugoku	Shimane-2	40			
2010	Hokkaido	Tomari-3	4			
2010	Chubu	Hamaoka-4	144			
		TOTAL	**401**	**133**		**4,678 kg**

Sources:
http://www.cnic.jp/english/topics/cycle/MOX/pluthermplans.html.
http://fissilematerials.org/blog/MOXtransportSummary10June2014.pdf.
http://www.aec.go.jp/jicst/NC/about/kettei/180731_e.pdf.

Japan finally initiated MOX fuel use from 2009 until the 2011 Fukushima accident, and resumed in 2016.[40] Masa Takubo reported in 2015 that Japan had imported MOX fuel including 4,390 kg of plutonium. Of that amount, 1,888 kg had been irradiated in LWRs, while 2,501 kg of plutonium remained in unirradiated MOX stored at reactor sites.[41] Table 3 summarizes Japan's MOX usage as of 2015 – i.e., prior to the 2011 Fukushima accident.

Since the restart of nuclear power after the Fukushima accident, four reactors have irradiated MOX, starting in 2016: Takahama-3 and -4, Genkai-3, and Ikata-3. However, a court injunction in December 2017 suspended operation of Ikata-3, so only three reactors were irradiating MOX at the time of this writing in July 2018. In addition, in 2017, Areva (now known as Orano) signed a new contract for fabrication of 32 MOX fuel assemblies for Takahama-3 and -4.[42] It is unknown if there are other contracts between Orano and Japanese utilities.

Table 3
MOX Fuel Irradiated in Japan Prior to the 2011 Fukushima Accident

Power Comp.	Reactor	MOX First Irradiated	Pu Irradiated (kg)
Kyushu	Genkai-3	November 2009	677
Shikoku	Ikata-3	March 2010	633
TEPCO	Fukushima-3	September 2010	210
KEPCO	Takahama-3	December 2010	368
		TOTAL	**1,888 kg**

Source: http://fissilematerials.org/blog/MOXtransportSummary10June2014.pdf.

Five other power reactors have been licensed for MOX but have not yet irradiated it.[43] Kashiwazaki-Kariwa-3 received its MOX license in 2000, but as noted above, prefectural approval was withdrawn in September 2002.[44] Chugoku Electric's Shimane-2 was licensed for MOX in October 2008, but the plant never received such fuel assemblies. Similarly, Tohoku Onagawa-3 and Hokkaido Tomari-3 were licensed in 2010, but neither has received MOX fuel assemblies. In July 2007, Chubu Electric's Hamaoka-4 was licensed for MOX, and 28 assemblies arrived in May 2009. However, upon inspection it was discovered that metal separators for three of the assemblies had become dislocated during shipment.[45] In December 2010, Chubu's president announced postponement in deploying MOX at Hamaoka-4, citing concerns about the unit's safety in the event of seismic activity. The 2011 Fukushima disaster then shuttered all of Japan's nuclear reactors. Chubu's application to restart is currently pending at the NRA. According to journalist Masakatsu Ota, the local government plans to hold a referendum on whether to start MOX use at the reactor.[46]

Economics

The JAEC estimated in 2011 that, including the cost of reprocessing, commercial MOX fuel production in Japan if it ever started would cost Japan 12 times as much as LEU fuel production.[47] A TEPCO official declined to comment when asked about this estimate. As for imported fuel, no Japanese utility that uses MOX will disclose the price per assembly. In 2017, however, an article in the *Japan Times* used data from the Finance Ministry and other sources to estimate the high and rising cost of MOX fuel from Europe. According to this report, the price of each MOX fuel assembly imported in 1999 by Tokyo Electric (now TEPCO) was $2 million, but by 2013 the average price had climbed to $8.6 million, and in 2016 KEPCO paid over $9.3 million per assembly. This price includes the cost of transport, private security, and insurance.[48] By comparison, the average cost per assembly of LEU fuel in 2013 was less than $1 million, at least nine times less expensive than MOX that year.[49]

In 2011, the JAEC stated that "the proportion of MOX fuel loaded in reactors is small and the effects of MOX fuel cost in the front-end costs are insignificant."[50] However, according to Nagasaki University Professor Tatsujiro Suzuki, who is former Vice-Chairman of the JAEC, Japanese consumers have been charged higher electricity prices due to reprocessing and MOX use since the electricity market was liberalized in 2016.[51] Former TEPCO official Atsufumi Yoshizawa confirmed in an interview that increased costs due to reprocessing and MOX are reflected in the electricity rates.[52] Yet, he emphasized that the price of the fuel itself is a minor fraction of the total cost of producing nuclear energy, which includes reactor construction costs. This is true for uranium fuel, although the operating costs increase substantially if MOX is used. Of the five power companies that have imported MOX fuel, all three that currently have MOX loaded in at least one reactor – KEPCO, Shikoku, and Kyushu – have raised their prices to reflect MOX costs.[53]

Security Issues

The 1988 U.S.-Japan nuclear cooperation agreement requires the United States to approve any transportation plans for shipment of plutonium produced with U.S.-supplied nuclear fuel or technology. In 1987, NCI reported that a European reprocessing company was on the verge of shipping plutonium oxide by air to Japan with a refueling stop in Alaska, despite failure to develop crash-proof shipping casks. In response to this disclosure, the U.S. Congress and President Ronald Reagan enacted a law in December 1987 that sharply increased safety standards on air shipping casks, effectively blocking that mode of transport and compelling Japan's plutonium to be shipped instead by sea.[54] In 1992, the U.S. government required that any sea shipments of Japanese plutonium oxide from Europe to Japan be escorted by a gunboat.[55]

Since 1999, fabricated MOX assemblies have been shipped from Europe to Japan, rather than pure plutonium oxide. Japan insists that the stringent physical protection required for transporting separated plutonium is unnecessary for MOX. While non-proliferation activists objected, the United States ultimately relaxed its stance and approved shipment of MOX fuel without an armed Japanese escort vessel. The first MOX fuel from Europe was shipped on BNFL's commercial freighters in 1999. Two ships, the Pacific Pintail and Pacific Heron, ostensibly protected one another during the shipment. The two ships were also guarded by 26 lightly-armed police officers onboard.[56] Information about which of the two ships held MOX assemblies was not disclosed for security purposes. Dozens of en-route countries condemned the sea shipments, citing environmental and proliferation concerns.[57] After the September 11, 2001 terrorist attacks, the U.S. Nuclear Regulatory Commission (NRC) changed its regulations to limit public disclosure of transport details for U.S.-controlled fissile material due to security concerns. This barred disclosure of the route, timing, and security provisions of future MOX fuel shipments.[58]

In 1997, K. Moriya of TEPCO's Nuclear Power Plan Management Department presented a paper at the International Atomic Energy Agency (IAEA) on Japanese security measures.[59] It acknowledged that increased security measures would be needed after the introduction of MOX, which is Category 1 material due to its plutonium content and potential to be stolen for use in nuclear weapons.[60] Under the UN's Physical Protection Convention, this category includes unirradiated materials with at least two kilograms (4.4 pounds) of plutonium, such as fresh MOX fuel.

While the 1997 TEPCO document highlighted the security risks of unirradiated MOX fuel, current Japanese government policies downplay such vulnerabilities. The JAEC's 2017 document on plutonium utilization in Japan states that, "MOX itself cannot be used for nuclear weapons purposes, and [is] considered to be nuclear proliferation resistant."[61] Journalist Masakatsu Ota says that this misrepresentation is prevalent in Japan's nuclear industry, which also erroneously claims that reactor-grade plutonium cannot be made into nuclear weapons.[62] Ota said that Ryukichi Imai, Japan's former ambassador to the UN Conference on Disarmament, had an enormous role in shaping Japan's official position. NCI reported that, in 1993, Imai falsely asserted that "reactor grade plutonium . . . is of a nature quite different from what goes into making of weapons . . . it is quite unfit to make a bomb."[63] According to Ota, Imai was warned about ignoring the dangers of reactor-grade plutonium by scientists at the U.S. Los Alamos National Laboratory, but he refused to change his stance.[64]

Japan's domestic unirradiated plutonium is stored at Rokkasho and nine other sites under security that is much lighter than required in other countries including the United States. Japan's government has resisted repeated requests to establish tougher security measures at Rokkasho beyond minimal IAEA guidelines, although it has reportedly adopted a "design basis threat."[65] Even after the 9/11 terrorist attacks, the Rokkasho plant's security still consisted of unarmed guards and a small police unit, and its 2,400 workers were not required to undergo stringent background checks.[66] Naoto Kan, the Prime Minister of Japan at the time of the Fukushima disaster, explained that while the United States faces threats from terrorist attacks, Japan did not consider terrorism a possibility within its own borders.[67] After the establishment of the NRA in the wake of the Fukushima disaster, the agency required more rigorous anti-terrorism measures at nuclear facilities, including credible emergency response exercises.[68]

Safety Concerns

In 1995, MEXT conducted a safety study of irradiating MOX fuel, based on a core design that did not change significantly from that of conventional LEU fuel. The study was based on two MOX fuel assemblies that were irradiated in the JAPC-Tsuruga-1 BWR from 1986 to 1989, and four MOX fuel assemblies that were irradiated at the Mihama-1 pressurized water reactor (PWR) from 1987 to 1991. These irradiation tests were performed as a joint research program with Japanese electric utilities.[69]

The safety study determined that "the thermal hydraulic characteristics between fuel cladding pipe and coolant are the same as uranium fuel."[70] The irradiation behavior also did not vary significantly from that of uranium fuel. The report concluded: "There is no particular safety problem to be found, so from now on, MOX fuel will be used as part of replacement fuel in LWRs."[71] MOX was limited to a maximum one-third of the reactor core, which obviated the need for additional control rods. Officials from both TEPCO and KEPCO confirm that no hardware changes were made before deploying MOX in their LWRs. However, such MOX use required the addition of burnable poisons to fuel assemblies and a higher concentration of boron in the refueling water storage tank and the boron injection tank, according to a 1995 presentation.[72]

The consensus among all interviewees is that MOX fuel has not caused any technical problems with reactor operations so far. However, most interviewees also agree that MOX has not yet been utilized sufficiently in Japan to make definitive statements on its performance and safety. Koshimuta Kazuhiro, a current TEPCO official, confirmed that the power company is unable to accurately evaluate maintenance costs because the utility company has deployed MOX for only a short time.

Selecting Reactors to Use MOX

Each utility was responsible for the plutonium separated from its spent fuel and so picked one or two reactors to recycle the plutonium in MOX fuel. The grounds for choosing which reactors to use MOX varied. The CEO of Kyushu Electric, Matsuo Kyushu, cited three reasons for deployment of MOX at Genkai-3. He explained that Kyushu's plans from the beginning were to operate only one unit with MOX at Genkai. The cores of Genkai-3 and Genkai-4 each comprised 193 assemblies, the largest operated by Kyushu, so either could have loaded 48 MOX fuel assemblies for a 25-percent MOX core. Unit 3 ultimately was chosen because the open space surrounding it was twice that of unit 4, making inspections easier.[73] For Fukushima, according to an interview with Atsufumi Yoshizawa, unit 3 was chosen to deploy MOX because it was the first power reactor constructed with domestic technology.[74] Yoshizawa says TEPCO decided that an indigenous unit would be best for MOX utilization, but other TEPCO officials could not confirm this.[75] Shikoku and KEPCO officials did not respond to inquiries about why Ikata-3, and the Takahama-3 and -4 reactors, respectively, were selected to use MOX.

Plutonium Storage

A majority of Japan's separated plutonium is stored in France and the UK, where Japanese utilities must pay for storage. The 1997 CNIC MOX assessment estimated the cost of plutonium storage at Sellafield and La Hague to be approximately two to four dollars per gram per year.[76] Even without inflation, that would now represent $75 million to $150 million annually. However, Shaun Burnie of Greenpeace says that, for Japanese utilities, storage at foreign sites is a fraction of the price to fabricate the plutonium into MOX fuel assemblies.

Burnie further notes that the UK has offered to take ownership of Japan's plutonium for a price. These plans are actively under discussion and supported by the UK's Nuclear Decommissioning Authority (successor to BNFL), which would receive payment from Japanese utilities. France, by contrast, favors Japanese utilities continuing to pay to have their plutonium fabricated into MOX fuel, because Orano is in dire financial condition and has no prospects of new reprocessing contracts for foreign spent fuel.

Public Perception

Most interviewees suggested that Japan's public does not differentiate between MOX and LEU fuel. However, a clear exception to this was in the village of Kariwa in Niigata prefecture. Mioko Smith, who advocated against MOX at Kashiwazaki-Kariwa, said the proposed introduction of MOX fuel at the plant magnified anti-nuclear sentiment. Before the referendum in 2001, anti-nuclear

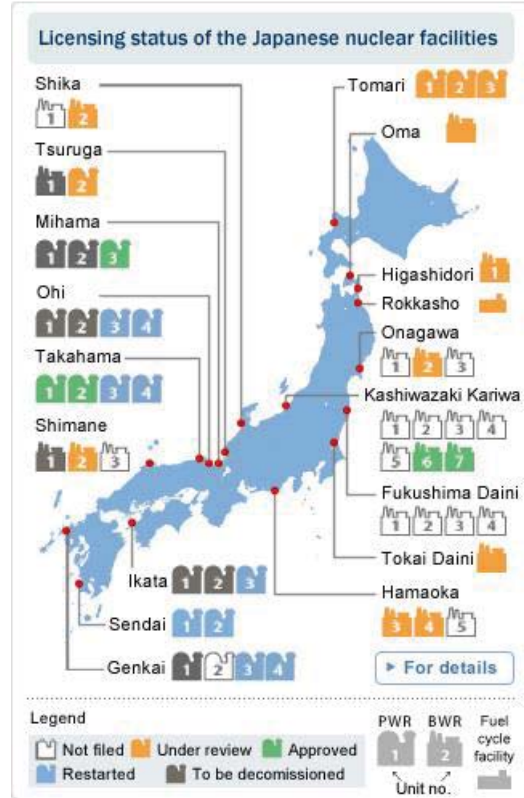
NGOs highlighted the potential dangers of MOX fuel and emphasized that no changes had been made to the evacuation plans in the event of an accident.[77] The 2001 referendum in Kariwa demonstrated that, although most of Japan's public might be unaware of the difference between MOX and LEU, concerted efforts by activists could turn voters against MOX fuel. At the same time, the reactor was permitted to continue operating with LEU fuel, underscoring that MOX can be more controversial than conventional nuclear energy.

According to Mioko Smith, "It's hard to explain to people that MOX can only be used once and that spent MOX has no place to go. We are trying to convince the local governments that spent MOX fuel in some way is a bigger headache for utilities because they have to keep it at their reactor sites since Rokkasho [even if the unfinished plant eventually were started commercially] cannot reprocess it. Storing spent MOX fuel on site also has additional safety concerns compared to LEU fuel."[78] Mioko Smith said that some electricity customers are aware that the extra costs of MOX will be passed down to consumers, but many people are apathetic. Most Japanese anti-nuclear advocates have focused on safety issues, not increased costs, to build public opposition to MOX fuel.

Takuya Hattori, a former TEPCO executive and now senior fellow at the Japan Atomic Industrial Forum, argues that anti-nuclear groups have spread propaganda to build fear. He said that in the 1990s, TEPCO worked hard to explain to local governments and residents that MOX had no extra safety issues. He criticized anti-nuclear energy attitudes and said they were emotional responses to the 1945 nuclear bombings in Hiroshima and Nagasaki. He also said that the media misreads small incidents at nuclear facilities and blows them out of proportion.

Most interviewees cited Japan's bureaucratic culture as a major explanation for the continued use of MOX. Retired bureaucrats often secure lucrative positions in the same companies that they had supervised as public servants, a practice known in Japan as *Amakudari*.[79] The national government is powerful and forges strong connections between the private and public sectors. Senior officials at power companies may acquiesce to national pro-MOX policies due to such personal loyalties.

Figure 1
Post-Fukushima Restart of Japan's Nuclear Power Reactors



Source: http://www.genanshin.jp/english/, July 2018.

Resuming MOX Use

Since the 2011 Fukushima accident, the NRA has cleared 14 LWRs to restart, and nine have done so, including four with some MOX fuel. However, as noted, only eight were online as of July 2018, including three with some MOX fuel. On average, a traditional LWR could use up to about 700 kg of plutonium in fresh fuel per year,[80] so that eventual deployment of MOX in 16 to 18 reactors could utilize more than 10 tonnes of plutonium annually.

Japan's national policy retains this longstanding plan to use MOX in 16 to 18 reactors, but utilities have yet to announce a new deadline for achieving that goal. The JAEC's 2017 proposal includes plans to deploy MOX eventually in only 12 reactors, which highlights the implausibility of the national policy. Moreover, several of these 12 are unlikely ever to use MOX. For example, in a January 2018 interview, former JAEC official Nobuyasu Abe confirmed that Shikoku's Ikata-3 reactor will not load additional MOX fuel.[81] In Shizuoka prefecture, after the governor was elected for the third time in 2017, he announced that he would not consent to the restart of Hamaoka-4.[82] Due to earthquake fault issues at Shimane-2 and Tomari-3, restarting these reactors would be difficult. This reduces to eight the number of reactors envisioned to use MOX. One of these, the under-construction J-Power Ohma reactor, is planned to utilize plutonium at a much higher rate because it would have a full MOX core. However, construction was suspended in 2011, and the license is still being considered by the NRA, so the reactor is not expected to deploy MOX until 2024 at the earliest.[83]

In a January 2018 study, Frank Von Hippel and Masafumi Takubo estimated that by later that year, four reactors – Takahama-3 and -4, Ikata-3, and Genkai-3 – would be loading MOX containing 2.2 tonnes of plutonium per year. If Shimane-2 and Tomari-3 eventually receive NRA approval in 2019, they together could irradiate another 0.6 tonnes of plutonium per year, resulting in a total of 2.8 tonnes of plutonium in MOX fuel loaded per year. However, since Ikata-3 no longer plans to use additional MOX, the amount of plutonium loaded and irradiated will be less. Several other reactors have been proposed to use plutonium fuel but they lack MOX licenses and in most cases also face additional hurdles.[84]

Moreover, less than two tonnes of plutonium in unirradiated MOX fuel is currently in Japan for potential use. While KEPCO has signed a contract with Orano for MOX fuel containing 1.45 tonnes of plutonium, it is not estimated to arrive for two to three years. Thus, during the next few years, it is estimated that Japan annually will load MOX fuel containing only about one tonne of plutonium, barely reducing its stockpile of 47 tonnes of unirradiated plutonium at home and abroad.[85]

Table 4
Annual Plutonium Loading (Tonnes) in Reactors Licensed for MOX

Reactor	Re-start?	Oper-ating?	Pu in MOX per Year *Now*	*Likely*	*Potential*	Notes
Takahama-3	Yes	Yes	0.5	0.5	0.5	
Takahama-4	Yes	Yes	0.5	0.5	0.5	
Genkai-3	Yes	Yes	0.6	0.6	0.6	
Ikata-3	Yes				0.6	December 2017 injunction halted operation. Ex-JAEC official: will not use more MOX.
Tomari-3					0.3	Earthquake concerns hinder restart.
Shimane-2					0.3	Earthquake concerns hinder restart.
Hamaoka-4					0.6	Governor opposes restart.
Onagawa-3					0.3	Has not applied for restart.
Kashiwazaki-Kariwa-3					0	Has not applied for restart. Prefecture withdrew MOX approval in 2002.
Maximum			**1.5**	**1.5**	**3.6**	

Note: Amounts are total plutonium, estimated from fissile plutonium, and are rounded to nearest tenth, so may not sum to maximum.
Sources: "Plans for the Utilization of Plutonium to be Recovered at the Rokkasho Reprocessing Plant (RRP), FY2010," March 15, 2010, http://www.fepc.or.jp/english/news/plans/__icsFiles/afieldfile/2010/03/16/attachment_1_0315.pdf. Masafumi Takubo and Frank Von Hippel, "An alternative to the continued accumulation of the bomb materials that destroyed Nagasaki," January 2018.

Domestic Fuel-Cycle Facilities

Japan has never produced MOX fuel for use in commercial LWRs, but the domestic Tokai Works has had two dedicated facilities for MOX fuel fabrication. The first was PNC's Plutonium Fuel Fabrication Facility (PFFF), which started production of MOX fuel for the fast reactor Joyo in 1972 and for the Fugen advanced thermal reactor (ATR) in 1975.[86] Based on this experience, a second plant, the Plutonium Fuel Production Facility (PFPF), came online in 1987. This plant started producing MOX for the JOYO fast reactor in 1988 and for the MONJU FBR in 1989.[87] The plant initially had performance problems, but eventually they were resolved. According to PNC's successor organization, "In the beginning of operation, the PFPF encountered difficulties in fuel fabrication caused by unaccustomed operation of fully automated equipment. However, those difficulties have been overcome by the improvement of process equipment and operational conditions in the PFPF."[88]

The first production line, PFFF, produced five tonnes of MOX for JOYO using one tonne of plutonium, and 139 tonnes of MOX for Fugen using 1.8 tonnes of plutonium. (Fugen had a 100-percent MOX core, but the fuel had a very low plutonium content because the reactor was moderated by heavy water.) After Fugen's operation ended in 2003, the PFFF was terminated and fuel fabrication for JOYO switched to the PFPF.[89] From 1988 to 2017, the PFPF produced 301 MOX fuel assemblies for JOYO, using an estimated 0.8 to 1.2 tonnes of plutonium, and 366 MOX fuel assemblies for Monju, using an estimated 2.6 to 3.9 tonnes of plutonium.[90]

The PFPF suffered substantial material accountancy failures. As early as 1988, operators noticed plutonium stuck to gloveboxes. While further changes were made to measure the residual holdup, *in situ*, the system still has a measurement uncertainty of about 15 percent. By 1994, the PFPF's Material Unaccounted For (MUF) was about 69 kg of plutonium.[91] PNC did not comply with the IAEA's repeated requests to cut open the gloveboxes and directly remove the buildup. Eventually, after a pressure campaign by NCI, the operator of the PFPF spent $100 million to clean the gloveboxes. In November 1996, PNC announced that the MUF was less than 10 kg. While the IAEA requires that such issues be resolved within one month of discovery, PNC in this case took two years.

The PFPF is a prototype for a larger MOX fabrication plant at Rokkasho-Mura, Japan.[92] In 2006, Tadahiro Katsuta and Tatsujiro Suzuki wrote about plans for this facility, which they reported required an investment of approximately $1.2 billion for construction.[93] The J-MOX plant is intended to fabricate MOX fuel

for both PWRs and BWRs, with a capacity of 130 tonnes of heavy metal per year. Currently, J-MOX is only 12-percent constructed, and the expected completion date has been delayed from 2010 to 2022.[94]

Although the Rokkasho plant to reprocess spent LEU fuel still has not started commercial operation, in 2011 the JAEC announced plans to build a second reprocessing facility to reprocess spent MOX fuel. In a 2018 interview, Koichiro Maruta, Deputy Director of the Nuclear Industry Division at METI, confirmed that the national policy remains unchanged and requires all spent fuel, including MOX, to be reprocessed.[95] However, Maruta stated that there is currently no way to reuse plutonium separated from spent MOX fuel and no ongoing research and development of recycling spent MOX fuel.

Japan's Tokai pilot reprocessing plant operated from 1981 to 2006. Plans for the facility were met with criticism from President Jimmy Carter's National Security Council on nonproliferation grounds, but the U.S. administration eventually acquiesced.[96] The plant reprocessed spent LEU fuel from LWRs and spent MOX fuel from the experimental Fugen ATR.[97] The Tokai plant had a nominal capacity to reprocess 210 tonnes of spent fuel per year but never reached this capacity and on average reprocessed only 40 tonnes per year.[98] Japan has announced that the plant will soon be decommissioned because the cost of upgrades to meet new, post-Fukushima safety regulations would be too high.[99]

Spent Fuel

With cooling ponds close to capacity, spent nuclear fuel storage is a pressing issue in Japan. The Japanese government shies away from discussing permanent direct disposal of spent fuel due to the political climate in Japan. As a condition of constructing the Rokkasho reprocessing plant in Aomori, the local populace understood that the prefecture would serve only as a temporary storage site for spent fuel, and that radioactive waste would be sent back to power companies after reprocessing. In 2010, as spent fuel pools at reactors and Rokkasho filled up, TEPCO and Japan Atomic Power Co (JAPC) started construction of an interim dry-cask storage facility in Mutsu in Aomori prefecture. The facility, still pending NRA approval, was designed to hold excess spent fuel that ostensibly would eventually be treated at a proposed second reprocessing plant, 40 kilometers away in Rokkasho. However, delays in starting commercial operations at the first Rokkasho reprocessing plant have spurred fears that the prefecture could serve as a final disposal site for spent fuel.[100] Accordingly, any discussion of abandoning reprocessing in favor of direct disposal of spent fuel would trigger calls from Aomori prefecture for the return to utilities of the approximately 3,000 tonnes of spent fuel stored there.[101]

This dynamic is illustrated by the case of KEPCO. Prior to restarting its reactors in 2016, that utility assured Fukui prefecture that past and future spent nuclear fuel would eventually be transferred to a site outside the prefecture. In 2018, reports surfaced that KEPCO had made a deal with Aomori Prefecture to send its spent fuel to Mutsu. However, this proposed arrangement was met with fierce resistance from the people of Mutsu and forced KEPCO to deny the report. Due to such opposition from Aomori, Japan's government is offering financial grants to other local governments to encourage dry cask-storage at nuclear power plants, according to a 2017 report.[102] However, after the Fukushima accident, no prefecture is likely to accept an interim storage facility within its borders, even though dry-cask storage is quite safe.

According to Shaun Burnie, Japanese utilities have little confidence that Rokkasho ever will commence commercial reprocessing. As early as 1996, TEPCO pushed for a change in the Japanese policy requiring reprocessing, and construction paused at Rokkasho while utilities attended a series of meetings on whether to proceed with the reprocessing plant. TEPCO was the lead utility pushing for a change in direction but was successfully opposed by Chubu and KEPCO, whom Burnie refers to as the "plutonium priesthood."[103] In an interview, Takuya Hattori, the former TEPCO official, argued that TEPCO was not against reprocessing but sought a more practical approach.[104] Hattori said that TEPCO could not fully depend on reprocessing, so the company wanted to develop a back-up plan. This would be consistent with TEPCO's significant investments in dry-cask storage of spent fuel.

Summary of Findings

Since the 1990s, Japan has attempted to implement its strategy of recycling separated plutonium in MOX for LWRs. However, due to data falsification scandals and increased anti-nuclear sentiment after the 2011 Fukushima accident, the initiative has been severely delayed and under-achieving. The MOX program finally started in 2009, more than a decade late, but soon was forced to pause after Fukushima. During this brief implementation, only four LWRs deployed MOX, and Japan's stockpile of approximately 50 tonnes of unirradiated plutonium decreased by less than two tons, or four percent.

While Japan seems to have increased security measures after the Fukushima disaster, it continues to assert falsely that MOX fuel is not a proliferation concern. In terms of safety, Japan continues to treat MOX fuel as equivalent to LEU fuel, although anti-nuclear activists have claimed for years that MOX increases accident risks. Economically, while the cost of MOX fuel is not officially disclosed, estimates suggest that imported MOX fuel costs nearly ten times as much as LEU fuel, and future domestically produced MOX would cost even more.

Following the post-Fukushima restart of Japan's nuclear program, only three Japanese reactors were using any MOX in summer 2018, and the plutonium stockpile had decreased by less than another two tonnes. Japan's current stocks and known orders of MOX fuel indicate that over the next several years, the country can irradiate only about one tonne annually of plutonium. It is implausible that Japan will come anywhere close to its national policy of deploying MOX in 16 to 18 reactors in the foreseeable future. Thus, if Japan proceeds with its plan to start commercial operation of the Rokkasho reprocessing plant, the country's already enormous plutonium stockpile could grow rapidly.

Recommendations

1. *Increase Transparency.* Japan's MOX fuel program has been characterized by its opaqueness. Japan has increased security measures after the 9/11 attacks and the Fukushima accident, indicating that the government is aware of the security dangers of fresh MOX and separated plutonium. However, official government

documents continue to underplay the security risks of commercial plutonium and falsely assert that MOX fuel is proliferation resistant. Japan's government should publicly acknowledge and address the security risks of MOX fuel. Japan's government and industry also obscure the economics of MOX fuel. Since the increased costs of MOX are passed on to consumers, utilities should publicly disclose the cost of MOX.

2. Announce Realistic Goals for Plutonium Consumption. Japan continues to affirm its policy of reducing its plutonium stockpile. However, utilities are legally allowed to continue reprocessing their spent fuel by claiming an intended use for the separated plutonium up to 50 years in the future. This makes the policy vague, ineffective, and illusory. The international community should pressure the Japanese government to prohibit further plutonium stockpiling and to limit the permissible time between future plutonium separation and use.

3. Delay Operation of the Rokkasho Reprocessing Plant. It is illogical for Japan to separate more plutonium before LWRs are licensed, and approved by local authorities, to consume it in MOX. Priority should be given to reducing Japan's in-country plutonium stockpile and its stocks in the UK and France.

4. Expand Dry-cask Storage of Spent Fuel. With most spent fuel pools close to capacity in Japan, and no need for the plutonium that would be separated by reprocessing additional spent fuel, plans should be developed to expand storage of spent fuel. Dry-cask storage is much safer than spent fuel ponds and would save money in the long run, compared to reprocessing.

5. Pay the UK to Take Title to Japanese Plutonium. In 2012, the British government announced that, "subject to compliance with inter-governmental agreements and acceptable commercial arrangements, the UK is prepared to take ownership of overseas plutonium stored in the UK."[105] Japan and the UK are reportedly in discussions to transfer ownership to the UK of Japanese plutonium stored there. Such a deal would be win-win. The UK's NDA would gain revenue from Japanese utilities, which in turn would save money by avoiding the costs of paying for fabrication of MOX fuel.

6. Adopt Once-Through Fuel Cycle. A once-through cycle is safer, more secure, and cheaper than reprocessing spent fuel and

recycling plutonium in MOX. While such a switch would have domestic political ramifications in Japan in the short-term, it would lead to a safer, more secure, and wealthier society over the long-term.

Conclusion

Most countries that once used MOX fuel have decided to phase out their programs due to economic and public acceptance concerns. Lessons from Japan similarly demonstrate that MOX fuel is expensive, increases security risks, and may prove unable to decrease large plutonium stocks. If Japan continues with its current plan to expand reprocessing and MOX recycling, it could set a precedent for other countries, especially in the region, to pursue similar programs, which could be destabilizing. South Korea, with spent fuel sites close to capacity, is seriously considering recycling spent fuel. China's plans are even more advanced, as the government already has announced plans to develop a closed nuclear fuel cycle.[106] This poses the danger of a latent nuclear arms race that could undermine efforts to persuade North Korea to dismantle its nuclear weapons program. The Japanese government could take steps towards resolving this problem by first admitting what it has known for years: MOX is not a viable long-term solution. Next, the government should transparently discuss options to revise its current policies, including by considering alternatives to the MOX program. Otherwise, Japan's refusal to change course could have detrimental security consequences for Japan, East Asia, and beyond.

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